

**SYNOPTIC AND MESOSCALE ANALYSIS OF A HIGH LATITUDE DERECHO -
SEVERE THUNDERSTORM OUTBREAK IN FINLAND ON 5 JULY 2002**

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Abstract

On 5 July 2002 a rapidly propagating bow echo formed over Eastern Finland causing severe wind damage in an exceptionally large area. The Ministry of the Interior's Emergency Response Centres received near 400 thunderstorm-related wind damage reports. The 5 July 2002 case is the highest latitude derecho that has ever been documented.

The bow echo developed ahead of a northeastward moving 500 hPa trough inside of the warm sector of a secondary low and moved north-northwestward on the eastern (warm) side of the quasi-stationary front. The leading edge of the bow echo was oriented perpendicular to the low level southerly wind shear and the convective system propagated along the 850 hPa θ_e ridge with a speed that was close to the maximum wind throughout the troposphere. It is particularly noteworthy that the synoptic pattern was oriented about 90 degrees counterclockwise when compared to the typical synoptic pattern associated with warm season derechos in the United States. This kind of synoptic situation associated along with the derecho MCS's motion towards the north-northwest has not been mentioned in literature before.

The mesoscale convective system started as a cluster of thunderstorms and became a bow echo a few hours later. The leading edge of the bow echo had a strong reflectivity gradient and the region of stratiform precipitation was behind the strongest echoes. At the most intense stage, a rear inflow notch was visible both in radar and satellite pictures. It was in good accordance with the location of an area of the most severe damage. Moreover, the storm-relative winds derived from the proximity sounding in the wake of the system showed the existence of rear-to-front flow above 850 hPa. The downdraft air appeared to originate from 4 km ASL, where the relative humidity was less than 50 %. This probably led to enhanced evaporative cooling and the intense cold pool which propagated faster than

the mean wind. In the mesoscale, the 5 July 2002 derecho had many similarities to other derecho MCSs that have been described in the literature.

1. Introduction

In the late 1800s straight-line convective windstorms were being studied in Europe and North America. In his studies in Germany, Dr. Wladimir Köppen's (1879; 1882; 1886; 1896) called such events "Gewitterböen" which can be interpreted in English as "thundersqualls". In the United States Dr. Gustavus Hinrichs (1888), director of the Iowa Central Weather Station, initially used the word "squalls" to define the straight-line convective windstorms in his studies. And this term was based on Köppen's terminology. However, Hinrichs (1888) was concerned because many straight-line convective windstorms in the state of Iowa were being mistakenly listed in government records as tornadoes (Court 1970; Galway 1985a; Galway 1985b). So, to assist in distinguishing the difference between the two, Hinrichs (1888) selected the term "derecho" to define long-lived convective straight-line windstorms. Derecho was a Spanish word which was defined as "straight" or "direct" and appeared to be the analog to the term "tornado" which is also of Spanish origin.

Although Hinrichs' term 'derecho' continued to appear in meteorological publications in Europe (e.g. Köppen 1896; Letzmann, 1923), it was never accepted or discussed in the North American meteorological community for nearly a century. Finally, in the later part of the 20th century the term derecho appeared in some historical publications concerning tornado researcher John Finley (Court 1970; Galway 1985a-b). After becoming aware of the term from Galway's historical study (before it was published), Johns and Hirt (1987) revived the term in describing "families of downburst clusters" (Fujita and Wakimoto 1981) which they experienced while forecasting severe convective storms. It was soon

discovered that derecho events were quite frequent phenomena in the United States (e.g. Duke and Rogash 1992; Bentley and Cooper 1997; Bentley and Mote 1998; Coniglio et al. 2004; Coniglio and Stensrud 2004).

According to Bentley and Sparks (2003) and Coniglio and Stensrud (2004) derechos in the United States are most frequent along two corridors. The northern corridor extends from the upper Mississippi Valley to Ohio and the southern corridor is located in the central and southern Great Plains. In Coniglio and Stensrud's 16-yr dataset 69% of the cases occurred from May through August and the less common cool season derechos were typically strongly forced events (associated with a well-defined upstream trough and low-level cyclone).

It's generally known that in the United States warm season violent convective straight-line wind events often form under moderate to strong northwesterly upper flow with a pool of low-level moisture in front of an east-west oriented frontal zone. Coniglio et al. (2004) suggest that the three most typical synoptic patterns associated with derecho cases are a well-developed upstream trough pattern, an anticyclonic ridge pattern and a low-amplitude zonal flow pattern. A very moist boundary layer with drier air above is the common vertical moisture pattern present in the derecho genesis and maturation regions (Johns 1993; Coniglio et al. 2004). It also seems that strong (weak) low-level shear is usually observed in low (high) instability cases which suggests that the lack of instability may be compensated by strong shear (Johns 1993; Evans and Doswell 2001; Coniglio et al. 2004). Ultimately, favorable conditions for derecho genesis may result in a fast-moving long-lived bow echo (or echoes) which travels through several states and causes a nearly continuous path of destructive straight-line winds.

A climatological study of Coniglio and Stensrud (2004) suggests an average of 15 derechos per year from 1986 to 2001 in the United States, but the large increase in the

recorded convective wind reports during this time period greatly limits the accuracy of this estimate. This is a non-meteorological change resulting from an increasingly thorough recording of wind reports, and it suggests that the actual average annual number of derechos per year in the United States is greater than 15. Derechos have also occurred in portions of North America near the United States including southern Canada (e.g. Cummine et al. 1992; Mainville 1999) and Cuba (Alfonso and Naranjo 1996). Although it is likely that derechos occur in other parts of the world, only two cases have been described in the literature, and both of these recently occurred in Europe. In July 2002, a bow echo producing a derecho hit the capitol region of Germany (Gatzen 2004) and in August 2003 a derecho MCS caused severe wind damage in northeastern Spain and southern France (Lopez and Arus 2004).

On 5 July 2002 a fast propagating severe bow echo formed over Eastern Finland. The Ministry of the Interior's Emergency Response Centres received nearly 400 thunderstorm-related wind damage reports at different locations (Fig.1) during a 6-hour period. According to the Finnish Forest Research Institute (K. Lipponen and A. Pouttu, personal communication 2003) the total volume of fallen trees was about 1 million cubic meters. This event met the criteria of a derecho, as defined by Johns and Hirt (1987), including the facts that damage of F1 intensity occurred in several places and the major axis length of the wind damage area in Finland was 450 km. The 5 July 2002 case in Finland is the highest latitude derecho that has ever been documented.

This study focuses on the synoptic and mesoscale conditions that were present in Finland and nearby regions on 5 July 2002. Comparisons to the other two documented cases in Europe will be made as well as comparisons to the typical derecho environment in the United States. In the next section the synoptic setting will be discussed. The mesoscale

structure of the derecho and the analysis of soundings are presented in the sections 3 and 4. The last section gives summary and conclusions.

2. The synoptic setting

2.1 4 July 2002

On the day before the derecho event, an upper level low was situated over the Norwegian Sea and a 300 hPa short wave trough was moving from Central Europe towards the Baltic countries (Fig. 2a). In the lower troposphere an area of warm humid air stretched from Eastern Europe northward to the Baltic countries and a low center was moving north along the Baltic Sea (Fig. 3a). A low-level jet had advected the moist and warm boundary layer air from the Baltic countries to Southern Finland. In the afternoon a cold front stretched from the Latvian coast southward and a warm front extended from the Gulf of Riga northeastward over the Gulf of Finland and Lake Ladoga (see Fig. 2d for geographic locations).

During the afternoon of 4 July a severe bow echo developed in the warm sector and traveled from Lithuania over Estonia to Southern Finland, where it gradually weakened. Wind damage was reported at several locations and wind gusts up to 30 m/s were measured in Estonia (M. Merilain, personal communication 2003). During the night the surface low continued its movement northward and a warm front with heavy precipitation propagated from Southern Finland to Lapland.

The 4 July bow echo track was at a great distance from the upper-level trough which was over Central Europe. The MCS developed south of the Baltic States close to the cold front and moved rapidly north with the strong low-level jet. During the later stages of its lifetime it reached the warm front and was affected by low-level warm air advection.

However, decreasing instability close to the warm front probably led to the decay of the system.

2.2 5 July 2002

Overnight and during the early morning on 5 July the upper trough amplified and moved from Poland to the Baltic countries (Fig. 2b). In the lower troposphere the cold front was almost stationary and there were some indications of the formation of a secondary low in the vicinity of the Gulf of Riga (Fig. 3b). The warm front had propagated to Northern Finland and the primary surface low had moved north along the Gulf of Bothnia.

According to the night sounding (0000 UTC 5 July, local time +3h) in Southern Finland the lower troposphere was nearly saturated and two upper inversions (at 900 and 800 hPa) were present (not shown). The wind profile was close to unidirectional and the wind speed within the low-level jet exceeded 20 m/s. Despite the abundant low-level moisture, satellite imagery showed clear skies over extensive areas in the warm sector (not shown).

Morning

By morning two secondary lows had developed south of the primary low center, one northwest of the Gulf of Riga and one southeast of the Gulf of Riga (Fig. 4a). As the day progressed, the secondary low northwest of the Gulf of Riga weakened. However, the one southeast of the Gulf of Riga moved northward and began to intensify. The meridional frontal zone was still stationary and located over western Estonia and Finland. Morning surface observations showed a weak pre-frontal convergence zone near Lake Peipsi which was close to the area of the initial thunderstorm development (Fig. 4a). The eastern edge of

the frontal cloud area was very sharp and the surface temperature contrast between eastern and western part of Estonia increased up to 10 °C by noon. The Central Finland morning sounding (0600 UTC 5 July) revealed inversions at 925 and 800 hPa (Fig. 5a). The temperature and dew point profiles showed that in order to break the cap the surface temperature would need to climb close to 30 °C. However, it is possible that upward motion associated with forcing from the advancing upper trough weakened the cap and lowered the threshold for thunderstorm initiation.

Thunderstorm initiation began around noon (0900 UTC) in Estonia and thunderstorms began to organize into a bow echo as they moved over the Gulf of Finland. The resulting bow echo MCS propagated from south-southeast to north-northwest on the eastern (warm) side of the quasi-stationary front and moved much faster than the secondary low (Fig. 6).

Afternoon

At 1200 UTC 5 July an upper-level trough was approaching Estonia and the secondary low was moving over western Estonia (Fig 2c). According to ECMWF analysis data upper-level positive vorticity advection was strongest south of the developing convective system (not shown). Analysis data showed also that temperature advection throughout the troposphere was weak in the warm sector. Thus, low-level warm advection, which is typical in the warm season derecho genesis region (Johns et. al. 1990), was not found in this case. However, the accuracy of model (analysis) data could not be verified due to the coarse sounding network. It should be emphasized that in the vicinity of the frontal zone only a minor change of the wind direction could significantly affect the amount of temperature advection.

The bow echo propagated with a speed around 20 m/s along the 850 hPa θ_e ridge which extended from the Baltic States to Eastern Finland (not shown). In the afternoon, the

pressure-weighted deep layer mean wind (0-6 km and 850-250 hPa) was estimated to be between 15 and 20 m/s in the bow echo area (based on the Jyväskylä 0600 UTC, Jokioinen 1200 UTC and St. Petersburg 1200 UTC soundings). Thus, the bow echo propagation speed was greater than the mean wind which Johns and Hirt (1987) found to be typical for warm season derechos. The southerly mid-level jet was around the 700 hPa height and it was located in the vicinity of the bow echo track. The afternoon sounding at St. Petersburg (1200 UTC 5 July) had a mean layer CAPE of around 600 J/kg but still contained convective inhibition (CIN) of 100 J/kg. The inversions and moderate amount of CIN appear to explain the clear skies over Eastern Finland before the arrival of the bow echo.

Evening and early morning

At 1800 UTC 5 July the upper-level trough was located over Estonia and the meridional frontal zone had pushed 50-100 km eastward. The secondary low had reached the Finnish south coast. Meanwhile, the derecho-producing mesoscale convective system had propagated to Central Finland and its eastern edge had partly decayed (Fig. 6). During the nighttime hours the remnants of the bow echo moved over Western Lapland coincident with the 850 hPa equivalent potential temperature maximum. After midnight, the precipitation area in Lapland re-intensified and the resulting MCS became bow shaped and moved beyond the range of the Lapland radar during the early morning hours of 6 July 2002.

2.3 Comparisons

The synoptic pattern associated with the 5 July Finland derecho appeared to have some similarities to the pattern associated with the Berlin derecho, which occurred five days later on 10 July 2002 (Gatzen 2004). Both occurred in the vicinity of the upstream trough,

developed in the warm sector in an area of high θ_e and were associated with a prefrontal convergence zone. However, deep layer flow in Finland was unidirectional and southerly with the strongest shear in a layer extending from the surface to the 700 hPa level, whereas in Germany the winds varied from southeasterly in lower troposphere to southwesterly at upper levels. According to the wind profiler and sodar data, in the Berlin case the strongest wind shear was located in the layer between the surface and 1 kilometer AGL (Gatzen 2004). In contrast to the Berlin case, the Finland bow echo did not move along a thermal boundary, but on the eastern (warm) side of it.

The Mediterranean derecho of 17 August 2003, studied by López and Arús (2004), was a hybrid derecho (Evans and Doswell 2001). It caused destructive surface winds over the northeast corner of the Iberian Peninsula and southeastern France. Wind gusts between 26 and 51 m/s were measured along a 550 km long path. Similar to the Finnish case, this derecho moved on the warm side of frontal boundary even though the orientations of the boundaries in the two cases were different. In both cases an elevated inversion was present and the mid-level air was relatively dry. It is also worth mentioning that the derecho MCS development in both, the Mediterranean and Berlin events, appeared to be associated with the left exit region of an upper jet streak, which was not the case with the Finland event (Fig. 2).

The 5 July 2002 derecho had similarities to both serial and progressive type events (Johns and Hirt 1987), and could therefore be classified in the hybrid category (Evans and Doswell 2001). Its progressive characteristics were that it was a bowing squall line of limited length and oriented normal to the mean wind. Its serial characteristics were that it was initiated in the warm sector, and it developed in the close proximity of an amplified upper trough and a surface low. By examining the derecho classification introduced by Coniglio et al. (2004) it seems that the 5 July case was an upstream trough type of event

(cluster 1). Thus, it was located closer to the trough axis than the ridge axis. However, it is noteworthy that the orientation of the frontal zones and the upper level trough axis are backed about 90° compared to the typical warm season derecho-producing synoptic pattern observed in the United States (Johns and Hirt 1987). As far as the authors know a meridional pattern of this extreme has not been documented in literature before.

3. Mesoscale structure and processes

The mesoscale convective system (MCS) initiated as a small cluster of thunderstorms in Estonia in an area of surface wind convergence at 1000 UTC 5 July. Three hours later over the Gulf of Finland the cluster began to evolve into a linear structure (Fig. 6a). Meanwhile, a north-south oriented line of thunderstorms developed in Central Finland in the vicinity of the stationary front.

Just after the MCS came ashore on the south coast of Finland, it formed into a large scale bow echo (Fig. 6b). The leading edge of the bow echo had a strong reflectivity gradient and some isolated thunderstorms that developed ahead of the bow echo merged into it between 1400 and 1600 UTC (Fig. 6b). These kinds of cell mergers with the bow echo were also observed with the Berlin derecho (Gatzen 2004). According to Przybylinski and DeCaire (1985), isolated cells tend to intensify after the merger and result in an even more pronounced reflectivity gradient at the leading edge of the bow echo MCS.

By early evening the MCS had developed a strong cold pool which could be easily seen on the surface chart (Fig 4b). The large scale pressure field was clearly modified by the cold pool and a weak pre-MCS mesolow was followed by a mesohigh (Johnson and Hamilton 1988). The cold pool progression speed mainly ranged from 50 to 70 km/h in the afternoon, but increased to 90 km/h by 1800 UTC. This increase in speed is similar to the

Berlin (Gatzen 2004) and Mediterranean (López and Arús 2004) derechos which were observed to increase their propagation speed during the mature stage.

At 1600 UTC the MCS continued to proceed north-northwest over Finland and the most intense radar echoes were located at the apex of the bow echo. The leading line was accompanied by a trailing region of stratiform precipitation. The north-south oriented line of thunderstorms gradually merged into the western edge of the MCS resulting in an L-shaped convective line. However, the most striking feature in the radar imagery was a rear inflow notch behind the bow echo apex (Fig. 6b-c). The rear inflow notch is a channel of relatively weak radar echoes just behind the leading convective line and it is often observed in strong mesoscale convective systems (Smull and Houze 1987). In this case it was also visible in satellite pictures (not shown). The track of the rear inflow notch was closely associated with the location of the most severe wind damage in Eastern Finland. Also, a few collapsing high reflectivity cores were observed at the leading edge of the bow echo (60 dBZ up to 8 km) which probably contributed to the strength of the violent downbursts (Teittinen and Punkka 2004).

During the evening, surface charts still showed the pressure field being modified by the bow echo MCS. However, by 1800 UTC the eastern half of the bow echo had started to decay and the rear inflow notch had vanished (Fig. 6d). Thunderstorm activity was mainly focused on the meridional frontal zone and the original bow echo was much smaller in extent. Quite often, squall lines tend to turn perpendicular to the low-level wind shear (Robe and Emanuel 2001). Also in this case, the leading edge of the bow echo was oriented perpendicular to the low-level southerly wind shear. Thus, the demise of the eastern edge of the bow echo may be a consequence of the lack of the line-normal wind shear. However, there is no observational data available to support this hypothesis. The cooling of the boundary layer air (the decreasing of convective available potential energy)

in the evening and the strength of the fast-moving cold pool may also have affected the weakening of the MCS (Rotunno et al. 1988).

After 1800 UTC in Southern Finland the development of a line-end vortex at the western flank of the bow echo was evident in a radar loop (not shown). However, that feature probably did not have significant influence on the rear inflow jet owing to the large distance between the vortex and the apex of the bow echo (450 km). By 1900 UTC the MCS within the warm air mass had almost dissipated. During the night, the remaining region of stratiform precipitation showed distinctive indications of a mesovortex as it moved over Western Lapland. The vortex was evident for several hours and was presumably a mesoscale convective vortex (MCV), which is sometimes generated by a severe MCS (Bartels and Maddox 1991). By 2200 UTC a new bowing line of thunderstorms developed in central Lapland and moved northward into northern Norway around 0000 UTC 6 July.

The 5 July derecho had some features in common with the Type 2 radar echo pattern introduced by Przybylinski (1995). It was a solid bowing squall line with a strong reflectivity gradient at the leading edge, one significant rear inflow notch behind the leading line and several isolated convective cells in front of the bow echo. Nevertheless, the orientation of the leading line and the direction of movement were different than Przybylinski (1995) presented. The synoptic pattern and the bow echo orientation were backed 90-135 degrees compared to the typical orientation in the US.

4. Analysis of soundings

The morning sounding (0600 UTC 5 July) in Central Finland showed strong low-level shear, close to unidirectional deep layer wind shear and a mid-level jet at 600-700 hPa (Fig. 5a). It has been suggested that strong wind shear in the lowest 2.5 km and

unidirectional winds above that are favorable for bow echo maintenance (Weisman 1993) and this has been found to be typical for many strongly forced derechos (Evans and Doswell 2001; Coniglio et al. 2004). The morning sounding also revealed two inversions that may have blocked deep convection before the arrival of the squall line. The lower one of these two was probably the consequence of a nocturnal inversion and warm air advection associated with the passage of warm front. A cap and unidirectional wind shear were also observed with the Mediterranean derecho on 17 August 2003 (López and Arús 2004).

The application of a surface temperature of 29 °C and a dew point temperature of 18 °C to the morning sounding yields the most unstable convective available potential energy value of around 1500 J/kg and a lifted index of -5 °C. These values might represent the pre-storm environment more accurately than the St. Petersburg 1200 UTC sounding (Fig. 5b) which was located over the eastern periphery of the bow echo track. In the St. Petersburg area dew points were 2-3 °C lower than over Eastern Finland. The St. Petersburg sounding showed a mean layer convective available potential energy value of around 600 J/kg and a lifted index value of -2.5 °C.

By comparing the 1200 UTC St. Petersburg vertical θ_e profile to the cold pool θ_e (a method used by Duke and Rogash 1992), the origin of the downdraft air was approximated to be around 4 km ASL. At that height the relative humidity was less than 50 % (Fig. 7). The mixing of dry air with the downdraft air increases the evaporative cooling, strengthens the downdraft and may lead to an intense, fast propagating cold pool. A layer of dry air at 3-7 km above the ground has been observed to be a common characteristic in most derecho cases (Johns 1993; Duke and Rogash 1992; Bentley and Cooper 1997; Coniglio et al. 2004). In the Berlin derecho case (Gatzen 2004) there was also dry air present near the surface which could further enhance evaporative cooling of the downdraft air.

The difference of θ_e values between the surface maximum and mid-level minimum has been used as a predictor of the downburst threat (Atkins and Wakimoto 1991). According to a rule of thumb, severe downbursts are likely to occur if the difference exceeds 25 °C. In the St. Petersburg afternoon sounding the difference was only 16 °C (Fig. 7), but on the derecho track in Eastern Finland it may well have exceeded 20 °C. An interesting detail, that supports this estimation, was a local θ_e minimum (within the large scale θ_e maximum) at the 800 hPa level over the region of the initial thunderstorm development in Estonia in the ECMWF analysis data (not shown). The θ_e difference between the minimum and the maximum below was around 25 °C. In the afternoon the θ_e minimum traveled towards Eastern Finland. However, it is nearly impossible to verify the accuracy of the ECMWF θ_e analysis.

The storm relative winds derived from pre- and post-storm soundings showed some evidence of the rear inflow jet (Fig. 8). The St. Petersburg 1200 UTC sounding, which was 150 km east of the apex of the developing bow echo, had front-to-rear storm relative winds throughout the troposphere. In contrast, the Jyväskylä 1800 UTC sounding, which was behind the MCS, showed storm relative rear-to-front flow above 850 hPa.

5. Summary and conclusions

An unusually intense mesoscale convective system traveled across Eastern Finland on 5 July 2002. This event met the criteria of a derecho, as defined by Johns and Hirt (1987), including the facts that damage of F1 intensity occurred in several places and the major axis length of the wind damage area in Finland was 450 km. About a million cubic meters of trees were blown down due to numerous downbursts.

This study strengthens the conception that derechos also occur in Europe and it shows that in the most extreme cases they can reach the latitude of 65N. The results also suggest

that derechos occur under a greater variety of synoptic patterns than has been described in previous studies. The most classic synoptic pattern in North America involves northwesterly flow aloft. In these cases a quasistationary front is typically oriented parallel to the upper flow and the bow echo system moves southeastward along or near the front and perpendicular to the upper flow. The orientation of the bow echo and synoptic pattern on 5 July 2002 in Finland was backed 90-135 degrees compared with the typical northwest flow pattern in the United States. The 5 July derecho MCS moved towards the north-northwest on the east side of the north-south oriented frontal zone. A derecho with the westerly motion component has not been documented in literature before. Although the 5 July 2002 case shows some unique characteristics, it also has many similarities to the derechos observed in the United States and elsewhere in Europe.

Other essential findings of the study are:

- The derecho formed in front of an upper-level trough within the 850 hPa equivalent potential temperature ridge on the warm side of the north-south oriented quasi-stationary front.
- Low-level warm advection and an upper level jet streak left exit region, which are commonly found in the derecho genesis region, were not observed.
- Two inversions were present which probably blocked the deep convection prior to the arrival of the bow echo.
- The leading line of the bow echo was oriented perpendicular to the low-level shear and it had a sharp reflectivity gradient.
- The bow echo moved 20-25 m/s to the north-northwest which was faster than the deep layer mean wind speed (15-20 m/s) estimated from the proximity soundings. The propagation speed increased during the mature stage.

- The rear inflow notch was evident in the radar and satellite imagery and its location was associated with the most severe wind damage.
- Isolated convective storms merged with the bow echo and a few collapsing reflectivity cores (60 dBZ up to 8 km height) were observed.
- Storm relative winds in the mid- and upper troposphere behind the bow echo were from rear to front, indicating the presence of a rear inflow jet.
- The origin of downdraft air was approximated to be around 4 km (ASL) where the relative humidity of surrounding air was under 50%. Consequently, the downdrafts and cold pool strength were enhanced by evaporative cooling.

Despite what we know about the meteorological parameters associated with derecho events, they are still a challenge to forecast for several reasons. They occur with varying combinations of wind shear, CAPE, DCAPE, and dynamic forcing (e.g. Evans and Doswell 2001). Trying to determine if the combination of parameters in a forecast environment is favorable enough for a bow echo MCS to develop and produce severe damaging winds at the surface over a large enough area to meet the derecho criteria is often difficult (see Section 4 in Johns 1993). Further, even in environments where the parameters appear to be favorable for derecho development, a bow echo system may not develop because of either a lack of initiation of deep convection or the initiation of convection is so widespread that a bow echo system cannot develop. This initiation problem is associated with the balance between dynamic forcing and the strength of the boundary layer inversions. It is often difficult to determine whether this balance is favorable for allowing isolated convection to develop and produce a bow echo MCS.

Of course, forecasting a derecho event is also a challenge in Finland and nearby regions due to the very low frequency of their occurrence. For example, the areas of sufficient wind shear and CAPE, which would be conducive for severe thunderstorm

development, seldom overlap each other. In Finland, the vast majority of thunderstorms are non-severe and occur in the absence of any convective inhibition. Therefore, having the “experience” of forecasting derechos in this region is extremely limited.

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References

- Alfonso, A. P., and L. R. Naranjo, 1996: The 13 March 1993 severe squall line over western Cuba. *Wea. Forecasting*, **11**, 89-102.
- Atkins, N. T., and R. M. Wakimoto, 1991: Wet microburst activity over the Southeastern United States: Implications for forecasting. *Wea. Forecasting*, **6**, 470-482.
- Bartels, D. L., and R. A. Maddox, 1991: Midlevel cyclonic vortices generated by mesoscale convective systems. *Mon. Wea. Rev.*, **119**, 104-118.
- Bentley, M. L., and S. R. Cooper, 1997: The 8 and 9 July 1993 Nebraska derecho: an observational study and comparison to the climatology of related mesoscale convective systems. *Wea. Forecasting*, **12**, 678-688.
- , and T. L. Mote, 1998: A climatology of derecho-producing mesoscale convective systems in the Central and Eastern United States, 1985-1996. Part I: Temporal and spatial distribution. *Bull. Amer. Meteor. Soc.*, **79**, 2527-2540.
- , and J. M. Sparks, 2003: A 15-yr climatology of derecho-producing mesoscale convective systems over the central and eastern United States. *Clim. Research*, **24**, 129-139.
- Coniglio, M. C., and D. J. Stensrud, 2004: Interpreting the climatology of derechos. *Wea. Forecasting*, **19**, 595-605.
- , D. J. Stensrud, and M. B. Richman, 2004: An observational study of derecho-producing convective systems. *Wea. Forecasting*, **19**, 320-337.
- Court, A., 1970: Tornado incidence maps. *ESSA Technical Memorandum ERLTM-NSSL 49*, NSSL, Norman OK, 76 pp.
- Cummine, J., P. McCarthy, and M. Leduc, 1992: Blowdown over northwestern Ontario: A derecho event - 18 July 1991. Preprints, *4th Workshop on Operational*

- Meteorology*, Whistler, British Columbia, Canada, Atmos. Environ. Service/Canadian Meteor. and Oceanogr. Soc., 311-317.
- Duke, J. D., and J. A. Rogash, 1992: Multiscale review of the development and early evolution of the 9 April 1991 derecho. *Wea. Forecasting*, **7**, 623-635.
- Evans, J. S., and C. A. Doswell III, 2001: Examination of derecho environments using proximity soundings. *Wea. Forecasting*, **16**, 329-342.
- Fujita, T. T., and R. W. Wakimoto, 1981: Five scales of airflow associated with a series of downbursts on 16 July 1980. *Mon. Wea. Rev.*, **109**, 1438-1456.
- Galway, J. G., 1985a: J. P. Finley: The first severe storms forecaster. Part 1. *Bull. Amer. Meteor. Soc.*, **66**, 1389-1395.
- Galway, J. G., 1985b: J. P. Finley: The first severe storms forecaster. Part 2. *Bull. Amer. Meteor. Soc.*, **66**, 1506-1510.
- Gatzen, C., 2004: A Derecho in Europe: Berlin, 10 July 2002. *Wea. Forecasting*, **19**, 639-645.
- Hinrichs, G., 1888: Tornadoes and derechos. *Amer. Meteor. J.*, **5**, 306-317, 341-349.
- Johns, R. H., 1993: Meteorological conditions associated with bow echo development in convective storms. *Wea. Forecasting*, **8**, 294-299.
- , and W. D. Hirt, 1987: Derechos: Widespread convectively induced windstorms. *Wea. Forecasting*, **2**, 32-49.
- , K. W. Howard, and R. A. Maddox, 1990: Conditions associated with long-lived derechos- An examination of the large scale environments. Preprints, *16th Conf. on Severe Local Storms*, Kananaskis Park, AB, Canada, Amer. Meteor. Soc., 408-412.
- Johnson, R. H., and P. J. Hamilton, 1988: The relationship of surface pressure features to the precipitation and airflow structures of an intense midlatitude squall line. *Mon. Wea. Rev.*, **116**, 1444-1472.

- Köppen, W., 1879: Beiträge zur Kenntniss der Böen und Gewitterstürme (Contributions to the knowledge of gusts and thunderstorm squalls). *Ann. Hydrogr. Marit. Meteor.*, **7**, 324-335. [In German]
- Köppen, W., 1882: Der Gewittersturm vom 9. August 1881 (The thunderstorm squall of 9 August 1881). *Ann. Hydrogr. Marit. Meteor.*, **10**, 595-619, 714-737. [In German]
- Köppen, W., 1886: Bericht über den Orkan vom 14. Mai in Crossen und Umgebung (Report on the devastating storm of 14 May in and around Crossen). *Ann. Hydrogr. Marit. Meteor.*, **14**, 295-276. [In German]
- Köppen, W., 1896: Die Windhose vom 5. Juli 1890 bei Oldenburg und die Gewitterböe vom 10. Juli 1896 in Ostholstein (The tornado on 5 July 1890 near Oldenburg and the thundersquall of 10 July 1896 in east Holstein). *Ann. Hydrogr. Marit. Meteor.*, **24**, 445-458, 493-508, 546-556. [In German]
- Letzmann, J. P., 1923: Das Bewegungsfeld im Fuss einer fortschreitenden Wind- oder Wasserhose (The flow field at the base of an advancing tornado). Dissertation Thesis, Acta Comm. Univ. Dorpat AIII, 1-136. [In German, available from www.essl.org/pdf/Letzmann1923/Letzmann1923.pdf]
- López, J. M., and J. Arús, 2004: A Mediterranean derecho: Catalonia (Spain), 17th August 2003. Preprints, *Third European Conference on Severe Storms*, León, Spain. CD-ROM, P53.
- Mainville, S., 1999: The derecho of 4-5 July 1999 in southern Quebec. Technical Note, Quebec Region, 99N-04, Environment Canada.
- Przybylinski, R. W., and D. DeCaire, 1985: Radar signatures associated with the derecho, a type of mesoscale convective system. Preprints, *14th Conf. on Severe Local Storms*, Indianapolis, IN, Amer. Meteor. Soc., 228-231.

- Przybylinski, R. W., 1995: The bow echo: Observations, numerical simulations, and severe weather detection methods. *Wea. Forecasting*, **10**, 203–218.
- Robe, F. R., and K. A. Emanuel, 2001: The effect of vertical wind shear on radiative-convective equilibrium states. *J. Atmos. Sci.*, **58**, 1427-1445.
- Rotunno, R., J. B. Klemp, and M. L. Weisman, 1988: A theory for strong, long-lived squall lines. *J. Atmos. Sci.*, **45**, 463-485.
- Smull, B. F., and R. A. Houze Jr., 1987: Rear inflow in squall-lines with trailing stratiform precipitation. *Mon. Wea. Rev.*, **115**, 2869-2889
- Teittinen, J., and A.-J. Punkka, 2004: Severe thunderstorm radar signatures of 5 July 2002 derecho in Finland. Preprints, *22nd Conf. on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., CD-ROM, 7A.4.
- Weisman, M. L., 1993: The genesis of severe, long-lived bow echoes. *J. Atmos. Sci.*, **50**, 645-670.

Figure captions

FIG. 1. Wind damage reports of fallen trees (grey shading) in southern half of Finland and the hourly locations of leading convective line (local time +3h). The length of the damage area is around 450 km.

FIG. 2. 300 hPa ECMWF model analysis of geopotential and wind speed on a) 4 July 2002 1200 UTC, b) 5 July 2002 0000 UTC and c) 5 July 2002 1200 UTC. Solid lines are isohypses and dashed lines isotachs. d) Geographic locations (sounding stations SP = St. Petersburg, JO = Jokioinen, JY = Jyväskylä).

FIG 3. 850 hPa ECMWF model analysis of geopotential (solid lines) and temperature (dashed lines). a) 4 July 2002 1200 UTC, b) 5 July 2002 0000 UTC and c) 5 July 2002 1200 UTC.

FIG. 4. Surface observations with manual analysis on 5 July at a) 0600 UTC and b) 1500 UTC. Solid lines are isobars and dashed lines isodrosotherms.

FIG. 5. Soundings on 5 July 2002 a) from Jyväskylä at 0600 UTC and b) St. Petersburg 1200 UTC (data source: University of Wyoming).

FIG. 6. CAPPI composite reflectivity images in Eastern Finland at a) 1330, b) 1545, c) 1645, d) 1845 UTC. Thick arrows show the location of the rear inflow jet.

FIG. 7. Vertical profiles for equivalent potential temperature (grey) and relative humidity (black) from the St. Petersburg, Russia sounding at 1200 UTC 5 July 2002.

FIG. 8. Storm relative winds calculated from the 1200 UTC St. Petersburg, Russia (black line) and 1800 UTC Jyväskylä, Finland (grey line) soundings on 5 July 2002. Mandatory levels in hPa are marked next to the lines.

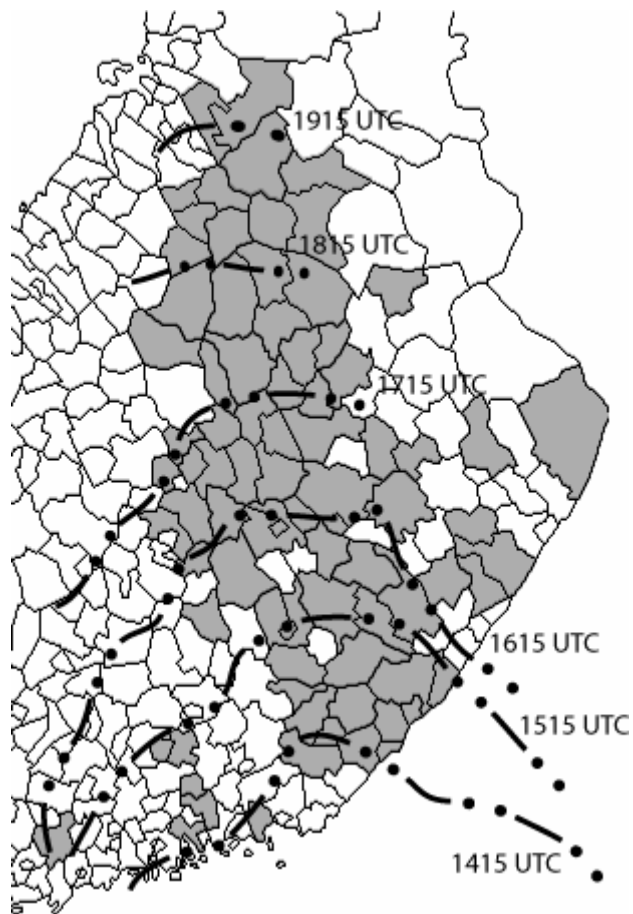


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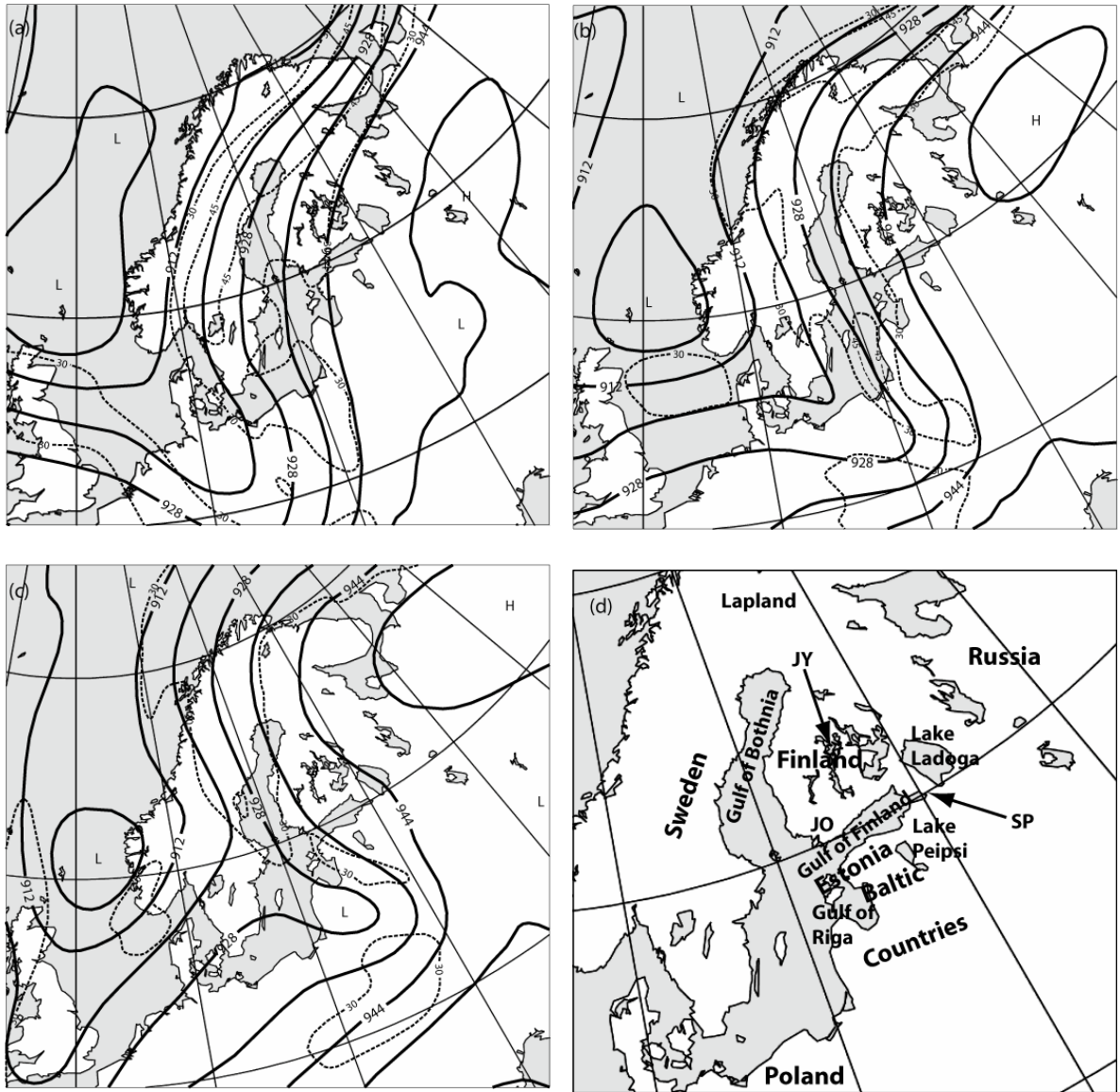


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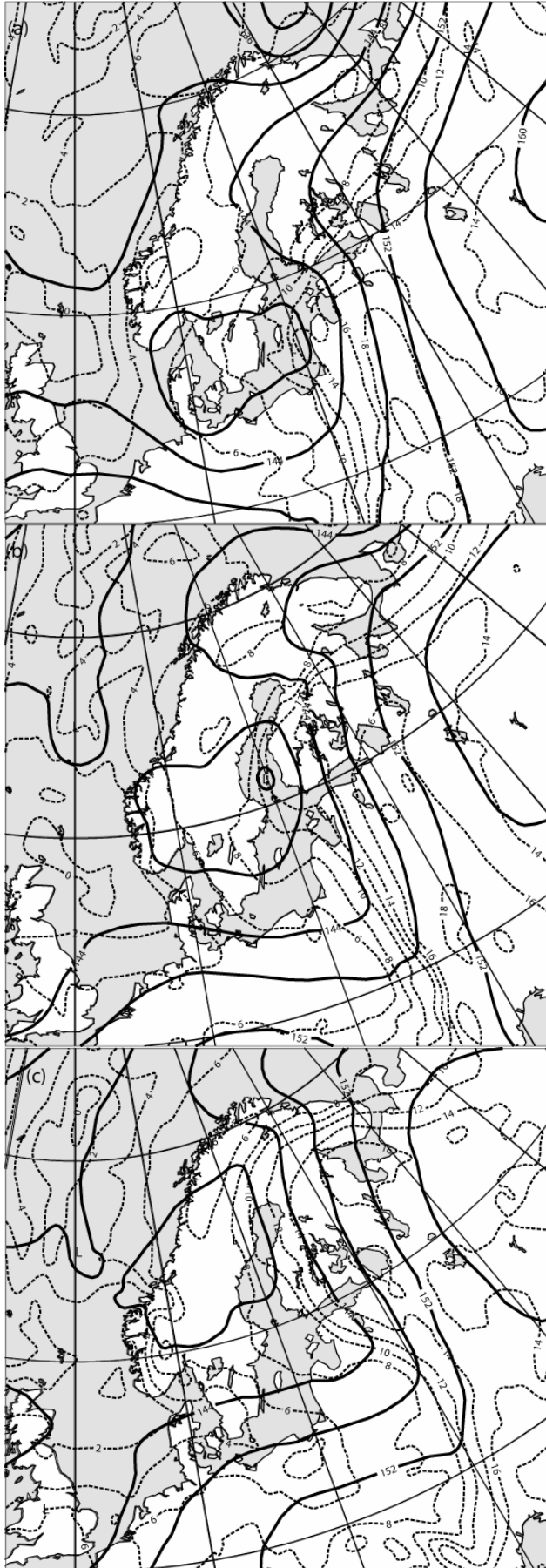
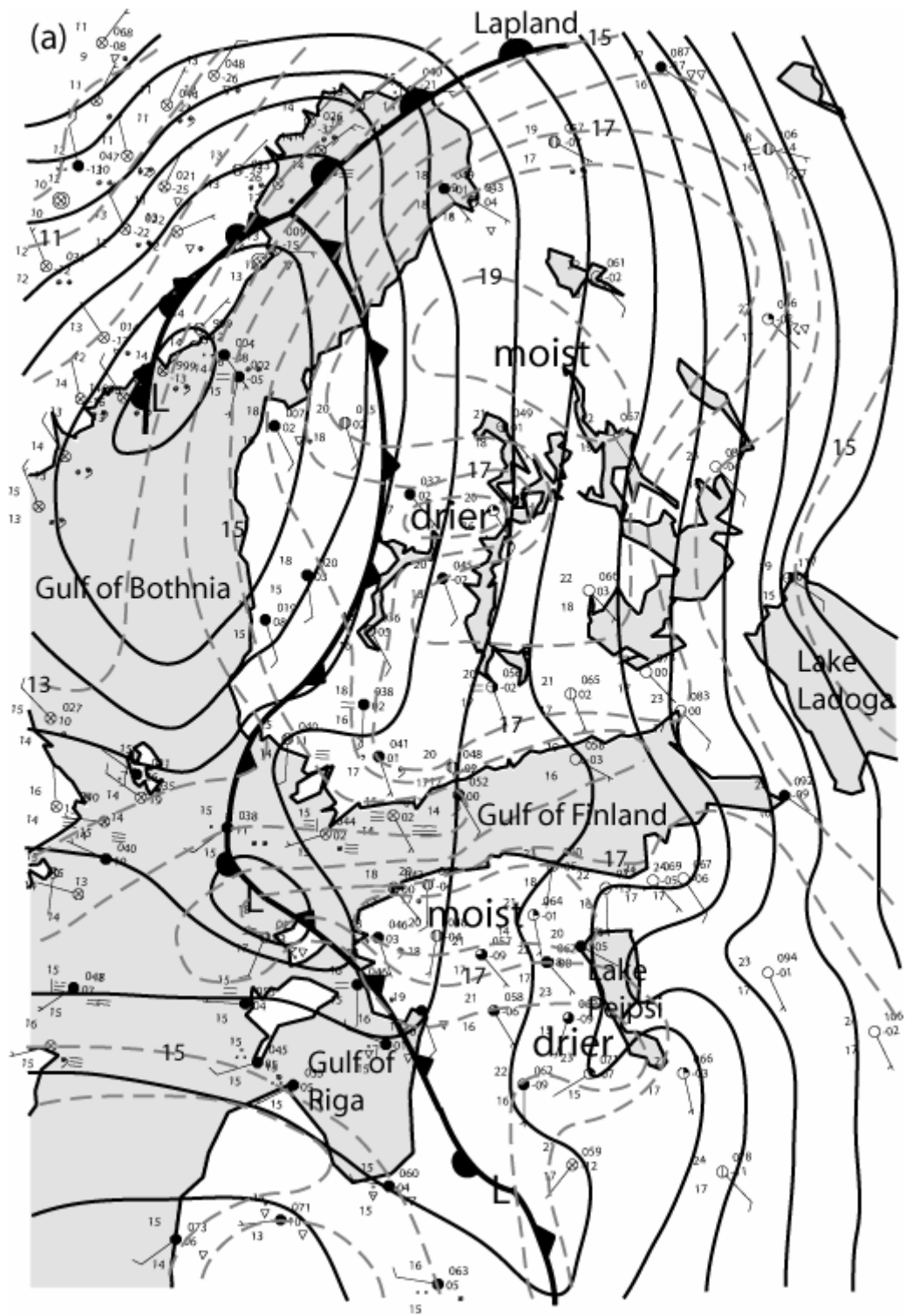


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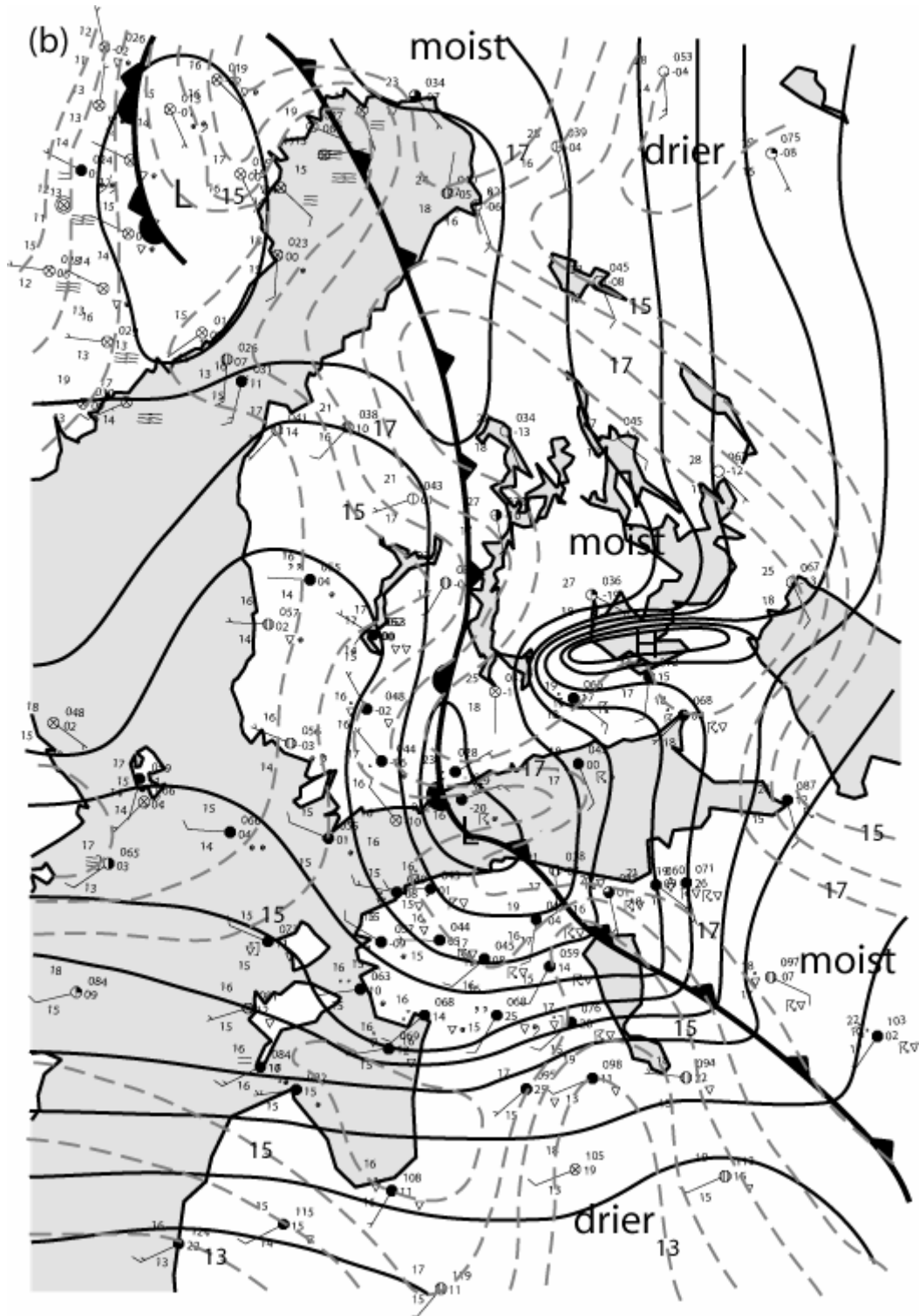


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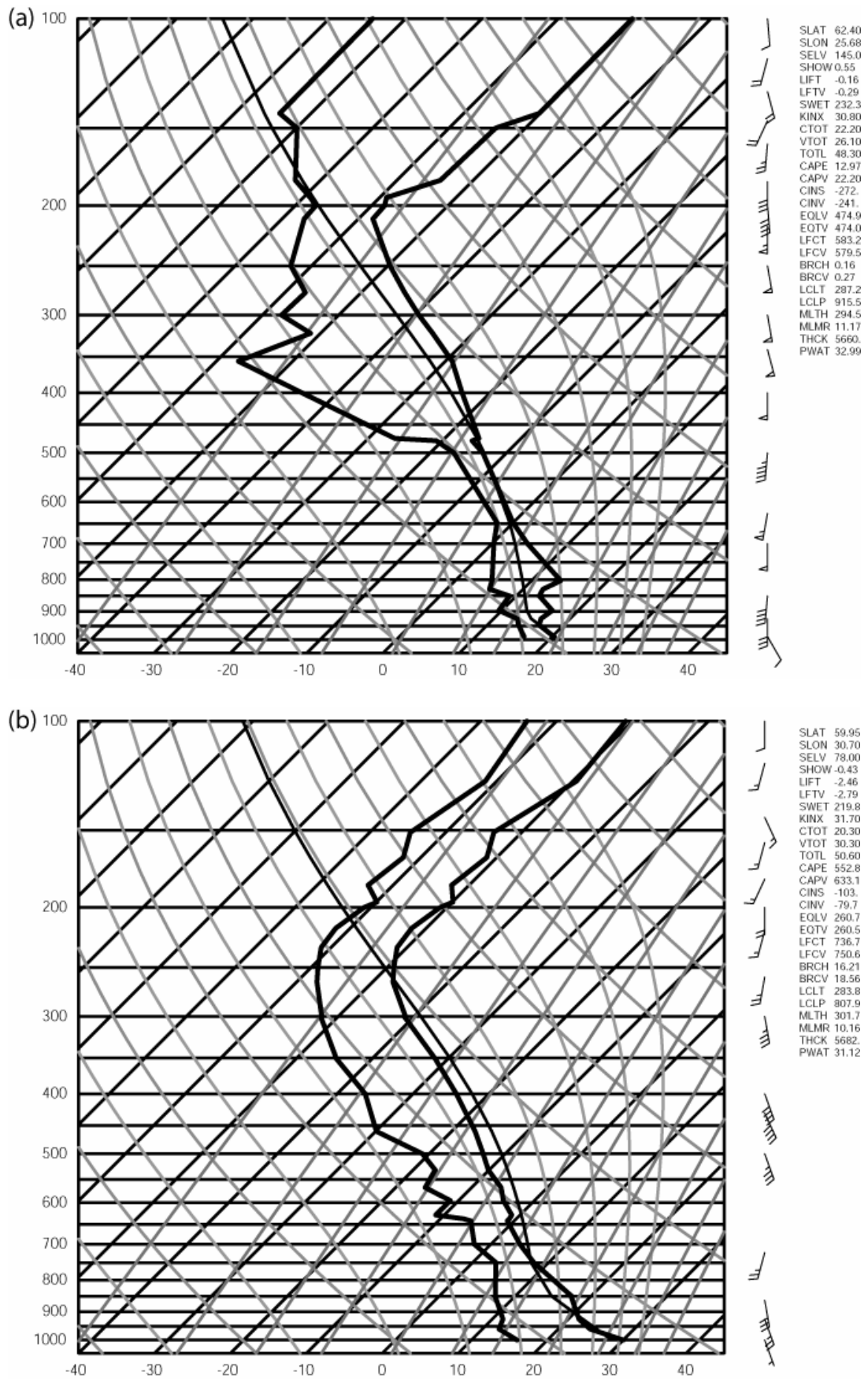


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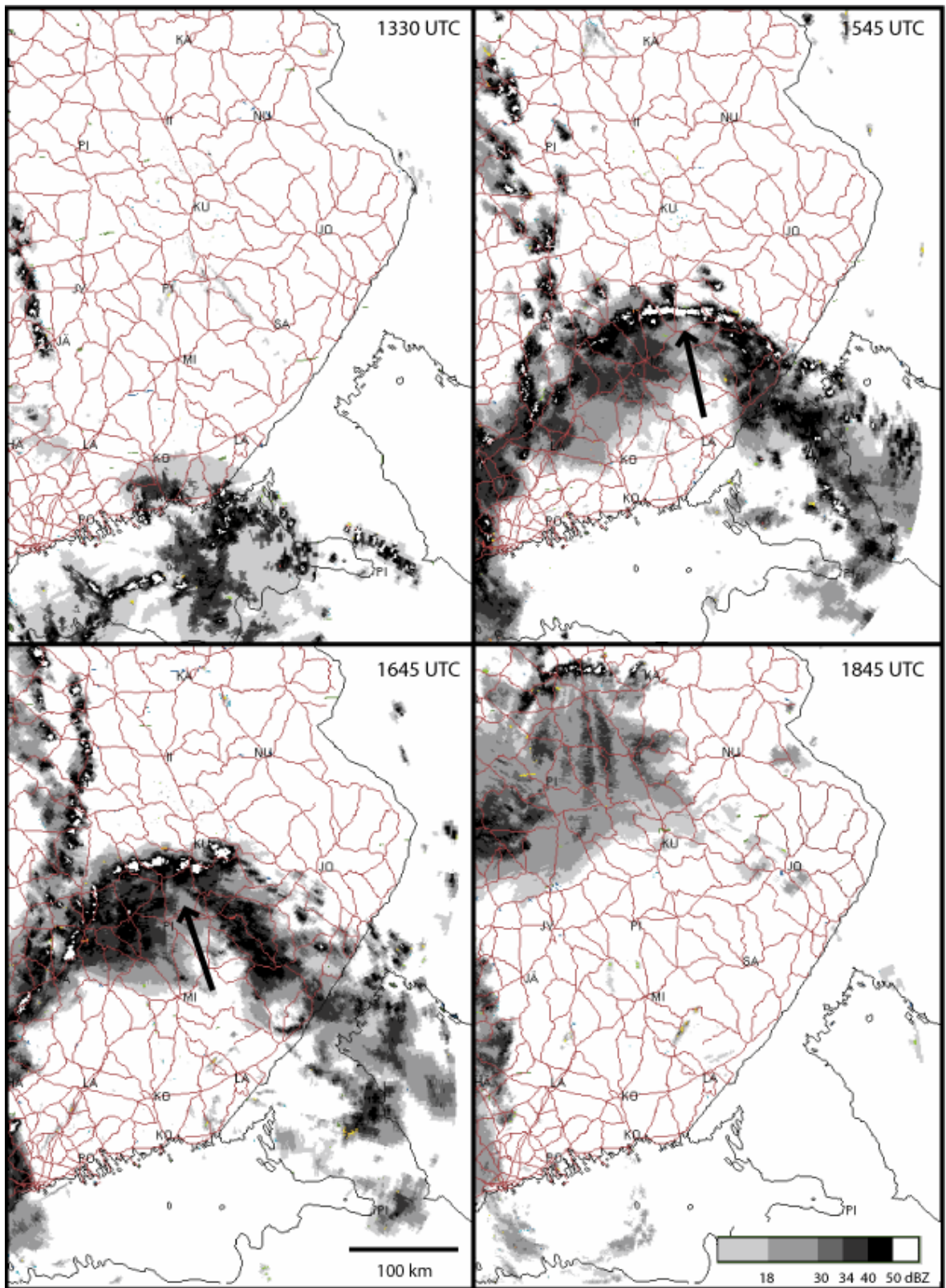


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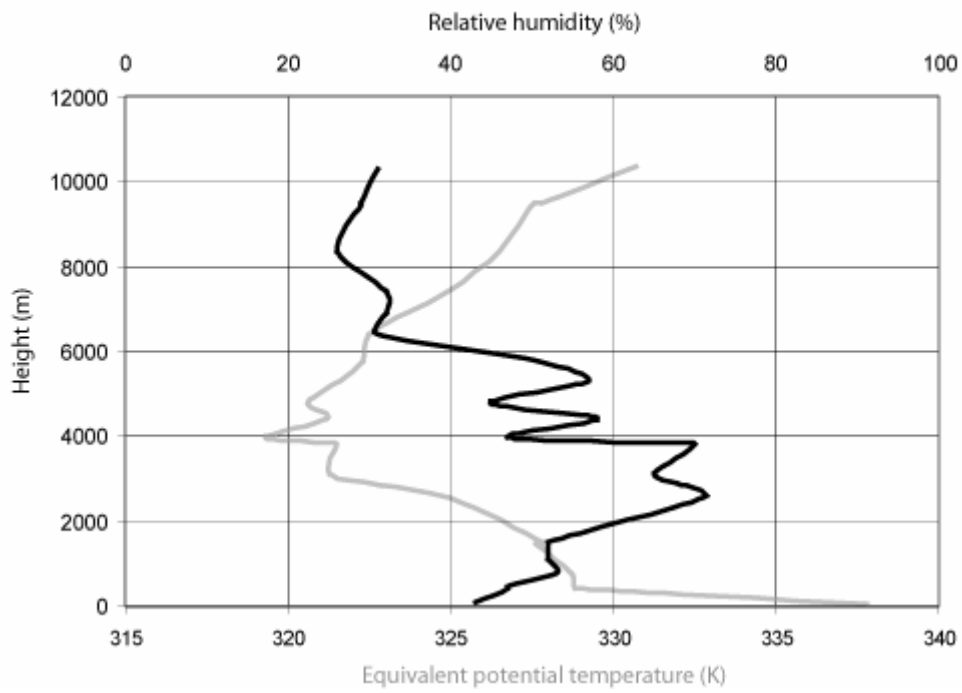


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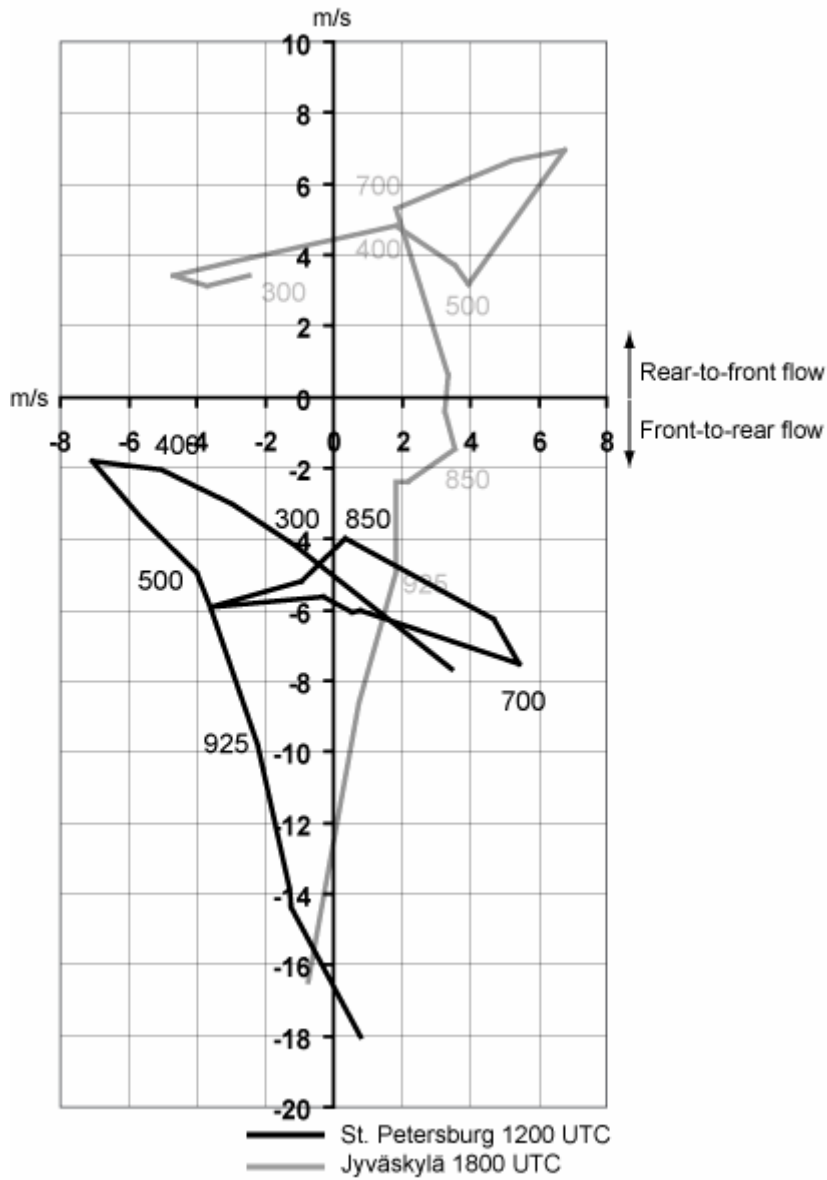


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