**An analysis of precipitation events associated with terrain-generated convergence in the Mohawk–Hudson River valleys**

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ABSTRACT

The unique terrain found in eastern New York plays a pivotal role in various weather phenomena in the Capital District Region. Several previous studies have documented the seasonal effects of channeled flow in the Mohawk and Hudson River valleys. However, a comprehensive and composited look at these cases in both the warm and cold seasons has never been formally investigated. The goal of this study was to composite the known cases of low-level convergence in both the warm and cold seasons where the Mohawk and Hudson River valleys. These cases are known pose a challenge to local forecasters and referred to as Mohawk-Hudson convergence (MHC) events. Many MHC events happen as enhancements to synoptic scale forcing but some can happen as a sole result of the lower-level convergence, which are referred to as pure MHC events. While MHC events are generally nuisance events, occasion they can result in particularly high-impact weather. Cold MHC related precipitation events can result in persistent light to moderate snow in the wake of a departing low pressure. Warm MHC cases can result in an unexpected thunderstorm to develop very close to the Albany International Airport. Occasionally, with the right amount of shear and Surface Cape, any warm MHC cell can become briefly severe.

Warm cases of MHC are characterized by weak warm air advection and southwesterly flow which allows for the advection of instability up the Hudson River valley. Cold cases of MHC are characterized by weak cold air advection on a northwesterly wind and boundary layer moisture in conjunction with cyclones departing off the coast of New England.

**Introduction**

The presence of two intersecting river valleys, can alter the wind flow in a way that can lead to weak surface convergence that can result in unpredicted and significant precipitation and even severe weather events. One case where these multiscale low-level flow channeling effects can be seen is in the Mohawk and Hudson River valleys of New York State. These are commonly referred to as Mohawk Hudson convergence (MHC) events which have been documented in both the cold and warm seasons. These events often happen with very little warning and can have local but significant societal impacts. The cold cases often create minor but annoying additional accumulation of snow on the tail of nor’easters. prolonging the plowing and salting of roads. Often times these isolated light to moderate snowfall events can extend a prolong periods of IFR or even LIFR at Albany International Airport. The warm cases can also quickly impact operations at Albany International Airport and effect the large Capital District Region through discrete “pop up” convection. Channeling effects in the Hudson River valley add to the instability and increase the vertical wind shear which can rapidly make these discrete cells become severe and even influence supercell and MCS development.

These events are highly driven by the topography of the region. The Hudson Valley is a broad and shallow river valley oriented in a north-south direction stretching from Southern Quebec to New York City. The Mohawk Valley is fairly narrow compared to the Hudson River valley and is oriented in an east-west direction stretching from Buffalo, NY to Albany, NY. Similar types of events occur in the Puget Sound in post-cold front environments as discussed in Mass and Clifford (1981) which is responsible for increased precipitation in the Seattle region. The Olympic Mountains of Washington State have a strong influence on the spatial distribution of precipitation (Anders et al. 2006). In an investigation into severe weather in the greater Capital District Region it was found that there was strong evidence that the underlying terrain influenced the distribution of severe weather (Wasula et al. 2009). The effect of topography is yet again echoed in Zhong 2008 where the presence of topography can lead to thermally and dynamically induced mesoscale wind fields. It is important that winds are directed through these valleys in order to induce low level flow regimes. Complex terrain can also influence the climatological surface winds due to these channeling effects (Jeglum and Hoch 2016). River valleys can offer a mix of complex flow regimes and topographic layout leading to mesoscale forcing.

Valley channeling is a very important result of topography and greatly impacts the winds near the surface. Even though the Hudson and Mohawk valleys are fairly shallow the can still create channeled flow. Gross and Wippermann looked at such a case in 1987 of the Rhine Valley in Germany. This valley depicted channeled flow even though the valley walls only extended to 500m in height. The Hudson and Mohawk valleys are deeper than the Rhine Valley therefore channeled flow. Studies have shown that the wind is bent toward a westerly flow in the Mohawk Valley, and in the case of cold weather MHC cases, northerly in the Hudson valley. During the warm MHC events, the wind is bent from southwest to south in the Hudson valley while west to southwest in the Mohawk Valley.

There are four main mechanisms from classical mechanics that can create channeled flow. First is thermally driven, which results from local diurnal cycles in causing up-valley winds during the day and down valley winds during the night. The second is driven by downward momentum transport, this is caused by vertical turbulent mixing by gravity waves and or friction. The third is forced channeling in which the geostrophic wind is channeled by the valley walls creating a flow up or down the valleys axis depending on the direction of the geostrophic wind. Lastly pressure driven channeling, which are driven by small difference is pressure along the valleys length. (Whiteman and Doran 1993) Most events in the Hudson and Mohawk valleys seem to be in a response to pressure driven channeling (Augustyniak 2008, Bloecker and Johnson 2011) either inducing at northerly or southerly flow in the Hudson Valley and always an easterly flow in the Mohawk Valley. Pressure driven channeling is also the predominant forcing for other river valleys in the region such as the St. Lawrence River Valley, which contributes to weather patterns around Montreal, Canada (Razy 2011).

Impacts from MHC events can vary from brief but moderate snowfall event in the cold cases to severe weather and supercell development in the warm cases. Often times these events happen without warning as these events are difficult to predict by local forecasters.

**Data and Methodology**

1. Case Selection

All cases were chosen based on radar analysis of the Capital Region to locate isolated precipitation within this convergence zone. Evidence for boundaries such as fronts, troughs and or cold pools were also analyzed and cases which contained these features were discarded. In all cases a surface analysis was also performed looking for prefrontal and frontal features and cases which exhibited these features were also discarded. The cases which remained were pure Mohawk-Hudson Convergence which means they happened without the influence of synoptic scale forcing.

In warm MHC cases, every event in which lightning was reported at Albany International Airport (KALB) was analyzed. Cases also had to start within a 10-mile radius of Albany Airport and reach a reflectivity of 30 dBZ. Cases were also verified for an abundance of surface based convective available potential energy (SBCAPE). There were a subset of convective cases which were initially the result of other mechanisms but were enhanced by the convergence zone. No cold similar MHC cases existed. In total, 19 pure warm cases were cited and from July 2003 to August 2014

Cold MHC case events were usually associated with coastal lows. These were examined to make sure no Lake effect or lake enhanced snow took place. Cold cases were only selected if other forcing features were not present. In many cases it was difficult to determine enhanced cold cases so only pure cases were kept. In total 12 pure cold cases were cited from November 2002 to September 2013.

1. Data

To analyze these events surface observations where received from the Iowa State Archive and radar data was received from the National Climate Data Center. To create the case composites a 0.5° resolution Reanalysis of the Climate Forecast Systems Reanalysis (CFSR) was used. In the 2 January 2008 case study the 21km resolution Rapid Update Cycle (RUC) initialized at 1200 UTC on 2 January 2008 was used to model the synoptic features.

**Results**

Warm Cases:

Warm cases of MHC typically happened in events with very weak or no synoptic scale forcing. Figure 1a represents the 1000-hPa wind composite of the warm cases. The composite shows an overall west to southwesterly flow across the Capital District region during the peaks in MHC events. The magnitudes of the winds in the Hudson Valley were generally less than 2 m s-1, while winds in the Mohawk Valley were slightly stronger, but generally less than 6 m s-1. The southerly component of the winds allows for channeling up the Hudson River valley while the westerly component allows for channeling down the Mohawk River valley. The deceleration in the wind as well as the confluent components of the wind being funneled down the valleys is an indicator of weak surface convergence. This surface convergence in a high convective available potential energy (CAPE) environment is enough forcing to cause upward vertical motion to initiate convection.

The warm cases also occurred in prefrontal environments which lacked forcing from a prefrontal trough. This is illustrated in figure 2a which represents the composite of mean sea level pressure. The surface low was directly north of the region situated over southern Quebec and during the time of peak MHC intensity the surface front was located just to the west of the region. Generally the cyclones which forced these events did not have extremely strong pressure gradients, with the minimum composite mean sea level pressure of only 1012-hPa. This is important because as seen in the wind analysis weak surface winds are necessary to induce channeling in the valleys.

 At 850-hPa as illustrated in figure 3a weak cold air advection in the prefrontal environment was occurring during the onset of these events over most of western New England. The composite shows weak cold air advection on the order of -0.4 *°*C h-1. Warm air advection can result in weak vertical motion but in this case not enough to initiate region wide convection on its own.

Figure 4a shows the relative vorticity at 500-hPa. Extremely weak advection of cyclonic vorticity occurred during the warm events in most of eastern and central New York. This suggests that cyclonic vorticity advection provided little help in the way of assisting the upward vertical motion in the region during the peaks of the warm MHC events. As with the weak 850-hPa warm air advection, the cyclonic vorticity advection in the region was insufficient to create region wide convection.

 At 300-hPa in figure 5a, a weak jet was centered to the northeast of the region over New Brunswick extending southwest into southern Quebec. With the jet this far removed most of the vertical motion associated with the upper level divergence in the right entrance region of the jet should be occurring over Northeast New England. Overall warm MHC cases lacked upper level forcing.

The composite sounding in figure 6a shows a warm surface around 28 *°*C and surface dew points around 19 *°*C. With a warm moist surface there is abundant CAPE. Surface winds are around 5 knots and the winds veer with height. Winds veering with height are representative of warm air advection, which was seen in the 850-hPa map. Weak upward vertical motions through the lower atmosphere coupled with instability leads to the firing of convection in the Mohawk Hudson convergence zone.

Cold Cases:

Like the warm MHC events, the cold cases of MHC also typically happen in the absence of synoptic scale forcing. In figure 1b 1000-hPa winds in the Hudson River valley were typically northerly while winds in the Mohawk River valley were more northwesterly. The magnitudes of the wind varied between 6 m s-1 in the Mohawk Valley to winds near 3 m s-1 in the northern Hudson Valley. The magnitude of the wind in the cold cases across the region is reasonably larger than that of the warm cases because the departing cyclones in the cold cases are associated with stronger pressure gradients and therefore a stronger pressure gradient force. The western component of the northwesterly winds flow down the Mohawk Valley and converge with the winds flowing down the Hudson Valley from the north. This convergent flow can create weak upward vertical motion in this convergence zone.

The composite consisting of these departing cyclones can be seen in figure 2b, which shows mean sea level pressure. The composite shows that during the peak of cold MHC events the cyclone is generally located east of New England. The mean sea level pressure in these cases composited to be around 1004-hPa. The gradient in sea level pressure is much higher than that of the warm cases which is consistent with the increased magnitude of the winds.

 In figure 3b at 850-hPa cold air advection dominates. The cold air advection in the region is generally stronger than in the warm cases and is around -0.8 *°*C h-1. Strong warm air advection is occurring in a majority of the western Atlantic due to the strengthening cyclone. Cold air advection in the low to middle levels acts to build stability by creating a weak inversion seen in many of the cold MHC cases.

Taking a look at figure 4b there is a maximum in 500-hPa relative vorticity over the region. This means the anti-cyclonic vorticity advection is occurring behind the 500-hPa trough. The anti-cyclonic vorticity advection indicates at least weak upper level descent in the atmosphere.

At 300-hPa depicted in figure 5b an intense jet stream maximum in the composite can be seen to the south of the region pushing off the northern North Carolina coast. The jet maximum peaks at over 100 knots. The location of this jet maximum puts the Capital District region in an area favorable for neither upper level divergence nor upper level convergence, as it is not collocated in an entrance or exit region of the jet. From 300-hPa there is no forcing for upper level ascent of decent.

The composite sounding in figure 6b shows backing through the mid layers of the atmosphere, consistent with the presence of weak cold air advection in the region. Though the composite can smooth out detailed features of the individual events, the remnants of a weak inversion can be seen in the mid-levels around 900-hPa. The sounding is saturated from the surface to 800-hPa and is entirely below 0 *°*C. Any precipitation that occurs in this environment is fairly shallow. With the only forcing coming from the lower levels with some weak upper level descending motion convection is confined to the lower levels of the atmosphere.

Case Study- 2 January 2008:

The 2 January 2008 MHC event occurred as an area of surface low pressure deepening off the coast of eastern New England moved away. This cyclone caused a few brief periods of heavy snow in eastern New York and western New England before departing. This case is particularly significant because of its’ duration, intensity, and low predictability in the Capital Region. Officially an additional 0.8 cm was reported at KALB, but weather watchers reported measurements of an additional 2.5-9.4 cm in various parts of Clifton Park, NY. As much as 12.7 cm more snow was reported in Cohoes, NY , on top of what the cyclone actual produced. Outside of this narrow area extremely little or no additional snow accumulations were reported.

At the surface in figure 7, much like in the composite there is a low located off the eastern New England coast with a central pressure lower than 1004-hPa. The cyclone tracked slightly west of 40°N, 70°W and eventually moved to the northeast nearing Newfoundland.

On the back side of this storm there was very little in the way of cold air advection at 850-hPa, as shown in figure 8. Values of cold air advection were less than 0.4 *°*C h-1 in the Capital Region, with much more prominent cold air advection occurring in the southeast United States.

 In figure 9, 500-hPa vorticity is shown. At this time most of the cyclonic vorticity was located in the base of the trough and is being advected off the coast of eastern New England where the cyclone was deepening as it moved away from Eastern New England. Neutral or very weak anti-cyclonic vorticity advection was occurring in the Capital District.

A jet maximum of over 100 knots at 300 hPa was located just southeast of eastern New York and western New England, which can be seen figure 10. The areas of maximum upper-level divergence and convergence were displaced from the Capital Region. Like in the composite cold cases, the region is not in an area of the jet favorable for upper level divergence of upper level convergence.

Figure 11 shows the observed sounding from KALB at 1200 UTC on 2 January 2008. Like in the composite case the boundary layer is very moist and stable with temperatures less than 0*°*C. The winds in the observed sounding veer in the lower layers from the surface to around 900-hPa, this is consistent with low level warm air advection. The winds above this level begin to back, which is consistent with the cold air advection through the remainder of the troposphere. Like in the composite sounding precipitation is exclusively happening in the low levels, with the forcing explicitly coming from the weak lower level warm air advection and convergent wind flow.

**Summary and Conclusion**

 Unique terrain the eastern New York pays a pivotal role in the Capital District Region. Through compositing cases we could understand the typical synoptic scale setup common to these types of events to produce better forecasts.

 The synoptic setup for warm cases of Mohawk-Hudson Convergence was a zonal jet at 300-hPa with weak cyclonic vorticity advection and weak cold air advection. Most importantly weak south or southwesterly winds can channel westerly down the Mohawk valley and southerly up the Hudson valley supplying rich and unstable air to the greater Capital District Region. The winds are also typically weak in Albany during the onset of these types of events.

 The synoptic setup for cold cases of Mohawk-Hudson Convergence was a relatively stronger jet with trough over the East Coast with the jet maximum off the coast of southern Virginia. Strong cyclonic vorticity leads to a deepening of the low off the New England Coast increasing our surface pressure gradient. This leads to moderate northerly flow in the Hudson valley and northwesterly flow in the Mohawk valley. These events happen largely away from synoptic scale forcing. Cold events are also characterized by an interestingly moist boundary layer with dry air in the upper levels.

 These types of events are hard to predict because of their seemingly innocuous conditions. But can quickly with slight assent from the river valleys cause upward vertical motion lead to thunderstorms and quick bursts of precipitation.

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