**3. Warm MHC**

*a. Surface wind roses*

In the warm cases of MHC surface observations from various ASOS sites around the Capital Region show the typical wind directions for these events. These wind observations can be seen in the wind roses of Figure 2a. The Utica and Rome stations, located in the western part of the Mohawk River Valley had various data outages during the cases. Utica and Rome typically saw winds from the west-northwest or the west-southwest, typically around a magnitude of 15 kt. Glens Falls, which is located north of the Capital Region typically saw Southerly winds with magnitudes that ranged from 6 to 12 kts. Poughkeepsie which is located to the south of the Capital Region typically saw winds from the south or southwest. The southerly winds were typically of stronger magnitude and ranged from 7 to 14 kts while the southwesterly winds typically ranged between 5 to 10 kts. The Albany ASOS station which is located at Albany International Airport (KALB) typically exhibited south-southwest wind with magnitudes ranging from 6 to 12 kts. Wasula et al. 2002 showed the surface winds associated with severe weather in the Capital Region were typically southerly at Albany and either easterly or westerly at Utica. The magnitudes of the winds at Albany were also consistent with the warm-MHC composite at less than 10 kt.

*b. Composites*

Warm cases of MHC tend to form in environments just before the passage of cold fronts. 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 warm-MHC events. The position of this surface cyclone would induce weak westerly geostrophic flow over the Capital Region and a more southwesterly geostrophic flow over Southern New England. The westerly geostrophic flow and southwesterly wind from the KALB surface wind rose, indicates warm cases of MHC tend to form in environments in advance of cold fronts. This warm-MHC, 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 the pre-frontal 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 (c.f., Lombardo and Colle 2010; Hurlburt and Cohen 2014). Weak cold-air advection can be seen occurring in the wake of the cold front moving through central New York.

Weak cyclonic curvature, with embedded vorticity maxima, is seen upstream of the Capital Region, indicative of possible shortwaves in the flow at 500 hPa (Fig. 5a). Weak advection of 500 hPa cyclonic relative vorticity occurs across eastern New York during warm-MHC events. Investigation of individual cases revealed that there is significant spatial variability in the location of upstream shortwaves during warm-MHC events (c.f., Lombardo and Colle 2010). The spatial variability in this feature may add to the difficulty of forecasting warm-MHC events.

At 300 hPa (Fig. 6a), the flow over the continental United States 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. However upper-level divergence in this composite is very weak and displaced to the east of the Capital Region.

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. Surface southwesterly winds around 5 kts veer with height, representative of warm air advection, which was seen in the 850 hPa composite map. The composite sounding contained 100 J kg-1, however knowing the composite likely reduced the amount of CAPE a review of the individual cases showed surface based CAPE was between 1000 and 3000 J kg-1 in the SPC mesoanalysis. Surface analysis and the wind rose show the actual winds in the Capital Region were more southerly compared to the flow produced by the CFSR.

**4. Cold MHC**

*a. Surface wind rose*

In the cold cases of MHC surface observations from various ASOS sites around the Capital Region show the typical wind directions for these events. These wind observations can be seen in the wind roses of Figure 2b. As in the previous section Utica and Rome ASOS stations experienced frequent outage. Utica and Rome typically saw winds from the north-northwest or the west-northwest, typically around a magnitude of 12 to 15 kts. Glens Falls, which is located north of the Capital Region typically saw northwesterly winds with magnitudes that ranged from 6 to 9 kts. Poughkeepsie which is located to the south of the Capital Region typically saw winds from the north or west-northwest. The winds typically ranged between 12 to 15 kts. The Albany ASOS station which is located at Albany International Airport typically exhibited northerly wind with magnitudes ranging from 0 to 13 kts. Augustyniak 2008 showed the surface winds associated with cases of cold-MHC in the Capital Region were typically north-northeasterly or northwesterly at Albany and west-northwesterly at Utica. The magnitudes of the winds at Albany were also consistent with the cold-MHC composite at less than 8 kt.

*b. Composites*

Cold cases of MHC typically occur after the passage of synoptically-forced precipitation. Cyclones typically track along the east coast of the United States while rapidly deepening over the warm waters of the Gulf Stream (Kocin and Uccellini 1990). The cold-MHC sea-level pressure composite (Fig. 3b) 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. 3a).

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 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 trough is over the eastern United States, this cyclonic curvature is co-located with a relative vorticity maximum south of the Capital Region over New Jersey (Fig. 5b). The 500 hPa thermal trough can be seen further upstream of the 500 hPa trough axis. In the Capital Region anticyclonic relative vorticity advection is occurring during the peak of cold-MHC events.

In the 300 hPa composite (Fig. 6b), an amplified flow pattern is seen, 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. Like the warm composite upper-level divergence was both weak and east of the Capital Region.

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). From the surface to 800 hPa, there is veering of the winds (see inset), which is associated with friction. Though the composite smooths out detailed features of the individual events, a weak stable layer can be seen around 900 hPa. The freezing level and dendritic growth zone (indicated by the blue line) extends from the surface to 600 hPa, providing a good environment for snow growth, particularly since the sounding is saturated from the surface to 800 hPa.

*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. Forecasters at the National Weather Service in Albany were caught off guard after dealing with a plethora of snowstorms in December 2007, and models at the time were not usually good at forecasting possible MHC conditions. Officially, an additional 0.8 cm of snow was reported at KALB, but local weather observers reported more significant accumulation 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 Figure 8. The event started as a broad swath of synoptically forced precipitation that ultimately organized into a banded feature with a north-northwest to south-south east orientation directly after the passage of the synoptic precipitation. 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. The surface observations show a moderate northwesterly wind at 10 to 15 kts, which is atypical compared to the wind rose composite in which northerly winds were favored.

At the surface (Fig. 9), much like in the composite, there is an area of low pressure located off the New England coast over Nova Scotia with a central pressure of 986 hPa according to the WPC surface analysis. 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. The surface observations at KALB exhibited northwesterly winds during a majority of the event.

At 850 hPa a deep positively-tilted trough can be seen along the east coast of the United States (Fig. 10), which is very similar to the height pattern in the cold-MHC composite (Fig. 4b). This induces a north-northwesterly flow over New York, indicative of cold-air advection. 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.

At 500 hPa, a deep, positively-tilted trough can be seen across the eastern United States with strong cyclonic relative vorticity in the base of the trough over the Southeast United States (Fig. 11). Associated with the departing surface cyclone, a cutoff, shortwave cyclone was located over Nova Scotia. At this time, approximately 2 hours before the peak of the MHC event, cyclonic vorticity advection was occurring in the Capital Region. Cyclonic vorticity advection leads to broad upward vertical motion responsible for the broad area of precipitation, but as this maximum passes the Capital Region the precipitation forms into a single band (Fig. 8)

At 300 hPa, a deep, positively-tilted trough is evident over the eastern United States (Fig. 12). This pattern is similar to the cold-MHC composite; however, the flow is more amplified and the Capital Region 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. Upper-level divergence can be seen happening near the Capital Region.

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 surface winds in the observed sounding show a northwesterly direction that rotates to a northerly direction around 800 hPa, consistent with the signal of warm-air advection seen at 850 hPa that was most likely an artifact of downslope warming in the lee of the Adirondacks (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. The northwesterly surface winds differ slightly from the wind rose which shows most cold-MHC cases exhibit northerly surface flow.

**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 west-northwesterly in the Mohawk valley and south-southeasterly in the Hudson valley supplying unstable air to the greater Capital Region. The winds are typically weak in the pre-frontal 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. A coastal low is located off the coast of Cape Cod inducing a north-northwesterly geostrophic flow over New York. In the presence of channeling this leads to north-northeasterly flow in the Hudson Valley with a magnitude between 0 and 13 kts and northwesterly flow in the Mohawk Valley with a magnitude of 12 to 15 kts . Cold-MHC events are also characterized by a moist boundary layer with weak warm-air advection in the low-levels most likely attributed to downslope warming off the lee of the Adirondacks. Drier air with cold-air advection is seen in the mid-levels.

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. The checklist highlights the surface and synoptic scale features that were found to be important to the development of the both warm- and cold- MHC.

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 wind observations and the derived surface convergence from the 109 stations in the New York State Mesonet at that time. Surface convergence was seen before the onset of the enhanced precipitation in the Capital Region making this data a great resource for forecasters. The New York State Mesonet will also provide forecasters with real time information about the in-valley winds significantly helping MHC forecasting. Multiple sites within the Mohawk and Hudson River Valleys will allow us to identify convergence during MHC events leading to better predictability.

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