**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-season 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-season 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 in the vicinity of 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 in which 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 a weak pressure gradients (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. In post-cold front environments, mesoscale convergence events, due to the topography surrounding Puget Sound, are responsible for spatial variations in the climatology of precipitation around Seattle (Mass and Clifford 1981). The effects of topography were also investigated in Zhong (2008), who found that the presence of complex terrain can lead to thermally and dynamically induced mesoscale wind fields in the Owens Valley of California. Complex terrain can also influence climatological surface winds due to channeling, such as in northwest Utah (Jeglum and Hoch 2016). Finally, the Saint Lawrence River Valley experiences channeled flow that contributes to locally higher precipitation amounts in Montreal due to pressure-driven channeling (Razy 2011). This channeling sometimes occurs in association with tropical cyclones undergoing extratropical transition, which establish a synoptic-scale pressure gradient along the southwest to northeast axis of the valley (Milrad 2012).

Channeled flow via the aforementioned mechanisms has been shown to occur even in very shallow river valleys. For example, Gross and Wippermann (1987) documented channeled flow in Germany’s Rhine Valley, where the valley walls only extended to 500 m in height. 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 fairly narrow compared to the Hudson River valley and 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. Around Albany and the greater Capital Region of New York State, 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 often happen with very little warning and can have significant societal impacts. Warm MHC events can quickly disrupt operations at Albany International Airport as discrete convective cells can rapidly develop. In warm MHC events channeled flow is also known to affect the formation of supercell tornadoes as topographic influences have been examined in cases such as the Duanesburg, NY (Tang et al. 2016) tornado on 22 May 2014. Differential heating caused by increased cloudiness in some areas resulted in a strengthening of the zonal pressure gradient causing the winds to slightly back to a more easterly direction. This more easterly flow resulted in terrain channeling leading to increased horizontal moisture flux convergence in the eastern Mohawk valley. The Mechanicville. NY (LaPenta et al. 2005), and Great Barrington, MA (Bosart et al. 2004) tornadoes were a result of channeled flow which enhanced the supercells inflow. Channeled, southerly flow up the Hudson River Valley can increase surface instability and enhance vertical wind shear, which can rapidly turn discrete cells severe and even influence supercell and mesoscale convective system development (Markowski and Dotzek 2011).

 Cold MHC can create moderate snowfall and additional accumulation of snow on the tail of nor’easters, prolonging the treatment of roads. Often times, these isolated light to moderate snowfall events can extend periods of instrument flight rules (IFR), or even low instrument flight rules (LIFR), conditions at Albany International Airport (KALB). Similar case studies for cold MHC events do not exist in the literature, nor has a composite analysis been undertaken. We will be looking at a case study from a cold MHC event from 2 January 2008 and completing a composite analysis of both warm and cold season MHC events.

The unique terrain in eastern New York State plays a pivotal role in both the warm and cold season weather of the region. Several previous case studies have documented the important role of MHC in modulating the low-level wind profile in cases of warm-season severe weather. MHC events only occur under specific atmospheric conditions, and in many cases when one key ingredient is missing, MHC does not occur. As such, MHC is challenging to predict, and many cases occur without warning. Through analysis of a composite of past events we are able to deduce synoptic and mesoscale patterns favorable for MHC events. The data and methodology are described in section 2. The results of the warm MHC composite analysis are presented in section 3 and the cold MHC analysis and case study from 2 January 2008 are presented in section 4. In section 5 we will end with a summary and conclusion about MHC events.

**2. Data and methodology**

*a. Case selection*

MHC events that occurred with southerly flow in the Hudson Valley were considered warm MHC events. For these warm MHC events, every event was analyzed for which lightning was reported within 16 km (10 miles) of Albany International Airport fitting the definition of a thunderstorm in the vicinity (VCTS) on the METARs. This is also the radius within which the airport most often reports a thunderstorm in the METAR (Corbosiero and Lazear 2013). Suspected MHC convection had to reach a minimum of 30 dBZ. Cases were also verified using the Storm Prediction Centers mesoscale analysis, 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. Using radar and surface analysis evidence for boundaries such as fronts, troughs, and/or cold pools from ongoing convection. There was a subset of 17 out of the 36 total warm events in which 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 clear MHC events, the cases that showed enhancement of convection, rather than initiation, of convection by MHC were not included. In total, 19 warm cases were identified (Table 1).

MHC events that occurred with northerly flow in the Hudson Valley were considered cold MHC events. For the cold MHC events, any surface low which tracked west of the 40°N, and 70°W benchmark was analyzed, because lows tracking further east of this benchmark nearly always have no impact to the Capital Region. There were no cases of cold MHC in which the cyclone passed east of this benchmark. Like the warm cases radar and surface analysis were used to find evidence for boundaries such as fronts, troughs, and/or ongoing synoptic scale precipitation. These events were examined to make sure no lake-effect, or lake-enhanced, snow took place and that the cases occurred independent of synoptic-scale forced precipitation. It is difficult to analyze *enhanced* cold events as they are often imbedded in large fields of synoptic scale precipitation. In total, 12 cold cases were identified (Table 2).

*b. Data*

 Surface observations were obtained from the National Centers for Environmental Information (NCEI) 1 minute automated surface observing systems (ASOS) data for Albany, Glens Falls, Poughkeepsie, Rome and Utica New York. ASOS data was incomplete in some cases at some sites in which entire days and months of data are missing. Radar data was obtained from the National Centers for Environmental Information. Warm and cold-season MHC composites were created using 0.5° Climate Forecast Systems Reanalysis (CFSR) (Saha et al. 2010). The composite was centered on the time of maximum reflectivity of each MHC event. Composite soundings were made centered on Albany International Airport. Although the resolution 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. The 2 January 2008 case study uses the 13-km resolution Rapid Update Cycle (RUC) model initialized at 1200 UTC 2 January 2008.