**Precipitation events associated with terrain-generated convergence in the Mohawk and Hudson River valleys of New York**

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**ABSTRACT**

The unique terrain of eastern New York State plays a pivotal role in both the warm and cold season weather of the region. The valleys of the west to east Mohawk River, and north to south Hudson River intersect in the Capital Region of New York, and can result in localized flow channeling and boundary layer convergence. Several previous case studies have documented the important role of Mohawk–Hudson convergence (MHC) in modulating the low-level wind profile in cases of warm-season severe weather. However, a comprehensive composite and case study analysis of these events, which pose a significant challenge to forecasters, has not been previously published.

 A composite analysis shows that warm-MHC precipitation events are characterized by low-level southwesterly geostrophic flow, with a surface low-pressure area located over eastern Quebec. The southwesterly flow is channeled in the valleys, which results in the northward advection of warm, moist air in the Hudson River Valley and westerly flow in the Mohawk River Valley, leading to boundary layer convergence. Cold-MHC events are characterized by weak cold-air advection from low-level, northwesterly geostrophic flow behind the cold front of a low-pressure system located off of Cape Cod. Surface winds are channeled westerly in the Mohawk Valley and northerly in the Hudson Valley. If low-level moisture persists after the passage of the cold front, the channeled low-level flow can lead to precipitation near the junction of the river valleys.

While most MHC events do not produce significant sensible weather, they can occasionally produce hazardous conditions if they occur with little warning and/or during peak travel times. Cold-MHC precipitation can result in persistent moderate to heavy snow in the wake of a departing cyclone, whereas warm-MHC cases often initiate an unexpected thunderstorm in the vicinity of Albany International Airport.

**1. Introduction**

 Channeled flow occurs when topographic features, such as breaks in mountain barriers or valleys through complex terrain, act to change the local wind direction and/or speed. Frequently, this phenomenon is associated with surface wind observations that differ systematically from surrounding observations and/or the geostrophic wind direction, and which occur only under certain synoptic conditions. As will be shown, the flow in the Capital Region of New York state, where the Mohawk and Hudson River valleys intersect (Figure 1), meets the characteristics for channeled flow in that the complex terrain of the surrounding Adirondack, Catskill, Berkshire, and Green Mountains acts to change the local winds and influence local weather.

 There are four main mechanisms described in Whiteman and Doran (1993) that have been identified as creating channeled flow. The first mechanism, thermal forcing, results from the diurnal cycle of heating in complex terrain, which causes up-valley winds during the day and down-valley winds during the night (e.g., Whiteman 1990; Rampanelli et al. 2004; Schmidli et al. 2009; Steafin et al. 2017). The second mechanism is downward momentum transport as a result of vertical turbulent mixing by gravity waves and/or friction (e.g., Jiang and Doyle 2008; Carrera et al. 2009; Serafin et al. 2017), generating in-valley winds that are of a similar direction as the ambient flow. The third mechanism is forced channeling, in which the wind is channeled by the valley walls creating a flow up or down the valley axis depending on the direction of the geostrophic wind. Sudden shifts in direction occur when the geostrophic winds shift across normal to the valley axis (Weber et al. 1998; Razy et al. 2011). Lastly, the fourth mechanism for channeled flow, pressure-driven channeling, is driven by the along-valley component of the large-scale geostrophic pressure gradient (Gross and Wippermann 1987; Kossmann and Sturman 2003; Carrera et al. 2009).

 There have been many studies documenting the role of complex terrain in the generation of mesoscale weather phenomena around the world. Due to the topography surrounding the Puget Sound in post-cold front environments, mesoscale convergence events are responsible for spatial variations in the climatology of precipitation around Seattle (Mass 1981; Ferber et al. 1993). The complex topography of the Owens Valley in California can lead to thermally and dynamically induced mesoscale wind fields (Zhong et al. 2008; Strauss et al. 2016; Serafin et al. 2017). This complex topography was responsible for high wind events in the valley which have been documented in Cohn et al. 2004 and Grubišić et al. 2008. Complex terrain can also influence climatological surface winds due to channeling, such as in northwest Utah. In this case it was believed that the binomial distribution in the surface wind climatology was mainly due to thermal forcing. Upon further analysis, it was found that the temperature difference between the Great Salt Lake and the surrounding topography led to a low-level pressure gradient inducing this pressure-driven channeling (Rife et al. 2002; Jeglum and Hoch 2016). The Saint Lawrence River Valley experiences channeled flow that contributes to locally higher precipitation amounts in Montreal due to pressure-driven channeling (Carrera et al. 2009; Razy 2011; Cholette et al. 2015). This channeling sometimes occurs in association with tropical cyclones undergoing extratropical transition, which, like the case in Utah, establishes a synoptic-scale pressure gradient along the southwest to northeast axis of the valley (Milrad et al. 2012). Finally, channeled flow via the aforementioned mechanisms has been shown to occur even in very shallow river valleys such as Germany’s Rhine Valley, where valley walls only extend to 500 m in height (Gross and Wippermann 1987).

The Hudson Valley is a broad and shallow river valley oriented north to south, stretching from near Glens Falls, NY to New York City. The Mohawk Valley is oriented from west to east stretching from Rome, NY to Albany, NY. As shown in Fig. 1, these two valleys intersect in the vicinity of Albany, NY, where the valleys are approximately 500 m deep and 60 km across. The intersection of the valleys can alter the flow in such a way that leads to locally strong, boundary layer convergence known as Mohawk–Hudson convergence (MHC), which can result in poorly predicted precipitation events and severe weather.

MHC events happen in two regimes, the first being in southerly flow which are considered warm occurrences and second northerly flow which are considered cold occurrences. Often MHC events happen with little warning, and can have significant societal impacts. For example, in warm-MHC events, or those events enhanced by warm-MHC, channeled flow has been shown to affect the formation of supercell tornadoes in cases such as the category 3 Fujita/Enhanced Fujita scale (F3/EF3) tornadoes that occurred on 29 May 1995 in Great Barrington, MA (Bosart et al. 2006), 31 May 1998 in Mechanicville, NY (LaPenta et al. 2005), and 22 May 2014 in Duanesburg, NY (Tang et al. 2016). In each of these cases, channeled, southerly flow up the Hudson River Valley increased surface instability (Riley and Bosart 1987; Bracken et al. 1998) and locally enhanced the vertical wind shear (e.g., Geerts et al. 2009; Peyraud 2013), turning discrete cells severe and strengthening supercells that propagated into the intersection of the valleys (LaPenta et al. 2005; Bosart et al. 2006; Tang et al. 2016).

Similar case studies for cold-MHC events do not exist in the literature, although their impacts, moderate additional snowfall accumulation on the tail of nor’easters and extended periods of instrument or low instrument flight rules at Albany International Airport (KALB), can be significant (Augustyniak 2008). Also missing from the literature is a composite analysis of MHC events, which may aid forecasters in identifying the specific synoptic-scale conditions under which MHC events are likely to occur. This study will conduct such a 13-year composite analysis of both warm and cold MHC events and present a case study of a cold-MHC event from 2 January 2008.

The data and methodology for this study are described in section 2. The results of the warm-MHC composite analysis are presented in section 3, while the cold-MHC analysis and case study are presented in section 4. A forecaster checklist and conclusions are given in section 5.

**2. Data and methodology**

*a. Case selection*

This study examines warm- (southerly) and cold- (northerly) MHC events from 2002–2014. Potential warm-MHC events were identified by the following criteria: 1) reflectivity >30 dBZ within 16 km (10 miles) of KALB; 2) southerly flow reported at KALB; and 3) at least one flash detected by the National Lightning Detection Network (Cummins and Murphy 2009) within 16 km (10 miles) of KALB, fitting the definition of a thunderstorm in the vicinity (VCTS) and the radius within which KALB most often reports a thunderstorm (Corbosiero and Lazear 2015). These selection criteria lead to the identification of 84 possible cases. However, in a large number of these cases it appears as though warm-MHC did not impact the thunderstorms leading to 48 null cases, leaving us with a total of 36 warm-MHC events. All cases of warm-MHC indicated a nose of increased, surface based convective available potential energy (SBCAPE) being advected northward in the Hudson River Valley in the Storm Prediction Center’s mesoscale analysis. Using radar and surface analyses, the 36 cases were examined for evidence for boundaries such as fronts, troughs, and/or cold pools from ongoing convection. This examination revealed that in 17 of the 36 warm-MHC events convection was initiated as the result of other mechanisms (e.g., prefrontal trough, cold pool dynamics, etc.), but was *enhanced* by MHC. As this paper seeks to analyze only pure MHC events, the cases that showed enhancement, rather than initiation, of convection by MHC were not included, leaving 19 warm-MHC cases to composite (Table 1).

 As cold-MHC events are known to occur as nor’easters depart the Capital Region (Augustyniak 2008), any day on which a surface low which tracked west of 40°N 70°W was considered a potential case. As a general forecasting rule of thumb lows tracking further east have little to no impact to the Capital Region. A total of 54 lows were analyzed over the 13-year climatology. Potential cold-MHC events were identified by the following criteria: 1) The KENX radar had to show the departing precipitation shield associated with the coastal cyclone and identify new precipitation over the Capital Region; 2) The KENX radar had to show no evidence of lake-effect, or lake enhanced, processes (e.g., Niziol et al. 1995). Of the total 54 cases that were analyzed only 12 cases of cold-MHC were identified (Table 2) due to the strict criteria applied (note that it is difficult to estimate the number of cold *enhanced* MHC events, as they are often embedded in large swaths of synoptic scale precipitation).

*b. Data*

 Surface observations for the Capital Region were obtained from the National Centers for Environmental Information (NCEI) 1 minute automated surface observing systems (ASOS) data for Albany (KALB), Glens Falls (KGFL), Poughkeepsie (KPOU), Rome (KRME) and Utica (KUCA) New York. ASOS data was incomplete in some cases, and at some sites entire days and months of data are missing significantly impairing my ability to access information for all the cases. Radar data for KENX was also obtained from NCEI. Reviews of surface based convective available potential energy (CAPE), temperatures and dewpoints for the individual warm-MHC cases was taken from the Storm Predictions Center (SPC) mesoanalysis. Warm- and cold- MHC composites were created using the 0.5° Climate Forecast Systems Reanalysis (CFSR) (Saha et al. 2010). Composites were centered on the time of maximum reflectivity of each MHC event and composite soundings were made at the grid point closest to Albany International Airport. Although the grid spacing of the CFSR doesn’t allow for the resolution of MHC-channeled flow, the composite analysis is used only for identifying synoptic-scale features leading to MHC to help develop forecaster awareness. For a more detailed, mesoscale analysis of a cold-MHC event, the 2 January 2008 case study uses output from the 13-km resolution Rapid Update Cycle (RUC) model initialized at 1200 UTC 2 January 2008. The Weather Predictions Center (WPC) surface analysis was also used to see observed surface pressure and location for this case.