Appendix A

Annual 2002 and 2018 Point Source Emissions in Tons in Minnesota$_{(MRPO)}$ Case for Minnesota by Stack

Minnesota Electric Generating Units				2002 Annual Emissions in Tons					Minnesota Electric Generating Units				2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NOX**	**SO2**	**VOC**	**PM25**	**NH3**	**COUNTY**	**FACID**	**STKID**	**FAC_NAME**	**NOX**	**SO2**	**VOC**	**PM25**	**NH3**
									Becker	ORIS700127	41	GENERIC UNIT	21		3	0	12
									Beltrami	ORIS700227	41	GENERIC UNIT	21		3	0	12
									Beltrami	ORIS7947	41	Solway CT	5				0
									Benton	ORIS800127	41	GENERIC UNIT	11		0		1
Blue_Earth	2701300015	SV001	NSP dba Xcel Energy - Key City	299	22		16		Blue_Earth	ORIS900127	41	GENERIC UNIT	543	851	18	110	16
Blue_Earth	2701300015	SV002	NSP dba Xcel Energy - Key City	307	34		16										
Blue_Earth	2701300015	SV004	NSP dba Xcel Energy - Key City	3			0										
Blue_Earth	2701300015	SV005	NSP dba Xcel Energy - Key City	2			0										
Blue_Earth	2701300015	SV006	NSP dba Xcel Energy - Key City	3			0										
Blue_Earth	2701300015	SV007	NSP dba Xcel Energy - Key City	2			0										
Blue_Earth	2701300078	GN001	Lake Crystal Utilities Commiss	2													
Brown	2701500008	GN001	Sleepy Eye Public Utility	2		0			Brown	2701500008	42	Sleepy Eye Public Utility	12				
Brown	2701500010	SV001	New Ulm Public Utilities-Munic	7		1	0										
Brown	2701500010	SV002	New Ulm Public Utilities-Munic	3		0											
Brown	2701500010	SV003	New Ulm Public Utilities-Munic	45		2	0										
Brown	2701500014	GN001	Springfield Power Plant	2													
Carver	2701900010	SV001	Great River Energy - St Bonifa	3	2												
Carver	2701900010	SV002	Great River Energy - St Bonifa	3	2												
									Carver	2701900059	SV001	MMPA - Minnesota River Station	2				0
									Clay	ORIS1978	41	Hawley	5				
Cook	2703100001	SV001	Minnesota Power - Taconite Har	552	818	2	35		Cook	2703100001	SV001	Minnesota Power - Taconite Har	381	669	6	58	5
Cook	2703100001	SV002	Minnesota Power - Taconite Har	1,090	1,260	4	55	0	Cook	2703100001	SV002	Minnesota Power - Taconite Har	412	681	5	51	5
Cook	2703100001	SV003	Minnesota Power - Taconite Har	665	1,030	3	46		Cook	2703100001	SV003	Minnesota Power - Taconite Har	406	673	5	51	5
									Cottonwood	2703300019	GN001	Mountain Lake Municipal Utilit	33				
Dakota	2703700003	SV001	NSP dba Xcel Energy - Black Do	6,460	3,070	18	224	1	Dakota	2703700003	SV001	NSP dba Xcel Energy - Black Do	9,365	7,530	23	221	19
Dakota	2703700003	SV020	NSP dba Xcel Energy - Black Do	15	217	2	60	0	Dakota	2703700003	SV020	NSP dba Xcel Energy - Black Do	34		3	0	11
Dakota	2703700015	SV001	NSP dba Xcel Energy - Inver Hi	25	0	0	1		Dakota	2703700015	SV001	NSP dba Xcel Energy - Inver Hi	9				0
Dakota	2703700015	SV002	NSP dba Xcel Energy - Inver Hi	14	0	0	0		Dakota	2703700015	SV002	NSP dba Xcel Energy - Inver Hi	9				0
Dakota	2703700015	SV003	NSP dba Xcel Energy - Inver Hi	23	0	0	1		Dakota	2703700015	SV003	NSP dba Xcel Energy - Inver Hi	9				0
Dakota	2703700015	SV004	NSP dba Xcel Energy - Inver Hi	21	0	0	0		Dakota	2703700015	SV004	NSP dba Xcel Energy - Inver Hi	9				0
Dakota	2703700015	SV005	NSP dba Xcel Energy - Inver Hi	21	0	0	0		Dakota	2703700015	SV005	NSP dba Xcel Energy - Inver Hi	9				0
Dakota	2703700015	SV006	NSP dba Xcel Energy - Inver Hi	23	0	0	0		Dakota	2703700015	SV006	NSP dba Xcel Energy - Inver Hi	9				0
Douglas	2704100004	GN001	Alexandria Light & Power	2					Douglas	2704100004	GN001	Alexandria Light & Power	3				
Faribault	2704300045	GN001	Wells Public Utilities	4	0	0			Faribault	2704300045	GN001	Wells Public Utilities	4				
Faribault	2704300045	GN001	Wells Public Utilities	8		1											
Fillmore	2704500001	GN001	Spring Valley Utilities	9	1	1											
Fillmore	2704500001	GN001	Spring Valley Utilities	3		0											
Fillmore	2704500029	GN001	Preston Public Utilities	5	0	0			Fillmore	2704500029	GN001	Preston Public Utilities	18				
Fillmore	2704500029	GN001	Preston Public Utilities	3		0											
Hennepin	2705300015	SV002	Xcel Energy - Riverside Genera	4,412	2,090	10	148	0	Hennepin	2705300015	SV002	Xcel Energy - Riverside Genera	59		10	1	35
Hennepin	2705300015	SV003	Xcel Energy - Riverside Genera	8,857	10,811	38	189	0									
Hennepin	2705301005	ITOTA	Woodlake Sanitary Landfill	9	2	1	1										
Isanti	2705900014	SV001	Great River Energy - Cambridge	2	1												
Itasca	2706100004	SV001	Minnesota Power Inc - Boswell	1,957	4,233	9	123		Itasca	2706100004	SV001	Minnesota Power Inc - Boswell	1,530	3,582	11	70	9
Itasca	2706100004	SV003	Minnesota Power Inc - Boswell	4,911	13,280	26	3	0	Itasca	2706100004	SV003	Minnesota Power Inc - Boswell	922	1,188	24	573	21
Itasca	2706100004	SV004	Minnesota Power Inc - Boswell	7,656	3,653	4	585	1	Itasca	2706100004	SV004	Minnesota Power Inc - Boswell	4,711	3,215	34	542	29
									Kanabec	2706500006	GN001	Mora Municipal Utilities	50				0
									Kandiyohi	2706700005	SV002	Willmar Municipal Utilities	112	230	0	5	0
Kandiyohi	2706700005	SV003	Willmar Municipal Utilities	191	687	1	17		Kandiyohi	2706700005	SV003	Willmar Municipal Utilities	587	1,460	2	44	2
Lake	2707500003	SV001	Northshore Mining Co - Silver	1,126	851	5	0		Lake	2707500003	41	Silver Bay Power ORIS10849	318	806	3	17	2
Lake	2707500003	SV002	Northshore Mining Co - Silver	1,821	1,371	8	0	0	Lake	2707500003	42	Silver Bay Power ORIS10849	613	1,544	5	32	5
Lake	2707500003	SV105	Northshore Mining Co - Silver			6											
Lake	2707500003	SV114	Northshore Mining Co - Silver			7											
Lake	2707500003	SV261	Northshore Mining Co - Silver			2											

Minnesota Electric Generating Units				2002 Annual Emissions in Tons					Minnesota Electric Generating Units				2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NOX**	**SO2**	**VOC**	**PM25**	**NH3**	**COUNTY**	**FACID**	**STKID**	**FAC_NAME**	**NOX**	**SO2**	**VOC**	**PM25**	**NH3**
Le_Sueur	2707900008	ITOTA	Interstate Power & Light - Mon	2	1												
Le_Sueur	2707900037	GN001	New Prague Water - Light - Pow	12	1	1			Le_Sueur	2707900037	GN001	New Prague Water - Light - Pow	83				0
Le_Sueur	2707900037	GN001	New Prague Water - Light - Pow	5		1											
McLeod	2708500002	SV002	Hutchinson Utilities Commissio	6	0		1		McLeod	2708500002	SV002	Hutchinson Utilities Commissio	17				
McLeod	2708500002	SV003	Hutchinson Utilities Commissio	12	0		1		McLeod	2708500002	SV003	Hutchinson Utilities Commissio	33				
									McLeod	2708500002	SV004	Hutchinson Utilities Commissio	19				
McLeod	2708500002	SV006	Hutchinson Utilities Commissio	6	0		1										
									McLeod	2708500002	SV007	Hutchinson Utilities Commissio	38				
									McLeod	2708500013	SV001	Glencoe Light & Power Commissi	3				
McLeod	2708500013	SV003	Glencoe Light & Power Commissi	2	0		0										
									McLeod	2708500013	SV004	Glencoe Light & Power Commissi	8				
McLeod	2708500013	SV005	Glencoe Light & Power Commissi	6	0		1		McLeod	2708500013	SV005	Glencoe Light & Power Commissi	8				
McLeod	2708500013	SV006	Glencoe Light & Power Commissi	5	0		1		McLeod	2708500013	SV006	Glencoe Light & Power Commissi	26				
McLeod	2708500013	SV011	Glencoe Light & Power Commissi	5	0		0		McLeod	2708500013	SV011	Glencoe Light & Power Commissi	35				
McLeod	2708500013	SV012	Glencoe Light & Power Commissi	4	0		0		McLeod	2708500013	SV012	Glencoe Light & Power Commissi	45				0
McLeod	2708500034	SV002	Hutchinson Utilities Commissio	25	0	0	1		McLeod	2708500034	SV002	Hutchinson Utilities Commissio	2				
McLeod	2708500034	SV004	Hutchinson Utilities Commissio	2			0										
Martin	2709100007	SV001	Interstate Power & Light - Fox	10	0	0	0	0									
Martin	2709100007	SV002	Interstate Power & Light - Fox	71	14	5	29	1									
Martin	2709100007	SV003	Interstate Power & Light - Fox	3	1												
Martin	2709100009	SV004	Fairmont Power Plant	14	1	0	2		Martin	2709100009	SV004	Fairmont Power Plant	5				
Martin	2709100009	SV005	Fairmont Power Plant	14	1	0	1		Martin	2709100009	SV005	Fairmont Power Plant	5				
Martin	2709100009	SV007	Fairmont Power Plant	2		0	0										
									Martin	2709100046	GN001	Truman Public Utilities	13				
Meeker	2709300001	GN001	Litchfield Public Utilities Co	6		1			Meeker	2709300001	GN001	Litchfield Public Utilities Co	16				
Mille_Lacs	2709500011	GN001	Princeton Public Utilities Com	10	1	1			Mille_Lacs	2709500011	41	Princeton Public Utilities Com	23				
Mower	2709900001	SV001	Austin Utilities - NE Power St	396	2,001	2	6	0	Mower	2709900001	SV001	Austin Utilities - NE Power St	397	839	2	14	2
Mower	2709900048	SV001	Great River Energy - Pleasant	15	0	0	7		Mower	2709900048	SV001	Great River Energy - Pleasant	10		0		1
Mower	2709900048	SV002	Great River Energy - Pleasant	8	0	0	4		Mower	2709900048	SV002	Great River Energy - Pleasant	8		0		1
Mower	2709900048	SV003	Great River Energy - Pleasant	22	5	0	34		Mower	2709900048	SV003	Great River Energy - Pleasant	11		0		1
Olmsted	2710900005	SV001	Olmsted Waste-to-Energy Facili	55	33	7	5										
Olmsted	2710900005	SV002	Olmsted Waste-to-Energy Facili	57	34	8	5										
Olmsted	2710900005	SV004	Olmsted Waste-to-Energy Facili	1		0	0										
Olmsted	2710900011	SV001	Rochester Public Utilities - S	48	69	0	5		Olmsted	2710900011	SV001	Rochester Public Utilities - S	764	1,087	2	20	2
Olmsted	2710900011	SV002	Rochester Public Utilities - S	124	185	0	11		Olmsted	2710900011	SV002	Rochester Public Utilities - S	795	1,133	2	20	2
Olmsted	2710900011	SV003	Rochester Public Utilities - S	192	873	1	11		Olmsted	2710900011	SV003	Rochester Public Utilities - S	387	1,128	51	572	306
									Olmsted	ORIS54262	43	Saint Marys Hospital Power Pla	2				
Olmsted	2710900020	SV001	Rochester Public Utility - Cas	10	0		0										
Olmsted	2710900020	SV005	Rochester Public Utility - Cas	3	0		0										
Olmsted	2710900020	SV006	Rochester Public Utility - Cas	2	0		0										
									Otter_Tail	2711100002	SV001	Otter Tail Power Co - Hoot Lak	192	210	0	14	1
Otter_Tail	2711100002	SV002	Otter Tail Power Co - Hoot Lak	1,794	2,821	9	72		Otter_Tail	2711100002	SV002	Otter Tail Power Co - Hoot Lak	1,203	3,850	11	103	10
									Otter_Tail	2711100002	SV005	Otter Tail Power Co - Hoot Lak	0				
Ramsey	2712300012	SV001	Xcel Energy - High Bridge Gene	5,612	3,806	16	205		Ramsey	2712300012	SV001	Xcel Energy - High Bridge Gene	69		11	1	41
Ramsey	2712300698	ITOTA	Zuel Co Inc			4											
Redwood	2712700038	SV001	Redwood Falls Public Utilities	3	0	0											
									Redwood	ORIS7982	41	South Generation	10				
									Redwood	ORIS7982	42	South Generation	10				
									Redwood	ORIS7982	43	South Generation	11				
Rice	2713100017	ITOTA	AAF/McQuay International - Far	4		17											
St_Louis	2713700013	SV001	Minnesota Power Inc - Laskin E	2,172	1,605	7	105		St_Louis	2713700013	SV001	Minnesota Power Inc - Laskin E	771	1,814	10	181	8
St_Louis	2713700027	SV001	Hibbing Public Utilities Commi	132	127	0	4		St_Louis	2713700027	SV001	Hibbing Public Utilities Commi	290	595	1	18	1
St_Louis	2713700027	SV002	Hibbing Public Utilities Commi	55	51	0	2		St_Louis	2713700027	SV002	Hibbing Public Utilities Commi	290	595	1	18	1
St_Louis	2713700027	SV003	Hibbing Public Utilities Commi	96	78	0	3		St_Louis	2713700027	SV003	Hibbing Public Utilities Commi	388	794	1	24	1
St_Louis	2713700028	SV002	Virginia Dept of Public Utilit	62	89	0	4		St_Louis	2713700028	SV002	Virginia Dept of Public Utilit	356	730	1	17	1

Minnesota Electric Generating Units				2002 Annual Emissions in Tons					Minnesota Electric Generating Units				2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NOX**	**SO2**	**VOC**	**PM25**	**NH3**	**COUNTY**	**FACID**	**STKID**	**FAC_NAME**	**NOX**	**SO2**	**VOC**	**PM25**	**NH3**
St_Louis	2713700028	SV003	Virginia Dept of Public Utilit	257	297	1	9		St_Louis	2713700028	SV003	Virginia Dept of Public Utilit	356	730	1	17	1
St_Louis	2713700028	SV004	Virginia Dept of Public Utilit	9		1	1	0									
Scott	2713900010	SV001	NSP dba Xcel Energy - Blue Lak	6	0		0		Scott	2713900010	41	NSP dba Xcel Energy - Blue Lak	13		0		1
Scott	2713900010	SV002	NSP dba Xcel Energy - Blue Lak	7	0		0		Scott	2713900010	42	NSP dba Xcel Energy - Blue Lak	13		0		1
Scott	2713900010	SV003	NSP dba Xcel Energy - Blue Lak	7	0		0										
Scott	2713900010	SV004	NSP dba Xcel Energy - Blue Lak	7	0		0										
Sherburne	2714100004	SV001	NSP - Sherburne Generating Pla	14,372	14,762	98	1,306	2	Sherburne	2714100004	SV001	NSP - Sherburne Generating Pla	11,548	9,658	102	10,116	88
Sherburne	2714100004	SV002	NSP - Sherburne Generating Pla	11,506	11,924	58	841	1	Sherburne	2714100004	SV002	NSP - Sherburne Generating Pla	8,284	5,940	65	809	56
Sherburne	2714100004	SV046	NSP - Sherburne Generating Pla	2													
Sherburne	2714100047	GN001	Elk River Municipal Utilites	3	0	0											
Stearns	2714500002	GN001	Melrose Public Utilities	3	0	0											
Steele	2714700002	SV002	Owatonna Public Utilities - Po	9		0	0	0									
Swift	2715100006	SV002	Benson Municipal Utilities	1													
									Waseca	2716100027	GN001	Janesville Municipal Utilities	5				
Washington	2716300005	SV001	Xcel Energy - Allen S King Gen	11,862	23,241	81	417		Washington	2716300005	SV001	Xcel Energy - Allen S King Gen	2,067	2,481	71	451	34
Washington	2716300005	SV008	Xcel Energy - Allen S King Gen	9		0	0	0									
Washington	2716300087	SV001	LSP Cottage Grove Cogeneration	18	1	1	5	1	Washington	2716300087	SV001	LSP Cottage Grove Cogeneration	7		1	0	4
Washington	2716300087	SV002	LSP Cottage Grove Cogeneration	6			0	20									
Washington	2716300087	SV003	LSP Cottage Grove Cogeneration	6			1	20									
Watonwan	2716500019	GN001	Madelia Light & Power Standby	2		0			Watonwan	2716500019	GN001	Madelia Light & Power Standby	52				0
Wright	2717100016	GN001	Delano Municipal Utilities	5	0	0											
Wright	2717100020	SV001	Great River Energy - Maple Lak	2	1												

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Aitkin	27001SW145	RPU00	Aitkin Area			16					16		
Aitkin	27001SW150	RPU00	Hickory Grove			12					12		
Anoka	2700300004	BO001	ISD 14 - Stevenson Elementary	2		0	0		2		0	0	
Anoka	2700300005	ITOTA	Minncast Inc			8	1				10	2	
Anoka	2700300010	BO002	Anoka Metro Regional Treatment	2		0			2		0		
Anoka	2700300019	SI003	Onan Corp	2	0	1			2	0	1		
Anoka	2700300019	SV423	Onan Corp	3	0	0			3	0	0		
Anoka	2700300020	SV026	United Defense LP	4		1	0	0	4		1	0	0
Anoka	2700300020	SV027	United Defense LP	4		1	0	0	4		1	0	0
Anoka	2700300031	ITOTA	Schwartzman Co Inc				14					7	
Anoka	2700300037	BO002	Unity Hospital	4		0	0		4		0	0	
Anoka	2700300073	BO002	Minnesota Correctional - Lino	4		1	0		4		1	0	
Anoka	2700300081	ITOTA	Honeywell - Commercial Aviatio	2	0	5			1		3		
Anoka	2700300136	ITOTA	Determan Brownie Inc		1	4	1		0	2	7	2	
Anoka	2700300156	SI001	Federal Cartridge Co - Anoka	2		0	0		2		0	0	
Anoka	2700300156	SI002	Federal Cartridge Co - Anoka	3		0	0	0	3		0	0	0
Anoka	2700300171	ITOTA	Gale's Auto Body Shop			3	1						
Anoka	2700300182	ITOTA	Waldoch Collision Center			3					2		
Anoka	2700300205	ITOTA	Kurt Manufacturing Co - Die Ca	5	2	1	6		7	2	2	7	
Anoka	2700300210	ITOTA	Lexington Manufacturing Inc				4					6	
Anoka	2700300222	IOTHE	Accent Home & Kitchen Center I			5					3		
Anoka	2700300224	ITOTA	Arrow Cryogenics Inc	0		4	4		1		6	7	
Anoka	2777700163	ITOTA	Commercial Asphalt Co - Plant	13	3	12	3		17	4	17	4	
Anoka	2777700284	ITOTA	Commercial Asphalt Co - Plant	12	1	13	3		16	1	18	4	
Anoka	27003SW008	RPU00	Johnson Bros/Lochness			59					59		
Anoka	27003SW028	RPU00	Waste Disposal Engineering			5					5		
Anoka	27003SW028	RPU00	Waste Disposal Engineering	1	0	20	0		1	0	20	0	
Anoka	27003SW043	RPU00	Oak Grove			6					6		
Anoka	27003SW043	RPU00	Oak Grove	1	0	23	0		1	0	23	0	
Anoka	27003SW047	RPU00	East Bethel			74					74		
Anoka	27003SW094	RPU00	Anoka Municipal Regional			16					16		
Anoka	27003SW094	RPU00	Anoka Municipal Regional	3	1	63	1		3	1	63	1	
Anoka	27003XANE	RPU00	ANOKA COUNTY-BLAINE ARPT(JA			1	0		0		2	1	
Anoka	27003XANE	RPU00	ANOKA COUNTY-BLAINE ARPT(JA	2	0	12	6		2	0	13	6	
Becker	2700500035	NF001	Sherbrooke Asphalt Inc - Nonme	4	0	0			3	0	0		
Becker	2711100016	SV001	Viking Gas Transmission - Fraz	118		25	3		118		25	3	
Becker	2711100016	SV002	Viking Gas Transmission - Fraz	121		25	3		121		25	3	
Becker	2711100016	SV003	Viking Gas Transmission - Fraz	114		24	3		114		24	3	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Becker	2711100016	SV006	Viking Gas Transmission - Fraz	25	1	0	1		21	1	0	1	
Becker	2777700304	ITOTA	Sherbrooke Asphalt Inc	16	11	3	2		22	15	4	3	
Becker	27005POTW	RPS00	Detroit Lakes WWTP			1		4			1		4
Becker	27005SW099	RPU00	Becker County			4					4		
Becker	27005SW099	RPU00	Becker County	1	0	16	0		1	0	16	0	
Beltrami	2700700006	ITOTA	Bemidji State University	9		0	2		5			1	
Beltrami	2700700010	ITOTA	North Country Regional Hospita	2									
Beltrami	2700700019	FS001	Northwood Panelboard Co				12					16	
Beltrami	2700700019	SI001	Northwood Panelboard Co	22		91			22		42		
Beltrami	2700700019	SI002	Northwood Panelboard Co	22		91			22		42		
Beltrami	2700700019	SI003	Northwood Panelboard Co	82	4		2		90	4		2	
Beltrami	2700700019	SI007	Northwood Panelboard Co	10	1	2	1		11	1	2	1	
Beltrami	2700700019	SI008	Northwood Panelboard Co	10	1	2	1		10	1	2	1	
Beltrami	2700700019	SI012	Northwood Panelboard Co	8	8		20		8	8		21	
Beltrami	2700700019	SI016	Northwood Panelboard Co			20	6				10	6	
Beltrami	2700700033	NF001	Gesell Concrete Products - Non	2		0			2				
Beltrami	2705700005	FS006	Potlatch - Bemidji				118					160	
Beltrami	2705700005	FS007	Potlatch - Bemidji				136					184	
Beltrami	2705700005	SI001	Potlatch - Bemidji	12	0	1	4		12	0	0	4	
Beltrami	2705700005	SI002	Potlatch - Bemidji	12	0	1	4		12	0	0	4	
Beltrami	2705700005	SI003	Potlatch - Bemidji	12	0	1	4		12	0	0	4	
Beltrami	2705700005	SI004	Potlatch - Bemidji	12	0	1	4		12	0	0	4	
Beltrami	2705700005	SI005	Potlatch - Bemidji	10	4		9		10	4		9	
Beltrami	2705700005	SI006	Potlatch - Bemidji	10	4		9		10	4		9	
Beltrami	2705700005	SI007	Potlatch - Bemidji	10	4		9		10	4		9	
Beltrami	2705700005	SI008	Potlatch - Bemidji				2					4	
Beltrami	2705700005	SI011	Potlatch - Bemidji				4					6	
Beltrami	2705700005	SI012	Potlatch - Bemidji				2					4	
Beltrami	2705700005	SI019	Potlatch - Bemidji	7	1	1			7	1	1		
Beltrami	2705700005	SI021	Potlatch - Bemidji	90	19	74	3		99	20	81	4	
Beltrami	2705700005	SI022	Potlatch - Bemidji	7			11		7			11	
Beltrami	2705700005	SI023	Potlatch - Bemidji	6			2		6			2	
Beltrami	2777700059	ITOTA	Thorson Inc - Boeing Asphalt P	2	2	0	0		3	3	1	0	
Beltrami	2777700150	ITOTA	Mark Sand & Gravel Acquisition	1	2	1	0		2	3	1	1	
Beltrami	2777700188	ITOTA	Thorson Inc - Boeing Asphalt P	11	11	3	2		15	16	3	2	
Beltrami	2777700307	ITOTA	Thorson Inc - Asphalt Plant 1	3	7	1	1		3	9	1	1	
Beltrami	27007POTW	RPS00	Bemidji WWTP			1		4			1		4
Beltrami	27007SW031	RPU00	Kummer			39					39		
Beltrami	27007SW051	RPU00	Eighty-Acre			4					4		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Beltrami	27007XBJI	RPU00	BEMIDJI-BELTRAMI COUNTY	1	0	0			2	0	1		
Beltrami	27007XBJI	RPU00	BEMIDJI-BELTRAMI COUNTY	0		2	1		0		3	1	
Beltrami	27007XBJI	RPU00	BEMIDJI-BELTRAMI COUNTY	0		2	1		0		3	1	
Beltrami	27007XBJI	RPU00	BEMIDJI-BELTRAMI COUNTY	2	0	2			2	0	2		
Benton	2700900006	SV002	Quebecor World St Cloud	5		12	0		5		16	0	
Benton	2700900027	ITOTA	Warren Wood Inc	1		0	2		1		0	3	
Benton	2700900029	ITOTA	X-cel Optical Co			4					2		
Benton	2700900031	ITOTA	Wilkie Sanderson			4	0				2	0	
Benton	2700900035	IOTHE	Bauerly Bros Inc - Nonmetallic				16					9	
Benton	2700900035	NF001	Bauerly Bros Inc - Nonmetallic	83	5	7			75	6	7		
Benton	2700900040	ITOTA	Phillips Recycling Systems Inc				5					3	
Benton	2700900041	ITOTA	Crystal Cabinet Works Inc - Sa	0			2		0			2	
Benton	2702500038	ITOTA	Bauerly Bros Inc - Plant 5	3	1	9	2		4	2	12	3	
Benton	2777700006	SV001	Bauerly Bros Inc - Plant 2	9	2	9	4		12	2	12	5	
Benton	2777700007	ITOTA	Bauerly Bros Inc - Plant 3	18	28	7	5		25	39	10	6	
Benton	2777700008	SV001	Bauerly Bros Inc - Plant 1	8	2	8	3		12	2	12	5	
Benton	2777700058	ITOTA	Thorson Inc - Asphalt Plant 4	18	25	5	3		25	33	7	4	
Benton	2777700270	ITOTA	Bauerly Bros Inc - Plant 4	10	22	4	3		13	30	6	4	
Big_Stone	2701100017	ITOTA	Bituminous Paving Inc - Barber	6	4	1	1		8	6	1	1	
Big_Stone	2701100026	IOTHE	Ortonville Stone Co - Nonmetal				8					4	
Big_Stone	27011SW096	RPU00	Big Stone County			10					10		
Blue_Earth	2701300006	SV009	ADM - Mankato				8					9	
Blue_Earth	2701300006	SV018	ADM - Mankato				32					39	
Blue_Earth	2701300006	SV032	ADM - Mankato	153	143	2			145	136	2		
Blue_Earth	2701300006	SV033	ADM - Mankato	4		0	0		4		0	0	
Blue_Earth	2701300006	SV034	ADM - Mankato	4		1	0		4		1	0	
Blue_Earth	2701300007	SI001	Cenex Harvest States Coop - Ma	13		1	0	0	13		1	0	0
Blue_Earth	2701300007	SI002	Cenex Harvest States Coop - Ma	42	0	6	3	1	42	0	6	3	1
Blue_Earth	2701300007	SI005	Cenex Harvest States Coop - Ma				3					4	
Blue_Earth	2701300007	SI009	Cenex Harvest States Coop - Ma	2		0			2		0		
Blue_Earth	2701300007	SI016	Cenex Harvest States Coop - Ma	3		0	0		3		0	0	
Blue_Earth	2701300007	SI019	Cenex Harvest States Coop - Ma	33	2	1	3		28	2	1	3	
Blue_Earth	2701300009	ITOTA	Minnesota State University - M	17	36	0	1		9	20		1	
Blue_Earth	2701300048	ITOTA	River Bend Asphalt Co - Cedar	3	1	0	0		5	2	1	0	
Blue_Earth	2701300072	ITOTA	Jones Metal Products Inc	0		5	5		1		8	9	
Blue_Earth	2701300073	ITOTA	Katolight Corp	1		4	3		4	0	10	8	
Blue_Earth	2701300075	IOTHE	Industrial Fabrication Service			3					2		
Blue_Earth	2701300077	ITOTA	Hiniker Co	0		10	7		1		18	12	
Blue_Earth	2701300079	ITOTA	City of Mankato - Central Gara	23	1	1	1		13	1	1	0	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Blue_Earth	2701300091	NF001	Southern MN Constr Co Inc - No	53	3	5			48	4	4		
Blue_Earth	27013POTW	RPS00	Mankato WWTP			9		21			9		21
Blue_Earth	27013SW064	RPU00	Mankato Public Works			4					4		
Blue_Earth	27013SW087	RPU00	Blue Earth/Ponderosa			116					116		
Blue_Earth	27013SW113	RPU00	Hansen			12					12		
Blue_Earth	27013XMKT	RPU00	MANKATO REGIONAL	1	0	6	3		1	0	6	3	
Brown	2701500007	SV003	Ochs Brick Co	20	21	3	10		25	31	4	14	
Brown	2701500009	SI001	Kraft Foods - New Ulm	3	0	0	0		3	0	0	0	
Brown	2701500009	SI002	Kraft Foods - New Ulm	3	0	0	0		3	0	0	0	
Brown	2701500027	ITOTA	Valley Asphalt Products Inc -	7	3	1	1		9	3	1	1	
Brown	2701500031	ITOTA	Anderson Custom Procesing Inc	4			19		4			21	
Brown	2701500032	ITOTA	Firmenich Inc	0			2		0			2	
Brown	2701500055	IOTHE	MR Paving & Excavating Inc - N				9					5	
Brown	2701500055	NF001	MR Paving & Excavating Inc - N	3	0	0			3	0	0		
Brown	2705301017	NF001	Northern Con-Agg Inc - Nonmeta	7	0	1			6	0	1		
Brown	27015POTW	RPS00	New Ulm WWTP			4		9			4		9
Brown	27015SW089	RPU00	Brown County			27					27		
Carlton	2701700002	SI002	Sappi Cloquet LLC			12		32			15		41
Carlton	2701700002	SV002	Sappi Cloquet LLC	149	5	0		1	195	6	0		1
Carlton	2701700002	SV003	Sappi Cloquet LLC	112	79	14	1	1	123	87	16	1	1
Carlton	2701700002	SV004	Sappi Cloquet LLC	72	0	9	5	11	77	0	9	5	12
Carlton	2701700002	SV005	Sappi Cloquet LLC	217	91	27	6	1	239	100	29	6	1
Carlton	2701700002	SV006	Sappi Cloquet LLC	399	6	7			524	8	9		
Carlton	2701700002	SV010	Sappi Cloquet LLC			13					17		
Carlton	2701700002	SV029	Sappi Cloquet LLC	223	0	1		4	293	1	2		5
Carlton	2701700002	SV036	Sappi Cloquet LLC			3		7			3		9
Carlton	2701700002	SV037	Sappi Cloquet LLC			3		7			3		9
Carlton	2701700002	SV038	Sappi Cloquet LLC			2		6			3		8
Carlton	2701700004	SI002	MCF - Moose Lake	2		0	0		2		0	0	
Carlton	2701700004	SI003	MCF - Moose Lake	2		0	0		2		0	0	
Carlton	2701700004	SI015	MCF - Moose Lake	2		0							
Carlton	2701700004	SI022	MCF - Moose Lake	2		0							
Carlton	2701700006	SI002	USG Interiors Inc - Cloquet				5					8	
Carlton	2701700006	SI003	USG Interiors Inc - Cloquet	10		1	6	0	10		1	9	0
Carlton	2701700006	SI004	USG Interiors Inc - Cloquet	9		1	6	0	9		1	8	0
Carlton	2701700006	SI005	USG Interiors Inc - Cloquet				5					8	
Carlton	2701700006	SI006	USG Interiors Inc - Cloquet	2		0			2		0		
Carlton	2701700006	SI007	USG Interiors Inc - Cloquet	2		0			2		0		
Carlton	2701700006	SI008	USG Interiors Inc - Cloquet	3		0			3		0		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Carlton	2701700006	SI014	USG Interiors Inc - Cloquet	2		0	1		3		0	1	
Carlton	2701700006	SI017	USG Interiors Inc - Cloquet	1			4		1		0	6	
Carlton	2701700006	SI018	USG Interiors Inc - Cloquet	0			4		1			5	
Carlton	2701700006	SI030	USG Interiors Inc - Cloquet	1			4		1			6	
Carlton	2701700006	SI040	USG Interiors Inc - Cloquet	2		0	2		2		0	3	
Carlton	2701700006	SI044	USG Interiors Inc - Cloquet	1			2		1			2	
Carlton	2701700006	SI045	USG Interiors Inc - Cloquet	1			2		1			2	
Carlton	2701700006	SI046	USG Interiors Inc - Cloquet	1			2		1			3	
Carlton	2701700006	SI047	USG Interiors Inc - Cloquet	1			2		1			3	
Carlton	2701700006	SI048	USG Interiors Inc - Cloquet	1			2		1			3	
Carlton	2701700006	SI049	USG Interiors Inc - Cloquet	1			2		1			3	
Carlton	2701700006	SI050	USG Interiors Inc - Cloquet	1			2		1			3	
Carlton	2701700006	SI051	USG Interiors Inc - Cloquet	1			2		1			3	
Carlton	2701700006	SI052	USG Interiors Inc - Cloquet	0			2		0			2	
Carlton	2701700006	SI060	USG Interiors Inc - Cloquet	1			4		1			6	
Carlton	2701700006	SI061	USG Interiors Inc - Cloquet	1			4		1			6	
Carlton	2701700006	SI065	USG Interiors Inc - Cloquet	3		0	5		3		0	7	
Carlton	2701700006	SI067	USG Interiors Inc - Cloquet	1		0	4		1		0	6	
Carlton	2701700006	SI069	USG Interiors Inc - Cloquet	1			4		1			6	
Carlton	2701700006	SI070	USG Interiors Inc - Cloquet	6		1	6		7		1	8	
Carlton	2701700006	SI072	USG Interiors Inc - Cloquet	33	0	4	8	0	35	0	5	11	0
Carlton	2701700006	SI074	USG Interiors Inc - Cloquet	0			4		0			6	
Carlton	2701700011	SV005	Northern Natural Gas Co - Wren	14	0	0	0		12	0		0	
Carlton	2701700011	SV006	Northern Natural Gas Co - Wren	15	0	0			12	0			
Carlton	2701700019	SV002	Northern Natural Gas Co - Carl	78		12	1		78		12	1	
Carlton	2701700041	NF001	Lundin Construction Co - Nonme	11	1	1			9	1	1		
Carlton	2701700042	NF001	Glacier Paving Inc - Nonmetall	6	0	0			5	0	0		
Carlton	2701700043	IOTHE	Ulland Brothers Inc North - No				3					2	
Carlton	2701700043	NF001	Ulland Brothers Inc North - No	37	2	3			33	3	3		
Carlton	2777700281	NF001	Dresel Aggregate Inc - Nonmeta	6	0	0			5	0	0		
Carlton	27017SW102	RPU00	Carlton County #2			19					19		
Carver	2701900001	SI003	Bongards' Creameries	0			14		1			16	
Carver	2701900001	SI004	Bongards' Creameries	0			14		1			16	
Carver	2701900001	SI005	Bongards' Creameries	0			14		1			16	
Carver	2701900001	SI006	Bongards' Creameries	0			14		1			16	
Carver	2701900001	SI007	Bongards' Creameries	49	101	2	2	1	49	101	2	2	1
Carver	2701900001	SI008	Bongards' Creameries	4		1			3		0		
Carver	2701900002	ITOTA	Wm Mueller & Sons Inc - Carver	1		0	1		1		0	1	
Carver	2701900020	BO002	United Sugars Corp - Chaska	2		0	0		2		0	0	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Carver	2701900038	ITOTA	Mammoth Inc	1		5	0		1		8	0	
Carver	2701900041	ITOTA	Rosemount Inc - Chanhassen Fac	1		2	0						
Carver	2701900044	ITOTA	Lake Region Manufacturing Co			12					6		
Carver	2701900053	IOTHE	Wm Mueller & Sons Inc - Nonmet				6						
Carver	2701900053	NF001	Wm Mueller & Sons Inc - Nonmet	4	0	0			4	0	0		
Carver	2701900059	SV001	MMPA - Minnesota River Station	12	0		1		10	0		1	
Carver	27019POTW	RPS00	Norwood Young America WWTP			1		2			1		2
Cass	2702100007	IOTHE	Hengel Ready Mix & Constr - No				2						
Cass	2702100007	NF001	Hengel Ready Mix & Constr - No	2		0			2				
Cass	2777700140	ITOTA	Anderson Brothers Construction	3	2	0	0		4	2	1	0	
Cass	27021SW033	RPU00	Maple			16					16		
Cass	27021SW169	RPU00	Cass County Longville-Remer			5					5		
Cass	27021SW179	RPU00	Cass County Walker Hackensack			7					7		
Cass	27021XPWC	RPU00	PINE RIVER REGIONAL			0	0				0	0	
Cass	27021XXVG	RPU00	LONGVILLE MUNI			0	0				0	0	
Cass	27021XY49	RPU00	WALKER MUNI			1	0				1	0	
Chippewa	2702300009	ITOTA	Cargill Inc - Maynard	2			7		1			4	
Chippewa	2702300034	IOTHE	SL - Montevideo Techology Inc			5					3		
Chippewa	27023POTW	RPS00	Montevideo WWTP			1		3			1		3
Chippewa	27023SW052	RPU00	Chippewa County			43					43		
Chippewa	27023XMVE	RPU00	MONTEVIDEO-CHIPPEWA COUNTY	0		1	0		0		1	0	
Chisago	2702500013	ITOTA	Zinpro Corp	3			1		4			1	
Chisago	2702500037	ITOTA	Concrete Pump Repair	0		4					3		
Chisago	2702500046	BO001	Close Custody Correctional - R	3		0	0		3		0	0	
Chisago	2702500046	GN001	Close Custody Correctional - R	2		0			2				
Chisago	27025POTW	RPS00	Chisago Lakes Joint STC			1		3			1		3
Chisago	27025SW072	RPU00	Pine Lane			5					5		
Chisago	27025SW072	RPU00	Pine Lane	1	0	18	0		1	0	18	0	
Clay	2702700001	SV001	American Crystal Sugar - Moorh	109	107	1	3		104	101	0	3	
Clay	2702700001	SV002	American Crystal Sugar - Moorh	98	82	0	3		93	78	0	3	
Clay	2702700001	SV003	American Crystal Sugar - Moorh	97	101	0	3		92	96	0	3	
Clay	2702700001	SV007	American Crystal Sugar - Moorh	12		2	11	0	12		2	13	0
Clay	2702700001	SV008	American Crystal Sugar - Moorh	11		1	12	0	11		1	14	0
Clay	2702700001	SV036	American Crystal Sugar - Moorh	0	0		0		1	0		0	
Clay	2702700008	BO002	Minnesota State University Moo	8		1	1	0	8		1	1	0
Clay	2702700014	ITOTA	Aggregate Industries Inc - Dil	3	4	0	1		4	5	1	1	
Clay	2702700022	SV009	Busch Agricultural Resources -	79	444	1	23	1	79	444	1	23	1
Clay	2702700022	SV010	Busch Agricultural Resources -		9					11			
Clay	2702700022	SV011	Busch Agricultural Resources -		9					11			

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Clay	2702700053	ITOTA	American Crystal Sugar - Resea					47					56
Clay	2702700063	BO000	ISD 146 - Barnesville High Sch	0		0	1		0		0	1	
Clay	2702700064	NF001	Aggregate Industries Inc - P-9	19	1	2			17	1	1		
Clay	2702700065	IOTHE	Northern Improvement Co - Nonm				7						
Clay	2702700066	IOTHE	Asplin Inc - Nonmetallic				2						
Clay	2702701006	ITOTA	Moorhead WWTP	2		1							
Clay	2711900070	IOTHE	Strata Corp - Nonmetallic				4					2	
Clay	27027SW034	RPU00	Clay County			1630					1630		
Clearwater	2702900004	SV001	Great Lakes Gas Transmission -	47	1	1	2		42	1	0	2	
Clearwater	2702900004	SV002	Great Lakes Gas Transmission -	385	2	1	5		341	2	1	5	
Clearwater	2702900004	SV003	Great Lakes Gas Transmission -	255	2	1	4		225	2	1	4	
Cook	2703100002	SI001	Hedstrom Lumber Co Inc - Grand	5	0	1	5		6	0	1	5	
Cook	2703100002	SI003	Hedstrom Lumber Co Inc - Grand	6					8				
Cook	2703100002	SI004	Hedstrom Lumber Co Inc - Grand				2					4	
Cook	27031SW294	RPU00	Cook County			10					10		
Cottonwood	2703300015	BO002	PM Windom	6		1	0	0	6		1	0	0
Cottonwood	2703300025	FS017	Ethanol 2000 LLP				4					5	
Cottonwood	2703300025	SV004	Ethanol 2000 LLP	11		46	3		12		49	3	
Cottonwood	2703300025	SV005	Ethanol 2000 LLP	11		47	2		12		51	2	
Cottonwood	2703300025	SV012	Ethanol 2000 LLP	16		2	1	0	16		2	1	0
Cottonwood	2703300025	SV018	Ethanol 2000 LLP	16		2	1	0	16		2	1	0
Cottonwood	2703300025	SV020	Ethanol 2000 LLP	11		8	2		11		8	2	
Cottonwood	27033POTW	RPS00	Windom WWTP			1		3			1		3
Cottonwood	27033SW143	RPU00	Cottonwood County			43					43		
Crow_Wing	2703500002	SI001	Missota Paper Co	2		0	0	0	2		0	0	0
Crow_Wing	2703500002	SI002	Missota Paper Co	6	18		1		6	18		1	
Crow_Wing	2703500002	SI003	Missota Paper Co	46	123	0	9		44	116	0	9	
Crow_Wing	2703500002	SI004	Missota Paper Co	47	120	0	3	0	45	114	0	3	0
Crow_Wing	2703500008	BO000	State of Minnesota Dept of Hum	3	16		0		6	28	0	0	
Crow_Wing	2703500008	BO002	State of Minnesota Dept of Hum	5		1	0	0	5		1	0	0
Crow_Wing	2703500031	SI001	Trus Joist - A Weyerhaeuser Bu	10	9	0	5		11	10	0	6	
Crow_Wing	2703500031	SI002	Trus Joist - A Weyerhaeuser Bu	55		1	9		56		1	9	
Crow_Wing	2703500031	SI003	Trus Joist - A Weyerhaeuser Bu	39		0	11		40		0	11	
Crow_Wing	2703500031	SI004	Trus Joist - A Weyerhaeuser Bu	11		1			11		1		
Crow_Wing	2703500031	SI005	Trus Joist - A Weyerhaeuser Bu	2	4		1		2	4		1	
Crow_Wing	2703500037	ITOTA	Lakeland Mold Co			14	13			0	18	17	
Crow_Wing	2703500043	ITOTA	Burlington Northern Railroad -	7	1	0			4	1	0		
Crow_Wing	2703500052	ITOTA	Mac Manufacturing Inc			6	1				3	1	
Crow_Wing	2713500021	NF001	Roberts Sand & Gravel Inc - No	4	0	0			4	0	0		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Crow_Wing	2777700002	ITOTA	Anderson Brothers Construction	10	6	2	1		13	8	3	2	
Crow_Wing	2777700087	ITOTA	Anderson Brothers Construction	12	8	3	2		17	11	4	3	
Crow_Wing	27035POTW	RPS00	Brainerd WWTP			4		9			4		9
Crow_Wing	27035SW111	RPU00	Crow Wing County (Old)			12					12		
Crow_Wing	27035SW111	RPU00	Crow Wing County (Old)	0		7			0		7		
Crow_Wing	27035SW181	RPU00	Crosby			4					4		
Crow_Wing	27035SW243	RPU00	Fifty Lakes Modified			2					2		
Crow_Wing	27035SW376	RPU00	Crow Wing County			74					74		
Crow_Wing	27035XBRD	RPU00	BRAINERD-CROW WING CO REGIO	1		0			2	0	0		
Crow_Wing	27035XBRD	RPU00	BRAINERD-CROW WING CO REGIO			1	0		0		2	1	
Crow_Wing	27035XBRD	RPU00	BRAINERD-CROW WING CO REGIO	0		3	1		0		3	1	
Crow_Wing	27035XBRD	RPU00	BRAINERD-CROW WING CO REGIO			0					0		
Crow_Wing	27035XBRD	RPU00	BRAINERD-CROW WING CO REGIO	2	0	1			2	0	1		
Dakota	2703700011	FS018	Flint Hills Resources LP - Pin			17					23		
Dakota	2703700011	FS019	Flint Hills Resources LP - Pin			15					20		
Dakota	2703700011	FS022	Flint Hills Resources LP - Pin			10					13		
Dakota	2703700011	FS024	Flint Hills Resources LP - Pin			12					16		
Dakota	2703700011	FS027	Flint Hills Resources LP - Pin			14					18		
Dakota	2703700011	FS029	Flint Hills Resources LP - Pin			9					11		
Dakota	2703700011	FS031	Flint Hills Resources LP - Pin			14					18		
Dakota	2703700011	FS032	Flint Hills Resources LP - Pin			10					14		
Dakota	2703700011	FS035	Flint Hills Resources LP - Pin			6					8		
Dakota	2703700011	FS036	Flint Hills Resources LP - Pin			7					9		
Dakota	2703700011	FS039	Flint Hills Resources LP - Pin			10					13		
Dakota	2703700011	FS041	Flint Hills Resources LP - Pin			21					28		
Dakota	2703700011	FS042	Flint Hills Resources LP - Pin			0					46		
Dakota	2703700011	FS045	Flint Hills Resources LP - Pin			35					77		
Dakota	2703700011	FS048	Flint Hills Resources LP - Pin			58					13		
Dakota	2703700011	FS052	Flint Hills Resources LP - Pin			10					16		
Dakota	2703700011	FS054	Flint Hills Resources LP - Pin			12					28		
Dakota	2703700011	FS055	Flint Hills Resources LP - Pin			21					13		
Dakota	2703700011	FS058	Flint Hills Resources LP - Pin			10					44		
Dakota	2703700011	FS060	Flint Hills Resources LP - Pin			34					15		
Dakota	2703700011	FS062	Flint Hills Resources LP - Pin			12					10		
Dakota	2703700011	FS063	Flint Hills Resources LP - Pin			8					2		
Dakota	2703700011	FS064	Flint Hills Resources LP - Pin			2					13		
Dakota	2703700011	FS069	Flint Hills Resources LP - Pin			9					20		
Dakota	2703700011	FS070	Flint Hills Resources LP - Pin			16					42		
Dakota	2703700011	FS075	Flint Hills Resources LP - Pin			32					22		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Dakota	2703700011	FS077	Flint Hills Resources LP - Pin			17					17		
Dakota	2703700011	FS079	Flint Hills Resources LP - Pin			13					15		
Dakota	2703700011	FS080	Flint Hills Resources LP - Pin			11					54		
Dakota	2703700011	FS083	Flint Hills Resources LP - Pin			41					8		
Dakota	2703700011	FS085	Flint Hills Resources LP - Pin			6					7		
Dakota	2703700011	FS087	Flint Hills Resources LP - Pin			5					8		
Dakota	2703700011	FS088	Flint Hills Resources LP - Pin			6					12		
Dakota	2703700011	FS091	Flint Hills Resources LP - Pin			9					6		
Dakota	2703700011	FS093	Flint Hills Resources LP - Pin			5					12		
Dakota	2703700011	FS095	Flint Hills Resources LP - Pin			9					21		
Dakota	2703700011	FS096	Flint Hills Resources LP - Pin			16					10		
Dakota	2703700011	FS099	Flint Hills Resources LP - Pin			8					6		
Dakota	2703700011	FS102	Flint Hills Resources LP - Pin			5					8		
Dakota	2703700011	FS104	Flint Hills Resources LP - Pin			6					6		
Dakota	2703700011	FS106	Flint Hills Resources LP - Pin			4					2		
Dakota	2703700011	RPU99	Flint Hills Resources LP - Pin					9					9
Dakota	2703700011	SI013	Flint Hills Resources LP - Pin	25	0	1			22	0	1		
Dakota	2703700011	SI016	Flint Hills Resources LP - Pin	19					19				
Dakota	2703700011	SI017	Flint Hills Resources LP - Pin	34			5		34			5	
Dakota	2703700011	SV004	Flint Hills Resources LP - Pin	2085	78	68	109		2085	78	68	109	
Dakota	2703700011	SV017	Flint Hills Resources LP - Pin	19					19				
Dakota	2703700011	SV019	Flint Hills Resources LP - Pin	729	2088	48	91		959	2746	36	119	
Dakota	2703700011	SV042	Flint Hills Resources LP - Pin		279					340			
Dakota	2703700011	SV078	Flint Hills Resources LP - Pin		51	3				62	3		
Dakota	2703700011	SV094	Flint Hills Resources LP - Pin		239					291			
Dakota	2703700011	SV104	Flint Hills Resources LP - Pin	1	118	8			1	126	9		
Dakota	2703700011	SV125	Flint Hills Resources LP - Pin	22	8	27	1		23	8	29	1	
Dakota	2703700014	SV004	Northern Natural Gas Co - Farm	18		3			18		3		
Dakota	2703700014	SV005	Northern Natural Gas Co - Farm	27		3	0		27		3	0	
Dakota	2703700014	SV007	Northern Natural Gas Co - Farm	7	0	0	1		6	0	0	1	
Dakota	2703700016	FS001	Gopher Resource Corp				4					7	
Dakota	2703700016	FS003	Gopher Resource Corp				5					9	
Dakota	2703700016	FS004	Gopher Resource Corp				5					9	
Dakota	2703700016	SV003	Gopher Resource Corp	52	1190	1	14		76	2337	2	28	
Dakota	2703700018	ITOTA	McNamara Contracting Inc	3	1	1	3		5	1	1	4	
Dakota	2703700027	ITOTA	Dakota Bulk Terminal Inc	0			6		0			3	
Dakota	2703700029	ITOTA	Pine Bend Paving HMA Plant	1		1	1		1		1	1	
Dakota	2703700032	ITOTA	Commercial Asphalt Co - Plant	15	1	17	4		20	2	23	6	
Dakota	2703700037	GN001	Unisys MACS - Eagan	10	1	1			8	1	1		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Dakota	2703700038	ITOTA	Danner Inc	25	9	5	0		31	10	6	0	
Dakota	2703700041	ITOTA	Commercial Asphalt Co - Plant	16	1	16	4		22	2	22	5	
Dakota	2703700043	SV001	Seneca Wastewater Treatment Pl	29	104	1			39	141	1		
Dakota	2703700050	ITOTA	CF Industries - Pine Bend Ware				10					6	
Dakota	2703700063	BO000	Minnesota Zoological Garden	2	10				4	18		0	
Dakota	2703700064	SV002	NSP dba Xcel Energy - Wescott	3		0			3		0		
Dakota	2703700066	SI001	Spectro Alloys Corp				4					8	
Dakota	2703700066	SI006	Spectro Alloys Corp				8					16	
Dakota	2703700066	SI011	Spectro Alloys Corp	24	53		1		41	105		1	
Dakota	2703700070	SV001	Anamax Corp	18	39	1	1	0	18	39	1	1	0
Dakota	2703700078	BO002	Marigold Foods Inc - Farmingto	3		0	0		3		0	0	
Dakota	2703700080	ITOTA	Regina Medical Center	4		0	0		2				
Dakota	2703700093	ITOTA	West Group Co - Eagan	9	1	26	1		11	1	31	1	
Dakota	2703700094	GN001	Northwest Airlines Inc - Build	5	0	0			4	0	0		
Dakota	2703700103	ITOTA	Ecolab - Engineering Center	2		4	32		3		6	45	
Dakota	2703700138	SI001	Pine Bend Electric	3	1		0		3	1		1	
Dakota	2703700138	SI002	Pine Bend Electric	29	5	0	1		24	5	0	1	
Dakota	2703700138	SI003	Pine Bend Electric	30	5	0	1		25	5	0	1	
Dakota	2703700138	SI004	Pine Bend Electric	2	0		0		2	1		0	
Dakota	2703700138	SI005	Pine Bend Electric	2	0		0		2	1		0	
Dakota	2703700171	ITOTA	CenterPoint Energy Minnegasco	3									
Dakota	2703700196	BO001	Blue Cross/Blue Shield of Minn	2		0	0		2		0	0	
Dakota	2703700196	GN001	Blue Cross/Blue Shield of Minn	2									
Dakota	2703700196	IOTHE	Blue Cross/Blue Shield of Minn			2							
Dakota	2703700205	ITOTA	Rosemount Aerospace Inc - Burn	25	1	4	3		14	1	2	1	
Dakota	2703700208	GN001	Northern Tool & Equipment Co	4	0	0			3	0	0		
Dakota	2703700211	BO002	Dakota Premium Foods LLC - S S	3		0	0		3		0	0	
Dakota	2703700213	ITOTA	Menasha Packaging - Lakeville	5			1		6			1	
Dakota	2703700218	IOTHE	Rupp Industries Inc - Preserve			3			1		1	1	
Dakota	2703700242	IOTHE	LaMettry's Collision Inc - Bur			3					2		
Dakota	2703700264	ITOTA	Bituminous Roadways Inc - 67D	2	0	2	1		3	0	2	2	
Dakota	2703700267	NF001	Bury & Carlson Inc - Nonmetall	24	2	2			22	2	2		
Dakota	2703700268	NF001	Cemstone Products - Nonmetalli	4	0	0			4	0	0		
Dakota	2703700269	NF001	Bituminous Roadways Inc - Nonm	2		0			2		0		
Dakota	2703700272	NF001	McNamara Contracting Inc - Non	14	1	1			13	1	1		
Dakota	2703700280	ITOTA	Endres Processing LLC	13	0	18	1		16	0	22	2	
Dakota	2703700284	ITOTA	Skyline Displays Inc - Intl De	0		4			0		2		
Dakota	2703700285	NF001	Aggregate Industries Inc - Non	4	0	0			4	0	0		
Dakota	2703700290	ITOTA	Rayfo Inc - Clayton	0		12	1		0		21	1	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Dakota	2703700292	ITOTA	Minerals Solutions Inc				2					3	
Dakota	2703700299	ITOTA	Travel Tags - Inver Grove Heig	29		63			34		75		
Dakota	2703700302	ITOTA	Cenex Harvest States - Inver G	3	0	1							
Dakota	2703700316	GN001	Blue Cross/Blue Shield of MN -	3		0			2		0		
Dakota	2703700324	ITOTA	Twin City Container Inc	7		16	1	0	4		9	1	0
Dakota	2703700325	ITOTA	Bernco Inc			2	4				1	2	
Dakota	2777700081	ITOTA	Commercial Asphalt Co - Plant	8	1	7	1		12	1	9	2	
Dakota	27037POTW1	RPS00	Northfield WWTP			3		7			3		7
Dakota	27037POTW3	RPS00	Met Council - Rosemount WWTP			1		3			1		3
Dakota	27037POTW4	RPS00	Met Council - Hastings WWTP			2		6			2		6
Dakota	27037POTW(	RPS00	Met Council - Empire WWTP			13		31			13		31
Dakota	27037SW016	RPU00	Crosby American (amt. that is			21					21		
Dakota	27037SW050	RPU00	Dakhue			82					82		
Dakota	27037SW057	RPU00	Freeway			277					277		
Dakota	27037XLVN	RPU00	AIRLAKE AIRPORT	1		6	3		1	0	6	3	
Dakota	27037XSGS	RPU00	SOUTH ST PAUL MUNI-RICHARD E	1		5	2		1		5	2	
Dodge	2703900004	ITOTA	Energy Economics Inc			1	3				1	2	
Dodge	2703900028	SV004	Al-Corn Clean Fuel	11		77	5		12		84	6	
Dodge	2703900028	SV005	Al-Corn Clean Fuel	9		1	1	0	9		1	1	0
Dodge	2703900028	SV010	Al-Corn Clean Fuel	16		3	1	0	16		3	1	0
Dodge	2703900028	SV012	Al-Corn Clean Fuel	4		0	0		4		1	0	
Dodge	2703900028	SV017	Al-Corn Clean Fuel	2									
Dodge	2777700071	ITOTA	Buffalo Bituminous - Plant 1	18	15	4	3		24	21	6	4	
Dodge	2777700176	ITOTA	Buffalo Bituminous Plant 2	14	18	4	3		19	24	6	4	
Dodge	27039POTW5	RPS00	Kasson WWTP			1		2			1		2
Dodge	27039SW121	RPU00	Dodge County			20					20		
Dodge	27039XTOB	RPU00	DODGE CENTER			0	0				0	0	
Douglas	2704100002	ITOTA	Northern Food & Dairy Inc	16	16	0	2		18	17	0	2	
Douglas	2704100020	ITOTA	Midcon Asphalt Co - Alexandria	3	1	0	0		3	1	0	0	
Douglas	2704100021	SI001	Pope/Douglas Waste Management	23	11	3	1		31	15	4	1	
Douglas	2704100021	SI002	Pope/Douglas Waste Management	21	10	3	1		29	14	4	1	
Douglas	2704100027	ITOTA	Alexandria Extrusion Co	0		0	23		0		0	30	
Douglas	2704100032	NF001	Central Specialties Inc - Nonm	28	2	2			25	2	2		
Douglas	2704100034	NF001	Morical Bros Inc - Nonmetallic	7	0	1			6	0	1		
Douglas	2704100037	ITOTA	TWF Industries Inc - Alexandri			6	1		0		10	1	
Douglas	2777700229	SV100	Central Specialties Inc - Plan	7	8	2	3		10	10	3	4	
Douglas	2777700229	SV200	Central Specialties Inc - Plan	9	1	1			8	1	1		
Douglas	2777700269	SV100	Central Specialties Inc - Plan	9	9	2	3		12	13	3	5	
Douglas	2777700269	SV200	Central Specialties Inc - Plan	9	1	1			8	1	1		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Douglas	2777700288	SI001	Central Specialties Inc - Plan	5	5	1	2		7	7	2	3	
Douglas	2777700288	SI002	Central Specialties Inc - Plan	8	1	1			7	1	1		
Douglas	27041POTW	RPS00	Alexandria Lake Area Sanitary			4		9			4		9
Douglas	27041SW029	RPU00	Kluver			30					30		
Douglas	27041SW141	RPU00	La Grande			8					8		
Douglas	27041XAXN	RPU00	CHANDLER FIELD			1	0				1	0	
Douglas	27041XAXN	RPU00	CHANDLER FIELD	0		2	1		0		2	1	
Faribault	2704300024	BO001	Seneca Foods Corp - Blue Earth	2		0	0		2		0	0	
Faribault	2704300041	SI004	Corn Plus			22					24		
Faribault	2704300041	SI006	Corn Plus			22					24		
Faribault	2704300041	SV009	Corn Plus	14		109	23		15		118	25	
Faribault	2704300041	SV010	Corn Plus	9		72	6		10		79	6	
Faribault	2704300041	SV011	Corn Plus	24		3	2	1	24		3	2	1
Faribault	2704300047	ITOTA	Wells Concrete Products Co - P			15	1				21	2	
Faribault	27043SW069	RPU00	Faribault County			46					46		
Faribault	27043XSBU	RPU00	BLUE EARTH MUNI	0		1	1		0		1	1	
Fillmore	2704500047	NF001	Pederson Brothers Inc - Nonmet	8	0	1			7	1	1		
Fillmore	2704500049	FS001	Pro-Corn LLC				6					8	
Fillmore	2704500049	SV004	Pro-Corn LLC	11		59	10		12		64	11	
Fillmore	2704500049	SV011	Pro-Corn LLC	15		2	1	0	15		2	1	0
Fillmore	2704500049	SV017	Pro-Corn LLC	13		2	1	0	13		2	1	0
Fillmore	2704500049	SV018	Pro-Corn LLC	8		7	1	0	8		8	1	0
Fillmore	2704500049	SV021	Pro-Corn LLC	1		12	0		1		12	0	
Fillmore	2704500049	SV022	Pro-Corn LLC			5	0				5	0	
Fillmore	27045SW049	RPU00	Ironwood			9					9		
Fillmore	27045XFKA	RPU00	FILLMORE COUNTY			0					0	0	
Freeborn	2704700027	ITOTA	Progress Casting Group Inc - A	3		0	24		4		0	30	
Freeborn	2704700034	SI001	Magellan Pipeline Co LLC - Alb	14			0		16			1	
Freeborn	2704700035	ITOTA	Alamco Wood Products Inc	1			4		1			7	
Freeborn	2704700050	ITOTA	Albert Lea Medical Center	3									
Freeborn	2704700051	ITOTA	Lou-Rich Inc	1		10	2		2		17	4	
Freeborn	2704700055	FS003	Agra Resources Coop dba EXOL				5					7	
Freeborn	2704700055	FS005	Agra Resources Coop dba EXOL				9					13	
Freeborn	2704700055	SV007	Agra Resources Coop dba EXOL	30		159	16	1	31		190	17	1
Freeborn	2704700055	SV010	Agra Resources Coop dba EXOL	18		2	1	1	18		2	1	1
Freeborn	2704700055	SV016	Agra Resources Coop dba EXOL	22		3	2	1	22		3	2	1
Freeborn	2704700057	IOTHE	Ulland Brothers Inc South - No				4					2	
Freeborn	2704700057	NF001	Ulland Brothers Inc South - No	13	1	1			12	1	1		
Freeborn	2704700059	SV001	Alliance Pipeline - Albert Lea	49	1	1	5		40	1	1	5	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Freeborn	2777700289	ITOTA	Ulland Brothers Inc - Plant 3	10	16	4	3		13	22	6	4	
Freeborn	27047POTW	RPS00	Albert Lea WWTP			6		14			6		14
Freeborn	27047SW085	RPU00	Albert Lea			98					98		
Freeborn	27047XAEL	RPU00	ALBERT LEA MUNI			1	0				1	0	
Freeborn	27047XAEL	RPU00	ALBERT LEA MUNI	0		2	1		0		2	1	
Freeborn	27047XAEL	RPU00	ALBERT LEA MUNI			0					0		
Goodhue	2704900001	SI009	ADM - Red Wing				2					3	
Goodhue	2704900001	SI011	ADM - Red Wing				11					13	
Goodhue	2704900001	SI020	ADM - Red Wing	22	47	1	3	0	22	47	1	3	0
Goodhue	2704900002	BO001	Minnesota Correctional Facilit	2		0			2		0		
Goodhue	2704900005	SV001	NSP dba Xcel Energy - Red Wing	264	49		2		264	49		2	
Goodhue	2704900005	SV002	NSP dba Xcel Energy - Red Wing	259	39		3		259	39		3	
Goodhue	2704900007	SV005	USG Interiors Inc - Red Wing		5	41	63			7	59	91	
Goodhue	2704900007	SV009	USG Interiors Inc - Red Wing	198	968	0	10		249	1390	0	14	
Goodhue	2704900009	ITOTA	Minnesota Malting Co	16	4	0	3		18	5	0	3	
Goodhue	2704900038	SI001	Red Wing Solid Waste Boiler Fa	7	8	17	1		10	10	23	1	
Goodhue	2704900038	SI002	Red Wing Solid Waste Boiler Fa	7	8	17	1		10	10	23	1	
Goodhue	2704900062	SV001	Dairy Farmers of America Inc -	8	7	1	1	0	8	7	1	1	0
Goodhue	2704900062	SV004	Dairy Farmers of America Inc -	1			4		1			5	
Goodhue	2704900067	ITOTA	Cannon Equipment Midwest	2			1		4			2	
Goodhue	2704900077	IOTHE	Luhman's Construction Co - Non				2		6	0	1		
Goodhue	2704900077	NF001	Luhman's Construction Co - Non	7	0	1							
Goodhue	2704900078	NF001	Holm Bros Construction - Nonme	6	0	0			5	0	0		
Goodhue	27049POTW	RPS00	Red Wing WWTP			3		8			3		8
Goodhue	27049POTW	RPS00	Zumbrota WWTP			1		2			1		2
Goodhue	27049SW157	RPU00	Goodhue Cooperative			4					4		
Goodhue	27049SW174	RPU00	Goodhue County (Red Wing)			27					27		
Goodhue	27049XSYN	RPU00	STANTON AIRFIELD			1	0		0		1	0	
Grant	27051XY63	RPU00	ELBOW LAKE MUNI			1	0				1	0	
Hennepin	2700300168	BO002	Minneapolis Water Works - Frid	4		0	0		4		0	0	
Hennepin	2701900018	ITOTA	Automated Building Components			4					2		
Hennepin	2705300002	SV001	Hennepin County Energy Center	10		2	1		10		2	1	
Hennepin	2705300002	SV004	Hennepin County Energy Center	11		1	1		12		1	1	
Hennepin	2705300002	SV005	Hennepin County Energy Center	8		1	0		9		1	1	
Hennepin	2705300006	SV008	Smith Foundry	1		0	3		1		0	5	
Hennepin	2705300010	SI031	Northwest Airlines Inc - Mpls/	4		1	0		4		1	0	
Hennepin	2705300010	SI032	Northwest Airlines Inc - Mpls/	4		1	0		4		1	0	
Hennepin	2705300010	SI033	Northwest Airlines Inc - Mpls/	3		0	0		3		0	0	
Hennepin	2705300010	SI034	Northwest Airlines Inc - Mpls/	3	3	10	2		4	4	14	3	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Hennepin	2705300010	SI046	Northwest Airlines Inc - Mpls/	2	1	0	0		2	1	0	0	
Hennepin	2705300010	SI047	Northwest Airlines Inc - Mpls/	2	1	0	0		2	1	0	0	
Hennepin	2705300011	SV001	NRG Energy Center Minneapolis	78	270	3	7	1	78	270	3	7	1
Hennepin	2705300011	SV002	NRG Energy Center Minneapolis	115	0	5	2	1	115	0	5	2	1
Hennepin	2705300011	SV003	NRG Energy Center Minneapolis	134	0	6		2	134	0	6		2
Hennepin	2705300011	SV007	NRG Energy Center Minneapolis	59		10	0		49		8	0	
Hennepin	2705300013	ITOTA	Metropolitan Airports Commissi	41	4	1	13		23	2	1	7	
Hennepin	2705300020	SV021	Pechiney Plastic Packaging Inc	0		29			0		53		
Hennepin	2705300025	BO001	Dayton's Plant	2		0	0		2		0	0	
Hennepin	2705300032	ITOTA	Kurt Manufacturing Inc - Quinc	0		3	1		1		5	1	
Hennepin	2705300043	SV003	GAF Building Materials Corp	1		1	7		1		1	10	
Hennepin	2705300048	SV020	ADM Milling - A Flour Mill	6		1	0	0	6		1	0	0
Hennepin	2705300061	SI001	Abbott Northwestern Hospital						1	2	0	0	
Hennepin	2705300061	SI002	Abbott Northwestern Hospital	2	5	0	0		2	8	0	0	
Hennepin	2705300061	SI003	Abbott Northwestern Hospital	6	15	0	1		8	25	1	1	
Hennepin	2705300061	SI004	Abbott Northwestern Hospital	13	57	1	3	0	22	97	1	4	0
Hennepin	2705300075	ITOTA	Veterans Agency Medical Center	14		0	1		7		0	0	
Hennepin	2705300078	FS002	CS McCrossan Inc - Stationary				2					2	
Hennepin	2705300078	SI001	CS McCrossan Inc - Stationary	4		2	0		6		3	0	
Hennepin	2705300079	ITOTA	Honeywell Inc - Military Avion	4		5	0		2		3	0	
Hennepin	2705300089	BO001	Thermo King Corp - Minneapolis	3		0	0		3		0	0	
Hennepin	2705300089	GN001	Thermo King Corp - Minneapolis	13	1	1			11	1	1		
Hennepin	2705300089	IOTHE	Thermo King Corp - Minneapolis			2							
Hennepin	2705300098	ITOTA	Hitchcock Industries Inc	5		12	8		6		15	10	
Hennepin	2705300099	SI001	Prospect Foundry Inc	3	2		1		5	3		1	
Hennepin	2705300099	SI002	Prospect Foundry Inc				4					8	
Hennepin	2705300099	SI005	Prospect Foundry Inc			2	1				3	1	0
Hennepin	2705300099	SI007	Prospect Foundry Inc	2		0			3		0		
Hennepin	2705300099	SI009	Prospect Foundry Inc	3	2		1		5	3		1	
Hennepin	2705300112	ITOTA	934th Airlift Wing	11	0	3	1		6	0	2	0	
Hennepin	2705300120	ITOTA	Gannett Offset - Minneapolis	2		70	0		3		83	0	
Hennepin	2705300121	ITOTA	Midwest Asphalt - Eden Prairie	3	1	1	3		4	1	1	4	
Hennepin	2705300127	SV019	Owens Corning - Mpls Plant	16	83	3	22		21	114	5	30	
Hennepin	2705300149	ITOTA	Marshall Field's Distribution	11					6				
Hennepin	2705300151	ITOTA	Caterpillar Paving Products -B	1		21			1		37		
Hennepin	2705300154	ITOTA	Davis - Frost Inc	1		2	1		2		3	1	
Hennepin	2705300167	ITOTA	Minneapolis city of - Asphalt	2	0	0	1		2	0	0	1	
Hennepin	2705300174	ITOTA	Industrial Container Services	4		2	3		2		1	2	
Hennepin	2705300180	ITOTA	PGI Companies Inc	0		59			0		70		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Hennepin	2705300201	ITOTA	Nilfisk-Advance Inc	4		7	1		7		12	2	
Hennepin	2705300235	ITOTA	Donaldson Co Inc	4		49	0		6	0	85	0	
Hennepin	2705300241	ITOTA	General Mills Operations Inc -	10	11	3	2		6	6	2	1	
Hennepin	2705300251	SV001	Interplastic Corp - Minneapoli	3		2	0		4		4	0	
Hennepin	2705300267	ITOTA	Intermet Co - Minneapolis Plan	4		4	9		6		6	12	
Hennepin	2705300315	ITOTA	Bituminous Roadways Inc - Minn	1	0	0	1		2	0	0	1	
Hennepin	2705300322	ITOTA	Alpha Ceramics Inc	2		1			3		1		
Hennepin	2705300329	BO000	Methodist Hospital Park Nicoll	16	83	1	1	0	28	142	1	2	0
Hennepin	2705300343	ITOTA	Liberty Carton Co	3	1		0		5	2		1	
Hennepin	2705300365	ITOTA	Gaines & Hanson Printing Co	1		45	0		1		54	0	
Hennepin	2705300370	ITOTA	Joyner's Die Casting & Plating		6	4	5			7	5	7	
Hennepin	2705300376	ITOTA	Inno-Flex Corp	0		46			0		55		
Hennepin	2705300384	SV001	Banta Catalog Group - Minneapo	1		10			1		12		
Hennepin	2705300384	SV002	Banta Catalog Group - Minneapo	1		11			1		13		
Hennepin	2705300384	SV007	Banta Catalog Group - Minneapo	1		74			1		88		
Hennepin	2705300384	SV009	Banta Catalog Group - Minneapo	1		31			1		37		
Hennepin	2705300399	BO002	Minnesota Veterans Home - Minn	2		0	0		2		0	0	
Hennepin	2705300399	GN001	Minnesota Veterans Home - Minn	4	0	0			3	0	0		
Hennepin	2705300400	SV001	Covanta Hennepin Energy Resour	214	5	3	6		288	7	4	9	
Hennepin	2705300400	SV002	Covanta Hennepin Energy Resour	217	9	9	7		293	11	12	9	
Hennepin	2705300403	BO000	Mpls Community & Technical Col	1	2				1	2			
Hennepin	2705300406	ITOTA	Nordic Press Inc			14					17		
Hennepin	2705300440	ITOTA	Progress Casting Group Inc - P	10	3	12	27	0	13	3	16	34	0
Hennepin	2705300445	SV007	Flying Cloud Sanitary Landfill	1					1				
Hennepin	2705300467	ITOTA	Qwest Communications - Minneap	13	0	0			7	0			
Hennepin	2705300474	ITOTA	Qwest Communications Inc - Ply	3	0				2				
Hennepin	2705300477	SV003	Ritrama Inc	0		55			0		114		
Hennepin	2705300477	SV004	Ritrama Inc	0		2			0		4		
Hennepin	2705300477	SV005	Ritrama Inc	0		6			0		13		
Hennepin	2705300483	BO002	Dakota Growers Pasta Co - New	6		1	0	0	6		1	0	0
Hennepin	2705300484	ITOTA	Cypress Semiconductor (Minneso	8		11	1	0	22	0	30	2	0
Hennepin	2705300489	BO002	MCTO - Heywood Garage	2		0	0		2		0	0	
Hennepin	2705300498	SI001	Bureau of Engraving Inc	3		0	0		3		0	0	
Hennepin	2705300602	ITOTA	Rosemount Inc - Eden Prairie F	9	1	3	0		5	0	2	0	
Hennepin	2705300648	SV003	Anagram International Inc	2		20			2		35		
Hennepin	2705300649	ITOTA	Mentor Urology - Minneapolis	1		16			1		29		
Hennepin	2705300657	ITOTA	Ziegler Inc - Bloomington	2	4	5	1		1	2	3	0	
Hennepin	2705300663	SI011	University of Minnesota - Camp	2	0	0							
Hennepin	2705300695	BO001	Wells Fargo Home Mortgage	2		0			2		0		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Hennepin	2705300695	GN001	Wells Fargo Home Mortgage	2									
Hennepin	2705300710	ITOTA	Phoenix Packaging Inc	2		25	0		2		30	0	
Hennepin	2705300778	SV001	Styrotech Inc			5					10		
Hennepin	2705300778	SV003	Styrotech Inc			5					10		
Hennepin	2705300790	BO002	NRG Riverside Plant	13		2	1	0	13		2	1	0
Hennepin	2705300792	ITOTA	LeJeune Steel Co	1		6	0		1		10	1	
Hennepin	2705300801	ITOTA	Honeywell-Plymouth Operations			8	0				23	0	
Hennepin	2705300805	BO000	General Mills Inc - Minneapoli	0	4				0	6			
Hennepin	2705300805	BO001	General Mills Inc - Minneapoli	2		0	0		2		0	0	
Hennepin	2705300810	ITOTA	North Memorial Medical Center	11			1		6			0	
Hennepin	2705300813	GN001	Target Financial Services	5	0	0			4	0	0		
Hennepin	2705300815	GN001	United Health Technology Cente	3		0			2		0		
Hennepin	2705300827	ITOTA	Mail Handling Inc/Bindery Expr	0		13			0		16		
Hennepin	2705300830	ITOTA	Smyth Companies Inc - Minneapo	1		39			1		46		
Hennepin	2705300831	ITOTA	Shapco Printing Inc	0		43			0		51		
Hennepin	2705300834	ITOTA	GE Osmonics Minnetonka Facilit	1	1	36	3		2	2	63	6	
Hennepin	2705300847	ITOTA	Twin City Die Castings Co - Mp	2		0	2		2		0	3	
Hennepin	2705300850	IOTHE	North Star International Truck			2							
Hennepin	2705300854	ITOTA	Bystrom Bros Inc	0		13			0		24		
Hennepin	2705300857	IOTHE	Star Exhibits Inc - Shingle Cr			2							
Hennepin	2705300862	ITOTA	Process Displays Co	0		48			0		57		
Hennepin	2705300885	GN001	American Express Financial Cor	12	1	1			10	1	1		
Hennepin	2705300896	ITOTA	Holcim US Inc - Minneapolis Te				2						
Hennepin	2705300904	ITOTA	Shriner's Hospital	4			0		2				
Hennepin	2705300924	IOTHE	LaMettry's Collision Inc - Ede			3					2		
Hennepin	2705300925	IOTHE	LaMettry's Collision Inc - Ric			3							
Hennepin	2705300930	ITOTA	Master Collision Group LLC - B			4					2		
Hennepin	2705300936	BO001	8100 Building	2		0	0		2		0	0	
Hennepin	2705300937	ITOTA	Superior Ford Inc	0		3	0		0		2	0	
Hennepin	2705300938	IOTHE	Collision Partners Inc dba Col			2							
Hennepin	2705300954	IOTHE	ABRA Auto Body & Glass - Brook			2							
Hennepin	2705300956	IOTHE	Hopkins Auto Body			4					2		
Hennepin	2705300964	GN001	City of Minneapolis Traffic Ma	6		1			5		1		
Hennepin	2705300965	ITOTA	133rd Airlift Wing - MN Air Na	13	0	2	1		7	0	1	0	
Hennepin	2705300967	ITOTA	Buhler Inc	1		2	3		0		1	2	
Hennepin	2705300969	IOTHE	Iten Chevrolet-GEO			3					2		
Hennepin	2705300977	ITOTA	Jim Lupient Harold Chevrolet			3					2		
Hennepin	2705300994	BO002	Hennepin Technical College Ede	3		0	0		3		0	0	
Hennepin	2705300995	BO001	Hennepin Technical College - B	2		0	0		2		0	0	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Hennepin	2705300999	ITOTA	Master Collision Group LLC - P			3							
Hennepin	2705301006	ITOTA	MTS Systems Corp	0		4	1		0		2	1	
Hennepin	2705301010	IOTHE	CS McCrossan Inc - Nonmetallic				17					9	
Hennepin	2705301011	IOTHE	Midwest Asphalt Corp - Nonmeta				11					6	
Hennepin	2705301011	NF001	Midwest Asphalt Corp - Nonmeta	7	0	1			6	0	1		
Hennepin	2705301018	IOTHE	Barton Sand & Gravel Co - Nonm				13					7	
Hennepin	2705301018	NF001	Barton Sand & Gravel Co - Nonm	152	10	13			138	11	13		
Hennepin	2705301023	ITOTA	Graco Inc - David A Koch Cente	2		9	1		3		16	2	
Hennepin	2705301034	NF001	Hassan Sand & Gravel Inc - Non	2									
Hennepin	2705301050	SV001	University of MN - Twin Cities	75	7	1	1		77	7	1	1	
Hennepin	2705301050	SV002	University of MN - Twin Cities	53	2	8	5	0	56	2	9	5	0
Hennepin	2705301050	SV005	University of MN - Twin Cities	28	0	3	2	0	30	0	3	2	0
Hennepin	2705301050	SV006	University of MN - Twin Cities	6	2	1			6	2	1		
Hennepin	2705301050	SV007	University of MN - Twin Cities	11	1	1	1		11	1	1	1	
Hennepin	2705301052	ITOTA	Robert B Hill Co				10					5	
Hennepin	2705301053	GN001	Target Stores Corporate Headqu	3	0	0			2	0	0		
Hennepin	2705301055	GN001	Qwest Communications - 12075	5	0	0			4	0	0		
Hennepin	2705301062	ITOTA	Bucks Unpainted Furniture Inc			2	0						
Hennepin	2705301063	ITOTA	Duke's Body Shop			31					17		
Hennepin	2705301078	ITOTA	NAPCO International Inc	0		4	0				2	0	
Hennepin	2705301120	BO000	Minneapolis Institute of Arts	1	2				1	2			
Hennepin	2705301127	ITOTA	Retailer Services Corp	1			2		1			3	
Hennepin	2705301129	GN001	Qwest Communications - GV/Orch	2		0			2		0		
Hennepin	2777700208	SI004	Intex Corp	13	1	1			12	1	1		
Hennepin	2777700285	ITOTA	Commercial Asphalt Co - Plant	24	2	33	8		33	3	45	11	
Hennepin	27053POTW	RPS00	Rogers WWTP			1		3			1		3
Hennepin	27053SW058	RPU00	Hopkins			33					33		
Hennepin	27053SW058	RPU00	Hopkins	0		7			0		7		
Hennepin	27053SW061	RPU00	Woodlake			40					40		
Hennepin	27053SW061	RPU00	Woodlake	4	1	74	1		4	1	74	1	
Hennepin	27053XFCM	RPU00	FLYING CLOUD			1	0		0		1	0	
Hennepin	27053XFCM	RPU00	FLYING CLOUD	3	0	15	7		3	0	16	8	
Hennepin	27053XFCM	RPU00	FLYING CLOUD			0					0	0	
Hennepin	27053XMIC	RPU00	CRYSTAL			0					0		
Hennepin	27053XMIC	RPU00	CRYSTAL	2	0	11	5		2	0	12	6	
Hennepin	27053XMSP	RPU00	MINNEAPOLIS-ST PAUL INTL/WOL	1678	163	310	8		2663	259	492	13	
Hennepin	27053XMSP	RPU00	MINNEAPOLIS-ST PAUL INTL/WOL	62	9	6	0		104	15	10	1	
Hennepin	27053XMSP	RPU00	MINNEAPOLIS-ST PAUL INTL/WOL	3	0	24	9		6	0	41	14	
Hennepin	27053XMSP	RPU00	MINNEAPOLIS-ST PAUL INTL/WOL	1		5	3		1		6	3	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Hennepin	27053XMSP	RPU00	MINNEAPOLIS-ST PAUL INTL/WOL	0		1	0		0		2	0	
Hennepin	27053XMSP	RPU00	MINNEAPOLIS-ST PAUL INTL/WOL	372	32	268	12		372	32	268	12	
Houston	2705500020	NF001	Roverud Construction Inc - Non	14	1	1			12	1	1		
Houston	27055POTW5	RPS00	Eitzen WWTP			5		12			5		12
Houston	27055SW126	RPU00	Houston County			16					16		
Houston	27055XCHU	RPU00	HOUSTON COUNTY			0					0		
Hubbard	2705700002	FS009	Potlatch - Lumbermill - Bemidj				3					4	
Hubbard	2705700002	FS010	Potlatch - Lumbermill - Bemidj				2					3	
Hubbard	2705700002	SV005	Potlatch - Lumbermill - Bemidj	33	4	3	1		36	4	3	1	
Hubbard	2705700006	SV001	Lamb Weston/RDO Frozen	32	46	5	3	0	34	49	6	3	0
Hubbard	27057SW130	RPU00	Pickett			5					5		
Hubbard	27057SW146	RPU00	Leech Lake			51					51		
Hubbard	27057XPKD	RPU00	PARK RAPIDS MUNI-KONSHOK FIE			0					1	0	
Hubbard	27057XPKD	RPU00	PARK RAPIDS MUNI-KONSHOK FIE	0		1	1		0		1	1	
Isanti	2705900001	BO000	Minnesota Extended Treatment O	1	8				3	14		0	
Isanti	2705900001	BO002	Minnesota Extended Treatment O	2		0							
Isanti	2705900023	ITOTA	Arrow Tank & Engineering Co	2		7	1		3		12	1	
Isanti	2705900030	ITOTA	RCS Acquisition LLC dba Isanti	0			3		1			3	
Isanti	2705900031	ITOTA	Freeport Finishing Inc				6					8	
Isanti	2777700273	NF001	County Line Construction - Non	17	1	1			15	1	1		
Isanti	27059POTW1	RPS00	Cambridge WWTP			1		3			1		3
Isanti	27059SW129	RPU00	Isanti-Chisago County			26					26		
Isanti	27059XCBG	RPU00	CAMBRIDGE MUNI	0		1	1		0		1	1	
Itasca	2706100001	SV003	Blandin Paper/Rapids Energy Ce	376	43	70	7		405	43	77	8	
Itasca	2706100001	SV031	Blandin Paper/Rapids Energy Ce	21		3	2		23		3	2	
Itasca	2706100001	SV036	Blandin Paper/Rapids Energy Ce	3		2	1	0	3		2	1	0
Itasca	2706100001	SV037	Blandin Paper/Rapids Energy Ce	5	0	4	2	1	5	0	4	2	1
Itasca	2706100010	SV001	Potlatch - Grand Rapids	32	1	1	4		32	1	1	4	
Itasca	2706100010	SV002	Potlatch - Grand Rapids	32	1	1	4		32	1	1	4	
Itasca	2706100010	SV003	Potlatch - Grand Rapids	21			0	0	21			0	0
Itasca	2706100010	SV004	Potlatch - Grand Rapids	20		0	0	0	20		0	0	0
Itasca	2706100010	SV005	Potlatch - Grand Rapids	0			6		0			6	
Itasca	2706100039	ITOTA	NorthPrint International Inc -	1		69			1		83		
Itasca	2706100046	ITOTA	Bergquist Co - Big Fork						2		10		
Itasca	2706100059	ITOTA	Grand Rapids WWTP			7	1				4	1	
Itasca	2706100063	NF001	Brink Sand & Gravel Inc - Nonm	6	0	0			5	0	0		
Itasca	2706100065	NF001	Hawkinson Construction Co - No	14	1	1			13	1	1		
Itasca	2706199999	SV999	West Mine projected						1153	387		619	
Itasca	2706100068	ITOTA	Midland Research Center				3						

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Itasca	2777700024	ITOTA	Hawkinson Construction Co Inc	8	8	2	1		11	11	3	2	
Itasca	2777700112	ITOTA	Hawkinson Construction Co Inc	10	9	3	2		13	12	4	2	
Itasca	2777700290	NF001	Wm J Schwartz & Sons Inc - Non	3		0			2	0	0		
Itasca	27061SW073	RPU00	Iron Range			8					8		
Itasca	27061SW135	RPU00	Grand Rapids Area			4					4		
Itasca	27061SW135	RPU00	Grand Rapids Area	1	0	15	0		1	0	15	0	
Itasca	27061XGPZ	RPU00	GRAND RAPIDS/ITASCA CO-GORD(	0		1	0		0		2	1	
Itasca	27061XGPZ	RPU00	GRAND RAPIDS/ITASCA CO-GORD(	0		1	1		0		2	1	
Itasca	27061XGPZ	RPU00	GRAND RAPIDS/ITASCA CO-GORD(	1		0			1		0		
Jackson	2777700029	ITOTA	Kruse Paving Inc - A-20	3	2	0	0		4	3	1	0	
Jackson	27063SW101	RPU00	Jackson County			13					13		
Jackson	27063XMJQ	RPU00	JACKSON MUNI			1	0				1	0	
Kanabec	27065POTW1	RPS00	Mora WWTP			1		2			1		2
Kanabec	27065SW017	RPU00	East Central Mixed Mun (kanabe			66					66		
Kanabec	27065XJMR	RPU00	MORA MUNICIPAL	0		1	1		0		1	1	
Kandiyohi	2706700004	BO000	Willmar Regional Treatment Cen	5	26	0	0		9	45	0	1	
Kandiyohi	2706700004	BO002	Willmar Regional Treatment Cen	19		2	1	1	19		2	1	1
Kandiyohi	2706700015	SI001	Magellan Pipeline Co LLC - Wil	18			1		21			1	
Kandiyohi	2706700053	IOTHE	Duininck Bros Inc - Nonmetalli				11					6	
Kandiyohi	2706700053	NF001	Duininck Bros Inc - Nonmetalli	17	1	1			16	1	1		
Kandiyohi	2706700054	BO001	Ridgewater College	2		0	0		2		0	0	
Kandiyohi	2706700055	IOTHE	Central-Allied Enterprises - N				2						
Kandiyohi	2706700058	GN001	Willmar Municipal SW Substatio	2									
Kandiyohi	2777700018	ITOTA	Duininck Bros Inc - Port Plant	18	13	4	2		25	18	5	3	
Kandiyohi	2777700019	ITOTA	Duininck Bros Inc - Port Plant	13	8	3	2		19	10	4	2	
Kandiyohi	2777700042	ITOTA	Duininck Bros Inc - Port Plant	9	5	2	1		12	7	2	1	
Kandiyohi	2777700287	ITOTA	Duininck Bros Inc - Port Plant	34	21	7	5		47	29	10	6	
Kandiyohi	27067POTW1	RPS00	Willmar WWTP			5		13			5		13
Kandiyohi	27067SW079	RPU00	Kandiyohi			161					161		
Kandiyohi	27067XILL	RPU00	WILLMAR MUNI-JOHN L RICE FIEL			0					0		
Kandiyohi	27067XILL	RPU00	WILLMAR MUNI-JOHN L RICE FIEL	0		1	1		0		1	1	
Kittson	2706900014	SV001	Great Lakes Gas Transmission -	320		52	2		283		49	2	
Kittson	2706900014	SV002	Great Lakes Gas Transmission -	314		56	2		277		52	3	
Kittson	2706900014	SV003	Great Lakes Gas Transmission -	185		39	2		164		37	2	
Kittson	2706900014	SV004	Great Lakes Gas Transmission -	126		64	3		112		59	3	
Kittson	2706900014	SV005	Great Lakes Gas Transmission -	5	1	0	2		4	1	0	2	
Kittson	2706900015	SV002	Viking Gas Transmission - Humb	25		15	2		25		15	2	
Kittson	2706900015	SV003	Viking Gas Transmission - Humb	26		15	2		26		15	2	
Kittson	2706900015	SV004	Viking Gas Transmission - Humb	11		7	1		11		7	1	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Kittson	2706900015	SV005	Viking Gas Transmission - Humb	18		12	1		18		12	1	
Kittson	27069SW092	RPU00	Mar-Kit (Anderson-Kittson)			29					29		
Kittson	27069SW115	RPU00	Karlstad			2					2		
Kittson	27069XHCO	RPU00	HALLOCK MUNI	0		1	1		0		2	1	
Koochiching	2707100002	SV170	Boise Cascade Corp - Internati			7					10		
Koochiching	2707100002	SV173	Boise Cascade Corp - Internati		4	30				5	39		
Koochiching	2707100002	SV177	Boise Cascade Corp - Internati			7					10		
Koochiching	2707100002	SV178	Boise Cascade Corp - Internati			7					10		
Koochiching	2707100002	SV179	Boise Cascade Corp - Internati			7					10		
Koochiching	2707100002	SV183	Boise Cascade Corp - Internati			70					92		
Koochiching	2707100002	SV302	Boise Cascade Corp - Internati			7					10		
Koochiching	2707100002	SV320	Boise Cascade Corp - Internati	343	0	8			451	0	10		
Koochiching	2707100002	SV322	Boise Cascade Corp - Internati	0	3	7		157	1	4	10		206
Koochiching	2707100002	SV325	Boise Cascade Corp - Internati			3					4		
Koochiching	2707100002	SV326	Boise Cascade Corp - Internati			3					4		
Koochiching	2707100002	SV340	Boise Cascade Corp - Internati	24	0				31	0			
Koochiching	2707100002	SV420	Boise Cascade Corp - Internati	104	1	12	7	3	104	1	12	7	3
Koochiching	2707100002	SV431	Boise Cascade Corp - Internati	331	48	130	15	0	364	60	135	17	0
Koochiching	2707100002	SV440	Boise Cascade Corp - Internati	25	0	0	5	2	25	0	0	5	2
Koochiching	2707100002	SV450	Boise Cascade Corp - Internati	4		1	1	0	4		1	1	0
Koochiching	2707100002	SV460	Boise Cascade Corp - Internati	2		1	1	0	2		1	1	0
Koochiching	2707100002	SV901	Boise Cascade Corp - Internati	12	12	38	1		13	13	41	1	
Koochiching	2707100015	SI001	International Bildrite Inc	10		1	21		11		1	31	
Koochiching	27071POTW	RPS00	North Koochiching WWTP			2		4			2		4
Koochiching	27071SW191	RPU00	Koochiching			58					58		
Koochiching	27071SW225	RPU00	Northome Modified			6					6		
Koochiching	27071XINL	RPU00	FALLS INTL	0		2	1		1		0		
Koochiching	27071XINL	RPU00	FALLS INTL	1		3	1		0		4	1	
Koochiching	27071XINL	RPU00	FALLS INTL	1		1			1		3	1	
Lac_qui_Parle	2707300002	SV016	Ag Processing Inc - Dawson	2		0	4		2		0	5	
Lac_qui_Parle	2707300002	SV017	Ag Processing Inc - Dawson	2		0	4		2		0	5	
Lac_qui_Parle	2707300002	SV052	Ag Processing Inc - Dawson	25	17	3	2	1	25	17	3	2	1
Lac_qui_Parle	2707300003	ITOTA	Municipal Castings Inc	22	1	1	9		28	1	2	11	
Lac_qui_Parle	2707300016	SV002	Associated Milk Producers Inc	5		1	0		5		1	0	
Lac_qui_Parle	2707300016	SV006	Associated Milk Producers Inc	3		0	54		3		0	62	
Lac_qui_Parle	27073XDXX	RPU00	MADISON-LAC QUI PARLE COUNT			0					0		
Lake	2707500003	SV261	Northshore Mining Co - Silver	99	9		1		121	11	3	5	
Lake	2707500003	SV114	Northshore Mining Co - Silver	295	29		38		296	29	7	38	
Lake	2707500003	SV105	Northshore Mining Co - Silver	307	30		39		294	29	5	39	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Lake	2707500003	SV266	Northshore Mining Co - Silver						481	21		37	
Lake	2707500005	FS017	Duluth Missabe & Iron Range Ra				3					4	
Lake	2707500019	SV001	Louisiana-Pacific Corp - Two H	17	0	2	4	0	18	0	2	4	0
Lake	27075POTW1	RPS00	Two Harbors WWTP			1		2			1		2
Lake	27075SW140	RPU00	Lake County			34					34		
Lake	27075XBFW	RPU00	SILVER BAY MUNICIPAL			0					0		
Lake	27075XTWM	RPU00	RICHARD B HELGESON			1	0				1	0	
Lake_of_the_V	27077SW171	RPU00	Lake of the Woods			5					5		
Lake_of_the_V	27077XBDE	RPU00	BAUDETTE INTL			0					0		
Lake_of_the_V	27077XBDE	RPU00	BAUDETTE INTL	0		1	0		0		1	0	
Le_Sueur	2707900007	ITOTA	River Bend Asphalt Co	11	10	3	2		15	13	4	3	
Le_Sueur	2707900009	SI001	Unimin Minnesota Corp - Kasota	3		0			4		0		
Le_Sueur	2707900017	SI016	Le Sueur Inc				6					11	
Le_Sueur	2707900019	SI001	Unimin Minnesota Corp - Le Sue	5		1			5		1		
Le_Sueur	2707900022	BO002	Seneca Foods Corp - Montgomery	5		1	0	0	5		1	0	0
Le_Sueur	2707900034	SI001	DAVISCO International Inc - Le	2		0	1		2		0	1	
Le_Sueur	2707900043	IOTHE	Johnson Aggregates - Nonmetall				7					4	
Le_Sueur	2707900043	NF001	Johnson Aggregates - Nonmetall	6	0	1			6	0	0		
Le_Sueur	2777700275	ITOTA	River Bend Asphalt Co - Plant	7	4	1	1		10	5	2	1	
Le_Sueur	27079SW063	RPU00	MN Sanitation Services			8					8		
Le_Sueur	27079SW067	RPU00	Tellijohn			55					55		
Le_Sueur	27079SW067	RPU00	Tellijohn	0		4			0		4		
Le_Sueur	27079SW091	RPU00	Sun Prairie			7					7		
Le_Sueur	27079X12Y	RPU00	LE SUEUR MUNI			0					0		
Lyon	2708300001	ITOTA	Farmers Coop Elevator Co - Cot				3						
Lyon	2708300019	ITOTA	McLaughlin & Schulz Inc - Plan	5	7	1	1		7	10	1	1	
Lyon	2708300038	FS003	ADM Corn Processing - Marshall				13					17	
Lyon	2708300038	FS004	ADM Corn Processing - Marshall				2					2	
Lyon	2708300038	SV006	ADM Corn Processing - Marshall		8	29	8			10	35	9	
Lyon	2708300038	SV009	ADM Corn Processing - Marshall		3		2			4		2	
Lyon	2708300038	SV010	ADM Corn Processing - Marshall		1	27				1	36		
Lyon	2708300038	SV011	ADM Corn Processing - Marshall	4	1	17	2		5	1	22	3	
Lyon	2708300038	SV012	ADM Corn Processing - Marshall	2	1				2	2			
Lyon	2708300038	SV013	ADM Corn Processing - Marshall	4		4			6		5		
Lyon	2708300038	SV014	ADM Corn Processing - Marshall	5					7				
Lyon	2708300038	SV016	ADM Corn Processing - Marshall	234	432	1	0		222	410	1	0	
Lyon	2708300038	SV019	ADM Corn Processing - Marshall	34	0	4	3	1	34	0	4	3	1
Lyon	2708300038	SV020	ADM Corn Processing - Marshall	30	0	6	3	1	30	0	6	3	1
Lyon	2708300046	ITOTA	Koch Materials - Marshall Asph	1		2	6		2		2	8	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Lyon	2708300055	NF001	McLaughlin & Schulz Inc - Nonm	3		0			2	0	0		
Lyon	2708300056	SV001	Northern Border Pipeline - Com	95	3	2	6		79	3	1	6	
Lyon	2708300057	GN001	Weiner Memorial Medical Center	10	1	1			9	1	1		
Lyon	27083POTW	RPS00	Marshall WWTP			3		8			3		8
Lyon	27083SW023	RPU00	Lyon County			140					140		
Lyon	27083XMML	RPU00	MARSHALL MUNI-RYAN FIELD	0		2	1		0		4	1	
Lyon	27083XMML	RPU00	MARSHALL MUNI-RYAN FIELD	0		1	0		0		1	1	
Mahnomen	2708700005	BO000	ISD 432 - Mahnomen Public Scho	1		1	2		1		1	2	
Mahnomen	27087SW122	RPU00	Mahnomen County			6					6		
Mahnomen	27087X3N8	RPU00	MAHNOMEN COUNTY										
Marshall	2708900012	SV001	Great Lakes Gas Transmission -	143	2	1	4		126	2	1	4	
Marshall	2708900012	SV002	Great Lakes Gas Transmission -	119	2	1	3		105	2	1	3	
Marshall	2708900026	NF001	M & J Construction Co - Nonmet	8	0	1			7	1	1		
Marshall	2708900027	NF001	Schenkey Inc - Nonmetallic	13	1	1			12	1	1		
Martin	2709100003	ITOTA	Watonwan Farm Service				4					2	
Martin	2709100043	SV003	Northern Border Pipeline - Com	94	3	2	6		78	3	1	6	
Martin	2709100057	NF001	W Hodgman & Sons Inc - Nonmeta	6	0	1			6	0	0		
Martin	2777700027	ITOTA	W Hodgman & Sons Inc - Plant 9	18	11	4	3		25	15	5	3	
Martin	27091POTW	RPS00	Fairmont WWTP			1		4			1		4
Martin	27091SW076	RPU00	Gofer			29					29		
Martin	27091XFRM	RPU00	FAIRMONT MUNI			1	0		0		2	1	
Martin	27091XFRM	RPU00	FAIRMONT MUNI			0					0		
McLeod	2708500035	BO002	Seneca Foods Corp - Glencoe	6		1	0	0	6		1	0	0
McLeod	2708500047	SI001	Waste Management - Spruce Ridg	5	3	2	4		5	3	2	4	
McLeod	2708500049	SI006	3M - Hutchinson Tape Manufactu			12					24		
McLeod	2708500049	SV065	3M - Hutchinson Tape Manufactu			56					115		
McLeod	2708500049	SV156	3M - Hutchinson Tape Manufactu			25					25		
McLeod	2708500049	SV199	3M - Hutchinson Tape Manufactu	0		7			0		13		
McLeod	2708500049	SV212	3M - Hutchinson Tape Manufactu	1		35			1		35		
McLeod	2708500049	SV213	3M - Hutchinson Tape Manufactu	2		15			2		15		
McLeod	2708500049	SV217	3M - Hutchinson Tape Manufactu	3		0	0		3		0	0	
McLeod	2708500049	SV219	3M - Hutchinson Tape Manufactu	4		0	0		4		0	0	
McLeod	2708500049	SV221	3M - Hutchinson Tape Manufactu	7	3	0	0		7	3	0	0	
McLeod	2708500049	SV222	3M - Hutchinson Tape Manufactu	49	168	1	2	1	49	168	1	2	1
McLeod	2708500049	SV223	3M - Hutchinson Tape Manufactu	50	169	1	2	1	50	169	1	2	1
McLeod	2708500049	SV257	3M - Hutchinson Tape Manufactu			2					2		
McLeod	2708500053	ITOTA	Associated Milk Producers Inc	6	4		0		6	5		0	
McLeod	27085POTW	RPS00	Glencoe WWTP			1		3			1		3
McLeod	27085POTW	RPS00	Hutchinson WWTP			3		8			3		8

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Meeker	2709300004	ITOTA	Mid-Minnesota Hot Mix Inc - Li	2	1	0	0		3	1	0	0	
Meeker	2709300033	ITOTA	RIE Coatings			11	0				18	0	
Meeker	27093POTW1	RPS00	Litchfield WWTP			3		6			3		6
Meeker	27093SW070	RPU00	Meeker County **			26					26		
Mille_Lacs	2706500025	NF001	Buckley Construction II - Nonm	7	0	1			6	0	1		
Mille_Lacs	2709500003	ITOTA	Smith System Manfacturing Co	1			2		1			4	
Mille_Lacs	2709500004	SV001	Viking Gas Transmission - Mila	142		22	2		142		22	2	
Mille_Lacs	2709500004	SV002	Viking Gas Transmission - Mila	143		23	2		143		23	2	
Mille_Lacs	2709500004	SV003	Viking Gas Transmission - Mila	141		22	2		141		22	2	
Mille_Lacs	2709500004	SV006	Viking Gas Transmission - Mila	23	0	0	1		19	0	0	1	
Mille_Lacs	2709500006	ITOTA	Woodcraft Industries - Foresto	12	1	4	10		7	0	2	8	
Mille_Lacs	27095SW082	RPU00	Mille Lacs			3					3		
Morrison	2709700019	BO000	St Gabriel's Hospital	2		2	6		2		2	6	
Morrison	2709700019	BO001	St Gabriel's Hospital	2		0			2		0		
Morrison	2709700019	GN001	St Gabriel's Hospital	9	1	1			7	1	1		
Morrison	2709700023	ITOTA	Camp Ripley	6	0	6	1	0	3		3	1	0
Morrison	2709700025	SI032	Larson-Glastron Boats Inc	0		16	0		0		30	0	
Morrison	2709700026	FS004	Central MN Ethanol Cooperative				3					5	
Morrison	2709700026	SV008	Central MN Ethanol Cooperative	74	0	53	12	1	79	0	57	13	1
Morrison	2709700027	IOTHE	Little Falls Machine Inc			5					3		
Morrison	2709700037	NF001	Kingsway Construction Inc - No	3	0	0			3	0	0		
Morrison	2709700038	NF001	Tri-City Paving Inc - Nonmetal	47	3	4			43	3	4		
Morrison	2709700040	NF001	DLL Excavating - Nonmetallic	3		0			2	0	0		
Morrison	27097POTW1	RPS00	Little Falls WWTP			2		5			2		5
Morrison	27097SW015	RPU00	Greater Morrison			4					4		
Morrison	27097XLXL	RPU00	LITTLE FALLS/MORRISON COUNTY								0		
Morrison	27097XLXL	RPU00	LITTLE FALLS/MORRISON COUNTY	0		2	1		0		2	1	
Mower	2709900002	SV001	Hormel Foods Corp - Austin	55	122	2	3	1	55	122	2	3	1
Mower	2709900011	BO002	Austin Utilities - 4th Ave Pla	2		0	0		2		0	0	
Mower	2709900011	GN001	Austin Utilities - 4th Ave Pla	15		3			14		2		
Mower	2709900050	ITOTA	Featherlite Graphics	0		7					4		
Mower	27099POTW1	RPS00	Austin WWTP			5		12			5		12
Mower	27099POTW1	RPS00	Austin WWTP			2		5			2		5
Mower	27099SW062	RPU00	Red Rock			80					80		
Mower	27099XAUM	RPU00	AUSTIN MUNI										
Mower	27099XAUM	RPU00	AUSTIN MUNI	0		2	1		0		2	1	
Murray	2710100020	ITOTA	ADM Corn Processing - Dovray				8					4	
Murray	27101SW104	RPU00	Murray County			14					14		
Nicollet	2701300093	ITOTA	Phenix Manufacturing Co Inc -	2	1		10		3	1		15	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Nicollet	2710300001	BO000	St Peter Regional Treatment Ce	10	49	0	1		16	85	1	1	0
Nicollet	2710300001	BO002	St Peter Regional Treatment Ce	2		0	0		2		0	0	
Nicollet	2710300013	ITOTA	Gustavus Adolphus College	6		0	0		4			0	
Nicollet	2710300023	SI003	DAVISCO International Inc - Ni	1			2		1			3	
Nicollet	2710300032	ITOTA	Hewitt Machine & Manufacturing	0		12	0		0		21	1	
Nobles	2710500001	SV001	Swift Pork Co - Worthington	8		1	1	0	8		1	1	0
Nobles	2710500001	SV002	Swift Pork Co - Worthington	10		1	1	0	10		1	1	0
Nobles	2710500018	ITOTA	McLaughlin & Schulz Inc - Wort	2	3	0	0		3	4	0	0	
Nobles	2710500051	IOTHE	Pronk Ready Mix Inc - Nonmetal				4					2	
Nobles	27105POTW	RPS00	Worthington WWTP			2		6			2		6
Nobles	27105SW011	RPU00	Nobles County			65					65		
Norman	2710700012	SV001	Viking Gas Transmission - Ada	240		27	3		240		27	3	
Norman	2710700012	SV002	Viking Gas Transmission - Ada	179		22	2		179		22	2	
Norman	2710700012	SV003	Viking Gas Transmission - Ada	462		59	6		462		59	6	
Norman	2710700012	SV006	Viking Gas Transmission - Ada	25	0	0	1		21	0	0	1	
Olmsted	2710900003	ITOTA	Rochester Sand & Gravel - Plan	11	33	5	3		15	46	7	4	
Olmsted	2710900004	ITOTA	All American Cooperative - Ste	4			8		2			4	
Olmsted	2710900006	SV003	IBM - Rochester	3		0	0		3		0	0	
Olmsted	2710900006	SV049	IBM - Rochester	12		2	1		12		2	1	
Olmsted	2710900010	SV001	Associated Milk Producers Inc	20	44	1	1	0	20	44	1	1	0
Olmsted	2710900015	ITOTA	Shamrock Enterprises - Oronoco	2	0	1	2		2	0	1	2	
Olmsted	2710900032	SI005	Quest International	3		0			3		0	0	
Olmsted	2710900036	BO002	Seneca Foods Corp - Rochester	7		1	1	0	7		1	1	0
Olmsted	2710900055	ITOTA	Rochester Sand & Gravel - Plan	2	6	1	1		3	9	1	1	
Olmsted	2710900084	SI014	Mayo Medical Center - Rocheste	25		1	1		27		1	1	
Olmsted	2710900084	SI015	Mayo Medical Center - Rocheste	26		1	1		27		1	1	
Olmsted	2710900084	SI016	Mayo Medical Center - Rocheste	95	0	4	0		102	1	5	1	0
Olmsted	2710900084	SI017	Mayo Medical Center - Rocheste	68	10	3	0	0	74	18	3	0	0
Olmsted	2710900084	SI028	Mayo Medical Center - Rocheste	7		1	1		7		1	1	
Olmsted	2710900084	SI029	Mayo Medical Center - Rocheste	6		1	1		7		1	1	
Olmsted	2710900084	SI030	Mayo Medical Center - Rocheste	10		1	1		11		2	1	
Olmsted	2710900084	SI032	Mayo Medical Center - Rocheste	2			0		2	0		0	
Olmsted	2710900084	SI039	Mayo Medical Center - Rocheste	7	3	31			11	5	47		
Olmsted	2710900084	SI043	Mayo Medical Center - Rocheste	77	1	0	2		64	1	0	2	
Olmsted	2710900084	SI048	Mayo Medical Center - Rocheste	1	6				1	6			
Olmsted	2710900095	NF001	Builders Sand & Gravel Co - No	8	0	1			7	1	1		
Olmsted	2710900097	IOTHE	Milestone Materials - Nonmetal				10					5	
Olmsted	2710900097	NF001	Milestone Materials - Nonmetal	108	7	9			98	8	9		
Olmsted	2710900098	IOTHE	Shamrock Enterprises - Nonmeta				8					4	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Olmsted	2710900098	NF001	Shamrock Enterprises - Nonmeta	13	1	1			11	1	1		
Olmsted	2777700120	ITOTA	Mathy Construction Co - Plant	2	10	1	1		3	14	1	2	
Olmsted	2777700228	ITOTA	Mathy Construction Co - Plant	7	16	3	2		10	22	4	3	
Olmsted	27109POTW	RPS00	Stewartville WWTP			1		2			1		2
Olmsted	27109SW005	RPU00	Olmsted County (Roch/Locoshona			153					153		
Olmsted	27109SW355	RPU00	Olmsted County-Kalmar			49					49		
Olmsted	27109XRST	RPU00	ROCHESTER INTERNATIONAL	20	2	5			31	4	7	0	
Olmsted	27109XRST	RPU00	ROCHESTER INTERNATIONAL	0		2	1		0		3	1	
Olmsted	27109XRST	RPU00	ROCHESTER INTERNATIONAL	1		5	2		1		5	2	
Olmsted	27109XRST	RPU00	ROCHESTER INTERNATIONAL	0		2	1		0		3	1	
Olmsted	27109XRST	RPU00	ROCHESTER INTERNATIONAL	7	1	5	0		7	1	5	0	
Otter_Tail	2711100021	ITOTA	Bongards' Creameries Inc - Per	16		0	22		18		0	24	
Otter_Tail	2711100024	ITOTA	Dairy Farmers of America Inc -	15	24		12		16	26		13	
Otter_Tail	2711100036	SI001	Perham Resource Recovery Facil	25	13	3	1		34	17	5	1	
Otter_Tail	2711100036	SI002	Perham Resource Recovery Facil	19	9	2	1		25	13	3	1	
Otter_Tail	2711100048	SI001	Fergus Falls Resource Recovery	22	22	1	6		29	30	1	8	
Otter_Tail	2711100048	SI002	Fergus Falls Resource Recovery	32	19	1	5		44	26	1	6	
Otter_Tail	2711100073	NF001	Aggregate Industries Inc - P-1	5	0	0			4	0	0		
Otter_Tail	2777700063	ITOTA	Mark Sand & Gravel Acquisition	22	21	5	3		31	29	7	4	
Otter_Tail	2777700306	ITOTA	Mark Sand & Gravel Acquisition	3	0		6		1			3	
Otter_Tail	27111POTW	RPS00	Pelican Rapids WWTP			1		2			1		2
Otter_Tail	27111POTW	RPS00	Fergus Falls WWTP			3		7			3		7
Otter_Tail	27111SW086	RPU00	Battle Lake Area			8					8		
Otter_Tail	27111SW178	RPU00	Northeast Ottertail			22					22		
Otter_Tail	27111SW184	RPU00	Fergus Falls			40					40		
Otter_Tail	27111XFFM	RPU00	FERGUS FALLS MUNI-EINAR MICK			1	0		0		2	1	
Pennington	2711300021	IOTHE	Concrete Inc - Nonmetallic				4					2	
Pennington	27113XTVF	RPU00	THIEF RIVER FALLS REGIONAL	1		3	1		1		3	1	
Pine	2711500011	SV001	Great River Energy - Rock Lake	2	1								
Pine	2711500023	IOTHE	DAKA Corp			2							
Pine	2711500029	IOTHE	Hopkins Sand & Gravel Inc - No				3					2	
Pine	2711500029	NF001	Hopkins Sand & Gravel Inc - No	2									
Pine	2711500031	GN001	Grand Casino Hinckley	3	0	0			2	0	0		
Pine	27115SW019	RPU00	Korf Bros.			25					25		
Pipestone	2711700015	ITOTA	Cargill Inc - Pipestone	2			6		1			3	
Pipestone	2711700023	ITOTA	ADM Corn Processing - Holland				7					4	
Pipestone	27117SW120	RPU00	Pipestone County			16					16		
Polk	2711900001	FS005	American Crystal Sugar - Crook				13					14	
Polk	2711900001	SV001	American Crystal Sugar - Crook	141	123	1	6		134	117	2	6	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Polk	2711900001	SV002	American Crystal Sugar - Crook	159	117	1	7		151	111	1	7	
Polk	2711900001	SV003	American Crystal Sugar - Crook	67	64	1	2		63	60	1	2	
Polk	2711900001	SV019	American Crystal Sugar - Crook	22		1		0	22		1		0
Polk	2711900001	SV020	American Crystal Sugar - Crook	31		1		0	31		1		0
Polk	2711900002	SV001	American Crystal Sugar - E Gra	330	357	1	19		313	339	1	18	
Polk	2711900002	SV002	American Crystal Sugar - E Gra	283	328	1	21		268	311	1	20	
Polk	2711900002	SV003	American Crystal Sugar - E Gra	15	0	2	25	1	15	0	2	25	1
Polk	2711900002	SV004	American Crystal Sugar - E Gra	15	0	2	31	0	15	0	2	31	0
Polk	2711900002	SV005	American Crystal Sugar - E Gra	14		2	38	0	14		2	38	0
Polk	2711900002	SV016	American Crystal Sugar - E Gra	6		1	0	0	6		1	0	0
Polk	2711900002	SV017	American Crystal Sugar - E Gra	1	1	0	1		1	1	0	1	
Polk	2711900016	SI004	University of Minnesota - Croo	14	19		2		14	19		2	
Polk	2711900029	SV001	Viking Gas Transmission - Angu	152		23	2		152		23	2	
Polk	2711900029	SV002	Viking Gas Transmission - Angu	154		23	3		154		23	3	
Polk	2711900029	SV003	Viking Gas Transmission - Angu	458		59	6		458		59	6	
Polk	2711900029	SV006	Viking Gas Transmission - Angu	16	0	0	1		14	0	0	1	
Polk	2711900051	SI001	Polk Cnty Solid Waste Resource	16	17	37	1		22	23	50	2	
Polk	2711900051	SI002	Polk Cnty Solid Waste Resource	16	17	37	1		22	23	50	2	
Polk	2711900068	IOTHE	Donarski Bros Inc - Nonmetalli				5					3	
Polk	2711900068	NF001	Donarski Bros Inc - Nonmetalli	2		0			2		0		
Polk	2711900069	IOTHE	J & S Gravel - Nonmetallic				7					4	
Polk	2711900069	NF001	J & S Gravel - Nonmetallic	11	1	1			10	1	1		
Polk	2777700254	ITOTA	Northern Paving Inc - Base 5	13	5	3	1		18	7	3	2	
Polk	27119SW124	RPU00	Polk County			100					100		
Polk	27119XCKN	RPU00	CROOKSTON MUNI KIRKWOOD FL			0					1	0	
Polk	27119XCKN	RPU00	CROOKSTON MUNI KIRKWOOD FL	0		2	1		0		2	1	
Polk	27119XFSE	RPU00	FOSSTON MUNI			1	0				1	0	
Pope	2712100017	IOTHE	MHC Inc - Glenwood								3		
Pope	27121XGHW	RPU00	GLENWOOD MUNI			0	0				0	0	
Ramsey	2705300004	ITOTA	Schwing America Inc	12	1	26	22	8	21	1	46	24	8
Ramsey	2712300016	SV084	3M - St Paul Main Plant	14	54	1	3	0	14	54	1	3	0
Ramsey	2712300016	SV085	3M - St Paul Main Plant	18	68	1	3	0	18	68	1	3	0
Ramsey	2712300016	SV086	3M - St Paul Main Plant	9	29	0	1	0	9	29	0	1	0
Ramsey	2712300019	SV001	Minnesota Brewing/Gopher State	13	0	2	1	0	13	0	2	1	0
Ramsey	2712300019	SV003	Minnesota Brewing/Gopher State	3		1	2		3		2	2	
Ramsey	2712300019	SV010	Minnesota Brewing/Gopher State			11					12		
Ramsey	2712300020	ITOTA	ADM Grain - St Paul - Elevator				4					3	
Ramsey	2712300021	SV026	Silgan Containers Mfg Corp - S			8					17		
Ramsey	2712300022	SI003	University of St Thomas	2		0	0		2		0	0	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Ramsey	2712300024	ITOTA	Smyth Companies Inc - St Paul	0		70			0		84		
Ramsey	2712300030	ITOTA	Regions Hospital	6	8	0	1		3	4		0	
Ramsey	2712300039	SI001	Ford Motor Co - Twin Cities As	7		1	1	0	7		1	1	0
Ramsey	2712300039	SV001	Ford Motor Co - Twin Cities As	4		0	0		4		0	0	
Ramsey	2712300039	SV002	Ford Motor Co - Twin Cities As	8		1	1	0	8		1	1	0
Ramsey	2712300039	SV010	Ford Motor Co - Twin Cities As								3		
Ramsey	2712300039	SV020	Ford Motor Co - Twin Cities As	11		238	32	0	11		489	64	0
Ramsey	2712300039	SV021	Ford Motor Co - Twin Cities As	3		4	0		3		8	0	
Ramsey	2712300039	SV022	Ford Motor Co - Twin Cities As	2		10	0		2		20	0	
Ramsey	2712300042	BO000	Macalester College	2	10				3	17		0	
Ramsey	2712300045	BO000	College of St Catherine	0	2				1	3			
Ramsey	2712300045	BO002	College of St Catherine	4		1	0		4		1	0	
Ramsey	2712300053	SV016	Metropolitan Wastewater Treatm	32	53	1			43	72	1		
Ramsey	2712300053	SV018	Metropolitan Wastewater Treatm	6		1	0	0	6		1	0	0
Ramsey	2712300053	SV019	Metropolitan Wastewater Treatm	7		1	1	0	7		1	1	0
Ramsey	2712300053	SV028	Metropolitan Wastewater Treatm	2	0	0			2	0	0		
Ramsey	2712300055	SV002	North Star Steel Minnesota - S	52	18	40	12		65	23	51	16	
Ramsey	2712300055	SV004	North Star Steel Minnesota - S	79	0	4	2	1	79	0	4	2	1
Ramsey	2712300056	ITOTA	Pier Foundry		1	3	1			1	4	1	
Ramsey	2712300063	SV001	District Energy St Paul Inc-Ha	188	709	1	119		188	709	1	119	
Ramsey	2712300063	SV002	District Energy St Paul Inc-Ha	5		1	0	0	5		1	0	0
Ramsey	2712300063	SV003	District Energy St Paul Inc-Ha	3		0	0		3		0	0	
Ramsey	2712300088	SI002	Versa Iron & Machine				6					12	
Ramsey	2712300093	ITOTA	Bethesda Rehabilitation Hospit	3									
Ramsey	2712300108	BO002	Hamline University	5		1	0	0	5		1	0	0
Ramsey	2712300139	ITOTA	St Joseph's Hospital - HealthE	4	1		0		2	0			
Ramsey	2712300149	ITOTA	T A Schifsky & Sons Inc	1	0	0	1		2	0	1	2	
Ramsey	2712300186	ITOTA	Midwest Asphalt - Plant 2 - Ne	4	0	12	3		6	1	16	4	
Ramsey	2712300187	ITOTA	Peavey Red Rock Elevator - St				10					5	
Ramsey	2712300189	ITOTA	City of St Paul Asphalt Plant	1		0	1		1	0	0	1	
Ramsey	2712300213	ITOTA	Koch Materials - St Paul Aspha	1		0	2		1		0	2	
Ramsey	2712300254	ITOTA	HealthEast Midway Health Servi	2									
Ramsey	2712300273	IOTHE	Rihm Motor Co			2							
Ramsey	2712300280	ITOTA	St Paul Community & Technical	3									
Ramsey	2712300288	SV015	Twin City Concrete Products Co	3					3				
Ramsey	2712300333	BO002	Energy Park Utility Co	3		0	0		3		0	0	
Ramsey	2712300347	SV001	Commercial Asphalt Co - Plant	3	0	6	2		4	1	8	3	
Ramsey	2712300398	ITOTA	Ashland Distribution			3					2		
Ramsey	2712300410	SV003	Waldorf Corp - A Rock-Tenn Co	1		112			1		143		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Ramsey	2712300410	SV004	Waldorf Corp - A Rock-Tenn Co	1		3			1		4		
Ramsey	2712300420	ITOTA	Qwest Communications - St Paul	7	0				4				
Ramsey	2712300433	BO001	Minnesota Historical Society	3		0	0		3		0	0	
Ramsey	2712300436	BO001	Bethel College and Seminary	2		0	0		2		0	0	
Ramsey	2712300456	ITOTA	Ramsey County Government Cente	2	0								
Ramsey	2712300458	ITOTA	Weyerhaeuser Co - White Bear -	2			2		2			3	
Ramsey	2712300489	GN001	State of MN - Transportation B	3	0	0			3	0	0		
Ramsey	2712300496	ITOTA	HB Fuller Co - Corporate Campu	3	0	1	0		6	0	1	0	
Ramsey	2712300498	ITOTA	Impressions Inc			68					81		
Ramsey	2712300601	SI001	Fox Packaging Inc			13					22	0	
Ramsey	2712300605	ITOTA	Americraft Carton Inc			39			0		46		
Ramsey	2712300606	ITOTA	Tursso Companies Inc			22					27		
Ramsey	2712300614	IOTHE	Quality Manufacturing Inc			5					3		
Ramsey	2712300622	ITOTA	Cardiac Pacemakers Inc	5	0	8	0		3		4	0	
Ramsey	2712300624	ITOTA	Brown-Wilbert Vault Co - Rosev			4	1				6	1	
Ramsey	2712300626	ITOTA	Certified Painting Inc	0		12	1		0		22	2	
Ramsey	2712300640	ITOTA	St John's Hospital (HealthEast	3	1	0			2	1			
Ramsey	2712300666	ITOTA	Buerkle Buick-Honda Co	2		5	0		1		3	0	
Ramsey	2712300680	ITOTA	Brenntag Great Lakes LLC	0		3					2		
Ramsey	2712300690	NF001	Crushers Inc - Nonmetallic	4	0	0			4	0	0		
Ramsey	2712300694	SI002	3M - Administrative Offices -	17	43	1	1	0	17	43	1	1	0
Ramsey	2712300694	SI003	3M - Administrative Offices -	61	120	2	2	1	61	120	2	2	1
Ramsey	2712300694	SI004	3M - Administrative Offices -	134	265	4	4	2	134	265	4	4	2
Ramsey	2712300694	SI005	3M - Administrative Offices -	149	224	5	5	2	149	224	5	5	2
Ramsey	2712300694	SI006	3M - Administrative Offices -	5	1	2	1	0	5	1	2	1	0
Ramsey	2712300702	GN001	MNDOT Metro Div Hq - Waters Ed	2									
Ramsey	2712300709	IOTHE	LaMettry's Collision Inc - Map			2							
Ramsey	2712300717	ITOTA	Metro Council - East Metro Tra	2		1							
Ramsey	2712300719	BO001	Meritex Enterprises Inc	2		0	0		2		0	0	
Ramsey	2712300721	ITOTA	M-Foods Dairy LLC	8		1	1		8		1	1	
Ramsey	2712300725	ITOTA	Unicircuit - Roseville			17			0		45	0	
Ramsey	2712300726	SI004	FM Frattalone Excavating & Gra	6	0	1			5	0	1		
Ramsey	2712300727	ITOTA	Signation Sign Group Inc			6	1				3	0	
Ramsey	2712300729	ITOTA	Modernistic Inc - Empire Dr	1		15	1		1		18	1	
Ramsey	2712300731	IOTHE	Structural Wood Corp			3							
Ramsey	27123XSTP	RPU00	ST PAUL DOWNTOWN HOLMAN FL	0		3	1		1		6	2	
Ramsey	27123XSTP	RPU00	ST PAUL DOWNTOWN HOLMAN FL	2	0	13	6		3	0	14	6	
Ramsey	27123XSTP	RPU00	ST PAUL DOWNTOWN HOLMAN FL	1		5	1		1		7	2	
Redwood	2712700013	ITOTA	Central Bi-Products - North Re	26	5	1	1	81	32	6	1	1	99

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Redwood	2712700023	GN001	Redwood Falls Public Utilities	16	1	1			13	1	1		
Redwood	2712700041	ITOTA	HBOS Manufacturing LP - Schult				4					5	
Redwood	27127POTW1	RPS00	Redwood Falls WWTP			1		3			1		3
Redwood	27127SW083	RPU00	Redwood County			35					35		
Renville	2712900014	FS001	Southern Minnesota Beet Sugar				18					20	
Renville	2712900014	SI999	Southern Minnesota Beet Sugar					53					63
Renville	2712900014	SV001	Southern Minnesota Beet Sugar	621	586	4	0	0	589	556	4	0	0
Renville	2712900014	SV002	Southern Minnesota Beet Sugar	31	102	0	5	1	31	102	0	5	1
Renville	2712900014	SV012	Southern Minnesota Beet Sugar				3					4	
Renville	2712900014	SV034	Southern Minnesota Beet Sugar	1	1		0		1	1		0	
Renville	2712900036	FS003	Minnesota Energy				11					15	
Renville	2712900036	SV005	Minnesota Energy	8		42	3		8		46	3	
Renville	2712900036	SV012	Minnesota Energy	10		2	1		11		2	1	
Renville	2712900045	NF001	Fairway Construction Inc - Non	3	0	0			3	0	0		
Renville	2712900046	SV001	Alliance Pipeline - Olivia 23-	72	1	1	6		60	1	1	6	
Renville	27129SW090	RPU00	Renville County			51					51		
Renville	27129X1D6	RPU00	HECTOR MUNI			1	0				1	0	
Rice	2713100006	ITOTA	St Olaf College	12	1	0	0		7	0	0	0	
Rice	2713100018	BO002	Carleton College	7		1	1	0	7		1	1	0
Rice	2713100022	SV003	Malt-O-Meal Co - Plant 2 - Nor	9		1	1	0	9		1	1	0
Rice	2713100022	SV004	Malt-O-Meal Co - Plant 2 - Nor	9		1	1	0	9		1	1	0
Rice	2713100027	ITOTA	Jennie-O Turkey Store - Feed M	3			2		3			2	
Rice	2713100050	ITOTA	Mercury Minnesota Inc			5					8		
Rice	2713100058	SV001	Northern Natural Gas Co - Fari	6	0		0		5	0		0	
Rice	2713100059	SI001	Minn Correctional Facility - F	2	15	0	0		4	26	0	0	0
Rice	2713100059	SI002	Minn Correctional Facility - F	9	55	1	0	0	15	95	1	1	0
Rice	2713100059	SI003	Minn Correctional Facility - F	12	72	1	1	0	20	124	1	1	0
Rice	2713100060	ITOTA	MN Residential Academies for t	2	2	0	0						
Rice	2713100062	NF001	Kielmeyer Construction Inc - N	20	1	2			18	1	2		
Rice	2713100063	IOTHE	Bituminous Materials Inc - Non				3					2	
Rice	2777700166	ITOTA	Bituminous Materials Inc - Pla	7	3	1	1		10	4	1	1	
Rice	27131POTW1	RPS00	Faribault WWTP			6		14			6		14
Rice	27131SW123	RPU00	Rice County			210					210		
Rice	27131XFBL	RPU00	FARIBAULT MUNI	0		2	1		0		2	1	
Rock	2713300023	FS001	Agri-Energy LLC				3					4	
Rock	2713300023	SV004	Agri-Energy LLC	15		103	12	0	16		111	13	0
Rock	2713300023	SV011	Agri-Energy LLC	22		2	1	1	22		2	1	1
Rock	27133POTW1	RPS00	Luverne WWTP			1		3			1		3
Rock	27133SW077	RPU00	Rock County			16					16		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Roseau	2713500002	SI012	Marvin Windows & Doors	3	0	1	1		3	0	1	1	
Roseau	2713500002	SI014	Marvin Windows & Doors	8	1	2	0		8	1	2	0	
Roseau	2713500002	SI015	Marvin Windows & Doors	7	1	1	0		7	1	1	0	
Roseau	2713500018	ITOTA	CB Hockey LLC			2							
Roseau	27135SW137	RPU00	Salol			44					44		
Roseau	27135XROX	RPU00	ROSEAU MUNI/RUDY BILLBERG FI			0					1	0	
Roseau	27135XROX	RPU00	ROSEAU MUNI/RUDY BILLBERG FI	0		2	1		0		2	1	
Roseau	27135XRRT	RPU00	WARROAD INTL-SWEDE CARLSON								0		
Roseau	27135XRRT	RPU00	WARROAD INTL-SWEDE CARLSON			1	0				1	0	
Scott	2713900003	FS001	Rahr Malting Co - Shakopee				13					18	
Scott	2713900003	SV003	Rahr Malting Co - Shakopee	13		1	1	0	13		1	1	0
Scott	2713900003	SV005	Rahr Malting Co - Shakopee		15					18			
Scott	2713900003	SV006	Rahr Malting Co - Shakopee	7	17	1	0		7	20	1	1	
Scott	2713900003	SV007	Rahr Malting Co - Shakopee		16					18			
Scott	2713900003	SV008	Rahr Malting Co - Shakopee	9	21	1	1		9	25	1	1	
Scott	2713900003	SV009	Rahr Malting Co - Shakopee	11	26	1	1		11	31	1	1	
Scott	2713900003	SV010	Rahr Malting Co - Shakopee	15	37	2	1	0	15	43	2	1	0
Scott	2713900005	SI001	Anchor Glass Container Corp -	340	187	5			259	142	4		
Scott	2713900005	SI002	Anchor Glass Container Corp -	434	228	5			331	174	4		
Scott	2713900009	ITOTA	Koch Materials Co - Savage	3		1	0		4		1	0	
Scott	2713900013	FS001	CertainTeed Corp				5					6	
Scott	2713900013	FS002	CertainTeed Corp				4					5	
Scott	2713900013	SV036	CertainTeed Corp	55	5	3	1	1	55	5	3	1	1
Scott	2713900041	SI030	Prior Lake Aggregates Inc	2	0	0			2	0	0		
Scott	2713900041	SI031	Prior Lake Aggregates Inc	2	0	0			2	0	0		
Scott	2713900041	SI033	Prior Lake Aggregates Inc	7	0	1			6	0	1		
Scott	2713900041	SI034	Prior Lake Aggregates Inc	2	0	0			2	0	0		
Scott	2713900041	SI040	Prior Lake Aggregates Inc	5	0	0			4	0	0		
Scott	2713900044	SI039	Superior Minerals Corp - Savag	4		1	0		4		1	0	
Scott	2713900073	BO001	St Francis Regional Medical Ce	2		0			2		0		
Scott	2713900091	IOTHE	Bryan Rock Products Inc - Nonm				4					2	
Scott	2713900091	NF001	Bryan Rock Products Inc - Nonm	34	2	3			31	2	3		
Scott	2713900092	NF001	River City Asphalt - Nonmetall	2		0			2		0		
Scott	2713900097	IOTHE	Phillips & Temro Industries In			3					2		
Scott	2713900098	ITOTA	MCES - Blue Lake WWTP	7		14	22		4		8	12	
Scott	2713900100	GN001	Lake Marion DG	2									
Scott	2713900106	ITOTA	Bituminous Roadways Inc - E500	3	7	1	1		4	9	2	2	
Scott	2777700145	ITOTA	Commercial Asphalt Co - Plant	14	1	16	4		19	1	22	5	
Scott	2777700179	SV002	Central Soils Remediation	7	7	2			10	9	3		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Scott	2777700265	ITOTA	River City Asphalt 3	40	35	9	1		55	48	13	1	
Scott	2777700276	IOTHE	Shakopee Gravel Inc - Nonmetal				11					6	
Scott	2777700276	NF001	Shakopee Gravel Inc - Nonmetal	8	0	1			7	1	1		
Scott	27139SW032	RPU00	Louisville			10					10		
Scott	27139SW032	RPU00	Louisville	2	1	40	1		2	1	40	1	
Sherburne	2714100003	SI001	Great River Energy - Elk River	5	15				7	22			
Sherburne	2714100003	SV003	Great River Energy - Elk River	158	13		16		158	13		16	
Sherburne	2714100003	SV004	Great River Energy - Elk River	196	17		20		196	17		20	
Sherburne	2714100006	ITOTA	Minnesota Correctional Facilit	6	5	1	0		3	3	0		
Sherburne	2714100030	ITOTA	Elk River Bituminous Inc	3	1	0	0		4	2	1	1	
Sherburne	2714100041	SV003	Waste Management Inc -Elk Rive	6	2	0	1		6	2	0	1	
Sherburne	2714100042	IOTHE	Elk River Machine Co			4					2		
Sherburne	2714100058	NF001	ConTeck Enterprises Inc - Nonm	5	0	0			4	0	0		
Sherburne	2714500148	IOTHE	Granite City Ready-Mix - Nonme				4					2	
Sherburne	2714500148	NF001	Granite City Ready-Mix - Nonme	6	0	1			6	0	0		
Sherburne	2777700023	ITOTA	Commercial Asphalt Co - Plant	16	2	14	2		22	3	19	3	
Sherburne	27141POTW1	RPS00	Elk River WWTP			1		4			1		4
Sherburne	27141POTW2	RPS00	Becker WWTP - Municipal			1		3			1		3
Sherburne	27141XSTC	RPU00	ST CLOUD REGIONAL	1	0	0			2	0	1		
Sherburne	27141XSTC	RPU00	ST CLOUD REGIONAL	0		2	1		0		4	1	
Sherburne	27141XSTC	RPU00	ST CLOUD REGIONAL	1		6	3		1	0	6	3	
Sherburne	27141XSTC	RPU00	ST CLOUD REGIONAL			0					0		
Sherburne	27141XSTC	RPU00	ST CLOUD REGIONAL	2	0	2			2	0	2		
Sibley	2701900029	ITOTA	Wm Mueller & Sons Inc - Blakel	9	10	3	2		13	14	4	3	
Sibley	2707900042	BO002	MG Waldbaum Co - Gaylord	6		1	0	0	6		1	0	0
Sibley	2713900093	IOTHE	Sibley Aggregates - Nonmetalli				6					3	
Sibley	2713900093	NF001	Sibley Aggregates - Nonmetalli	12	1	1			11	1	1		
Sibley	2714300009	ITOTA	Dairy Farmers of America Inc -	10	1		16		11	1		17	
Sibley	2714300014	SV004	Heartland Corn Products	12		88	10		13		96	10	
Sibley	2714300014	SV006	Heartland Corn Products	25		3	2	1	25		3	2	1
Sibley	2714300014	SV010	Heartland Corn Products	13		2	1	0	13		2	1	0
Sibley	2714300014	SV011	Heartland Corn Products	12		88	10		13		96	10	
Sibley	2714300016	BO001	Seneca Foods Corp - Arlington	2		0	0		2		0	0	
Sibley	27143POTW1	RPS00	Arlington WWTP			1		2			1		2
Sibley	27143SW002	RPU00	Sibley County			9					9		
St_Louis	2713700005	FS002	US Steel Corp - Minntac				29					40	
St_Louis	2713700005	SV001	US Steel Corp - Minntac	14		1	0	0	14		1	0	0
St_Louis	2713700005	SV002	US Steel Corp - Minntac	17		1	0	0	17		1	0	0
St_Louis	2713700005	SV003	US Steel Corp - Minntac	7		0	0	0	7		0	0	0

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
St_Louis	2713700005	SV004	US Steel Corp - Minntac	14		1	0	0	14		1	0	0
St_Louis	2713700005	SV005	US Steel Corp - Minntac	16		1	0	0	16		1	0	0
St_Louis	2713700005	SV024	US Steel Corp - Minntac				24					32	
St_Louis	2713700005	SV045	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV047	US Steel Corp - Minntac				2					3	
St_Louis	2713700005	SV049	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV054	US Steel Corp - Minntac				6					8	
St_Louis	2713700005	SV056	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV057	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV059	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV060	US Steel Corp - Minntac				14					19	
St_Louis	2713700005	SV065	US Steel Corp - Minntac				2					3	
St_Louis	2713700005	SV072	US Steel Corp - Minntac				6					7	
St_Louis	2713700005	SV075	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV077	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV081	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV083	US Steel Corp - Minntac				2					2	
St_Louis	2713700005	SV085	US Steel Corp - Minntac				8					10	
St_Louis	2713700005	SV093	US Steel Corp - Minntac				2					3	
St_Louis	2713700005	SV095	US Steel Corp - Minntac				2					3	
St_Louis	2713700005	SV096	US Steel Corp - Minntac				3					4	
St_Louis	2713700005	SV097	US Steel Corp - Minntac				2					3	
St_Louis	2713700005	SV103	US Steel Corp - Minntac	2194	462	9	393		2195	324	9	393	
St_Louis	2713700005	SV109	US Steel Corp - Minntac				2					3	
St_Louis	2713700005	SV118	US Steel Corp - Minntac	3601	380	13	304		2521	380	13	412	
St_Louis	2713700005	SV122	US Steel Corp - Minntac				101					138	
St_Louis	2713700005	SV127	US Steel Corp - Minntac	2879	380	32	51		2015	380	32	51	
St_Louis	2713700005	SV129	US Steel Corp - Minntac				9					13	
St_Louis	2713700005	SV138	US Steel Corp - Minntac				8					11	
St_Louis	2713700005	SV142	US Steel Corp - Minntac				34					46	
St_Louis	2713700005	SV143	US Steel Corp - Minntac				43					58	
St_Louis	2713700005	SV144	US Steel Corp - Minntac	3652	380	18	79		2557	380	18	79	
St_Louis	2713700005	SV146	US Steel Corp - Minntac				95					129	
St_Louis	2713700005	SV149	US Steel Corp - Minntac				32					44	
St_Louis	2713700005	SV150	US Steel Corp - Minntac				40					55	
St_Louis	2713700005	SV151	US Steel Corp - Minntac	2525	343	22	59		1767	343	22	59	
St_Louis	2713700005	SV153	US Steel Corp - Minntac				96					130	
St_Louis	2713700011	FS004	EVTAC Mining - Mine				8					10	
St_Louis	2713700015	SV001	Minnesota Power Inc - ML Hibba	414	132	52	5		414	132	52	5	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
St_Louis	2713700022	SV001	Duluth Steam Cooperative Assoc	250	217	1	10		255	221	1	10	
St_Louis	2713700022	SV004	Duluth Steam Cooperative Assoc	72	62	0	3		73	64	0	3	
St_Louis	2713700022	SV005	Duluth Steam Cooperative Assoc	7	6		0		7	6		0	
St_Louis	2713700023	ITOTA	AGP Grain Ltd				3					2	
St_Louis	2713700030	SI001	Hill Wood Products	1			2		1			2	
St_Louis	2713700030	SI002	Hill Wood Products	0			2		0			2	
St_Louis	2713700031	SV022	Georgia-Pacific - Duluth Hardb	2	2		4		2	2		4	
St_Louis	2713700031	SV024	Georgia-Pacific - Duluth Hardb	20	133	0	1	0	20	133	0	1	0
St_Louis	2713700032	FS001	Northshore Mining Co - Babbitt				3					4	
St_Louis	2713700032	FS003	Northshore Mining Co - Babbitt				6					8	
St_Louis	2713700032	FS004	Northshore Mining Co - Babbitt				34					46	
St_Louis	2713700032	FS005	Northshore Mining Co - Babbitt				6					8	
St_Louis	2713700032	SI003	Northshore Mining Co - Babbitt	3	21		0		3	21		0	
St_Louis	2713700032	SI004	Northshore Mining Co - Babbitt	1	3				1	3			
St_Louis	2713700039	SV001	University of Minnesota - Dulu	2		0	0		2		0	0	
St_Louis	2713700039	SV002	University of Minnesota - Dulu	4	0	1	0		5	0	1	0	
St_Louis	2713700039	SV003	University of Minnesota - Dulu	9	1	1	1		10	1	1	1	
St_Louis	2713700042	ITOTA	Staver Foundry Co	1		1	2		1		1	2	
St_Louis	2713700061	FS025	Hibbing Taconite Co				25					34	
St_Louis	2713700061	SV017	Hibbing Taconite Co				4					5	
St_Louis	2713700061	SV024	Hibbing Taconite Co	2066	197	22	61		1797	197	22	83	
St_Louis	2713700061	SV028	Hibbing Taconite Co	1933	185	21	61		1682	185	21	82	
St_Louis	2713700061	SV029	Hibbing Taconite Co	2202	211	24	66		1916	211	24	89	
St_Louis	2713700061	SV033	Hibbing Taconite Co				8					11	
St_Louis	2713700061	SV034	Hibbing Taconite Co				8					11	
St_Louis	2713700061	SV035	Hibbing Taconite Co				9					12	
St_Louis	2713700062	FS007	Ispat Inland Mining Co				18					24	
St_Louis	2713700062	SI001	Ispat Inland Mining Co				19					25	
St_Louis	2713700062	SV017	Ispat Inland Mining Co	3254	155	47	54		3254	155	64	74	
St_Louis	2713700063	FS007	Keewatin Taconite Operations				6					9	
St_Louis	2713700063	FS015	Keewatin Taconite Operations				6					9	
St_Louis	2713700063	SV020	Keewatin Taconite Operations				2					2	
St_Louis	2713700063	SV026	Keewatin Taconite Operations				64					87	
St_Louis	2713700063	SV030	Keewatin Taconite Operations	6048	704	93	367		6049	464	126	498	
St_Louis	2713700073	SV010	ME Global Inc	2	1		0		2	1		1	
St_Louis	2713700073	SV014	ME Global Inc						2	1		0	
St_Louis	2713700083	SV001	Potlatch - Cook	99	1	23	5		100	1	23	5	
St_Louis	2713700083	SV002	Potlatch - Cook				12					12	
St_Louis	2713700083	SV003	Potlatch - Cook	34	3	2	10		37	3	2	11	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
St_Louis	2713700083	SV004	Potlatch - Cook	34	8	19	3		37	9	20	4	
St_Louis	2713700083	SV005	Potlatch - Cook	56	8		2		57	8		2	
St_Louis	2713700086	ITOTA	Mesabi Bituminous Inc - Schley	1	0	0	0		2	0	0	1	
St_Louis	2713700088	BO001	Virginia Regional Medical Cent	2		0	0		2		0	0	
St_Louis	2713700090	ITOTA	Duluth Superior Blacktop Inc	1	0	0	1		1	0	0	1	
St_Louis	2713700098	BO000	ISD 2142 - Cherry High School	1	8		0		1	8		0	
St_Louis	2713700101	BO000	ISD 2142 - Cotton High School	1	7		0		1	7		0	
St_Louis	2713700108	BO000	College of St Scholastica	3	14		0		5	24	0	0	
St_Louis	2713700108	BO002	College of St Scholastica	3		0	0		3		0	0	
St_Louis	2713700112	SV024	Western Lake Superior Sanitary			32					43		
St_Louis	2713700113	FS001	EVTAC Mining - Fairlane Plant				2					3	
St_Louis	2713700113	SV012	EVTAC Mining - Fairlane Plant				2					2	
St_Louis	2713700113	SV013	EVTAC Mining - Fairlane Plant				2					2	
St_Louis	2713700113	SV014	EVTAC Mining - Fairlane Plant				2					2	
St_Louis	2713700113	SV016	EVTAC Mining - Fairlane Plant				6					8	
St_Louis	2713700113	SV025	EVTAC Mining - Fairlane Plant				7					9	
St_Louis	2713700113	SV026	EVTAC Mining - Fairlane Plant				7					10	
St_Louis	2713700113	SV040	EVTAC Mining - Fairlane Plant				3					3	
St_Louis	2713700113	SV042	EVTAC Mining - Fairlane Plant				128					173	
St_Louis	2713700113	SV049	EVTAC Mining - Fairlane Plant	1764	3222	152	13		1764	3222	171	18	
St_Louis	2713700113	SV070	EVTAC Mining - Fairlane Plant				3					4	
St_Louis	2713700113	SV046	EVTAC Mining - Fairlane Plant						2626	53		50	
St_Louis	2713700136	BO000	ISD 2142 - John F Kennedy High	3	13		0		5	23		0	
St_Louis	2713700141	FS002	Stora Enso DPM & DRPM				4					6	
St_Louis	2713700141	FS004	Stora Enso DPM & DRPM				2					3	
St_Louis	2713700141	SI005	Stora Enso DPM & DRPM	2	0	0							
St_Louis	2713700170	BO000	ISD 2142 - Albrook High School	1	8		0		1	9		0	
St_Louis	2713700171	BO000	ISD 2142 - Cook High School	1	15		1		1	16		1	
St_Louis	2713700172	BO000	ISD 2142 - Orr High School	1	8		0		1	8		0	
St_Louis	2713700243	GN001	Cub Foods - Duluth	2		0			2				
St_Louis	2713700245	BO001	Duluth Entertainment & Convent	2		0			2		0		
St_Louis	2713700245	GN001	Duluth Entertainment & Convent	3		0			2		0		
St_Louis	2713700256	ITOTA	General Electric Int'l Inc - M	0		0	2						
St_Louis	2713700283	BO001	ISD 2154 - Eveleth-Gilbert Hig	2		0			2		0		
St_Louis	2713700289	NF001	Wissota Sand & Gravel Co - Non	2					2				
St_Louis	2713700290	IOTHE	Louis Leustek & Sons Inc - Non				4					2	
St_Louis	2713700290	NF001	Louis Leustek & Sons Inc - Non	7	0	1			7	0	1		
St_Louis	2713700295	NF001	Northland Crushing Inc - Nonme	5	0	0			4	0	0		
St_Louis	2713700298	NF001	Hoover Construction Co - Nonme	4	0	0			4	0	0		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
St_Louis	2713700299	SI005	NTT of Minnesota Inc - Metalli	3	0	0			3	0	0		
St_Louis	2713700302	SI004	Northland Crushing Inc - Metal	5	0	0			5	0	0		
St_Louis	2713700318	SV999	Mesabi Nugget						820	344		474	
St_Louis	2713799999	SV999	East Mine projected						114	24		348	
St_Louis	2777700144	ITOTA	Ulland Brothers Inc - Plant 14	7	10	2	2		10	14	3	3	
St_Louis	2777700297	ITOTA	Ulland Brothers Inc - Plant 34	15	16	4	3		21	22	6	4	
St_Louis	27137POTW1	RPS00	Hibbing WWTP North Plant			1		2			1		2
St_Louis	27137POTW1	RPS00	Hibbing WWTP South Plant			2		5			2		5
St_Louis	27137POTW4	RPS00	Ely WWTP			1		2			1		2
St_Louis	27137POTW7	RPS00	Eveleth WWTP			1		2			1		2
St_Louis	27137POTW9	RPS00	Virginia WWTP			2		6			2		6
St_Louis	27137SW038	RPU00	Hoyt Lakes			8					8		
St_Louis	27137SW065	RPU00	WLSSD (Duluth Disposal Co)			147					147		
St_Louis	27137SW068	RPU00	Northwoods			11					11		
St_Louis	27137SW097	RPU00	East Mesaba **			44					44		
St_Louis	27137SW128	RPU00	Hudson			8					8		
St_Louis	27137SW161	RPU00	Hibbing			101					101		
St_Louis	27137SW163	RPU00	Brookston			6					6		
St_Louis	27137SW164	RPU00	Floodwood Modified			2					2		
St_Louis	27137SW175	RPU00	Cotton Area Modified			2					2		
St_Louis	27137SW177	RPU00	Vermillion Modified			9					9		
St_Louis	27137SW204	RPU00	Orr			2					2		
St_Louis	27137SW237	RPU00	Cook Area Modified			3					3		
St_Louis	27137SW262	RPU00	Highway 77 Seasonal			6					6		
St_Louis	27137SW405	RPU00	St. Louis Co Regional SW			98					98		
St_Louis	27137XDLH	RPU00	DULUTH INTL	18	2	3			28	3	5		
St_Louis	27137XDLH	RPU00	DULUTH INTL	0		2	1		0		3	1	
St_Louis	27137XDLH	RPU00	DULUTH INTL	1		5	2		1		5	2	
St_Louis	27137XDLH	RPU00	DULUTH INTL	0		4	1		1		6	2	
St_Louis	27137XDLH	RPU00	DULUTH INTL	6	0	5	0		6	0	5	0	
St_Louis	27137XHIB	RPU00	CHISHOLM-HIBBING	0		2	1		0		3	1	
Stearns	2700900011	SI003	International Paper - Sartell	696	764	10	7		703	772	17	7	
Stearns	2700900011	SI010	International Paper - Sartell	6		0	0	0	6		0	0	0
Stearns	2700900011	SI013	International Paper - Sartell	47	103		2		44	98		1	
Stearns	2700900026	SV001	Grede - St Cloud Inc	4	0	1	10		4	1	2	16	
Stearns	2700900026	SV102	Grede - St Cloud Inc			12	1				20	2	
Stearns	2700900026	SV103	Grede - St Cloud Inc			12	1				20	1	
Stearns	2705301077	IOTHE	Hardrives Inc - Nonmetallic				6					3	
Stearns	2705301077	NF001	Hardrives Inc - Nonmetallic	11	1	1			10	1	1		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Stearns	2714500001	SI001	Kraft Foods Inc - Albany	3	7	0	1		3	7	0	1	
Stearns	2714500001	SI002	Kraft Foods Inc - Albany	3	7	0	1		3	7	0	1	
Stearns	2714500001	SI006	Kraft Foods Inc - Albany				2					2	
Stearns	2714500003	SV001	Melrose Dairy Proteins LLC	15	16	1	2	0	15	16	1	2	0
Stearns	2714500003	SV002	Melrose Dairy Proteins LLC	42	7	2	1	0	42	7	2	1	0
Stearns	2714500008	SV001	St Johns University Order of S	32	59	0	19		33	61	0	20	
Stearns	2714500008	SV002	St Johns University Order of S	31	59		4		31	60		4	
Stearns	2714500022	ITOTA	Hardrives Inc - Plant 701	2		7	2		3		9	2	
Stearns	2714500026	SV001	St Cloud State University	22	63	1	3	0	35	109	2	6	0
Stearns	2714500032	SV001	Associated Milk Producers - Pa	12	7	1	0		12	8	1	0	
Stearns	2714500037	ITOTA	Veterans Affairs Medical Cente	8	0		0		5			0	
Stearns	2714500074	BO002	St Cloud Hospital	9		1	1	0	9		1	1	0
Stearns	2714500074	GN001	St Cloud Hospital	4	0	0			3	0	0		
Stearns	2714500080	SV007	Nahan Printing Inc	1		13			1		23		
Stearns	2714500097	ITOTA	Polar Tank Trailer Inc - Co Rd	1	4	12			2	6	20		
Stearns	2714500099	SI001	Granit-Bronz Foundry				2					5	
Stearns	2714500099	SI002	Granit-Bronz Foundry				2					5	
Stearns	2714500099	SI003	Granit-Bronz Foundry				2					5	
Stearns	2714500101	ITOTA	Fingerhut Fulfillment	4					2				
Stearns	2714500104	IOTHE	Felling Products Inc			3					2		
Stearns	2714500107	ITOTA	Belgrade Steel Tank Co Inc		2	3	1		0	3	5	1	
Stearns	2714500108	ITOTA	Merrill/May Inc dba Merrill Co			30			0		35		
Stearns	2714500113	IOTHE	Park Industries			3					2		
Stearns	2714500116	ITOTA	DCI Inc	0		3	1		0		4	3	
Stearns	2714500121	GN001	TC\American Monorail Inc	5		1			4		1		
Stearns	2714500121	IOTHE	TC\American Monorail Inc			3							
Stearns	2714500143	BO001	ISD 742 - St Cloud Technical H	2		0			2		0		
Stearns	2714500144	BO001	ISD 742 - St Cloud Apollo High	2		0			2		0		
Stearns	2714500149	NF001	Stommes Construction Inc - Non	16	1	1			14	1	1		
Stearns	2714500151	ITOTA	Minnesota Sawdust & Shavings C	1			4		1			5	
Stearns	2714500164	ITOTA	Ben's Tool & Iron			4	0				5	1	
Stearns	2777700022	ITOTA	Hardrives Inc - Plant 41	11	16	3	2		15	23	4	3	
Stearns	2777700119	ITOTA	Hardrives Inc - Plant 51	10	12	2	1		14	17	3	2	
Stearns	2777700266	ITOTA	American Iron	37	3	16	15		20	1	9	8	
Stearns	27145POTW1	RPS00	Melrose WWTP			3		7			3		7
Stearns	27145POTW4	RPS00	Cold Spring WWTP			1		2			1		2
Stearns	27145POTW5	RPS00	Holdingford WWTP			1		3			1		3
Stearns	27145POTW7	RPS00	Sauk Centre WWTP			1		2			1		2
Stearns	27145SW018	RPU00	Bueckers #1			4					4		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Stearns	27145SW035	RPU00	St. Augusta (Landfill, Inc.)	0		6			0		6		
Stearns	27145SW116	RPU00	Sauk Centre			12					12		
Stearns	27145SW172	RPU00	Paynesville			48					48		
Steele	2714700005	ITOTA	SPX Service Solutions	1		3			2		6		
Steele	2714700009	SV001	Northern Natural Gas Co - Owat	5	0	0	1		4	0	0	1	
Steele	2714700022	ITOTA	ATOFINA Chemicals Inc	6		13	0		8		18	0	
Steele	2714700027	ITOTA	Jostens Inc - Owatonna	1			3		1			4	
Steele	2714700029	ITOTA	Truth Hardware Corp - Owatonna	3		5	0		5		9	0	
Steele	2714700039	ITOTA	Cybex Inc			0	6					3	
Steele	2714700040	ITOTA	Owatonna Public Utilities - We	7		0	0		4			0	
Steele	2714700044	ITOTA	Wenger Corp	1		6	1		0		3	0	
Steele	2714700045	ITOTA	Blount Inc	0		6	1		1		11	2	
Steele	2714700056	IOTHE	Owatonna Construction Co - Non				9					5	
Steele	2714700056	NF001	Owatonna Construction Co - Non	13	1	1			12	1	1		
Steele	2714700059	IOTHE	Christian Bros Cabinets Inc			5					3		
Steele	2714700060	ITOTA	AAF/McQuay International - Owa	1		8			1		14		
Steele	2714700061	ITOTA	Viracon Inc	2	0	34	0		4	0	59	1	
Steele	2777700117	ITOTA	Crane Creek Construction - Pla	39	4	6	3		53	5	8	5	
Steele	2777700277	ITOTA	Crane Creek Construction - Por	13	1	3	1		7	1	1	1	
Steele	27147POTW	RPS00	Owatonna WWTP			5		12			5		12
Steele	27147SW131	RPU00	Steele County			101					101		
Steele	27147XOWA	RPU00	OWATONNA DEGNER RGNL	0		1	1		0		2	1	
Stevens	2714900003	ITOTA	University of MN - Morris	6		0	0		3			0	
Stevens	2714900004	ITOTA	Cargill Inc - Alberta	1			3						
Stevens	2714900012	ITOTA	Riley Bros Construction Inc	2	0	2	1		3	0	2	2	
Stevens	2714900013	SV017	Diversified Energy Co LLC	16		2	1	0	16		2	1	0
Stevens	2714900013	SV019	Diversified Energy Co LLC	8		41	9		9		44	10	
Stevens	2714900016	ITOTA	WestMor Industries LLC - Tank		0	4	1		0	0	6	1	
Stevens	2777700261	FS002	Riley Bros Construction Inc -				2					3	
Stevens	2777700261	SI001	Riley Bros Construction Inc -	3	3	1	1		4	4	1	1	
Stevens	27149SW066	RPU00	Stevens County			16					16		
Stevens	27149XMOX	RPU00	MORRIS MUNI										
Stevens	27149XMOX	RPU00	MORRIS MUNI			0	0				0	0	
Swift	2715100026	SV005	Chippewa Valley Ethanol Co LLL	11		1	1	0	11		1	1	0
Swift	2715100026	SV006	Chippewa Valley Ethanol Co LLL	2	0	0			2	0	0		
Swift	2715100026	SV008	Chippewa Valley Ethanol Co LLL	2	0	0			2	0	0		
Swift	2715100026	SV013	Chippewa Valley Ethanol Co LLL	11		1	1	0	11		1	1	0
Swift	27151SW108	RPU00	Benson			21					21		
Swift	27151XBBB	RPU00	BENSON MUNI			0	0				0	0	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Todd	2715300001	ITOTA	Land O'Lakes - Browerville	5			27		5			29	
Todd	2715300004	SV001	Viking Gas Transmission - Cush	201		25	3		201		25	3	
Todd	2715300004	SV002	Viking Gas Transmission - Cush	203		25	3		203		25	3	
Todd	2715300004	SV003	Viking Gas Transmission - Cush	201		25	3		201		25	3	
Todd	2715300004	SV006	Viking Gas Transmission - Cush	25	0	0	1		20	0	0	1	
Todd	2715300023	BO001	Long Prairie Packing Co - Long	3		0	0		3		0	0	
Todd	27153SW039	RPU00	Long Prairie			21					21		
Todd	27153SW078	RPU00	Killian			12					12		
Todd	27153X14Y	RPU00	TODD FIELD			0	0				1	0	
Traverse	27155XETH	RPU00	WHEATON MUNI			0					0	0	
Wabasha	2715700024	BO002	Lakeside Foods Inc - Plainview	6		1	0	0	6		1	0	0
Wabasha	2715700025	ITOTA	Engineering Laboratory Design			2							
Wabasha	27157POTW1	RPS00	Lake City WWTP			1		2			1		2
Wabasha	27157POTW4	RPS00	Plainview-Elgin Sanitary Distr			1		3			1		3
Wabasha	27157SW154	RPU00	Wabasha County			16					16		
Wadena	2715900003	ITOTA	Wadena Asphalt Inc						2	1	0	0	
Wadena	2715900022	NF001	Menahga Concrete Products - No	5	0	0			5	0	0		
Wadena	27159SW007	RPU00	Wadena			28					28		
Wadena	27159SW114	RPU00	Anderson			3					3		
Wadena	27159XSAZ	RPU00	STAPLES MUNI			1	0		0		1	0	
Waseca	2716100013	SV014	Brown Printing Co - Waseca Div	7		258		0	7		307		0
Waseca	2716100030	GN001	ITRON Inc	3	0	0			3	0	0		
Waseca	27161POTW1	RPS00	Waseca WWTP			2		4			2		4
Waseca	27161SW100	RPU00	Waseca County			25					25		
Waseca	27161XACQ	RPU00	WASECA MUNI	0		1	0		0		1	1	
Washington	2716300001	SV003	Andersen - Main	34	2	1	17		38	2	1	18	
Washington	2716300002	SI020	3M Cottage Grove Specialty Add	6	2	0			10	3	1		
Washington	2716300003	FS001	Marathon Ashland Petroleum LLC			36					47		
Washington	2716300003	FS002	Marathon Ashland Petroleum LLC			16					21		
Washington	2716300003	FS003	Marathon Ashland Petroleum LLC			15					19		
Washington	2716300003	FS005	Marathon Ashland Petroleum LLC			6					8		
Washington	2716300003	FS008	Marathon Ashland Petroleum LLC			15					20		
Washington	2716300003	FS009	Marathon Ashland Petroleum LLC			13					17		
Washington	2716300003	FS010	Marathon Ashland Petroleum LLC			32					42		
Washington	2716300003	FS011	Marathon Ashland Petroleum LLC								2		
Washington	2716300003	FS014	Marathon Ashland Petroleum LLC								2		
Washington	2716300003	FS016	Marathon Ashland Petroleum LLC			10					13		
Washington	2716300003	FS017	Marathon Ashland Petroleum LLC			33					44		
Washington	2716300003	FS018	Marathon Ashland Petroleum LLC			4					5		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	**FACID**	**STKID**	**FAC_NAME**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**	**NO_X**	**SO_2**	**VOC**	**PM_{25}**	**NH_3**
Washington	2716300003	FS021	Marathon Ashland Petroleum LLC			6					8		
Washington	2716300003	FS022	Marathon Ashland Petroleum LLC			8					11		
Washington	2716300003	FS023	Marathon Ashland Petroleum LLC			13					17		
Washington	2716300003	FS024	Marathon Ashland Petroleum LLC			23					30		
Washington	2716300003	FS025	Marathon Ashland Petroleum LLC			23					30		
Washington	2716300003	FS026	Marathon Ashland Petroleum LLC			12					16		
Washington	2716300003	FS027	Marathon Ashland Petroleum LLC			2					2		
Washington	2716300003	FS029	Marathon Ashland Petroleum LLC			3					5		
Washington	2716300003	FS030	Marathon Ashland Petroleum LLC			6					7		
Washington	2716300003	FS031	Marathon Ashland Petroleum LLC			32					42		
Washington	2716300003	FS038	Marathon Ashland Petroleum LLC			2					2		
Washington	2716300003	FS046	Marathon Ashland Petroleum LLC			2					2		
Washington	2716300003	FS047	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS048	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS049	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS050	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS051	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS052	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS053	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS054	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS055	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS056	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS057	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS058	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS059	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS060	Marathon Ashland Petroleum LLC			11					14		
Washington	2716300003	FS063	Marathon Ashland Petroleum LLC			16					20		
Washington	2716300003	FS064	Marathon Ashland Petroleum LLC			5					6		
Washington	2716300003	FS065	Marathon Ashland Petroleum LLC			31					41		
Washington	2716300003	FS066	Marathon Ashland Petroleum LLC			4					5		
Washington	2716300003	FS068	Marathon Ashland Petroleum LLC			6					8		
Washington	2716300003	RPU99	Marathon Ashland Petroleum LLC					4					4
Washington	2716300003	SV001	Marathon Ashland Petroleum LLC	4	0	0	0		4	0	0	0	
Washington	2716300003	SV002	Marathon Ashland Petroleum LLC	21	22	1	2		19	30	1	2	
Washington	2716300003	SV003	Marathon Ashland Petroleum LLC	272	691	323	185	207	179	909	242	243	272
Washington	2716300003	SV004	Marathon Ashland Petroleum LLC	11	1	1	1		6	1	1	1	
Washington	2716300003	SV005	Marathon Ashland Petroleum LLC	41	2	2	3		21	2	2	3	
Washington	2716300003	SV006	Marathon Ashland Petroleum LLC	7	1	0	0		7	1	0	0	
Washington	2716300003	SV007	Marathon Ashland Petroleum LLC	101	146	1	4		58	200	1	5	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Washington	2716300003	SV008	Marathon Ashland Petroleum LLC	6	1	0	0		6	1	0	0	
Washington	2716300003	SV009	Marathon Ashland Petroleum LLC	10	1	1	1		5	1	1	1	
Washington	2716300003	SV010	Marathon Ashland Petroleum LLC	16	2	1	1		8	2	1	1	
Washington	2716300003	SV011	Marathon Ashland Petroleum LLC	17	1	1	1		9	1	1	1	
Washington	2716300003	SV012	Marathon Ashland Petroleum LLC	6	0	0	0		6	0	0	0	
Washington	2716300003	SV013	Marathon Ashland Petroleum LLC	45	101	1	3		37	138	1	4	
Washington	2716300003	SV014	Marathon Ashland Petroleum LLC	61	106	1	3		36	146	1	3	
Washington	2716300003	SV015	Marathon Ashland Petroleum LLC	33	95	0	2		25	130	0	3	
Washington	2716300003	SV016	Marathon Ashland Petroleum LLC	28	25	1	3		28	25	1	3	
Washington	2716300003	SV017	Marathon Ashland Petroleum LLC	7	1	0	1		7	1	0	1	
Washington	2716300003	SV018	Marathon Ashland Petroleum LLC	9	1	0	1		9	1	0	1	
Washington	2716300003	SV019	Marathon Ashland Petroleum LLC	2	0		0		2	0		0	
Washington	2716300003	SV020	Marathon Ashland Petroleum LLC	2	0	0	0		2	0	0	0	
Washington	2716300003	SV021	Marathon Ashland Petroleum LLC	5	1	1	1		5	1	1	1	
Washington	2716300003	SV022	Marathon Ashland Petroleum LLC	4	1	0	1		4	1	0	1	
Washington	2716300003	SV023	Marathon Ashland Petroleum LLC	3	1		3		3	1		3	
Washington	2716300003	SV050	Marathon Ashland Petroleum LLC	16	1	1	1		8	1	1	1	
Washington	2716300003	SV062	Marathon Ashland Petroleum LLC	3	9	12			3	11	15		
Washington	2716300004	ITOTA	Minnesota Correctional Facilit	2	0	6			1	0	3		
Washington	2716300014	ITOTA	Tower Asphalt Inc	23	7	3	8		32	9	4	12	
Washington	2716300025	SI006	3M - Cottage Grove Corporate I	64	0	0	4	0	123	1	0	8	0
Washington	2716300039	BO001	Lakeview Hospital	2		0			2		0		
Washington	2716300049	ITOTA	Black Diamond Inc	1			9		2			12	
Washington	2716300050	ITOTA	Commercial Asphalt Co - Plant	10	1	12	3		14	1	16	4	
Washington	2716300051	ITOTA	NRG Energy Resource Recovery -				3						
Washington	2716300056	ITOTA	Ecowater Systems Inc	1		27			2		47	0	
Washington	2716300080	SI999	3M - Cottage Grove - Tape Manu					2					3
Washington	2716300109	NF001	Custom Crushing & Screening In	5	0	0			4	0	0		
Washington	2716300112	ITOTA	Marathon Ashland Petroleum - C			9					9		
Washington	2716300127	ITOTA	Advance Corp - Cottage Grove	3		6			1		3		
Washington	27163POTW1	RPS00	Met Council - Eagles Point WWT			3		7			3		7
Washington	27163POTW2	RPS00	Met Council - St Croix Valley			5		12			5		12
Washington	27163SW001	RPU00	Washington County			5					5		
Washington	27163SW001	RPU00	Washington County	1	0	20	0		1	0	20	0	
Washington	27163X21D	RPU00	LAKE ELMO	1	0	6	3		1	0	7	3	
Watonwan	27165POTW1	RPS00	Madelia WWTP			1		2			1		2
Watonwan	27165POTW2	RPS00	St James WWTP			1		3			1		3
Watonwan	27165SW081	RPU00	Watonwan County			52					52		
Watonwan	27165XJYG	RPU00	ST JAMES MUNICIPAL			0	0				0	0	

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Wilkin	27167SW022	RPU00	Barnesville			4					4		
Winona	2716900007	ITOTA	Midwest Metal Products Inc	0		8	1		0		10	1	
Winona	2716900010	ITOTA	Winona State University	14	1	0	1		7	1	0	0	
Winona	2716900013	SV005	Froedtert Malt - Winona		11					14			
Winona	2716900013	SV006	Froedtert Malt - Winona		10					12			
Winona	2716900013	SV026	Froedtert Malt - Winona	4		1	0		4		1	0	
Winona	2716900018	ITOTA	Brom Machine & Foundry Co				0					0	
Winona	2716900022	ITOTA	Winona River & Rail Inc				6					3	
Winona	2716900024	ITOTA	United Machine & Foundry	1	0	3			1	0	4		
Winona	2716900036	ITOTA	Fusion Coatings Inc - Div of R	1		3	1		2		6	2	
Winona	2716900049	ITOTA	Modern Transport Terminal				6					3	
Winona	2716900052	ITOTA	Community Memorial Hospital	8	0	0	0		5	0		0	
Winona	2716900067	ITOTA	Technical Die-Casting Inc	4	3	2	3		5	4	3	4	
Winona	2716900078	BO001	St Mary's University	2		0			2		0		
Winona	2716900078	GN001	St Mary's University	2									
Winona	27169POTW	RPS00	Winona WWTP			5		13			5		13
Winona	27169POTW	RPS00	Whitewater River Pollution Con			1		2			1		2
Winona	27169SW025	RPU00	Winona County			111					111		
Winona	27169SW026	RPU00	Geisler			2					2		
Winona	27169XONA	RPU00	WINONA MUNI-MAX CONRAD FLD			0					0		
Winona	27169XONA	RPU00	WINONA MUNI-MAX CONRAD FLD			1	0				1	0	
Wright	2717100019	SV001	NSP dba Xcel Energy Monticello	2	1		0	0	2	1		0	0
Wright	2717100024	ITOTA	Mid-Minnesota Hot Mix - Annand	7	2	1	1		9	3	1	1	
Wright	2717100025	ITOTA	Omann Brothers Inc - St Michae	6	4	1	1		9	6	1	1	
Wright	2717100030	ITOTA	Munson Lakes Nutrition LLC - H	4			0		5			0	
Wright	2717100061	IOTHE	Aero Fiberglass Co			3							
Wright	2717100077	IOTHE	Star West Chev-Olds-GEO			3							
Wright	2717100080	NF001	Buffalo Bituminous - Nonmetall	3		0			2	0	0		
Wright	2717100081	NF001	Annandale Rock Products - Nonm	4	0	0			4	0	0		
Wright	2717100085	SV002	Minnesota Diversified Products			53					110		
Wright	2717100086	ITOTA	Twin City Die Casting Co - Mon	1		0	2		1		0	2	
Wright	27171POTW	RPS00	St Michael WWTP			1		2			1		2
Wright	27171POTW	RPS00	Monticello WWTP			1		3			1		3
Wright	27171POTW	RPS00	Buffalo WWTP			2		6			2		6
Wright	27171POTW	RPS00	Delano WWTP			1		2			1		2
Wright	27171SW044	RPU00	Lindenfelser			4					4		
Wright	27171SW044	RPU00	Lindenfelser	1	0	14	0		1	0	14	0	
Wright	27171SW059	RPU00	French Lake			11					11		
Wright	27171SW060	RPU00	Forest City Road (Yonak)			54					54		

Minnesota Non-Utility Point Sources				2002 Annual Emissions in Tons					2018 Annual Emissions in Tons				
COUNTY	FACID	STKID	FAC_NAME	NO_X	SO_2	VOC	PM_{25}	NH_3	NO_X	SO_2	VOC	PM_{25}	NH_3
Wright	27171SW060	RPU00	Forest City Road (Yonak)	2	1	33	1		2	1	33	1	
Wright	27171SW117	RPU00	Lindala			33					33		
Wright	27171X8Y2	RPU00	BUFFALO MUNI	0		2	1		0		2	1	
Yellow_Medic	2714500150	IOTHE	Martin Marietta Materials - No				12					7	
Yellow_Medic	2717300008	ITOTA	ADM - Prairie Grain Partners -	35	0	1	8		19		1	4	
Yellow_Medic	2717300037	ITOTA	ADM Corn Processing - Burr				9					5	
Yellow_Medic	27173SW042	RPU00	Yellow Medicine			20					20		

Appendix B
Post Emissions Modeling File Changes for Base Year 2002 and Future Year 2018 Estimates for Minnesota.

Table 1: Source Location and Stack Parameter Fixes (in 2002 and 2018):

Facility ID	County	Emission Unit	Unit Name	Stack ID	FIXED Stack ID	Facility Name	FIXED X (LCCm)	FIXED Y (LCCm)	FIXED Stack Height (m)	FIXED Dia. (m)	FIXED Exit Temp (K)	FIXED Exit Vel. (m/hr)
2703100001	Cook	EU001/2/3		SV001/2/3		Minnesota Power – Taconite Harbor	**460845.4**	**851070.0**				
2713700063	St_Louis			SV016		Keewatin Taconite Operations	**298631.2**	**828978.7**				
2713700063	St_Louis			SV020		Keewatin Taconite Operations	**298631.2**	**828978.7**				
2713700063	St_Louis			SV022		Keewatin Taconite Operations	**298631.2**	**828978.7**				
2713700063	St_Louis			SV024		Keewatin Taconite Operations	**298631.2**	**828978.7**				
2713700063	St_Louis			SV026		Keewatin Taconite Operations	**298631.2**	**828978.7**				
2706100004	Itasca	EU001/2		SV001	**SV003**	Minnesota Power-Boswell			**700**	**29**	**175**	**56147.82**
2713700063	St_Louis	EU030	Grate Kiln - Indurator Waste Gas, Phase II	SV030	**SV051***	Keewatin Taconite Operations	**298631.2**	**828978.7**	**48.768**	**5.79**	**329**	**54697.19**
2713700063	St_Louis			SV032		Keewatin Taconite Operations	**298631.2**	**828978.7**				
2707100002	Koochiching	EU430	Boiler 2	SV431	**SV430**	Boise Cascade Corp – International Falls			**35.54**	**2.29**	**478**	**75753.88**
2713700022	St_Louis	EU003	boiler 3	SV005	**SV001**	Duluth Steam Cooperative Assoc			**73.15**	**3.96**	**511**	**26344.02**
2703700011	Dakota	EU111	EU-45002 SRU3 only	SV094	**SV093**	Flint Hills Resources LP – Pine Bend			**60.96**	**1.45**	**547**	**55359.74**

* Changed to SV051 in 2018 only, see text associated with Table 3 below.

Table 2: Addition of Minnesota Sources to 2018 Model Input File*:

Facility_ID	Stack ID	Facility Name	X (m)/(lat)	Y (m)/(long)	Stack Hgt (m)	Stack Dia. (m)	Exit Temp (K)	Exit Vel. (m/hr)	Flow Rate (m3/hr)
2707500003	SV261	Northshore Mining Co - Silver	435385.5	824585.8	49.4	1.8	333.2	60241	
2707500003	SV114	Northshore Mining Co - Silver	435385.5	824585.8	16.9	1.0	435.2	51133	
2707500003	SV105	Northshore Mining Co - Silver	435385.5	824585.8	40.8	1.8	333.2	60241	
2707500003	SV266-8	Northshore Mining Co - Silver	435385.5	824585.8	49.4	1.8	333.2	45756	
2713700113	SV046	Evtac Line 1	332382.3	817667.5	42.7	3.0	327.1	85954	
2713700318	SV999	Mesabi Nugget	47.59	-92.19	60.0	4.2	358.0	90000	90000
2706199999	SV999	West Mine	47.38	-93.22	60.0	4.7	318.2	54900	54900
2713799999	SV999	East Mine	47.60	-92.14	38.1	1.6	370.4	71316	71316

Facility_ID	Stack ID	Facility Name	NO (ton/d)	NO2 (ton/d)	PAR (ton/d)	TOL (ton/d)	FORM (ton/d)	NR (ton/d)	PEC (ton/d)	POA (ton/d)	PSO4 (ton/d)	CCRS (ton/d)
2707500003	SV261	Northshore Mining Co - Silver	0.2452	0.0272	0.0016	0.0002	0.0003	0.0040	0.0000	0.0001	0.0002	0.0028
2707500003	SV114	Northshore Mining Co - Silver	0.7276	0.0808	0.0047	0.0005	0.0009	0.0123	0.0015	0.0065	0.0145	0.1892
2707500003	SV105	Northshore Mining Co - Silver	0.7561	0.0840	0.0041	0.0005	0.0008	0.0106	0.0016	0.0068	0.0151	0.1965
2707500003	SV266-8	Northshore Mining Co - Silver	0.4401	0.0777								
2713700113	SV046	Evtac Line 1	7.0404	0.7823								
2713700318	SV999	Mesabi Nugget	1.8819	0.2091							0.2455	
2706199999	SV999	West Mine	3.1542	0.3505							0.0007	
2713799999	SV999	East Mine	0.3166	0.0352							0.0315	

- Add all missing Northshore Mining Silver Bay sources to 2018 non-utility file;
- Add Northshore Mining Silver Bay Furnace 5;
- EVTAC Mining – Fairlane Plant Line 1 did not operate in 2002 or 2003. It started up again in 2004, thus was added to 2018;
- Add Mesabi Nugget;
- Add two mines to reflect growth, West Mine (like Minnesota Steel) and East Mine (like Polymet).

Table 3: Subtract out Growth and Revise Control at Existing Taconite Facilities in 2018 Model Input Files*.

Facility ID	Facility Name	Pollutant ID	Stack ID	Orig. 2002 (tons/day)	Orig. Growth Factor	Orig. Grown 2018 (tons/day)	Orig. Control Factor	Orig. Control 2018 (tons/day)	New Growth Factor	New Control Factor	New Control 2018 (tons/day)	Difference new - old	Percent Change	2018 Cutfactor
2713700005	US Steel Corp - Minntac	SO2	SV103				**SUM:**	1.224			0.852	-0.371	-30	0.697
2713700005	US Steel Corp - Minntac	NOX	SV118	9.133	1.000	9.133	1.000	9.133	1.000	0.700	6.393	-2.740	-30	0.700
2713700005	US Steel Corp - Minntac	NOX	SV127	6.178	1.000	6.178	1.000	6.178	1.000	0.700	4.325	-1.853	-30	0.700
2713700005	US Steel Corp - Minntac	NOX	SV144	8.907	1.000	8.907	1.000	8.907	1.000	0.700	6.235	-2.672	-30	0.700
2713700005	US Steel Corp - Minntac	NOX	SV151	6.649	1.000	6.649	1.000	6.649	1.000	0.700	4.654	-1.995	-30	0.700
2713700061	Hibbing Taconite Co	NOX	SV024	6.046	1.000	6.046	1.000	6.046	1.000	0.870	5.260	-0.786	-13	0.870
2713700061	Hibbing Taconite Co	NOX	SV028	5.280	1.000	5.280	1.000	5.280	1.000	0.870	4.594	-0.686	-13	0.870
2713700061	Hibbing Taconite Co	NOX	SV029	5.156	1.000	5.156	1.000	5.156	1.000	0.870	4.486	-0.670	-13	0.870
2713700062	Ispat Inland Mining Co	NOX	SV017				**SUM:**	12.921			9.522	-3.399	-26	0.737
2713700062	Ispat Inland Mining Co	SO2	SV017				**SUM:**	0.616			0.454	-0.162	-26	0.737
2713700063	Keewatin Taconite Operations	NOX	SV051				**SUM:**	17.614			12.980	-4.634	-26	0.737
2713700063	Keewatin Taconite Operations	SO2	SV051				**SUM:**	2.049			0.997	-1.053	-51	0.486
2713700113	EVTAC Mining - Fairlane Plant	NOX	SV049				**SUM:**	4.754			4.302	-0.452	-10	0.905
2713700113	EVTAC Mining - Fairlane Plant	SO2	SV049				**SUM:**	8.849			7.856	-0.992	-11	0.888

- * US Steel Minntac new SO_2 control added for MACT required installation of wet scrubber;
- * US Steel Minntac new NO_X control proposed as BART involving burning wood and natural gas on lines 4 and 5 and Coal/NG on lines 6 and 7 after 2002, a 20% reduction from fuel blending (although not specifically proposed as BART that appears in recent inventories; and a 10% reduction from installation of lo-NO_X burners in pre-heat zone in lines 4 through 7;
- * Hibbing Taconite control proposed as BART reflecting fuel use efficiency projects completed in 2005 and 2006;
- * Keewatin Taconite Operations stack SV051 with associated new wet scrubbers CE110 and CE111 connected to two existing multiclones CE030 and CE031 as of October 1, 2005, to comply with MACT. SV051 replaces previous stacks SV030 and SV031;
- * Keewatin Taconite Operations primary fuel natural gas, but after 2005 started also burning coal;
- * EVTAC Mining line 2.

Appendix C
Annual 2005 and 2018 Emissions in Tons in MRPO 2005 Case by Source and Category for Minnesota and Surrounding States.

2005 (baseM) Emissions

State	SrcGroup		SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
MINNESOTA	**Point**		129,000	158,000	1,510	3,030	36,500	36,500
	Area		15,700	57,600	188,000	17,800	67,500	117,000
	Mobile	**On-road**	2,450	146,000	6,270	1,600	2,630	92,100
		Non-road	9,460	102,000	76	4,900	5,330	116,000
	Biogenics		0	34,700	0	0	0	602,000
	Minnesota TOTAL:		**157,000**	**498,000**	**196,000**	**27,300**	**112,000**	**964,000**
	(no biogenics) TOTAL:		157,000	464,000	196,000	27,300	112,000	362,000
IOWA	**Point**		178,000	113,000	3,310	10,100	23,800	36,000
	Area		5,660	9,420	267,000	8,440	35,600	72,200
	Mobile	**On-road**	1,760	92,900	3,380	1,150	1,770	73,800
		Non-road	7,810	86,200	59	4,820	5,300	58,600
	Biogenics		0	38,700	0	0	0	224,000
	Iowa TOTAL:		**193,000**	**340,000**	**274,000**	**24,500**	**66,500**	**465,000**
	(no biogenics) TOTAL:		193,000	302,000	274,000	24,500	66,500	241,000
NORTH DAKOTA	**Point**		154,000	88,300	378	2,690	3,310	649
	Area		5,220	15,400	78,700	1,040	1,430	64,000
	Mobile	**On-road**	522	19,200	754	289	433	12,200
		Non-road	7,490	82,900	68	322	586	19,200
	Biogenics		0	24,200	0	0	0	132,000
	North Dakota TOTAL:		**167,000**	**230,000**	**79,900**	**4,340**	**5,760**	**228,000**
	(no biogenics) TOTAL:		167,000	206,000	79,900	4,340	5,760	96,000
SOUTH DAKOTA	**Point**		13,200	20,300	70	1,000	1,220	1,240
	Area		9,200	6,280	115,000	1,620	4,330	28,600
	Mobile	**On-road**	665	23,700	935	366	546	14,100
		Non-road	6,740	65,500	46	343	596	18,200
	Biogenics		0	26,500	0	0	0	212,000
	South Dakota TOTAL:		**29,800**	**142,000**	**116,000**	**3,330**	**6,690**	**274,000**
	(no biogenics) TOTAL:		29,800	116,000	116,000	3,330	6,690	62,100
WISCONSIN	**Point**		242,000	108,000	865	118	11,500	28,100
	Area		8,860	22,800	116,000	11,900	14,200	110,000
	Mobile	**On-road**	2,640	149,000	5,770	1,780	2,790	58,600
		Non-road	6,940	68,500	63	3,630	3,990	116,000
	Biogenics		0	25,800	0	0	0	527,000
	Wisconsin TOTAL:		**260,000**	**374,000**	**123,000**	**17,400**	**32,500**	**840,000**
	(no biogenics) TOTAL:		260,000	348,000	123,000	17,400	32,500	313,000

2018 (baseM) Emissions

State	SrcGroup		SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
MINNESOTA	**Point**		75,800	102,000	800	16,800	36,900	37,600
	Area		16,500	63,600	219,000	13,900	43,900	128,000
	Mobile	**On-road**	624	47,800	7,760	1,020	2,170	43,100
		Non-road	1,870	64,500	87	2,470	2,720	77,900
	Biogenics		0	34,700	0	0	0	602,000
	Minnesota TOTAL:		**94,800**	**313,000**	**228,000**	**34,200**	**85,700**	**889,000**
	(no biogenics) TOTAL:		94,800	278,000	228,000	34,200	85,700	287,000
IOWA	**Point**		153,000	93,600	5,010	12,000	22,600	50,100
	Area		6,480	10,600	368,000	7,100	27,800	84,900
	Mobile	**On-road**	377	37,200	4,360	631	1,320	37,800
		Non-road	641	49,200	73	2,530	2,830	36,100
	Biogenics		0	38,700	0	0	0	224,000
	Iowa TOTAL:		**160,000**	**229,000**	**377,000**	**22,300**	**54,600**	**433,000**
	(no biogenics) TOTAL:		160,000	191,000	377,000	22,300	54,600	209,000
NORTH DAKOTA	**Point**		139,000	98,000	376	5,900	8,670	3,850
	Area		5,080	20,300	108,000	1,570	10,200	75,000
	Mobile	**On-road**	78	6,080	877	136	281	5,890
		Non-road	187	58,300	87	2,220	2,350	13,000
	Biogenics		0	24,200	0	0	0	132,000
	North Dakota TOTAL:		**144,000**	**207,000**	**109,000**	**9,830**	**21,500**	**230,000**
	(no biogenics) TOTAL:		144,000	183,000	109,000	9,830	21,500	97,700
SOUTH DAKOTA	**Point**		6,250	10,900	279	543	1,600	2,260
	Area		10,500	7,050	158,000	2,230	14,900	33,400
	Mobile	**On-road**	102	7,870	1,150	179	371	7,130
		Non-road	87	43,100	63	1,840	1,950	11,500
	Biogenics		0	26,500	0	0	0	212,000
	South Dakota TOTAL:		**16,900**	**95,400**	**159,000**	**4,790**	**18,800**	**266,000**
	(no biogenics) TOTAL:		16,900	68,900	159,000	4,790	18,800	54,300
WISCONSIN	**Point**		177,000	83,500	1,370	7,300	17,800	33,100
	Area		7,980	23,700	108,000	13,200	14,900	111,000
	Mobile	**On-road**	583	45,400	6,510	1,020	2,090	23,300
		Non-road	1,540	39,800	70	1,830	2,060	73,500
	Biogenics		0	25,800	0	0	0	527,000
	Wisconsin TOTAL:		**187,000**	**218,000**	**116,000**	**23,400**	**36,900**	**768,000**
	(no biogenics) TOTAL:		187,000	192,000	116,000	23,400	36,900	241,000

Appendix D

Meteorological Modeling
Protocol and Performance Evaluation

Meteorological Modeling Protocol
For Application to PM2.5 / Haze / Ozone Modeling Projects

Kirk Baker

December 12, 2004

Lake Michigan Air Directors Consortium
Midwest Regional Planning Organization
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INTRODUCTION

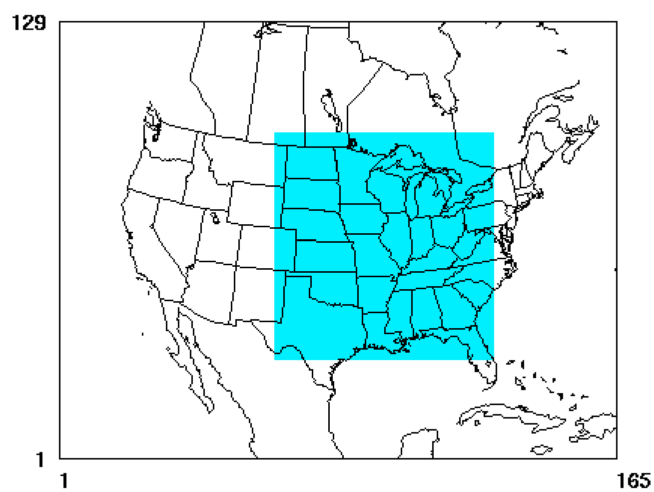
The purpose of this document is to outline the configuration and application of MM5 to support photochemical and emissions modeling projects. All information provided in this document is relevant to NCAR's 5th generation Mesoscale Model version 3.6.3 Dudhia, 1993 and Grell et al, 1994). The computing platform supported by LADCO/Midwest RPO is the Red Hat version 7.X Linux operating system and the Portland Group Fortran compiler. MM5 consists of the Mesoscale model MM5 and a suite of pre-processors including PREGRID, REGRIDDER, RAWINS, LITTLE R, INTERPF, INTERPX, and TERRAIN.

The model parameterizations and physics options outlined in this document are based on a series of sensitivity runs that indicate an optimal configuration for the Upper Midwest (Johnson, 2003). The model configuration and parameterizations outlined in this document describe recent MM5 applications. Evolving science in meteorological modeling and photochemical modeling necessitate that this document change to reflect the state of the science.

The annual 2002 36 km MM5 simulation was completed by Matthew Johnson at Iowa DNR. The 36/12 km 2-way nested simulation for the Summer of 2002 was conducted jointly by Steven King at Illinois EPA and Kirk Baker at LADCO.

TERRAIN

The TERRAIN processor defines the horizontal grid of the MM5 application. The 24 category USGS 10 minute (~19 km) data is used for the National RPO 36-km domain, and 5 minute (~9 km) data for 12-km domains. The National RPO grid is a Lambert conic projection centered at coordinates –97, 40 with first and second true latitudes at 33 and 45 degrees (See Figure).



The 36 km grid contains 165 x 129 km grid cells and the 12 km has 193 x 199 grid cells (See Table 1). The 12 km grid is two-way nested within the mother grid to allow fine grid feedback into the coarse grid. Additional options are set to allow generation of data to support the Pleim-Xu land surface module. Variables LSMDATA and IEXTRA are both set equal to TRUE.

Domain ID	Grid	X Cells (East-West)	Y Cells (North-South)	Cell Size (km)	Mother Domain ID	Lower Left X,Y of Nest
1	National RPO	165	129	36	1	1, 1
2	Upper Midwest	193	199	12	1	66, 30

PREGRID

The PREGRID processor converts meteorological analyses data such as NCEP or Eta to an intermediate data format that the REGRIDDER processor can utilize. Eta/AWIP 3D and SF analyses data (ds609.2) will be used to initialize the REGRID processor. Snow cover will be estimated from water equivalent snow depth. The input analyses will be processed 3 hourly (10,800 seconds). The AWIP grib definition tables will be used to map Eta data into MM5. The ETA skin temperature is used as the source of sea surface temperature. The Eta analysis files with the extension ".tm12" are not used since they are the "cold start" global analysis files.

REGRIDDER

The REGRIDDER processor takes the data extracted from analyses fields and interpolates the data to user specified pressure levels and to the user specified horizontal grid.

LITTLE R

The RAWINS and LITTLE R processors perform objective analysis on the output from REGRIDDER using surface and upper air observation data. Since these observations are incorporated into the Eta analysis fields this step is considered redundant. Sensitivity tests where Eta 3 hourly analysis was used to initialize with and without RAWINS objective analysis showed no difference in model performance (Baker, 2002).

Even though this step is redundant, LITTLE R is applied to enable surface nudging of soil moisture and temperature in the Pleim-Xu land surface module. NCEP ADP surface (ds 464.0) and upper air (ds 353.1 and ds 353.4) data are the appropriate data to input into LITTLE R and/or RAWINS.

k(MM5)	sigma	press.(mb)	height(m)	depth(m)
34	0.000	10000	14662	1841
33	0.050	14500	12822	1466
32	0.100	19000	11356	1228
31	0.150	23500	10127	1062
30	0.200	28000	9066	939
29	0.250	32500	8127	843
28	0.300	37000	7284	767
27	0.350	41500	6517	704
26	0.400	46000	5812	652
25	0.450	50500	5160	607
24	0.500	55000	4553	569
23	0.550	59500	3984	536
22	0.600	64000	3448	506
21	0.650	68500	2942	480
20	0.700	73000	2462	367
19	0.740	76600	2095	266
18	0.770	79300	1828	259
17	0.800	82000	1569	169
16	0.820	83800	1400	166
15	0.840	85600	1235	163
14	0.860	87400	1071	160
13	0.880	89200	911	158
12	0.900	91000	753	78
11	0.910	91900	675	77
10	0.920	92800	598	77
9	0.930	93700	521	76
8	0.940	94600	445	76
7	0.950	95500	369	75
6	0.960	96400	294	74
5	0.970	97300	220	74
4	0.980	98200	146	37
3	0.985	98650	109	37
2	0.990	99100	73	36
1	0.995	99550	36	36
0	1.000	100000	0	--SURF--

INTERPF

The INTERPF processor takes the REGRIDDER/LITTLE R output that is at standard pressure levels and interpolates that data to the vertical grid defined by the user. The vertical grid is defined in terms of sigmas, where 1 is the surface and 0 is the top of the model atmosphere. The top of the MM5 simulation is 100 millibars, which is approximately 15 kilometers above ground level.

The vertical atmosphere is resolved to 34 layers, with thinner layers in the planetary boundary layer. This is to capture the important diurnal variations in the boundary layer while also having layers in the upper troposphere to try and resolve convective activity. Output from the INTERPF processor is ready for input into MM5.

INTERPX

The INTERPX processor is used to extract the soil temperature and soil moisture data from MM5 output files and overwrite the soil temperature and moisture fields on the MMINPUT file for the next 5 day simulation block. This allows soil moisture and temperature to be carried over to subsequent modeling simulations.

For example, to simulate 20 days in 4 blocks of 5 days, the first block of 5 days would use the standard MMINPUT to run MM5, and the subsequent 3 blocks of 5 days would take the MM5 output and extract soil temperature and moisture data for the next 5 day block.

This option was only used for the 36 km annual simulation of 2002. This option is no longer recommended since it has been shown to introduce a cold bias for the temperature field, particularly in the winter months (Olerud, 2003).

MM5

The output from INTERPF, LITTLE R, and TERRAIN processors were used to run MM5. These files must be in the "./MM5/Run" directory and have the generic filenames given directly out of these processors. 3D analysis nudging for the wind field, temperatures, and moisture were applied above the boundary layer only. Analysis nudging was not performed on the rotational wind field. In addition, the observation nudging flag was turned off. This type of nudging is appropriate usually when you have a very dense set of observation data from a field study, which this application lacked. The default nudging weighting factors were used for all simulations: 2.5×10^{-4} for wind fields and temperatures and 1.0×10^{-5} for moisture fields.

Table 3

Configuration	**36km and 12km Domains**
Explicit Moisture	Mixed Phase (Reisner I)
Cumulus	Kain-Fritsch 2
PBL	Pleim-Chang (ACM)
Radiation	RRTM
Multi-Layer Soil Model	Pleim-Xu
Shallow convection	No
4-D Data Assimilation	Analysis nudging on above PBL
Moist Physics Table	No

Table 3 outlines the model configuration used for MM5 modeling up to the date of this document. All simulations use the mixed phase moisture rather than simple ice so that all four phases of water will be explicitly output by MM5. This is important since the photochemical model is applied for an annual basis and correctly characterizing the phase of water is important for several physiochemical processes.

Atmospheric radiation is calculated every 15 minutes in the model. Vertical moisture and temperature advection are set to use linear interpolation. Other important variables switched to ON include: moist vertical diffusion in clouds, temperature advection using potential temperature, diffusion using perturbation temperature, 3D coriolis force, and upper radiative boundary condition. Sea surface temperature and snow cover are set to vary with time.

The Pleim-Xu land surface module requires that 3 additional variables be set in the MM5 deck: ISMRD, NUDGE, and IFGROW. ISMRD is set to use soil moisture fields from the Eta analyses. NUDGE is set to nudge soil moisture data to the analyses fields. IFGROW is set to option 2, which takes vegetative growth into account based on vegetative fraction data from the TERRAIN file.

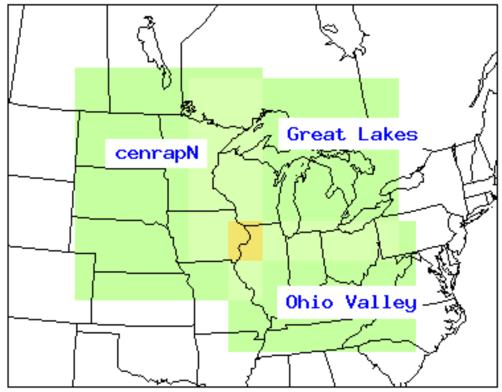
MODEL EXECUTION

MM5 was executed in 5 day blocks (7200 minute simulation) with a 90 second time step. Model results are output every 60 minutes and the model output files are written out (i.e. split) every 24 hours to accommodate post-processing utilities. The start and end times are 12Z. Only 4 days from each block will be used for input to a photochemical model: 5Z to 5Z, which means the first 17 hours of the MM5 simulation are ramp-up and there are 5 hours at the end of the simulation that are not used.

The 2002 annual simulation was initiated at 12Z December 16, 2001 and was run through 12Z January 1, 2003. The 5 day blocks are evenly divided between these 2 dates. Alternatively, the following table illustrates how each month from the 2001 summer and 2003 annual simulations will be modeled using 5 day blocks. This standardized approach to simulating each month reduces post-processing burden.

MM5 Run	start date	start time	end date	end time	total days	total hours	ramp up hours	extra hours
1	MM/01/YY	12Z	MM/06/YY	12Z	5	120	17	5
2	MM/05/YY	12Z	MM/10/YY	12Z	5	120	17	5
3	MM/09/YY	12Z	MM/14/YY	12Z	5	120	17	5
4	MM/13/YY	12Z	MM/18/YY	12Z	5	120	17	5
5	MM/17/YY	12Z	MM/22/YY	12Z	5	120	17	5
6	MM/21/YY	12Z	MM/26/YY	12Z	5	120	17	5
7	MM/25/YY	12Z	MM/30/YY	12Z	5	120	17	5
8	MM/29/YY	12Z	NEXTMM/02/YY	12Z	5	120	17	5
PCM Run	start date	start time	end date	end time	total days	total hours		
1	MM/02/YY	5Z	MM/06/YY	5Z	4	97		
2	MM/06/YY	5Z	MM/10/YY	5Z	4	97		
3	MM/10/YY	5Z	MM/14/YY	5Z	4	97		
4	MM/14/YY	5Z	MM/18/YY	5Z	4	97		
5	MM/18/YY	5Z	MM/22/YY	5Z	4	97		
6	MM/22/YY	5Z	MM/26/YY	5Z	4	97		
7	MM/26/YY	5Z	MM/30/YY	5Z	4	97		
8	MM/30/YY	5Z	NEXTMM/01/YY	5Z	4	97		

MODEL PERFORMANCE



The performance of MM5 will be analyzed qualitatively by comparing output surface fields of temperature, winds, convective activity, and cloud cover to 12 hourly UNISYS surface weather maps and satellite cloud cover images. Vertical sounding plots of temperature, humidity, wind speed, and wind direction will be analyzed for select upper air stations in the Midwest. Vertical sounds plots will show model predictions against Forecast Systems Laboratory (FSL) / National Climatic Data Center (NCDC) Radiosonde data archive (RAOBS) upper air data at 0Z and 12Z.

Model performance will be assessed quantitatively with the METSTAT tool from Environ (Emery et al, 2001). The metrics used to quantify model performance include mean observation, mean prediction, bias error, gross error, root mean square error (including systematic and unsystematic components), and index of agreement. These metrics will compare model predictions to Techniques Data Laboratory U.S. and Canada surface hourly observations (NCAR dataset ds472.0).

The MM5 model outputs approximately 15 meter predictions while observations are at 10 meters. METSTAT applies micro-meteorological adjustments to the MM5 estimates to approximate 10-m values. MM5 outputs near-instantaneous values (90 second time step) as opposed to the values with longer averaging times taken at monitor stations, so that should be kept in consideration when interpreting model performance metrics and making qualitative comparisons to satellite maps.

Model performance metrics will be applied to sub-regions of the Upper Midwest, meaning the metrics are hourly spatial averages of multiple monitor locations. This will be done to gain a better understanding of MM5 performance for 2 geographically and meteorologically diverse regions: Great Lakes and Ohio Valley. All metrics are calculated for all sites within the specified model performance region for an hourly and daily time period (0Z to 23Z). Mean wind direction is estimated by averaging the U and V wind vector components and converting those averages to an average wind direction in compass degrees.

MPE Region	Great Lakes	Ohio Valley
X Coordinate SW (km)	200	450
X Coordinate NE (km)	1500	1600
Y Coordinate SW (km)	100	-472
Y Coordinate NE (km)	1200	300
~ NX 36km cells	36	32
~ NY 36km cells	31	22
Surface Met Stations (jan 2000)	273	179
Surface Met Stations (july 2001)	283	210

Additional analysis of rainfall will be done on a seasonal basis. Rainfall totals in each grid cell by season will be compared to the corresponding seasonal totals at observation sites.

Annual simulations present a challenge in terms of adequately assessing model performance so photochemical modelers will know the strengths and weaknesses of the meteorological inputs. A report will be compiled with the following elements: select vertical sounding plots at Upper Midwest sounding stations, daily metrics output by METSTAT, rainfall analysis results, and any qualitative comparisons between model output and UNISYS plots.

PERFORMANCE METRICS

The *bias error* (bias) is the degree of correspondence between the mean prediction and the mean observation, with lower numbers indicative of better performance. Values less than 0 indicate under-prediction. The *gross error*, or mean absolute error, is the mean of the absolute value of the residuals from a fitted statistical model. Lower numbers indicate better model performance.

Root Mean Square Error (RMSE) is a good overall measure of model performance. The weighting of (*prediction-observation*) by its square tends to inflate RMSE, particularly when extreme values are present. With respect to a good model the root mean square error should approach zero. RMSE can be divided into a systematic and unsystematic component by least-squares regression. Since differences described by systematic RMSE can be described by a linear function, they should be relatively easy to dampen by a new parameterization of the model. Unsystematic RMSE can be interpreted as a measure of potential accuracy or noise level (Emery et al, 2001). With respect to a good model the systematic difference should approach zero while the unsystematic difference approaches RMSE.

Index of Agreement is a relative measure of the degree of which predictions are error-free. The denominator accounts for the model's deviation from the mean of the observations as well as to the observations deviation from their mean. It does not provide information regarding systematic and unsystematic errors. The index of agreement approaches one when model performance is best.

POST PROCESSING FOR PHOTOCHEMICAL MODELS

The meteorological fields output by MM5 are prepared for use by the photochemical models with processing utilities. These programs translate certain meteorological parameters from the MM5 grid to the photochemical grid. Additionally, these processors must estimate parameters that are not explicitly output by MM5. Cloud cover is not output by MM5 and must be diagnosed based on moisture ratios. Vertical mixing is based on vertical diffusivity coefficients. This is a key variable not output by MM5 using the configuration outlined in this protocol.

The vertical diffusivities are calculated inside the CMAQ model based on the PBL height output by MM5. CAMx4 and REMSAD have vertical diffusivities based on the O'Brien 1970 vertical diffusivity algorithm. This scheme takes the PBL height output by MM5 and creates a well-mixed atmosphere inside the PBL. The minimum vertical diffusivity coefficient for CAMx4, REMSAD, and CMAQ are 0.1 m^2/s. The CMAQ coefficient is established (and modified from the default of 1.0 m^2/s) in the model code. A processing utility was applied to the vertical diffusivity coefficient input files for CAMx4 and REMSAD. A minimum vertical diffusivity coefficient of 1.0 m^2/s is assigned to all grid cells with an urban land use fraction up to 350 meters above ground (model layer 5). This is done to better represent the greater vertical mixing overnight in urban areas. Since the meteorological processing programs for each model not only translate data, but also diagnose certain key parameters, this step must be scrutinized to achieve optimal model results.

The vertical resolution used in MM5 consists of 34 sigma layers that represent the terrain following atmosphere up to 100 millibars. The table below displays each vertical layer in terms of sigma level, pressure (millibars), height above ground level (meters) and layer thickness (meters). The relationship to the layer structure used in the photochemical models is also shown. The photochemical model layer structure avoids layer collapsing in the lower boundary layer to better resolve the mixing depth. A compromise in the upper troposphere is met by employing layer collapsing to reduce computational effort and still maintain some upper troposphere resolution for long-range transport.

k(MM5)	sigma	p(mb)	depth(m)	k(PCM)	depth(m)
34	0.000	100	1841	16	5597
33	0.050	145	1466		
32	0.100	190	1228		
31	0.150	235	1062		
30	0.200	280	939	15	2549
29	0.250	325	843		
28	0.300	370	767		
27	0.350	415	704	14	2533
26	0.400	460	652		
25	0.450	505	607		
24	0.500	550	569		
23	0.550	595	536	13	1522
22	0.600	640	506		
21	0.650	685	480		
20	0.700	730	367	12	634
19	0.740	766	266		
18	0.770	793	259	11	428
17	0.800	820	169		
16	0.820	838	166	10	329
15	0.840	856	163		
14	0.860	874	160	9	318
13	0.880	892	158		
12	0.900	910	78	8	155
11	0.910	919	77		
10	0.920	928	77	7	153
9	0.930	937	76		
8	0.940	946	76	6	151
7	0.950	955	75		
6	0.960	964	74	5	148
5	0.970	973	74		
4	0.980	982	37	4	37
3	0.985	987	37	3	37
2	0.990	991	36	2	36
1	0.995	996	36	1	36
--SURF--	1	1000	0	--SURF--	--SURF--

It is difficult to establish an optimal vertical grid resolution for ozone and PM applications, so it should meet certain scientific criteria outlined in the WRAP modeling protocol (Tonnesen et al, 2001). The layer structure chosen for a modeling application should be capable of adequately resolving the diurnal variations in the boundary layer growth and mixing, long-range transport processes, wind shear, as well as transport to and from the free troposphere.

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Meteorological Modeling Performance Summary

For Application to PM2.5 / Haze / Ozone Modeling Projects

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February 18, 2005

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INTRODUCTION

The purpose of this document is to outline the model configuration and application of the Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) v3.6.3 to support photochemical and emissions modeling projects (Dudhia, 1993 and Grell et al, 1994) at Lake Michigan Air Directors Consortium (LADCO) and the Midwest Regional Planning Organization (Midwest RPO). The computing platform supported by LADCO/Midwest RPO is the Red Hat Linux operating system and the Portland Group Fortran compiler. MM5 consists of the Mesoscale model MM5 and a suite of pre-processors including PREGRID, REGRIDDER, RAWINS, LITTLE R, INTERPF, INTERPX, and TERRAIN.

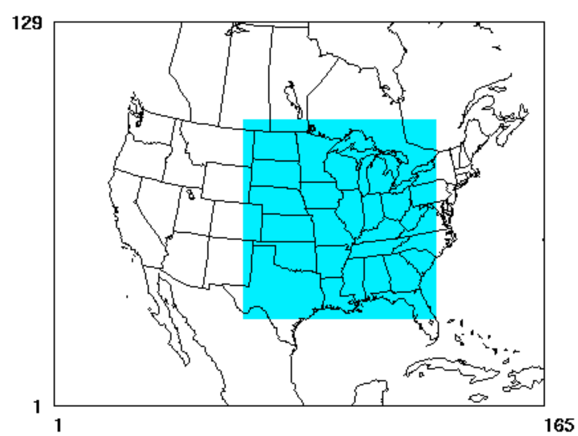
The model parameterizations and physics options outlined in this document were chosen based on the results of a series of sensitivity runs. The performance of the sensitivity tests provided a clear indication of an optimal configuration for the Upper Midwest (Johnson, 2003). The model configuration and parameterizations outlined in this document describe recent MM5 applications.

The annual 2002 36 km MM5 simulation was completed by Matthew Johnson at Iowa DNR. The 36/12 km 2-way nested simulation for the summers of 2001, 2002, and 2003 were conducted jointly by Steven King at Illinois EPA and Kirk Baker at LADCO. The 36 km non-summer portion of the annual 2003 simulation was conducted by Wusheng Ji at Wisconsin DNR.

TERRAIN

The TERRAIN processor defines the horizontal grid of the MM5 application. The 24 category USGS 10 minute (~19 km) data is used for the National RPO 36-km domain, and 5 minute (~9 km) data for 12-km domains. The National RPO grid is a Lambert conic projection centered at coordinates –97, 40 with first and second true latitudes at 33 and 45 degrees (See Figure 1).

Figure 1



The 36 km grid contains 165 x 129 grid cells and the 12 km has 193 x 199 grid cells. The 12 km grid is two-way nested within the mother grid to allow fine grid feedback into the coarse grid. Additional options are set to allow generation of data to support the Pleim-Xu land surface module. Variables LSMDATA and IEXTRA are both set equal to TRUE.

Table 1

Domain ID	Grid	X Cells (East-West)	Y Cells (North-South)	Cell Size (km)	Mother Domain ID	Lower Left X,Y of Nest
1	National RPO	165	129	36	1	1, 1
2	Upper Midwest	193	199	12	1	66, 30

PREGRID

The PREGRID processor converts meteorological analyses data such as NCEP or ETA to an intermediate data format that the REGRIDDER processor can utilize. For PREGRID, the following options were set:

- ETA/AWIP 3D and SF analyses data (ds609.2) is used to initialize the REGRID processor.
- Snow cover is estimated from water equivalent snow depth.
- The input analyses data is processed 3 hourly (10,800 seconds).
- The AWIP grib definition tables are used to map ETA data into MM5.
- The ETA skin temperature is used as the source of sea surface temperature. The ETA analysis files with the extension ".tm12" are not used since they are the "cold start" global analysis files.

REGRIDDER

The REGRIDDER processor takes the data extracted from analyses fields and interpolates the data to user specified pressure levels and to the user specified horizontal grid.

LITTLE R

The RAWINS and LITTLE R processors perform objective analysis on the output from REGRIDDER using surface and upper air observation data. Since these observations are incorporated into the ETA analysis fields this step is considered redundant.

Results of sensitivity tests where ETA 3-hourly analysis was utilized to initialize with and without RAWINS objective analysis demonstrated little or no difference in model performance (Baker, 2002).

Even though this step is redundant, LITTLE R is applied to enable surface nudging of soil moisture and temperature in the Pleim-Xu land surface module. NCEP ADP surface (ds 464.0) and upper air (ds 353.1 and ds 353.4) data are the appropriate data to input into LITTLE R and/or RAWINS.

INTERPF

The INTERPF processor takes the REGRIDDER/LITTLE R output that is at standard pressure levels and interpolates that data to the vertical grid defined by the user (Table 2). The vertical grid is defined in terms of sigmas, where 1 is the surface and 0 is the top of the model atmosphere. The top of the MM5 simulation is 100 millibars, which is approximately 15 kilometers above ground level.

The vertical atmosphere was resolved to 34 layers, with thinner layers in the planETAry boundary layer. The layer configuration was selected to capture the important diurnal variations in the boundary layer while also having layers in the upper troposphere to try and resolve convective activity. Output from the INTERPF processor is ready for input into MM5.

Table 2

k(MM5)	sigma	press.(mb)	height(m)	depth(m)
34	0.000	10000	14662	1841
33	0.050	14500	12822	1466
32	0.100	19000	11356	1228
31	0.150	23500	10127	1062
30	0.200	28000	9066	939
29	0.250	32500	8127	843
28	0.300	37000	7284	767
27	0.350	41500	6517	704
26	0.400	46000	5812	652
25	0.450	50500	5160	607
24	0.500	55000	4553	569
23	0.550	59500	3984	536
22	0.600	64000	3448	506
21	0.650	68500	2942	480
20	0.700	73000	2462	367
19	0.740	76600	2095	266
18	0.770	79300	1828	259
17	0.800	82000	1569	169
16	0.820	83800	1400	166
15	0.840	85600	1235	163
14	0.860	87400	1071	160
13	0.880	89200	911	158
12	0.900	91000	753	78
11	0.910	91900	675	77
10	0.920	92800	598	77
9	0.930	93700	521	76
8	0.940	94600	445	76
7	0.950	95500	369	75
6	0.960	96400	294	74
5	0.970	97300	220	74
4	0.980	98200	146	37
3	0.985	98650	109	37
2	0.990	99100	73	36
1	0.995	99550	36	36
0	1.000	100000	0	--SURF--

INTERPX

The INTERPX processor is used to extract the soil temperature and soil moisture data from MM5 output files and overwrite the soil temperature and moisture fields on the MMINPUT file for the next 5 day simulation block. This allows soil moisture and temperature to be carried over to subsequent modeling simulations.

For example, to simulate 20 days in 4 blocks of 5 days, the first block of 5 days would use the standard MMINPUT to run MM5, and the subsequent 3 blocks of 5 days would take the MM5 output and extract soil temperature and moisture data for the next 5 day block. This option has been shown to introduce a cold bias for the temperature field, particularly in the winter months (Olerud, 2003). INTERPX was not used for any of the MM5 simulations.

MM5

The output from INTERPF, LITTLE R, and TERRAIN processors were used to run MM5. These files must be in the "./MM5/Run" directory and have the generic filenames given directly out of these processors. 3D analysis nudging for the wind field, temperatures, and moisture were applied above the boundary layer only. Analysis nudging was not performed on the rotational wind field. In addition, the observation nudging flag was turned off. This type of nudging is appropriate when there is a very dense set of observation data from a field study, which this application lacked. The default nudging weighting factors were used for all simulations: 2.5×10^{-4} for wind fields and temperatures and 1.0×10^{-5} for moisture fields.

Table 3

Configuration	36km and 12km Domains
Explicit Moisture	Mixed Phase (Reisner I)
Cumulus	Kain-Fritsch 2
PBL	Pleim-Chang (ACM)
Radiation	RRTM
Multi-Layer Soil Model	Pleim-Xu
Shallow convection	No
4-D Data Assimilation	Analysis nudging on above PBL
Moist Physics Table	No

Table 3 outlines the model configuration used for MM5 modeling up to the date of this document. All simulations use the mixed phase moisture scheme so that all four phases of water will be explicitly output by MM5. This is important since the photochemical model is applied for an annual basis and correctly characterizing the phase of water is important for several physiochemical processes.

Atmospheric radiation is calculated every 15 minutes in the model. Vertical moisture and temperature advection are set to use linear interpolation. Other important variables switched to ON include: moist vertical diffusion in clouds, temperature advection using potential temperature, diffusion using perturbation temperature, 3D coriolis force, and upper radiative boundary condition. Sea surface temperature and snow cover are set to vary with time.

The Pleim-Xu land surface module requires that 3 additional variables be set in the MM5 deck: ISMRD, NUDGE, and IFGROW. ISMRD is set to use soil moisture fields from the ETA analyses. NUDGE is set to nudge soil moisture data to the analyses fields. IFGROW is set to option 2, which takes vegETAtive growth into account based on vegETAtive fraction data from the TERRAIN file.

MODEL EXECUTION

MM5 was executed in 5 day blocks (7200 minute simulation) with a 90 second time step. Model results are output every 60 minutes and the model output files are written out (i.e. split) every 24 hours to accommodate post-processing utilities. The 2002 annual simulation was initiated at 12Z December 16, 2001 and was run through 12Z January 1, 2003.

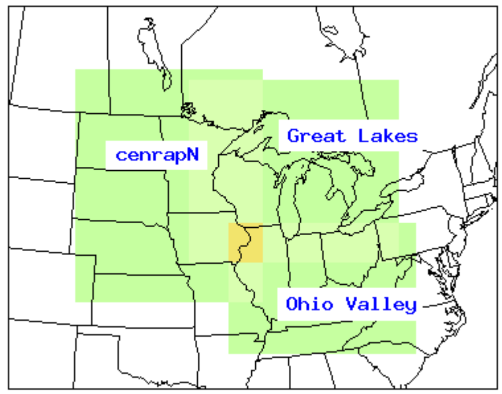
MODEL PERFORMANCE EVALUATION

Model performance was assessed quantitatively with the METSTAT tool from Environ (Emery et al, 2001). The metrics used to quantify model performance include mean observation, mean prediction, bias error, gross error, root mean square error (including systematic and unsystematic components), and index of agreement. These metrics compare model predictions to Techniques Data Laboratory U.S. and Canada surface hourly observations (NCAR dataset ds472.0).

The MM5 model outputs predictions approximately 15 meters above the surface while observations are at 10 meters. METSTAT applies micro-meteorological adjustments to the MM5 estimates to approximate 10-m values. MM5 also outputs near-instantaneous values (90 second time step) as opposed to the values with longer averaging times taken at monitor stations. This should be considered when interpreting model performance metrics and making qualitative comparisons to satellite maps.

Model performance metrics were applied to a sub-region of the Upper Midwest (Figure 2), meaning the metrics are hourly spatial averages of multiple monitor locations. This will be done to gain a better understanding of MM5 performance in the Great Lakes region. All metrics are calculated within the specified model performance region for an hourly and daily time period (0Z to 23Z). Mean wind direction is estimated by averaging the U and V wind vector components and converting those averages to compass degrees.

Figure 2



Additional analysis of rainfall is done on a monthly basis. Rainfall observation analysis data is available from the National Weather Service Climate Prediction Center on an hourly basis for the Continental United States (http://www.cpc.ncep.noaa.gov/products/precip/realtime/retro.html). The rainfall analysis resolution is 0.25 degree longitude by 0.25 degree latitude and extends from 140W to 60W and 20N to 60N.

PERFORMANCE METRICS

The *bias error* (bias) is the degree of correspondence between the mean prediction and the mean observation, with lower numbers indicative of better performance. Values less than 0 indicate under-prediction. The *gross error*, or mean absolute error, is the mean of the absolute value of the residuals from a fitted statistical model. Lower numbers indicate better model performance.

Root Mean Square Error (RMSE) is a good overall measure of model performance. The weighting of (*prediction-observation*) by its square tends to inflate RMSE, particularly when extreme values are present. With respect to a good model the root mean square error should approach zero. RMSE can be divided into a systematic and unsystematic component by least-squares regression. Since differences described by systematic RMSE can be described by a linear function, they should be relatively easy to dampen by a new parameterization of the model. Unsystematic RMSE can be interpreted as a measure of potential accuracy or noise level (Emery et al, 2001). With respect to a good model the systematic difference should approach zero while the unsystematic difference approaches RMSE.

Index of Agreement is a relative measure of the degree of which predictions are error-free. The denominator accounts for the model's deviation from the mean of the observations as well as to the observations deviation from their mean. It does not provide information regarding systematic and unsystematic errors. The index of agreement approaches one when model performance is best.

MODEL PERFORMANCE: ANNUAL 2002 36 km

The biggest issue with the performance in the Great Lakes region is the existence of a cool diurnal temperature bias in the winter and warm temperature bias over-night during the summer. The wind fields are good, although it should be noted that some diurnal errors in wind speed may not be adequately represented in the daily metric plots. The model appears to be too wet in the late spring and summer months in the Eastern United States. Mosaic tile plots showing daily bias and gross error for humidity, temperature, wind speed, and wind direction are shown in the Figures below.

Performance in the other regions is similar to the Great Lakes except where noted. The Ohio Valley has slightly worse performance for day-time wind speed and wind direction. The central Plaines (CenrapN and CenrapS) have low peak wind speeds and a warm temperature bias in the southern Plaines/Texas region due to over-predicted night-times lows.

The Mid-Atlantic region has performance similar to the Great Lakes region. The southeast region is very wet compared to observations during the entire year. The northeast region shows degraded wind field performance compared to the other Eastern regions.

Figure 3. Daily humidity bias and gross error (day 1 top row, last day of month bottom row)

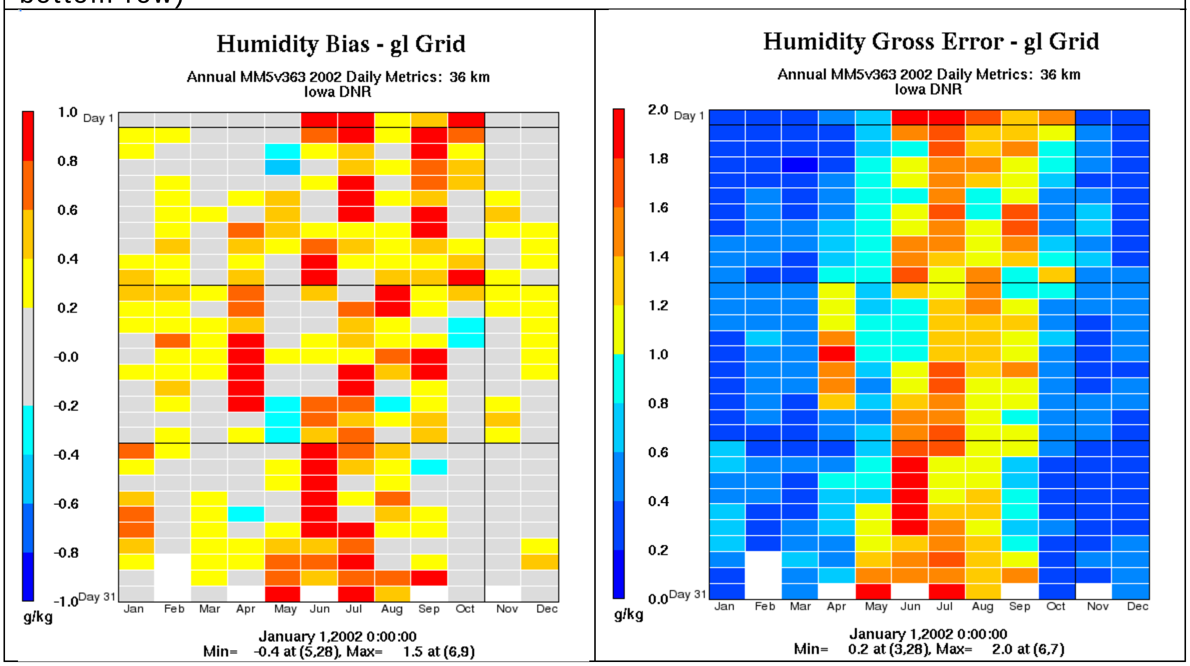


Figure 4. Daily temperature bias and gross error (day 1 top row, last day of month bottom row)

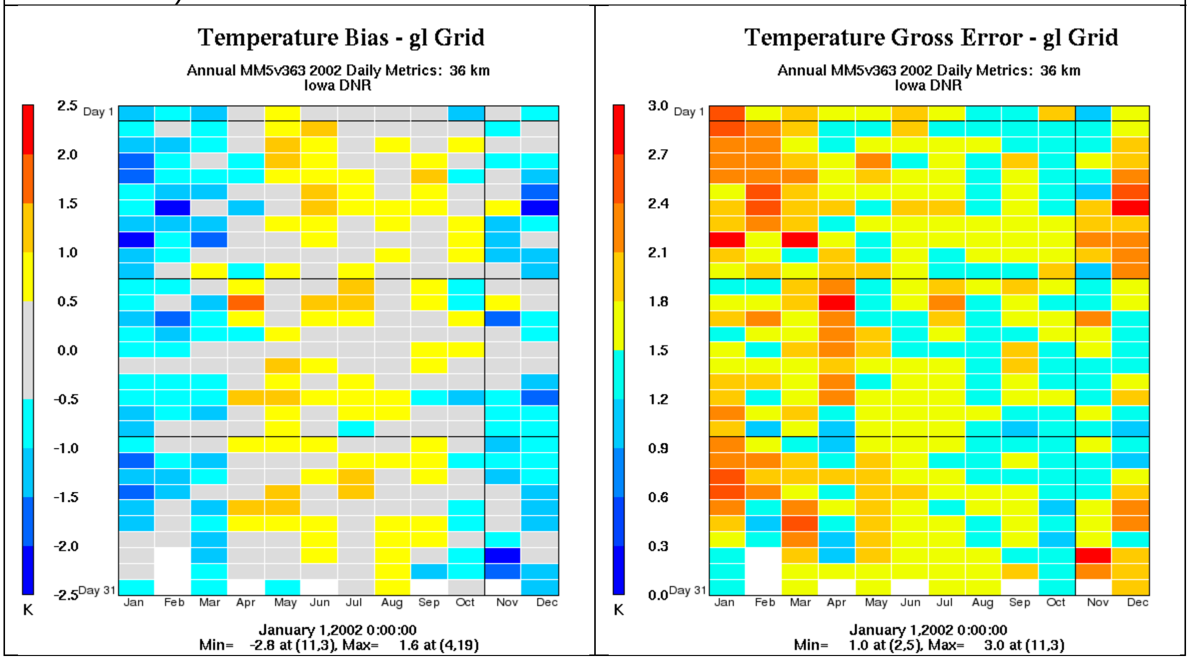


Figure 5. Daily wind direction bias and gross error (day 1 top row, last day of month bottom row)

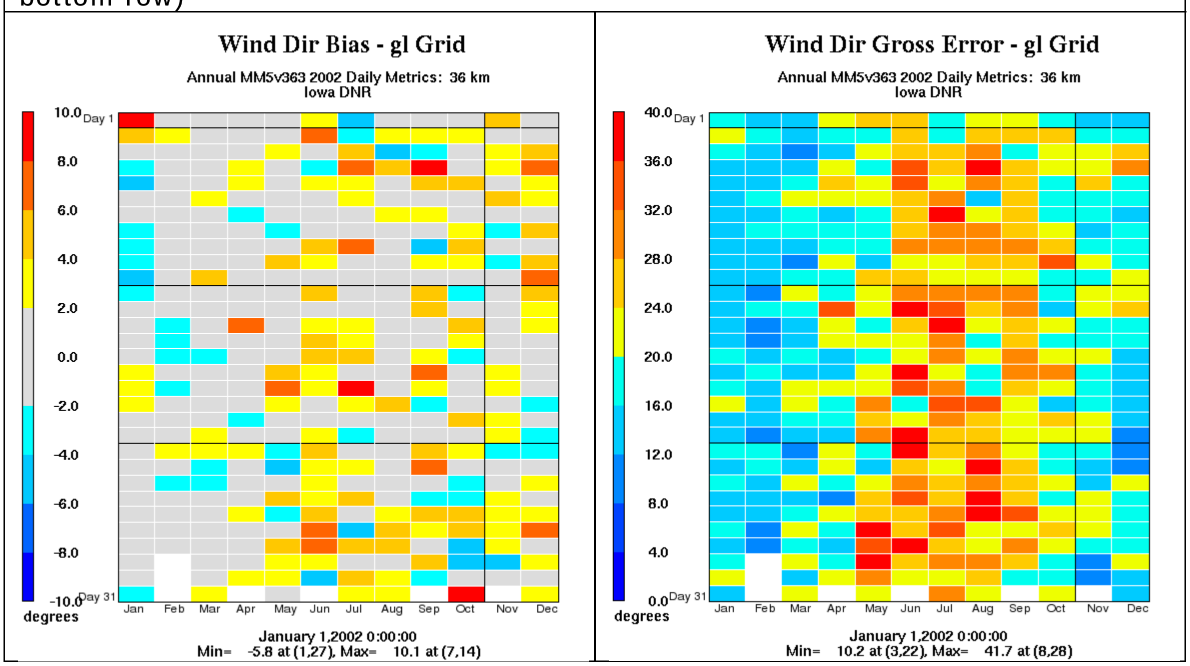
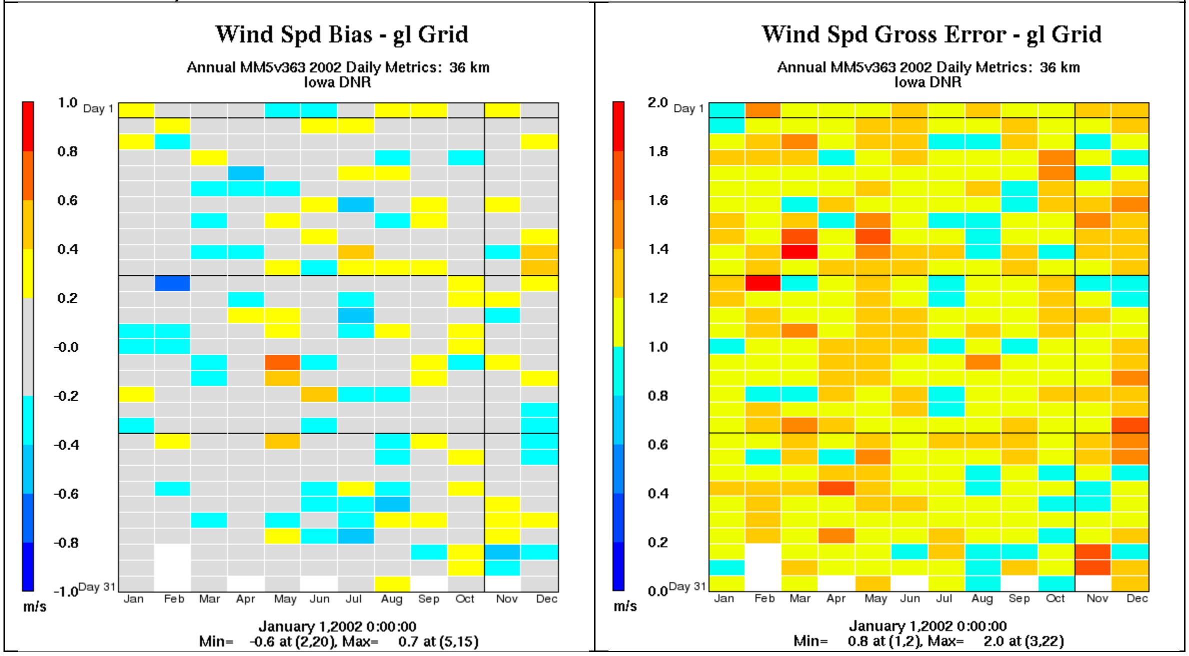


Figure 6. Daily wind speed bias and gross error (day 1 top row, last day of month bottom row)

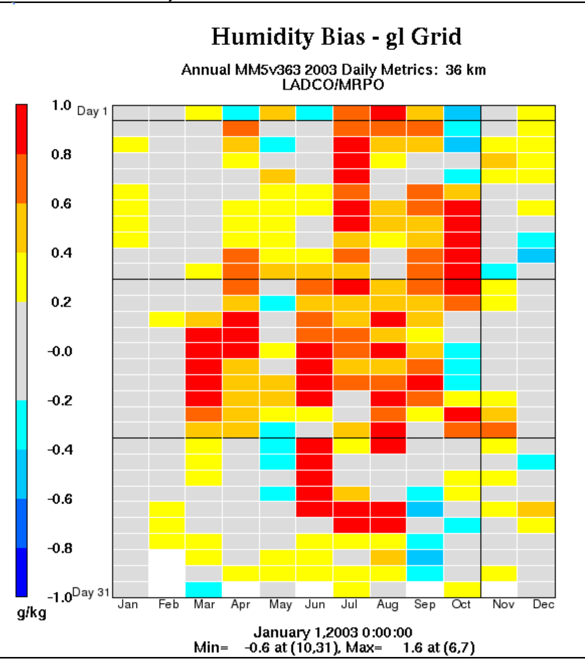


MODEL PERFORMANCE: Annual 2003 36 km

Model performance for the 2003 36 km simulation is very similar to the 2002 36 km annual simulation. Similar diurnal and seasonal issues are seen for both annual simulations in the Great Lakes/Upper Midwest region. The humidity error is highest in the summer and tends to be over-predicted. There is a cool temperature bias in the winter and slight warm bias in the summer. Temperature errors are highest in the winter months.

The wind fields are good; wind direction errors are highest in the summer and no seasonal trends are seen in the bias. Daily wind speed bias and error appear good, although similar diurnal performance problems are seen that are similar to the 2002 annual simulation. Rainfall is over-predicted in terms of magnitude in the summer months. The spatial patterns of rainfall tend to look good and performance for rainfall is very good in the winter months.

Figure 7. Daily humidity bias and gross error (day 1 top row, last day of month bottom row)



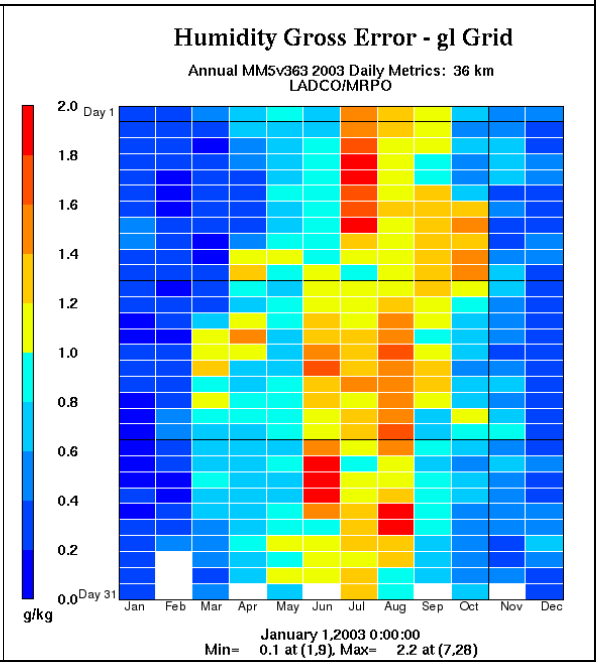
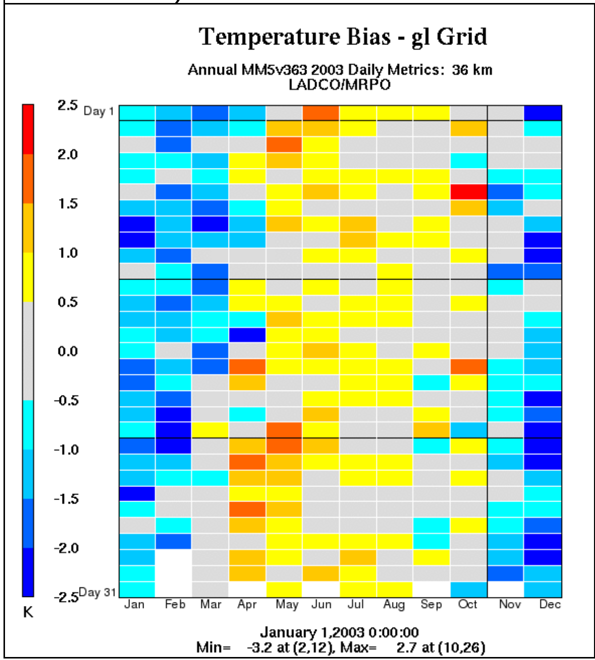


Figure 8. Daily temperature bias and gross error (day 1 top row, last day of month bottom row)



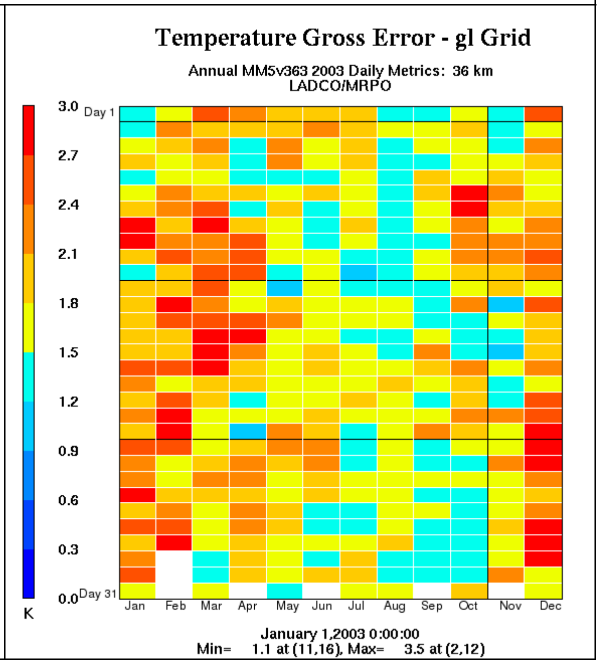


Figure 9. Daily wind direction bias and gross error (day 1 top row, last day of month bottom row)

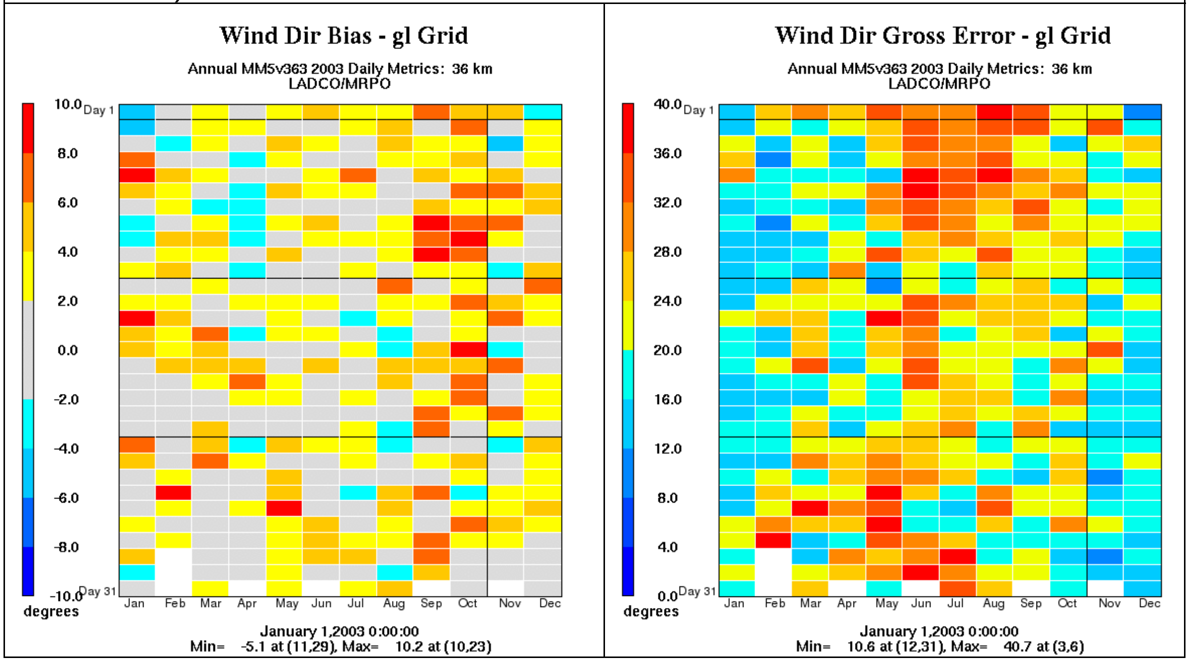
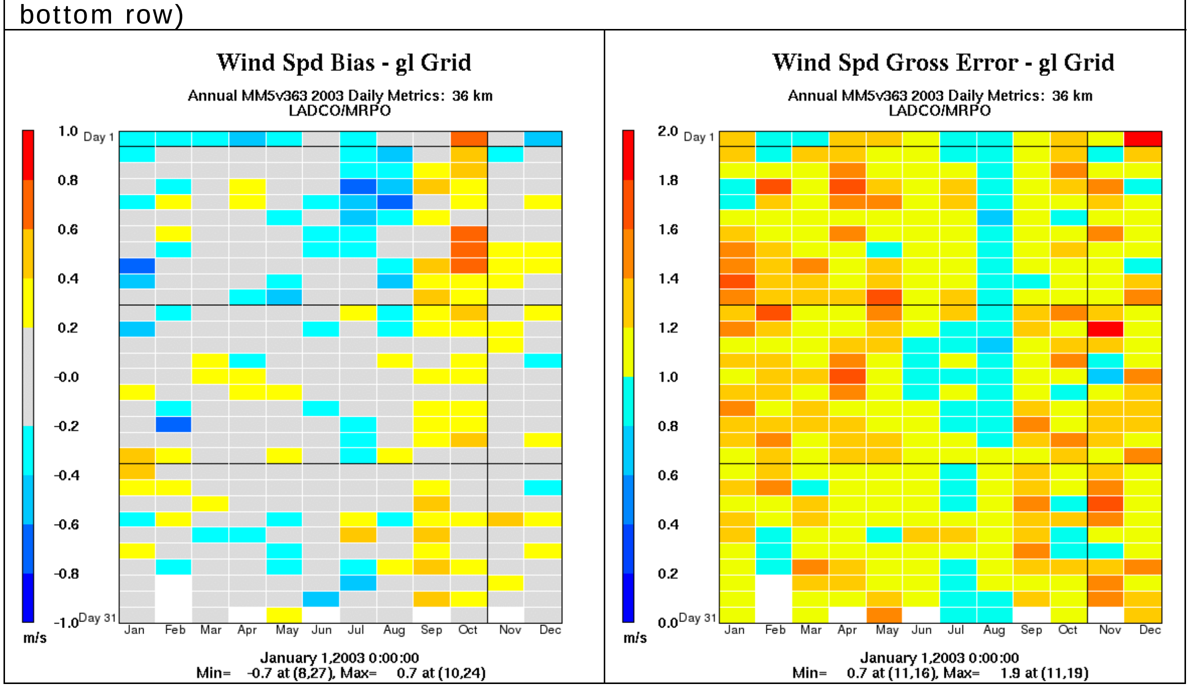


Figure 10. Daily wind speed bias and gross error (day 1 top row, last day of month bottom row)



MODEL PERFORMANCE: RAINFALL (2002 and 2003)

Convective and non-convective rainfall was totaled for each 36 km grid cell in the Eastern United States by month. The National Weather Service rainfall analysis field was mapped to the same grid projection and domain and totaled by month. These plots are shown side by side in Appendix A.

The modeled and observed rainfall totals show good agreement spatially and in terms of magnitude in the winter, fall, and early spring months of 2002 and 2003. There are large over-predictions of rainfall in the late spring and summer months. These over-predictions are seen spatially and in magnitude over the entire domain, particularly in the Southeast United States. These over-predictions are likely due to excessive convective rainfall being predicted in MM5. The summer month over-predictions are seen in 2002 and 2003 and vary in magnitude.

MODEL PERFORMANCE: 36 km v 12 km (2002 annual simulation)

The 12 km nest was 2-way nested and the feedback option was turned off, thus preventing the 12 km data from overwriting the 36km fields. This allows for a true evaluation of 36 v. 12 km performance. The boundary conditions are updated for the 12 km grid at every time-step in this method of 2-way nesting in MM5. This provides an advantage over the hourly updates to the 12 km grid if running MM5 in 1-way nesting mode.

Model performance comparing the 36 and 12 km performance in the Great Lakes region is shown in the form of mosaic difference plots in Appendix B. In the Great Lakes region, a winter-time performance degradation is seen in the 12 km run compared to the 36 km run for the wind field and temperature. The temperatures have a cold bias at 36 km and get even colder at 12 km.

Daytime wind speed bias improves at 12 km, but nighttime bias degrades. The mixing ratio performance improves slightly in the Ohio Valley region at 12 km. Overall, the 12 km grid results in little if any benefit in terms of statistical model performance.

MODEL PERFORMANCE: Summers of 2001, 2002, and 2003

The model performance for the summers of 2001, 2002, and 2003 focusing on the Great Lakes Region is shown in prediction-observation time series plots in Appendix C. The predictions and observations are averages over many observation sites in the sub-region of interest. A summary of performance in the Upper Midwest is given below.

Summer of 2001:

- MM5 performs well for temperatures and wind field
- Not quite capturing temperature peaks during August 2001 ozone episode
- Overall moisture and rainfall slightly over-predicted, but spatial patterns look good

Summer of 2002:

- Capturing temperate peaks ok, but over-predicting night time minimums

- Over-predictions of moisture and rainfall in the Ohio Valley; large over-predictions of rainfall in the South
- Wind fields look ok; diurnal wind speed day time peaks not always captured during the ozone episodes

Summer of 2003:

- Wind field ok; diurnal wind speed patterns not quite captured in August ozone episode
- Temperatures ok; not getting night time minimums consistently
- Rainfall ok in Upper Midwest; over-predictions in the South

MODEL PERFORMANCE: New 2002 v. Old 2002 Simulation

An annual MM5 simulation for 2002 was previously completed using an older version of MM5, simple ice microphysics, surface nudging, and continuous soil moisture (INTERPX). The figures in Appendix D show the differences between the previous annual simulation and the current annual simulation with mosaic difference plots.

Temperatures in general show a slight degradation in the new simulation, in particular in the winter. Wind speed performance improved and wind direction improved in the Central and Western United States. Humidity results are almost the same in both simulations. The difference in model performance is largely due to the inclusion of surface nudging in the previous annual 2002 simulation. That practice improves surface performance statistics but tends to create unusual meteorological artifacts like super-adiabatic lapse rates.

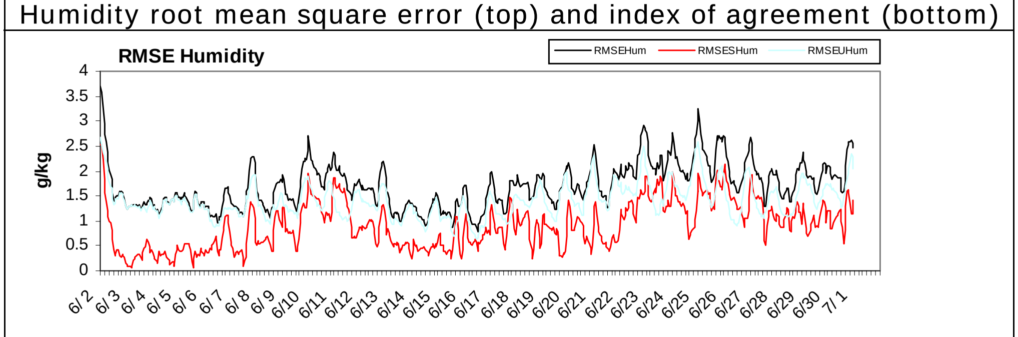
MODEL PERFORMANCE: Other Notes

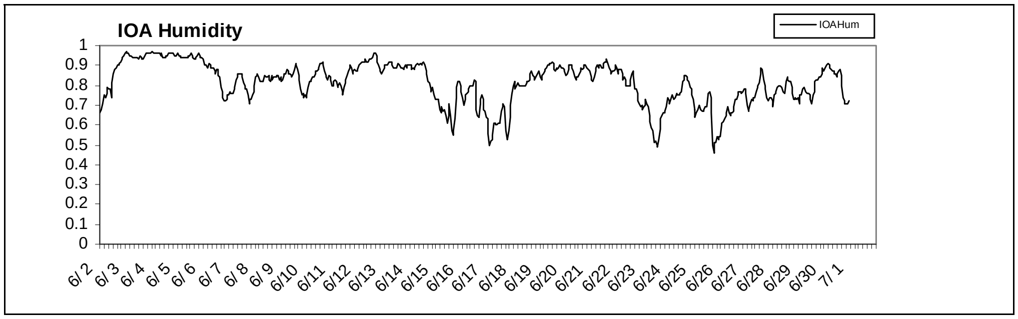
The index of agreement hourly metrics for humidity are interesting in that periods of poor index of agreement do not necessarily match up to poor error. Since the metrics are averaged over a sub-domain, the hourly index of agreement tends to degrade when fronts move across the domain. This causes very different model predictions and observations on the front and back side of the frontal passage.

This lack of agreement results in a degraded index of agreement metric even though the error and actual model performance is not poor. This should be acknowledged when interpreting index of agreement over a spatial region; degraded IOA may actually show a frontal passage and not truly reflect poor performance.

The time series plots below show RMSE and IOA for June 2002. Frontal passages pass through the area on the 16th, 18th, 24th, and 27th and degrade IOA.

Humidity root mean square error (top) and index of agreement (bottom)





CONCLUSION & DISCUSSION

This document contains an overview of MM5 performance. The results shown are intended to provide a context for future meteorological modeling applications, to identify deficiencies in the MM5 output that may result in poor photochemical model performance, and to increase confidence in the photochemical modeling applications that use these meteorological modeling estimates.

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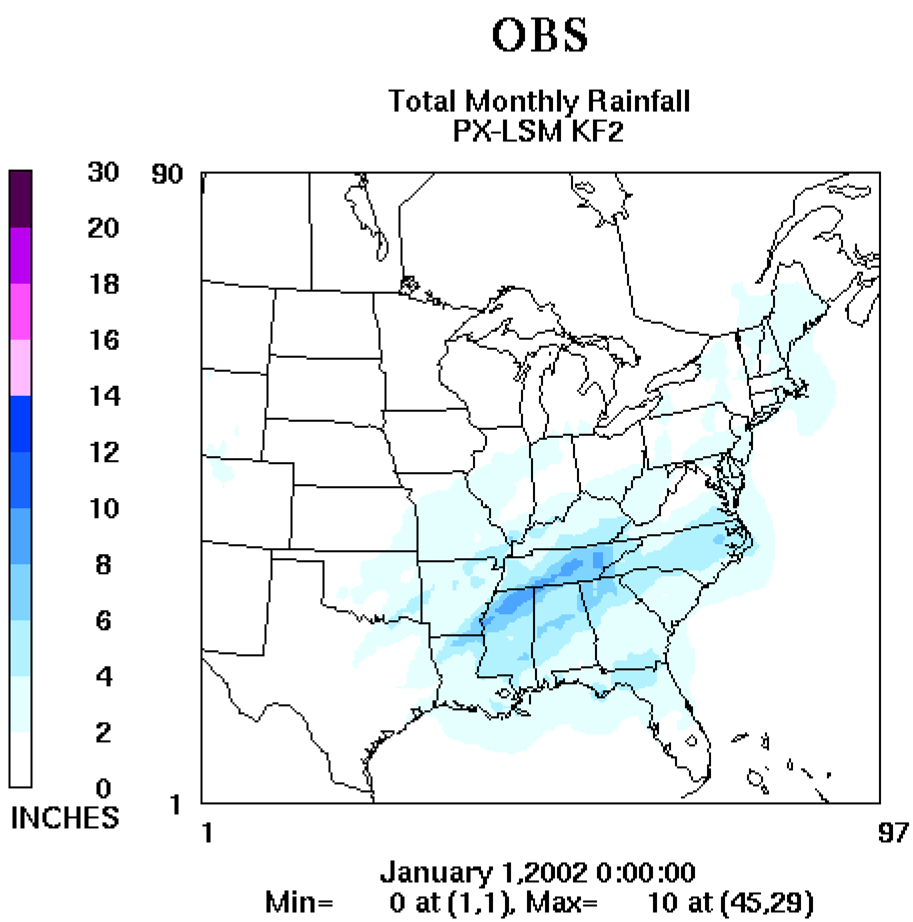
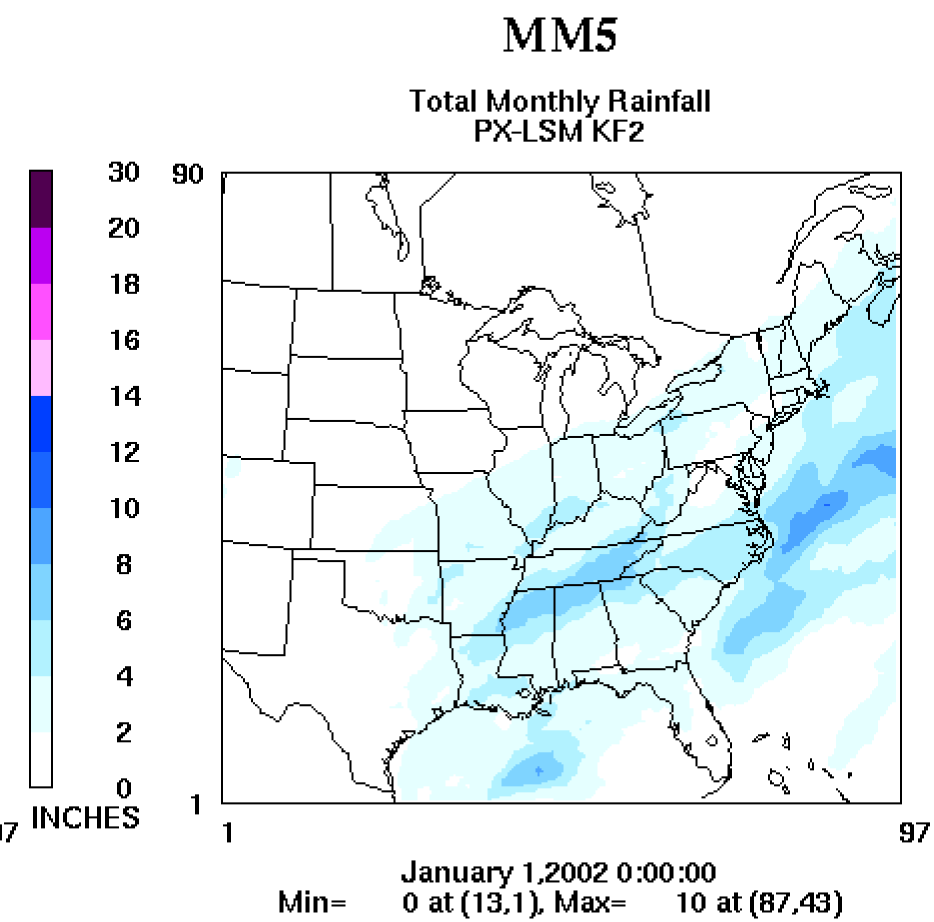
APPENDIX A

Rainfall Analysis

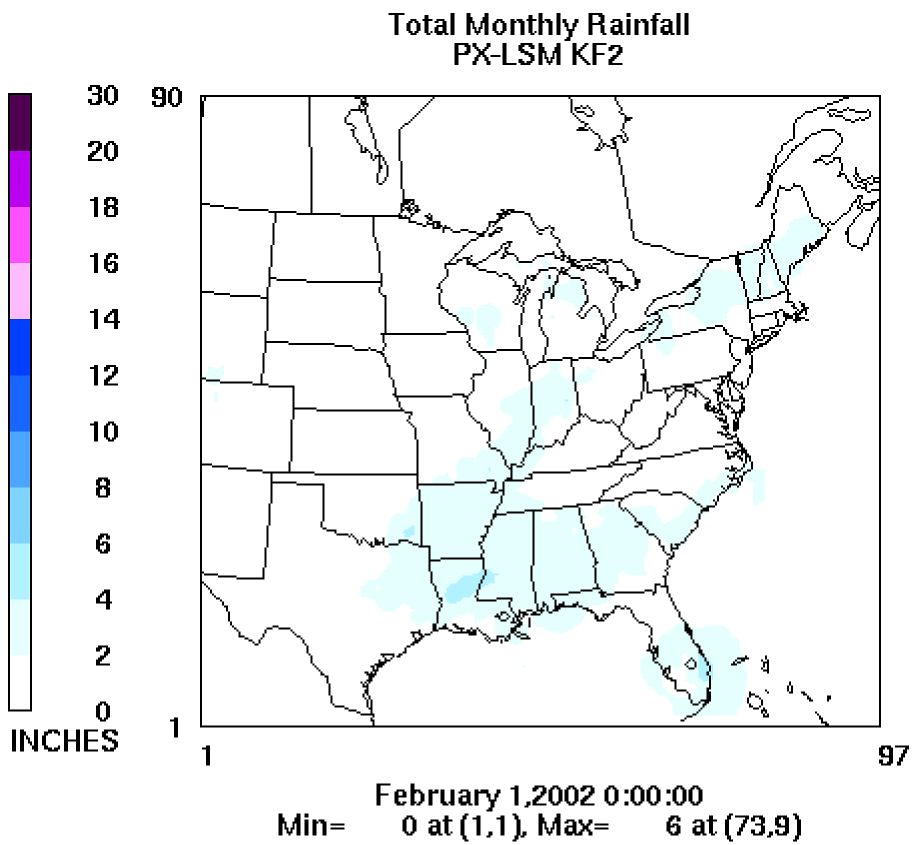
January 2002



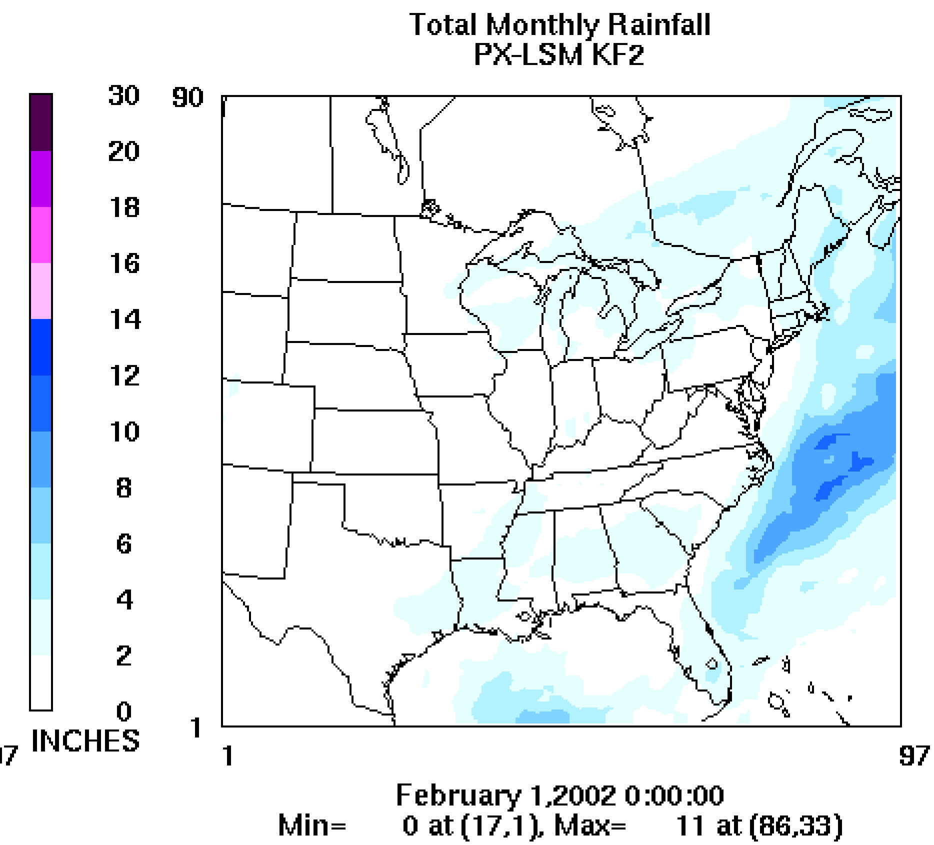


February 2002

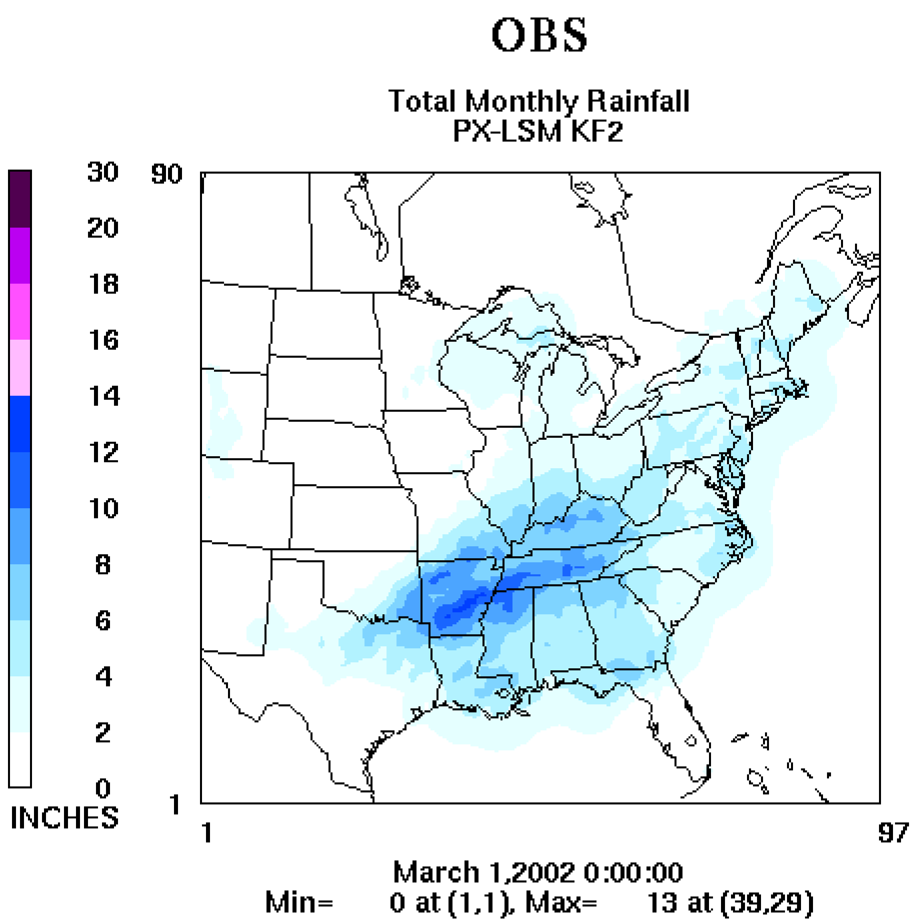
OBS



MM5



March 2002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Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
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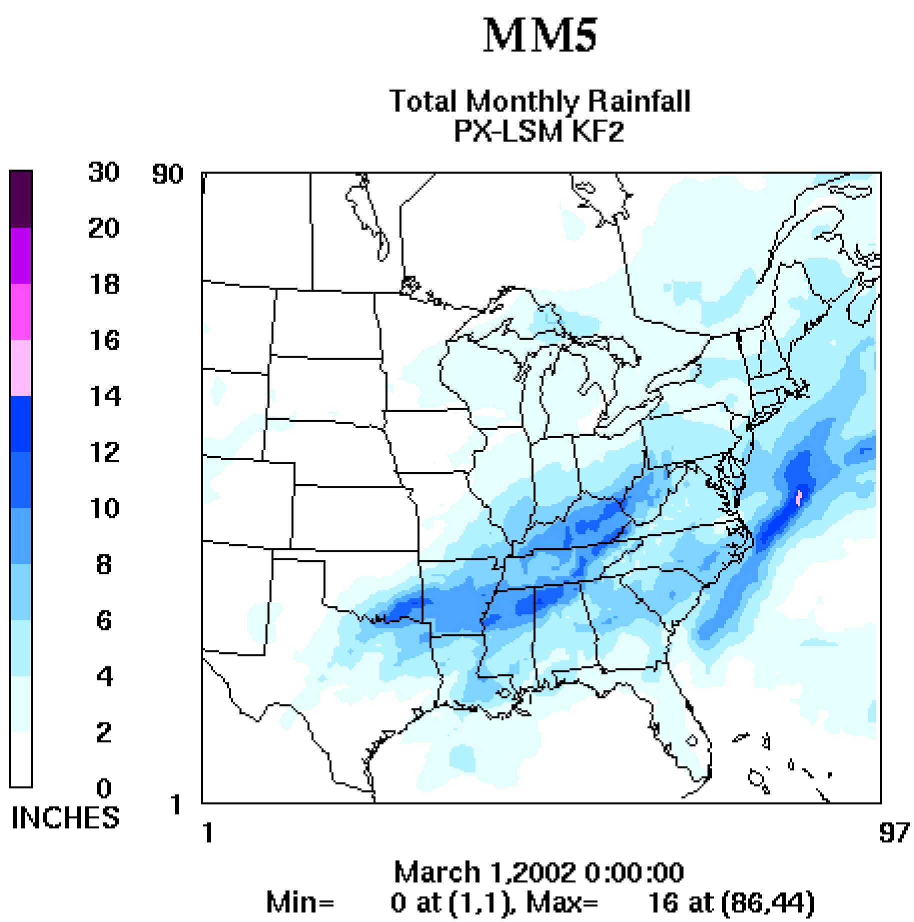
INCHES
90
1
1
97
March 1,2002 0:00:00
Min= 0 at (1,1), Max= 13 at (39,29)


MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
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90
1
1
97
March 1,2002 0:00:00
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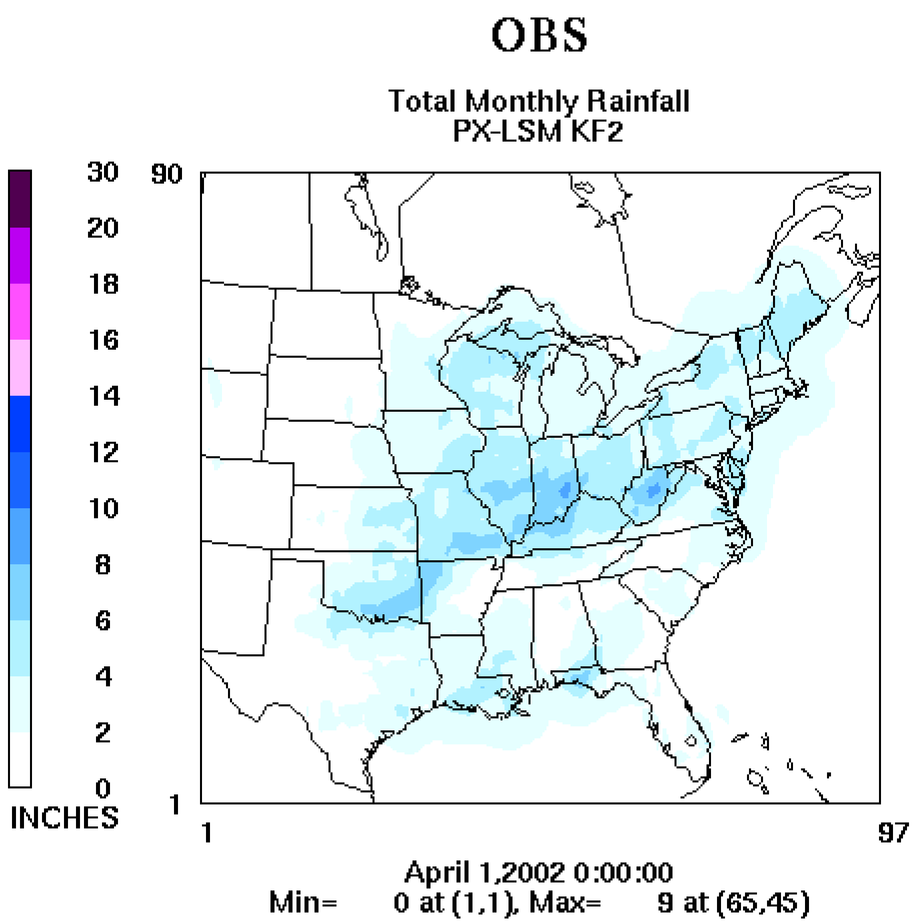
April 2002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Total Monthly Rainfall
PX-LSM KF2
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20
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16
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12
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1
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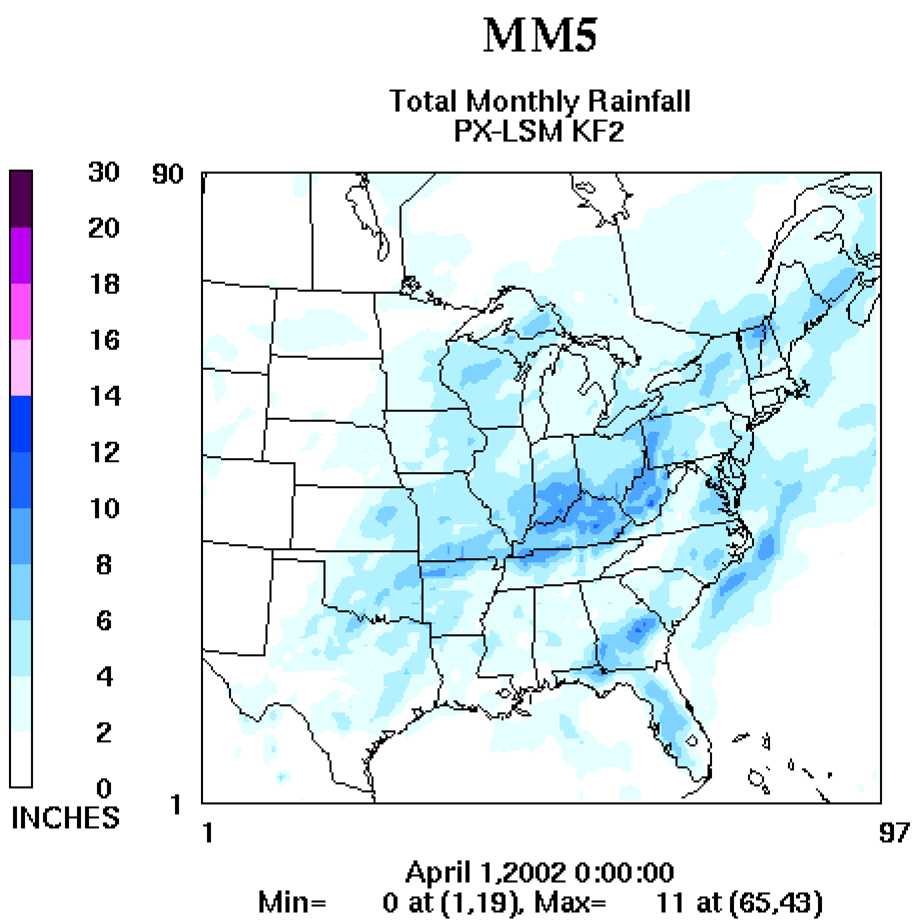
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Total Monthly Rainfall
PX-LSM KF2
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6
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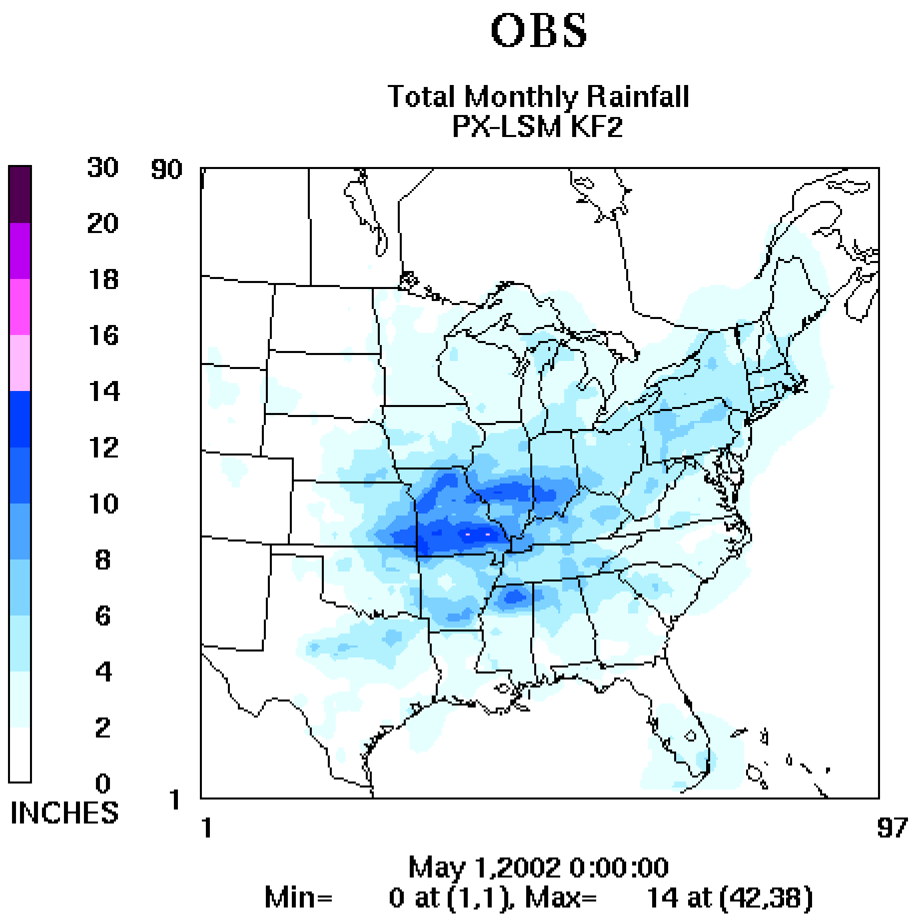
May 2002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Total Monthly Rainfall
PX-LSM KF2
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10
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1
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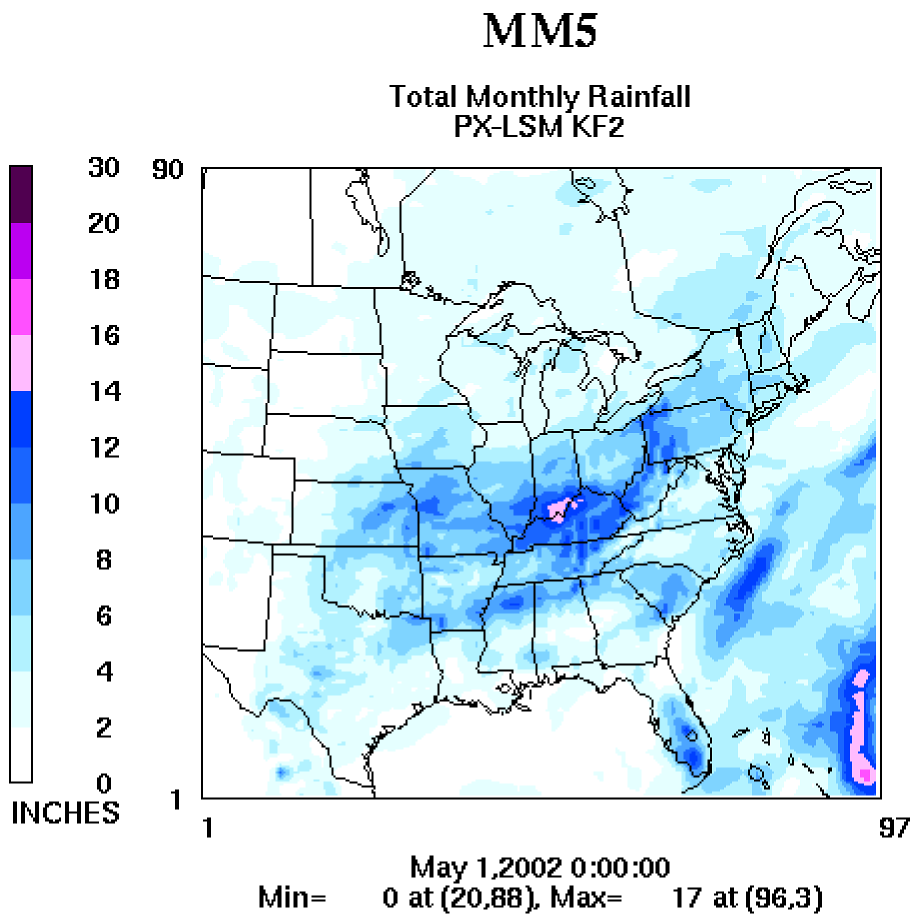
MM5
Total Monthly Rainfall
PX-LSM KF2
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16
14
12
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8
6
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1
97
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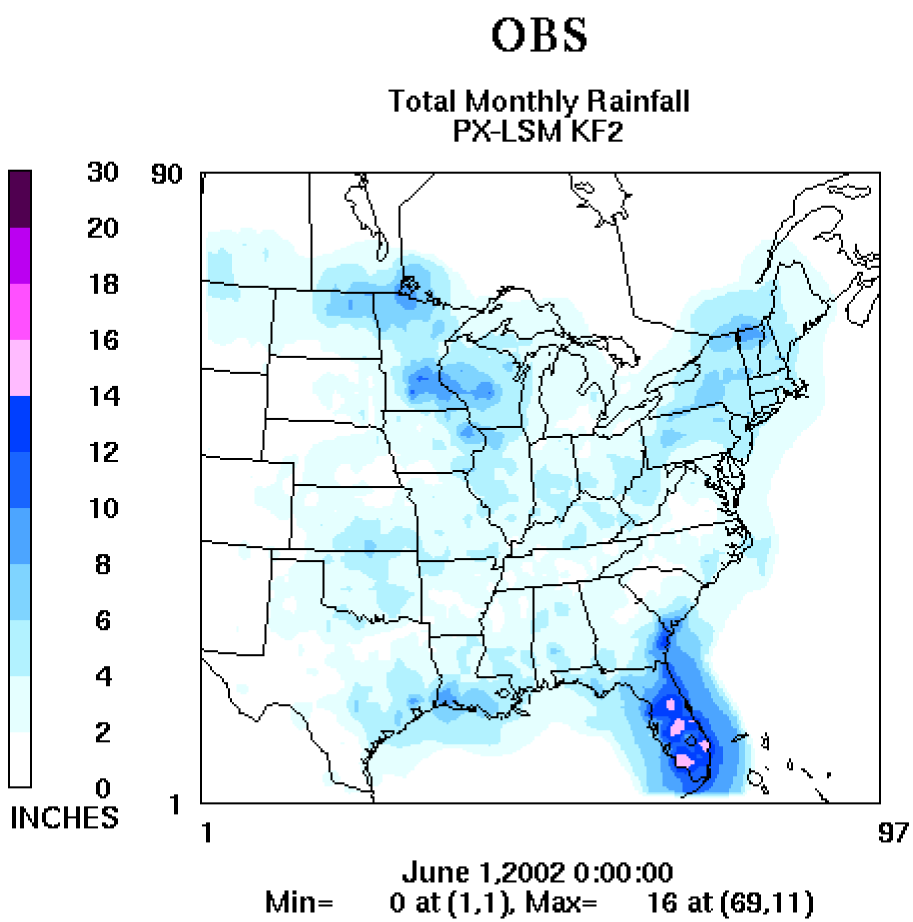
Min= 0 at (20,88), Max= 17 at (96,3)

June 2002


OBS
Total Monthly Rainfall
PX-LSM KF2
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18
16
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12
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1
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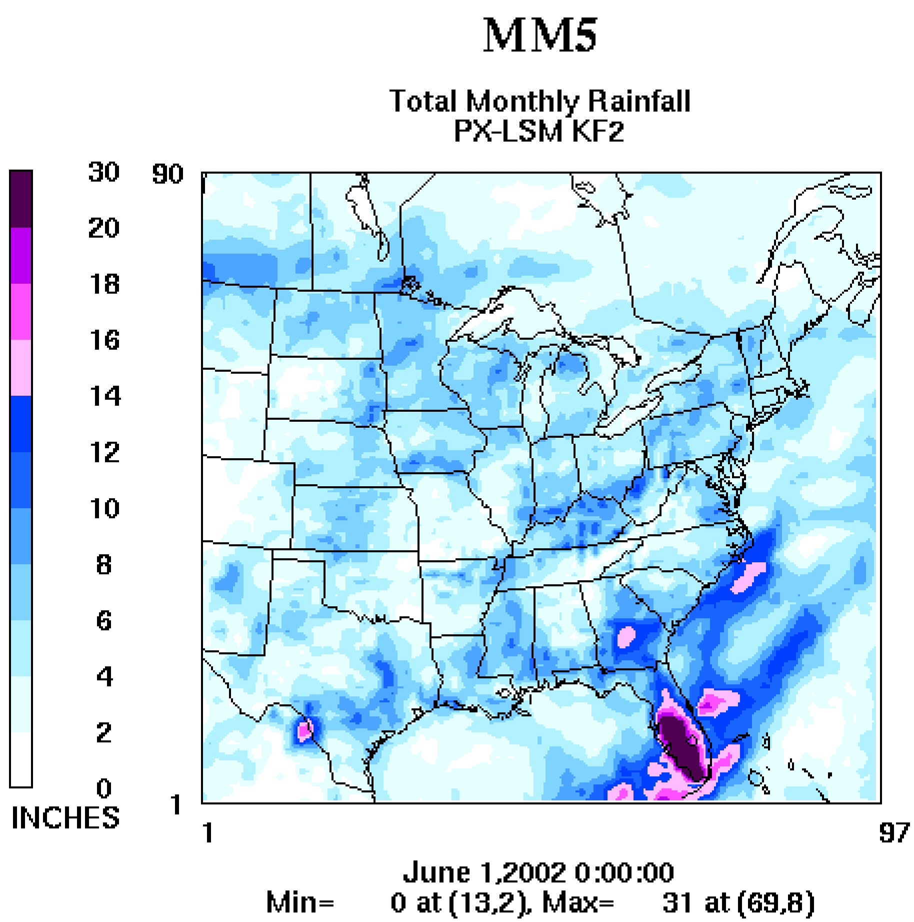
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Total Monthly Rainfall
PX-LSM KF2
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10
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6
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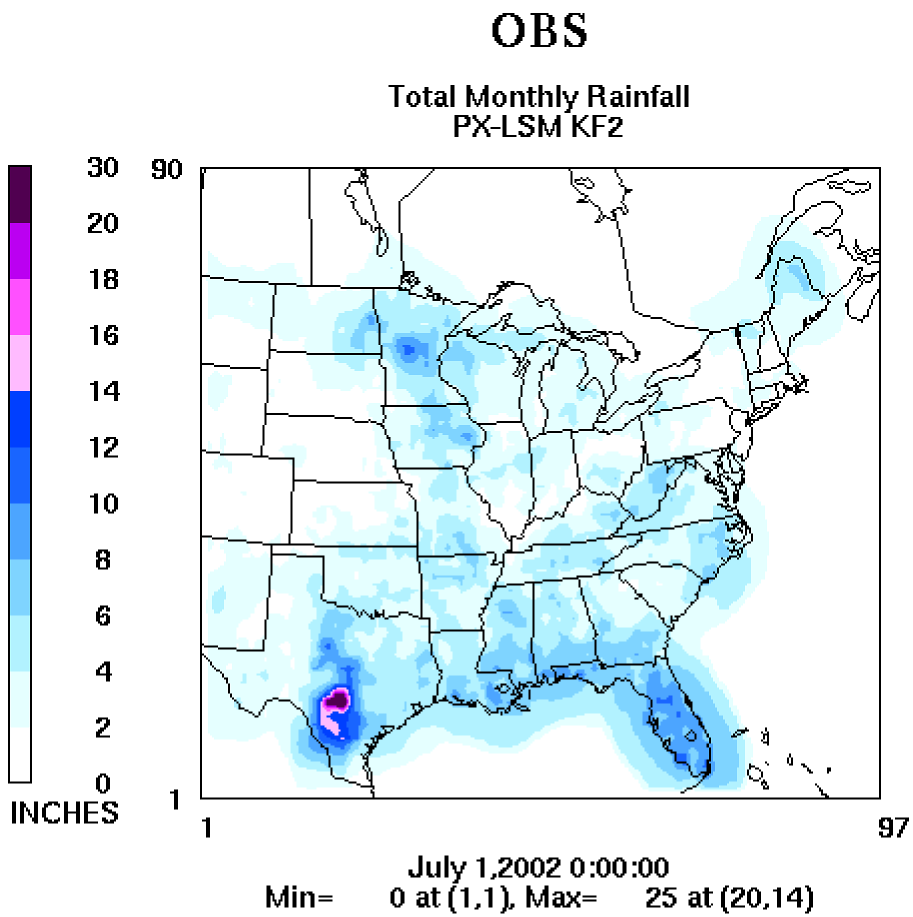
July 2002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Total Monthly Rainfall
PX-LSM KF2
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16
14
12
10
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1
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July 1,2002 0:00:00
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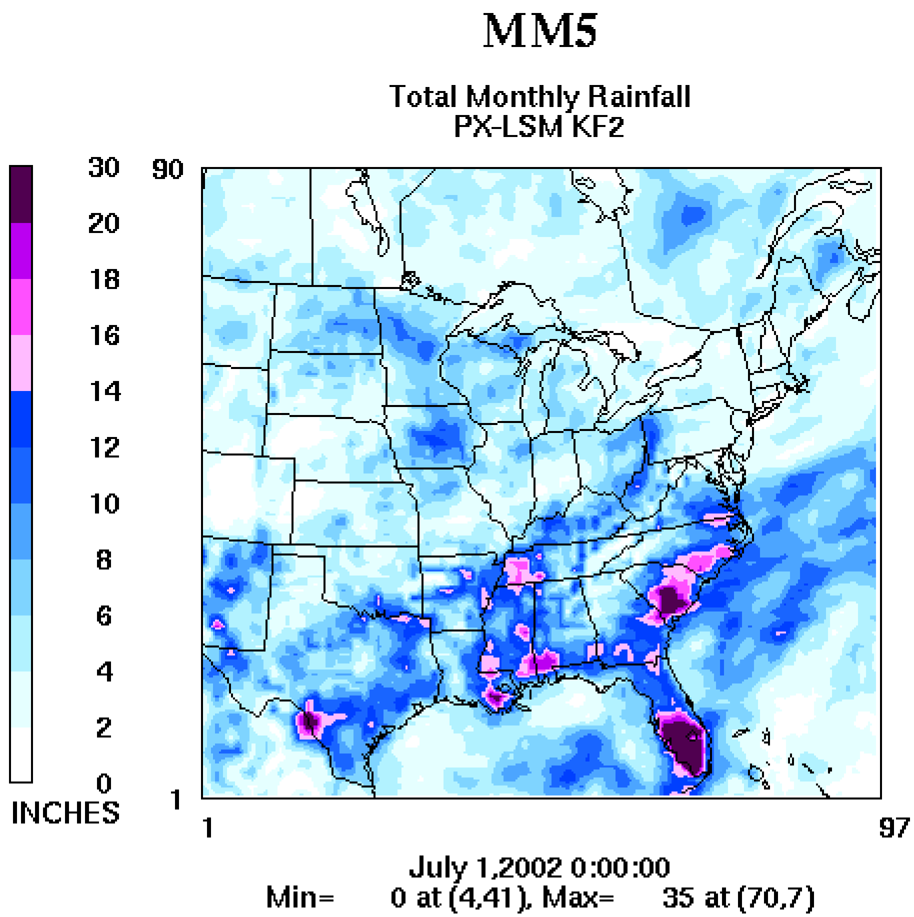
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Total Monthly Rainfall
PX-LSM KF2
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16
14
12
10
8
6
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2
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1
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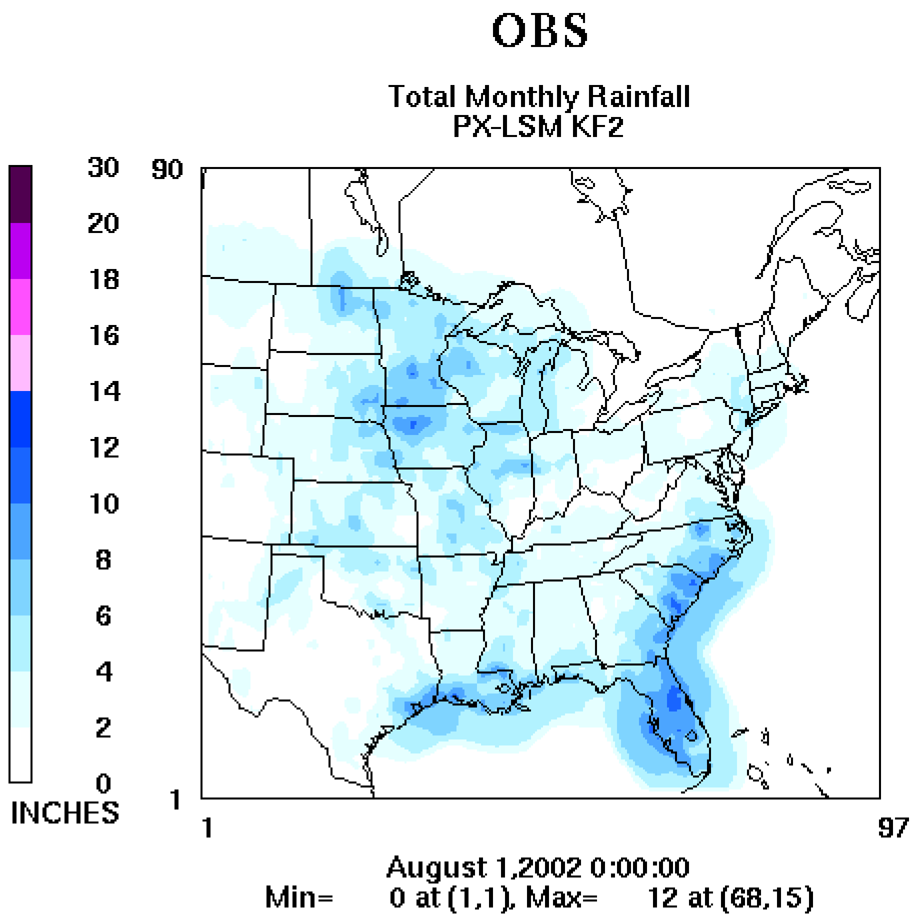
August 2002


OBS
Total Monthly Rainfall
PX-LSM KF2
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20
18
16
14
12
10
8
6
4
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INCHES
90
1
1
97
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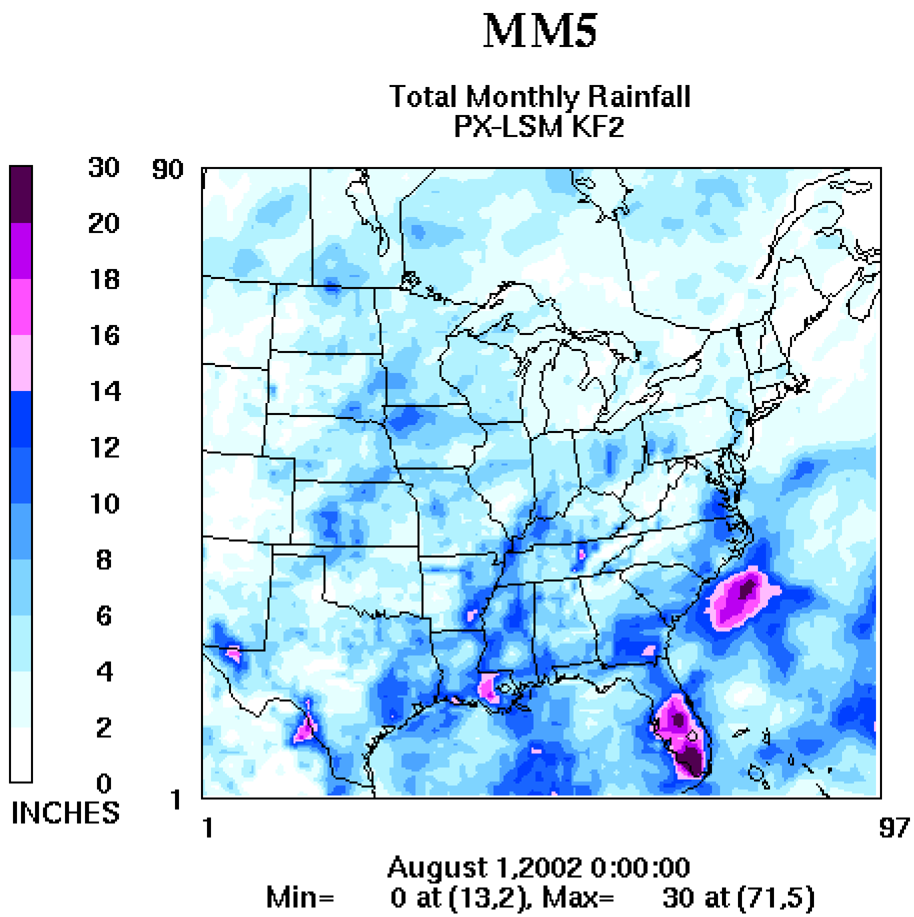
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Total Monthly Rainfall
PX-LSM KF2
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20
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16
14
12
10
8
6
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2
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1
97
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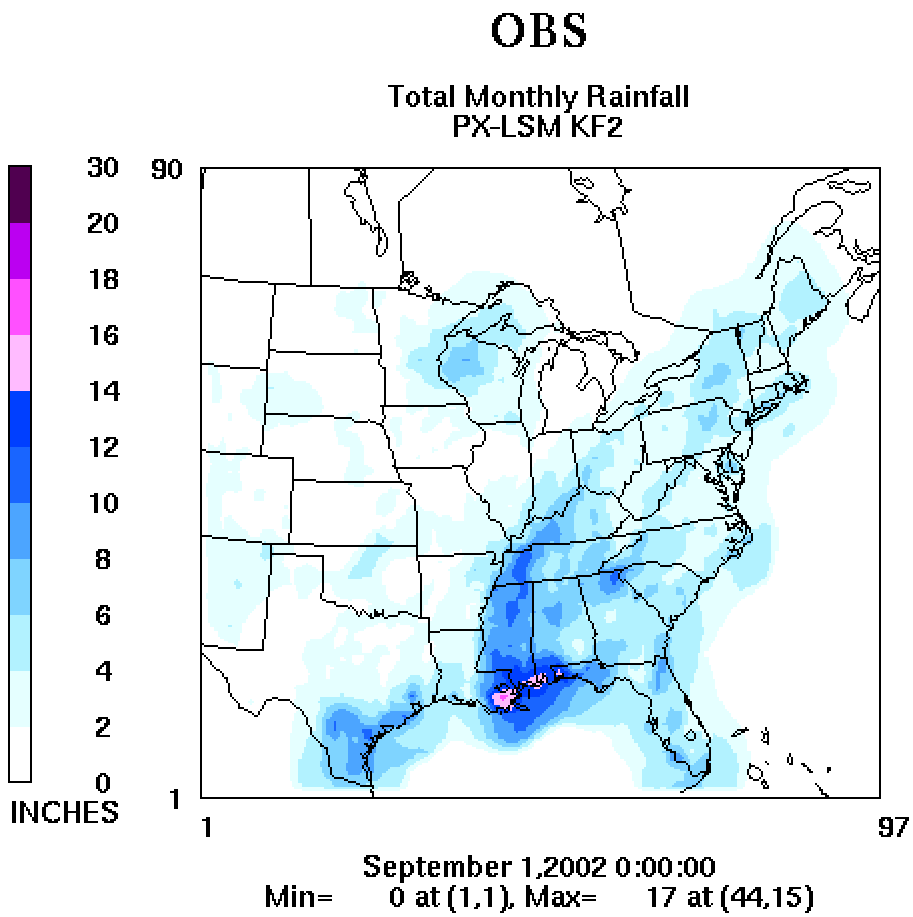
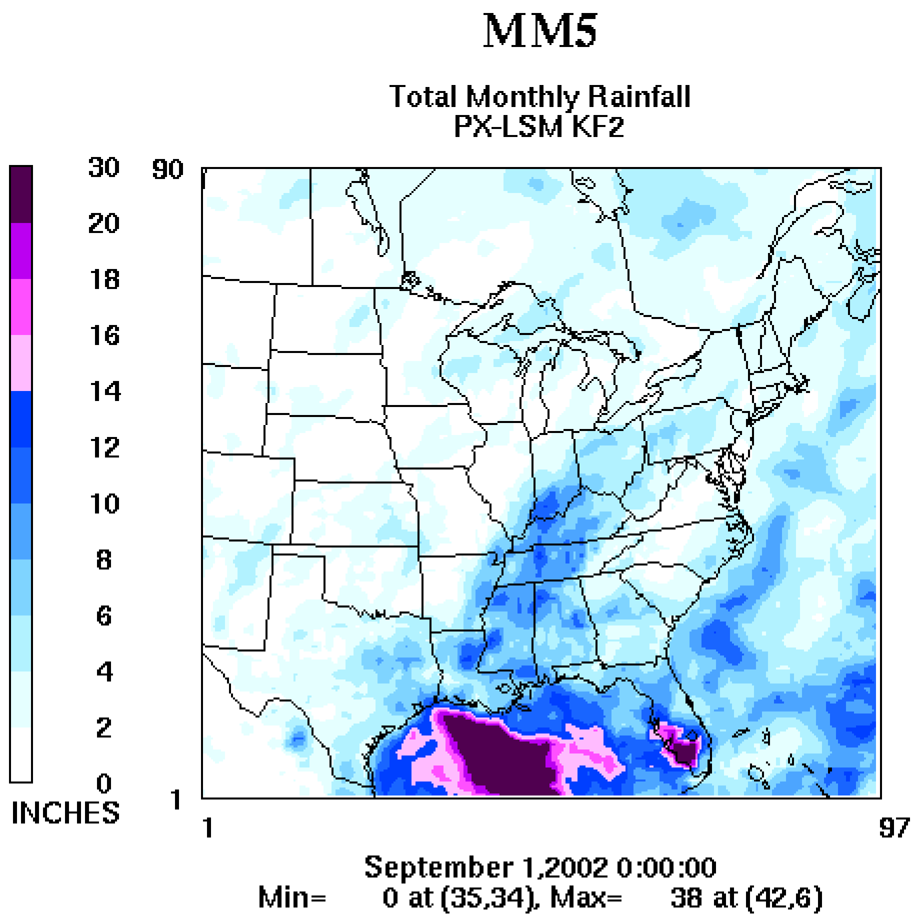
September 2002





October 2002

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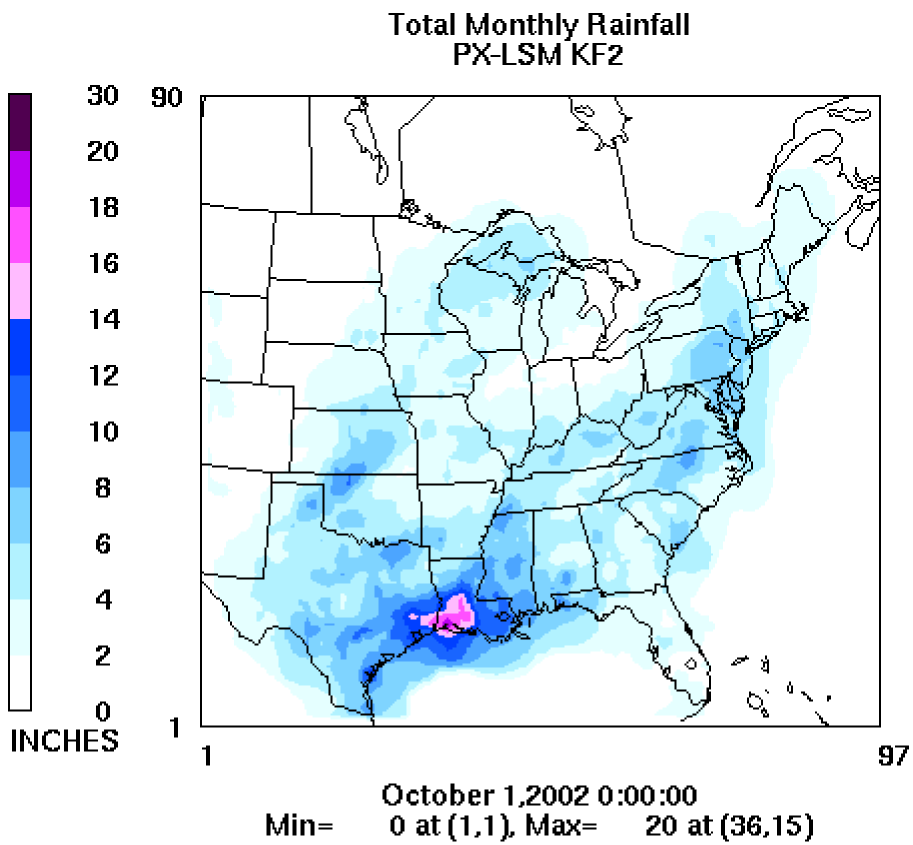
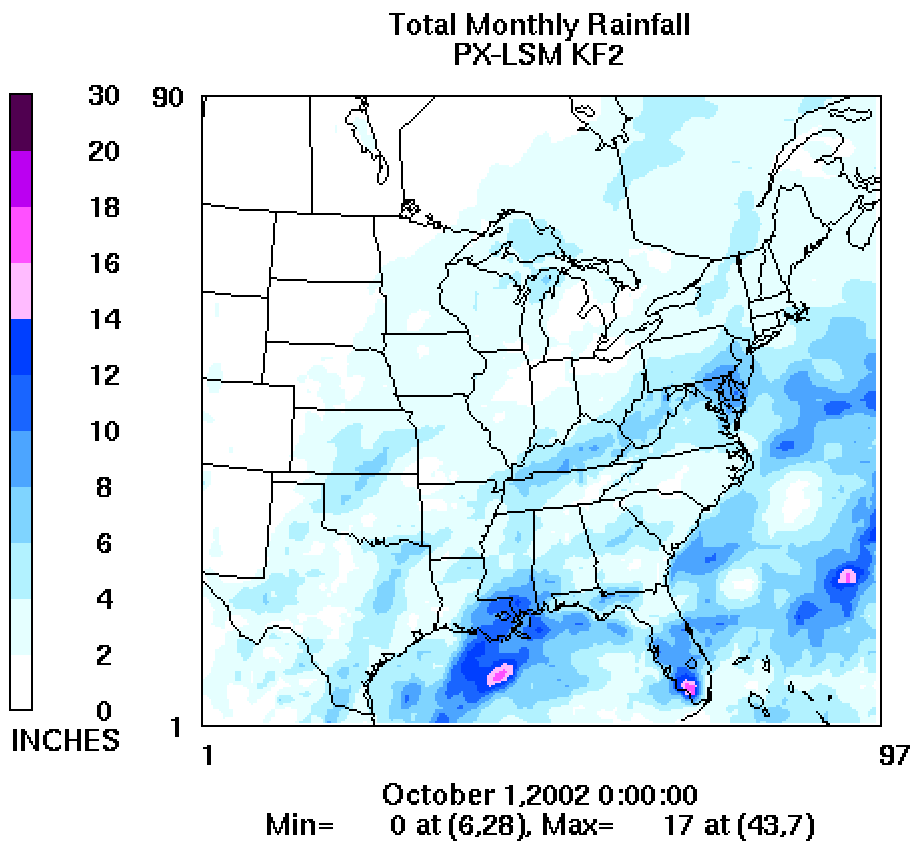


MM5



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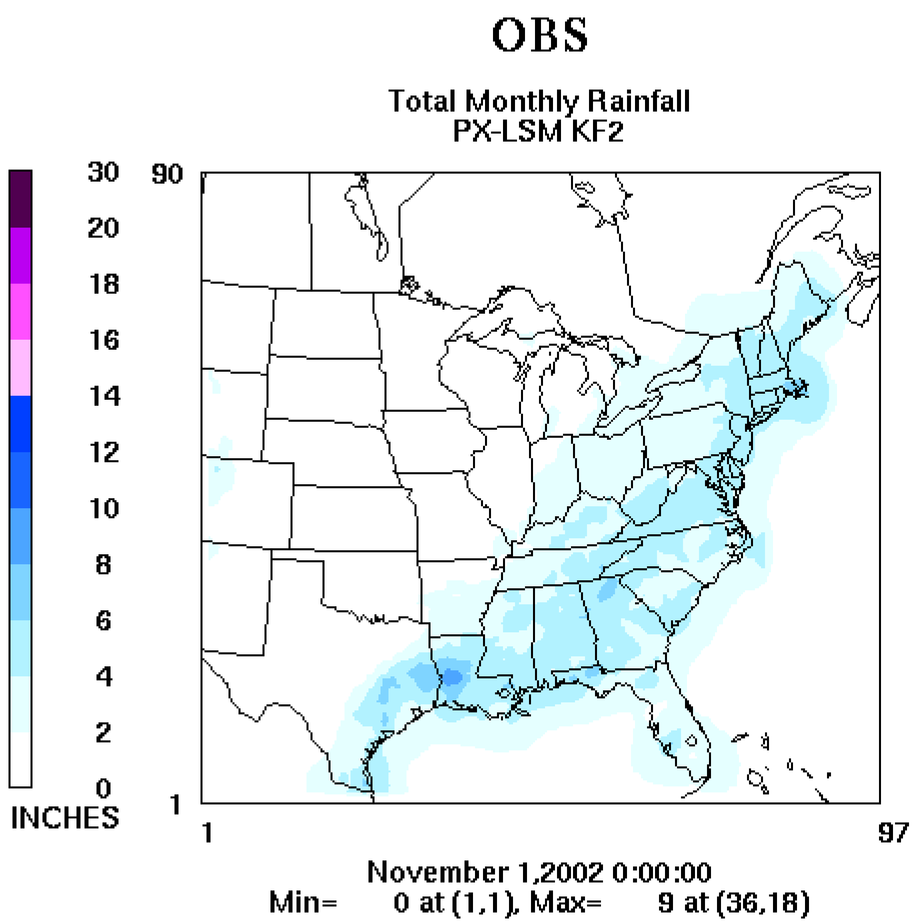

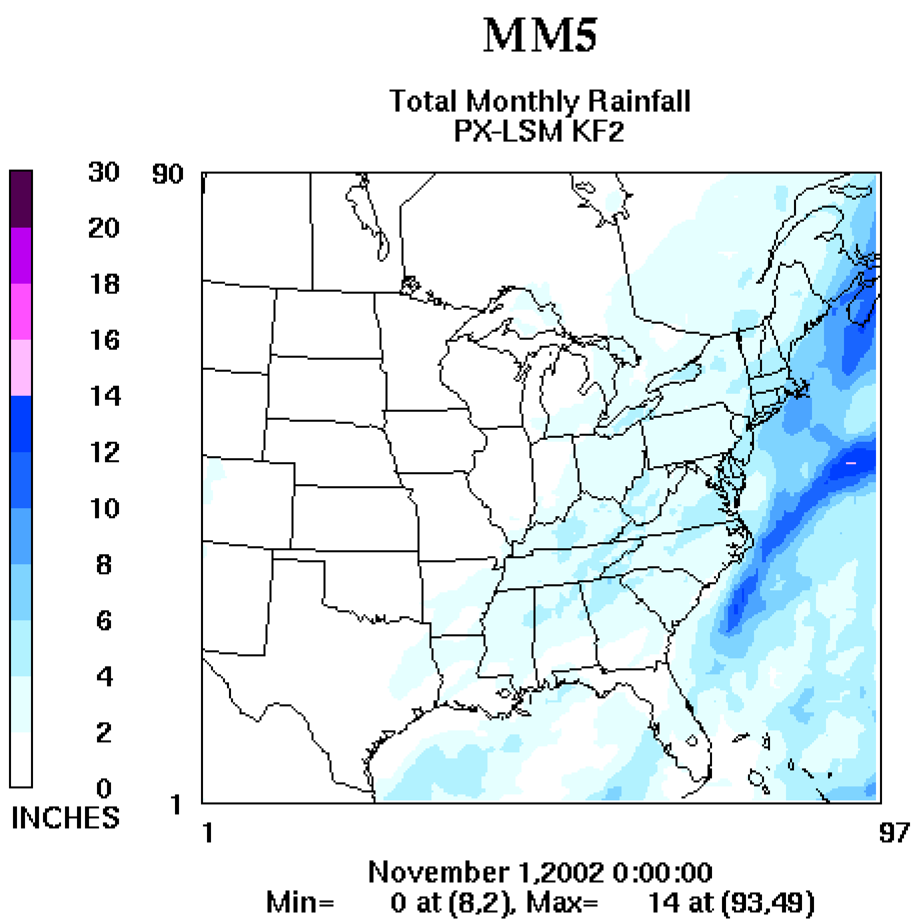

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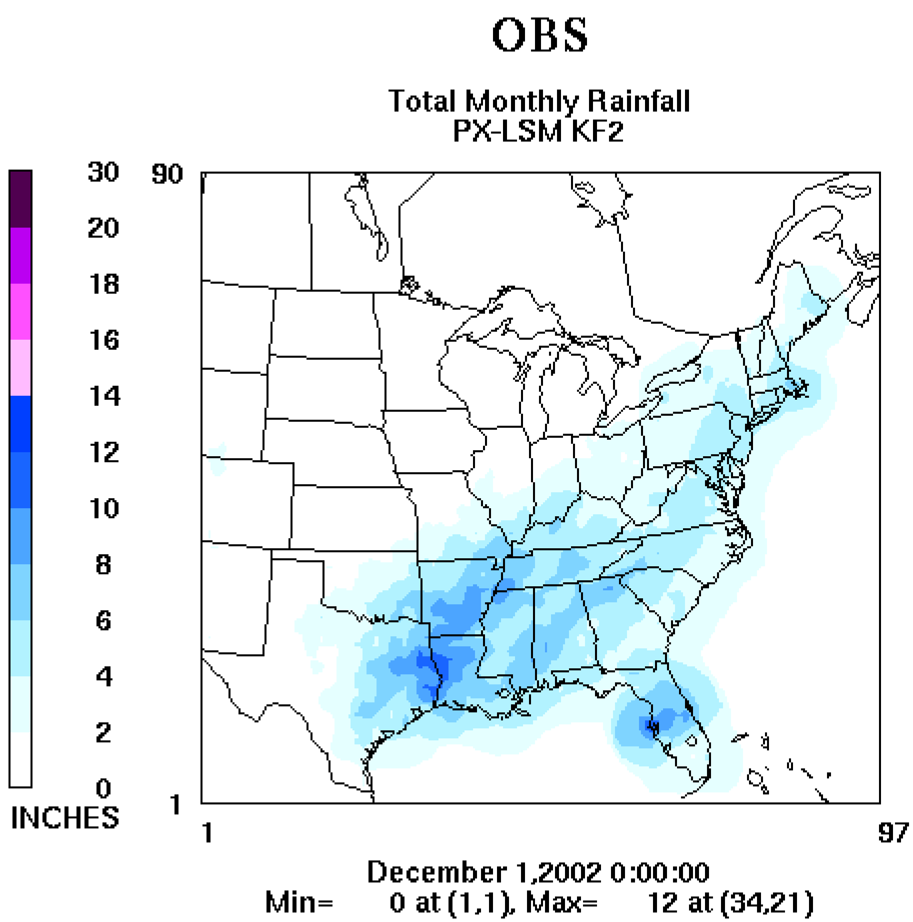

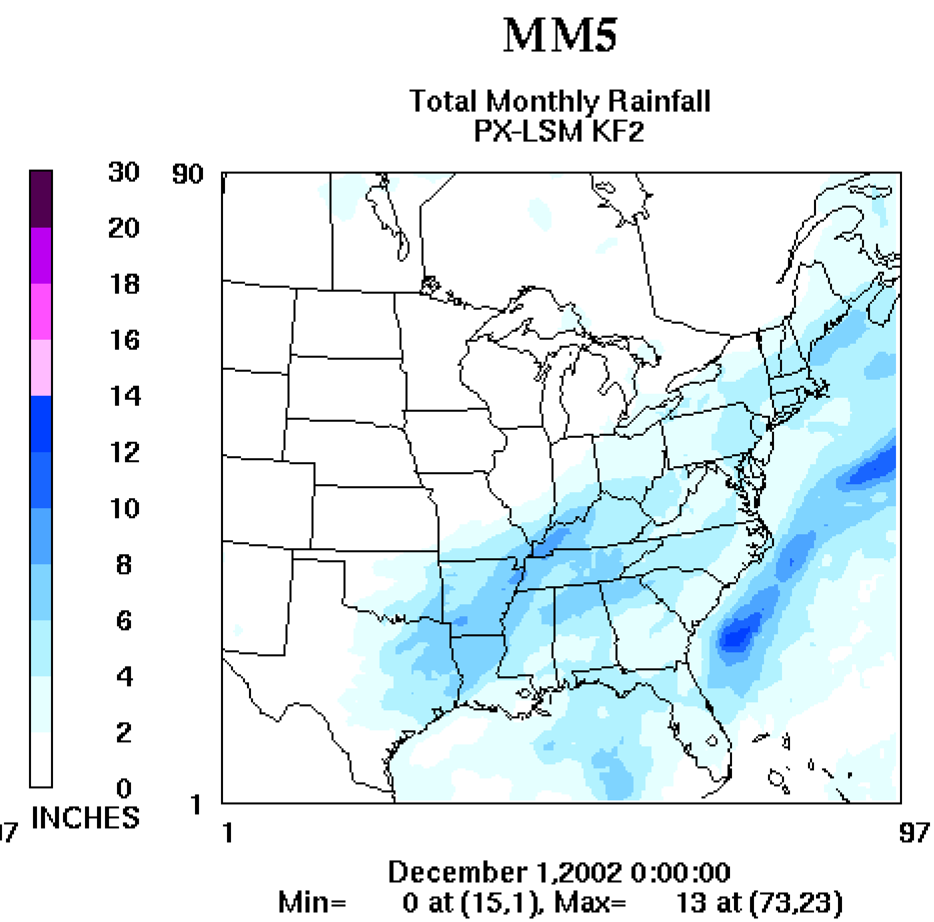

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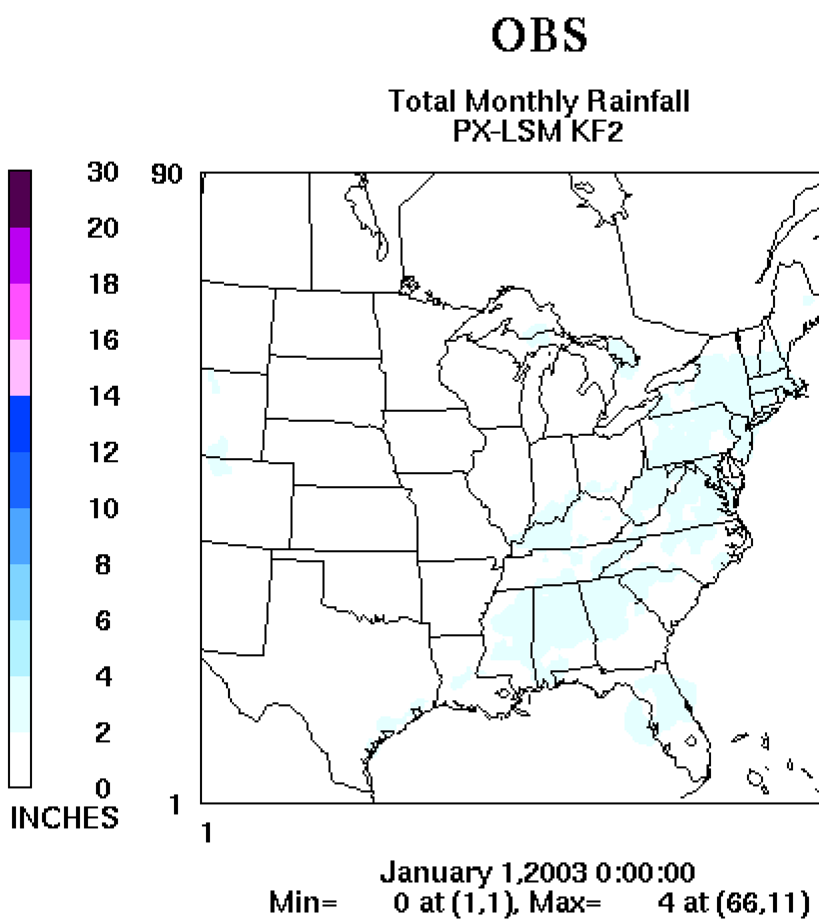

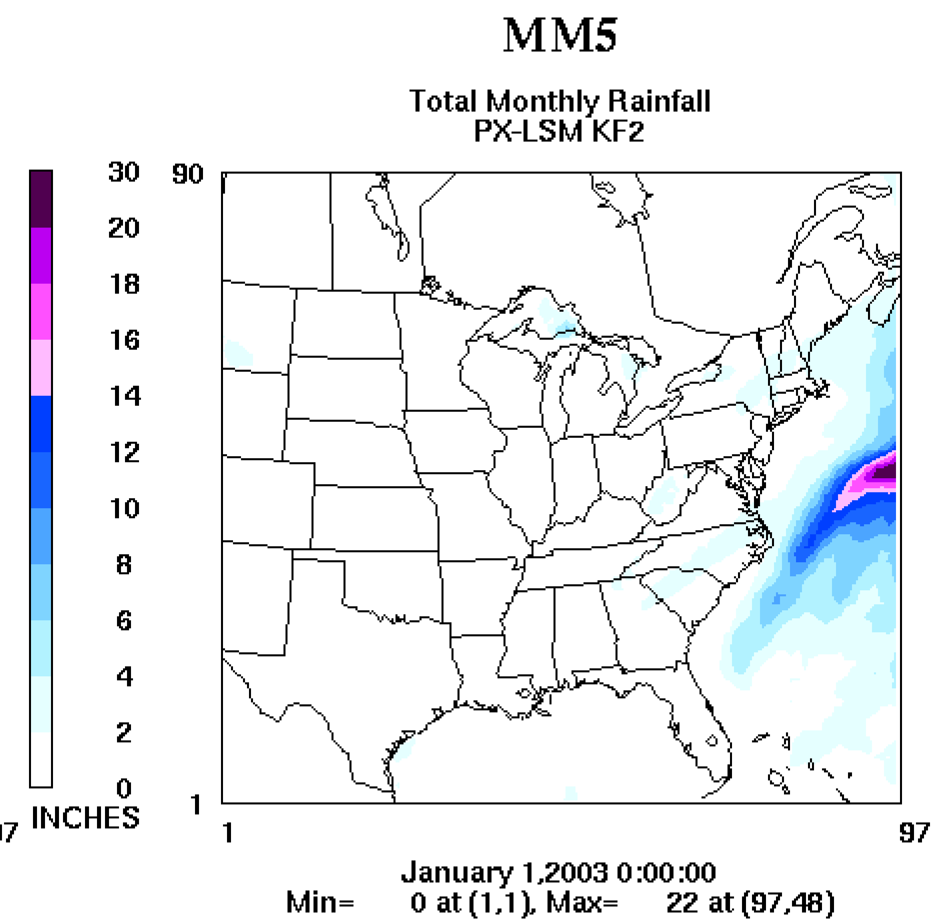

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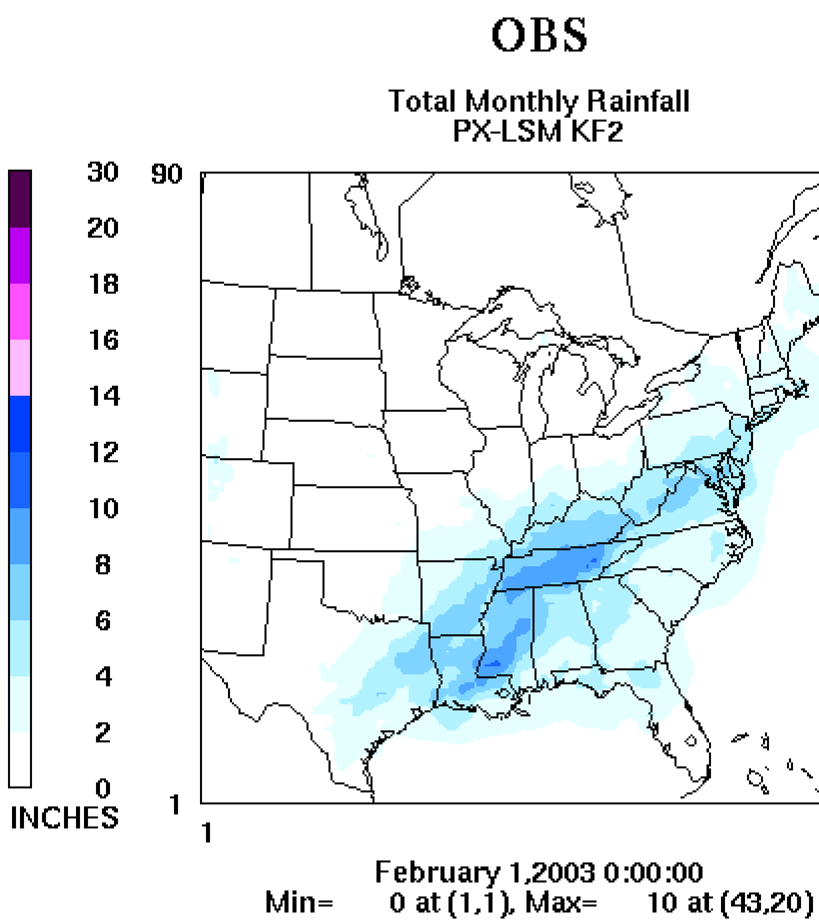

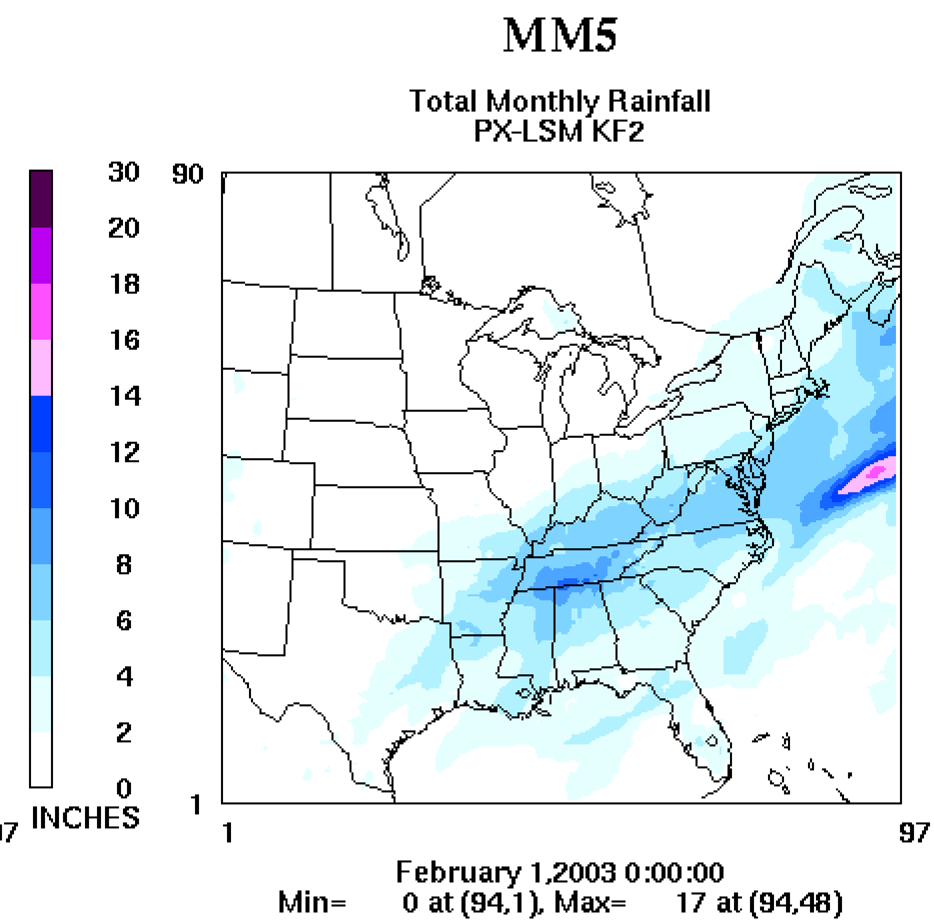

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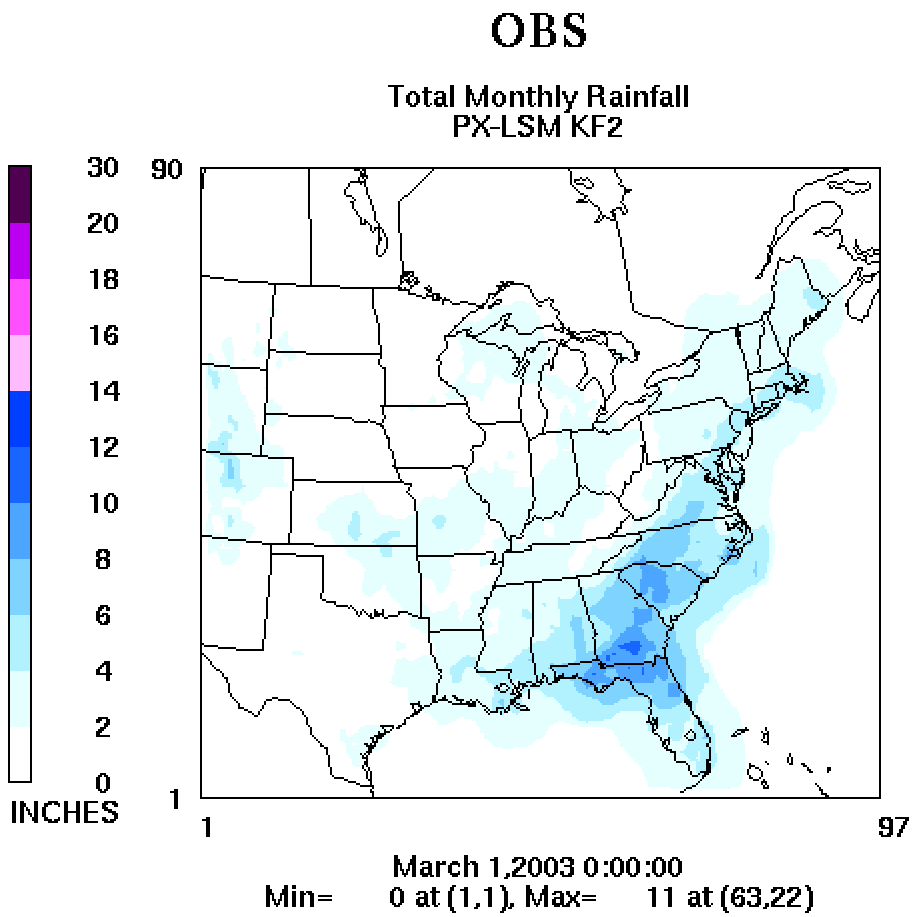
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PX-LSM KF2
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12
10
8
6
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INCHES
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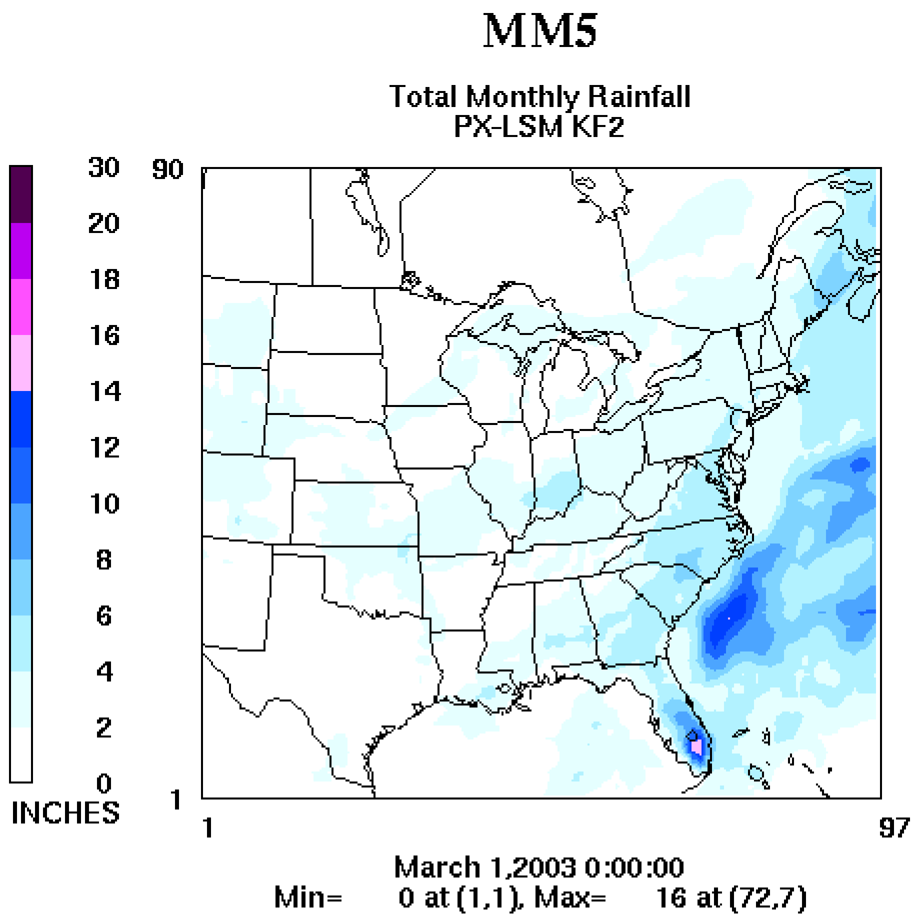
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PX-LSM KF2
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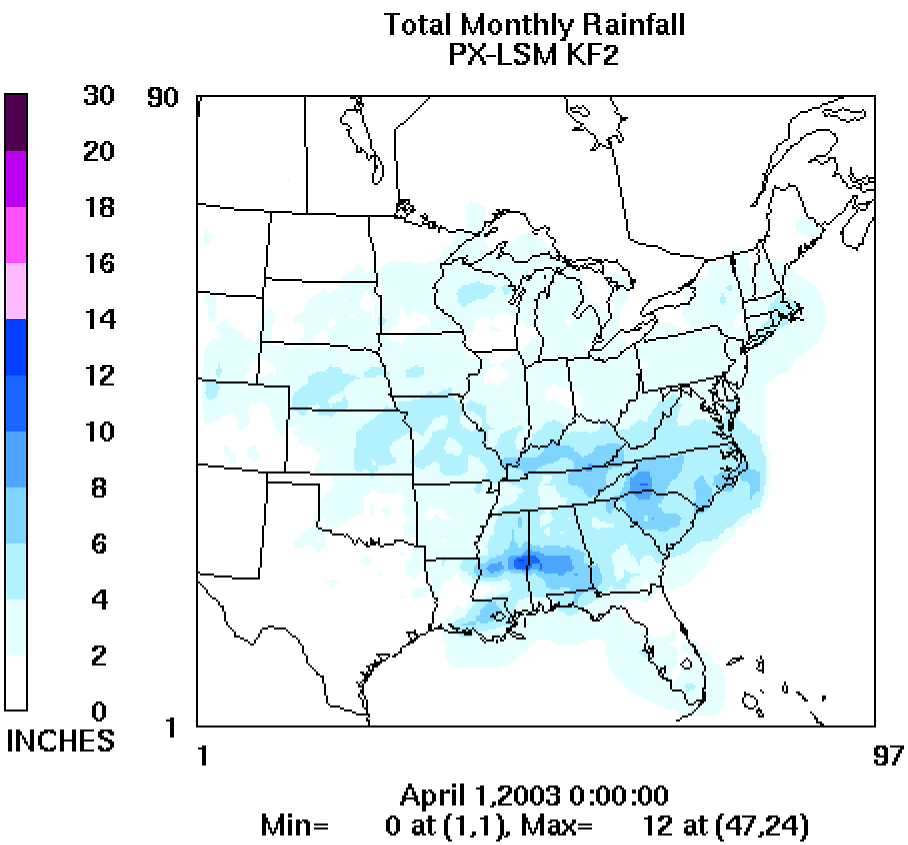
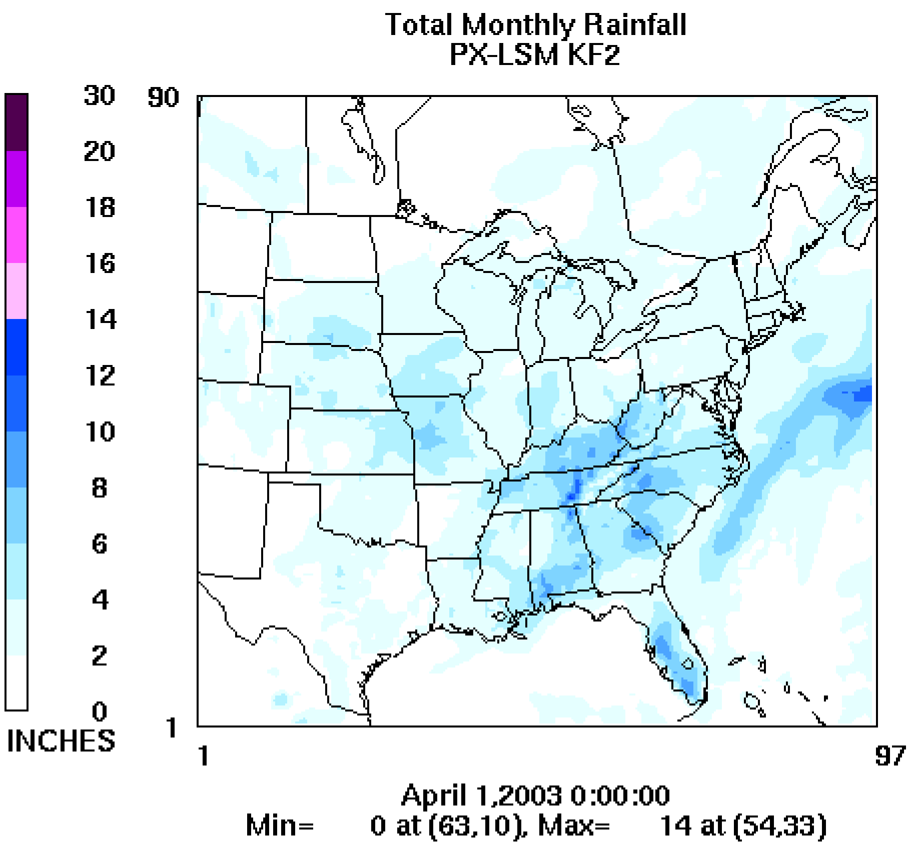
April 2003

OBS



MM5



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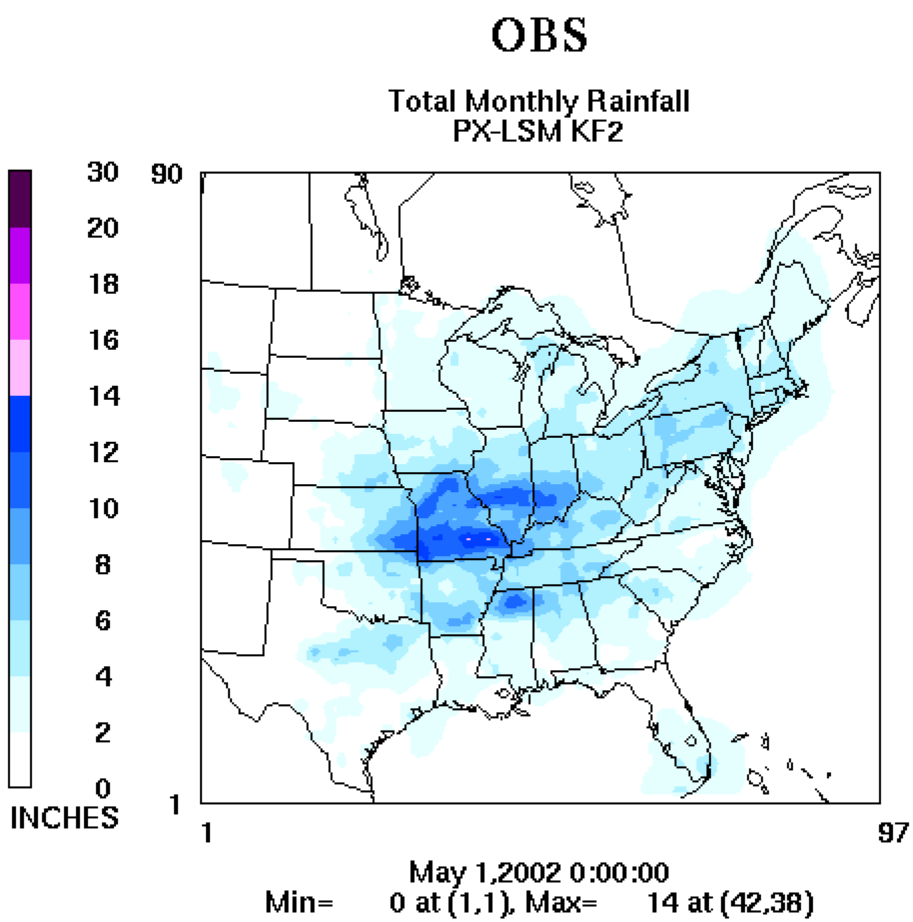
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Total Monthly Rainfall
PX-LSM KF2
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10
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1
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May 1,2002 0:00:00
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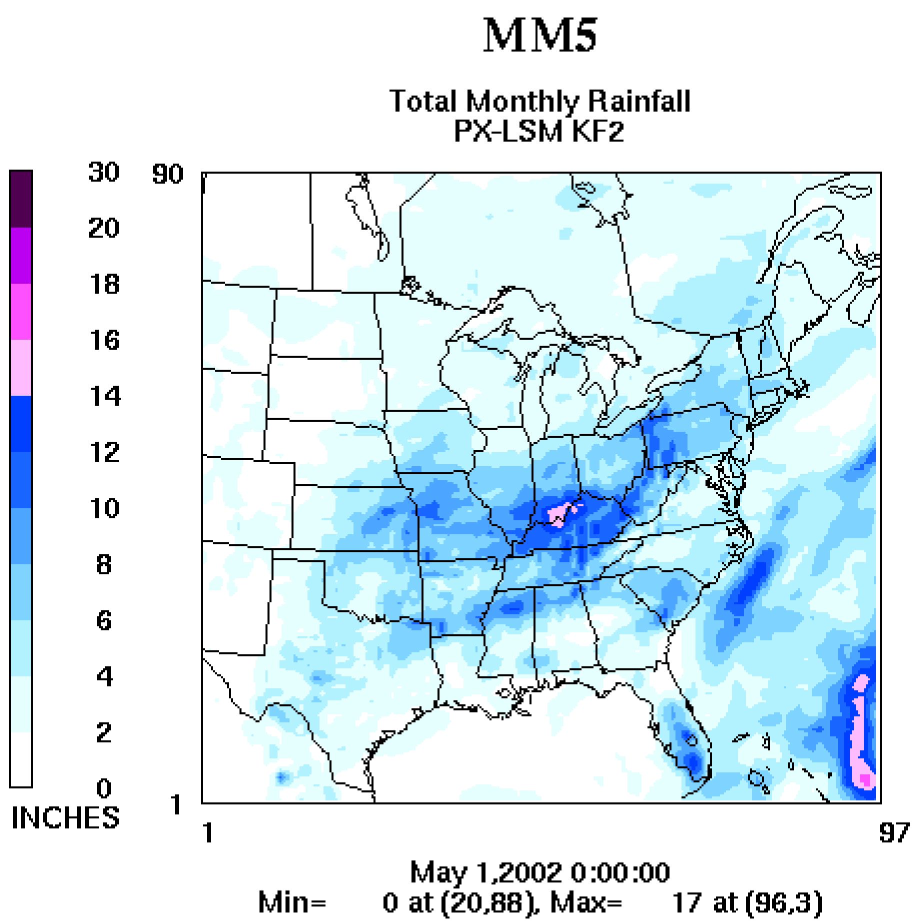
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PX-LSM KF2
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1
97
May 1,2002 0:00:00
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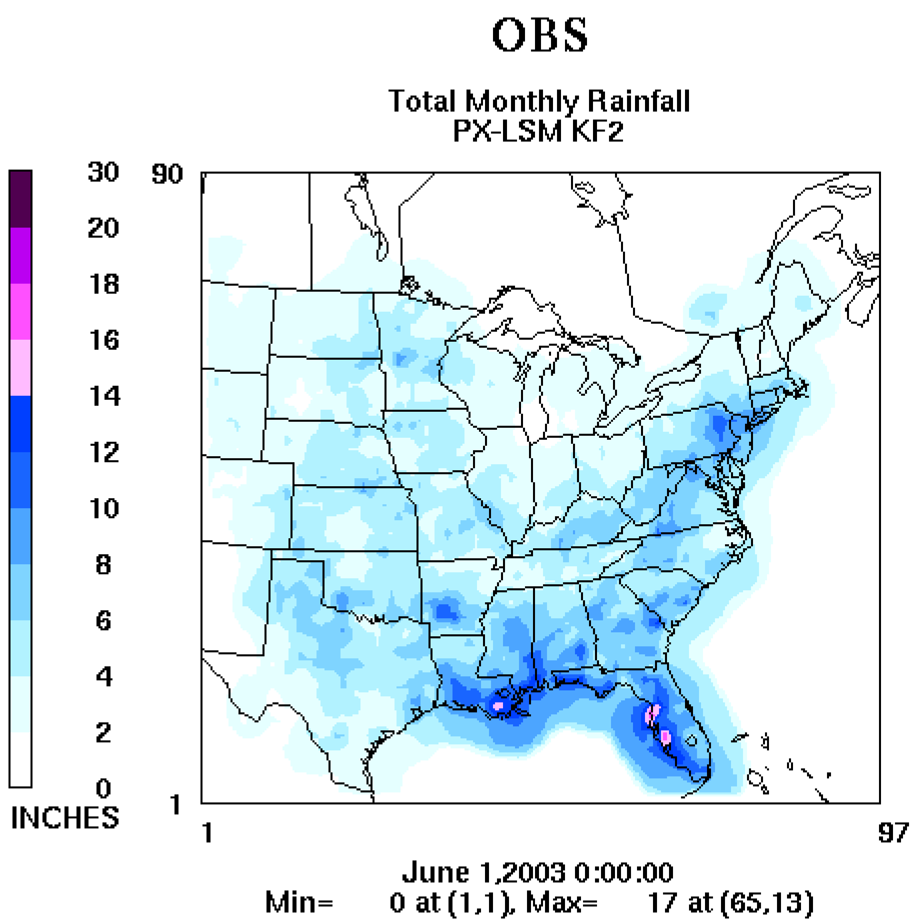
June 2003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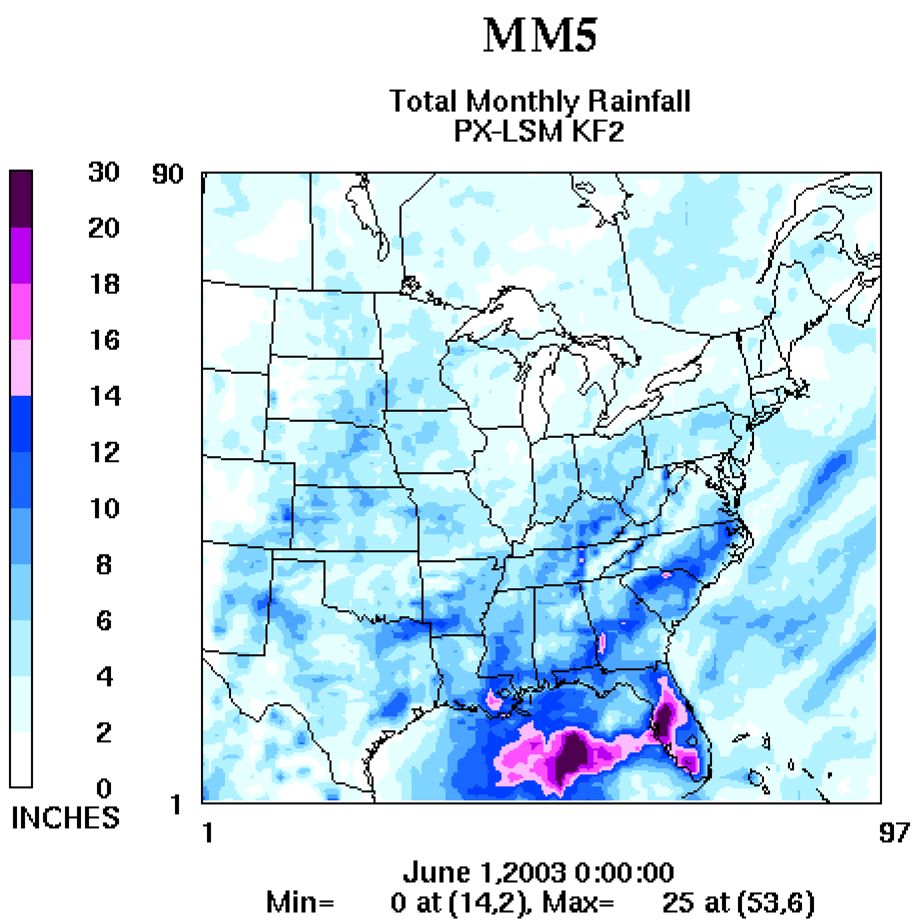
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Total Monthly Rainfall
PX-LSM KF2
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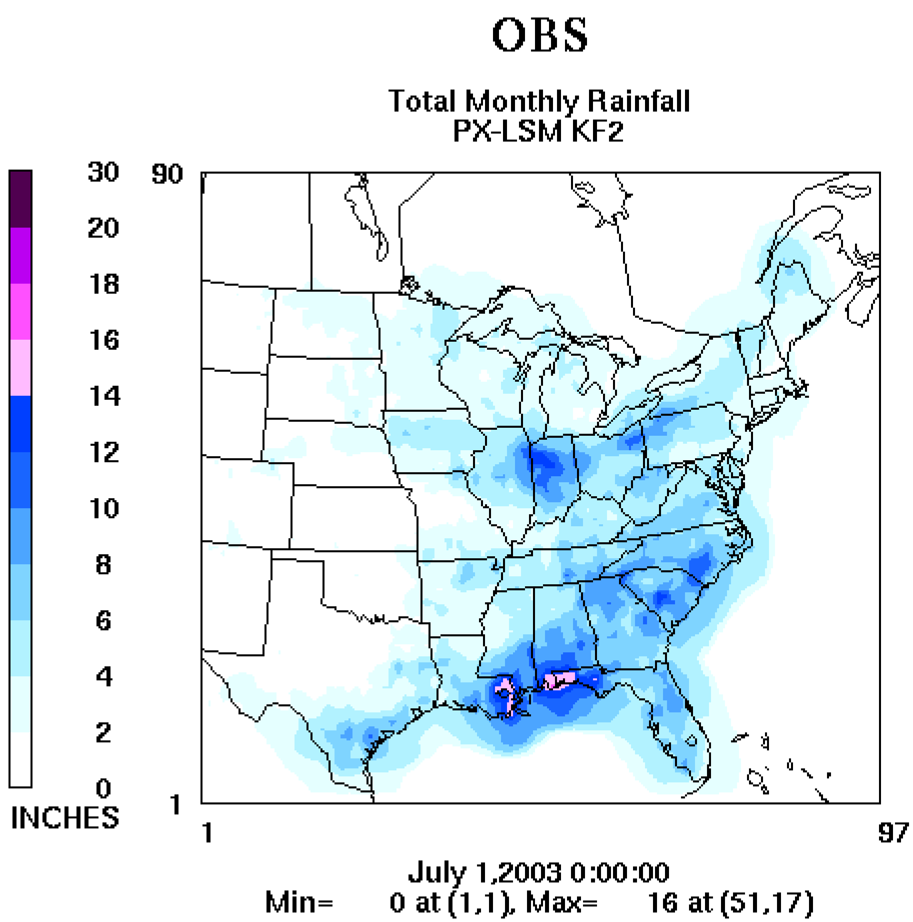
July 2003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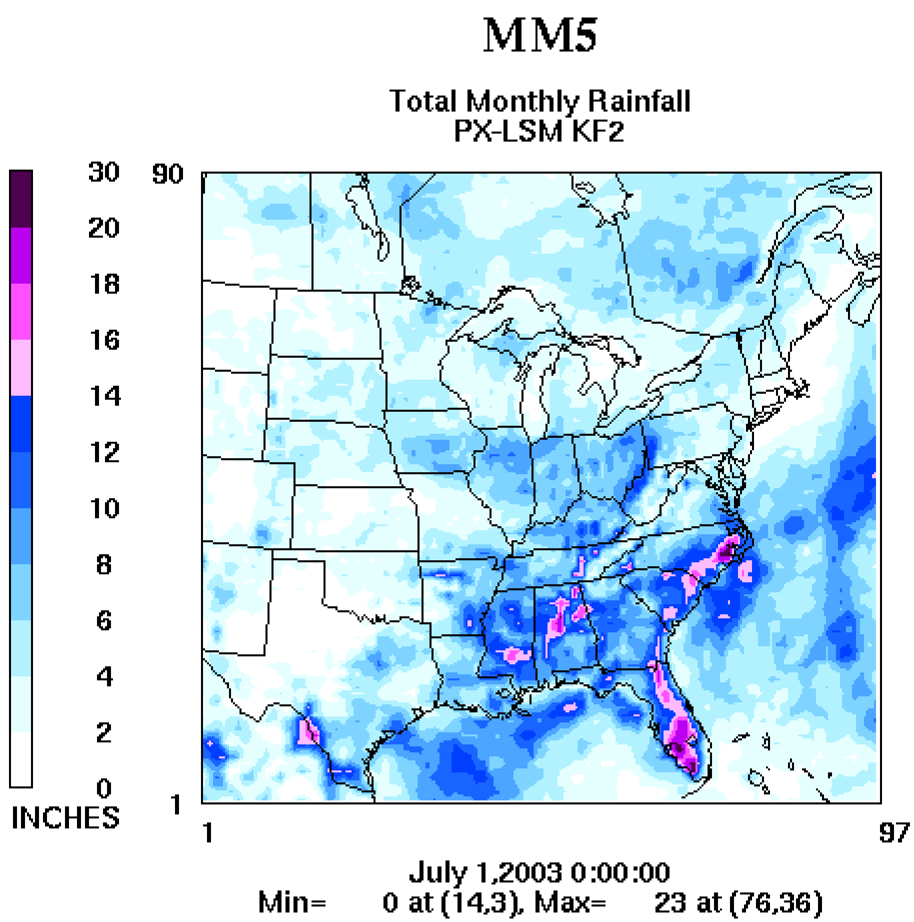
MM5
Total Monthly Rainfall
PX-LSM KF2
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1
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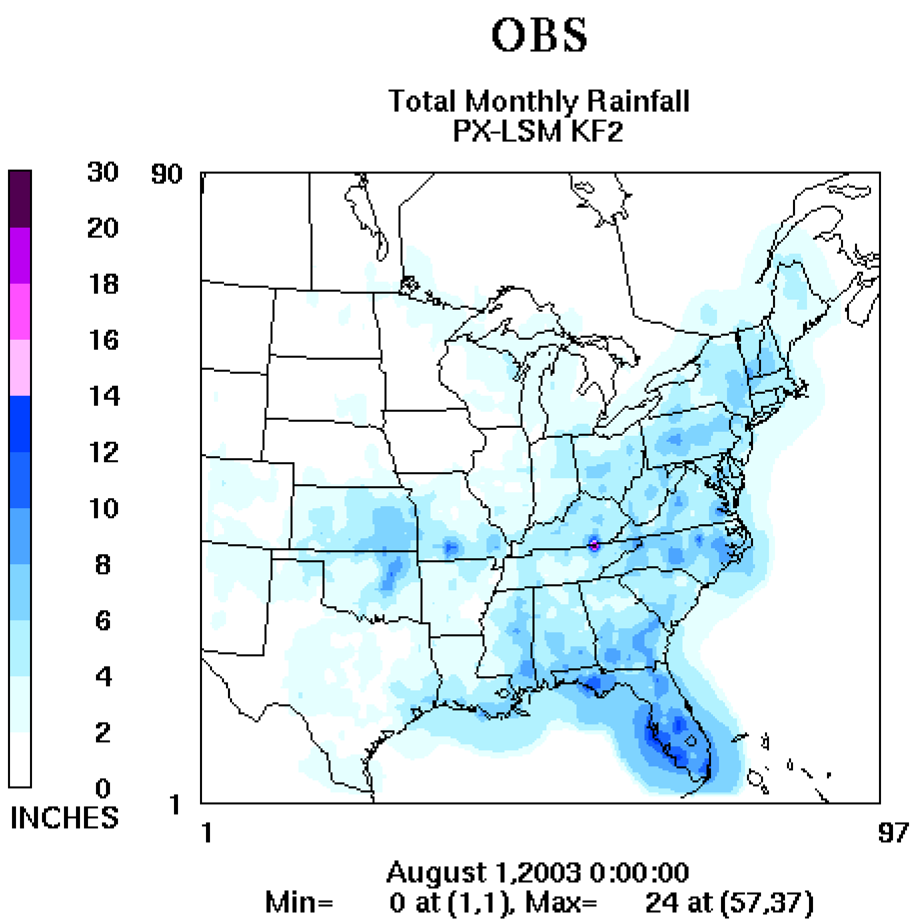
August 2003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Total Monthly Rainfall
PX-LSM KF2
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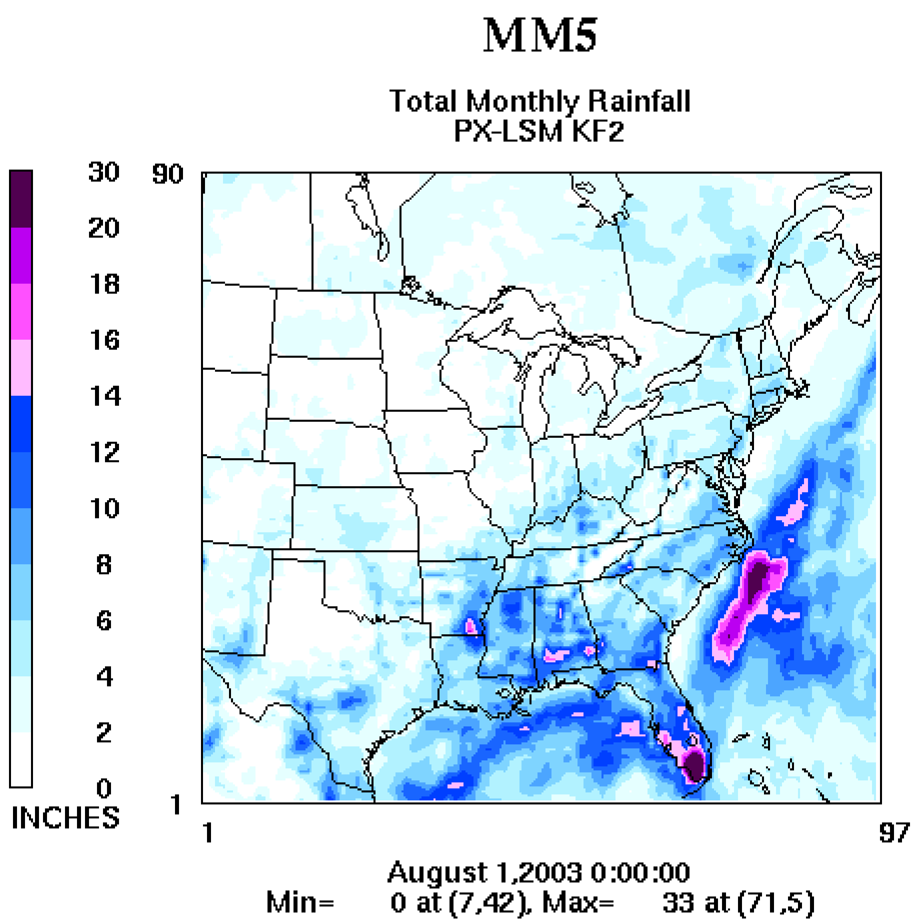
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PX-LSM KF2
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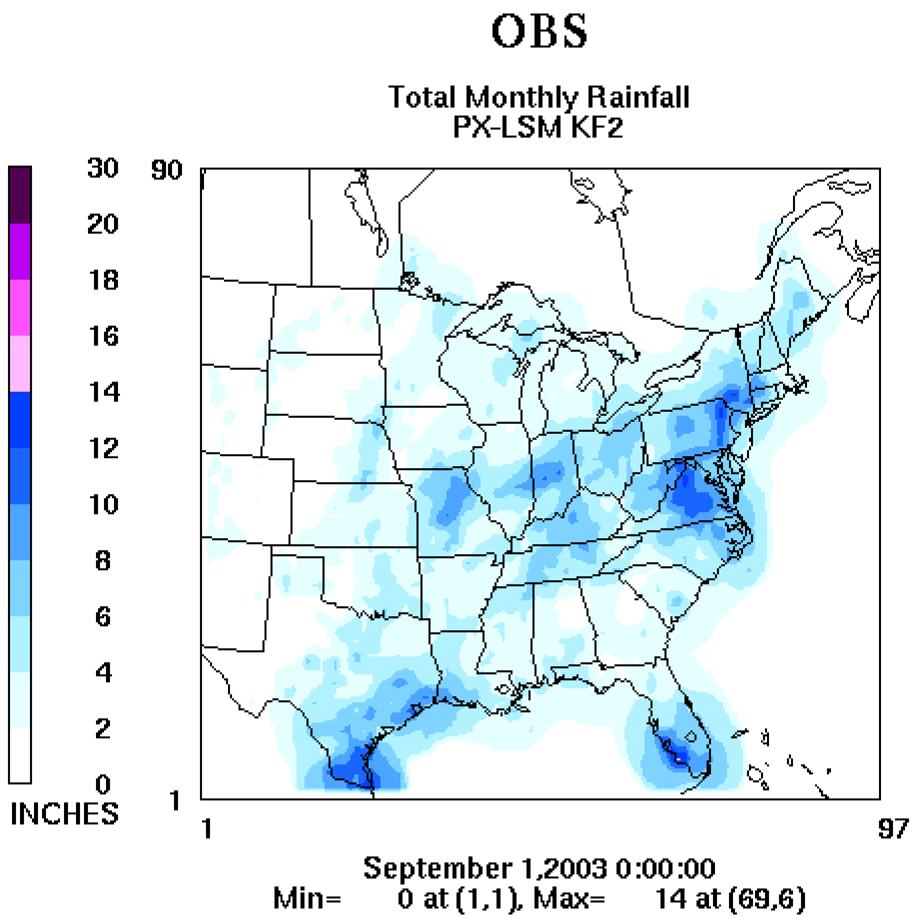
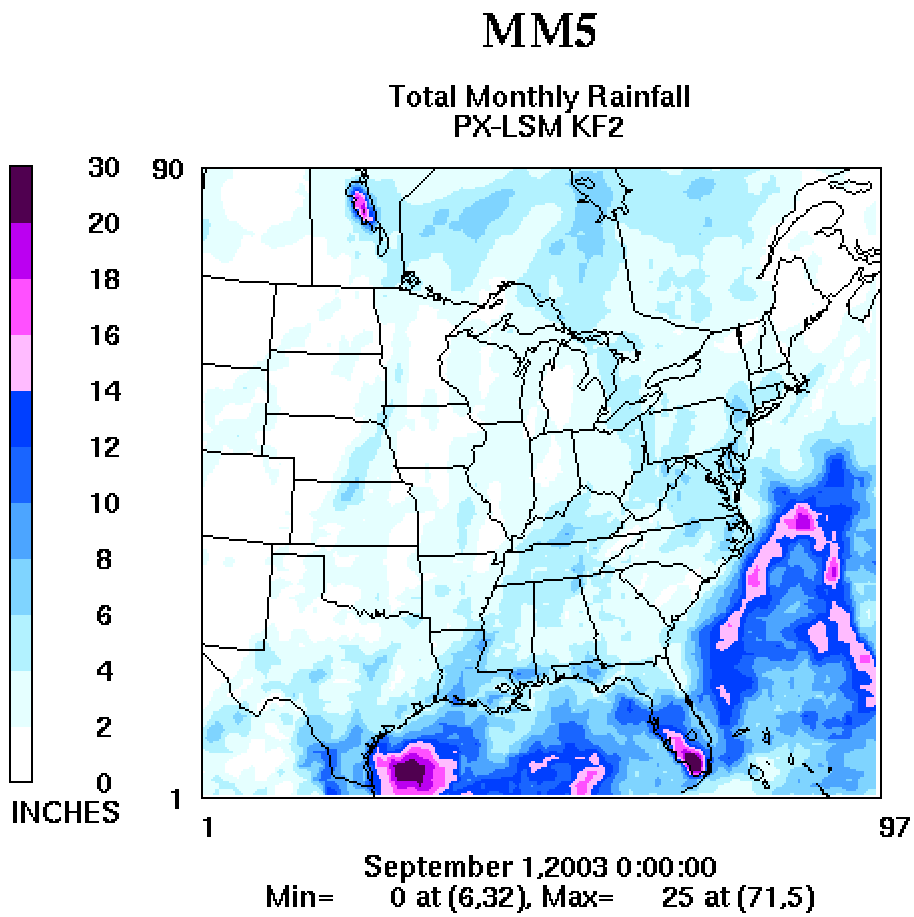
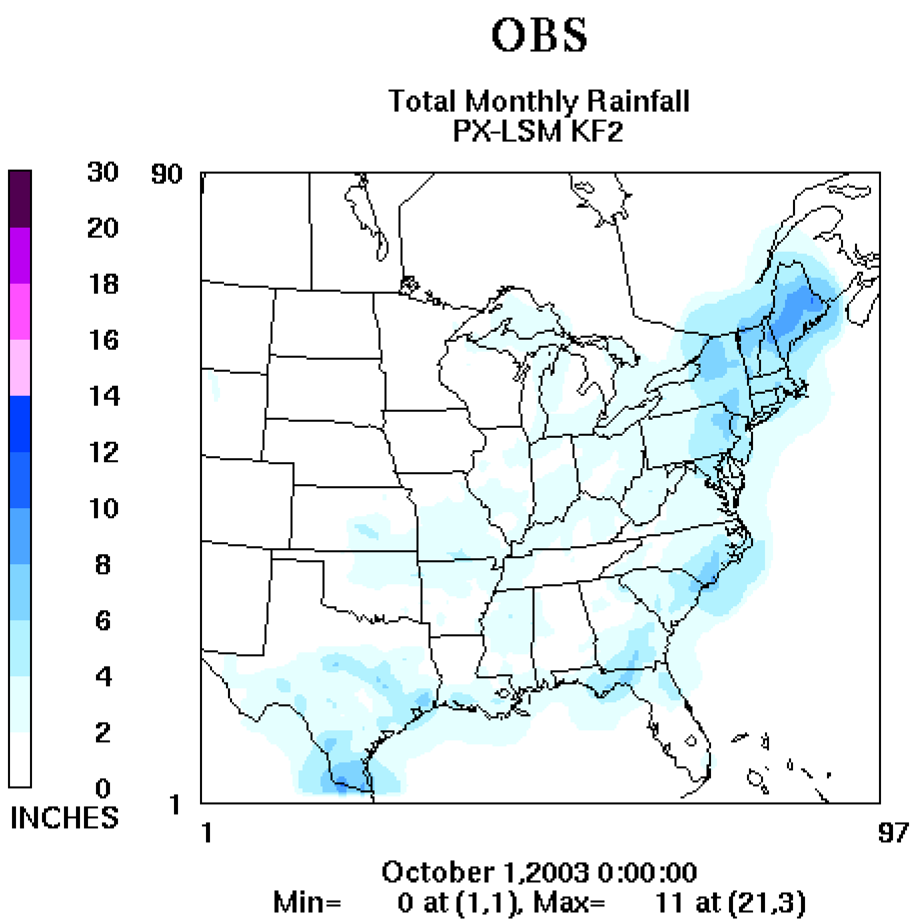
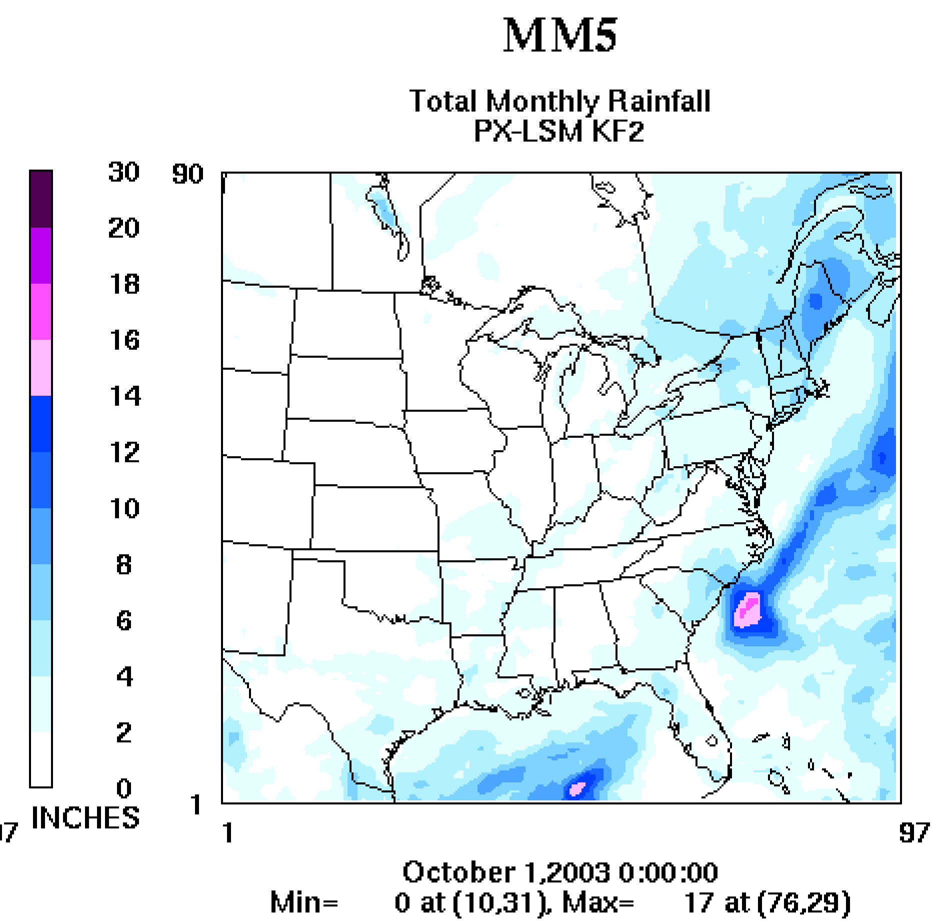
September 2003



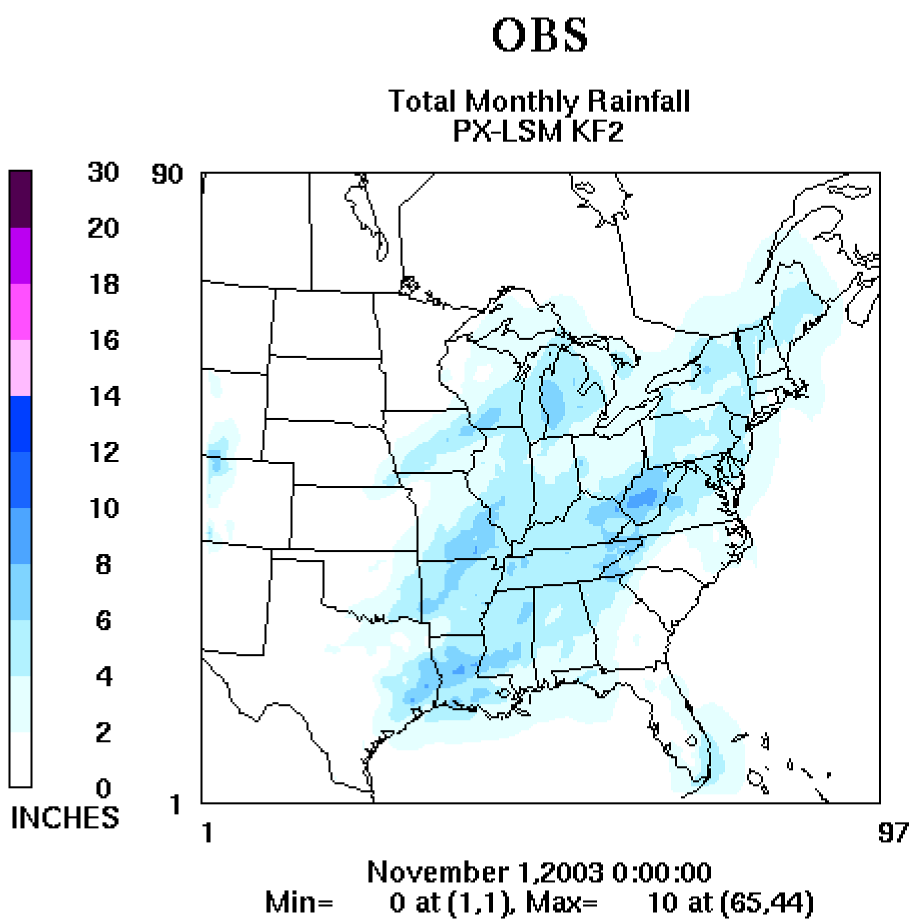


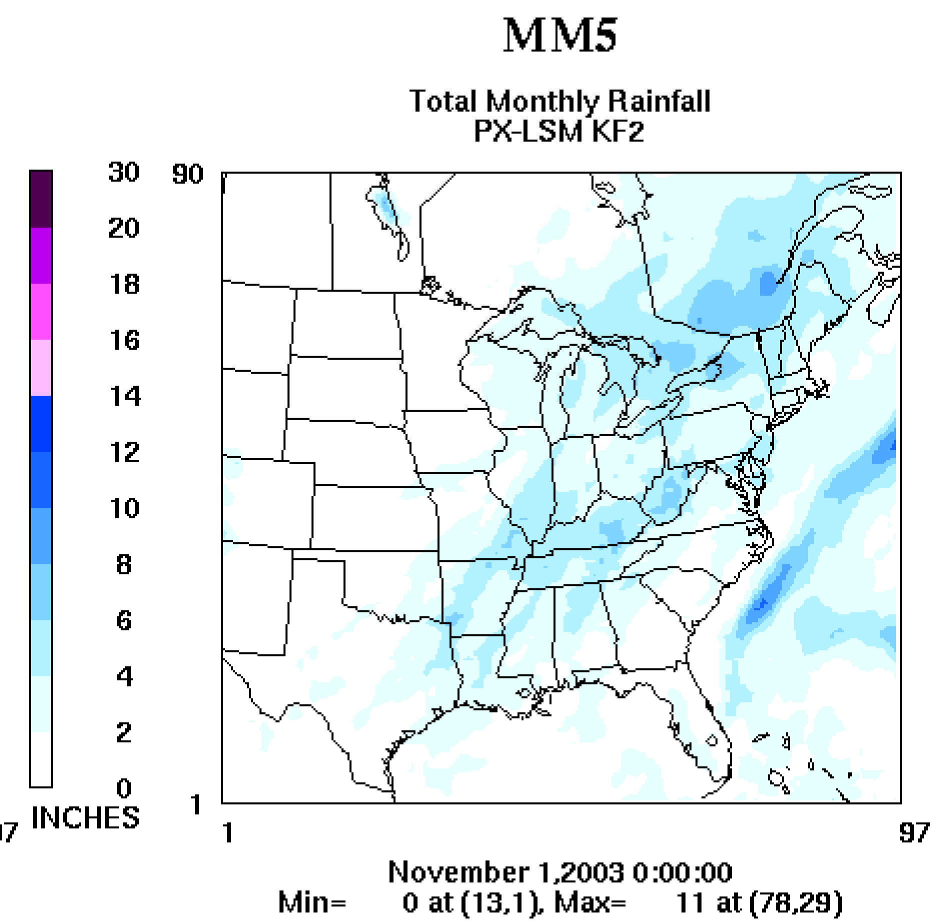
October 2003



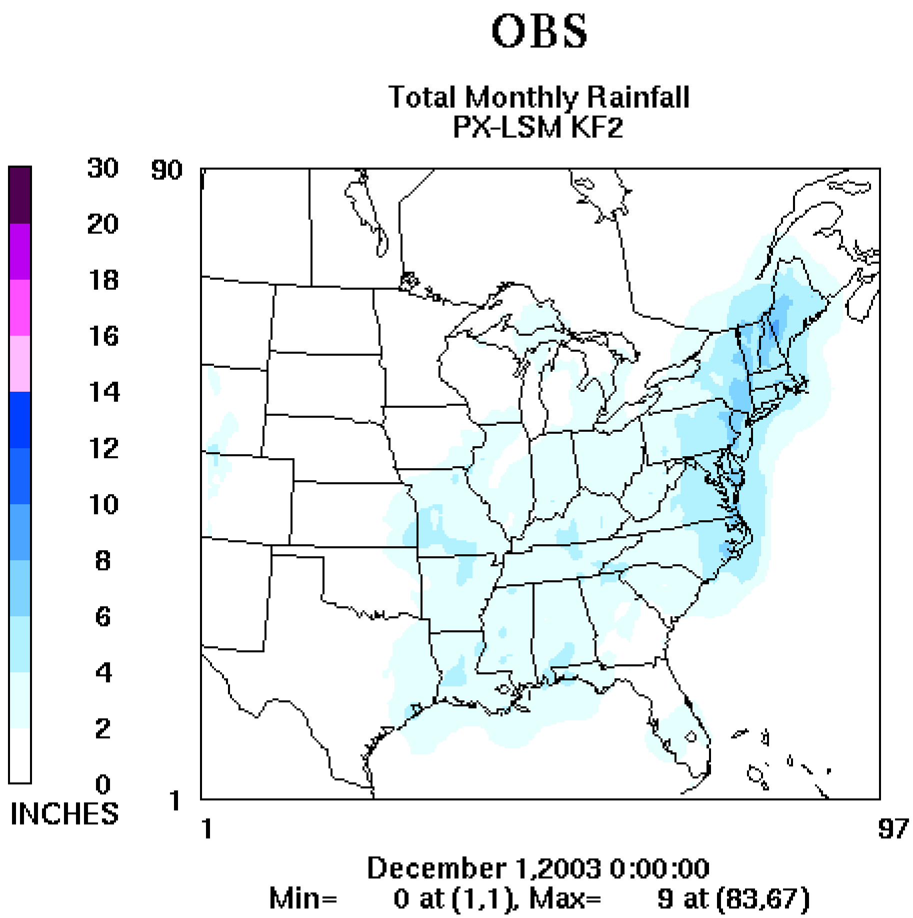


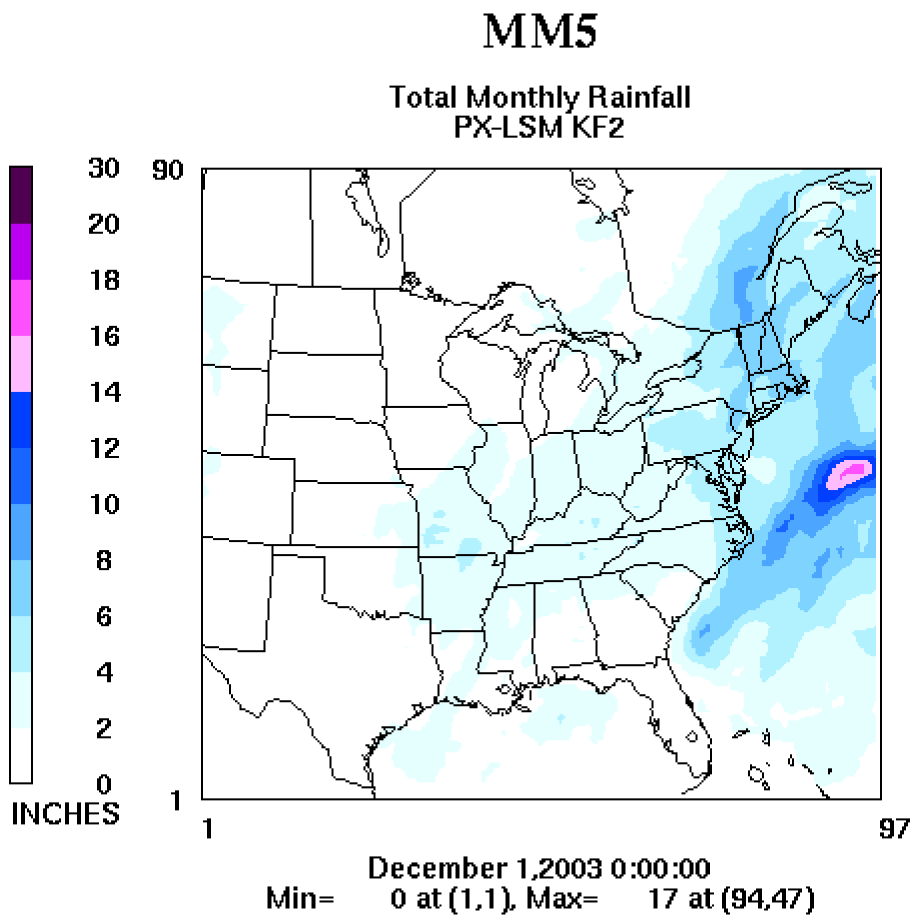
November 2003





December 2003

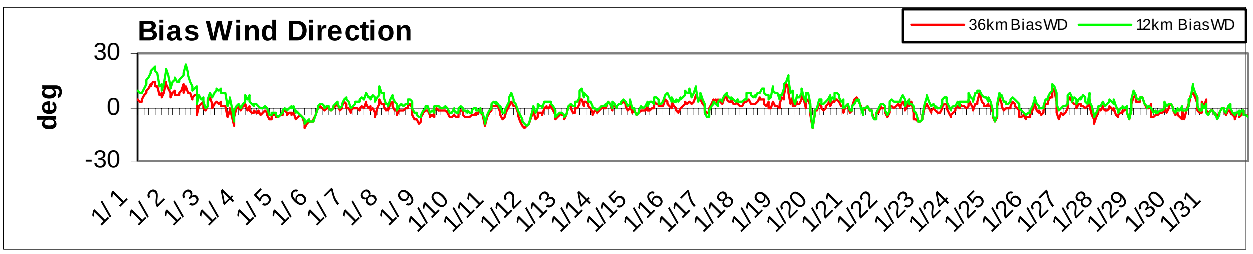


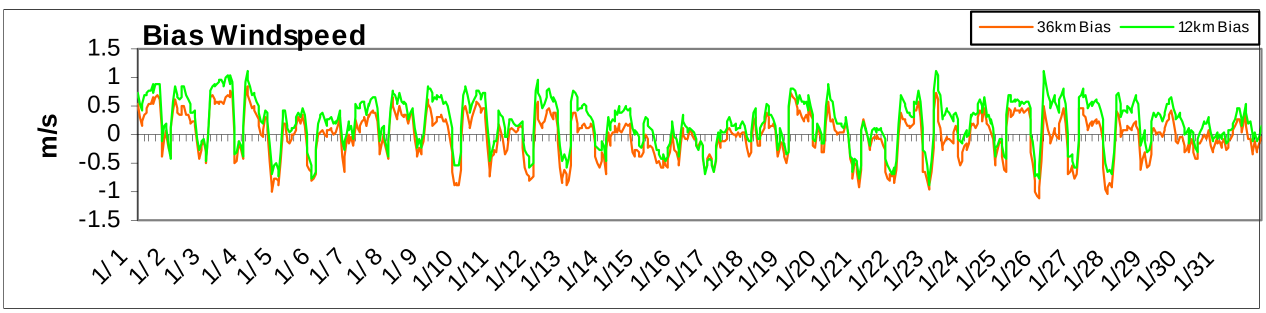


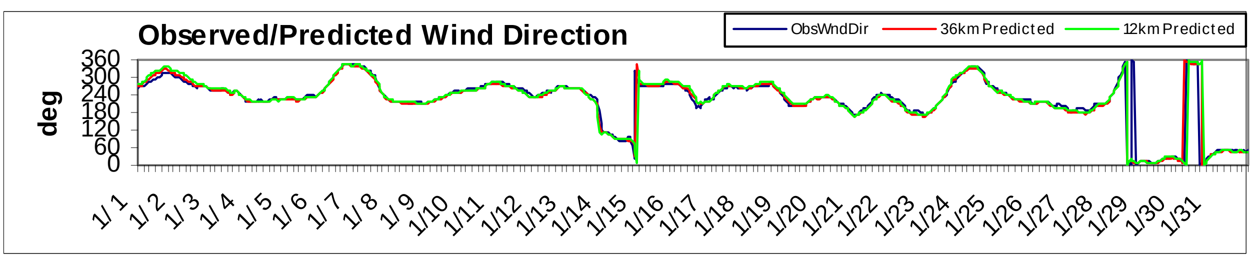
APPENDIX B

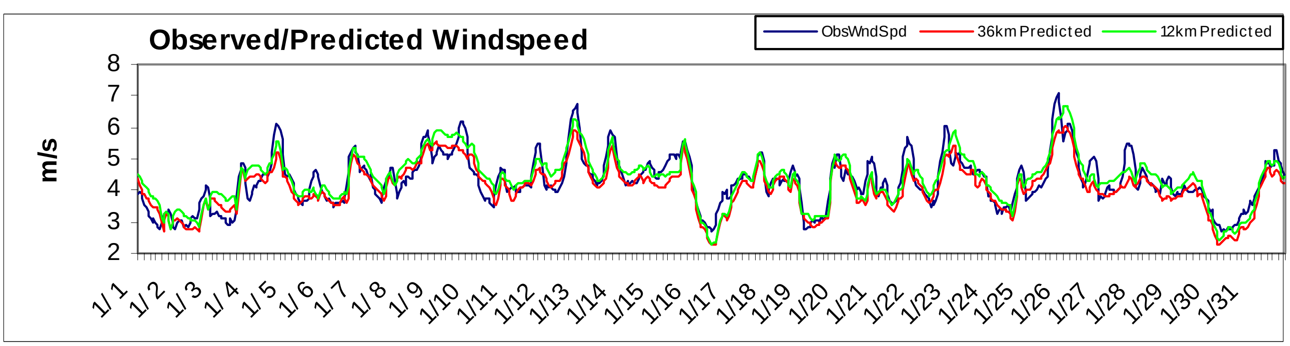
12 v 36 km Performance

Great Lakes Jan 2002

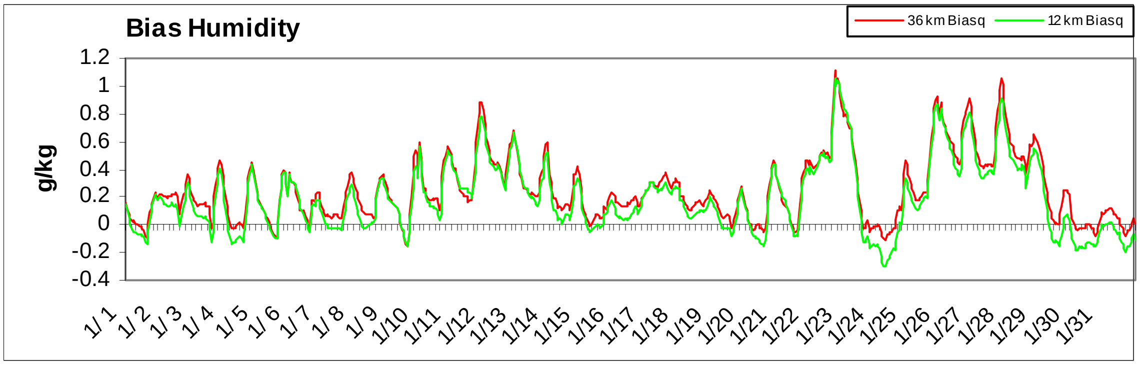


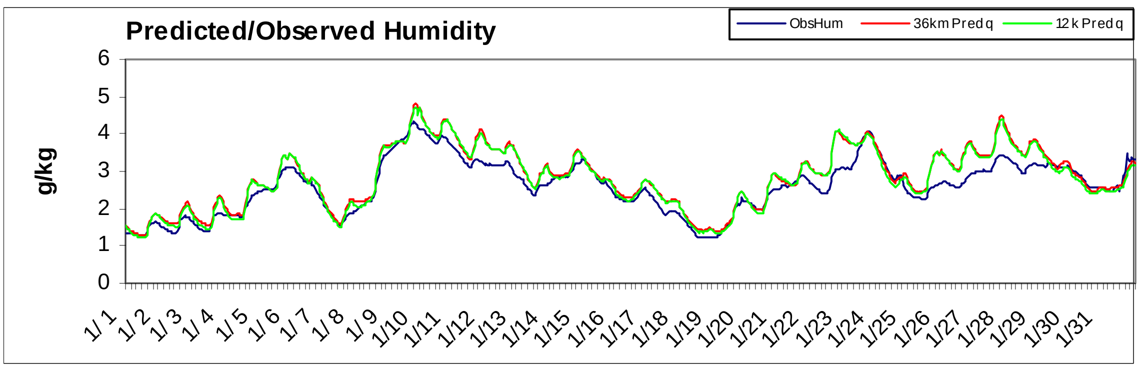


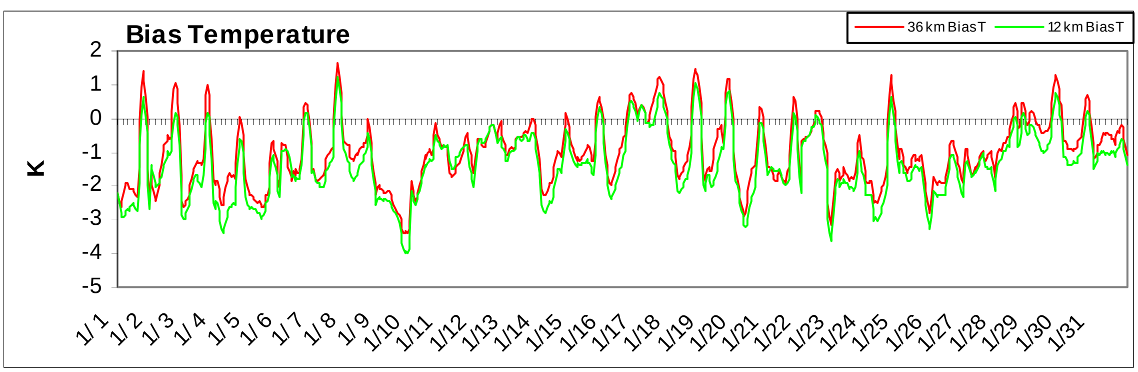


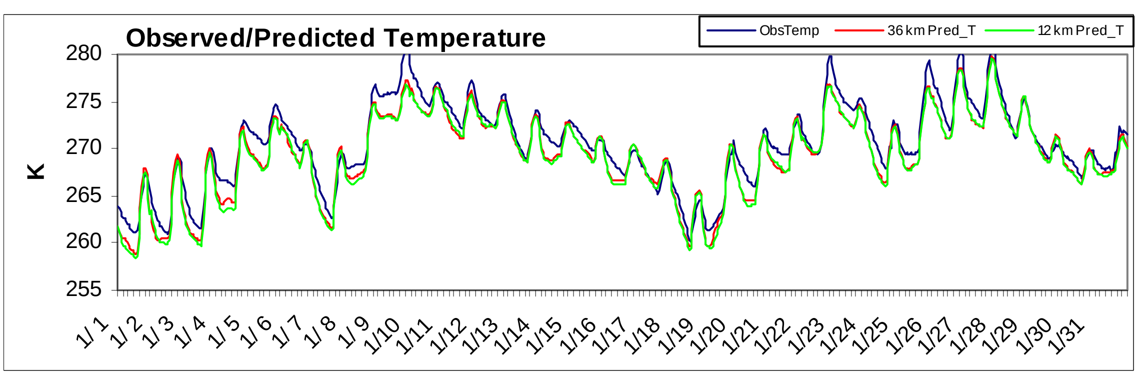


Great Lakes Jan 2002

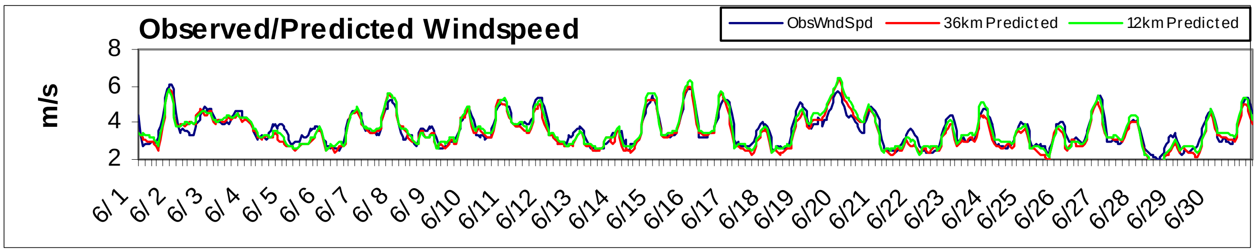


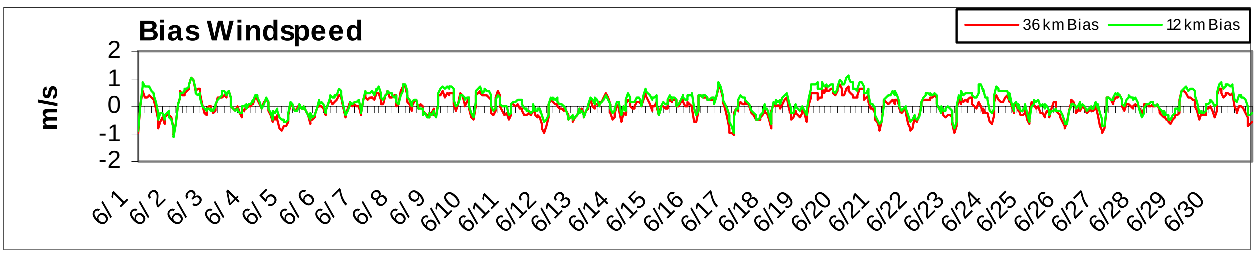


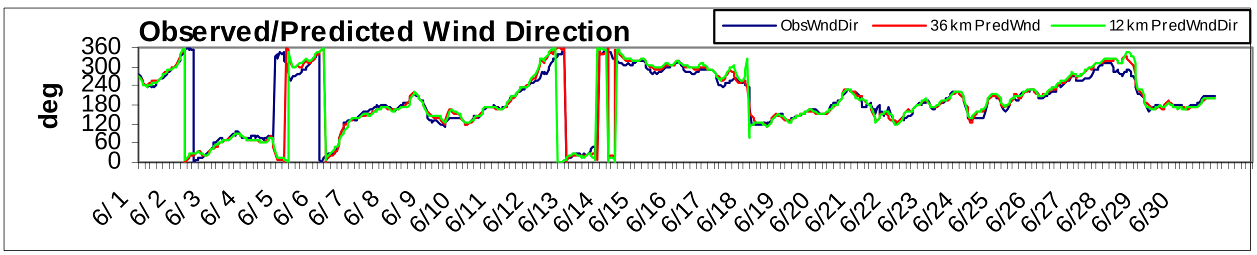


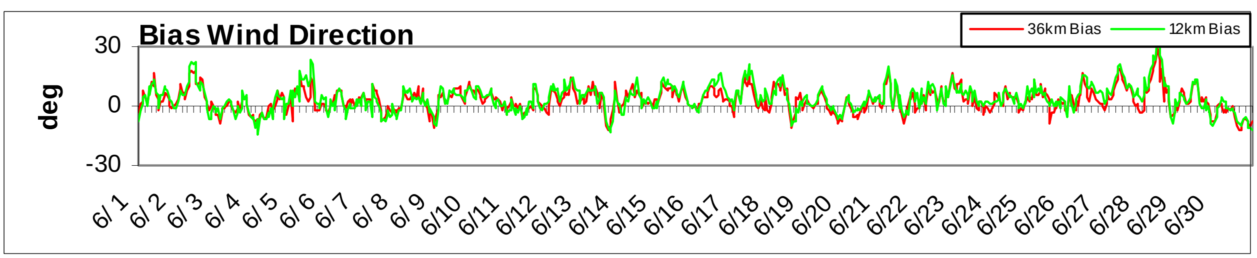


Great Lakes June 2002

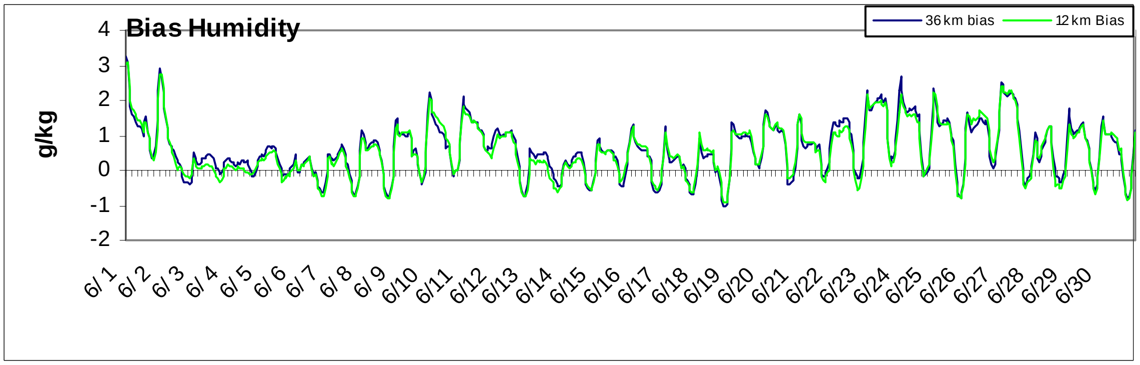


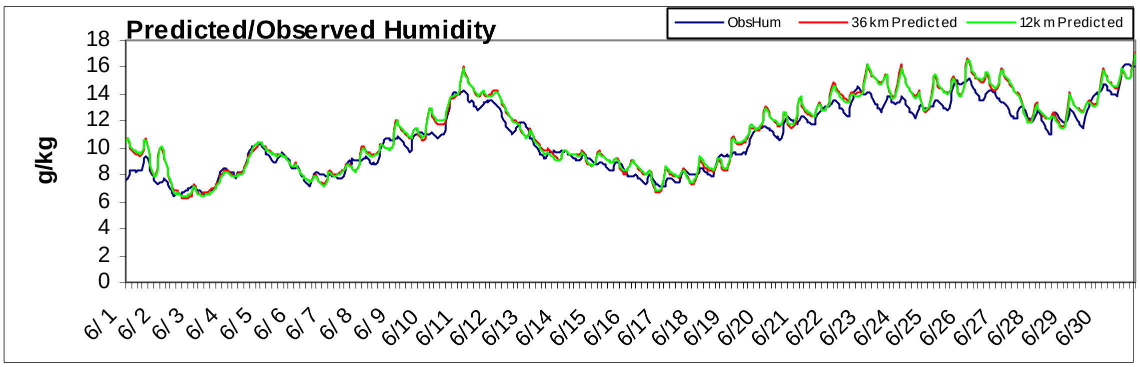


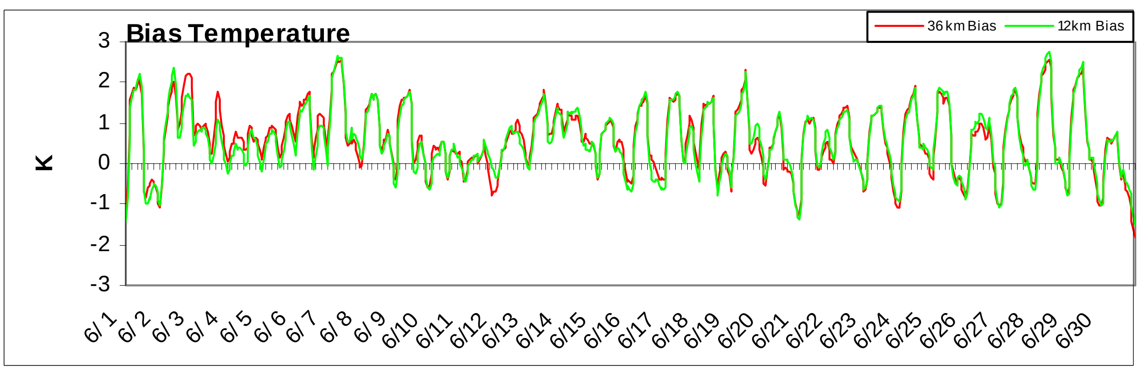


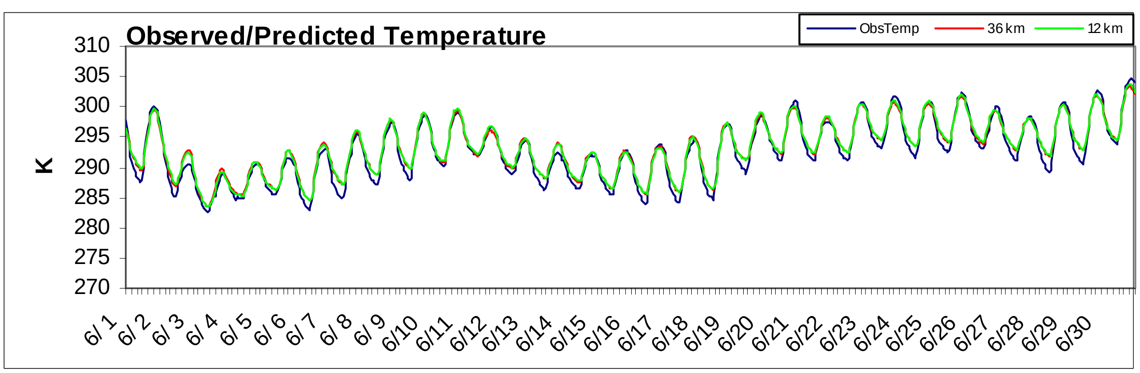


Great Lakes June 2002

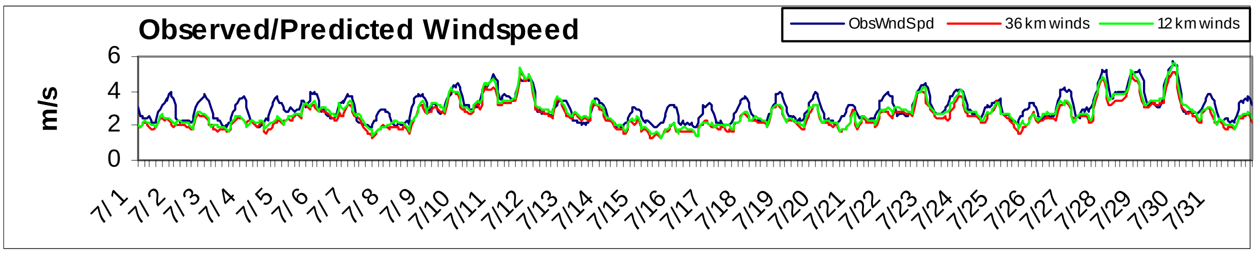


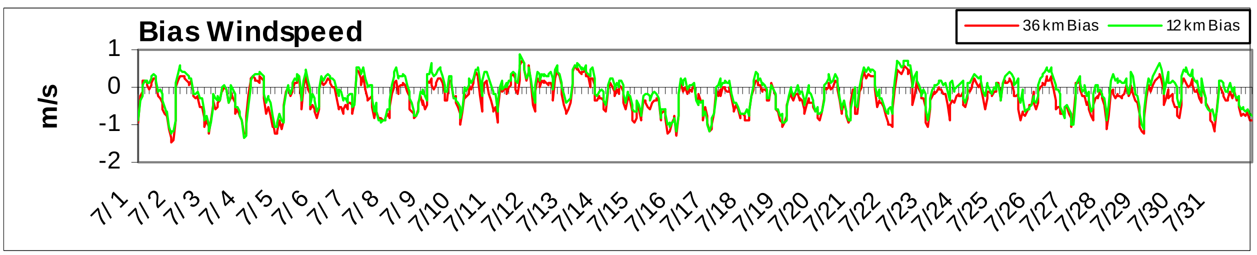


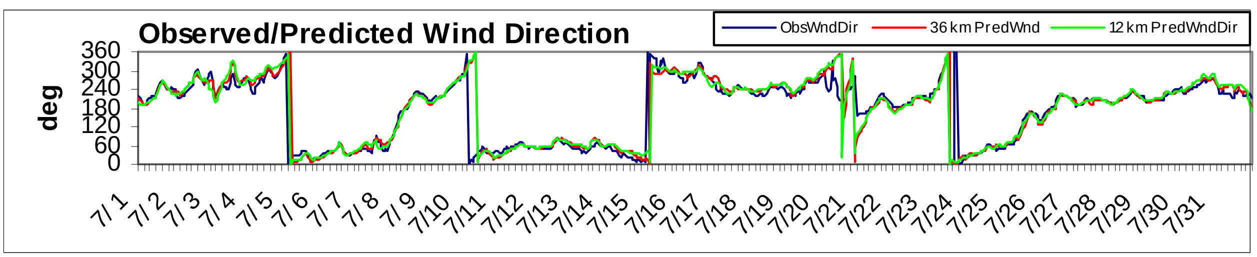


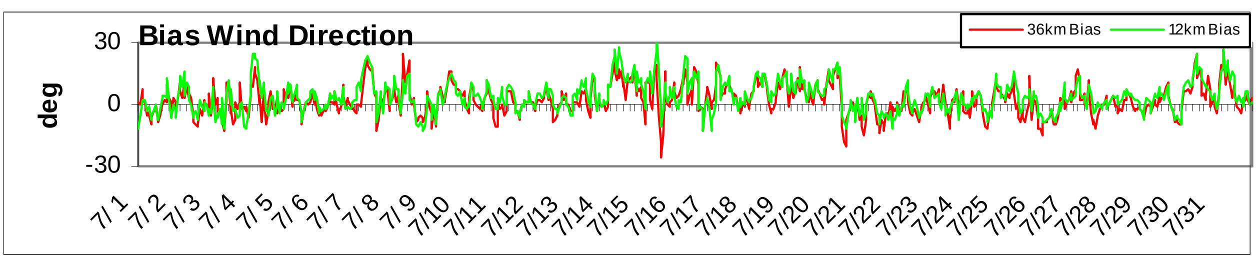


Ohio Valley July 2002

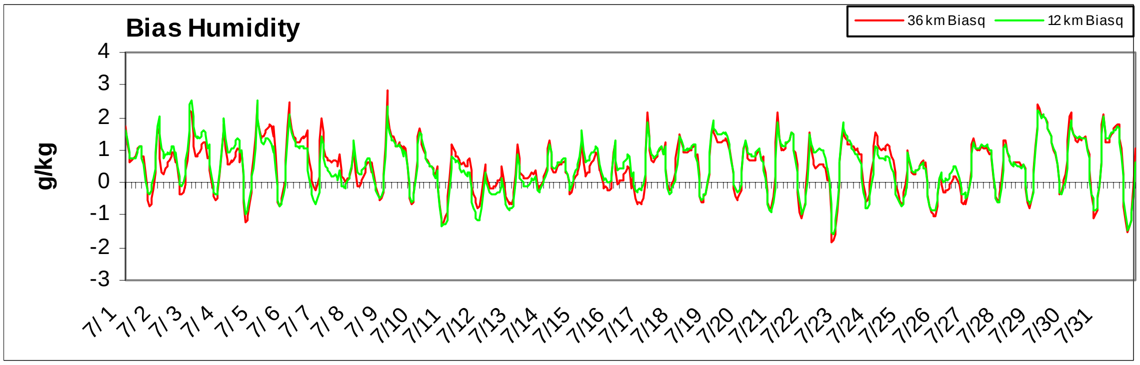


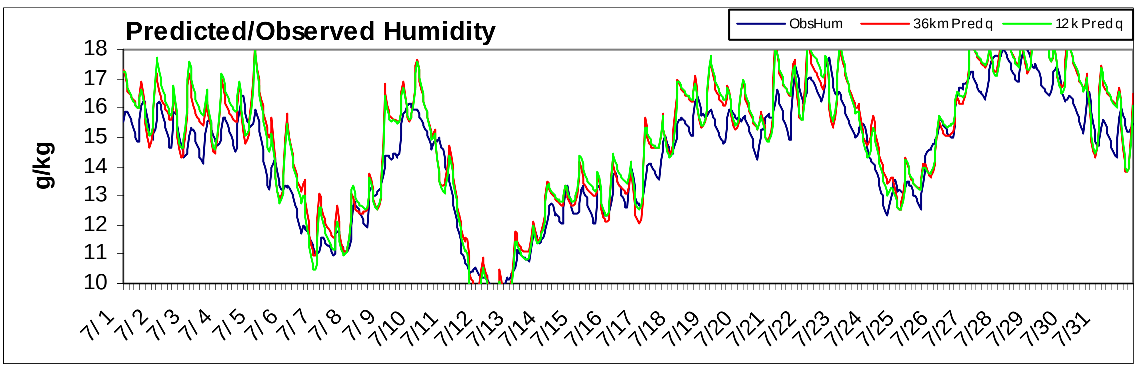


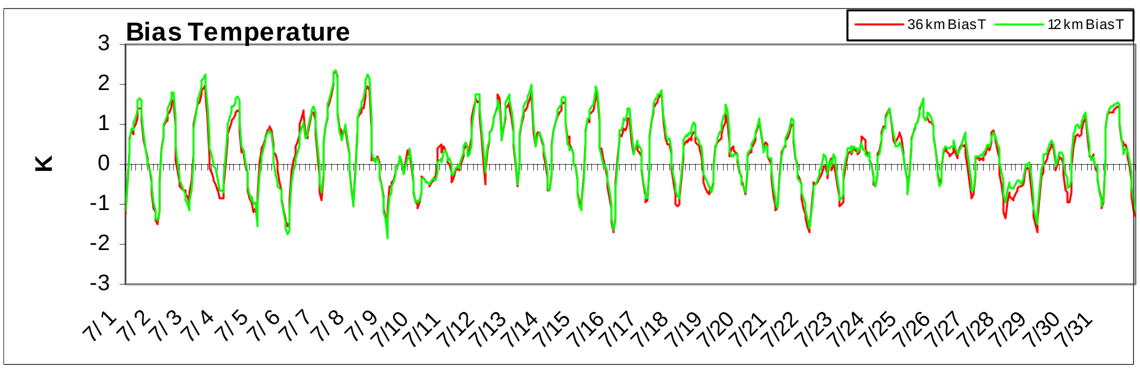


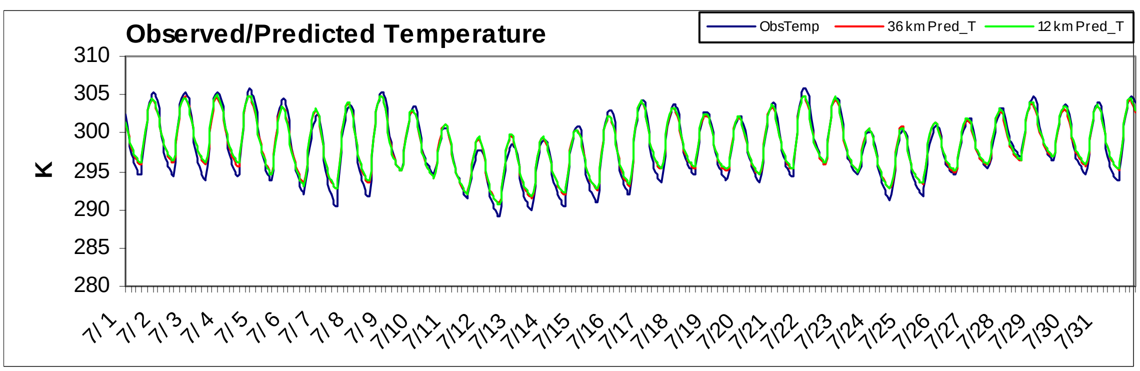


Ohio Valley July 2002





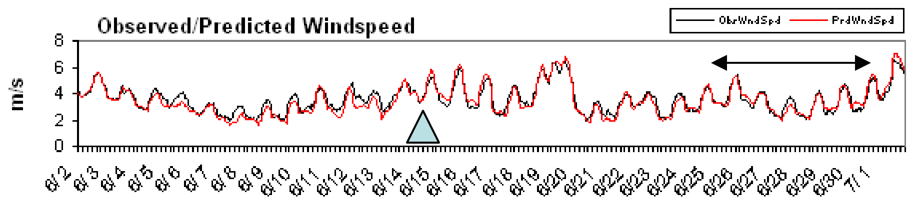


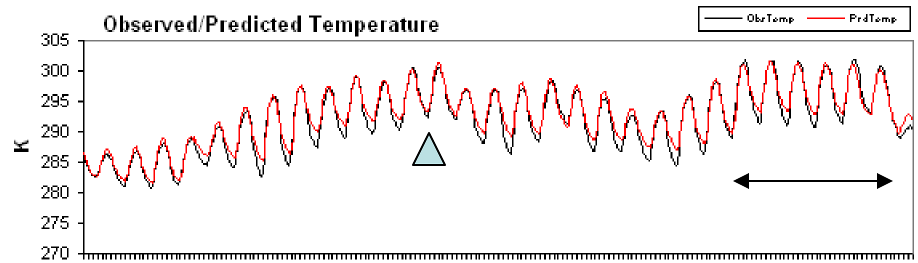


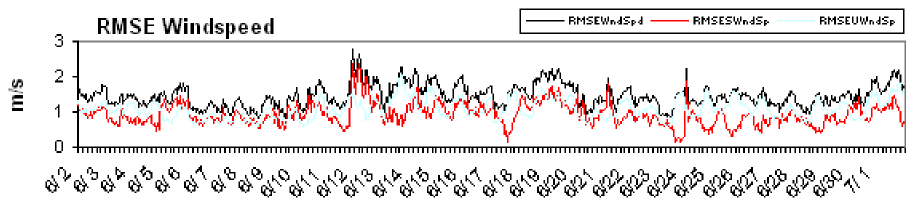
APPENDIX C

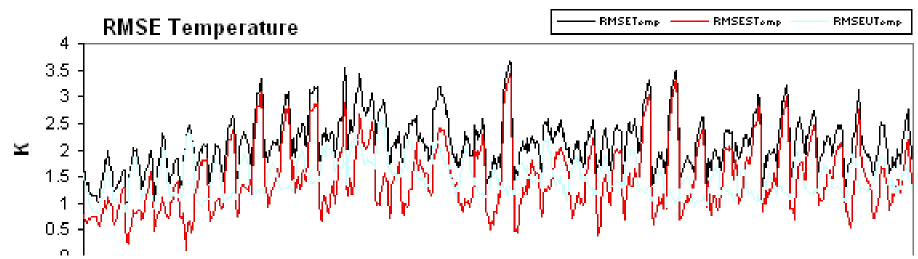
Performance for Summers 2001, 2002, and 2003

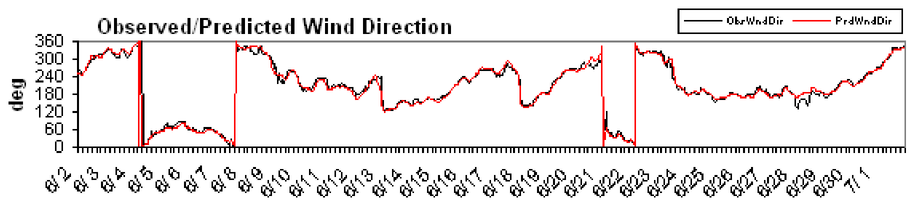
JUNE 2001

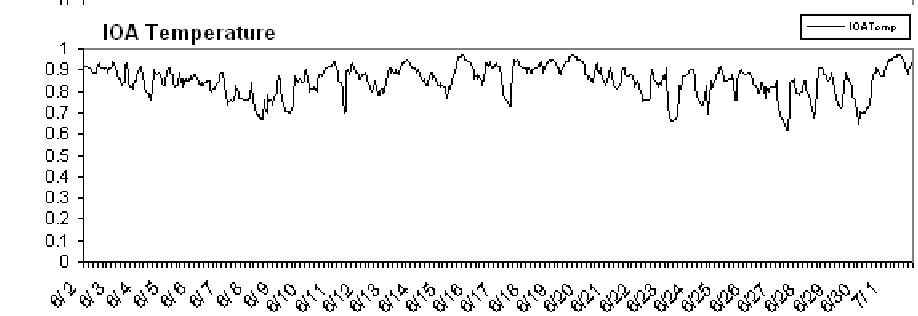

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

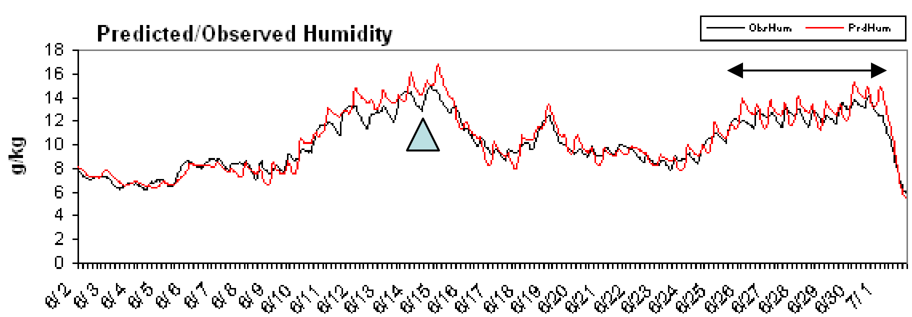

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

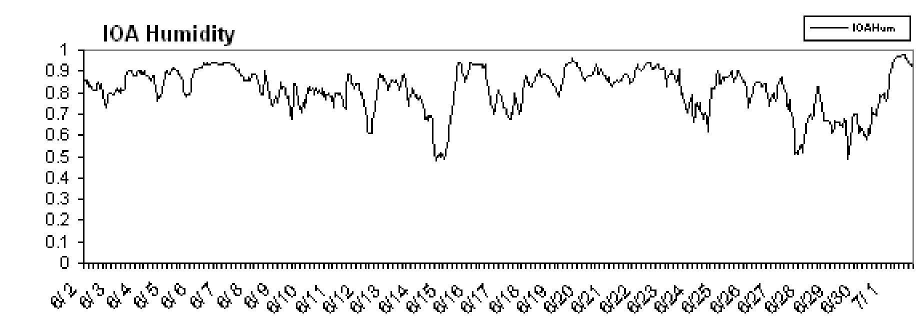

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s


RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K

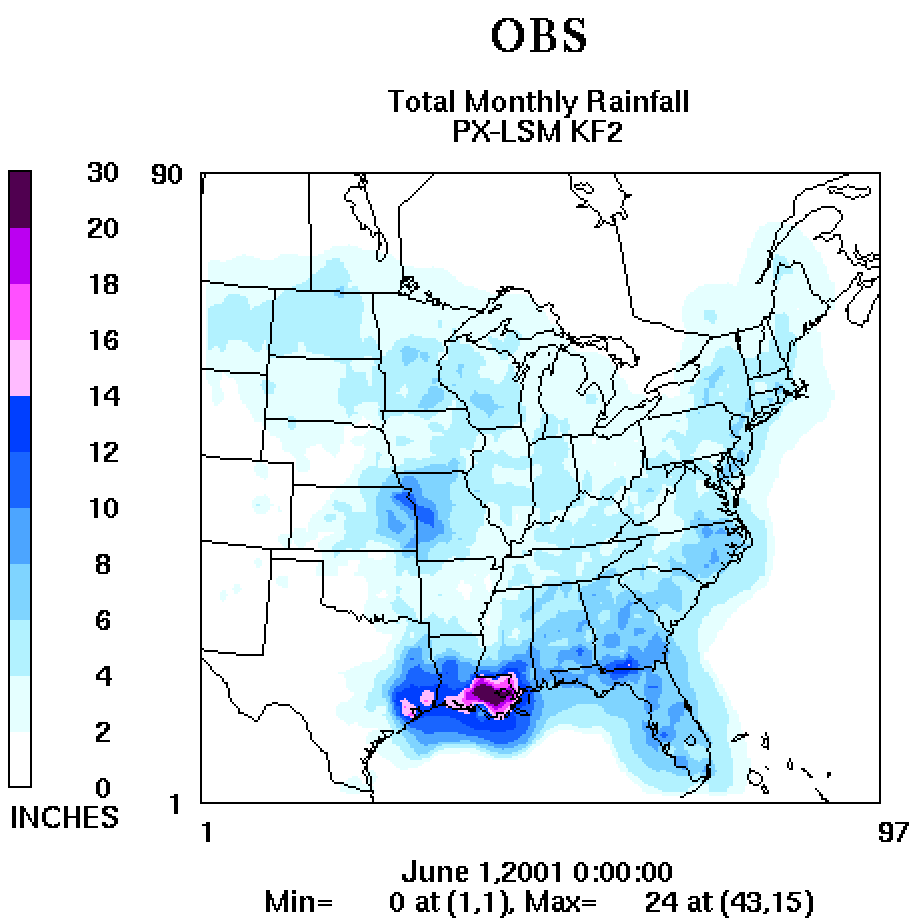

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg

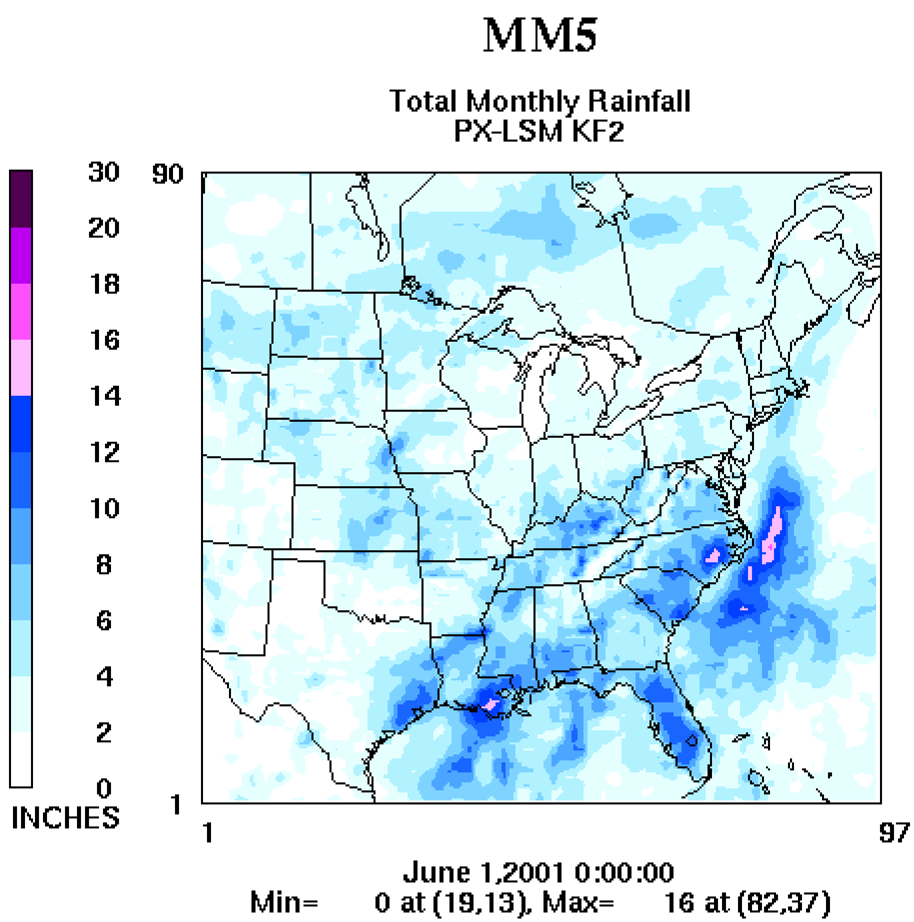

IOA Temperature
IOATemp


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

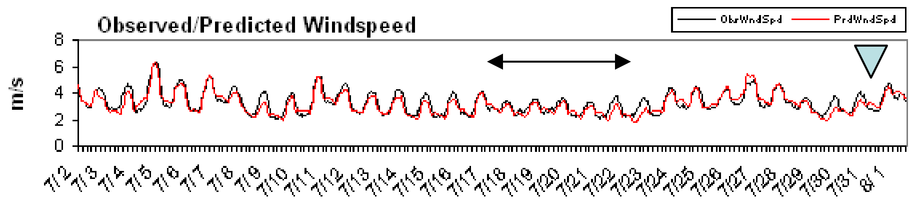

IOA Humidity
IOAHum

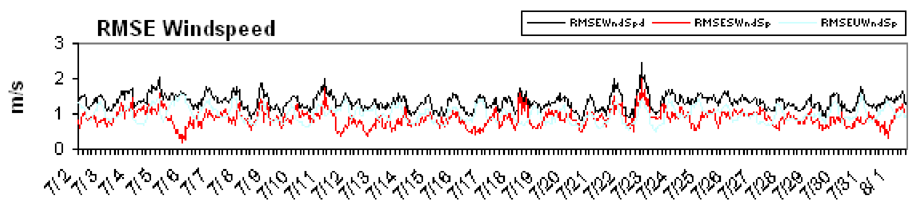
June 2001

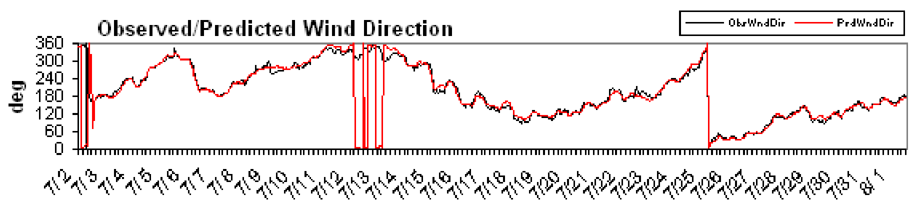

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2001 0:00:00
Min= 0 at (1,1), Max= 24 at (43,15)

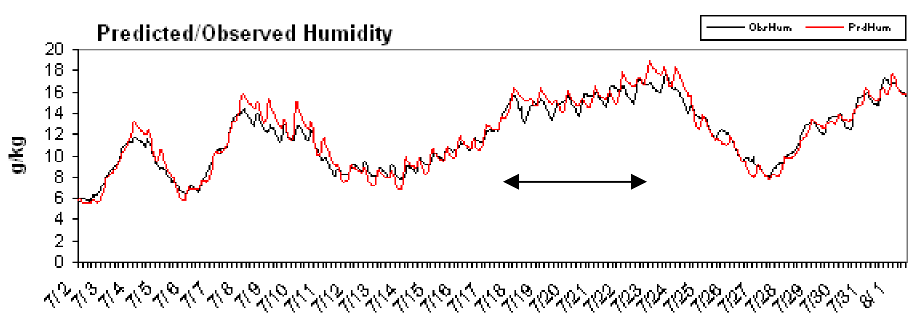

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2001 0:00:00
Min= 0 at (19,13), Max= 16 at (82,37)

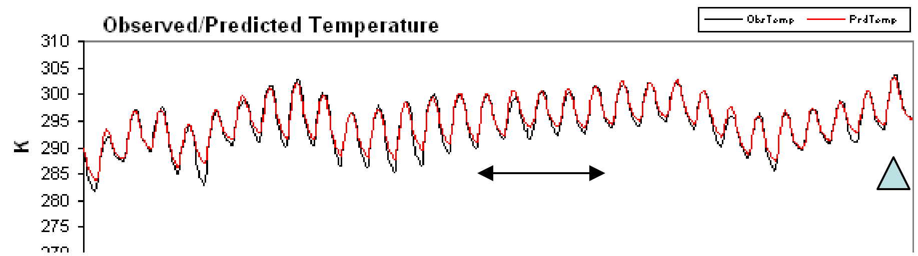
JULY 2001

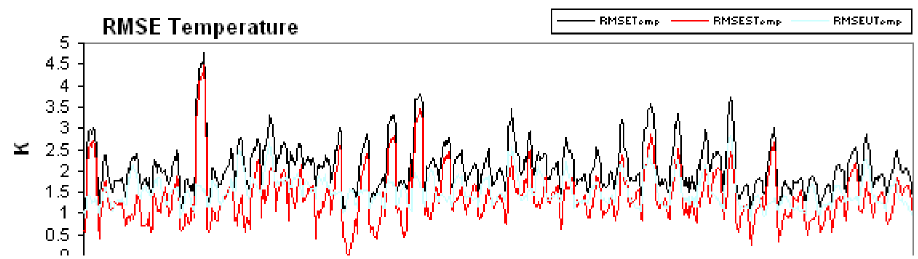

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

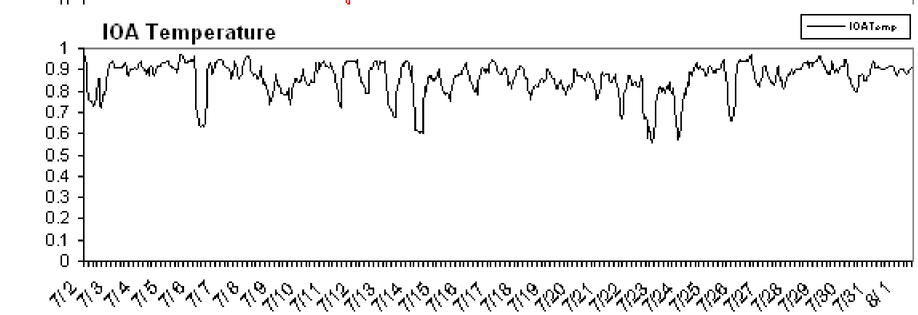

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

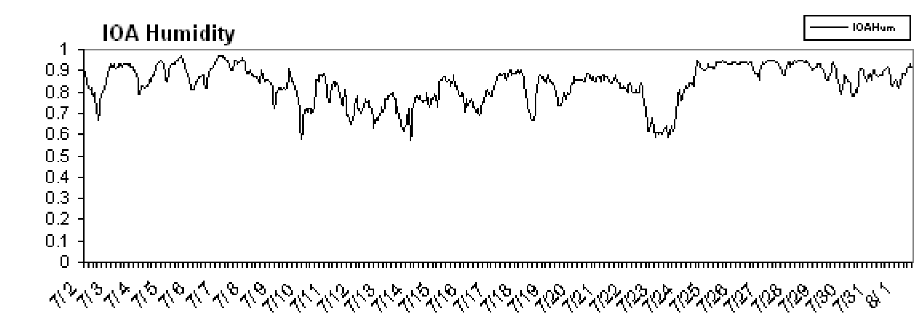

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

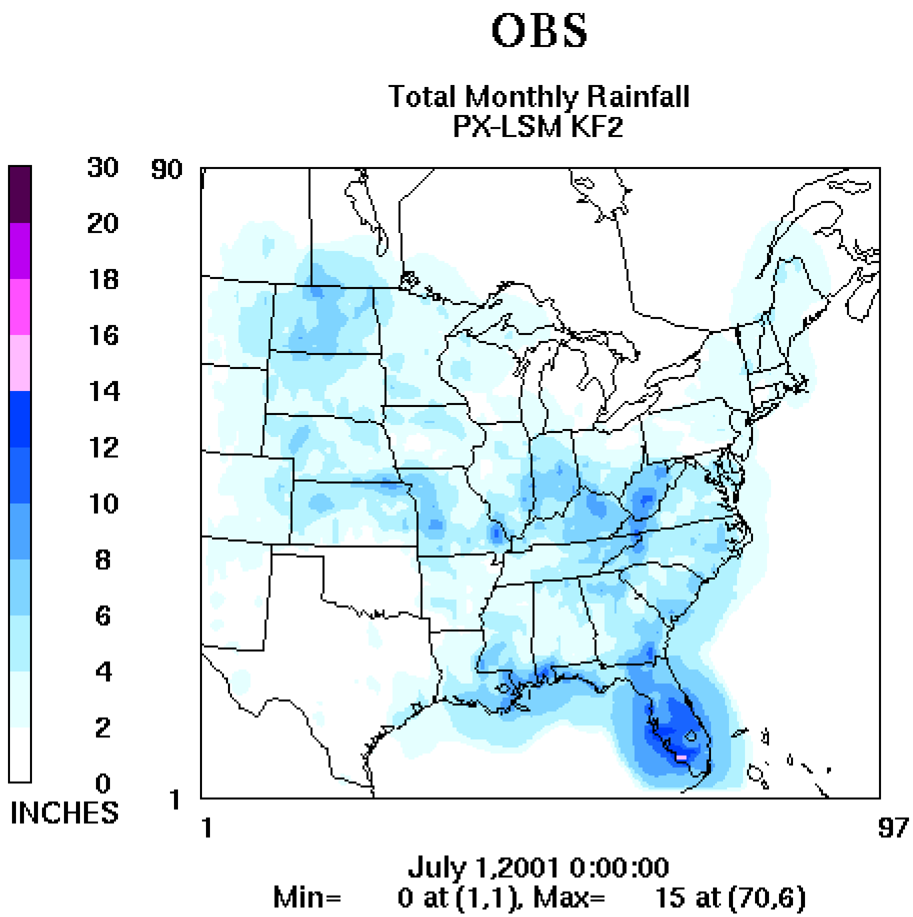

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

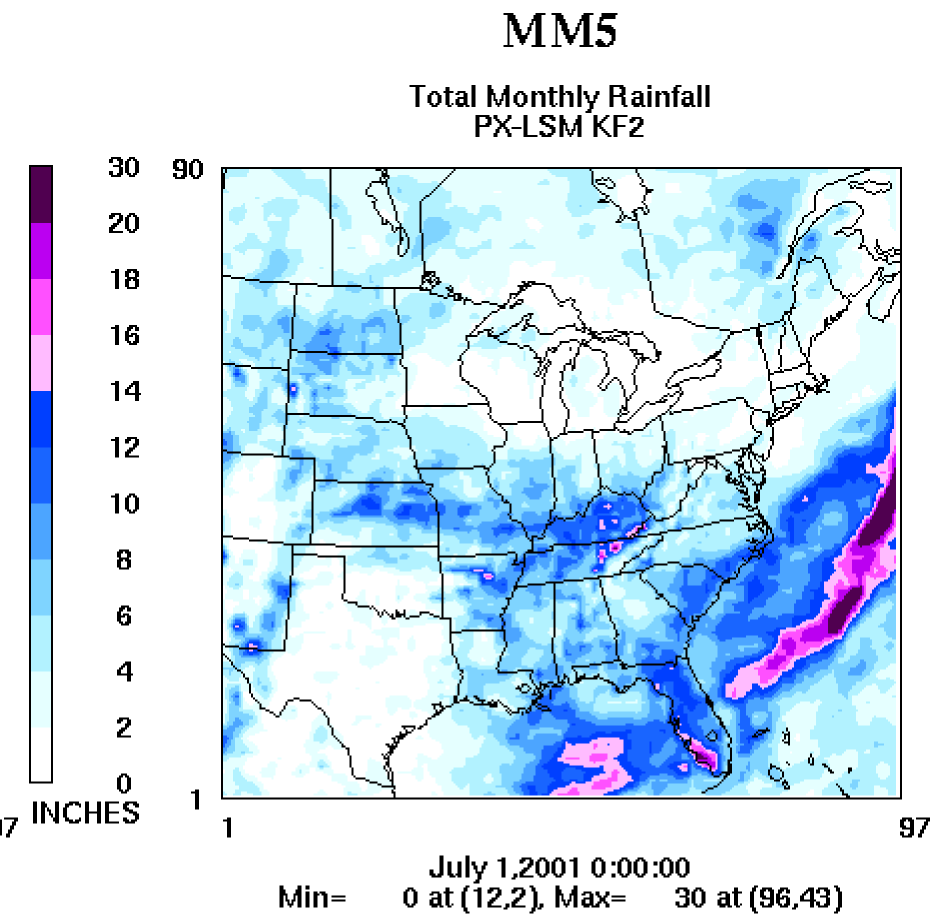

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

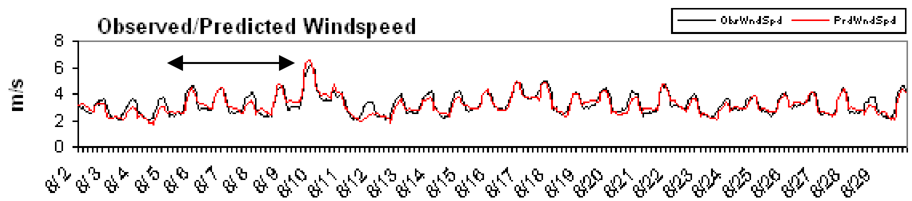

IOA Humidity
IOAHum

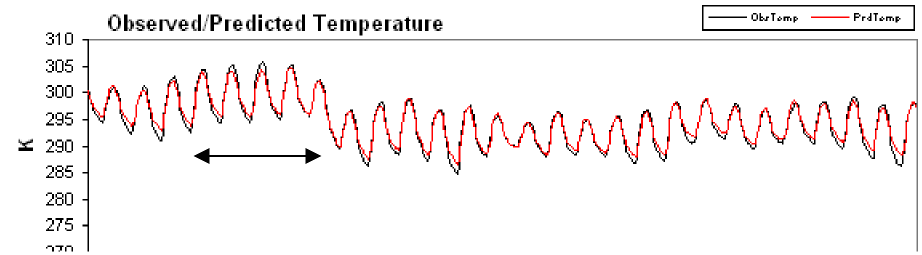
July 2001

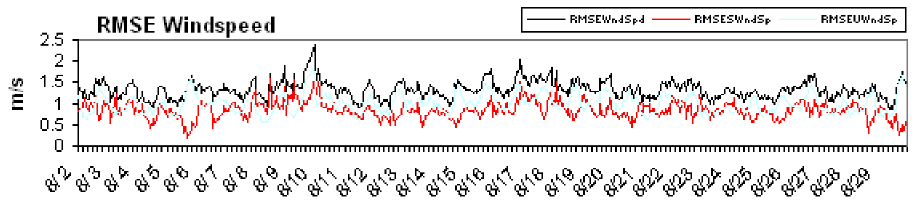

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2001 0:00:00
Min= 0 at (1,1), Max= 15 at (70,6)

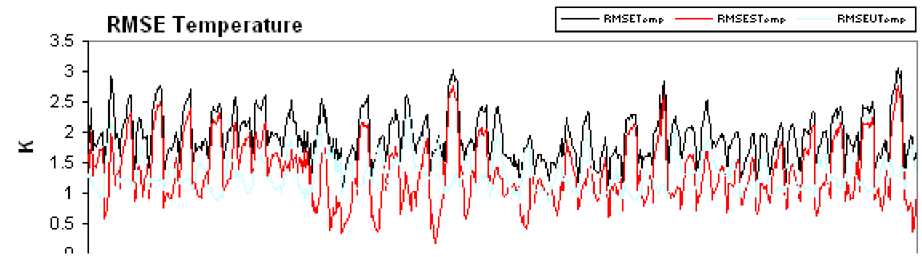

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2001 0:00:00
Min= 0 at (12,2), Max= 30 at (96,43)

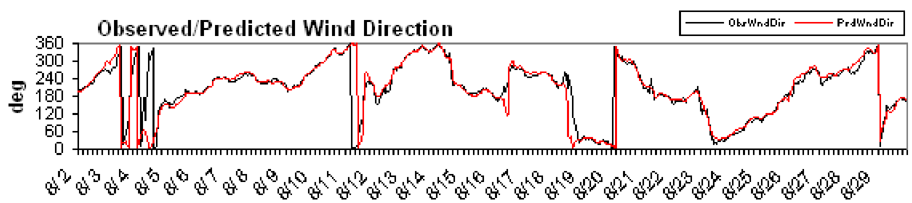
AUGUST 2001

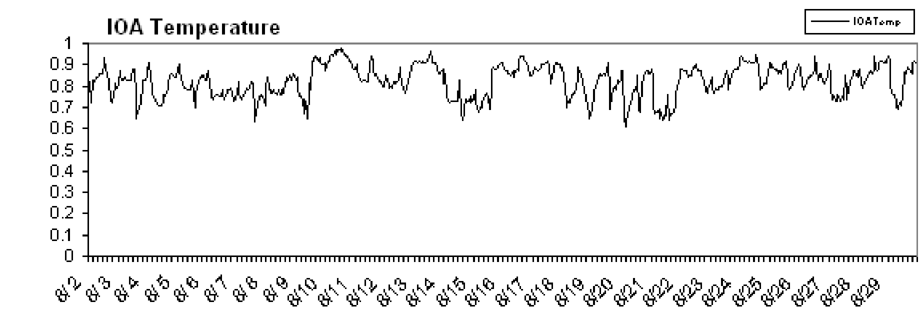

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

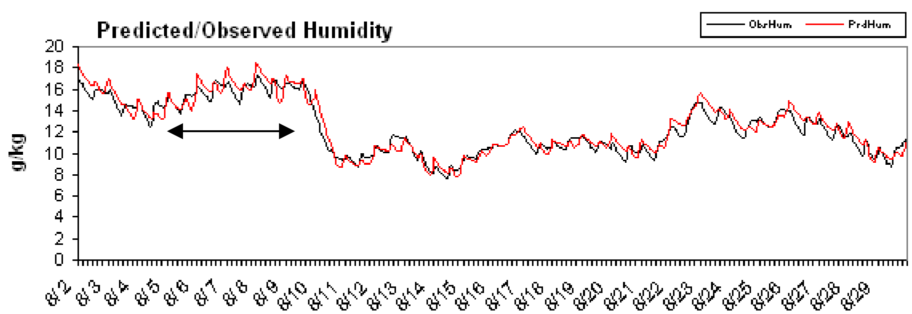

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

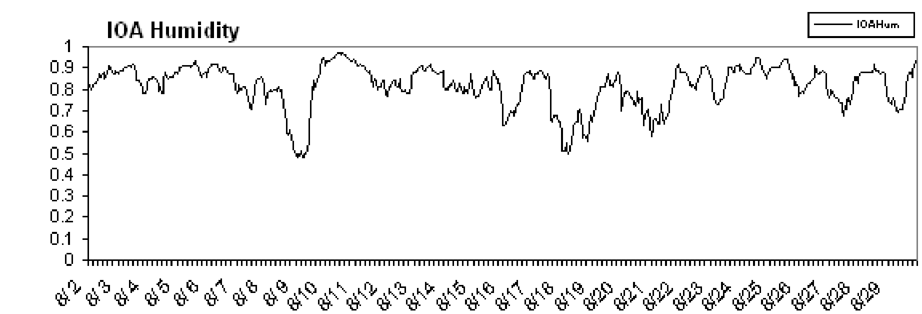

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s


RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K

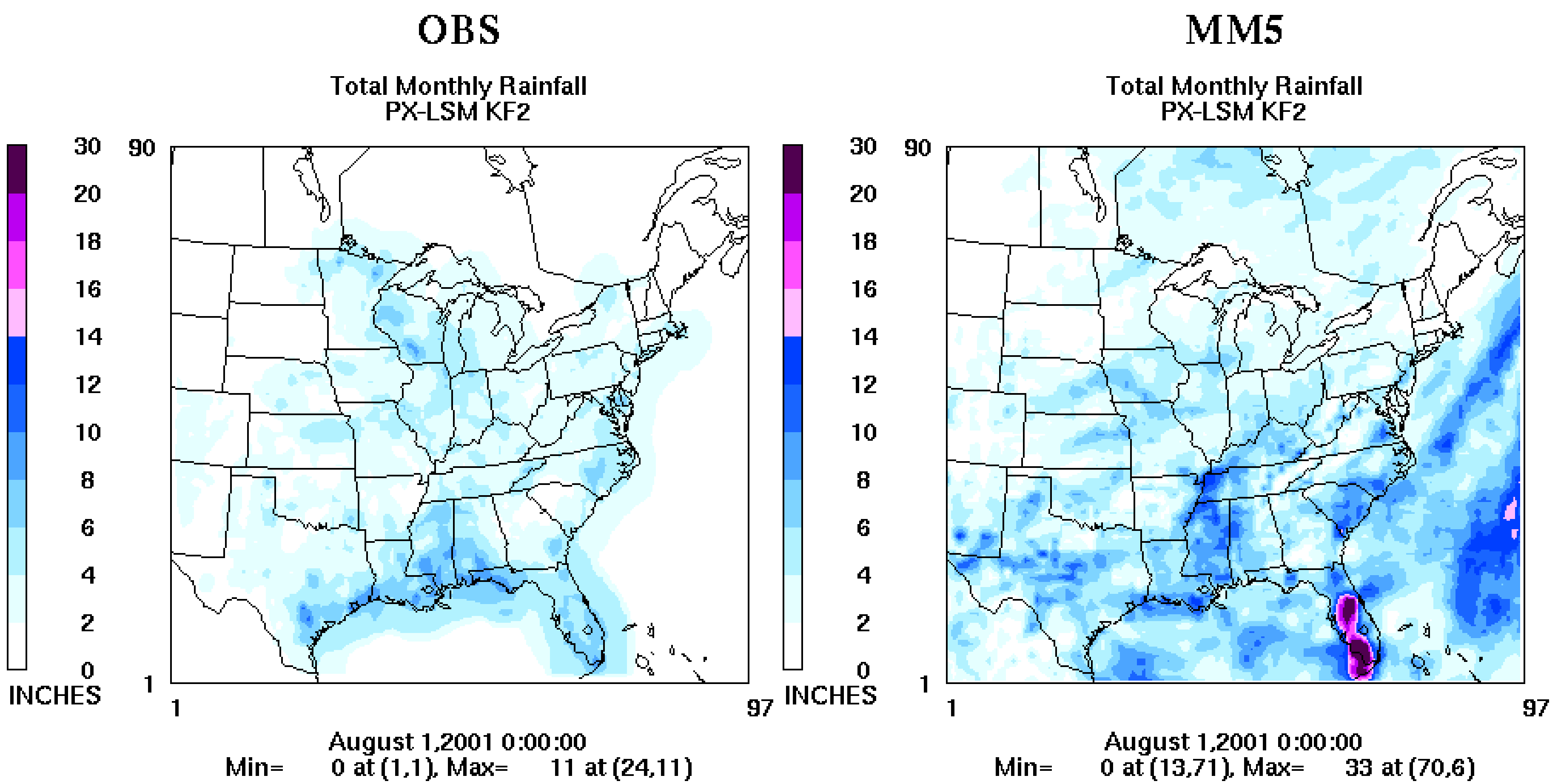

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


IOA Temperature
IOATemp

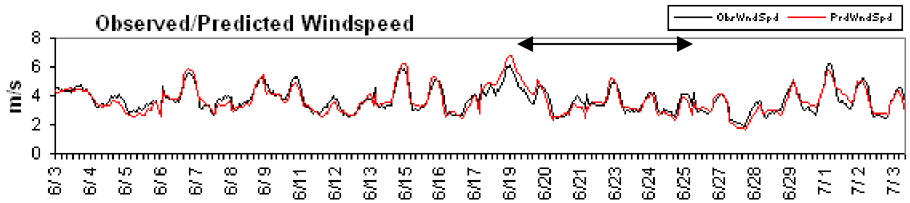

Predicted/Observed Humidity
ObsHum
PrdHum
g/kg


IOA Humidity
IOAHum

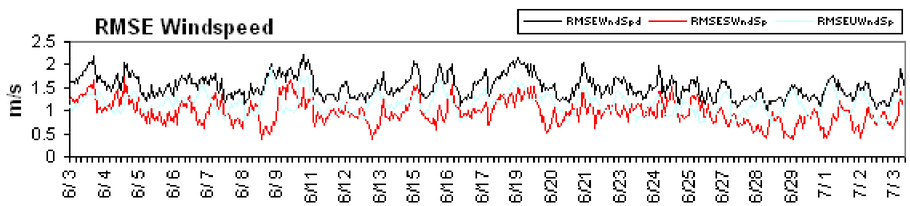
August 2001


OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2001 0:00:00
Min= 0 at (1,1), Max= 11 at (24,11)
MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2001 0:00:00
Min= 0 at (13,71), Max= 33 at (70,6)

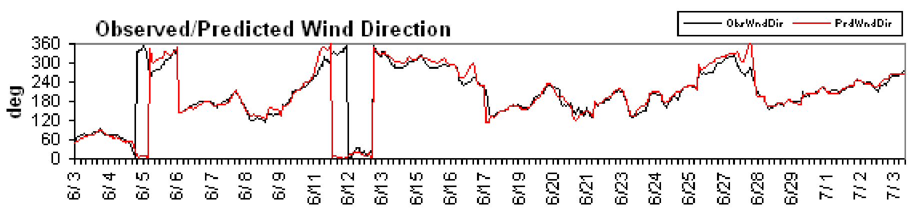
JUNE 2002



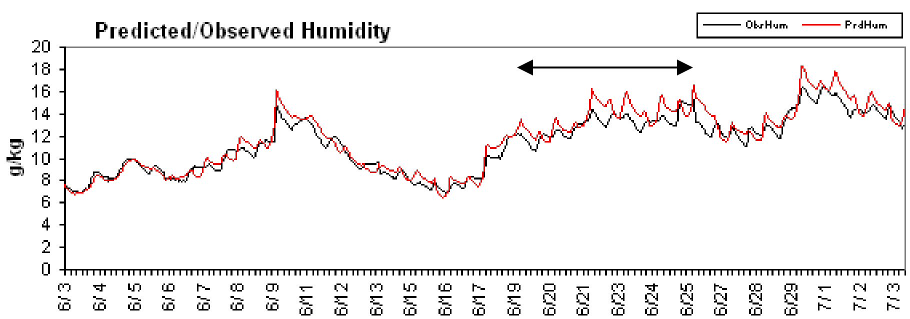
Observed/Predicted Windspeed
m/s



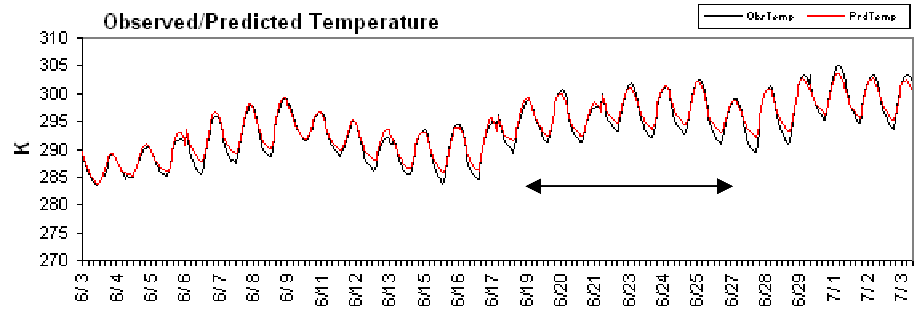
RMSE Windspeed
m/s



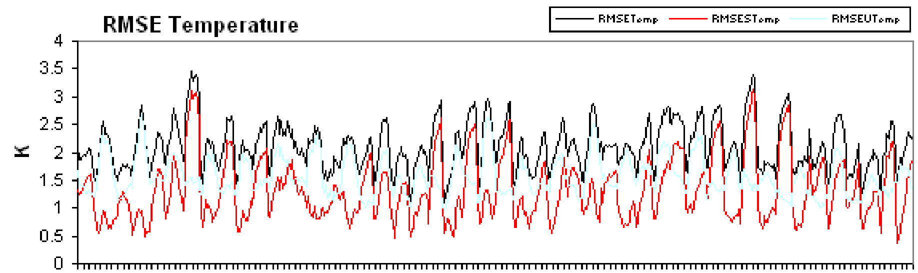
Observed/Predicted Wind Direction
deg



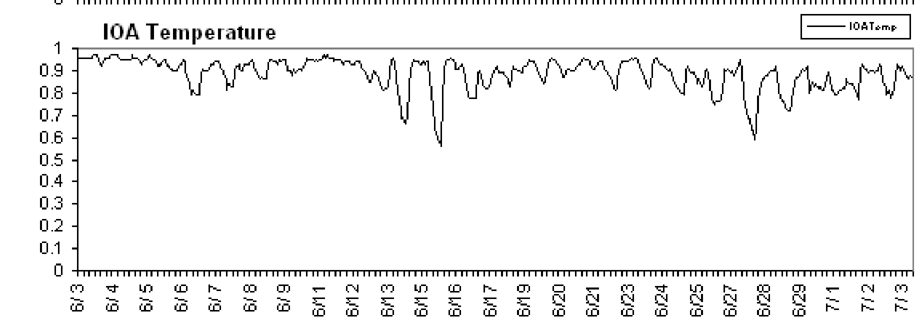
Predicted/Observed Humidity
g/kg



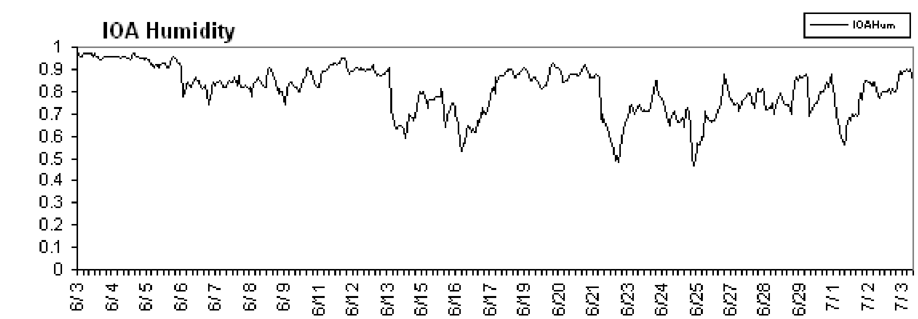
Observed/Predicted Temperature
K



RMSE Temperature
K

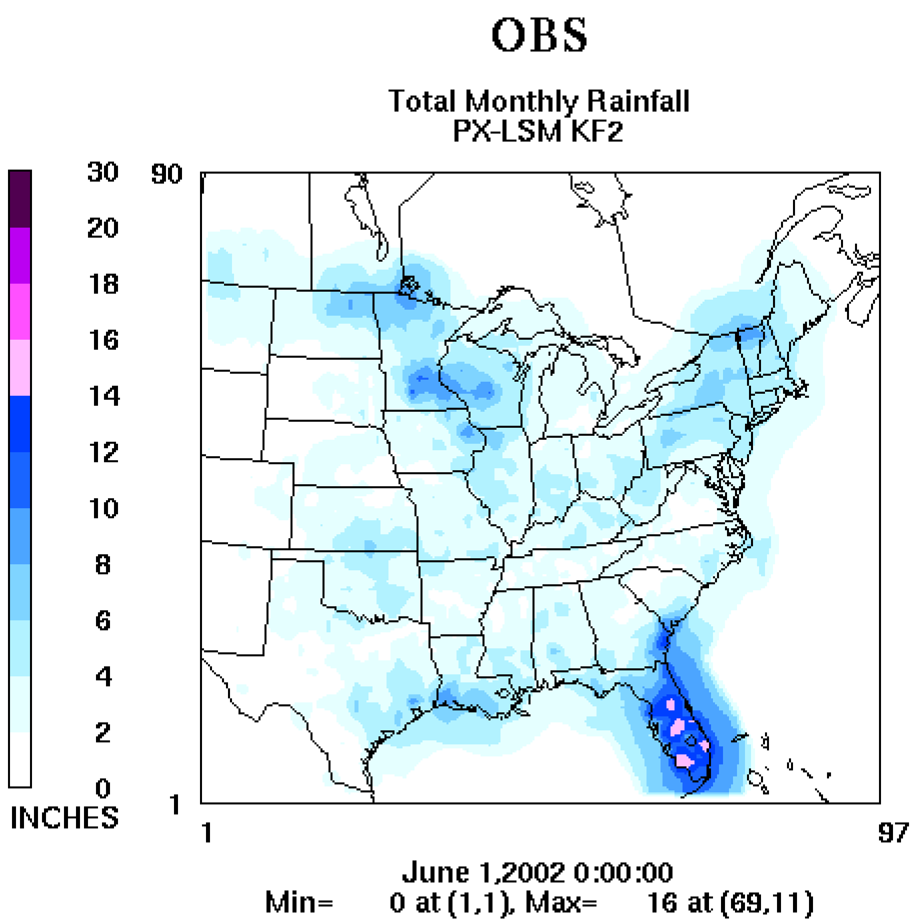


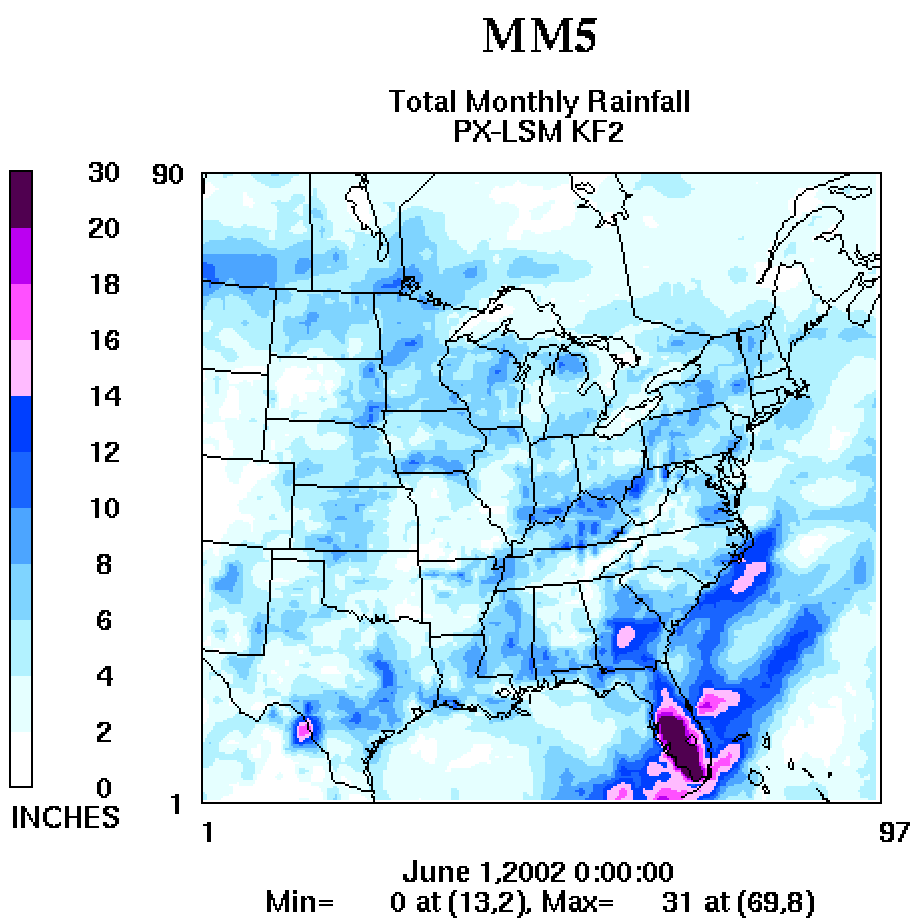
IOA Temperature



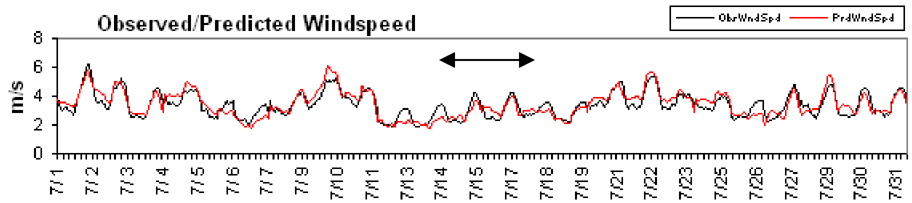
IOA Humidity

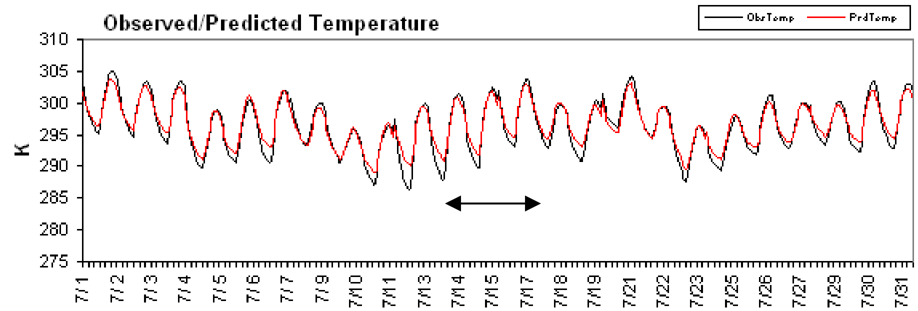
June 2002

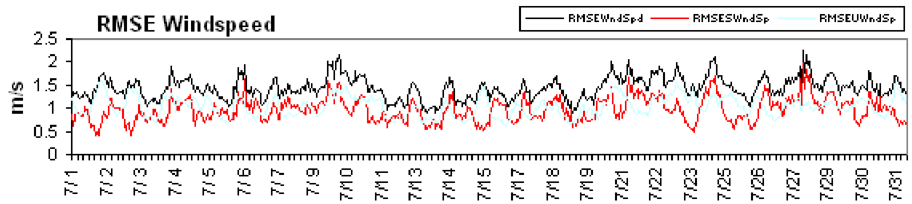

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2002 0:00:00
Min= 0 at (1,1), Max= 16 at (69,11)

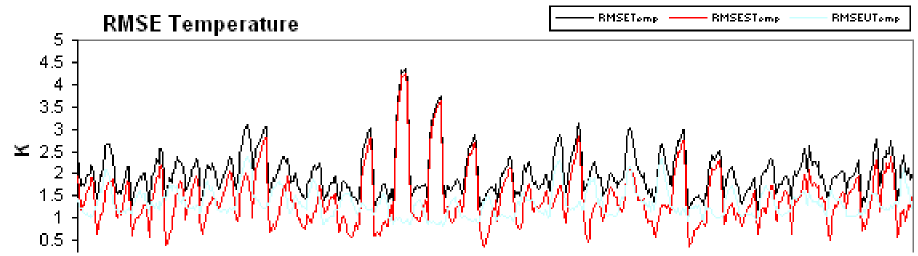

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2002 0:00:00
Min= 0 at (13,2), Max= 31 at (69,8)

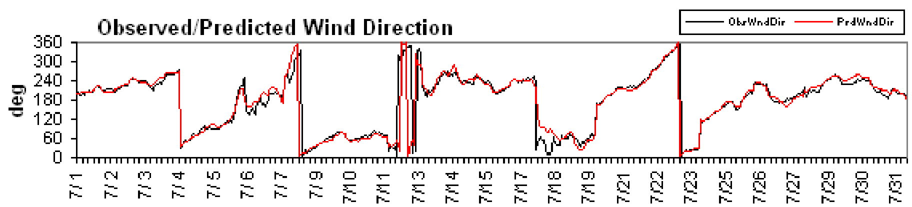
JULY 2002

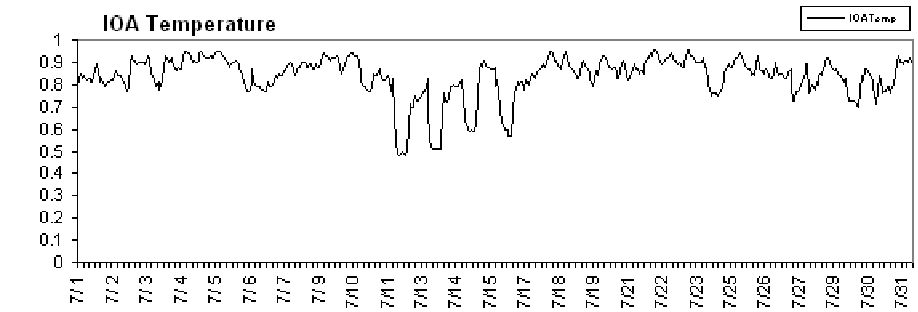

Observed/Predicted Windspeed
m/s
ObsWndSpd
PrdWndSpd

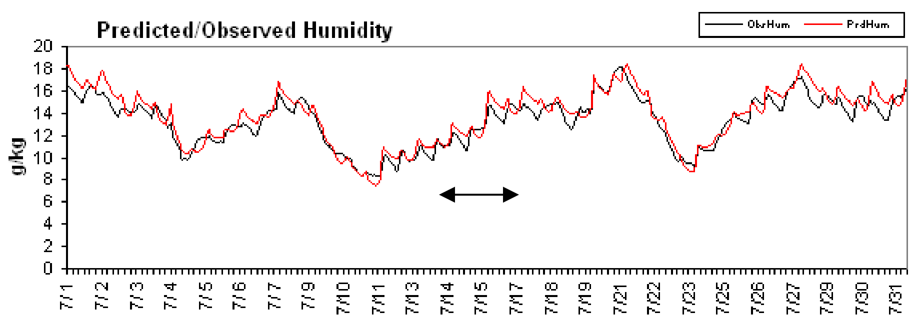

Observed/Predicted Temperature
K
ObsTemp
PrdTemp

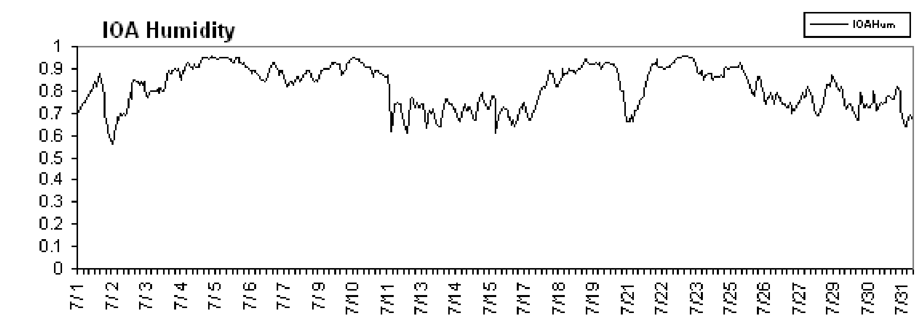

RMSE Windspeed
m/s
RMSEWndSpd
RMSESWndSp
RMSEUWndSp


RMSE Temperature
K
RMSETemp
RMSESTemp
RMSEUTemp

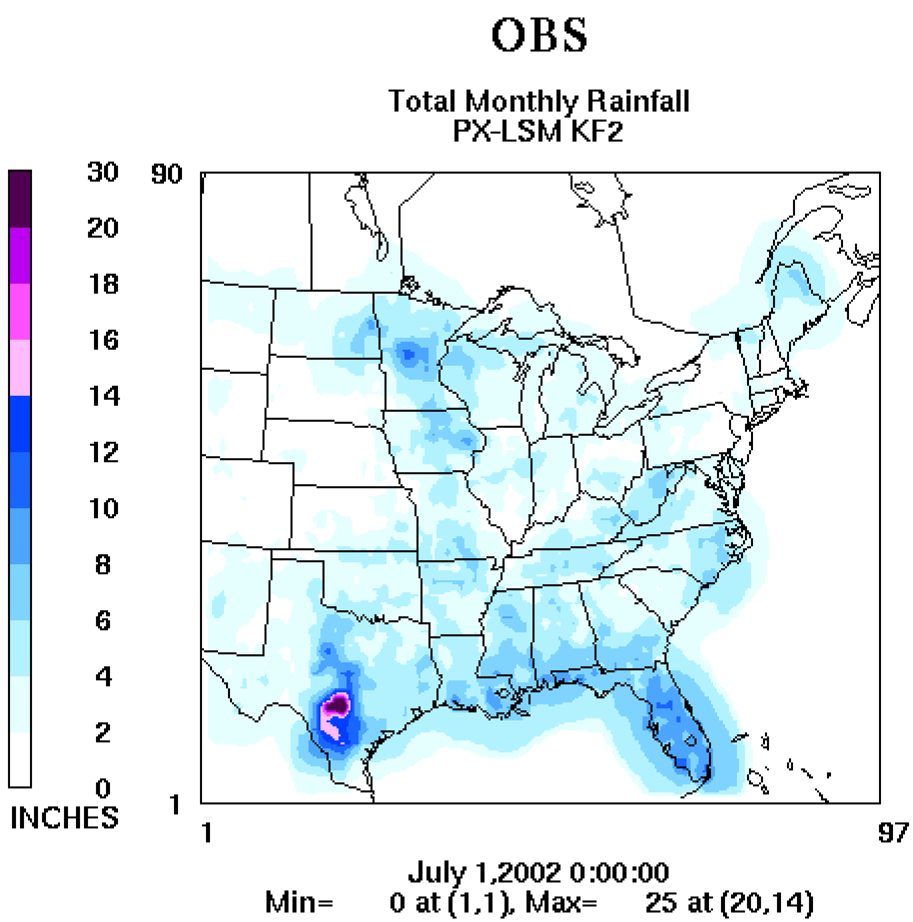

Observed/Predicted Wind Direction
deg
ObsWndDir
PrdWndDir

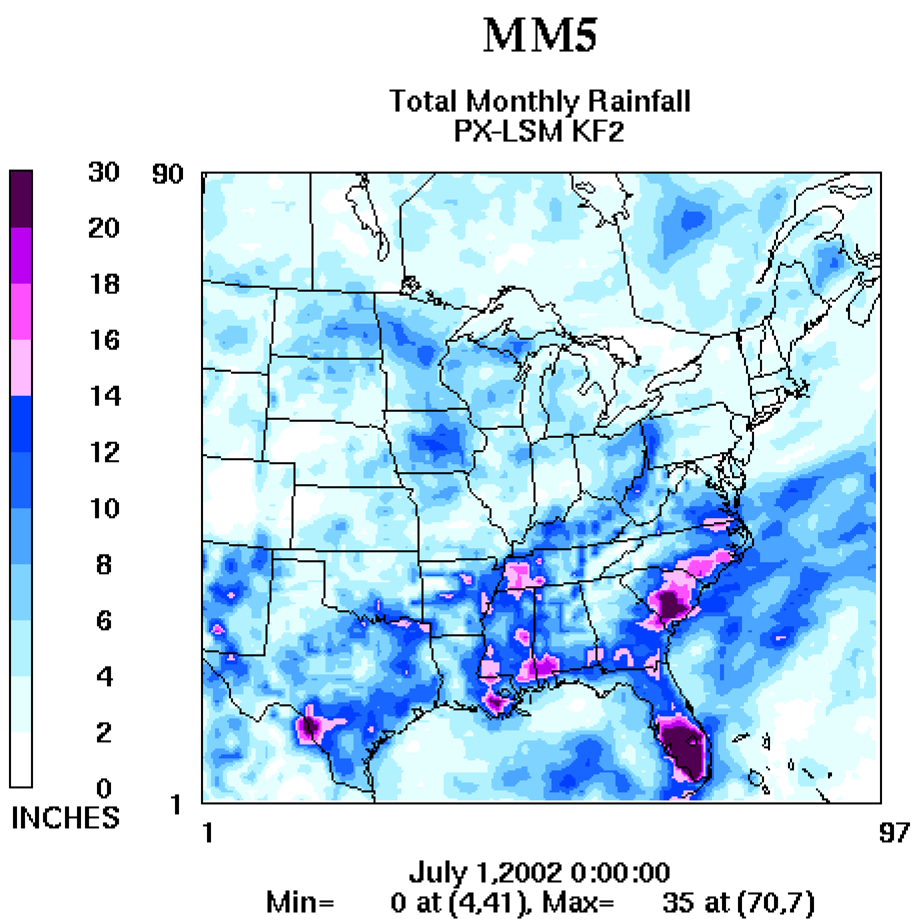

IOA Temperature
IOATemp


Predicted/Observed Humidity
g/kg
ObsHum
PrdHum

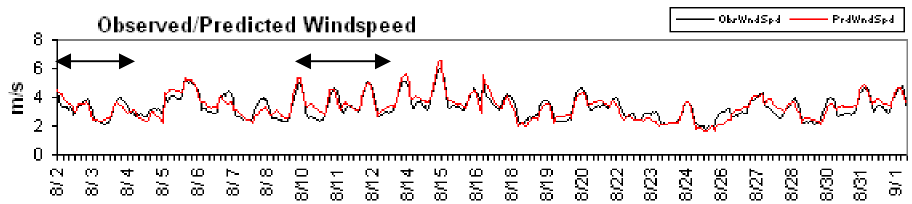

IOA Humidity
IOAHum

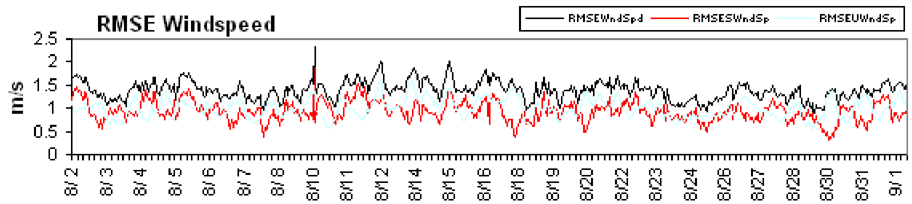
July 2002

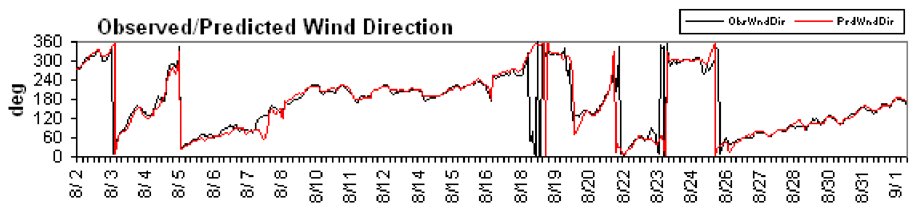

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2002 0:00:00
Min= 0 at (1,1), Max= 25 at (20,14)

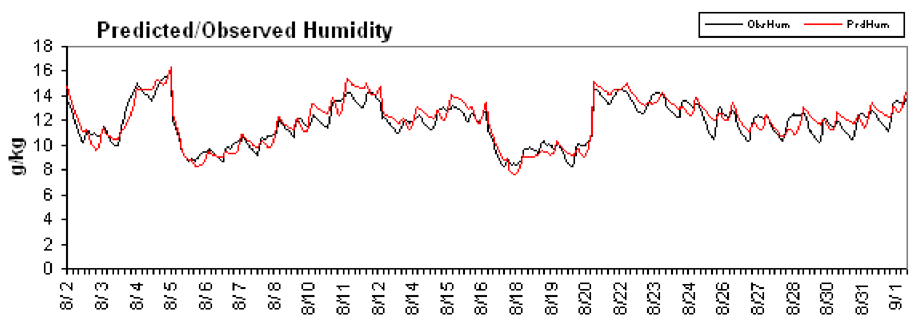

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2002 0:00:00
Min= 0 at (4,41), Max= 35 at (70,7)

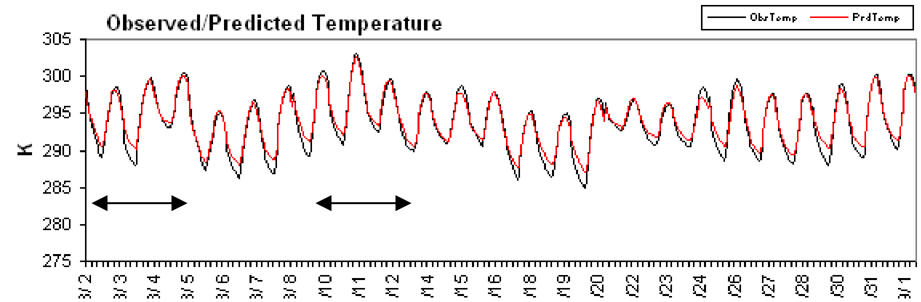
AUGUST 2002

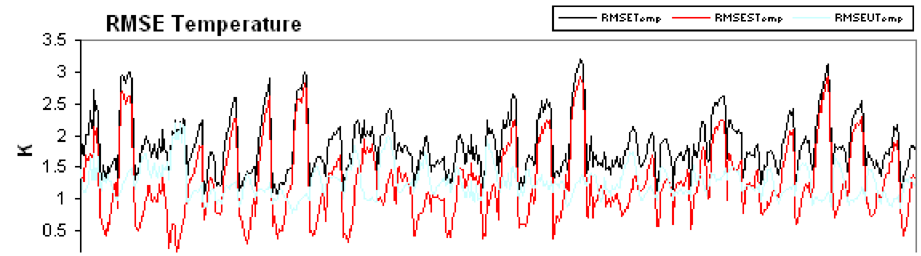

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

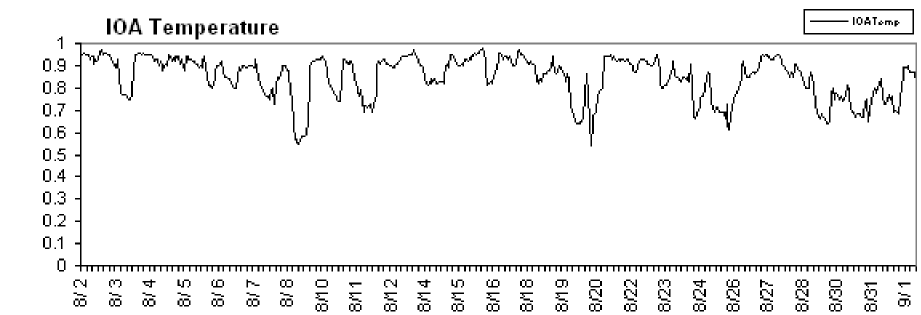

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

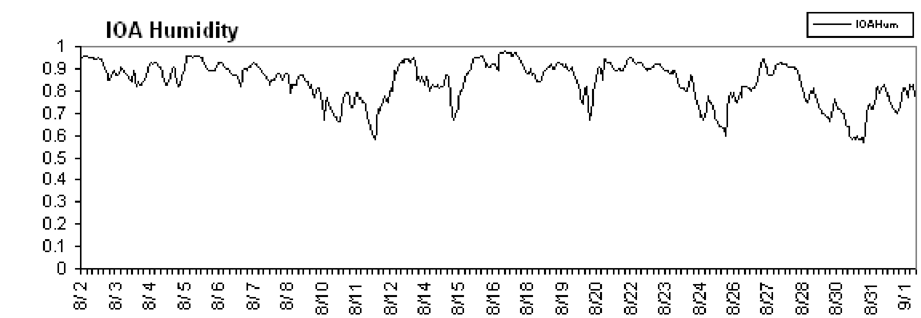

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

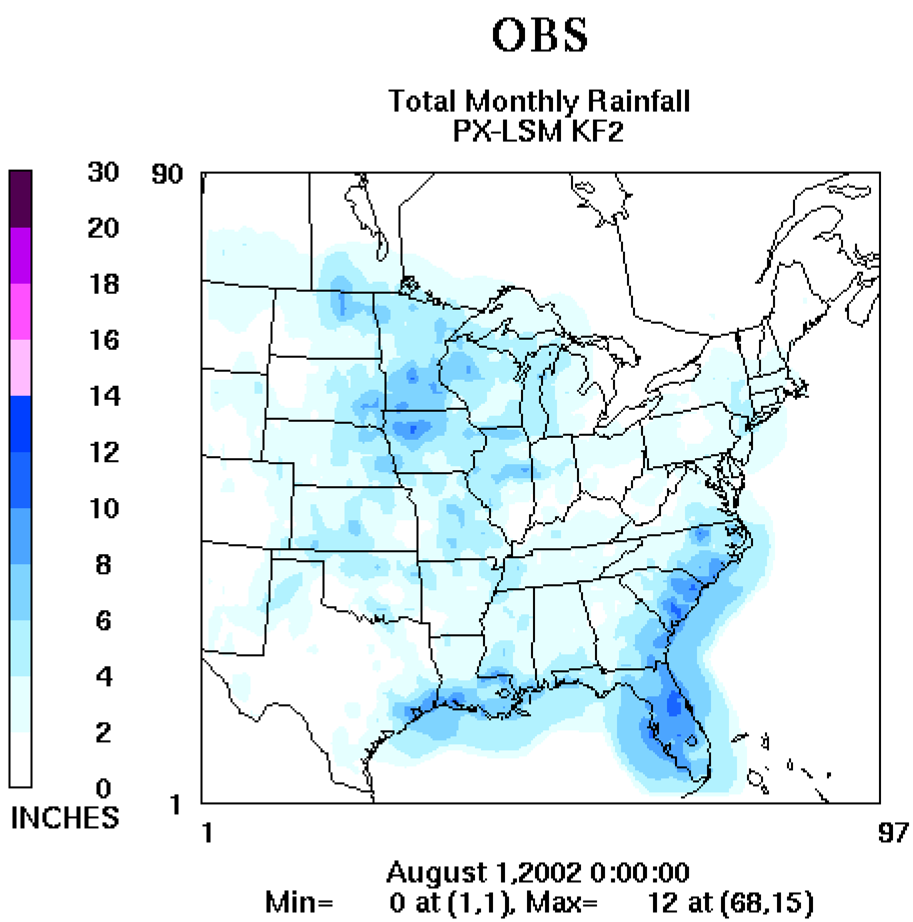

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

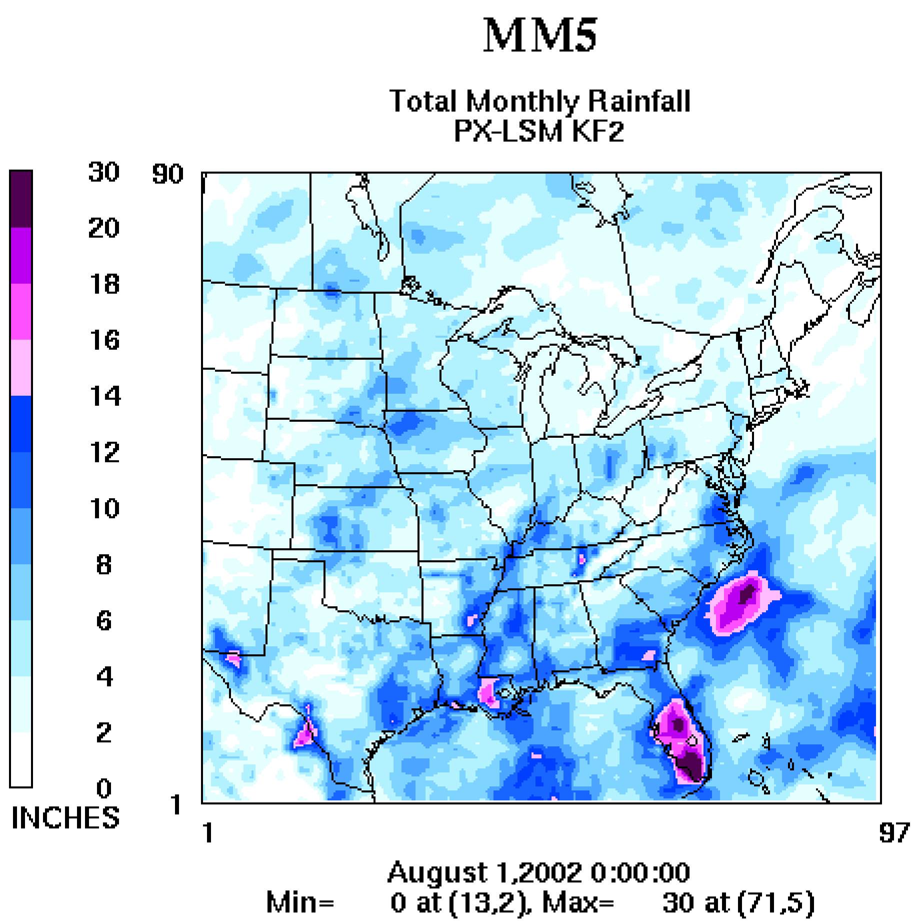

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

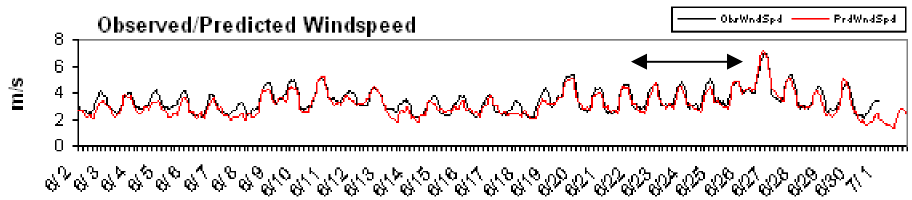

IOA Humidity
IOAHum

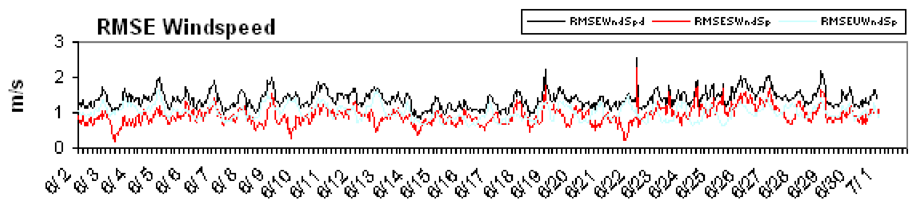
August 2002

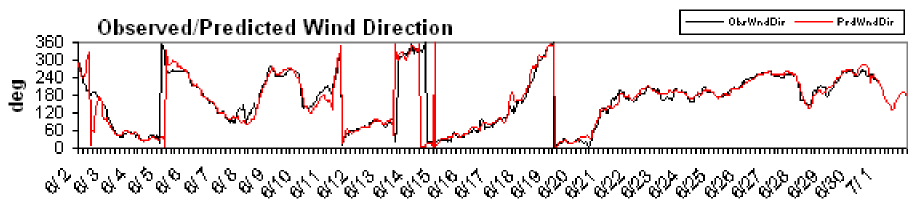

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2002 0:00:00
Min= 0 at (1,1), Max= 12 at (68,15)

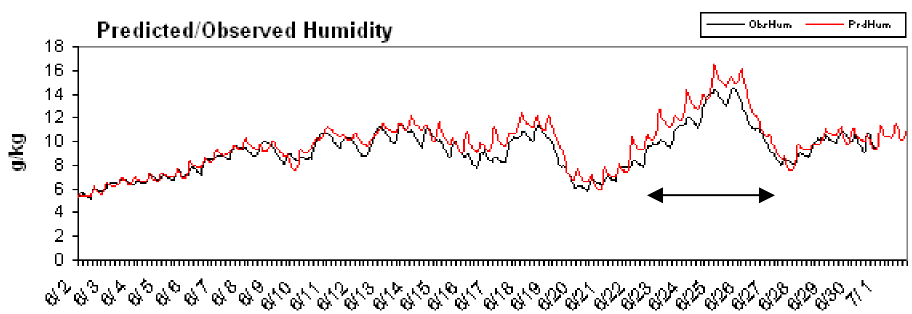

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2002 0:00:00
Min= 0 at (13,2), Max= 30 at (71,5)

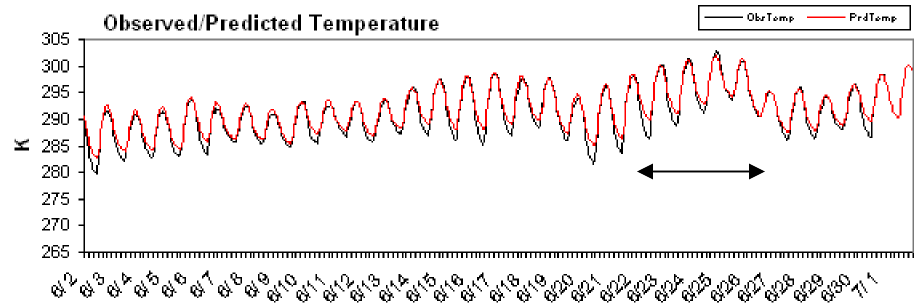
JUNE 2003

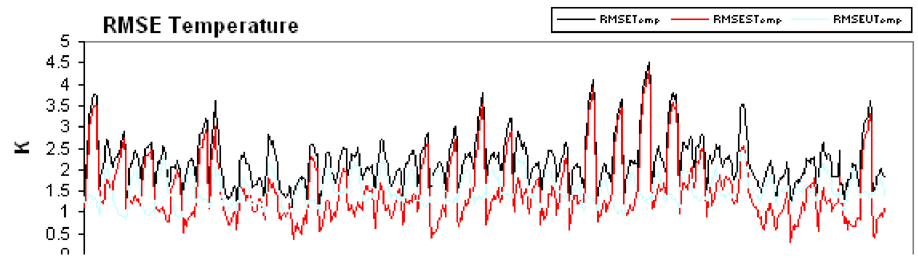

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

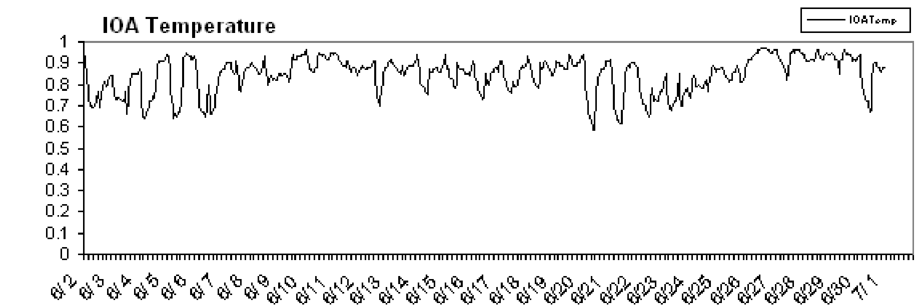

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

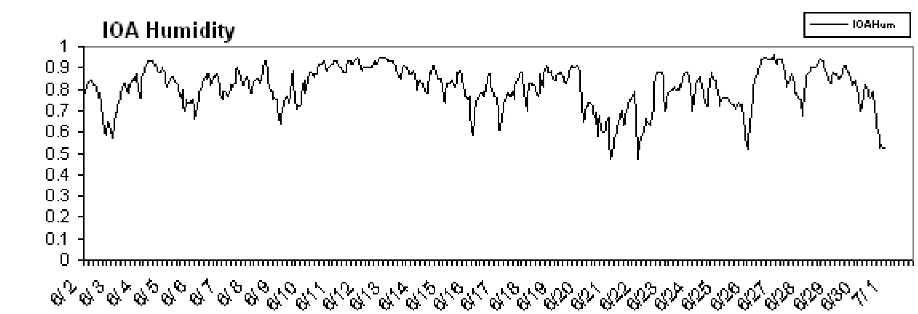

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

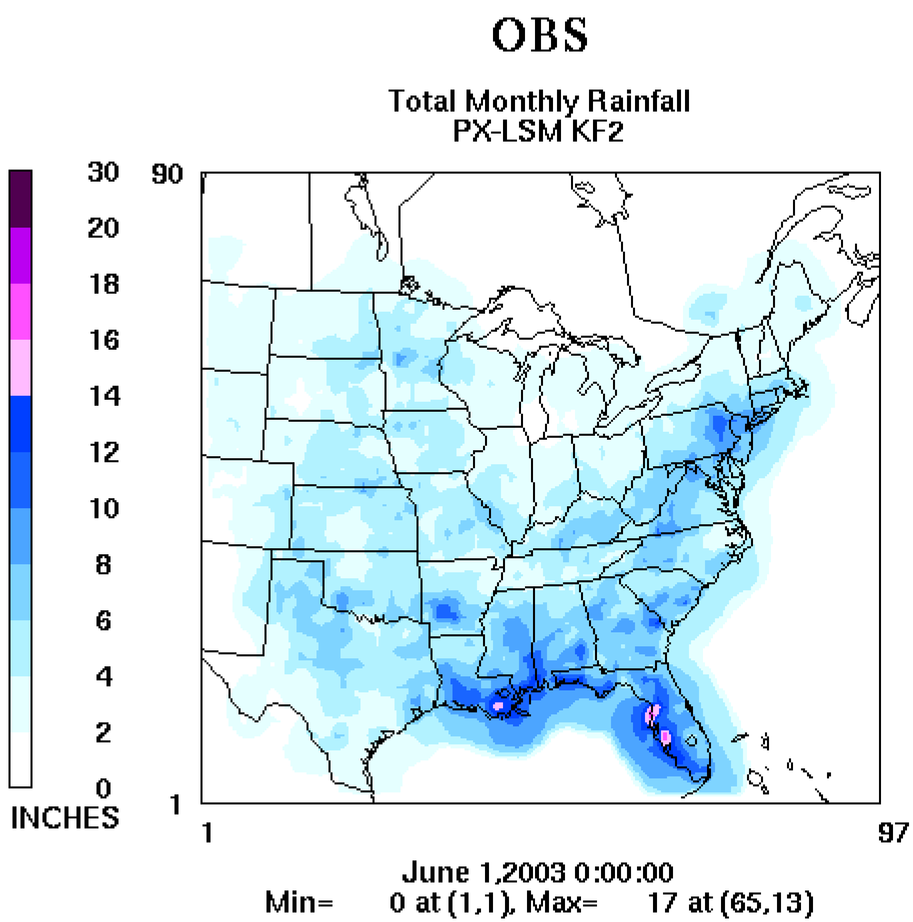

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

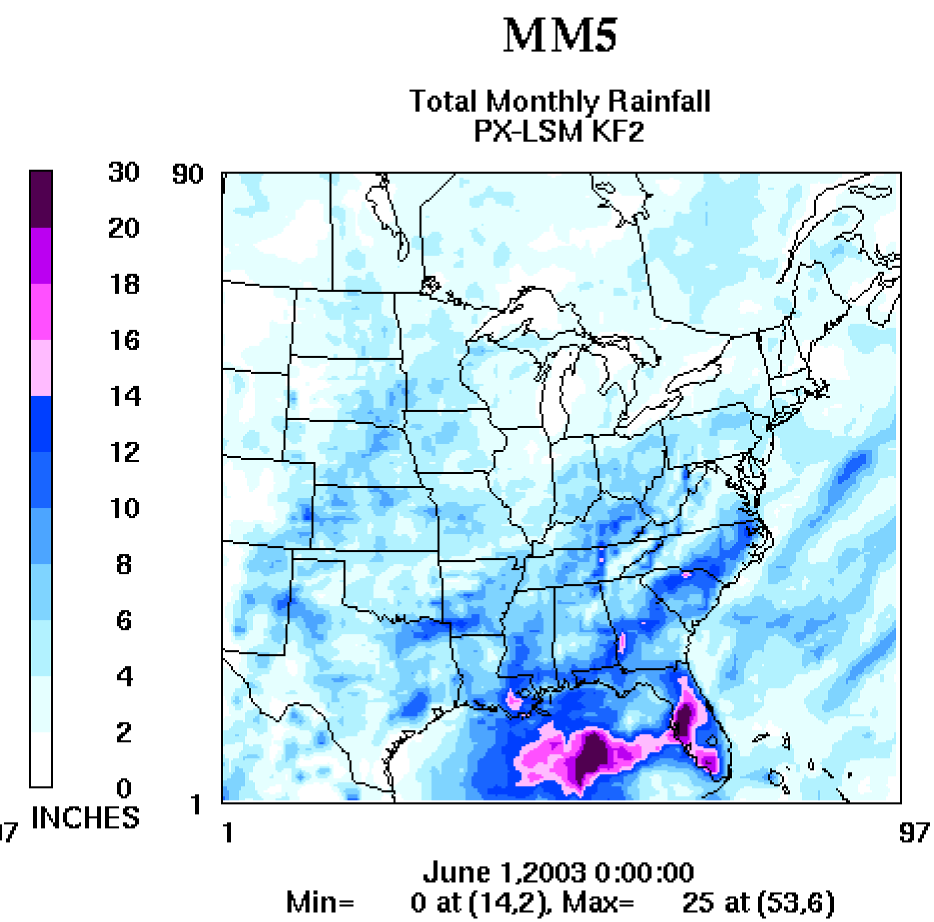

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

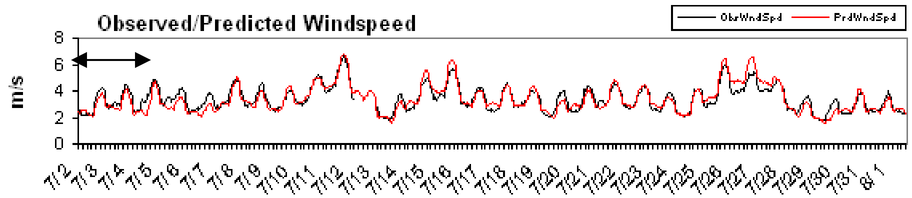

IOA Humidity
IOAHum

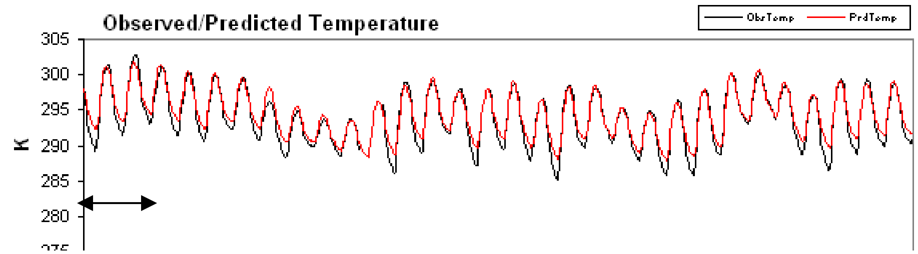
June 2003

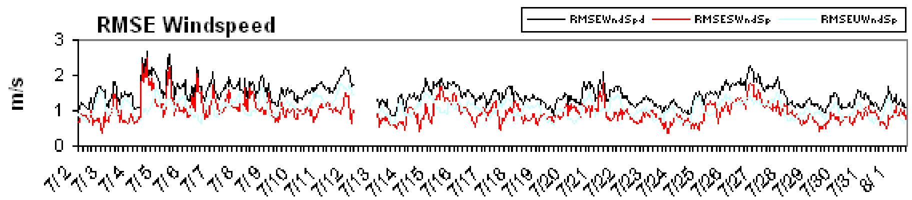

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2003 0:00:00
Min= 0 at (1,1), Max= 17 at (65,13)

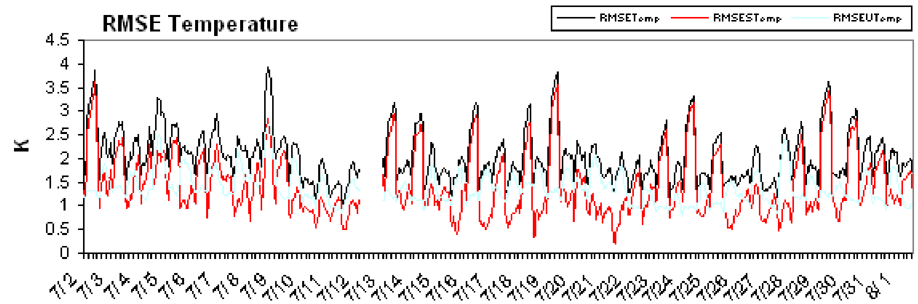

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2003 0:00:00
Min= 0 at (14,2), Max= 25 at (53,6)

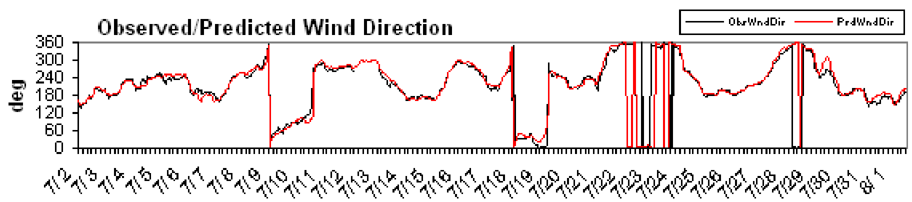
JULY 2003

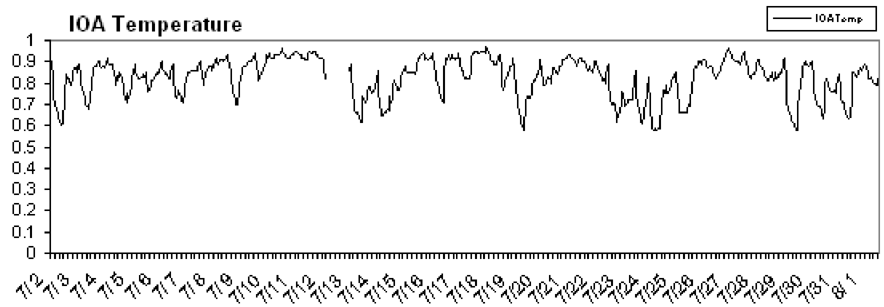

Observed/Predicted Windspeed
m/s

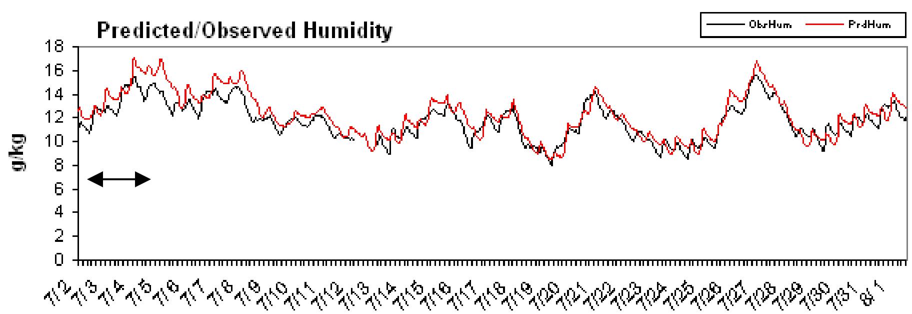

Observed/Predicted Temperature
K

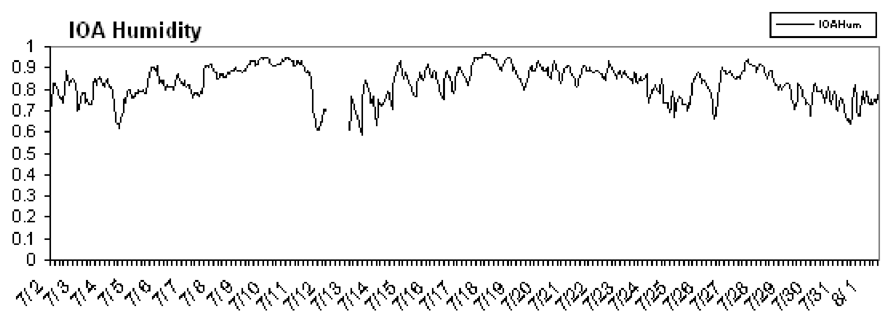

RMSE Windspeed
m/s


RMSE Temperature
K

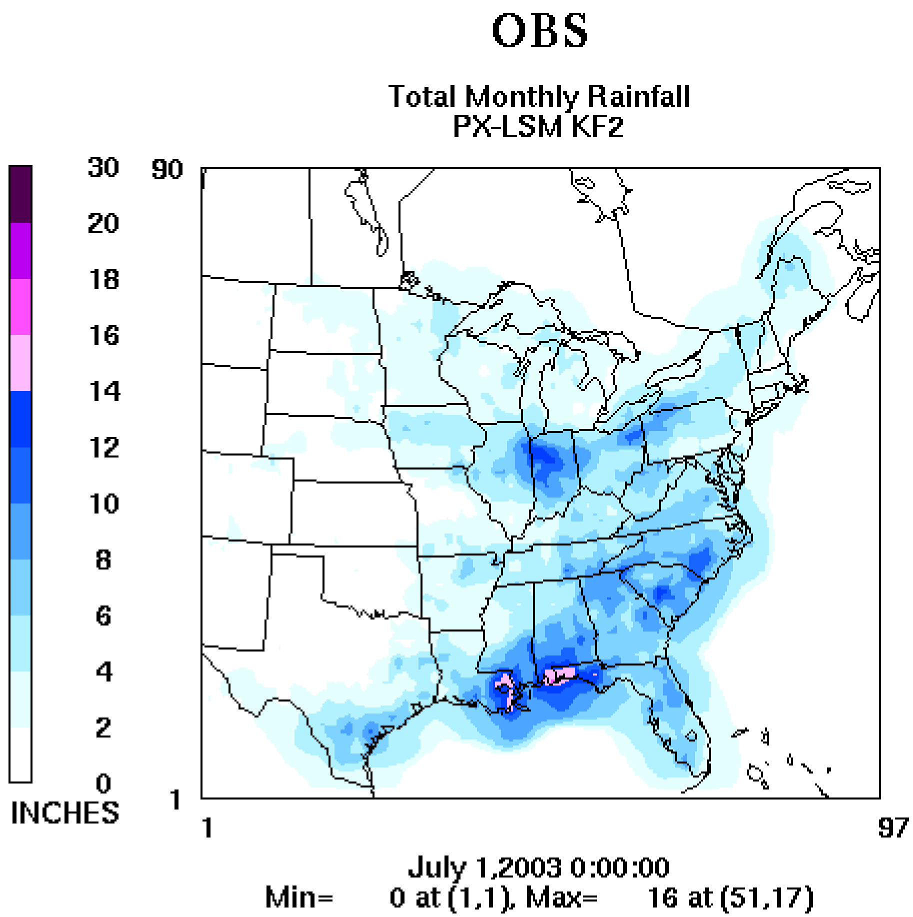

Observed/Predicted Wind Direction
deg

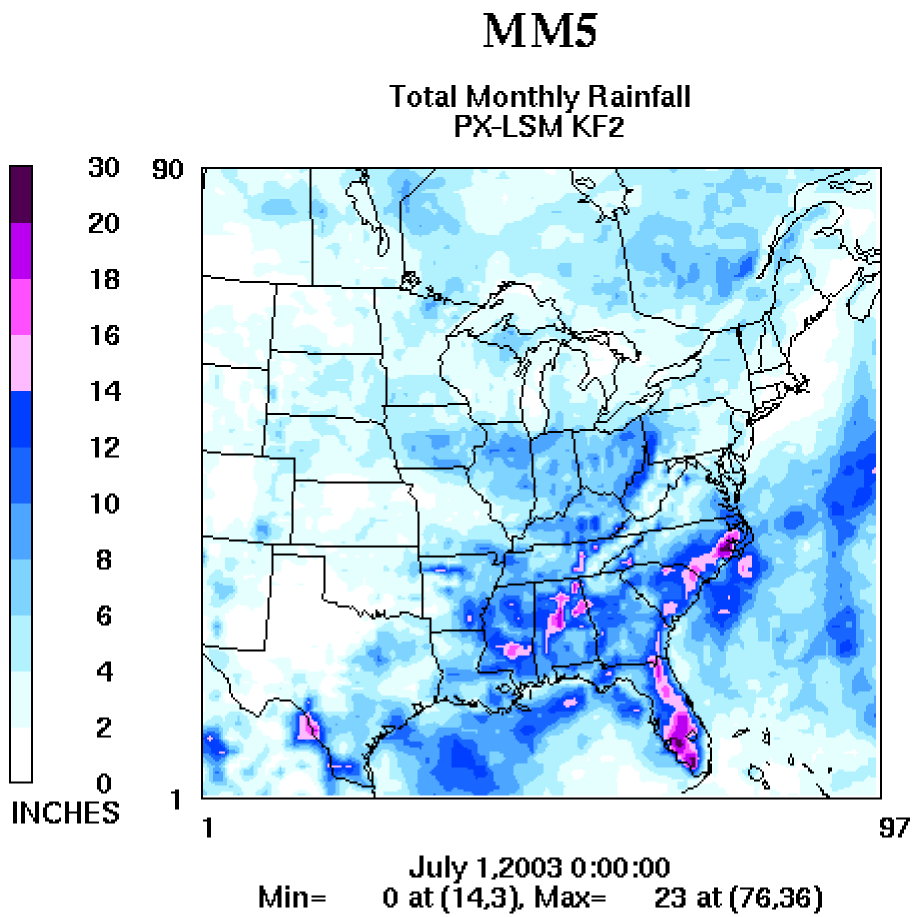

IOA Temperature


Predicted/Observed Humidity
g/kg

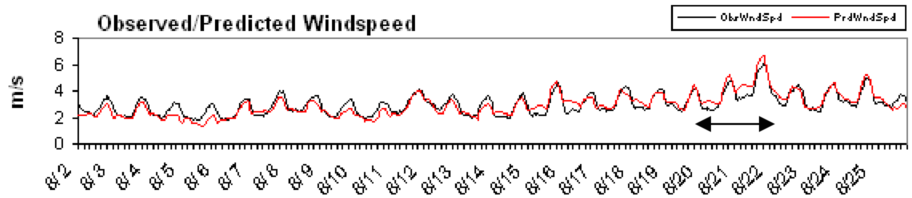

IOA Humidity

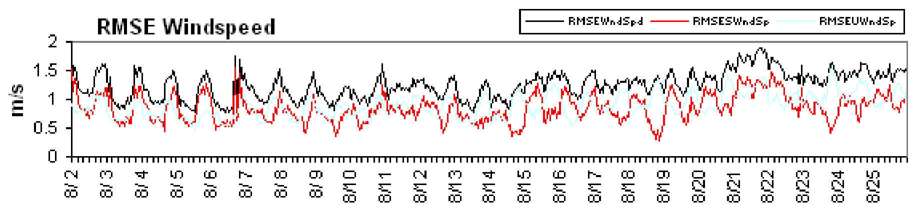
July 2003

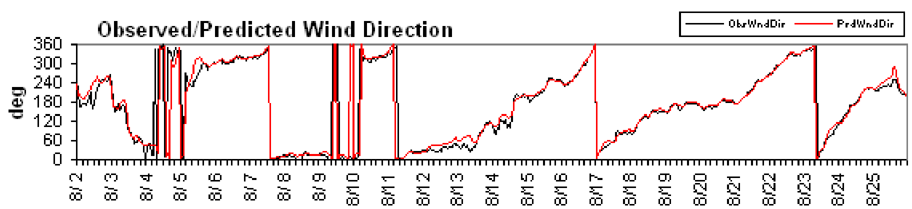

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2003 0:00:00
Min= 0 at (1,1), Max= 16 at (51,17)

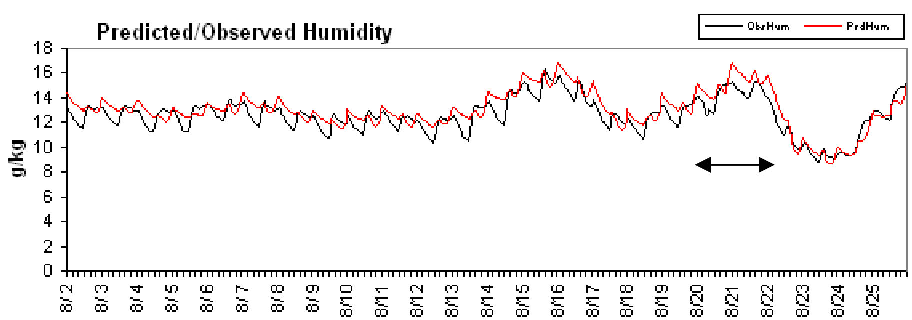

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2003 0:00:00
Min= 0 at (14,3), Max= 23 at (76,36)

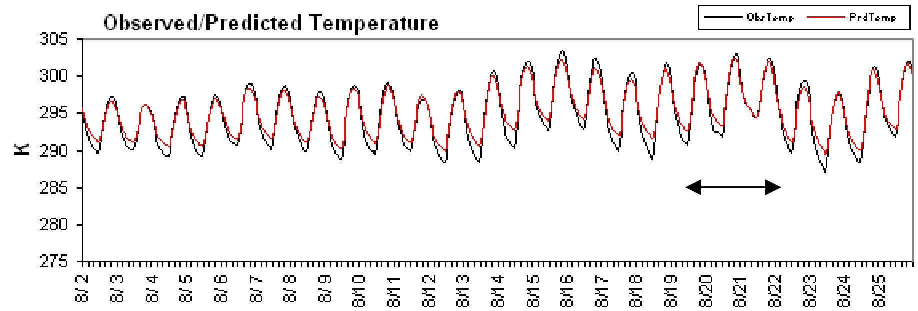
AUGUST 2003

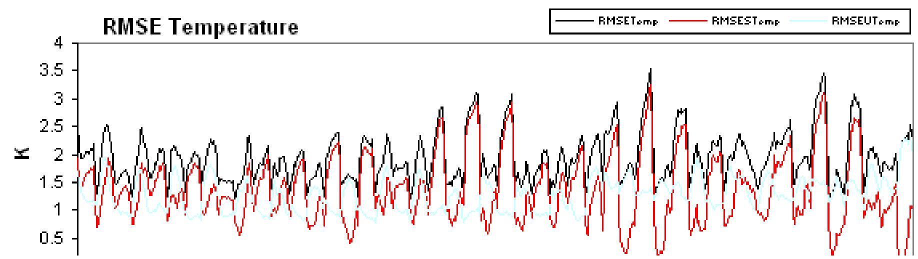

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

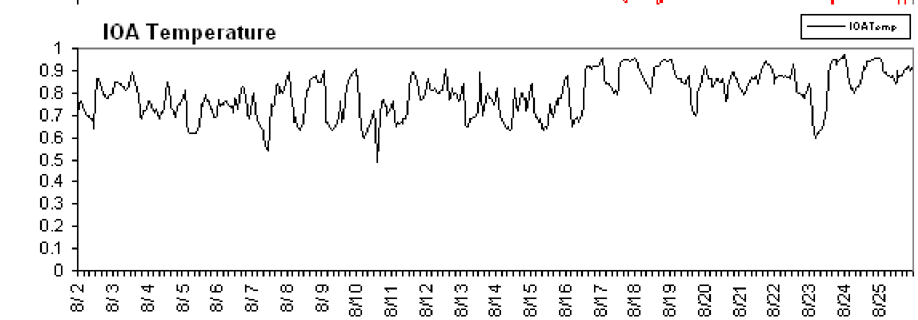

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

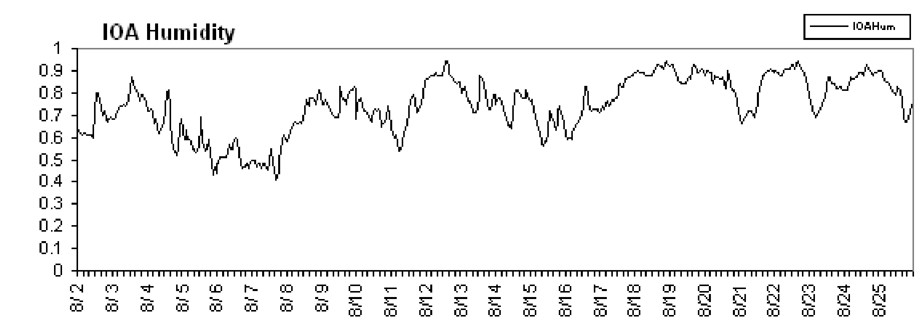

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

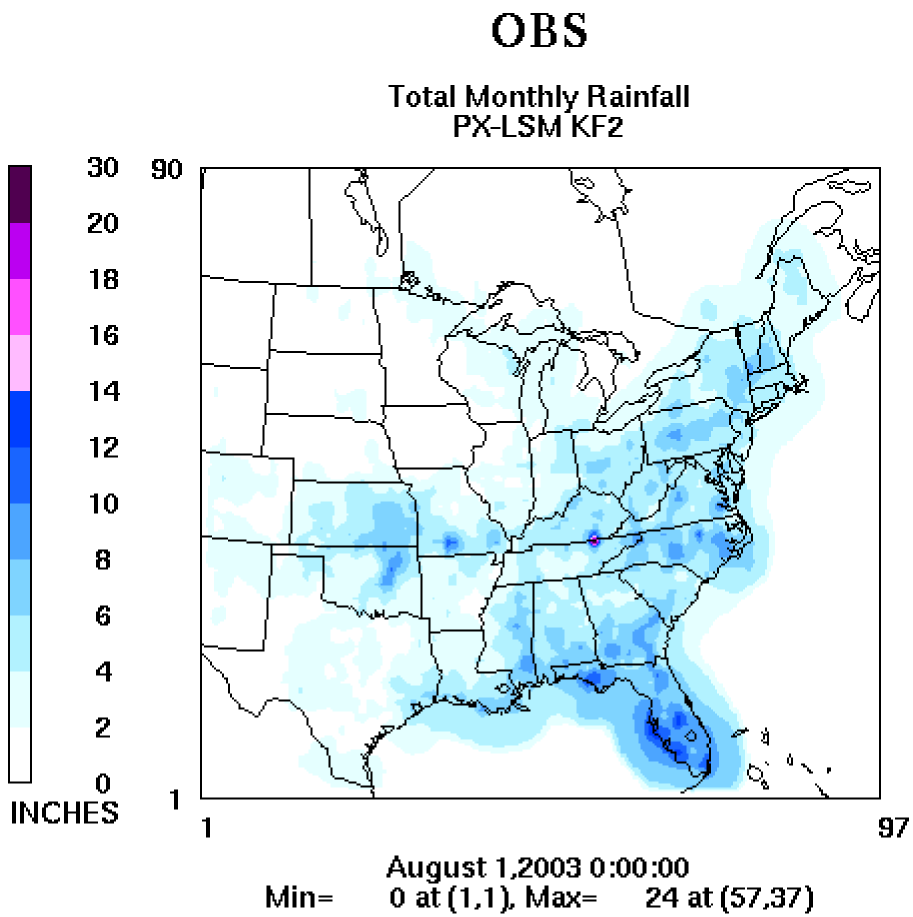

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

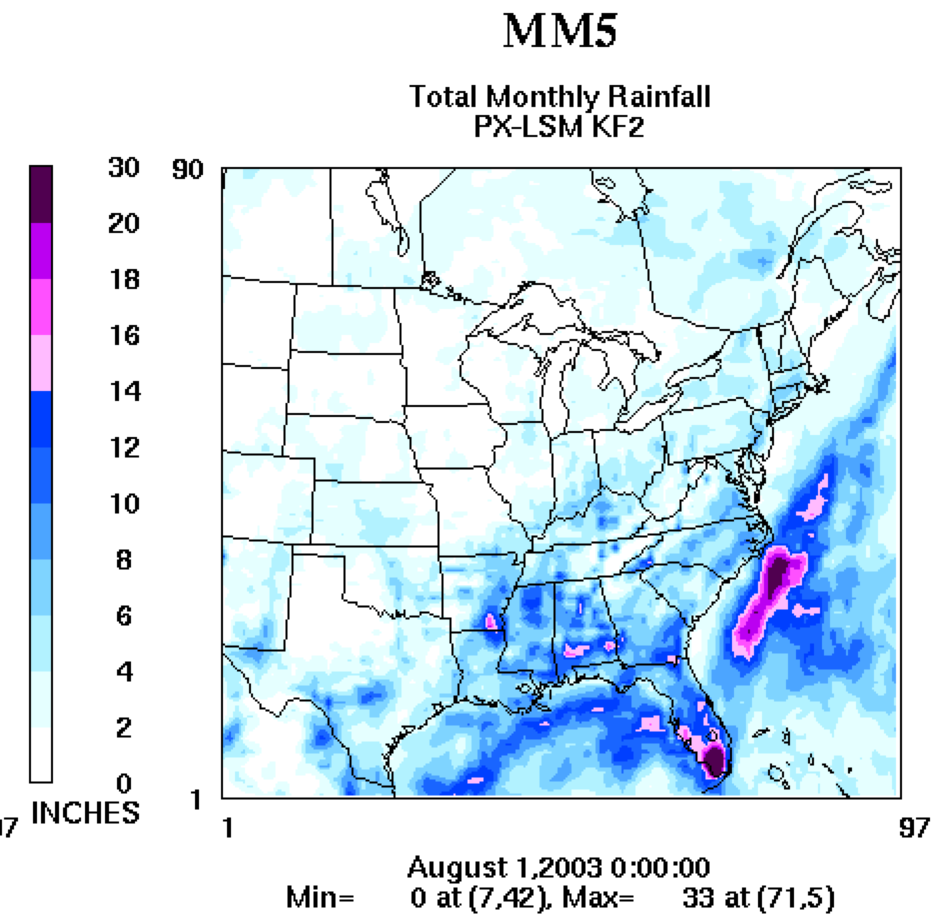

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp


IOA Humidity
IOAHum

August 2003


OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2003 0:00:00
Min= 0 at (1,1), Max= 24 at (57,37)


MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2003 0:00:00
Min= 0 at (7,42), Max= 33 at (71,5)

Upper Midwest High Ozone Days

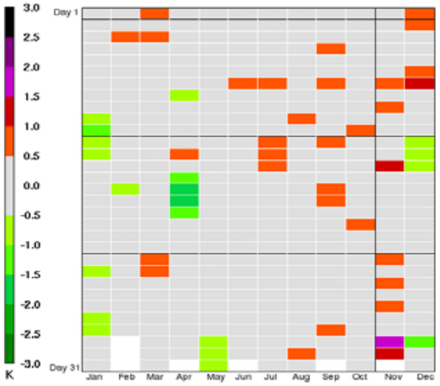
- 2001:
  - June 13-14, 18-19, 25-30
  - July 16-20; July 31 – Aug 2
  - Aug 5-8
- 2002:
  - June 19-25
  - July 7-8, 14-17
  - Aug 1-4, 9-13
- 2003:
  - June 22-26
  - July 1-3
  - Aug 20-21

APPENDIX D

Performance Comparison: Old v. New Annual 2002 Simulation

Temperature RMSE Difference - gl Grid

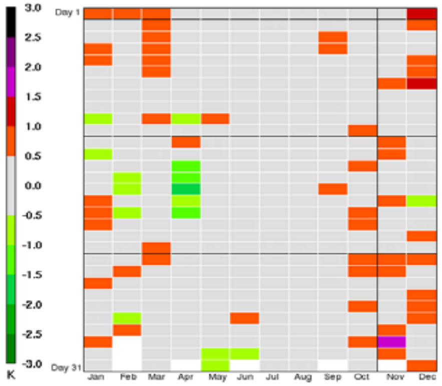
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.8 at (4,16), Max= 1.7 at (11,3)

Temperature RMSE Difference - cenrapN Grid

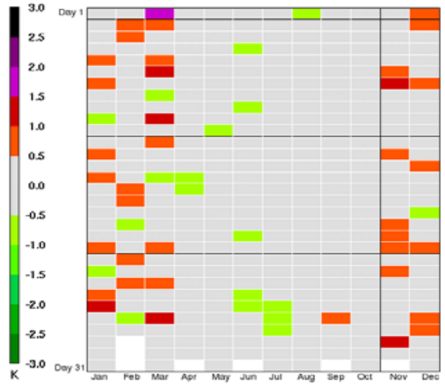
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.8 at (4,16), Max= 1.8 at (11,3)

Temperature RMSE Difference - cenrapS Grid

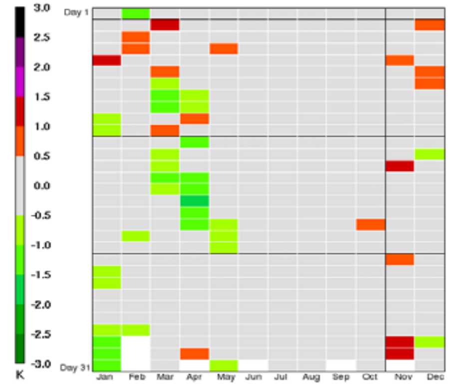
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.8 at (1,22), Max= 1.6 at (3,31)

Temperature RMSE Difference - ohioval Grid

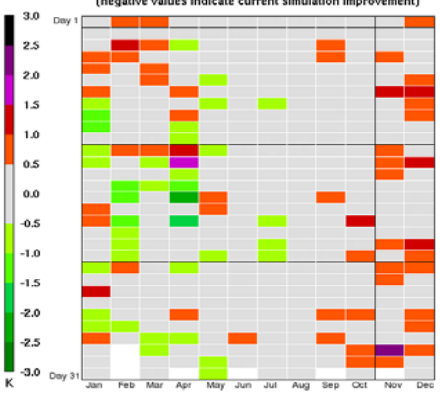
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.5 at (4,15), Max= 1.4 at (11,2)

Temperature RMSE Difference - Iowa Grid

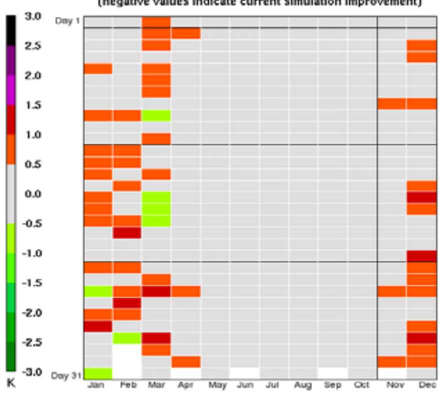
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -2.1 at (4,16), Max= 2.1 at (11,3)

Temperature RMSE Difference - SE Grid

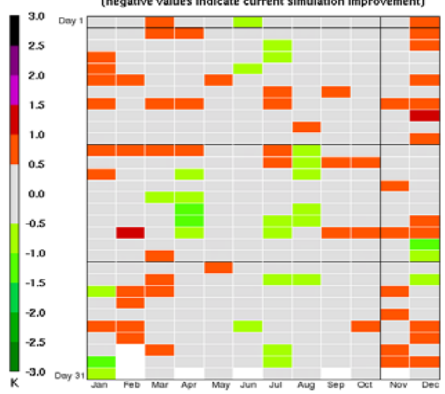
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.0 at (2,4), Max= 1.2 at (12,11)

Temperature RMSE Difference - MidAtlantic Grid

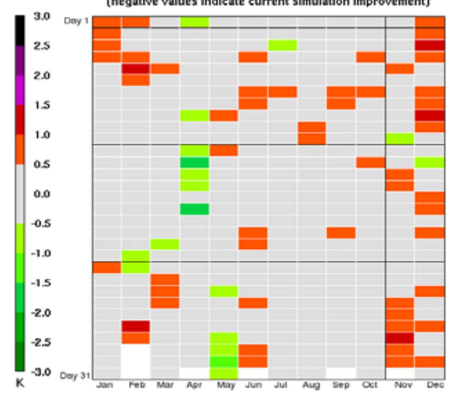
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.5 at (12,12), Max= 1.4 at (2,13)

Temperature RMSE Difference - NE Grid

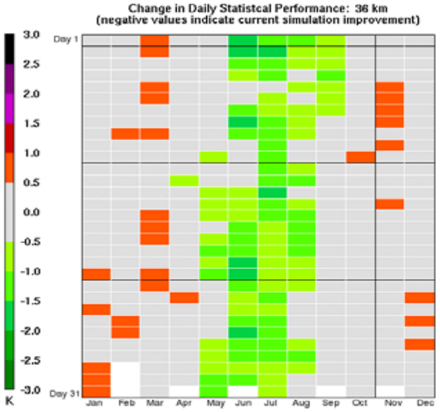
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.7 at (4,15), Max= 1.3 at (2,5)

Temperature RMSE Difference - DessertSW Gric

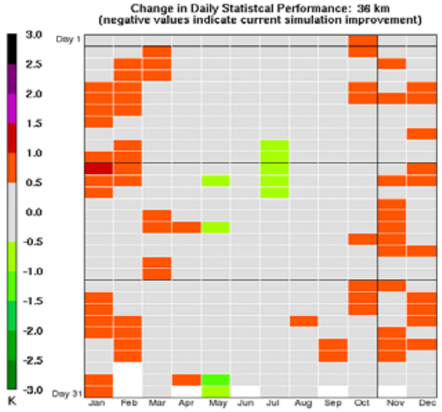
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.8 at (7,18), Max= 1.0 at (2,6)

Temperature RMSE Difference - SW Grid

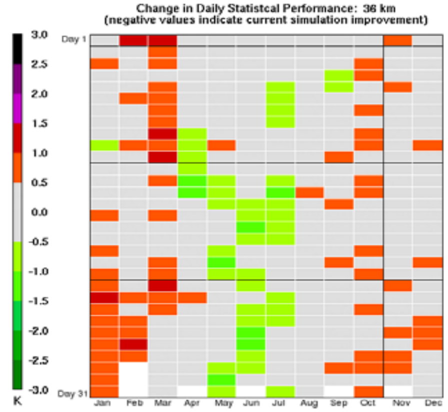
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -1.0 at (5,2), Max= 1.1 at (1,20)

Temperature RMSE Difference - North Grid

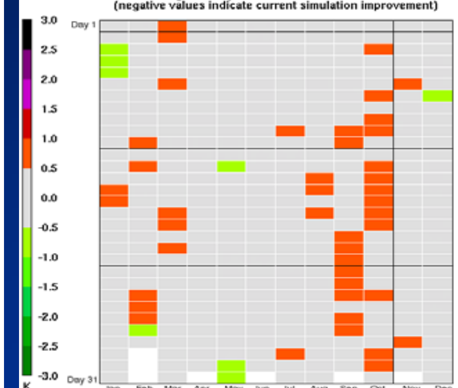
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



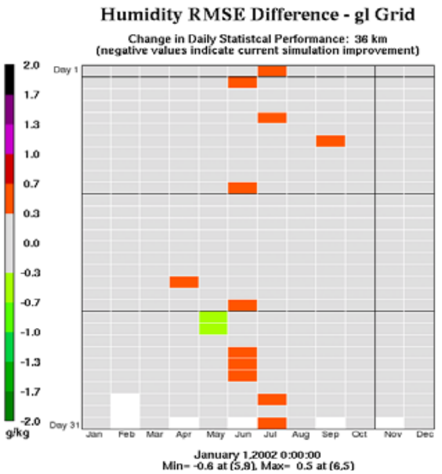
January 1,2002 0:00:00
Min= -1.4 at (4,18), Max= 1.3 at (2,5)

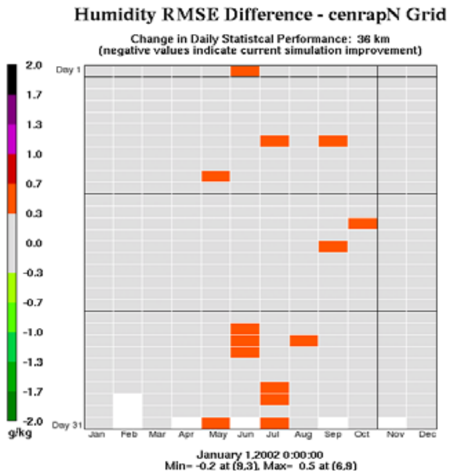
Temperature RMSE Difference - PacificNW Grid

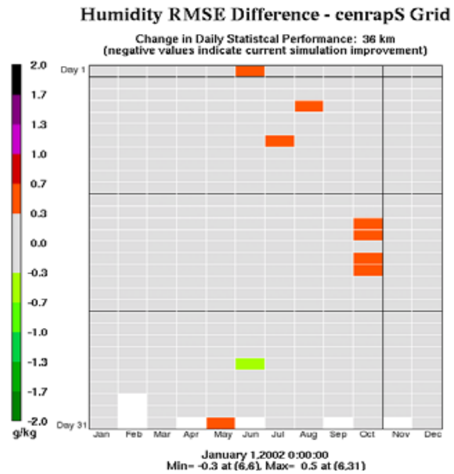
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)

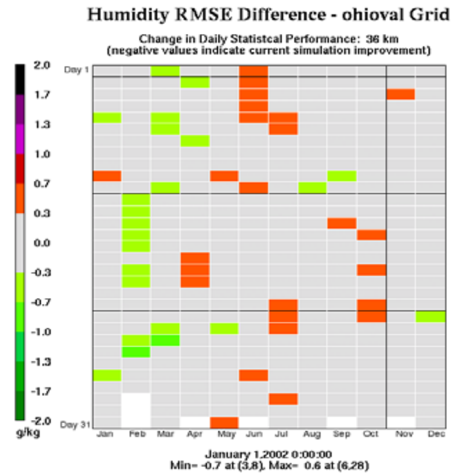


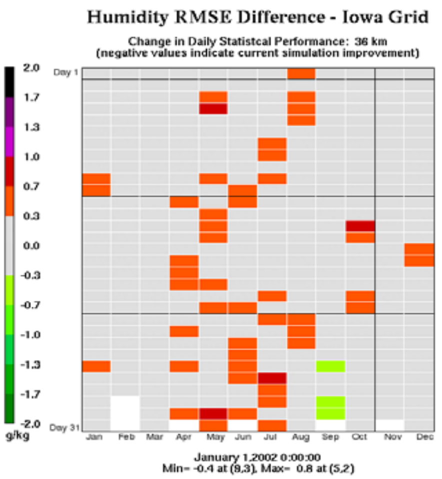
January 1,2002 0:00:00
Min= -0.8 at (2,5), Max= 1.0 at (10,3)

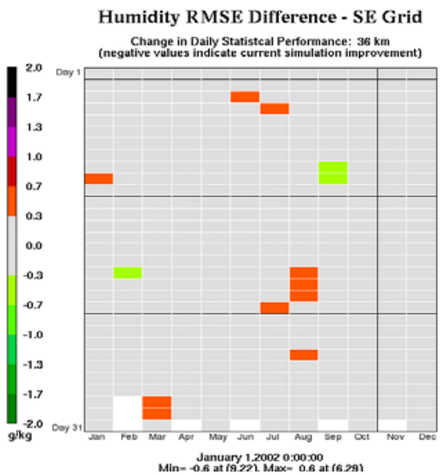

Humidity RMSE Difference - gl Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.6 at (5,8), Max= 0.5 at (6,5)

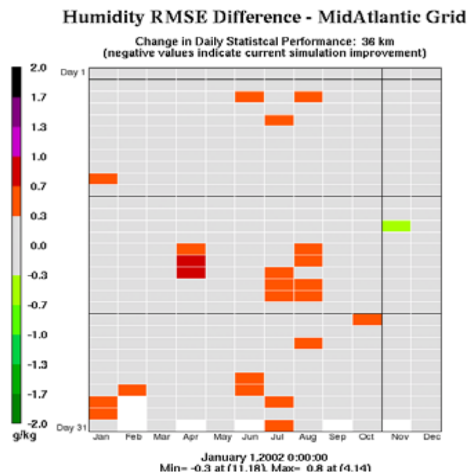

Humidity RMSE Difference - cenrapN Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.2 at (9,3), Max= 0.5 at (6,8)

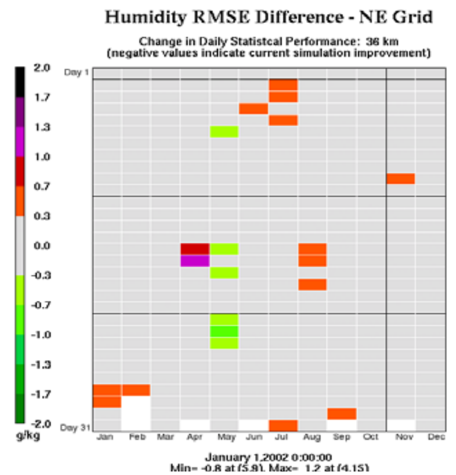

Humidity RMSE Difference - cenrapS Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.3 at (6,6), Max= 0.5 at (6,31)

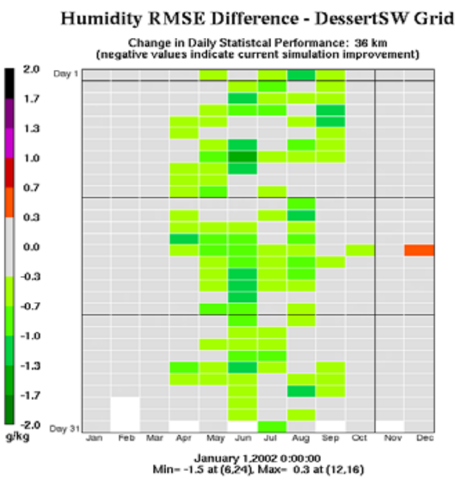

Humidity RMSE Difference - ohioval Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.7 at (3,8), Max= 0.6 at (6,28)

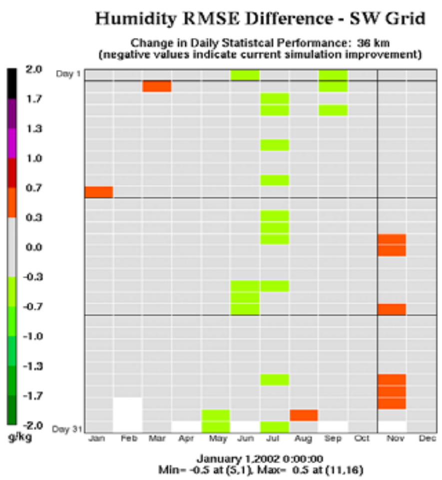

Humidity RMSE Difference - Iowa Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.4 at (8,3), Max= 0.8 at (5,2)

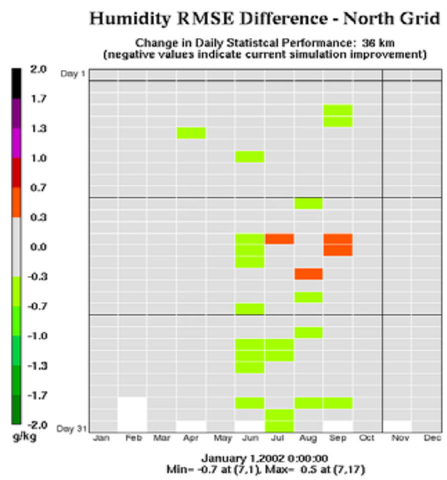

Humidity RMSE Difference - SE Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.6 at (9,22), Max= 0.6 at (6,29)

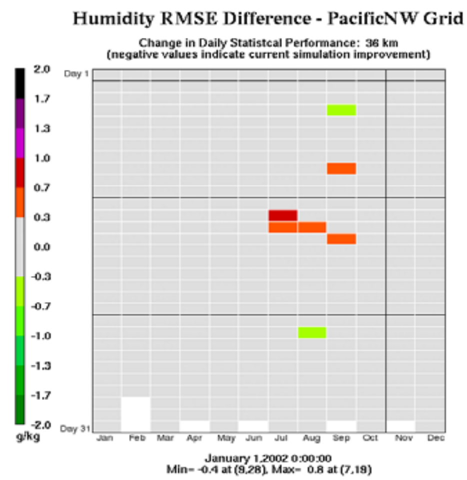

Humidity RMSE Difference - MidAtlantic Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.3 at (11,18), Max= 0.8 at (4,14)


Humidity RMSE Difference - NE Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.8 at (5,8), Max= 1.2 at (4,15)


Humidity RMSE Difference - DessertSW Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -1.5 at (6,24), Max= 0.3 at (12,16)

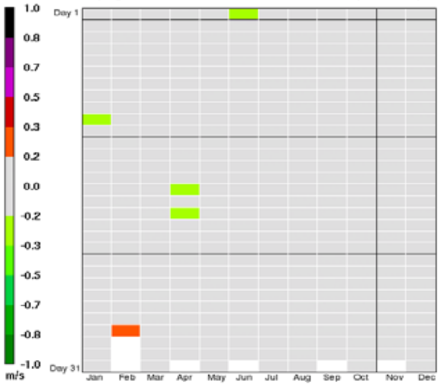

Humidity RMSE Difference - SW Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.5 at (5,1), Max= 0.5 at (11,16)


Humidity RMSE Difference - North Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.7 at (7,1), Max= 0.5 at (7,17)


Humidity RMSE Difference - PacificNW Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -0.4 at (8,28), Max= 0.8 at (7,18)

Wind Spd RMSE Difference - gl Grid

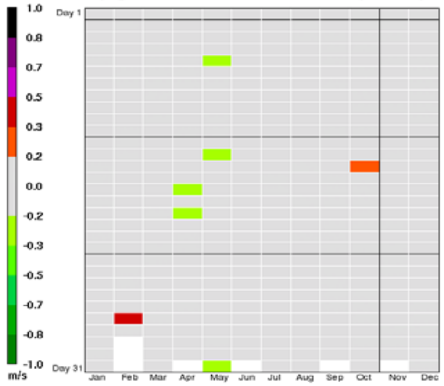
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.3 at (4,16), Max= 0.2 at (2,4)

Wind Spd RMSE Difference - cenrapN Grid

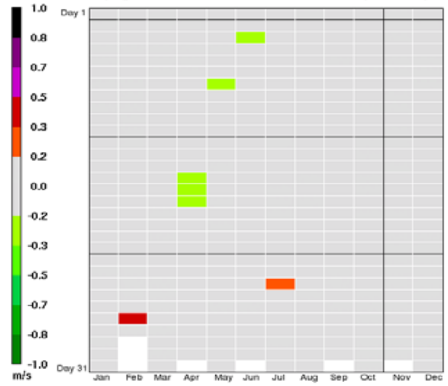
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.2 at (4,16), Max= 0.5 at (2,5)

Wind Spd RMSE Difference - cenrapS Grid

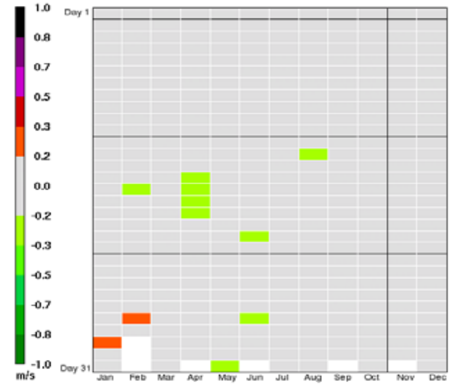
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.2 at (4,16), Max= 0.4 at (2,5)

Wind Spd RMSE Difference - ohioval Grid

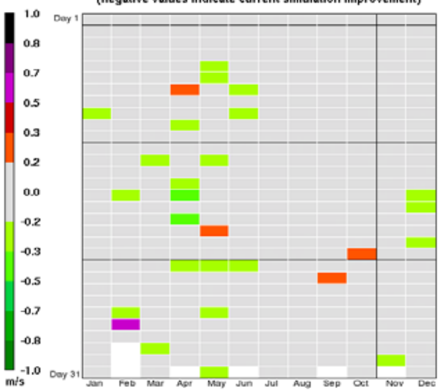
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.3 at (4,16), Max= 0.3 at (2,5)

Wind Spd RMSE Difference - Iowa Grid

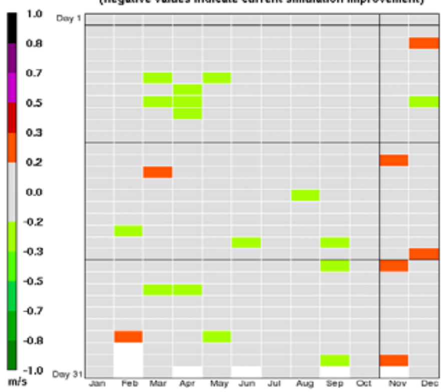
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.5 at (4,16), Max= 0.5 at (2,5)

Wind Spd RMSE Difference - SE Grid

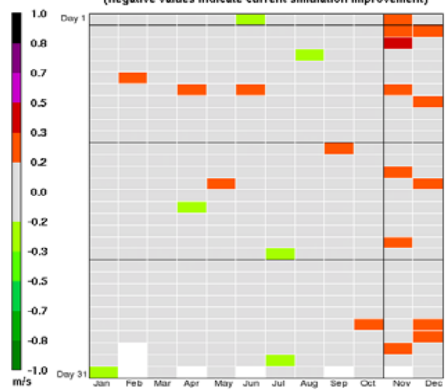
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.3 at (4,8), Max= 0.2 at (12,28)

Wind Spd RMSE Difference - MidAtlantic Grid

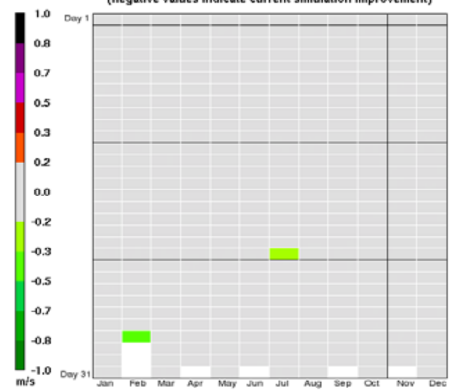
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.3 at (7,2), Max= 0.3 at (11,28)

Wind Spd RMSE Difference - NE Grid

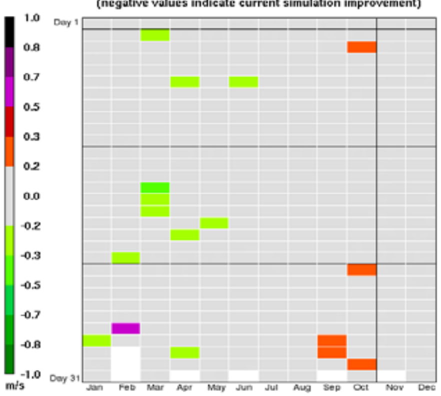
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.4 at (2,4), Max= 0.1 at (6,30)

Wind Spd RMSE Difference - SW Grid

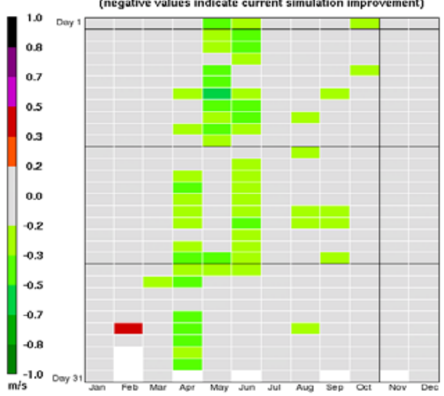
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.4 at (3,17), Max= 0.5 at (2,5)

Wind Spd RMSE Difference - DessertSW Grid

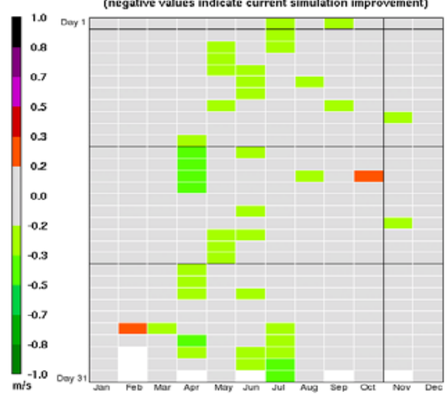
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.5 at (5,25), Max= 0.3 at (2,5)

Wind Spd RMSE Difference - North Grid

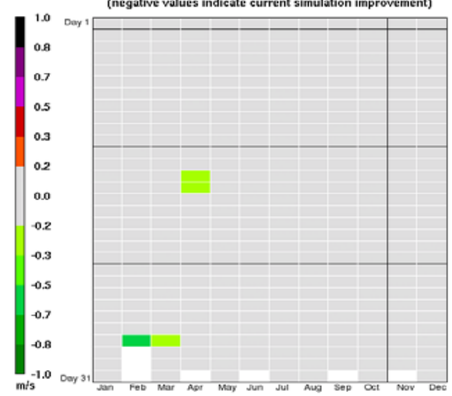
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



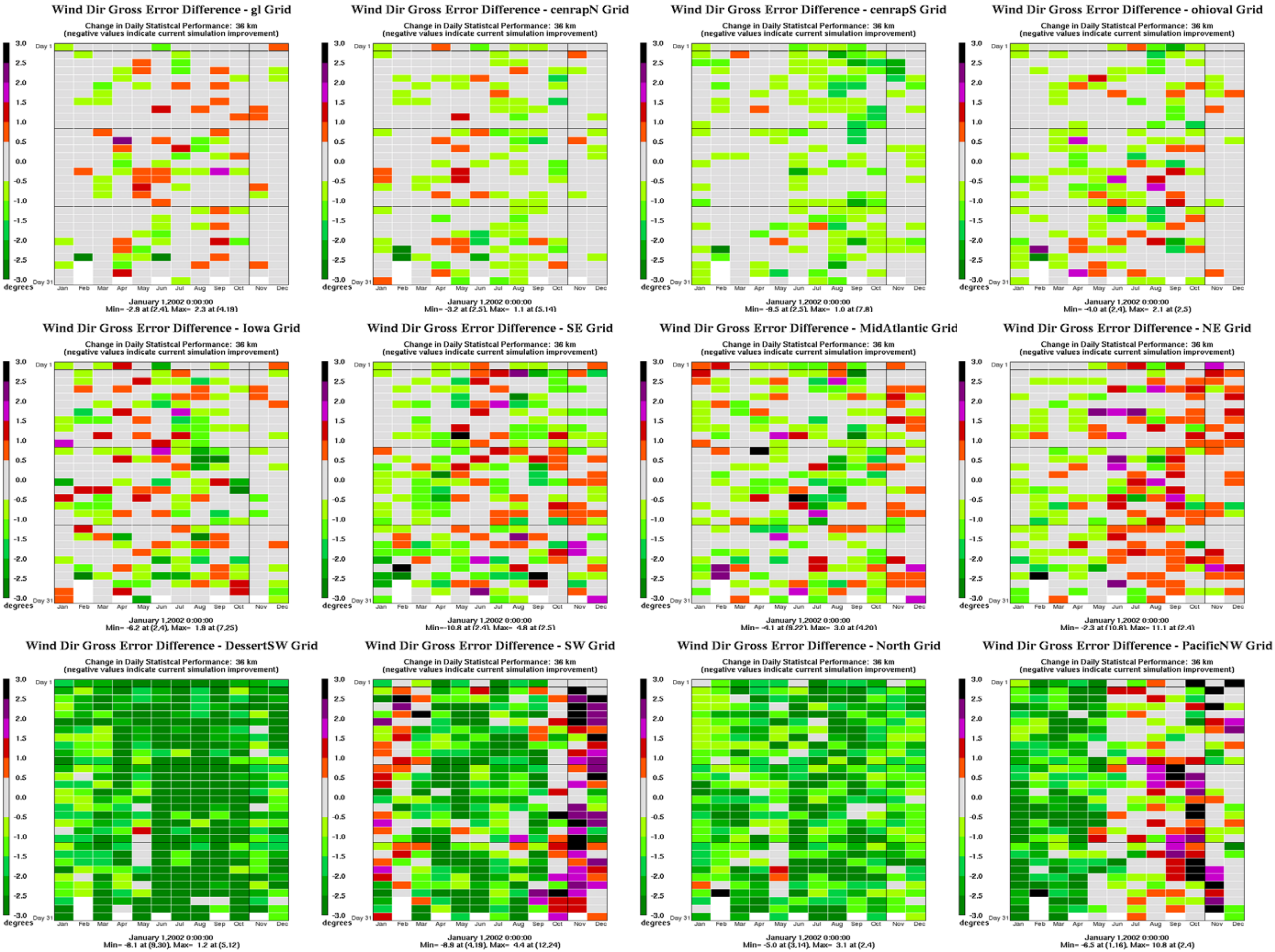
January 1,2002 0:00:00
Min= -0.5 at (4,18), Max= 0.3 at (2,5)

Wind Spd RMSE Difference - PacificNW Grid

Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)



January 1,2002 0:00:00
Min= -0.6 at (2,4), Max= 0.2 at (7,11)


Wind Dir Gross Error Difference - gl Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -2.8 at (2,4), Max= 2.3 at (4,18)
Wind Dir Gross Error Difference - cenrapN Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -3.2 at (2,5), Max= 1.1 at (5,14)
Wind Dir Gross Error Difference - cenrapS Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -8.5 at (2,5), Max= 1.0 at (7,8)
Wind Dir Gross Error Difference - ohioval Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -4.0 at (2,4), Max= 2.1 at (2,5)
Wind Dir Gross Error Difference - Iowa Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -6.2 at (2,4), Max= 1.8 at (7,25)
Wind Dir Gross Error Difference - SE Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min=-10.8 at (2,4), Max= 4.8 at (2,5)
Wind Dir Gross Error Difference - MidAtlantic Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -4.1 at (9,22), Max= 3.0 at (4,20)
Wind Dir Gross Error Difference - NE Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -2.3 at (10,8), Max= 11.1 at (2,4)
Wind Dir Gross Error Difference - DessertSW Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -8.1 at (8,30), Max= 1.2 at (5,12)
Wind Dir Gross Error Difference - SW Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -8.8 at (4,18), Max= 4.4 at (12,24)
Wind Dir Gross Error Difference - North Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -5.0 at (3,14), Max= 3.1 at (2,4)
Wind Dir Gross Error Difference - PacificNW Grid
Change in Daily Statistcal Performance: 36 km
(negative values indicate current simulation improvement)
January 1,2002 0:00:00
Min= -6.5 at (1,16), Max= 10.8 at (2,4)

Meteorological Model Performance Evaluation of an Annual 2002 MM5 (version 3.6.3) Simulation

Matthew T. Johnson
Iowa Department of Natural Resources

2004 - 2007

v2.0.3

Table of Contents

1. INTRODUCTION

1.1 BACKGROUND

Projects pursing PM2.5, 8-hour ozone, and regional haze are generating modeling requirements at spatial and temporal scales only recently confronted within the regulatory air quality community. The scope of recent legislative and executive decisions has created the need to implement sophisticated models developed for regional scale multi-pollutant environments encompassing diverse climatological regimes. Computational limitations have historically bound the modeler's ability to investigate broad and complex scenarios with sufficient resolution. Exponential growth in computational efficiency has partially minimized this hurdle. As scientific theory and model complexity evolve, computational innovations remain moderately offset. Currently, a balance has been achieved which permits the development of large modeling databases such as annual continental scale simulations.

Annual continental scale air quality simulations require the implementation of a triumvirate modeling system composed of meteorological, emissions, and air quality models. Meteorological modeling is the first component addressed as meteorological data supports both the emissions and air quality models. In preparation for regulatory requirements involving regional haze, PM2.5, and ozone, the Iowa Department of Natural Resources (IDNR) developed a continental scale annual meteorological dataset designed for use in air quality applications. This document details the methods employed to create the annual meteorological simulation and provides performance evaluation results.

1.2 MODEL SELECTION

Due to scientific progression, historical application, community support, and availability, the Fifth Generation Penn State University/National Center for Atmospheric Research Mesoscale Model (MM5) was selected for the development of an annual meteorological dataset. Originally formulated in the 1970s at Penn State and first documented by Anthes and Warner (1978), the MM5 modeling system maintains its status as a state-of-the-science[1] model through enhancements provided by a broad user community (*e.g.* Chen and Dudhia, 2001; Dudhia, 1993; Stauffer and Seaman, 1990; Stauffer and Seaman, 1991; Xiu and Pleim, 2000). The MM5 modeling system is routinely employed in operational forecasting frameworks as well as research applications spanning meteorological disciplines from synoptic to mesoscale. Utilization of MM5 within air quality applications is also a conventional practice. The MM5 modeling system was recently selected to generate three continental scale annual simulations: 1996, 2001, and 2002. The 1996 and 2001 simulations were conducted through EPA contracts (Olerud et al., 2000; McNally, 2003). The 2002 simulation was conducted in support of regional haze modeling for the Visibility Improvement – State and Tribal Association of the Southeast (VISTAS) regional planning organization (RPO) (Olerud and Sims, 2004). This list is not exhaustive as both public and private organizations continue to pursue annual meteorological modeling episodes.

Additional information regarding MM5 is available at: http://www.mmm.ucar.edu/mm5/

[1] True during project implementation. MM5 is no longer regularly updated as the focus has shifted to WRF.

2. SENSITIVITY PROJECTS

The MM5 modeling system consists of several pre-processors, the core prognostic model, and post-processing tools. Each component contains highly configurable control files; together they control the aspects of grid structure, first-guess fields, model physics, temporal operation, and ultimately results visualization. The inherit complexity of the MM5 modeling system complicates the development of a sound model configuration suitable for regional scale annual episode air quality applications. Although the complete matrix of configuration options reduces in size as inappropriate options are eliminated, a large matrix of potentially acceptable model configurations remains with most applications. The first step in developing the annual MM5 dataset was therefore completion of a series of sensitivities studies designed to identify the configuration yielding optimum results.

The first sensitivity study project began in 2002 and involved a collaborative project lead by Kirk Baker with the Lake Michigan Air Directors Consortium (LADCO) and Matthew Johnson (IDNR). Wyat Appel and Mike Abraczinskas with the North Carolina Division of Air Quality participated through the generation of a summary analysis for select sensitivity runs. The project was conducted in coordination with sensitivity work performed by Dennis McNally (with Alpine Geophysics). Components evaluated included, for example, PBL schemes, microphysical schemes, convective parameterizations, land surface parameterizations, and snow models. Two one-month long episodes were selected for evaluation, January and July of 2001. The performance evaluation of each sensitivity run included, but was not limited to, temperatures, wind vectors, cloud cover, precipitation, and mixing ratios.

Following the sensitivity study, the IDNR completed a 2002 annual simulation. This simulation utilized surface moisture and temperature nudging. Within implementation of the Pleim-Xiu (PX) land surface model (LSM), soil moisture and soil temperatures were modeled in continuum from one 5-day episode block to the next. The model performance evaluation revealed an extreme cold bias over the Central U.S. While unrelated to the cold bias, utilization of surface nudging techniques was abandoned following discussion with the modeling community, as this practice has lead to the generation of super-adiabatic lapse rates near the surface. The optimum IDNR/LADCO configuration was thus modified accordingly and this annual simulation was deemed unsuitable for use in air quality modeling projects.

In a similar timeframe, VISTAS contracted with Baron Advanced Meteorological Systems, LLC (BAMS) for the development of an annual MM5 dataset (Olerud and Sims, 2004). The work of VISTAS (through Olerud and Sims, 2004) also included a series of sensitivity studies. Independent results from the VISTAS project yielded findings similar to the conclusions reached by IDNR and LADCO. The compilation of all project results subsequently produced the configuration utilized by the IDNR in development of an annual metrological dataset suitable for regional scale air quality modeling.

3. MODELING SYSTEM CONFIGURATION

3.1 OVERVIEW

Version 3.6.3 of the MM5 modeling system was utilized in the second[1] (and final) 2002 IDNR annual meteorological simulation. The 3.6.3 release represented the most current version available at the time of project inception. Other than the necessary configuration parameters, no modeling system code modifications capable of altering results were rendered.

3.1.1 TERRAIN

The terrain processor is used to define grid structure and assign various surface features. Terrain elevation, the dominant landuse category, and vegetative and soil data were assigned using the 2-minute 24-category USGS data. The horizontal grid structure consists of a 36 km domain conforming to the RPO meteorological grid specifications. A nested 12 km grid was also included. The RPO 36 km meteorological domain consists of a Lambert Conic Conformal projection centered at 90º W longitude, 40º N latitude, with true latitudes of 33 and 45º N. The horizontal extent of the RPO domain was engineered according to the bounds of the Eta 212 grid. Domain development involved the implementation of TERRAIN through a series of sensitivity runs designed to extract the largest domain which remains within the borders of the Eta 212 grid. The 12 km grid was designed to achieve a balance between computational resources while maximizing coverage of Iowa-centric upwind and downwind flows. Both grid structures are described in Table 3.1 and depicted in Figure 3.1.

Table 3.1. Grid data, referencing MM5 terminology specifications refer to dot points.

Grid	Resolution (km)	NX	NY	Nest Location (x,y)	Southwest Coordinate (km offset)
1	36	165	129	1,1	(-2952, -2304)
2	12	193	199	66,30	(-612, -1260)

3.1.2 PREGRID/REGRIDDER

The PREGRID processor prepares archived gridded meteorological data for use within MM5 through conversion to an intermediate data format readable by MM5. REGRIDDER invokes a horizontal interpolation scheme to translate data to the MM5 domain. The 3-hour Eta analysis and surface fields (ds609.2) were used to supply initial and boundary conditions to MM5. As the Eta analysis fields obtained from NCAR are a compressed (tar) file, the data were first uncompressed prior to use within PREGRID. The tar files also include the undesirable 12 hourly cold start files. All cold start files (*.tm12) were deleted prior to running PREGRID.

[1] The first simulation was deemed unsuitable for use in air quality modeling projects and has been deleted.

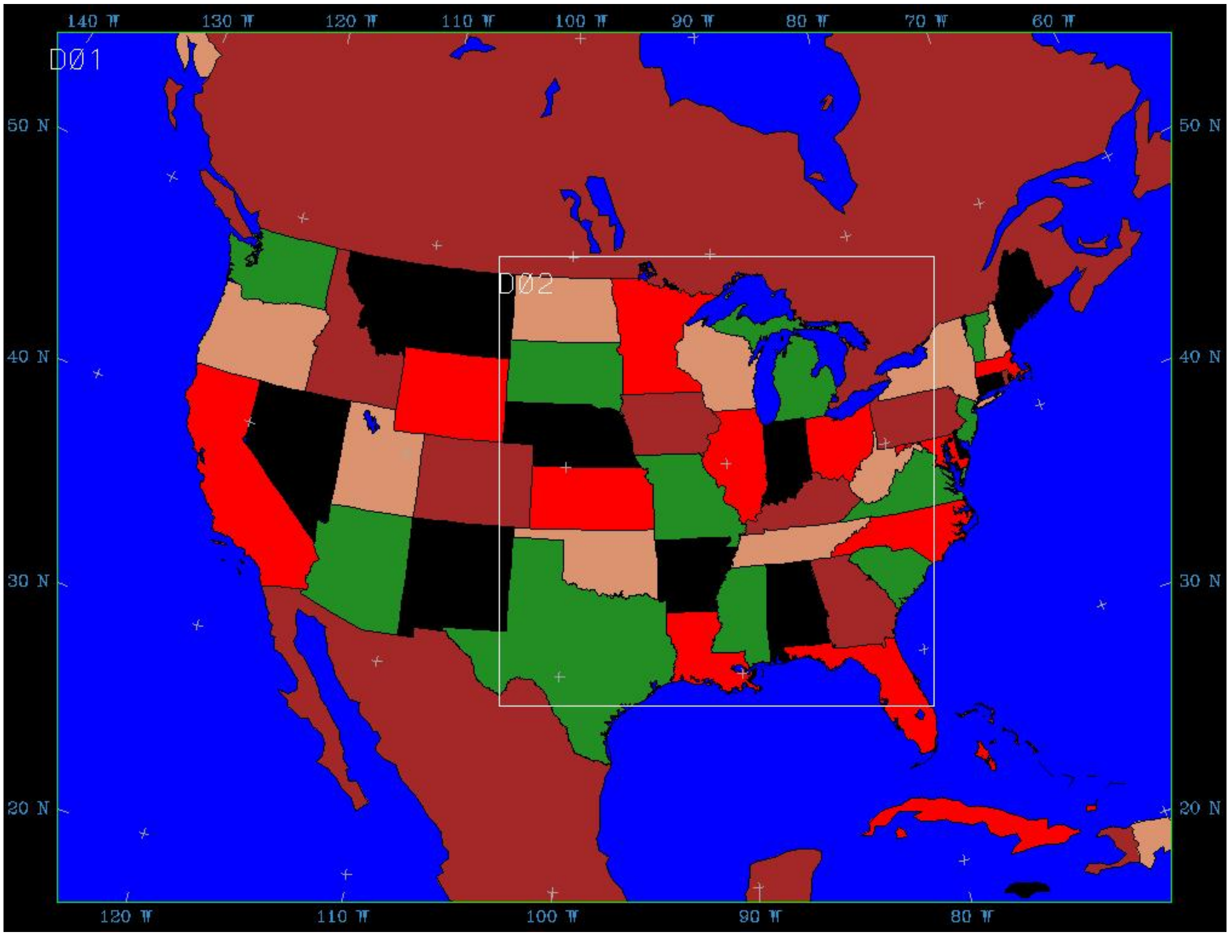


Figure 3.1. Twelve and 36 km domains utilized in the IDNR 2002 MM5v363 annual simulation.

In the first IDNR 2002 MM5 simulation, NCEP data was included in PREGRID to supply time-variant sea-surface temperature (SST) data, as the Eta surface files supply only a time-invariant SST approximation known as skin-temperature. Upon further examination of SST data sources, the temporally variable NCEP SST data was found to lead to unrealistic diurnal temperature profiles over the Great Lakes and near shorelines. Figure 3.2 shows the NCEP-based Great Lakes SSTs for July 4, 2002, at 12 and 18Z. Over this 6-hour span, temperature fluctuations over many areas of the Great Lakes (particularly Lake Erie, and most shorelines) reach 20º F. While some variability is expected along shorelines and other shallow areas, the magnitudes observed through use of the NCEP data are unrealistic. Observed SST data from buoy 45007 (located in the southern end of Lake Michigan yet far removed from the shoreline, see Figure 3.3) for the period July 4 – July 9 are provided in Figure 3.4. The maximum temperature variation throughout July 4 at this site was less than 3º F. Figure 3.5 depicts the 5-day SST timeseries produced using the NCEP SST data within REGRIDDER for the 36 km grid cell corresponding to the location of buoy 45007. The NCEP data yields a diurnal temperature range of approximately 7º F in this cell on July 4. The NCEP data also generates unrealistic diurnal profiles with a net upward trend in SST over this five-day period. In contrast, the observed data show less variability and a downward trend in SST. Utilization of the Eta skin-temperature data produces the constant SST boundary conditions shown in Figure 3.6. The corresponding Eta skin-temperature for the location of buoy 45007 is ~294 K. While this yields warmer surface temperatures than observed throughout the July 4 – July 9 period, no questionable diurnal variability or artificial warming trends are present.

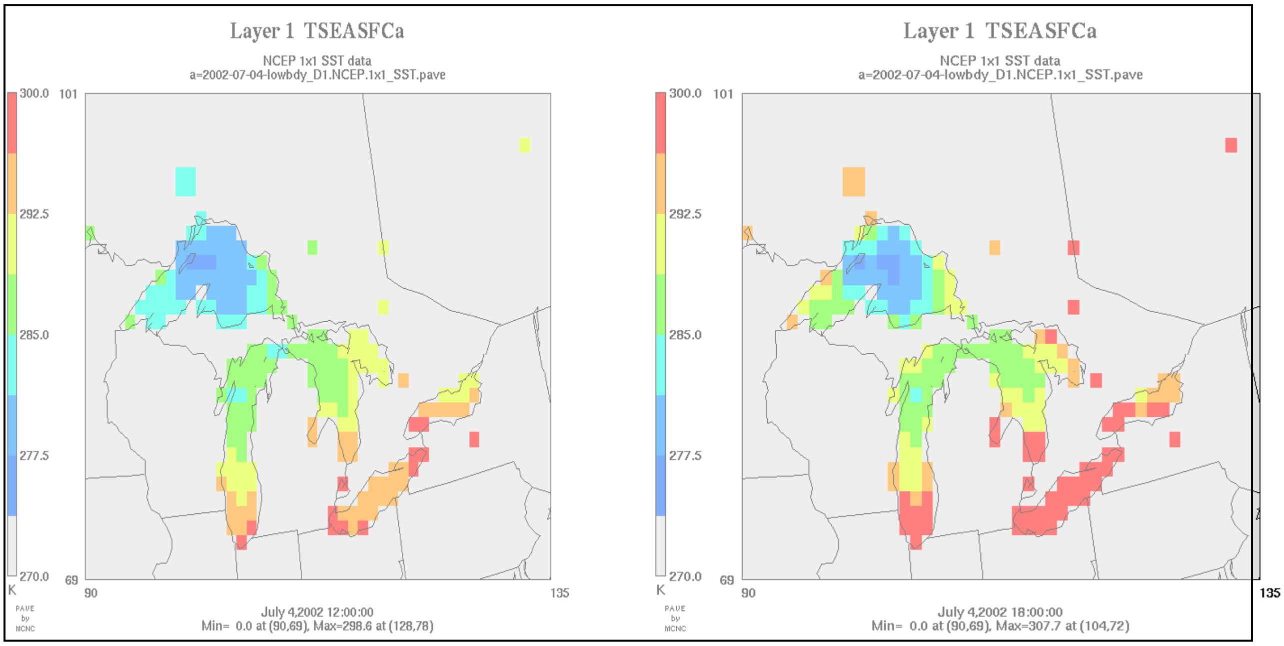


Figure 3.2. Lake temperature variability across a 6 hour span, from 12Z 7/4/2002 to 18Z 7/4/2002, using the NCEP SST data.

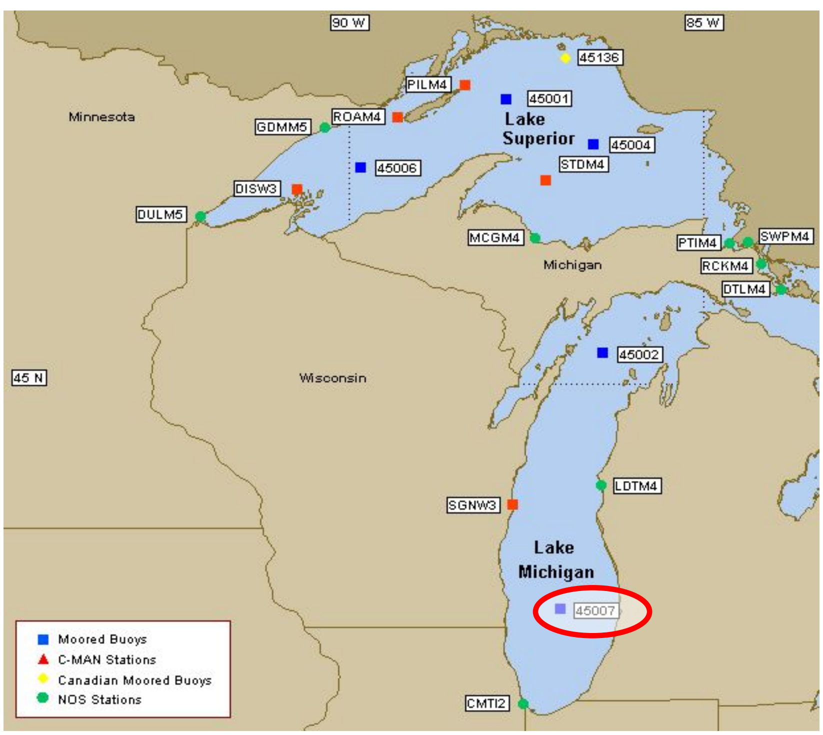


Figure 3.3. Great Lake buoy locations.

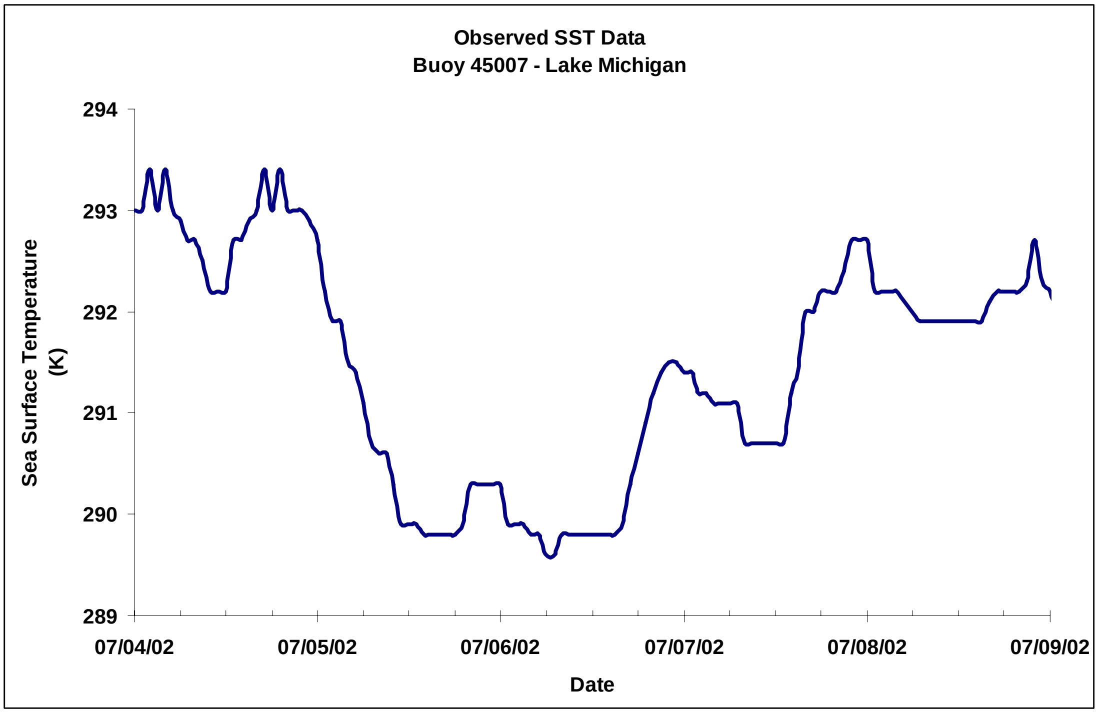


Figure 3.4 Observed SST temperature data for buoy 45007.

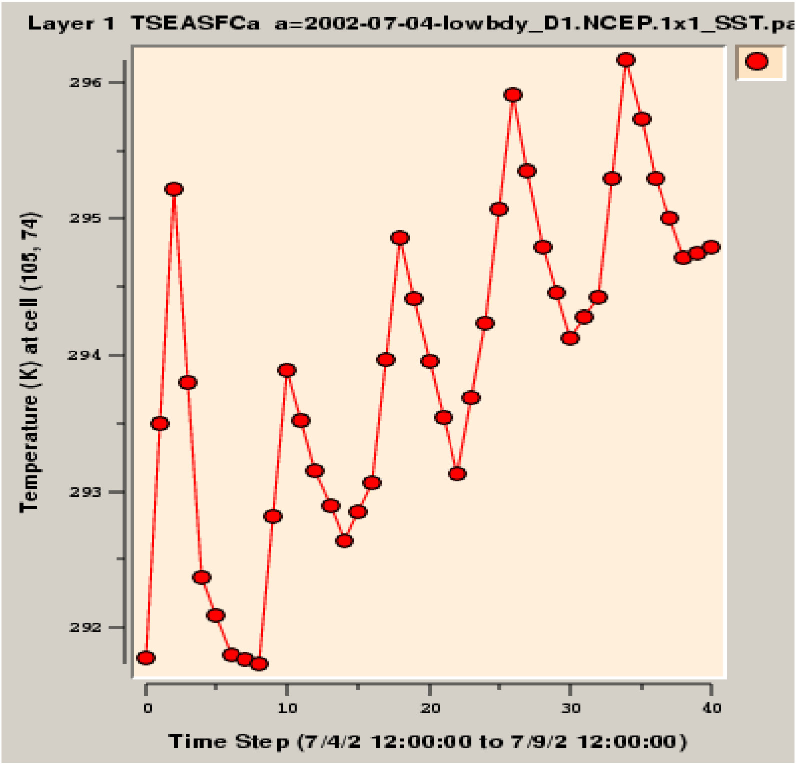


Figure 3.5 NCEP derived SST profile for the grid cell corresponding to the location of buoy 45007.

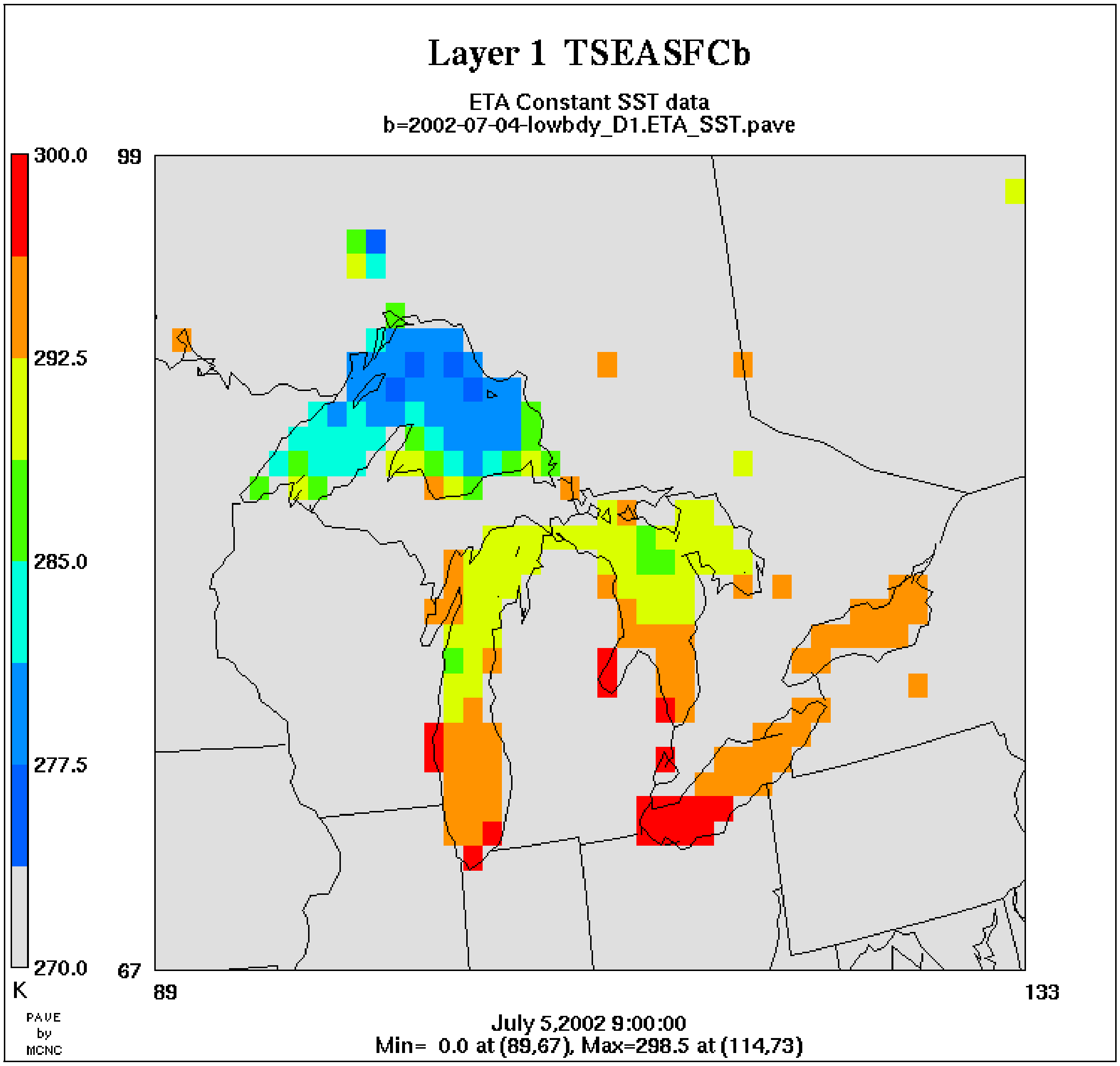


Figure 3.6. Constant SST data derived from Eta skin-temperatures for the period 12Z 7/4/2002 through12Z 7/9/2002.

3.1.3 LIITLE_R

LITTLE_R was originally designed to improve the REGRIDDER output by using objective analysis techniques to blend observational data into the gridded first-guess fields. Following traditional practices, the NWS upper air (ds353.4) and surface (ds464.0) datasets supply the observations. As the Eta fields already contain these NWS datasets, the implementation of LITTLE_R is viewed as partially redundant. However, LITTLE_R also generates the files used in both the four-dimensional data assimilation (FDDA) and Pleim-Xiu soil moisture nudging schemes and therefore must be invoked. The implementation of LITTLE_R does not negatively affect model performance when the Eta surface and analysis data provide the first-guess fields (Baker, 2002).

3.1.4 INTERPF

The IDNR 2002MM5v363 simulation uses a 34 vertical layer structure defined through the INTERPF preprocessor. The layer interfaces, provided in Table 3.2, were designed through coordination with Dennis McNally to parallel the vertical structure in use by EPA. INTERPF interpolates the pressure level data developed in the previous preprocessors to MM5's native vertical system - terrain following sigma coordinates. Sigma levels are defined according to Eq. 3.1, where p_s equals the surface pressure, and p_t equals the pressure at model top. The model top was defined at 100 mb, or approximately 14,662 meters above ground level. Approximate sigma heights are calculated using Eqs. 3.1 – 3.3, with the user-defined variables assigned the following values: p_s = 1000 mb; p_t = 100 mb; T_s = 275 K; A = 50 K. R and g represent the gas and gravitational constants of 287 J/(kg K) and 9.8 m/s^2, respectively.

$$\sigma = \frac{p - p_t}{p_s - p_t} \tag{3.1}$$

$$p = \sigma \cdot \left(p_s - p_t\right) + p_t \tag{3.2}$$

$$z = -\left[\frac{R \cdot A}{2g} \cdot \ln\left(\frac{p}{p_s}\right)^2 + \frac{R \cdot T_s}{g} \ln\left(\frac{p}{p_s}\right)\right] \tag{3.3}$$

Table 3.2. Details of the 34-layer vertical structure.

Level	Sigma	Height (m)	p (mb)	Depth (m)
34	0.000	14662	100	1841
33	0.050	12822	145	1466
32	0.100	11356	190	1228
31	0.150	10127	235	1062
30	0.200	9066	280	939
29	0.250	8127	325	843
28	0.300	7284	370	767
27	0.350	6517	415	704
26	0.400	5812	460	652
25	0.450	5160	505	607
24	0.500	4553	550	569
23	0.550	3984	595	536
22	0.600	3448	640	506
21	0.650	2942	685	480
20	0.700	2462	730	367
19	0.740	2095	766	266
18	0.770	1828	793	259
17	0.800	1569	820	169
16	0.820	1400	838	166
15	0.840	1235	856	163
14	0.860	1071	874	160
13	0.880	911	892	158
12	0.900	753	910	78
11	0.910	675	919	77
10	0.920	598	928	77
9	0.930	521	937	76
8	0.940	445	946	76
7	0.950	369	955	75
6	0.960	294	964	74
5	0.970	220	973	74
4	0.980	146	982	37
3	0.985	109	987	37
2	0.990	73	991	36
1	0.995	36	996	36
0	1.000	0	1000	0

3.2 MM5

An overview of the physics parameterization configuration used in the IDNR 2002MM5v363 simulation is provided in Table 3.3. As previously discussed, the configuration emerges from the cumulative efforts of several sensitivity studies, in combination with guidance from the Ad-Hoc Meteorological Modeling community. In comparison with the original IDNR 2002 simulation, the cessation of continuous soil field techniques within the PX LSM is one of the most notable modifications.[1] With the PX LSM no longer restricted to sequential operation, the annual simulation was generated from 95 independent simulations initialized at 12Z and integrated through five days (versus 5-day blocks arranged in quarterly sequential simulations in the original run). This temporal structure allows maximum air quality modeling flexibility as photochemical simulations can be initialized using midnight local time or midnight GMT without the need to split any given 24-hour period across multiple MM5 simulation blocks. While this methodology does increase the number of runs required to complete an annual simulation (versus initialization at 00Z with a 5.5 day run time), the increased computational requirements are not prohibitive. An example of the temporal structure is provided in Appendix A. To allow for approximately a two week photochemical model spin-up period, the simulation started at 12/16/2001 12Z. The completion date occurred at 12Z on 1/1/2003. A 90 second timestep was used with output written every hour. The output files were split every 24 hours to simplify the post-processing (and photochemical pre-processing) stages.

Table 3.3 Description of the options selected within the IDNR 2002 annual MM5v363 run.

Option	Configuration	Details
Microphysics	Mixed-Phase (Reisner I)	
Cumulus Scheme	Kain-Fritsch 2	
PBL	Asymmetric Convective Model *	Required by Pleim-Xiu LSM
Radiation	RRTM	Calculated every 15 minutes
Land Surface Model	Pleim-Xiu	No continuous soil fields
Shallow Convection	Not enabled	
SST Data source	Eta Skin-Temperature	
Snow Cover Effects	Considered	IFSNOW=1
Timestep	90 seconds	(PX uses an internal 40s timestep)

*The Asymmetric Convective Model (ACM) is also referred to as the Pleim-Chang PBL. The ACM parameterization is a derivative of the Blackadar scheme (Pleim and Chang, 1992).

[1] While discussion of the complete list of configuration variability between the original and 2020MM5v363 simulations is beyond the scope of this document, additional key updates include: the abandonment of NCEP SST data in favor of Eta-Skin temperatures; the addition of the 12 km domain; use of a more recent modeling system release; and a new temporal structure.

Additional configuration details include the following: Sea surface temperatures remained constant during the simulation as Eta skin temperatures were used as surrogate sea surface temperatures. Snow cover effects were considered. Analysis nudging of the temperature, mixing ratio, and wind fields was applied above the PBL. At the surface only the wind field was nudged. The default nudging strengths of 2.5×10^{-4} and 1.0×10^{-4} were used for the temperature and wind fields at 36 and 12 km, respectively. A nudging coefficient of 1.5×10^{-5} was established for the mixing ratios at both 36 and 12 km. The rotational wind field was not nudged, nor were observational nudging techniques applied. Optimal observational nudging methods require a station density not available across a continental scale annual simulation.

Referencing Baker et al. (2004) the following details are provided:

> Vertical moisture and temperature advection are set to use linear interpolation. Other options incorporated include: moist vertical diffusion in clouds, temperature advection using potential temperature, diffusion using perturbation temperature, and an upper radiative boundary condition. The Pleim-Xiu land surface module requires the addition of three variables in the MM5 deck: ISMRD, NUDGE, and IFGROW. ISMRD was set to use soil moisture fields from the ETA analyses. NUDGE was assigned to adjust the soil moisture data to the analyses fields. Finally, IFGROW was set to option 2, which takes vegetative growth into account based on vegetative fraction data from the TERRAIN file.

The configuration of the 12 km grid pictured in Figure 3.1 closely resembles the 36 km grid methodology. The explicit exceptions include a decrease in the wind and temperature nudging strengths. While the terminology is questionable, the nesting technique employed is commonly referred to as “a two-way nested run without feedback”. In this method, the 12 km model solution is not feed back to the master domain, but the grids are run simultaneously to allow the fine grid to receive boundary condition updates at every timestep.

3.3 COMPUTATIONAL SUMMARY

Seven dual CPU Linux workstations were acquired to complete the annual simulation. Six machines were equipped with dual 3.06 GHz Intel Pentium Xeon processors, with the final machine a dual 2.0 GHz processor. Each machine[1] was equipped with 2 Gb of RAM, and Ultra 320 SCSI local hard drives for model I/O. Upon completion of each run, output data was transferred via NFS to a SCSI-IDE RAID array. In summation, 41 wall-clock days were required to complete the annual simulation. This represents each machine computing two independent simulations simultaneously (essentially each CPU was tasked with one simulation at any given time). Open MP was not an available option due to the implementation of PX. Approximately 100 wall-clock hours was required for a 3.06 GHz machine to complete two simulations running simultaneously. Storage requirements reached 1.1 terabytes, with the 36 km simulation occupying 400 Gb and the 12 km data using 700 Gb.

[1] The 2.0 GHz machine had only 1 Gb of onboard RAM.

4. MODEL PERFORMANCE EVALUATION

4.1 BACKGROUND

No rigid guidelines exist for systematically and objectively evaluating the quality of meteorological simulations. However, sound comprehensive philosophies exist. A seven point approach outlined by Tesche (1994) provides the framework for a thorough model performance evaluation. The framework can be classified into two components: an operational evaluation and a scientific evaluation (Emery and Tai, 2001). The scientific evaluation requires rigorous examinations of model formulation and algorithm development, methods beyond the scope of most modeling projects. Historical development and applications of MM5 within the scientific community (including air quality and prognostic projects published through peer-reviewed journal articles) must then serve to support the scientific evaluation. Thus the performance evaluation of the IDNR 2002MM5v363 annual simulation will focus upon operational criteria.

4.2 METHODS

Climatic variability, complex mesoscale meteorological phenomena, and scientific unknowns contribute to meteorological modeling difficulties and force modelers to take a subjective approach to model performance. Objective statistical measures which offer a quantitative model assessment exist, but implementation of the metrics is subjective to a degree. For example, defining the area over which domain averaged metrics are calculated is a subjective decision, buffered only through guidelines. In general, metrics averaged over large meteorological modeling domain are avoided, as error cancellation dilutes relevance. Conversely, splitting the modeling domain into small subdomains renders sample sizes unrepresentative. The logical approach falls well within the bounds of the extremes, leaving optimum subdomain definition open to interpretation. As one means of addressing the issue, a subjective grid decomposition technique was applied, resulting in the twelve rectangular[1] subdomains pictured in Figure 4.1.

Model performance measures must also minimally include a review of upper air features in tandem with surface statistics. Upper air features are key variables in terms of air quality modeling given the importance of fields such as three dimension wind flows and PBL depths. Evaluation of the upper atmosphere also introduces a level of complexity exceeding the difficulty associated with assessing surface features. The sheer volume of upper air model data, in combination with a relatively sparse observing network gathering only twice daily soundings, creates problems in terms of scale. A limited set of data analysis tools also restricts the review process. In an attempt to achieve a balance between available resources and the level of detailed review, the upper air evaluation includes review of PBL features and focuses upon observed versus modeled soundings. To improve the efficiency and simplify the review of soundings, a new software tool was developed in-house: RAOBPLOT. In the final aspect of the upper air evaluation, an independent review of precipitation prediction, conducted by Kirk Baker, is briefly summarized. While technically a surface feature, the precipitation evaluation indirectly enhances the upper air review given the three dimensional nature of precipitation events.

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[1] Processing requirements necessitated that subdomains be simple rectangles defined only through a southwest and northeast grid coordinate.

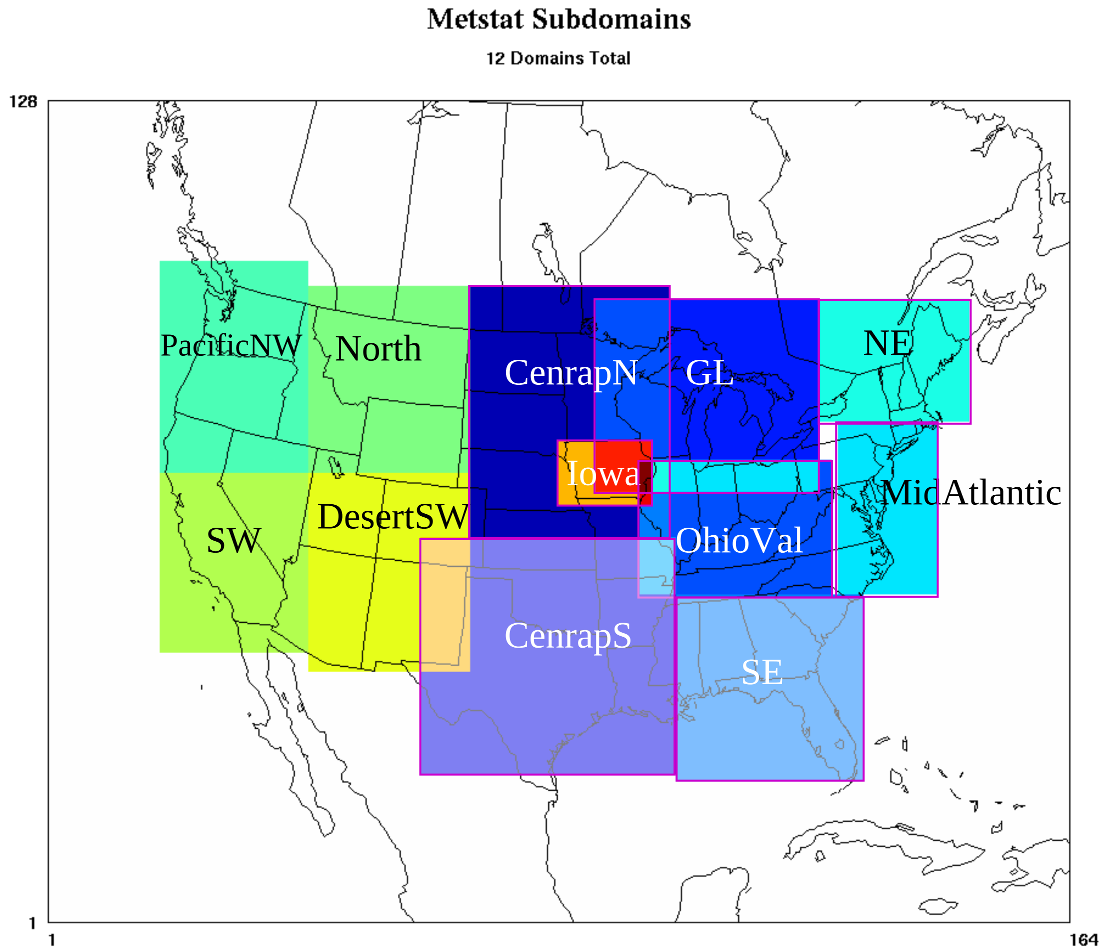


Figure 4.1. Decomposition of the continental scale MM5 domain into simple rectangular subregions designed for targeted model performance evaluation. Areas of overlap are shaded differently and outlines have been added to highlight individual subdomain boundaries.

4.3 STATISTICAL MEASURES

Within the statistical degrees of freedom available to the meteorological modeler, a subset of standard statistical measures has emerged, outlined in Table 4.1. These metrics are calculated based upon data contained within a given subdomain (See Figure 4.1). Metrics are calculated using hourly and daily averages. While no strict criteria establishing acceptable model performance exist, the general guidelines established by Emery and Tai (2001) provide a community adopted frame of reference. A summary of the guidelines is provided in Table 4.2.

Table 4.1. List of statistical measures commonly discussed in meteorological model evaluations. The DH designation represents that both daily and hourly averaged values are calculated for a particular metric. Conversely, D or H indicates that the value is available only on a daily or hourly average, respectively.

Statistical Measure	Wind Speed	Wind Direction	Temperature	Humidity
Obs. vs Predicted Timeline	DH	DH	DH	DH
Bias	DH	DH	DH	DH
Gross Error	D	D	D	D
Total RMSE	DH		DH	DH
Systematic RMSE	DH		DH	DH
Unsystematic RMSE	DH		DH	DH
Index of Agreement	DH		DH	DH

Table 4.2. Guidelines for meteorological model performance. Source: ***Meteorological Modeling and Performance Evaluation of the September 13-20, 1999 Ozone Episode*** *(Emery and Tai, 2001). Data pertain to daily averaged values.*

Wind Speed			Wind Direction			Temperature			Humidity		
RMSE	≤	2 m/s	Gross Error	≤	30 deg	Gross Error	≤	2 K	Gross Error	≤	2 g/kg
Mean Bias	≤	±0.5 m/s	Mean Bias	≤±	10 deg	Mean Bias	≤	±0.5 K	Mean Bias	≤	±1 g/kg
IOA	≥	0.6				IOA	≥	0.8	IOA	≥	0.6

An overview of the significance for each metric is provided by Baker et al. (2004):

> "*Bias error* (bias) is the degree of correspondence between the mean prediction and the mean observation, with lower numbers indicative of better performance. Values less than 0 indicate under-prediction. The *gross error*, or mean absolute error, is the mean of the absolute value of the residuals from a fitted statistical model. Lower numbers indicate better model performance.
>
> *Root Mean Square Error* (RMSE) is a good overall measure of model performance. The weighting of (prediction-observation) by its square tends to inflate RMSE, particularly when extreme values are present. With respect to a good model the root mean square error should approach zero. RMSE can be divided into a systematic and unsystematic component by least-squares regression. Since differences described by systematic RMSE can be described by a linear function, they should be relatively easy to dampen by a new parameterization of the model. Unsystematic RMSE can be interpreted as a measure of potential accuracy or noise level (Emery et al., 2001). With respect to a good model the systematic difference should approach zero while the unsystematic difference approaches RMSE.

> *Index of Agreement* is a relative measure of the degree of which predictions are error-free. The denominator accounts for the model's deviation from the mean of the observations as well as to the observations deviation from their mean. It does not provide information regarding systematic and unsystematic errors. The index of agreement approaches one when model performance is best."

The basis of the statistical analysis if formed through a comparison of the modeled fields with the Techniques Data Laboratory U.S. and Canada surface hourly observations (ds472.0). Hourly and daily averaged bias, error, RMSE (total, systematic, and unsystematic), and index of agreement metrics for wind speed, wind direction, temperature and humidity were generated using the Metstat program and MS Excel post-processing macro developed by Environ. Time series of modeled and observed conditions were also prepared via Metstat. As continental-scale domain averaged statistical measures are susceptible to error cancellation, metrics were calculated over the twelve subdomains illustrated in Fig. 4.1.

The volume of data associated with the annual simulation can quickly overwhelm standard time series displays or similar attempts at numerical data presentation. As a solution Kirk Baker developed and ingenious method of data display. PAVE is used to plot daily metrics, aligned vertically by month, and horizontally by date. This allows for an annual graphical display of daily averaged metrics in a single plot, simplifying the identification of error trends or pervasive biases. Even with this method of simplification, a detailed discussion of all twelve subdomains becomes excessive. The statistical analysis therefore focuses upon those regions encompassing the CENRAP and Midwest RPO states, primarily the regions: CenrapN, CenrapS, GL (Great Lakes), OhioVal (Ohio Valley), and Iowa.

5. SURFACE EVALUATION (36 KM)

The daily averaged metrics described below are provided graphically in the form of a "Bakergram". The Bakergram, developed by Kirk Baker, allows for the meaningful depiction of an annual set of daily averaged statistical values in a single plot. For example, Figure 5.1 consists of a compilation of four Bakergrams, one each for the wind speed bias, wind speed error, wind direction bias, and wind direction error. Focusing on the wind speed bias Bakergram in Figure 5.1 (top left), 365 daily averaged metrics are provided. Twelve columns are provided, which each column containing a monthly dataset. The individual days are provided in rows, with the first of the month displayed at the top, with days descending from top to bottom. The concept is repeated (for example, see Figure 5.2) with temperature and mixing ratio metrics plotted.

5.1 GREAT LAKES

In previous sensitivity studies, the Pleim-Chang/Pleim-Xiu PBL/LSM configuration was found to improve wind vector performance versus the use of alterative PBL parameterizations. Consistent with this discovery, the wind vector performance in the GL region is encouraging. Wind speed metrics are generally favorable, and no clear trends in error or bias are evident (see Figure 5.1). A notable caveat, daily metrics may hide inconsistencies occurring within the diurnal profile.[1] Turning to the wind direction evaluation, again results are satisfactory, with one exception found, an increase in the summertime gross error.

In the Great Lakes region, the problems of greatest concern lie in the wintertime cold temperature biases, the warm summertime biases, and the summertime positive moisture biases (See Figure 5.2). Examining the temperature biases from a diurnal[2] perspective, the warm bias is predominantly caused by nighttime temperatures remaining warmer than observed. The cold wintertime temperature bias is often traced to underpredicted high temperatures, evening temperatures falling too rapidly, and nighttime lows often colder than observed. Caution should be exercised when generalizing the wintertime bias trends though, as exceptions are more abundant than with the summertime warm biases. Turning to the mixing ratio (humidity) evaluation (see Figure 5.2), although the gross error metrics are generally within the statistical guidelines, the summertime positive bias is a concerning trend. Only on rare occasions do negative biases occur. The likely culprit is MM5's tendency to overpredict precipitation.

5.2 NORTHERN AND SOUTHERN CENRAP

In general, the statistical evaluation for the CenrapN subdomain (Figures 5.3 - 5.4) yields results similar to the Great Lakes region. A notable exception being the nearly consistently negatively biased wind speeds. Examining the wind speed bias in greater detail (through diurnal profiles), this fault is predominantly influenced by the underprediction in the daily peak wind speeds. Keeping these errors in perspective, the magnitude of the underprediction typically remains below 1 m/s. Examining the mixing ratio performance, the most serious issue remains the abundance of summertime surface moisture. While arguable trivial, CenrapN does differ from the GL subdomain during May, where several surface moisture underpredictions occur.

[1] Diurnal metrics are examined in Chapter 6.
[2] Ibid.

Turning to the Southern CENRAP subdomain (Figures 5.5 - 5.6), wind direction performance remains encouraging, similar to the performance for the CenrapN and GL regions. As found in CenrapN, wind speeds are generally negatively biased, but more pronounced in this region. The mixing ratio biases reveal excess moisture, although a drier than observed fall was predicted. Examining temperature performance, late winter/early spring temperatures yielded positively biased trends, in contrast to the pervasive cold winter biases found in the CenrapN and GL regions. Examination of the diurnal profiles revealed the biases were attributable to warm nighttime lows.

5.3 OHIO VALLEY

Once again, the wind speeds are generally too low, however, the associated error is well within the acceptable guidelines. Wind directions errors are also generally small, but an increase in error is found in the summer months. Mixing ratios are consistently too moist, except in the mid-October timeframe. As in the Great Lakes regions, a cold winter bias is found, while summer temperatures remain too warm (predominantly over the nighttime hours). The results are depicted in Figures 5.7 - 5.8.

5.4 IOWA

Within the Iowa subdomain wind vector performance is favorable, with wind speed bias and error measures predominantly meeting the statistical goals. Wind directions exhibit greater errors in the late summer/early fall timeframe versus the CenrapN and GL subdomains, but are not cause for severe alarm (see Figure 5.9). As is common, cold winter and warm summer biases are present (Figure 5.10). In terms of the moisture bias, the Iowa domain exhibits greater springtime negative moisture bias versus CenrapN, otherwise similar performance is shown (this result is not unexpected, given the superposition of the Iowa subdomain over CenrapN).

5.5 EASTERN REGIONS

A detailed discussion of model performance for all areas is beyond the scope of this document. Alternatively, summary remarks are provided. Over the MidAtlantic, no serious abnormalities are found beyond the errors identified previously in Central U.S. subdomains. As is common to MM5, a positive moisture bias exists, affecting both the MidAtlantic and SE regions. Examining the NE region, wind speed, and wind direction errors approach the upper extreme of acceptable performance. Again, the moisture bias is positively biased, with errors maximized over the summer months. Given moisture carrying capacity is a non-linear function of temperature, the relatively small mixing ratio gross errors occurring in the wintertime of regions with colder climates should not be interpreted as superior model performance. The daily averaged statistical results are provided in Appendix B for each of the individual Eastern subregions.

5.6 WESTERN REGIONS

The daily averaged statistical results for the western subdomains are also provided in Appendix B. The complex topography found in the Western United States clearly introduces a degree of modeling difficulty not found in other regions. Performance metrics are discouraging when viewed initially, however, the appropriateness of the statistical measures are questionable as model resolution is not designed to capture the topographically induced near-field flows affecting many of the local observations.

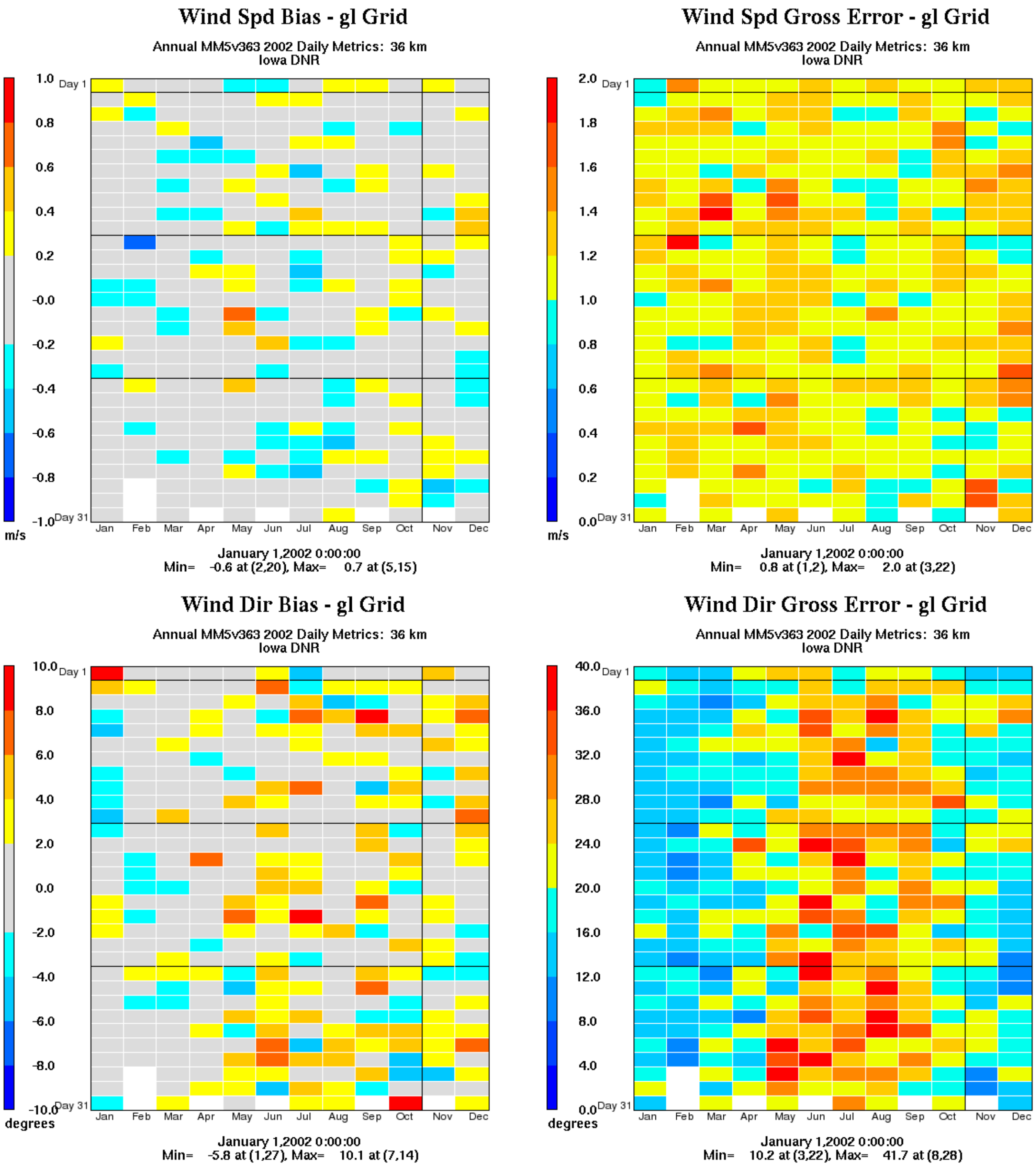


Figure 5.1. Daily averaged wind speed/direction metrics for the Great Lakes (GL) subdomain.

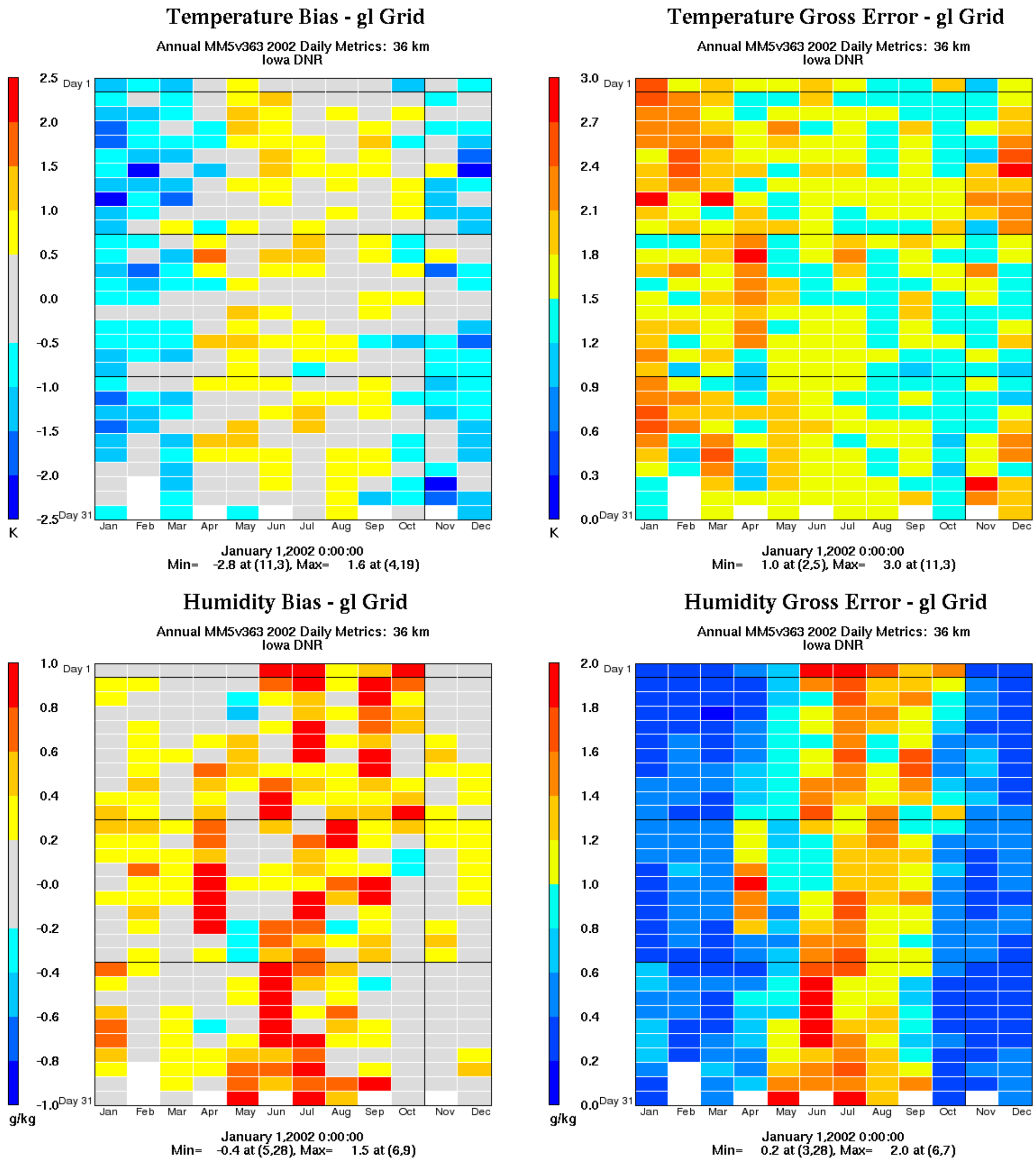


Figure 5.2. Daily averaged temperature and mixing ratio metrics for the Great Lakes (GL) subdomain.

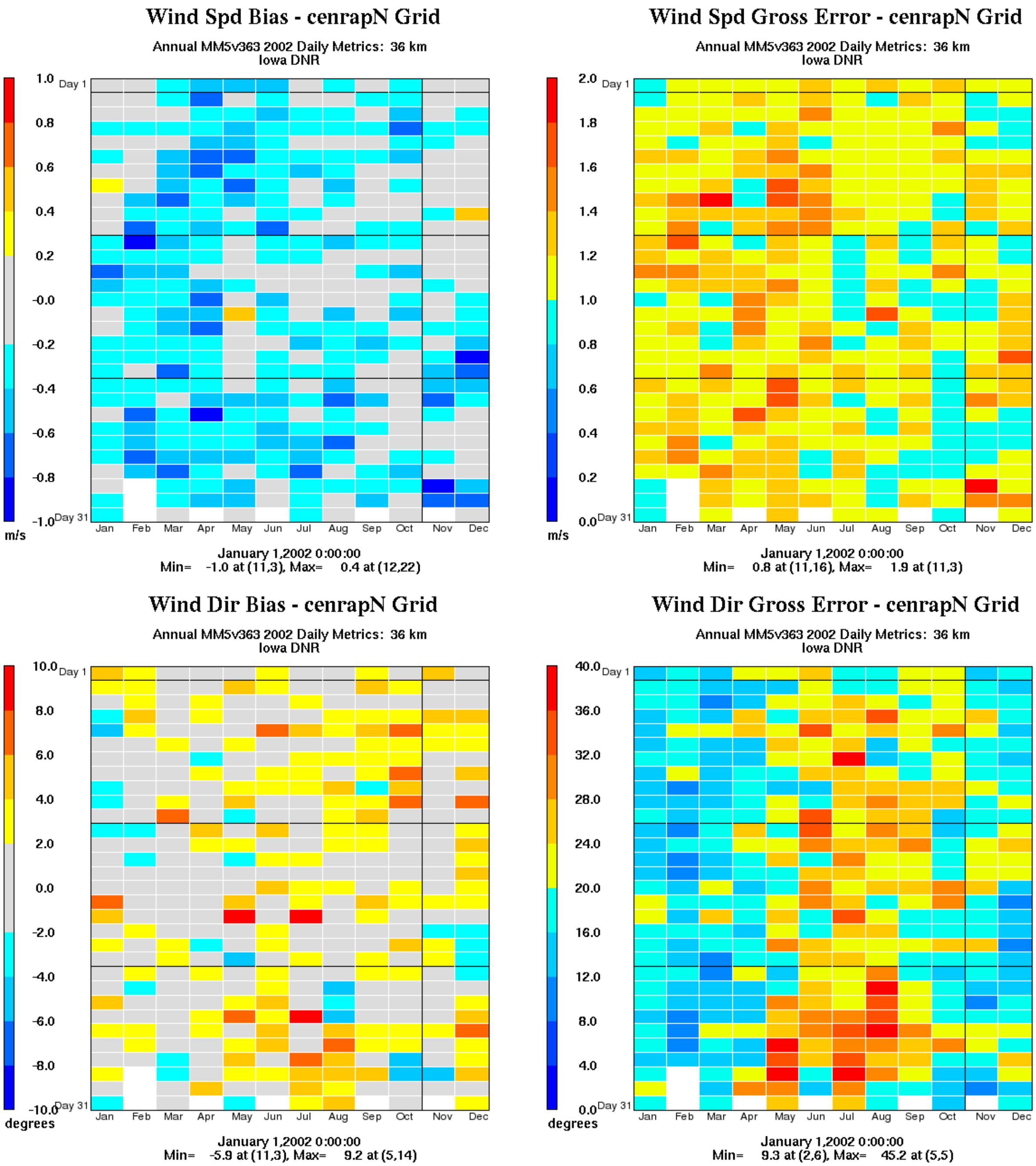


Figure 5.3. Daily averaged wind speed/direction metrics for the CenrapN subdomain.

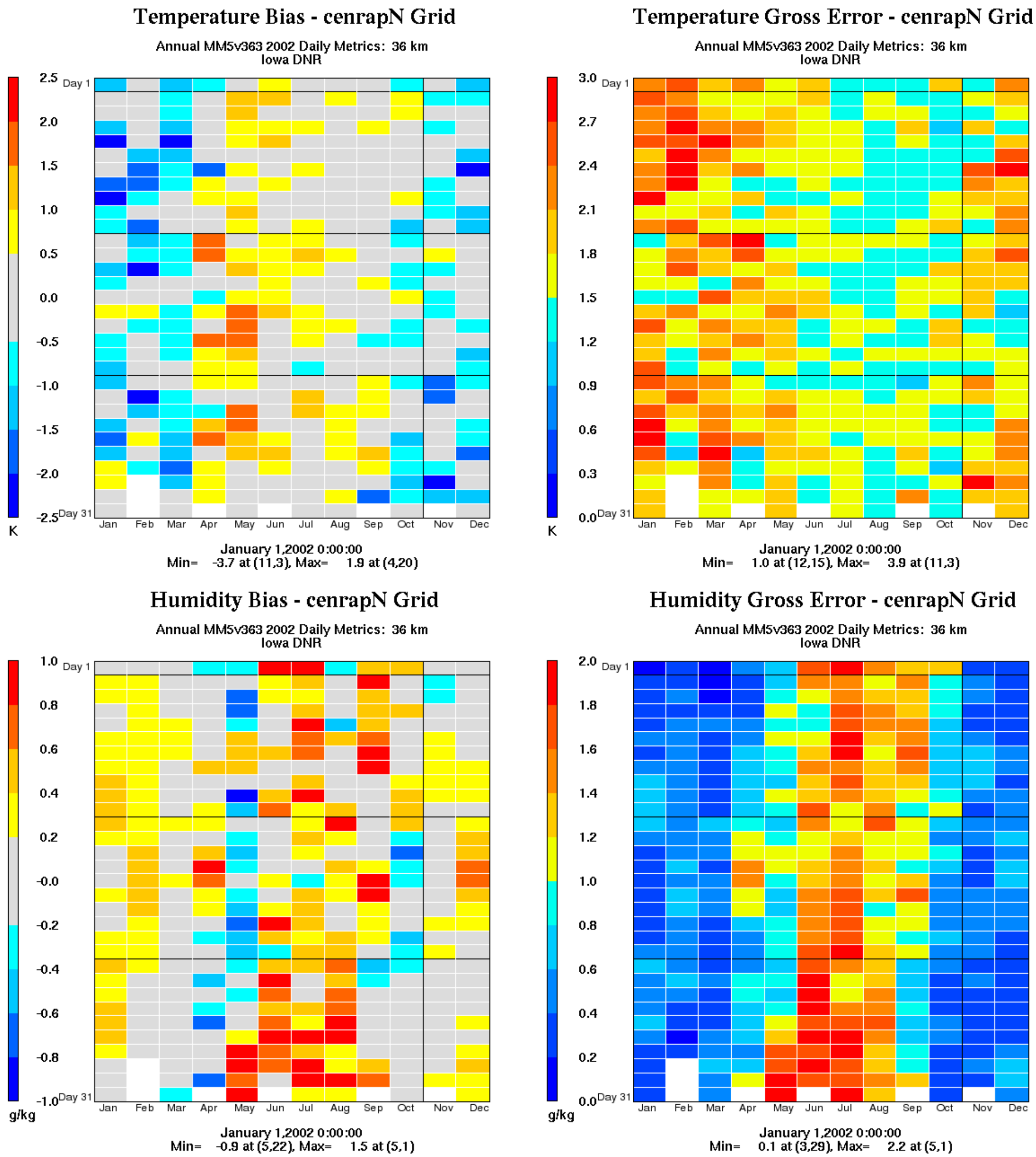


Figure 5.4. Daily averaged temperature and mixing ratio metrics for the CenrapN subdomain.

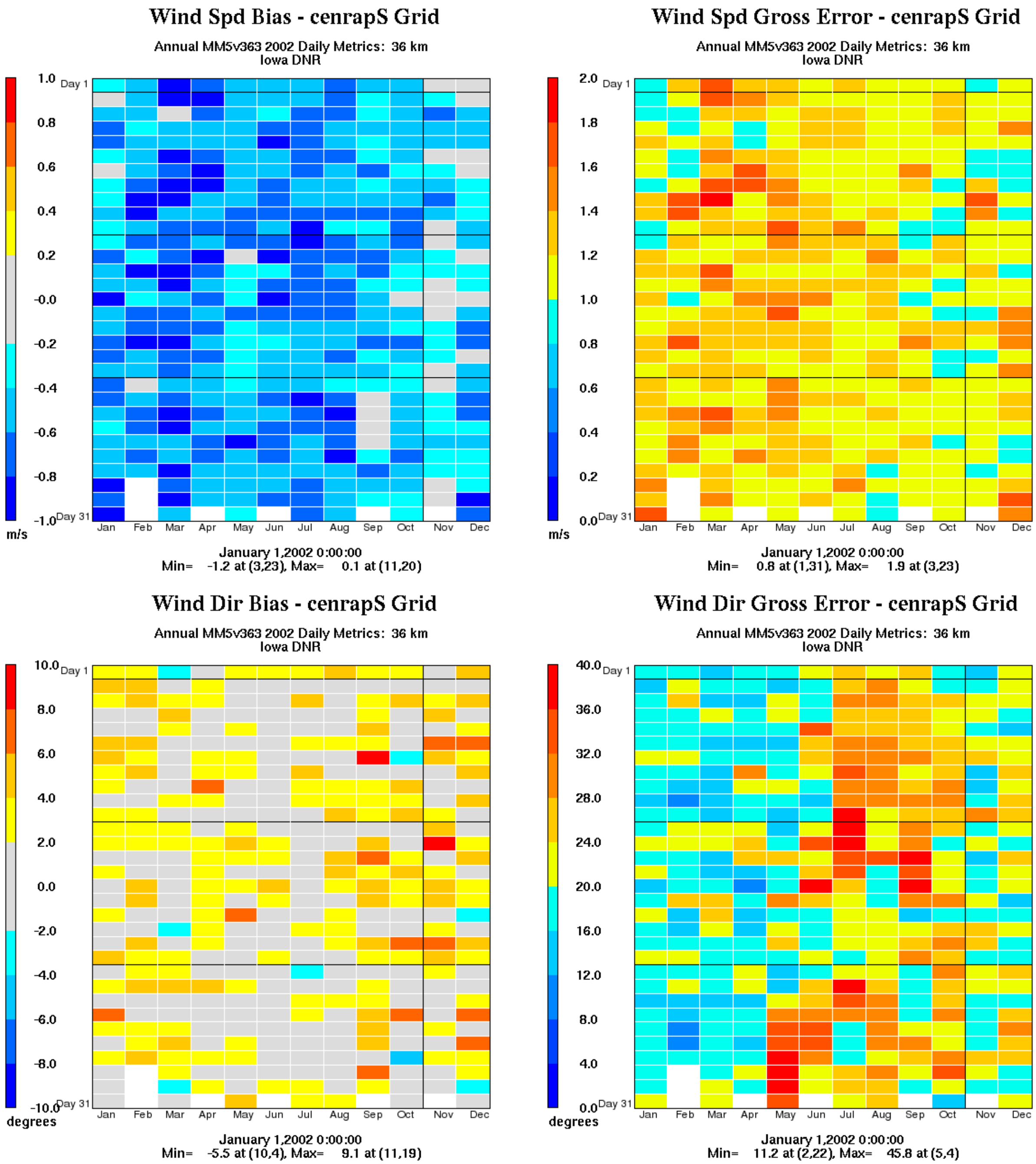


Figure 5.5. Daily averaged wind speed/direction metrics for the CenrapS subdomain

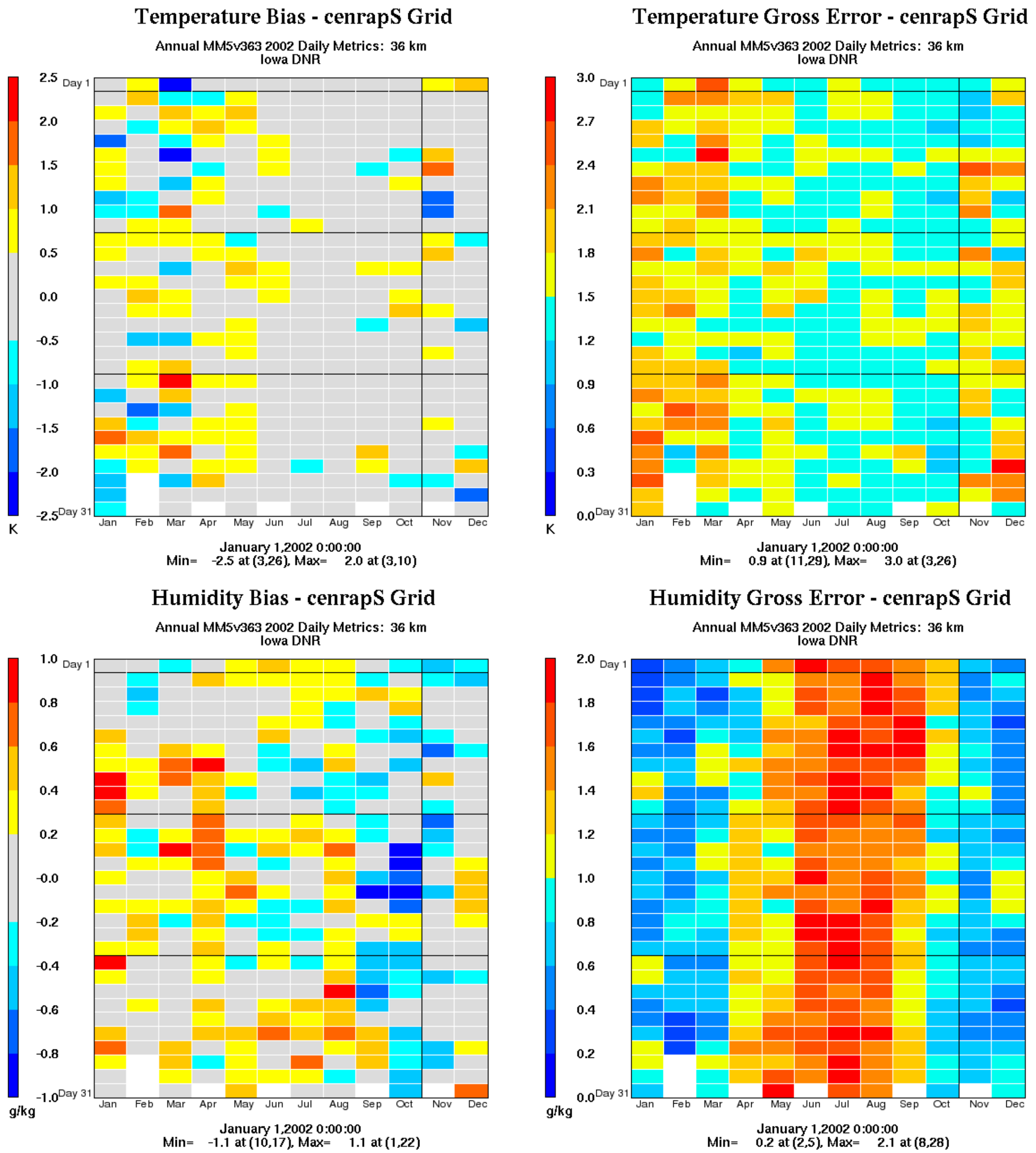


Figure 5.6. Daily averaged temperature and mixing ratio metrics for the CenrapS subdomain.

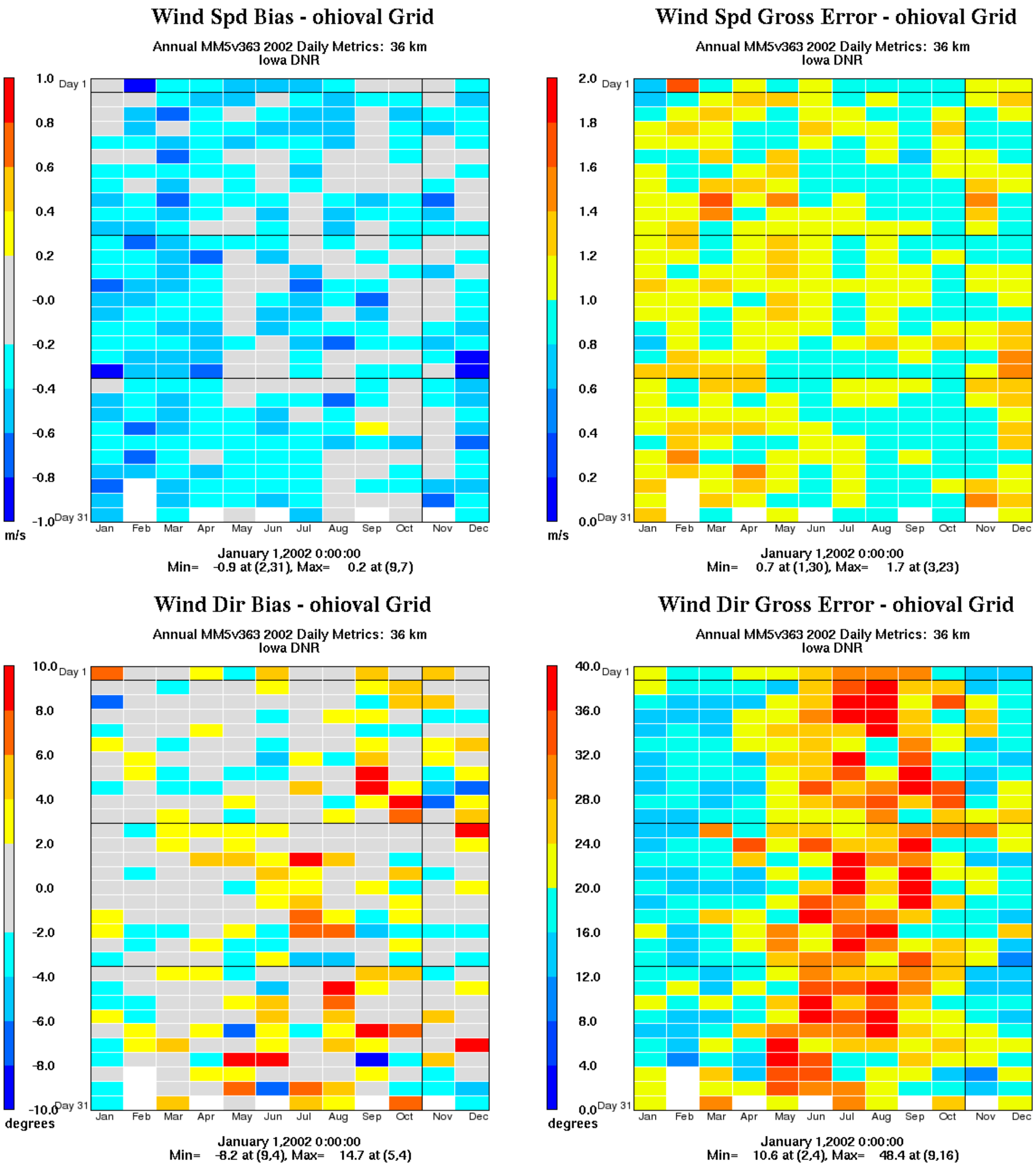


Figure 5.7. Daily averaged wind speed/direction metrics for the OhioVal subdomain.

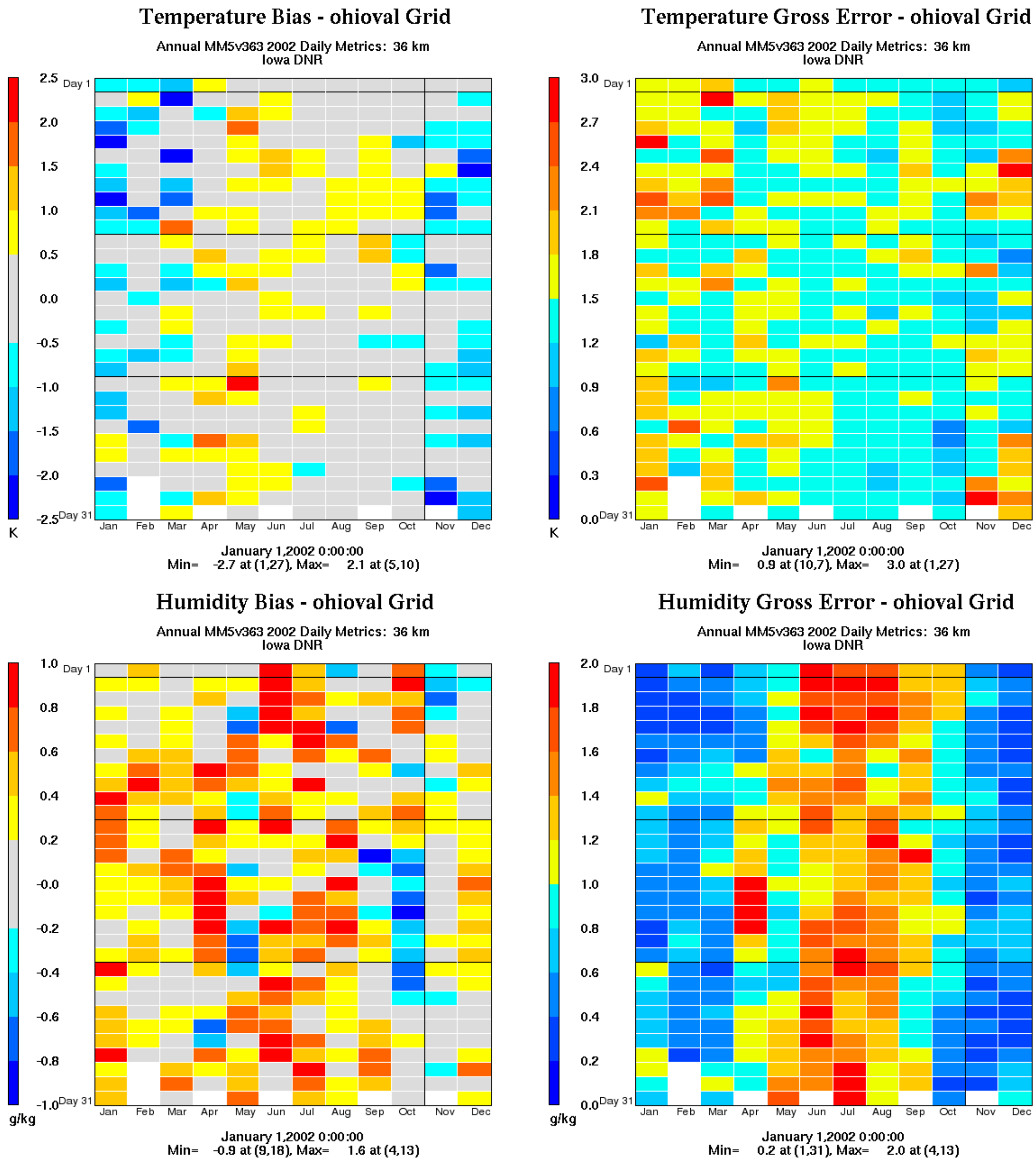


Figure 5.8. Daily averaged temperature and mixing ratio metrics for the OhioVal subdomain.

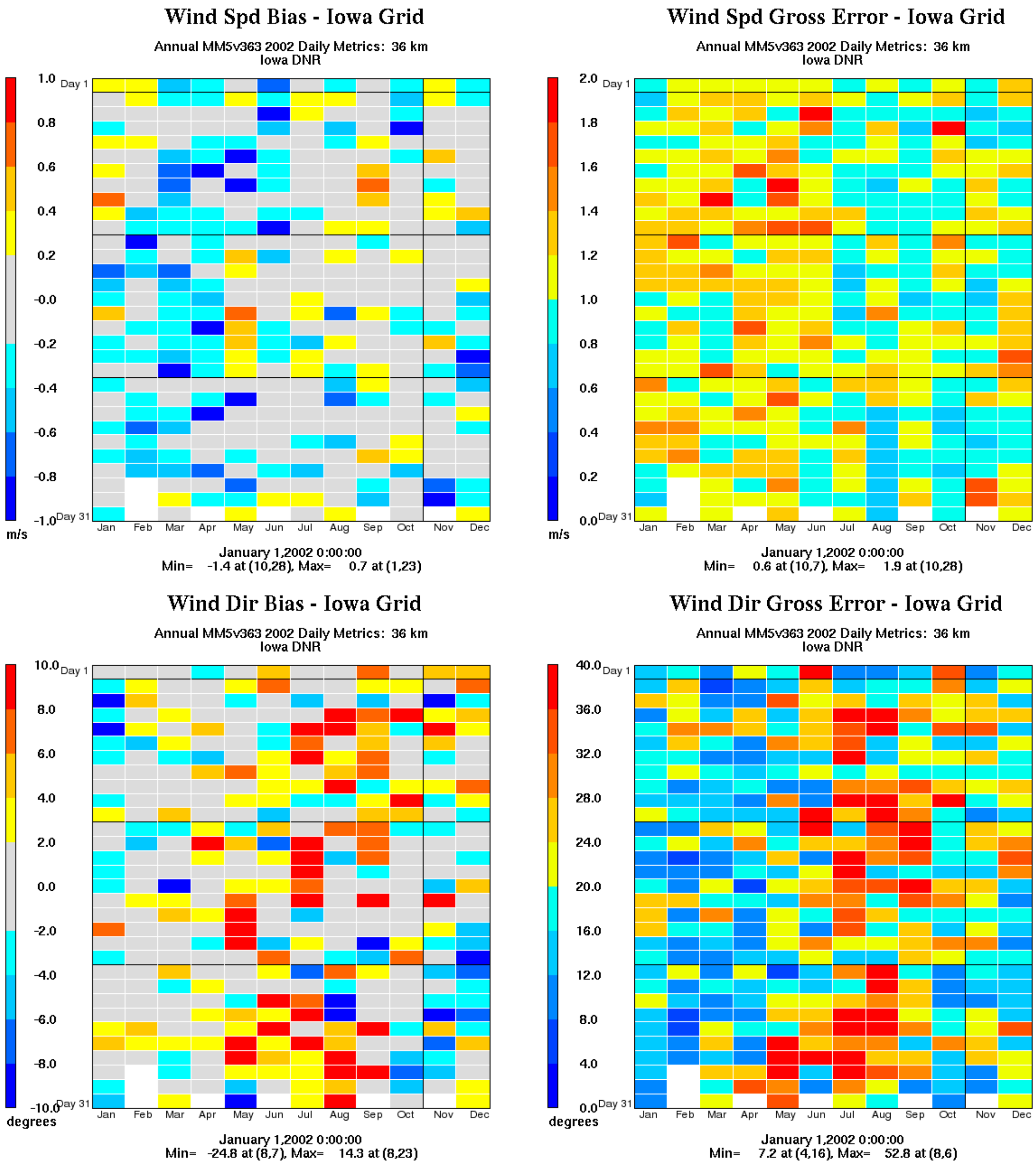


Figure 5.9. Daily averaged wind speed/direction metrics for the Iowa subdomain.

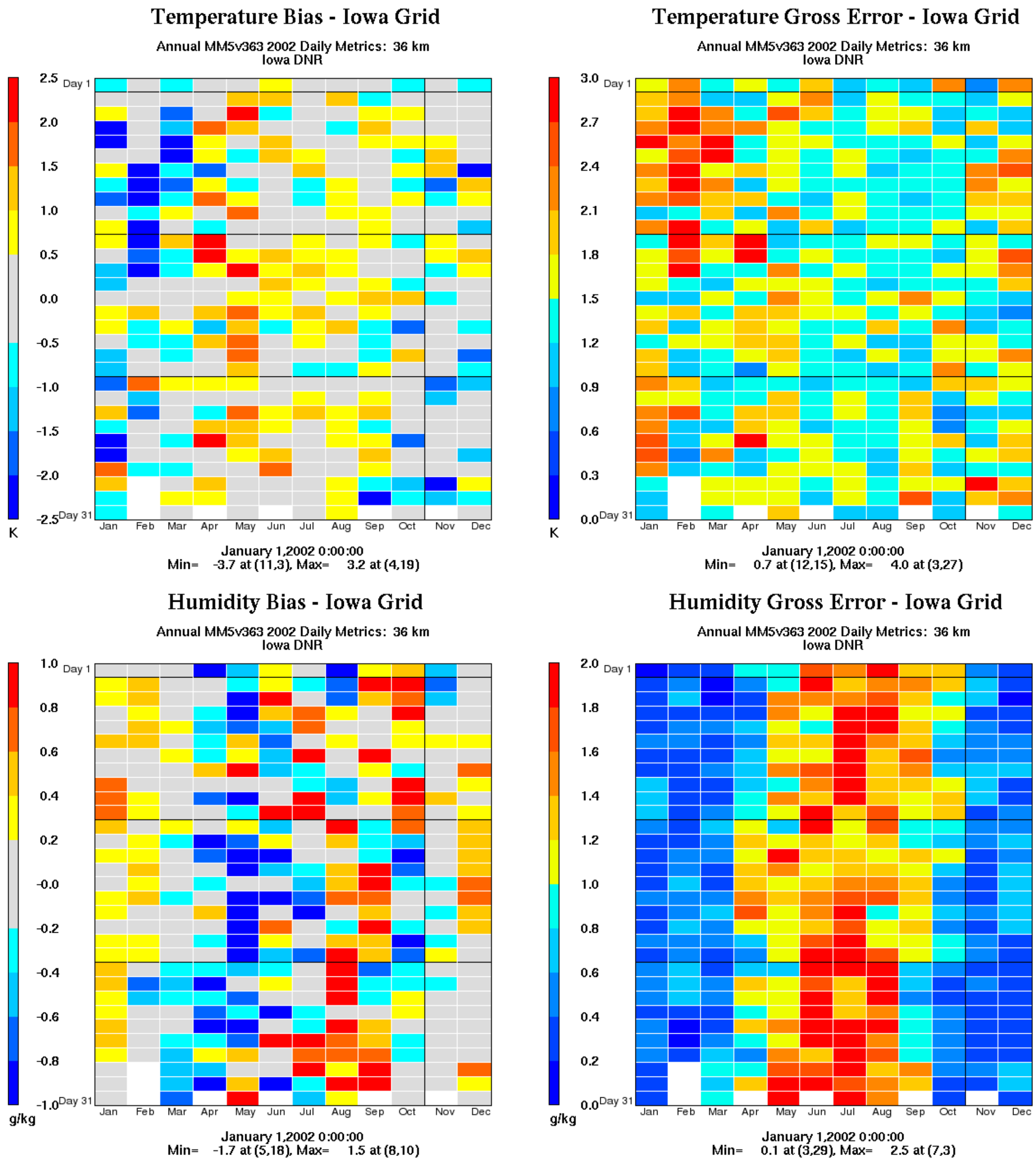


Figure 5.10. Daily averaged temperature and mixing ratio metrics for the Iowa subdomain.

6. TWELVE KILOMETER EVALUATION

6.1 DAILY AVERAGED STATISTICS

Generalizing the impacts of the 12 km domain upon the Great Lakes region, in terms of daily averaged metrics, a decrease in simulation accuracy during the winter months is found, while only negligible changes occur across the remainder of the year. This trend is prevalent for wind speed, wind direction[1] and temperature errors. The wintertime temperature cold bias (found at 36 km resolution) is thus even more pronounced in the 12 km domain. Mixing ratio statistics were generally uninfluenced by domain resolution. These results are depicted in Figures 6.1 – 6.2, where the Bakergram concept is maintained, however, the results are presented in terms of the differences between the 36 and 12 km results. The plots were generated by subtracting the 36 km daily averaged statistical values from the 12 km data. As the comparison only involves gross and root mean square error metrics, negative values indicate an improvement in model performance at 12 km resolution. This methodology is maintained for Figures 6.1 - 6.8.

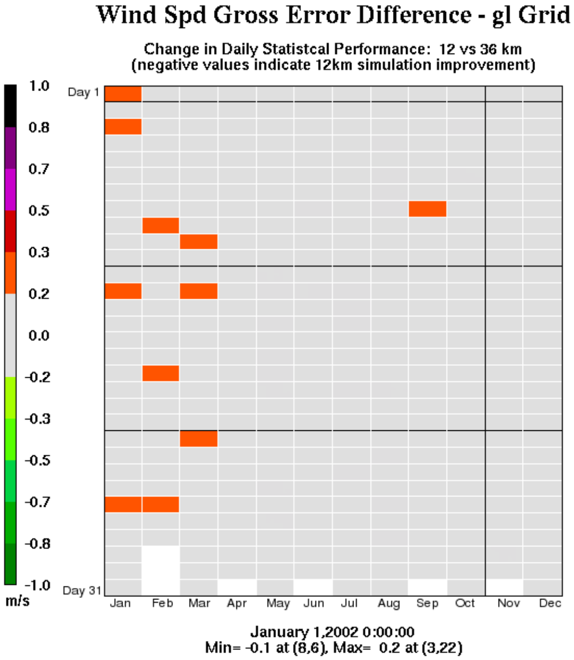
The CenrapN regions shows only minor variations in the temperature fields, with the greatest change concentrated to the cooler months, with slight performance disbenefits. Wind direction metrics produced a drastically different trend, as nearly all days showed poorer performance. Figures 6.3 – 6.4 provide a graphical depiction of the 12 km domain impacts upon the daily averaged metrics for this subdomain.

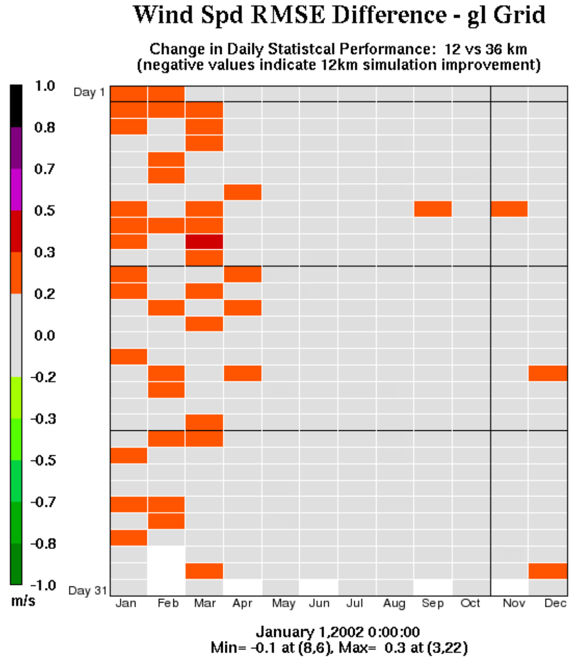
Over the Ohio Valley, only minor differences were calculated between the 12 and 36 km daily averaged statistical results, in general. A slight improvement in the mixing ratio fields was computed. As in CenrapN, wind direction gross errors encountered widespread performance degradation during the winter and early spring months. Keeping the increasing errors in perspective, additional error remained below 3.5 degrees. See Figures 6.5 - 6.6.

In terms of daily averaged statistical measures, the Iowa subdomain receives few benefits from increased resolution. Wind speeds generally exhibit slightly greater error in the winter, spring, and fall, while demonstrating little variability during the summer. Consistent with nearby subdomains, wind direction performance suffers. While mixing ratios impacts were negligible, most months exhibited days with increased temperature error, particularly in the winter. Fortunately, gross error degradation remained below 0.5 K. The results are depicted in Figures 6.7 - 6.8.

Due to the spatial extent of the 12 km domain, neither the CenrapS domain, nor any other subdomain, is eligible for comparison.

[1] With additional errors occurring into the early spring months.





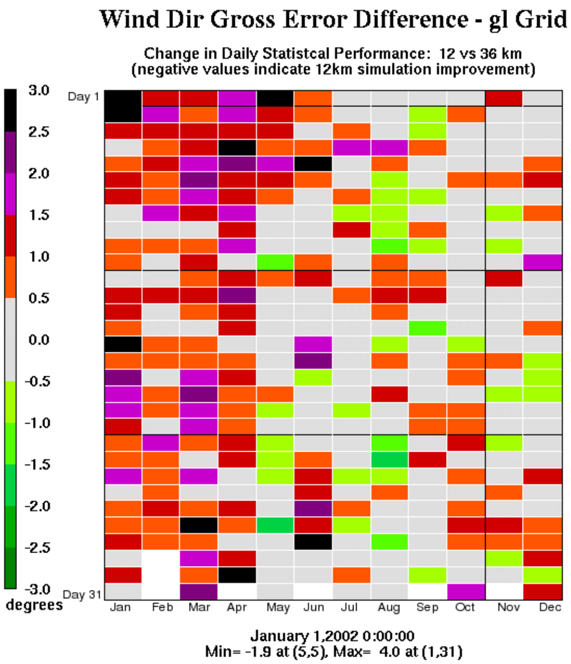


Figure 6.1. Twelve km domain daily averaged statistical performance for selected wind metrics in relation to the 36 km grid for the Great Lakes (GL) subdomain.

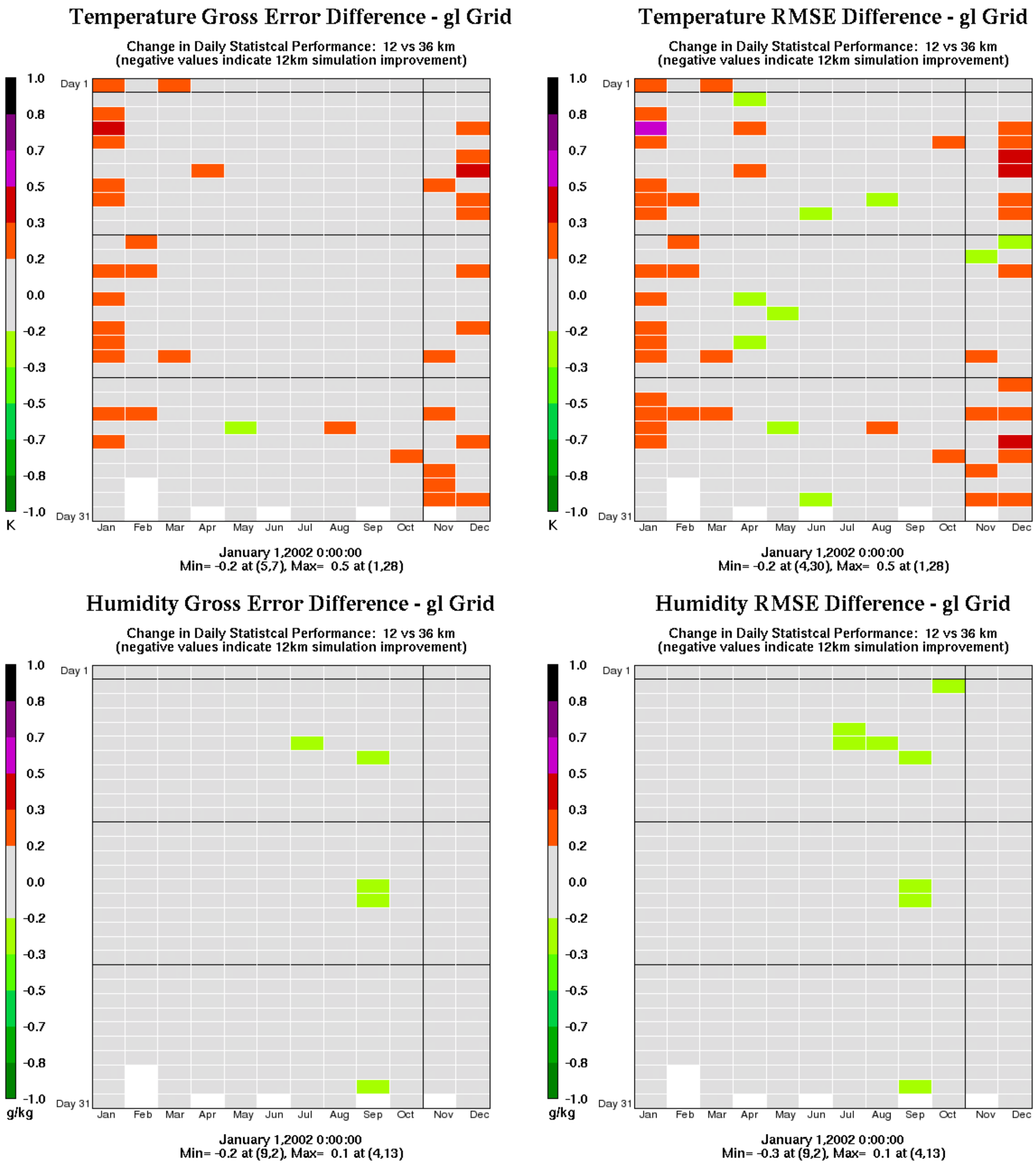


Figure 6.2. Twelve km domain daily averaged statistical performance for selected temperature and mixing ratio metrics in relation to the 36 km grid for the Great Lakes (GL) subdomain.

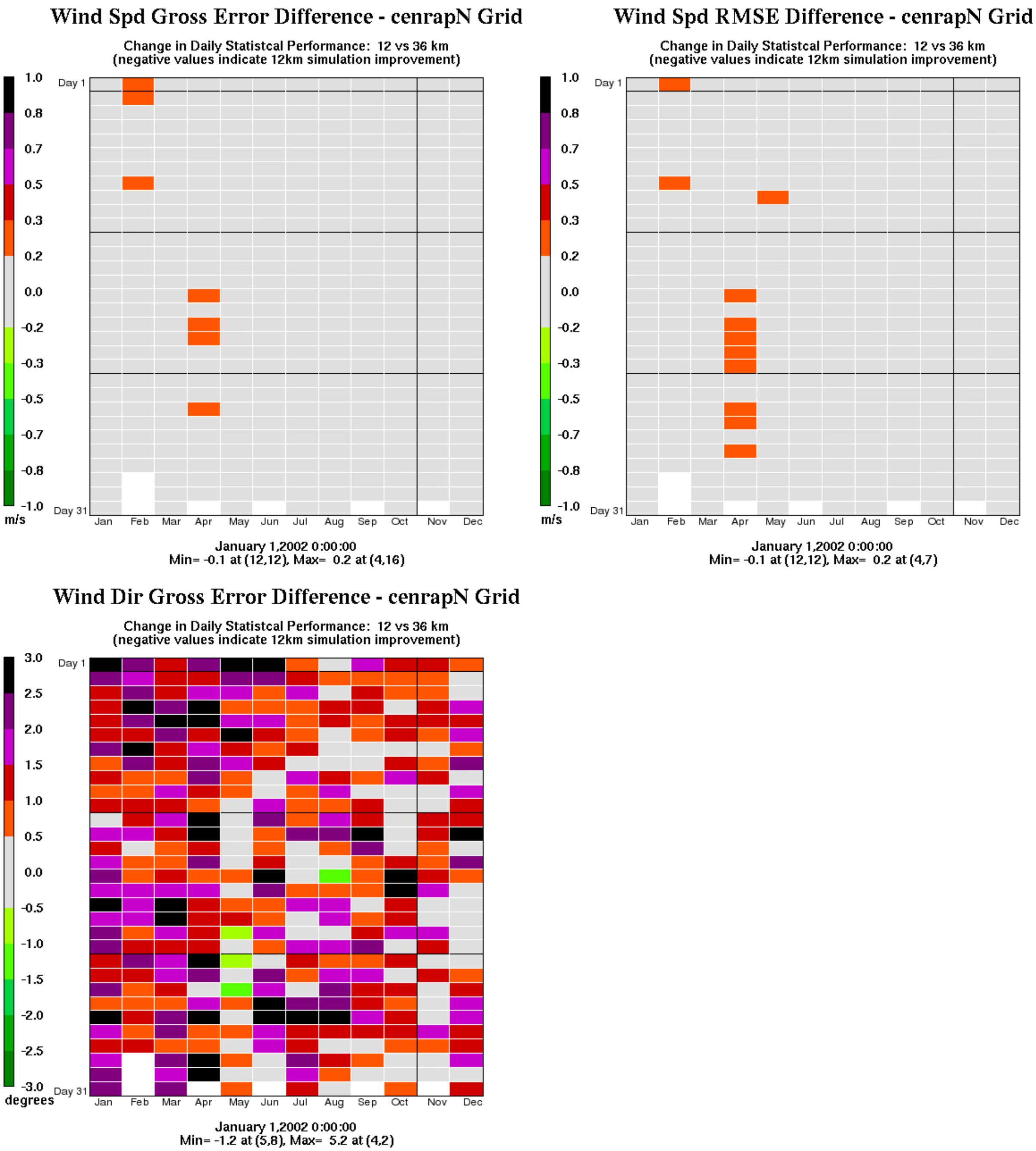


Figure 6.3. Twelve km domain daily averaged statistical performance for selected wind metrics in relation to the 36 km grid for the CenrapN subdomain.

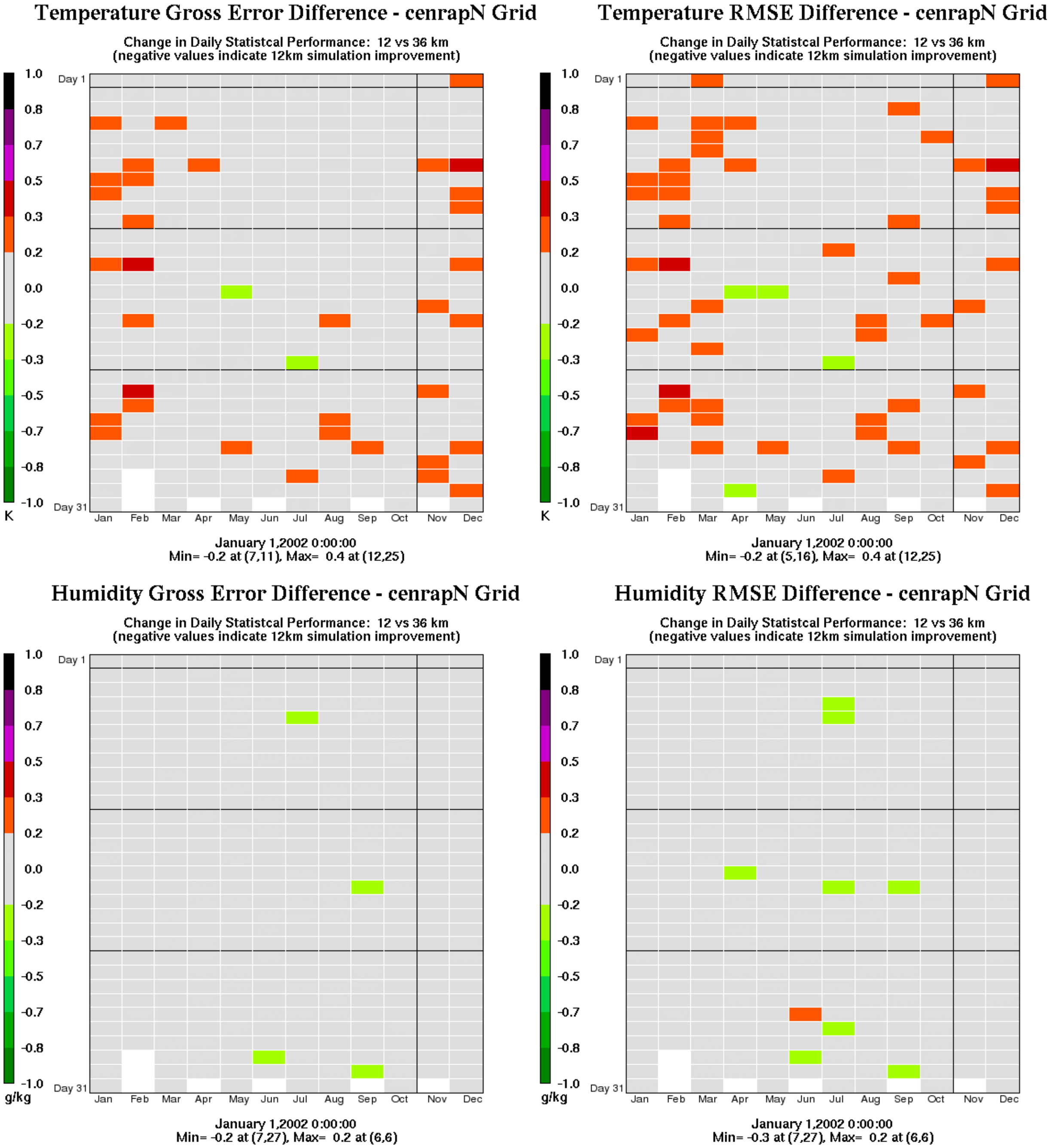


Figure 6.4. Twelve km domain daily averaged statistical performance for selected temperature and mixing ratio metrics in relation to the 36 km grid for the CenrapN subdomain.

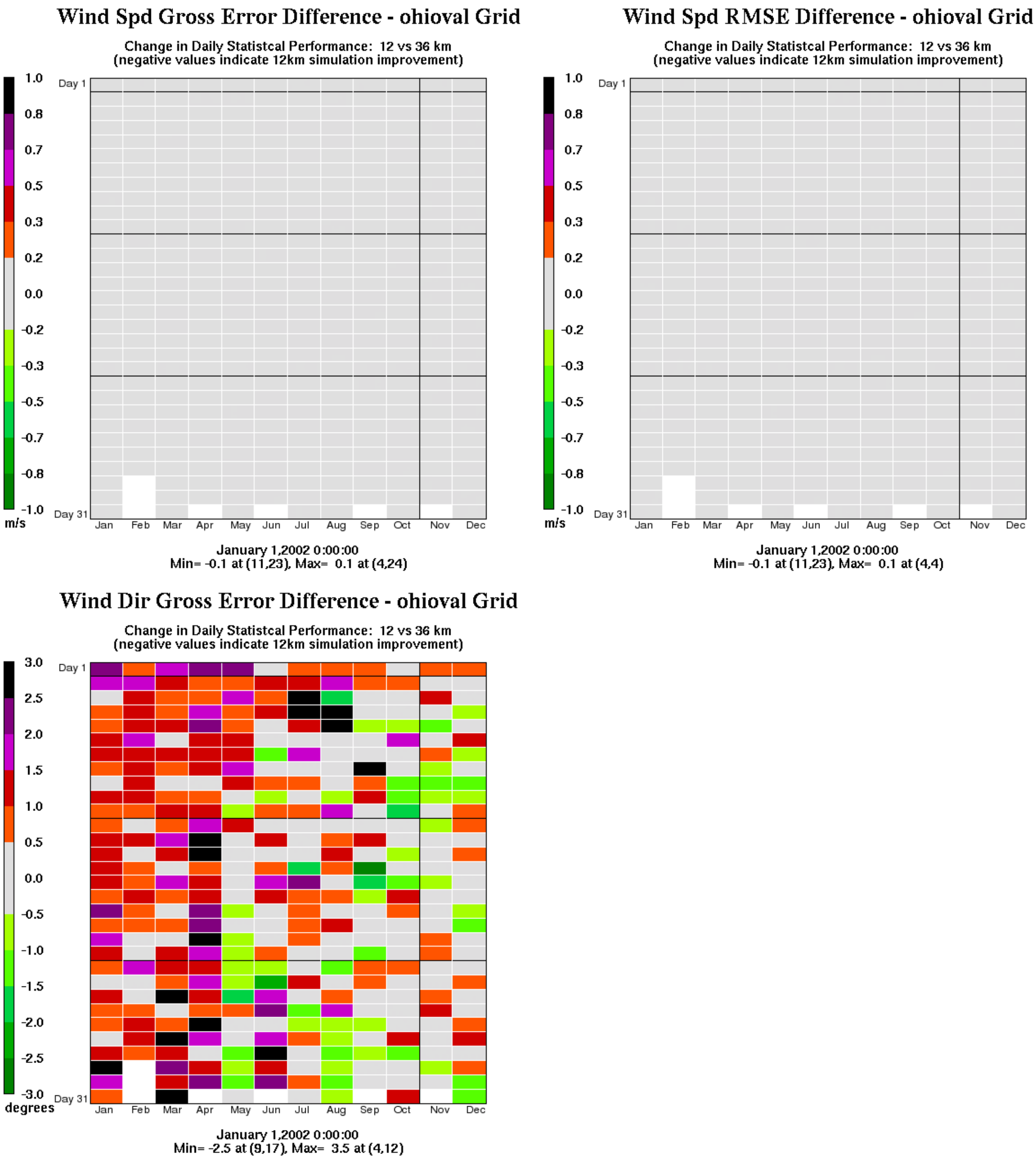


Figure 6.5. Twelve km domain daily averaged statistical performance for selected wind metrics in relation to the 36 km grid for the OhioVal subdomain.

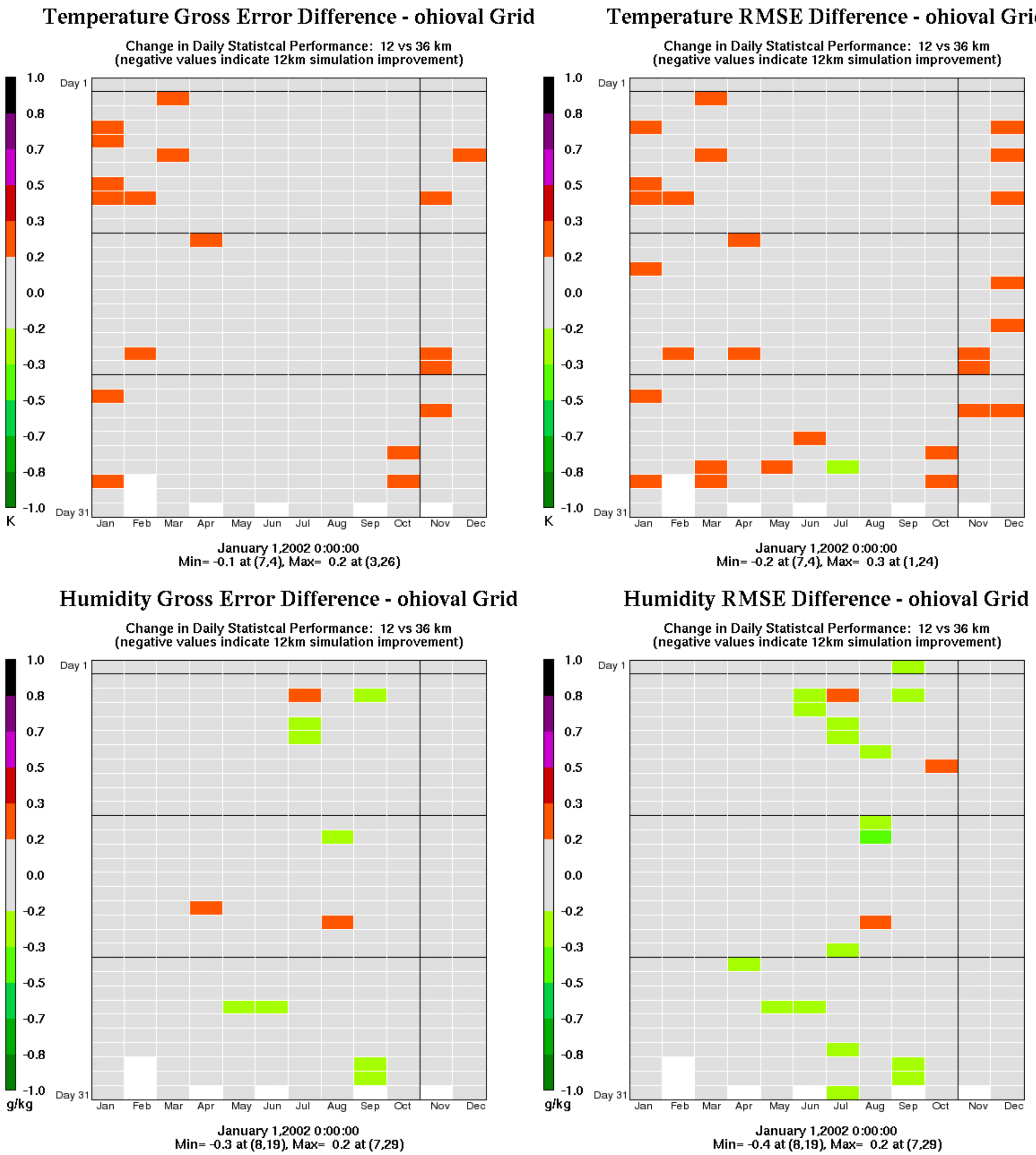


Figure 6.6. Twelve km domain daily averaged statistical performance for selected temperature and mixing ratio metrics in relation to the 36 km grid for the OhioVal subdomain.

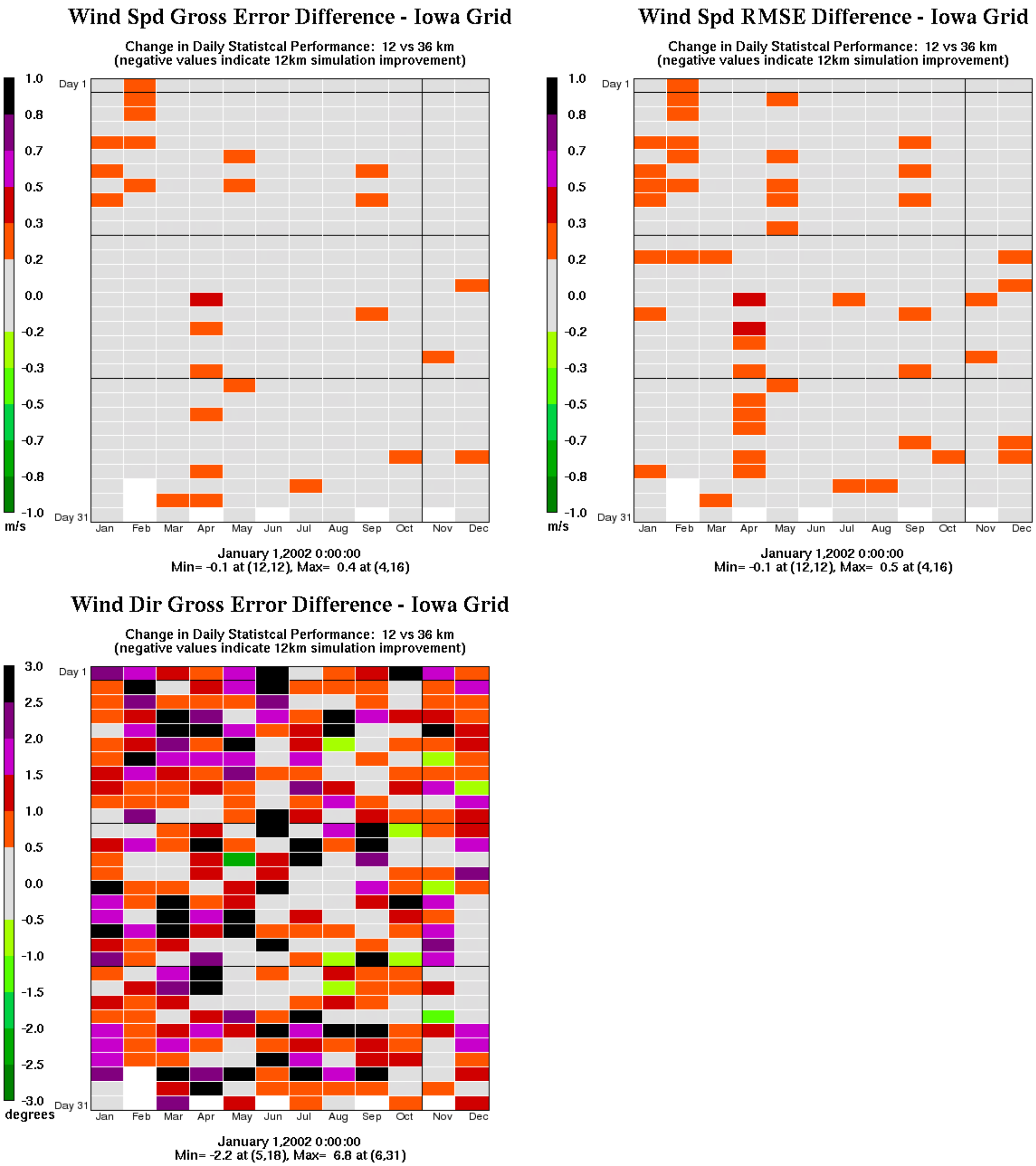


Figure 6.7. Twelve km domain daily averaged statistical performance for selected wind metrics in relation to the 36 km grid for the Iowa subdomain.

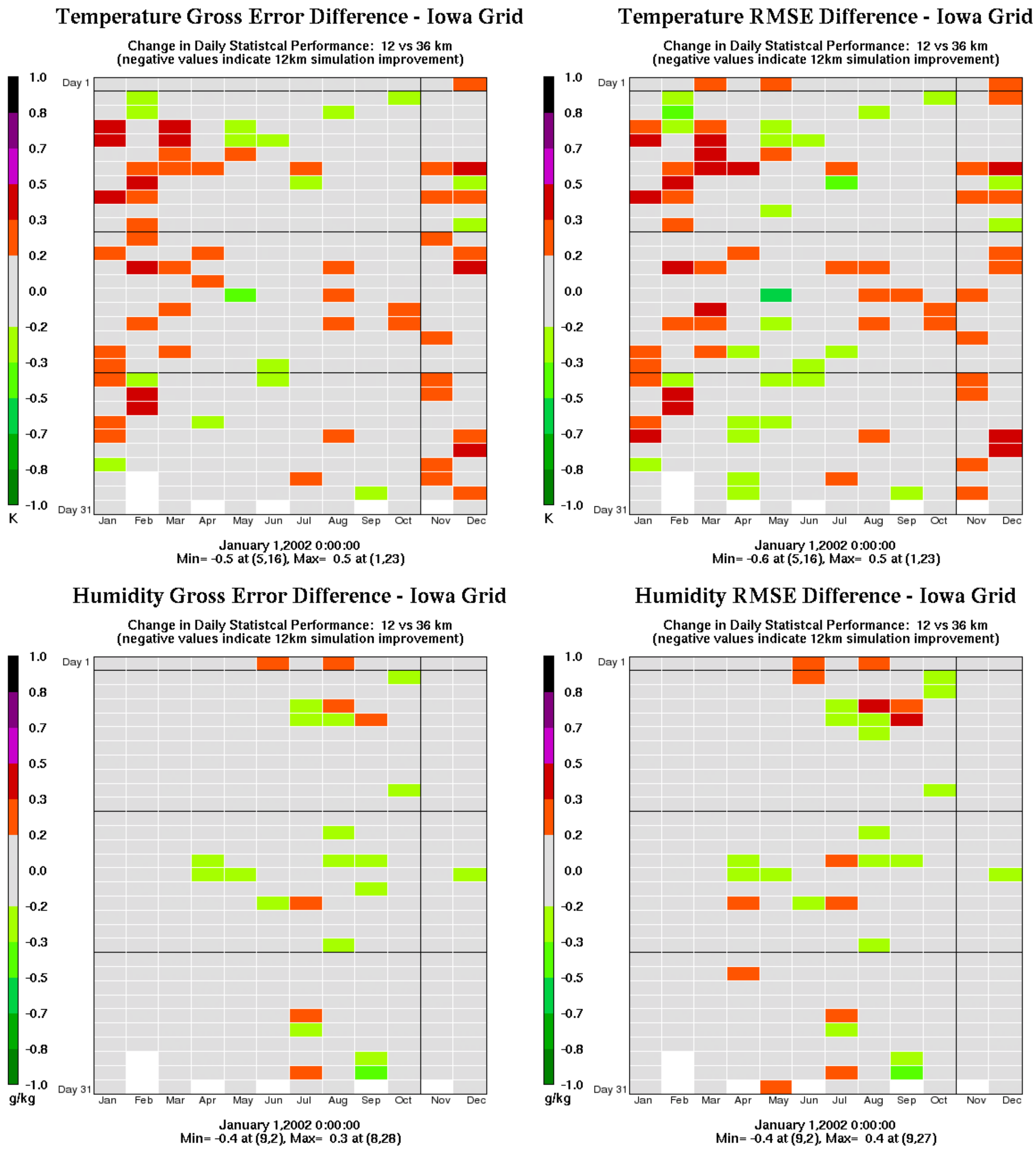


Figure 6.8. Twelve km domain daily averaged statistical performance for selected temperature and mixing ratio metrics in relation to the 36 km grid for the Iowa subdomain.

6.2 HOURLY STATISTICS

Additional comparisons between the 36 and 12 km simulations are provided below through review of hourly timeseries. Modeled (both 36 and 12 km) versus observed conditions are plotted below, with the associated bias also depicted. The hourly time series evaluation eliminates the statistical smoothing associated with the daily averaging periods. These charts also serve as the diurnal profile data source referenced in previous chapters, however, the discussion below will primarily focus upon differences between the 12 and 36 km simulations.

Assessing the timeseries from a winter (January) and summer (June) monthly subset of the annual simulation for the Great Lakes region (Figures 6.9 - 6.10) leads to a general conclusion that improvement occurs in the daytime wind speed biases with implementation of the 12 km grid, while nighttime disbenefits are observed. At 12 km resolution, the wintertime cold bias is even more pronounced versus the 36 km domain, as nighttime low temperatures dip further below observed values (Figure 6.11). The ultimate cause for the low temperature bias is unknown, but this is not an uncommon feature of MM5 simulations (Ad-Hoc Meteorological Modelers Meeting group discussion, 2007). For the GL region, no significant differences are found in either temperature or humidity during the summer month of June (Figure 6.12). Appendix C provides additional January and June hourly 12 versus 36 km statistical charts for the Great Lakes, OhioVal, CenrapN, and Iowa subdomains.

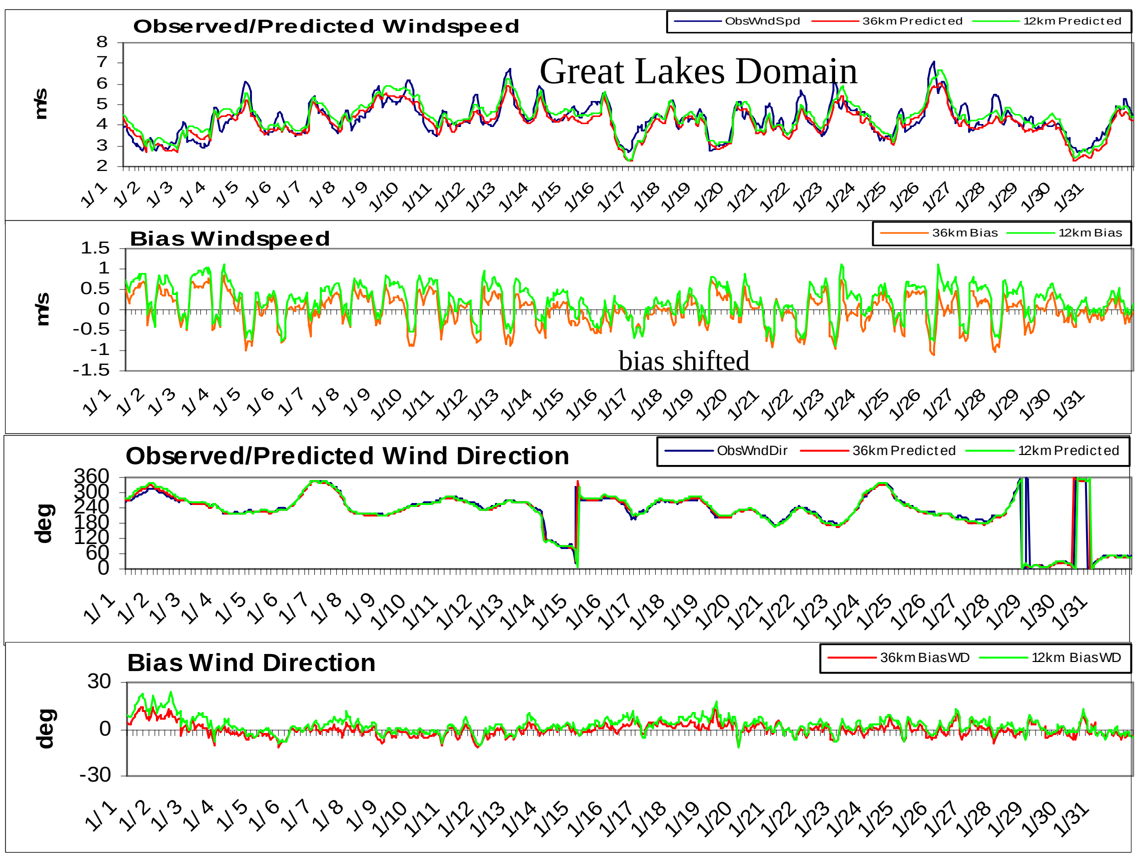


Figure 6.9. Twelve and 36 km hourly wind vector statistics for the Great Lakes subdomain for January, 2002.

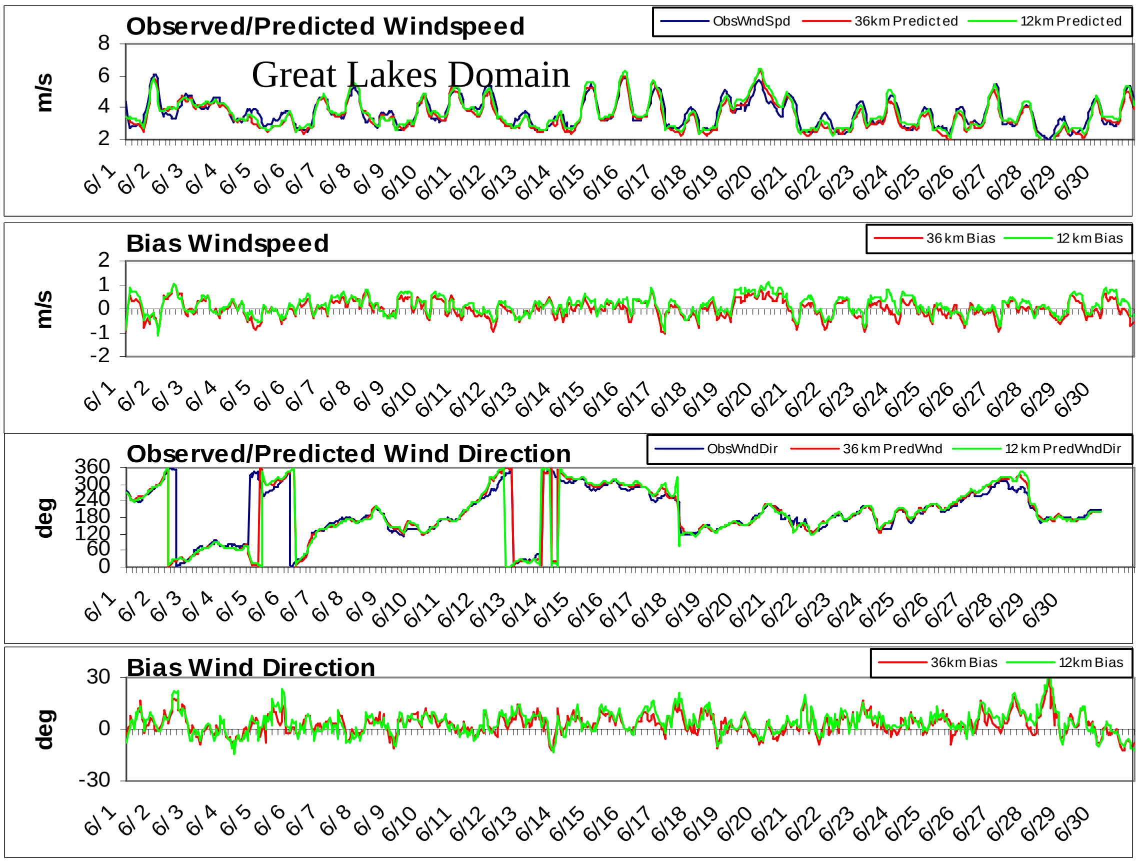


Figure 6.10. Twelve and 36 km hourly wind vector statistics for the Great Lakes subdomain for June, 2002.

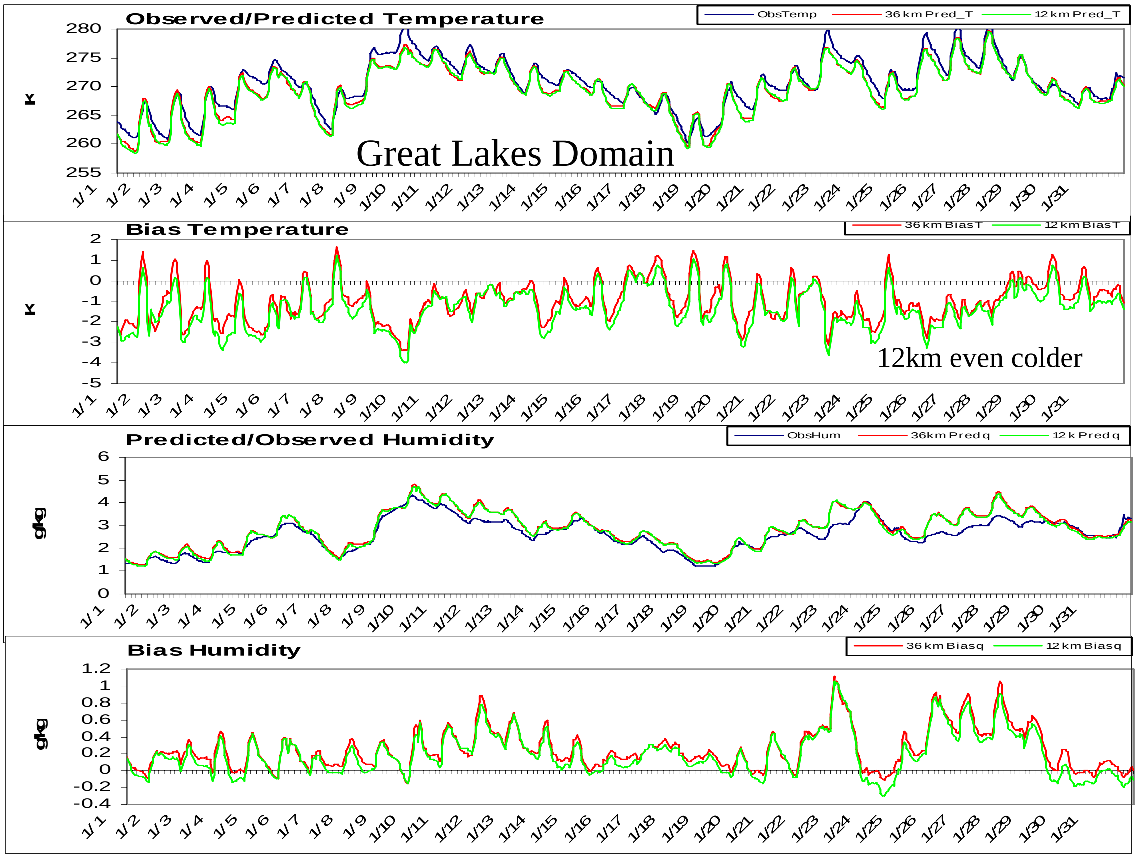


Figure 6.11. Twelve and 36 km hourly temperature and moisture statistics for the Great Lakes subdomain for January, 2002.

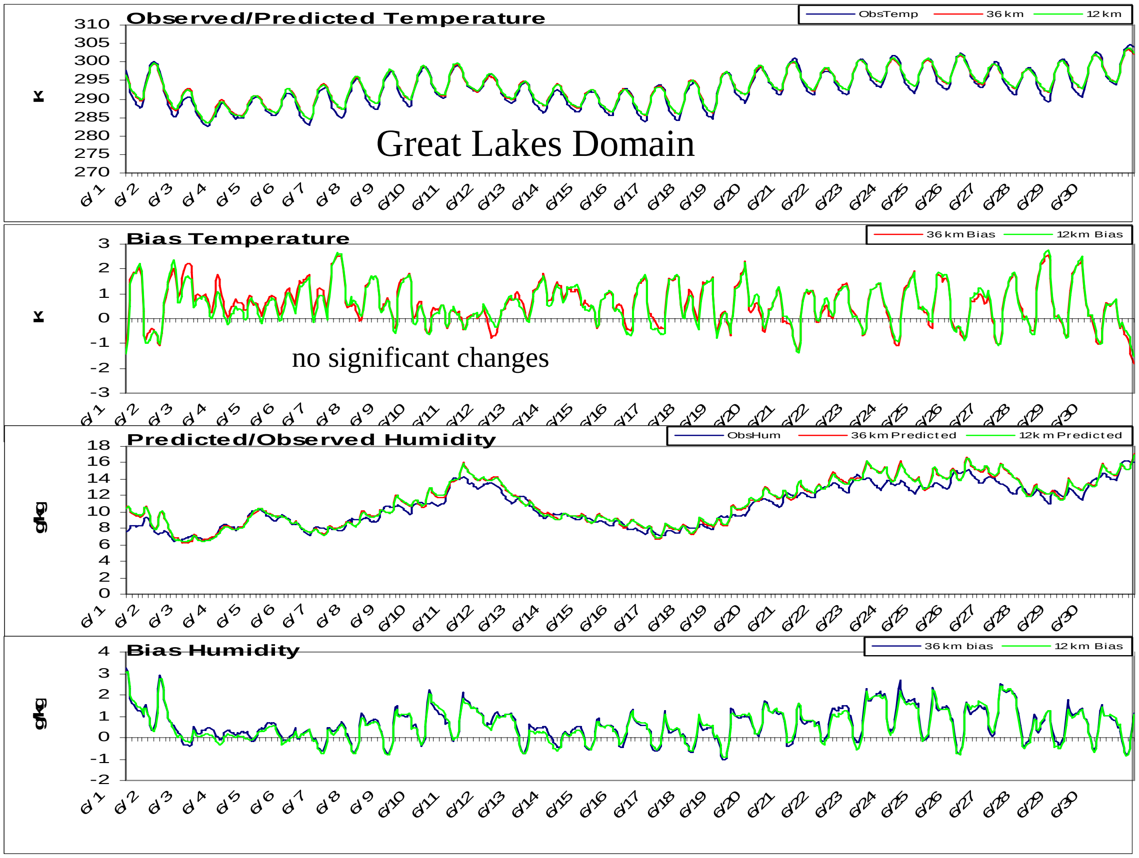


Figure 6.12. Twelve and 36 km hourly temperature and moisture statistics comparison for the Great Lakes subdomain for June, 2002.

7. UPPER AIR EVALUATION

7.1 SOUNDINGS

A comprehensive assessment of model performance cannot be completed through the evaluation of surface statistical measures alone. A rigorous evaluation requires the examination of additional features such as precipitation fields, PBL depths, and vertical profiles of temperature, moisture, and wind vectors. As readily available tools have not been identified which yield objective measures of such parameters, evaluations are typically subjective. A precipitation evaluation of the 36 km dataset has been completed by Kirk Baker (Baker et al., 2004) and is summarized below. In combination with the precipitation evaluation, the most efficient method available for an upper air analysis is to focus upon radiosonde observations. To aid in the review of upper air feature, the IDNR created the RAOBPLOT software tool that efficiently displays modeled versus observed radiosonde upper air measurements. With twice-daily soundings available from approximately 70 observing stations, roughly 51,100 modeled versus observed soundings are available for examination from the 36 km annual simulation alone. Clearly a complete examination is resource prohibitive. The volume of data available, in combination with only inefficient subjective methods for evaluations highlights a current deficiency in annual scale regional modeling applications. While inelegant, the immediately practicable solution requires a targeted review of specific data.

A brief review of the modeled versus observed sounding for many sites in the Central U.S. was conducted, with no terminal deficiencies discovered. A more focused evaluation upon the Davenport, Iowa, station was completed over the simulated summer months, with the following conclusions reached: Upper level wind vectors are well simulated. The temperature fields below approximately 900 mb yielded a tendency toward underprediction at 0Z, while the moisture fields were generally overstated during the same region and time. At 12Z, temperatures were generally underpredicted below 900 mb. In terms of estimated PBL depths, the mixed layer commonly appears shallower than observed. While error is never desired, in terms of modeling air quality (in a conservative sense) a shallow PBL is preferred versus excessive depth. A sample of the observed versus modeled sounding produced by RAOBPLOT is provided in Figure 7.1.

7.2 PRECIPITATION

Kirk Baker with the Lake Michigan Air Directors Consortium was provided a complete copy of the 36 km meteorological dataset and subsequently completed a model performance evaluation examining precipitation fields. In summary, both rainfall totals and precipitation spatial coverage are generally well simulated in the fall, winter, and springtime periods. As is common with many MM5 simulations, summertime precipitation events produce an excess of precipitation. Rainfall patterns also exhibit greater spatial coverage than observed. Additional detail, including graphical representation of predicted and observed rainfall, is available in Baker et al., 2004.

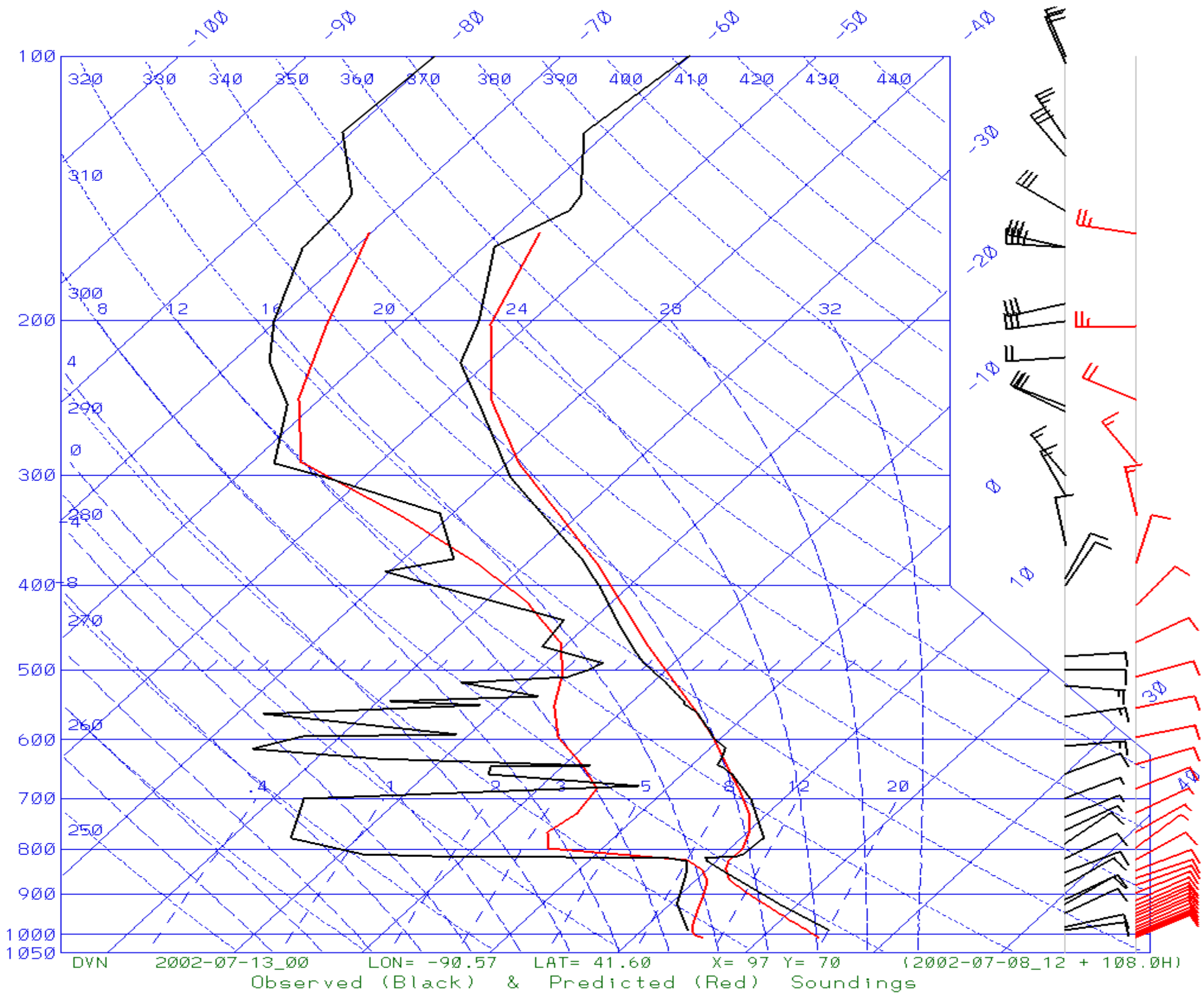


Figure 7.1. Sample ROABPLOT observed versus predicted (36 km domain) sounding for Davenport Iowa, on July 13, 2007, at 0Z. Wind speed and directions are accurately simulated throughout the depth of the sounding. The temperature profile performance is more than adequate. As is common, a positive moisture bias exists at (and above the surface), while the estimated PBL depth remains too shallow.

7.3 PBL DEPTHS

Additional upper air analyses included a limited comparison of the 36 and 12 km predicted PBL heights. Figure 7.2 provides an example comparison. As expected, the degree of agreement between the 36 and 12 km results exceeds variability. Areas in Western Illinois and Eastern Texas (among others) do display deviations. In Eastern Texas, MM5 predicts a precipitation event (which is weakly supported by observations, see Figures 7.3 - 7.4). The reduction in PBL heights in Western Illinois would appear to be precipitation driven as well, but no convective or non-convective rainfall was predicted by MM5 during this time. The observed radar reflectivities also suggests no precipitation occurred during this time. In summary, the 12 km grid yields improved feature detail yet the accuracy of such fields, across a continental scale annual simulation, is difficult to assess within a reasonable timeframe.

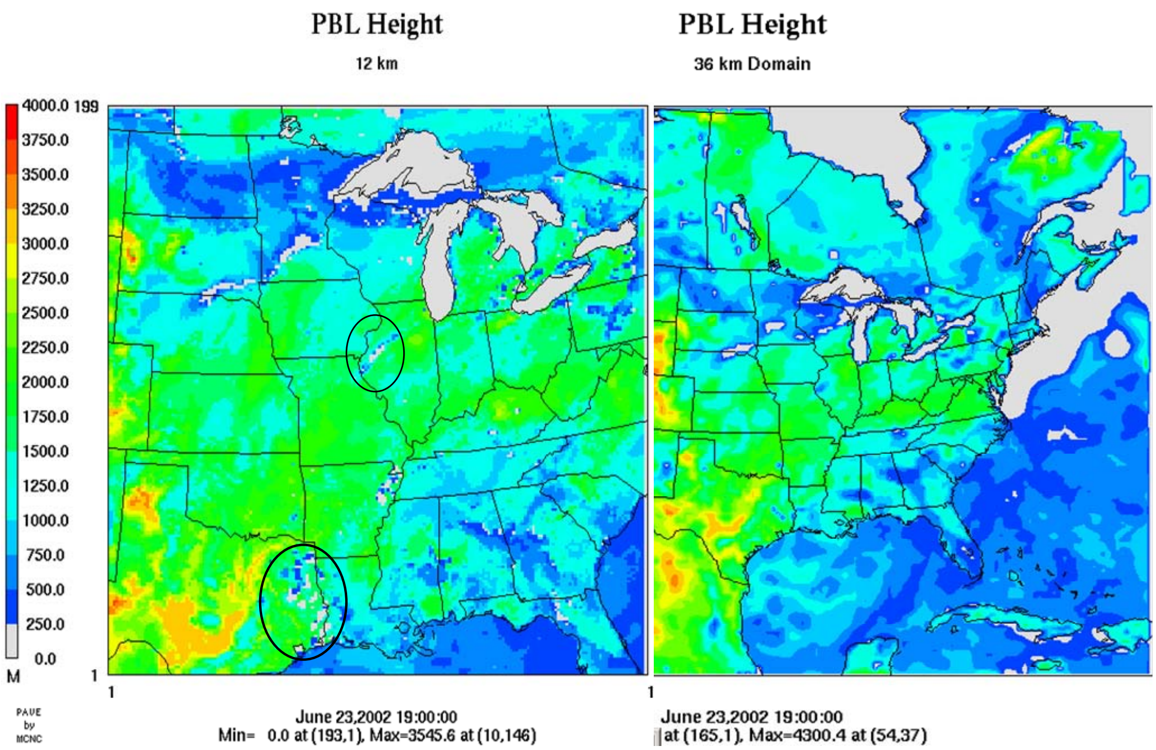


Figure 7.2. PBL heights predicted by MM5 for June 23, 2002, at 19Z. for the 12 and 36 km modeling domains.

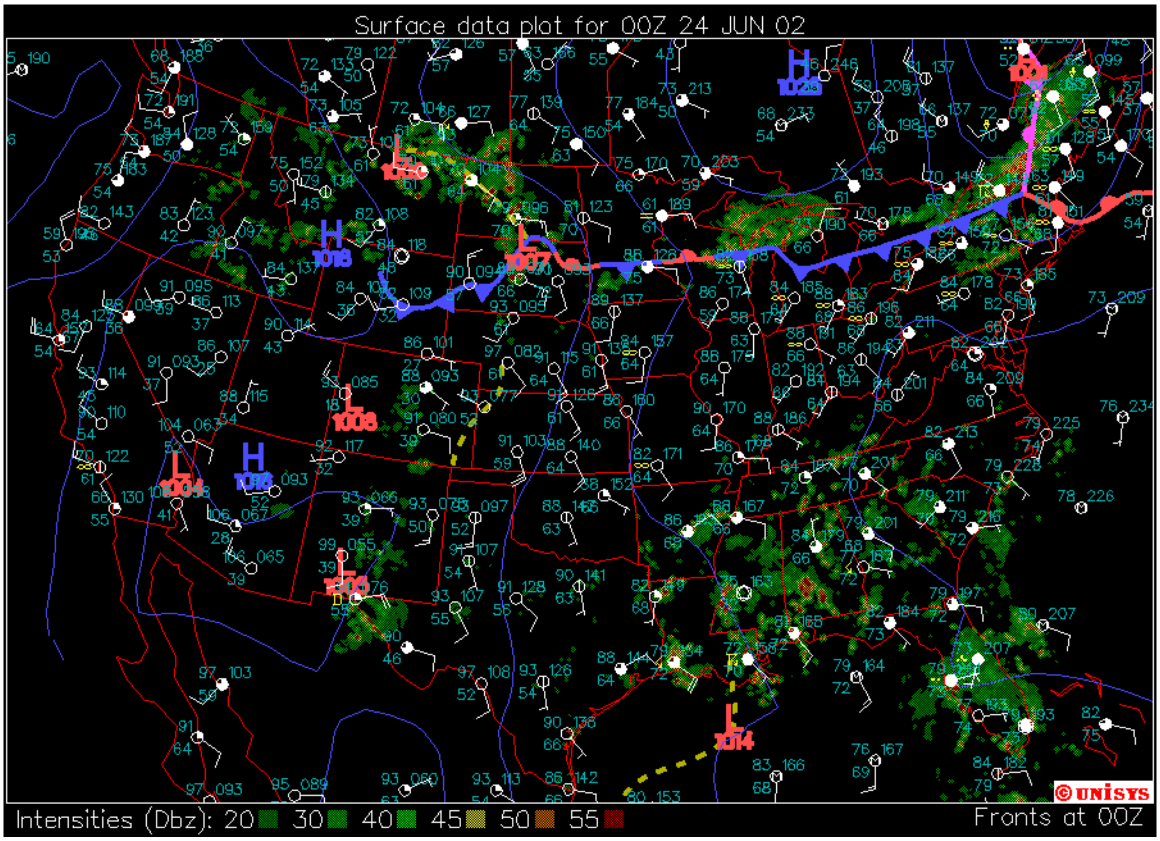


Figure 7.3. Observed conditions on June 24, 0Z.

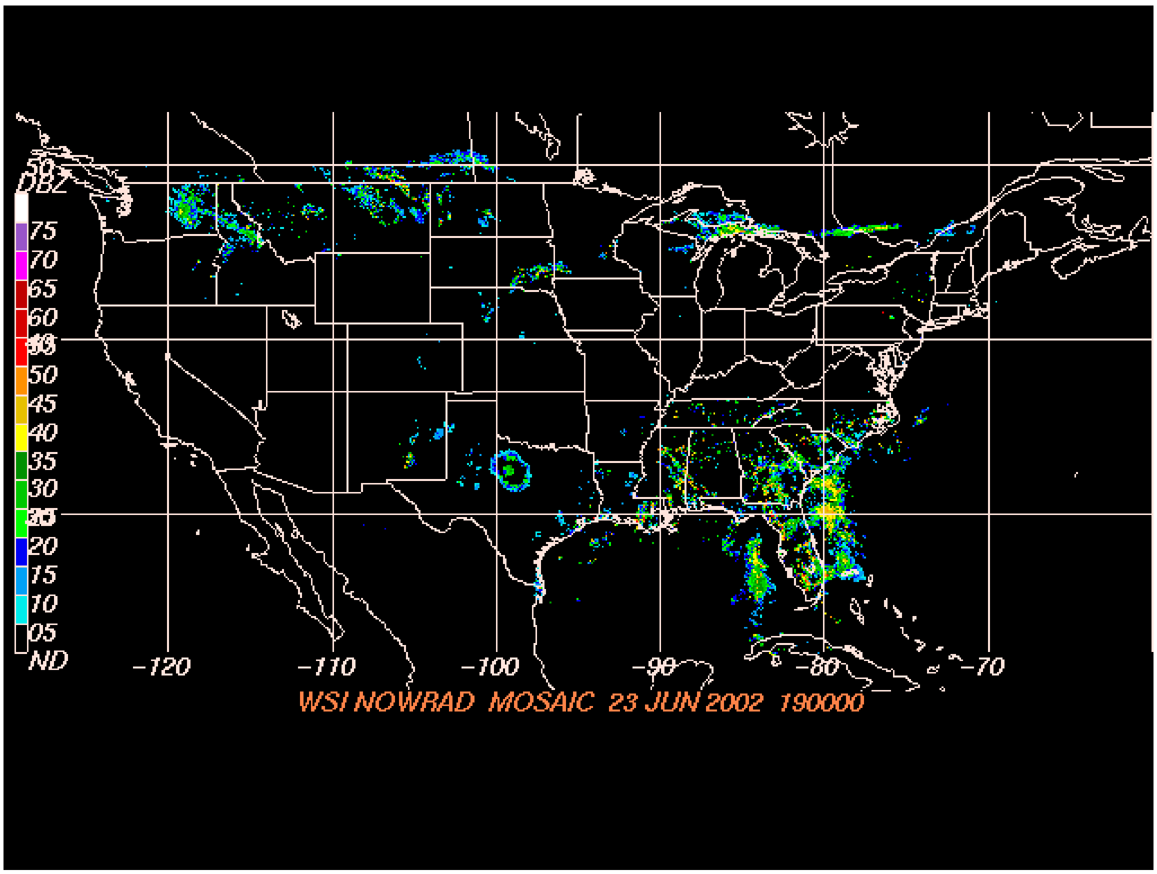


Figure 7.3. Radar reflectivity on June 23, 2002 at 19Z.

8. CONCLUSIONS

In the northern half of the Central U.S. through the Ohio River valley, the surface statistical evaluation reveals a dominant wintertime cold bias, with cool conditions typically present in the evening hours, while overly aggressive nighttime lows and weak high temperatures also contribute to the cold bias. The summer months exhibit a warm bias, attributable to the overprediction of nighttime temperatures. Wind speed and direction predictions over the central and northern Central U.S. exhibit low statistical error and provide for an increase in model confidence. Continuing the evaluation into the Western U.S. yields a reduction in model confidence, as error measures increase across all fields. As discussed, this result is not completely unexpected given complex Western topography. Regions within the Eastern U.S. demonstrate prediction skill above Western regions, yet statistical accuracy falls below that found in the Midwest.

Expanding the evaluation into upper air features reveals no fundamental flaws jeopardizing the adequacy of the simulation in terms of air quality modeling. A tendency to slightly underpredict summertime PBL depths over Eastern Iowa was discovered. In subjective terms, such error is acceptable as perfect model performance is unattainable. A similar conclusion is reached for the precipitation shortfalls discussed by Baker et al., 2004.

Within the Central U.S, increasing the horizontal resolution from 36 to 12 km yielded no benefits from a surface-feature statistical evaluation perspective. Within the Great Lakes subdomain, the 12 km simulation appears to improve daytime wind speed predictions, however, nighttime predictions suffer. Overall, wind speed error showed little variability between the 36 and 12 km domains. Beyond the statistical evaluation, additional field detail is resolved by the 12 km domain as expected. As in the upper air analysis for the 36 km grid, no fundamental flaws were identified in review of 12 km upper air features.

In summary, the statistical evaluation yields results predominantly within acceptable guidelines for the principal regions of interest (the States near and within LADCO and the northern two-thirds of CENRAP). Concurrently, no major simulation deficiencies were revealed during the upper air review. The 36 and 12 km Iowa DNR 2002MM5v363 datasets are thus judged acceptable for use in regional scale air quality modeling studies focused within the central United States.

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APPENDIX A

Temporal structure example for the 2002 annual simulation.

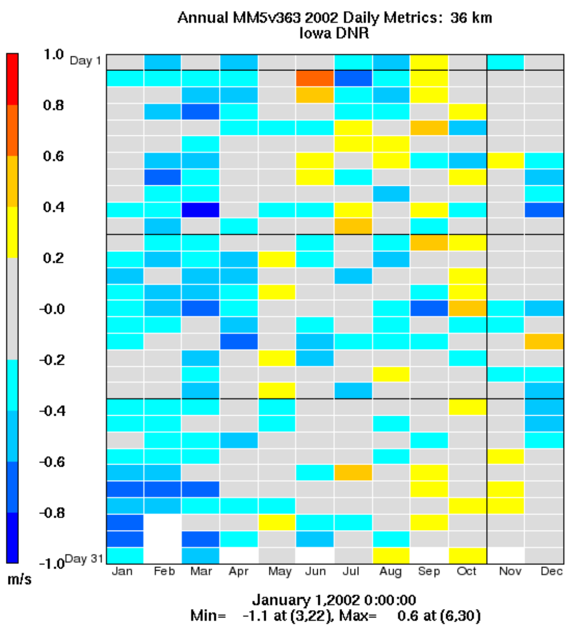
Start BLOCK	End BLOCK	Start (Z)	End (Z)	Filename	Metstat Usable Start (Z)	Metstat Usable End (Z)
12/28/2001 12:00	**1/2/2002 12:00**	12/28/2001 12:00	12/28/2001 12:00	**MMOUT_DOMAIN1_00**		
		12/28/2001 13:00	12/29/2001 12:00	**MMOUT_DOMAIN1_01**	12/29/2001 0:00	12/29/2001 12:00
		12/29/2001 13:00	12/30/2001 12:00	**MMOUT_DOMAIN1_02**	12/29/2001 13:00	12/30/2001 12:00
		12/30/2001 13:00	12/31/2001 12:00	**MMOUT_DOMAIN1_03**	12/30/2001 13:00	12/31/2001 12:00
		12/31/2001 13:00	1/1/2002 12:00	**MMOUT_DOMAIN1_04**	12/31/2001 13:00	1/1/2002 12:00
		1/1/2002 13:00	1/2/2002 12:00	**MMOUT_DOMAIN1_05**	1/1/2002 13:00	1/1/2002 23:00
1/1/2002 12:00	**1/6/2002 12:00**	1/1/2002 12:00	1/1/2002 12:00	**MMOUT_DOMAIN1_00**		
		1/1/2002 13:00	1/2/2002 12:00	**MMOUT_DOMAIN1_01**	1/2/2002 0:00	1/2/2002 12:00
		1/2/2002 13:00	1/3/2002 12:00	**MMOUT_DOMAIN1_02**	1/2/2002 13:00	1/3/2002 12:00
		1/3/2002 13:00	1/4/2002 12:00	**MMOUT_DOMAIN1_03**	1/3/2002 13:00	1/4/2002 12:00
		1/4/2002 13:00	1/5/2002 12:00	**MMOUT_DOMAIN1_04**	1/4/2002 13:00	1/5/2002 12:00
		1/5/2002 13:00	1/6/2002 12:00	**MMOUT_DOMAIN1_05**	1/5/2002 13:00	1/5/2002 23:00
1/5/2002 12:00	**1/10/2002 12:00**	1/5/2002 12:00	1/5/2002 12:00	**MMOUT_DOMAIN1_00**		
		1/5/2002 13:00	1/6/2002 12:00	**MMOUT_DOMAIN1_01**	1/6/2002 0:00	1/6/2002 12:00
		1/6/2002 13:00	1/7/2002 12:00	**MMOUT_DOMAIN1_02**	1/6/2002 13:00	1/7/2002 12:00
		1/7/2002 13:00	1/8/2002 12:00	**MMOUT_DOMAIN1_03**	1/7/2002 13:00	1/8/2002 12:00
		1/8/2002 13:00	1/9/2002 12:00	**MMOUT_DOMAIN1_04**	1/8/2002 13:00	1/9/2002 12:00
		1/9/2002 13:00	1/10/2002 12:00	**MMOUT_DOMAIN1_05**	1/9/2002 13:00	1/9/2002 23:00

APPENDIX B

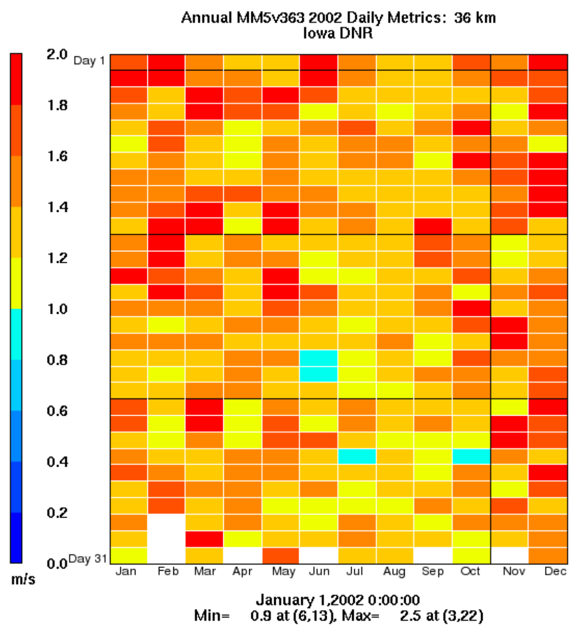
Daily averaged metrics from the 36 km simulation.

Eastern Subdomains

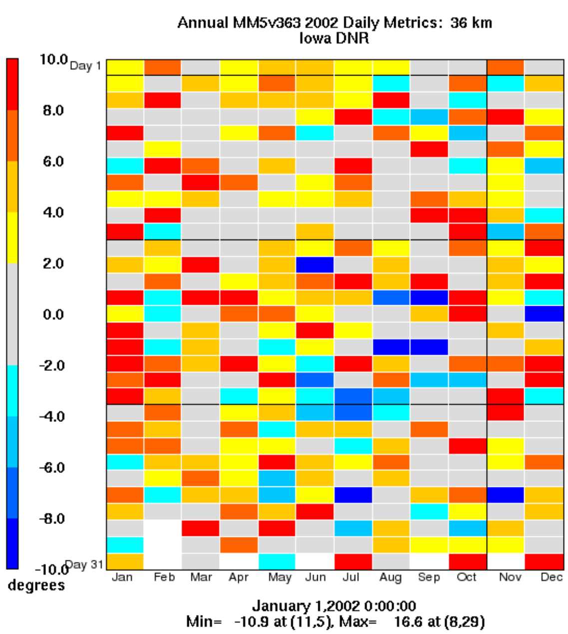
Wind Spd Bias - NE Grid



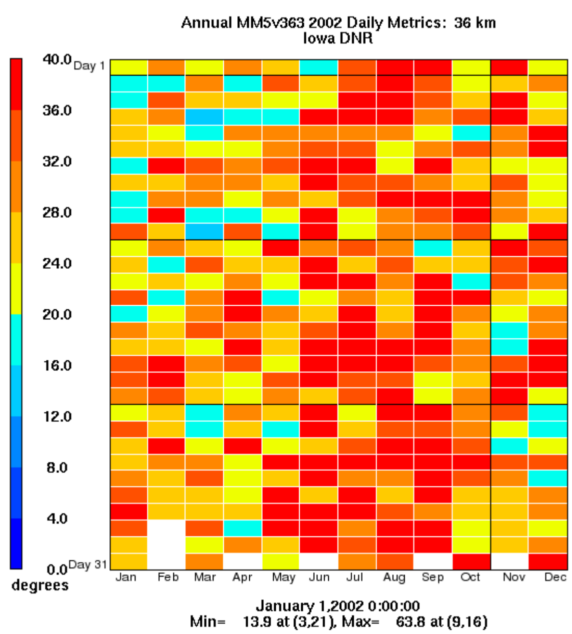
Wind Spd Gross Error - NE Grid

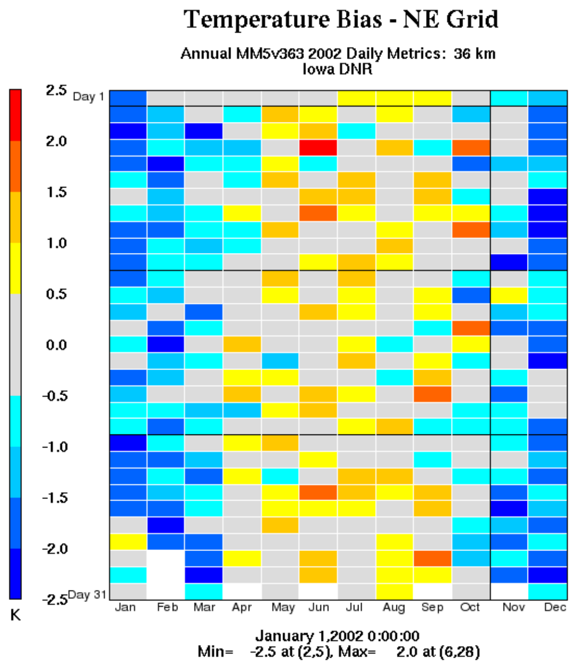


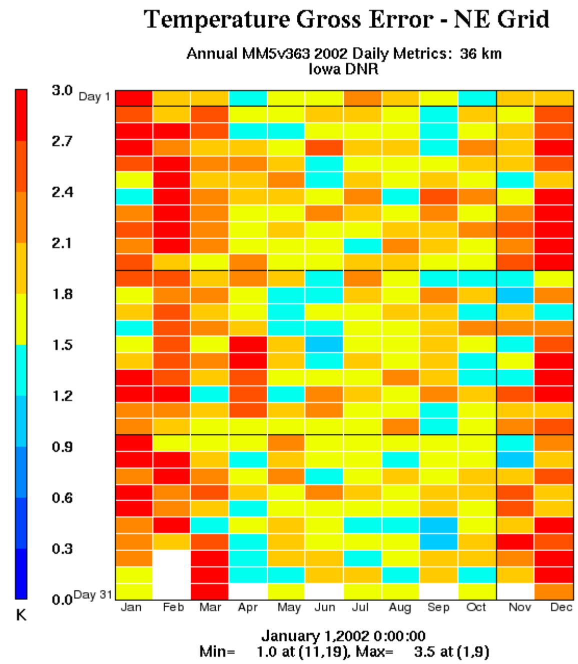
Wind Dir Bias - NE Grid

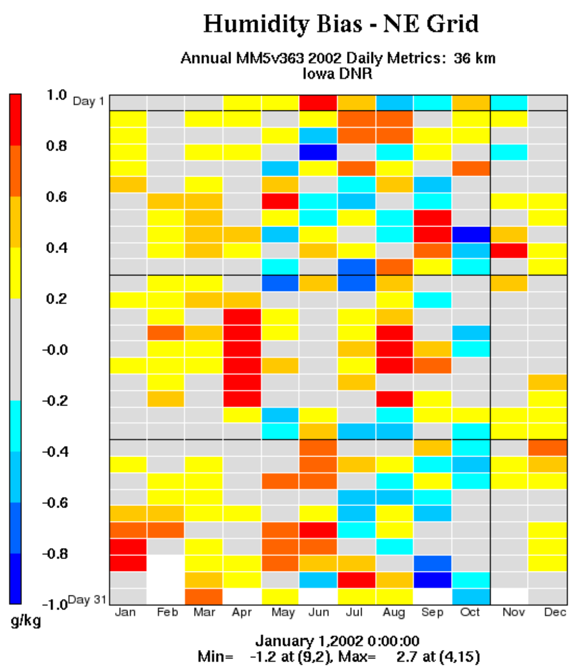


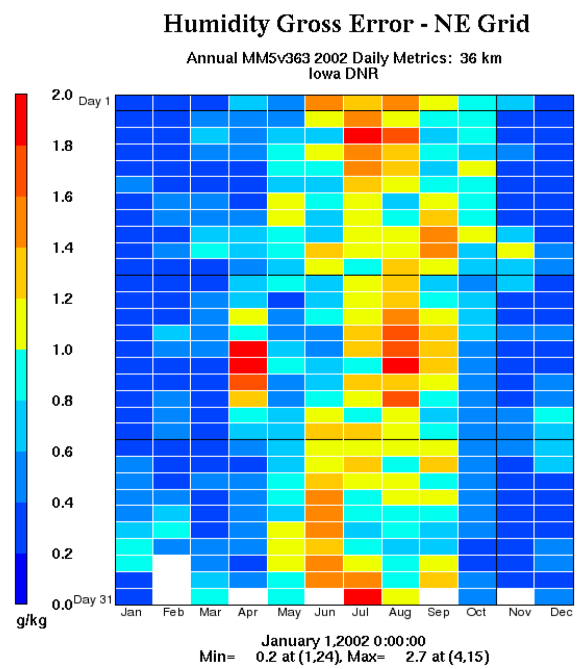
Wind Dir Gross Error - NE Grid

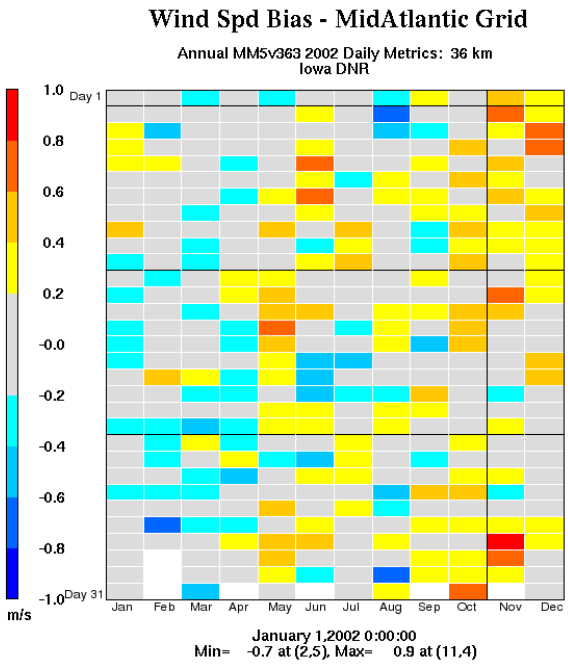


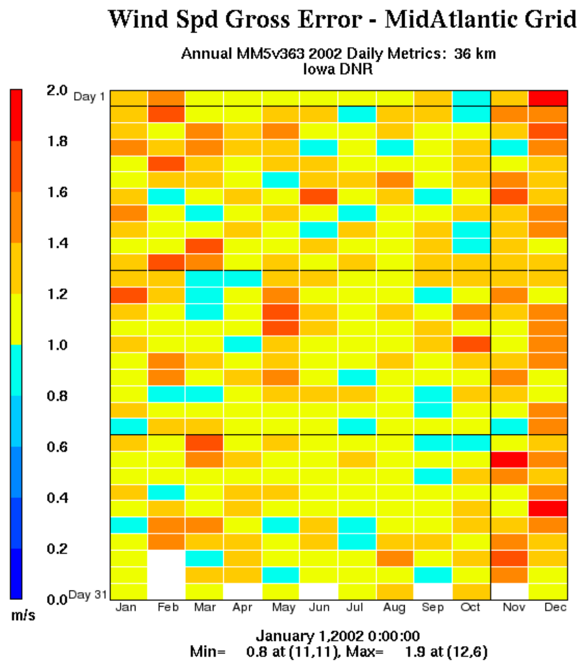

Temperature Bias - NE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
K
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -2.5 at (2,5), Max= 2.0 at (6,28)

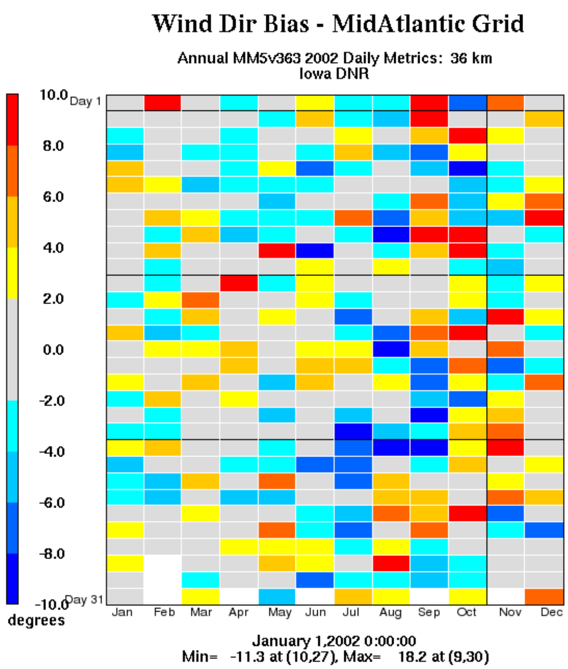

Temperature Gross Error - NE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
K
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 1.0 at (11,19), Max= 3.5 at (1,9)

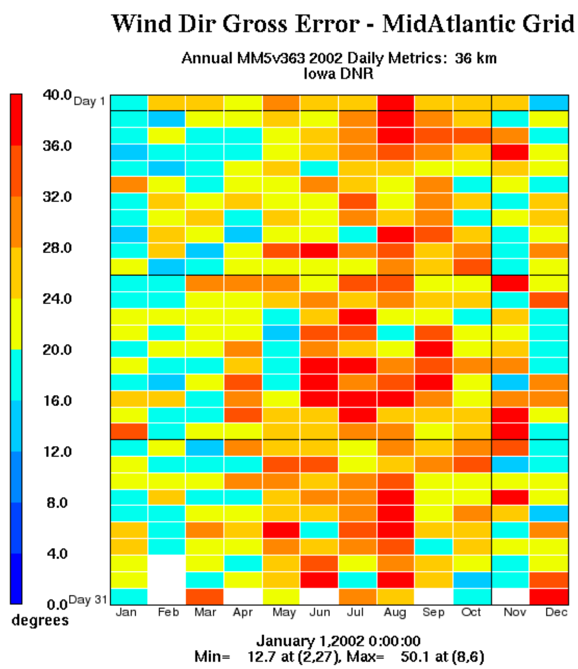

Humidity Bias - NE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
g/kg
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -1.2 at (9,2), Max= 2.7 at (4,15)

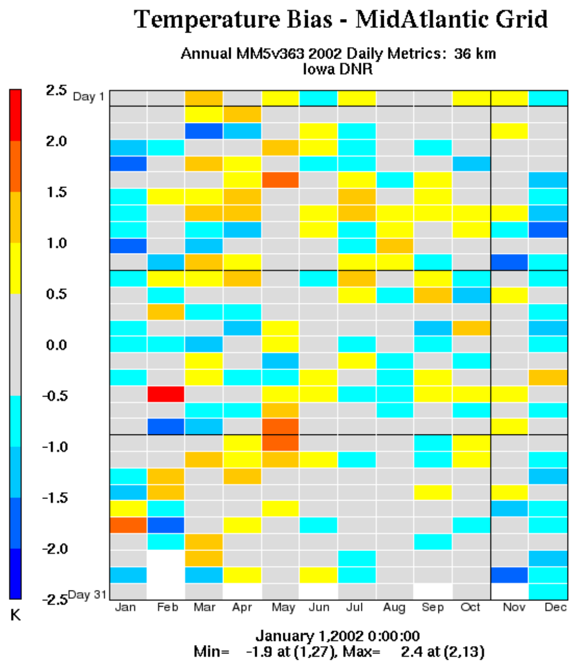

Humidity Gross Error - NE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
g/kg
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 0.2 at (1,24), Max= 2.7 at (4,15)

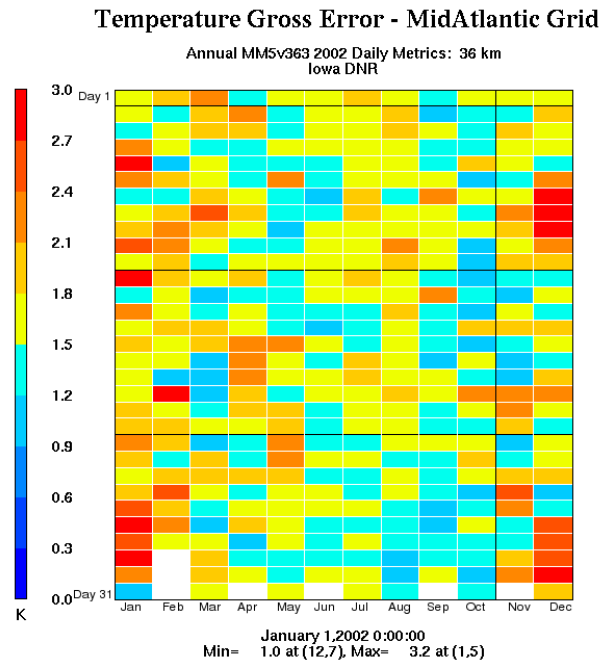

Wind Spd Bias - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
January 1,2002 0:00:00
Min= -0.7 at (2,5), Max= 0.9 at (11,4)

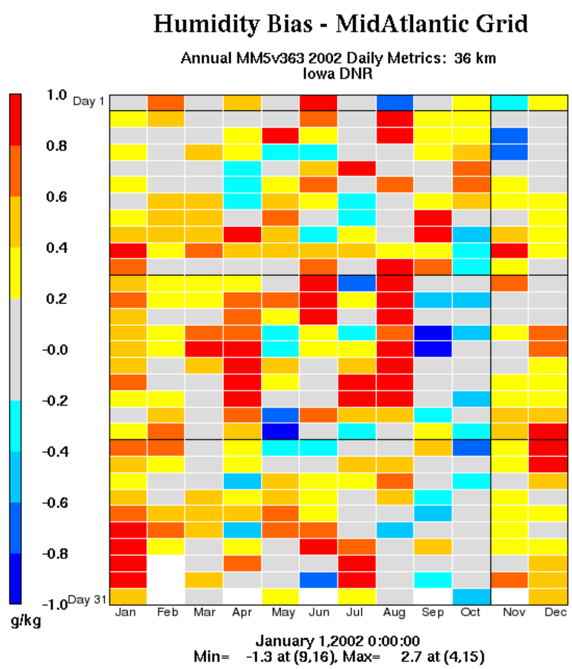

Wind Spd Gross Error - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
January 1,2002 0:00:00
Min= 0.8 at (11,11), Max= 1.9 at (12,6)

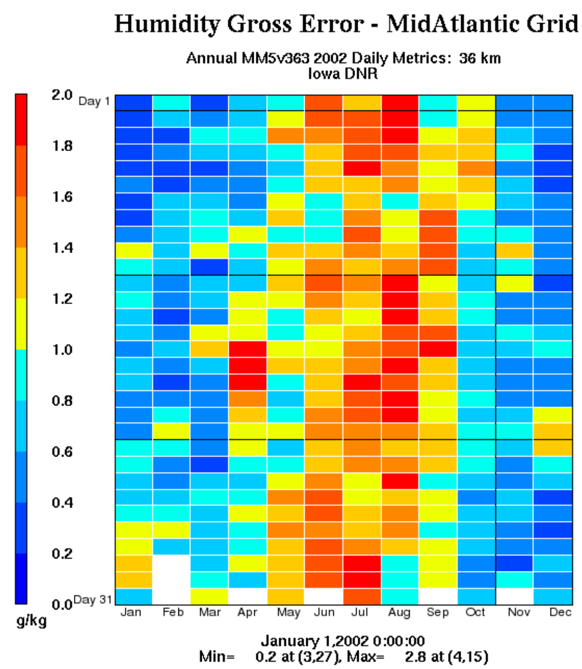

Wind Dir Bias - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
January 1,2002 0:00:00
Min= -11.3 at (10,27), Max= 18.2 at (9,30)

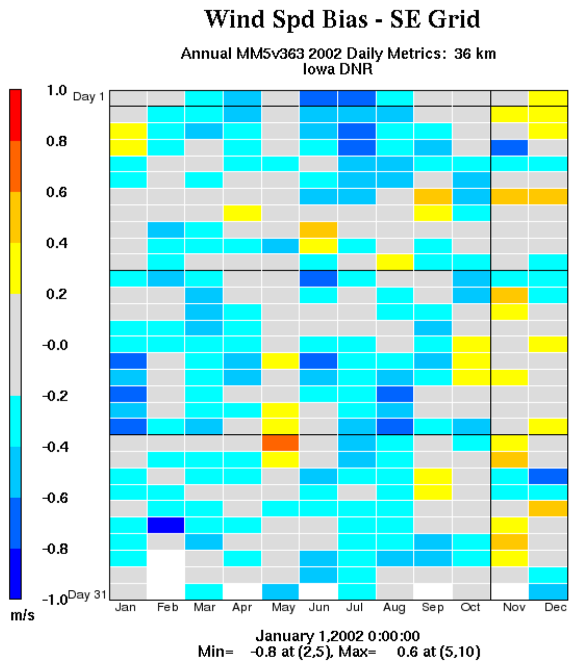

Wind Dir Gross Error - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
January 1,2002 0:00:00
Min= 12.7 at (2,27), Max= 50.1 at (8,6)

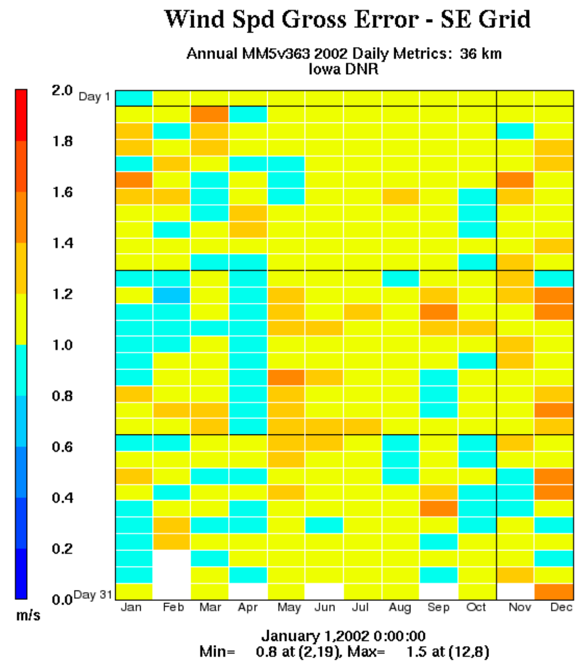

Temperature Bias - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1.5 -2.0 -2.5
K
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -1.9 at (1,27), Max= 2.4 at (2,13)

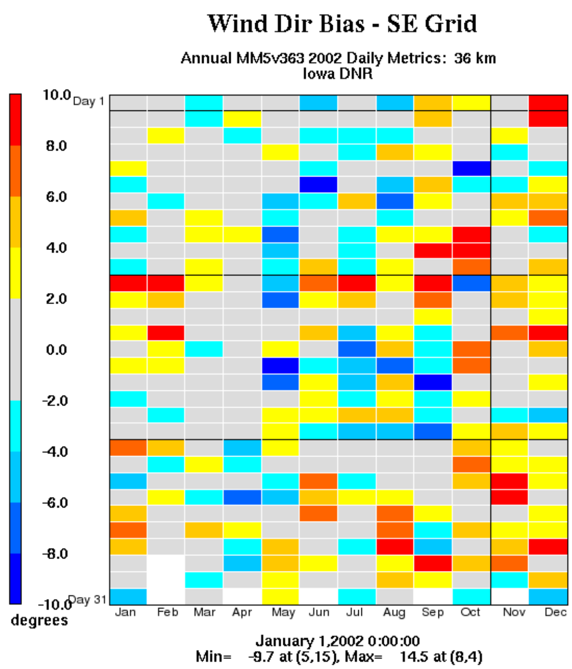

Temperature Gross Error - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
3.0 2.7 2.4 2.1 1.8 1.5 1.2 0.9 0.6 0.3 0.0
K
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 1.0 at (12,7), Max= 3.2 at (1,5)

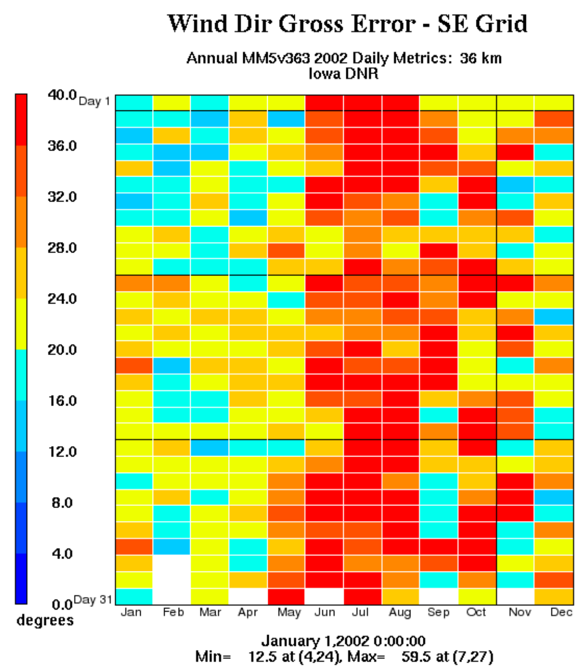

Humidity Bias - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
1.0 0.8 0.6 0.4 0.2 -0.0 -0.2 -0.4 -0.6 -0.8 -1.0
g/kg
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -1.3 at (9,16), Max= 2.7 at (4,15)


Humidity Gross Error - MidAtlantic Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
g/kg
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 0.2 at (3,27), Max= 2.8 at (4,15)

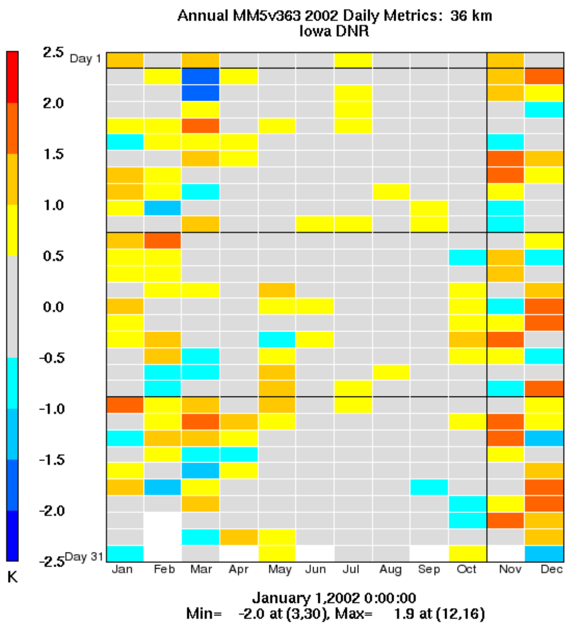

Wind Spd Bias - SE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
m/s
January 1,2002 0:00:00
Min= -0.8 at (2,5), Max= 0.6 at (5,10)


Wind Spd Gross Error - SE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
m/s
January 1,2002 0:00:00
Min= 0.8 at (2,19), Max= 1.5 at (12,8)

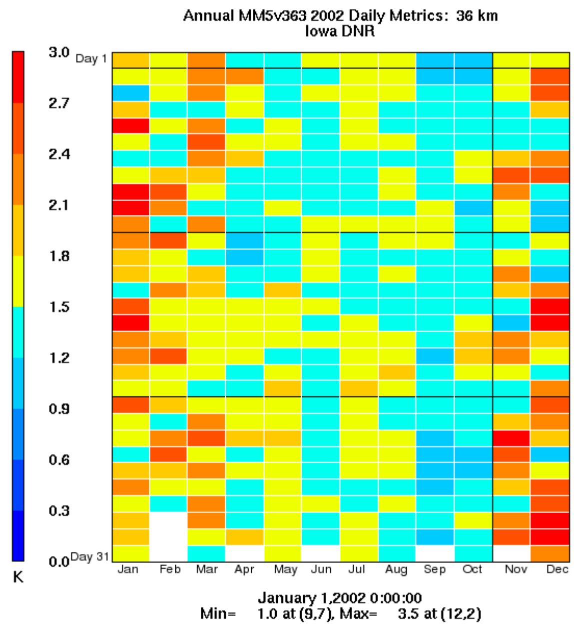

Wind Dir Bias - SE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
degrees
January 1,2002 0:00:00
Min= -9.7 at (5,15), Max= 14.5 at (8,4)


Wind Dir Gross Error - SE Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
degrees
January 1,2002 0:00:00
Min= 12.5 at (4,24), Max= 59.5 at (7,27)

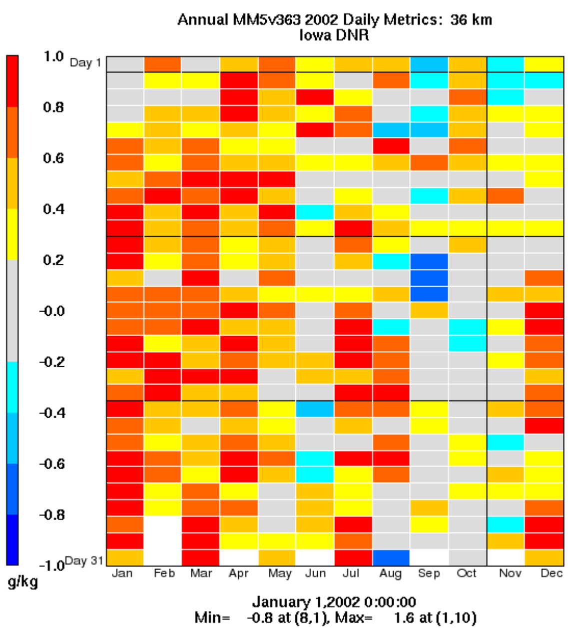
Temperature Bias - SE Grid



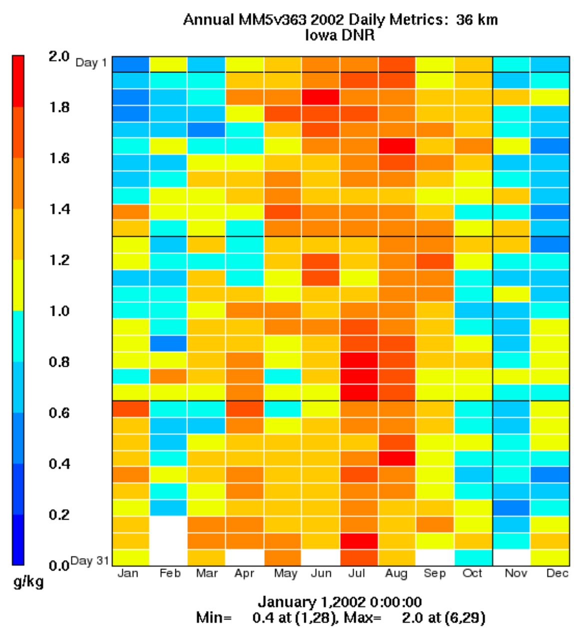
Temperature Gross Error - SE Grid



Humidity Bias - SE Grid

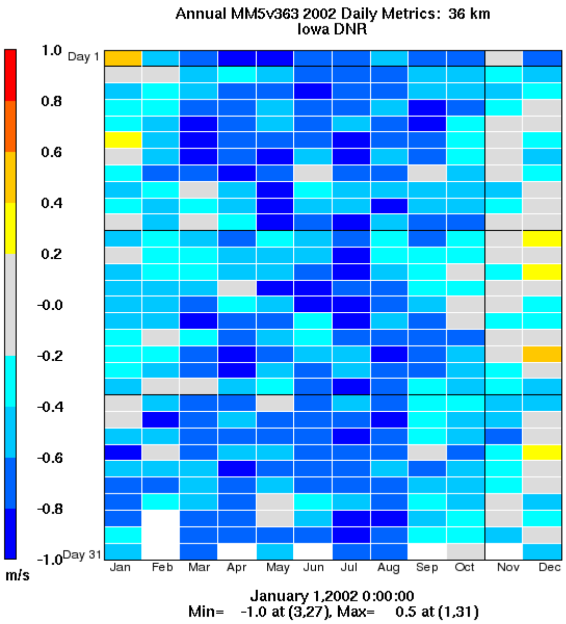


Humidity Gross Error - SE Grid

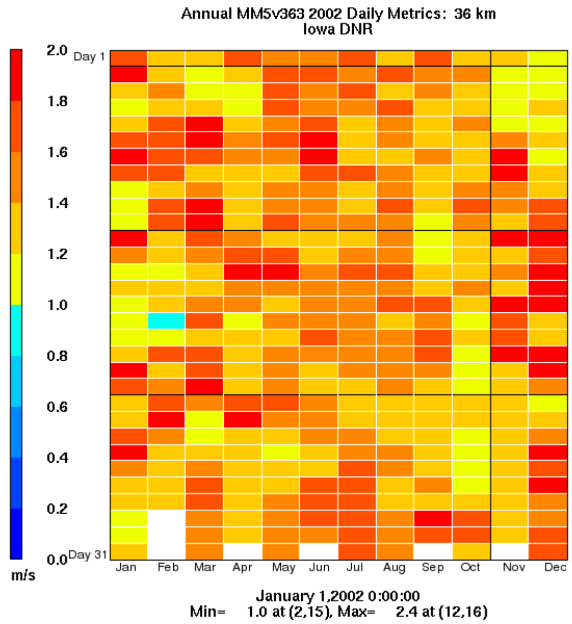


Western Subdomains

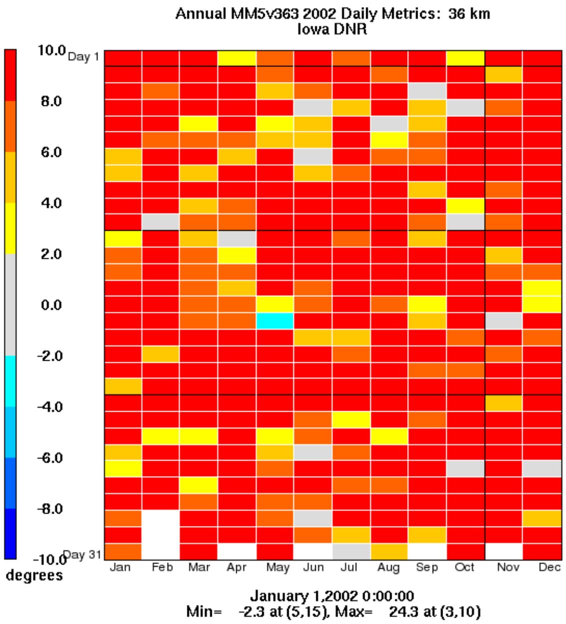
Wind Spd Bias - PacificNW Grid



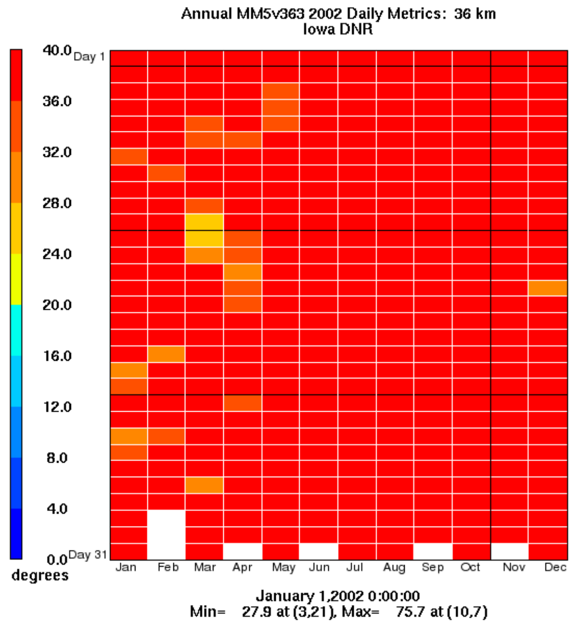
Wind Spd Gross Error - PacificNW Grid



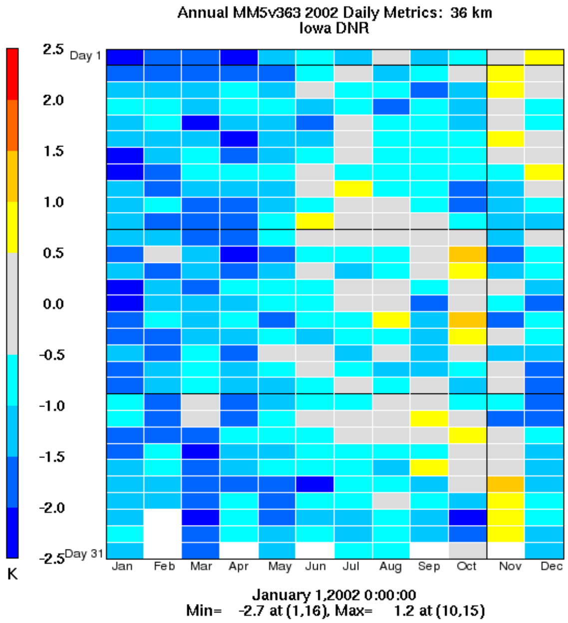
Wind Dir Bias - PacificNW Grid



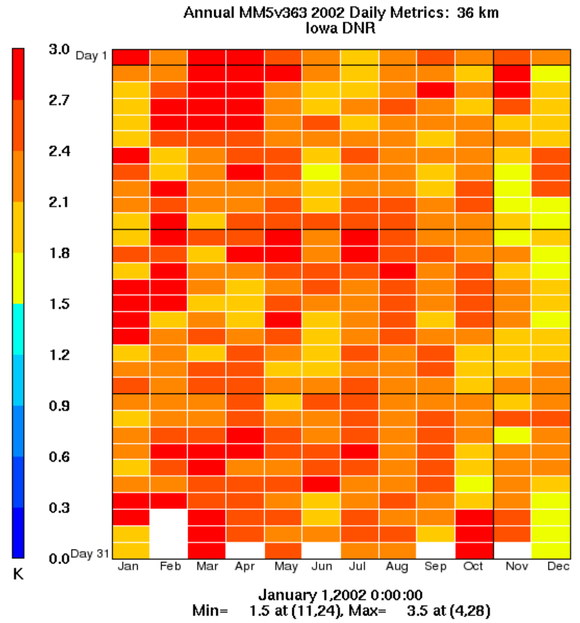
Wind Dir Gross Error - PacificNW Grid



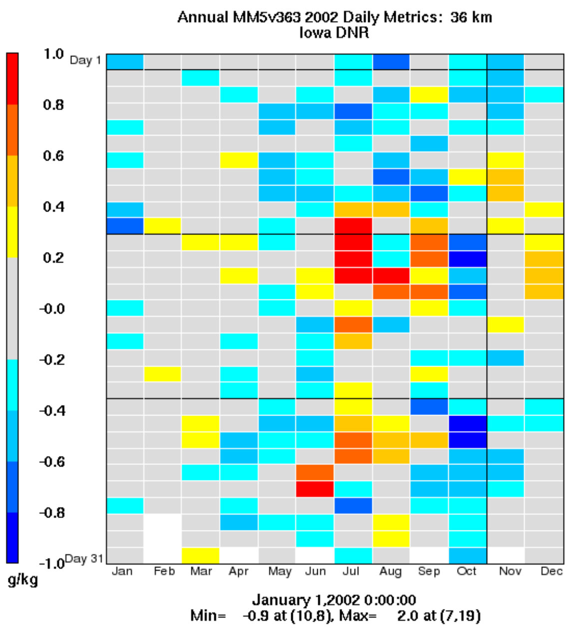
Temperature Bias - PacificNW Grid



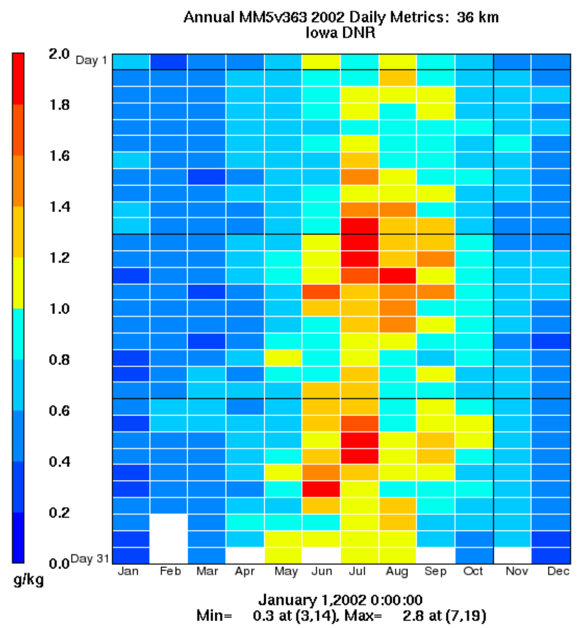
Temperature Gross Error - PacificNW Grid

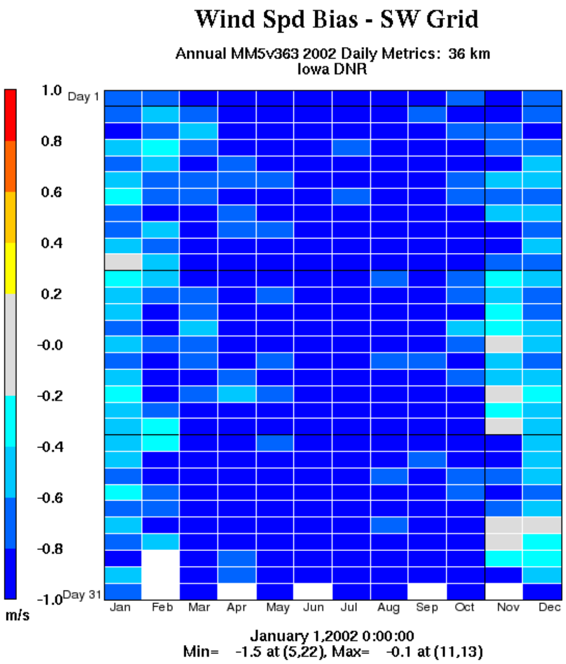


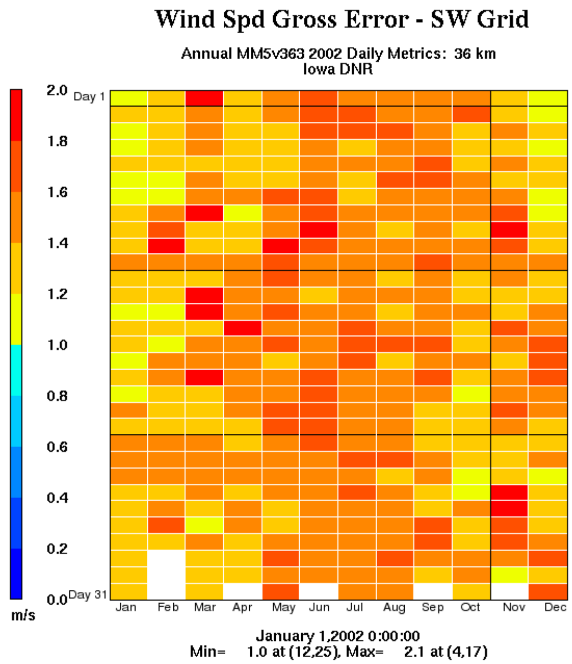
Humidity Bias - PacificNW Grid

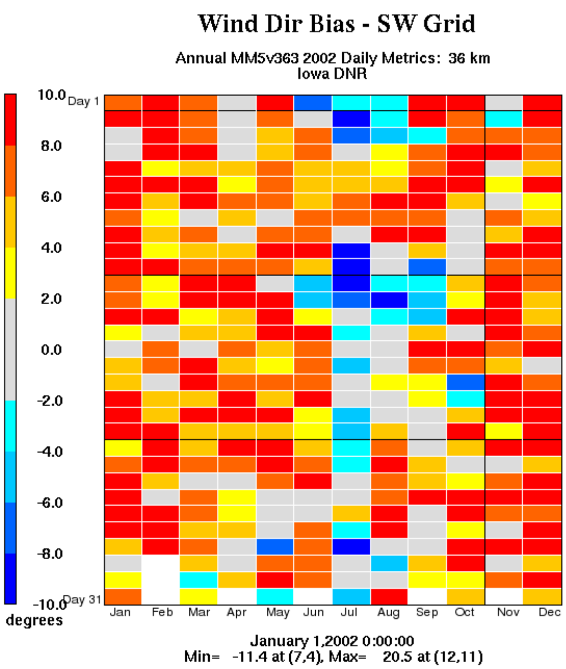


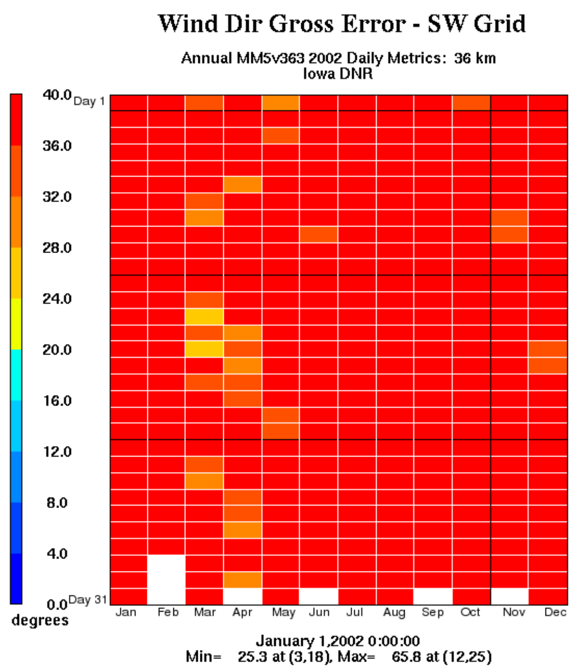
Humidity Gross Error - PacificNW Grid



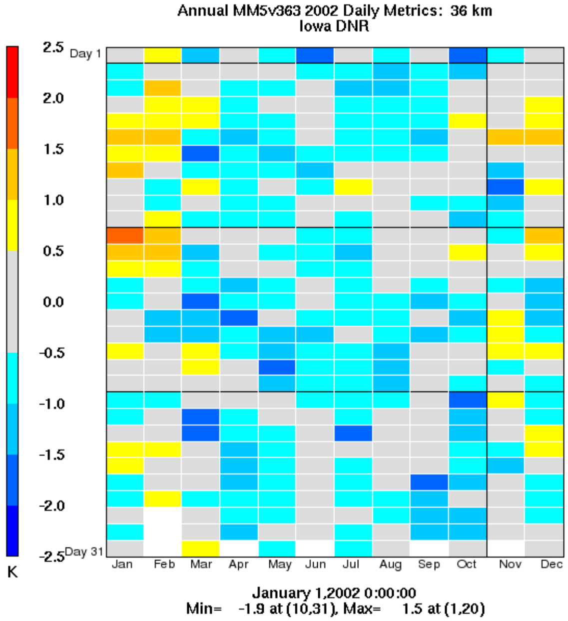

Wind Spd Bias - SW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
m/s
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -1.5 at (5,22), Max= -0.1 at (11,13)


Wind Spd Gross Error - SW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
m/s
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 1.0 at (12,25), Max= 2.1 at (4,17)

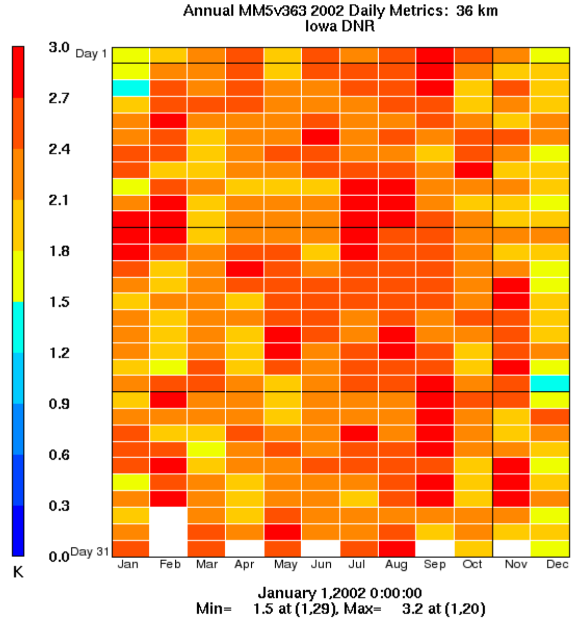

Wind Dir Bias - SW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
degrees
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -11.4 at (7,4), Max= 20.5 at (12,11)


Wind Dir Gross Error - SW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
degrees
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 25.3 at (3,18), Max= 65.8 at (12,25)

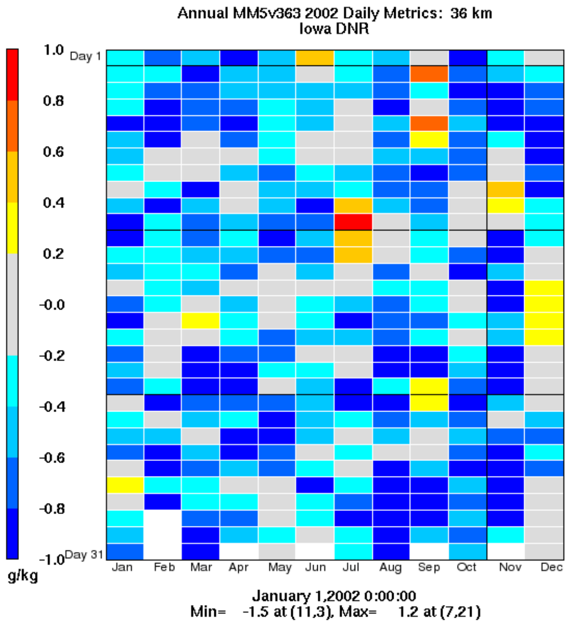
Temperature Bias - SW Grid



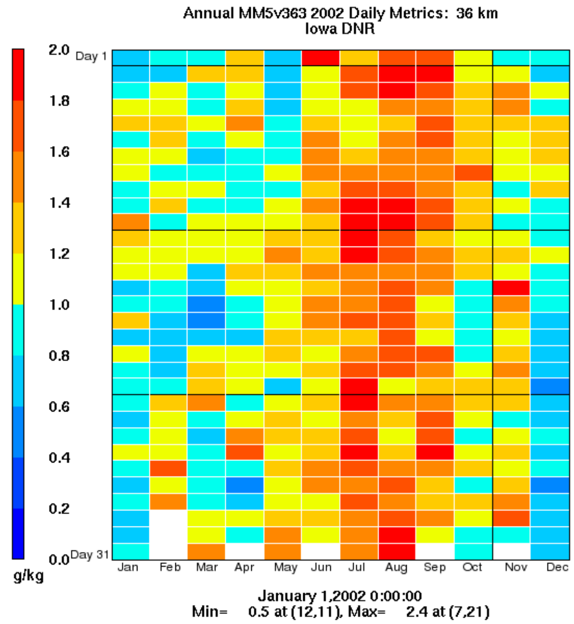
Temperature Gross Error - SW Grid

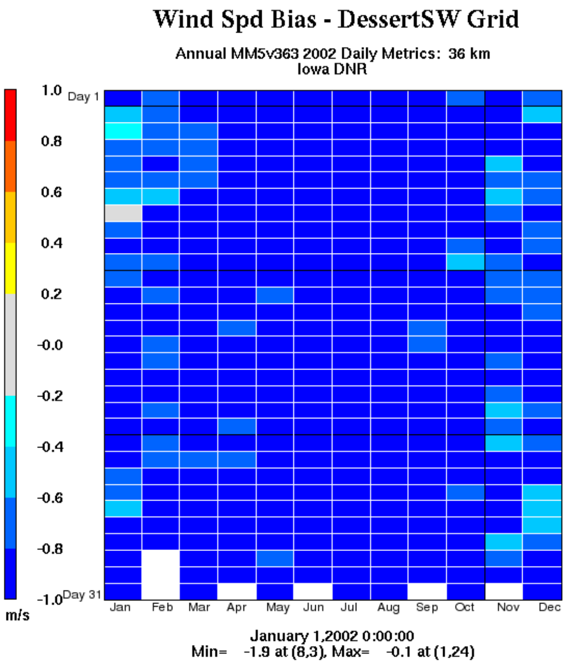


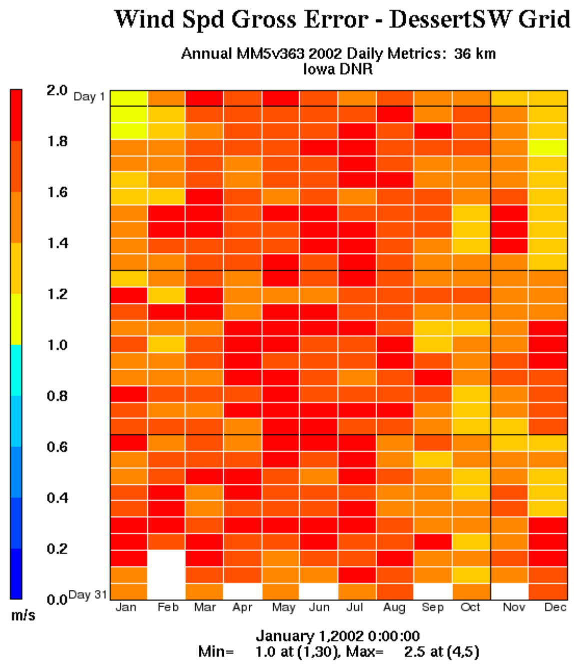
Humidity Bias - SW Grid

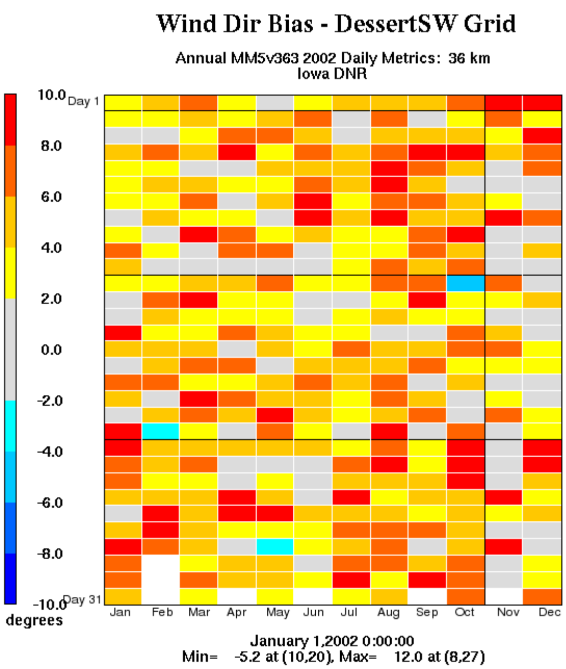


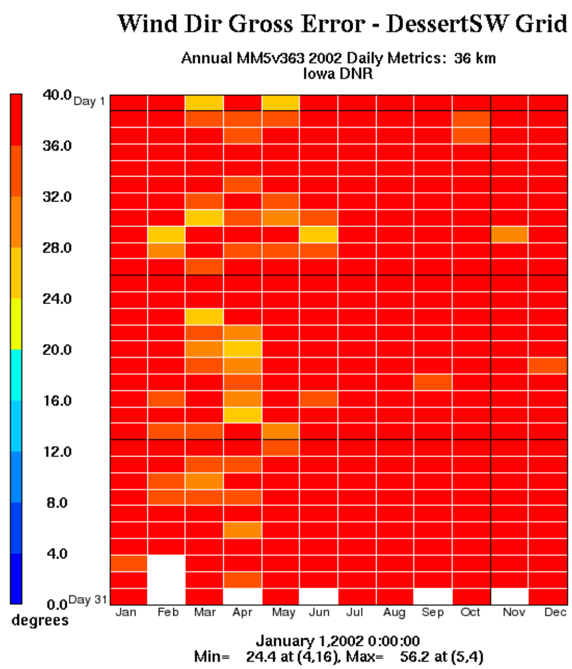
Humidity Gross Error - SW Grid



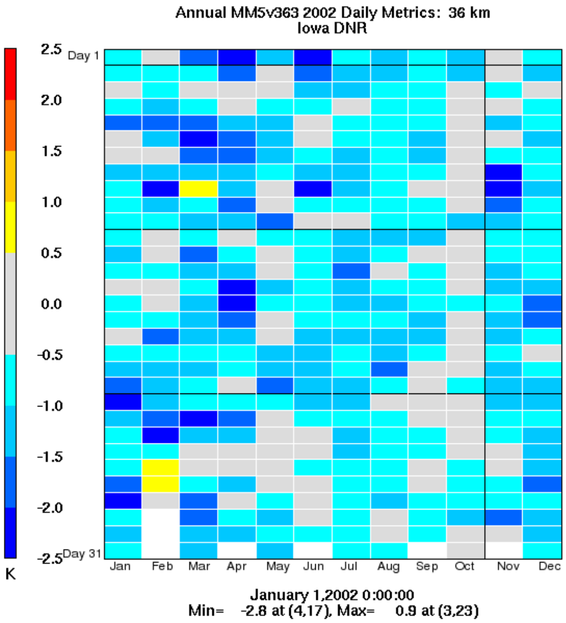

Wind Spd Bias - DessertSW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
m/s
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -1.9 at (8,3), Max= -0.1 at (1,24)


Wind Spd Gross Error - DessertSW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
m/s
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 1.0 at (1,30), Max= 2.5 at (4,5)

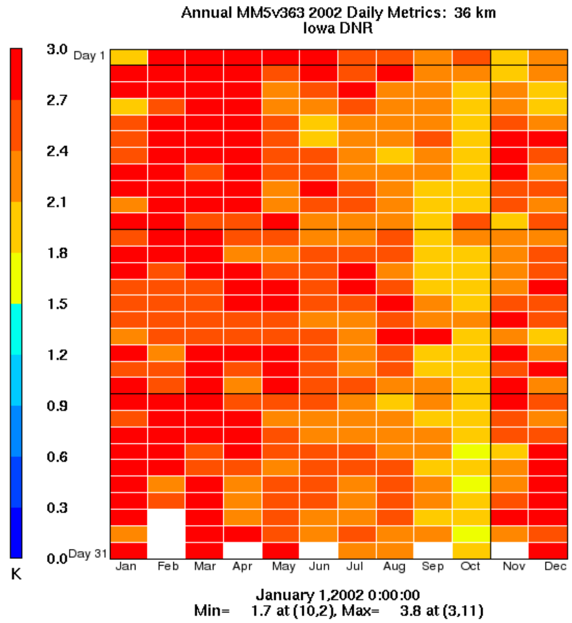

Wind Dir Bias - DessertSW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
degrees
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= -5.2 at (10,20), Max= 12.0 at (8,27)


Wind Dir Gross Error - DessertSW Grid
Annual MM5v363 2002 Daily Metrics: 36 km
Iowa DNR
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
degrees
Day 1
Day 31
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
January 1,2002 0:00:00
Min= 24.4 at (4,16), Max= 56.2 at (5,4)

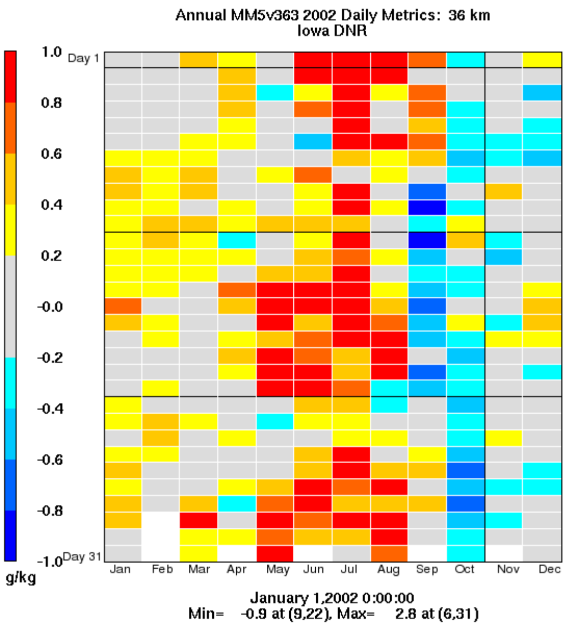
Temperature Bias - DessertSW Grid



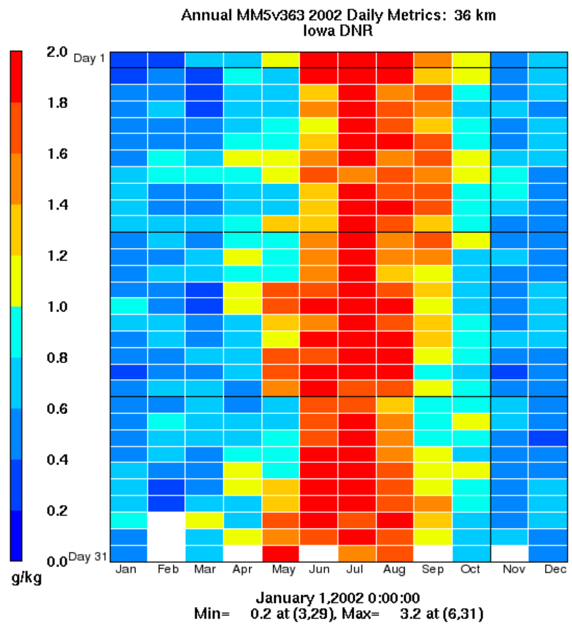
Temperature Gross Error - DessertSW Grid



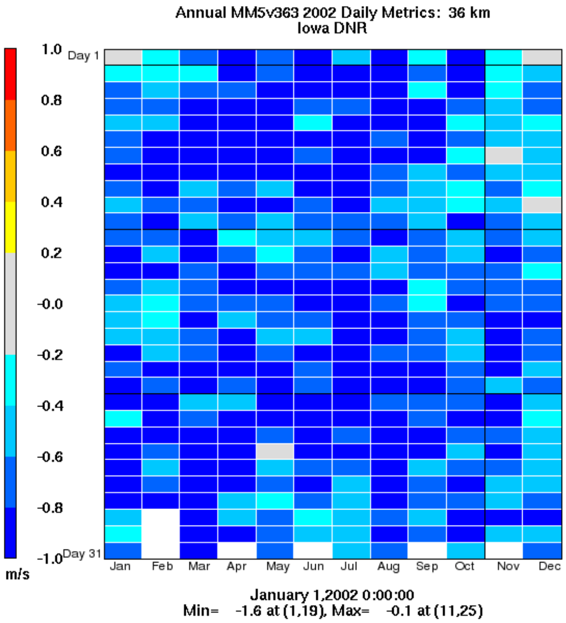
Humidity Bias - DessertSW Grid



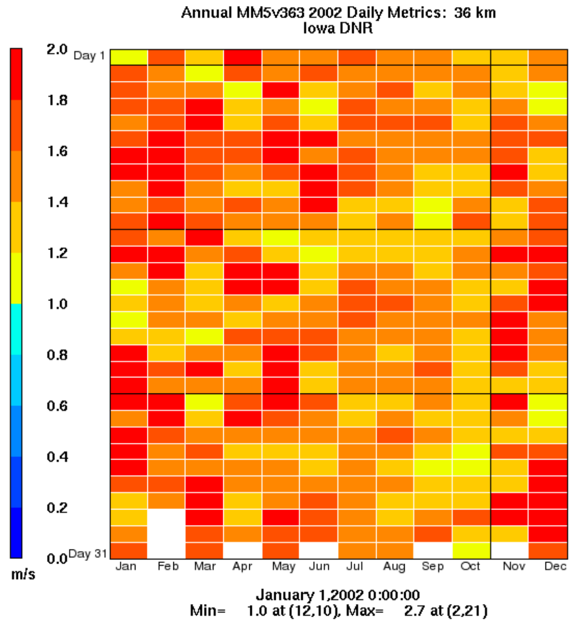
Humidity Gross Error - DessertSW Grid



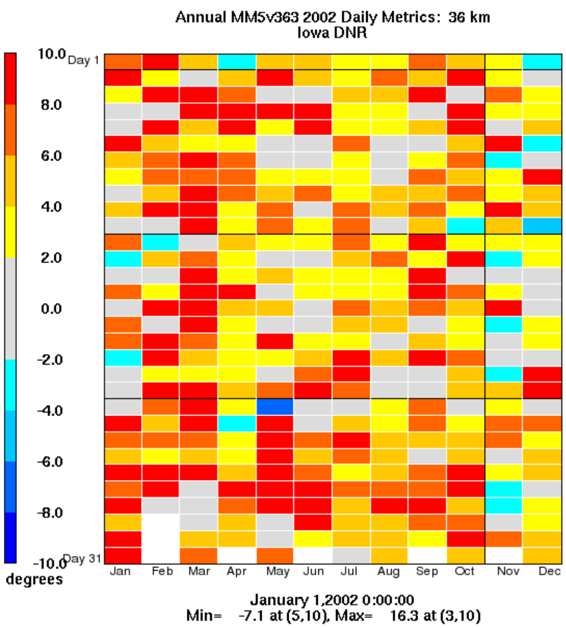
Wind Spd Bias - North Grid



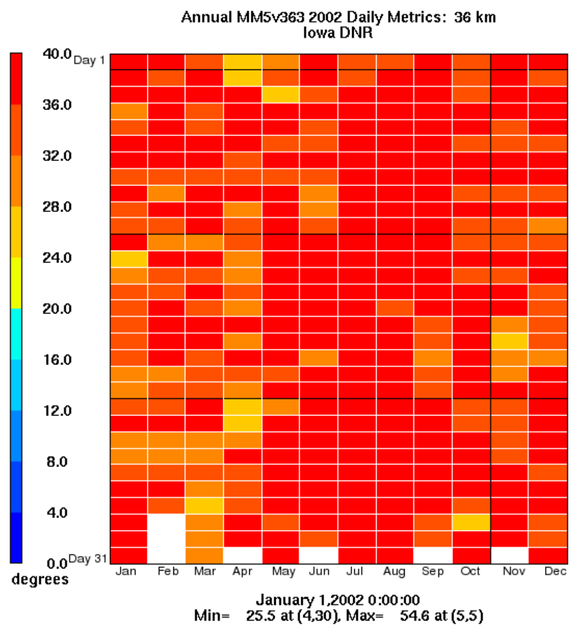
Wind Spd Gross Error - North Grid



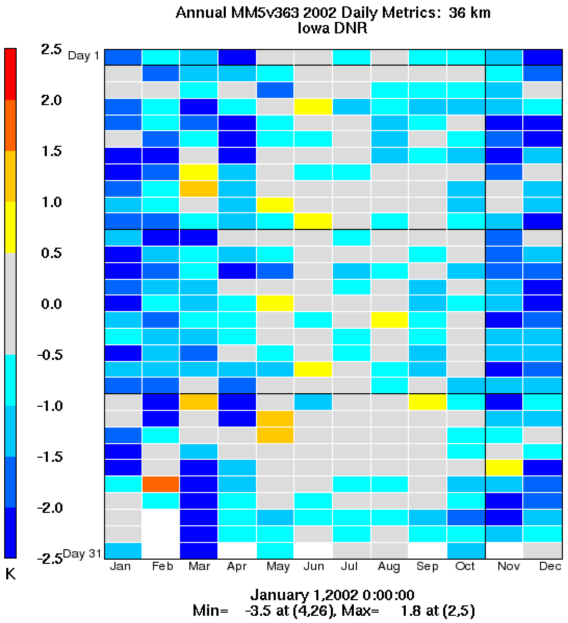
Wind Dir Bias - North Grid



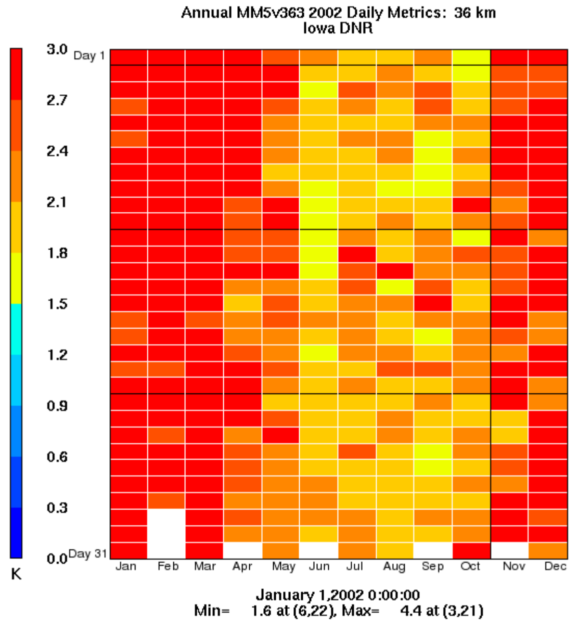
Wind Dir Gross Error - North Grid



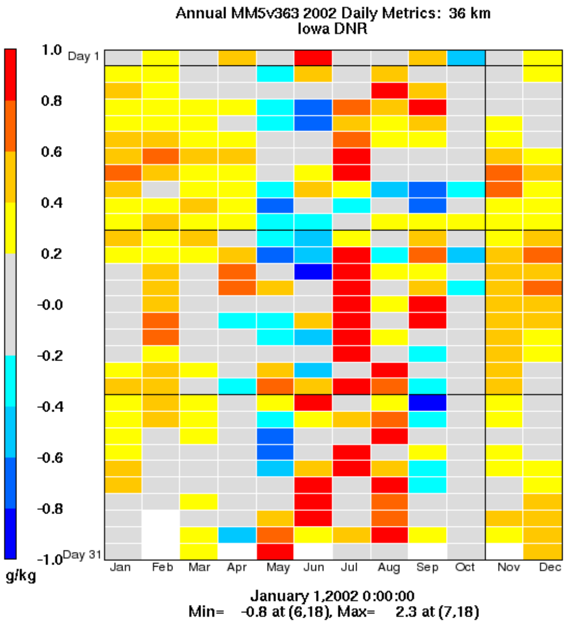
Temperature Bias - North Grid



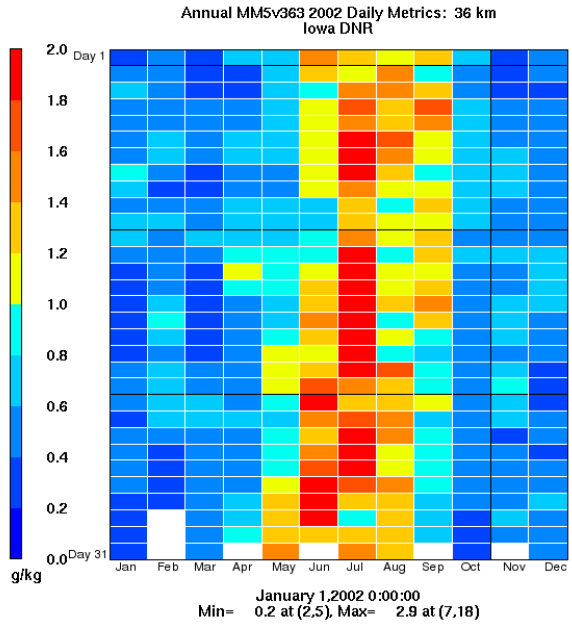
Temperature Gross Error - North Grid



Humidity Bias - North Grid



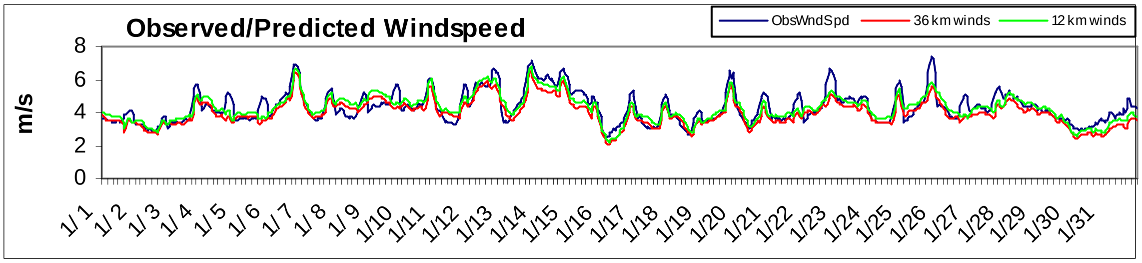
Humidity Gross Error - North Grid

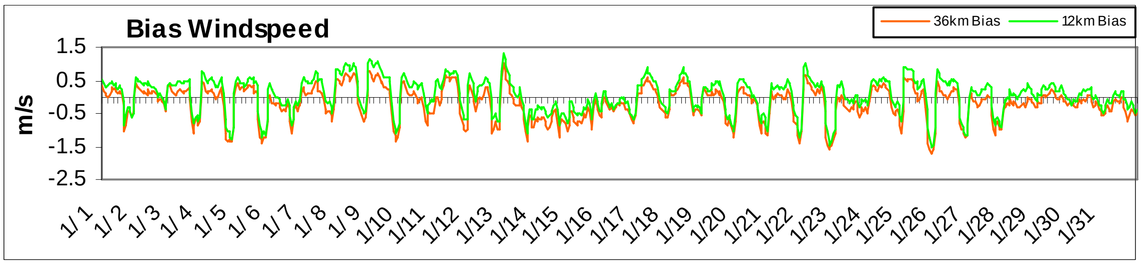


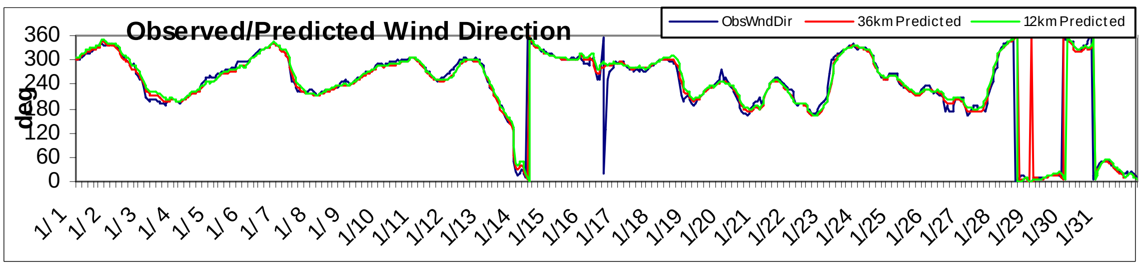
APPENDIX C

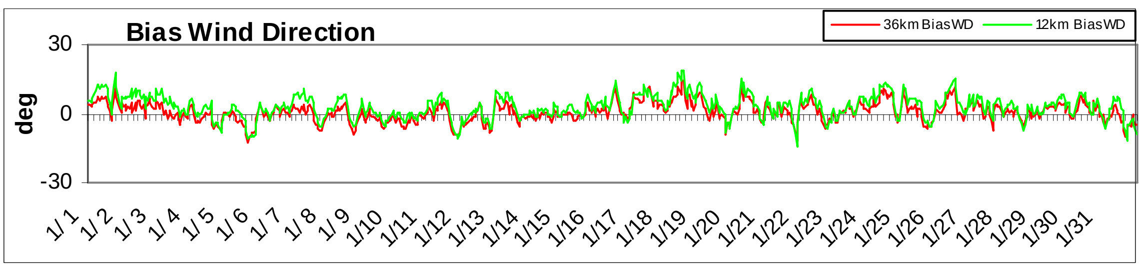
Hourly statistical results for both the 36 and 12 km grids.

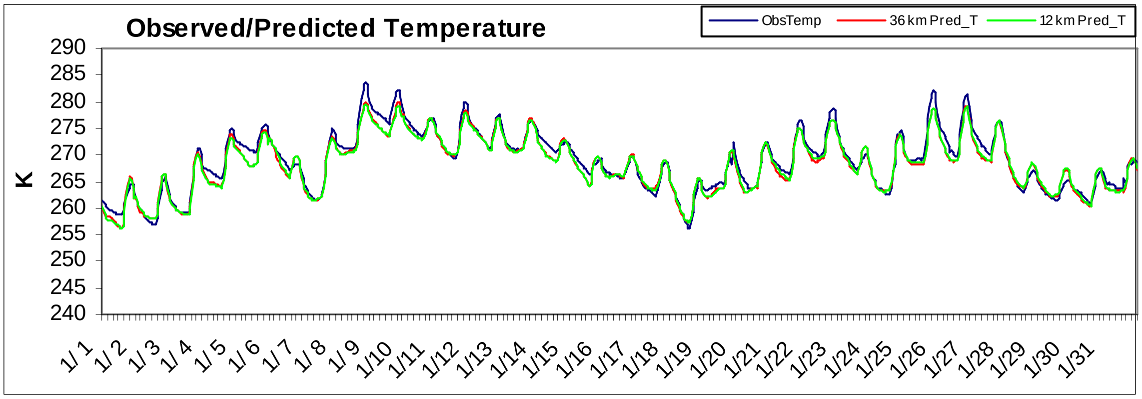
CenrapN: January 2002

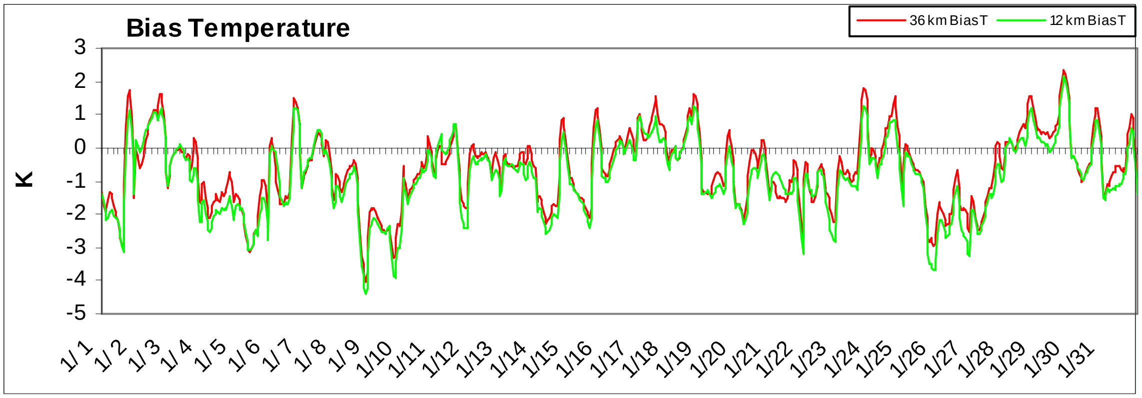









Observed/Predicted Temperature
ObsTemp
36 km Pred_T
12 km Pred_T
K
290
285
280
275
270
265
260
255
250
245
240
1/1
1/2
1/3
1/4
1/5
1/6
1/7
1/8
1/9
1/10
1/11
1/12
1/13
1/14
1/15
1/16
1/17
1/18
1/19
1/20
1/21
1/22
1/23
1/24
1/25
1/26
1/27
1/28
1/29
1/30
1/31


Bias Temperature
36 km BiasT
12 km BiasT
K
3
2
1
0
-1
-2
-3
-4
-5
1/1
1/2
1/3
1/4
1/5
1/6
1/7
1/8
1/9
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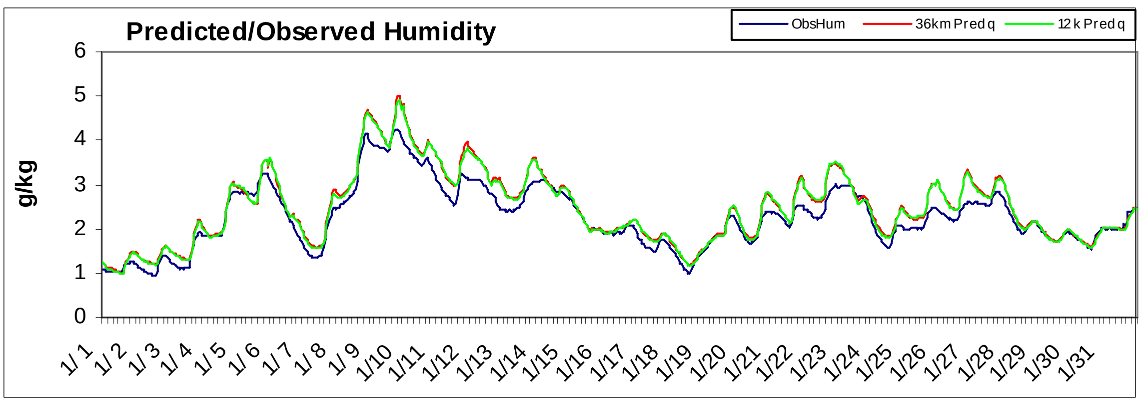
Predicted/Observed Humidity
ObsHum
36km Pred q
12 k Pred q
g/kg
6
5
4
3
2
1
0
1/1
1/2
1/3
1/4
1/5
1/6
1/7
1/8
1/9
1/10
1/11
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1/29
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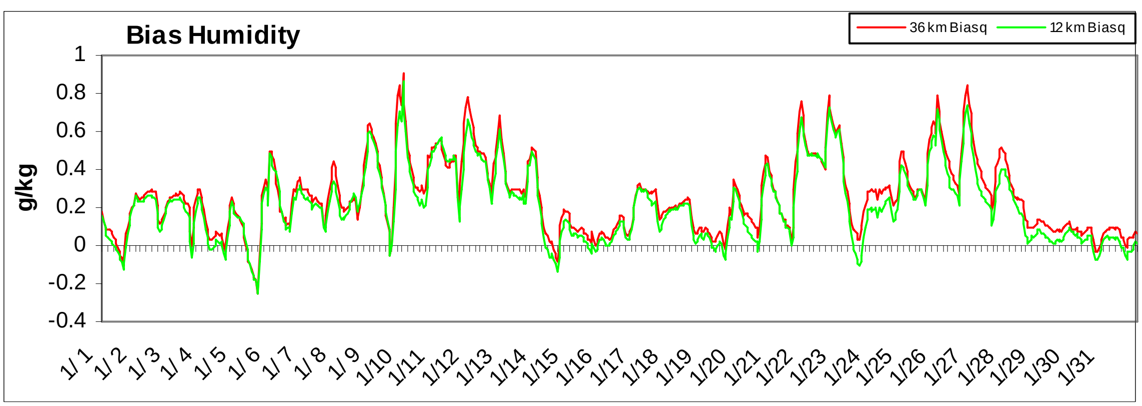
Bias Humidity
36 km Biasq
12 km Biasq
g/kg
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1/1
1/2
1/3
1/4
1/5
1/6
1/7
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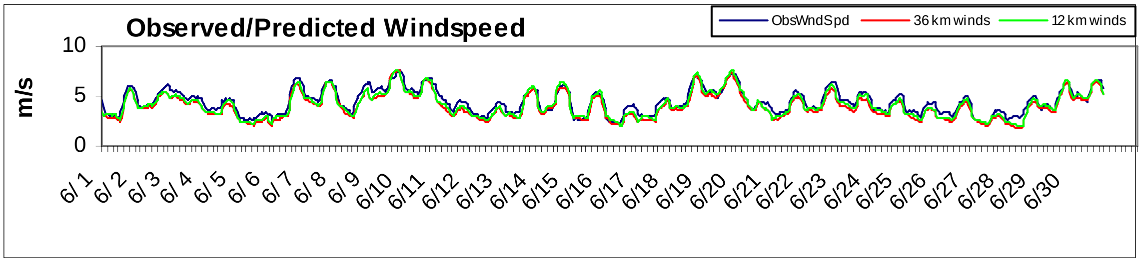
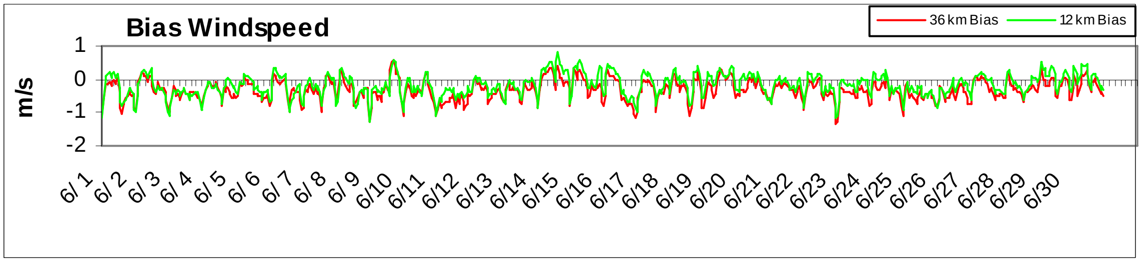
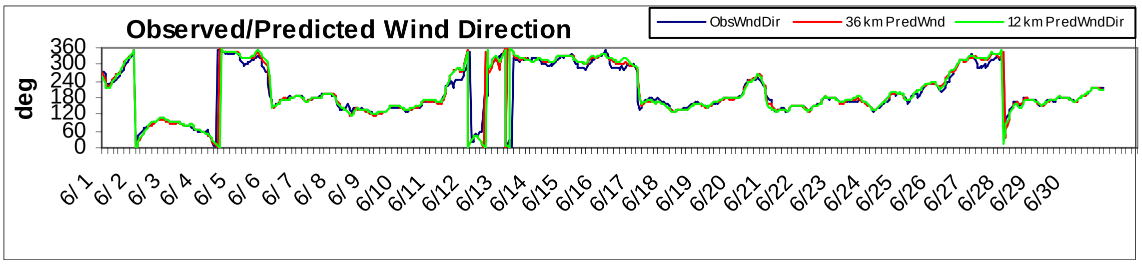
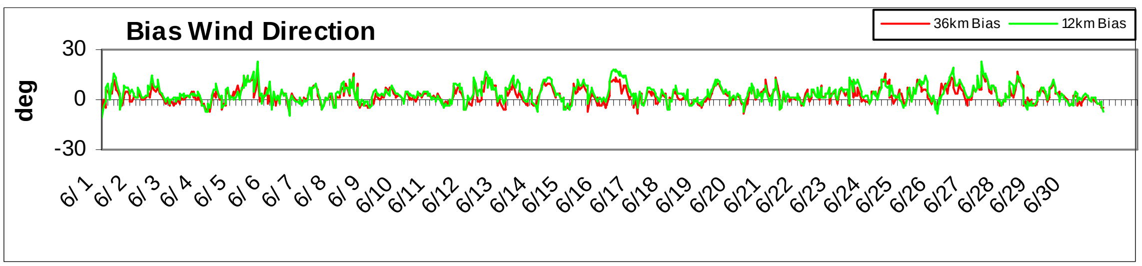
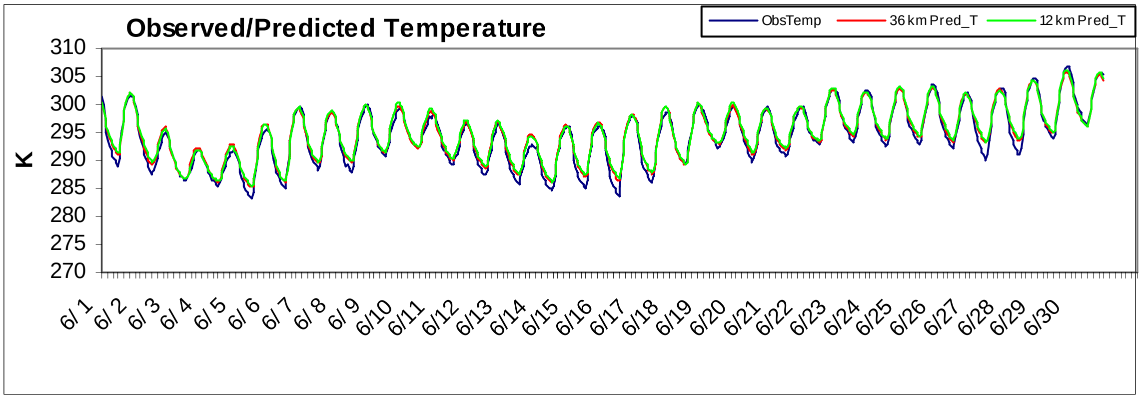
<u>**CenrapN: June 2002**</u>










Observed/Predicted Temperature
ObsTemp
36 km Pred_T
12 km Pred_T
K
310
305
300
295
290
285
280
275
270
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
6/ 7
6/ 8
6/ 9
6/10
6/11
6/12
6/13
6/14
6/15
6/16
6/17
6/18
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6/20
6/21
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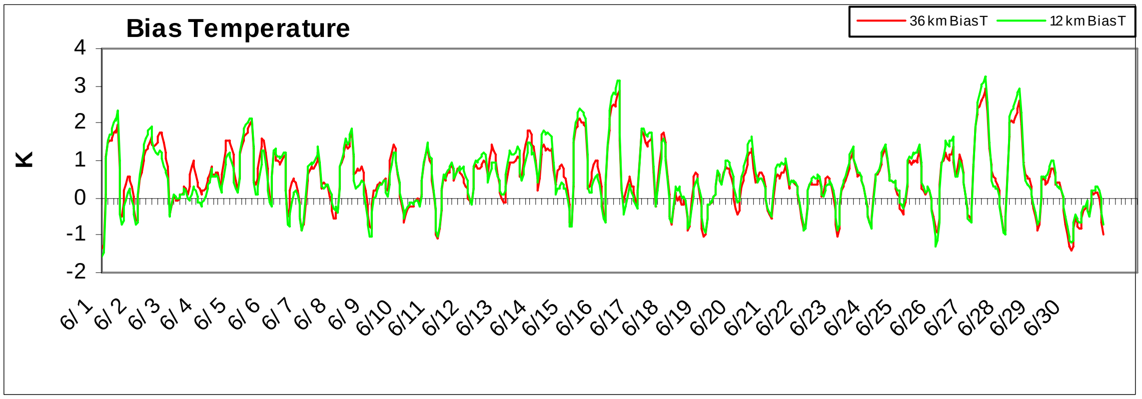
6/25
6/26
6/27
6/28
6/29
6/30


Bias Temperature
36 km BiasT
12 km BiasT
K
4
3
2
1
0
-1
-2
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
6/ 7
6/ 8
6/ 9
6/10
6/11
6/12
6/13
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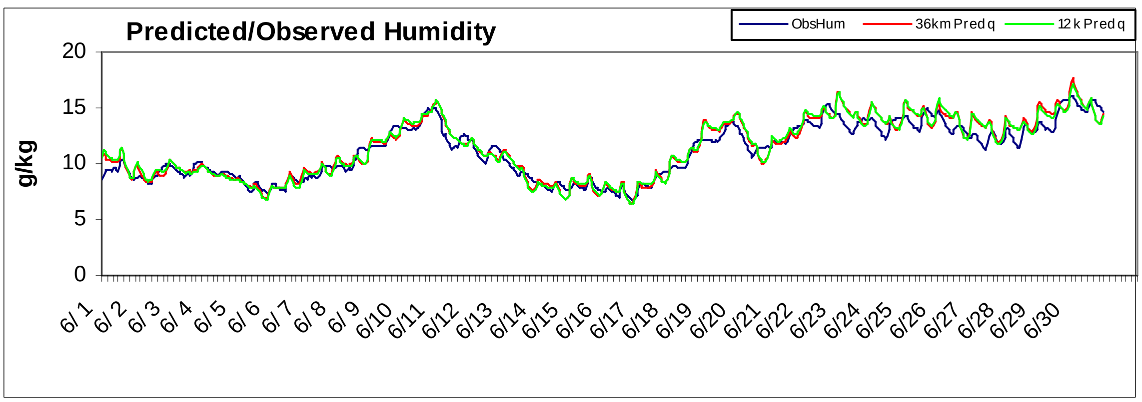
Predicted/Observed Humidity
ObsHum
36km Pred q
12 k Pred q
g/kg
20
15
10
5
0
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
6/ 7
6/ 8
6/ 9
6/10
6/11
6/12
6/13
6/14
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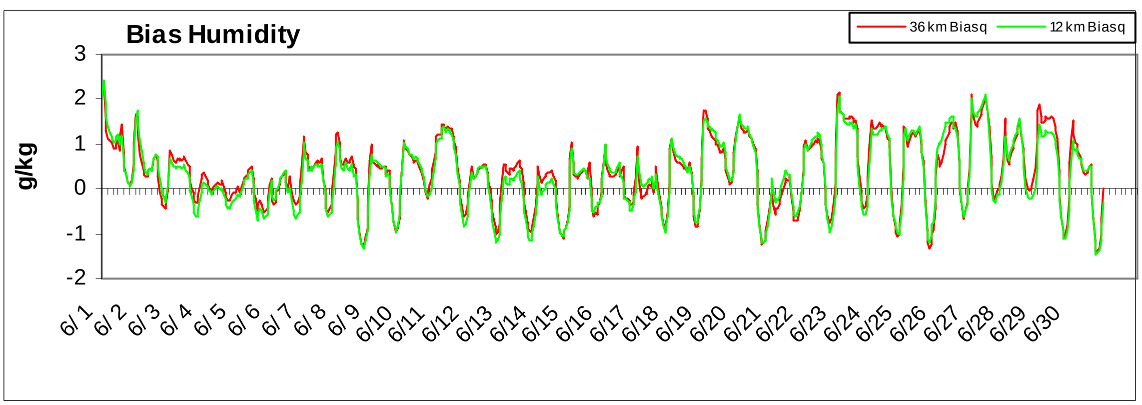
Bias Humidity
36 km Biasq
12 km Biasq
g/kg
3
2
1
0
-1
-2
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
6/ 7
6/ 8
6/ 9
6/10
6/11
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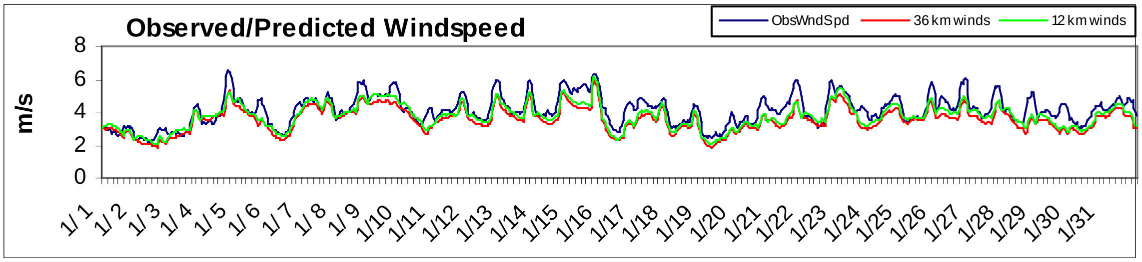
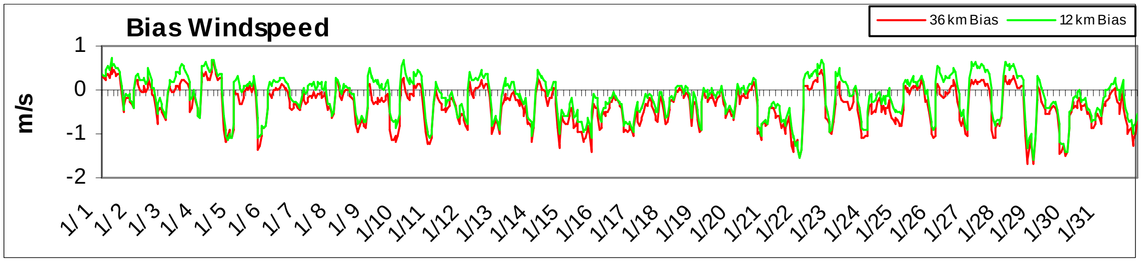
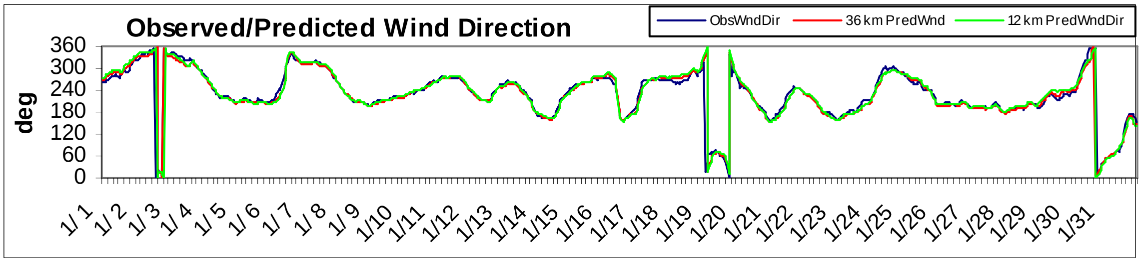
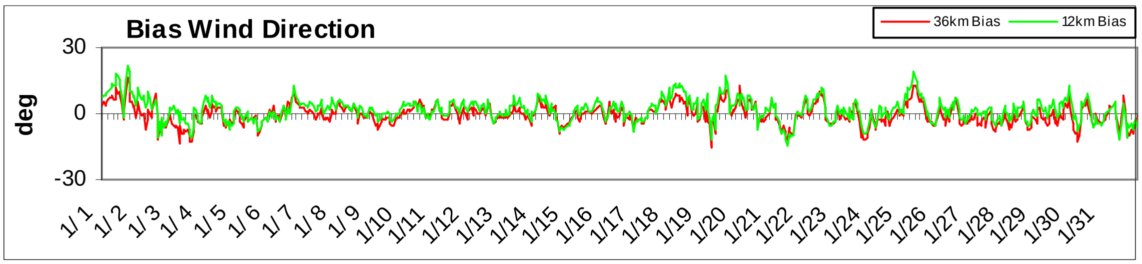
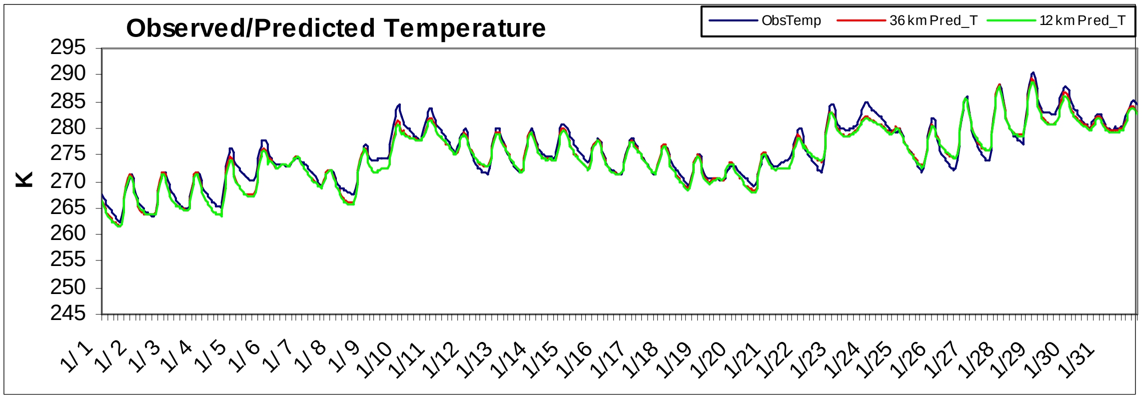
OhioVal: January 2002










Observed/Predicted Temperature
ObsTemp
36 km Pred_T
12 km Pred_T
K
295
290
285
280
275
270
265
260
255
250
245
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
1/ 8
1/ 9
1/10
1/11
1/12
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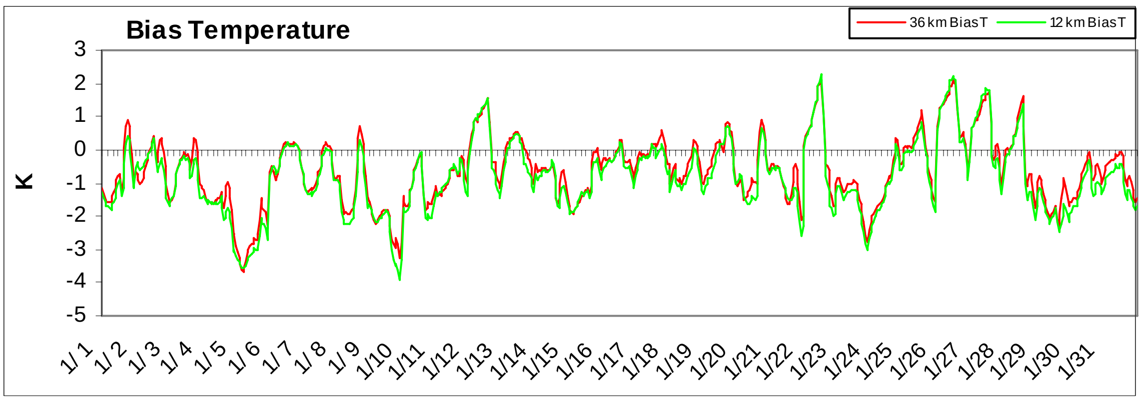
Bias Temperature
36 km BiasT
12 km BiasT
K
3
2
1
0
-1
-2
-3
-4
-5
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
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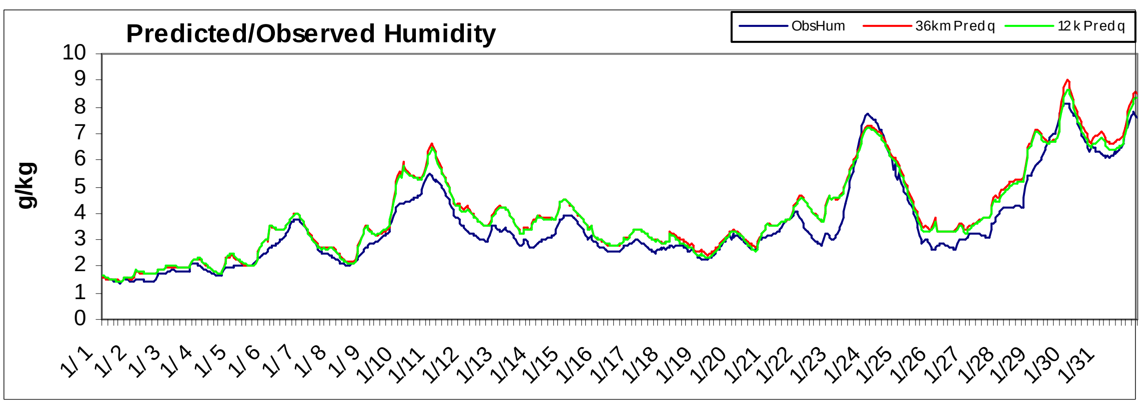
Predicted/Observed Humidity
ObsHum
36km Pred q
12 k Pred q
g/kg
10
9
8
7
6
5
4
3
2
1
0
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
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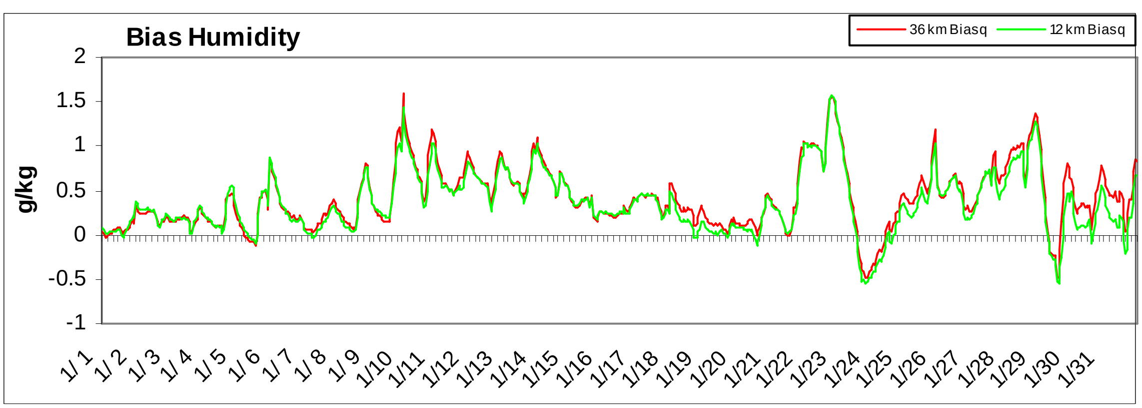
Bias Humidity
36 km Biasq
12 km Biasq
g/kg
2
1.5
1
0.5
0
-0.5
-1
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
1/ 8
1/ 9
1/10
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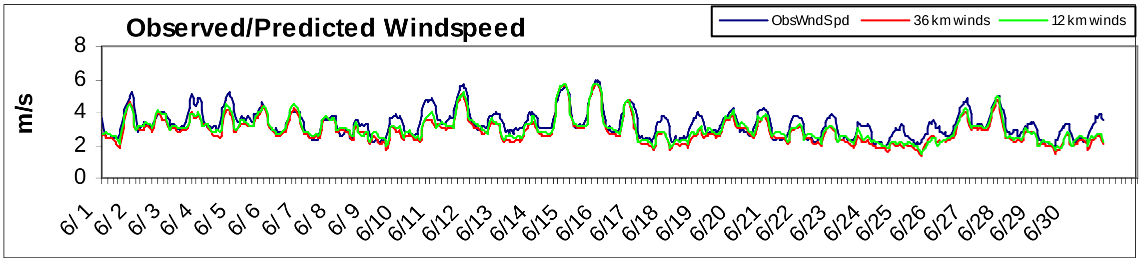
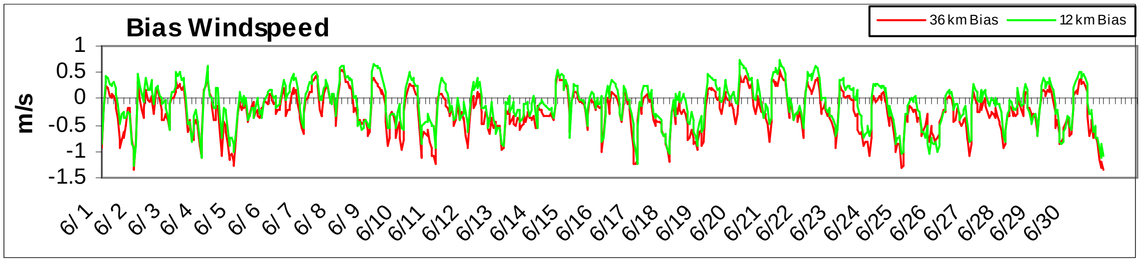
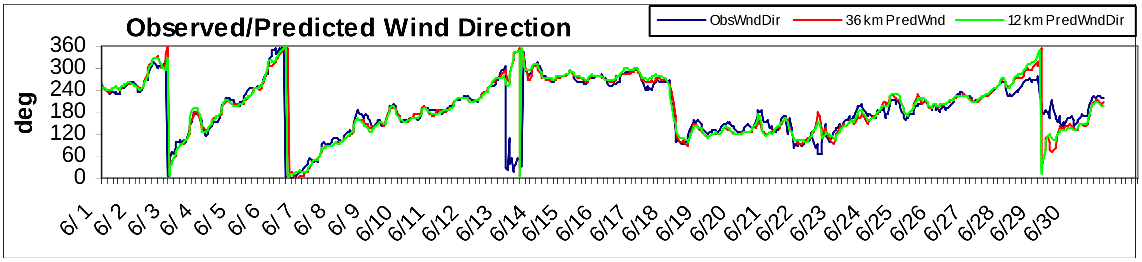
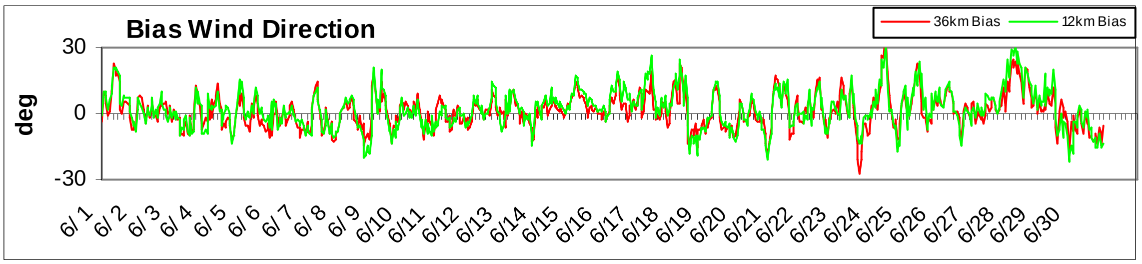
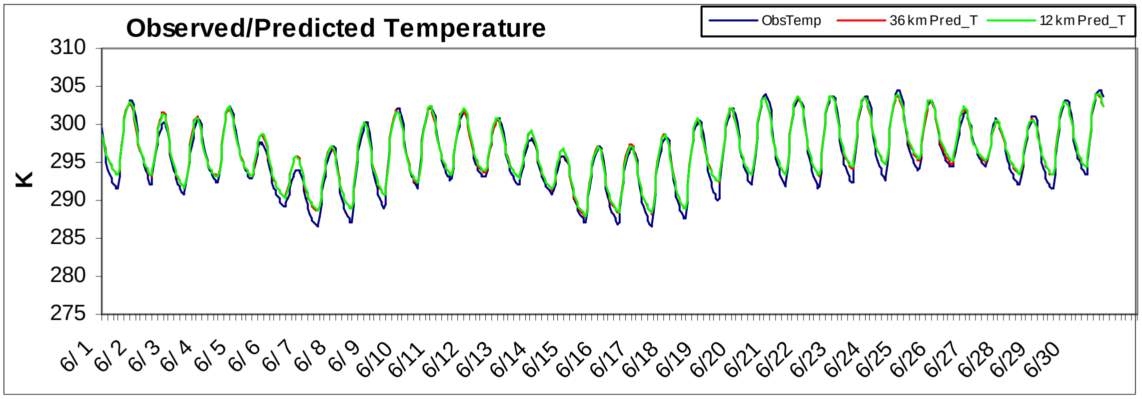
OhioVal: June 2002










Observed/Predicted Temperature
ObsTemp
36 km Pred_T
12 km Pred_T
K
310
305
300
295
290
285
280
275
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
6/ 7
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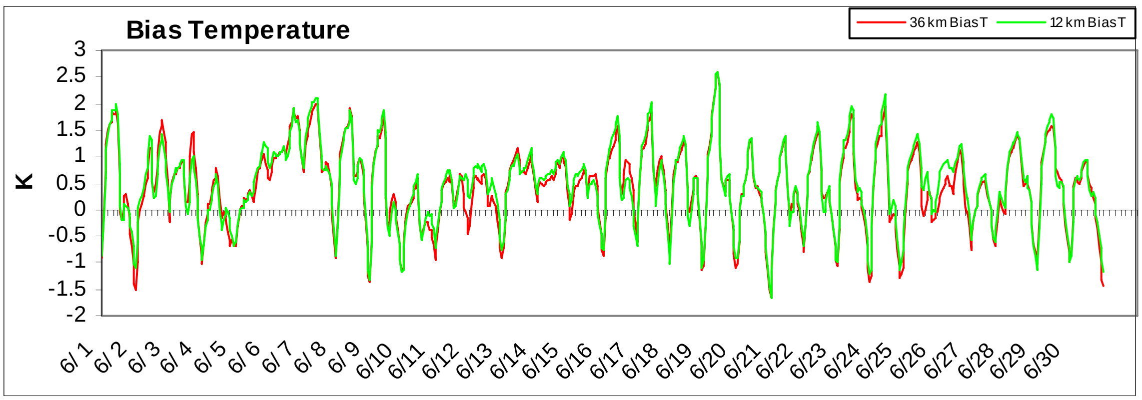
Bias Temperature
36 km BiasT
12 km BiasT
K
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
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6/11
6/12
6/13
6/14
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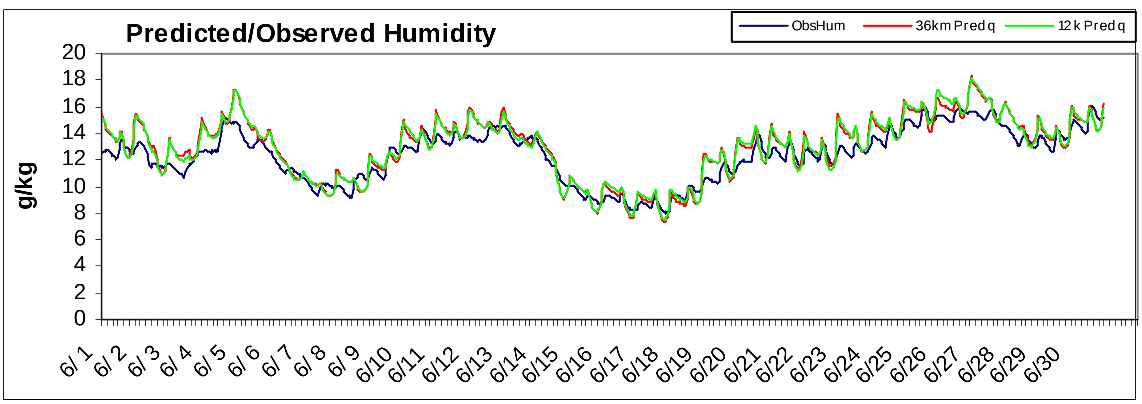
Predicted/Observed Humidity
ObsHum
36km Pred q
12 k Pred q
g/kg
20
18
16
14
12
10
8
6
4
2
0
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
6/ 7
6/ 8
6/ 9
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6/11
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6/14
6/15
6/16
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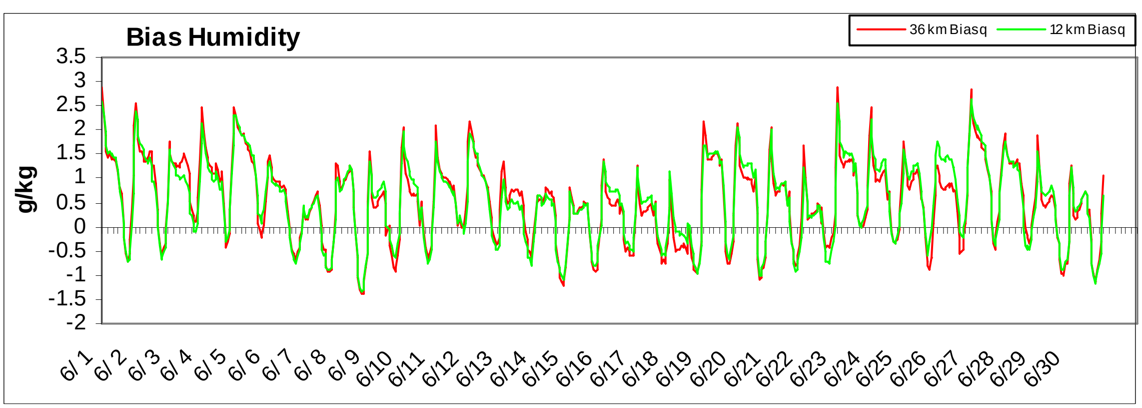
Bias Humidity
36 km Biasq
12 km Biasq
g/kg
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
6/ 1
6/ 2
6/ 3
6/ 4
6/ 5
6/ 6
6/ 7
6/ 8
6/ 9
6/10
6/11
6/12
6/13
6/14
6/15
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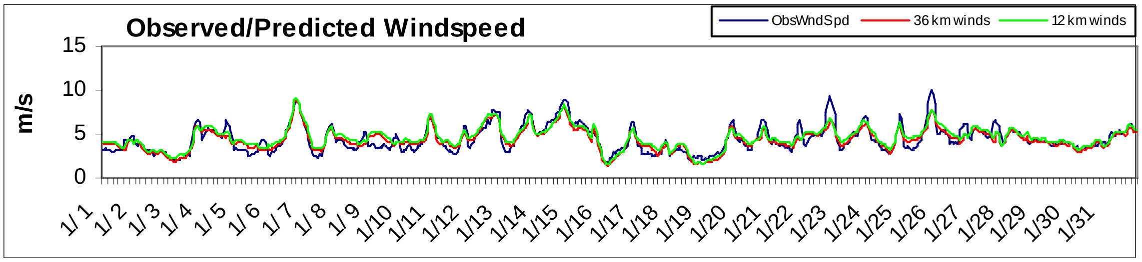
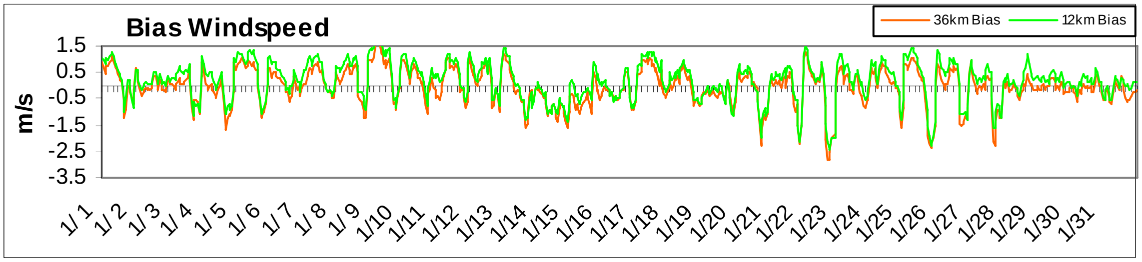
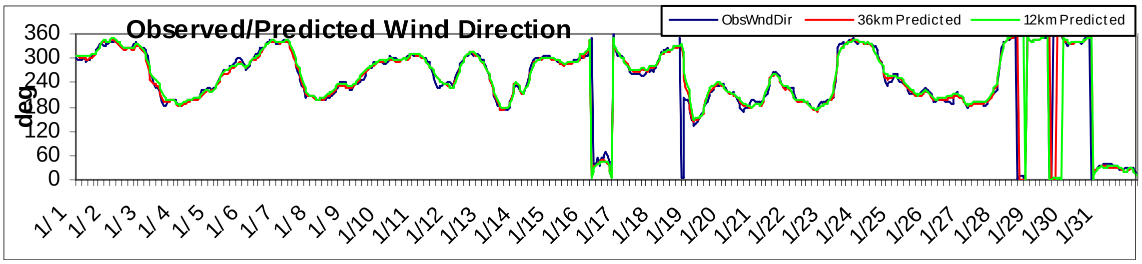
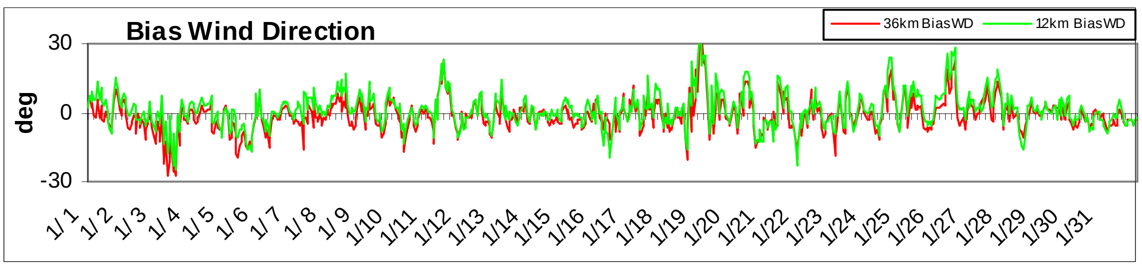
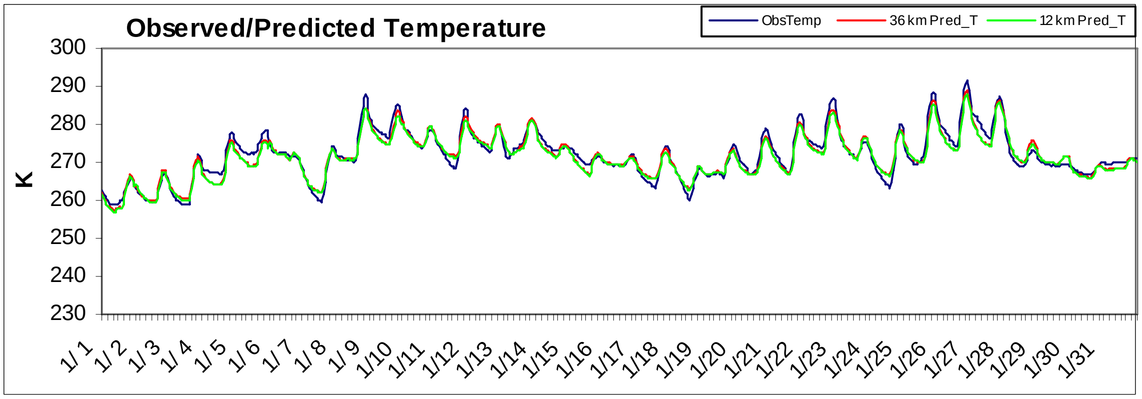
Iowa: January 2002










Observed/Predicted Temperature
ObsTemp
36 km Pred_T
12 km Pred_T
K
300
290
280
270
260
250
240
230
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
1/ 8
1/ 9
1/10
1/11
1/12
1/13
1/14
1/15
1/16
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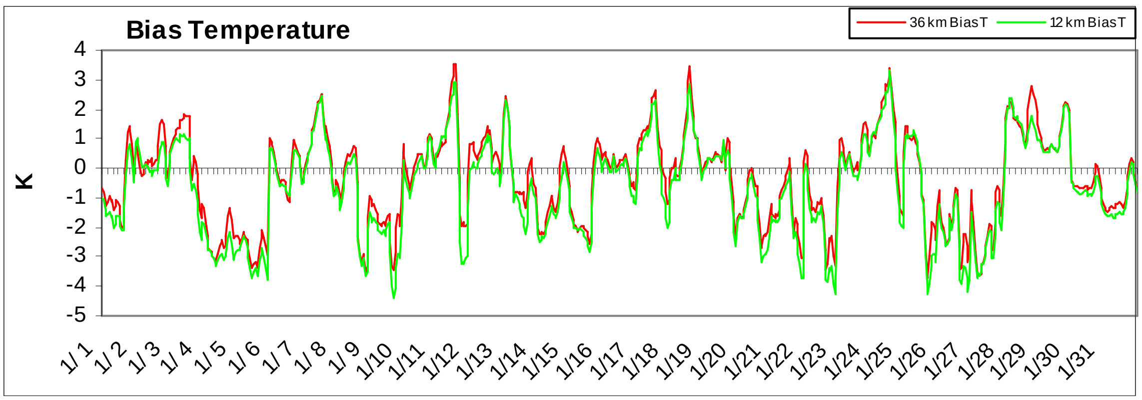
Bias Temperature
36 km BiasT
12 km BiasT
K
4
3
2
1
0
-1
-2
-3
-4
-5
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
1/ 8
1/ 9
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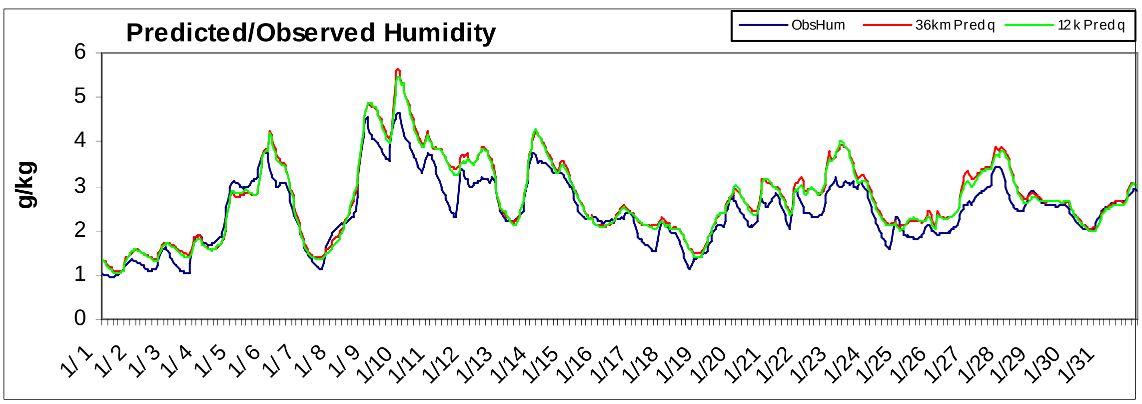
Predicted/Observed Humidity
ObsHum
36km Pred q
12 k Pred q
g/kg
6
5
4
3
2
1
0
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
1/ 8
1/ 9
1/10
1/11
1/12
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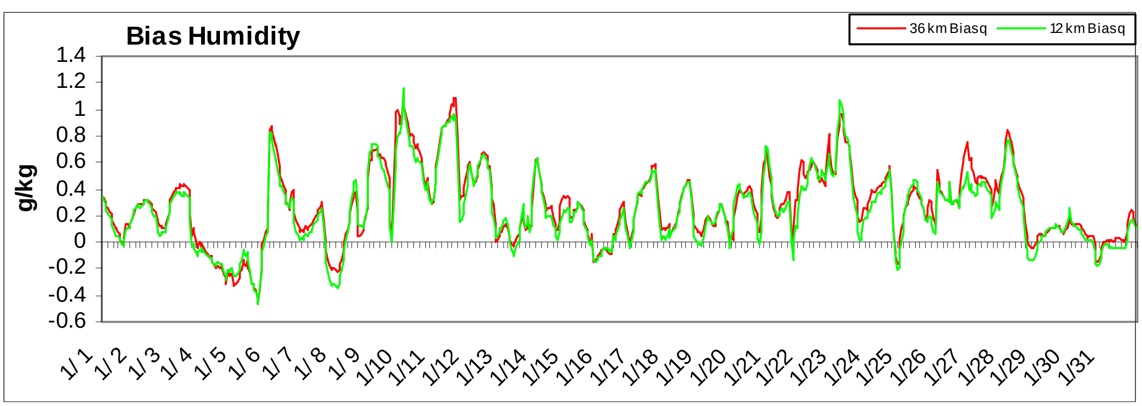
Bias Humidity
36 km Biasq
12 km Biasq
g/kg
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1/ 1
1/ 2
1/ 3
1/ 4
1/ 5
1/ 6
1/ 7
1/ 8
1/ 9
1/10
1/11
1/12
1/13
1/14
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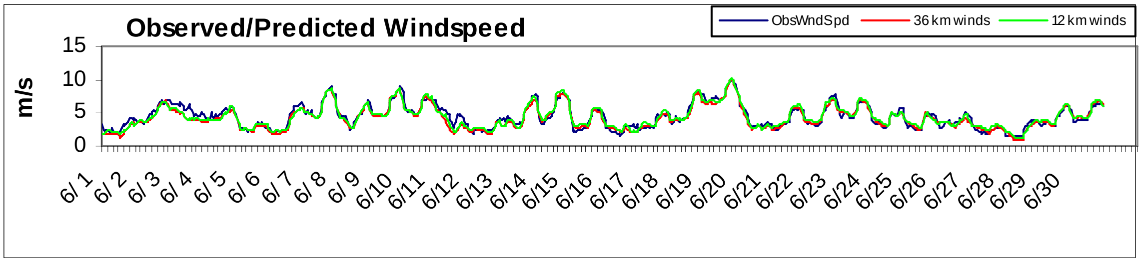
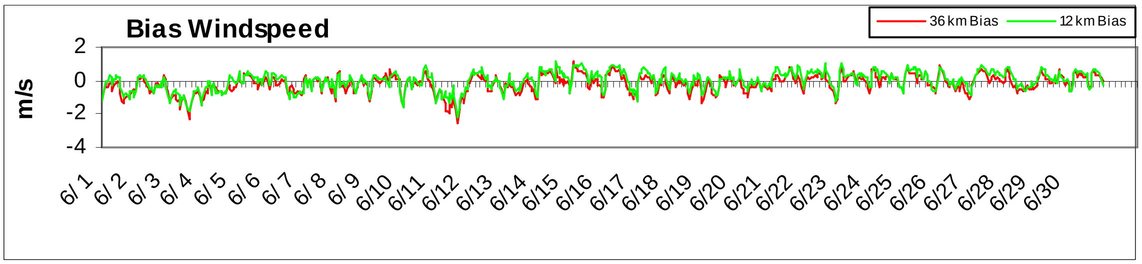
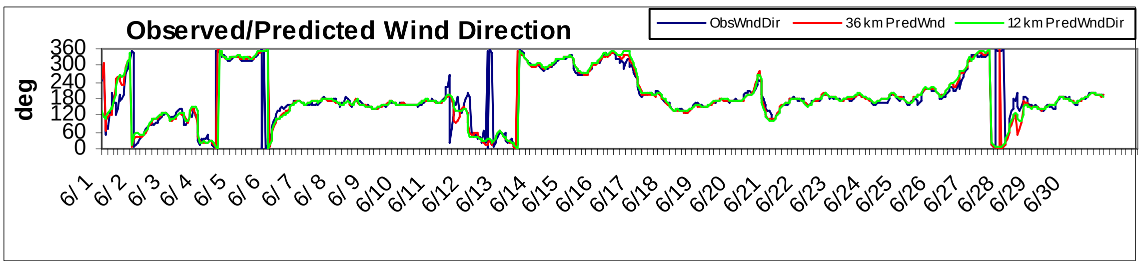
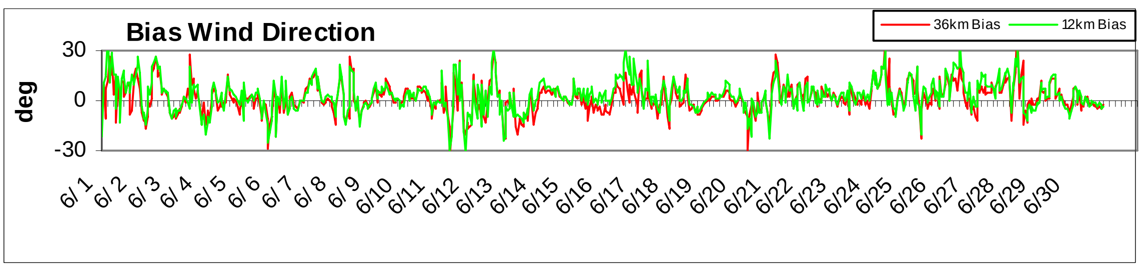
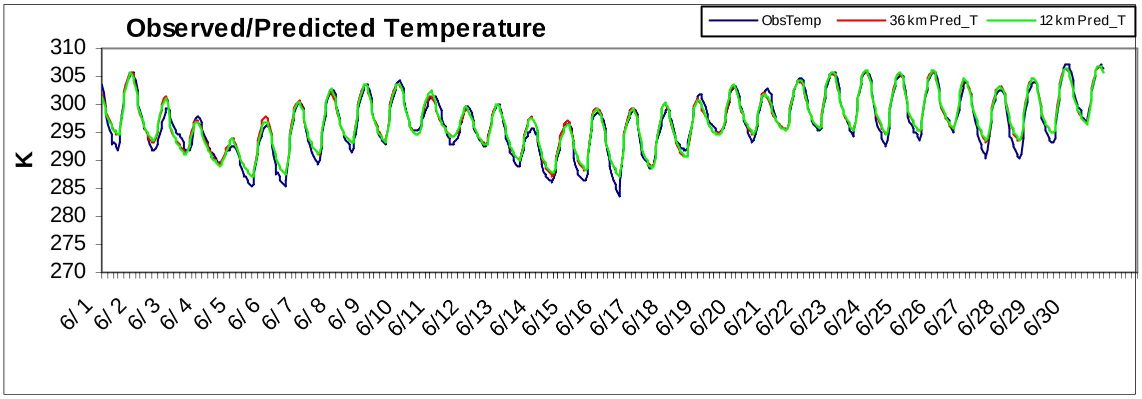
Iowa: June 2002










Observed/Predicted Temperature
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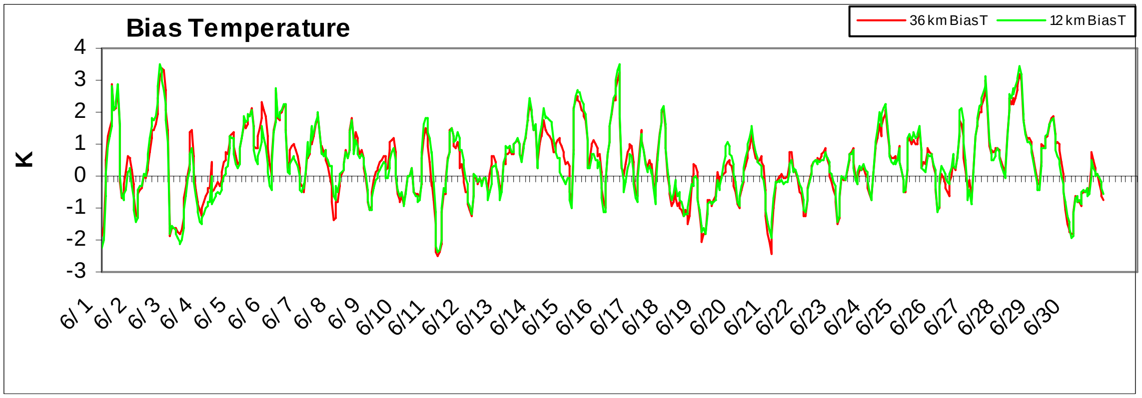
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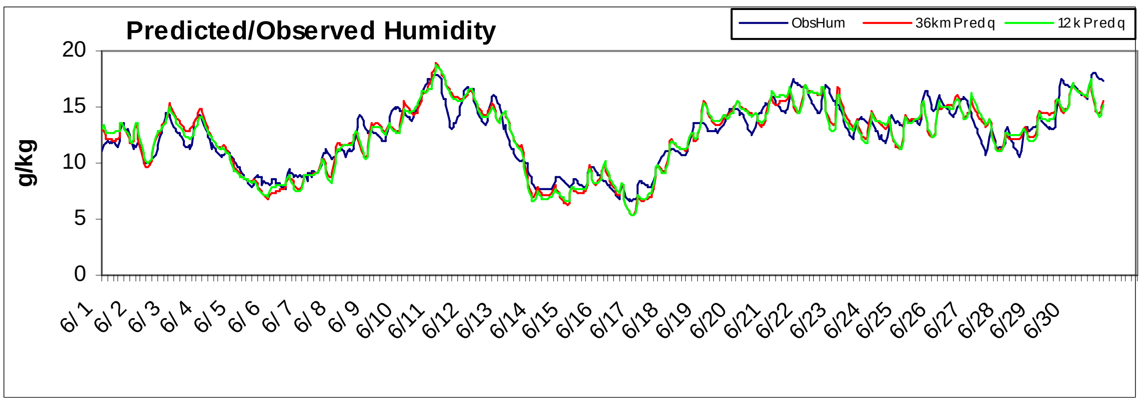
Predicted/Observed Humidity
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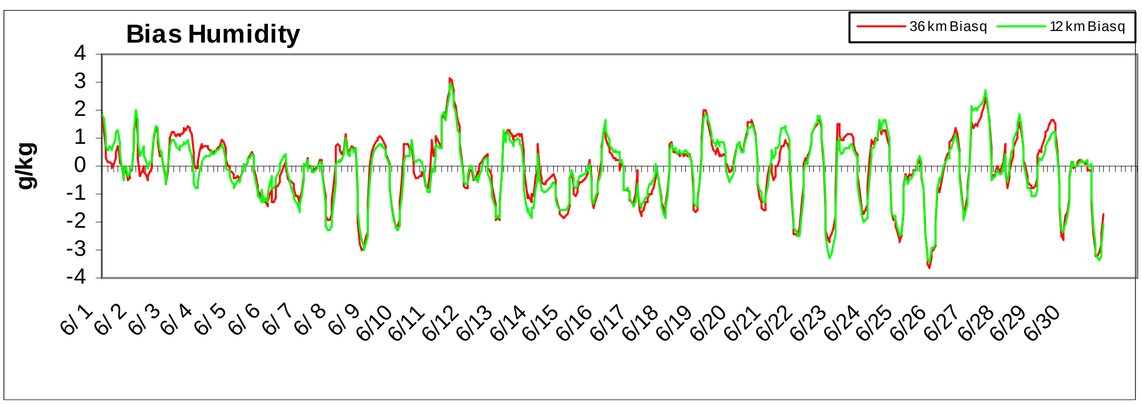
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Appendix E
MRPO Air Quality Modeling Protocol

Modeling Protocol: 2002 Basecase Technical Details

Kirk Baker

October 15, 2007

Lake Michigan Air Directors Consortium
Midwest Regional Planning Organization

Rosemont, Illinois

1. INTRODUCTION

The purpose of this addendum is to provide technical details related to the photochemical transport modeling done to support State Implementation Plans (SIPs) for ozone, particulate matter less than 2.5 microns (PM2.5), and regional haze. Documents that relate to a conceptual description of ozone, PM2.5, and regional haze in the Upper Midwest are available on the organization website: www.ladco.org.

Modeling Platform

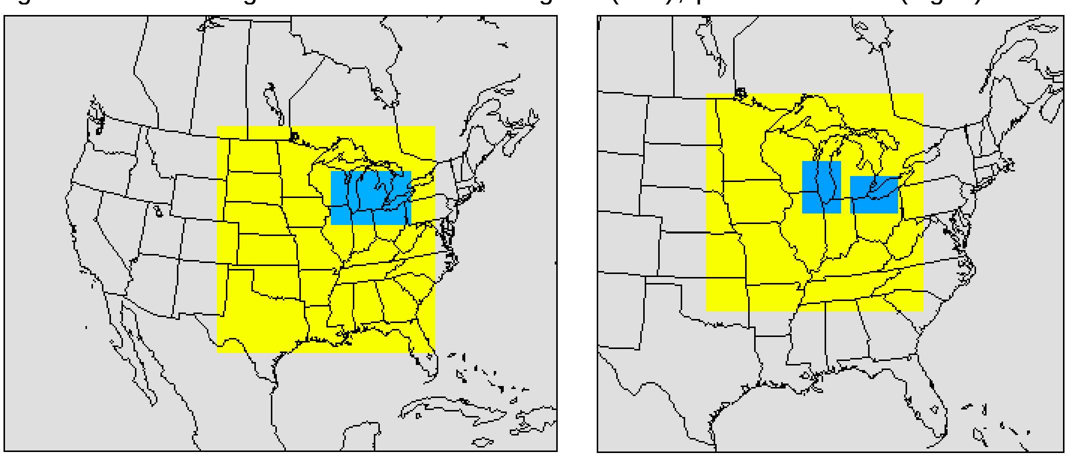
The computing platforms are Intel-based PCs running variations of the Linux operating system. The Portland Group (PGI) Fortran compiler is used to create all executables.

2. METHODOLOGY

Grid Projection and Domains

All models are applied with a Lambert projection centered at (-97, 40) and true latitudes at 33 and 45. The 36 km photochemical modeling domain consists of 97 cells in the X direction and 90 cells in the Y direction covering the central and eastern United States with 36 km grid cells (Figure 2.1; Table 2.1). The 2-way nested 12 km photochemical domain covers most of the upper Midwest region. A 2-way nested 4 km photochemical domain is situated over the lower portion of Lake Michigan and over Detroit-Toledo-Cleveland.

Figure 2.1 Modeling Domains: Meteorological (left), photochemical (right)



The 36 km meteorological modeling domain covers the entire continental United States (Figure 2.1; Table 2.1). The 12 km meteorological domain covers most of the central and eastern United States and the 4 km domain covers the lower portion of the Great Lakes.

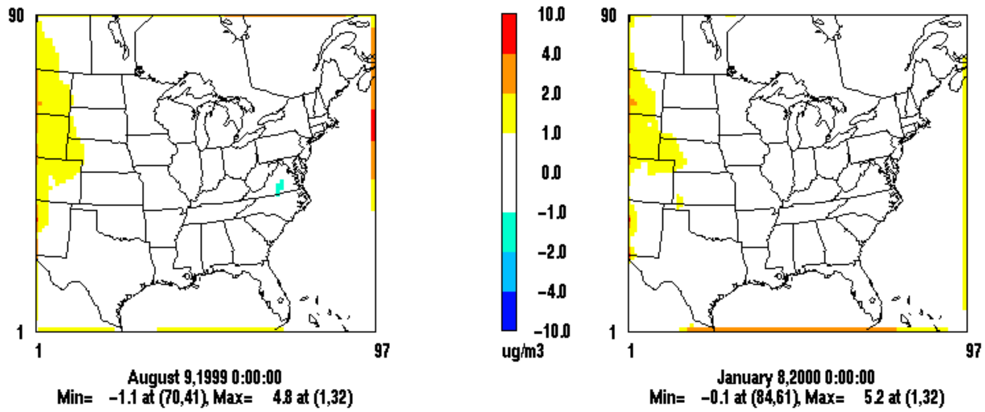
CAMx4 is applied with the vertical atmosphere resolved with 16 layers up to approximately 15 kilometers above ground level.

Table 2.1 Modeling Domains

Grid	Cell Size	XY Origin (km)	NX, NY
Emissions	36 km	(-2628., -1980.)	147, 111
Meteorological	4 km	(576., 108.)	214, 142
Meteorological	12 km	(-648., -1260.)	193, 199
Meteorological	36 km	(-2952., -2304.)	165, 129
Photochemical	36 km	(-900., -1620.)	97, 90
Photochemical (chimil)	4 km	(680., 176.)	56, 83
Photochemical (detcle)	4 km	(1040., 176.)	74, 56
Photochemical/Emissions	12 km	(-48., -552.)	131,131

The photochemical model is not being applied to the entire 36 km Continental U.S. domain to maximize resources. A sensitivity study was conducted to compare winter and summer episode averaged PM2.5 concentrations between a Continental U.S. domain and Central/Eastern U.S. domain using clean boundary conditions released with the CMAQ model. The episode average differences in PM2.5 were less than 1 ug/m3 in the Midwest RPO States and neighboring States (Figure 2.2).

Figure 2.2 Continental Domain – Central/Eastern U.S. Domain Episode Average PM2.5 Difference Plots for Summer (left) and Winter (right) episodes

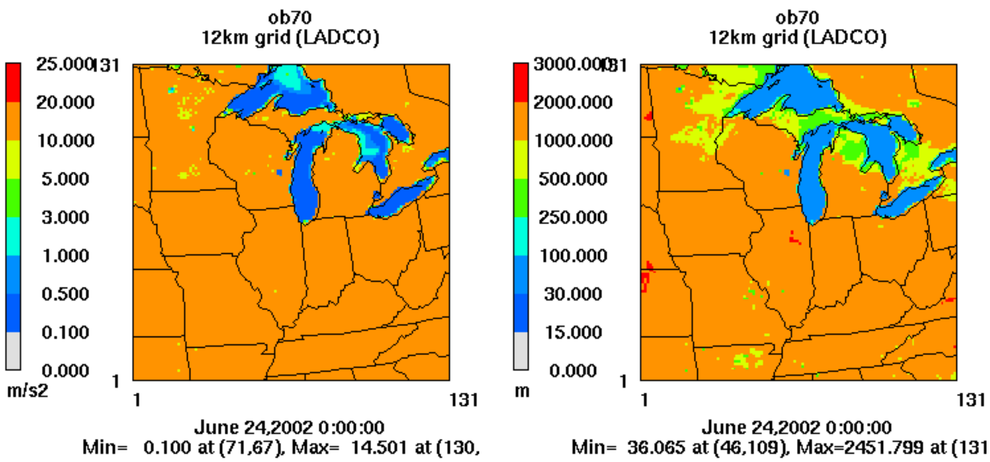


Meteorological Inputs

Meteorological input data for the photochemical modeling runs are processed using the National Center for Atmospheric Research (NCAR) 5th generation Mesoscale Model (MM5) version 3.6.1 (Dudhia, 1993; Grell et al, 1994). Important MM5 parameterizations and physics options include mixed phase (Reisner 1) microphysics, Kain-Fritsch 2 cumulus scheme, Rapid Radiative Transfer Model, Pleim-Chang planetary boundary layer (PBL), and the Pleim-Xiu land surface module. Analysis nudging for temperature and moisture is only applied above the boundary layer. Analysis nudging of the wind field is applied above and below the boundary layer. These parameters and options are selected as an optimal configuration for the central United States based on multiple MM5 simulations using a variety of physics and configuration options (Johnson, 2003; Baker 2004a).

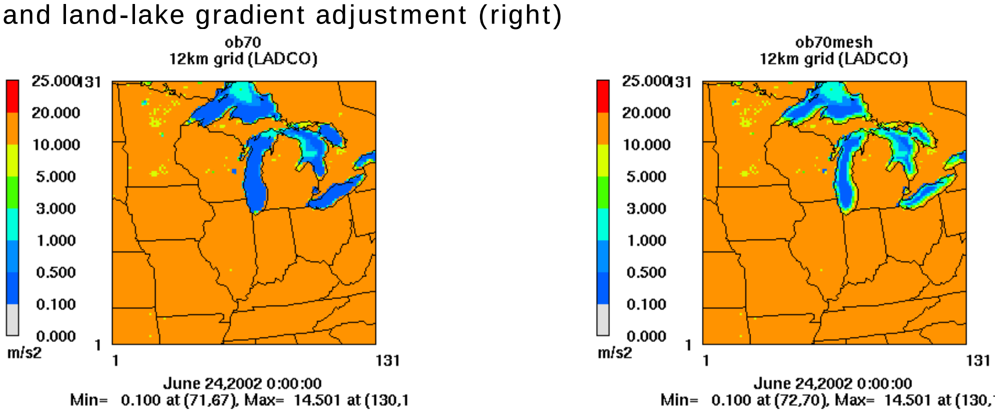
The meteorological fields output by MM5 are prepared for use by the photochemical model with processing utilities. These programs translate certain meteorological parameters from the MM5 grid to the photochemical grid. Additionally, these processors estimate parameters such as vertical diffusivity coefficients that are not explicitly output by MM5. The MM5CAMx version 4.4 utility is used to translate MM5 output to CAMx input. The vertical diffusivity coefficients are based on the O'Brien 1970 vertical diffusivity algorithm. This scheme takes the PBL height output by MM5 and creates a well-mixed atmosphere inside the PBL. The minimum vertical diffusivity coefficient is 0.1 m^2/s. A landuse-weighted vertical diffusivity coefficient (maximum of 1.0 m^2/s in a completely urban grid cell) is assigned to all grid cells up to approximately 150 meters above ground (model layer 3). This is done to better represent the greater mechanical mixing overnight in urban areas. An additional adjustment to vertical diffusivity coefficients creates a transitional gradient in values from shore to large water bodies. Figure 2.4 shows maximum vertical diffusivity coefficients and PBL height for a typical model episode day.

Figure 2.4 Peak Kv (m/s^2) values and peak PBL (m) values



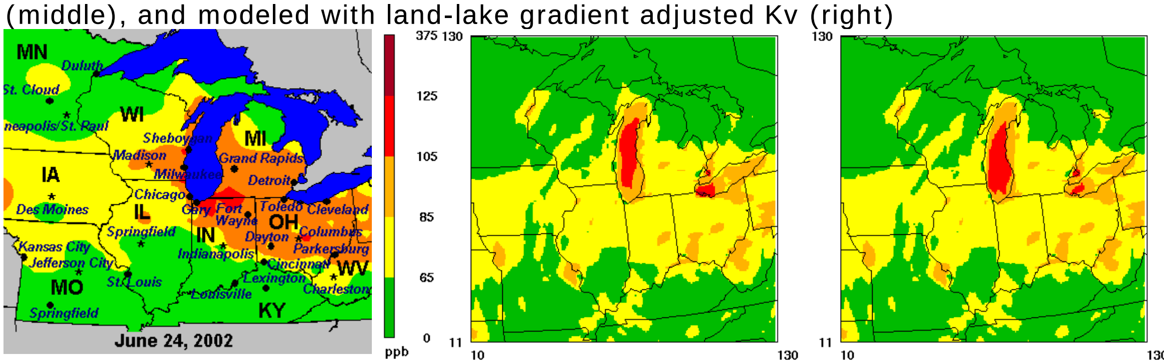
The gradient from land to lake vertical diffusivity coefficients extends over an order of magnitude during mid-day peak photochemical activity. PBL heights at a land cell are typically over 1000 meters and the adjacent cell over one of the Great Lakes is 30 meters. Air over the Great Lakes is typically stable and has low mixing, but the model does not have any transition from land to lake. An adjustment scheme is employed when cells having greater than 75% water have a vertical diffusivity coefficient equal to the average of the 5 x 5 group of cells centered on that particular grid cell.

Figure 2.5. Vertical diffusivity coefficients (m/s^2) using standard MM5 output (left) and land-lake gradient adjustment (right)



The land-lake vertical diffusivity adjustments are shown for an episode day in Figure 2.5. These adjustments result in minimal change to model performance (Figure 2.6) and a reduction in extreme NOX disbenefit response in grid cells near the lake-shore.

Figure 2.6. Peak 8-hr O3 (ppb) observations (left), modeled with standard Kv (middle), and modeled with land-lake gradient adjusted Kv (right)



The vertical resolution used in MM5 consists of 34 sigma layers that represent the terrain following atmosphere up to 100 millibars. Figure 2.7 displays each vertical layer in terms of sigma level, pressure (millibars), height above ground level (meters) and layer thickness (meters). The relationship to the layer structure used in the photochemical models is also shown. The photochemical model layer structure avoids layer collapsing in the lower boundary layer to better resolve the mixing depth.

Figure 2.7 Vertical Layer Structure

k(MM5)	sigma	p(mb)	depth(m)	k(PCM)	depth(m)
34	0.000	100	1841	16	5597
33	0.050	145	1466		
32	0.100	190	1228		
31	0.150	235	1062		
30	0.200	280	939	15	2549
29	0.250	325	843		
28	0.300	370	767		
27	0.350	415	704	14	2533
26	0.400	460	652		
25	0.450	505	607		
24	0.500	550	569		
23	0.550	595	536	13	1522
22	0.600	640	506		
21	0.650	685	480		
20	0.700	730	367	12	634
19	0.740	766	266		
18	0.770	793	259	11	428
17	0.800	820	169		
16	0.820	838	166	10	329
15	0.840	856	163		
14	0.860	874	160	9	318
13	0.880	892	158		
12	0.900	910	78	8	155
11	0.910	919	77		
10	0.920	928	77	7	153
9	0.930	937	76		
8	0.940	946	76	6	151
7	0.950	955	75		
6	0.960	964	74	5	148
5	0.970	973	74		
4	0.980	982	37	4	37
3	0.985	987	37	3	37
2	0.990	991	36	2	36
1	0.995	996	36	1	36
--SURF--	1	1000	0	--SURF--	--SURF--

A compromise in the upper troposphere is met by employing layer collapsing to reduce computational effort and still maintain some upper troposphere resolution for long-range transport. The layer structure chosen for a modeling application should be capable of adequately resolving the diurnal variations in the boundary layer growth and mixing, long-range transport processes, wind shear, as well as transport to and from the free troposphere.

Emissions Inputs

Emissions data is processed using EMS-2003. The EMS-2003 model is selected for its ability to efficiently process the large requirements of regional and daily emissions processing. In addition to extensive quality assurance and control capabilities, EMS-2003 also performs basic emissions processes such as chemical speciation, spatial allocation, temporal allocation, and control of area, point, and mobile source emissions (Janssen, 1998; Wilkinson et al, 1994). Outputs from EMS-2003 include a coordinate-based elevated point source file and gridded emissions estimates for low-point, area, mobile, and biogenics sources. Anthropogenic emission estimates are made for a weekday, Saturday, and Sunday for each month. The biogenic emissions are day-specific. Volatile organic compounds are speciated to the Carbon Bond IV (CB4) chemical speciation profile (Carter, 1996).

Table 2.2 CAMx Emissions Species

SPECIE	DESCRIPTION
ALD2	Aldehydes
ETH	Ethylene
FORM	Formaldehyde
ISOP	Isoprene
OLE	Olefins - Anthropogenic
OLE2	Olefins - Biogenic (OVOC)
PAR	Paraffins
TOL	Toluene
XYL	Xylene
NH3	Ammonia
CO	Carbon monoxide
NO2	Nitrogen dioxide
NO	Nitrogen oxide
SULF	Sulfur
SO2	Sulfur dioxide
PEC	Primary PM-fine elemental carbon
PNO3	Primary PM-fine nitrate
POA	Primary PM-fine organic aerosol
PSO4	Primary PM-fine sulfate
CCRS	Primary PM-coarse crustal
FCRS	Primary PM-fine crustal
CPRM	Primary PM-coarse "other"
FPRM	Primary PM-fine "other"

The point and area source inventories are based on the State Consolidated Emissions Reporting Rule (CERR) submittals, other RPOs, and the 2002 National Emission Inventory (EPA, 2006). Continuous emissions monitoring data were used to develop temporal profiles for electrical generating units. These new profiles account for month of year and day of week variations and are unit specific.

On-road emissions are estimated using MOBILE6.2 emission factors and VMT from the 2002 NEI. The MOBILE6 inputs were supplied by the MRPO States, Iowa, and

Minnesota and from the 2002 NEI for all other States. Updated on-road temporal data is based on an analysis of traffic count data in Michigan, Wisconsin, and Minnesota. Default temporal tables are modified to represent a more complex distribution of vehicle miles traveled for the weekend.

Off-road emissions are estimated with the NONROAD2004 and NMIM models using data from the State CERR submittals, EPA's 2002 NEI, and local data for agricultural equipment for the MRPO States plus Iowa and Minnesota. Contractor supplied emissions estimates are used for commercial marine and locomotive non-road categories. NMIM was run with fuel parameter inputs consistent with the on-road emissions modeling. These emissions do not include permeation effects.

Biogenic emissions are estimated with EMS-2003 using the BEIS3 model (Guenther et al, 2000). The BELD3 land use dataset is input to the biogenic model for fractional land-use and vegetative speciation information (US EPA, 2006b; Kinnee et al. 1997; Kinnee et al. *in press*). Other inputs to the biogenic emissions model include hourly satellite photosynthetically activated radiation (PAR) and 15 m (above ground level) temperature data output from MM5 (Pinker and Laszlo, 1992).

Ammonia emissions are based on the July 2004 version (v3.6) of Carnegie Mellon University's (CMU) ammonia model using 2002 census of agriculture data (Strader et al. 2005; Pinder et al., 2004; Goebes et al., 2003). CMU ammonia emissions estimates are not used from the following categories: humans, dogs, cats, and deer. These omissions are based on the low likelihood that ammonia emissions from these sources would make it out of domestic dwellings in the case of humans, cats, and dogs and forested areas in the case of deer. Ammonia emissions are removed from other RPO's point source inventory to eliminate double-counting confined animal operations with CMU model estimates. Updated monthly and diurnal profiles were developed using the new process based ammonia model. The new profile represents beef, hogs, and dairy. Hog farms are assumed to represent poultry since the new process based ammonia model did not have a fully functional poultry housing model.

Currently, there are no anthropogenic Mexican emissions in the emissions input files. Canadian emissions are based on a 2000 inventory made available by Environment Canada to the Environmental Protection Agency.

The speciation profiles used by EMS are obtained from the latest version of EPA's SPECIATE database. MRPO contracted improved speciation profiles for certain emission categories. Details of this project are available in "Improving Modeling Inventory Data: Speciation Profiles – February 17, 2005" and available by request.

The development of the future year and even the base year emissions are continually being updated. The best place to find the most recent explanation of the base and future year scenarios is at the LADCO website (LADCO, 2006).

Landuse

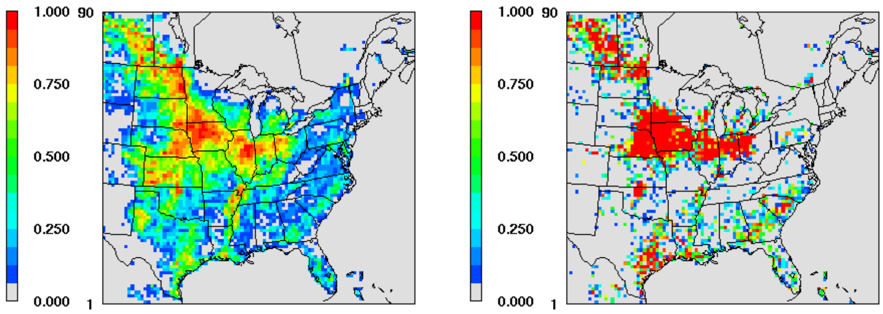
The photochemical model uses 11 land use categories to describe the surface. The land use file is based on BELD3 1 km data (US EPA, 2006b; Kinnee et al. 1997; Kinnee et al. *in press*). The 1 km data was aggregated to the appropriate grid resolution for photochemical modeling. Surface roughness varies by season and land use category and are taken from EPA's AERMET User's Guide (EPA, 2004; ENVIRON, 2005).

Table 2.3 Landuse categories

Category	Landuse
1	Urban
2	Agricultural
3	Rangeland
4	Deciduous forest
5	Coniferous forest
6	Mixed forest
7	Water
8	Mixed agriculture/forest
9	Non-forested wetlands
10	Mixed agriculture/range
11	Rocky with low shrubs

USGS data was previously used for landuse information. The BELD3 was chosen because it incorporates the USGS data with other sources of information such as satellite data. A spatial comparison of the agriculture (category 2) landuse fractions are shown below.

Figure 2.8 BELD3 (left) and USGS (right) agriculture landuse



Drought Stress and Snow Cover

The Palmer Drought Severity Index (PDSI) is an indicator of unusual excess or deficient moisture. The PDSI is calculated for 350 climatic divisions in the United States and Puerto Rico. PDSI data is available for each week of a calendar year and is obtained from the National Weather Service Climate Prediction Center (National Weather Service, 2005). The dry deposition calculations for non-water landuse categories are impacted by vegetative response to drought stress (ENVIRON, 2005).

Snow cover is also input to CAMx4 for the deposition scheme. Three-hourly snow cover data for each grid cell is extracted from MM5 output files. If snow exists in a grid cell, the deposition characteristics of the landuse are switched from “winter” to “winter with snow.” This switch has an impact on surface resistances for dry deposition, surface roughness, and chemistry due to the ultraviolet albedo being changed to the maximum class (ENVIRON, 2005).

Photolysis Rates

Many chemical reactions in the atmosphere are started by the photolysis of certain trace gases. Photochemical models require these rates be input to accurately estimate these reactions. CAMx4 is applied with day specific photolysis rate look-up tables.

The Tropospheric Ultraviolet-Visible (TUV) radiation model is used to calculate photolysis rates based on solar zenith angle, height above ground, ultraviolet albedo of the ground, atmospheric turbidity, and total ozone column density. The TUV generates rates for each day as a function of 11 heights, 10 solar zenith angles, 5 ozone column values, 5 albedo values, and 3 turbidity values (ENVIRON, 2005; NCAR, 2006).

The ozone column data is derived from daily TOMS satellite observations (NASA, 2006). The albedo data varies by month and is based on over 10 years of TOMS satellite reflectivity observations. Actinic flux is estimated using the discrete ordinate algorithm. The two-stream delta-Eddington method is also available in the TUV model, but was not selected because the discrete ordinate approach is more accurate.

A sensitivity application with CMAQ using TOMS derived photolysis rates and rates based on seasonal average ozone column showed differences in ozone up to 3 ppb and differences in sulfate ion up to 1.5 ug/m^3. These differences suggest day specific ozone column data from satellites should be used rather than seasonal averages and that accurate photolysis rates are important for ozone and particulate matter applications.

For those days that do not have TOMS ozone column data, the data from the previous day is used instead. This option is more realistic than defaulting to a seasonal average, which may create a rather large discontinuity between the missing day and adjoining simulation days.

Initial and Boundary Conditions

Boundary conditions represent pollution inflow into the model from the lateral edges of the grid and initial conditions provide an estimation of pollution that already exists. In the past a spin-up period of two to three days was used to eliminate initial condition effects for ozone modeling.

CAMx4 source apportionment runs show ozone attributed to initial concentrations does not exceed 5 ppb anywhere in the domain by the 7th day of the episode; ozone modeling episodes will be spun up with 11 days. The monitors used in model performance evaluation are far enough away from the boundaries that boundary influence is considered minimal.

CAMx4 particulate source apportionment (PSAT) runs show PM2.5 sulfate ion, nitrate ion, and ammonium ion contributions from initial concentrations fall below 0.05 µg/m^3 by the seventh day of the episode. PM2.5 elemental carbon, PM2.5 soil, and coarse mass have less than 1 ng/m^3 contribution from initial concentrations on the first day of the model episode everywhere in the modeling domain. Since gas phase chemistry is coupled with particulate formation, the annual simulations have two weeks of spin-up to minimize initial condition influence.

The initial and boundary conditions are based on monthly averaged species output from an annual (calendar year 2002) application of the GEOS-CHEM global chemical transport model (Jacob et al, 2005; Bey et al, 2001). Boundary conditions vary by month and in the horizontal and vertical direction. Where an initial or boundary concentration is not specified for a pollutant the model will default to a near-zero concentration.

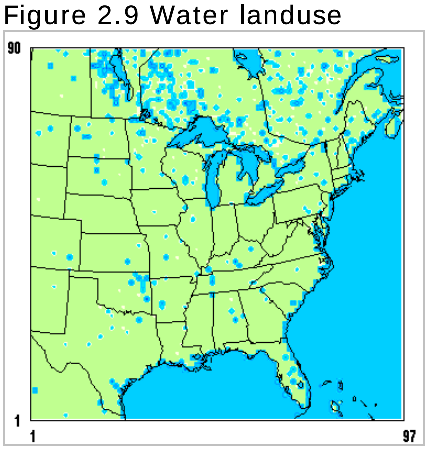
A study applying CMAQ with monthly averaged and 3-hr GEOS-CHEM initial and boundary conditions showed almost no change in model performance for any PM2.5 species. The error for total PM2.5 and each of the chemical species differed by less than 0.04 ug/m^3 at IMPROVE and EPA STN monitor sites (Morris et al, 2004b). Considering the need to model multiple annual simulations and potential issues related with inconsistencies between in-flows and out-flows between the GEOS-CHEM meteorology and the MM5 simulation used for regional modeling, the monthly averaged concentrations are used to support photochemical modeling applications.

Quality Assurance of Model Inputs

The model input files are checked for reasonableness to ensure they accurately represent the underlying data used to create the files. The checks described in this document are steps that are in addition to the extensive QA done in the emission inventory compilation process, EMS emissions modeling, and MM5 modeling process.

The landuse files are converted to a CAMx4 output file format and directly viewed in PAVE over a political map. An example of the water landuse category is shown in the figure in this section.

Figure 2.9 Water landuse



The initial and boundary conditions processor outputs an ASCII file showing the specie concentration at each vertical layer. This is visualized in EXCEL to make sure the data is correctly mapped in the vertical direction. The initial and boundary concentration files themselves are also directly viewed in PAVE and the spatial representation is checked. The ozone column, albedo, and turbidity data are kept in ASCII files. Each file is checked to ensure the data looks spatially reasonable and that bad data did not get included in the file.

The emissions inputs are extensively checked for appropriateness. The steps taken in manipulating EMS-2003 output files to CAMx4 input files and the quality assurance of those files are detailed in "Emissions Processing and QA" (Baker, 2004b). Each emission file is checked for spatial and temporal agreement with EMS-2003 and for reasonableness. Additionally, the mass for each species is totaled by State and over the entire modeling domain and compared to EMS-2003 QA reports.

The MM5 output used to support the photochemical modeling is extensively evaluated from a meteorological perspective. An additional layer of quality assurance is done by evaluating model performance of the air quality model input meteorological data at several monitor locations. This is done for temperature, relative humidity, wind speed, and wind direction.

Photochemical model simulations also provide a level of quality assurance since deficiencies in emissions and meteorological inputs will be apparent in the photochemical model performance.

Photochemical Model Configuration

The Comprehensive Air Quality Model with Extensions (CAMx) version 4.30 uses state of the science routines to model particulate matter formation and removal processes over a large modeling domain (Nobel et al. 2002; Tanaka et al. 2003; Chen et al. 2003; Morris, Mansell, Tai, 2004). The model is applied with ISORROPIA inorganic chemistry, SOAP organic chemistry, regional acid deposition model (RADM) aqueous phase chemistry, and an updated carbon-bond IV (CB4) gas phase chemistry module (ENVIRON, 2005; Nenes et al, 1998; Carter, 1996). CAMx4 is applied using the PPM horizontal transport scheme and an implicit vertical transport scheme with the fast CMC chemistry solver (ENVIRON, 2005).

The photochemical model is initiated at midnight Eastern Standard Time and run for 24 hours for each episode day. The summer 2002 simulation is initiated on June 2 and run through August 31. The annual simulation is run separately by calendar quarter and is initiated 2 weeks prior to each quarter: December 17 (2001), March 15, June 15, and September 15. The base and future year scenarios submitted as support for the annual PM2.5 standard will be using a horizontal grid resolution of 12 km. The modeling to support the 8-hr Ozone NAAQS will be at 12 km horizontal resolution over the entire upper Midwest and 2-way nested grids over the lower portion of Lake Michigan and over the Detroit-Toledo-Cleveland region.

CAMx4 models PM particles in the fine and coarse size fraction. There is no mechanism in the model to transfer mass between these 2 size sections. The particle density and diameter does not change from specie specific input values during a model simulation for either particle size bin.

Future year simulations will be applied with the same model configuration as for the base case simulation. All inputs except for emissions will be the same in the future year and base year simulations to assess changes in ozone, visibility, and PM2.5 due to control strategies and future growth. The terms base case and base line emissions inventories are one in the same, both referring to day specific biogenics and monthly weekday, Saturday, Sunday anthropogenic emissions.

Gas Phase Chemistry

CB4 was originally developed for application to high NOx conditions, such as those that exist in urban areas (Tonnesen et al, 2001). RADM and SAPRC were developed specifically for low NOx conditions, such as those that exist in rural areas. The United States Environmental Protection Agency ran CMAQ with CB4 and RADM gas-phase chemistry and found the ozone predictions to be very comparable. However, the run times associated with RADM were twice as long as those with CB4 (Timin, 2002). SAPRC chemistry also typically has run times much longer than CB4, usually at least twice as long.

Starting in version 4.20, CAMx4 contains 17 new inorganic reactions that improve the science in the model without being inconsistent with the evaluation of CB4 against smog chamber data. The new reactions have little impact on predicted PM2.5, but increase ozone concentrations regionally. This regional increase in ozone improves model performance in the Midwest United States and is due to reactions that recycle NOX. These reactions include the photolysis of organic nitrates and nitric acid and are included in other mechanisms including SAPRC99 and CBM-Z (ENVIRON, 2005; Carter, 2000; Zaveri and Peters, 1999).

Deposition

Deposition processes are an important factor in pollution and visibility estimation. Wet and dry removal play an even more important role in regional modeling as the spatial and temporal scope of application increase. The wet deposition routine in CAMx4 has been upgraded to improve cloud and rainfall estimation (Kemball-Cook et al, 2004). The dry deposition routine is based on the equations developed by Wesley (ENVIRON, 2005; Wesley, 1989). The dry deposition equation is modified to adjust for special properties of certain chemical species such as nitric acid (very sticky) and ammonia (very reactive, fairly sticky, and shows a high degree of near-field deposition).

The ammonia RSCALE factor in the chemistry parameters input file to CAMx4 is set to 0.0, which is the same as nitric acid to account for the chemical characteristics of ammonia and physical processes (near-field deposition) not in the deposition model. A field study at a Colorado alpine tundra location showed that ammonia and nitric acid deposition velocities were very similar: both 1.3 ± 0.6 cm/s (Rattray et al., 2001). The photochemical landuse model annual mean ammonia deposition velocity for all sites is 3.0 cm/s and the annual mean estimated nitric acid deposition velocity is 2.5 cm/s. The modeled ammonia and nitric acid deposition velocities agree within the uncertainty provided for in the Colorado alpine tundra field study.

Nesting

Nested grids are useful to keep computational and data management resources acceptable while addressing important model application issues such as complex terrain, land-sea or land-lake breezes, and spatial emission gradients. They may also be useful to keep large point source plumes in smaller grid cells in lieu of having explicit sub-grid scale plume treatments.

CAMx4 allows for the inclusion of a fine grid within the coarse grid in a 2-way nesting mode. The 2-way nesting mode allows for interaction between the larger coarse grid with the smaller fine grid. This improves pollutant transport around the boundaries of the fine grid since a parcel of air may move from the fine grid, out to the coarse grid, and back into the fine grid depending on the shifting wind fields. This re-circulation is impossible in 1-way nesting applications.

Several modeling applications have shown minimal benefit to PM2.5 model performance from the inclusion of a nested 12 km grid (Baker, 2004b; Morris, Koo et al, 2004). The EPA modeling guidance recommends that modeling to support the annual PM2.5 NAAQS be applied at a 12 km horizontal grid resolution so that grid resolution will be used to support the SIP. A 2-way nested 4 km grid will be applied over the lower portion of Lake Michigan and over the Cleveland-Toledo-Detroit area to better resolve the complex interaction between high density urban emissions and land-Lake meteorology.

Plume-in-Grid

The GREASD sub-grid plume treatment option is being applied in CAMx4 for the summer season 12 km ozone simulations. This option is selected to improve the model treatment of large NOx plumes being released near Lake Michigan and Lake Erie. Sources included for the plume-in-grid treatment include any source near the Great Lakes with NOx emissions greater than 12 tons per day for any day of the summer in 2002 and 6 tons per day in future year scenarios.

At high grid resolutions of 4 km or finer, sub-grid scale treatment of plumes should not be applied since the fine grid appropriately captures the small scale physical and chemical processes.

Probing Tools (Source Apportionment)

Probing tools are valuable from a scientific and regulatory perspective for one-atmosphere modeling. Use of source apportionment is more desirable for regulatory applications than the use of the “zero-out” approach to determine geographic and emissions sector culpability for annual modeling simulations. Zeroing out emissions for large regions such as entire States fundamentally changes the atmospheric chemistry and makes interpretation of the results difficult.

An option in CAMx is employed to force elevated point sources into particular regions rather than placement based on coordinates and the 12 km geographic region map. This ensures that elevated emissions are placed in the appropriate geographic region and not incorrectly grouped with another region when a grid cell contains the boundary for more than one region. A good example of this is the Ohio River Valley where many large stationary point sources exist along State boundaries and could be grouped into the wrong region based on the 12 km grid cell source region map. This option improves the confidence in the source apportionment results for stationary point sources.

Ozone

CAMx4 contains a variety of ozone source apportionment tools, which includes the standard ozone source apportionment tool (OSAT). The anthropogenic pre-cursor culpability assessment (APCA) tool assesses regional and emission sector contribution to ozone formation and provides information that is most policy relevant. The APCA tool is chosen over the other options, including the standard OSAT option (ENVRION, 2005).

When ozone is formed under VOC limited conditions due to biogenic VOC +anthropogenic NOx then OSAT attributes it to the biogenic VOC sources. When ozone is formed under NOx-limited conditions due to biogenic VOC + anthropogenic

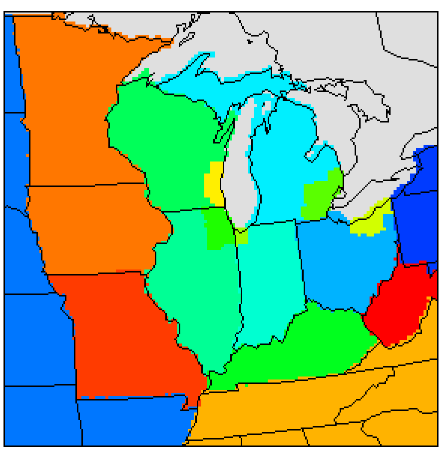
NOx then OSAT attributes it to the anthropogenic NOx sources. APCA is designed to provide more control strategy relevant information and recognizes that there are source categories such as biogenics that can not be controlled so the model attributes ozone to biogenics when it is due to the interaction of biogenic VOC+biogenic NOx. In the case where ozone formed to biogenic VOC + anthropogenic NOx under VOC-limited conditions, OSAT attributes it to biogenic VOC, but APCA redirects the attribution to anthropogenic NOx. In NOx-limited conditions both OSAT and APCA attribute the ozone to anthropogenic NOx. There is a similar situation with biogenic NOx + anthropogenic VOC but this rarely happens in the eastern United States (ENVIRON, 2005).

The source apportionment data is the average contribution over all modeled hours where predicted ozone at the monitor is greater than a threshold concentration value. Two different thresholds are used to examine different distributions of high modeled 8-hour ozone: 75 and 85 ppb (Baker, 2007). The geographic regions tracked for ozone contribution are listed in Table 2.4 and shown graphically in Figure 2.10 over the 12 km modeling domain. The contribution from the lateral and top boundaries of the model is also tracked for each receptor location.

Table 2.4 Complete list of source regions tracked for ozone contribution

Canada	Illinois Chicago non-attainment (NA) Counties
Northeast States (MANE-VU)	Detroit NA Counties
Central/Western States (CENRAP+ WRAP)	Indiana Chicago NA Counties
Ohio	Cleveland NA Counties
Michigan	Milwaukee NA Counties
Indiana	Southeast States (VISTAS)
Illinois	Minnesota+Iowa
Wisconsin	Missouri
Kentucky	West Virginia

Figure 2.10 Source regions tracked in the 12 km grid domain



Six emissions source sectors are tracked for contribution to ozone: onroad mobile, offroad mobile, area, electrical generating units, non-electrical generating units, and biogenics. Offroad mobile emissions include sources such as construction equipment, locomotives, commercial marine vessels, and airports. Two distinct groups of stationary point sources are tracked for contribution to ozone: electrical generating units and non-electrical generating units.

Particulate Matter and Visibility

The Particulate Source Apportionment Tool (PSAT) tracks contributions of PM2.5 sulfate ion, nitrate ion, ammonium ion, elemental carbon, and primary emissions of organic aerosol, soil, and coarse mass. Secondary organic aerosol tracking is also part of the tool but not employed for this study due to resource constraints. Secondary organic aerosol contributions from biogenic and anthropogenic sources are part of the standard CAMx output and included in the analysis.

Source apportionment results will be estimated on an annual average basis and on a daily 24-hr basis to be relevant to the annual and 24-hr PM2.5 NAAQS. The 24-hr average source apportionment results for the 20% worst and 20% best days at the Class I area receptors will be converted to light extinction then averaged together using the latest IMPROVE Steering Committee recommended equation (IMPROVE, 2006). Contributions from initial conditions are quantified to determine an optimal amount of spin-up time required to minimize the impacts from initial concentrations.

The geographic regions tracked for contribution are listed in Table 2.5 and shown graphically in Figure 2.11. The contribution from the lateral and top boundaries of the model is also tracked for each receptor location.

Figure 2.11 Source regions tracked by PSAT

Table 2.5 Complete list of source regions tracked for contribution

Canada	Illinois Chicago non-attainment (NA) Counties
Northeast States (MANE-VU)	Detroit NA Counties
Central/Western States (CENRAP+ WRAP)	Indiana Chicago NA Counties
Ohio	Cleveland NA Counties
Michigan	Milwaukee NA Counties
Indiana	Southeast States (VISTAS)
Illinois	Minnesota
Wisconsin	Minneapolis-St. Paul [visibility only]

Kentucky	West Virginia
Iowa	North Dakota [visibility only]
Missouri	

Seven emissions source sectors are tracked for contribution to particulate matter: onroad mobile, offroad mobile, area, electrical generating units, non-electrical generating units, agricultural ammonia, and biogenics.

Probing Tools (Other)

Currently, none of the PM models include process analysis for inorganic, secondary organic aerosol, or aqueous phase chemistry. A limited amount of information regarding nitric acid formation is available as process analysis implementation is limited to gas phase chemistry reactions. Process analysis will not be emphasized until further development makes it useful beyond gas phase chemistry.

3. Model Performance Evaluation

State Implementation Plans will include modeling the impacts of emission control scenarios with 3-D Eulerian photochemical transport models. Model performance is typically evaluated on an operational basis and rarely to support a diagnostic (dynamic) assessment. Operational evaluations for ozone modeling purposes include matching model estimates with observation data for ozone, nitrogen oxides (NO_X), and total volatile organic compounds (VOC). Operational evaluations for PM2.5 and visibility modeling purposes include matching model estimates with observation data for chemically speciated PM2.5 and important pre-cursor species including sulfur dioxide, nitric acid, and ammonia.

A diagnostic evaluation assesses how appropriately the modeling system responds to emissions adjustments. Since the modeled attainment demonstration includes modeling current and future year emissions it is important to have confidence that the model will predict concentrations appropriately when emissions change (US EPA, 2007). This type of evaluation includes modeling two different ozone episodes that are separated by enough years that large emissions differences exist. The diagnostic evaluation is an important assessment to make in addition to an operational evaluation because it is directly linked to the end use of the model, which is modeling the change in ozone concentrations after emissions adjustments.

A comparison between observed and estimated ozone for the summers of 2002 and 2005 is useful for a diagnostic assessment because high quality emission inventories were developed for each year and a large NO_X emissions reduction occurred between these years due in part to NO_X SIP Call compliance. Modeling two full summer seasons provides an opportunity to make another diagnostic evaluation which assesses model performance for high ozone by day of the week (Baker, 2007b). Emissions change substantially from weekday to weekend and having two full summers provides enough days with high ozone on each day of the week to make this type of evaluation useful.

The photochemical modeling applications are designed to support the development of regional control strategies for PM2.5 and Regional Haze. EPA guidance states that an attainment test for either standard will require the use of chemically speciated PM relative reduction factors (US EPA, 2007). Additionally, the model will be used to assess improvements in PM2.5 concentrations and visibility as a result of changes in emissions. These prominent end-uses of the modeling applications make comprehensive evaluations important. Clearly, reliance on model performance for PM2.5 total mass would be misleading since it is likely that the model and ambient data could estimate the same total mass but very different chemical composition. This scenario would compromise the development and interpretation of potential regulatory control strategies (Baker, 2004d).

The species to be compared to monitor concentrations include ozone, total VOC, NOX, SO2, NH3, HNO3, and speciated PM2.5 (see Table 3.1). Initially, scatter-plots of point-to-point relationships for all monitors in the domain for all episode days will be used for analysis for PM. This will allow for identification of gross model over or under-prediction by specie. Gas and aerosol data are taken from a variety of monitor networks for comparison to modeled estimates: IMPROVE, EPA Speciation Trends (STN), AIRS, and PAMS. The data is obtained directly from the VIEWS website and from the AFS database; a comparison of the monitor species to model species is shown below. PM2.5 ammonium ion is only measured at EPA Speciation Trends locations so the model performance for this chemical specie is dominated by, but not limited to, urban measurement locations.

Table 3.1 Species mapping between modeled and observed species (observed species from the VIEWS website)

	IMPROVE	STN	CAMx4 species
Sulfate aerosol	SO4f	SO4f	PSO4
Nitrate aerosol	NO3f	NO3f	PNO3
Ammonium aerosol		NH4f	PNH4
Organic aerosol	OCf*FACTOR FACTOR = 1.6 rural 2.1 urban	OCf*FACTOR FACTOR = 1.6 rural 2.1 urban	SOA1+SOA2+ SOA3+SOA4+ SOA5+POA
Elemental carbon	ECf	ECf	PEC
Soil/Crustal	SOILf	SOIL = 2.2*ALf + 2.49*SIf+1.63*CAf+ 2.42*FEf+1.94*TIf	FCRS
PM2.5 other	MF-RCFM	MF-(RCFM)	FPRM
Coarse mass	CM_calculated		CPRM+CCRS
PM2.5	MF	MF	PSO4+PNO3+PNH4+POA+ SOA1+SOA2+SOA3+SOA4+ SOA5+PEC+NA+PCL+ FPRM+FCRS
Re-constructed fine mass	RCFM	RCFM = SO4f+NO3f+ NH4f+OCf*FACTOR+ ECf+(SOIL)	1.375*PSO4+1.29*PNO3+ POA+SOA1+SOA2+SOA3+ SOA4+SOA5+PEC+NA+ PCL+FPRM+FCRS
Re-constructed bext	aerosol_bext		fRH*[4.125*PSO4+ 3.87*PNO3]+4*(SOA1+SOA2+ SOA3+SOA4+SOA5+POA)+ 10*PEC+NA+PCL+FPRM+FCRS+ 0.6*(CPRM+CCRS)

Model performance evaluation plots and metrics will be based on matching predictions and observations in time and space. There will not be any averaging over multiple-cell regions to match with an observation value. Qualitative evaluation will be done largely through graphical comparison of predictions and observations using spatial plots, time series plots, and scatter plots. The US EPA modeling guidance recommends against using any bright-line evaluation of performance metrics to determine whether the modeling is satisfactory (US EPA, 2007).

3.1 Particulate Matter and Regional Haze

The components of the visibility equation match up very closely to the prominent chemical forms of PM2.5: nitrate ion, sulfate ion, ammonium ion, organic carbon, elemental carbon, and soil (US EPA, 2007). Since these modeling applications will support PM2.5/Haze rules, model performance will be most rigorous for each of these PM2.5 species and coarse mass.

One of the problems related to PM model performance evaluation involves matching inconsistent monitor methodologies and model specie definition. Additionally, speciated measurements rarely add up to measurements of total fine mass. This unexplained fraction is usually attributed to the retention of water on the weighed samples (Timin, 2002). Other problems with comparing speciation samples and FRM measurements include volatilization of nitrate and positive and negative organic carbon artifacts (Timin, 2002).

Organic material is typically estimated from organic carbon using a 1.4 factor, which is based on the assumption that carbon accounts for 70% of the organic mass. Recent literature recommends a factor of 1.6 ± 0.2 for urban aerosol and 2.1 ± 0.2 for non-urban areas that would see more aged aerosol (Turpin and Lim, 2001; IMPROVE, 2006). These factors are applied to the observation data based on landuse type before being compared to model output. These factors may also be used to reduce modeled estimates of organic material to organic carbon.

Performance metrics used to describe model performance for PM2.5 species include mean bias, gross error, fractional bias, and fractional error (Table 3.2) (US EPA, 2007; Boylan et al, 2006). The bias and error metrics are used to describe performance in terms of the measured concentration units ($\mu g/m^3$). Even though the distribution of PM2.5 is log-normal, the data is not transformed for this analysis. The model attainment tests outlined by EPA for the PM2.5 NAAQS and Regional Haze rule require relative reduction factors to be applied to actual concentrations and not transformed concentrations. No minimum value is used to eliminate data points for the purposes of this analysis.

Table 3.2. Model Performance Metrics.

Mean Bias	$=\frac{1}{N\times M}\sum_{i=1}^{N}\sum_{j=1}^{M}(P_i^j - O_i^j)$
Gross Error	$=\frac{1}{N\times M}\sum_{i=1}^{N}\sum_{j=1}^{M}\lvert P_i^j - O_i^j \rvert$
Fractional Bias	$=\frac{1}{N\times M}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(2\times\frac{P_i^j - O_i^j}{P_i^j + O_i^j}\right)$
Fractional Gross Error	$=\frac{1}{N\times M}\sum_{i=1}^{N}\sum_{j=1}^{M}\left\lvert 2\times\frac{P_i^j - O_i^j}{P_i^j + O_i^j}\right\rvert$

*P=model prediction; O=observation; N=number of days; M=number of monitors

Fractional bias and fractional error metrics are useful for comparison of model performance between species that tend to have large concentrations and those with small concentrations. It also helps compare performance of the same specie if concentrations are very large in some seasons and very small in others. The fractional metrics are best when close to 0 and worst when close to 2.

3.2 Ozone

Hourly running 8-hour averaged surface ozone observations from EPA's AIRS database are matched to hourly running 8-hour averaged layer 1 (30 m height) model estimates for evaluation. Only monitors in the 12 km modeling domain are included in the analysis. Model performance evaluation plots and metrics are based on matching predictions and observations in time and space. EPA has suggested several statistical metrics to describe model performance and include mean normalized bias error (MNBE) and mean normalized gross error (MNGE) (see Table 3.3) (US EPA, 2007).

This modeling system is used to support regulatory applications, so the model performance analysis reflects this end-use of the modeling results. It is well known that ozone data tends to follow a log-normal distribution and for the purposes of scientific evaluations the data is often log-transformed before evaluation (Hogrefe et al, 2003). Observations and predictions used in the attainment test may not be transformed, so the data used for model performance evaluation will likewise not be transformed.

Table 3.3 Model Performance Metric Definitions.

Metric	Equation
Mean Normalized Bias Error (MNBE)	$=\frac{1}{N\times M}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(\frac{P^{j}-O_i^j}{O_i^j}\right)$
Mean Normalized Gross Error (MNGE)	$=\frac{1}{N\times M}\sum_{i=1}^{N}\sum_{j=1}^{M}\left\lvert\frac{P_i^{j}-O_i^j}{O_i^j}\right\rvert$

**P=model prediction; O=observation; N=number of days; M=number of monitors*

These metrics have traditionally been calculated when the observation value exceeds a certain minimum value, often 60 ppb for 1-hour ozone evaluation (Hogrefe et al, 2003). The MNBE and MNGE will be estimated using 3 different minimum 8-hour ozone thresholds: 20, 40, and 60 ppb. The 60 ppb minimum threshold level excludes prediction-observation pairs that are not of direct regulatory importance since the 8-hour ozone attainment test only applies to days with high ambient concentrations (US EPA, 2007). The 20 and 40 ppb minimum thresholds are included in the evaluation to get a better idea about how well the model is performing at predicting diurnal formation and removal processes and for days between high ozone episodes.

The metrics are estimated for all stations in the 12 km modeling domain for each day of the summer episode. The episode average metrics are estimated from the daily metrics.

3.3 Deposition

Wet deposition is measured at several monitoring networks and is also output by the photochemical model. The National Trends Network (NTN) and the Atmospheric Integrated Research Monitoring Network (AIRMoN) make up the National Atmospheric Deposition Program (NADP). NTN sites collect weekly measurements of wet deposition fluxes of sulfate and nitrate anions and the ammonium cation. NADP network stations measure wet deposition as mass per volume (mg/L) and the model outputs mass per area (g/ha or mole/ha). CAMx4 wet deposition output is matched to NTN/NADP measurement data in units of kg/km^2 according to the details outlined below.

The calculations used to convert CAMx wet deposition output to compare to NTN/NADP network data:

SPECIE_WD (g/ha) * (1 ha / 2.5 acres) * (1 acre / 0.0040469 km^2) * (1 kg / 1000 g)

The calculations used to convert NTN/NADP data to compare with CAMx output data:

SPECIES (mg/L) * (1 L / 1,000,000 mm^3) * precipitation in mm * (1 mm^2 / 0.000000000001 km^2) * (1 g / 1000 mg) * (1 kg / 1000 g)

The table below outlines the matching of observed species to CAMx output species.

Table 3.4 Observed and Modeled Wet Deposition		
	NADP/NTN	CAMx4
Sulfate	SO4	PSO4_WD + SULF_WD
Nitrate	NO3	PNO3_WD + HNO3_WD
Ammonium	NH4	PNH4_WD + NH3_WD
Crustal	Ca + Cl + Mg +K + Na	FCRS_WD + FPRM_WD

4. Attainment Tests

Visibility

Visibility may be estimated by two similar methods that relate light extinction to ambient PM2.5 concentrations (FLAG, 2000; US EPA, 2007). Visibility will be estimated using the new equation recommended by the IMPROVE steering committee (IMPROVE, 2006). The new and old equations produce very similar estimates of light extinction in the upper Midwest. The new equation will be emphasized for the SIP modeling demonstration due to its more up to date science.

The equation shown below relates PM2.5 specie concentrations to light extinction. Additional factors of f(RH) are included that change the light scattering of sulfate and nitrate based on climatologically averaged relative humidity.

β_{ext} = 2.2*f_SRH*[small sulfate] + 2.4*f_S(RH)*[small nitrate] + 4.8*f_LRH*[large sulfate] + 5.1*f_L(RH)*[large nitrate]+ 2.8*[small OCM] + 6.1*[large OCM] + 10*EC + 1*SOIL + 0.6*CM + 1.7*f_{SS}(RH)*SS + $\beta_{rayleigh}$

Bext	Estimated extinction coefficient (Mm-1)
Sulfate	Sulfate associated with ammonium (SO4*1.375)
Nitrate	Nitrate associated with ammonium (NO3*1.29)
OCM	Organic carbon Mass
EC	Elemental carbon
SOIL	Inorganic primary PM2.5 (soil, crustal, other)
CM	Coarse fraction particulate matter
SS	Sea salt
$\beta_{rayleigh}$	Light scattering due to Rayleigh scattering (site specific)
fRH	Relative humidity adjustment factor

The apportionment of sulfate, nitrate, and organic carbon mass into small and large size fractions is shown below using ‘X’ as a placeholder for these species.

Large X = ([Total X] / [20 ug/m3]) * [Total X], where [Total X] $<$ 20 ug/m3

Large X = [Total X], where [Total X] $\geq$ 20 ug/m3

Small X = [Total X] – [Large X]

The fRH values are long-term averages that are site and month specific (US EPA, 2003a; US EPA 2003b; FLAG, 2000). The light scattering due to Rayleigh is site specific (IMPROVE, 2006). The NO_2 component to the light extinction equation is not included since it is not measured at Class I areas in the upper Midwest. The visibility equation is expressed as an extinction coefficient (β_{ext}) and is converted to deciviews using the equation below.

$$\text{Deciview} = 10\ln(\beta_{ext}/\ \beta_{rayleigh})$$

The reasonable progress test to determine the relationship between current and future year visibility is expressed in deciview units. The changes in deciview between the current and future year strategy is the reasonable progress test and is shown below.

$$\text{Change in Deciview} = 10\ln[(\beta_{ext})_{future} / (\beta_{ext})_{base}]$$
- or -
$$\text{Change in Deciview} = \text{Deciview}_{base} - \text{Deciview}_{future}$$

Visibility will be estimated for key Class I area in the Midwest for the base year and various future year scenarios. The changes in visibility between the base line and future year will be assessed using procedures in U.S. EPA's modeling guidance document (US EPA, 2007).

1. The visibility in deciviews will be ranked from high to low at each Class I area for the calendar years 2000-2004 using the monthly and site specific fRH values and the more recent IMPROVE light extinction equation.
2. The mean deciviews for the 20% days with the best and the 20% days with the worst visibility is estimated for each Class I area for each year of the 2000-04 baseline period.
3. The mean observed extinction coefficient for the days during the modeling period (2002) with the 20% best and 20% worst visibility will be calculated.
4. The mean predicted extinction coefficient for the corresponding 20% best and 20% worst days of the modeling period of the base case and future year strategy will be calculated using monthly site specific fRH values.
5. The relative reduction factor for the 20% best and 20% worst group of days for each site for each of the particulate matter species in the light extinction equation are estimated.
6. The relative reduction factors are multiplied by daily measured PM data during the 2000-04 baseline to estimate future daily values of these species.
7. These future daily PM estimates are used to estimate light extinction for each of the previously identified 20% best and 20% worst days of monitored data. Light extinction is converted to deciviews and the mean value for the best and worst days for each year of the baseline period is estimated.
8. The 5 mean deciview values for the worst and best days (one from each of the 5 years) are averaged together for a mean value for the best and worst days.
9. The future year mean deciview values in step 8 are compared to the observed values from step 2. The differences are compared to established goals for reasonable progress to determine if reasonable progress is demonstrated.

Annual PM2.5 Standard

Progress in meeting the annual PM2.5 standard will be assessed by application of the procedures outlined by the U.S. EPA modeling guidance document (US EPA, 2007). The major steps of this attainment test are outlined below:

1. Chemically speciated IMPROVE and STN PM2.5 data from 2000-2004 is spatially interpolated to match the grid domain and resolution used for the photochemical modeling. Spatial fields are developed for each PM2.5 chemical species for each season using the SAS statistical software package PROC KRIG function (EPA, 2004b).
2. The estimated fractional composition of each species by quarter is multiplied by the 5 year weighted average 2000-2004 FRM quarterly mean

concentrations at each FRM monitor, resulting in estimated quarterly mean ambient concentrations of PM2.5 components sulfate, nitrate, ammonium, elemental carbon, organic carbon, particle bound water, and crustal material.

3. Estimate the modeled quarterly mean concentration for each chemical component of PM2.5 in the base year and future scenarios.
4. Calculate quarterly relative reduction factors for sulfate, nitrate, elemental carbon, organic carbon, and crustal material. The RRF is the ratio of the future year to the base year.
5. Quarterly specific RRFs are multiplied by the quarterly average species concentration from step 2 to estimate future case quarterly average concentrations for each of the PM2.5 species.
6. Calculate the quarterly average future scenario concentrations for ammonium and particle bound water using estimated ambient concentrations of sulfate, nitrate, and degree of sulfate neutralization. Particle bound water is estimated with an empirical equation.
7. Sum the quarterly future species concentrations to estimate the future quarterly average PM2.5 concentration.
8. The annual average future scenario concentration is the average of the 4 future year quarterly average PM 2.5 concentrations.
9. Compare value to annual NAAQS standard of 15 ug/m^3. If value is $\leq$ 15 ug/m^3 then the test is passed.

Organic carbon mass is estimated using a mass balance approach (EPA, 2006). The organic carbon spatial fields are only used to supply a minimum value for OCM when OCM estimated by mass balance is less than OC*1.4*0.7. A spatial field of the degree of sulfate neutralization is developed to estimate PM2.5 ammonium. Particle bound water is estimated using an empirical equation with spatially interpolated PM2.5 sulfate ion, FRM equivalent PM2.5 nitrate ion, and FRM equivalent PM2.5 ammonium ion (EPA, 2006).

Ozone

Progress in meeting the 8-hour ozone standard will be assessed in part using the modeled attainment test outlined by the U.S. EPA's "Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hour Ozone, PM2.5, and Regional Haze" (US EPA, 2007). The attainment test is only applicable to monitors with design values $\geq$ 75 ppb. The major steps of the attainment test are described below:

1. Calculate the 8-hour ozone design value at each monitor location; the design value used in the attainment test is the average of 3 consecutive 3 year averaged design values: 2000-2002, 2001-2003, and 2002-2004.
2. Apply the photochemical model to a current year and future year to estimate a monitor specific relative reduction factor.
3. Calculate the future year design value by multiplying the monitor-specific observed design value by the monitor-specific relative reduction factor.
4. If the future year design value is $\leq$ 84 ppb then the test is passed at that monitor location.

The highest 8 hour daily maximum predicted in the 3x3 (or 7x7 for 4 km modeling) group of cells surrounding and including the cell in which the monitor is located will be used in the attainment test. The attainment test will be applied to all days during the summer of 2002 that meet the meet the inclusion criteria for the relative reduction factor calculation (US EPA, 2007). An episode day must have a peak 8-hr ozone model prediction > 85 ppb at a specific monitor or near the monitor (definition of near mentioned above) to be included in the attainment test. If there are less than 10 days of estimated peak 8-hr ozone at a monitor then the threshold for inclusion to the relative reduction factor is decreased until the number of days equals 10 or the threshold goes below 70 ppb (US EPA, 2007). If there are less than 4 days in the relative reduction factor calculation then the attainment test is not applied for that monitor.

Unmonitored Area Analysis

An un-monitored area analysis is an additional review to identify areas that might exceed the 8-hr ozone or annual PM2.5 NAAQS if monitors were present (US EPA, 2007). This analysis uses interpolated spatial fields of ambient concentrations and photochemical model estimated concentrations to develop "model adjusted spatial fields of observations" (US EPA, 2007). The model adjusted spatial fields are developed for the base year. Future year concentrations are estimated by applying RRFs to the base year model adjusted spatial field.

8-hr Ozone NAAQS

1. Ambient 8-hr ozone design values are interpolated to create the ambient spatial field. The design values are the average of the 2000-2002, 2001-2003, and 2002-2004 8-hr ozone design values.
2. The ambient spatial field is adjusted using gridded ozone seasonal average base year model output gradients.
3. Gridded RRFs are applied to the adjusted spatial field developed in step 2.
4. If any grid cell exceeds 84 ppb then that grid cell is predicted to exceed the 8-hr ozone NAAQS in the future scenario.

Annual PM2.5 NAAQS

1. Quarterly PM2.5 chemical species are interpolated to create the ambient spatial fields.
2. The ambient spatial field is adjusted using gridded ozone seasonal average base year model output gradients.
3. Quarterly gridded RRFs for each PM2.5 species are applied to the adjusted spatial field developed in step 2.
4. If any grid cell exceeds 15 ug/m3 then that grid cell is predicted to exceed the annual PM2.5 NAAQS in the future scenario.

US EPA intends to provide software that incorporates monitor observation data and CAMx output to generate the gridded future year 8-hr ozone and annual PM2.5 estimates (US EPA, 2007). This software will be used to apply the un-monitored area analysis.

24-hr PM2.5 Standard

Progress in meeting the new 24-hr PM2.5 standard will be assessed by application of the procedures outlined by the U.S. EPA document "Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze" (US EPA, 2007). The major steps of this attainment test are outlined below:

1. Chemically speciated IMPROVE and STN PM2.5 data from 2000-2004 is spatially interpolated to match the grid domain and resolution used for the photochemical modeling. Spatial fields are developed for each PM2.5 chemical species for each season using the SAS statistical software package PROC KRIG function (EPA, 2004b). Rather than interpolating seasonal averages, the top 15% of reconstructed PM2.5 mass samples are used as the basis of the chemically speciated data used for seasonal spatial fields.
2. Estimate the observed 98^{th} percentile value for each year of the 5 year baseline period. Additionally, the next highest concentration in each quarter is identified. This results in data for each year and site which contains one quarter that equals the 98^{th} percentile and 3 quarters which are less than or equal to the 98^{th} percentile.
3. The quarterly maximum daily concentration is multiplied by the fractional composition of PM2.5 species based on the spatial fields.
4. PM2.5 component specific relative reduction factors are estimated at each monitor for each quarter.
5. The component specific RRFs are multiplied by the observed values to estimate future year concentrations.
6. The quarterly components are summed to estimate the quarterly future year 98^{th} percentile value.
7. The 3 consecutive future year 98^{th} percentiles are averaged together to estimate 3 different future year design values. The 3 future year design values are averaged to estimate a single 5-year weighted average 24-hour design value.
8. If this 5 year weighted average 24-hour design value is less than 35 ug/m3 then the test is passed.

The relative reduction factor is only estimated for days with 24-hour average modeled PM2.5 greater than 35 ug/m3. If less than 10 days in a quarter meet this criteria, then the threshold is lowered until the number of days equals 10 or the threshold goes below 20 ug/m3. If there are less than 5 days in the RRF calculation then that quarter is not used for the estimation of the future year design value. If no quarter has more than 5 days included in the RRF calculation then the attainment test is not applied for that monitor.

5.0 Other Issues

Technology Transfer and Modeling Capacity Building

States that are part of the Midwest Regional Planning Organization and cooperating organizations have to opportunity to acquire a turn-key modeling system. This will include all the model inputs, scripts, and support documents to perform model simulations. States participate in an extensive sensitivity projects and preliminary strategy rounds which are designed in part to allow States to develop modeling expertise in-house.

The model input data will be available on an FTP site. The drawback is that transfer times will be long since the files are rather large, but the benefit is that as improvements and updates to input files, model code, and processing utilities become available they will immediately be available to everyone. This approach greatly reduces the resource burden involved with data distribution of media (i.e. hard drives or DLT tapes) via the mail system.

Where very large datasets need to be transferred USB/firewire drives will be sent via the mail system. A general figure where USB drives will be used for transfer instead of FTP would be 50+ gigabytes of data.

States and cooperating organizations will also participate in regular conference calls and face to face meetings to discuss problems, progress, and outline cooperative work objectives.

Ultimately, States that are inclined will be able to use the model inputs developed by the Midwest Regional Planning Organization as the basis for local emphasis modeling projects.

Data Management and Storage

The file storage requirements for annual modeling are large and data backup is an important consideration. Important files including raw emissions and meteorological files will be stored redundantly on multiple hard drives. Additionally, all the model inputs will have a redundant copy at each member State as they will be using them for model simulations as part of the technology transfer and capacity building.

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Appendix F
Julian and Gregorian Calendar
Cross-Reference for the Year 2002

Gregorian/Julian Calendar for 2002

Quarter 1 ?

January

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
		1	2	3	4	5
6	7	8	9	10	11	12
6	7	8	9	10	11	12
13	14	15	16	17	18	19
13	15	16	16	17	18	19
20	21	22	23	24	25	26
20	21	22	23	24	25	26
27	28	29	30	31		
27	28	29	30	31		

February

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
					32	33
3	4	5	6	7	8	9
34	35	36	37	38	39	40
10	11	12	13	14	15	16
41	42	43	44	45	46	47
17	18	19	20	21	22	23
48	49	50	51	52	53	54
24	25	29	27	28		
55	56	57	58	59		

March

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
					60	61
3	4	5	6	7	8	9
62	63	64	65	66	67	68
10	11	12	13	14	15	16
69	70	71	72	73	74	75
17	18	19	20	21	22	23
76	77	78	79	80	81	82
24	25	26	27	28	29	30
83	84	85	86	87	88	89
31						
90						

Quarter 2 ?

April

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
	91	92	93	94	95	96
7	8	9	10	11	12	13
97	98	99	100	101	102	103
14	15	16	17	18	19	20
104	105	106	107	108	109	110
21	22	23	24	25	26	27
111	112	113	114	115	116	117
28	29	30				
118	119	120				

May

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			1	2	3	4
			121	122	123	124
5	6	7	8	9	10	11
125	126	127	128	129	130	131
12	13	14	15	16	17	18
132	133	134	135	136	137	138
19	20	21	22	23	24	25
139	140	141	142	143	144	145
26	27	28	29	30	31	
146	147	148	149	150	151	

June

Sun	Mon	Tue	Wed	Thu	Fri	Sat
						1
						152
2	3	4	5	6	7	8
153	154	155	156	157	158	159
9	10	11	12	13	14	15
160	161	162	163	164	165	166
16	17	18	19	20	21	22
167	168	169	170	171	172	173
23	24	25	26	27	28	29
174	175	176	177	178	179	180
30						
181						

Quarter 3 ?

July

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
	182	183	184	185	186	187
7	8	9	10	11	12	13
188	189	190	191	192	193	194
14	15	16	17	18	19	20
195	196	197	198	199	200	201
21	22	23	24	25	26	27
202	203	204	205	206	207	208
28	29	30	31			
209	210	211	212			

August

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1	2	3
				213	214	215
4	5	6	7	8	9	10
216	217	218	219	220	221	222
11	12	13	14	15	16	17
223	224	225	226	227	228	229
18	19	20	21	22	23	24
230	231	232	233	234	235	236
25	26	27	28	29	30	31
237	238	239	240	241	242	243

September

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
244	245	246	247	248	249	250
8	9	10	11	12	13	14
251	252	253	254	255	256	257
15	16	17	18	19	20	21
258	259	260	261	262	263	264
22	23	24	25	26	27	28
265	266	267	268	269	270	271
30	31					
272	273					

Quarter 4 ?

October

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
		274	275	276	277	278
6	7	8	9	10	11	12
279	280	281	282	283	284	285
13	14	15	16	17	18	19
286	287	288	289	290	291	292
20	21	22	23	24	25	26
293	294	295	296	297	298	299
27	28	29	30	31		
300	301	302	303	304		

November

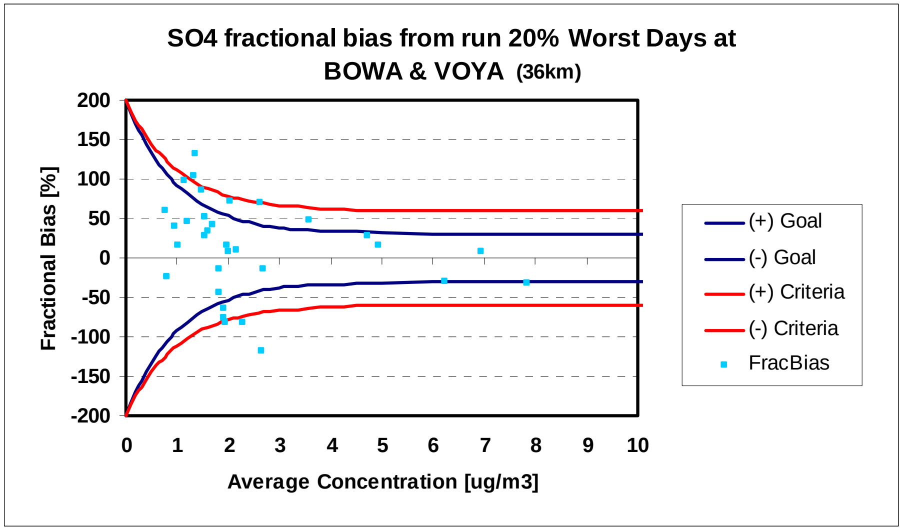
Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
					305	306
3	4	5	6	7	8	9
307	308	309	310	311	312	313
10	11	12	13	14	15	16
314	315	316	317	318	319	320
17	18	19	20	21	22	23
321	322	323	324	325	326	327
24	25	26	27	28	29	30
328	329	330	331	332	333	334

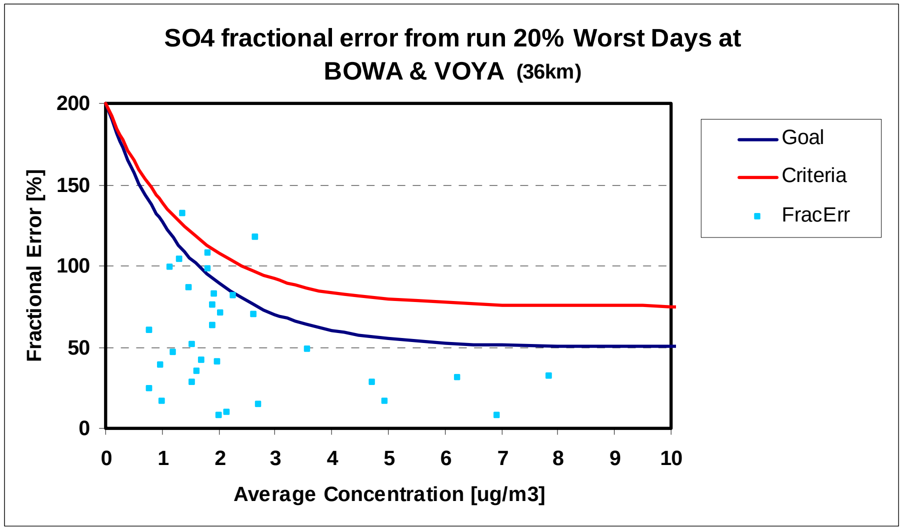
December

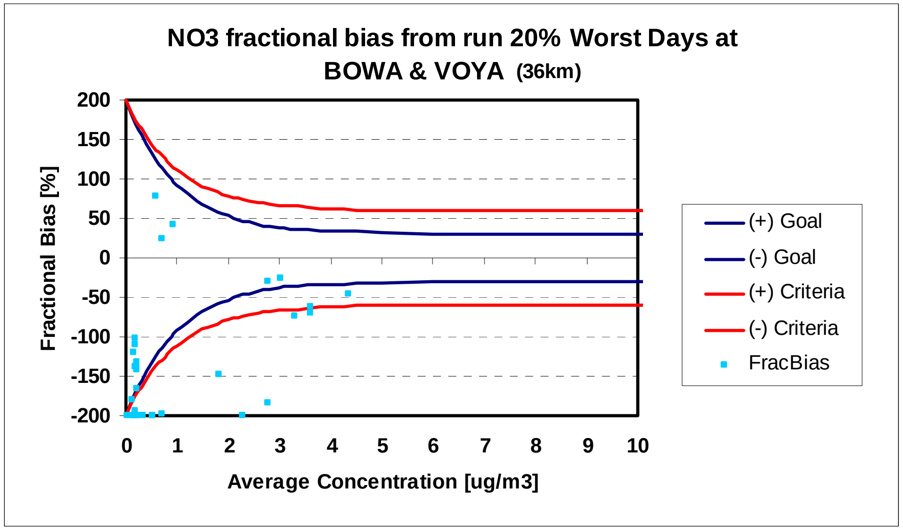
Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
335	336	337	338	339	340	341
8	9	10	11	12	13	14
342	343	344	345	346	347	348
15	16	17	18	19	20	21
349	350	351	352	353	354	355
22	23	24	25	26	27	28
356	357	358	359	360	361	362
29	30	31				
363	364	365				

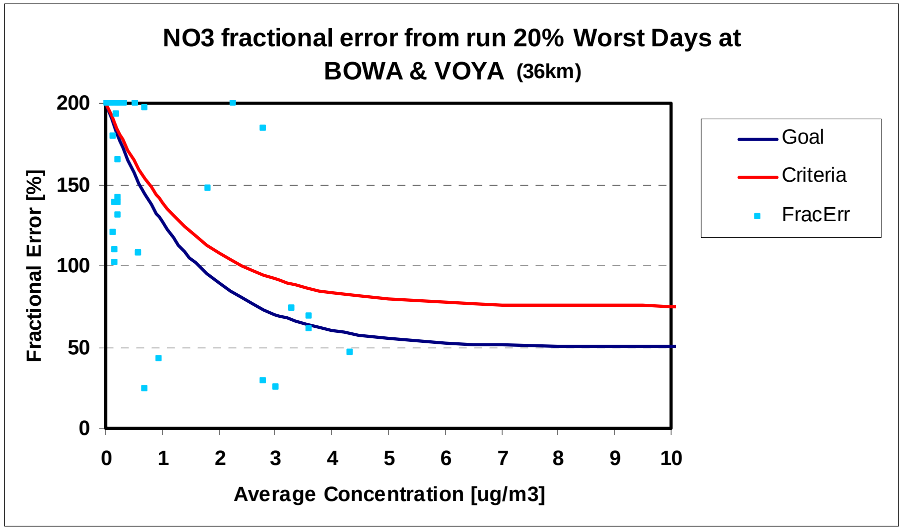
Appendix G
Minnesota$_{(MRPO)}$ Air Quality Model
Performance Evaluation Plots

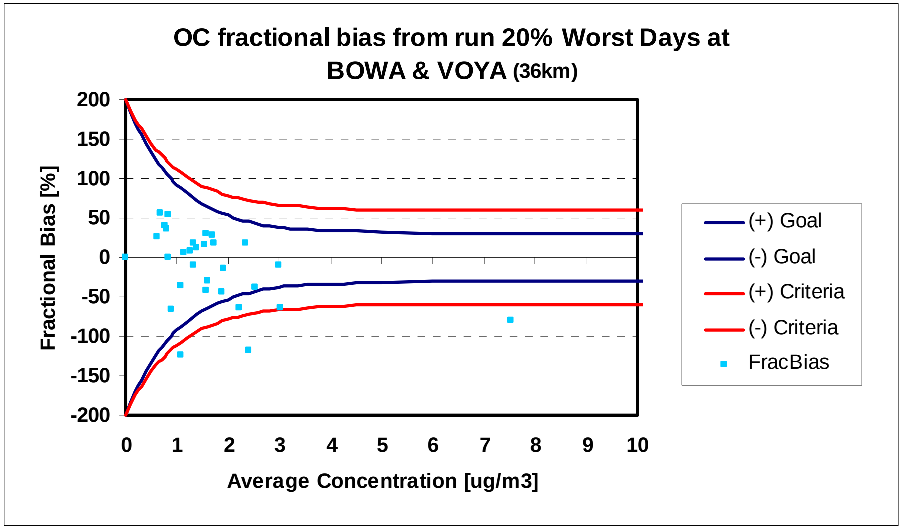
Figures 1 - 12 Fractional Bias and Error for 36km Grid at 20% Worst Days at BOWA and VOYA

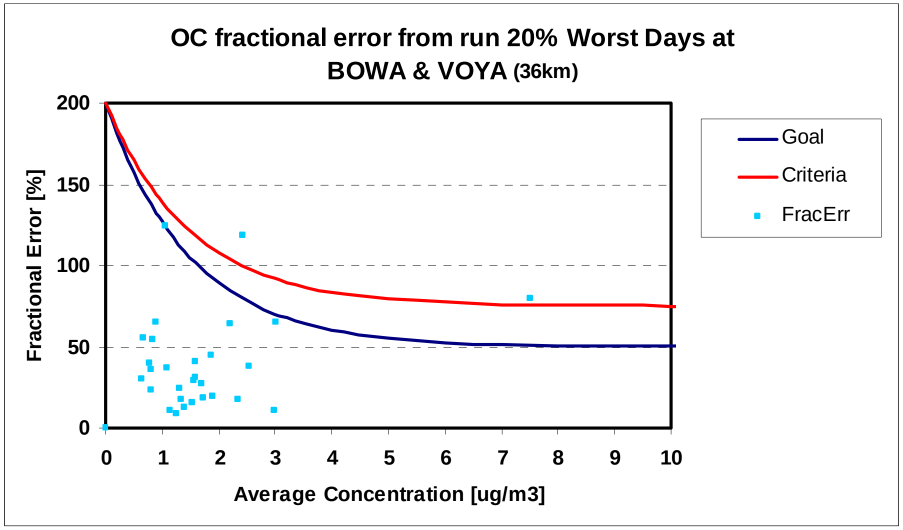


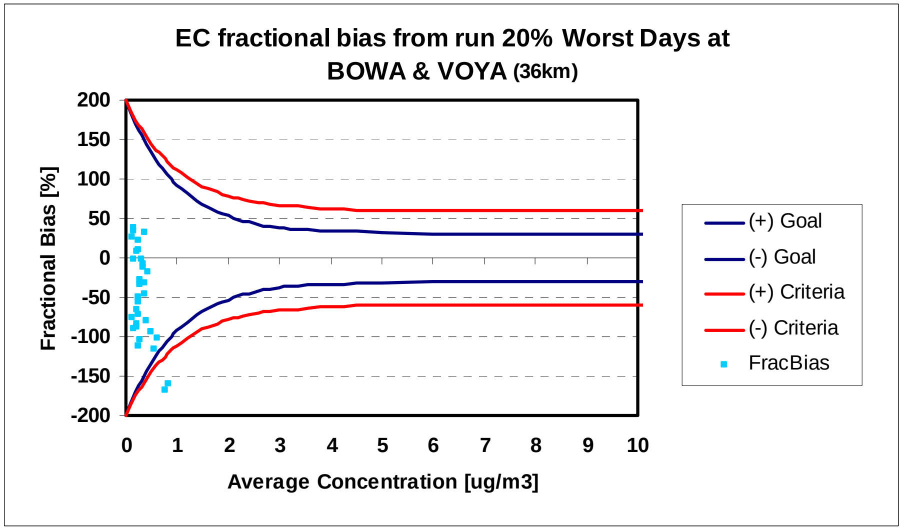


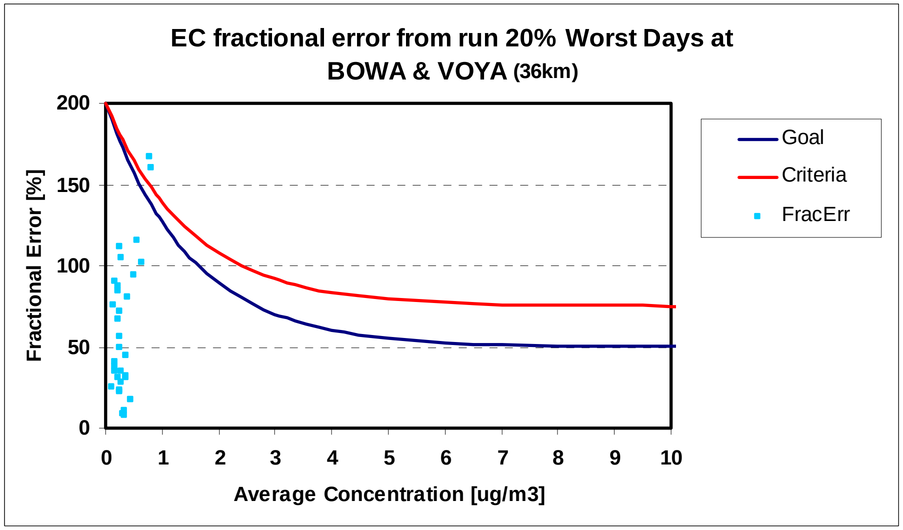


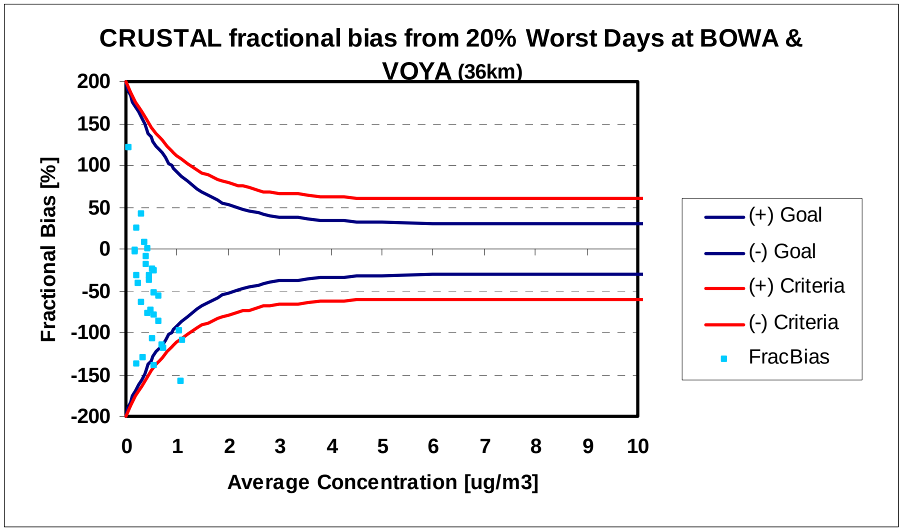


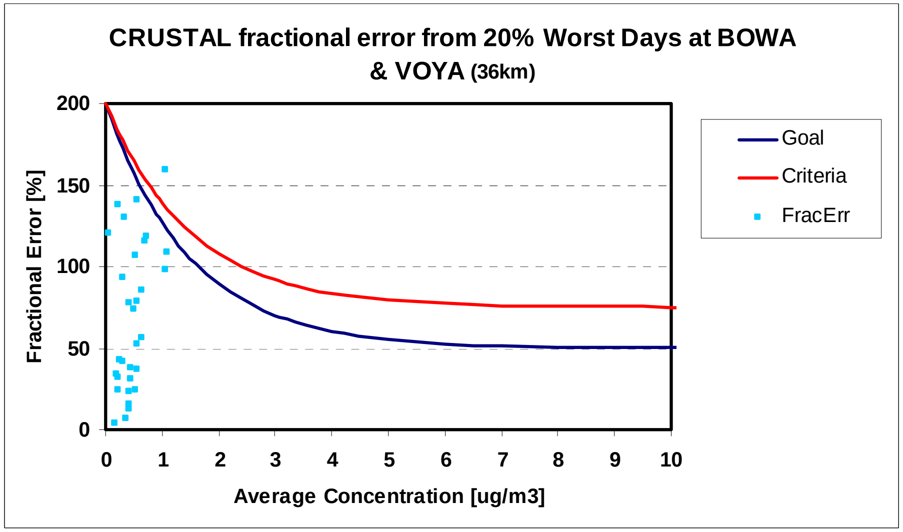

OC fractional bias from run 20% Worst Days at
BOWA & VOYA (36km)
Fractional Bias [%]
Average Concentration [ug/m3]
(+) Goal
(-) Goal
(+) Criteria
(-) Criteria
FracBias

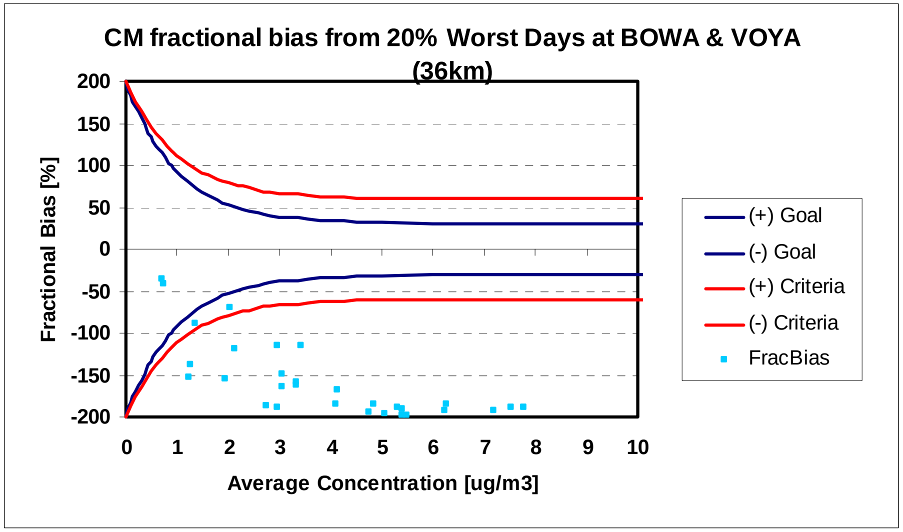

OC fractional error from run 20% Worst Days at
BOWA & VOYA (36km)
Fractional Error [%]
Average Concentration [ug/m3]
Goal
Criteria
FracErr


EC fractional bias from run 20% Worst Days at
BOWA & VOYA (36km)
Fractional Bias [%]
Average Concentration [ug/m3]
(+) Goal
(-) Goal
(+) Criteria
(-) Criteria
FracBias


EC fractional error from run 20% Worst Days at
BOWA & VOYA (36km)
Fractional Error [%]
Average Concentration [ug/m3]
Goal
Criteria
FracErr


CRUSTAL fractional bias from 20% Worst Days at BOWA & VOYA (36km)
Fractional Bias [%]
Average Concentration [ug/m3]
(+) Goal
(-) Goal
(+) Criteria
(-) Criteria
FracBias


CRUSTAL fractional error from 20% Worst Days at BOWA & VOYA (36km)
Fractional Error [%]
Average Concentration [ug/m3]
Goal
Criteria
FracErr


CM fractional bias from 20% Worst Days at BOWA & VOYA (36km)
Fractional Bias [%]
Average Concentration [ug/m3]
(+) Goal
(-) Goal
(+) Criteria
(-) Criteria
FracBias

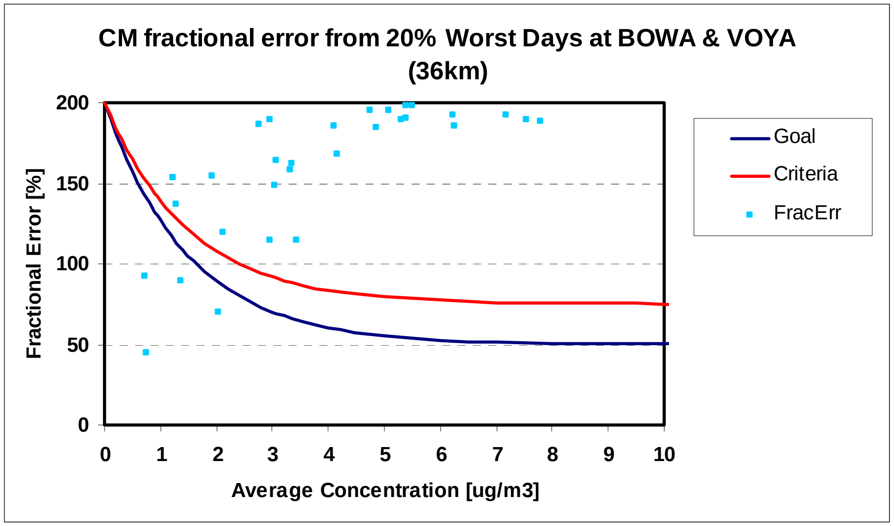
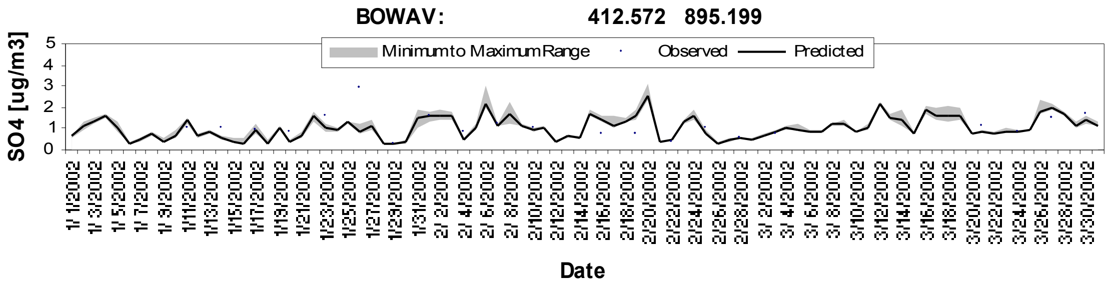
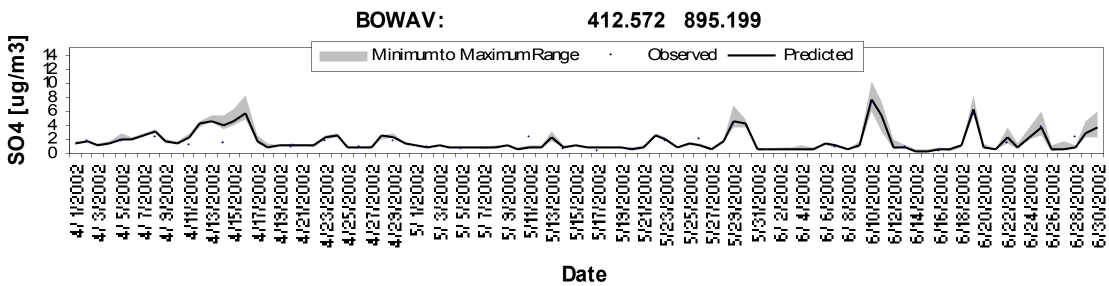
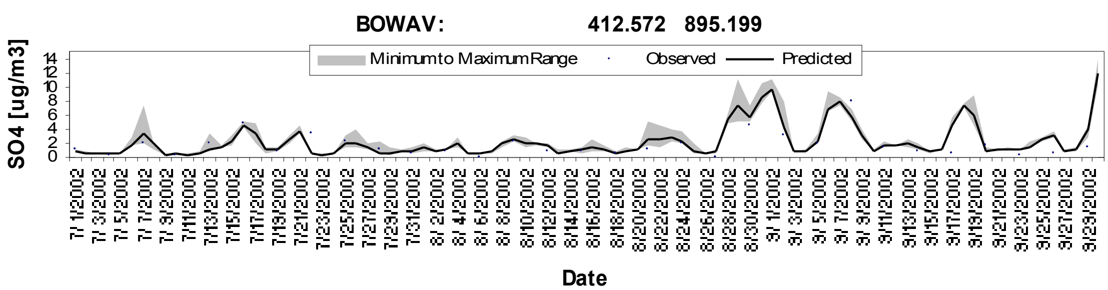

CM fractional error from 20% Worst Days at BOWA & VOYA (36km)
Fractional Error [%]
Average Concentration [ug/m3]
Goal
Criteria
FracErr

Figure 13. Time Series 36km - Sulfate at Boundary Waters Canoe Area:







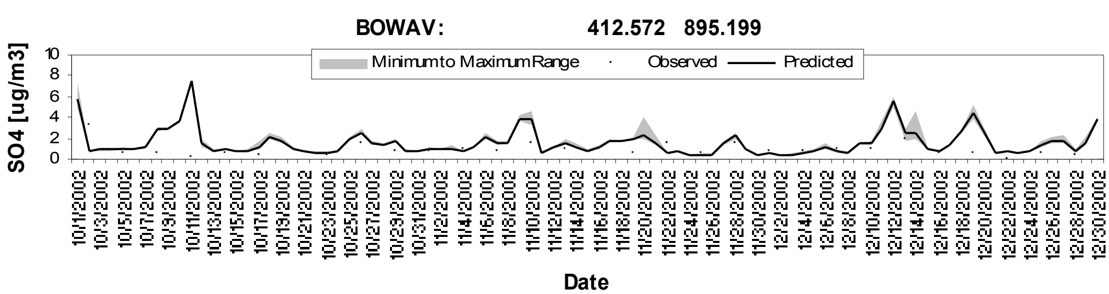
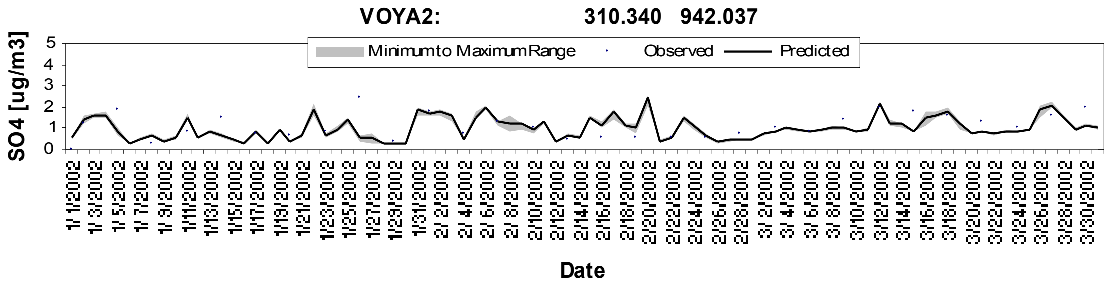
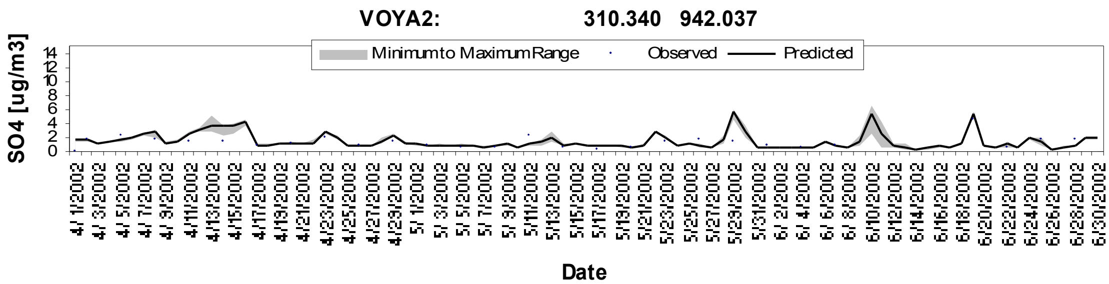
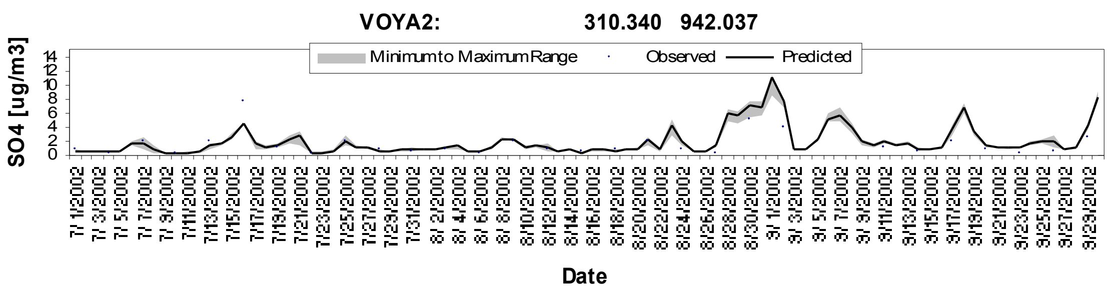


Figure 14. Time Series 36km - Sulfate at Voyageurs







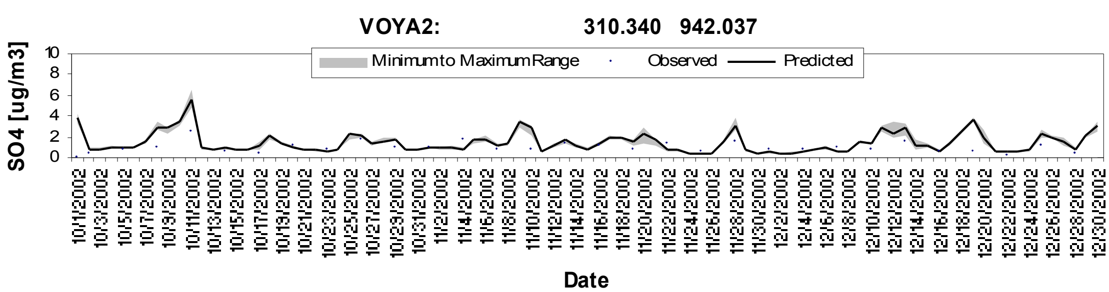
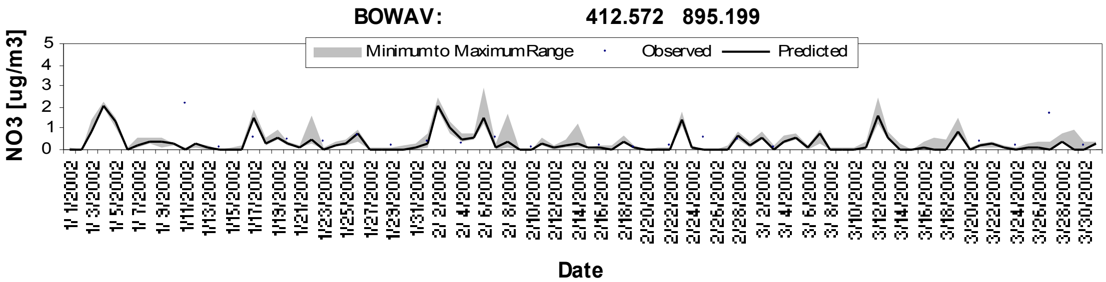
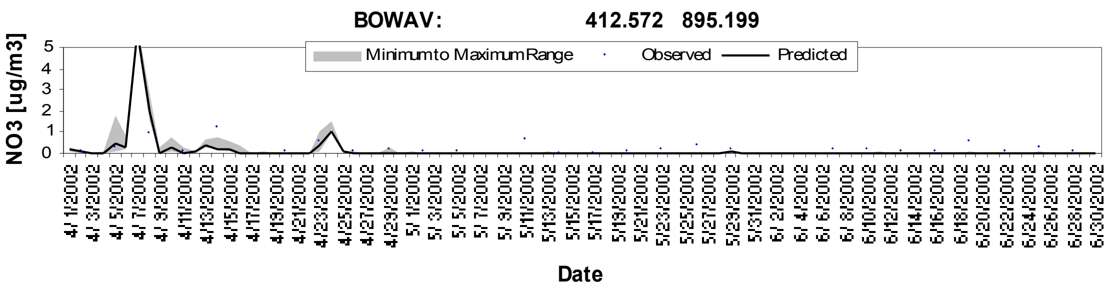
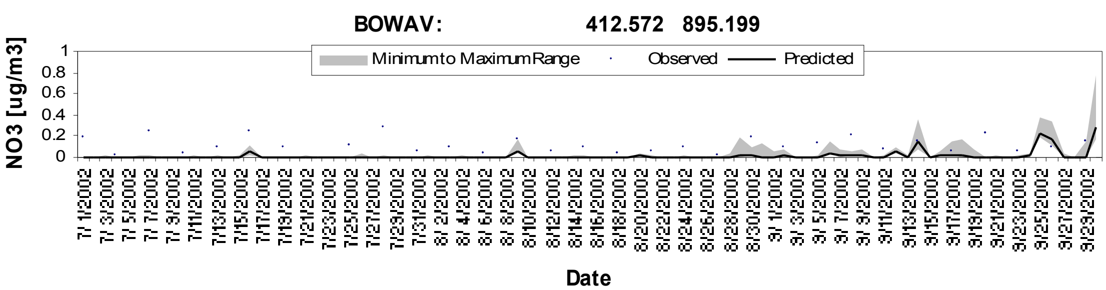


Figure 15. Time Series 36km - Nitrate at Boundary Waters Canoe Area:







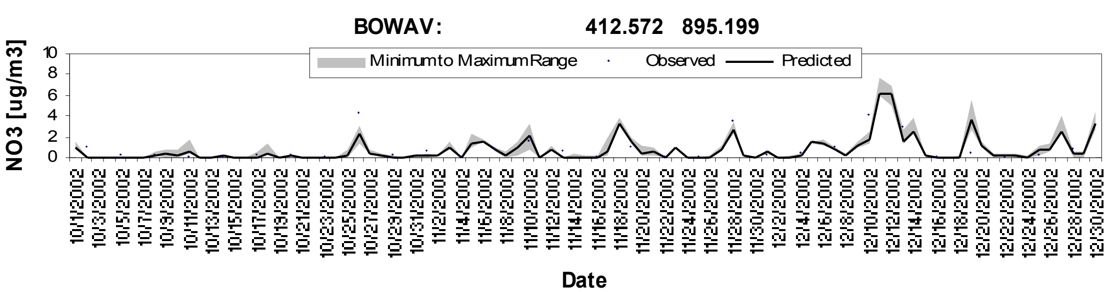
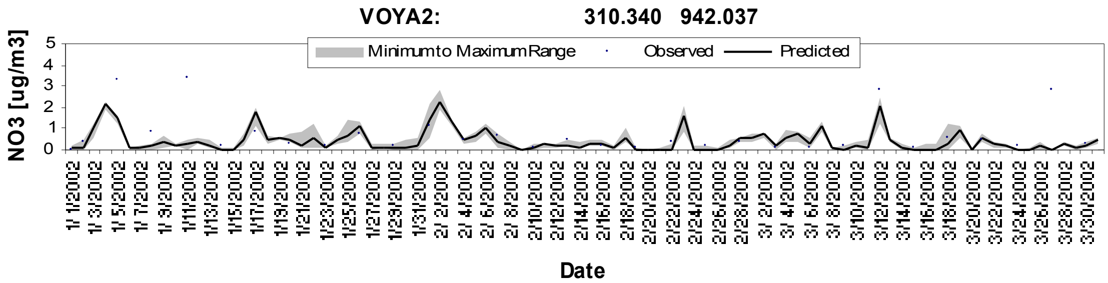
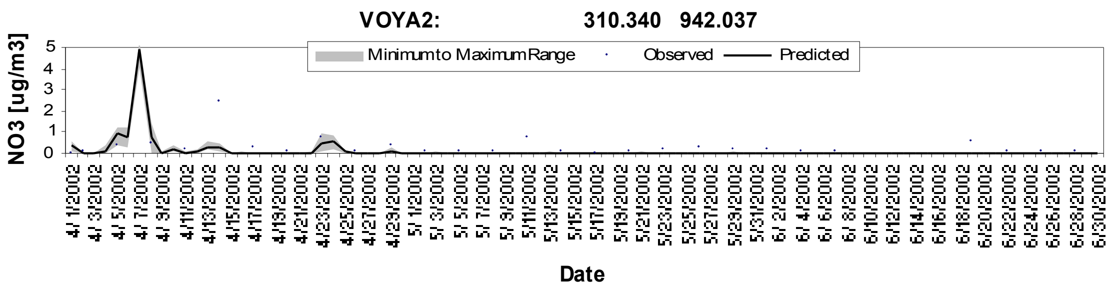
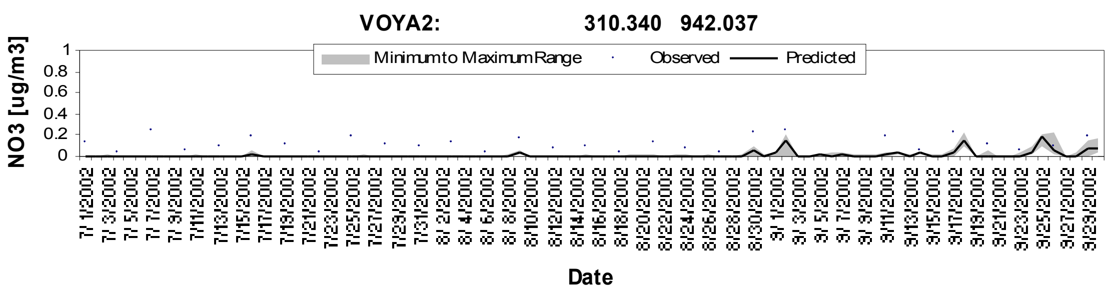


Figure 16. Time Series 36km - Nitrate at Voyageurs:







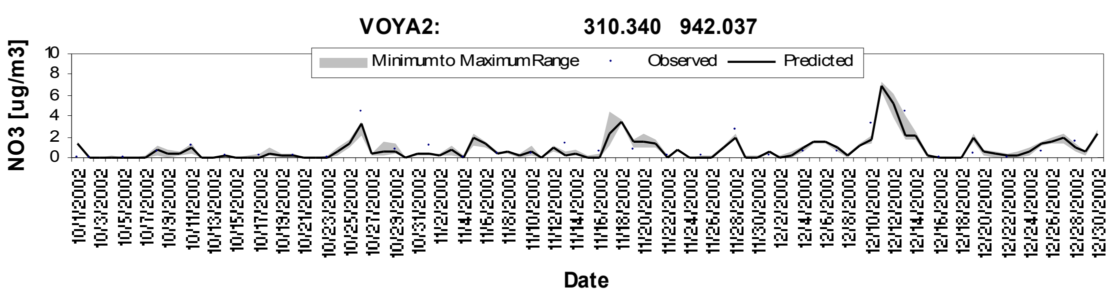


Figure 17. Time Series 36km – Elemental Carbon at Boundary Waters:

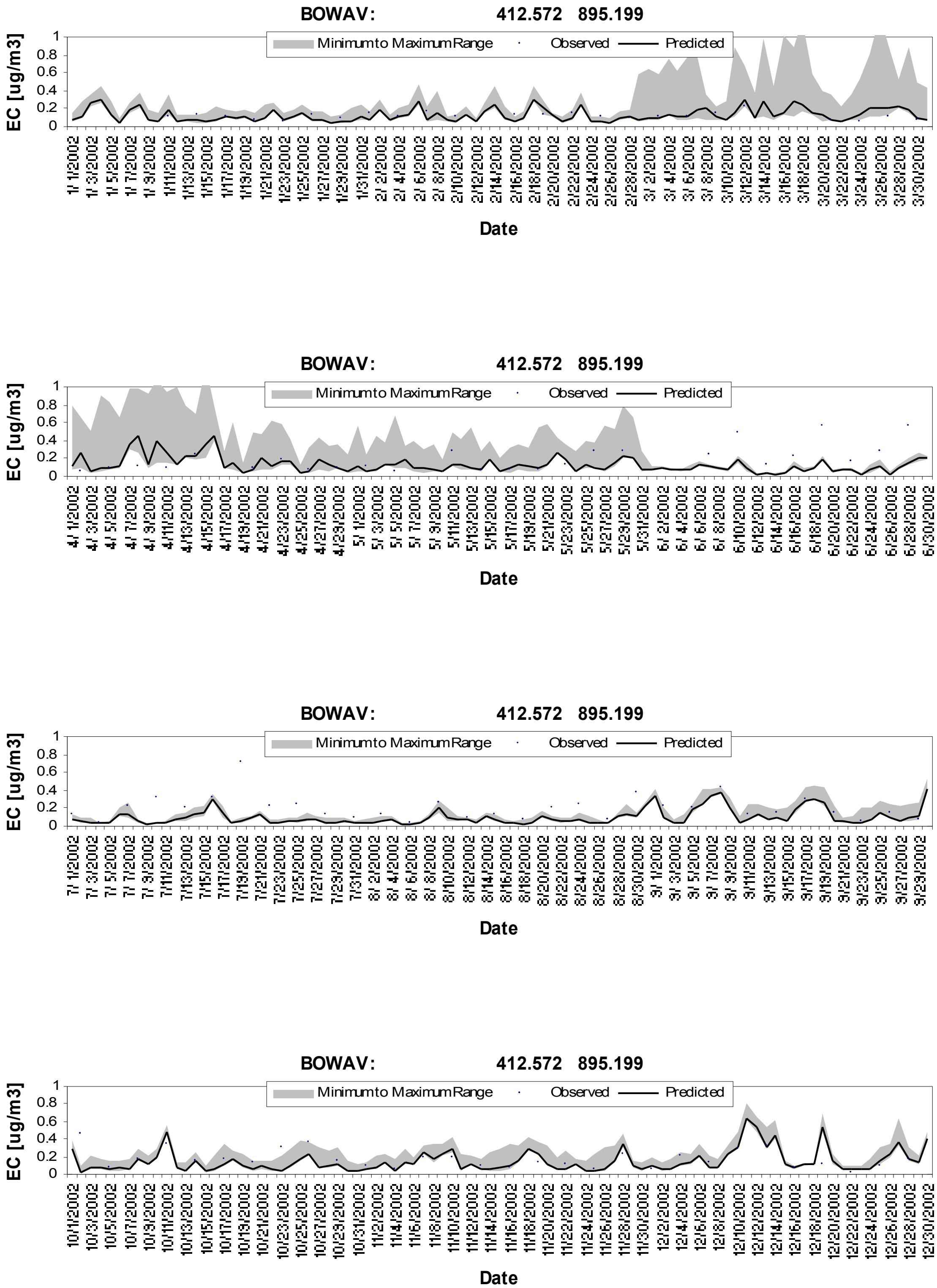
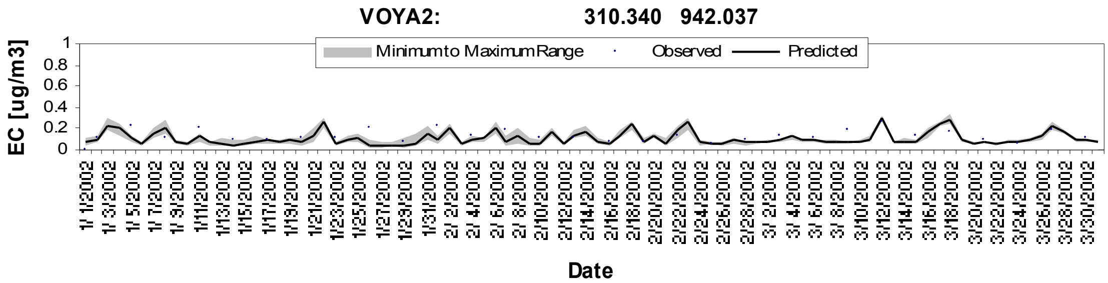
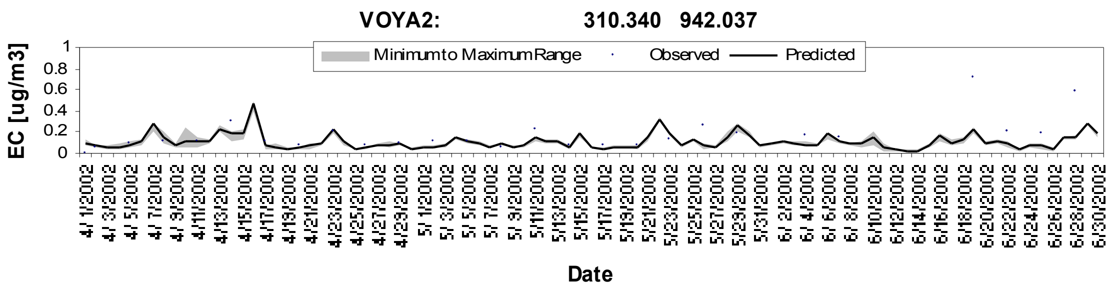
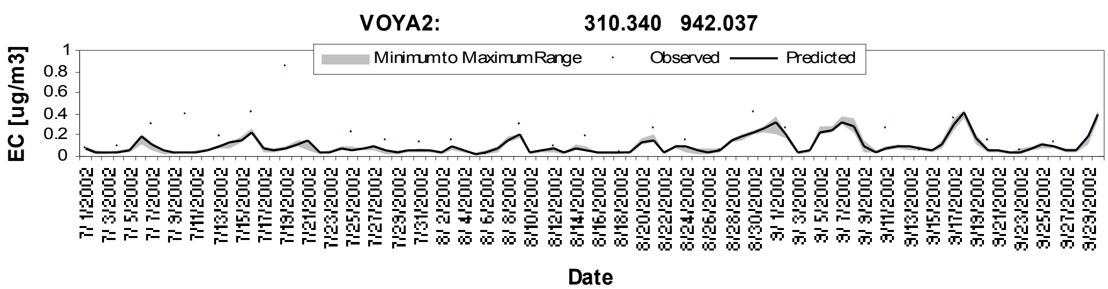


Figure 18. Time Series 36km – Elemental Carbon at Voyageurs:







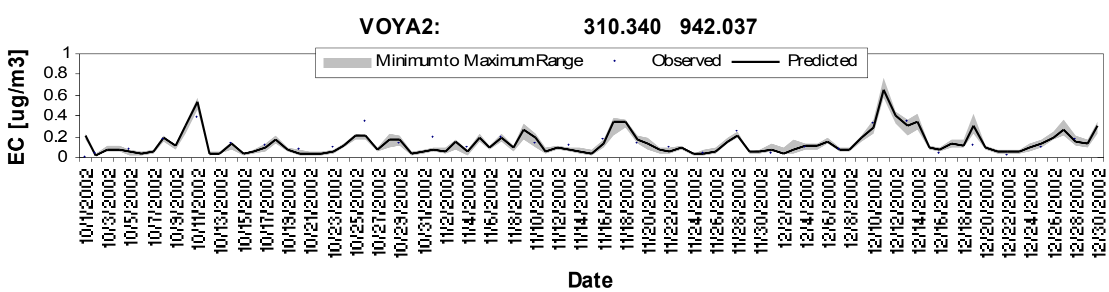
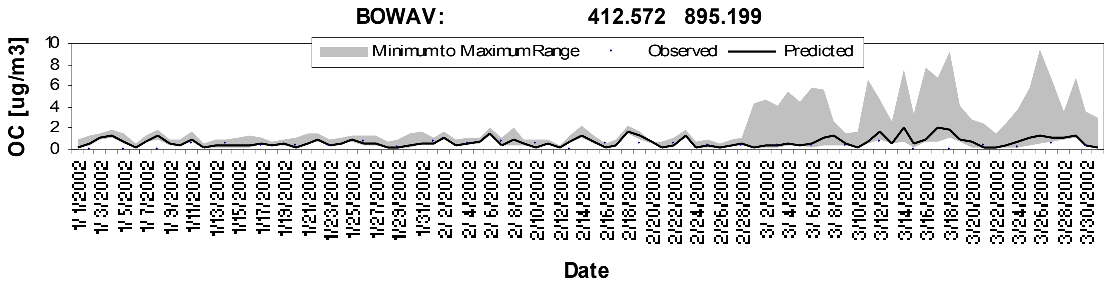
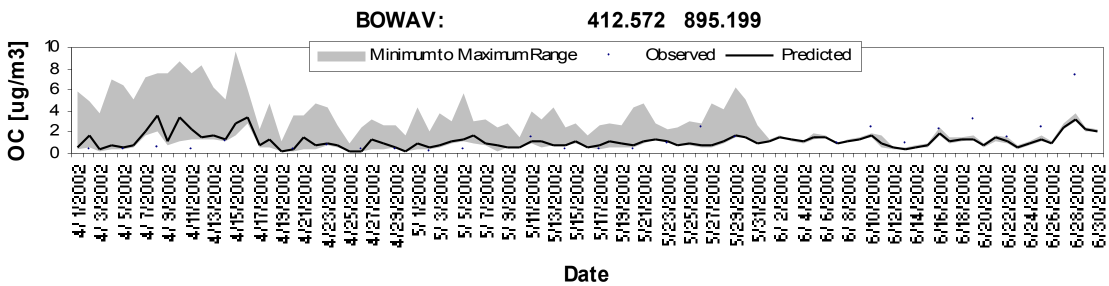
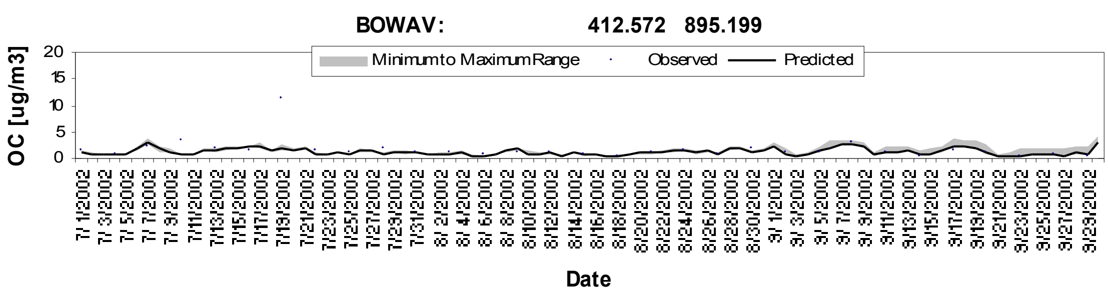


Figure 19. Time Sseries 36km – Organic Carbon at Boundary Waters:







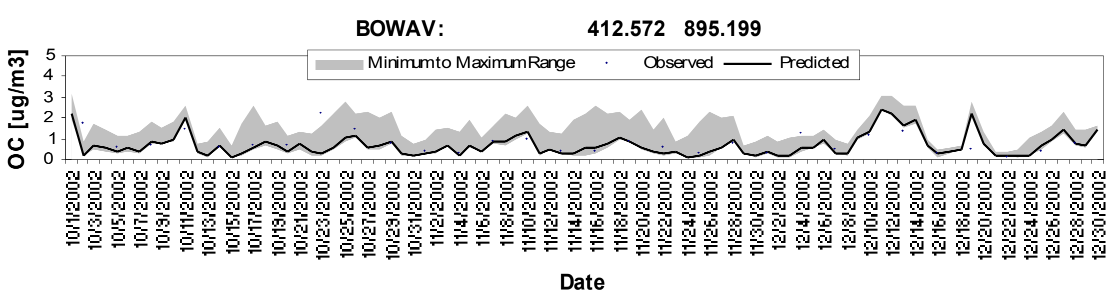
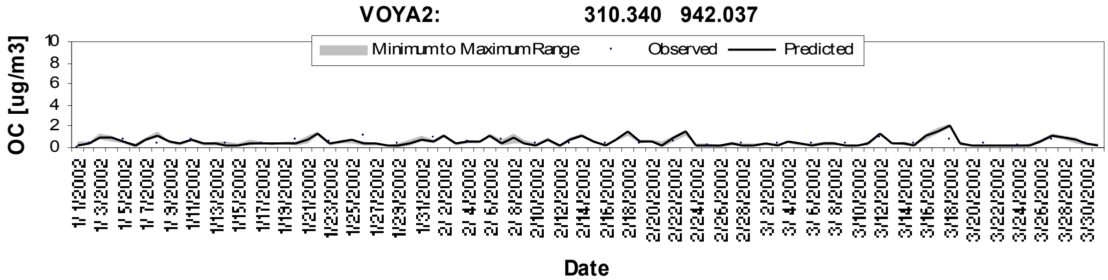
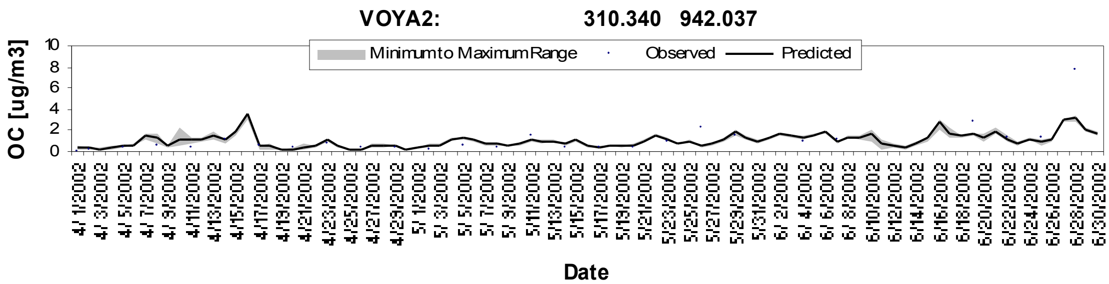
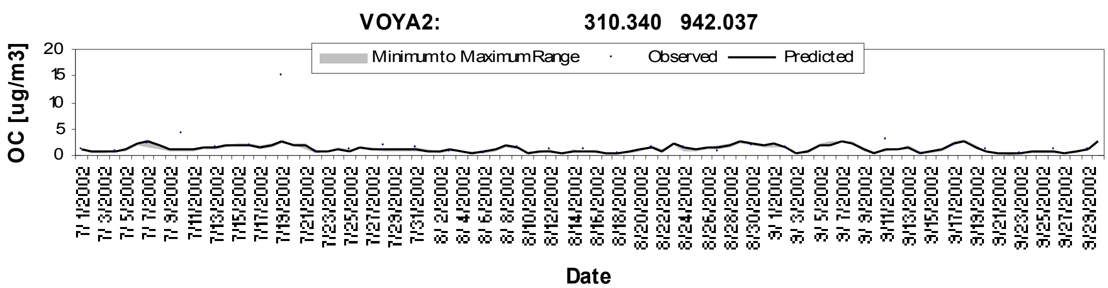


Figure 20. Time Series 36km – Organic Carbon at Voyageurs:







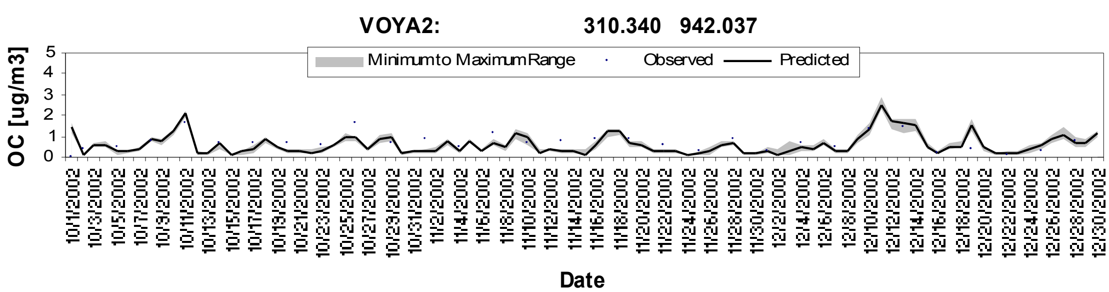
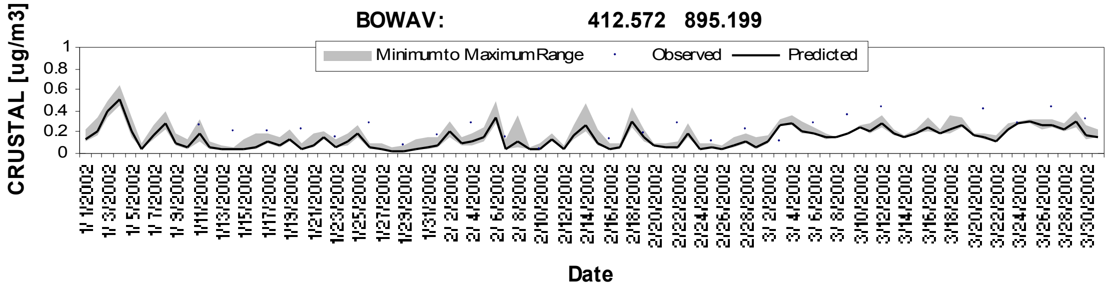
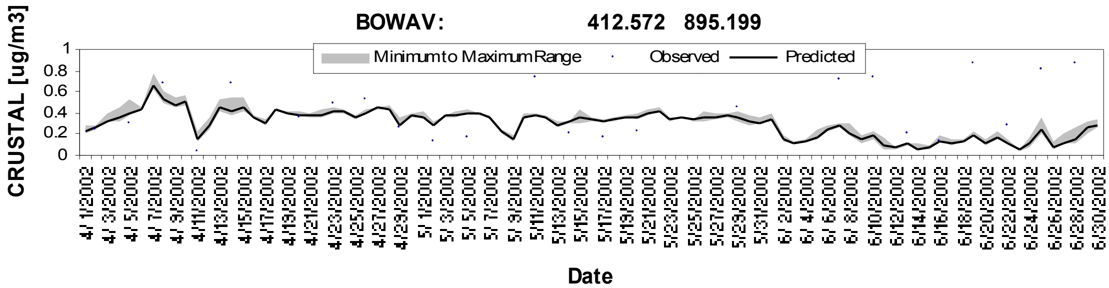
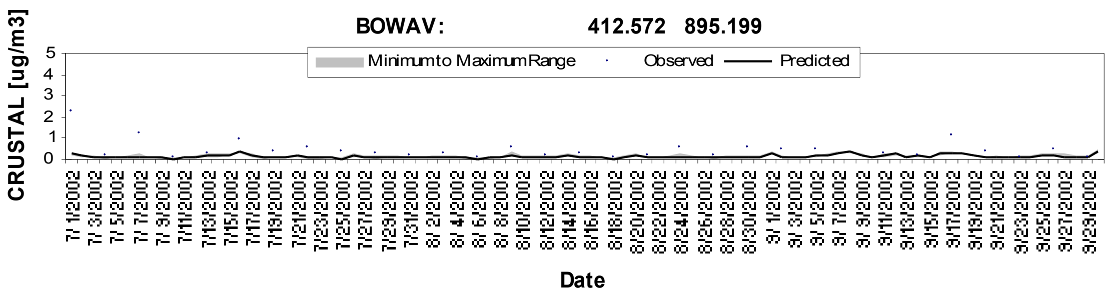


Figure 21. Time Series 36km – Crustal/Soil at Boundary Waters:







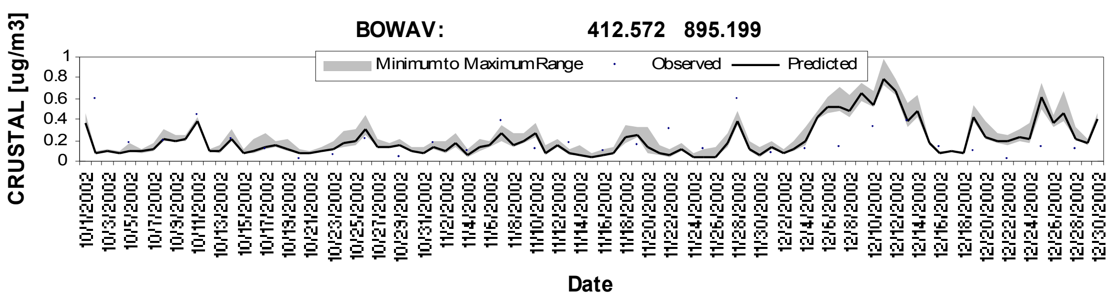
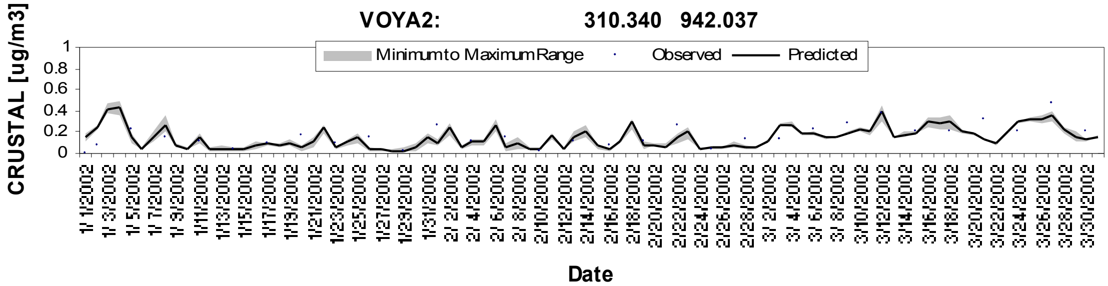
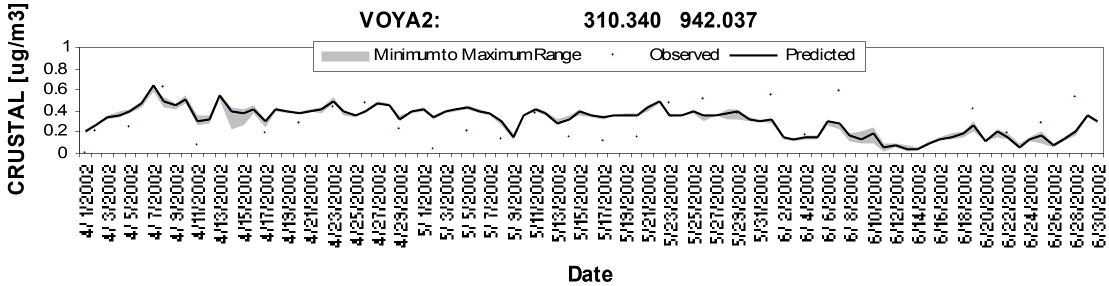
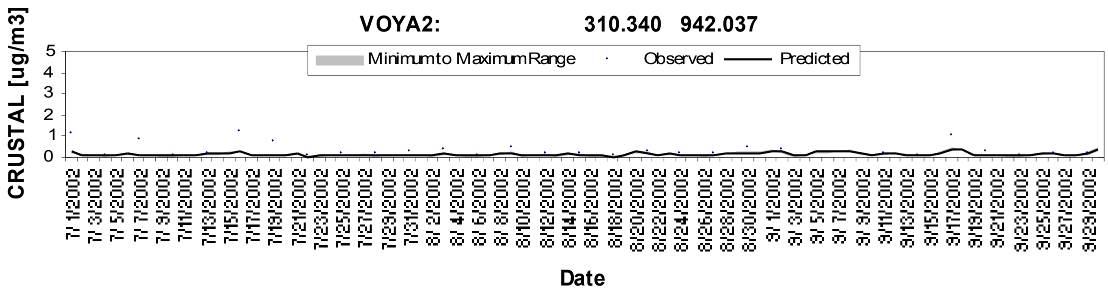


Figure 22. Time Series 36km – Crustal/Soil at Voyageurs:







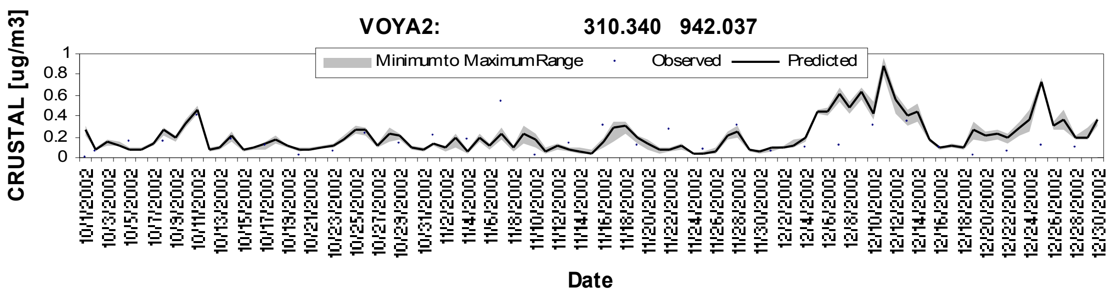
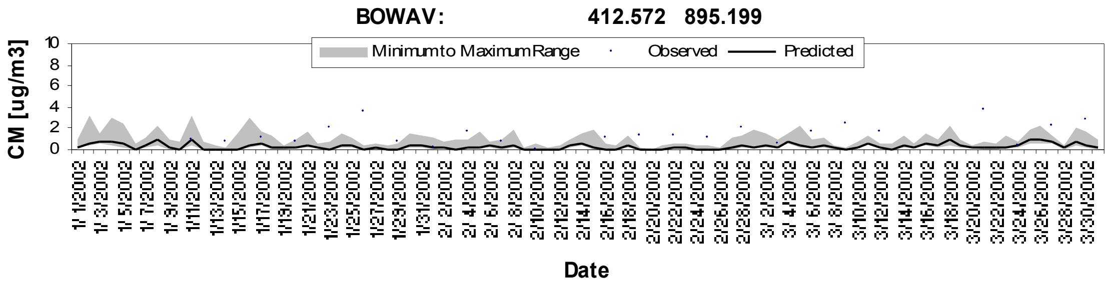
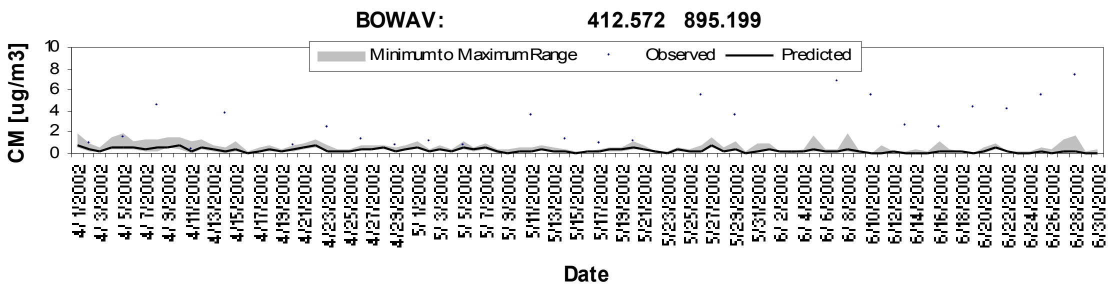
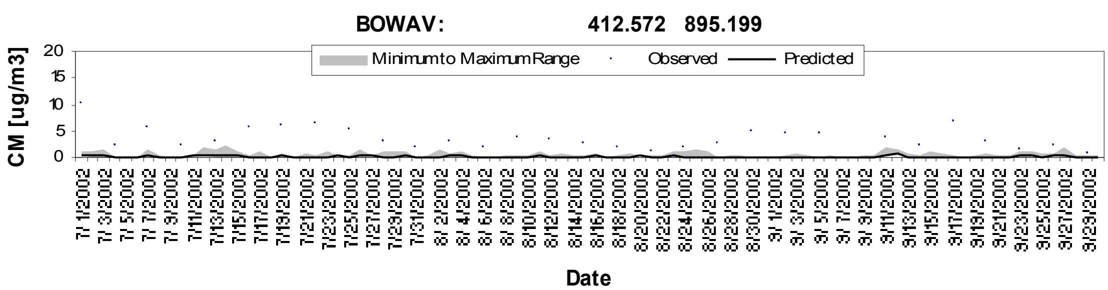


Figure 23. Time Series 36km – Coarse Mass at Boundary Waters:







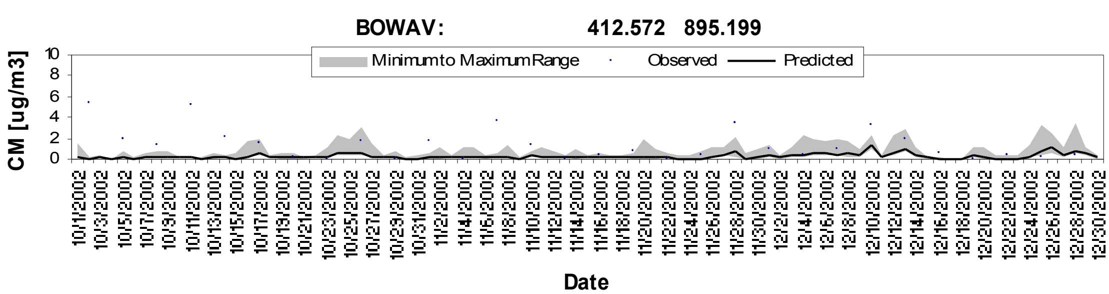
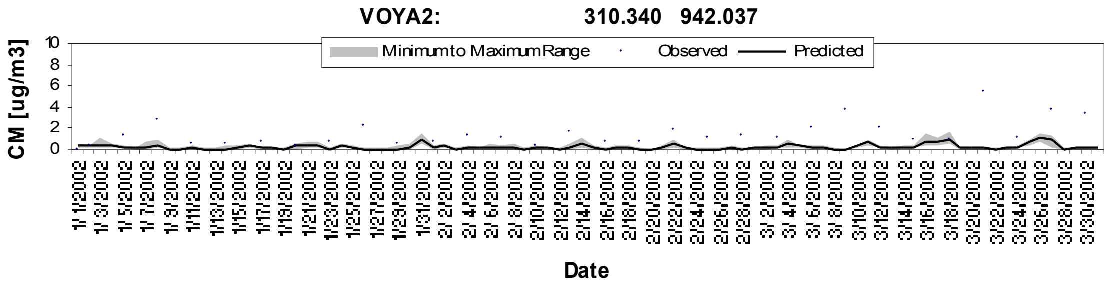
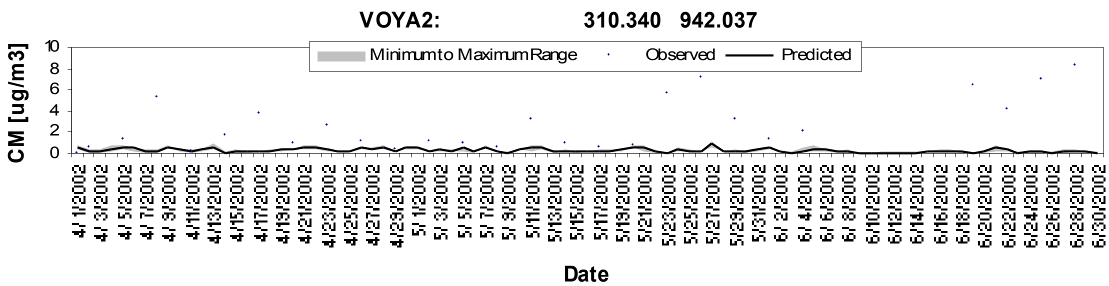
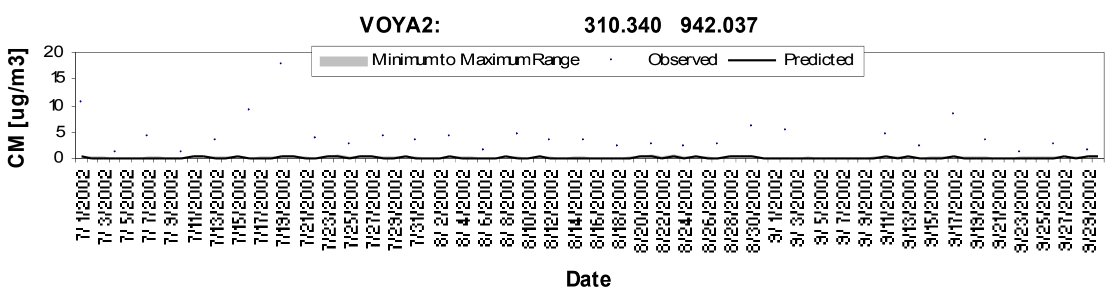
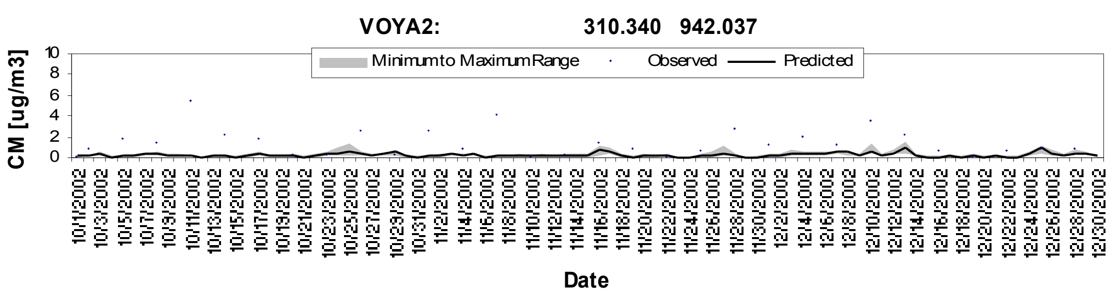


Figure 24. Time Series 36km – Coarse Mass at Voyageurs:





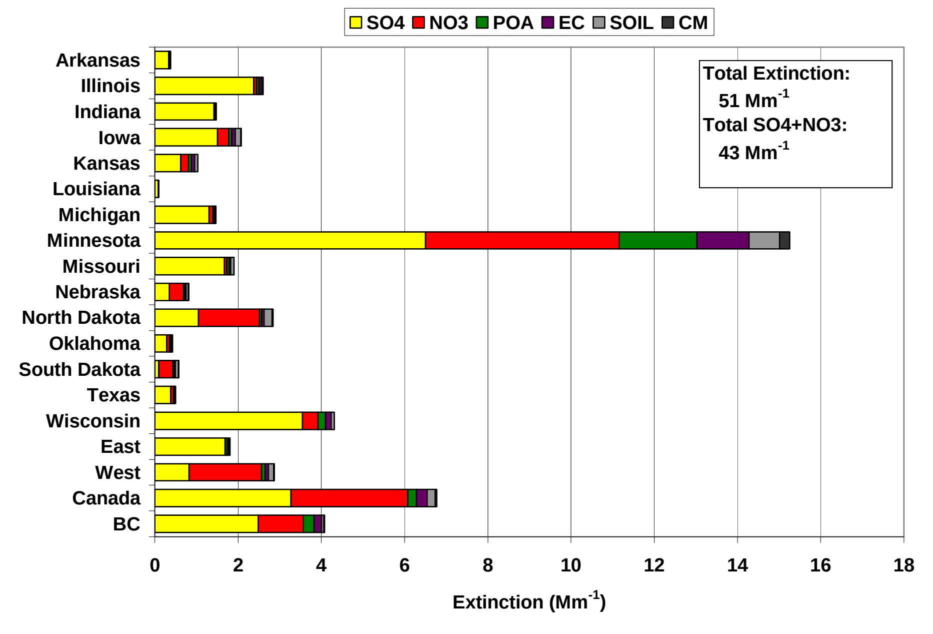


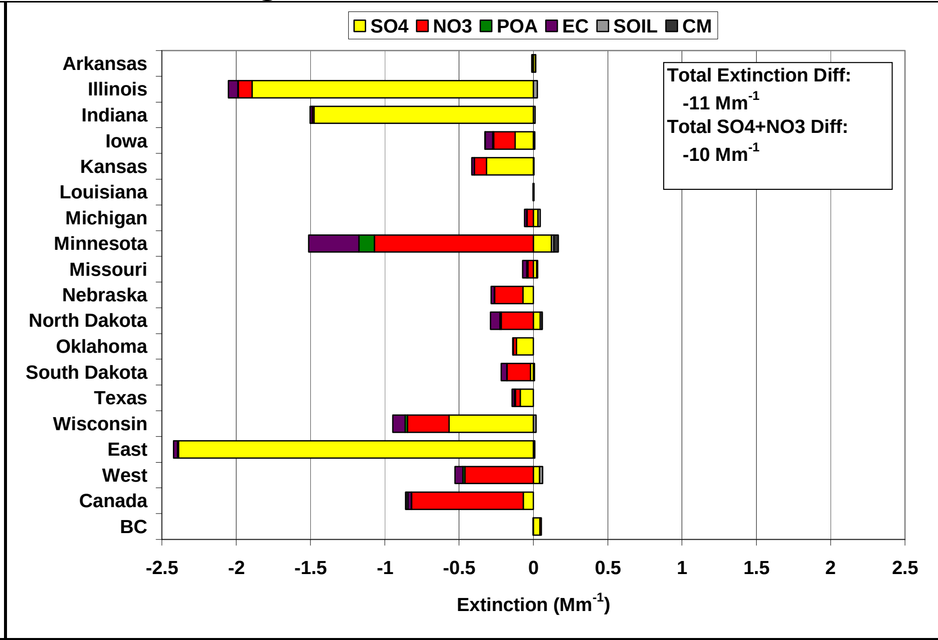


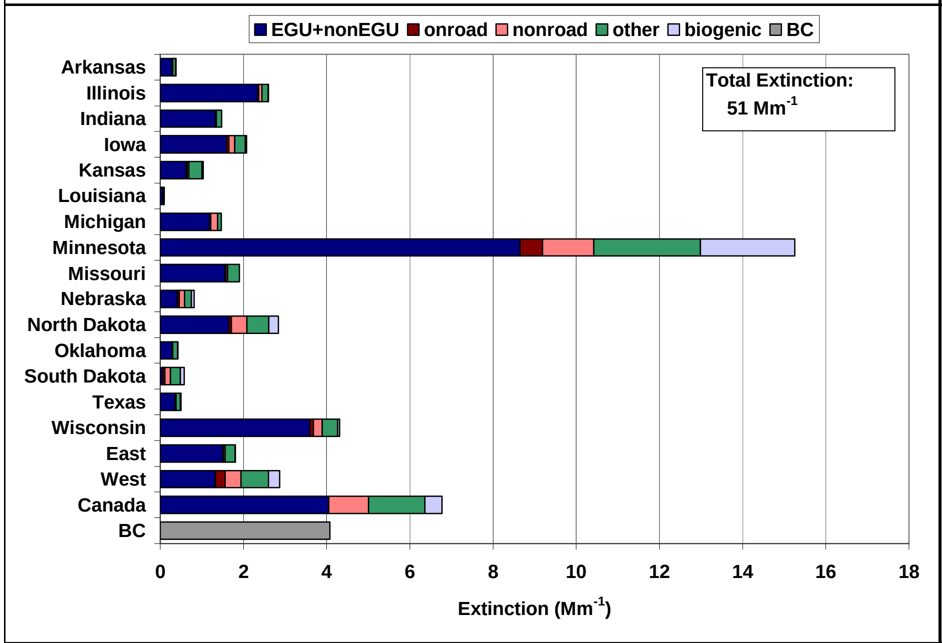
Appendix H
Particulate Source Appportionment Results for CENRAP and MRPO Cases

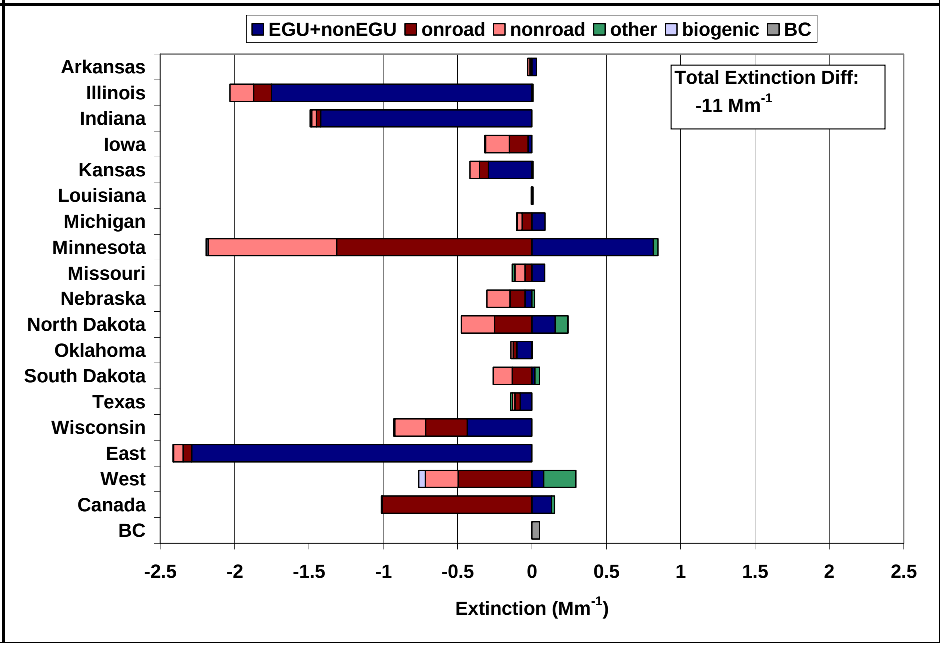
CENRAP BaseF **Boundary Waters:** **Extinction Contribution by Specie and Sector for Each Region on the 20 Percent Worst Days**

Figures H.1 and H.3: 2018 **Figures H.2 and H.4: 2018 minus 2002**



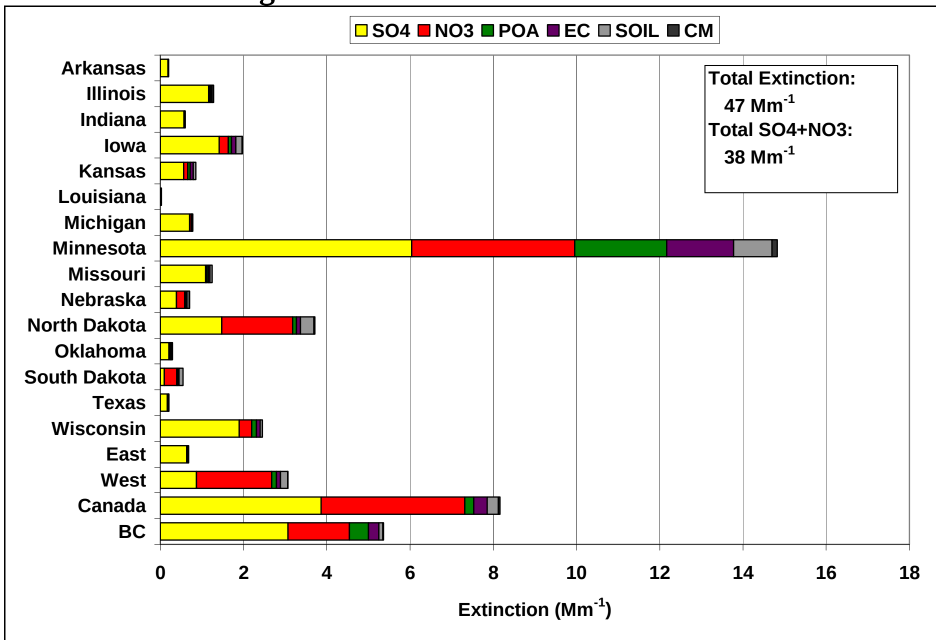


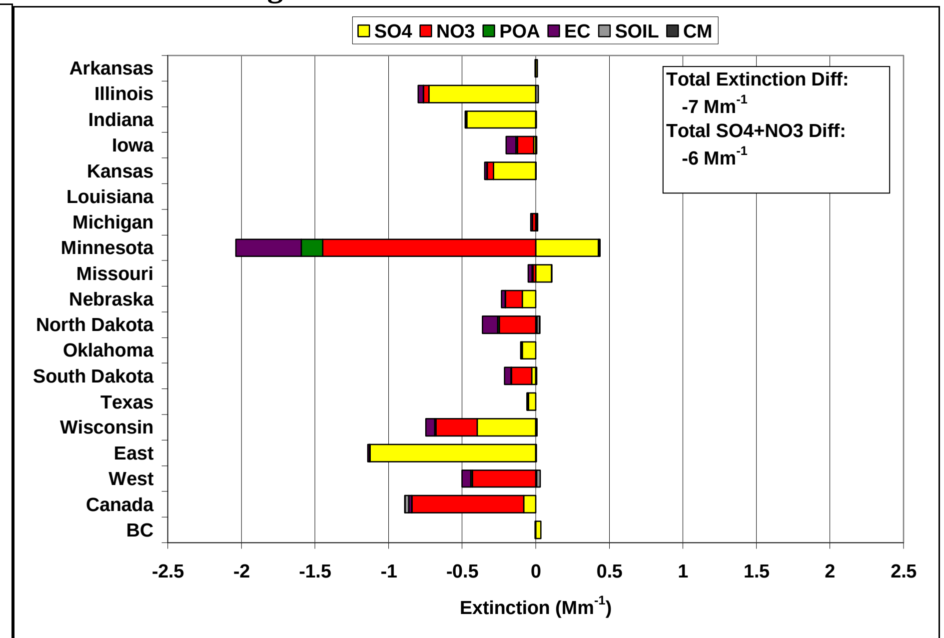


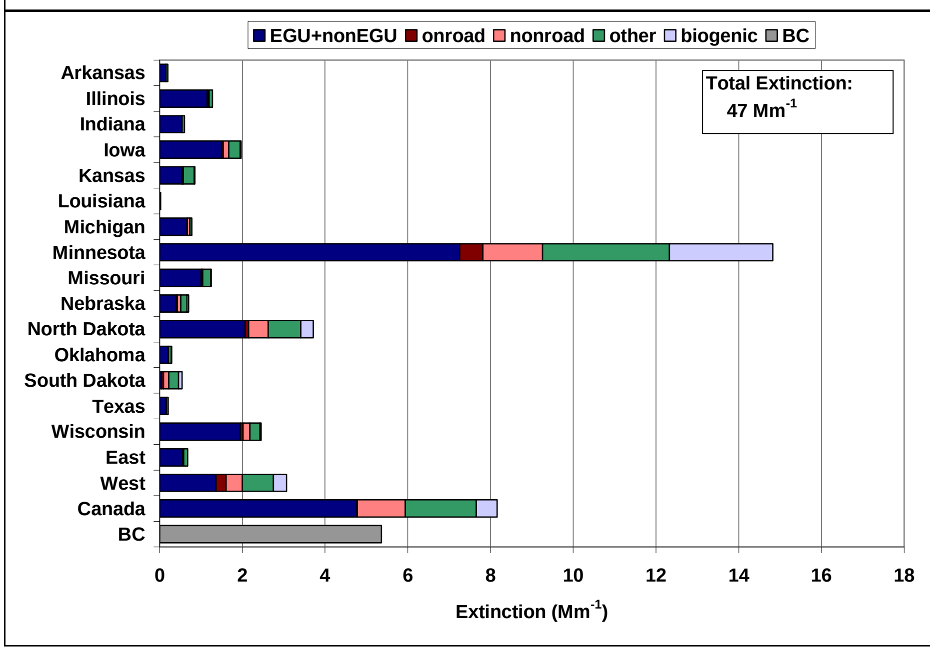


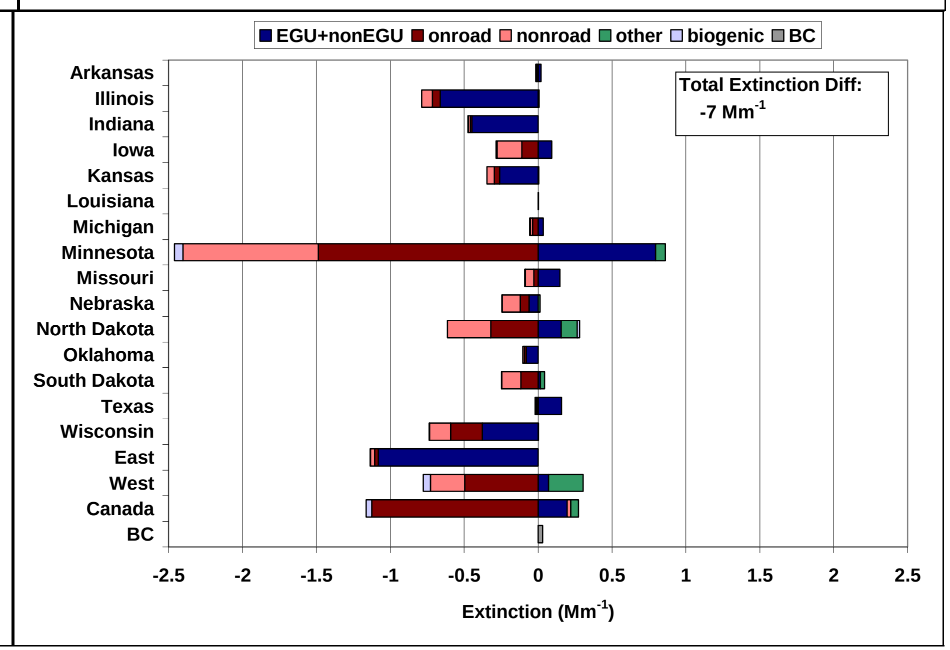
CENRAP BaseF **Voyageurs:** **Extinction Contribution by Specie and Sector for Each Region on the 20 Percent Worst Days**

Figures H.5 and H.7: 2018 **Figures H.6 and H.8: 2018 minus 2002**



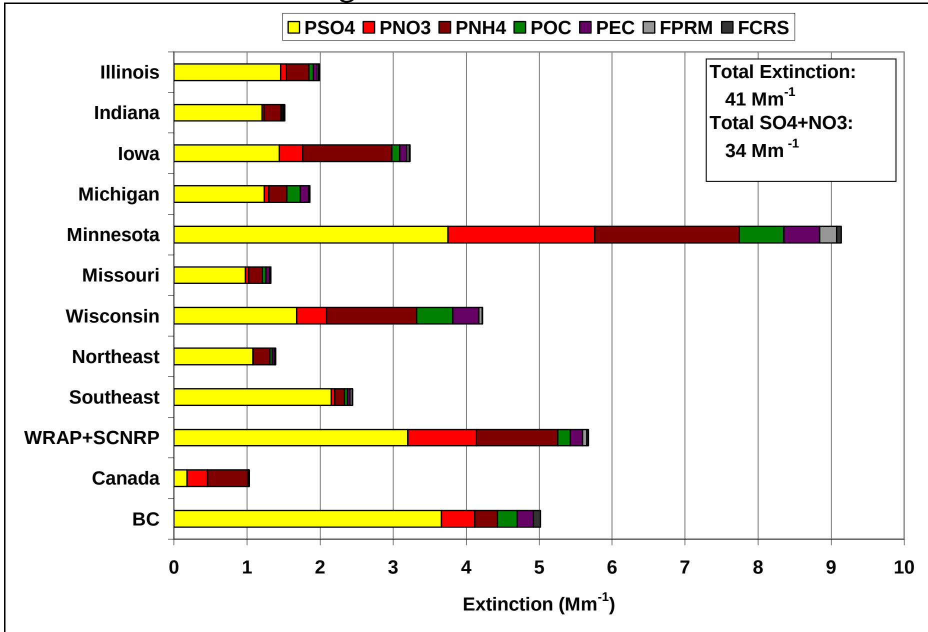


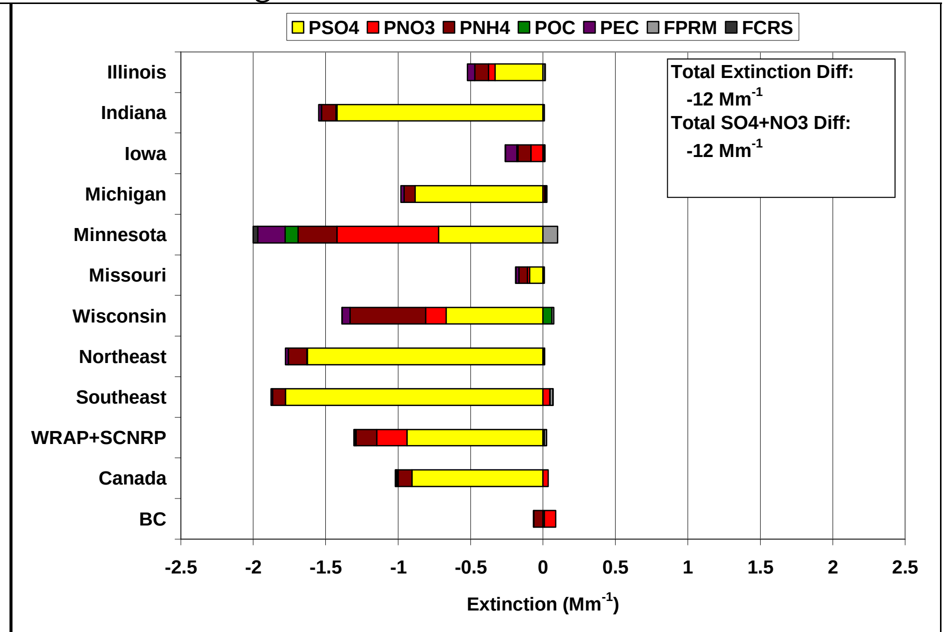


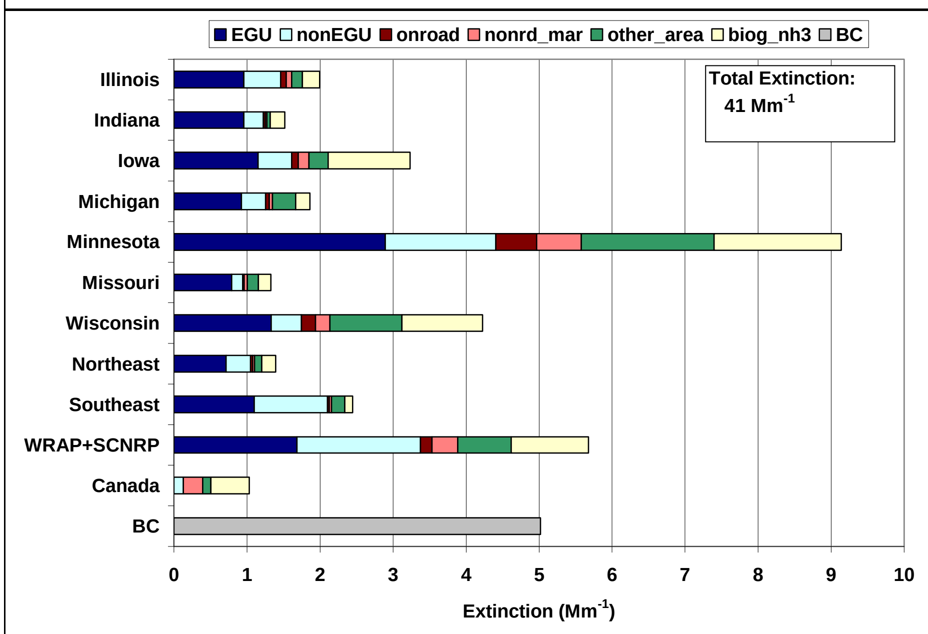


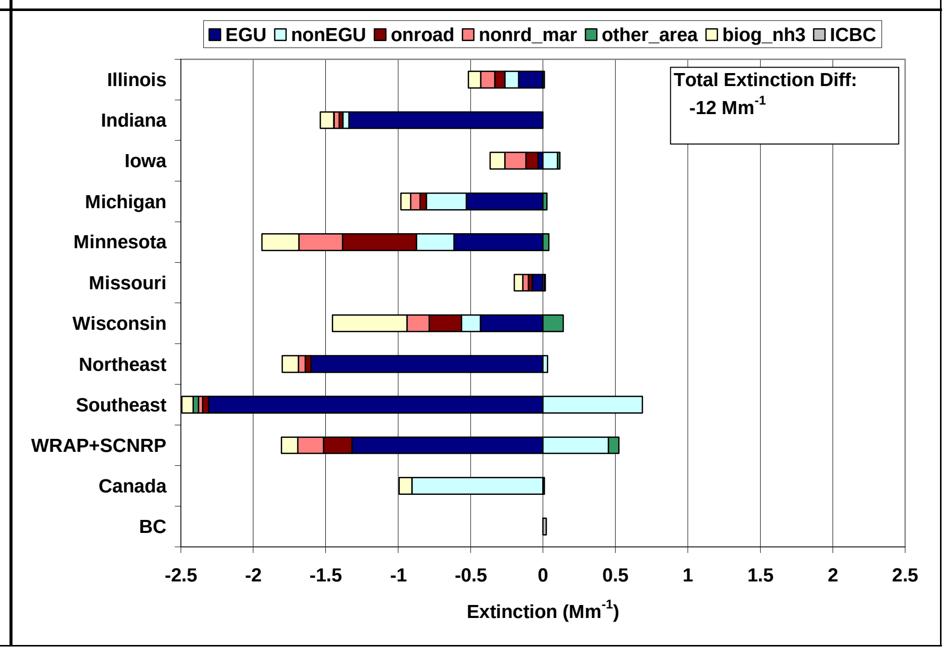
MRPO BaseM <u>**Boundary Waters:**</u> **Extinction Contribution by Specie and Sector for Each Region on the 20 Percent Worst Days**

Figures H.9 and H.11: 2018 **Figures H.10 and H.12: 2018 minus 2005**









MRPO BaseM **Voyageurs:** Extinction Contribution by Specie and Sector for Each Region on the 20 Percent Worst Days

Figures H.13 and H.15: 2018

Figures H.14 and H.16: 2018 minus 2005