# Forecasting Topographically-generated winter weather hazards (focus on the eastern U.S.)

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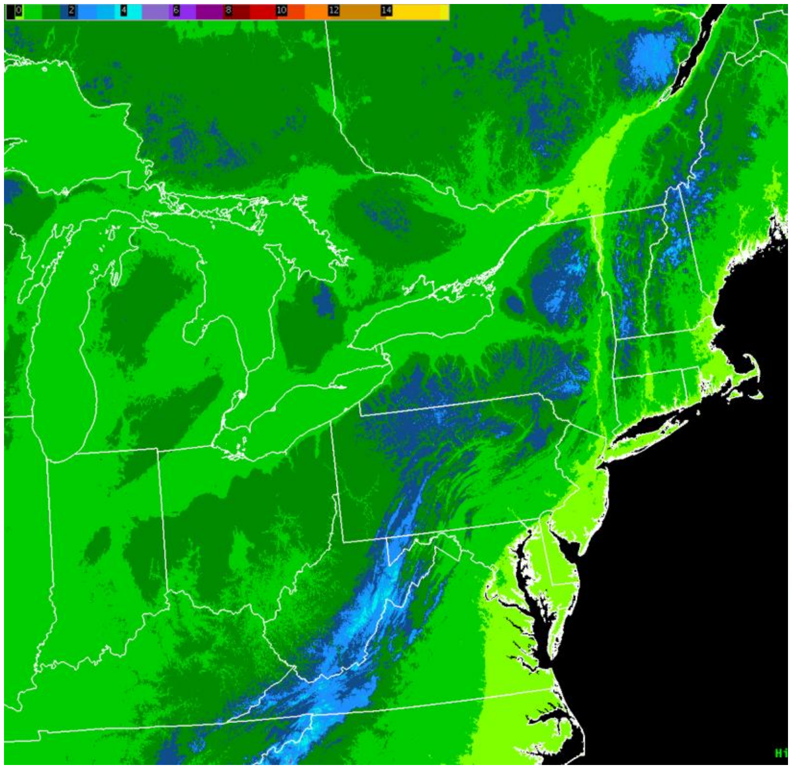
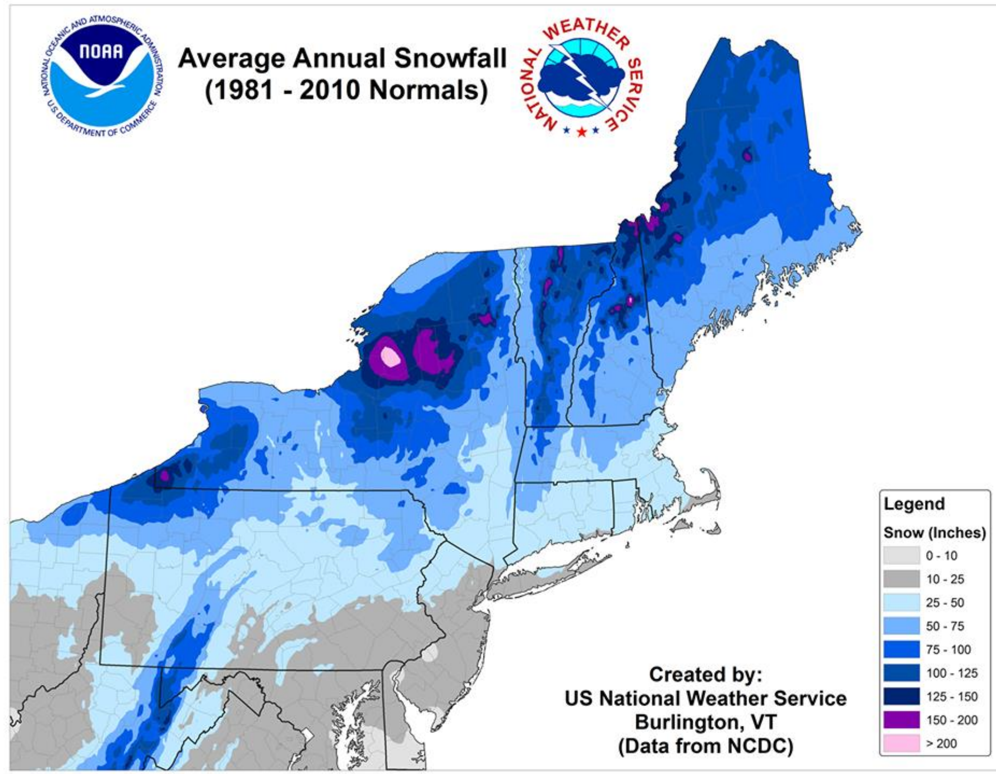
# Outline

- Snowfall Climatology and Elevation
- Cold-air damming
- Effects of stability and wind
- High resolution model forecasts
- Summary

# Elevation vs. annual snowfall

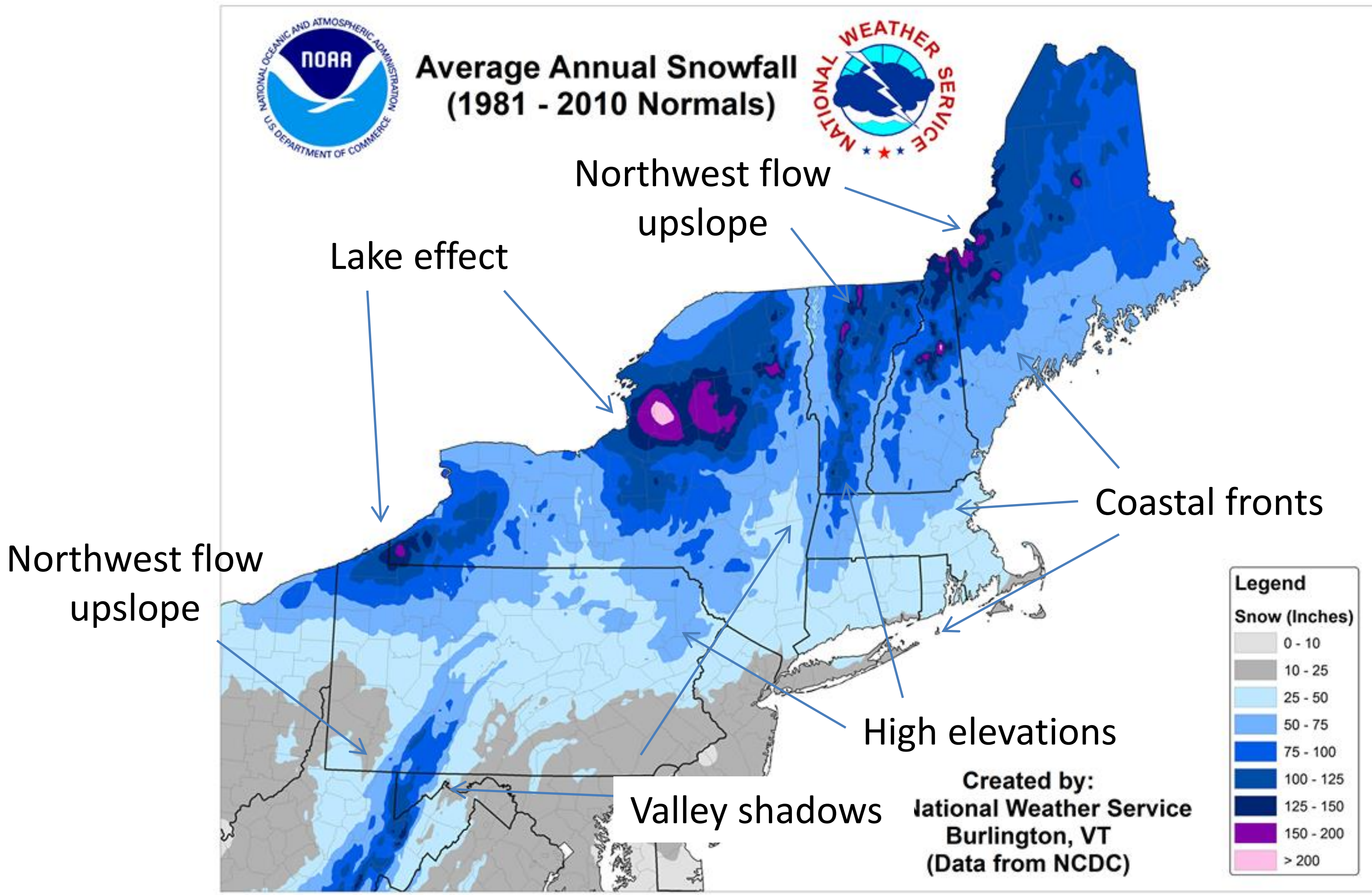





Eastern U.S. topography

Average annual snowfall

# Eastern U.S. topographic factors



# Cold-air damming

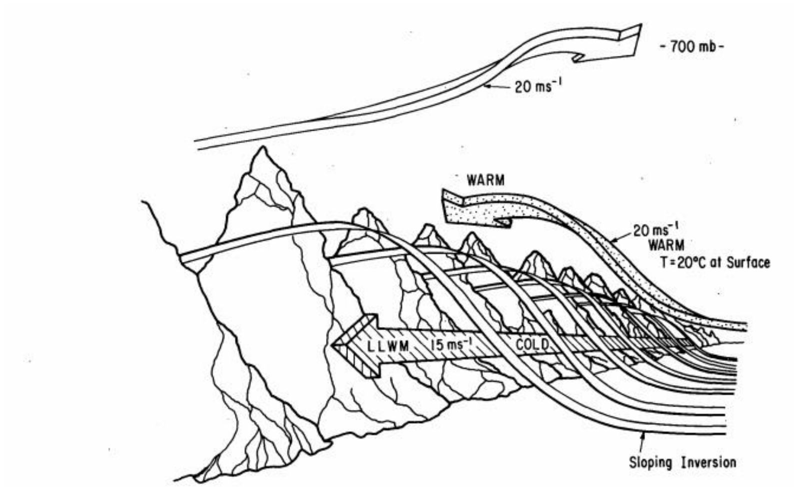
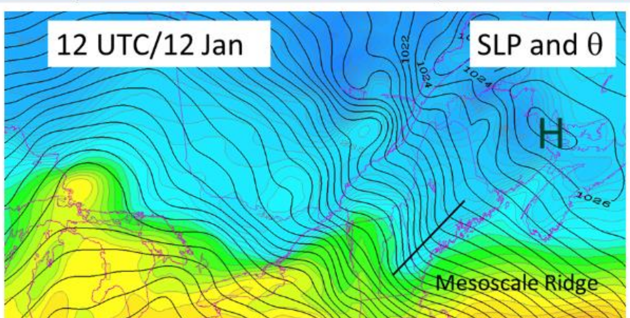



FIG. 22. Conceptual model of the cold-air damming region as it existed at 1200 UTC 22 March 1985. Note the strong low-level wind maximum (LLWM) within the cold dome, the easterly (or southeasterly) flow just above the cold dome associated with strong warm advection into the warm air above the dome, the sloping inversion of the cold dome top, and the southerly and southwesterly winds above 700 mb associated with the advancing short-wave trough west of the Appalachians.

Bell and Bosart 1985

CAD Example – 12 UTC 12 January 2012




Hoffman et al. – NESC - 2018

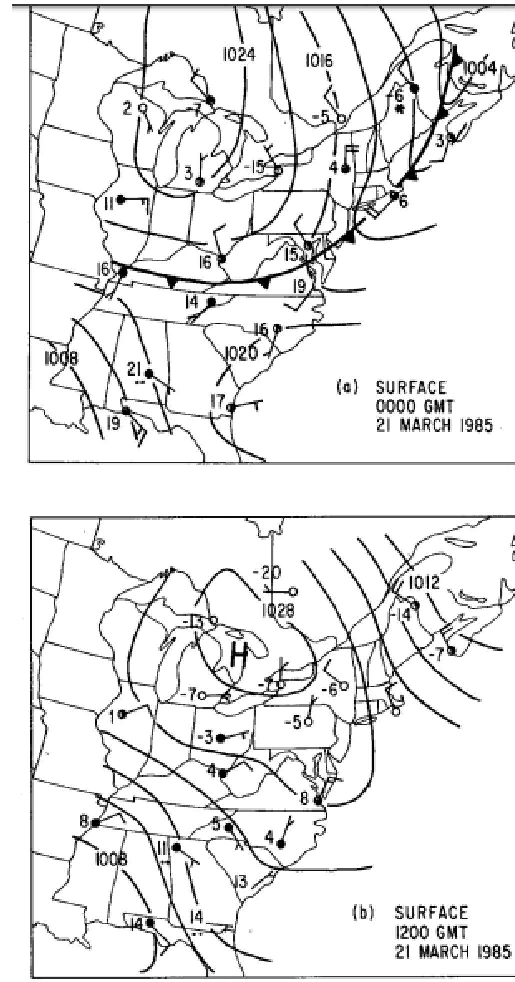



FIG. 4. National Meteorological Center sea level pressure analysis valid (a) 0000 UTC 21 March and (b) 1200 UTC 21 March 1985. Winds in m $s^{-1}$ with one pennant, one full barb, and one half barb equal to 25, 5, and 2.5 m $s^{-1}$, respectively. Plotted temperatures in degrees Celsius. Cold frontal boundary indicated by thick line. Isobar interval is 4 mb. Conventional presentation of weather symbols.

# Cold-air damming

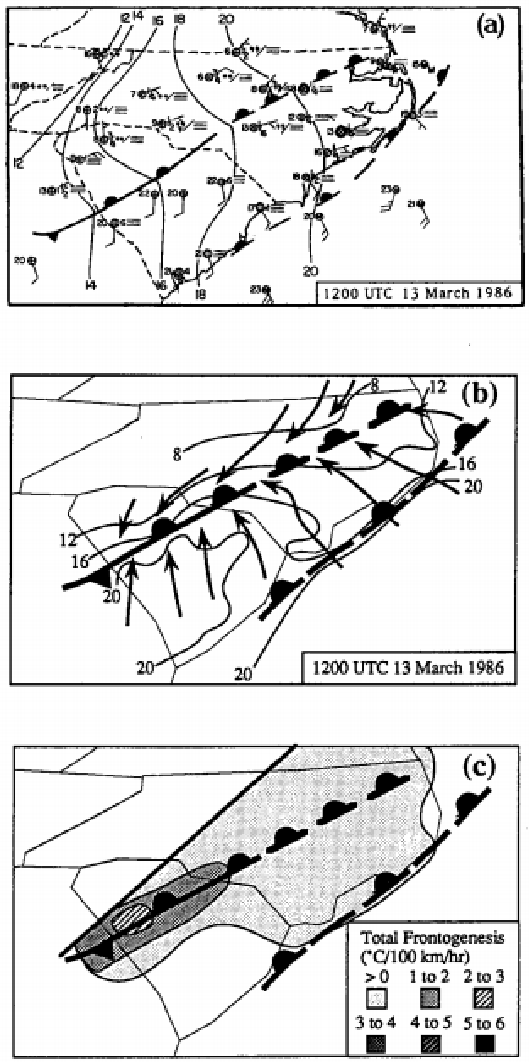



FIG. 6. Same as Fig. 5 except for 1200 UTC 13 March 1986.

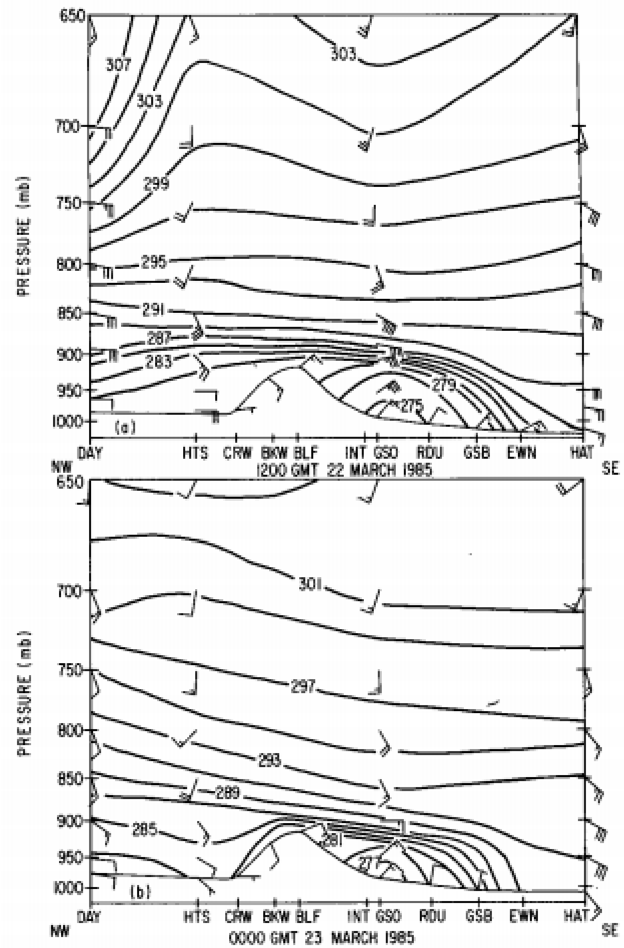
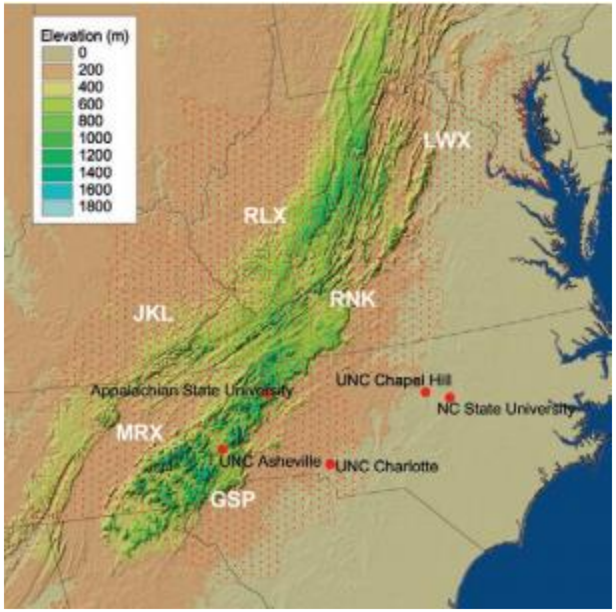



FIG. 14. Potential temperature cross sections normal to the cold dome and Appalachian Mountains, as indicated by the heavy solid line in Fig. 1, valid (a) 1200 UTC 22 March and (b) 0000 UTC 23 March 1985. Contours every 2 K. Winds as in Fig. 4.

Keeter et al. 1995

# Northwest flow upslope



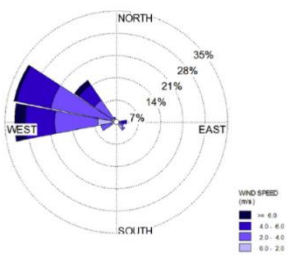




FIG. 7. Frequency of surface wind directions, and associated speeds, for all snow events at Poga Mountain from 2006 to 2012.

- Most often occur with shallow moisture / subsidence inversion.
- Moisture often in the -10 to -20 C snow growth zone.
- Can occur with deeper moisture (next slide).

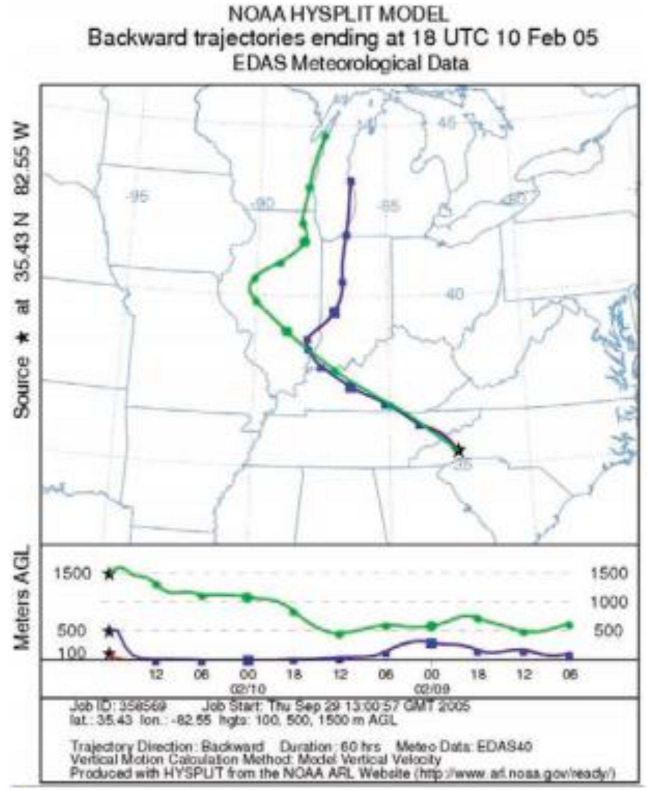



**FIG. 9. Air parcel backward trajectory analysis for 10 Feb 2005, from NOAA's Air Resources Laboratory HYSPLIT model, using the 40-km Eta Model data analysis system (EDAS) in this example. Two trajectories are shown, one ending over western NC at the 1500-m AGL level (green) and the other ending at the same location at the 500-m AGL level (blue). Vertical profiles of the two trajectories are shown in the bottom inset portion, with the trajectory ending time/altitude on the left side and the origination time/altitude of the trajectories 60 h prior on the right side.**

# Northwest flow upslope and Sandy

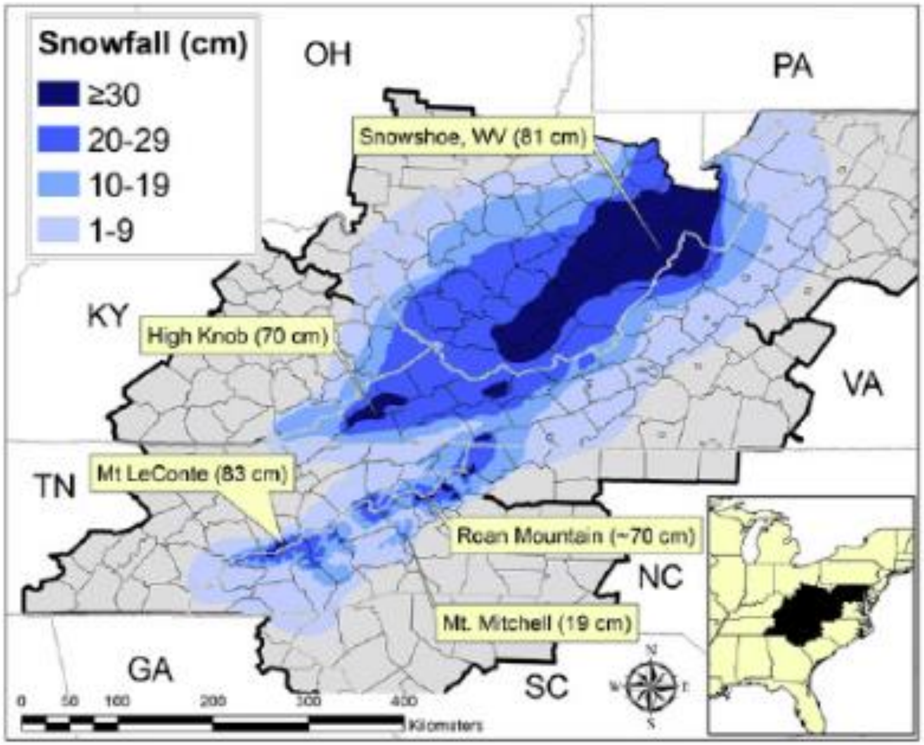
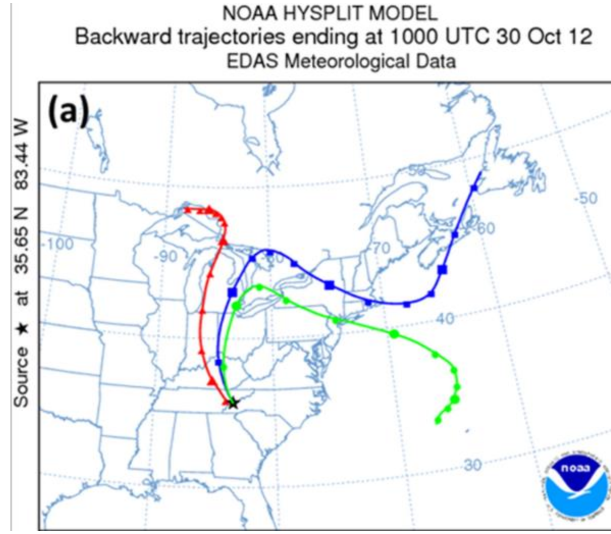
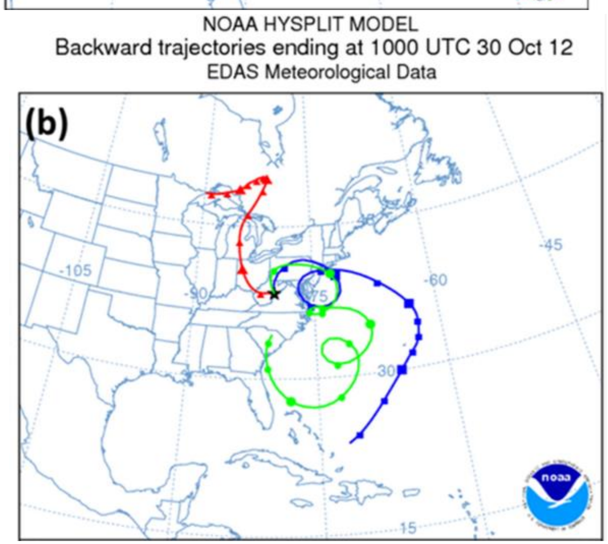



FIG. 2. Storm total snow accumulation (cm) for the remnants of Sandy for 29–31 Oct 2012. [Adapted from Martin (2013).]



# Local effects – northern Vermont

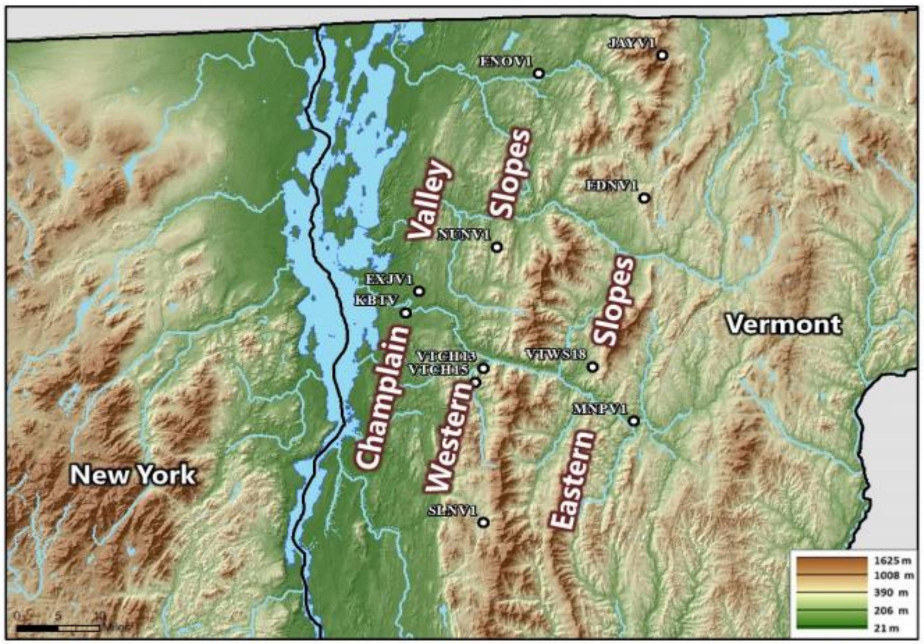
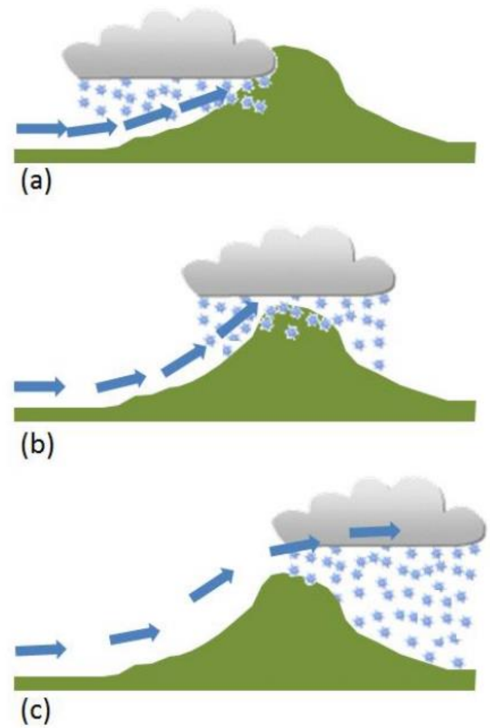



**Figure 1.** Locations of the Champlain Valley, the Western Slopes, the Eastern Slopes, and of the eleven sites used in Table 1. Topography is shaded blue for Lake Champlain, dark green for




**igure 6.** Blocked flow as seen on the top (a), contrasted with near critical flow in the middle (b), and unblocked flow on the bottom (c).

Blocked flow – heavy snow upstream from the mountain barrier.
Unblocked flow – heavy snow over and downstream from the barrier.

# Froude number and snowfall

Froude number = (Wind Speed) / (Stability) x (Barrier Height)

Fr < 1 – Blocked Flow.  Fr > 1 – Unblocked Flow

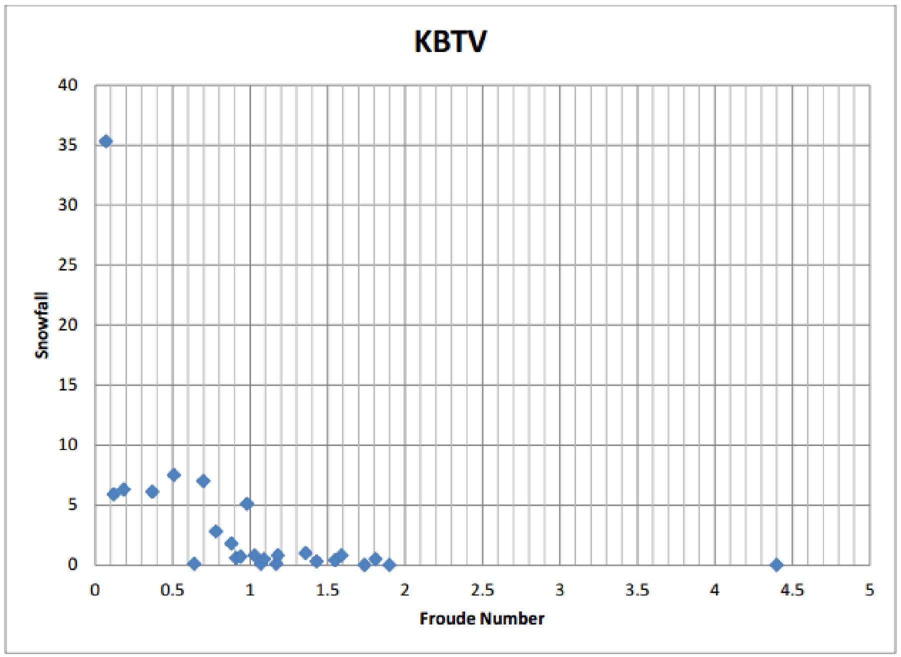



**Figure 9.** Snowfall amounts (inches) at Burlington International Airport (KBTV) versus the Froude number for 25 upslope snow cases between 2007-2012.

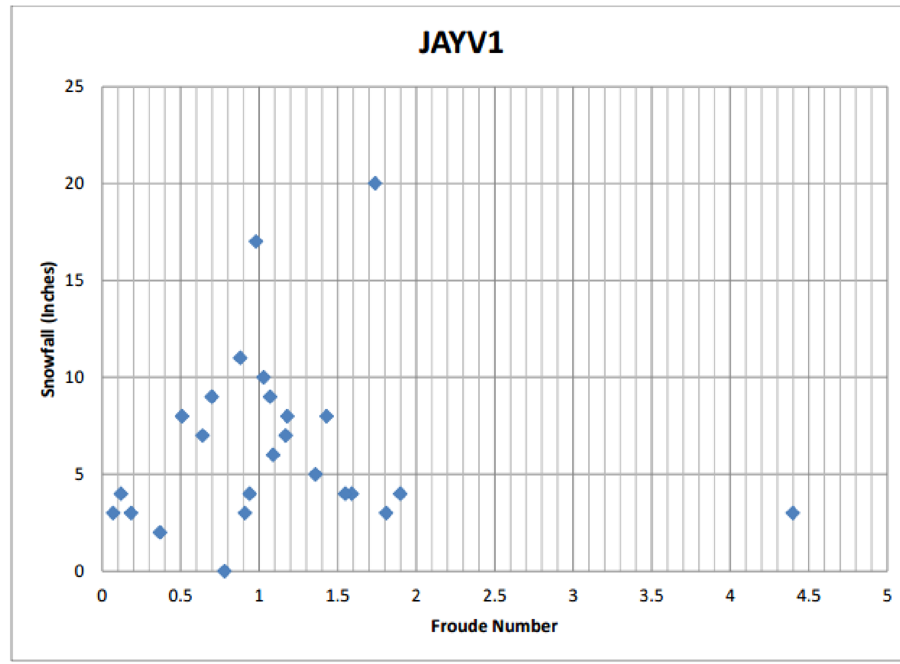
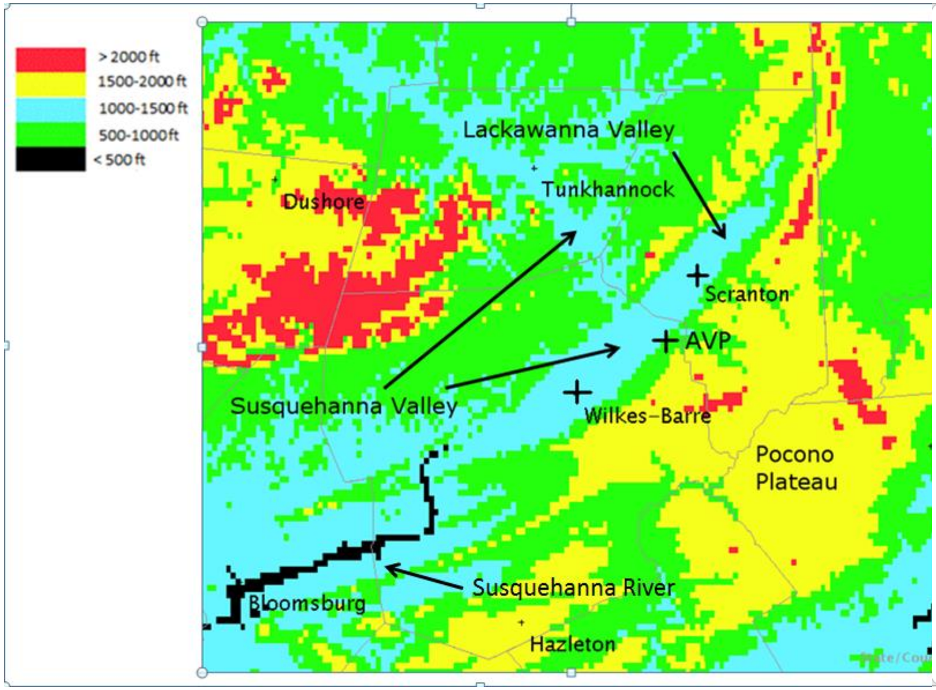
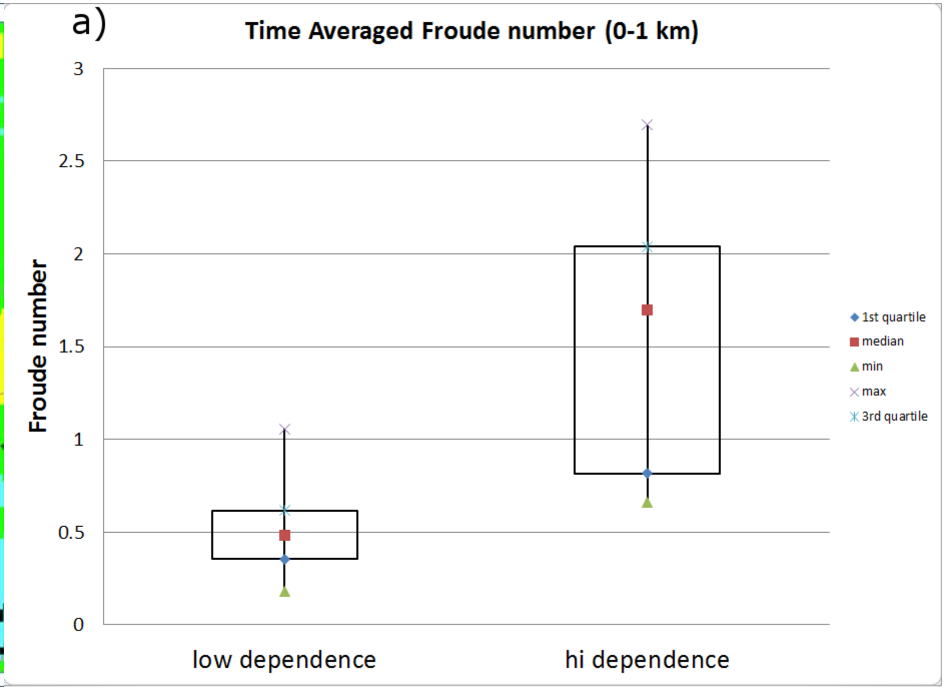



**Figure 11.** Snowfall amounts (inches) at Jay Peak (JAYV1) plotted versus the Froude number for 25 upslope snow cases between 2007-2012.

Burlington (in the valley) gets heavy snow with blocked flow
Jay Peak gets heavy snow over a wider range of flow patterns

# Local effects – northeast Pa



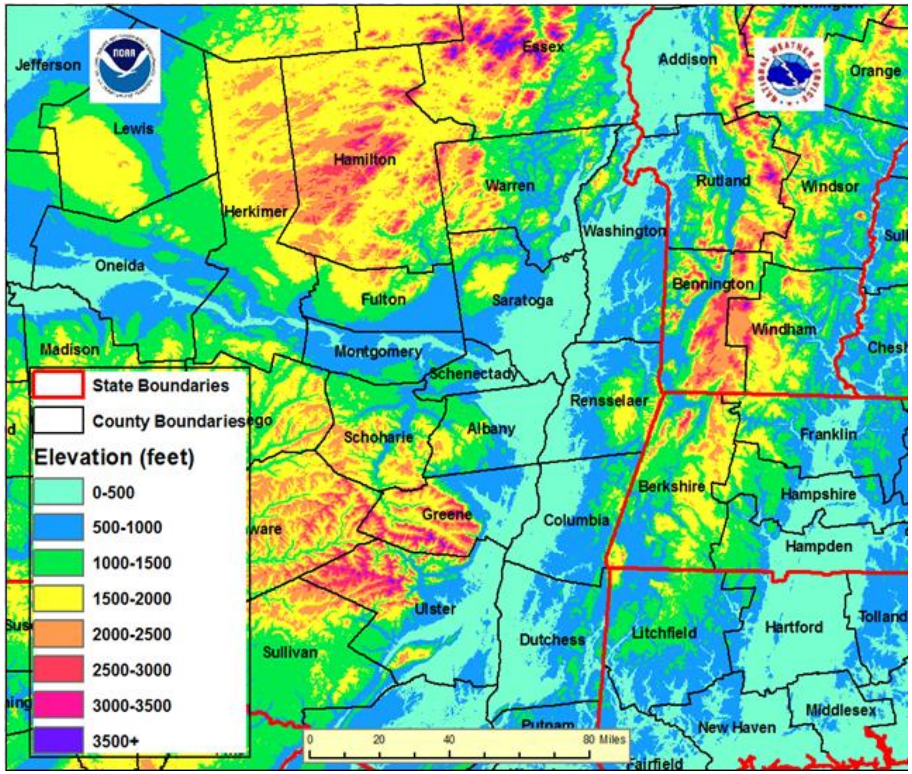



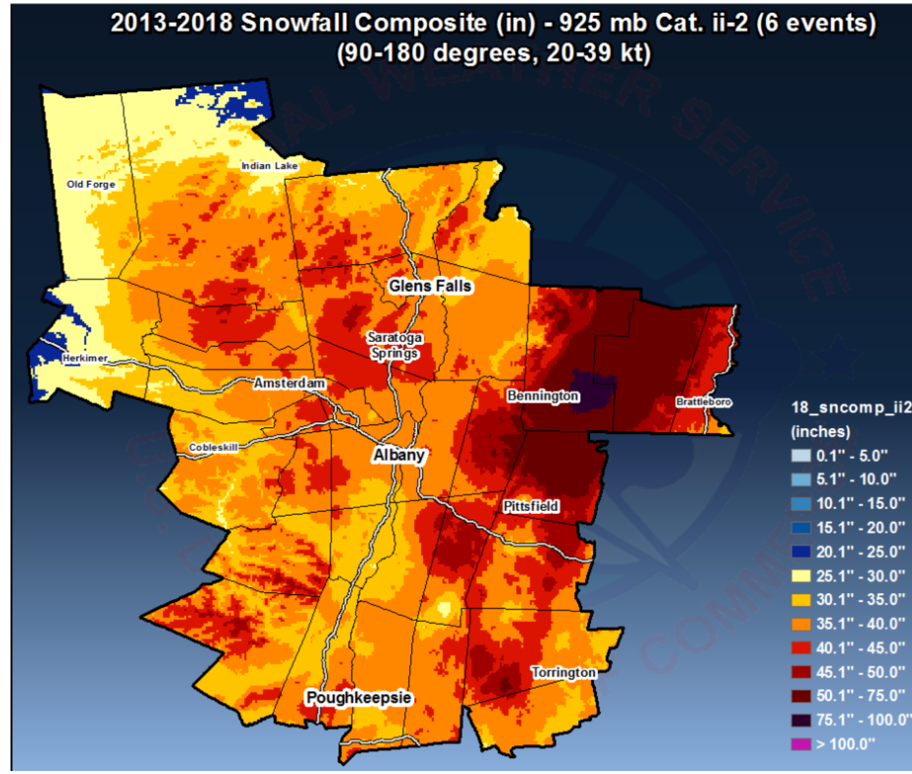

Blocked Flow (stable / light winds) associated with lower orographic ratio

Unblocked Flow (less stable / stronger winds) associated with larger orographic ratio

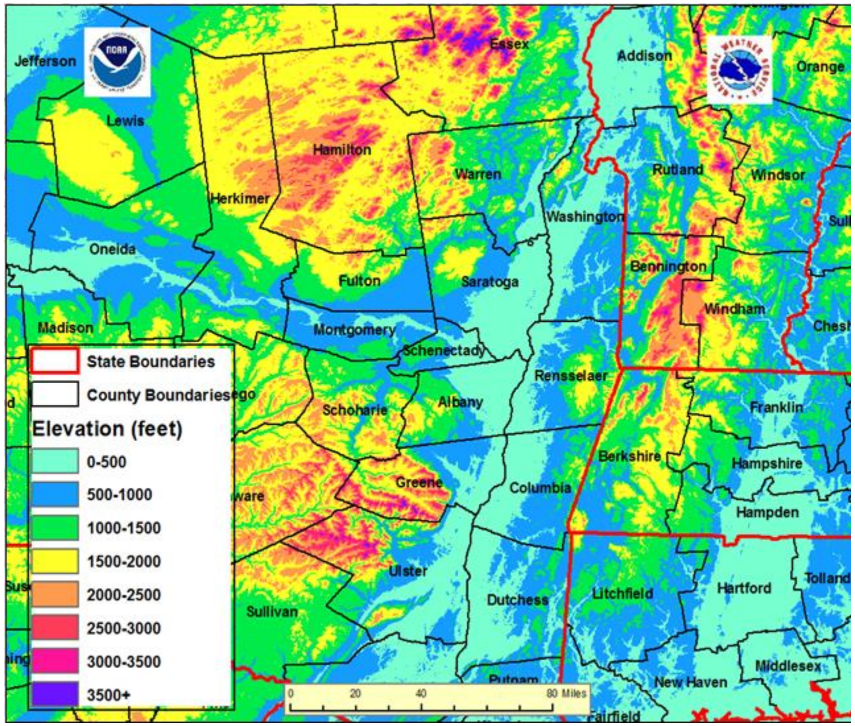
Other factors – included surface temperature (near 32 associated with larger ratio)

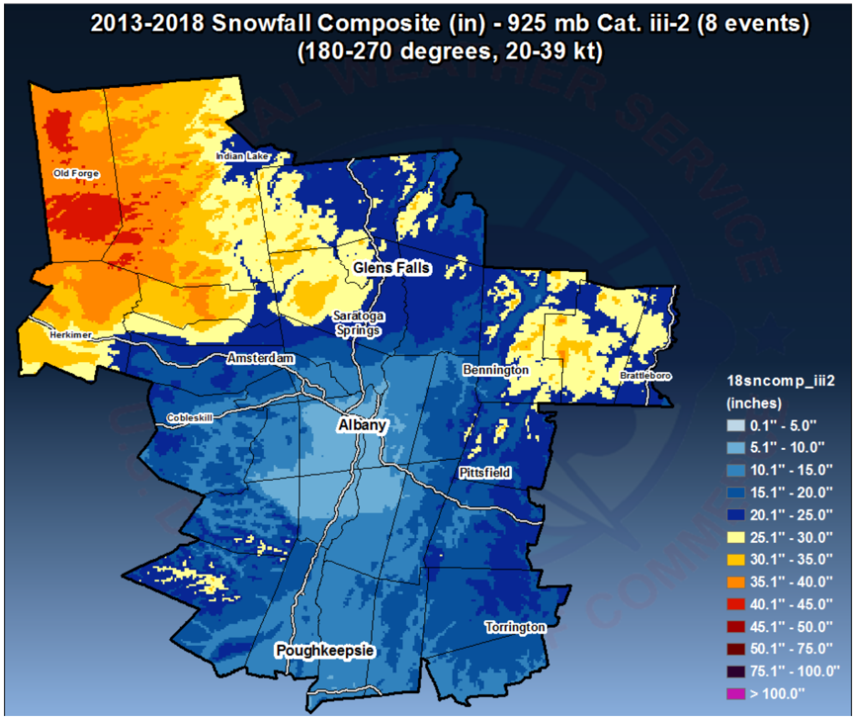
# Terrain and composite snowfall – southeast flow



# Terrain and composite snowfall – southwest flow



# Local effects – Hudson / Mohawk convergence

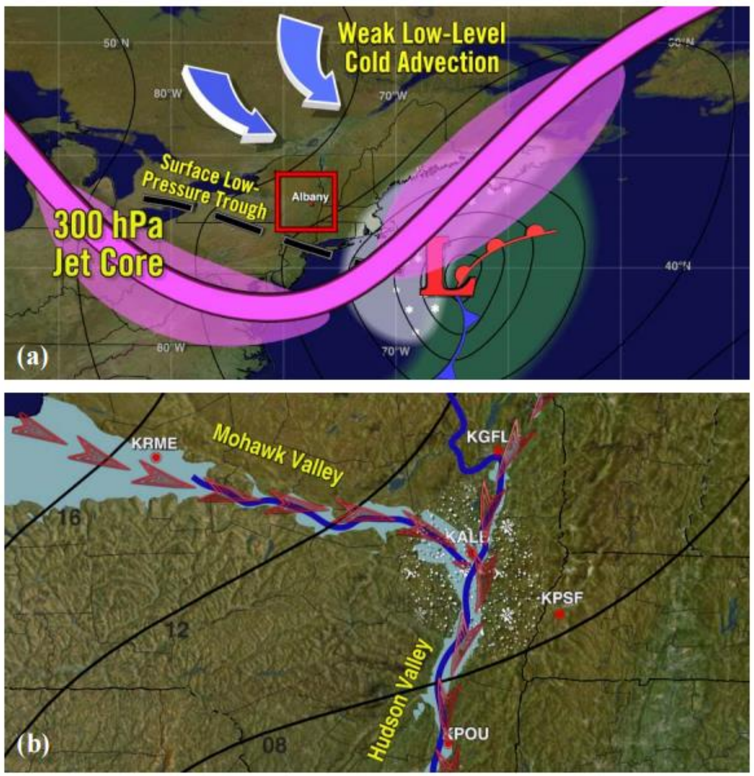
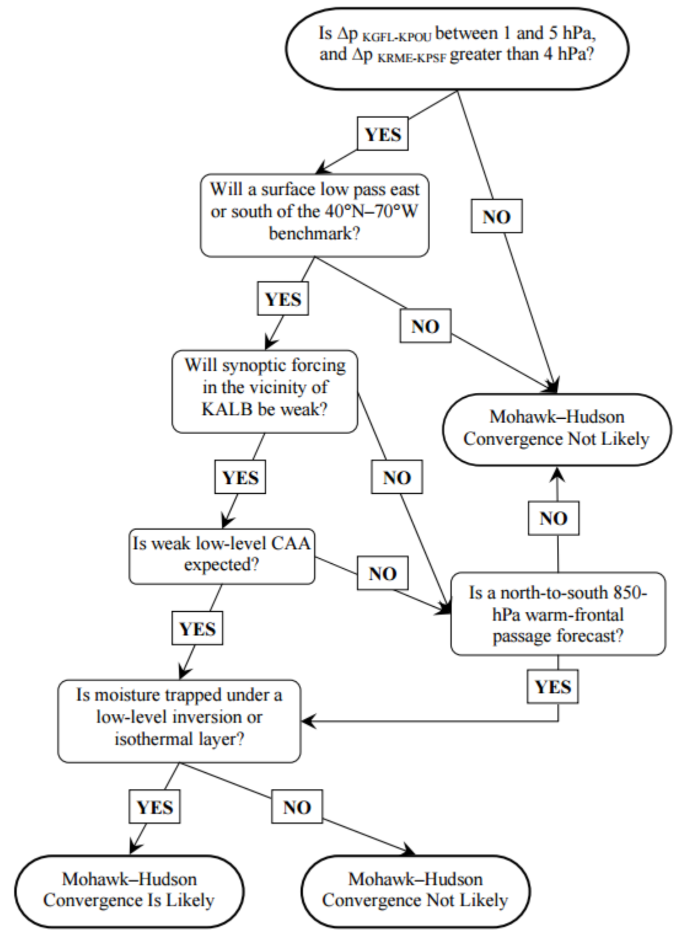
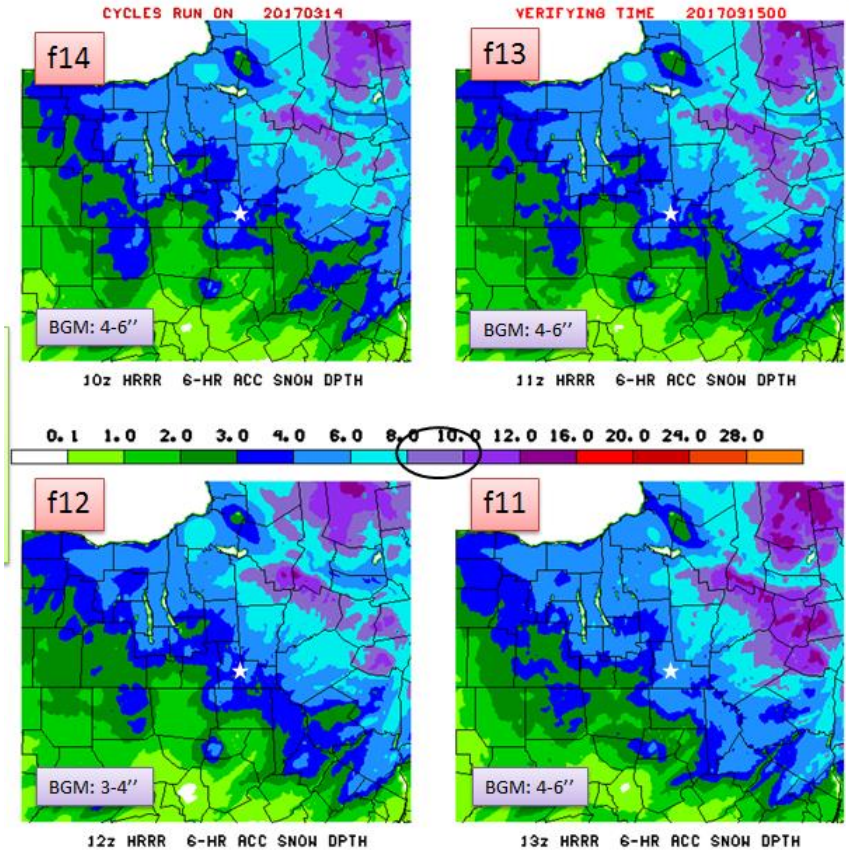
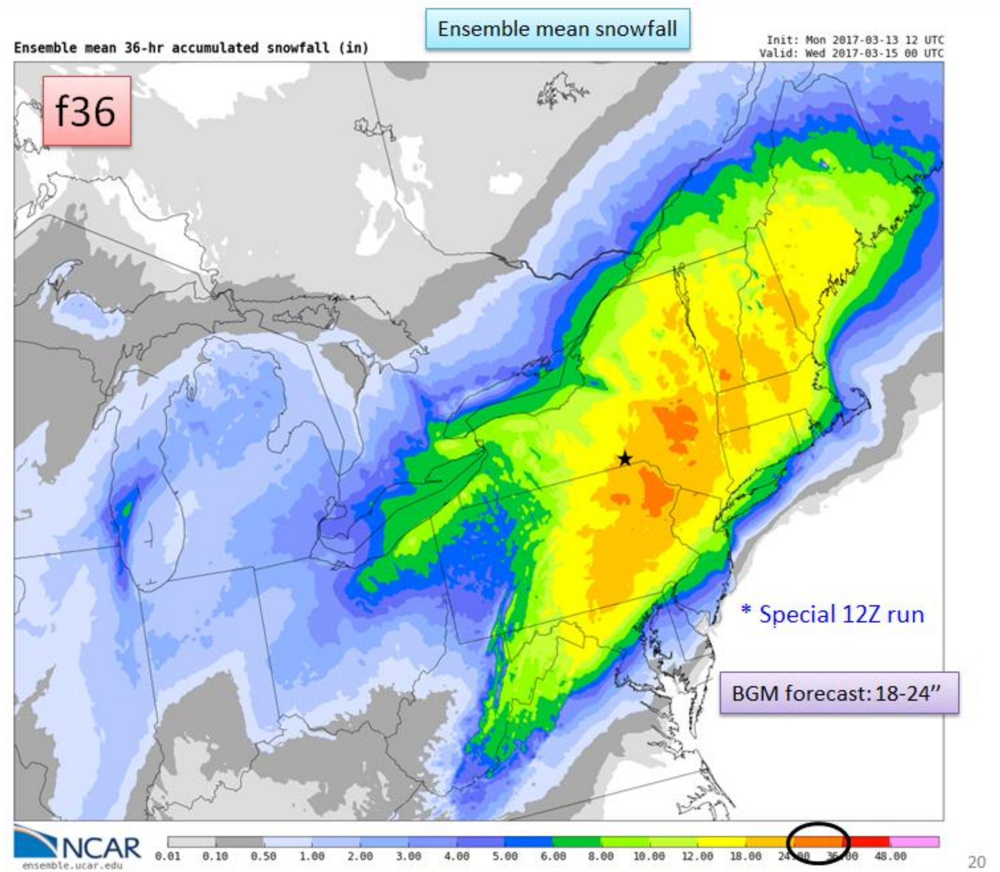



Figure 4.1: Schematic of the key features observed during a prototypical MHC event on the (a) synoptic-scale and (b) mesoscale. Shown in (a) are: an intensifying area of surface low pressure located southeast of 40°N, 70°W, and moving northeastward (red "L"); sea level isobars (solid black lines); a trough of surface low pressure; the attendant areas of synoptic-scale snow (white shading) and rain (green shading); the axis of 300-hPa maximum winds (heavy pink line) and jet streaks (pink shading); weak low-level cold advec-tion from the north; the area which bounds the MHC domain (red box).

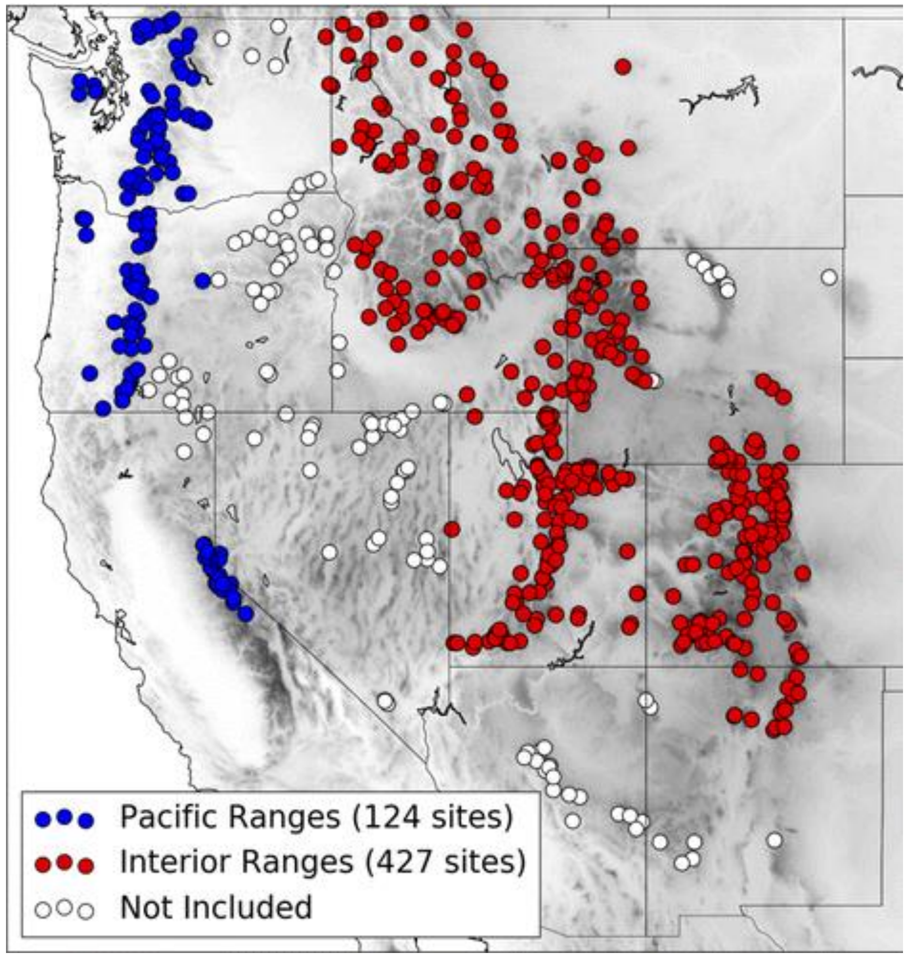


# High resolution model snowfall forecasts – March 14, 2017 blizzard

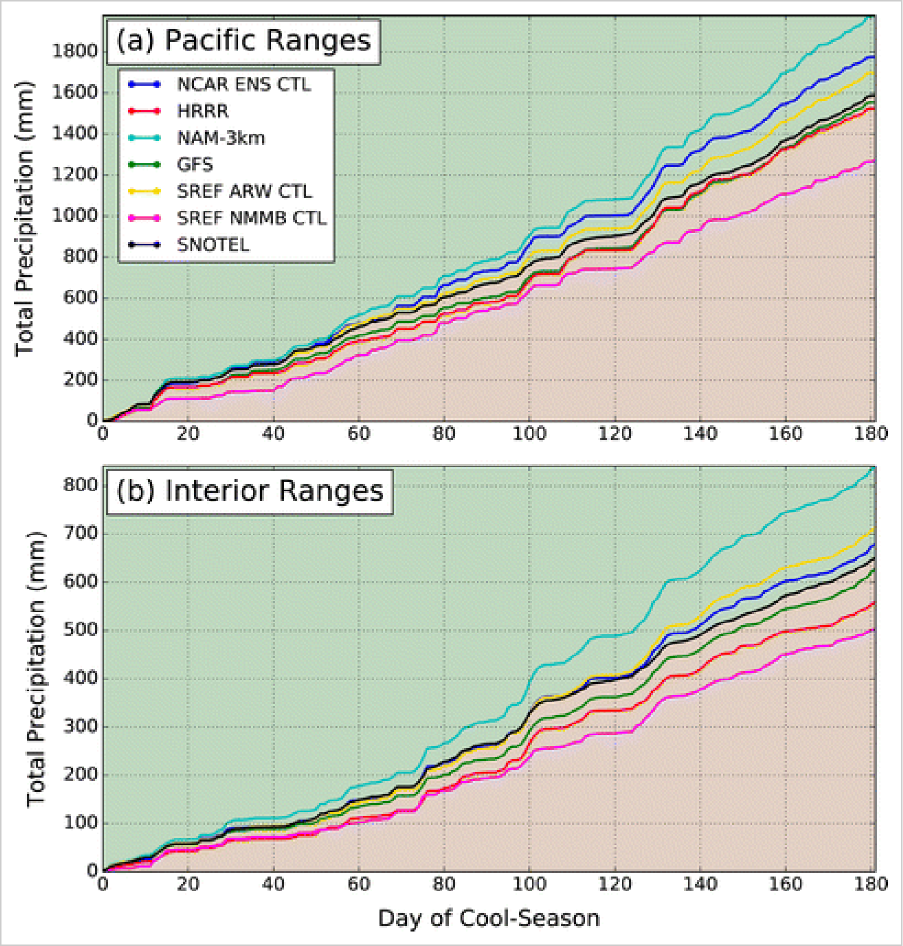


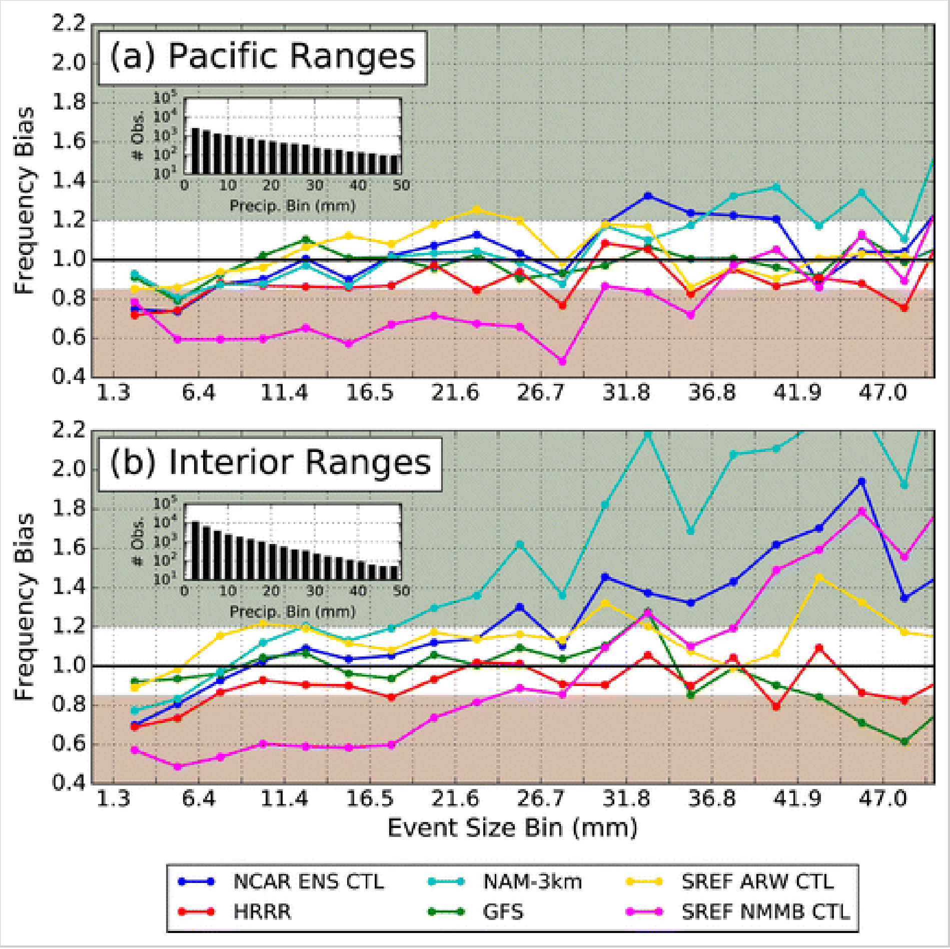
# Examination of high resolution model performance – Gowan et al. 2018



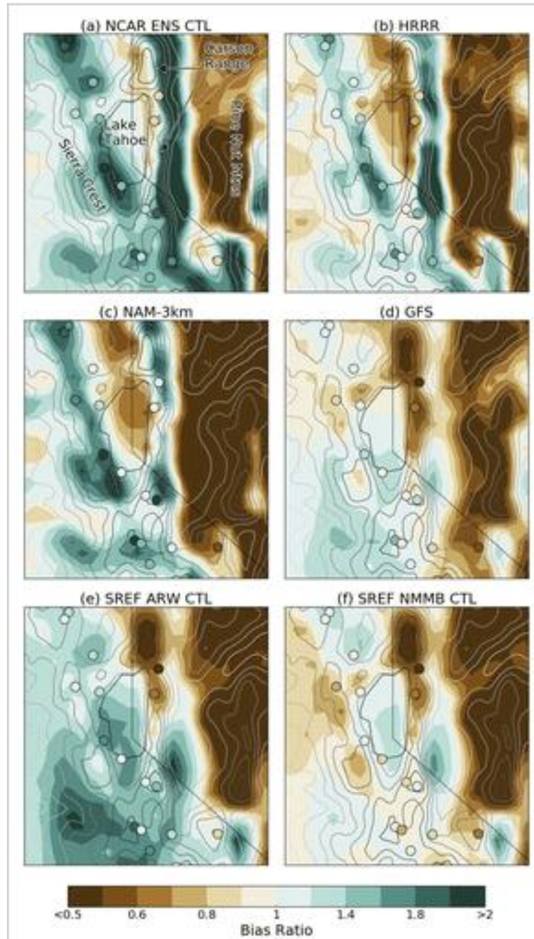
# Model biases at SNOTEL stations



# Frequency biases



# Localized biases – too much precipitation downstream from the Sierra crest

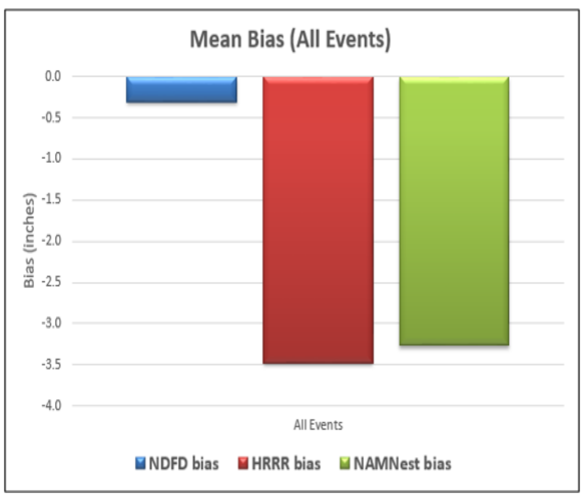


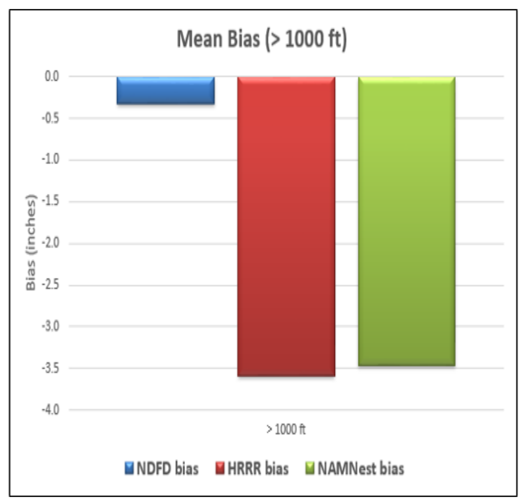
# Local WFO Albany Study

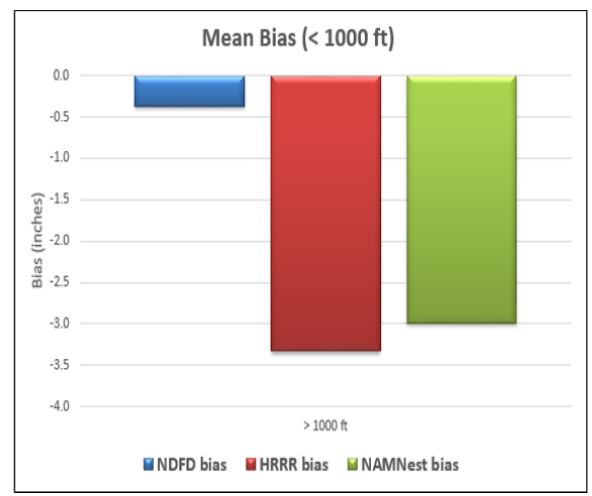
- Examine several winter storms from 2017-2019.
- Compare observations to high resolution model forecasts.
- Partition cases into categories such as high / low stability, northeast / southeast flow, high / low Froude number, high / low orographic number.
- Do these factors contribute to model performance?
- Do models have biases related to elevation / topography?

# Initial results from 12 events 2017-2018

- Average elevation ratio was 1.3
- Strong correlations between stability, Froude number and elevation ratio (weaker with sfc temp)
- Model bias of snow depth change



# Summary

- Complex terrain results in a myriad of topographically enhanced winter weather hazards.
- Many of these hazards occur at small-scales.
- High-resolution models can be very helpful to determine impacts of terrain, but biases and errors exist.
- Local experience and expertise is critical for effective forecasts, warnings and decision support.

# References

Bell, G.D., and L. F. Bosart: Appalachian cold-air damming, MWR 1987.

Evans, M.S, M. Jurewicz and R. Kline: The elevation dependance of snowfall in the Appalachian Ridge and Valley region of northeast Pennsylvania, Journal of Operational Meteorology, 2017.

Gowan, T.M., J.W. Steenburgh and C.S. Schwartz: Validation of mountain precipitation forecasts from the convection-permitting NCAR ensemble and operational forecast systems over the western United States. WAF 2018.

Keighton, S., D. Miller, D.K. Holtz, P.D. Moore, L.B. Perry, L.G. Lee and D.T. Martin: Northwest flow snow aspects of hurricane Sandy, WAF, 2015.

Muccilli, M.: Using the Froude number to improve orographic snow forecasts in the Green Mountains of Vermont. ER Tech Attachment, 2015.