**3. Warm MHC**

*a. Surface wind roses*

*b. Composites*

The composite mean, sea-level pressure for warm-MHC events shows a weak and diffuse surface cyclone located over southern Quebec during the time of peak reflectivity associated with the event (Figure 2a). The position of this surface cyclone would induce weak southwesterly geostrophic flow over New York and New England. The westerly geostrophic flow and XXX wind from the KALB surface wind rose, indicates warm cases of MHC tend to form in environments in advance of cold fronts. This warm-season, prefrontal environment over the northeastern United States generally features weak synoptic-scale forcing in the presence of abundant convective instability (e.g., Lombardo and Colle 2010, 2011; Hurlburt and Cohen 2014), which increases the importance of mesoscale processes, like MHC, in initiating convective storms. Note that although a pressure trough can also be seen in the prefrontal environment over eastern New York (c.f. Lombardo and Colle 2011), this prefrontal trough did not directly initiate the convection in the composite cases as discussed in the previous section.

At 850 hPa (Fig. 4a), a weak trough can be seen over the east coast of the United States with a broad ridge positioned over the central United States. The composite flow is west-southwesterly over New York and New England, with warm-air advection in the prefrontal environment on the order of 0.4 *°*C h-1. Weak cold-air advection can be seen occurring in the wake of the cold front moving through central New York.

Weak advection of 500-hPa cyclonic relative vorticity occurs across eastern New York during warm-MHC events (Fig. 5a). Weak cyclonic curvature, with embedded vorticity maxima, is seen upstream of the Capital Region, indicative of possible shortwaves in the flow at 500 hPa. Investigation of individual cases revealed that there is significant spatial variability in the location of upstream shortwaves during warm-MHC events, again highlighting the importance of mesoscale processes in the initiation of convection.

At 300 hPa (Fig. 6a), the flow over the continental U.S. features a broad, weak trough over the eastern United States and a ridge anchored over the Intermountain West. The Capital Region is just downstream of the trough axis and in the equatorward entrance region of a jet streak over eastern Canada, locations known to be favorable for upper-level divergence.

The composite sounding (Fig. 7a) for warm-MHC cases shows a warm surface temperature around 28 *°*C and a surface dew point of 19 *°*C. With a warm, moist surface, the lack of any significant capping inversion, and steep mid-level lapse rates. Surface southwesterly winds around 5 kt veer with height, representative of warm-air advection, which was seen in the 850-hPa composite map (Fig. 4a). Reviewing the cases generally surface based CAPE was between 1000 and 3000 J kg-1. In the individual cases the actual winds were more southerly in the valley due to the terrain-channeled flow.

**4. Cold MHC**

*a. Surface wind roses*

*b. Composites*

The cold-MHC sea-level pressure composite (Fig. 2b) shows that during the peak of cold MHC events a surface cyclone is located just to the east of Cape Cod. The pressure pattern implies surface geostrophic winds would be northeasterly across New York State and the composite gradient in sea-level pressure is much larger than that of the warm cases (Fig. 2a).

At 850 hPa, a positively-tilted trough is located over the east coast of the United States with north-northwesterly flow present over New York and New England (Fig. 4b). Behind the departing cyclone, strong cold-air advection dominates eastern New York State. Looking closely at the Capital Region, however, a noticeable minimum in the cold air advection is evident (see inset). This minimum is indicative of neutral- or weak warm-air advection occurring in the lower levels of the atmosphere (see the composite sounding in Fig. 7b) and could possibly be due to downslope warming in the lee of the Adirondacks.

At 500 hPa, a maximum in relative vorticity is located over the Capital Region (Fig. 5b), implying no advection of relative vorticity at the peak of the MHC event. The thermal wind is parallel to the thickness contours, showing anticyclonic vorticity advection by the thermal wind would soon be occurring in the Capital Region. By the Sutcliffe-Trenberth form of the quasi-geostrophic omega equation predicts that the Capital Region will be in an area of downward vertical motion at 500 hPa.

In the 300-hPa composite (Fig. 6b), a more amplified flow pattern is seen compared to the warm-MHC cases, with a deep trough over the eastern United States and a ridge over the West Coast. A 100-kt jet maximum is located in the base of the trough, located just off the coast of North Carolina. The location of the jet streak places the Capital Region on the central poleward side of the jet, an area not associated with upper-level divergence.

The cold-MHC composite sounding (Fig. 7b) shows backing winds from the surface through the mid-troposphere, consistent with the presence of 850-hPa cold air advection (Fig. 4b). At the lowest levels, there is veering of the winds, which is associated with friction and terrain-channeled flow. Though the composite smooths out detailed features of the individual events, a weak inversion can be seen around 900 hPa. The sounding is saturated from the surface to 800 hPa and the dendritic growth zone (indicated by the blue lines) extends from the surface to 600 hPa, providing a for a good environment for snow growth.

*c. Cold MHC case study: 2 January 2008*

The 2 January 2008 MHC event was significant because of its duration, intensity, and low predictability in the Capital Region. Officially, an additional 0.8 cm of snow was reported at KALB, but local weather observers reported more significant accumulations attributed to MHC in various parts of the region, with 12.7 cm of additional snow reported in Cohoes, NY, on top of the nearly 28 cm produced by the cyclone’s synoptically-forced precipitation. The evolution of the event is shown in the radar and surface observation data in Fig. 8. The event started as a broad swath of precipitation that ultimately organized into a banded feature with a north-northwest to south-south east orientation. The location of Cohoes, NY (red dot) coincides with where the highest reflectivity was reported. Outside of this narrow band, little or no additional snow accumulations were reported.

At the surface (Fig. 9), much like in the cold-MHC composite (Fig. 2b), there is an area of low pressure located off the New England Nova Scotia with a central pressure of 986 hPa. The cyclone tracked slightly west of 40°N, 70°W, which allowed the synoptic-scale precipitation to impact the Capital Region and induce northeasterly geostrophic flow.

On the backside of the storm, there was cold-air advection at 850 hPa over most of New York State (Fig. 10). Two notable exceptions are the warm-air advection south of Lake Ontario and over the Capital Region (see inset).. As described in the cold-MHC composite section, the warm-air advection could be associated with downsloping winds off the eastern Adirondack Mountains, or the veering of the winds due to friction and terrain channeling. Much like the cold-MHC composite (Fig. 4b), the trough was positively tilted inducing a north/northwesterly wind over New York.

At 500 hPa, a deep, positively-titled trough can be seen across the eastern United States with strong cyclonic relative vorticity in the base of the trough over the Southeast U.S. (Figure 11).. Associated with the departing surface cyclone, a cutoff, shortwave cyclone was located over Nova Scotia. At this time, cyclonic vorticity advection was occurring in the Capital Region, just prior to the evolution of the MHC event from a broad area of precipitation to a single band (Fig. 8).

A 300 hPa, a deep, positively-titled trough is evident over the eastern United States (Figure 12). This pattern is similar to the cold-MHC composite; however, the flow is more amplified and Albany is located downstream of the trough axis, instead of along the axis (Fig. 6b). A jet maximum of over 165 kt (Fig. 12) was also located downstream of the trough axis, off the East Coast, indicating a lifting trough.

Figure 13 shows the observed KALB sounding at 1200 UTC 2 January 2008, two hours prior to the MHC-maximum reflectivity. As in the composite for cold-MHC cases, the boundary layer is moist with temperatures below 0 *°*C. The winds in the observed sounding veer from the surface to around 800 hPa, consistent with low-level warm air advection (Fig. 10). The winds above this level back, which is consistent with cold-air advection throughout the remainder of the troposphere, very similar to the composite sounding.

**5. Summary and conclusions**

The Mohawk and Hudson River valleys, as well as the Catskill, Adirondack, Berkshire, and Southern Green Mountains, play a pivotal role in altering wind flow in the Capital Region of New York State. Through composite analysis and a case study, this study has documented the synoptic-scale setup common to Mohawk–Hudson Convergence (MHC) events that will hopefully improve forecasts of these challenging events.

The synoptic setup for warm cases of MHC includes a broad trough at 300 hPa over the eastern United States, weak cyclonic vorticity advection associated with an upstream shortwave at 500-hPa, and weak, 850-hPa warm air advection associated with the warm sector of a surface cyclone. Most importantly, weak boundary layer geostrophic southwesterly winds are channeled westerly in the Mohawk valley and southerly in the Hudson valley supplying unstable air to the greater Capital Region. The winds are typically weak in the prefrontal environment with little upper-level forcing for ascent.

The synoptic setup for cold cases of MHC is a strong, upper-tropospheric jet within the base of a trough located over the East Coast. Strong cyclonic vorticity advection leads to the deepening of an area of low pressure off the New England coast, increasing the surface pressure gradient over eastern New York. This strengthening of the pressure gradient leads to moderate northerly flow in the Hudson Valley and northwesterly flow in the Mohawk Valley. Cold-MHC events are also characterized by a moist boundary layer with weak cold air advection in the low-levels and drier air with cold advection in the midlevels. The low-level warm air advection suggests rising motion in the lower atmosphere, capped by mid-level descent as a cyclonic relative vorticity maximum moves past the Capital Region. The low-level rising motion being capped by mid-level descent supports the fact that these cases seem to be bound to the lowest levels of the atmosphere.

MHC events are hard to predict because of their seemingly innocuous conditions on the large-scale, though they can quickly turn into high-impact weather events. Low-level convergence in the river valleys can lead to thunderstorms during the warm season, and locally heavy precipitation during the cold season. Figure 14 shows a checklist for forecasters to help them determine if MHC is probable.

Future advances in surface observation such as the New York State Mesonet will significantly help the prediction of MHC events as often surface level winds can show convergence before the onset of precipitation. Observations from the New York State Mesonet showed such surface convergence before the onset of precipitation in a case of *enhanced* cold MHC on 9 February 2017. Figure 15 shows the surface observations and the derived surface convergence from the 109 stations in the New York State Mesonet. Surface convergence was seen before the onset of the enhanced precipitation in the Capital Region making this data great resource for forecasters.

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**References**

Anders, A. M., G. H. Roe, D. R. Durran, and J. R. Minder, 2007: Small-scale spatial gradients in climatological precipitation on the Olympic Peninsula. *J. Hydrometeor.*, **8**, 1068–1081.

Augustyniak, M., 2008: A multiscale examination of surface flow convergence in the Mohawk and Hudson valleys. http://cstar.cestm.albany.edu/CAP\_Projects/Project13/index.htm

Bosart, L. F., A. Seimon, K. D. LaPenta, and M. J. Dickinson, 2006: Supercell tornadogenesis over complex terrain: The Great Barrington, Massachusetts, tornado on 29 May 1995. *Wea. Forecasting*, **21**, 897–922.

Bracken, W. E., L. F. Bosart, A. Seimon, K. D. LaPenta, J. S. Quinlan, and J. W. Cannon, 1998: Supercells and tornadogenesis over complex terrain: The Great Barrington (MA) Memorial Day (1995) tornado. Preprints, *19th Conf. on Severe Local Storms*, Minneapolis, MN, Amer. Meteor. Soc., 18–21.

Carrera, M. L., J. R. Gyakum, and C. A. Lin, 2009: Observational study of wind channeling within the St. Lawrence River valley. *J. Appl. Meteor. Climatol.*, **48**, 2341–2361.

Cholette, M., R. Laprise, and J. M. Thériault, 2015: Perspectives for very high-resolution climate simulations with nested models: Illustration of potential in simulating St. Lawrence River Valley channeling winds with the fifth-generation Canadian Regional Climate Model. *Climate*, **3**, 283–307.

Corbosiero, K. L., and R. A. Lazear, 2015: Application of the National Lightning Detection Network in the analysis of the variability of warm season thunderstorm occurrence. *Seventh Conf. on the Meteorological Applications of Lightning Data*, Phoenix, AZ, Amer. Meteor. Soc..

Cummins, K. L., and M. J. Murphy, 2009: An overview of lightning locating systems: History, techniques, and data uses, with an in depth look at the U.S. NLDN. IEEE Trans. *Electromag. Compat.*, **51**, 499–518.

Ferber, G. K., C. F. Mass, G. M. Lackmann, and M. W. Patnoe, 1993: Snowstorms over the Puget Sound lowlands. *Wea. Forecasting*, **8**, 481–504.

Geerts, B., T. Andretta, S. Luberda, J. Vogt, Y. Wang, L. Oolman, J. Finch, and D. Bikos, 2009: A case study of a long-lived tornadic mesocyclone in a low-CAPE complex-terrain environment. *Electron. J. Severe Storms Meteor.*, **4** (3).

Gross, G., and F. Wippermann, 1987: Channeling and countercurrent in the Upper Rhine valley: Numerical simulations. *J. Climate Appl. Meteor.*, **26**, 1293–1304.

Hurlbut, M. M., and A. E. Cohen, 2014: Environments of northeast U.S. severe thunderstorm events from 1999 to 2009. *Wea. Forecasting*, **29**, 3–22.

Jeglum, M. E., and S. W. Hoch, 2016: Multiscale characteristics of surface winds in an area of complex terrain in Northwest Utah. . *J. Climate Appl. Meteor.*, **55**, 1549–1563.

Jiang, Q., and J. D. Doyle, 2008: Diurnal variation of downslope winds in Owens Valley during the Sierra Rotor experiment. *Mon. Wea. Rev.*, **136**, 3760–3780.

Kossmann, M., and A. P. Sturman, 2003: Pressure-driven channeling effects in bent valleys. *J. Appl. Meteor.*, **42**, 151–158.

LaPenta, K. D., L. F. Bosart, T. J. Galarneau, and M. J. Dickinson, 2005: A multiscale examination of the 31 May 1998 Mechanicsville, New York, tornado. *Wea. Forecasting*, **20**, 494–516.

Lombardo, K. A., and B. A. Colle, 2010: The spatial and temporal distribution of organized convective structures over the northeast United States and their ambient conditions. *Mon. Wea. Rev.*, **138**, 4456–4474.

Lombardo, K. A., and B. A. Colle, 2011: Convective storm structures and ambient conditions associated with severe weather over the northeast United States. *Wea. Forecasting*, **26**, 940–956.

Mass, C. F., 1981: Topographically forced convergence in western Washington State. *Mon. Wea. Rev.*, **109**, 1335–1347.

Milrad, S. M. , E. H. Atallah, and J. R. Gyakum, 2012: Precipitation modulation by the Saint Lawrence River Valley in association with transitioning tropical cyclones. *Wea. Forecasting*, **28**, 331–352.

Niziol, T. A., W. R. Snyder, and J. S. Waldstreicher, 1995: Winter weather forecasting throughout the eastern United States. Part IV: Lake effect snow. *Wea. Forecasting*, **10**, 61–77.

Peyraud, L., 2013: Analysis of the 18 July 2005 tornadic supercell over the Lake Geneva region. *Wea. Forecasting*, **28**, 1524–1551.

Rampanelli, G., D. Zardi, and R. Rotunno, 2004: Mechanisms of upvalley winds. *J. Atmos. Sci.*, **61,** 3097–3111.

Razy, A., S. M. Milrad, E. H. Atallah, and J. R. Gyakum, 2012: Synoptic-scale environments conducive to orographic impacts on cold-season surface wind regimes at Montreal, Quebec. *J. Appl. Meteor. Climatol.*, **51**, 598–616.

Riley, G. T., and L. F. Bosart, 1987: The Windsor Locks, Connecticut tornado of 3 October 1979: An analysis of an intermittent severe weather event. *Mon. Wea. Rev.*, **115**, 1655–1677.

Saha, S., et al. 2010: NCEP Climate Forecast System Reanalysis (CFSR) Selected Hourly Time-Series Products, January 1979 to December 2010. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. <https://doi.org/10.5065/D6513W89>.

Schmidli, J., G. S. Poulos, M. H. Daniels, and F. K. Chow, 2009: External influences on nocturnal thermally driven flows in a deep valley. *J. Appl. Meteor. Climatol.,* **48**, 3–23.

Serafin, S., L. Strauss, and V. Grubišić, 2017: Climatology of westerly wind events in the lee of the Sierra Nevada. *J. Appl. Meteor. Climatol.,* **56**, 1003–1023.

Tang, B., M. Vaughan, R. Lazear, K. Corbosiero, L. F. Bosart, T. A. Wasula, I. R. Lee, and K. S. Lipton, 2016a: Topographic and boundary influences on the 22 May 2014 Duanesburg, New York, tornadic supercell. *Wea. Forecasting*, **31**, 107–127.

Wasula, A. C., L. F. Bosart, and K. D. LaPenta, 2002: The influence of terrain on the severe weather distribution across interior eastern New York and western New England. *Wea. Forecasting*, **17**,1277–1289.

Weber, R. O., and P. Kaufmann, 1998: Relationship of synoptic winds and complex terrain flows during the MISTRAL field experiment. *J. Appl. Meteor.*, **37**, 1486–1496.

Whiteman, C. D., 1990: Observations of thermally developed wind systems in mountainous terrain. *Atmospheric Processes over Complex Terrain, Meteor. Monogr*., No. 23, Amer. Meteor. Soc., 5–42.

Whiteman, C. D., and J. C. Doran, 1993: The relationship between overlying synoptic-scale flows and winds within a valley. J. Appl. Meteor., **32**, 1669–1682.

Zhong, S., J. Li, C. D. Whiteman, X. Bian, and W. Yao, 2008: Climatology of high wind events in the Owens Valley, California. *Mon. Wea. Rev.*, **136**,3536–3552.