GIS Applications in NWS Operations & Lake Effect Snow Forecasting

ATM 362 – Forecasting & NWS Operations Course

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March 15, 2021

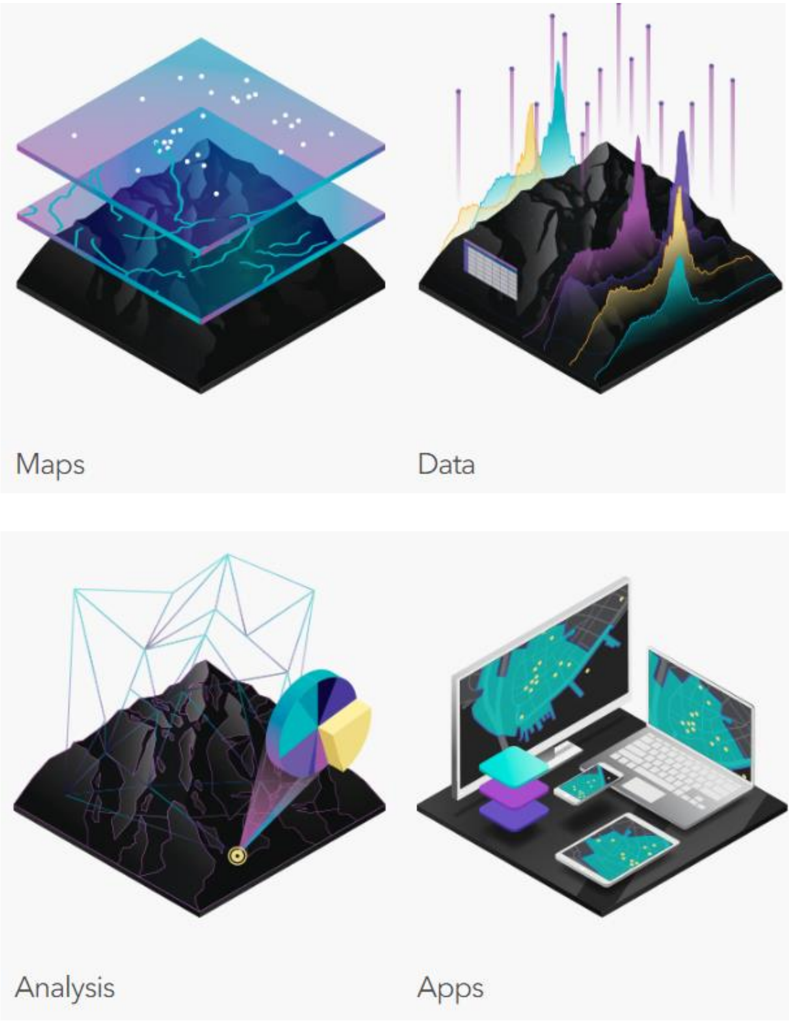
Outline

- Introduction to GIS
- Elevation mapping
- Flash Flood Potential Index
- Rainfall/Snowfall analysis maps
- NWS zone-based verification
- NWS forecast error maps
- Snowfall composites stratified by flow regime
- Hi-res model verification
- Automation "GAZPACHO" program
- Forecasting Lake Effect Snow (Albany forecast area)

Introduction to Geographic Information Systems

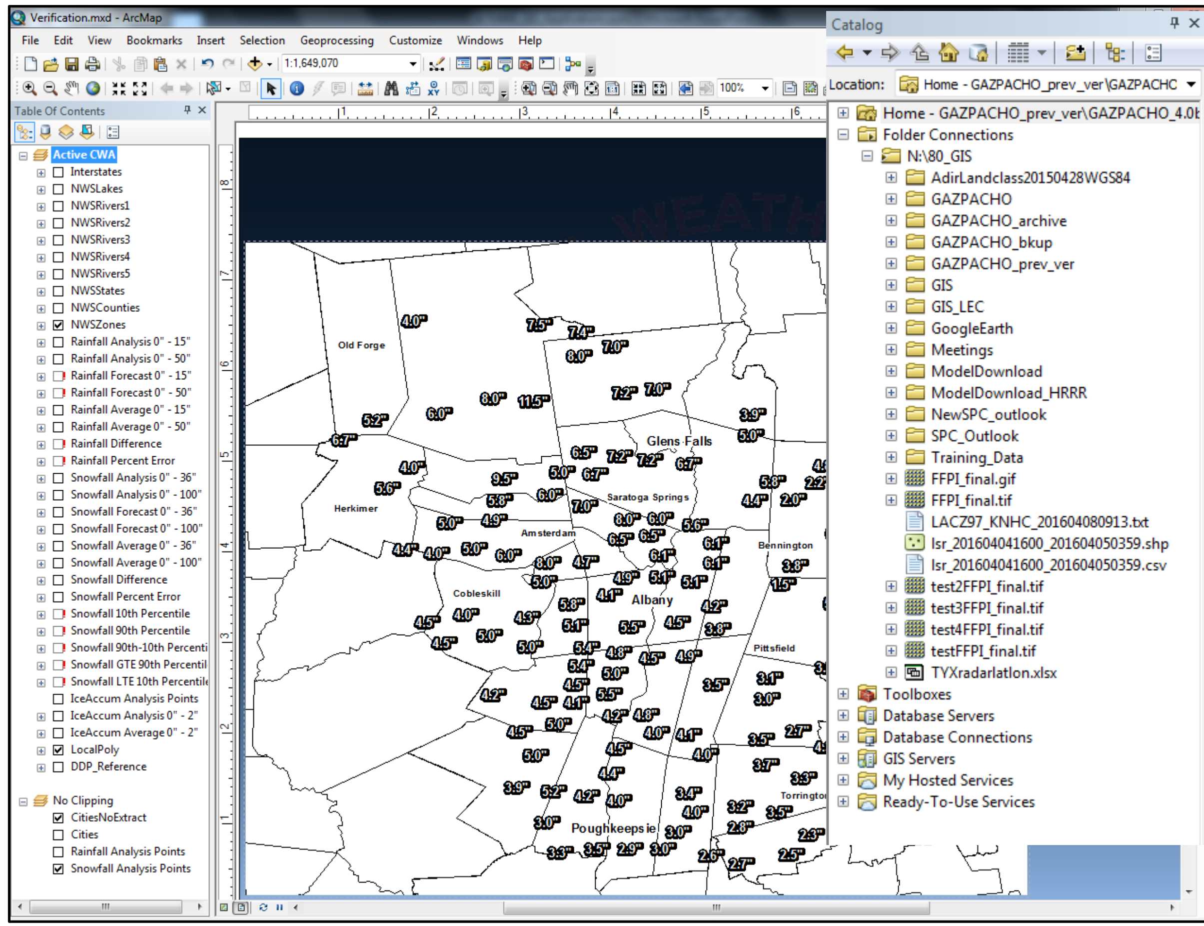
- What is GIS?

  From ESRI.com: "A geographic information system (GIS) is a framework for gathering, managing, and analyzing data. Rooted in the science of geography, GIS integrates many types of data. It analyzes spatial location and organizes layers of information into visualizations using maps and 3D scenes. With this unique capability, GIS reveals deeper insights into data, such as patterns, relationships, and situations—helping users make smarter decisions. "



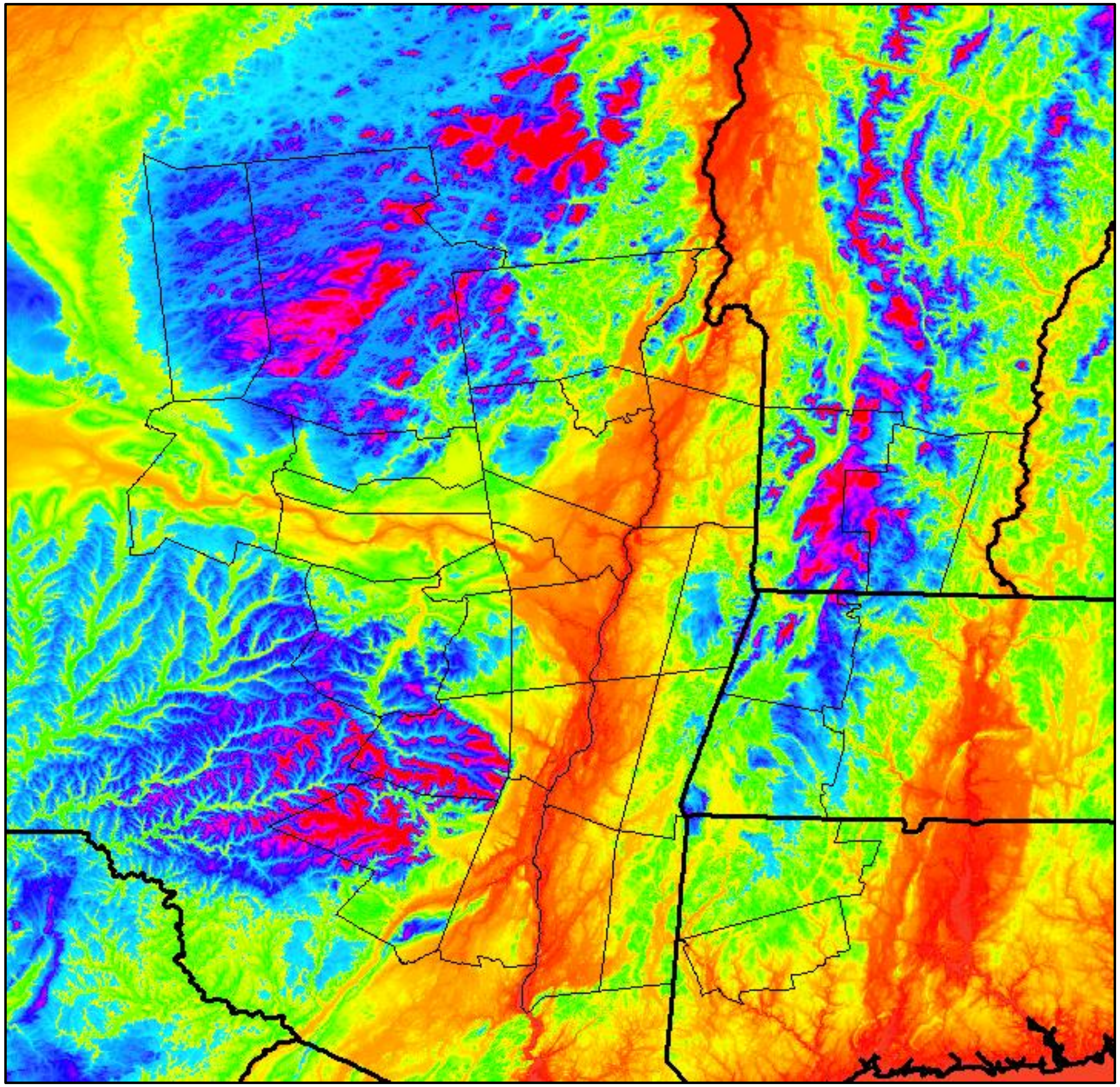
Introduction to GIS

- **ArcMap** is the main ArcGIS software used at NWS Albany (contains **ArcCatalog** for organizing GIS files)
- Powerful mapping application: creation of shape files **rasters** (digital dataset made up of grid points)
- Crucial aspect of Rasters   can be mathematically manipulated



Local Applications: Elevation Maps

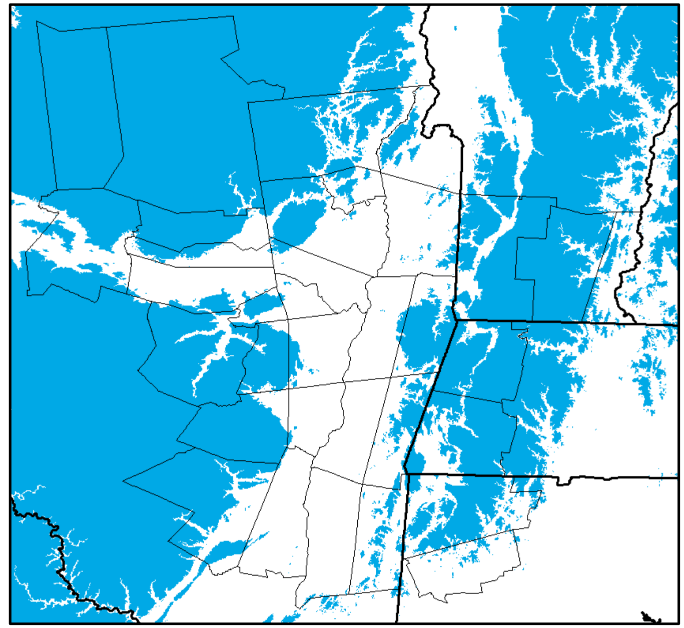
- Uses USGS Digital Elevation Model (DEM) data 30 meter resolution
- Download in tiles, then mosaic using ArcMap



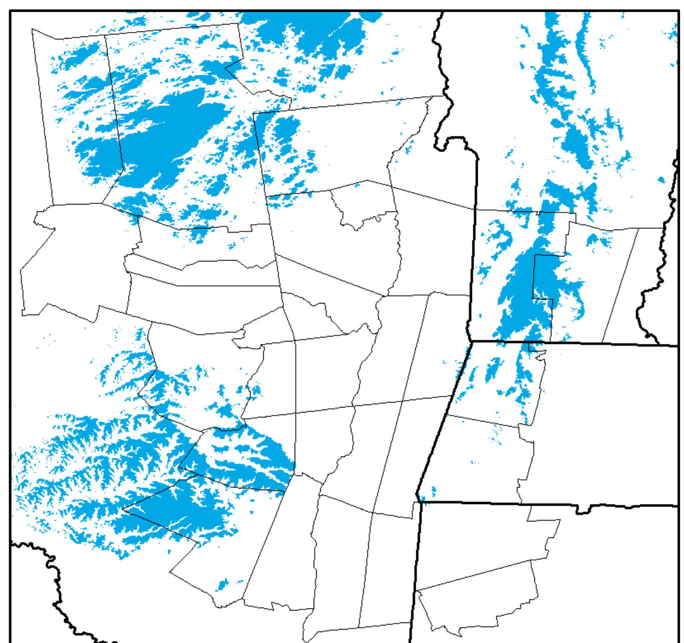
DEM Mosaic in ArcMap

Local Applications: Elevation Maps

- Delineate elevation thresholds in 500 ft increments for elevation-specific maps



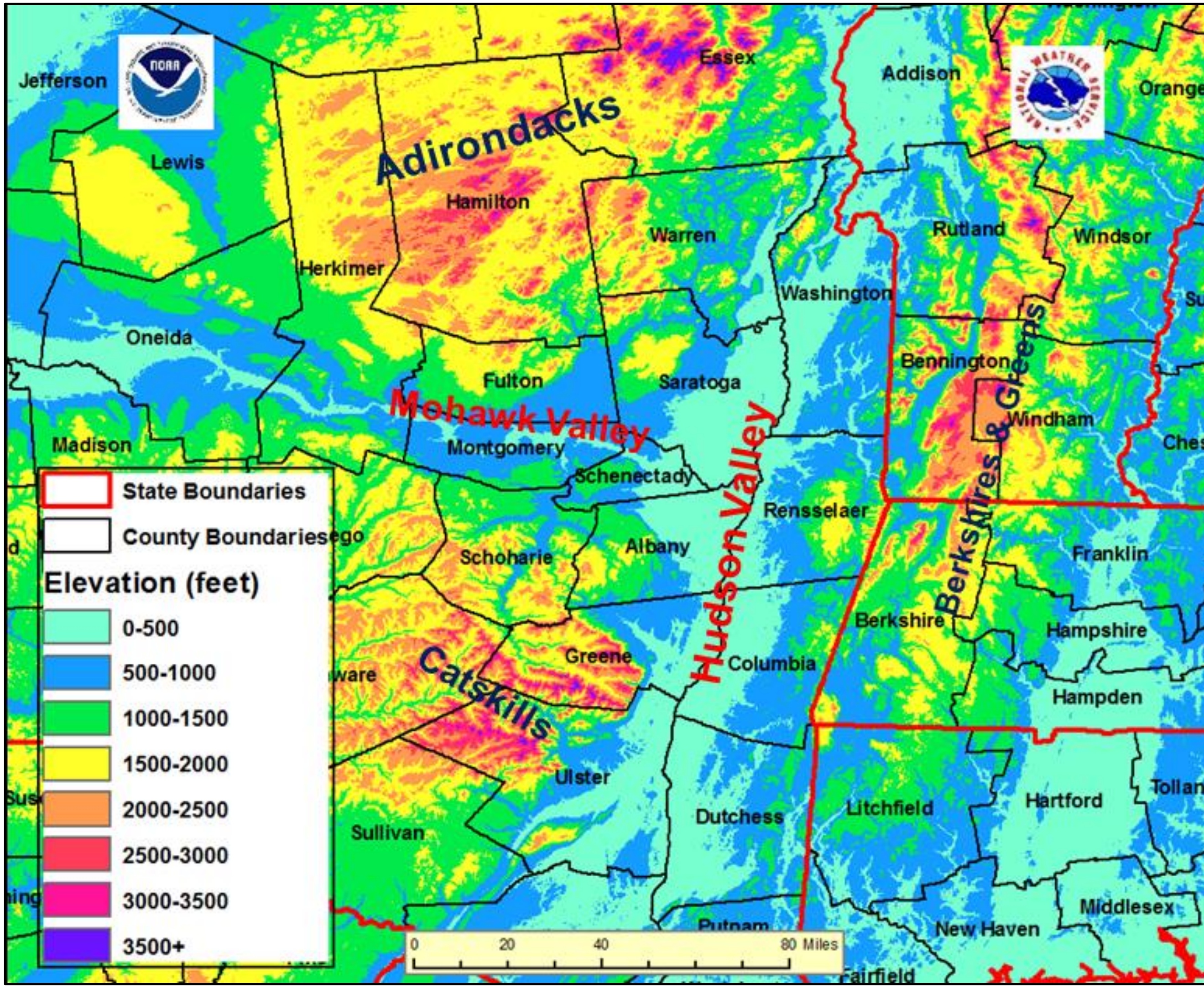
> 1000 ft



> 2000 ft

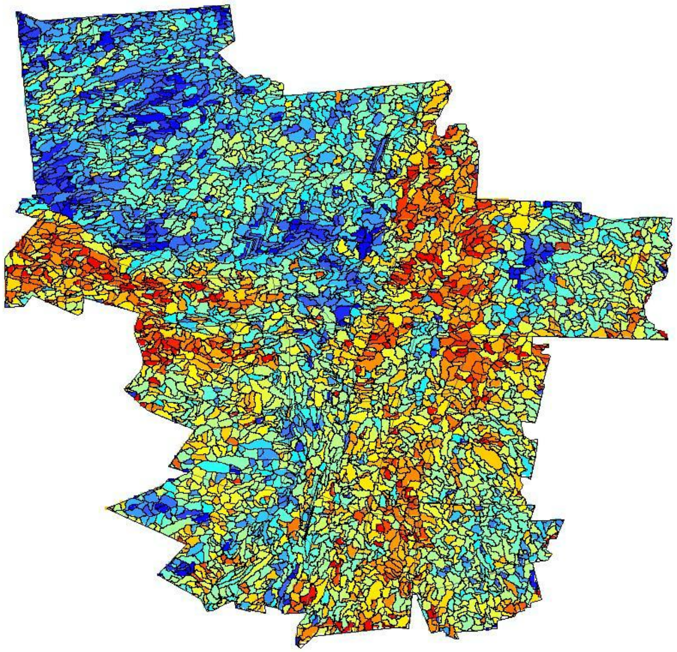
Local Applications: Elevation Maps

- Create contoured elevation map with 500 ft range bins
- Select different color for each range bin
- Useful for visualizing key topographic features in the Albany forecast area



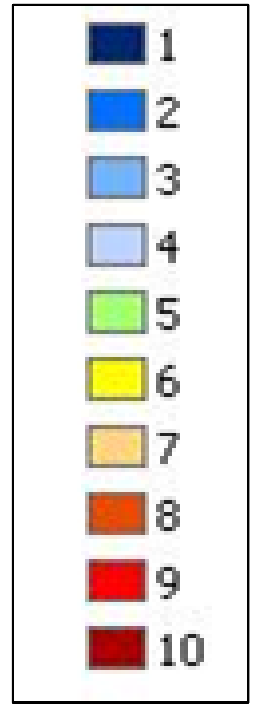
Flash Flood Potential Index (FFPI)

- The **FFPI** incorporates physiographic characteristics of an individual drainage basin to determine its hydrologic response
- For Flash Flooding, hydrologic response influenced by four main factors:
  1. **Soil type**
  2. **Terrain slope**
  3. **Vegetation and forest canopy**
  4. **Land use, especially urbanization**



Flash Flood Potential Index (FFPI)

- High resolution maps obtained and converted to raster datasets using GIS software (ArcMap)
- Data processed over the domain of interest (ALY forecast area)
- Use ArcMap tools to resample, reclassify and combine the data
- Result is a numerical index of flash flood potential specific to the ALY forecast area (2011)



Lowest Flash Flood potential

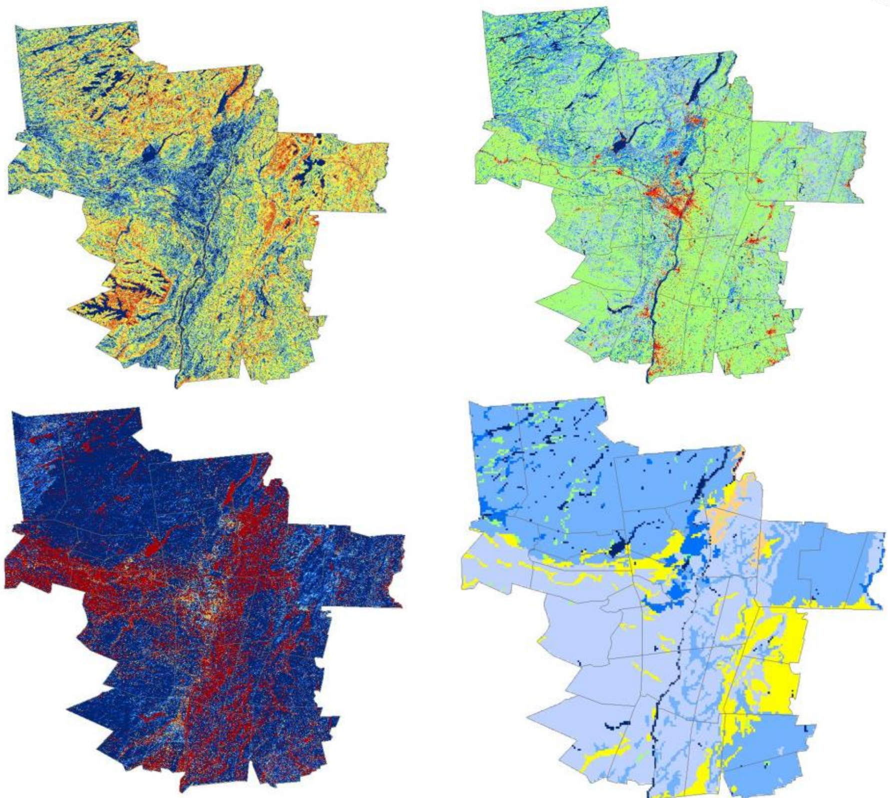
Highest Flash Flood potential

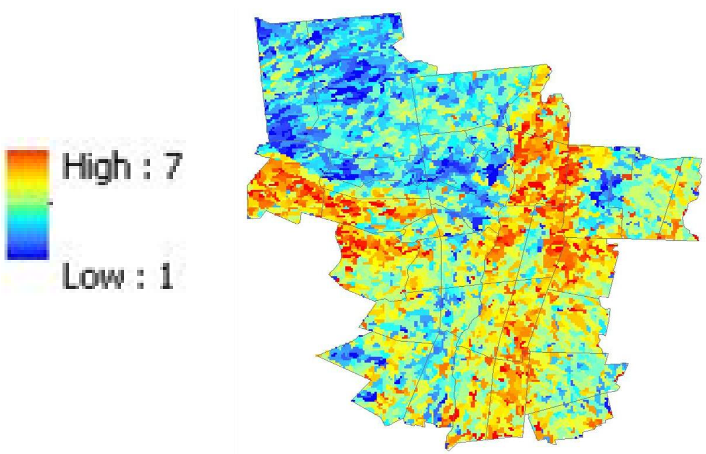
Flash Flood Potential Index (FFPI)

- Combine slope, land use, soil type and forest density using the following formula:

- **FFPI=(1.5*Slope + LU + FD + Soil)/ N**

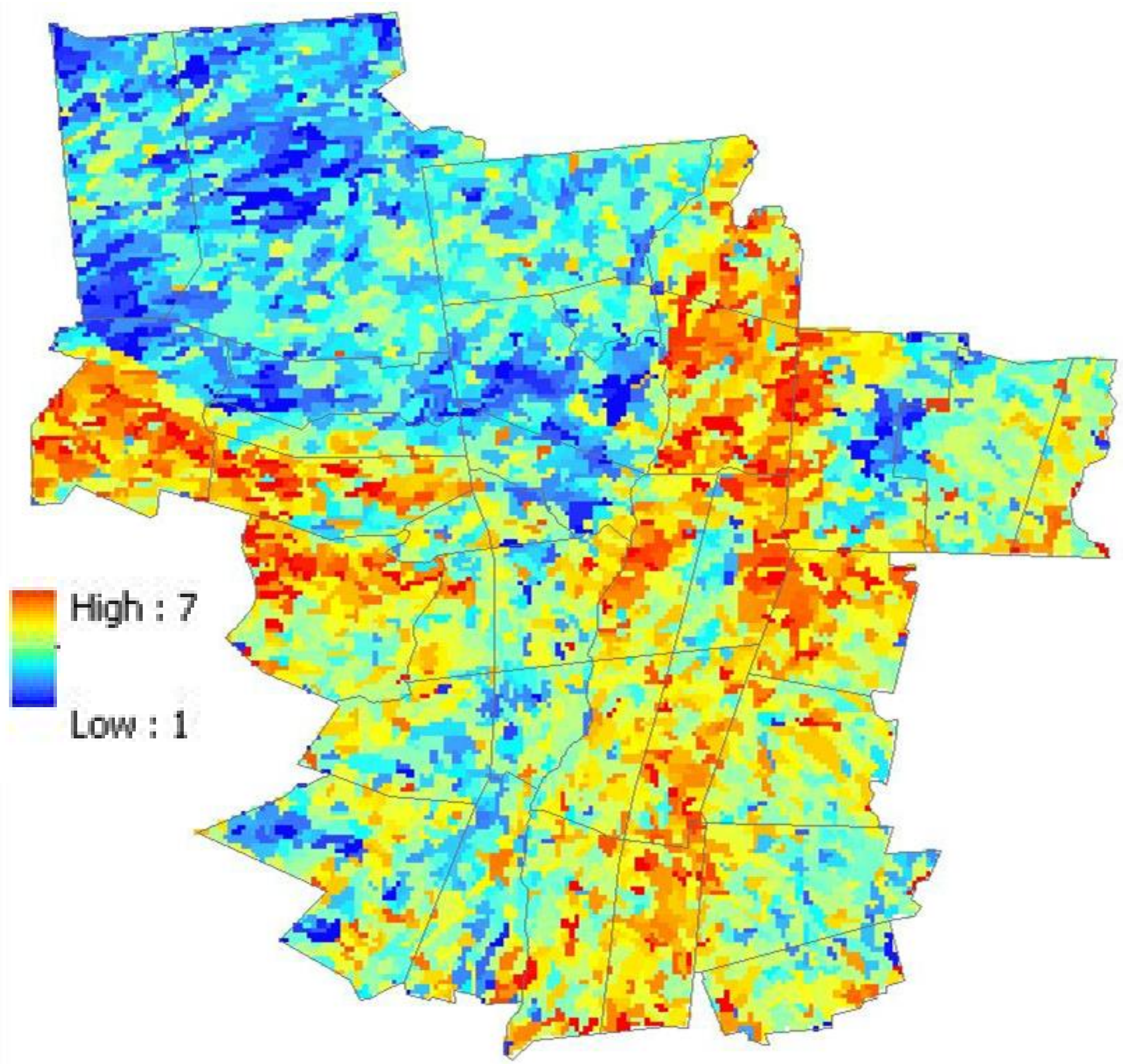
- Average the index over each basin





Flash Flood Potential Index (FFPI)

- Helps identify areas of greater/lesser Flash Flood Potential
- Areas of steep slope, agricultural use, and urban areas have higher FF potential
- Areas of dense forest, lakes/ponds, and less slope have lower FF potential

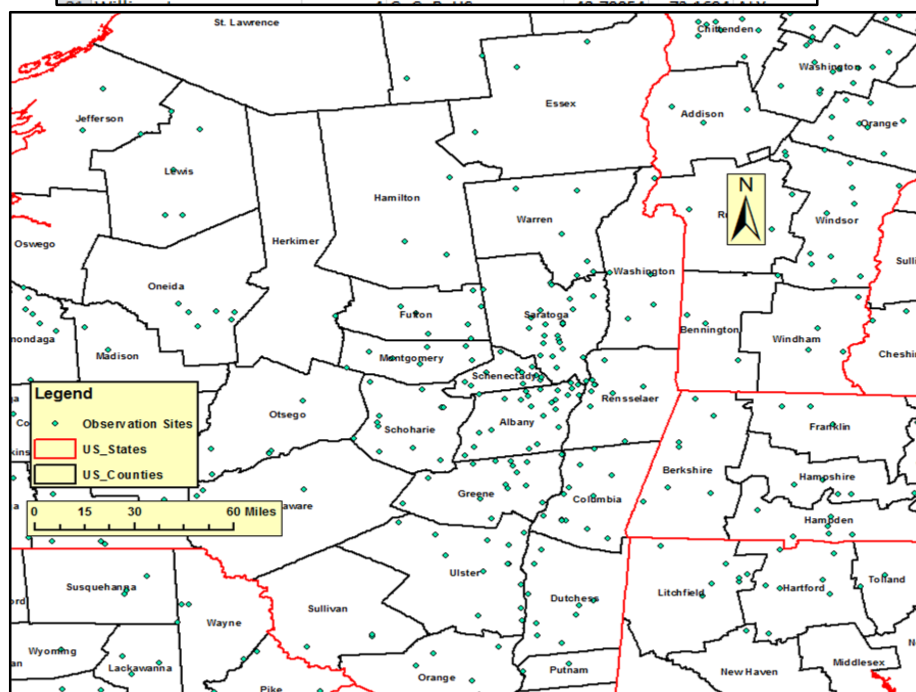


Rainfall/Snowfall Analysis Maps

- Create interpolated rainfall/snow maps from observations

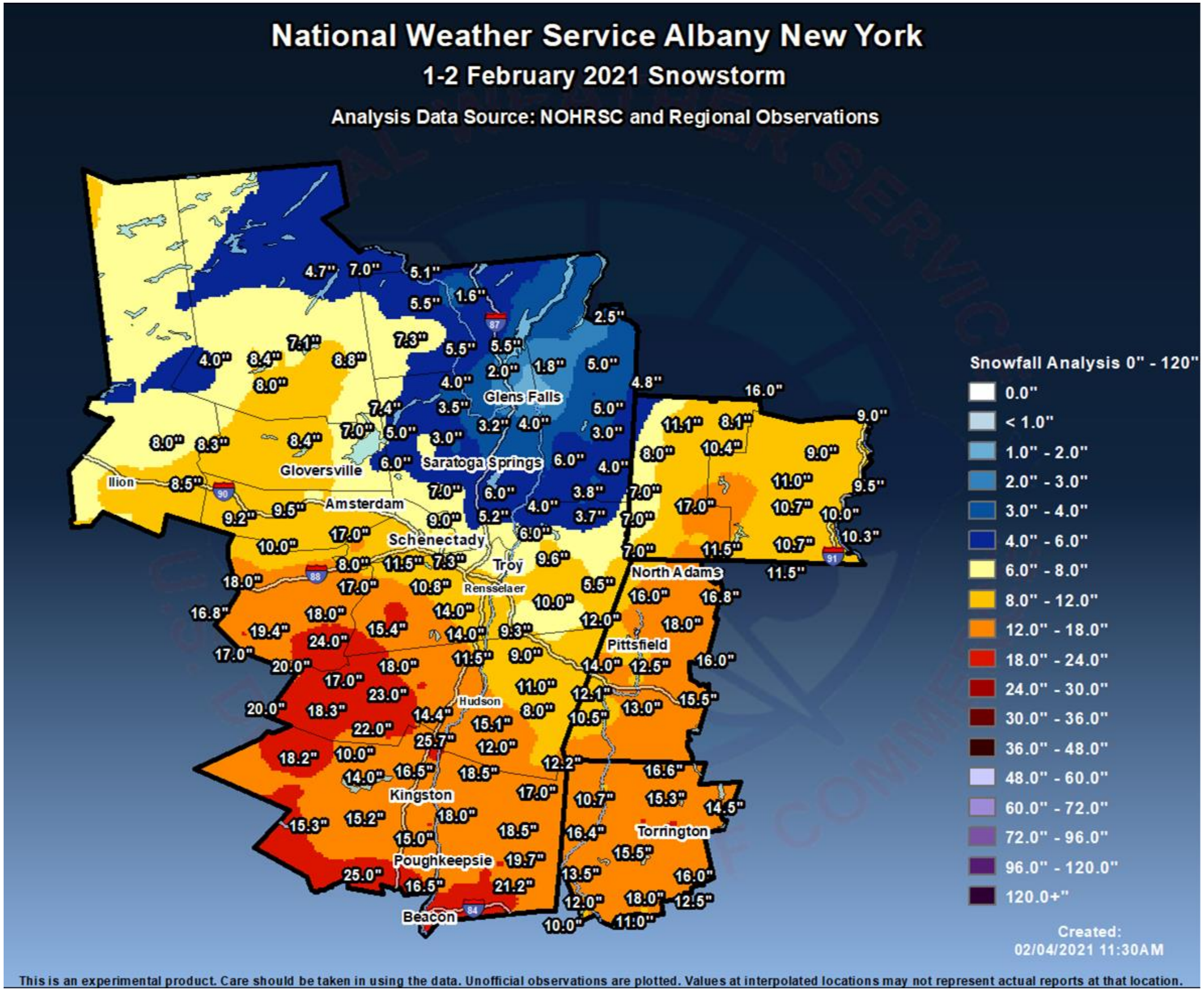
- Compile snow/rain reports from Public Information Statement
- Generate GIS shape file of snowfall reports from spreadsheet using ArcCatalog
- Import into ArcMap

	A	B	C	D	E	F
1	Site name	Snowfall	Source	LAT	LON	LOC
2	Bakersville	6.2	Co-Op Observer	41.85833	-73.0103	ALY
3	New Hartford	6.2	CoCoRaHS	41.8417	-73.0092	ALY
4	Canaan	6	WeatherNet6	42.01215	-73.3505	ALY
5	Norfolk	6	Co-Op Observer	41.9725	-73.2208	ALY
6	Winsted	6	CoCoRaHS	42.002	-73.0825	ALY
7	Litchfield	4.9	CoCoRaHS	41.77445	-73.169	ALY
8	Woodbury Center	3.5	Amateur Radio	41.5558	-73.2261	ALY
9	New Milford	3	CoCoRaHS	41.51472	-73.436	ALY
10	New Milford	3	Amateur Radio	41.5885	-73.4068	ALY
11	Roxbury	3	Amateur Radio	41.5539	-73.305	ALY
12	New Milford	2.6	CoCoRaHS	41.59392	-73.4515	ALY
13	Woodbury Center	2	Amateur Radio	41.5466	-73.207	ALY
14	Savoy	20.3	WeatherNet6	42.59784	-73.0436	ALY
15	Pittsfield	7.2	Trained Spotter	42.4518	-73.2609	ALY
16	Lenoxdale	7	Social Media	42.337	-73.2456	ALY
17	Pittsfield	6.5	CoCoRaHS	42.47878	-73.2738	ALY
18	Housatonic	6	CoCoRaHS	42.2379	-73.3503	ALY
19	Housatonic	6	CoCoRaHS	42.28983	-73.3195	ALY
20	Sandisfield	4.5	Social Media	42.09872	-73.1377	ALY



Rainfall/Snowfall Analysis Maps

- Run an Inverse Distance Weighting (IDW) function in ArcMap
- IDW takes into account distance between points & interpolates
- Creates a Raster (digital) dataset and contoured rainfall or snowfall map



Snowfall Example

Rainfall/Snowfall Analysis Maps

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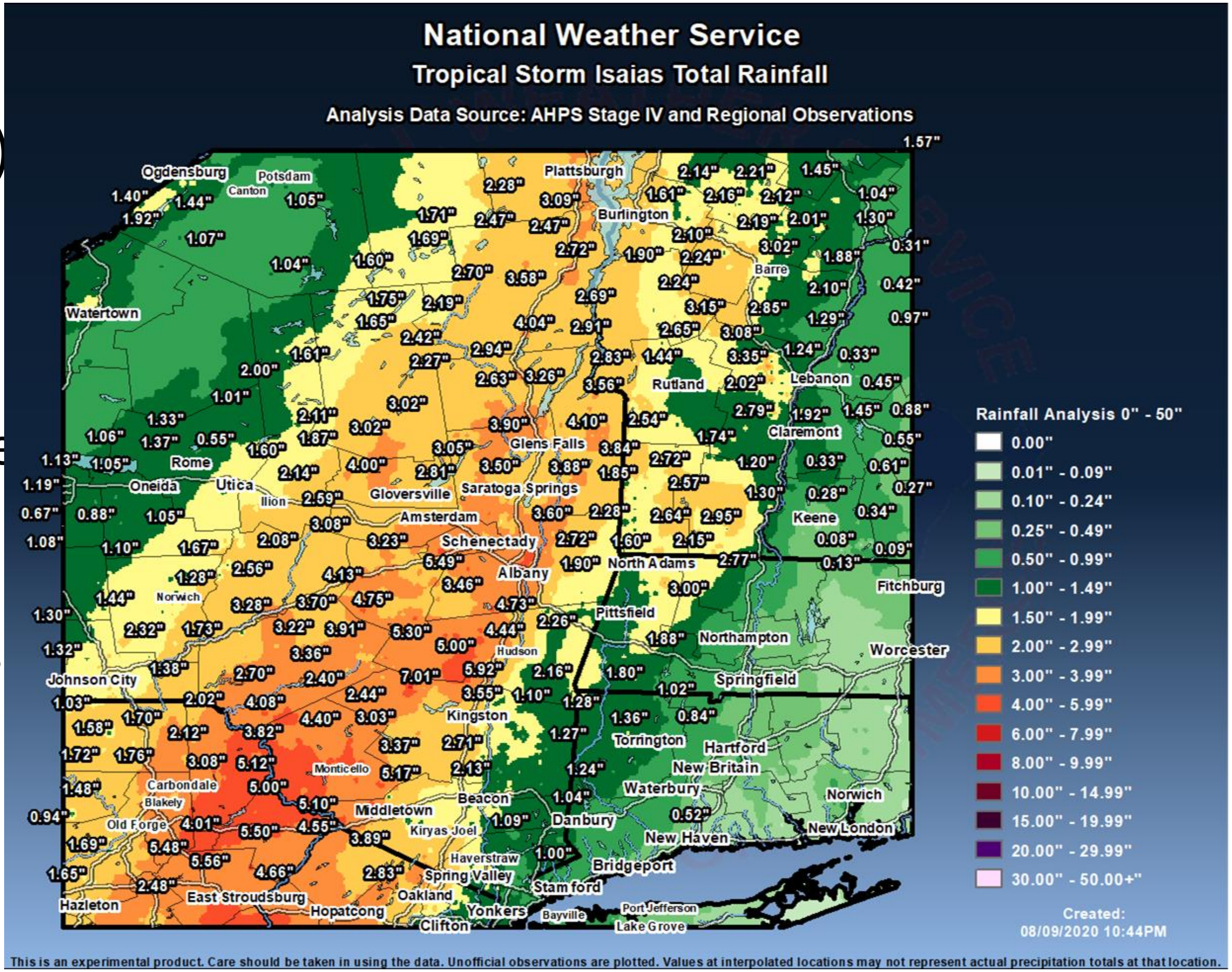


Rainfall Example

Zone-based Snowfall Verification

- NWS Verification computed from mean snowfall in each forecast zone
- Run Zonal Statistics in ArcMap (including mean) on the observed snowfall analysis Raster

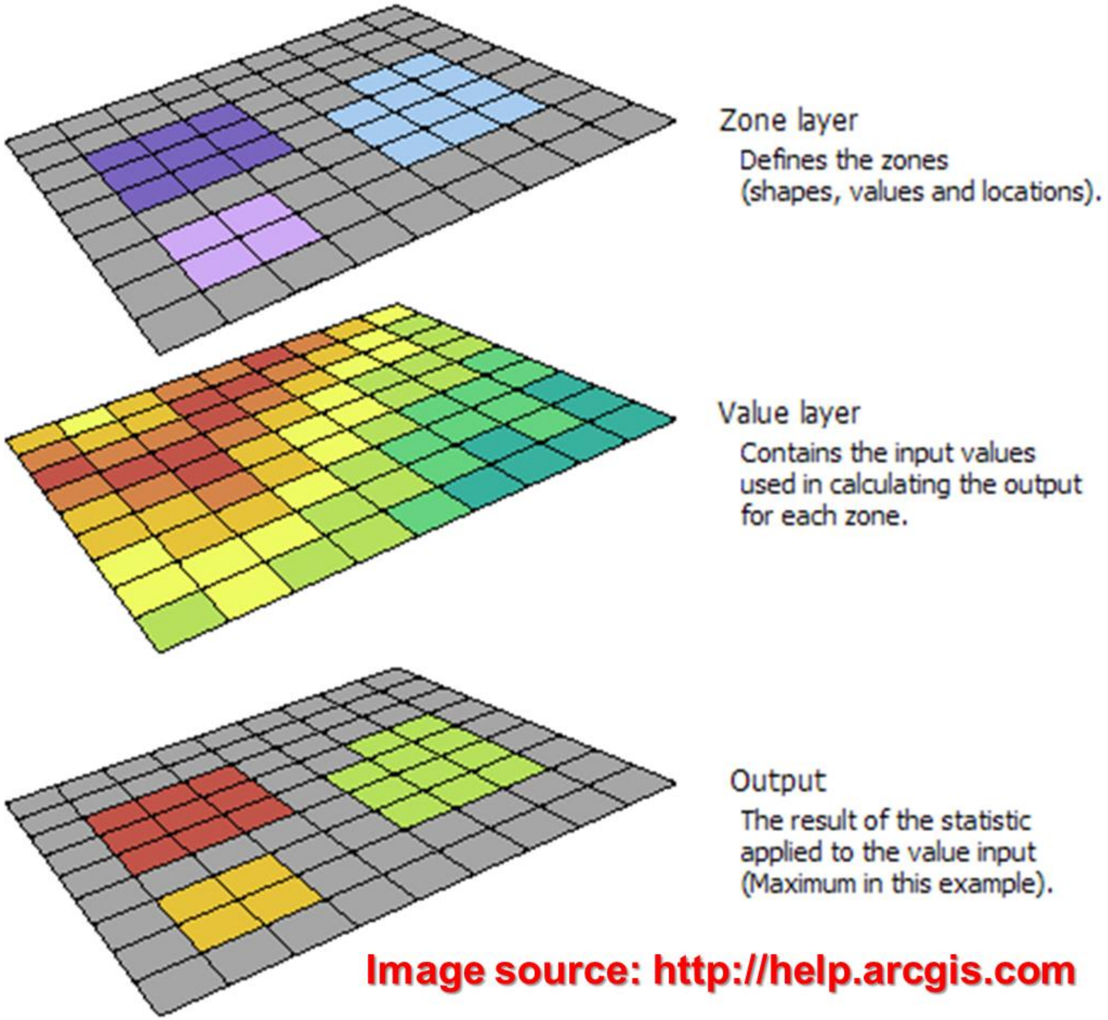
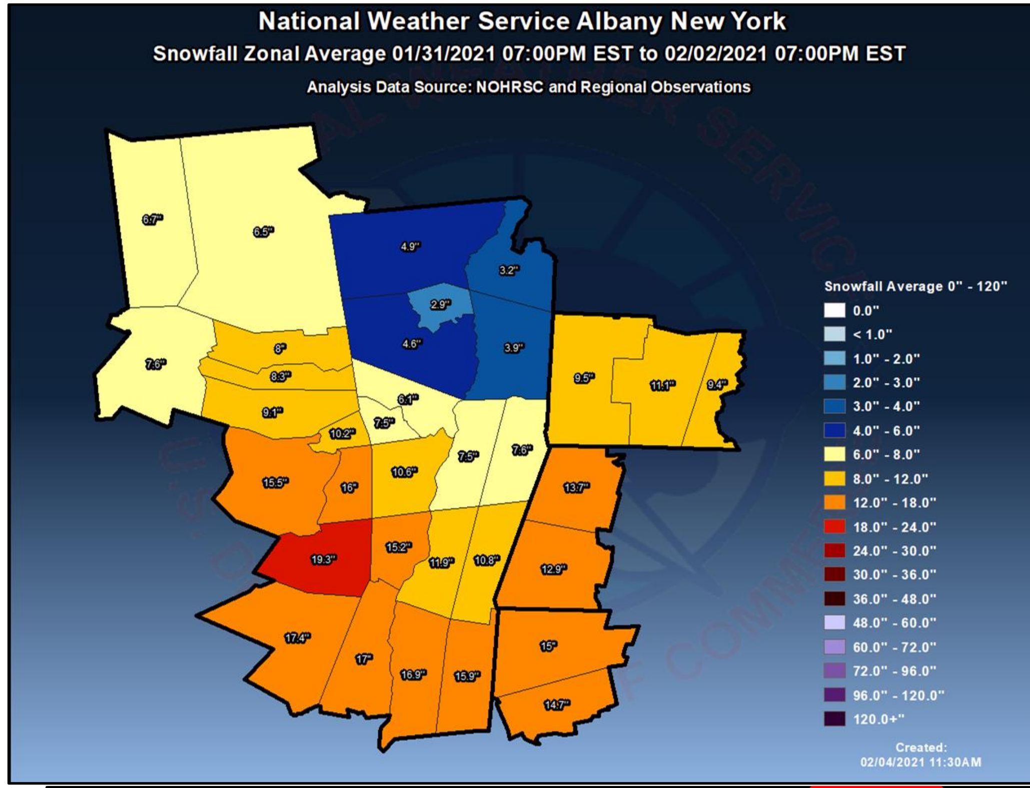


Image source: http://help.arcgis.com

Zone-based Snowfall Verification

- Output via map, with more specific data in spreadsheet format
- **Mean** snowfall for each zone used for NWS snowfall verification

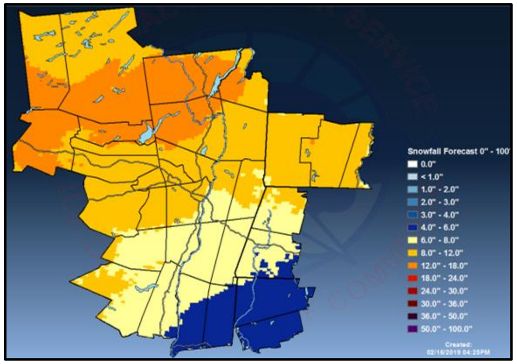


	A	B	C	D	E	F
1	NAME	MIN	MAX	RANGE	MEAN	STD
2	NY083:Southeast Warren	12.1	23.4	11.3	21	1.4
3	NY050:Southern Saratoga	13	21.1	8.1	18	1.3
4	NY057:Delaware	7.9	17	9.1	12.3	1.8
5	NY060:Western Columbia	5.6	12	6.4	8.9	1.3
6	NY038:Southern Herkimer	10.3	20.4	10.1	15.6	2.7
7	NH007:Sullivan	7.4	13.4	5.9	10.6	1.5
8	NY052:Eastern Albany	10.4	17.2	6.8	13.9	0.9
9	NY032:Northern Herkimer	11	19.3	8.3	15.4	2.5
10	NY046:Otsego	8.2	19.1	10.9	13.5	2.2
11	NY029:Southeastern St. Lawrence	10	13.9	3.8	12.2	0.7
12	NY042:Northern Warren	13	23.4	10.5	19.5	2.1
13	VT015:Eastern Windham	9.4	15.4	6	12.7	1

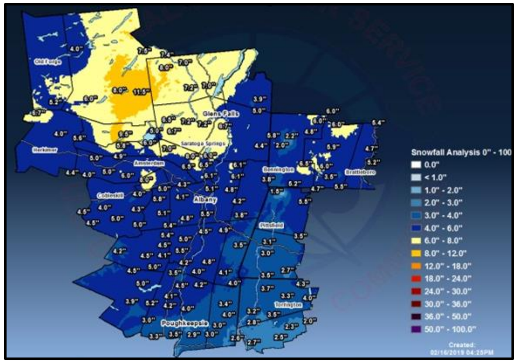
Creation of Forecast Error Maps

- Methodology: Create gridded observed snowfall map after an event, then subtract from the forecast snowfall (obtained via NWS **N**ational **D**igital **F**orecast **D**atabase)

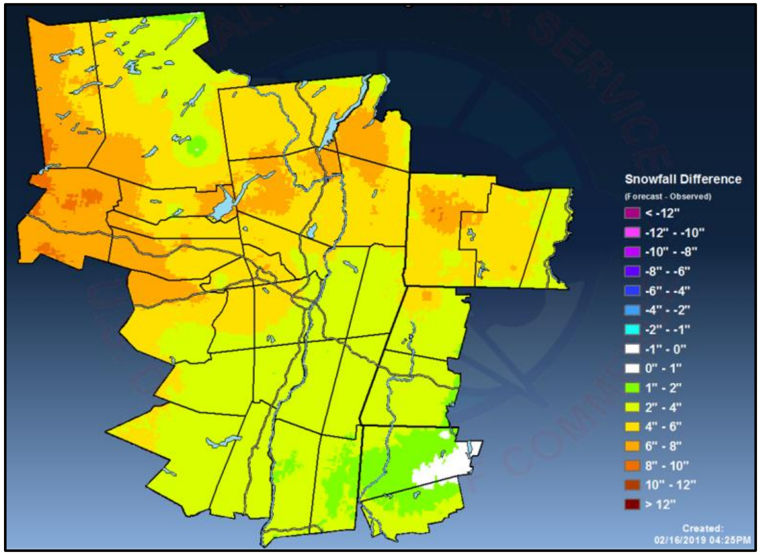
NDFD Forecast Snow



Minus



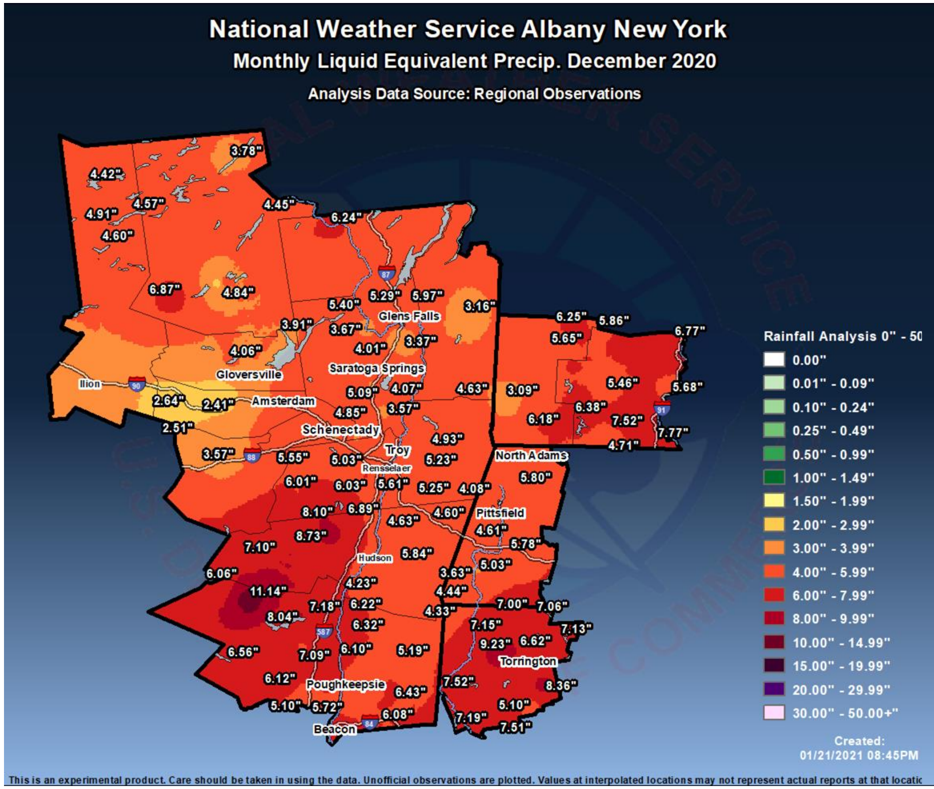
Observed Snow



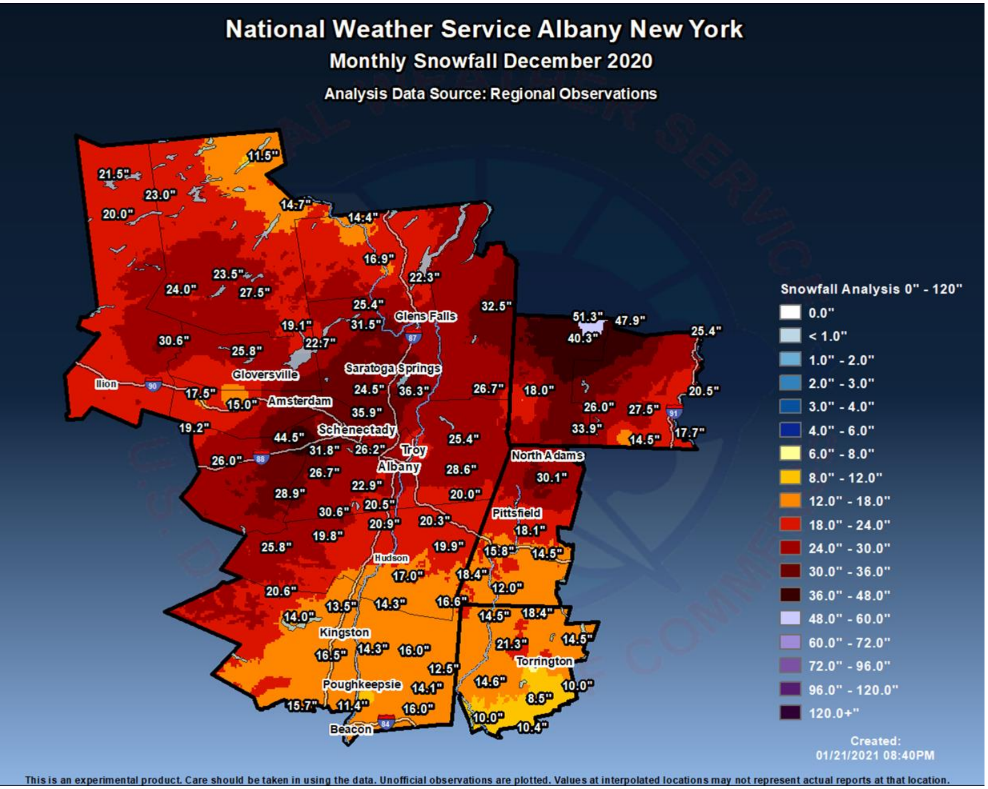
Difference

Monthly Rainfall/Snowfall Maps

Rainfall December 2020



Snowfall December 2020

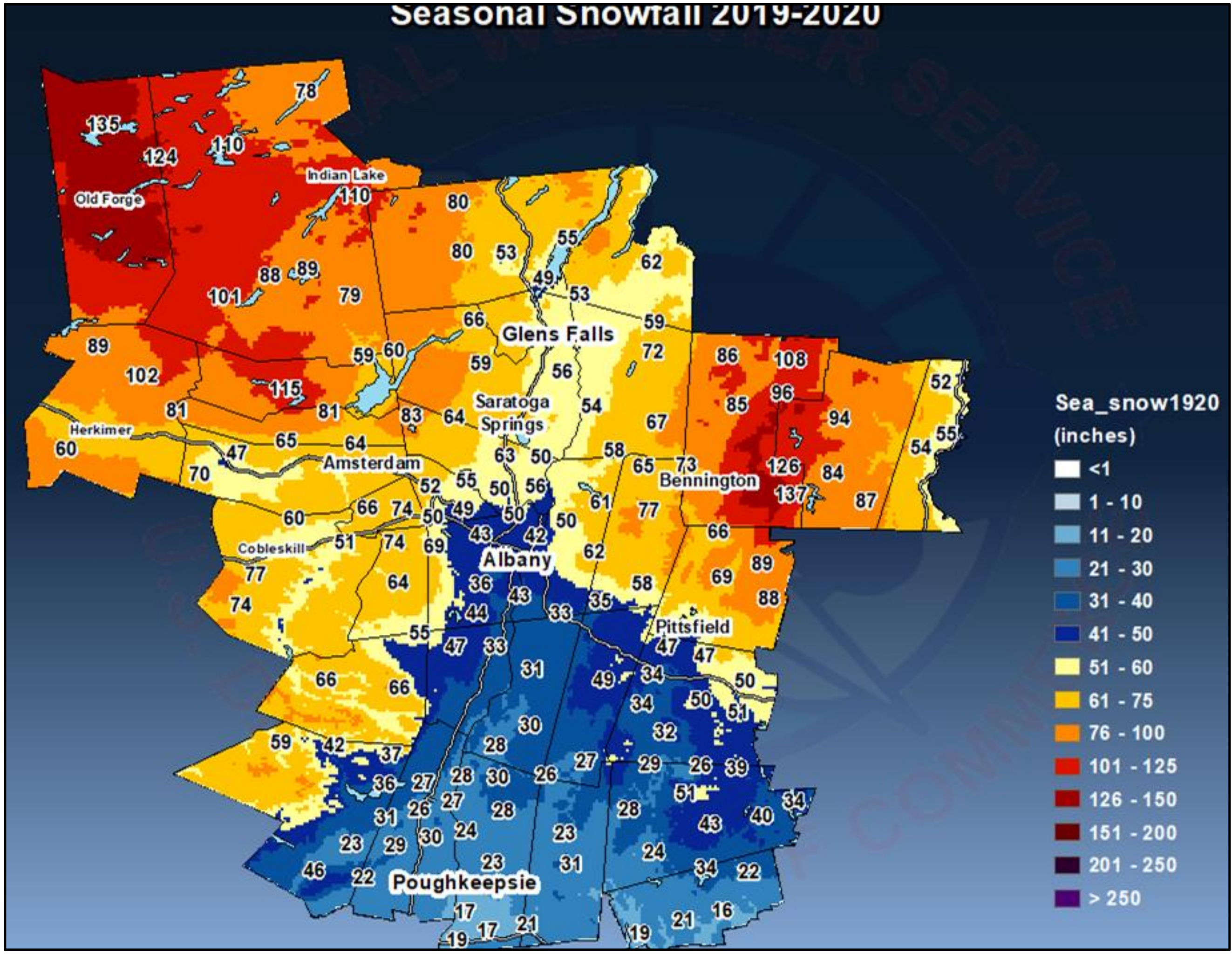


- Same method used for event precipitation analysis maps, but instead using monthly rainfall/snowfall reports (based on local reports from observers)

Seasonal Snowfall Map

- Methodology: Compile (SUM) monthly observed snowfall maps from October through April using ArcMap
- Color scale & range bins must be altered to account for large snow totals

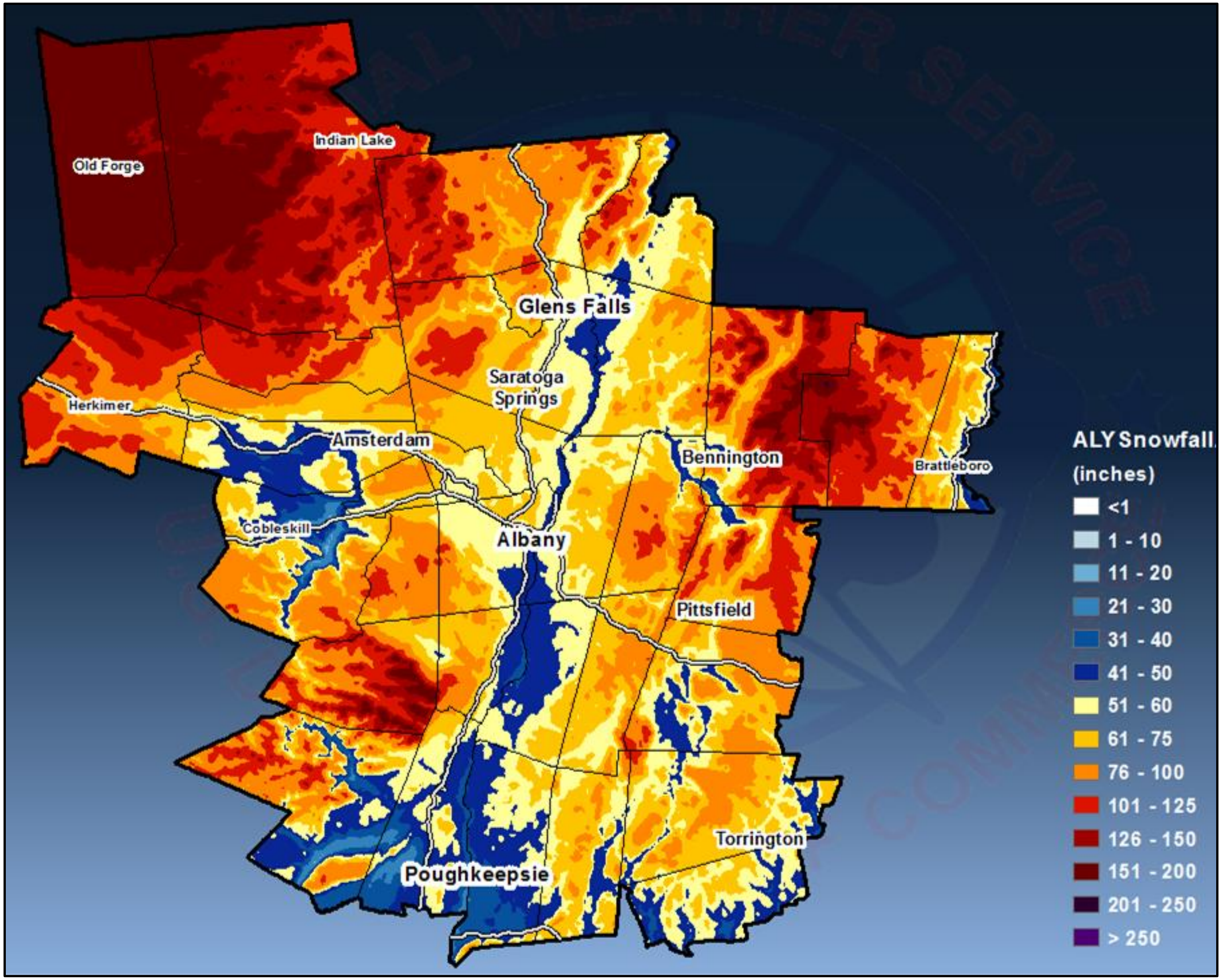
2019-20 Seasonal Snowfall



Climatology Snowfall Map

- Use 30-year climate normals from Cooperative Weather Observers to create a snowfall analysis

1981-2010 Seasonal Snowfall Climatology



Snowfall Composites Stratified by 925mb Flow Regime

- Identify patterns of snowfall distribution based on low level flow regime
- Use Albany, NY sounding data to determine wind at 925 mb
- Sounding time (0000 UTC or 1200 UTC) closest to midpoint of each event

KALB (72518) 30/00 4245 -7348 92m LI (500mb):
WMO PARTS INCLUDED: TTAA TTBB PPBB TTCC TTDD PPDD

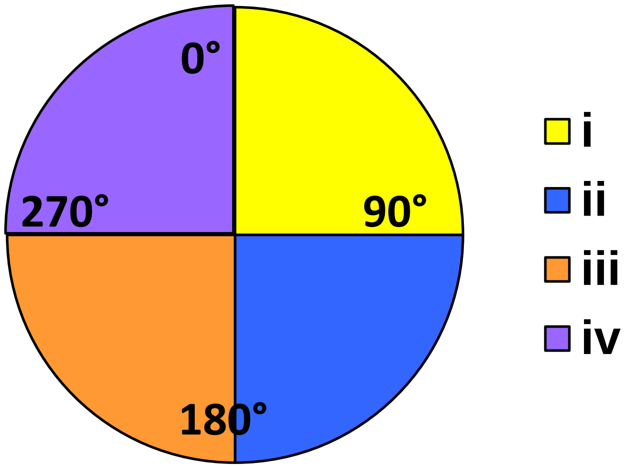
PRESS MB	TEMP C	DWPT C	WDIR DEG	WSPD KNTS	HGHT M	THTA K
1010.0	17.4	12.7	0.0	0.0	92.0	289.7
1000.0	16.2	11.2	35.0	3.0	179.0	289.4
985.3	15.4	9.1	55.0	5.0	304.8	289.7
965.0	14.2	6.2	92.1	5.6	481.3	290.3
950.5	13.0	6.4	110.0	7.0	609.6	290.4
925.0	11.0	6.7	130.0	11.0	837.0	290.6
923.0	11.0	7.0	131.3	11.2	856.4	290.7
916.6	10.8	6.6	135.0	12.0	914.4	291.1
892.0	9.8	5.1	154.0	8.0	1140.6	292.3
886.0	9.8	0.8	161.6	7.3	1196.9	292.9
883.6	9.7	0.9	165.0	7.0	1219.2	293.0
875.0	9.2	1.2	159.4	6.6	1300.4	293.3
865.0	9.2	-5.8	152.1	6.3	1395.5	294.3
850.0	8.8	-7.2	140.0	6.0	1540.0	295.4
844.0	8.4	-7.6	136.4	4.2	1602.2	295.5
829.0	9.0	-16.0	28.3	1.0	1751.8	297.7
821.3	8.7	-16.7	345.0	3.0	1828.8	298.2
792.0	7.6	-19.4	149.4	1.9	2126.8	300.1
791.3	7.6	-19.4	150.0	2.0	2133.6	300.1
783.0	7.0	-19.0	168.3	1.7	2219.7	300.4
762.3	5.1	-8.8	220.0	2.0	2438.4	300.7
759.0	4.8	-7.2	227.7	2.0	2473.7	300.7
746.0	5.2	-3.8	254.3	2.4	2614.1	302.7
734.2	4.2	-4.8	270.0	3.0	2743.2	303.0
707.0	2.0	-7.0	180.0	3.0	3048.0	303.8
700.0	1.4	-7.6	165.0	7.0	3128.0	304.0

Example of Data Selection

Snowfall Composites Stratified by 925 mb Flow Regime

- Stratify by wind direction & speed at 925 mb:
  - **4 quadrants for wind direction**
  - **3 categories for speed**
- **= 12 combined categories**

Quadrants



Speed category	
1	0-19 kt
2	20-39 kt
3	40+ kt

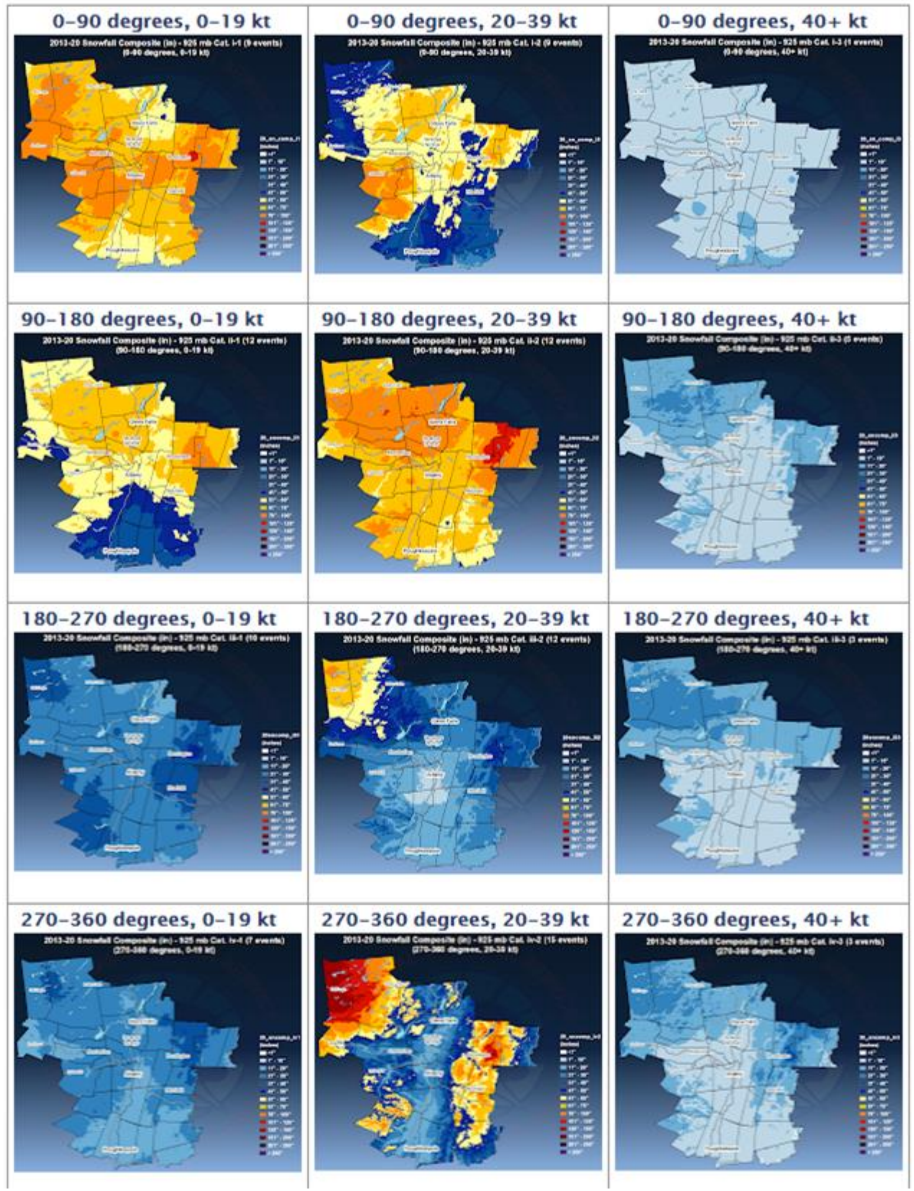
Snowfall Composites Stratified by 925 mb Flow Regime

	A	B	C	D	E	F	G
1	925 mb	I-1	I-2	I-3		II-1	II-2
2		20170331_0600-20170401_1800	20170123_1800-20170125_1800	20130307_1800-20130308_1800		20170212_1200-20170213_1800	20170117_1800-20170118_1800
3		20170314_0000-20170315_1200	20160205_0600-20160205_1800			20170131_1200-20170201_1200	20161207_0000-20161207_1800
4		20170107_0000-20170108_1200	20150126_1800-20150128_0600			20150208_0600-20150210_1200	20161205_0000-20161205_1800
5		20160208_1200-20160209_1200	20141209_0600-20141211_1200			20140204_1800-20140206_0000	20150202_0000-20150203_0000
6		20160117_1800-20160118_1200	20140312_1200-20140313_1800				20131214_1200-20131215_1800
7		20140121_1800-20140122_1200	20140213_1200-20140214_1800				
8		20140102_0000-20140103_1800	20130318_1800-20170319_1800				
9		20130208_0600-20130209_1800					
10							
11							
12							
13							
14							
15	850 mb	I-1	I-2	I-3		II-1	II-2
16		20170209_0600-20170210_0000	20150126_1800-20150128_0600	20140213_1200-20140214_1800		20170331_0600-20170401_1800	20170212_1200-20170213_1800
17		20170107_0000-20170108_1200	20141209_0600-20141211_1200			20170314_0000-20170315_1200	20170123_1800-20170125_1800
18		20140121_1800-20140122_1200	20130318_1800-20170319_1800			20140204_1800-20140206_0000	20160208_1200-20160209_1200
19			20130307_1800-20130308_1800				20140102_0000-20140103_1800
20							20131214_1200-20131215_1800
21							20130208_0600-20130209_1800

- Separate events into the 12 categories using a spreadsheet
- 81 total events from 2014-2019 winter seasons

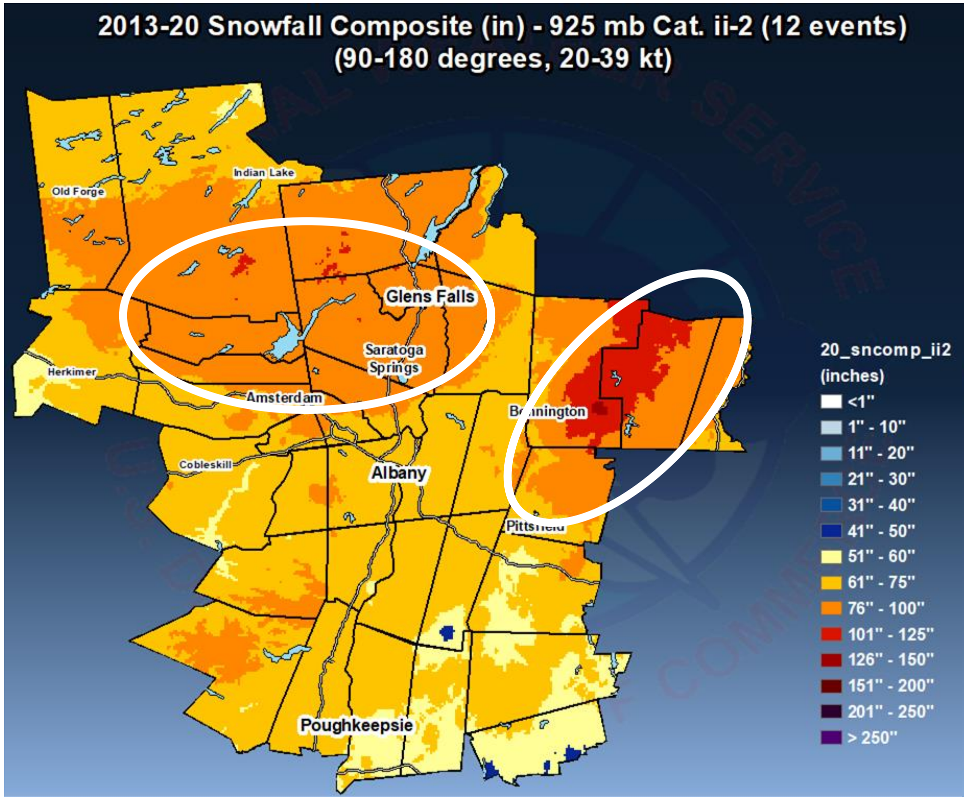
Snowfall Composites Stratified by 925 mb Flow Regime

- Sum the snowfall analyses for events in each of the 12 categories using 925 mb wind at Albany



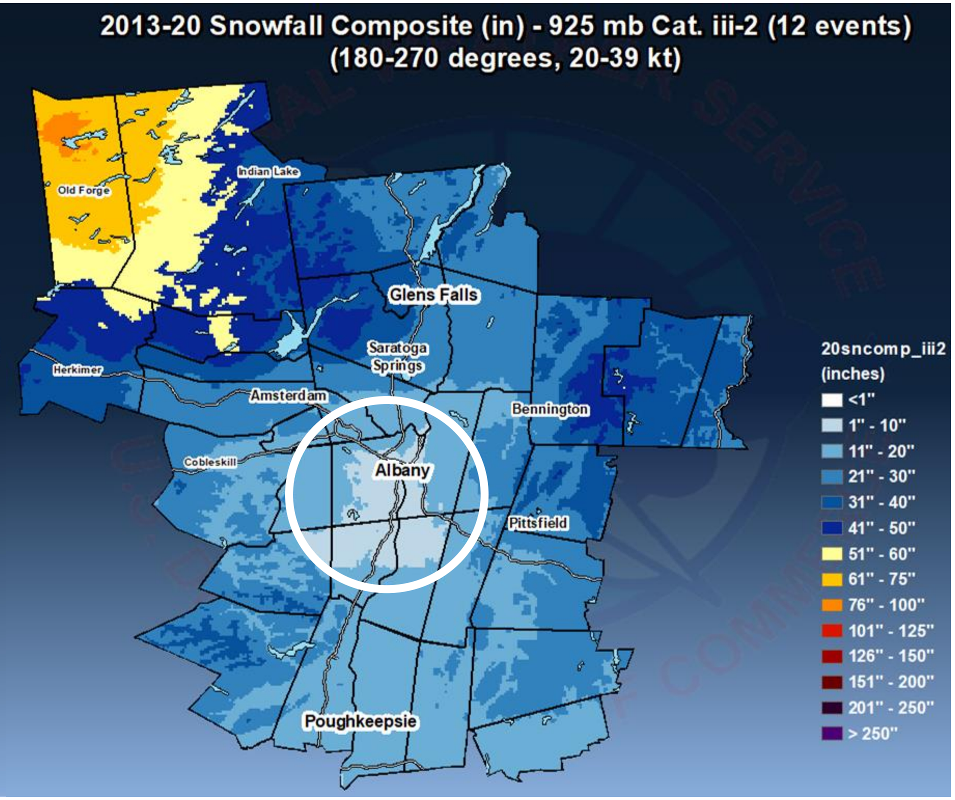
Snowfall Composites: Notable Regimes

Moderate SE Flow



Maximum snowfall in favored upslope areas north and east of Albany

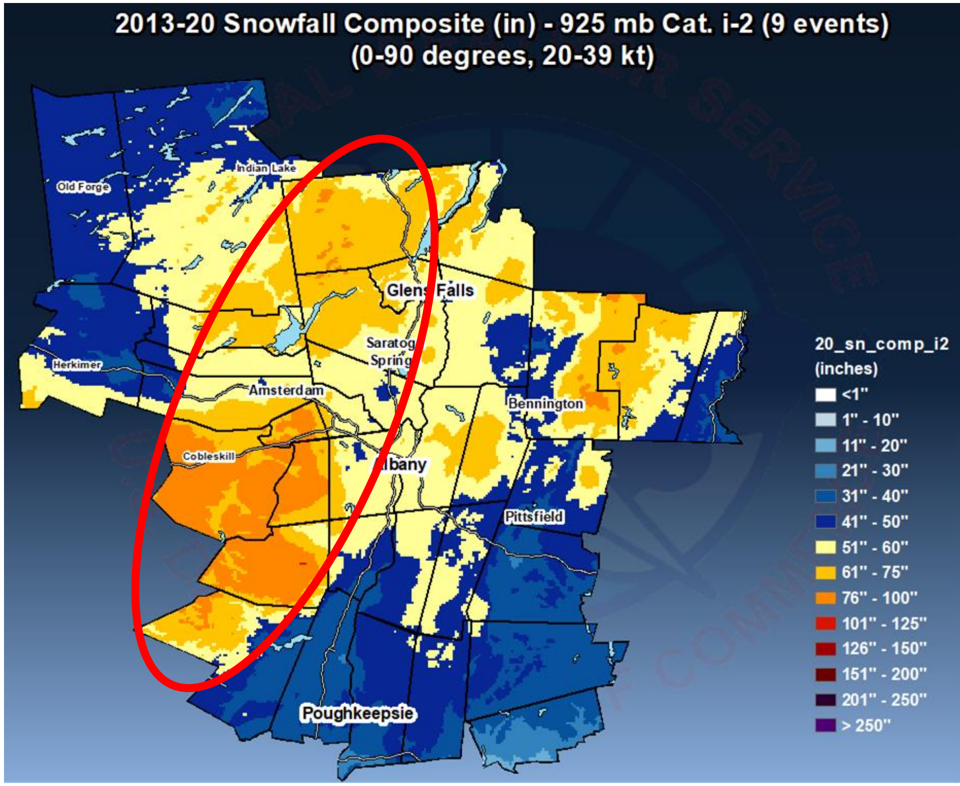
Moderate SW Flow



"Snow hole" in Albany area due to down-sloping off Catskills

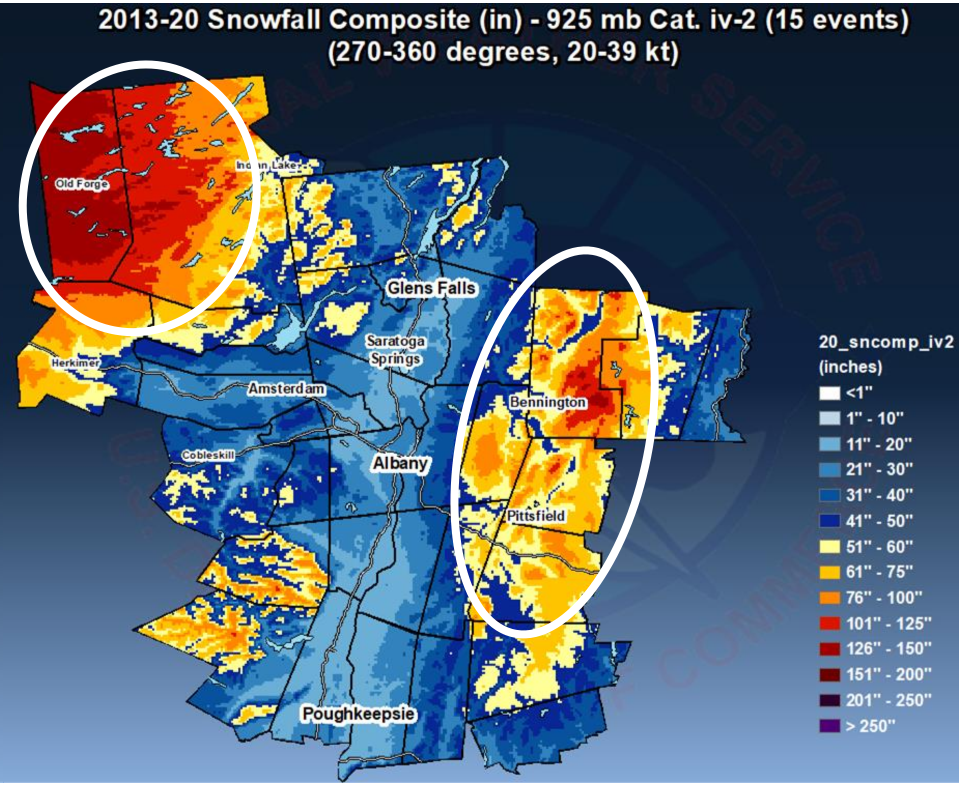
Snowfall Composites: Notable Regimes

Moderate NE Flow



Snowfall dominated by Nor'Easters

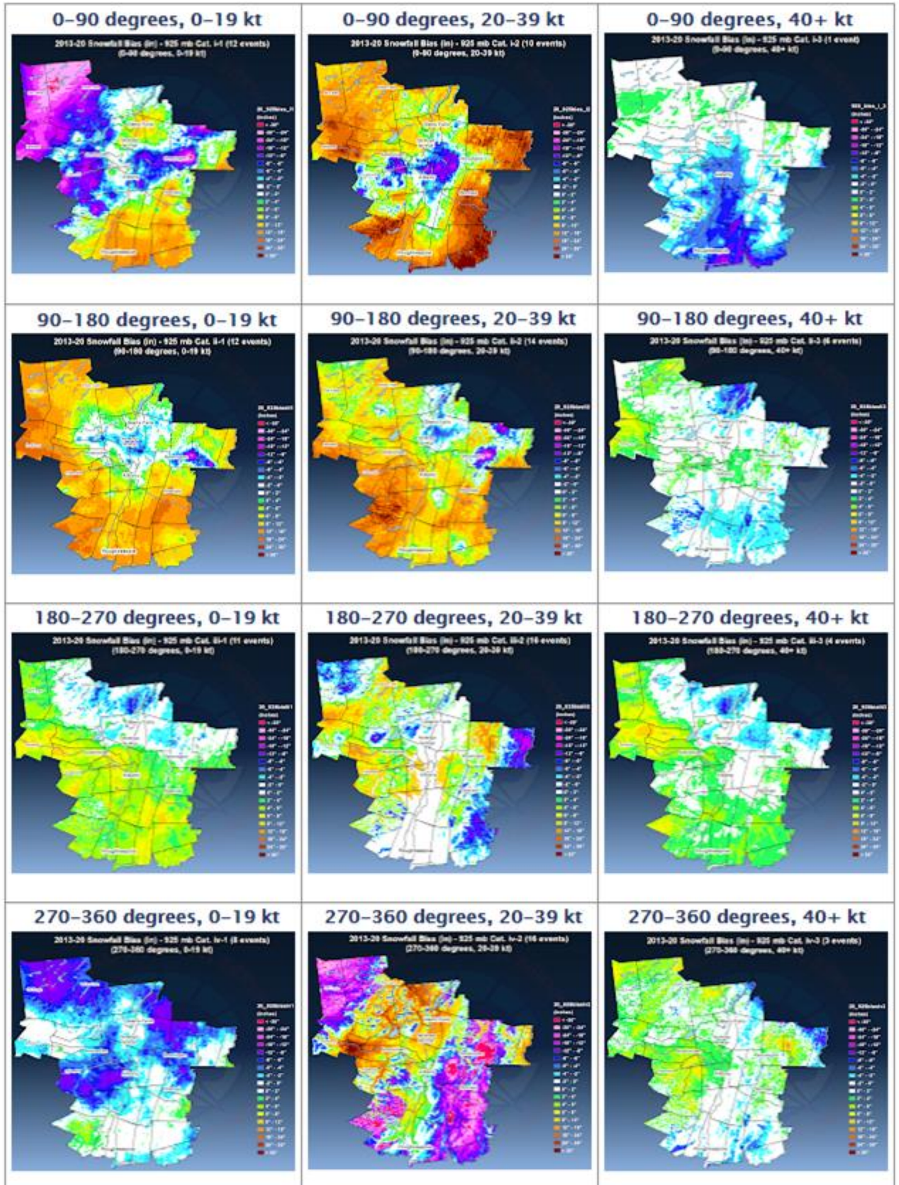
Moderate NW Flow



Maximum snowfall in favored upslope areas of Adirondacks and Taconics, Green Mountains & Berkshires

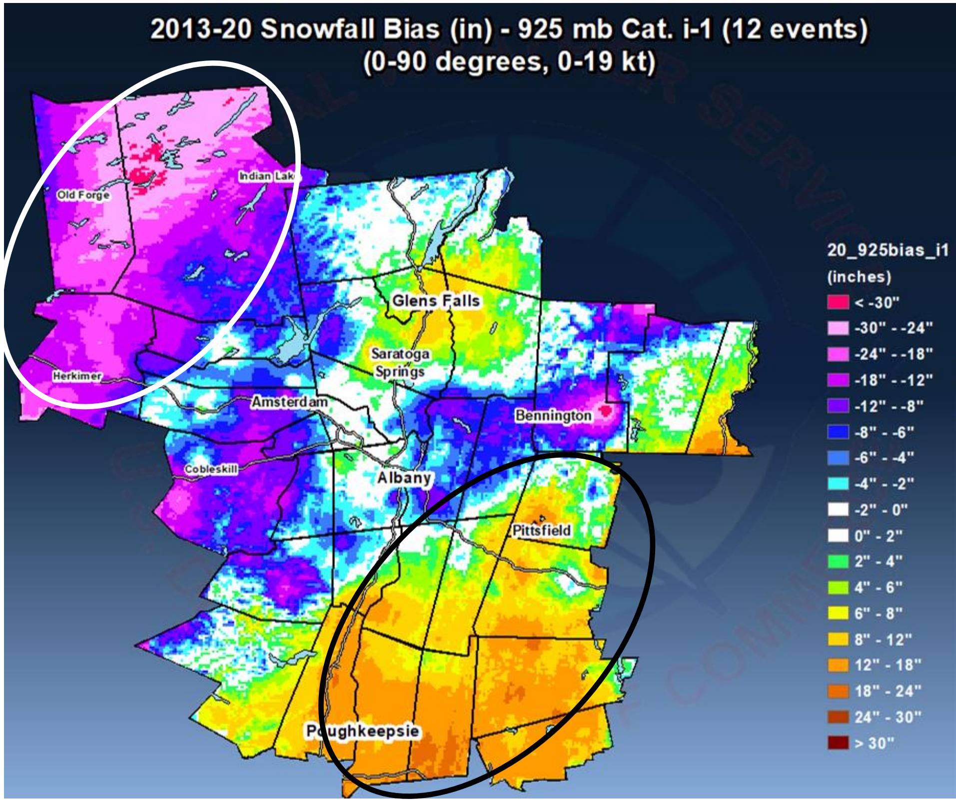
Snowfall Error Maps Stratified by Flow Regime

- Same methodology as snowfall composites, but summing difference maps for events in each of the 12 categories using 925 mb wind at Albany
- Used for assessing +/- forecast biases



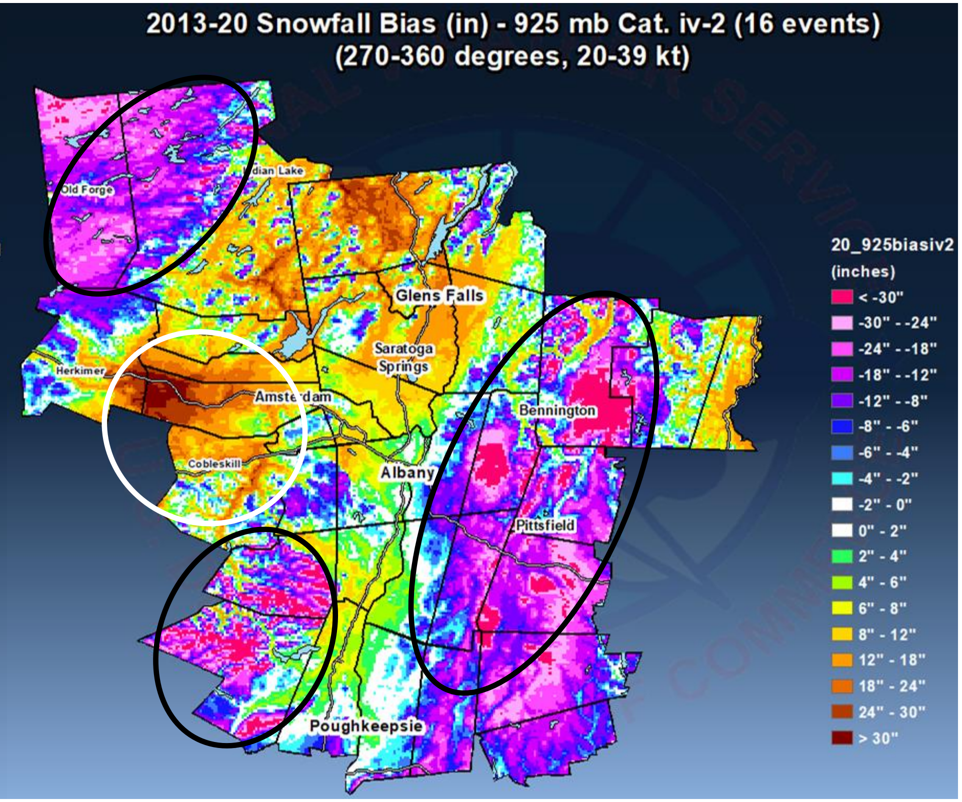
Error Maps: Notable Regimes

Weak NE Flow



Negative/positive snowfall forecast errors likely due to max QPF displacement error

Moderate NW Flow

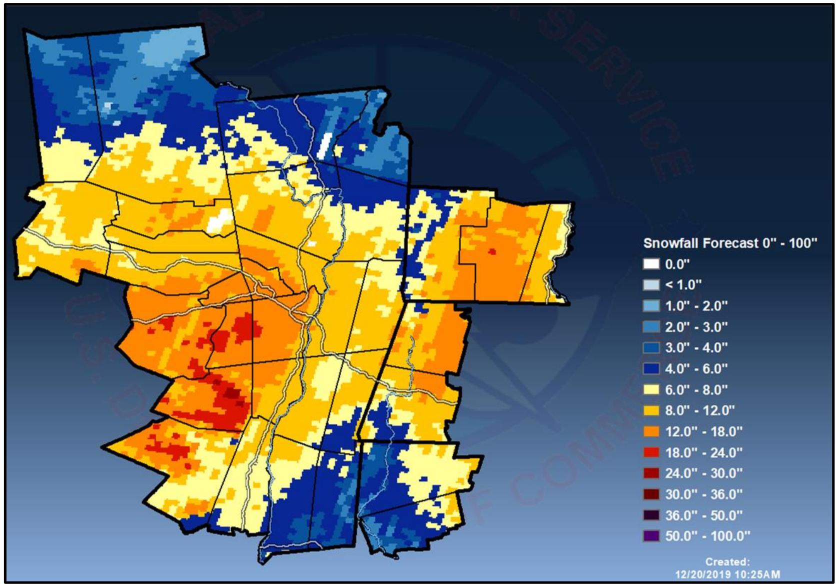


Under-forecast of upslope and lake effect snow

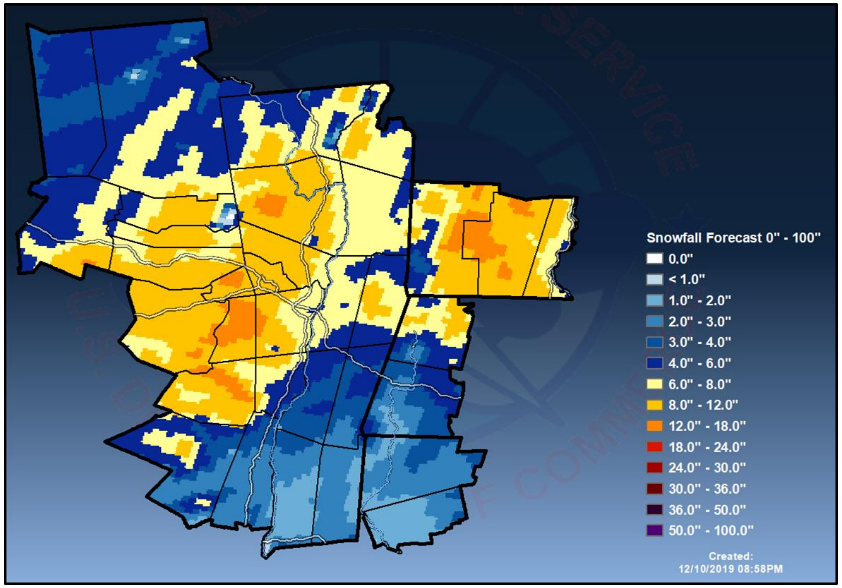
Over-forecast in “snow shadowing” areas

HRRR and NAMNest Snowfall Verification

- NWS Albany verifies snowfall from high-resolution models such as the 3 km HRRR and NAMNest
- Use **positive snow depth change** from beginning to end of an event



HRRR
1-3 Dec 2019

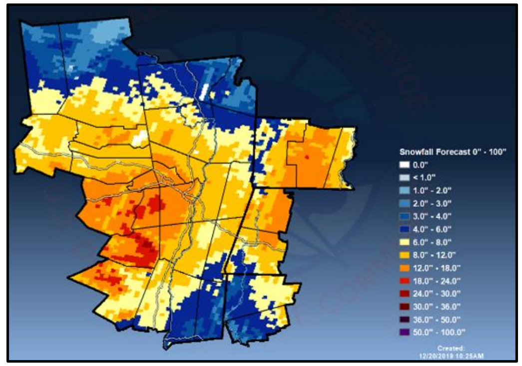


NAMNest
1-3 Dec 2019

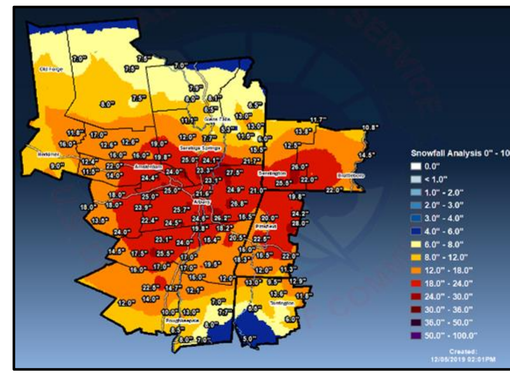
HRRR and NAMNest Snowfall Verification

- The change in snow depth more accurately depicts model snowfall (correspondence with EMC)
- Subtract observed snowfall from model positive snow depth change (using ArcMap) for each event to determine model forecast error

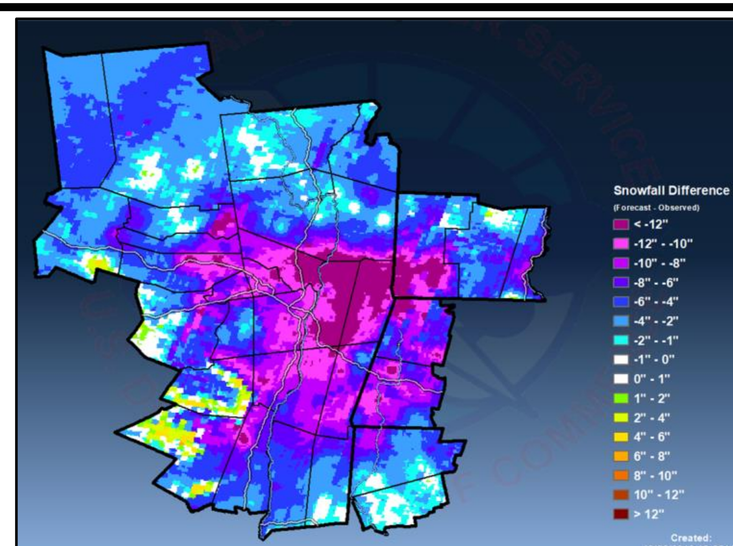
HRRR Pos SD Change



Minus



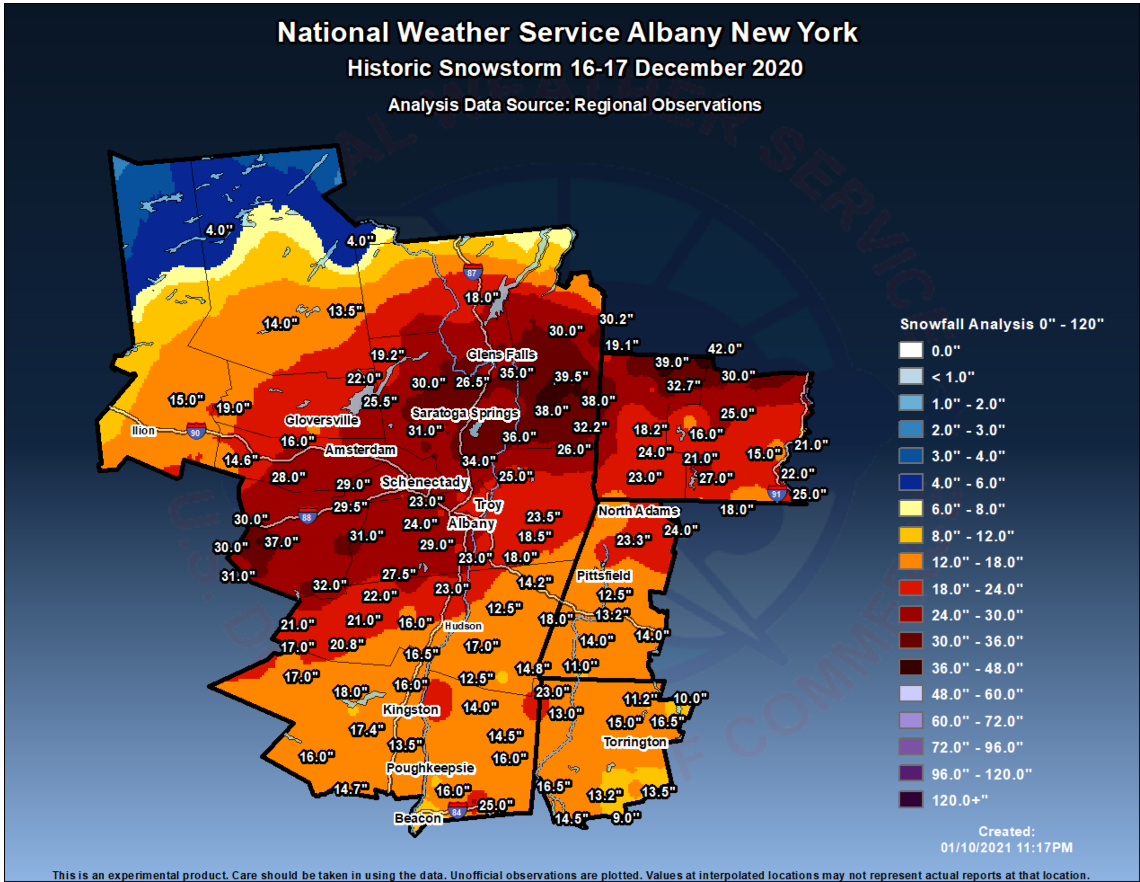
Observed Snow



Difference

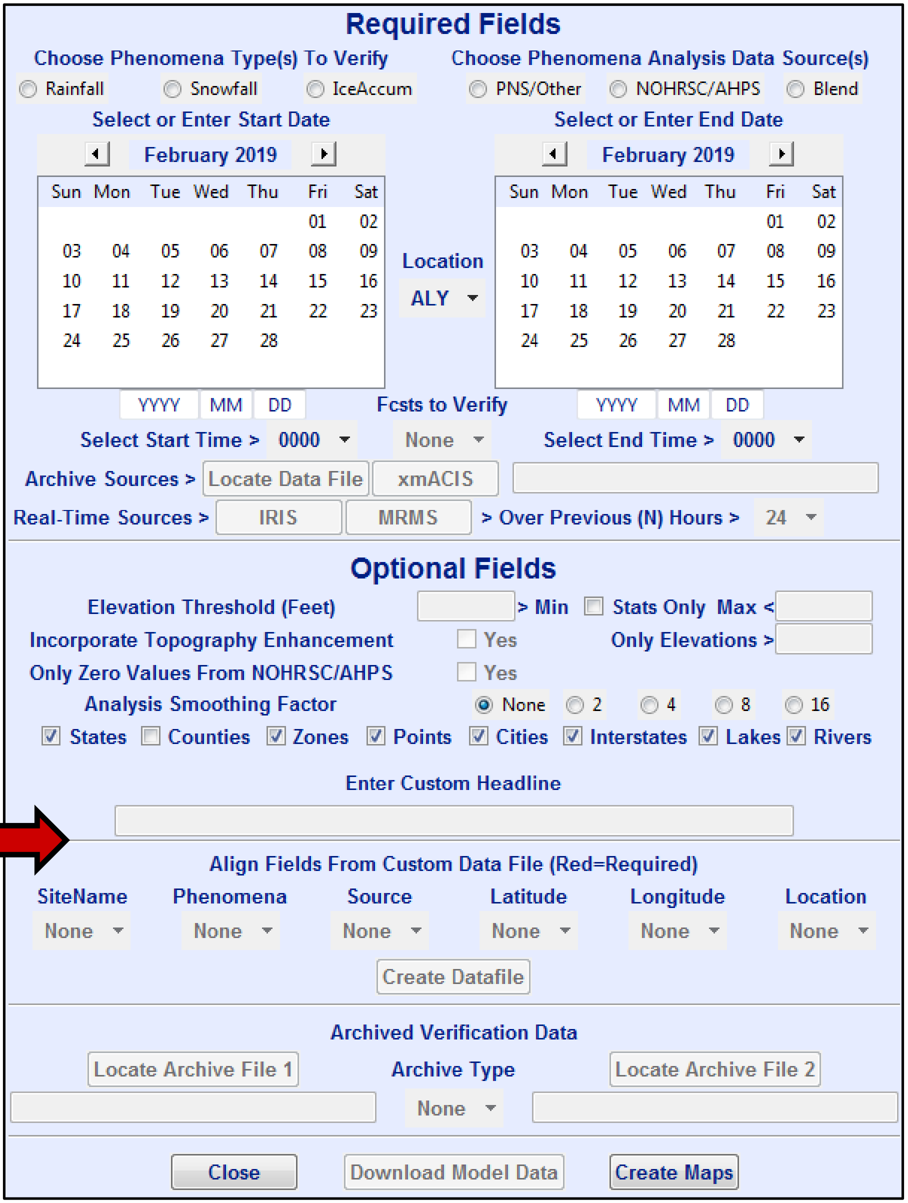
Automation using GIS Scripting: The "GAZPACHO" Program

- Not talking about cold soup here…
- **GAZPACHO =** Gridded Automated Zonal Precipitation And Complete Hi-res Output
- GAZPACHO is a program that was created to assist NWS Weather Forecast Offices with snowfall verification (rainfall added)



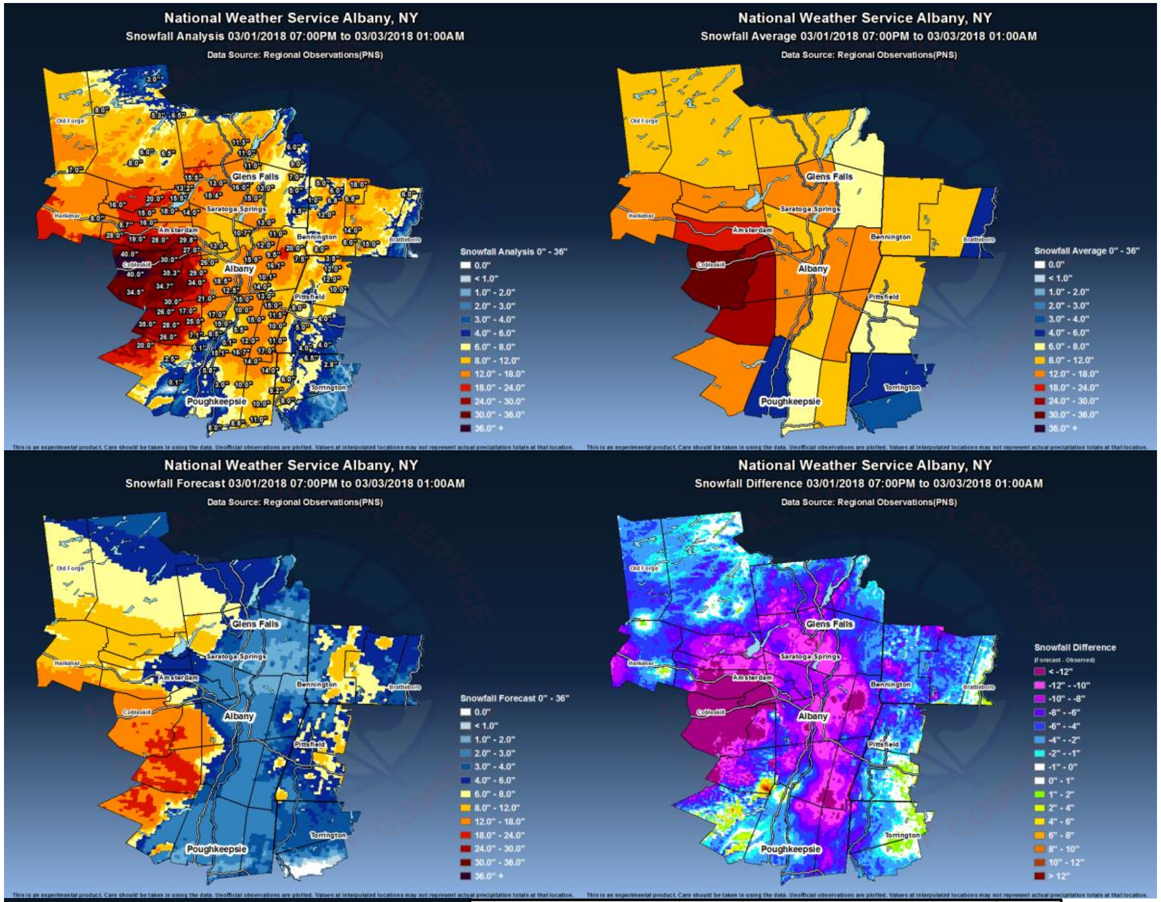
Automation using GIS Scripting: The "GAZPACHO" Program

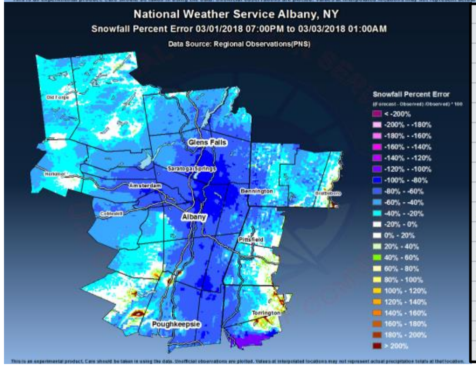
- Created by Danny Gant (Morristown, TN), Vasil Koleci & Joe Villani (Albany, NY)
- Uses ArcGIS software and Python scripts
- GAZPACHO is run on a PC (with ArcGIS 10.8 installed) via a simple GUI



What is GAZPACHO

- Creates maps of:
- Observed precipitation (rain or snow)
- Zone-average rain/snow
- NWS forecast or model rain/snow (HRRR, NAMNest and NAM)
- Difference (or error) maps of forecast minus observed rain/snow (inches and %)
- Spreadsheet table of zone-average statistics

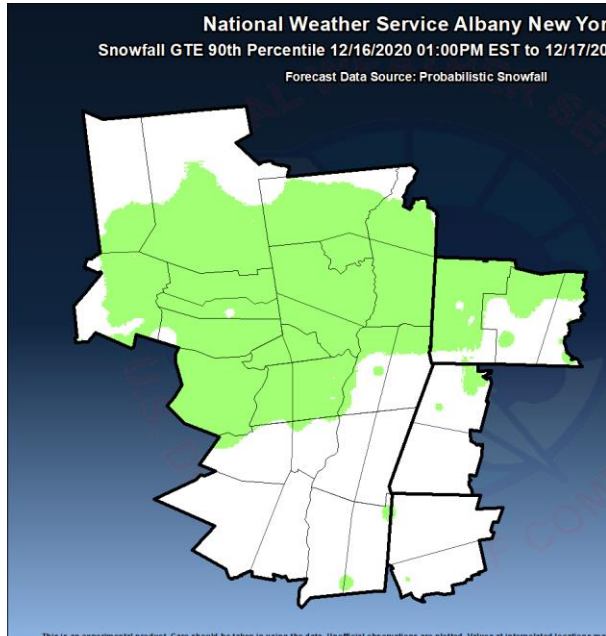


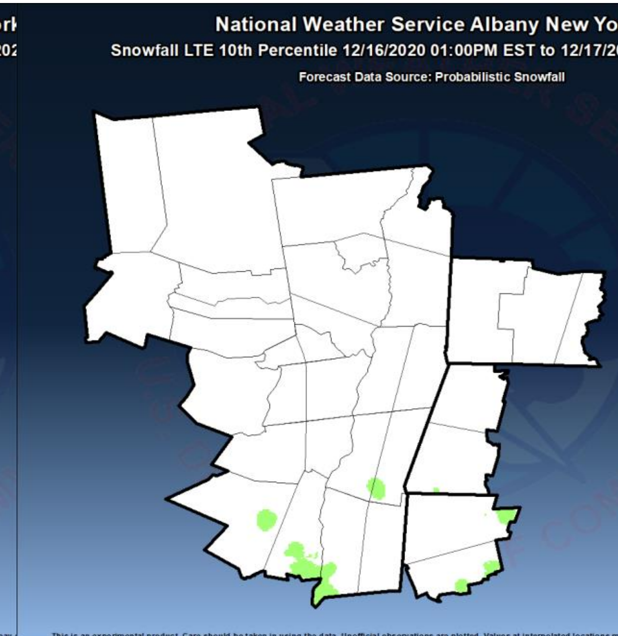


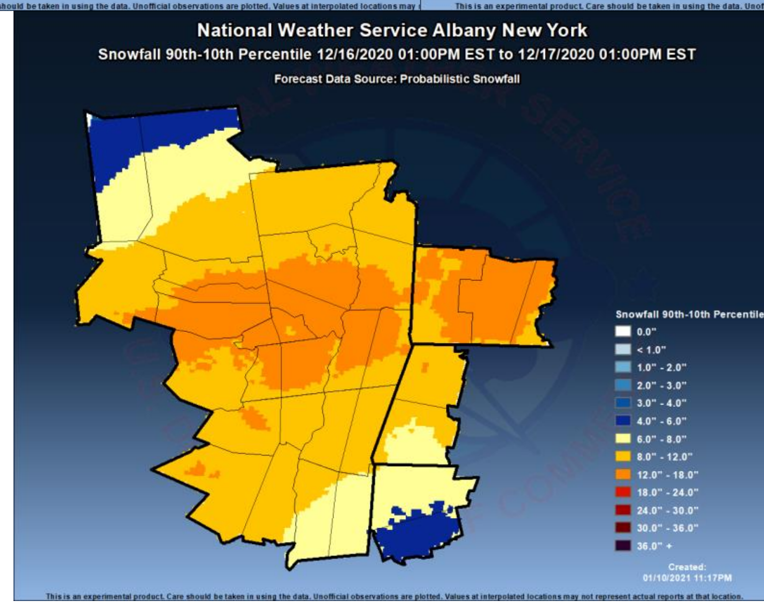
	A	B	C	D	E	F	G
1	NAME	MIN	MAX	RANGE	MEAN	STD	SUM
2	NY033:Hamilton	2	20.3	18.3	9	3.4	68045.7
3	NY040:Montgomery	8.7	32	23.4	21.8	5	36949.1
4	NY047:Schoharie	24.4	41.4	17	33.1	3.2	84837
5	VT013:Bennington	0.6	18.1	17.4	10.1	3	28266.1
6	CT001:Northern Litchfield	0.3	17	16.7	5.8	2.8	13861.1
7	CT013:Southern Litchfield	0.4	9.2	8.8	3.5	1.5	5005.8
8	MA025:Southern Berkshire	1.5	18.2	16.8	6.8	2.6	14415.9
9	MA001:Northern Berkshire	3	15.8	12.8	8.9	2.3	15532
10	NY084:Southern Washington	2.4	14.3	11.9	7.8	2.1	15503.6
11	NY043:Northern Washington	1.8	16.4	14.6	7.4	2.9	11254.5
12	NY042:Northern Warren	3	20.1	17	11.1	3	36642.1
13	NY083:Southeast Warren	6.6	18.1	11.4	13	2.4	7398.6
14	NY039:Southern Fulton	13.6	21.6	8	17.2	1.9	14898.4
15	NY082:Northern Fulton	13.5	22.9	9.4	17.9	2.2	23869.2
16	NY032:Northern Herkimer	7	14.7	7.7	10.8	1.8	34557
17	NY038:Southern Herkimer	7	23.7	16.8	15.2	3.3	43453.4

What is GAZPACHO

- Also verifies some Probabilistic Snowfall Forecast data:
- Areal coverage of observed (analyzed) snowfall > 90th percentile
- Areal coverage of observed (analyzed) snowfall < 10th percentile
- Difference of 90th minus 10th percentile ('goal posts')

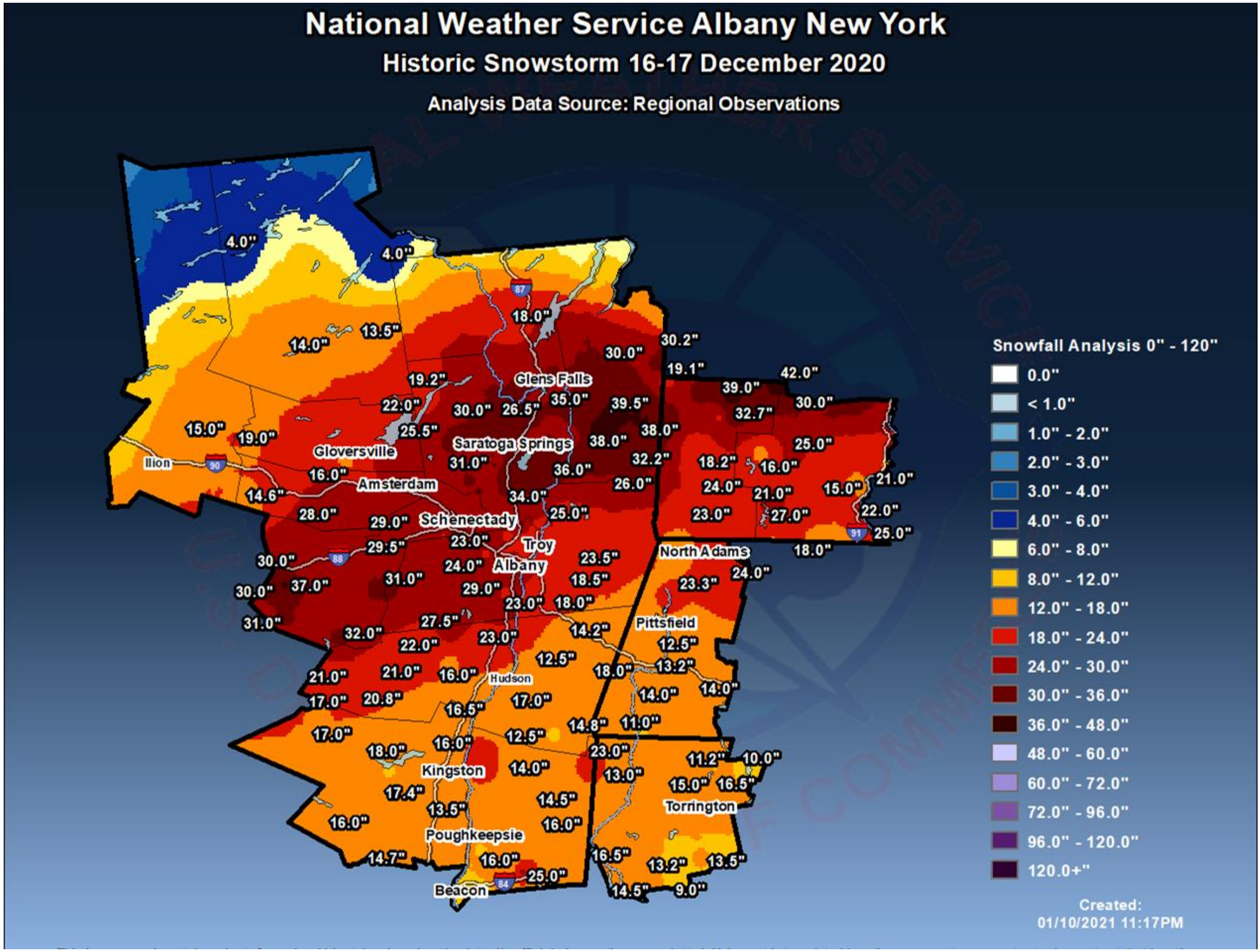






Case Study using GAZPACHO

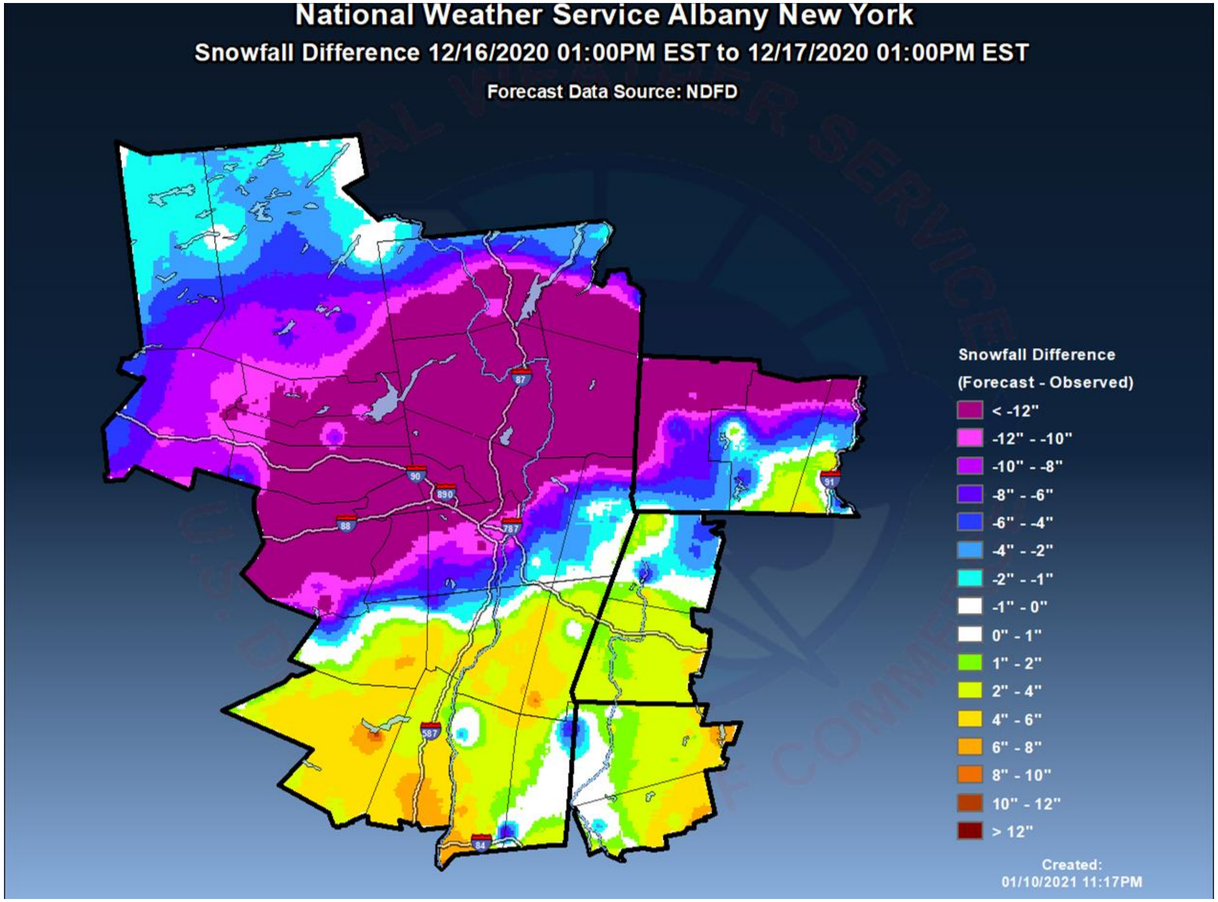
- **Snowfall analysis** based on interpolated observations from 16-17 December 2020 Snowstorm



Observed Snowfall 16-17 December 2020

Case Study using GAZPACHO

- **Difference map** computed from official NWS Albany forecast minus observed analysis
- Large under-forecast error in the Capital District and areas north/west
- Large errors due to both band placement and magnitude of snowfall rates

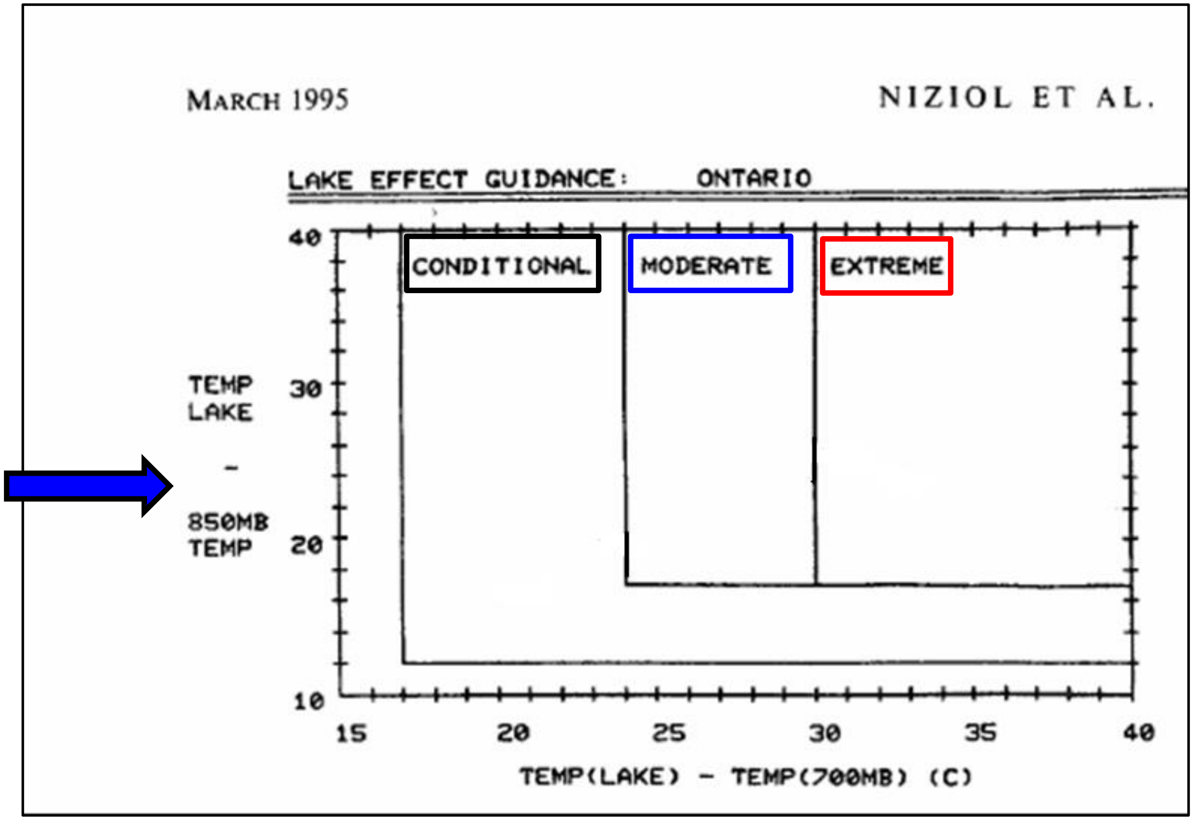


Forecast Error
16-17 December 2020

Forecasting Lake Effect Snow

- Instability Class (derived from lake/air temp differences) used to assess potential strength of lake effect snow bands

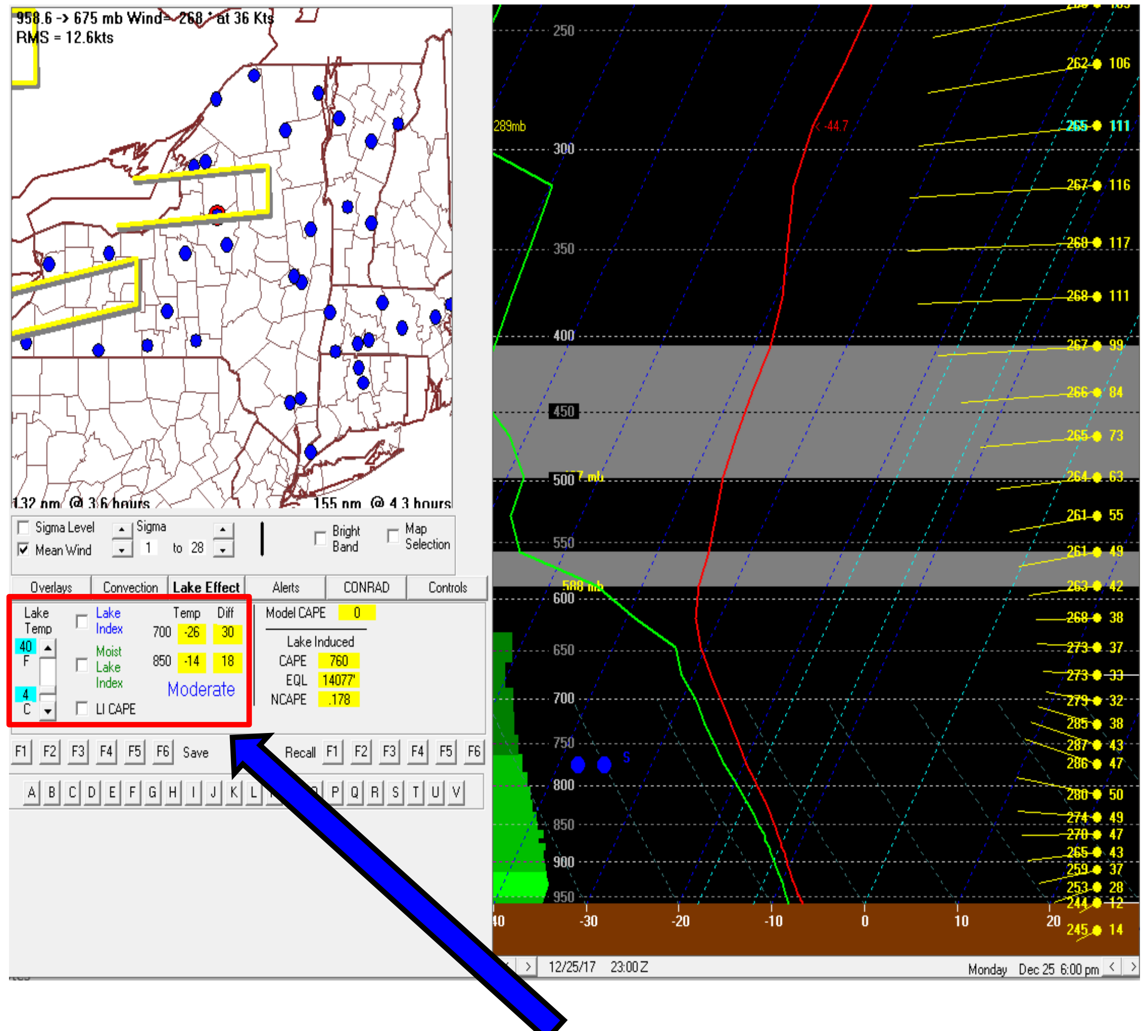
- Three main categories:
  1) **Conditional**
  2) **Moderate**
  3) **Extreme**



Niziol Instability Class

Forecasting Lake Effect Snow

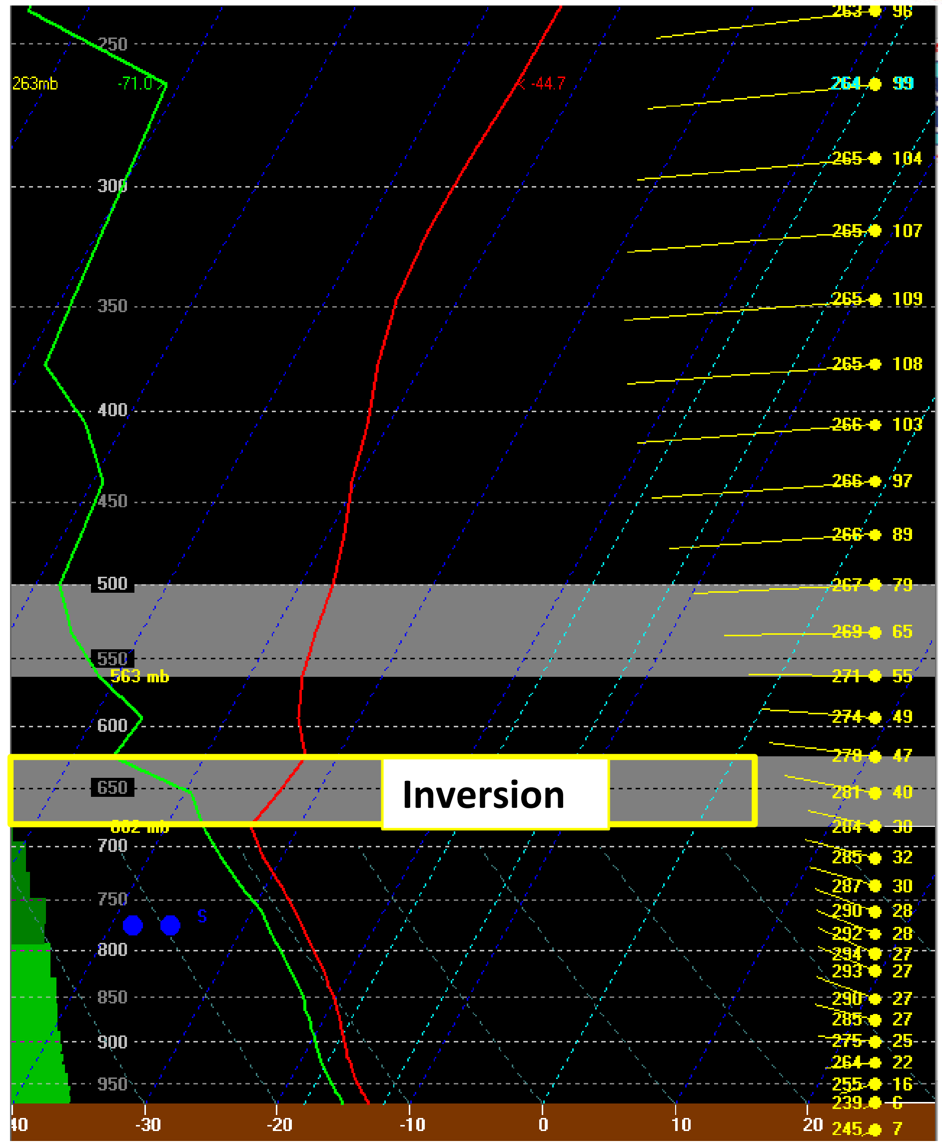
- From Niziol, 1987
- **Conditional:** Heavy snowfall rates possible with trajectories along the longest fetch of the lake and 500 mb cyclonic vorticity advection (CVA)
- **Moderate:** Heavy snowfall rates can occur with moderately long trajectories & 500 mb CVA
- **Extreme:** Heavy snowfall rates possible with little dependence on fetch or CVA



BUFKIT – Instability category (must obtain observed lake temperature too)

Forecasting Lake Effect Snow

- **<u>Inversion heights</u>** also used to determine potential strength of lake effect snow bands
- Higher inversion heights result in a deeper mixed layer and taller convective plumes
- Inversion heights of 750 mb (~2.5 km) and higher can be associated with intense snow bands, assuming other favorable factors are present

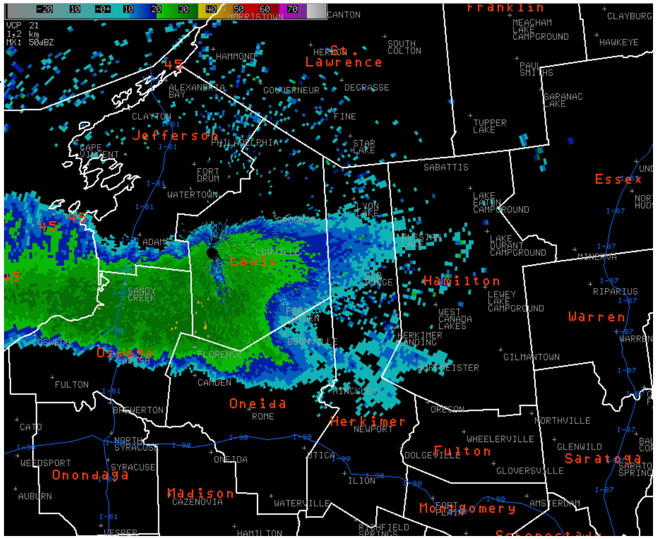


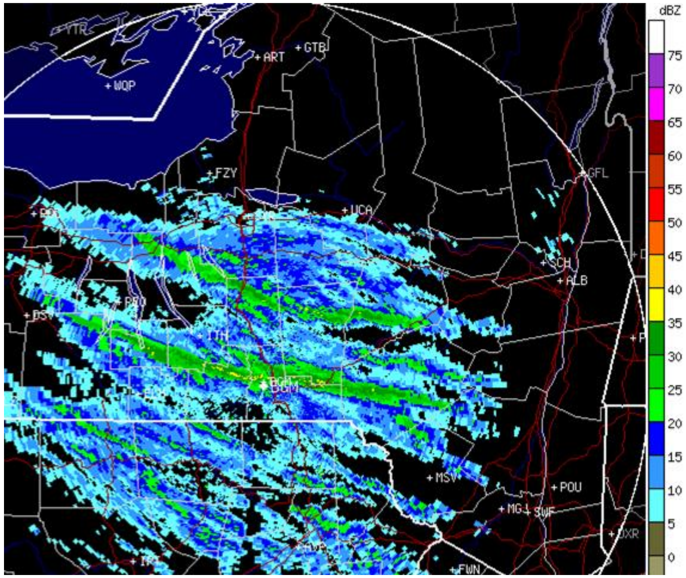
BUFKIT – KRME NAM 26 December 2017

Forecasting Lake Effect Snow

Flow trajectory can be determined by using the mean wind in the mixed layer. Flow trajectory and fetch modulate the location and classification of snow bands as:

Single Band: wider in shape; typically more intense

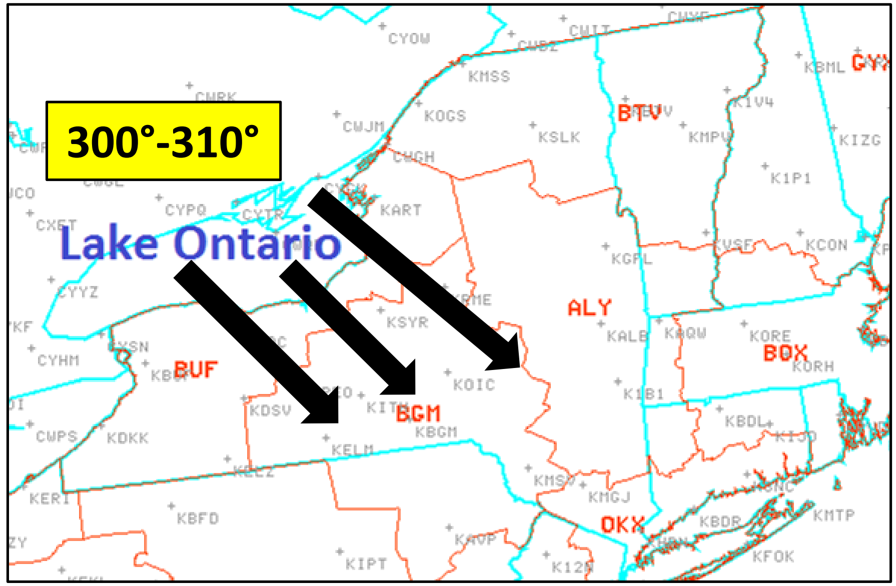




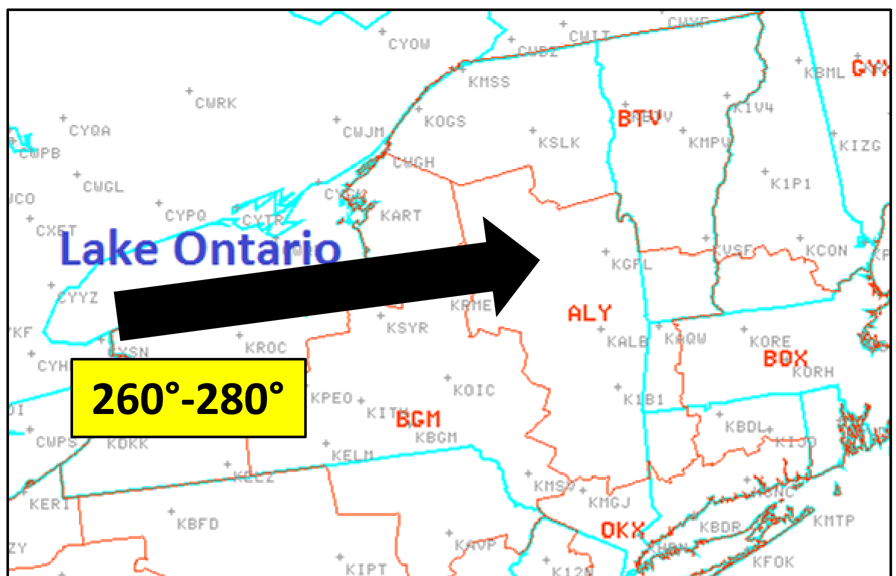
Multi Band: narrower; typically weaker due to smaller fetch

Forecasting Lake Effect Snow

- **<u>Multi bands</u>** typically affect the southern Mohawk Valley, Schoharie Valley, and eastern Catskills with a 300° to 310° flow trajectory



- **<u>Single bands</u>** can affect the central and northern Mohawk Valley (even rarely the Capital District), and especially the western Adirondacks with a 260° to 280° flow trajectory



Limiting Factors

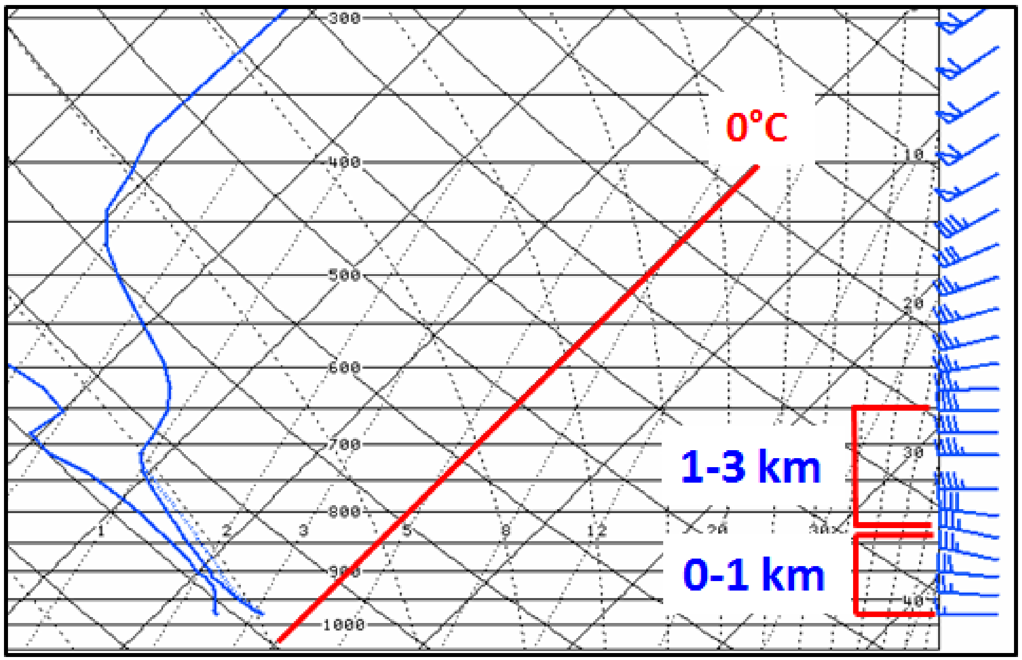
- Shallow inversion heights result in very weak snow showers/flurries
- If the directional wind shear is > 30° snow bands tend to become less organized or break up
- Diurnal mode especially early/late season, as bands tend to become cellular during the daylight hours

Forecast Challenges

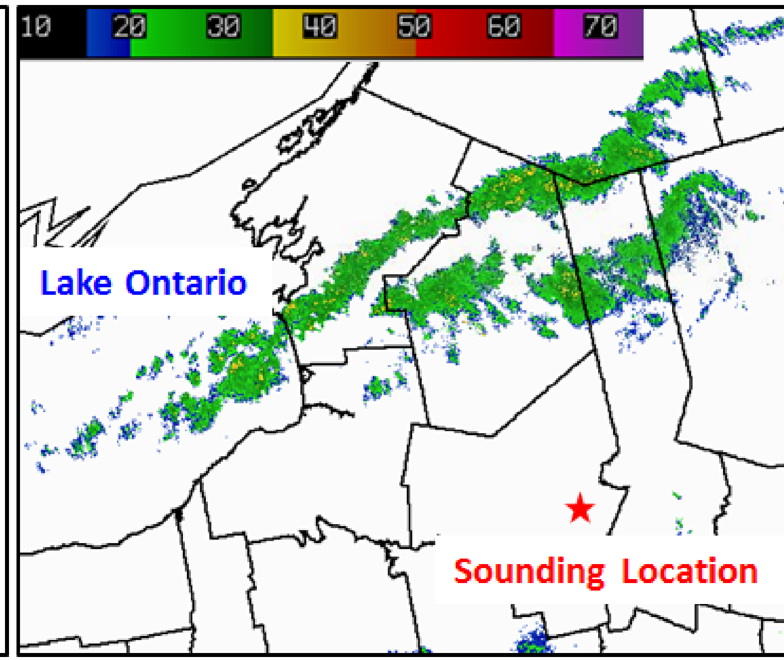
- Inland extent of snow bands: Not always modulated by wind speed; can lead to over-forecasting significant events
- Model forecasts of QPF associated with LES can be highly inaccurate at times
- Snow to liquid ratios can range from 15:1 to as much as 30:1 (even rare occasions of > 50:1)

Favorable Env. far-reaching Inland Extent

- Type A
- MLC present (not shown)
- Strong 0-1 km shear; weak shear in 1-3 km layer
- Conditional lake-induced instability



(a)

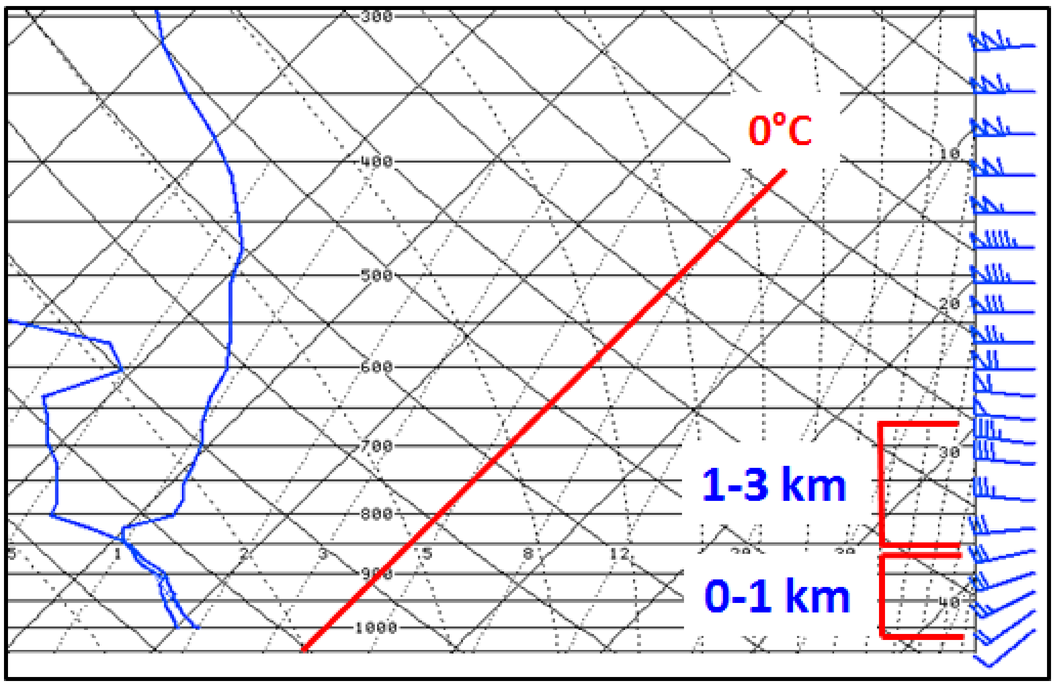


(b)

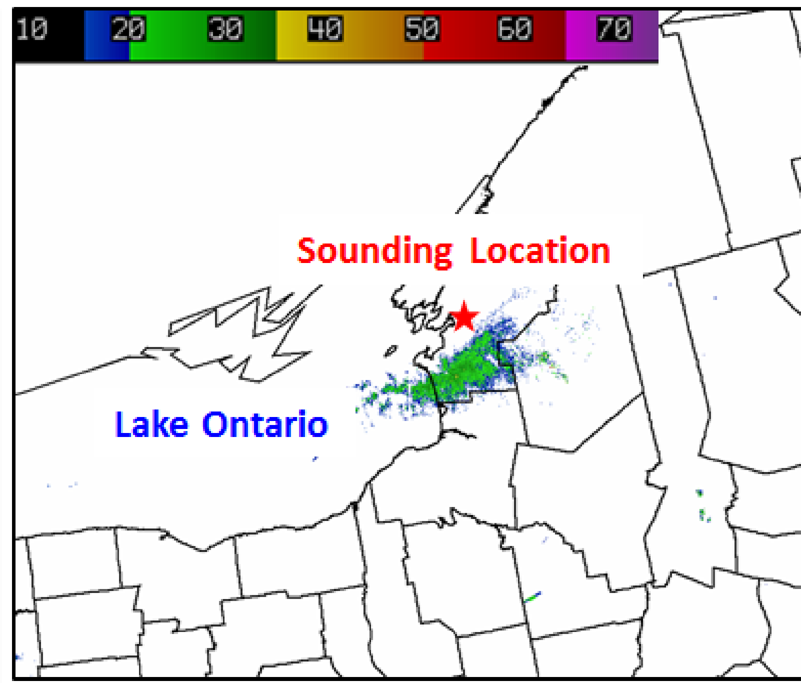
(a) Example of a Type A sounding (0-hr NAM sounding from near KUCA) featuring strong 0–1-km bulk shear (weak in 1–3-km layer) and conditional instability. (b) Associated 0.5° reflectivity (dBZ) at time of sounding. Sounding and radar image from 1200 UTC 2 January 2012

Non-Favorable Env. far-reaching Inland Extent

- Type B
- MLC not present (not shown)
- Weak 0-1 km shear; stronger shear in 1-3 km layer
- Extreme lake-induced instability



(a)



(b)

As in previous figure except for a Type B event from 1200 UTC 8 January 2014.

Questions/Comments?

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