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# A GRIDDED SNOWFALL VERIFICATION METHOD USING ARCGIS

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## ABSTRACT

*National Weather Service Weather Forecast Offices verify snowfall for Winter Storm Warnings by computing the mean snowfall within each NWS forecast zone. To determine the mean snowfall within each zone, snowfall reports are added together and divided by the number of reports. This legacy method does not factor in distance between points and is heavily weighted towards areas of greater population where typically more snowfall observations exist. This method can be unrepresentative of outlying and higher terrain areas where snowfall can vary significantly.*

*A gridded snowfall verification method using Geographic Information Systems has been developed at NWS Albany, New York. The verification is still performed by calculating the zone-averaged snowfall, but utilizes a gridded methodology for a more innovative and representative approach. A contoured snowfall analysis map is created using an interpolation scheme to obtain a graphical representation of observed snowfall across a given area. Zonal statistics are then calculated using the observed snowfall analysis map, resulting in a more representative mean snowfall for each forecast zone. The end result is a more precise snowfall verification.*

*A method for creating error plots for gridded snowfall forecasts has also been developed and is introduced. The error plots are calculated by taking the difference between NWS gridded snowfall forecasts and observed snowfall analysis maps after an event. Examples of observed snowfall maps and forecast error plots from the 2013-2014 winter season are presented and discussed.*

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## 1. Introduction

The National Weather Service (NWS) uses snowfall observations to verify Winter Storm Warnings (WSW) (NWS Directive 10-513). This verification process entails computing the mean snowfall within each NWS forecast zone (NWS Directive 10-507). To determine the mean snowfall within each zone, snowfall reports (via trained weather spotters, media sources, emergency managers, general public, Facebook™ and Twitter™, etc.), in inches, are added together and divided by the number of reports. This technique does not factor in the spatial variability of snowfall reports. Additionally, these snowfall reports may not be representative of an entire zone, since they do not account for areal gaps between observation points.

A more representative gridded verification methodology has been developed at the NWS Albany, New York Weather Forecast Office (WFO ALY) that utilizes Geographic Information Systems (GIS) technology and software. Using ArcGIS software packages ArcCatalog and ArcMap (version 10.2), a contoured snowfall analysis map (raster dataset) utilizing observed snowfall data is created by applying an inverse distance weighted (IDW) interpolation scheme between snowfall observation points (ESRI online help page IDW (Spatial Analyst) 2014). Once an observed snowfall analysis map is generated, zonal statistics for snowfall can be calculated for each NWS forecast zone (ESRI online help page Zonal Statistics (Spatial Analyst) 2014). Several statistics can be computed, including the mean, maximum, and minimum, although the mean is used for gridded verification. The zonal mean is then used for verifying a WSW. Locally in the WFO ALY county warning area (CWA) (NWS Directive 10-507), the warning criteria for snowfall is 18 cm (7 inches) in 12 hours and 23 cm (9 inches) in 24 hours. In addition, a verification map can be produced with different colors representing various ranges of snowfall based on local warning and/or advisory criteria.

Because all NWS forecasts are based on a gridded format (NWS Directive 10-201) forecast error plots of snowfall can also be generated. The observed snowfall analysis maps can be compared to snowfall forecasts from a NWS WFO's forecast gridded database by subtracting the observed snowfall from the forecast snowfall in ArcMap. This difference between forecast and observed snowfall represents the forecast error for a particular event. Forecast error plots can be complied over an entire winter season or multiple winter seasons to obtain forecast bias for snowfall. NWS WFOs will be able to assess their forecast bias for snowfall represented spatially. This yields valuable information that has previously not been available. Uncovering any consistent biases over certain areas will likely aid in improving future snowfall forecasts.

An overview of the gridded snowfall verification process is detailed in the Data and Methodology section, while step-by-step procedures for implementing the method can be found in the Appendix. Results from using the gridded snowfall verification during the 2013-2014 winter season are also examined. A discussion regarding the advantages of employing the gridded verification method then follows, along with potential future work.

## 2. Data and Methodology

The gridded snowfall verification process begins by ensuring all snowfall reports included in a NWS office's final Public Information Statement (PNS) for an event undergo thorough quality control (QC)

at the local WFO level. The entire verification method is only successful if this initial input data is sound. The greater the number of snowfall reports, the more representative the snowfall analysis map will be. Once a thorough QC of the snowfall reports is completed, a final storm-total snowfall PNS is issued via ECLAIRS (NWS ERS 02-2003). With each PNS issuance, a local hydrometeorological data message (RRM) (NWS Directive 10-922) file (Fig. 1) is created which contains the data required to be used in ArcGIS. The critical data in the RRM files consists of the location name, snowfall amount, and latitude (LAT) and longitude (LON) of each observation site. RRM files are then compiled from surrounding offices in addition to the local office. This is necessary for the interpolation scheme to be representative along CWA borders. It is imperative to use the final storm-total PNS after a snowfall event (this may require brief communication with surrounding offices inquiring if a final PNS has been issued). The data from the RRM files is then combined and entered into a spreadsheet (Table 1) via an automated script (further details in Step 1 of the Appendix).

The next steps entail using ArcGIS software ArcMap and ArcCatalog to create the observed snowfall analysis map, zonal statistics, and forecast error plots (see Steps 2-5 of the Appendix). In ArcCatalog, a shapefile can be created from the snowfall reports, location name, and LAT/LON. In ArcMap, the newly created shapefile containing snowfall reports is then added to the data frame.

After the shapefile has been added, an interpolation scheme is run, which creates a contoured snowfall analysis map (raster dataset) (see Step 2 of the Appendix). There are several interpolation schemes that can be run from the Spatial Analyst toolbox in ArcGIS (Ormsby 2010). Some of the more common interpolation schemes include IDW, Kriging, and Natural Neighbor (ESRI online help page 2014). An example of each of these interpolation schemes is shown for the 14-15 December 2013 event (Figs. 2-4). IDW was chosen as the interpolation scheme at ALY because of its simplicity and ability to quickly generate map output. One weakness of the IDW scheme, however, is that it is an exact interpolator and is sensitive to clustering and outliers. The authors acknowledge that other interpolation schemes can be used such as the Barnes scheme (Barnes 1964; Koch et al. 1983; Lanciani and Salvati 2008). Additionally, a NWS national snowfall analysis (http://www.nws.noaa.gov/os/notification/tin15-05bigrsc_snowfall.htm) was also in development in late 2014. However, at this time the national analysis does not translate well to the local WFO scale for verification purposes due to time constraints which limit the number of reports that can be included, as well as a less stringent QC of snowfall reports.

Zone-averaged statistics for snowfall can be calculated once the interpolation scheme has been run and the resulting observed snowfall analysis map is complete (ESRI online help page Zonal Statistics (Spatial Analyst) 2014) (see Step 3 of the Appendix). The zone-averaged statistics are calculated within the borders of each NWS forecast zone using the observed snowfall analysis map. A table of the resulting statistics is then created in ArcMap. A variety of statistics are calculated, but the most significant is the mean, which is used in verifying whether warning criteria snowfall has occurred. A map depicting zone-averaged snowfall can also be created, which gives a graphical representation of the mean snowfall derived from the observed snowfall analysis map. This map can be classified based on local WFO warning and advisory criteria.

In addition to creating an observed snowfall analysis map, a forecast snowfall map from an NWS WFO's gridded database can also be generated (see Step 4 of the Appendix). Taking the difference of these two datasets yields a forecast error of snowfall for an event. The snowfall forecast associated with the issuance of the last WSW prior to onset of snowfall is used for error calculations. After the new gridded forecast storm total snow map is created, the observed snowfall analysis can be subtracted from the forecast snowfall to obtain the forecast error (see Step 5 of the Appendix). Both the forecast and observed snowfall analysis maps need to be clipped to the CWA borders before subtracting them in order to assess the error across a local CWA. The result is a new error plot which can be classified to any interval (in inches) and color scheme the user desires.

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RRMALY
HYDROLOGIC OBSERVATIONS
NATIONAL WEATHER SERVICE ALBANY NY


.A X4270731 0320 Z DH0924/DVH11/SFV 1.0"LAT=42.733410 LON=-73.072480  CLARKSBURG  WEATHERNET6 "/
.A X4330728 0320 Z DH1017/DVH11/SFV 6.5"LAT=43.291580 LON=-72.838540  LANDGROVE  WEATHERNET6 "/
.A X4260730 0320 Z DH0245/DVH11/SFV 0.5"LAT=42.597840 LON=-73.043570  SAVOY  WEATHERNET6 "/
.A X4310745 0320 Z DH0921/DVH11/SFV 1.0"LAT=43.145310 LON=-74.489020  CAROGA LAKE  WEATHERNET6 "/
.A X4370737 0320 Z DH0203/DVH11/SFV 0.5"LAT=43.692910 LON=-73.718710  BRANT LAKE  WEATHERNET6 "/
.A X4280741 0320 Z DH0957/DVH11/SFV 0.8"LAT=42.793778 LON=-74.088728  PRINCETOWN  WEATHERNET6 "/
.A X4280739 0320 Z DH0100/DVH11/SFV 0.1"LAT=42.840400 LON=-73.894500  1 SSW AQUEDUCT  NWS EMPLOYEE "/
.A X4330736 0320 Z DH0932/DVH11/SFV 1.5"LAT=43.306680 LON=-73.576650  HUDSON FALLS  WEATHERNET6 "/
.A X4330738 0320 Z DH0933/DVH11/SFV 1.0"LAT=43.256280 LON=-73.832810  LAKE LUZERNE  WEATHERNET6 "/
.A X4300738 0320 Z DH0208/DVH11/SFV 1.0"LAT=42.975240 LON=-73.793540  MALTA  WEATHERNET6 "/
.A X4290730 0320 Z DH1006/DVH11/SFV 2.2"LAT=42.888640 LON=-73.012480  WOODFORD  WEATHERNET6 "/
.A X4350738 0320 Z DH0940/DVH11/SFV 3.0"LAT=43.490050 LON=-73.786560  WARRENSBURG  WEATHERNET6 "/
.A X4310739 0320 Z DH0307/DVH11/SFV 0.4"LAT=43.137275 LON=-73.881064  PORTER CORNERS  WEATHERNET6 "/
.A X4330737 0320 Z DH0309/DVH11/SFV 1.2"LAT=43.326210 LON=-73.689785  QUEENSBURY  WEATHERNET6 "/
.A X4310740 0320 Z DH0836/DVH11/SFV 0.3"LAT=43.137411 LON=-73.976125  MIDDLE GROVE  WEATHERNET6 "/
.A X4280738 0320 Z DH0330/DVH11/SFV 0.3"LAT=42.829340 LON=-73.820800  2 S CLIFTON PARK CENTER  NWS EMPLOYEE
.A X4310739 0320 Z DH0050/DVH11/SFV 0.2"LAT=43.060680 LON=-73.856897  MILTON  WEATHERNET6 "/

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**Fig. 1.** Example of output from an RRM file originating at ALY.

**Table 1**. Example of a spreadsheet with relevant data extracted from an RRM file.

| SITE NAME | SNOWFALL | SOURCE | LAT | LON |
|---|---|---|---|---|
| HALCOTT CENTER | 11 | WEATHERNET6 | 42.21346 | -74.48086 |
| EAST DUMMERSTON | 10 | TRAINED SPOTTER | 42.9322 | -72.5536 |
| GERMANTOWN | 11 | WEATHERNET6 | 42.15435 | -73.8674 |
| RICHMONDVILLE | 11 | WEATHERNET6 | 42.62709 | -74.58513 |
| NISKAYUNA | 12.5 | TRAINED SPOTTER | 42.8171 | -73.898 |
| KINDERHOOK | 12.2 | TRAINED SPOTTER | 42.3946 | -73.7041 |
| KNOX | 12.8 | WEATHERNET6 | 42.7317 | -74.14485 |
| 4 SSE POUGHKEEPSIE | 7 | COCORAHS | 41.647 | -73.897 |
| SAUGERTIES | 10.5 | TRAINED SPOTTER | 42.0748 | -73.9483 |
| CAROGA LAKE | 10.5 | WEATHERNET6 | 43.14531 | -74.48902 |
| NISKAYUNA | 10.6 | CO-OP OBSERVER | 42.796389 | -73.876667 |
| HYDE PARK | 7.8 | TRAINED SPOTTER | 41.7843 | -73.9343 |
| GUILDERLAND CENTER | 12.2 | WEATHERNET6 | 42.702879 | -73.965771 |
| SE NEW BALTIMORE | 8 | COCORAHS | 42.442943 | -73.786628 |
| 3 E FREEHOLD | 10 | COCORAHS | 42.36045 | -73.983468 |
| 6 SSW BECKET | 7.5 | COCORAHS | 42.25906 | -73.13213 |
| CAIRO | 10.5 | WEATHERNET6 | 42.30229 | -74.03186 |
| 8 S HUDSON | 10 | COCORAHS | 42.133493 | -73.767857 |
| SLINGERLANDS | 11 | PUBLIC | 42.6292 | -73.865 |
| NORTH BLENHEIM | 9.8 | TRAINED SPOTTER | 42.4735 | -74.4375 |
| HUDSON | 10 | WEATHERNET6 | 42.25567 | -73.77682 |
| 3 SE MILLBROOK | 5 | COCORAHS | 41.7523 | -73.6488 |
| MALTA | 13 | CO-OP OBSERVER | 43.006667 | -73.860556 |
| ALFORD | 9 | WEATHERNET6 | 42.221612 | -73.429589 |
| GREENWICH | 10.9 | TRAINED SPOTTER | 43.0866 | -73.4967 |
| STOTTVILLE | 7 | FACEBOOK | 42.2892 | -73.7523 |
| MECHANICVILLE | 11 | TRAINED SPOTTER | 42.904 | -73.6901 |
| HIGHLAND | 8.1 | TRAINED SPOTTER | 41.7173 | -73.9657 |
| WINSTED | 8 | TRAINED SPOTTER | 41.927 | -73.0669 |
| LANESBOROUGH | 10 | WEATHERNET6 | 42.50229 | -73.27087 |
| CLIFTON PARK | 11.7 | NWS EMPLOYEE | 42.8548 | -73.8085 |
| WATERFORD | 11 | FACEBOOK | 42.7918 | -73.6794 |

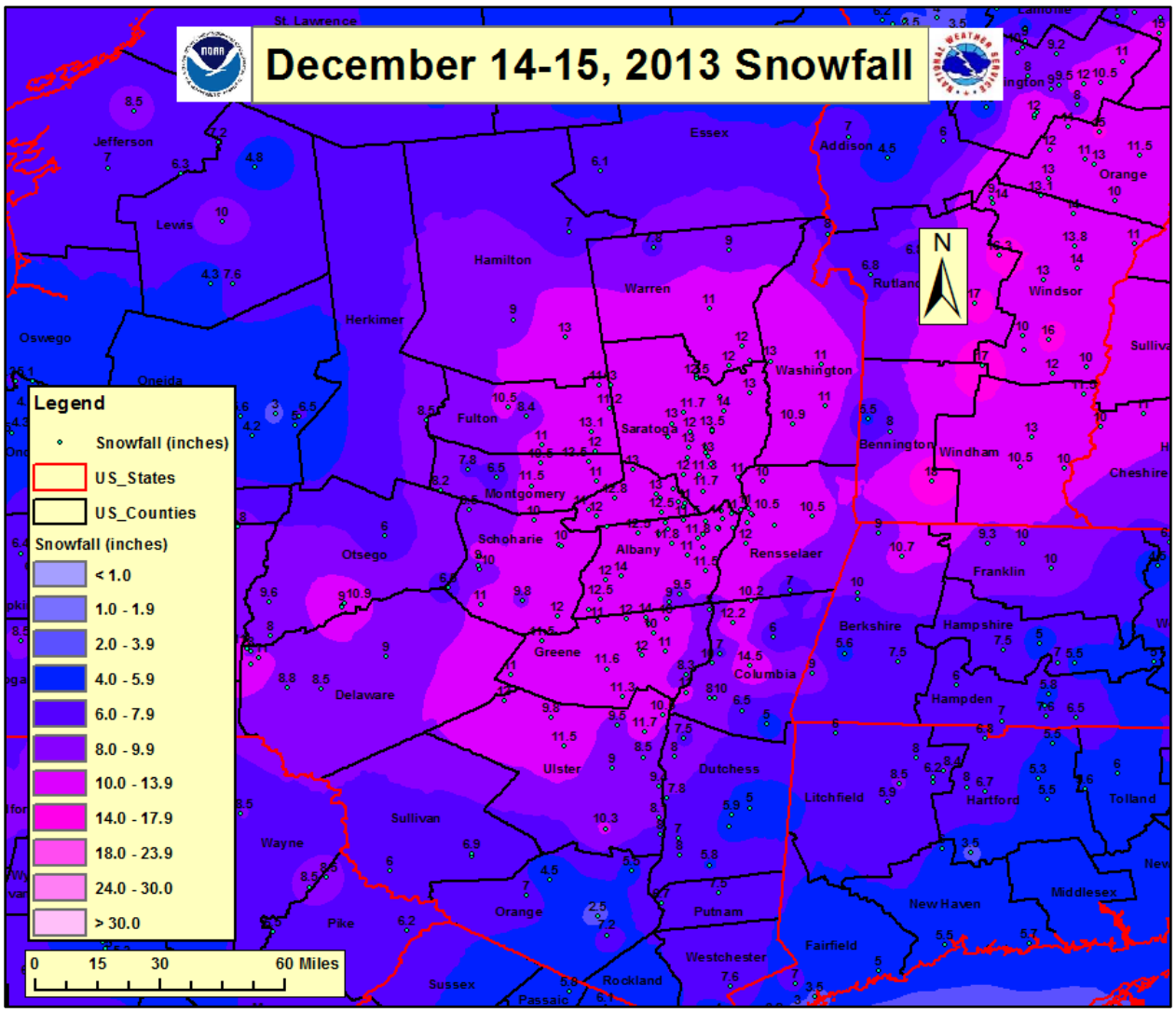


**Fig. 2.** Observed snowfall analysis map using IDW interpolation from 14-15 December 2013. Point values represent actual snowfall observations, while color contours represent interpolated data.

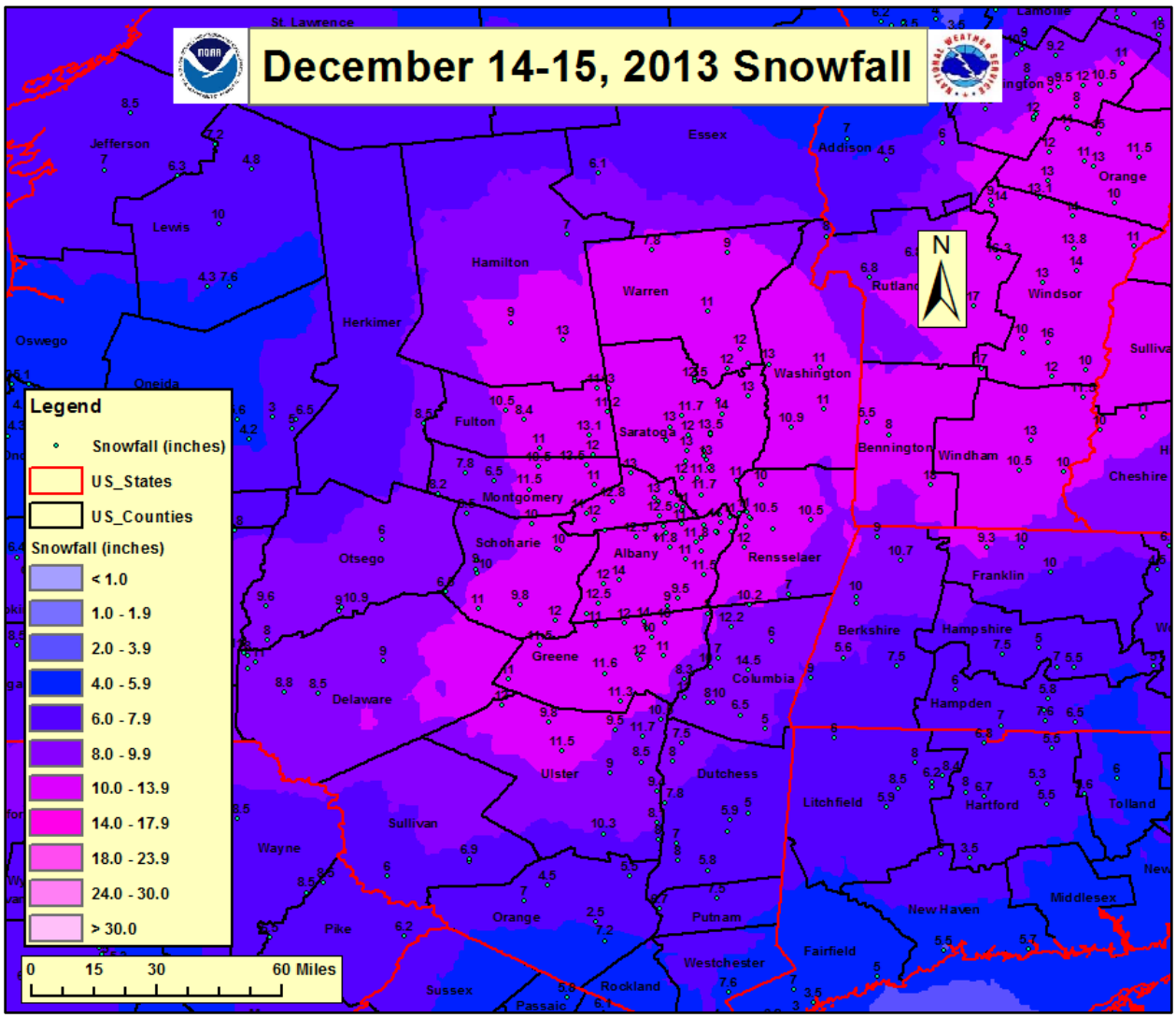


**Fig. 3.** Observed snowfall analysis map using Kriging interpolation from 14-15 December 2013. Point values represent actual snowfall observations, while color contours represent interpolated data.

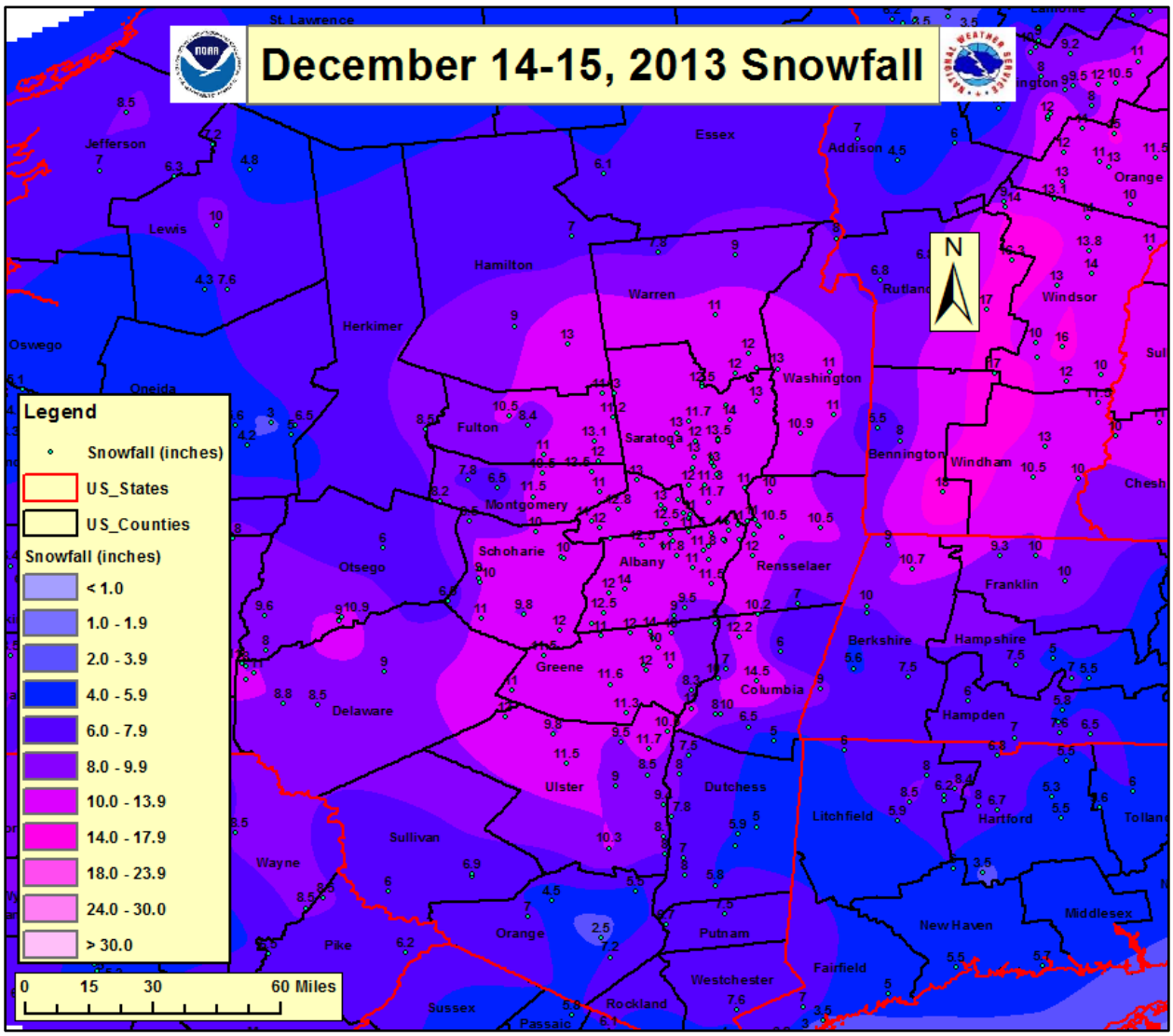


**Fig. 4.** Observed snowfall analysis map using Natural Neighbor interpolation from 14-15 December 2013. Point values represent actual snowfall observations, while color contours represent interpolated data.

## 3. Results

Many of the more significant snowfall events from the 2013-2014 winter season are examined, with output from the gridded verification method shown. The first example is a snowstorm that impacted the ALY CWA from 14-15 December 2013. The output of the shapefile generated from the snowfall observations can be seen in Fig. 5. Figure 2 shows the observed snowfall analysis map using IDW interpolation, overlaid with actual snowfall observations for specific points. A zone-averaged snowfall map (Fig. 6) displays which ALY forecast zones reached various snowfall thresholds corresponding to NWS ALY advisory and warning criteria (10 to < 18 cm [4 to < 7 inches], 18 to < 23 cm [7 to < 9 inches], and > 23 cm [> 9 inches]). Lastly, the zone-averaged statistics table using the gridded method can be seen in Table 2. The mean snowfall is used to determine if each

forecast zone received warning criteria snow.

The legacy method of zone-averaged snowfall consists of summing the snowfall totals in each zone and dividing by the number of reports. In comparing the legacy method to the gridded verification method, some differences are apparent from the 14-15 December 2013 event. The mean snowfall table using the legacy method and the difference from the gridded method are also shown in Table 2. For some of the zones, the difference in zone-averaged snowfall between the two methods is as large as 2.5 to 5 cm (1 to 2 inches). An example of why these differences occurred could be attributed to a lack of snowfall reports within a particular zone. With the legacy method, there may be only one or two reports in an entire zone. This can yield a very rough estimate for mean snowfall. However, the gridded method incorporates data within the entire forecast zone. This is possible since the zone-average is computed using the observed gridded snowfall. This is a significant advantage of the gridded method.

Specific differences can be seen by comparing results for zones NY038 (southern Herkimer County), NY043 (northern Washington County), and NY061 (eastern Columbia County) in Table 2. There were even two zones in this event, NY032 (northern Herkimer County) and CT013 (southern Litchfield County), in which there were no snowfall reports. In this situation, the gridded method at least yielded an approximate value for mean snowfall even without any reports in the zone due to deriving data from the observed snowfall analysis. These interpolated values can be used for verification to objectively represent reasonable snowfall approximation. Using the legacy method would result in no data for the zone. A caveat of using the gridded method is when no snowfall reports exist in a zone it is possible for data to be misrepresented depending on the situation, especially if outliers are present.

One more example from the 14-15 December 2013 event shows why the gridded method is more representative. This is depicted in zone NY039 (southern Fulton County). Observed snowfall reports were all clustered in the eastern half of the zone. Using the legacy method, this resulted in the mean snowfall for the entire zone being skewed towards the higher snowfall totals in the eastern half of the zone. However, when looking at the observed snowfall analysis map (Fig. 7) and using the gridded method, a west to east gradient in the snowfall can clearly be seen. The gridded method accounts for this gradient and thus yields a better representation of the mean snowfall across the entire zone.

The observed snowfall analysis maps for the 1-3 January 2014 and 13-14 February 2014 snowstorms are also shown in Figs. 8 and 9 respectively. For the 13-14 February 2014 event, forecast error plots have been generated. This is done by comparing the ALY forecast storm total snow grid preceding the event (concurrent with WSW issuance), to the observed snowfall analysis map. As detailed in the Data and Methodology section, the observed snowfall analysis is subtracted from the forecast snowfall in ArcMap to determine the forecast error. Figure 10 shows the ALY gridded forecast snowfall map preceding this event. Figure 11 displays the forecast error for the 13-14 February 2014 event, with cold colors (negative error) representing an under-forecast of snowfall and warm colors (positive error) representing an over-forecast of snowfall. The forecast error for this event was generally negative (under-forecast) across east central New York from around the Saratoga region and Capital District

southward, with a positive error (over-forecast) across the western and southern Adirondacks of New York, the Berkshires of western Massachusetts, and the Litchfield Hills of northwest Connecticut. See Fig. 12 for a map of geographic descriptors across the ALY CWA for reference.

Another significant event in which a forecast error plot was generated was from the 12-13 March 2014 winter storm. This event featured a very sharp gradient with regards to observed snowfall, as seen in Fig. 13. The forecast error plot for this event is displayed in Fig. 14, where there was generally a positive (over-forecast) error across the Mohawk Valley and western Adirondacks of NY, as well as across southern Vermont.

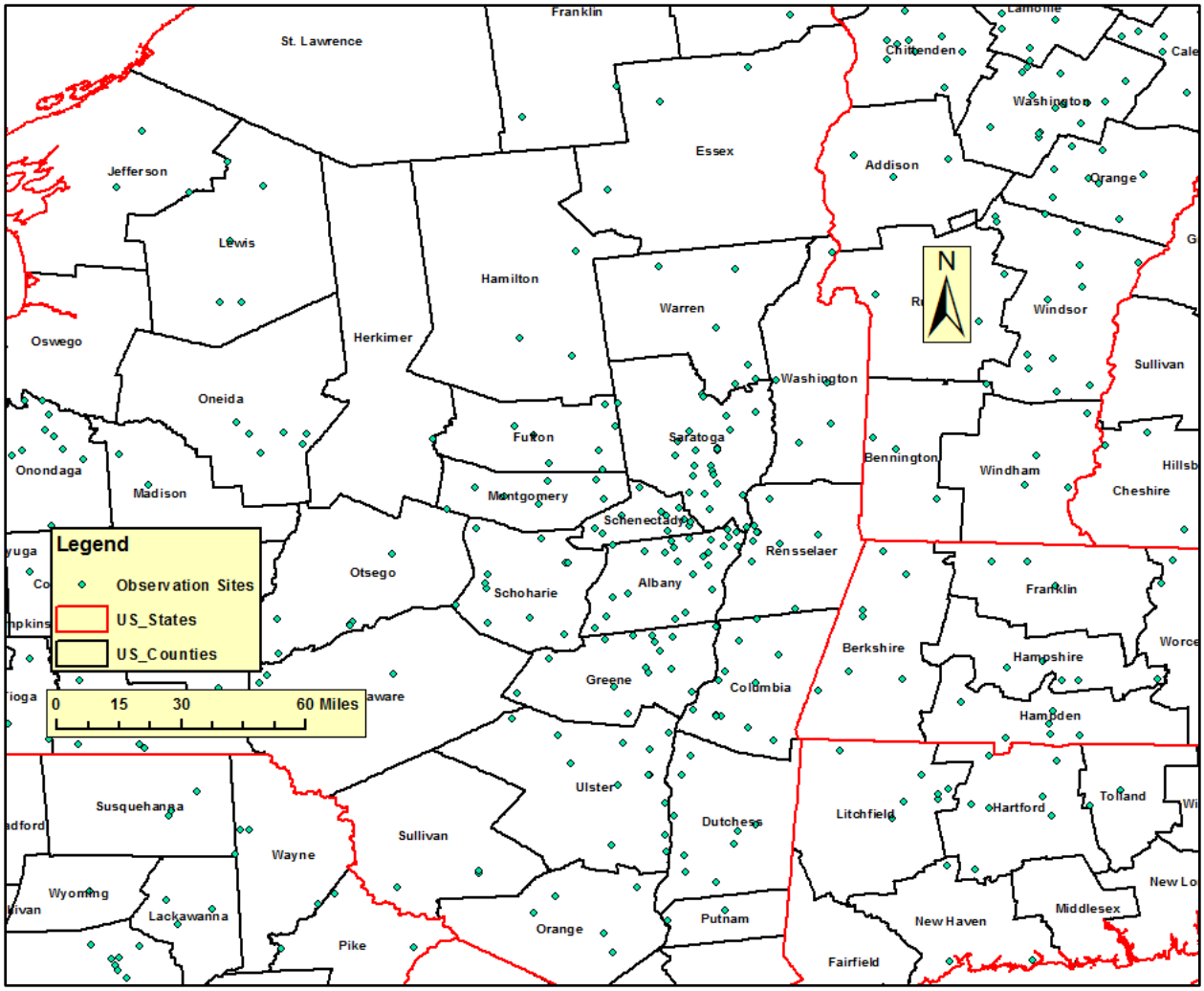


**Fig. 5.** Output of the shapefile (points) generated from snowfall observations for the 14-15 December 2013 snow storm.

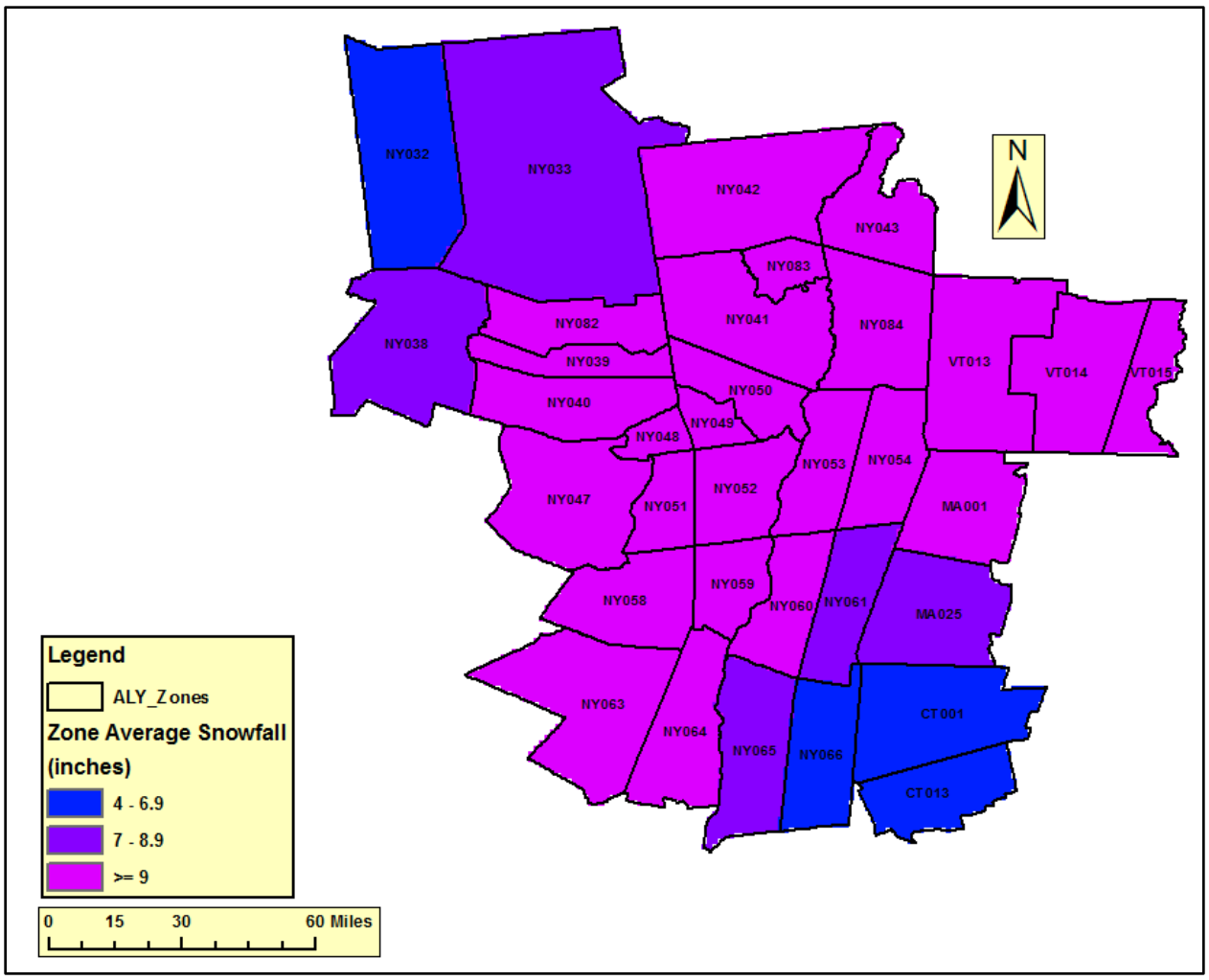


**Fig. 6.** Zone-averaged snowfall map for the ALY CWA from 14-15 December 2013 using the interpolated data.

**Table 2.** Zone-averaged statistics table displaying mean snowfall from 14-15 December 2013 comparing gridded and legacy verification methods.

| STATE_ZONE | GRIDDED MEAN (INCHES) | LEGACY MEAN (INCHES) | DIFFERENCE (INCHES) | NAME |
|---|---|---|---|---|
| NY041 | 12.44 | 12.60 | -0.16 | Northern Saratoga |
| NY049 | 12.43 | 12.20 | 0.23 | Eastern Schenectady |
| NY051 | 12.37 | 12.38 | -0.01 | Western Albany |
| VT014 | 12.18 | 11.75 | 0.43 | Western Windham |
| NY050 | 12.08 | 12.01 | 0.07 | Southern Saratoga |
| NY083 | 12.06 | 11.93 | 0.13 | Southeast Warren |
| NY048 | 12.06 | 11.93 | 0.13 | Western Schenectady |
| NY052 | 11.52 | 11.62 | -0.10 | Eastern Albany |
| NY058 | 11.29 | 11.40 | -0.11 | Western Greene |
| VT013 | 11.18 | 12.12 | -0.94 | Bennington |
| NY084 | 10.82 | 11.48 | -0.66 | Southern Washington |
| VT015 | 10.73 | 10.75 | -0.02 | Eastern Windham |
| NY053 | 10.69 | 10.53 | 0.16 | Western Rensselaer |
| NY047 | 10.44 | 10.05 | 0.39 | Schoharie |
| NY059 | 10.43 | 10.87 | -0.44 | Eastern Greene |
| NY039 | 10.40 | 12.03 | -1.63 | Southern Fulton |
| NY082 | 10.36 | 10.28 | 0.08 | Northern Fulton |
| NY042 | 9.98 | 9.27 | 0.71 | Northern Warren |
| NY040 | 9.94 | 9.85 | 0.09 | Montgomery |
| NY043 | 9.86 | 8.00 | 1.86 | Northern Washington |
| NY063 | 9.85 | 10.70 | -0.85 | Western Ulster |
| NY054 | 9.63 | 8.75 | 0.88 | Eastern Rensselaer |
| NY060 | 9.54 | 9.93 | -0.39 | Western Columbia |
| MA001 | 9.11 | 8.98 | 0.13 | Northern Berkshire |
| NY064 | 9.10 | 9.44 | -0.34 | Eastern Ulster |
| NY033 | 8.72 | 9.67 | -0.95 | Hamilton |
| NY061 | 7.92 | 5.50 | 2.42 | Eastern Columbia |
| NY065 | 7.46 | 7.36 | 0.10 | Western Dutchess |
| MA025 | 7.21 | 7.37 | -0.16 | Southern Berkshire |
| NY038 | 7.03 | 8.50 | -1.47 | Southern Herkimer |
| NY032 | 6.89 | No reports | N/A | Northern Herkimer |
| CT001 | 6.80 | 7.03 | -0.23 | Northern Litchfield |
| CT013 | 6.34 | No reports | N/A | Southern Litchfield |
| NY066 | 6.12 | 5.47 | 0.65 | Eastern Dutchess |

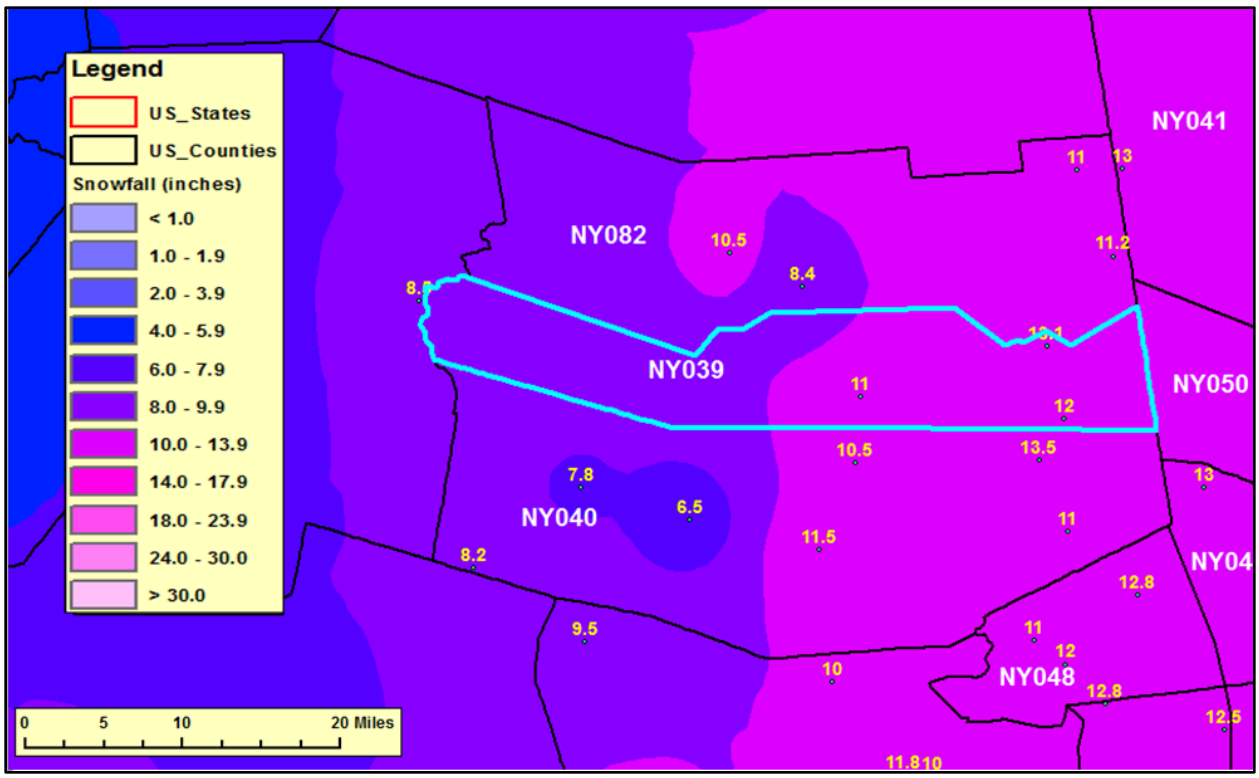


**Fig. 7.** Zoomed-in view of zone NY039 (southern Fulton County) outlined by light blue color.

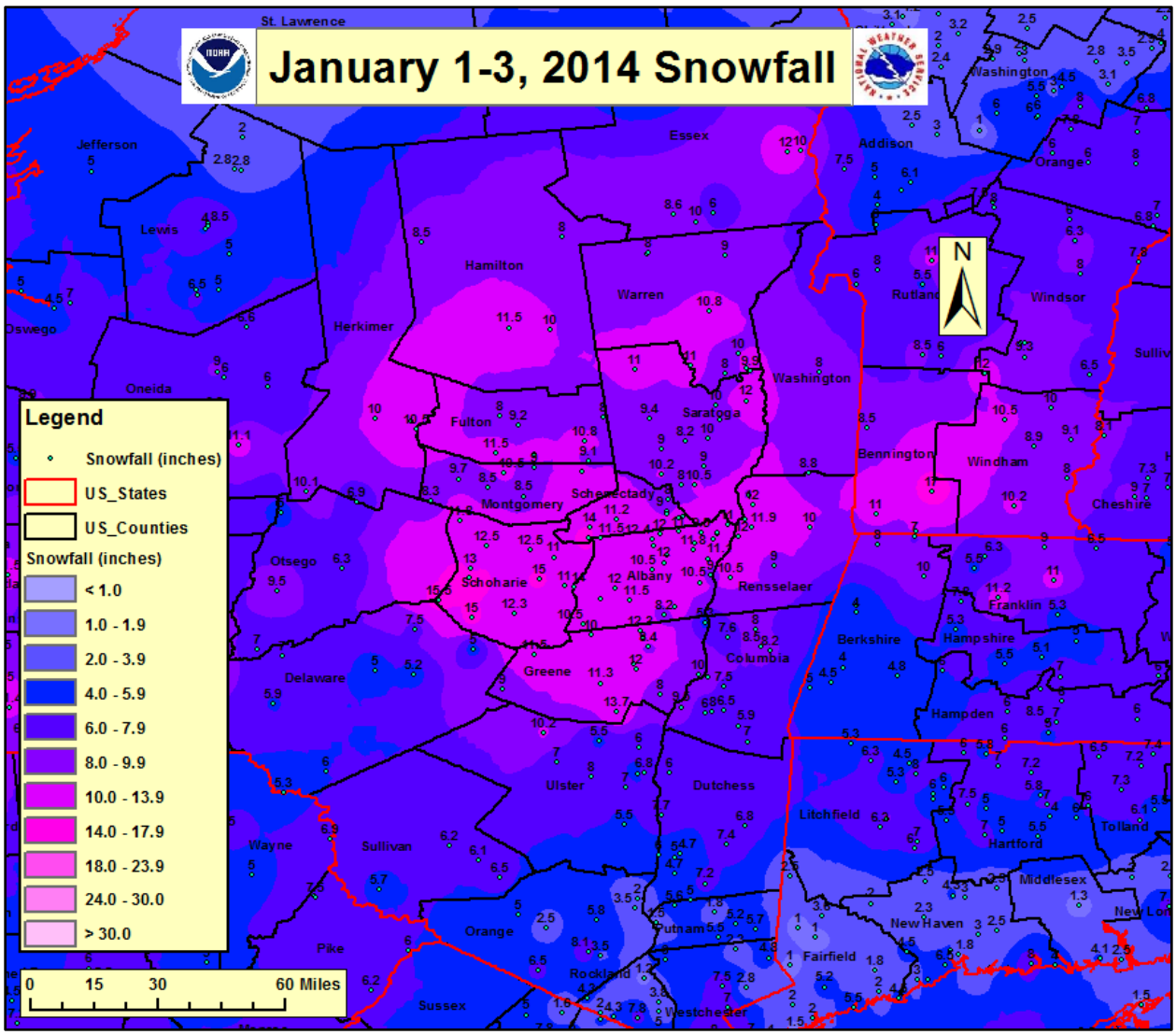


**Fig. 8**. Observed snowfall analysis map from 1-3 January 2014 overlaid with snowfall observations. Point values represent actual snowfall observations, while color contours represent interpolated data.

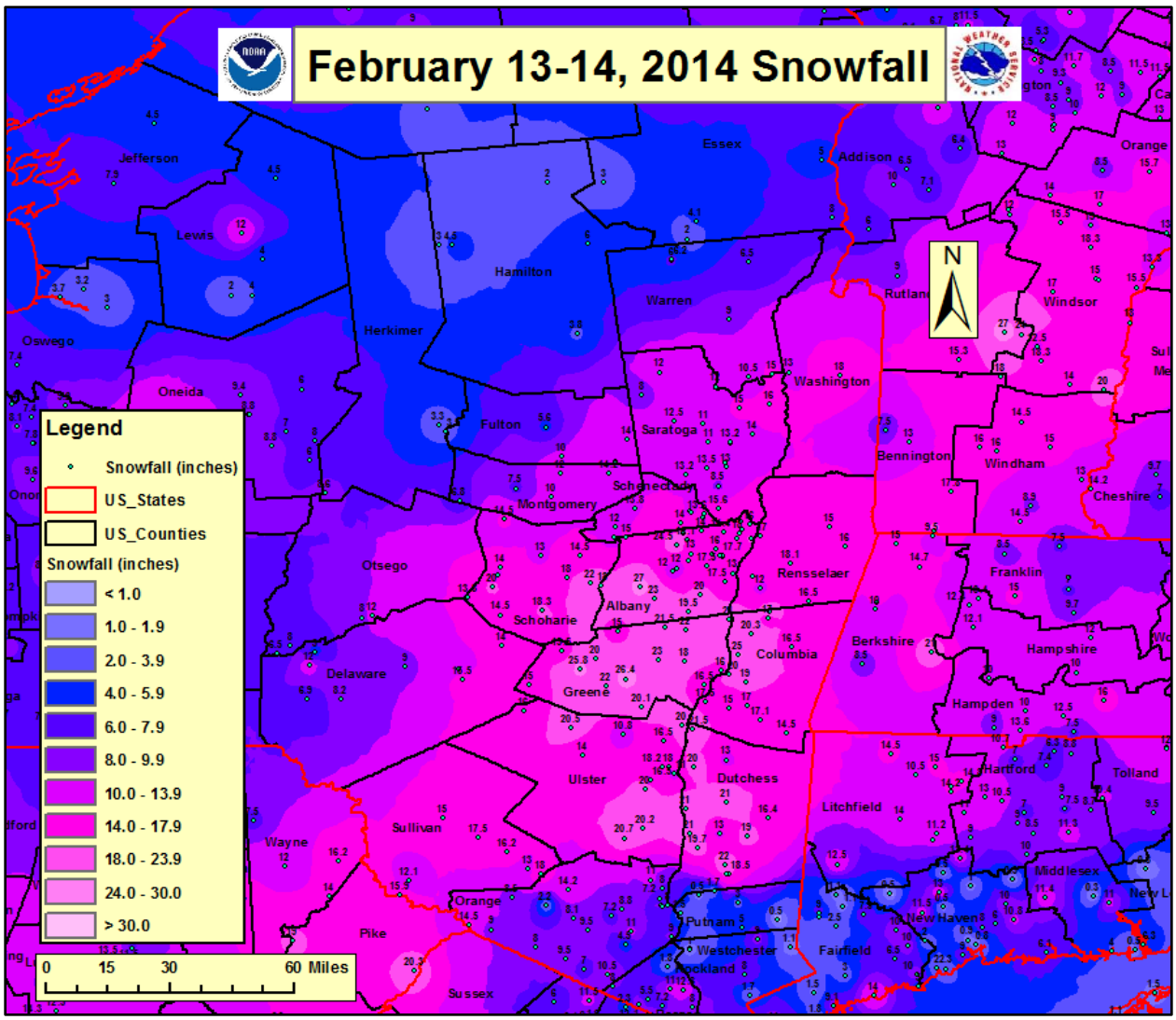


**Fig. 9.** Observed snowfall analysis map from 13-14 February 2014 overlaid with snowfall observations. Point values represent actual snowfall observations, while color contours represent interpolated data.

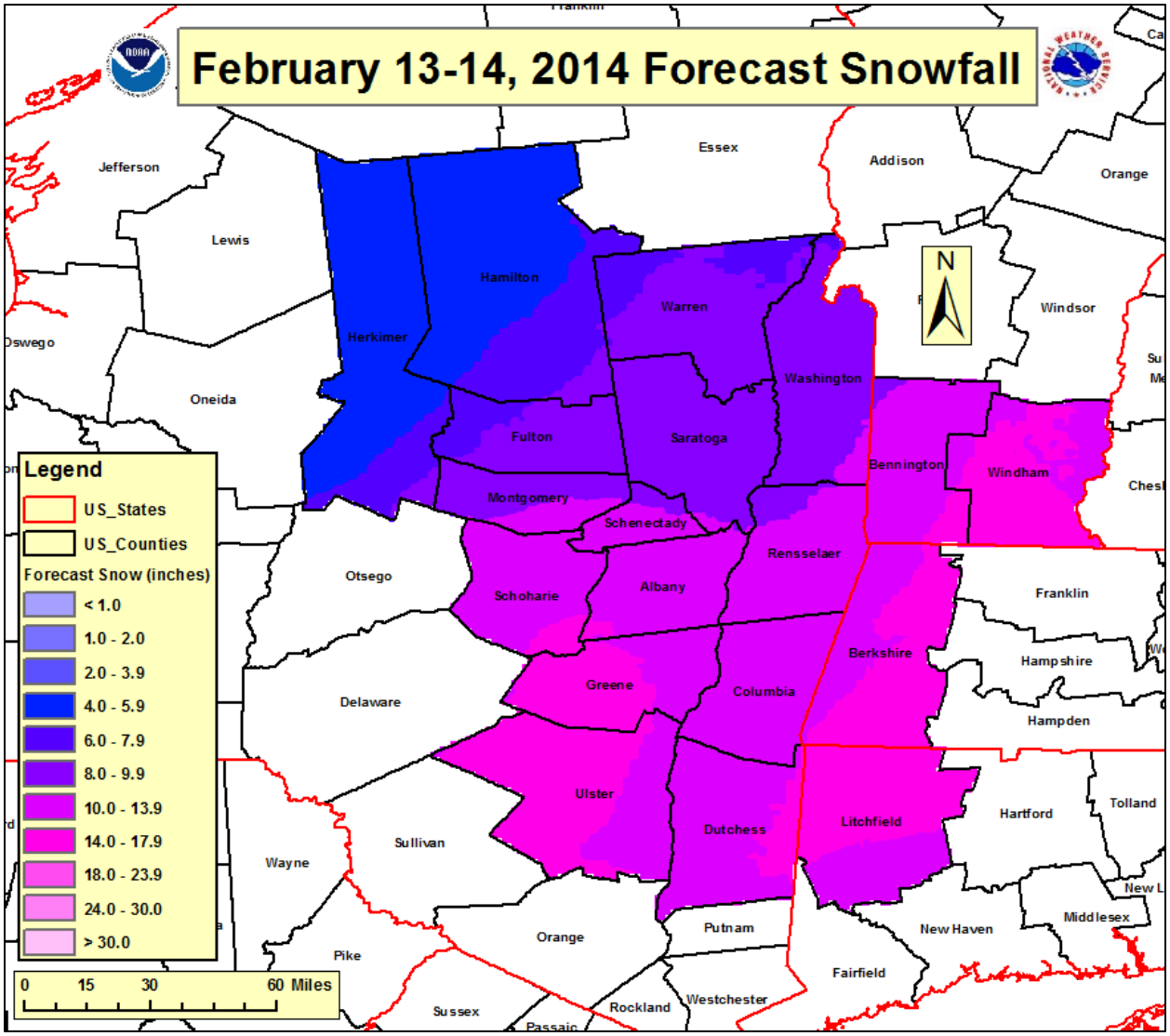


**Fig. 10.** ALY gridded forecast snowfall preceding the 13-14 February 2014 snow storm.

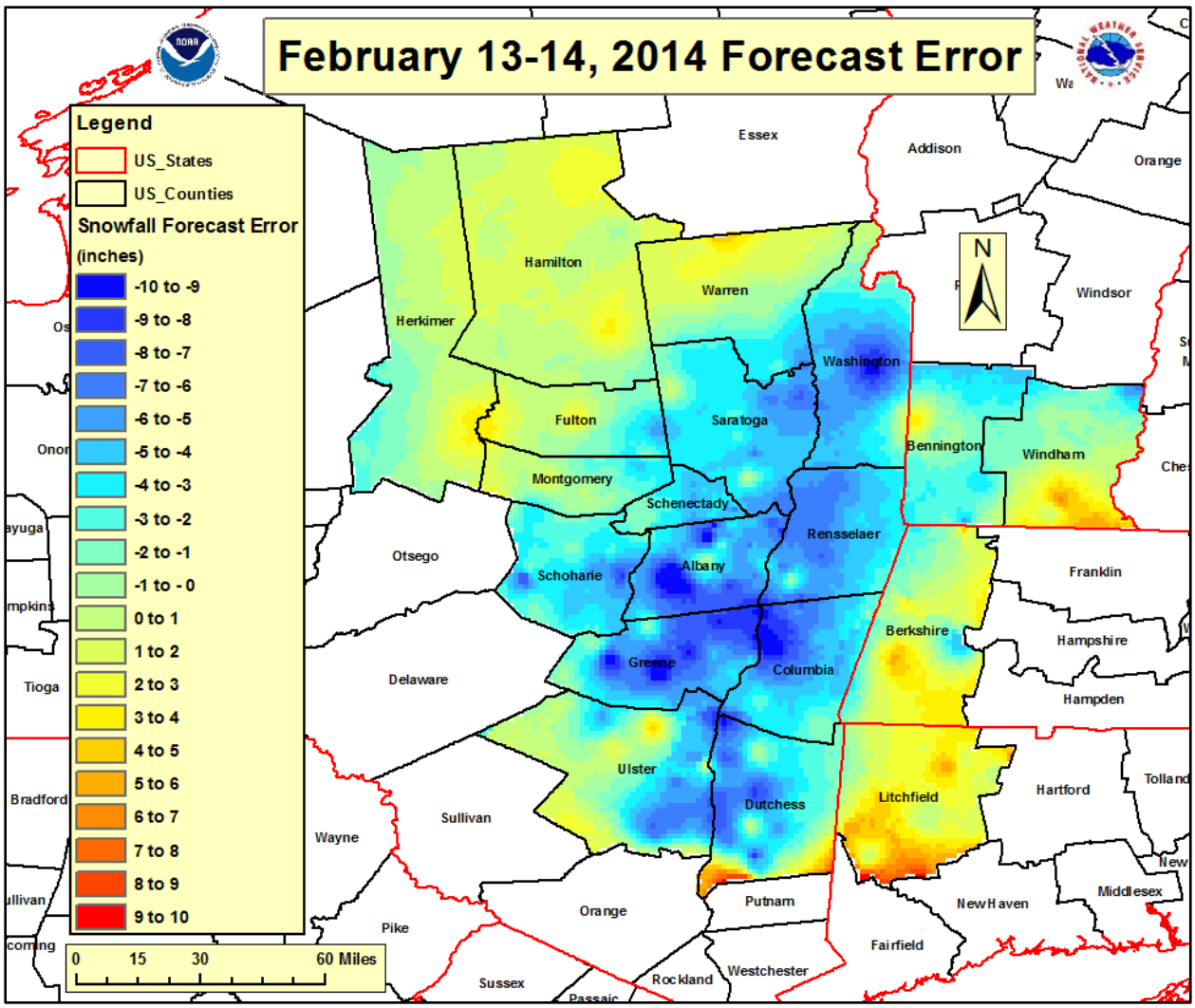


**Fig. 11.** ALY snowfall forecast error for the 13-14 February 2014 snow storm.

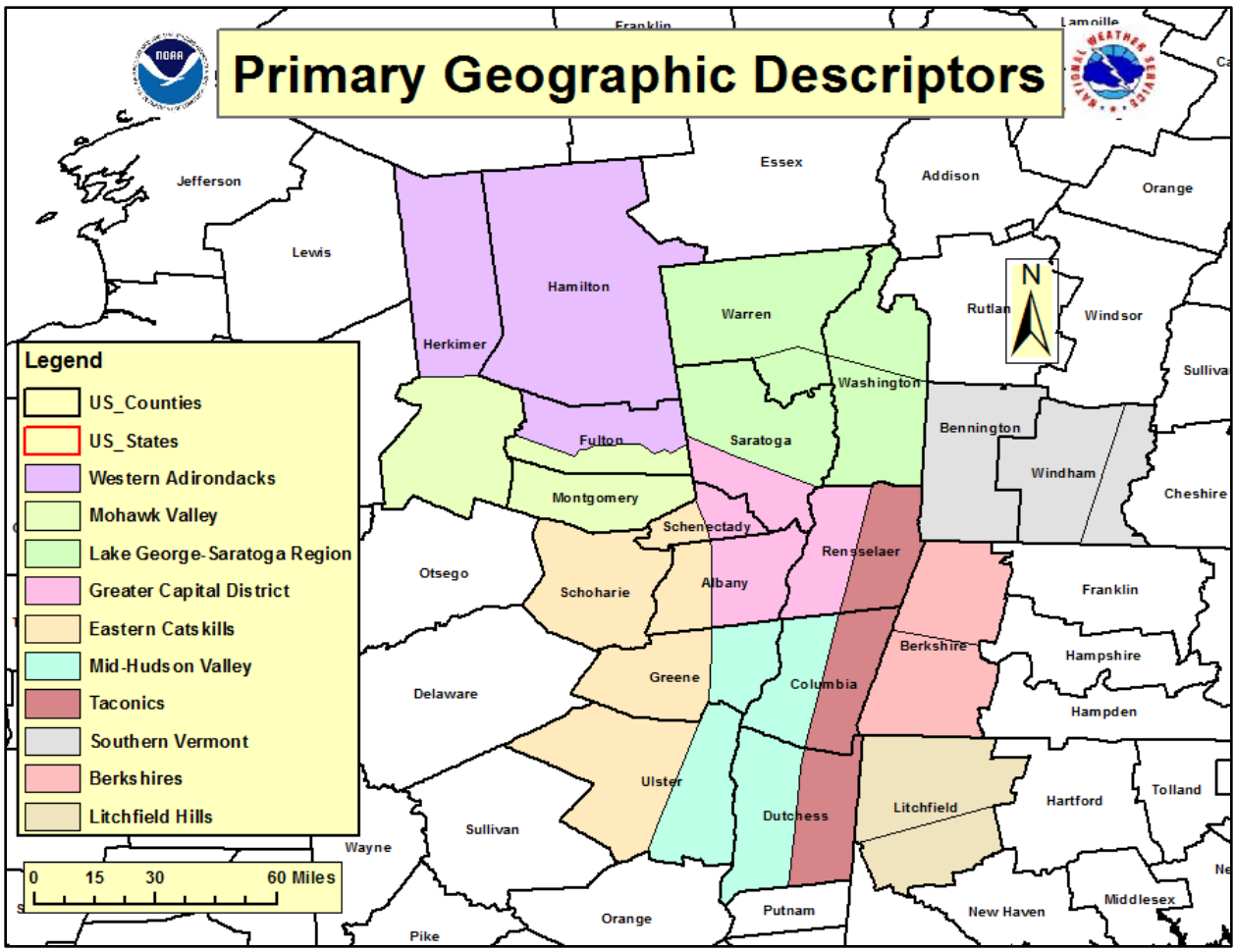


**Fig. 12.** Map of primary geographic descriptors for the ALY CWA.

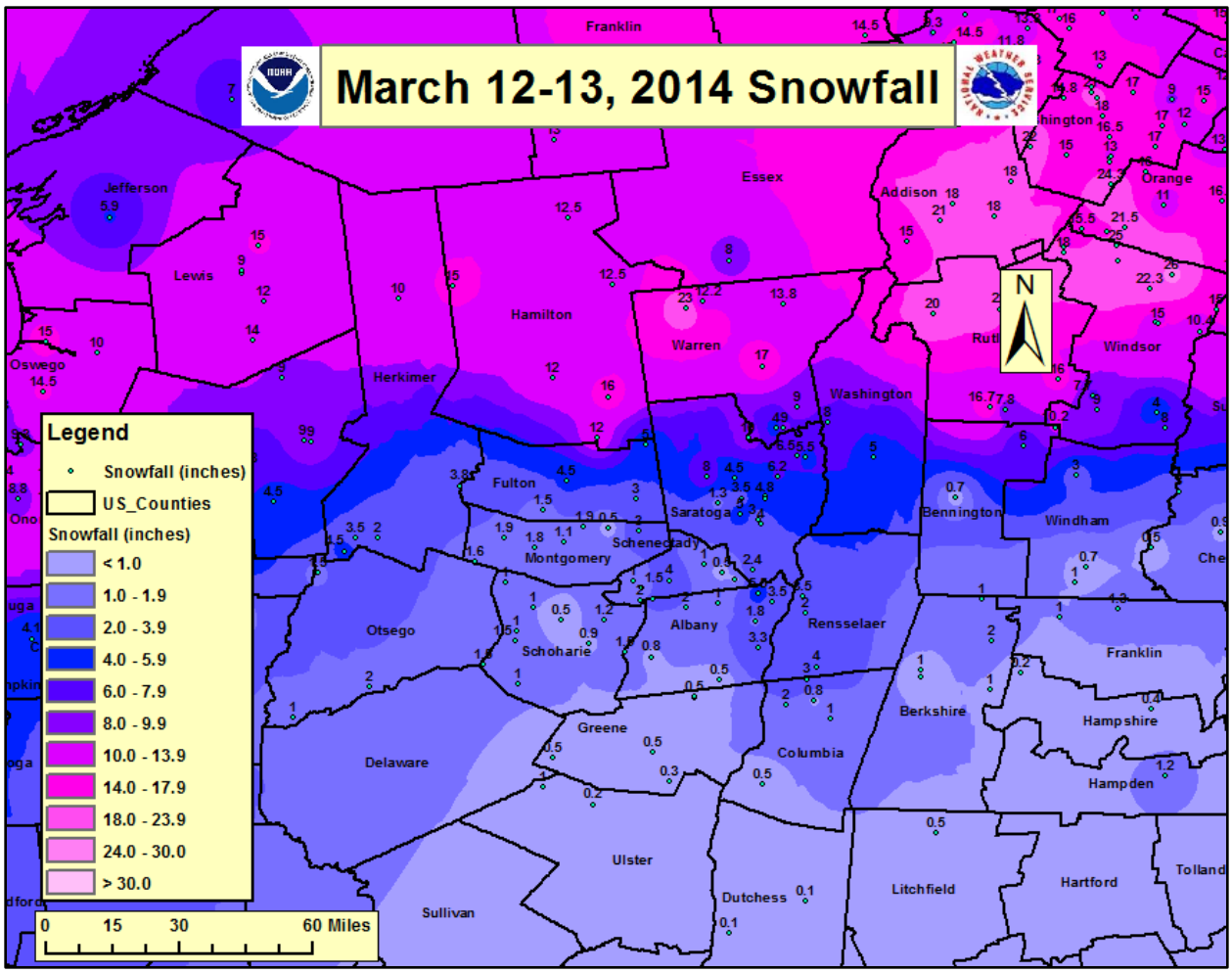


**Fig. 13.** Observed snowfall analysis map from 12-13 March 2014 overlaid with snowfall observations. Point values represent actual snowfall observations, while color contours represent interpolated data.

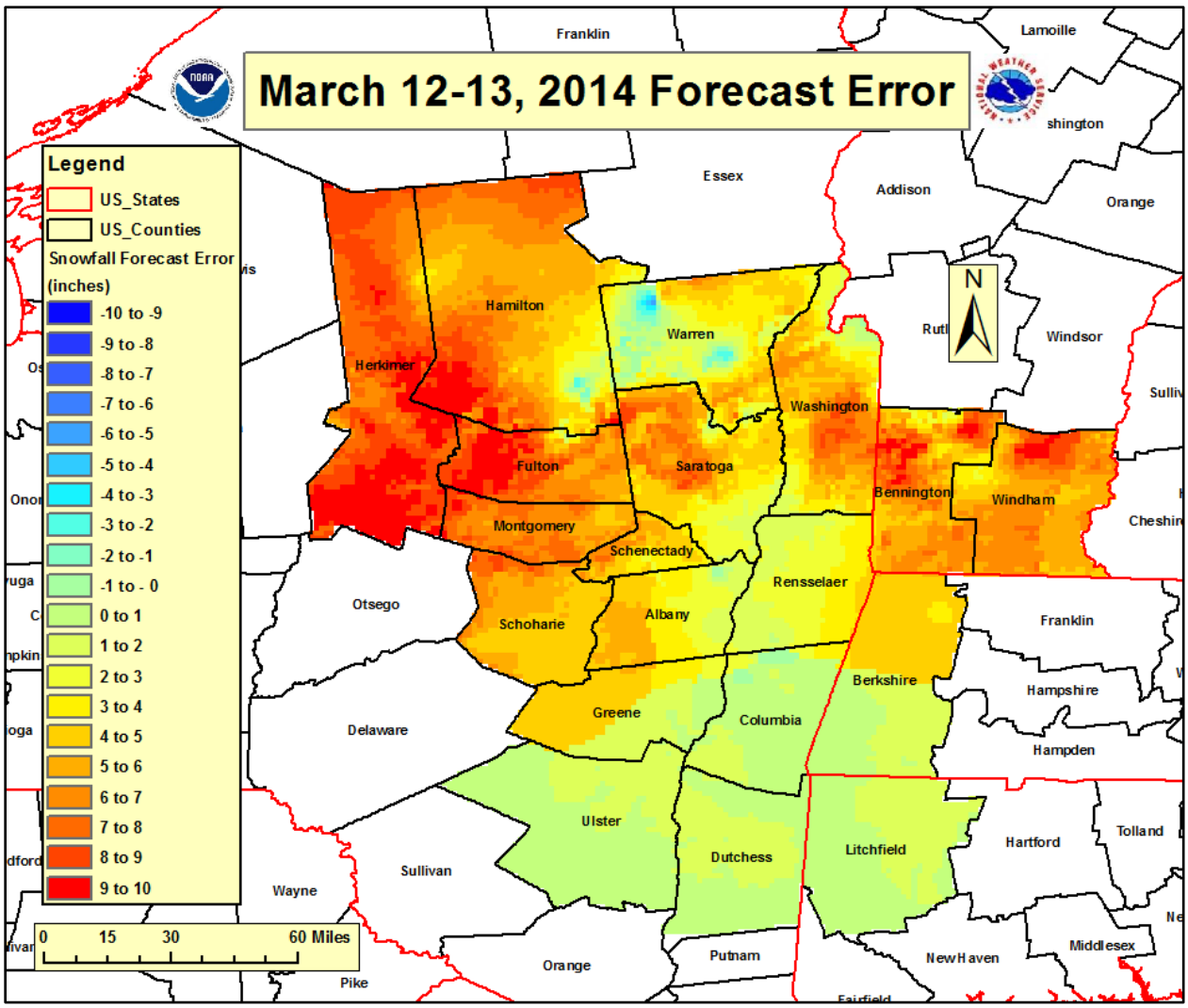


**Fig. 14.** ALY snowfall forecast error for the 12-13 March 2014 winter storm.

## 4. Discussion

The WFO ALY staff endorsed the gridded snowfall verification method to become official before the 2013-2014 winter season. After a full season of using this new verification scheme, the ALY staff has provided positive feedback. As shown in the Results section, this method improves upon the legacy practice of summing snowfall reports and dividing by the number of reports for each forecast zone. Creating gridded observed snowfall maps yields a more representative depiction of snowfall spatially across a CWA and aides in conducting zone-based verification in a more thorough manner. Other NWS offices can adopt this gridded snowfall verification while still maintaining NWS zone-based verification.

For NWS offices that would like to implement this gridded snowfall verification method, job sheets (found in the Appendix) have been constructed detailing each step of the process, from creating the initial shapefile based on snowfall reports, to generating observed snowfall analysis maps and generating forecast error plots for snowfall. Any NWS office that has access to GIS software can adopt this method.

Another advantage of generating gridded snowfall maps is that they can be

easily displayed in a variety of graphical formats. Any GIS-based format can be generated as output such as KMZ, KML files (Google Keyhole Markup Language 2014), as well as common digital image formats. The graphics can be used for Decision Support Services dissemination, as well as in post-mortem reviews of snow events. The forecast ranges and color scales can easily be adapted to match the latest standardized NWS Eastern Region forecast snowfall ranges.

In addition to computing snowfall verification for storm-total snowfall, 24-hour snowfall can also be verified. This can be accomplished by summing 6-hour snowfall grids from the NWS gridded forecast database over a 24-hour period, typically ending 1200 UTC. This is when many trained weather spotters regularly report precipitation to NWS WFO's. Additional time steps can also be analyzed based on user preference.

Internally, forecast error plots of snowfall events can be compiled over entire winter seasons to compute potential positive or negative biases that may exist consistently over certain areas. This would be particularly beneficial to NWS forecasters in potentially improving snowfall forecasts. Biases for events could be stratified into different flow regimes, as well as storm tracks. At a base level, it would be valuable for NWS WFO's to simply start looking at forecast biases since it is difficult to improve forecasting snowfall without knowing spatially how forecasts verify. This gridded verification method can enable NWS WFO's to start examining potential forecast biases relatively quickly and easily.

## 5. Future Work

Many of the stages of the gridded snowfall verification in the job sheets (see Appendix) created at WFO ALY must currently be performed manually by a user. This can be a lengthy process, especially to those who have limited experience using GIS software. Therefore, automating most of the verification process would be advantageous. Automation will be a crucial step going forward in making this method more accessible to a wider audience. The authors plan to develop automation techniques for this gridded verification method.

Improvements in the interpolation scheme for snowfall analysis will also be attempted by exploring more intensive interpolation schemes, such as the Barnes objective analysis (Barnes 1964; Koch et al. 1983; Lanciani and Salvati 2008) in the future. The NWS national snowfall analysis currently in development at the time of this writing, utilizes a version of the Barnes interpolation scheme. Improving the interpolation for snowfall analysis will lead to more accurate representation of snowfall spatially and by extension, zone-based verification and error plots.

Computing forecast biases for snowfall is just beginning to tap the potential for using statistics based on gridded maps. More advanced statistics can eventually be developed for snowfall. In addition, this verification method may potentially be used for other variables such as rainfall, temperature, dewpoint, and wind speed, although this still has to be evaluated.

## Acknowledgements

The authors would like to thank Conor Lahiff from NWS Burlington, VT, for assistance in obtaining information for converting a NetCDF file to a shapefile. The authors would also like to acknowledge Luigi Meccariello from NWS Albany, NY, for assisting in creating observed snowfall analysis maps during the 2013-2014 winter season. The authors also thank John Quinlan from NWS Albany, NY, for providing conceptual ideas for computing zone-averaged statistics. Finally, the authors would like to acknowledge Warren Snyder from NWS Albany, NY, and Brian Miretzky from NWS Eastern Region Headquarters, Scientific Services Division, for reviewing this paper.

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Lanciani, A., and Salvati, M., 2008: Spatial interpolation of surface weather observations in Alpine meteorological services. *FORALPS Technical Report*, **2**. Università degli Studi di Trento, Dipartimento di Ingegneria Civile e Ambientale, Trento, Italy, 40 pp.

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APPENDIX

The following Appendix outlines instructions necessary to create observed and forecast snowfall maps, as well as forecast error plots. The instructions outlined in this Appendix are based on the assumption that the user following these instructions has a basic level of understanding with ArcGIS software and computer programming. ArcGIS version 10.2 was used for testing these procedures. While ArcGIS is recommended, this method can be amended for other GIS software platforms.

Questions concerning the gridded snowfall verification method outlined in this paper should be directed to Joe.Villani@noaa.gov. Questions concerning GIS software analysis discussed in this Appendix should be directed to Ian.Lee@noaa.gov. Questions concerning software development and directory structure should be directed to Vasil.Koleci@noaa.gov.

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# Step 1: Creating a Spreadsheet for GIS Maps via PNS/RRM Files

This section outlines the instructions necessary to create Microsoft Excel .xls spreadsheets containing snowfall data from PNS/RRM files. This spreadsheet is generated off the **final storm total PNS** after an event occurs. Careful QC must be done **before** issuing the final storm total PNS.

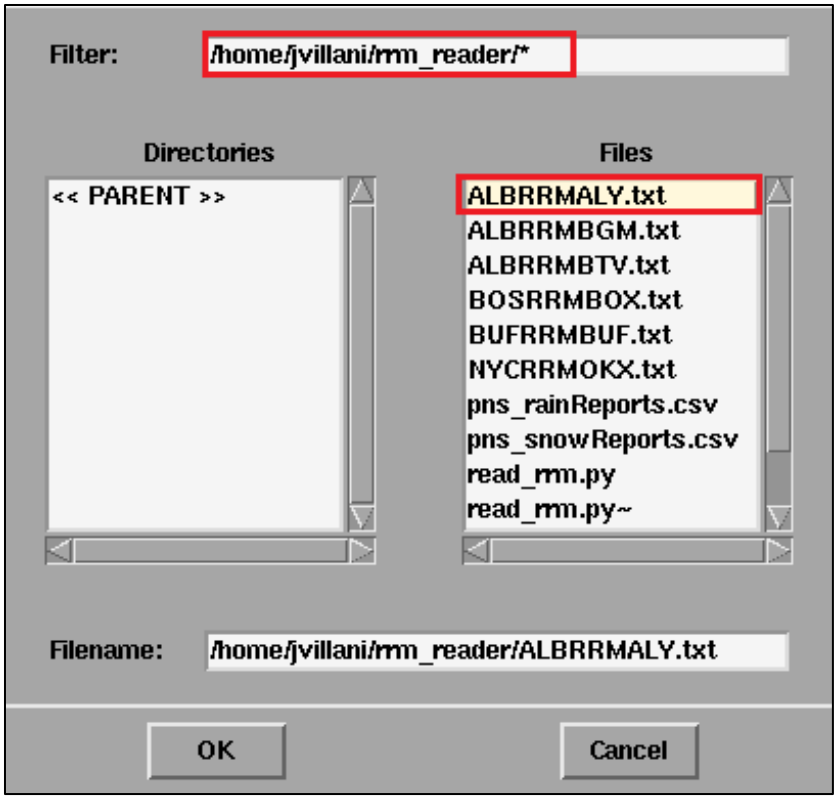
***To obtain the Python program (read_rrm.py) and AWIPS directory structure needed for this section, send an email request to Vasil.Koleci@noaa.gov**

1. In an AWIPS text workstation, open up a text window
2. Call up your office's most recent RRM file after an event, along with the RRM files from your surrounding offices (dependent upon surrounding office's IDs)
    a. Make sure each RRM file is recent and matches the final PNS you wish to include in the spreadsheet by looking at the times in the headers to make sure the RRM and PNS files match. It is imperative to use the **final** storm total PNS after an event (this may require brief communication with surrounding offices inquiring if a final PNS has been issued)

```
NOUS41 KALY 201333
PNSALY
CTZ001-013-MAZ001-025-NYZ032-033-038>043-047>054-058>061-063>066-082>084-
VTZ013>015-210133-

PUBLIC INFORMATION STATEMENT
SPOTTER REPORTS
NATIONAL WEATHER SERVICE ALBANY NY
933 AM EDT SAT APR 20 2013

THE FOLLOWING ARE UNOFFICIAL OBSERVATIONS TAKEN DURING THE PAST 6
HOURS FOR THE STORM THAT HAS BEEN AFFECTING OUR REGION. APPRECIATION
IS EXTENDED TO HIGHWAY DEPARTMENTS...COOPERATIVE OBSERVERS...SKYWARN
SPOTTERS AND MEDIA FOR THESE REPORTS. THIS SUMMARY IS ALSO AVAILABLE
ON OUR HOME PAGE AT WEATHER.GOV/ALBANY

********************STORM TOTAL RAINFALL********************

LOCATION           STORM TOTAL     TIME/DATE   COMMENTS
                      RAINFALL           OF
                      /INCHES/   MEASUREMENT

MASSACHUSETTS

...BERKSHIRE COUNTY...
   PITTSFIELD            0.85   645 AM  4/20  WEATHERNET6
   LANESBOROUGH          0.80   610 AM  4/20  WEATHERNET6

NEW YORK

...ALBANY COUNTY...
   RAVENA                1.75   637 AM  4/20  WEATHERNET6
   LATHAM                1.22   632 AM  4/20  WEATHERNET6
   1 ENE MCKOWNVILLE     0.90   800 AM  4/20  NWS OFFICE

...COLUMBIA COUNTY...
   LIVINGSTON            1.22   827 AM  4/20  WEATHERNET6
   TAGHKANIC             1.11   822 AM  4/20  WEATHERNET6
   HUDSON                1.00   745 AM  4/20  WEATHERNET6
   NORTH CHATHAM         0.97   736 AM  4/20  WEATHERNET6
   GERMANTOWN            0.33   558 AM  4/20  WEATHERNET6

...DUTCHESS COUNTY...
   MILLBROOK             0.92   634 AM  4/20  WEATHERNET6
   RHINEBECK             0.90   714 AM  4/20  SPOTTER
   RED OAKS MILL         0.58   510 AM  4/20  SPOTTER

...FULTON COUNTY...
   BROADALBIN            1.15   817 AM  4/20  WEATHERNET6
   FISHHOUSE             1.02   555 AM  4/20  WEATHERNET6

...GREENE COUNTY...
   HALCOTT CENTER        1.10   907 AM  4/20  WEATHERNET6
   GREENVILLE            0.77   457 AM  4/20  SPOTTER
   GREENVILLE CENTER     0.77   522 AM  4/20  WEATHERNET6
   CAIRO                 0.68   622 AM  4/20  WEATHERNET6

...HAMILTON COUNTY...
```

```
SRUS41 KALY 201333
RRMALY
HYDROLOGIC OBSERVATIONS
NATIONAL WEATHER SERVICE ALBANY NY


.A NY-DT-12 0420 Z DH1200/DVH24/PPV 0.89"LAT=41.684600 LON=-73.720500  3 NE LAGR
.A NY-SR-4 0420 Z DH1000/DVH24/PPV 0.86"LAT=43.060320 LON=-73.780087  1 S SARATO
.A NY-CB-8 0420 Z DH1200/DVH24/PPV 1.22"LAT=42.133076 LON=-73.785373  1 SSW LIVI
.A PHON6 0420 Z DH1106/DVH24/PPV 1.25"LAT=42.066389 LON=-74.337500  PHOENICIA  C
.A X4330736 0420 Z DH1107/DVH6/PPV 0.75"LAT=43.306680 LON=-73.576650  HUDSON FAL
.A X4280737 0420 Z DH1034/DVH6/PPV 1.10"LAT=42.794310 LON=-73.652170  SPEIGLETOW
.A BLLC3 0420 Z DH1000/DVH24/PPV 0.27"LAT=41.650000 LON=-73.483333  BULLS BRIDGE
.A NY-DT-4 0420 Z DH1100/DVH24/PPV 0.97"LAT=41.553480 LON=-73.786330  2 SSE HOPE
.A ELLN6 0420 Z DH1200/DVH24/PPV 1.68"LAT=41.719444 LON=-74.397222  ELLENVILLE
.A X4300744 0420 Z DH1104/DVH6/PPV 0.74"LAT=42.952940 LON=-74.374060  FONDA  WEA
.A NY-SR-16 0420 Z DH1030/DVH24/PPV 0.81"LAT=42.990000 LON=-73.800000  3 ESE BAL
.A X4170739 0420 Z DH0910/DVH6/PPV 0.58"LAT=41.655700 LON=-73.873600  RED OAKS M
.A X4310738 0420 Z DH1230/DVH6/PPV 0.86"LAT=43.063880 LON=-73.779260  SARATOGA S
.A VT-WH-12 0420 Z DH1100/DVH24/PPV 0.64"LAT=43.003345 LON=-72.533363  2 WNW PUT
.A X4270738 0420 Z DH1200/DVH6/PPV 0.90"LAT=42.689440 LON=-73.829900  1 ENE MCKO
.A NY-HR-4 0420 Z DH1000/DVH24/PPV 0.71"LAT=43.016588 LON=-75.055279  1 WNW ILIO
.A X4240740 0420 Z DH0922/DVH6/PPV 0.77"LAT=42.415000 LON=-74.009280  GREENVILLE
.A X4260746 0420 Z DH1120/DVH6/PPV 0.91"LAT=42.627090 LON=-74.585130  RICHMONDVI
.A X4220739 0420 Z DH0958/DVH6/PPV 0.33"LAT=42.154350 LON=-73.867400  GERMANTOWN
.A X4220745 0420 Z DH1307/DVH6/PPV 1.10"LAT=42.217727 LON=-74.468658  HALCOTT CE
.A VT-WH-9 0420 Z DH1202/DVH24/PPV 0.52"LAT=42.785607 LON=-72.769472  SE WEST HA
.A MA-BE-10 0420 Z DH1100/DVH24/PPV 0.85"LAT=42.478778 LON=-73.273809  2 NNW PIT
.A BRUN6 0420 Z DH1100/DVH24/PPV 1.25"LAT=42.743056 LON=-73.655000  BRUNSWICK  C
.A NY-UL-1 0420 Z DH1100/DVH24/PPV 0.82"LAT=41.928600 LON=-74.019500  1 W KINGST
.A X4230740 0420 Z DH1022/DVH6/PPV 0.68"LAT=42.302290 LON=-74.031860  CAIRO  WEA
.A X4260742 0420 Z DH1112/DVH6/PPV 0.95"LAT=42.562544 LON=-74.232808  MIDDLEBURG
.A X4230738 0420 Z DH1145/DVH6/PPV 1.00"LAT=42.255670 LON=-73.776820  HUDSON  WE
.A NY-UL-6 0420 Z DH1205/DVH24/PPV 1.09"LAT=41.714048 LON=-74.086557  2 S NEW PA
.A ROCC3 0420 Z DH1000/DVH24/PPV 0.06"LAT=41.583333 LON=-73.433333  ROCKY RIVER
.A SUNV1 0420 Z DH1100/DVH24/PPV 1.10"LAT=43.090833 LON=-73.124444  2 S SUNDERLA
.A X4250733 0420 Z DH1010/DVH6/PPV 0.80"LAT=42.502290 LON=-73.270870  LANESBOROU
.A NY-DT-10 0420 Z DH0900/DVH24/PPV 0.58"LAT=41.647000 LON=-73.897000  4 SSE POU
.A X4210738 0420 Z DH1227/DVH6/PPV 1.22"LAT=42.134440 LON=-73.785610  LIVINGSTON
.A NSKN6 0420 Z DH1100/DVH24/PPV 0.56"LAT=42.796389 LON=-73.876667  NISKAYUNA  C
.A X4340743 0420 Z DH1144/DVH6/PPV 0.72"LAT=43.439430 LON=-74.316150  WELLS  WEA
.A MA-BE-4 0420 Z DH1100/DVH24/PPV 0.85"LAT=42.259060 LON=-73.132130  6 SSW BECK
.A NY-GR-5 0420 Z DH1100/DVH24/PPV 0.71"LAT=42.442943 LON=-73.786628  SE NEW BAL
.A DLSN6 0420 Z DH1100/DVH24/PPV 0.91"LAT=42.728611 LON=-74.186667  DELANSON  CO
.A NY-GR-6 0420 Z DH0930/DVH24/PPV 0.81"LAT=42.360450 LON=-73.983468  3 E FREEHO
.A TMSC3 0420 Z DH1200/DVH24/PPV 0.40"LAT=41.694722 LON=-73.062222  THOMASTON DA
.A BSVN6 0420 Z DH1100/DVH24/PPV 0.80"LAT=42.037500 LON=-74.149167  BEARSVILLE
.A NY-DT-8 0420 Z DH1030/DVH24/PPV 0.92"LAT=41.752300 LON=-73.648800  3 SE MILLB
.A MLTN6 0420 Z DH1100/DVH24/PPV 0.95"LAT=43.006667 LON=-73.860556  MALTA  CO-OP
.A X4210737 0420 Z DH1222/DVH6/PPV 1.11"LAT=42.090870 LON=-73.675570  TAGHKANIC
.A X4310741 0420 Z DH0955/DVH6/PPV 1.02"LAT=43.142660 LON=-74.137420  FISHHOUSE
.A X4250733 0420 Z DH1045/DVH6/PPV 0.85"LAT=42.478852 LON=-73.274056  PITTSFIELD
.A NY-AB-29 0420 Z DH1050/DVH24/PPV 0.69"LAT=42.619315 LON=-73.820274  1 ESE DEL
.A X4210743 0420 Z DH1105/DVH6/PPV 1.25"LAT=42.065910 LON=-74.337540  PHOENICIA
.A X4330734 0420 Z DH1021/DVH6/PPV 1.33"LAT=43.296630 LON=-73.399060  HEBRON  WE
.A POUN6 0420 Z DH1100/DVH24/PPV 0.89"LAT=41.650833 LON=-73.945000  POUGHKEEPSIE
.A NY-AB-6 0420 Z DH1100/DVH24/PPV 0.83"LAT=42.719762 LON=-73.930371  6 SSW SCHE
.A NY-CB-6 0420 Z DH1100/DVH24/PPV 0.97"LAT=42.472700 LON=-73.643900  1 W NORTH
```

3. Save each RRM file by clicking **File→Export to File→**then navigate to the directory where the Python program is stored via the **'Directories'** section of the **Export to File** window
    a. In the **'Files'** section of the text window, click on the .txt file that matches each specific RRM you are saving and click OK to save the file (this overwrites the old file)




   b. For example, for ALBRRMALY, click the ALBRRMALY.txt file, then click **'OK'** to save

4. Check to make sure all the .txt files have updated times to ensure you saved them:
   a. Open a **Terminal** window in any AWIPS workstation
   b. Navigate to your office's **rrm_reader** AWIPS directory location and type **ls -ltr** which lists all the files and the date/time they were saved in that directory

```
xt5-aly{jvillani}101: cd /home/jvillani/rrm_reader/
xt5-aly{jvillani}102: ls -ltr
total 132
-rw-rw-r-- 1 jvillani fxalpha   849 Feb 21 14:51 rrmaly.txt
-rwxrwxr-x 1 vkoleci  fxalpha   970 Feb 22 20:49 vk_readrrm.py
-rw-rw-r-- 1 jvillani fxalpha   970 Mar  5 15:00 read_rrm.py~
-rw-rw-r-- 1 jvillani fxalpha  5180 Mar 19 15:01 BUFRRMBUF.txt
-rw-rw-r-- 1 jvillani fxalpha 10171 Mar 19 15:01 NYCRRMOKX.txt
-rw-rw-r-- 1 jvillani fxalpha  6519 Mar 19 20:17 ALBRRMBGM.txt
-rw-rw-r-- 1 jvillani fxalpha 11138 Mar 19 20:18 ALBRRMBTV.txt
-rw-rw-r-- 1 jvillani fxalpha 13318 Mar 19 20:19 BOSRRMBOX.txt
-rw-rw-r-- 1 jvillani fxalpha 20290 Mar 26 16:39 ALBRRMALY.txt
-rw-r--r-- 1 jvillani fxalpha     0 Mar 26 16:39 pns_rainReports.csv
-rw-r--r-- 1 jvillani fxalpha 33007 Mar 26 16:39 pns_snowReports.csv
-rwxrwxr-x 1 jvillani fxalpha  1306 Apr 15 15:00 read_rrm.py
xt5-aly{jvillani}103:
```

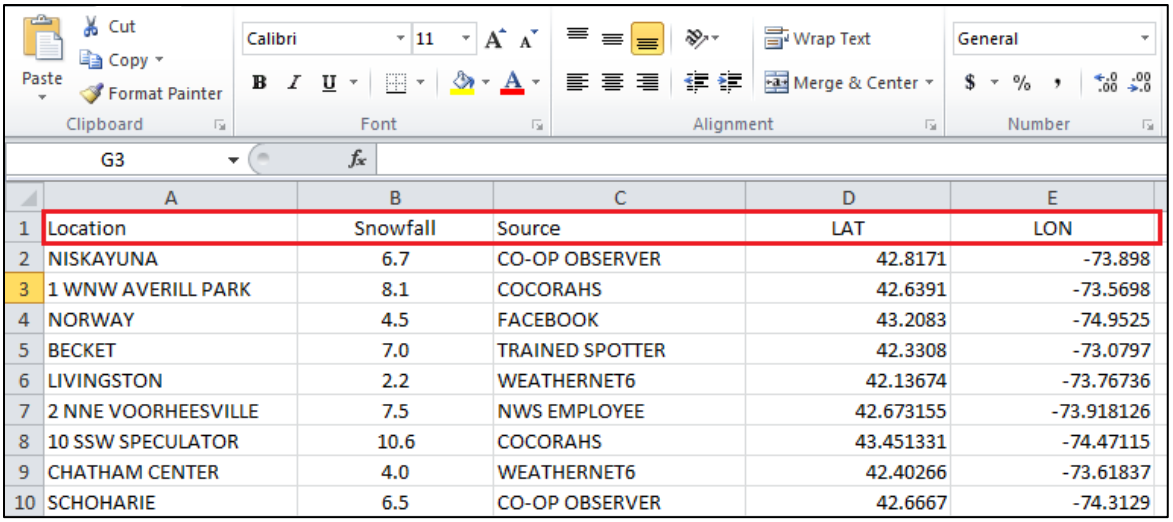
5. Once you confirm that all the RRM files have been saved (Step 4), type **python read_rrm.py** on the command line of the **Terminal** window to run the Python program
   a. Running this program will compile all of the RRM files into a single .csv file

b. The name of the newly created .csv file will be **pns_snowReports.csv**
    i. This program also creates a rainfall .csv file as well (pns_rainReports.csv)

6. Check to make sure the **pns_snowReports.csv** file has updated to ensure it was saved:
    a. Make sure you are still in your office's **rrm_reader** AWIPS directory and type **ls -ltr** and check the time of the **pns_snowReports.csv** file to make sure it was saved

```
xt5-aly{jvillani}101: cd /home/jvillani/rrm_reader/
xt5-aly{jvillani}102: ls -ltr
total 132
-rw-rw-r-- 1 jvillani fxalpha   849 Feb 21 14:51 rrmaly.txt
-rwxrwxr-x 1 vkoleci  fxalpha   970 Feb 22 20:49 vk_readrrm.py
-rw-rw-r-- 1 jvillani fxalpha   970 Mar  5 15:00 read_rrm.py~
-rw-rw-r-- 1 jvillani fxalpha  5180 Mar 19 15:01 BUFRRMBUF.txt
-rw-rw-r-- 1 jvillani fxalpha 10171 Mar 19 15:01 NYCRRMOKX.txt
-rw-rw-r-- 1 jvillani fxalpha  6519 Mar 19 20:17 ALBRRMBGM.txt
-rw-rw-r-- 1 jvillani fxalpha 11138 Mar 19 20:18 ALBRRMBTV.txt
-rw-rw-r-- 1 jvillani fxalpha 13318 Mar 19 20:19 BOSRRMBOX.txt
-rw-rw-r-- 1 jvillani fxalpha 20290 Mar 26 16:39 ALBRRMALY.txt
-rw-r--r-- 1 jvillani fxalpha     0 Mar 26 16:39 pns_rainReports.csv
-rw-r--r-- 1 jvillani fxalpha 33007 Mar 26 16:39 pns_snowReports.csv
-rwxrwxr-x 1 jvillani fxalpha  1306 Apr 15 15:00 read_rrm.py
xt5-aly{jvillani}103:
```

7. Send the newly created **pns_snowReports .csv** file to the PC using your office's local method of transferring AWIPS files to a PC
    a. The **pns_snowReports.csv** file will appear in the specified PC directory that your office has already set up
8. Open the **pns_snowReports.csv** file using Microsoft Excel and save the file with a .xls extension
    a. ***IMPORTANT TO PERFORM THE FOLLOWING QC STEPS BEFORE FINAL SAVE*** (QC must be performed to ensure that the most accurate GIS map is created)
        i. Check for and delete bad lat/lon pairs (ex. 99.99, 999, or any combo of 9's)
        ii. Delete any snowfall reports of Trace (T) - this yields errors in the interpolation
        iii. If headers at the top of the spreadsheet have not been created, create the following headers: **Location, Snowfall, Source, Lat, Lon**



| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Location | Snowfall | Source | LAT | LON |
| 2 | NISKAYUNA | 6.7 | CO-OP OBSERVER | 42.8171 | -73.898 |
| 3 | 1 WNW AVERILL PARK | 8.1 | COCORAHS | 42.6391 | -73.5698 |
| 4 | NORWAY | 4.5 | FACEBOOK | 43.2083 | -74.9525 |
| 5 | BECKET | 7.0 | TRAINED SPOTTER | 42.3308 | -73.0797 |
| 6 | LIVINGSTON | 2.2 | WEATHERNET6 | 42.13674 | -73.76736 |
| 7 | 2 NNE VOORHEESVILLE | 7.5 | NWS EMPLOYEE | 42.673155 | -73.918126 |
| 8 | 10 SSW SPECULATOR | 10.6 | COCORAHS | 43.451331 | -74.47115 |
| 9 | CHATHAM CENTER | 4.0 | WEATHERNET6 | 42.40266 | -73.61837 |
| 10 | SCHOHARIE | 6.5 | CO-OP OBSERVER | 42.6667 | -74.3129 |

9. After saving the file with the new .xls extension (**pns_snowReports.xls**), move the file into your office's GIS directory tree
   a. ***RECOMMENDED OFFICE DIRECTORY TREE STRUCTURE***

      **Home Directory → GIS → Projects → SnowVer → Events → Season → EventDate**

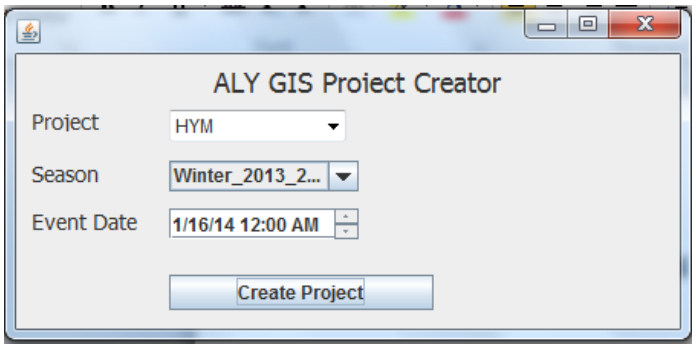
      Example: C:/GIS/Projects/SnowVer/Events/Winter_2014_2015/2014_Dec_09/

   b. ***SETTING UP EVENT GIS DIRECTORY***
      Email **Vasil.Koleci@noaa.gov** for a Java script (**runGISDir.bat**) that creates the recommended directory structure

      The script will need to be stored in your office's GIS directory (recommended to set up a **Scripts** directory in the **Home Directory → GIS** directory)

      Example: C:/GIS/Scripts

      i. Open the Java script **runGISDir.bat** by double-clicking on it, and a new window will pop up below




      ii. Select **SnowVer** under the **'Project'** pulldown menu
      iii. Make sure the **'Season'** pulldown menu is set to the correct season

iv. Select the **'Event Date'** by manually clicking in the month, date, and year sections and using the up and down arrow keys to select the correct date (format = month/day/year time)
v. When finished, hit the **'Create Project'** button

c. The newly-created Event directory will now be organized in the following:
**Home Directory →GIS → Projects → SnowVer → Events → Season → Event Date**

Example: C:/GIS/Projects/SnowVer/Events/Winter_2014_2015/2015_Feb_05/

d. Each **'Event Date'** directory will be organized in the following:
i. **'Input Data'** (this directory contains the following:)
1. **'shape_files'**
2. **'snowfall_IDW'**
3. **'verification_input'**
4. **'zone_avg_snow'**
ii. **'Output Data'** (this directory contains the following:)
1. **'verification_output'**
iii. **EventDate.mxd ArcMap** file
iv. A **Template.mxd** file can be obtained by emailing **Ian.Lee@noaa.gov** (can be customizable for each office)

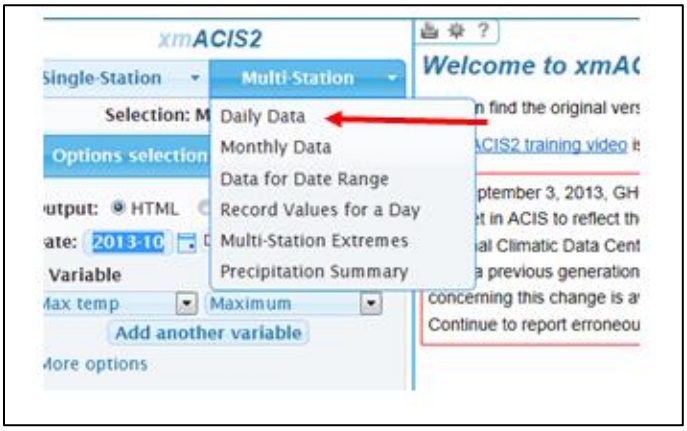
10. Move the **pns_snowReports.xls** file to the **'shape_files'** directory for the particular **EventDate** you are working on
a. The .xls file is now ready to go to be created as a shapefile using **ArcCatalog**

## Step 1a: Adding Supplemental Data Using xmACIS2 (optional)

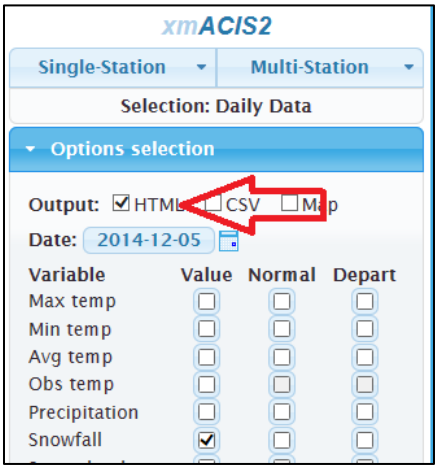
*** If this data supplement is not needed, go directly to Step 2 on Page 11.**

This section outlines the instructions necessary to add supplemental snowfall data using xmACIS2 to the **pns_snowReports.xls** spreadsheet. This optional step can be used to replace areas of no snowfall reports, as it gathers locations (COOP, CoCoRaHS, METAR) that reported 0.0 inches of snow. This alternative step can also be used in cases where surrounding offices do not have an updated RRM file.

1. Import daily snowfall data from surrounding sites using the xmACIS2 website:
    a. Open another sheet in the **pns_snowReports.xls** spreadsheet (ex. Sheet2)
    b. Rename each sheet in the spreadsheet (Sheet1, Sheet2, etc.) using the 3-letter ID for each surrounding office in which you are gathering data for
    c. Go to the xmACIS2 site, and select the data: http://xmacis.rcc-acis.org/
        i. Click **'Daily Data'** under the **'Multi-Station'** tab

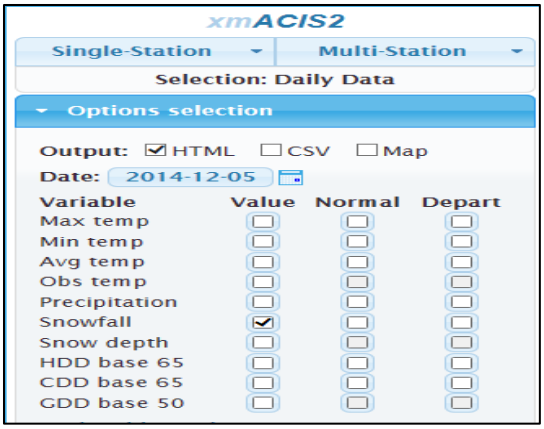



        ii. A new options submenu will open up. Select **'HTML'** for the output

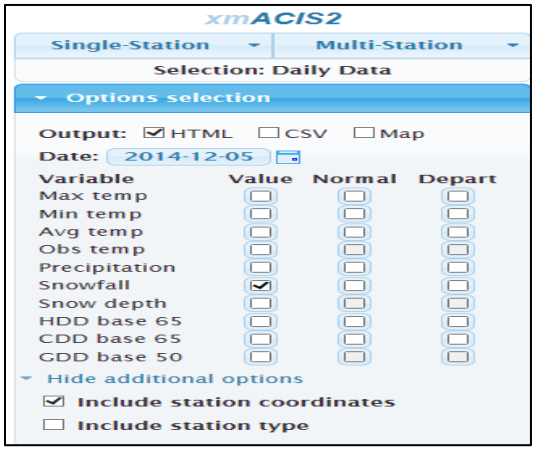



        iii. Make sure the date corresponds to the date you wish to gather data for

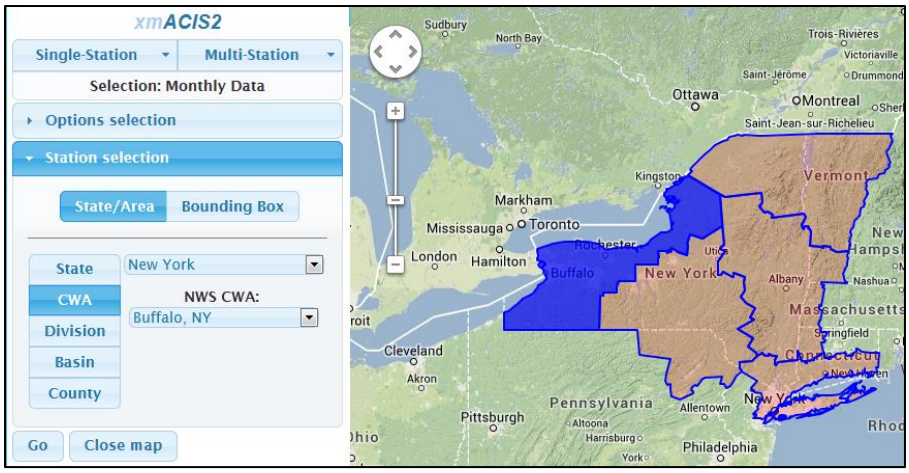
        iv. Make sure the only variable selected is **'Snowfall'**




v. Click to open up the **'More Options'** submenu and make sure that **'Include station coordinates'** is the only checked box

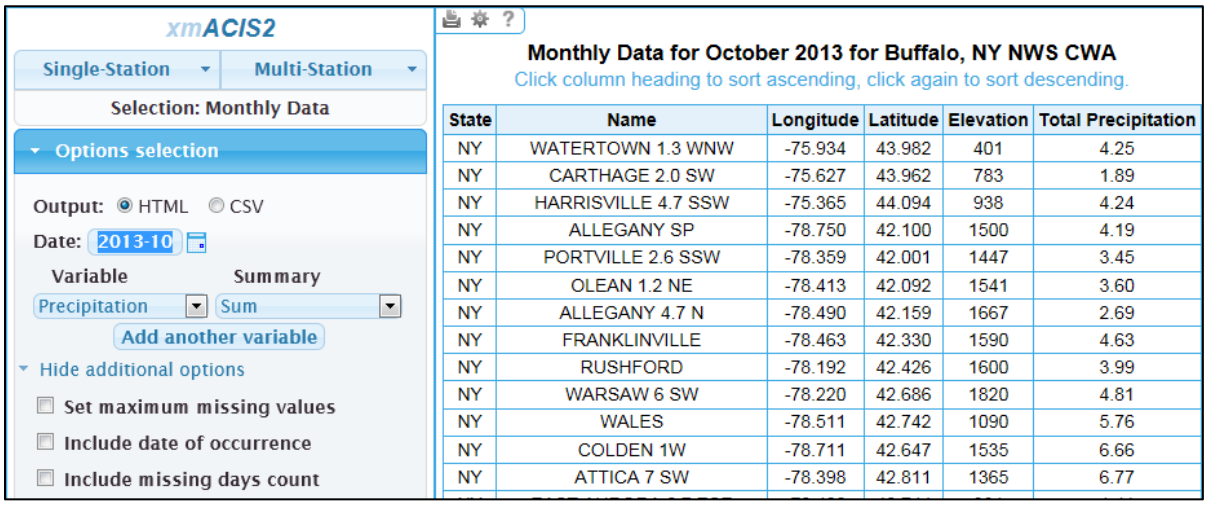



vi. Open the **'Station Selection'** submenu and select the appropriate forecast office county warning area (CWA), then click **'Go'**




vii. A new HTML spreadsheet will pop up to the right. Before copying the data, QC it and make note of any erroneous data or M's that will need to be deleted from

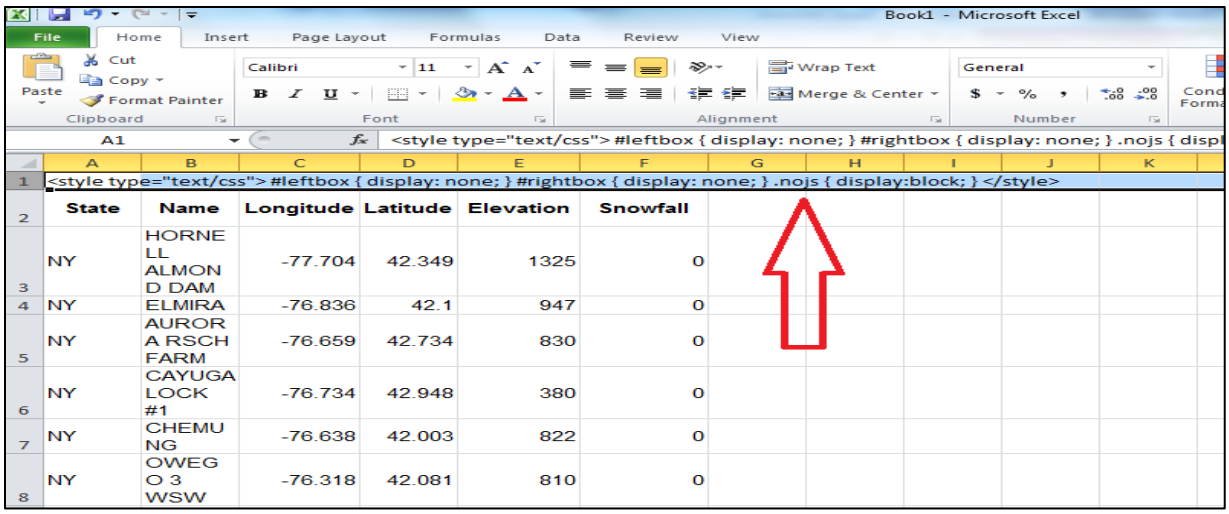
the spreadsheet. (ex. values too low) ***YOU WILL ALSO NEED TO DELETE ANY TRACES OF SNOW FROM THE SPREADSHEET***




| State | Name | Longitude | Latitude | Elevation | Total Precipitation |
|---|---|---|---|---|---|
| NY | WATERTOWN 1.3 WNW | -75.934 | 43.982 | 401 | 4.25 |
| NY | CARTHAGE 2.0 SW | -75.627 | 43.962 | 783 | 1.89 |
| NY | HARRISVILLE 4.7 SSW | -75.365 | 44.094 | 938 | 4.24 |
| NY | ALLEGANY SP | -78.750 | 42.100 | 1500 | 4.19 |
| NY | PORTVILLE 2.6 SSW | -78.359 | 42.001 | 1447 | 3.45 |
| NY | OLEAN 1.2 NE | -78.413 | 42.092 | 1541 | 3.60 |
| NY | ALLEGANY 4.7 N | -78.490 | 42.159 | 1667 | 2.69 |
| NY | FRANKLINVILLE | -78.463 | 42.330 | 1590 | 4.63 |
| NY | RUSHFORD | -78.192 | 42.426 | 1600 | 3.99 |
| NY | WARSAW 6 SW | -78.220 | 42.686 | 1820 | 4.81 |
| NY | WALES | -78.511 | 42.742 | 1090 | 5.76 |
| NY | COLDEN 1W | -78.711 | 42.647 | 1535 | 6.66 |
| NY | ATTICA 7 SW | -78.398 | 42.811 | 1365 | 6.77 |

viii. Copy the data and paste it into the respective sheet in the **pns_snowReports.xls** spreadsheet

ix. Delete the extraneous top header from the sheet if necessary in Microsoft Excel (delete the row)




| State | Name | Longitude | Latitude | Elevation | Snowfall |
|---|---|---|---|---|---|
| NY | HORNELL ALMOND DAM | -77.704 | 42.349 | 1325 | 0 |
| NY | ELMIRA | -76.836 | 42.1 | 947 | 0 |
| NY | AURORA RSCH FARM | -76.659 | 42.734 | 830 | 0 |
| NY | CAYUGA LOCK #1 | -76.734 | 42.948 | 380 | 0 |
| NY | CHEMUNG | -76.638 | 42.003 | 822 | 0 |
| NY | OWEGO 3 WSW | -76.318 | 42.081 | 810 | 0 |

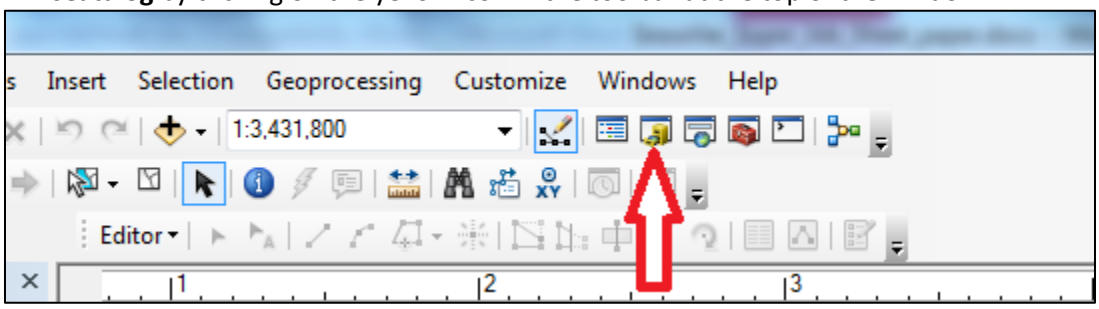
x. Do this repeatedly until all of the surrounding sites' data has been copied into the spreadsheet

d. Save the **pns_snowReports.xls** spreadsheet that now includes a combination of RRM and xmACIS2 snowfall data

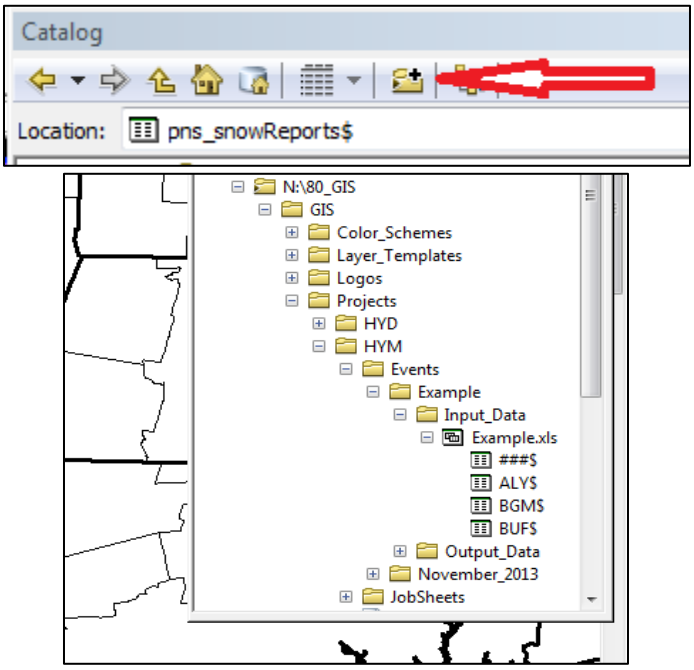
## Step 2: Creating Observed Snowfall Map

This section outlines the instructions necessary to create **ArcMap** shapefiles using the **pns_snowReports.xls** spreadsheet, as well as creating the observed snowfall map.

1. Open Windows Explorer and open the '**EventDate.mxd'** file that is stored in the appropriate **Event Date** folder
   a. **ArcMap** will open after a few seconds (make sure to save frequently!)
2. Open **ArcCatalog** by clicking on the yellow icon in the toolbar at the top of the window




   a. In **ArcCatalog**, navigate to the directory containing the **pns_snowReports.xls** spreadsheet by clicking on the **+** signs
      i. If your directory does not show up, you may need to connect to that folder first

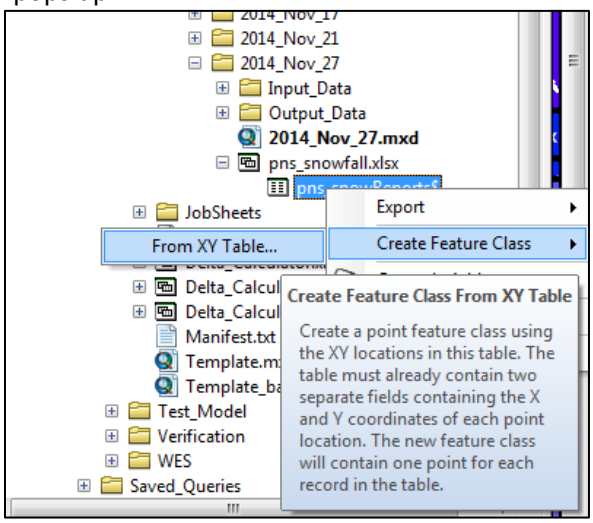



3. Import each individual sheet(s) into **ArcMap** to create a shapefile(s)
   a. If the **pns_snowReports.xls** spreadsheet contains all RRM files, import the **pns_snowReports$** sheet

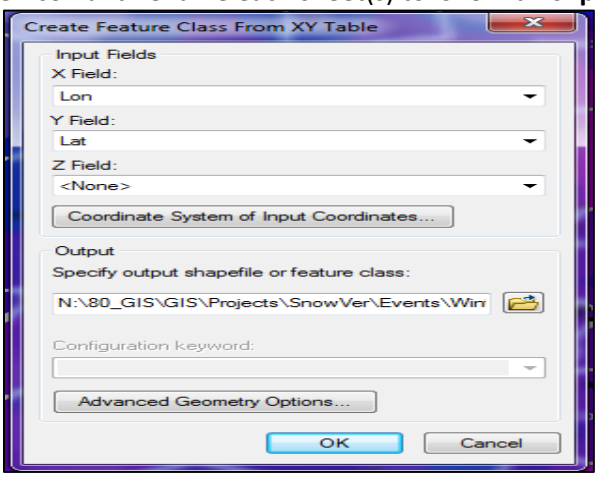
      i. * Optional – use only if adding supplemental data

(a) (If the spreadsheet contains a combination of RRM files and xmACIS2 data, import each individual sheet )
(b) Example: Two sheets from a combo of RRM/xmACIS2 data from ALY and BGM (Binghamton, NY)
(c) First sheet imported would be **pns_snowReports$** (ALY data)
(d) Second sheet imported would be **BGM$** (would containing BGM xmACIS2 snowfall data)

b. Set up the shapefile parameters
   i. Right-click on each sheet(s), and scroll down to **'Create Feature Class'** and hover over it until **'From XY Table'** pops up



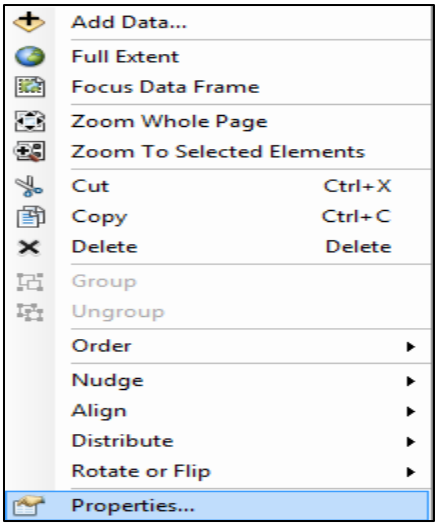

c. Click **'From XY Table'** to open up a new window
   i. For the **'X Field'** set it to **'Lon'** (or **'Longitude'** if using xmACIS2 data) and set the **'Y Field'** to **'Lat'** (or **'Latitude'** if using xmACIS2 data). Set the **'Z Field'** to **'Snowfall'**. Set the **'Output'** to the **'shape_files'** directory in the respective **EventDate** directory by clicking on the folder icon and rename each sheet(s) to **'snowfall.shp'**




   ii. If using multiple sheets, rename each additional sheet as snowfall1.shp, snowfall2.shp, etc.
   iii. Set the **'Coordinate System of Input Coordinates'** to **'NAD 1983'** under **'Geographic Coordinate Systems' → 'North America'**

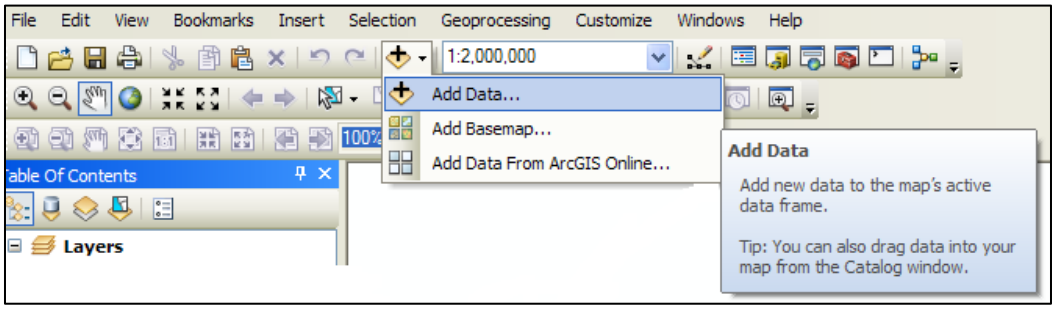
d. Do this process for each individual sheet (if necessary)
    i. This process converts the data into GIS shapefiles

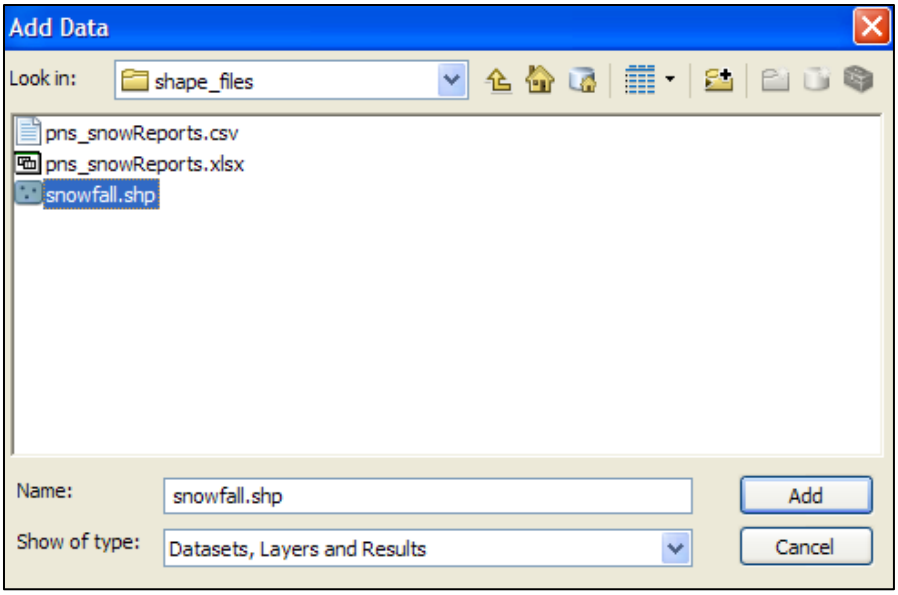
4. Close **ArcCatalog**
5. Right-click anywhere in the Data Frame and select **'Properties'**



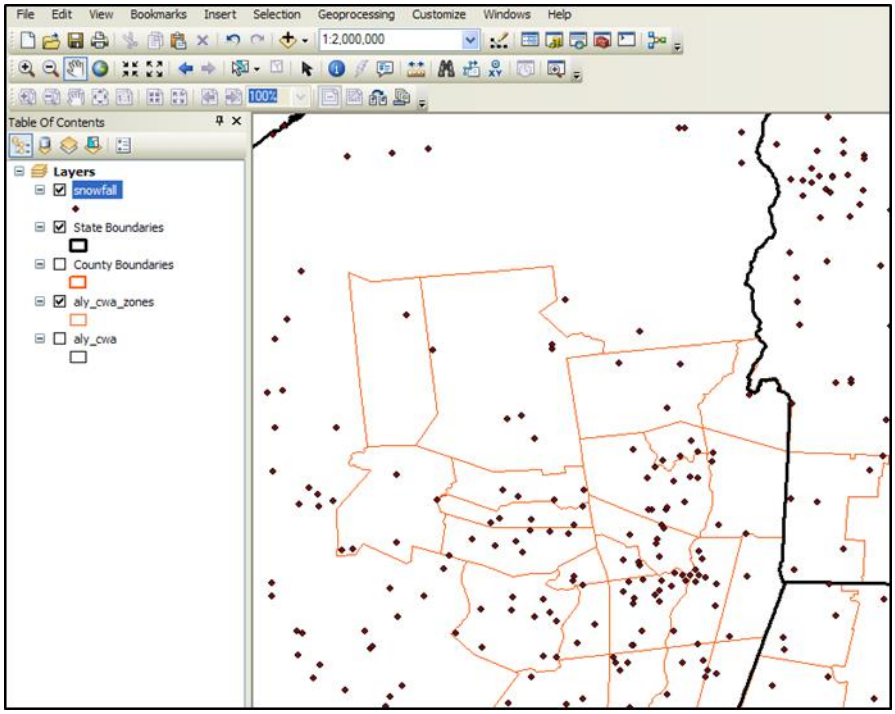

a. Make sure the data frame coordinate system is set to **'NAD 1983'** following the same step outlined in Step 3-c-iii

6. Add the newly-created shapefile **'snowfall.shp'** to the map along with any other desired layers
    a. Add any additional shapefiles as well (ex. snowfall1.shp, snowfall2.shp, etc.)

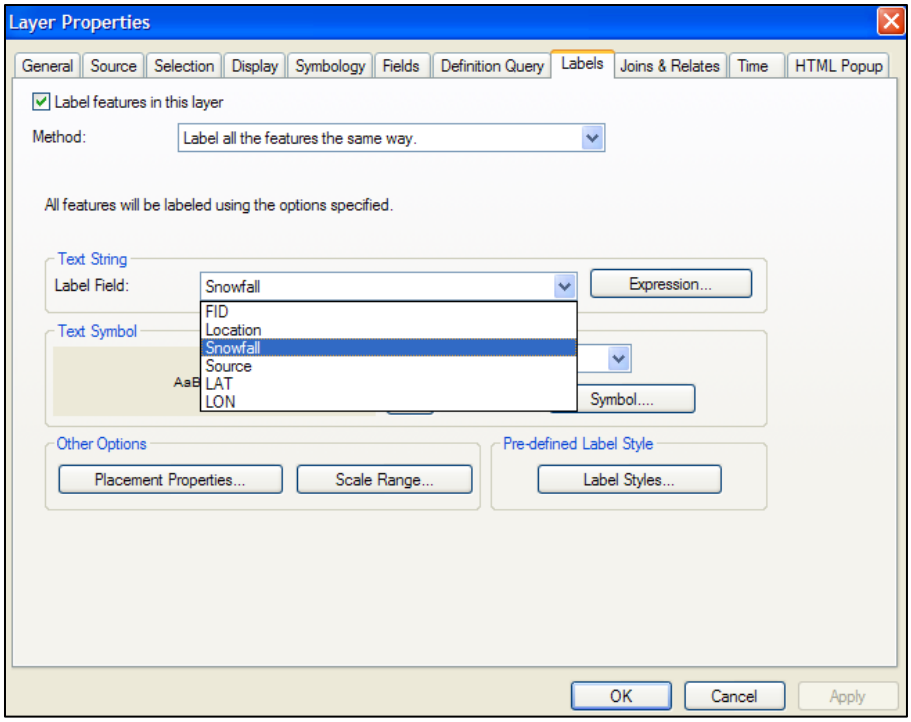




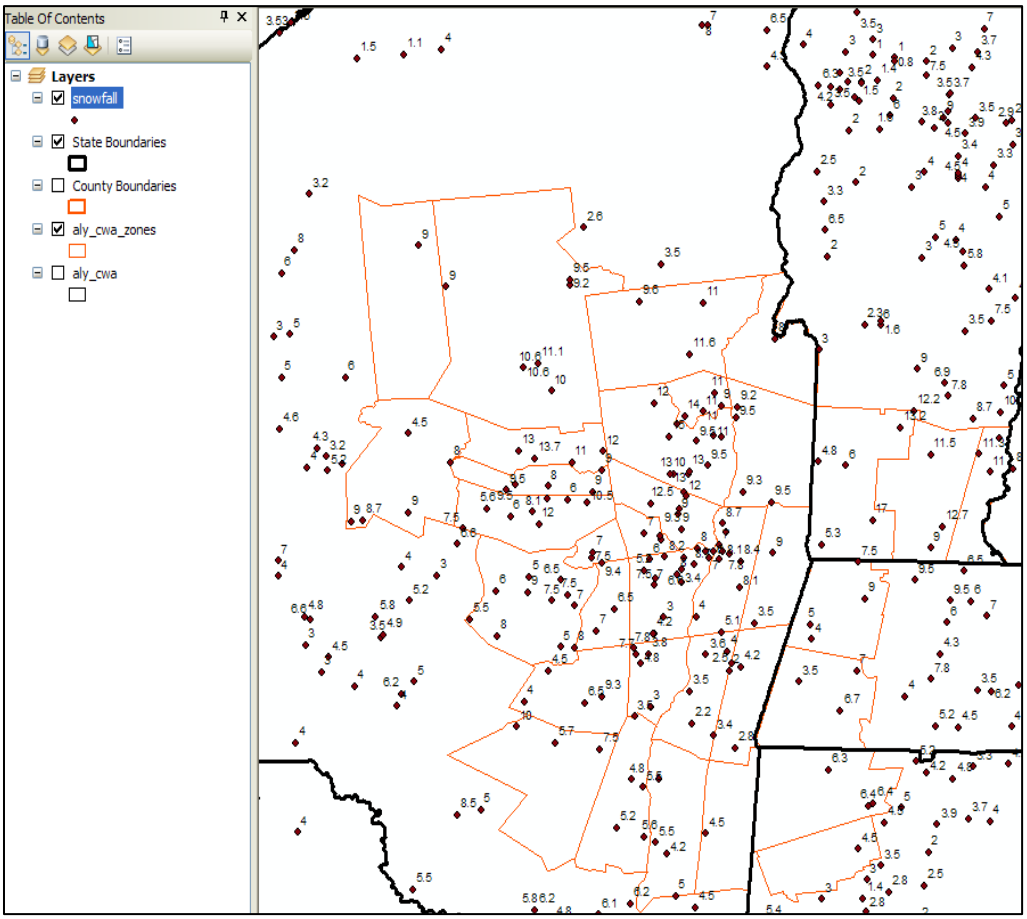

b. The map will display as points after the shapefile is loaded




7. Edit the labels of the shapefile by right-clicking and then choosing the **'Properties'** option and clicking the **'Labels'** tab. Edit as necessary, based on how you want the reports to be displayed. Change the **'Label Field'** to **'Snowfall'** to display the snowfall reports.

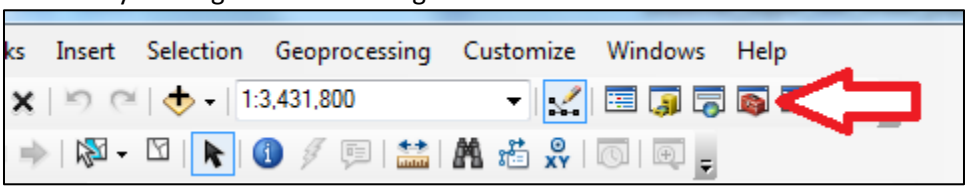



8. After changing the label field, the map will display the snowfall reports after clicking **'OK'**

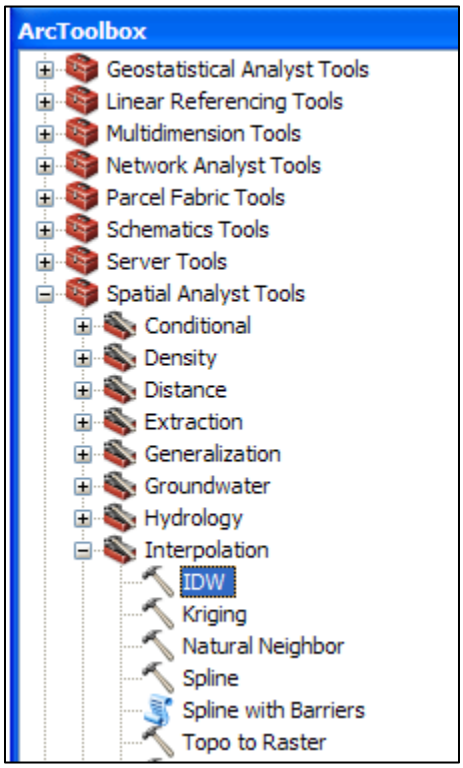


9. Once the shapefile has been added and edited, you can run an interpolation spatial analysis based on the snowfall data the shapefile contains. For snowfall spatial analysis, you can use one of 4 common interpolation schemes available in ArcMap, version 10.2:
   a. **Inverse Distance Weighted (IDW)**
   b. **Kriging**
   c. **Natural Neighbor**
   d. **Spline**
      i. Each office is free to choose which interpolation scheme to use. Each has its strengths and weaknesses. IDW is the most simple and least computationally-intensive. This job sheet will go through the IDW interpolation method. For more information on the other interpolation methods, click on this link: http://resources.arcgis.com/en/help/main/10.2/index.html

10. Open **ArcToolbox** by clicking on the following icon in the toolbar:



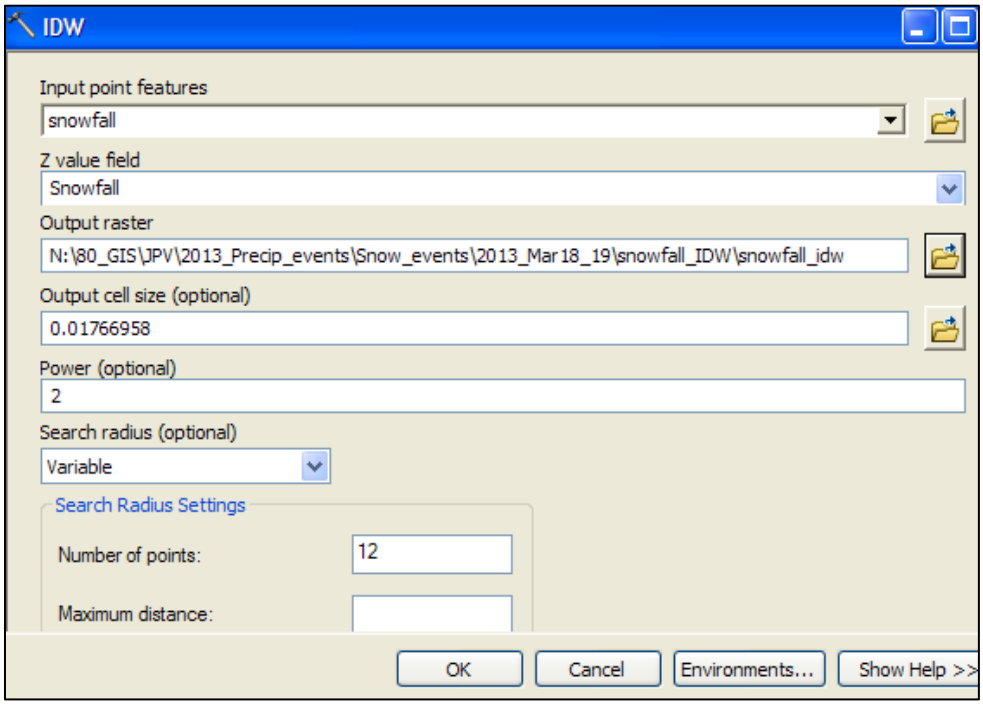

11. Navigate to the following: **'Spatial Analyst Tools' → 'Interpolation' → 'IDW'** and double-click on **'IDW'** to open it



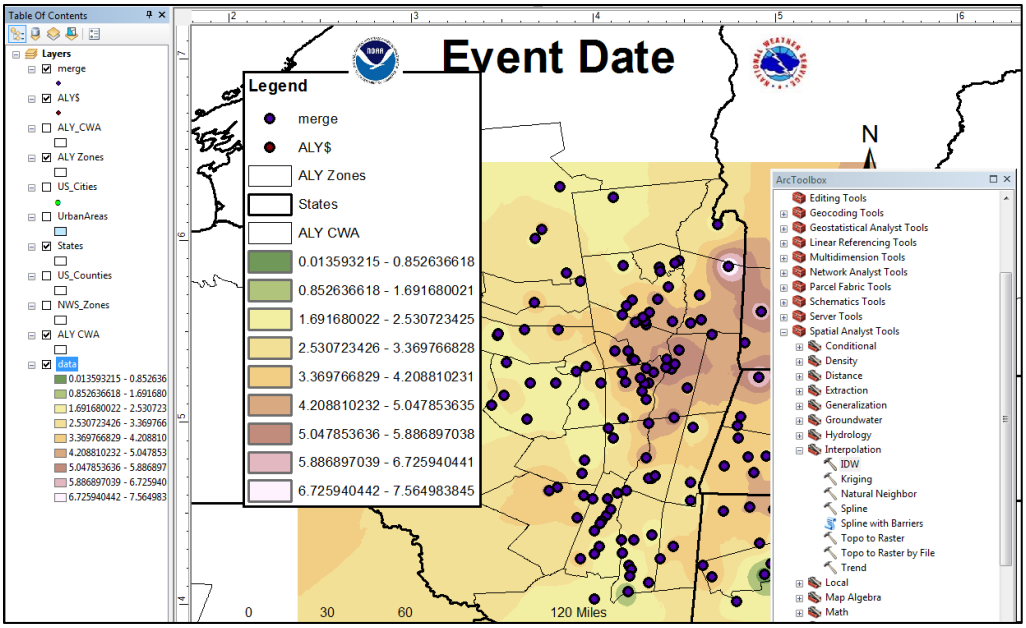
12. In the IDW edit window, select the **'snowfall.shp'** shapefile under the **'Input point features'** drop down bar, the **'Z value field'** will be the desired variable to be interpolated (Snowfall), and set the **'Output raster'** to the following:
    a. Name: **'snowfall_idw'**
    b. File directory: **'snowfall_IDW'** (located within the specific **Event Date →Input_Data** directory)
        i. Despite the directory being labeled as IDW, any interpolation method can be stored here
    c. The **'Output cell size'**, **'Power'**, **'Search Radius'**, **'Search Radius Settings'**, and **'Input barrier polyline features'** are additional options to further tweak the IDW interpolation scheme
        i. Leaving these optional fields alone is the Default

***NOTE: If using multiple shapefiles containing both RRM/xmACIS2 data, go directly to Step 2a**

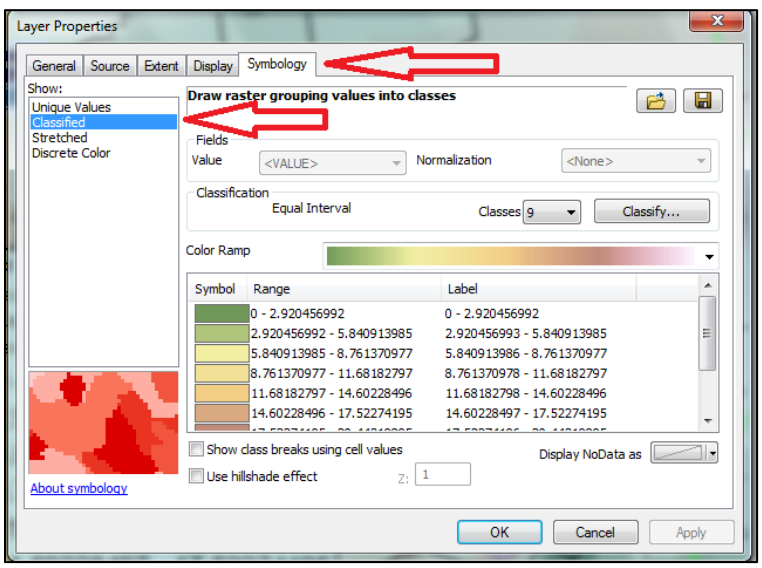
    d. Click **'OK'** to run the IDW interpolation (may take a few minutes)




    e. The newly-created IDW map will look similar to the following:



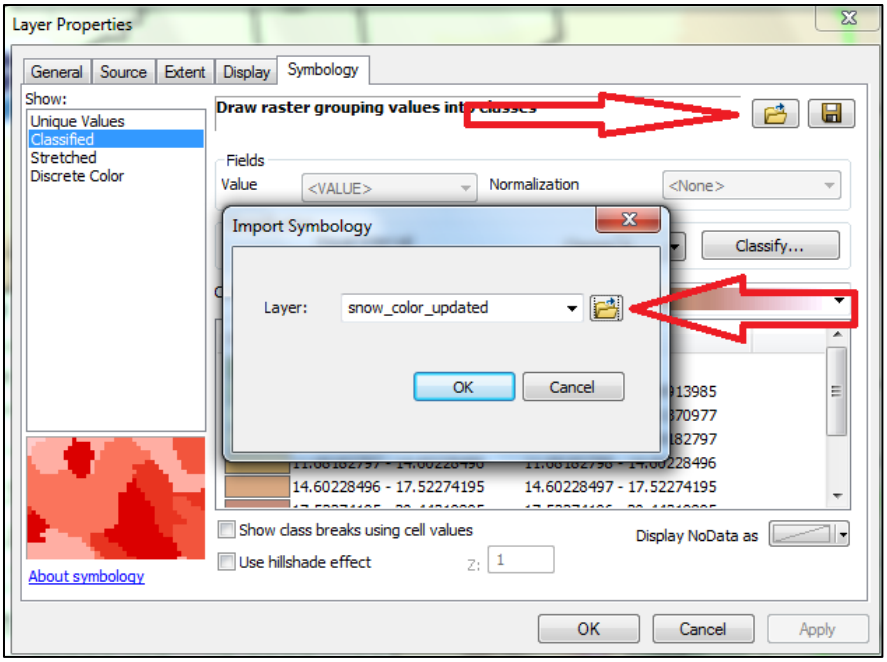

13. After the IDW (or other interpolation method) map has been created, the values will need to be reclassified to match the NWS Eastern Region forecast snowfall graphics.
    a. Right-click on the interpolated raster layer and click on **'Properties'** to open the **'Layer Properties'** popup window
    b. Click on the **'Symbology'** tab (if not already selected)
    c. Make sure it is set to **'Classified'** (left side of the popup window)




    d. Click the **'Open'** button to import the **'snow_color_updated.lyr'** color scheme from the **'Import Symbology'** popup window (navigate to the directory where the color scheme is saved)
    ***RECOMMENDED OFFICE DIRECTORY TREE STRUCTURE FOR COLOR SCHEMES***

    **Home Directory →GIS → Color_Schemes**
    Example: C:/GIS/Color_Schemes/

    *To obtain the **'snow_color_updated.lyr'** color scheme, email **Ian.Lee@noaa.gov**




e. After clicking **'OK'** the **'snow_color_updated.lyr'** color scheme will update and should resemble the legend below (this scheme is already pre-formatted and does not require any further editing):

f. Click **'OK'** again to apply the color scheme changes to the interpolated map

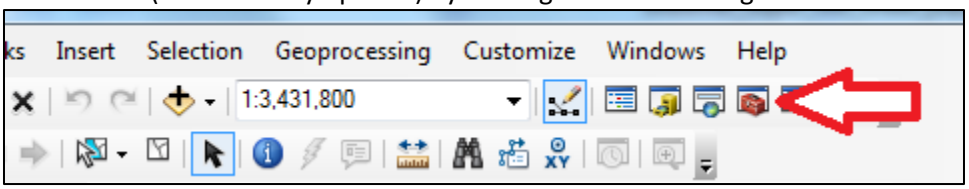
14. Make any final changes to the map as necessary (exs. legend, title, scale, disclaimer, north arrow, adding additional layers, etc.)
15. **'Print Screen'** and crop and save the image using **Paint** as a .png file
    a. Name the image using a common nomenclature (ex. Observed_Snowfall_121214.png)
    b. Save the image in the specific **Event Date → Output_Data → verification_output** directory

## Step 2a: Merging Multiple Shapefiles (optional)

***Skip this step if only using one shapefile where observations are solely from PNS/RRM and go directly to Step 3 on Page 26.**

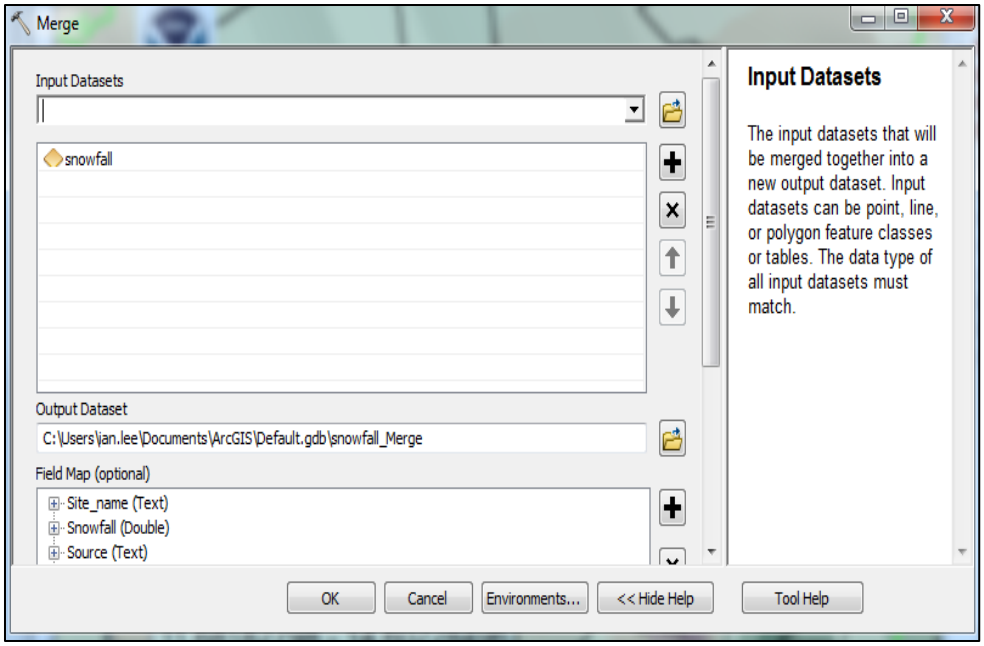
This section outlines the instructions necessary to merge multiple **ArcMap** shapefiles using a **pns_snowReports.xls** spreadsheet that contains RRM and xmACIS2 data, as well as creating the observed snowfall map.

1. Merge all the imported shapefiles into one shapefile using the **'Merge'** tool
    a. Using multiple shapefiles such as snowfall.shp, snowfall1.shp, snowfall2.shp, etc.
2. Open **ArcToolbox** (if not already opened) by clicking on the following icon in the toolbar:




3. Navigate to the following: '**Data Management Tools' → 'General' → 'Merge'** and double-click on **'Merge'** to open it and a new popup window

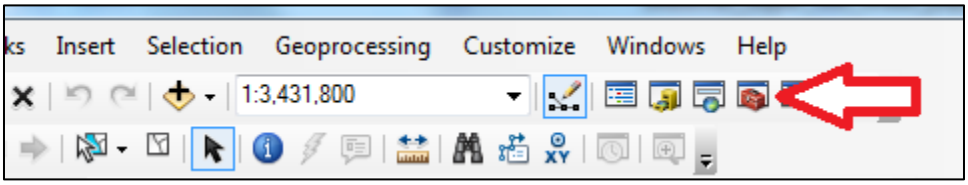
    a. Under **'Input Datasets'** add all of the snowfall shapefiles. They will appear in the window below.
    b. Set the **'Output Dataset'** to the **'shape_files'** directory and save the new shapefile as **'merge.shp'**



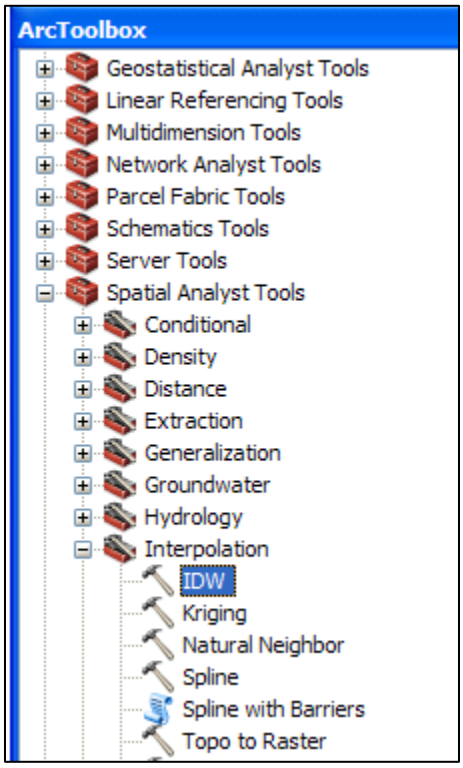

   c. Click 'OK' to run the **'Merge'** tool

4. Add the **'merge.shp'** shapefile to the map
5. Once the **'merge.shp'** shapefile has been added and edited, you can run an interpolation spatial analysis based on the snowfall data the shapefile contains. For snowfall spatial analysis, you can use one of 4 common interpolation schemes available in ArcMap 10.2:
   a. **Inverse Distance Weighted (IDW)**
   b. **Kriging**
   c. **Natural Neighbor**
   d. **Spline**
      i. Each office is free to choose which interpolation scheme to use. Each has its strengths and weaknesses. IDW is the most simple and least computationally-intensive and will be the method of choice for this job sheet. For more information on the other interpolation methods, click on this link: http://resources.arcgis.com/en/help/main/10.2/index.html

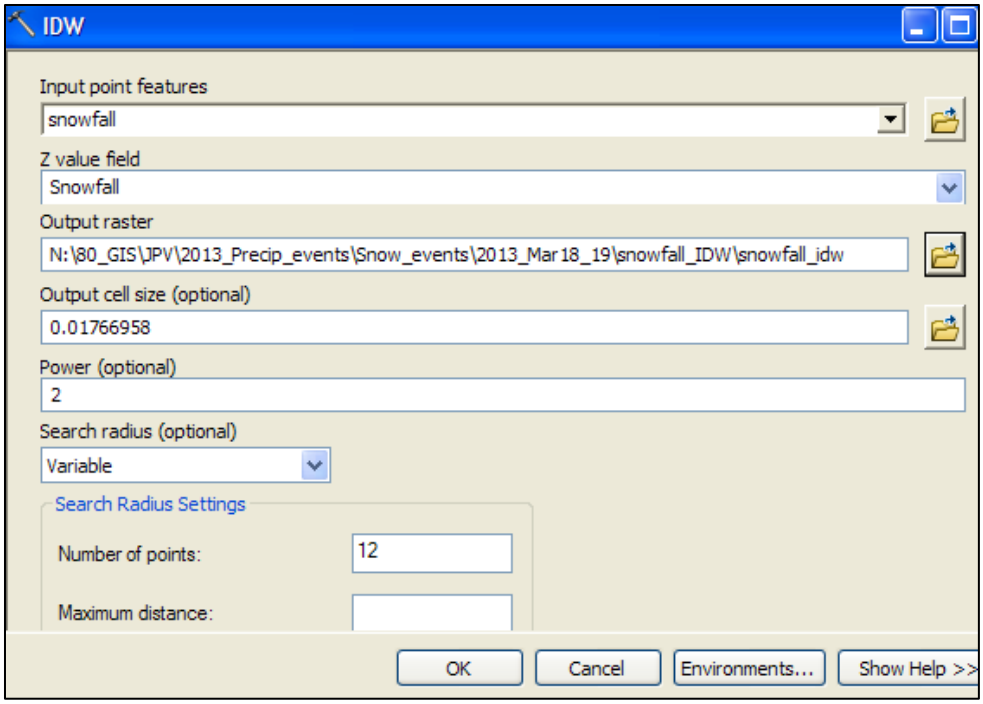
6. Open **ArcToolbox** by clicking on the following icon in the toolbar:



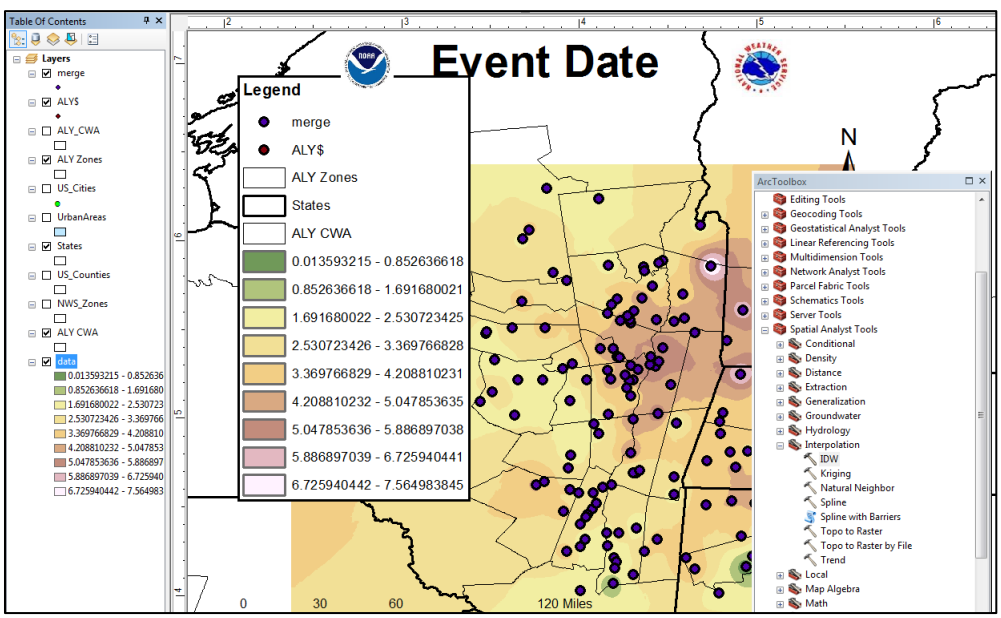

7. Navigate to the following: '**Spatial Analyst Tools' → 'Interpolation' → 'IDW'** double-click on **'IDW'** to open it



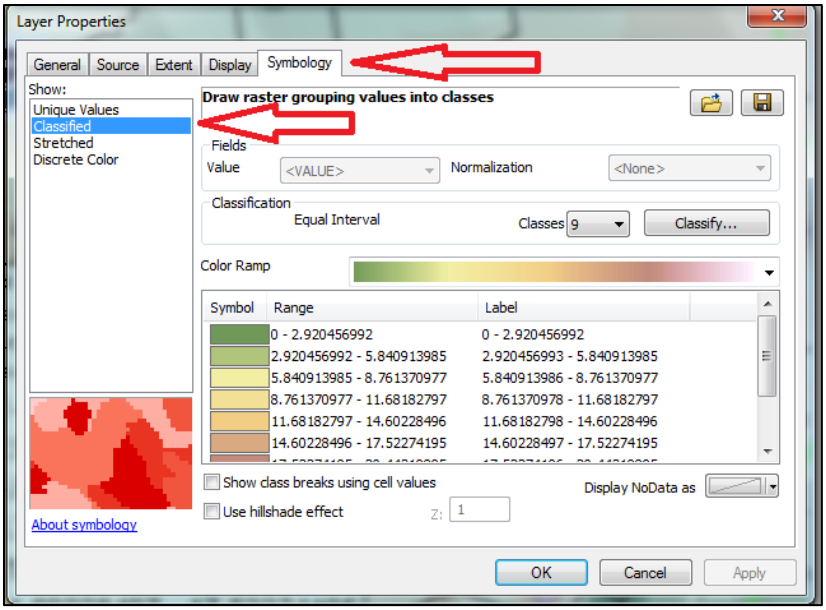

8. In the IDW edit window, select the **'snowfall.shp'** shapefile under the **'Input point features'** drop down bar, the **'Z value field'** will be the desired variable to be interpolated (snowfall), and the **'Output raster'** will be set to the following:
    a. Name: **'snowfall_idw'**
    b. File directory: **'snowfall_IDW'** (located within the specific **Event Date →Input_Data** directory)
        i. Despite the directory being labeled as IDW, any interpolation can be stored here
    c. The **'Output cell size'**, **'Power'**, **'Search Radius'**, **'Search Radius Settings'**, and **'Input barrier polyline features'** are additional options to further tweak the IDW interpolation scheme
        i. Leaving these optional fields alone is the Default
    d. Click **'OK'** to run the IDW interpolation (may take a few minutes)




e. The newly-created interpolated map will look similar to the following:




9. After the observed interpolated map has been created, the values will need to be reclassified to match the NWS Eastern Region forecast snowfall graphics.
   a. Right-click on the interpolated raster layer and click on **'Properties'** to open the **'Layer Properties'** popup window
   b. Click on the **'Symbology'** tab (if not already selected)
   c. Make sure it is set to **'Classified'** (left side of the popup window)



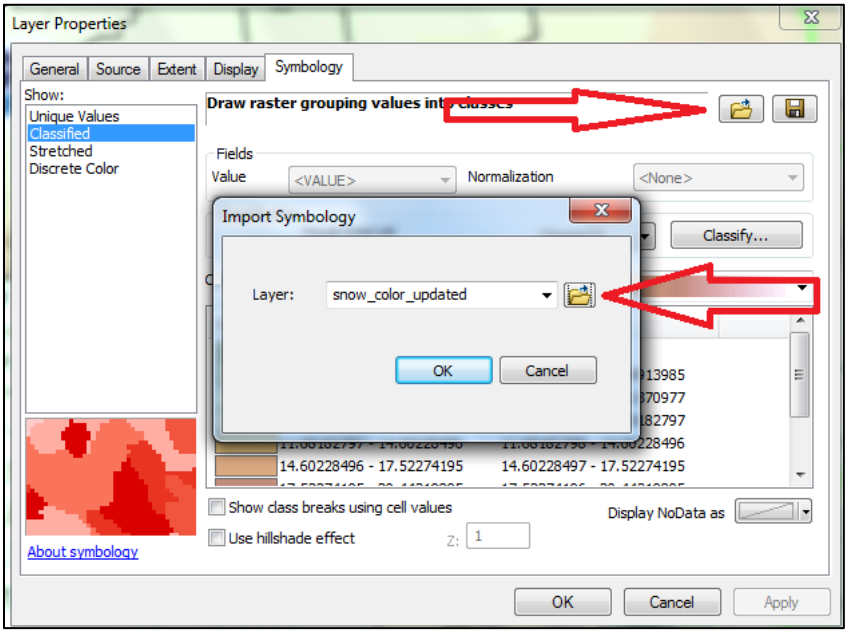

d. Click the **'Open'** button to import the **'snow_color_updated.lyr'** color scheme from the **'Import Symbology'** popup window (navigate to the directory where the color scheme is saved)

   i. ***RECOMMENDED OFFICE DIRECTORY TREE STRUCTURE FOR COLOR SCHEMES***

**Home Directory →GIS → Color_Schemes**

Example: C:/GIS/Color_Schemes/

*To obtain the **'snow_color_updated.lyr'** color scheme, email **Ian.Lee@noaa.gov**



e. After clicking **'OK'** the **'snow_color_updated.lyr'** color scheme will update and should resemble the legend below (this scheme is already pre-formatted and does not require any further editing):

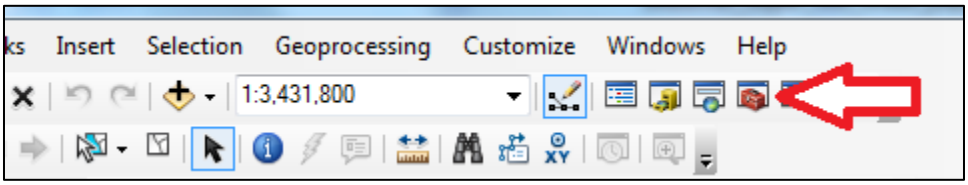
f. Click **'OK'** again to apply the color scheme changes to the interpolated map

10. Make any final changes to the map as necessary (exs. legend, title, scale, disclaimer, north arrow, adding additional layers, etc.)
11. **'Print Screen'** and crop and save the image using **Paint** as a .png file
    a. Name the image using a common nomenclature (ex. Observed_Snowfall_121214.png)
    b. Save the image in the specific **Event Date → Output_Data → verification_output** directory

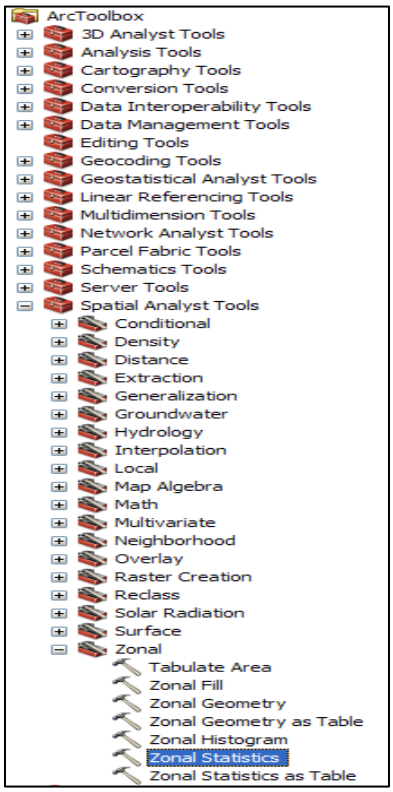
## Step 3: Zone-Average Verification

This section outlines the instructions necessary to perform the zone-average verification from the observed snowfall map. The observed snowfall map **MUST BE COMPLETED** before running the zone-average verification.

1. Open **ArcToolbox** (if not already opened) by clicking on the following icon in the toolbar:

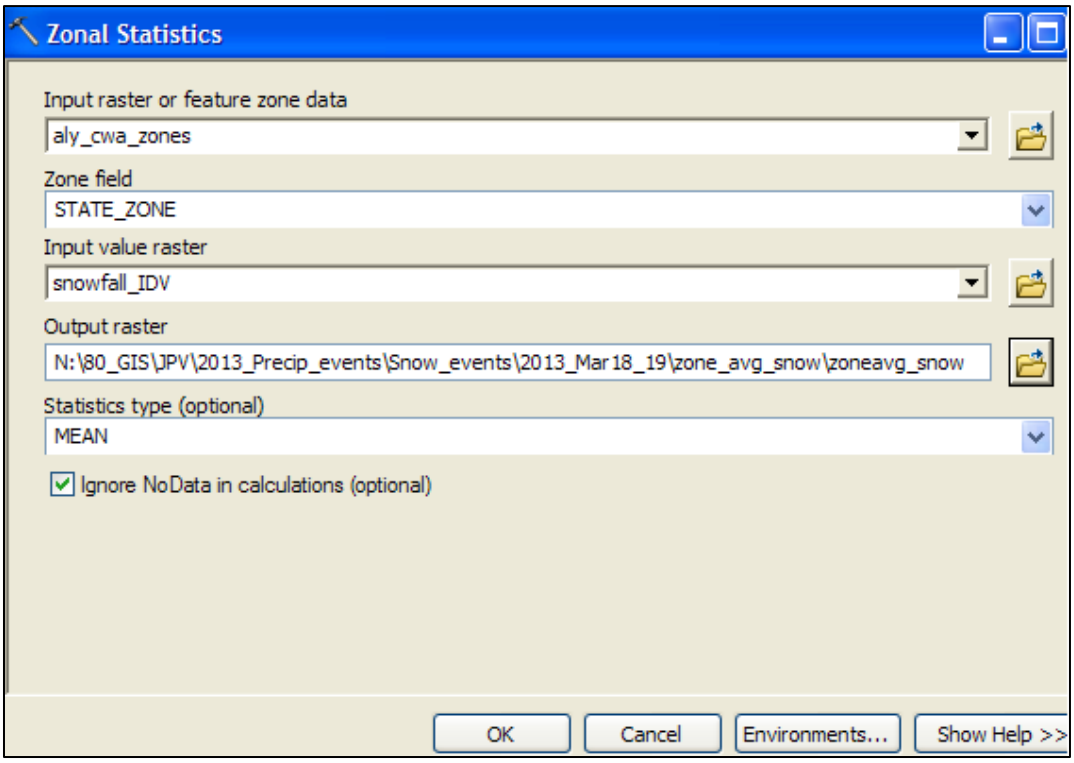



2. Navigate to the following: '**Spatial Analyst Tools' → 'Zonal' → 'Zonal Statistics'** and double-click on **'Zonal Statistics'** to open a new popup window

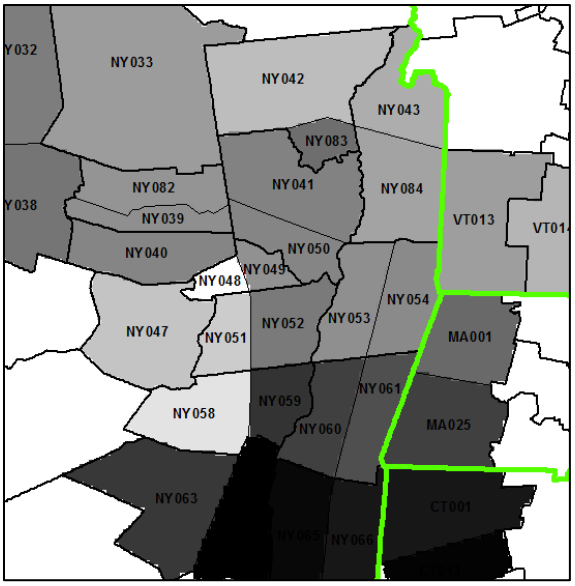



   a. For **'Input raster or feature zone data'**, select your **'CWA_Zones'** shapefile
   b. For **'Zone field'**, select **'STATE_ZONE'**
      i. To obtain the **'NWS_Zones'** shapefile, email **Ian.Lee@noaa.gov** (or visit the [National Weather Service GIS Data Portal]()
   c. Select the interpolated snowfall observation map created in Step 2 or Step 2a for the **'Input value raster'**
   d. For **'Output raster'**, name it **'zone_avg_snow'** and save it in the **'verification_input'** directory

e. For **'Statistics type'** select **'MEAN'**
f. Make sure the **'Ignore NoData in calculations'** checkbox is checked
g. Click **'OK'** to run the **'Zonal Statistics'** tool



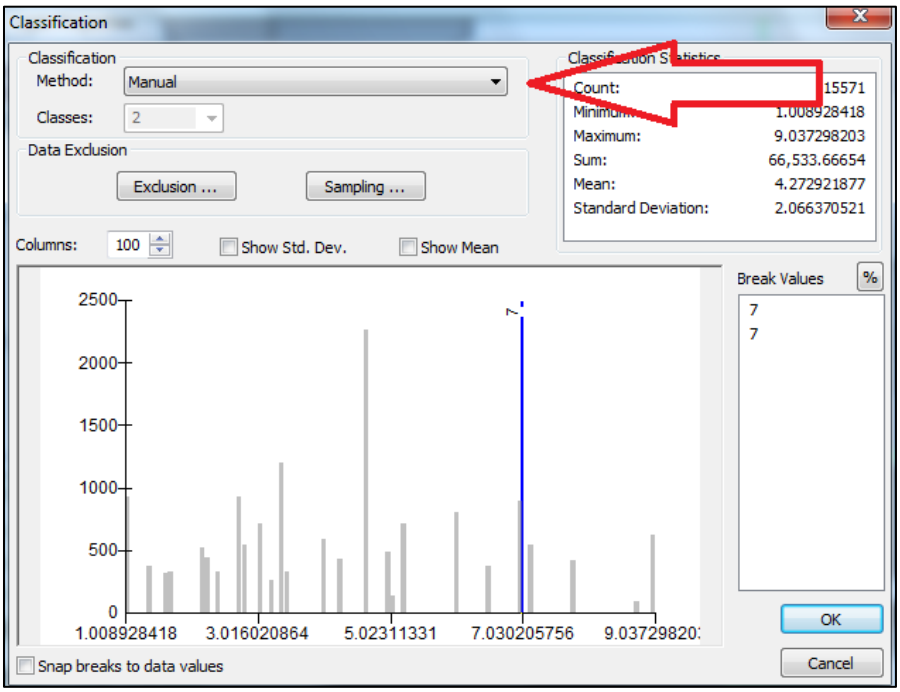

3. The output will look similar to the following:



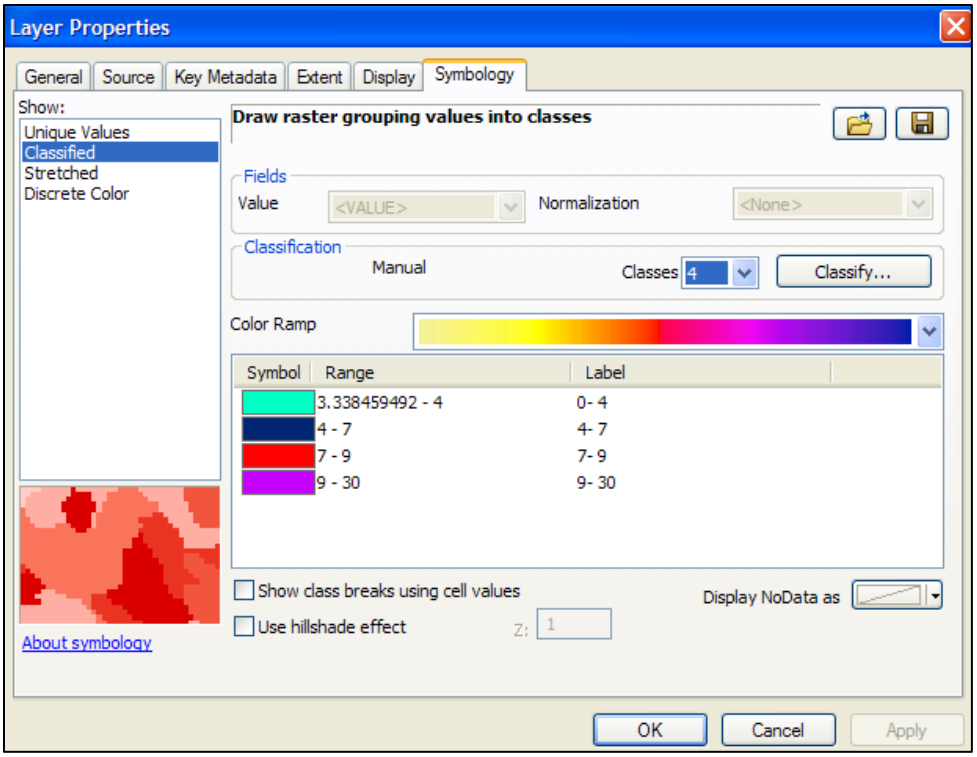

4. After the Zonal Statistics map is created, the values will need to be reclassified

a. Right-click on the **'zone_avg_snow'** raster layer and click on **'Properties'** to open the **'Layer Properties'** popup window
b. Click on the **'Symbology'** tab (if not already selected)
c. Make sure it is set to **'Classified'** (left side of the popup window)

5. Choose '**Manual Classification'** by selecting it from the **'Classify'** button

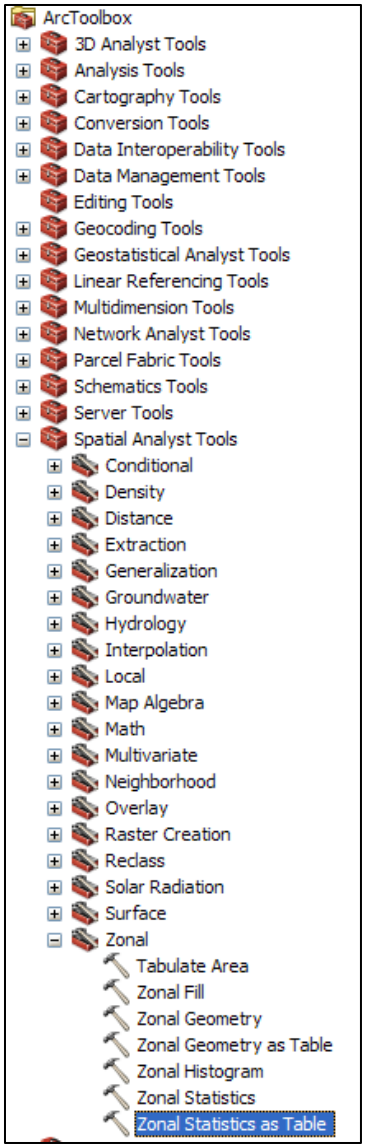



6. Select '**4 classes'** corresponding to the categories for snowfall verification: sub-advisory, advisory, 12-hour warning, 24-hour warning (these criteria will vary from office to office)

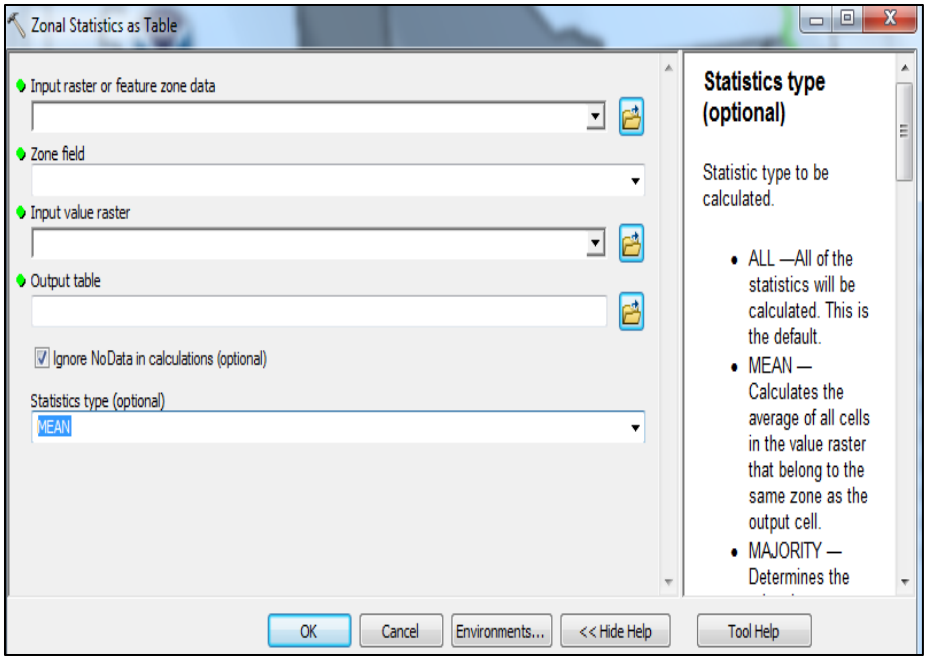



a. Click **'OK'** again to apply the changes to the **'zone_avg_snow'** raster

7. Make any final changes to the map as necessary (exs. legend, title, scale, disclaimer, north arrow, adding additional layers, etc.)
8. **'Print Screen'** and crop and save the image using **Paint** as a .png file
    a. Name the image using a common nomenclature (ex. Zone_Avg_Ver_121214.png)
    b. Save the image in the specific **Event Date → Output_Data →verification_output** directory
9. Generate a table of the zone-average verification statistics
    a. Open **ArcToolbox** (if not already open)
    b. Navigate to the following: '**Spatial Analyst' → 'Zonal' → 'Zonal Statistics as Table'** and double-click on **'Zonal Statistics as Table'** to open a new popup window




c. Input same parameters as for **'Zonal Statistics'** in Step 2a-g
d. Type **'Table'** for your output table name and choose the same directory as for **'Zonal Statistics'**
e. For **'Statistics type'** select **'MEAN'**
f. Click **'OK'** to generate the zonal statistics table




g. After the table is created, right-click and open to view the table

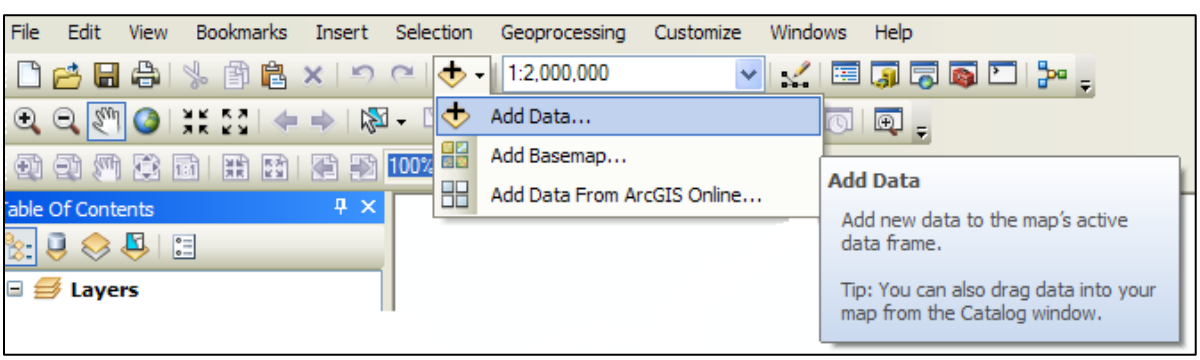
10. **'Print Screen'** and crop and save the image using **Paint** as a .png file
    a. Name the table using a common nomenclature (ex. Zone_Avg_Ver_Table_121214.png)
    b. Save the table in the specific **Event Date → Output_Data →verification_output** directory

## Step 4: Creating Forecast Snowfall Map

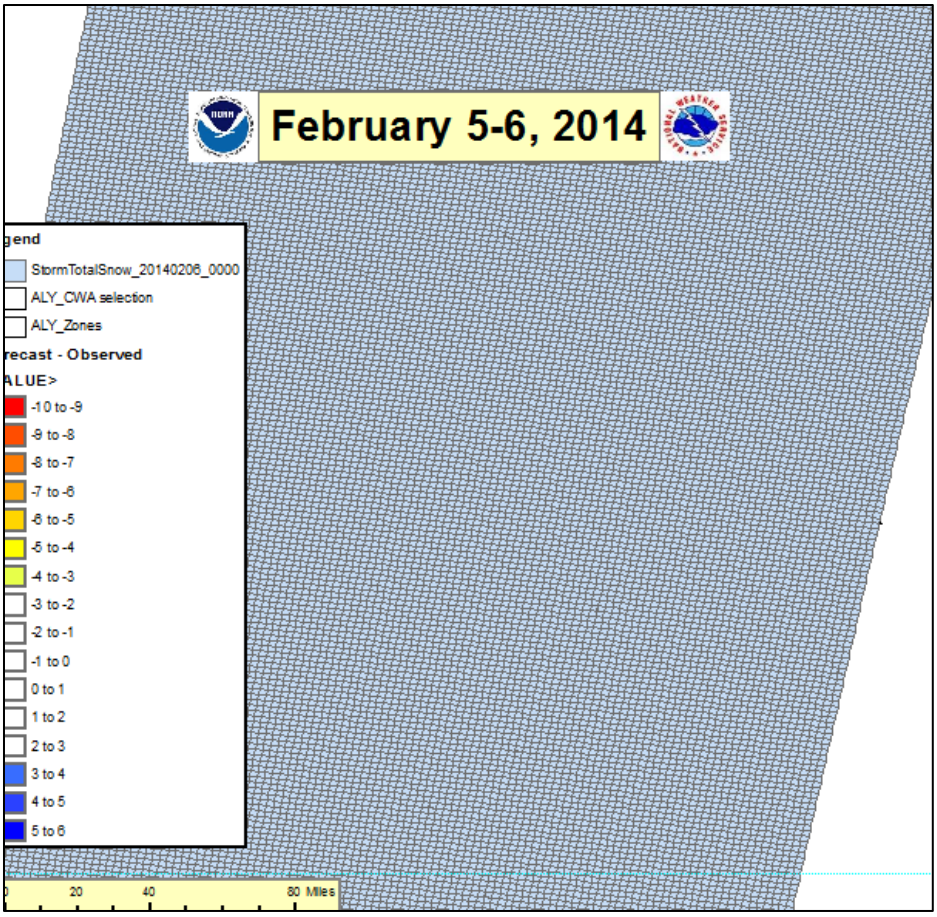
This section outlines the instructions necessary to create the forecast snowfall map via a netCDF to shapefile conversion taken directly from the Graphical Forecast Editor (GFE). The forecast snowfall map to be used at ALY is the **latest storm total forecast snowfall map taken prior to the onset of snowfall across any portion of the CWA**. For complex, or multi-day events, it is recommended to create multiple observed snowfall maps and zone-average verification maps based on issuances of Watches/Warnings/Advisories. The steps outlined below are specifically for storm total snowfall netCDF files; however, this script can be modified to generate any GFE netCDF file.

*To obtain the net2shp script information and directory structure, email **Vasil.Koleci@noaa.gov**

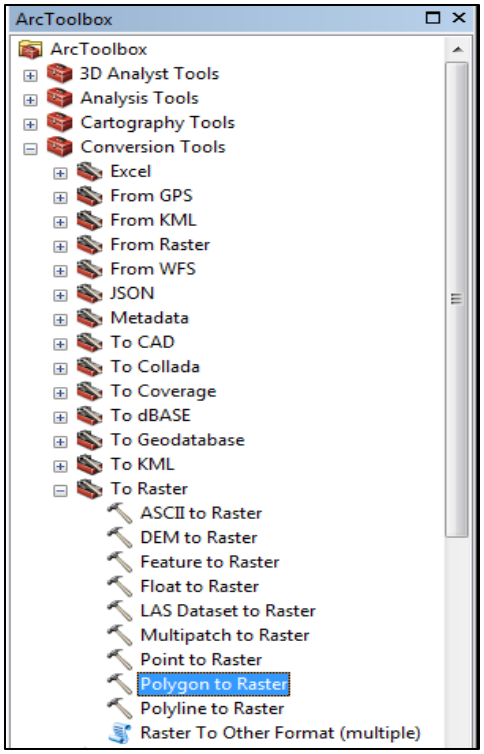
1. Retrieve the netCDF storm total forecast snowfall file using the **net2shp.sh** script
    a. Open a **Terminal** window at an AWIPS workstation
    b. Navigate to the following directory by typing the following command:
    **cd /awips/dev/localapps/net2shp/net2shp**
    c. Run the **net2shp.sh** shell script in AWIPS by typing the following command:
    **./run_net2shp.sh**
        i. This shell script grabs the storm total snowfall netCDF file straight from GFE, converts it to a polygon shapefile (at the grid resolution each office has set for their GFE), and sends it over to the PC
        ii. This script generates 3 files, a .shp, .shx, and .dbf file – all required for the shapefile to be imported into **ArcMap**
    d. Navigate to the PC directory where the net2shp data is stored
        i. As an example, WFO ALY uses **G:/AWIPS/net2shp/**
        ii. Each shapefile will be saved with the following nomenclature:
        **GFEVariable_yyyymmdd_time.shp (or .dbx/.shx)**
        iii. Example: StormTotalSnow_20141212_1200.shp
    e. Copy or cut the storm total snowfall shapefile and the 3 shapefile extensions (**.dbf, .shp, .shx**) into the **'verification_input'** directory within the **EventDate →Input_Data** directory you are using for the event
2. Create the forecast storm total snowfall raster
    a. Open **ArcMap** (if not already opened)
    b. Add the forecast storm total snowfall shapefile to the map along with any other desired layers as described in Step 2



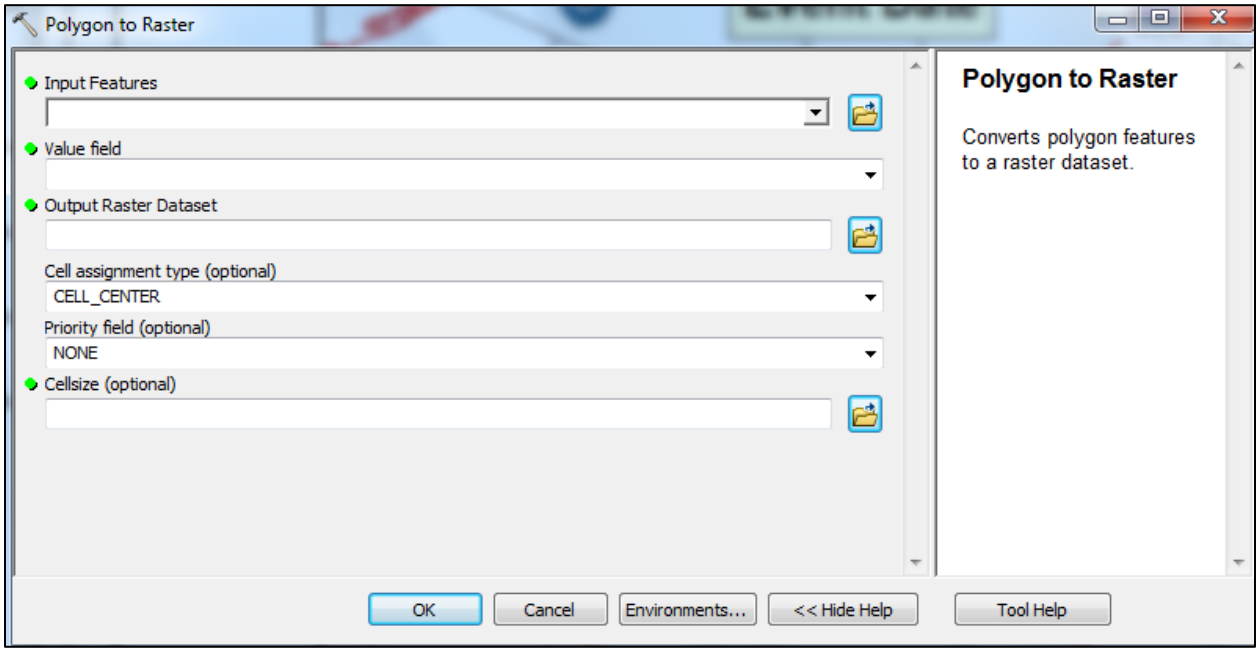

    c. The map will display a polygon after the shapefile is loaded similar to the one below:



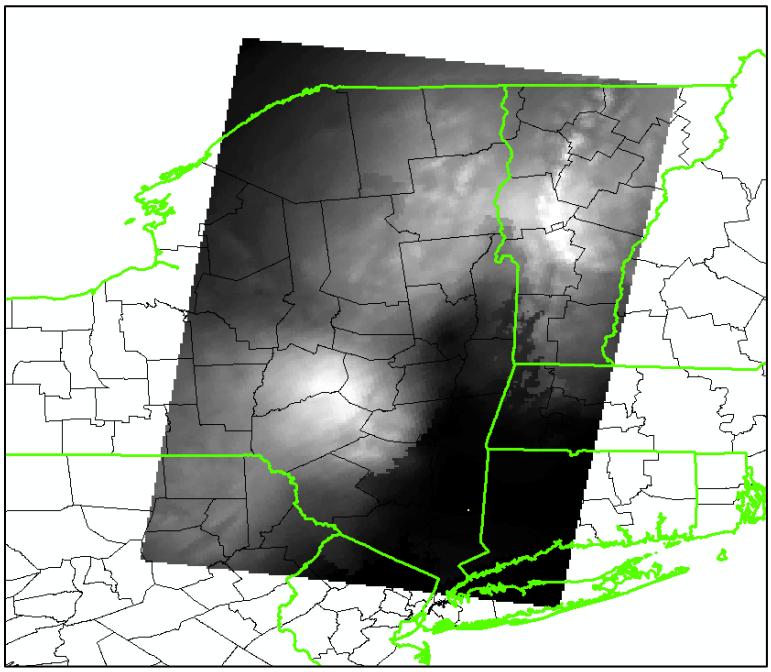

d. Convert the forecast storm total snowfall shapefile to a raster
   i. Open **ArcToolbox** (if not already opened)
   ii. Navigate to the following: '**Conversion Tools' → 'To Raster' → 'Polygon to Raster'** and double-click on **'Polygon to Raster'** to open a new popup window




iii. For **'Input Features'**, select the forecast storm total snowfall shapefile
iv. For **'Value field'**, select **'Value'**
v. For **'Output Raster Dataset'**, name it **'fsnow'** and save it in the **'verification_input'** directory
vi. Leave the **'Cell assignment type'**, **'Priority field'**, and **'Cellsize'** as is
vii. Click **'OK'** to run the **'Polygon to Raster'** tool



viii. The forecast storm total snowfall raster will populate in the map and look similar to the following:

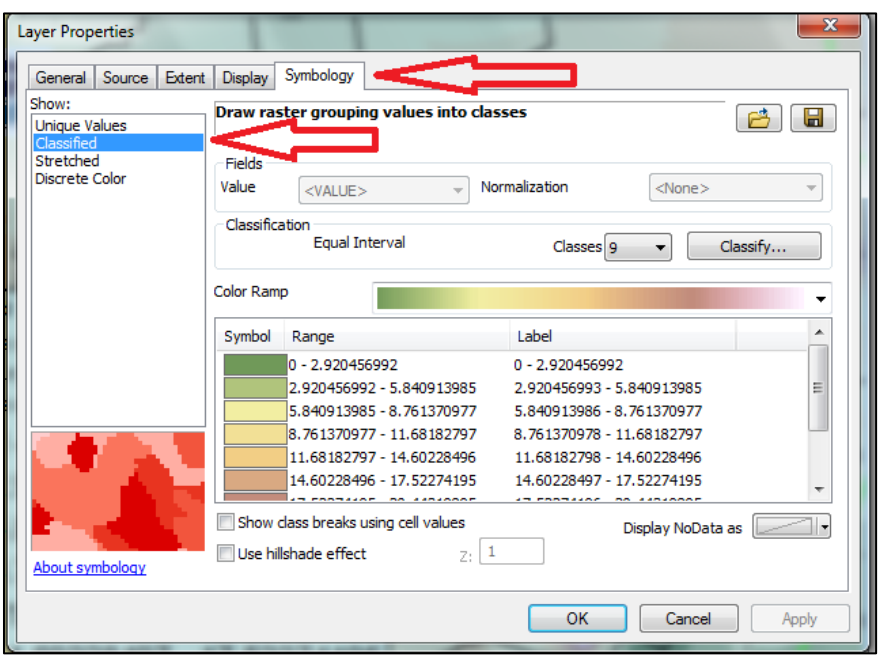


e. After the forecast interpolated map has been created, the values will need to be reclassified to match the NWS Eastern Region forecast snowfall graphics.

i. Right-click on the forecast raster layer and click on **'Properties'** to open the **'Layer Properties'** popup window

ii. Click on the **'Symbology'** tab (if not already selected)

iii. Make sure it is set to **'Classified'** (left side of the popup window)



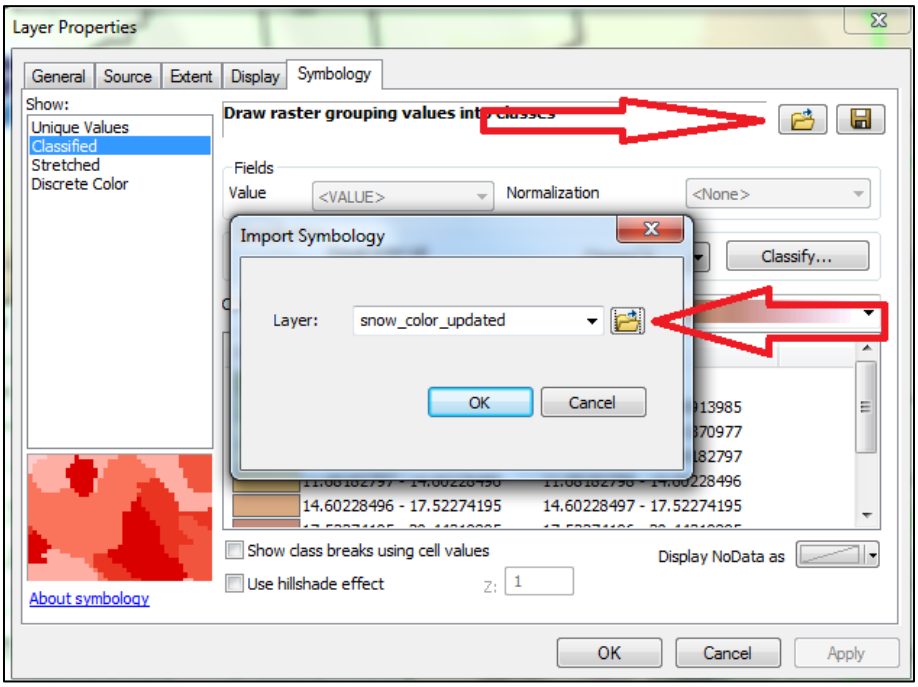
iv. Click the **'Open'** button to import the **'snow_color_updated.lyr'** color scheme from the **'Import Symbology'** popup window (navigate to the directory where the color scheme is saved)

i. ***RECOMMENDED OFFICE DIRECTORY TREE STRUCTURE FOR COLOR SCHEMES***

**Home Directory →GIS → Color_Schemes**

Example: C:/GIS/Color_Schemes/

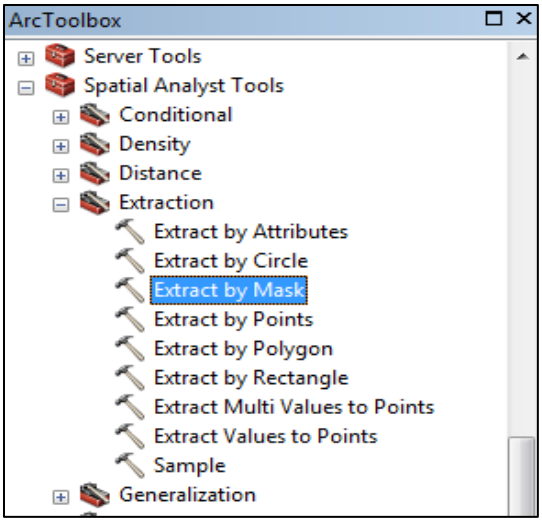
*To obtain the **'snow_color_updated.lyr'** color scheme, email **Ian.Lee@noaa.gov**



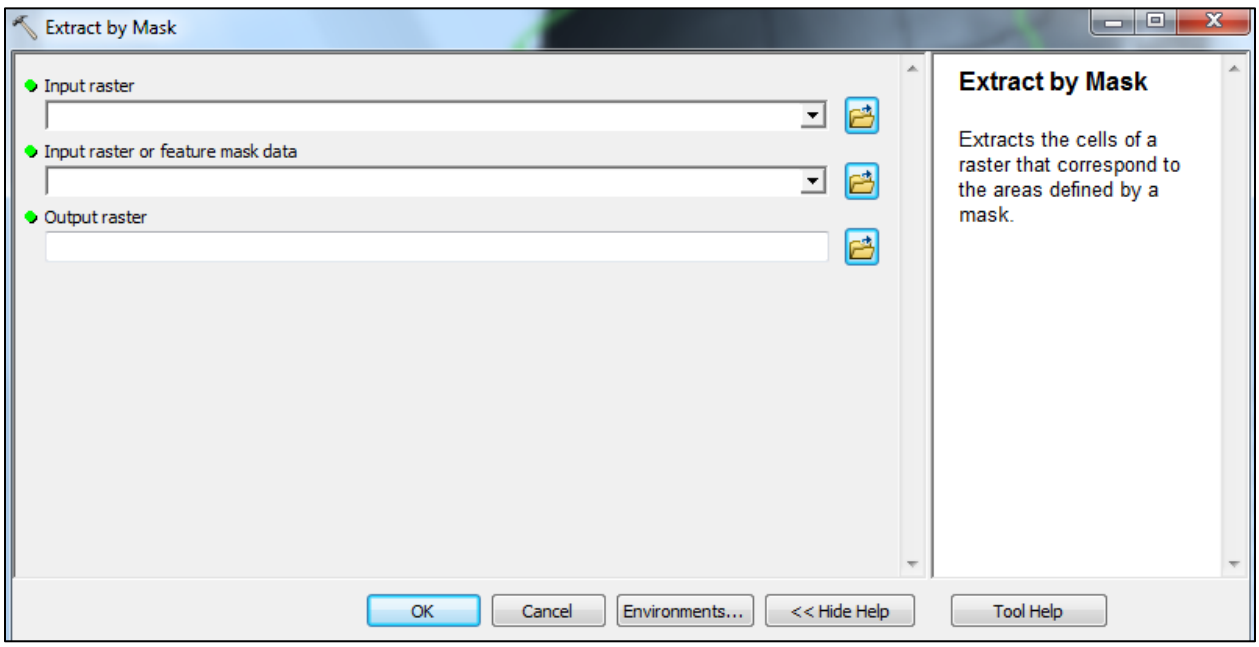

v. After clicking **'OK'** the **'snow_color_updated.lyr'** color scheme will update and should resemble the legend below (this scheme is already pre-formatted and does not require any further editing):

vi. Click **'OK'** again to apply the color scheme changes to the interpolated map

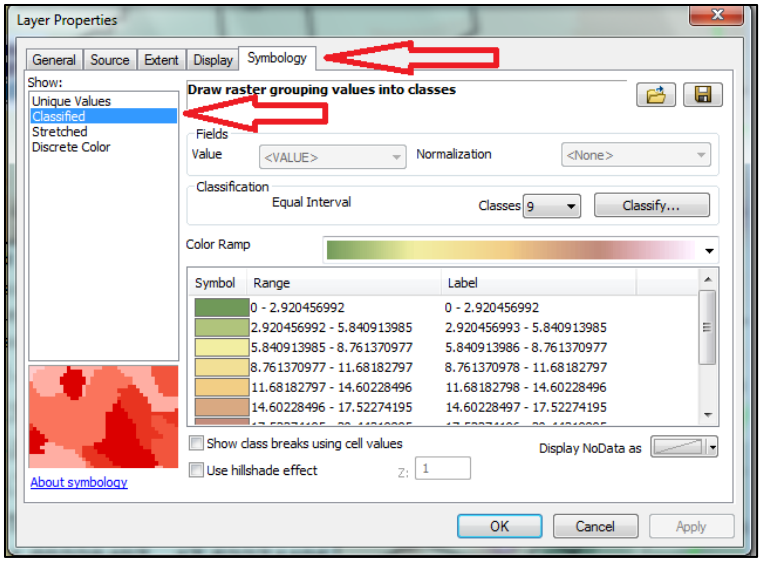
3. Clip the forecast raster to your local CWA border
   a. Open **ArcToolbox** (if not already opened)
   b. Navigate to the following: **'Spatial Analyst Tools' → 'Extraction' → 'Extract by Mask'** and double-click on **'Extract by Mask'** to open a new popup window




c. For **'Input raster'**, select the forecast raster
d. For **'Input raster or feature mask data'**, select your office CWA border shapefile
e. For **'Output Raster'**, name it **'fsnow_extract'** and save it in the **'verification_input'** directory
f. Click **'OK'** to run the **'Extract by Mask'** tool




g. The output will display on the map confined to your office CWA border
    i. Turn off the **fsnow** raster layer, as you only want to see the clipped raster
h. After the forecast interpolated map has been clipped to the CWA border, the values will need to be reclassified to match the NWS Eastern Region forecast snowfall graphics.
    i. Right-click on the forecast raster layer and click on **'Properties'** to open the **'Layer Properties'** popup window
    ii. Click on the **'Symbology'** tab (if not already selected)
    iii. Make sure it is set to **'Classified'** (left side of the popup window)



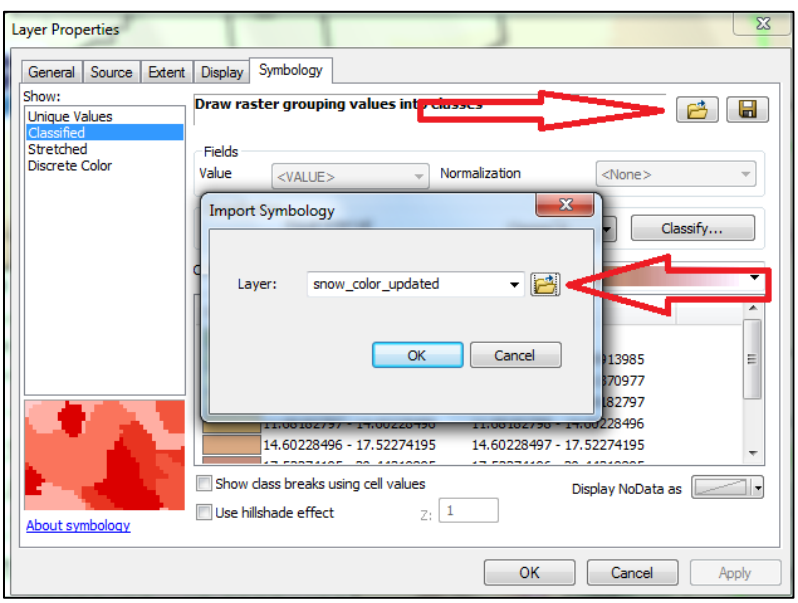

iv. Click the **'Open'** button to import the **'snow_color_updated.lyr'** color scheme from the **'Import Symbology'** popup window (navigate to the directory where the color scheme is saved)

   i. ***RECOMMENDED OFFICE DIRECTORY TREE STRUCTURE FOR COLOR SCHEMES***

**Home Directory →GIS → Color_Schemes**

Example: C:/GIS/Color_Schemes/

*To obtain the **'snow_color_updated.lyr'** color scheme, email **Ian.Lee@noaa.gov**




v. After clicking **'OK'** the **'snow_color_updated.lyr'** color scheme will update and should resemble the legend below (this scheme is already pre-formatted and does not require any further editing):

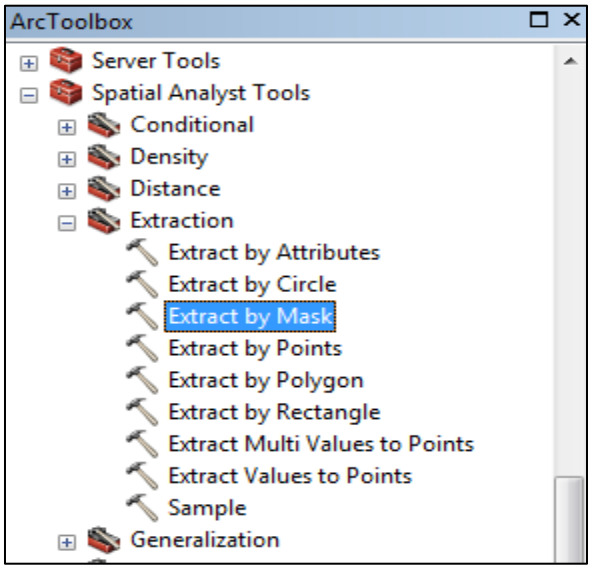
vi. Click **'OK'** again to apply the color scheme changes to the interpolated map

4. Make any final changes to the map as necessary (exs. legend, title, scale, disclaimer, north arrow, adding additional layers, etc.)
5. **'Print Screen'** and crop and save the image using **Paint** as a .png file
    a. Name the image using a common nomenclature (ex. Forecast_Snowfall_121214.png)
    b. Save the image in the specific **Event Date → Output_Data → verification_output** directory

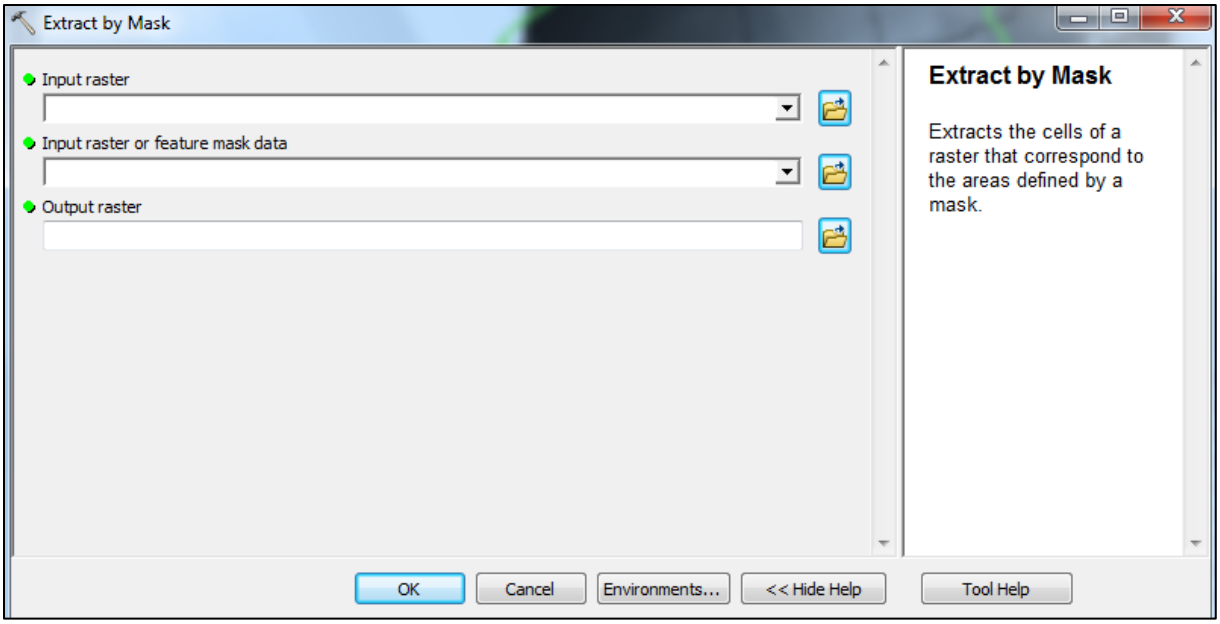
## Step 5: Creating Forecast Error Map

This section outlines the instructions necessary to create the forecast error plot in order to see areas of overestimation and underestimation in the forecast. This error plot is recommended to be confined to your office local CWA boundary, in order to assess forecast error relative to your office CWA.

1. Clip the observed snowfall raster to your local CWA border
    a. Open **ArcToolbox** (if not already opened)
    b. Navigate to the following: '**Spatial Analyst Tools' → 'Extraction' → 'Extract by Mask'** and double-click on **'Extract by Mask'** to open a new popup window

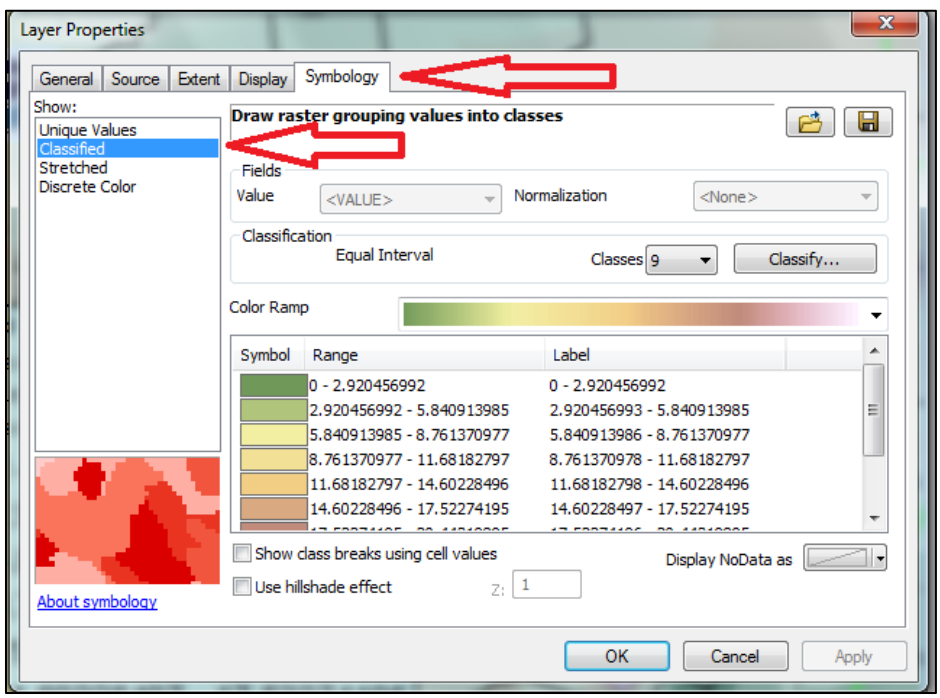



    c. For **'Input raster'**, select the observed snowfall raster created during Step 2/2a
    d. For **'Input raster or feature mask data'**, select your office CWA border shapefile
    e. For **'Output Raster'**, name it **'obs_extract'** and save it in the **'verification_input'** directory
    f. Click **'OK'** to run the **'Extract by Mask'** tool

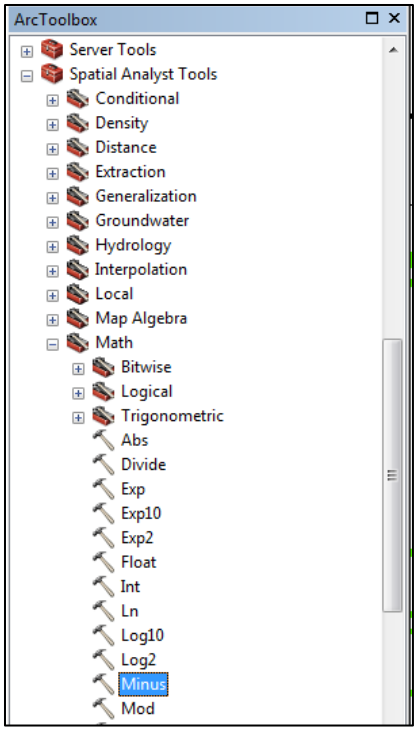



g. The output will display on the map confined to your office CWA border

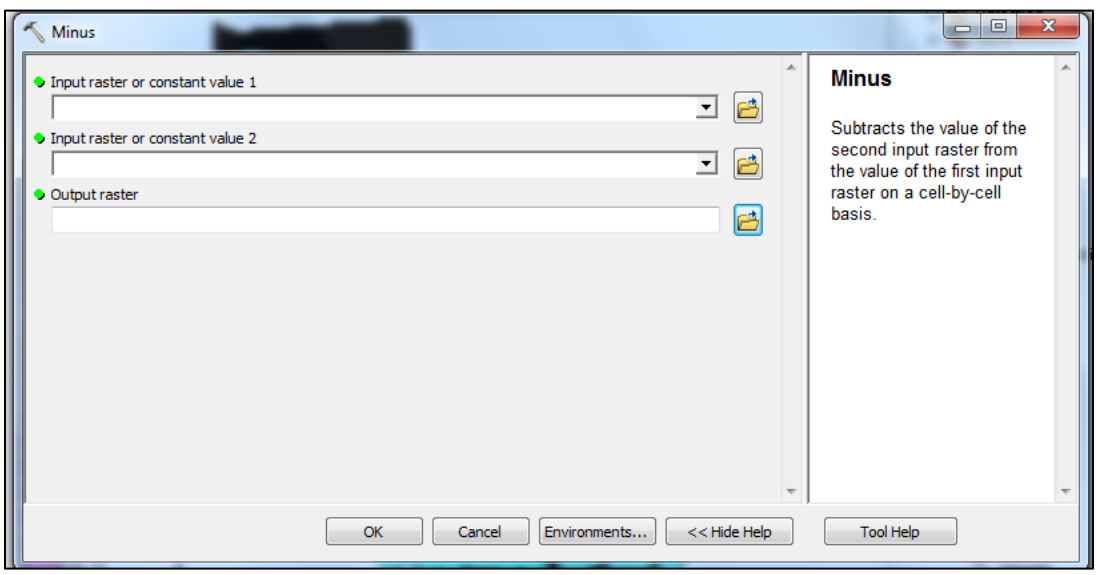
2. Right-click on the new, clipped observed snowfall raster and make sure the **'Symbology'** is set to **'Classified'** (no need to change the colors for this step)



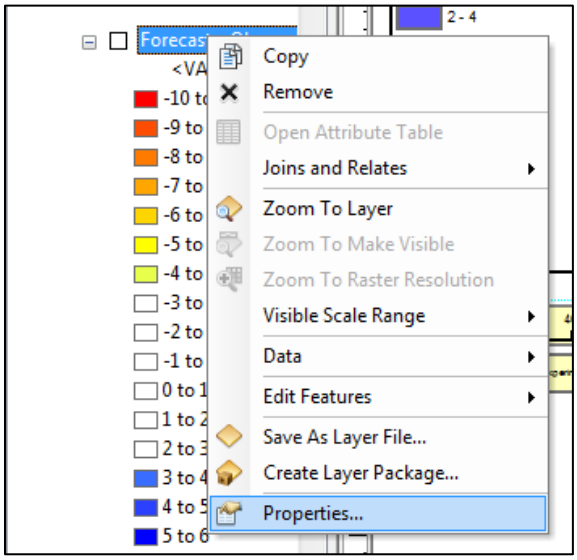

3. Create the forecast error plot
   a. Open **ArcToolbox** (if not already opened)
   b. Navigate to the following: '**Spatial Analyst Tools**' → '**Math**' → '**Minus**' and double-click on '**Minus**' to open a new popup window



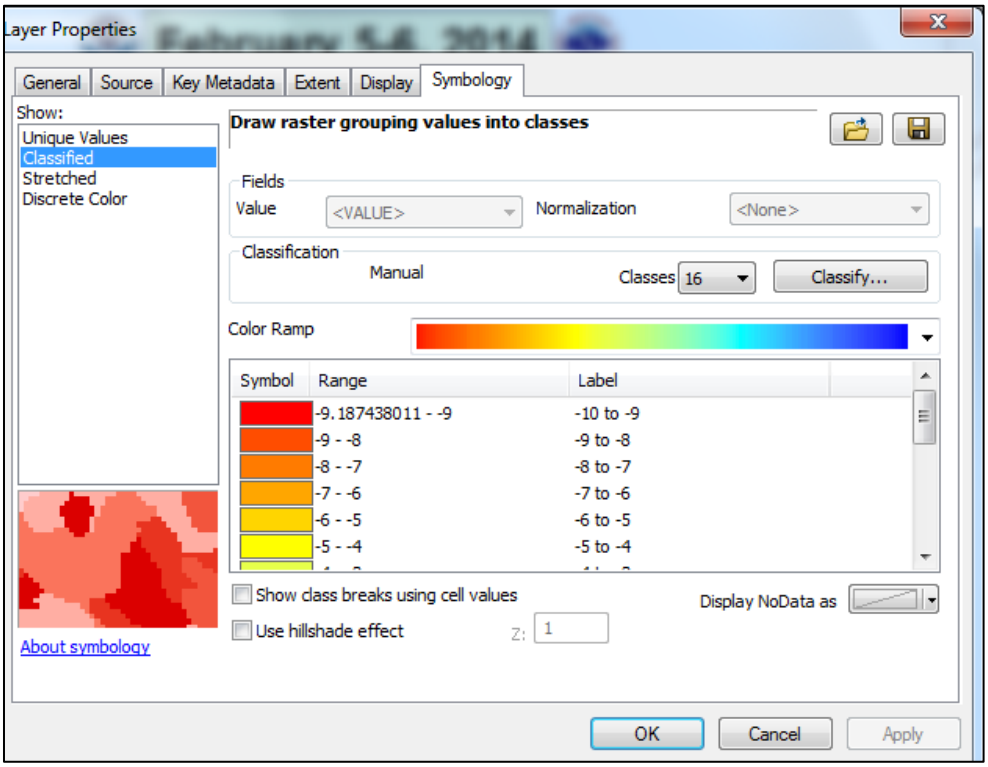

c. For **'Input raster or constant value 1'**, select the **'fsnow_extract'** forecast snowfall raster created during Step 4
d. For **'Input raster or constant value 2'**, select the **'obs_extract'** observed snowfall raster created during Step 2/2a
e. For **'Output Raster'**, name it **'error'** and save it in the **'verification_input'** directory
f. Click **'OK'** to run the **'Minus'** tool
    i. This tool will subtract the observed raster from the forecast raster, with positive results indicating areas of forecast overestimation and negative results indicating areas of forecast underestimation.



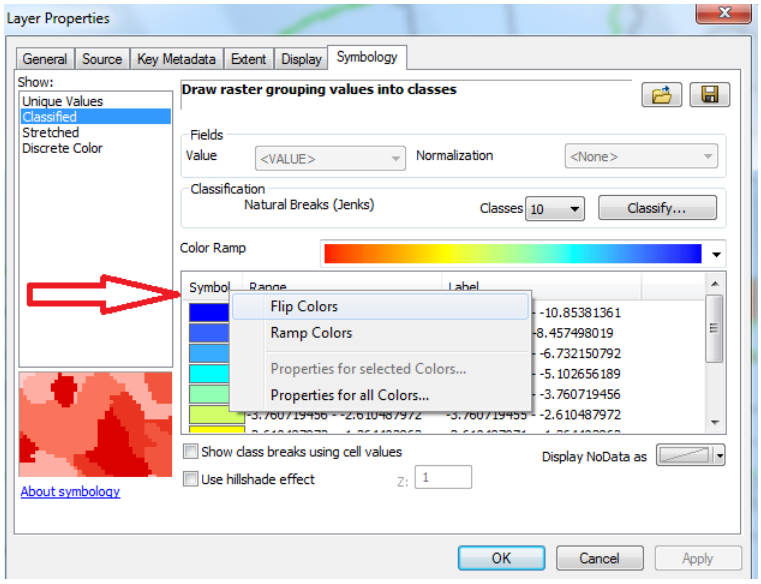
4. Customize the color scale and ranges by reclassifying
   a. Right-click on the **'error'** raster and click on **'Properties'**




   b. Click on the **'Symbology'** tab and make sure it is set to **'Classified'**




   c. Leave the number of **'Classes'** alone – it will automatically default to the appropriate number based on the range of values in the **'error'** raster
   d. Change the color ramp to the color ramp shown in the above image
   e. Left-click where it says **'Symbol'** and click **'Flip Colors'** so that cooler colors represent negative values, or underestimation of the forecast and warmer colors represent positive values, or overestimation of the forecast




f. Click **'OK'** to apply the changes

5. Make any final changes to the map as necessary (exs. Legend, title, scale, disclaimer, north arrow, adding additional layers, etc.)
6. **'Print Screen'** and crop and save the image using **Paint** as a .png file
   a. Name the image using a common nomenclature (ex. Forecast_Snowfall_121214.png)
   b. Save the image in the specific **Event Date → Output_Data → verification_output** directory