4. Discussion

This thesis contains data collected from case studies of seven MHC events, all of which occurred between November 2002 and January 2008. The synoptic and mesoscale weather features present during each case were examined, and statistical analyses of wind speed and SLP were carried out for seven case studies. Observational findings and results from the statistical analyses were presented in sections 3.1 and 3.2, respectively, were summarized in section 3.3, and are discussed in section 4.1. A discussion of the findings in this thesis in relation to preexisting research on low-level flow channeling follows in section 4.2. Finally, section 4.3 contains a proposed methodology to aid in the operational forecasting of MHC events.

4.1 Composite Results of Case Studies

Weak mid- and upper-level forcing (i.e., from the 700-hPa level and above) is present during the seven MHC case studies presented in this thesis. The case studies, analyses, and the observational data instead indicate that surface and lower-tropospheric weather features exert the greatest influence on MHC development. Particularly important is a positive west–east (north–south) pressure difference along the Mohawk (Hudson) valley, which is the key to driving the low-level confluent flow observed during all seven cases. This setup is illustrated vividly during the January 2008 event. In this event, MHC-related precipitation began to appear on radar (Figs. 3.76a–f) after a positive SLP difference between KGFL and KPOU developed at 0700 UTC 2 January 2008 (Fig. 3.82). The SLP differences involved in any case must be great enough to promote air motion down the valleys and ascent where the confluent airstreams meet, but not so large that the orographic effects are overwhelmed and damped out by the synoptic-scale flow.

Measurements of SLP across the MHC domain (see Fig. 1.2) show that higher values were present along the northern and western sides of the domain, as compared to the southern and eastern sides, during all seven case studies. A statistical analysis shows that SLP differences between two pairs of bellwether sites (KGFL and KPOU in the north–south direction; KUCA and KPSF in the west–east direction), recorded hourly during ongoing MHC events, fell within a consistent range for the five case studies between November 2002 and March 2006 (Fig. 3.5a). In these cases, the west–east (north–south) SLP difference measured from 4 to 7 hPa (1 to 5 hPa).

Similar calculations were made for the January 2007 case study (Fig. 3.6); during this study, SLP-difference values in the north–south direction also fell within the 1–5-hPa range. Unfortunately, due to the cessation of reports from KUCA and the slow implementation of a reliable replacement site, it is impossible to draw a parallel conclusion regarding SLP differences in the west–east direction. The pattern of higher SLP values to the west is, however, observed in both the January 2007 and January 2008 cases (Figs. 3.35 and 3.82). It is proposed that, in future studies, SLP differences calculated between KRME and KPSF be used to develop a set of values to indicate the likelihood of an MHC event.

At any given hour during the case studies, the SLP difference seen in the west–east direction was always greater than that in the north–south direction; however no strong correlation was found between the magnitude of west–east versus north–south SLP differences (Fig. 3.5a). When SLP-difference measurements were grouped and analyzed as a function MHC event maturity (i.e., those taken at the beginning, middle, or end of an event; see Figs. 3.5b–d), no clear-cut signals emerged. Nevertheless, SLP differences in the north–south direction tend to be larger at the beginning of events than at the end of events.

The aforementioned SLP differences present across the Mohawk and Hudson Valleys promote a confluent low-level wind signature within these valleys, as revealed in the wind climatology of MHC events. Winds at KGFL regularly blew from the northeast or east-northeast during MHC events (Fig. 3.1a), consistent with well-channeled winds within the upper Hudson valley. Likewise, west-northwest winds occurred frequently at KUCA (and KSYR) during MHC events (Fig. 3.2a), consistent with well-channeled winds within the Mohawk valley. The low-level airflows in each of these valleys converged in the vicinity of KALB, which shows a bimodal wind climatology during MHC events (Fig. 3.3a) owing to the intersection of both valleys. Northwest winds were experienced at KALB with nearly the same frequency as northeast winds, with a slight preference for north or northeast winds to occur at the beginning of events (Fig. 3.4a), and a slight preference for northwest winds to occur at the end of events (Fig. 3.4b).

Several distinctive synoptic weather features gave rise to the aforementioned SLP and wind patterns. At the surface, during all MHC events, SLP isobars over eastern New York and western New England exhibited a “reverse-S” shape, with a weak ridge of high pressure frequently located over northern New York, and a weak trough of low pressure located south of the Mohawk Valley. This trough commonly originated from an offshore surface low and extended westward or west-northwestward approximately along the border between New York and Pennsylvania. In all cases, this surface low center was intensifying as it tracked offshore, commonly south and east (i.e., "outside") of a reference point at 40°N, 70°W. All MHC events occur in the wake of a coastal cyclone, and following the passage of its synoptic-scale precipitation shield. The presence of such a cyclone appears to be a dominant influence on the formation and duration of MHC, as illustrated on 29 January 2007 during a particularly long-lived MHC event. In this case, MHC-related precipitation began as one intensifying surface low tracked from off the North Carolina coast to well southeast of Nova Scotia (Figs. 3.24a–d), and continued as a second low intensified and followed a similar track (Figs. 3.24d–f).

On the other hand, surface low centers which pass over or just north or west (i.e., "inside") of the reference point located at 40°N, 70°W should not be ignored. Some surface lows that track slightly inside of this reference point, such as the low in the January 2008 case study, are also capable of producing MHC-related precipitation. Likewise, the passage of an 850-hPa warm front from north to south across the region, as seen in the 23–24 January 2003 case, can generate winds with a westerly (northerly) component in the Mohawk (Hudson) valley, and is a potential mechanism for creating MHC.

It is important to note that strong forcing for vertical motion (ascent or descent) can act to upset the delicate balance of conditions that can lead to MHC events. Strong CAA, for example, could lead to the downward mixing of higher momentum from aloft to the surface. The pressure-driven channeled wind flows at the surface could be disrupted or damped out by such downward momentum mixing. Moreover, the subsidence associated with strong CAA could lead to drying of the PBL, whereas a moist PBL is necessary for MHC-generated precipitation. At the same time, CAA at middle levels led in several case studies to the development and lowering of a subsidence inversion, which acted to lower atmospheric mixing heights and reduce the downward transfer of horizontal momentum. This effect is shown nicely in the KSCH profiler data from 1800 to 2100 UTC 27 November 2002 (Fig. 3.20), during the period when MHC-forced precipitation had reached its peak intensity. At that time wind speeds were 5 m s^{-1} or less from the surface to 950 hPa, with wind speeds ranging from 5 to 10 m s^{-1} in the 950–800-hPa layer. Inversions seen on the radiosonde soundings of other MHC case studies have a similar "shielding" effect on low-level winds, and also indicate an atmosphere that is stable with respect to surface-based convection.

Strong vertical motions are lacking at any level in all of the case studies examined in this thesis, even during the warm-front case of January 2003 which featured a maximum vertical motion of −5.0 μb s^{-1} at 550 hPa (not shown). The ascent attributed to MHC itself was shown in all case studies to maximize at a height of 925 hPa or below, generally at a value of −1.0 μb s^{-1}. In cases where the dendritic snow-growth region lies near or below 925 hPa, forecasters should be aware of the potential for enhanced snowfall rates and totals.

Upper-air forcing for vertical motions also must be weak so as not to damp out the more subtle SLP-driven channeling effects present at the surface. At jet-stream level (300 hPa), forcing for ascent is lacking in all case studies. The MHC domain is consistently under confluent flow at 300 hPa or the downward motion associated with the circulation around jet streaks, or both. At 500 hPa, cyclonic curvature of geopotential height contours is present in all MHC case studies. Horizontal advection of both cyclonic and anticyclonic absolute vorticity is present at 500 hPa during the MHC events, but in all cases these advection regimes are weak.

It appears that MHC is far more common during the cold season than the warm season simply because the necessary antecedent weather conditions and synoptic regimes are more common at that time of year. Aside from the lower likelihood of these ingredients coming together, there seems to be no reason why MHC could not occur during the warm season.

4.2 Relationships to Preexisting Research on Low-Level Flow Channeling

The thrust of this research is to gain an understanding of the physical processes which drive MHC, and to synthesize from these findings a forecast methodology aimed at increasing its predictability. Criteria developed by Gross and Wippermann (1987) through their study of the flow-channeling effectiveness of Germany's upper Rhine Valley show that the Mohawk and Hudson River valleys are also effective flow-channeling features. The Mohawk and Hudson valleys, like the Tennessee valley, were also shown to susceptible to pressure-driven flow channeling, one of the four processes presented by Whiteman and Doran (1993) that produce in-valley winds which differ from ambient winds. Wasula et al. (2002) found that the Mohawk and Hudson valleys strongly modulate the surface wind climatology of the region, showing that surface winds frequently align with the valley axes. Severe weather reports were also found to occur preferentially south of the Mohawk valley into the Catskills and Berkshires (from the Mohawk valley west of KALB extending northward into the southern Adirondacks) on northwest-flow (southwest-flow) severe weather days, indicating that the valleys act to channel the ambient flow. LaPenta et al. (2005) and Bosart et al. (2006) found that channeling of near-surface southerly flow contributed to an increase in directional and speed shear (compared to surrounding areas) by producing more clockwise-turned hodographs, and by lengthening these hodographs. Given a day favorable for severe weather over the Northeast, such resulting shear changes might contribute to areas of increased numbers of tornadoes. Wasula et al. (2002), LaPenta et al. (2005), and Bosart et al. (2006), however, do not mention the presence of a topographically forced low-level convergence zone in eastern New York and western New England, such as that present during MHC.

There is a strong resemblance between MHC and the PSCZ, a phenomenon that has been studied extensively. The frequency with which each phenomenon occurs varies seasonally [shown for the PSCZ by Mass (1981)]. The PSCZ is shown by Mass (1981) and Chien and Mass (1997) to form as a narrow range of surface wind directions along the coast of western Washington develop in a post cold-frontal environment. This environment is similar to the one in which MHC typically forms; i.e., following the departure of a surface low pressure system and in the presence of weak CAA. Weak synoptic-scale forcing is present during MHC and the PSCZ (Mass 1981; Chien and Mass 1997), with a specific SLP pattern giving rise to light-to-moderate surface winds (generally 2.5–7.5 m s^{-1}). Chien and Mass (1997) showed, using computer modeling, that if the unique orographic features of the Puget Sound did not exist, the confluent flow seen during these events also would not develop. This thesis has shown that the topography of eastern New York and western New England is likewise critical to the formation of MHC. Both phenomena generate low-levels ascent, with Mass (1981) and

Chien and Mass (1997) showing that ascent is maximized at ~850 hPa (~1.2 km AGL) in the case of the PSCZ, while maximum ascent in MHC cases is shown to occur at ~925 hPa (~0.5 km AGL). Whitney et al. (1993) formulated a decision tree, employed by the Seattle, Washington (SEW), National Weather Service Forecast Office to aid in the medium-range prediction of PSCZ events. This decision tree is the basis for a similar scheme developed to aid in the prediction of MHC, as discussed in section 4.3.

Several differences between MHC and the PSCZ are also noted. Chien and Mass (1997) show, through the use of computer modeling, that latent heat release is important in the formation and strength of the PSCZ. The low precipitable-water values in MHC cases (generally less than 10 mm; see Table V), however, argue that the effects of latent heat release on MHC are negligible. The PSCZ also significantly modifies the precipitation climatology for the Puget Sound region, while the MHC does not appear to affect the climatology of eastern New York and western New England. The reasons for this difference are straightforward: MHC occurs much less frequently than, and is not as strong as, the PSCZ. Reasons for these differences may include: (1) the presence of more-subtle terrain features in eastern New York and western New England than in the Puget Sound region, and (2) the lower overall moisture content of air involved during MHC events (of the continental-polar classification) versus during PSCZ (of the maritime-polar classification).

The environment of the Longmont anticyclone (LA), studied by Wesley et al. (1995), also bears a clear resemblance to MHC. In both cases, significant advections of temperature or absolute geostrophic vorticity are noticeably lacking. Both phenomena also feature light, and sometimes calm, surface winds in the vicinity of the center of convergence, and generally light precipitation amounts. The ability of the LA to enhance preexisting precipitation is documented by Wesley et al. (1995), an effect which is seen during the MHC event of 23–24 January 2003 as well.

4.3 A Proposed Methodology for Forecasting MHC

Much the same as Mass (1981) and Whitney et al. (1993) deemed that accurate forecasts of the PSCZ could be made, MHC is also inherently predictable. A consistent set of weather features and conditions have been identified (in section 4.1) to be present each time MHC occurs, and schematics of the idealized synoptic-scale and mesoscale weather features associated with MHC events are shown in Figs. 4.1a,b, respectively. The intent is that these schematic diagrams be used in conjunction with a decision tree (shown in Fig. 4.2) to improve the accuracy of operational forecasts of MHC.

The SLP pattern across the Mohawk and Hudson valleys is the driving force behind MHC, and this ingredient is addressed at very beginning (top) of the decision tree. Of primary importance is that higher SLP values be located north and west of KALB in order to drive airflow simultaneously down the Mohawk and Hudson valleys. Empirical evidence suggests that the SLP difference in the north–south direction (between KGFL and KPOU) must fall in the 1–5-hPa range.

Specific values of west–east SLP difference have not yet been established, owing to the recent location changes and reliability issues of surface observation sites in the western Mohawk Valley. However, for the five case studies occurring from November 2002 to March 2006, the SLP difference between KUCA and KPSF consistently falls in the 4–7-hPa range. As the synoptic-scale pressure pattern during MHC events has higher pressures located to the west, it is safe to reason that the lower bound in the zonal direction is 4 hPa, if KRME or KSYR are used in place of KUCA.

Of secondary importance to the formation of MHC is the orientation of surface features, such that pressure-driven airflow is directed into and along the Mohawk and Hudson valleys simultaneously. The "reverse-S" sea level isobar pattern that is present over eastern New York and western New England during every case arises when an intensifying surface low tracks off the East Coast. In most instances, this low center passes "outside" (i.e., to the east or south) of a benchmark point at 40°N, 70°W. This benchmark rule should only be considered a guideline, however, and storms tracking over or just "inside" of 40°N, 70°W should also be monitored closely.

Most MHC cases occur in a post-storm environment that remains moist at low levels, contains a low- or mid-level "cap," and features weak synoptic-scale forcing. If all of the preceding conditions are met, MHC is likely. However, a second (if less common) set of circumstances can also trigger MHC. This scenario, which involves the passage of an equatorward-moving 850-hPa warm front across the region, is accounted for on the right hand side of the decision tree (Fig. 4.2).

If an MHC event is deemed likely, traditional rules governing snowfall forecasting apply. The location of the dendritic snow-growth layer, where air temperatures are between approximately −12° and −18°C, should be considered. If the dendritic snow-growth layer extends through 925 hPa, forecast snowfall accumulations should be increased accordingly. Particularly strong convergence events can produce snowfall rates to 2.5 cm h^{-1} or more.

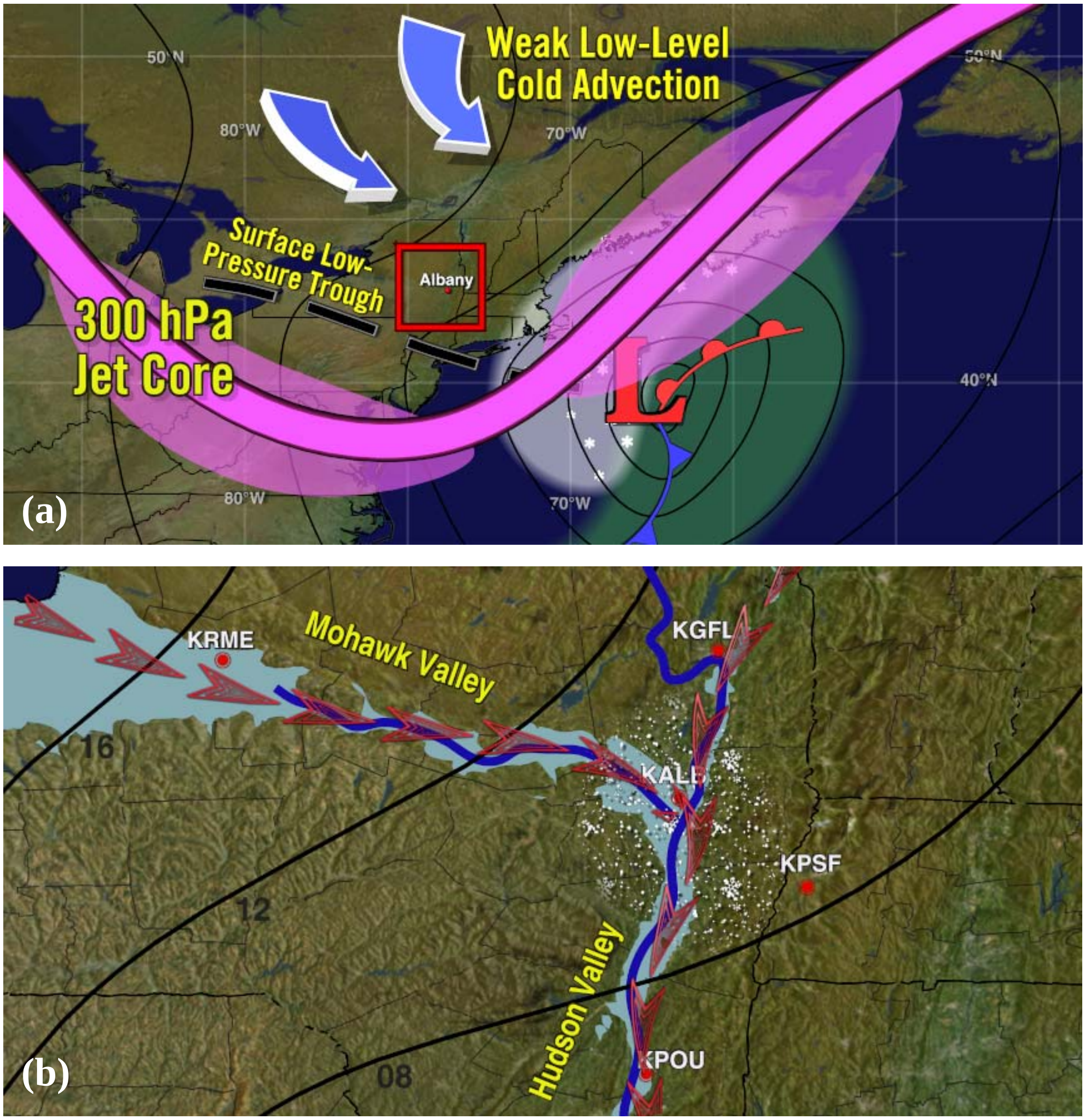

Figure 4.1: Schematic of the key features observed during a prototypical MHC event on the (a) synoptic-scale and (b) mesoscale. Shown in (a) are: an intensifying area of surface low pressure located southeast of 40°N, 70°W, and moving northeastward (red "L"); sea level isobars (solid black lines); a trough of surface low pressure; the attendant areas of synoptic-scale snow (white shading) and rain (green shading); the axis of 300-hPa maximum winds (heavy pink line) and jet streaks (pink shading); weak low-level cold advec-tion from the north; the area which bounds the MHC domain (red box). Shown in (b) are: the Mohawk and Hudson Rivers (royal blue line) and their associated valleys (light blue shading); low-level channeled flow (red arrows); sea level isobars with higher pressures indicated to the north and west (solid black lines); the approximate location of mesoscale snow forced by MHC effects (stippled shading); the locations of bellwether surface observation sites used in seven case studies (red circles and corresponding station codes.

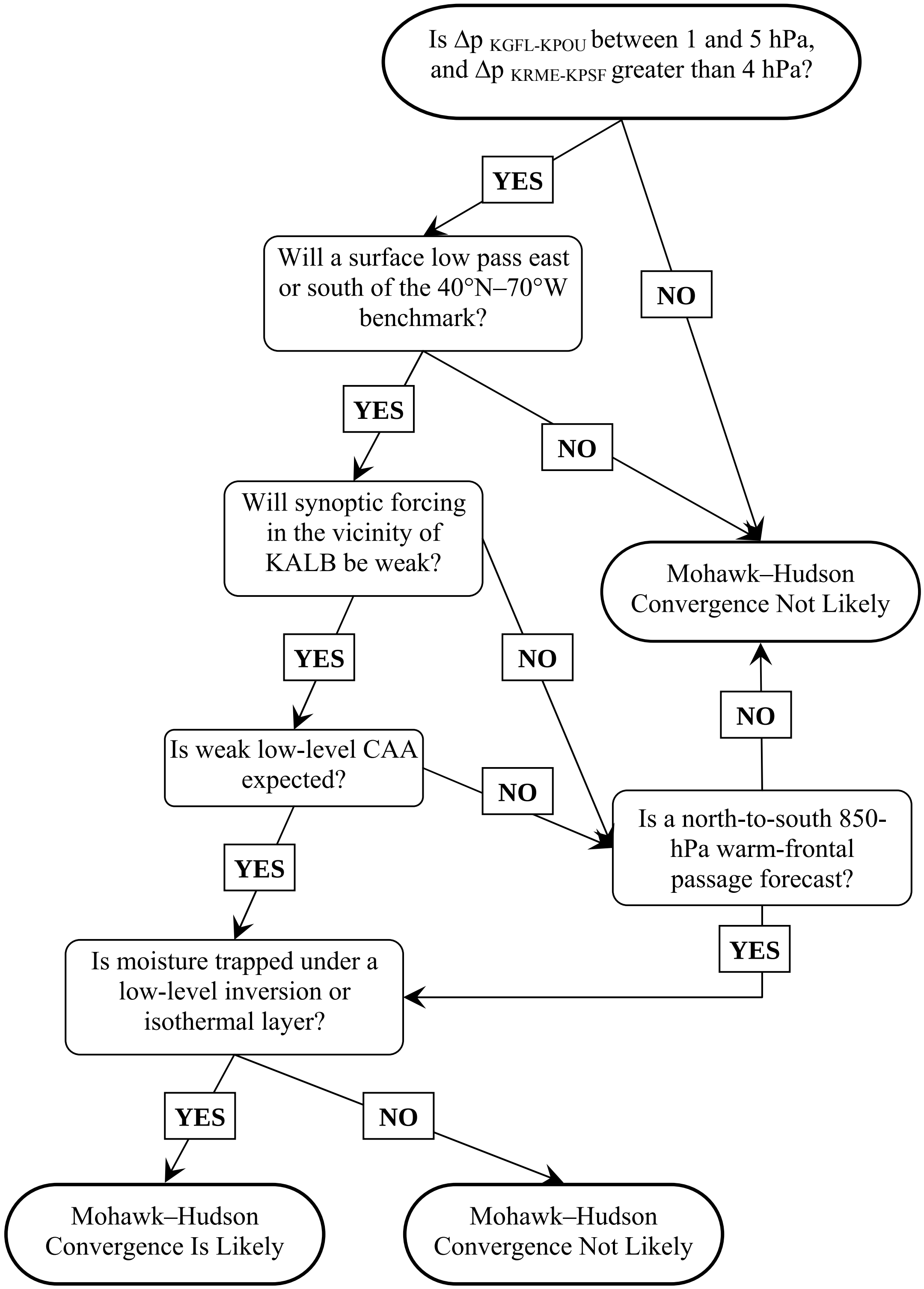

Figure 4.2: A decision tree for forecasting MHC. Adapted from Fig. 2 of Whitney et al. (1993).