Minnesota's Meteorological Site Selection Tool (BETA) Technical Support and User's Guide

The meteorological site selection tool (MSST) was created by the Minnesota Pollution Control Agency (MPCA) to aid in the selection of representative meteorological sites for facilities undergoing regulatory air dispersion modeling. The only sites considered by the MSST, are the meteorological sites pre-processed by the MPCA for air dispersion modeling. While the MPCA's modeling practices manual explains the measures used to determine representativeness of meteorological sites, creating technical support of those measures could pose a challenge to those without expertise in Geographic Information Systems (GIS). This online tool requires no GIS experience, and produces information on facilities and meteorological sites that could otherwise take days of work and an expensive ArcGIS license to produce. The output is formatted to directly address the items of interest called out in MPCA's modeling practices manual, providing all the justification necessary for meteorological site selection in Minnesota. Those items of interest are proximity, terrain, surface characteristics, urban vs. rural and snow cover. A discussion on wind patterns and a wind similarity chart are also included near the end of this document.

The MSST does not make any requirements or establish any rules, it simply provides a technically sound, objective selection of meteorological data for facilities undergoing regulatory air dispersion modeling. If a user disagrees with the site selected by the MSST, a different site can be selected using the justification provided by the tool. If a user is considering additional analysis beyond what's provided by the MSST, MPCA recommends the user contact MPCA's air modelers to determine whether the proposed approach can be technically justified.

MSST parameters

Proximity

As stated in the Environmental Protection Agency (EPA) Region 5's draft meteorological processing guidance (EPA, 2018), while the nearest site is often reasonably representative, it is important to examine whether the surface characteristics of the source are reasonably representative of the surface characteristics of the meteorological site. Surface stations located further away from a source could be more representative. Even though sites further away from a source could be more representative, the temporal correlation with other weather variables also needs to be conserved to meet the considerations requested in the Guideline on Air Quality Models (EPA, 2016). A study done by the Iowa Department of Natural Resources found that when comparing temporal correlation of weather variables such as temperature, pressure, and cloud cover, distances beyond 284 km caused correlation coefficients to drop below 0.80 (Krzak & Fizel, 2015). Assuming Iowa's findings are generally representative of the Upper Midwest, we wanted to find the minimum distance within that 284 km that would allow each source to have at least two meteorological sites to compare for consideration. The buffer radius that allowed this comparison for all facilities was 150 km, with the exception of some facilities along Lake Superior, which require 200 km. Another exception to the 150 km buffer is for facilities within the Twin Cities Urban Heat Island. Due to the unique climate inside the heat island (see urban/rural section) and the fact that there are four sites within the Twin Cities to choose from, the MSST will only consider meteorological sites inside the heat island for facilities inside the heat island.

The proximity buffers select the potential meteorological sites for which further analysis will be completed. All else being equal, the MSST will always select the meteorological site nearest to the facility. However, when representativeness of the nearest site is negatively affected by terrain, surface roughness, urban/rural determinations or snow cover, the MSST allows sites other than the nearest site to be chosen.

Terrain

Stable atmospheric conditions, can promote the formation and buildup of air pollution (Snow, 1987). In a stable atmosphere, valley locations can be sheltered from external wind flow, causing the winds to decouple from the environment external to the valley (Sheridan et al. 2014). This decrease in wind speeds, decreases horizontal dispersion. In addition, under these stable conditions, the temperature at the bottom of a valley can be several degrees Kelvin below the environmental mean, even for shallow valleys (Vosper and Brown, 2008). A colder surface temperature implies locally increased stability, which can further limit dispersion. These stable conditions that develop in valleys can even linger several hours past sunrise (Berkowicz & Fitzpatrick, 1987). Therefore, under stable conditions, a facility in a valley has a greater potential to experience meteorological conditions that inhibit dispersion. Due to these factors, it is important to protect against using meteorological data from a hilltop location, to represent facilities located within valleys when possible. Also, while it would be conservative, it would not be representative to use meteorological data from a valley to represent a facility on a hilltop.

In order to capture where valleys exist in the state, it was necessary to determine what differentiates flat terrain from terrain that contains valleys. To do this, the MPCA automated a process to calculate the standard deviation of the terrain at all the locations from the 2014 Minnesota emissions inventory. The National Elevation Dataset (NED) with 10-meter resolution was used to assign terrain elevations. Using a buffer radius of 12.5 km around each point and a standard deviation threshold of 23 meters, the MSST was able to capture where the river valleys, hills and flat plains are located throughout Minnesota.

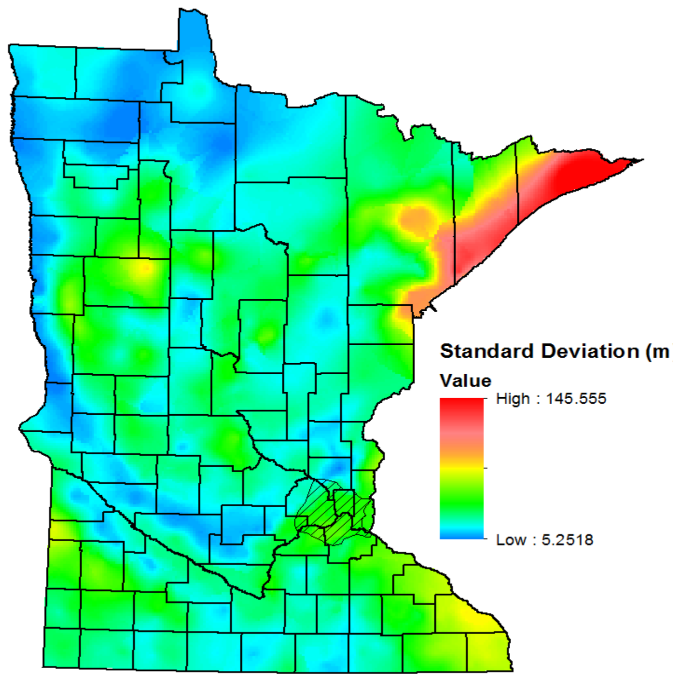

Figure 1. Standard deviation of terrain elevations

Figure 1 shows the standard deviation of the terrain across the state. Regions colored in blue are the regions considered “flat” for the purposes of meteorological site selection (standard deviation < ~23 m). Brighter colors denote where more significant terrain variability exists (standard deviation > ~23 m). Note these settings resolve the Minnesota, Mississippi, and St. Croix River valleys as well as the terrain along the north shore of Lake Superior, the Buffalo Ridge in southwest Minnesota, the Mesabi Iron Range and the hilly terrain of northwest Minnesota. Within these brighter colors is where the MSST determines whether facilities and meteorological sites are in valleys, on hills or near the average terrain elevation. For a location to be considered in a valley, it must be in an area with standard deviation of the terrain elevation greater than 23 meters, and it must be at or below the 30th percentile of the terrain elevations within the 12.5 km buffer. The 30th percentile is used because stable conditions develop first in the bottoms of valleys, with valley bottoms remaining colder than valley sides (Sheridan et al., 2014), so it is important to capture where the lowest terrain exists. If the elevation is between the 30-70th percentiles, the site is categorized as being in “near average” terrain. If a site is at or above the 70th percentile, it is categorized as being on a hill. For the MSST, a margin of one category is allowed. For example, if the meteorological site is near the average elevation of the surrounding terrain and the facility is in a valley or on a hill, it is considered an acceptable terrain match because the classifications are only one category apart. Flat terrain is also considered an acceptable terrain match for the “near average” and “hill” categories, as these can all represent similar terrain features (e.g. plains and bluffs surrounding river valleys). If however, a meteorological site is on a hill and a facility is in a valley or vice versa, the terrain is not considered a good match because they are two categories apart. The “valley” and “flat” categories are not considered a match either due to differences in exposure and atmospheric stability. The only exception to these settings is along Lake Superior.

Due to the dominant influence of the lake on weather conditions near the shoreline, any locations that are at a latitude >= 46.54 and a longitude >=-92.26 (northeast of Duluth), that are at or below an elevation of 260 meters, are considered “Lakeshore” sites for terrain. If a facility is along the lake, the MSST will force selection of a meteorological site also in the “Lakeshore” regime.

Surface roughness

Surface roughness is another surface characteristic considered in determining the representativeness of a meteorological station. It has been noted that for low release heights, surface roughness is the most important surface characteristic in determining modeled concentrations (Carper & Ottersburg, 2004). Surface roughness also impacts turbulence and wind speed. In order to characterize the representativeness of the surface roughness at a meteorological site for a given facility, surface roughness categories are calculated. AERSURFACE (EPA, 2008) is the standard processing tool to create surface data for use in AERMOD. The buffer radius recommended to evaluate surface roughness in the AERSURFACE users guide is 1 km, so this is the buffer used in the MSST. One difference from the AERSURFACE implementation of surface roughness analysis is that the MSST uses 2011 land-use/land-cover data vs. 1992, to make sure it is capturing the latest land-use/land-cover around Minnesota. This implementation also anticipates the next version of AERSURFACE will use more up-to-date land-use/land-cover data.

Table A-3 of the AERSURFACE user’s guide (EPA, 2008) gives seasonal surface roughness values for each land cover class in the 1992 National Land Cover Database. While many categories remained the same for Minnesota, a few new categories were created for the 2011 classification system. These are “barren”, “developed open space”, “shrub/scrub”, and “developed medium intensity”. The old barren class encompassed bare rock, sand and clay and was broken up between arid and non-arid regions. For the MSST the surface roughness characteristics from the non-arid regions were used for the new barren classification. In the end however, it did not matter which barren class was chosen, as the surface roughness was the same for all seasons and both arid and non-arid classes. For the new “developed open space” class, the surface roughness from the old “urban and recreational grasses” class was used. For “shrub/scrub”, the surface roughness from the old “non arid shrubland” category was used. In addition, for “developed medium intensity”, the MSST simply takes an average of the old “developed low intensity” and “developed high intensity” surface roughness values. Plotting the minimum, maximum and mean seasonal surface roughness values for each class, revealed three general surface roughness categories which have been labeled low, medium and high (Figure 2). The box and whisker plot in Figure 3 also reveals the distinctive surface roughness of each category.

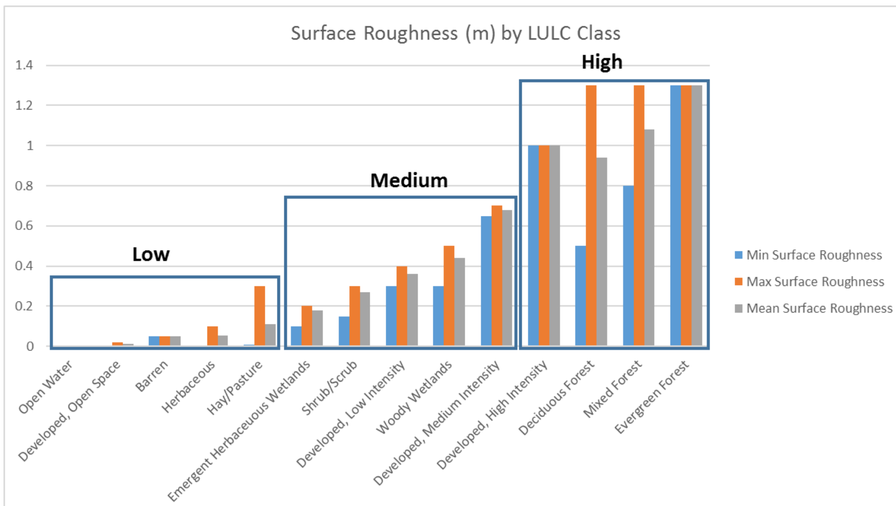

Figure 2. Surface roughness categories determined for 2011 NLCD land use classes

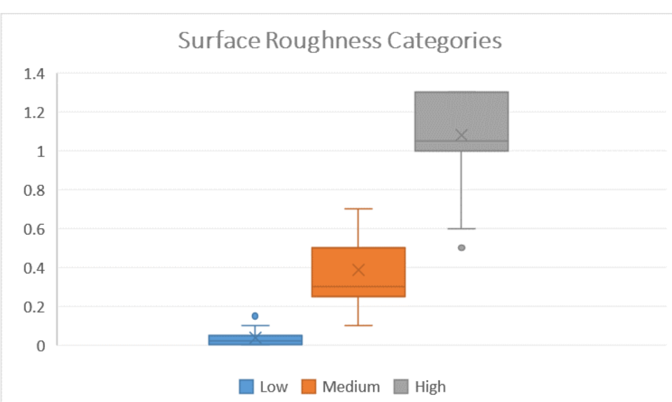

Figure 3. Box and whisker plot of the MSST surface roughness categories

The MSST uses these categories to determine similarity between facility surface roughness and meteorological site surface roughness. The MSST first creates a table with the total area of each land-use/land-cover class within the 1 km buffer. Then the areas for each class are summed within the low, medium and high bins. The label for the bin with the greatest area is assigned to the selected site.

One category difference is allowed when determining whether the meteorological surface roughness is a good match with the facility's surface roughness. So for example, if the meteorological surface roughness is medium, and the facility's surface roughness is low or high, it is counted as a match. However if meteorological surface roughness is low and the facility's surface roughness is high, or vice versa, the surface roughness is not considered a good match. Since surface roughness has the highest impact on modeled results for stack heights less than approximately 30 meters (~ 100 feet) (Tables 3 & 4, Carper & Ottersburg, 2004), more weight is given to a surface roughness match when the lowest modeled release height is below 30 meters.

Urban/Rural

The urban/rural determination is considered for meteorological site selection for the same reason it is considered for dispersion modeling. Weather and climate patterns are markedly impacted by unique dynamics that take place within the urban boundary layer. This is due to the absorption and reemission of longwave radiation, decreased outgoing longwave radiation, increased shortwave radiation absorption, added heat from industrial operations, and decreased evaporation (Markowski & Richardson, 2010). At nighttime, this can have significant effects on the depth and stability of the boundary layer and therefore winds and temperatures (Oke, 1995). As such, urban/rural determinations play an important role in the representativeness of a meteorological site for a given facility.

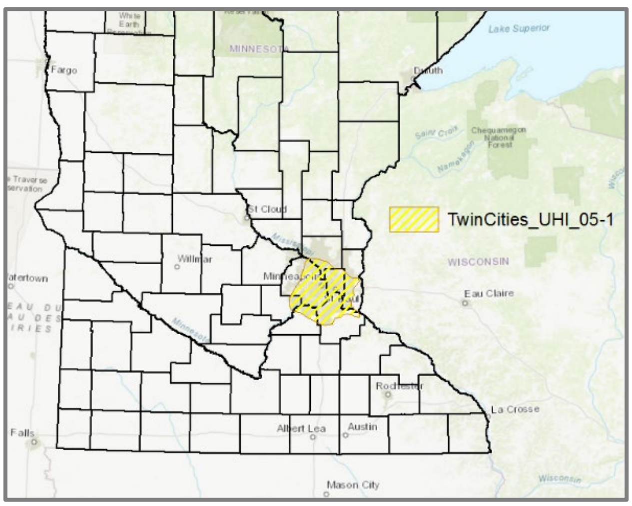

Figure 4. Twin Cities urban heat island extent

The MSST follows recommendations from section 7.2.1.1.i of the Guideline on Air Quality Models (EPA, 2016) to determine whether a selected site is in an area characterized by urban or rural dispersion. This section states that urban/rural determinations for air dispersion modeling should be based on the land use within a 3 km radius buffer of the selected site. If the percentage of developed land use inside the buffer is greater than or equal to 50%, the site should be classified as urban. Otherwise, rural dispersion coefficients should be used. As such, the MSST creates buffers with a radius of 3 km around the meteorological sites and the selected facility. The developed area within the buffers is summed and divided by the total area inside the buffer. If over 50 % of the area is developed the site is labeled urban, otherwise it is labeled rural. The spatial extent of the Twin Cities urban heat island study was also incorporated into the urban/rural analysis (Smoliak et al., 2015). If the land use technique does not lead to an urban determination, but a site is within the core of the known Twin Cities urban heat island (Figure 4, > ~1.5 C anomaly during worst-case events), the site will automatically be labeled urban.

The determination from this parameter is either rural, urban or Twin Cities UHI. Only exact category matches will be considered a good match. If a facility is in an urban area outside the Twin Cities and a meteorological site is within the Twin Cities UHI, it is considered an urban scale mismatch due to the sheer size of the Twin Cities Metro compared to other "urban" locations within the state. If a facility is in a rural area and a meteorological site is within the Twin Cities UHI, the match will be penalized due to the wide disparity in weather and climate between the urban core and rural areas as described above.

Snow cover

Snow cover is another important factor in determining representativeness of meteorological data. Snow cover increases the surface albedo as sunlight is reflected back to space. This acts to reduce surface temperatures and decrease vertical mixing in the boundary layer (EPA, 2018). If snow cover is overestimated in an air dispersion modeling demonstration, it could lead to reduced dispersion and overestimated pollutant concentrations. If snow cover is underestimated, pollutant concentrations could be underestimated. Therefore, it is important that the snow cover at the meteorological site is representative of snow cover at the facility conducting modeling.

Snow cover data was gathered from the NOHRSC site cooperative snow observer stations for 2012 to 2016. From that data, a snow ratio was calculated for each month from December through March that gives the ratio of the number of days with at least one inch of snow depth, to days with less than an inch of snow depth. The average snow ratio was then calculated for each year, and then across the five years of snow data. ArcGIS's Empirical Bayesian Kriging tool was then used to estimate snow ratios at each meteorological site. Then an additional kriging was done with the same tool to plot the average winter snow ratios for the 2012-2016 period across Minnesota (Figure 5).

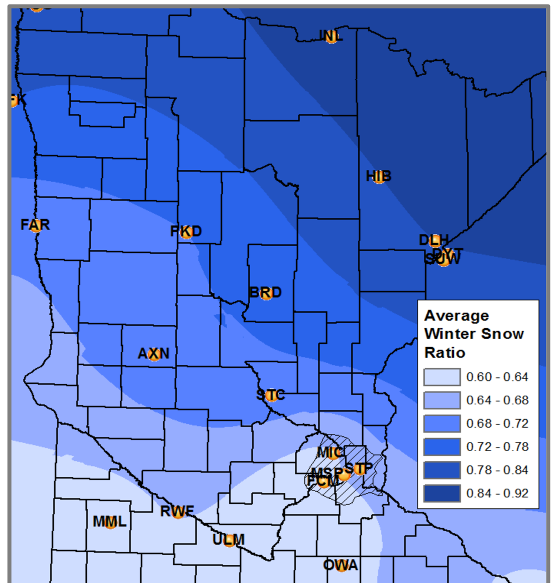

Figure 5. Average winter snow ratios 2012-2016

There is a wide range of snow climatology across Minnesota ranging from 60% of the days having at least one inch of snow on the ground from December through March in the southwest, to over 90% in the northeast. This equates to an average difference in snow cover duration of 38 days. However, it can also be seen from the graphic that fairly large differences exist over even shorter distances such as from the Twin Cities to Brainerd with snow ratios of 0.6 to 0.71 respectively. Using the professional judgement of MPCA's meteorologists regarding known differences in the snow climatology across Minnesota, an average difference in snow ratios greater than 0.1 (around 12 days) warrants a site being labeled a mismatch for snow. Fortunately, the proximity buffers described in the beginning of this document make most potential sites a match for snowfall. Therefore, snow cover will only rarely affect determination of meteorological site selection.

Scoring system

For sources modeling release heights below 30 meters, there are six available points, and only five are required. Both terrain and surface roughness matches are given two points, as these are the most important parameters in determining meteorology and modeled outcomes. For sources only modeling release heights above 30 meters, surface roughness matches are only given one point due to the reduced influence surface roughness has on modeled results for tall stacks. In that case, the point requirement is also decreased to four, as there are only five available points. Urban/rural matches and snow cover matches are given one point each. If the MSST attempts to match a rural site with a site within the Twin Cities UHI, a one-point penalty is given. Other mismatches receive zero points. As the geoprocessing script completes, the meteorological sites are placed in order of proximity from nearest to farthest. The nearest site that has achieved the required points is displayed as the selected site. In the case where none of the sites garner the required points, all sites are considered again with one less point required. If no sites can get at least three points (low releases) or two points (high releases), then the MSST simply selects the nearest meteorological site. The only exception to this scoring system is for sources along Lake Superior, where all meteorological sites (currently only KDYT) along Lake Superior automatically receive all the required points. So for facilities along Lake Superior, the MSST simply looks for the nearest meteorological site along the lake.

Additional analysis

Wind roses

If a user determines multiple sites received identical points and a selection was based primarily on a negligible difference in distance from the source, wind roses are another useful tool in determining whether a meteorological site is representative of an area being modeled. Wind roses are available from the MPCA website. A chart is included below that shows the Structural Similarity Index (Wang & Bovik 2009, Wang et al. 2004) comparing each wind rose. Values closer to one indicate strong similarity between wind roses, while lower values indicate less similarity. Similarity values take into account differences in both wind speed and direction. If the SSIM is relatively high (*green cells) between the sites that received identical points, then there probably is not much basis to choose something other than the selected site. If however the SSIM is low (*red cells) between the high scoring sites, there may be a valid terrain or land use justification that goes beyond the scope of the MSST. Please contact MPCA's air modeling unit to discuss a terrain or land use justification beyond the scope of the MSST before initiating a lengthy analysis.

	AXN	BRD	DLH	DYT	FAR	FCM	FSD	GFK	HCO	HIB	INL	LSE	MJQ	MML	MSP	OWA	PKD	RST	STC	STP	ULM
AXN	1.00	0.82	0.82	0.71	0.80	0.79	0.82	0.83	0.82	0.85	0.81	0.82	0.83	0.84	0.86	0.82	0.88	0.83	0.86	0.81	0.83
BRD	0.82	1.00	0.78	0.80	0.85	0.75	0.90	0.87	0.85	0.85	0.79	0.88	0.88	0.86	0.83	0.85	0.81	0.89	0.86	0.82	0.86
DLH	0.82	0.78	1.00	0.75	0.79	0.74	0.78	0.79	0.78	0.83	0.78	0.79	0.80	0.82	0.81	0.79	0.82	0.79	0.82	0.78	0.81
DYT	0.71	0.80	0.75	1.00	0.79	0.64	0.77	0.74	0.76	0.77	0.74	0.76	0.77	0.77	0.75	0.79	0.71	0.77	0.76	0.76	0.78
FAR	0.80	0.85	0.79	0.79	1.00	0.70	0.84	0.86	0.91	0.85	0.76	0.87	0.85	0.86	0.81	0.88	0.82	0.86	0.85	0.86	0.88
FCM	0.79	0.75	0.74	0.64	0.70	1.00	0.75	0.74	0.71	0.75	0.76	0.74	0.74	0.72	0.75	0.71	0.78	0.73	0.77	0.70	0.72
FSD	0.82	0.90	0.78	0.77	0.84	0.75	1.00	0.87	0.85	0.83	0.78	0.85	0.88	0.85	0.82	0.84	0.81	0.89	0.85	0.81	0.87
GFK	0.83	0.87	0.79	0.74	0.86	0.74	0.87	1.00	0.88	0.85	0.75	0.86	0.88	0.86	0.81	0.84	0.82	0.89	0.84	0.80	0.86
HCO	0.82	0.85	0.78	0.76	0.91	0.71	0.85	0.88	1.00	0.85	0.75	0.88	0.86	0.87	0.80	0.86	0.83	0.87	0.85	0.84	0.88
HIB	0.85	0.85	0.83	0.77	0.85	0.75	0.83	0.85	0.85	1.00	0.79	0.86	0.84	0.87	0.84	0.85	0.85	0.83	0.90	0.85	0.86
INL	0.81	0.79	0.78	0.74	0.76	0.76	0.78	0.75	0.75	0.79	1.00	0.79	0.76	0.77	0.84	0.78	0.83	0.79	0.80	0.80	0.78
LSE	0.82	0.88	0.79	0.76	0.87	0.74	0.85	0.86	0.88	0.86	0.79	1.00	0.87	0.83	0.82	0.85	0.83	0.87	0.87	0.87	0.87
MJQ	0.83	0.88	0.80	0.77	0.85	0.74	0.88	0.88	0.86	0.84	0.76	0.87	1.00	0.88	0.82	0.85	0.83	0.90	0.84	0.82	0.89
MML	0.84	0.86	0.82	0.77	0.86	0.72	0.85	0.86	0.87	0.87	0.77	0.83	0.88	1.00	0.83	0.86	0.82	0.87	0.85	0.82	0.87
MSP	0.86	0.83	0.81	0.75	0.81	0.75	0.82	0.81	0.80	0.84	0.84	0.82	0.82	0.83	1.00	0.84	0.85	0.83	0.85	0.86	0.84
OWA	0.82	0.85	0.79	0.79	0.88	0.71	0.84	0.84	0.86	0.85	0.78	0.85	0.85	0.86	0.84	1.00	0.84	0.88	0.85	0.86	0.90
PKD	0.88	0.81	0.82	0.71	0.82	0.78	0.81	0.82	0.83	0.85	0.83	0.83	0.83	0.82	0.85	0.84	1.00	0.83	0.87	0.83	0.85
RST	0.83	0.89	0.79	0.77	0.86	0.73	0.89	0.89	0.87	0.83	0.79	0.87	0.90	0.87	0.83	0.88	0.83	1.00	0.85	0.84	0.90
STC	0.86	0.86	0.82	0.76	0.85	0.77	0.85	0.84	0.85	0.90	0.80	0.87	0.84	0.85	0.85	0.85	0.87	0.85	1.00	0.85	0.88
STP	0.81	0.82	0.78	0.76	0.86	0.70	0.81	0.80	0.84	0.85	0.80	0.87	0.82	0.82	0.86	0.86	0.83	0.84	0.85	1.00	0.87
ULM	0.83	0.86	0.81	0.78	0.88	0.72	0.87	0.86	0.88	0.86	0.78	0.87	0.89	0.87	0.84	0.90	0.85	0.90	0.88	0.87	1.00

Figure 6. Structural Similarity Index (SSIM) comparing meteorological sites across Minnesota. *Green cells indicate SSIM equal to or greater than one standard deviation above the average SSIM. Red cells have SSIM equal to or greater than one standard deviation below the average SSIM.

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User's guide

From MPCA's air modeling website, navigate to the "Data and tools" link at the bottom of the page, and then "Meteorological data". On this page, you can see the available surface weather stations that have been pre-processed by the MPCA. These are the only sites that will be considered by the MSST. Click on the Meteorological Site Selection Tool – BETA to launch the application. Upon navigating to the application, you will see a blank base map of Minnesota and an input geoprocessing section on the right side of the map (Figure 7).

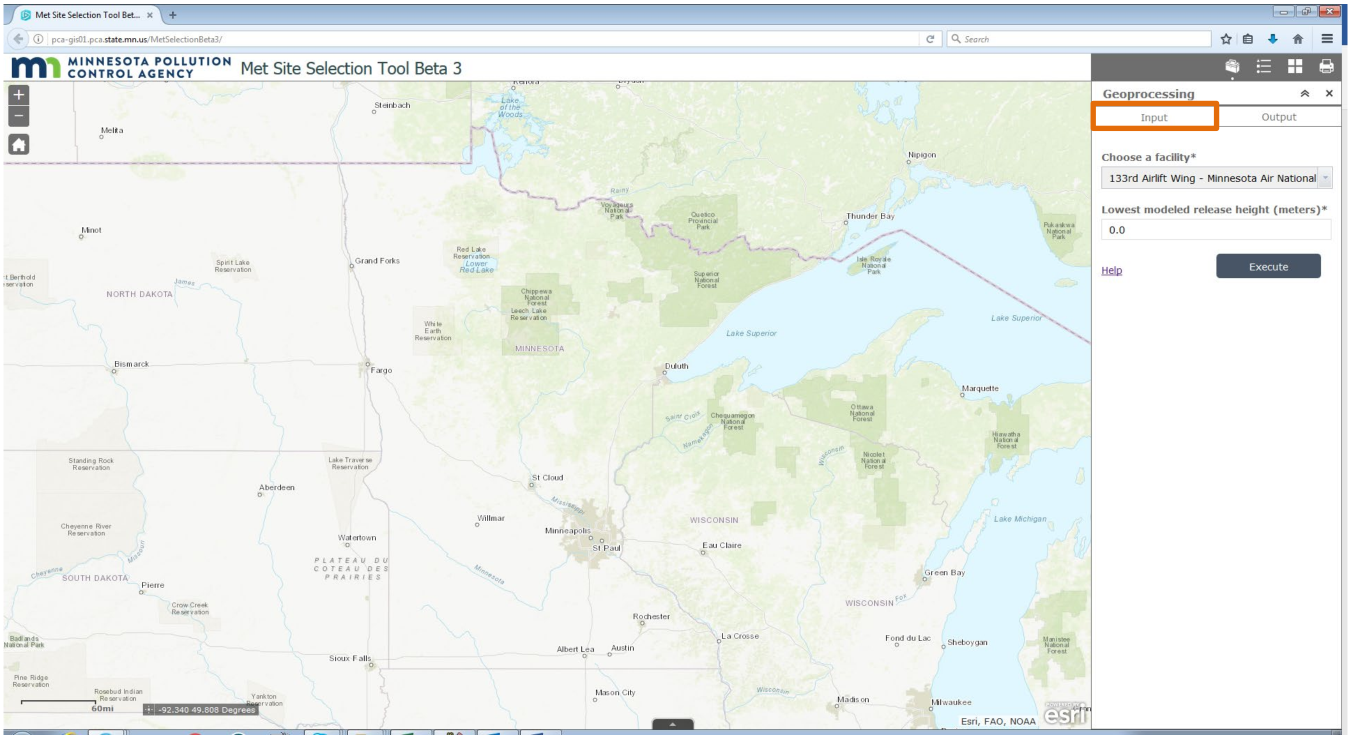


Figure 7. Landing page for the MSST

To run the MSST, choose the facility that will be conducting modeling, and enter the lowest release height that will be modeled at that facility for the current modeling demonstration. Once the inputs have been entered, click the "Execute" button to run the tool. Due to the extensive analysis being performed on each meteorological site, processing can take up to five minutes. When the tool is running, it will display three pulsing dots in the output geoprocessing window. It is okay to run other programs while the tool is running.

Once the tool has finished, the map will zoom to the selected meteorological site (Figure 8), which will be displayed with a yellow spherical marker. Other sites that were within the proximity buffer but were not selected will be displayed with orange spherical markers. The selected facility will be marked with a green pushpin. The map may need to be zoomed out to see all the meteorological sites considered.

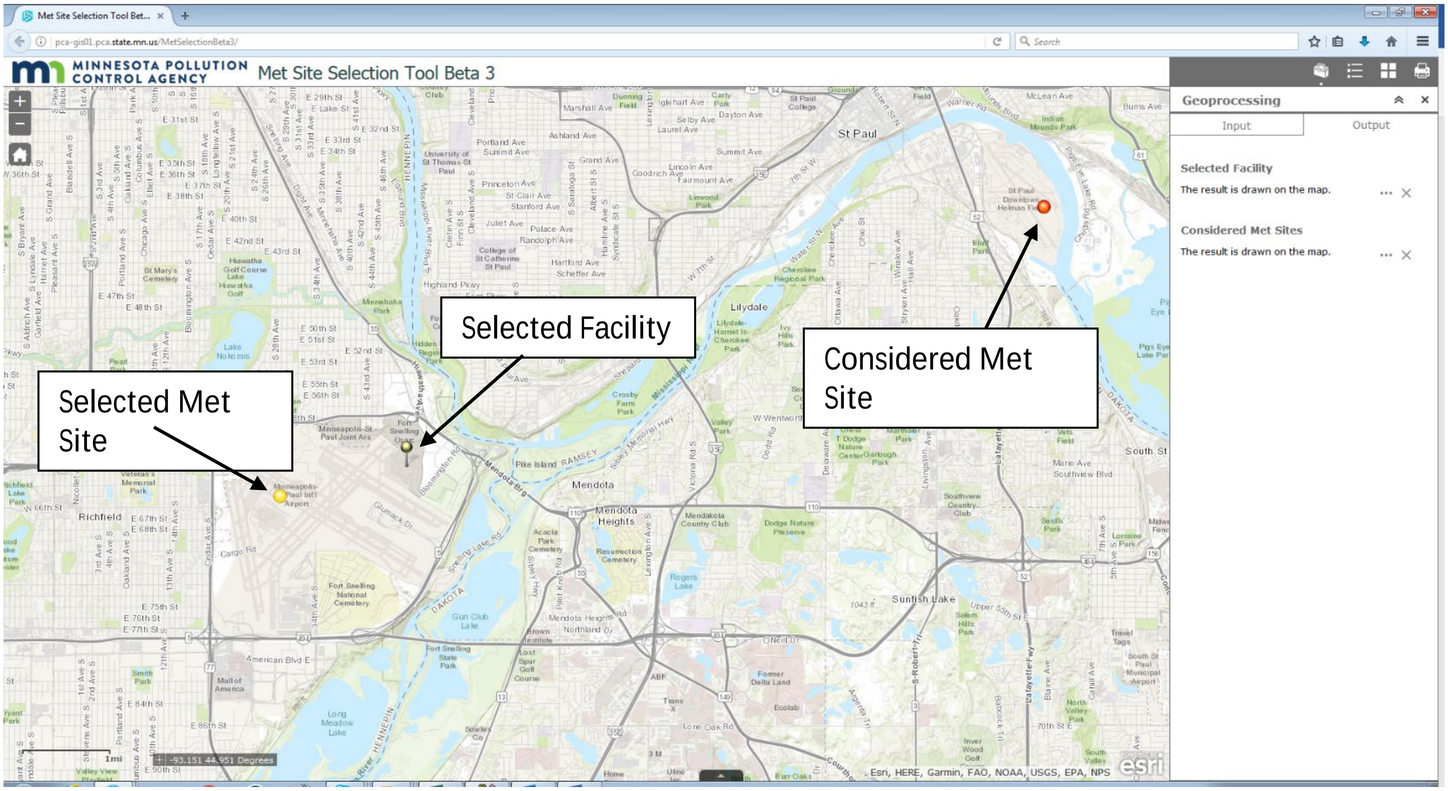


Figure 8. MSST output. Text and arrows added for clarity.

There are a number of options to view the output of the MSST. To view the options, click the three dots next to the Final Meteorological Sites output layer (Figure 9).

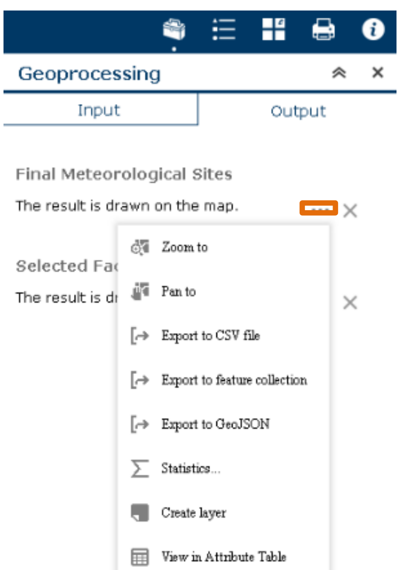


Figure 9. MSST output options

There are several options to export the output to different types of files, as well as to create an ArcGIS layer file. You can also view the attribute table of the tool output for each site. The sites displayed in the attribute table are controlled by the map view, so <u>if you would like to view results for all the considered sites, you will need to either zoom out until all the considered sites are in view, or click the "Filter by map extent" button above the attribute table</u>. The export options are not controlled by the map view and will provide data for all the considered sites.

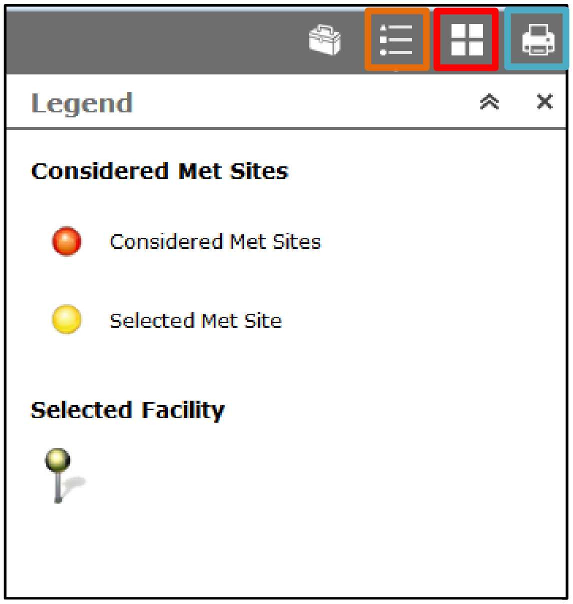
The MSST creates numerous columns of data for each considered site, which are described below (Figure 10).

MSST output description

Column Label	Description
OBJECTID	ID given by ArcGIS. Sites are sorted in order of proximity to the facility.
F_	Database ID.
Call_Sign	Call sign of the meteorological site.
Location	Location of the meteorological site.
Code	Same as call sign.
USAF	USAF site number.
WBAN	WBAN site number.
WMO	WMO site number.
State	State of the meteorological site.
County	County of the meteorological site.
X	Longitude of the meteorological site.
Y	Latitude of the meteorological site.
Elevation	Elevation of the meteorological site.
FAA_Statio	ASOS vs. AWOS designation.
MetDist	Distance in meters between the meteorological site and the selected facility.
Fac_Stable	Terrain determination for the selected facility. Potential values are hill, near average, valley, flat and lakeshore.
FacElevSTD	Standard deviation of the terrain elevations around the facility (meters).
MetElevSTD	Standard deviation of the terrain elevations around the meteorological site (meters).
Met_Stable	Terrain determination for the meteorological site. Potential values are hill, near average, valley, flat and lakeshore.
Fac_z0	Surface roughness determination around the facility.
Met_z0	Surface roughness determination around the meteorological site.
Fac_UrbRur	Urban/rural determination around the facility.
Fac_UrbPer	Percentage of developed land-use/land-cover around the facility.
Met_UrbRur	Urban/rural determination around the meteorological site.
Met_UrbPer	Percentage of developed land-use/land-cover around the meteorological site.
NearUppAir	Call sign of the nearest upper air location.
FacSnow	Average winter snow ratio around the selected facility.
MetSnow	Average winter snow ratio around the meteorological site.
Pros	A list of the measures that were considered good matches between the facility and the meteorological site.
Cons	A list of the measures that were not considered good matches between the facility and the meteorological site.
Sel_Site	Selected site will be marked with a “Y”. Other sites will be marked with an “N”.
x	UTM coordinates of the meteorological site (easting).
y	UTM coordinates of the meteorological site (northing).
wkid	ID for the processor.
Points	Total points awarded to each met site. The nearest site with the most points is selected.

Figure 10. Description of MSST output parameters.

Other options



Legend Button – Click to display the legend of the markers displayed after processing is complete.

Basemap Gallery – Click to choose a different basemap.

Print Button – Click to print the map to one of the listed formats.

Figure 11. Other map options