A Predictability Study of a Polar Low Linked to a Tropopause Polar Vortex

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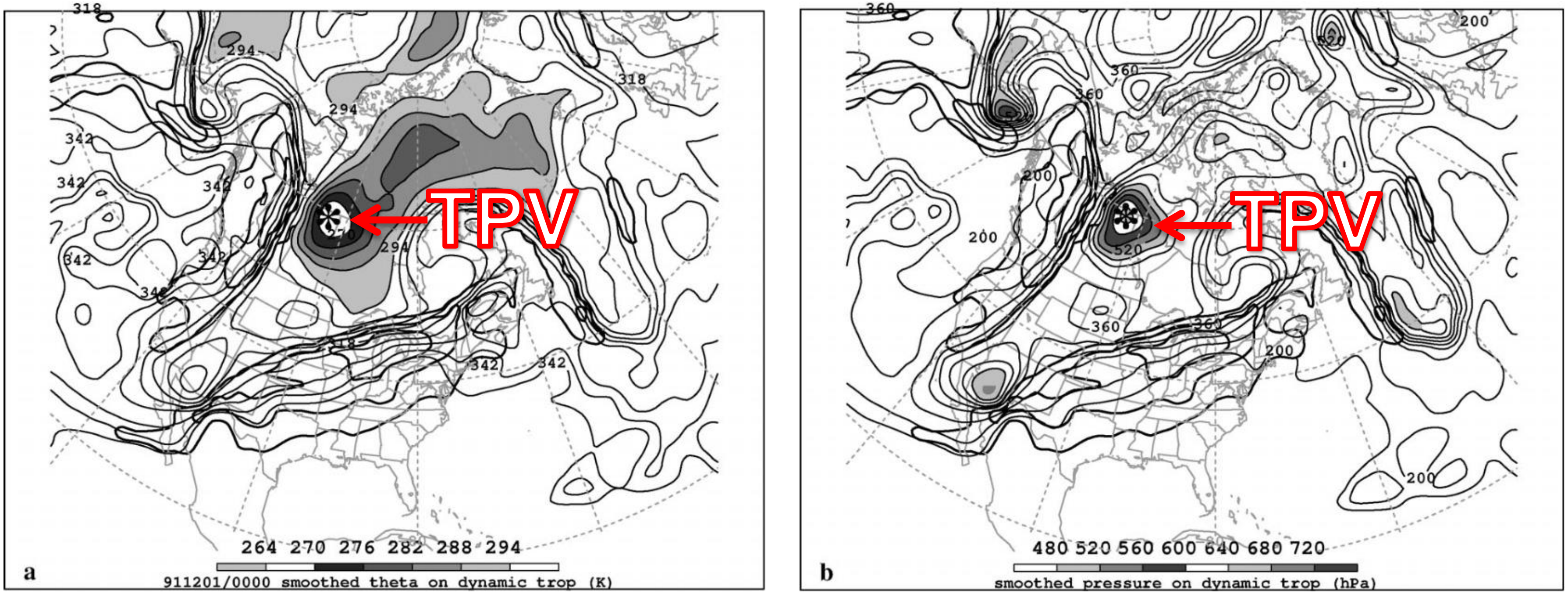
What are Tropopause Polar Vortices (TPVs)?

- TPVs are defined as tropopause-based vortices of high-latitude origin and are material features (Pyle et al. 2004; Cavallo and Hakim 2009, 2010, 2012, 2013)



(left) Dynamic tropopause (DT) wind speed (every 15 m s^{-1} starting at 50 m s^{-1}, thick contours) and DT potential temperature (K, thin contours and shading) on 1.5-PVU surface valid at 0000 UTC 1 Dec 1991; **(right)** same as left except DT pressure (hPa, thin contours and shading). Adapted from Fig. 11 in Pyle et al. (2004).

What are Polar Lows?

- Polar lows are small, intense cyclones characterized by short horizontal scales and lifetimes (e.g., Rasmussen and Turner 2003)

- Polar lows often form within, or at the leading edge of, a cold air mass moving over warmer sea surfaces in high latitudes (e.g., Shapiro et al. 1987)

Motivation

- Polar lows may be associated with strong surface winds and heavy precipitation, posing hazards to ships and infrastructure (e.g., Businger and Reed 1989)

- TPVs may act as precursors for the development of polar lows (e.g., Kolstad 2011)

Outline

- **Analyze the evolution of a polar low linked to a TPV**

- Investigate factors influencing the predictability of the evolution of the polar low

Climatology of Polar Lows

- Obtain polar lows from Sea Surface Temperature and Altimeter Synergy for Improved Forecasting of Polar lows (STARS) database of polar lows over the Norwegian and Barents Seas (Sætra et al. 2010)
  - STARS database covers the 2002–2011 period, for a total of 140 polar lows

Link for STARS Database: http://polarlow.met.no/stars-dat/

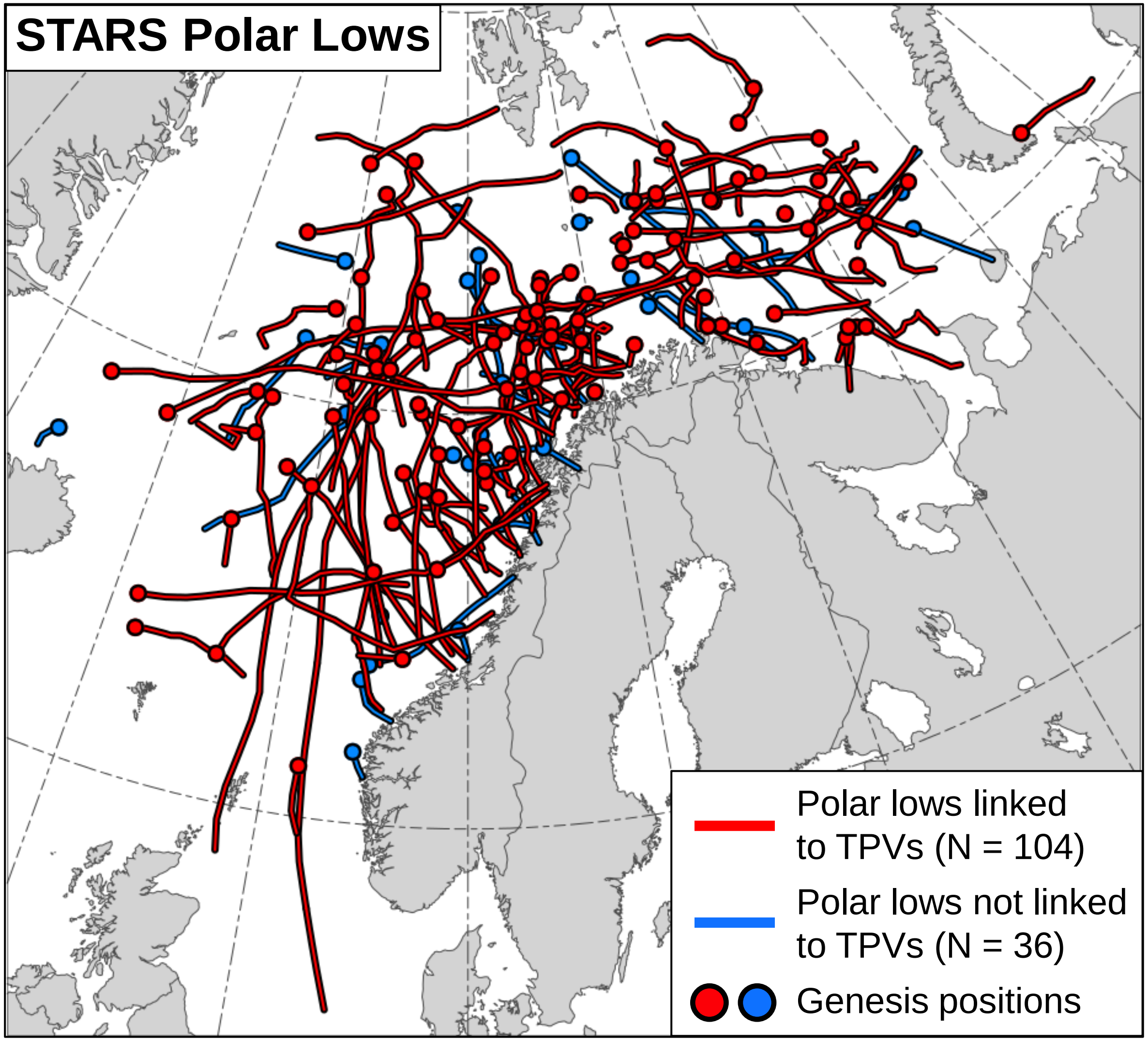
Climatology of Polar Lows Linked to TPVs

- Compare STARS database with a 1979–2015 database of TPVs constructed using the ERA-Interim (Dee et al. 2011) and an objective TPV tracking algorithm (Szapiro and Cavallo 2018)

- Determine which polar lows may be linked to TPVs by requiring that a polar low be located within 500 km of at least one TPV at any point in the lifetime of the polar low

Climatology of Polar Lows Linked to TPVs

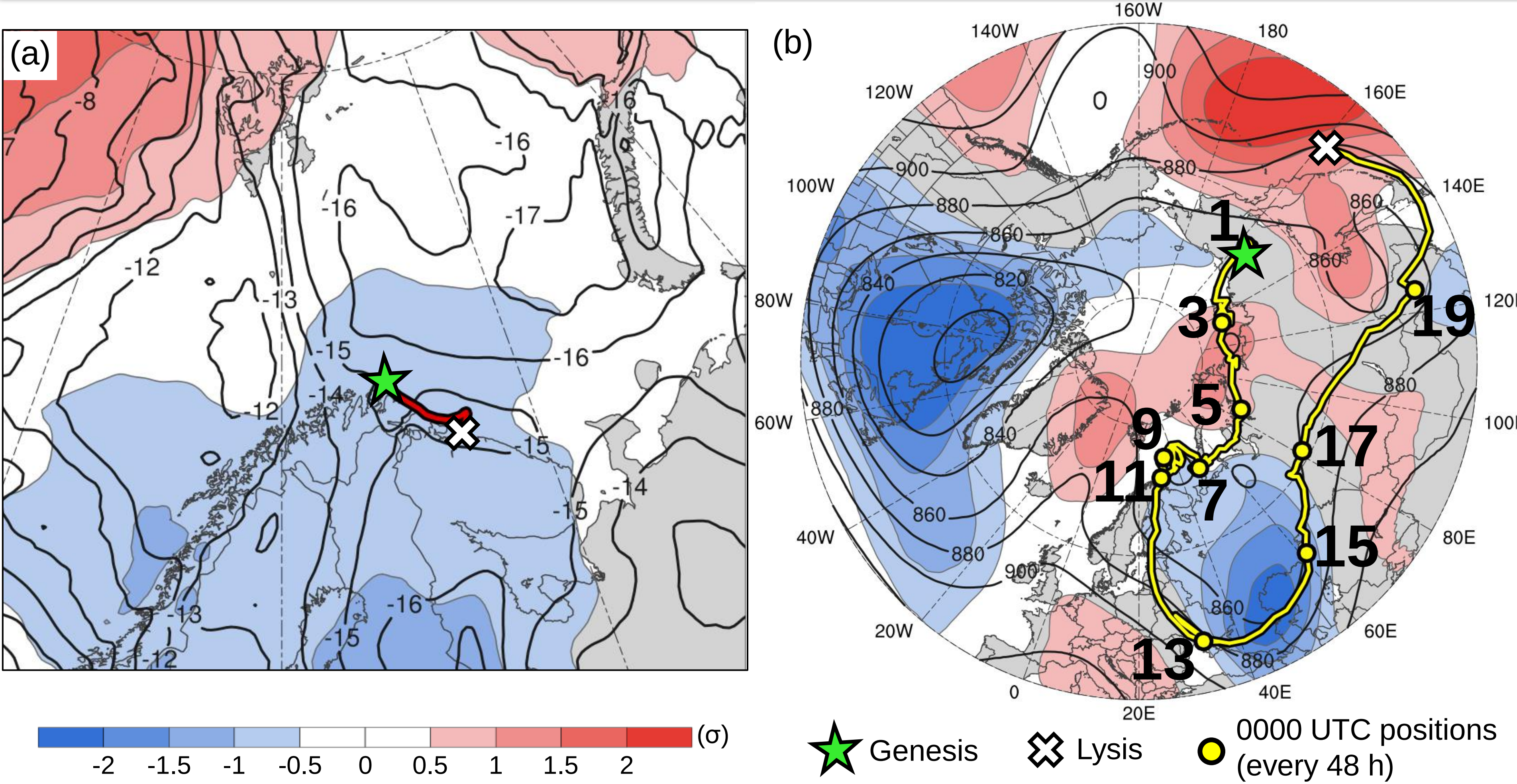
- 104 out of the total 140 polar lows, or 74.3%, match with at least one TPV



Case Selection

- Use the ERA5 (Hersbach and Dee 2016) downloaded at 0.3° horizontal resolution for analysis of a polar low case
- Choose a case for which a polar low is trackable in the ERA5
- Choose a case for which the polar low is clearly linked to a single TPV

The Polar Low and TPV

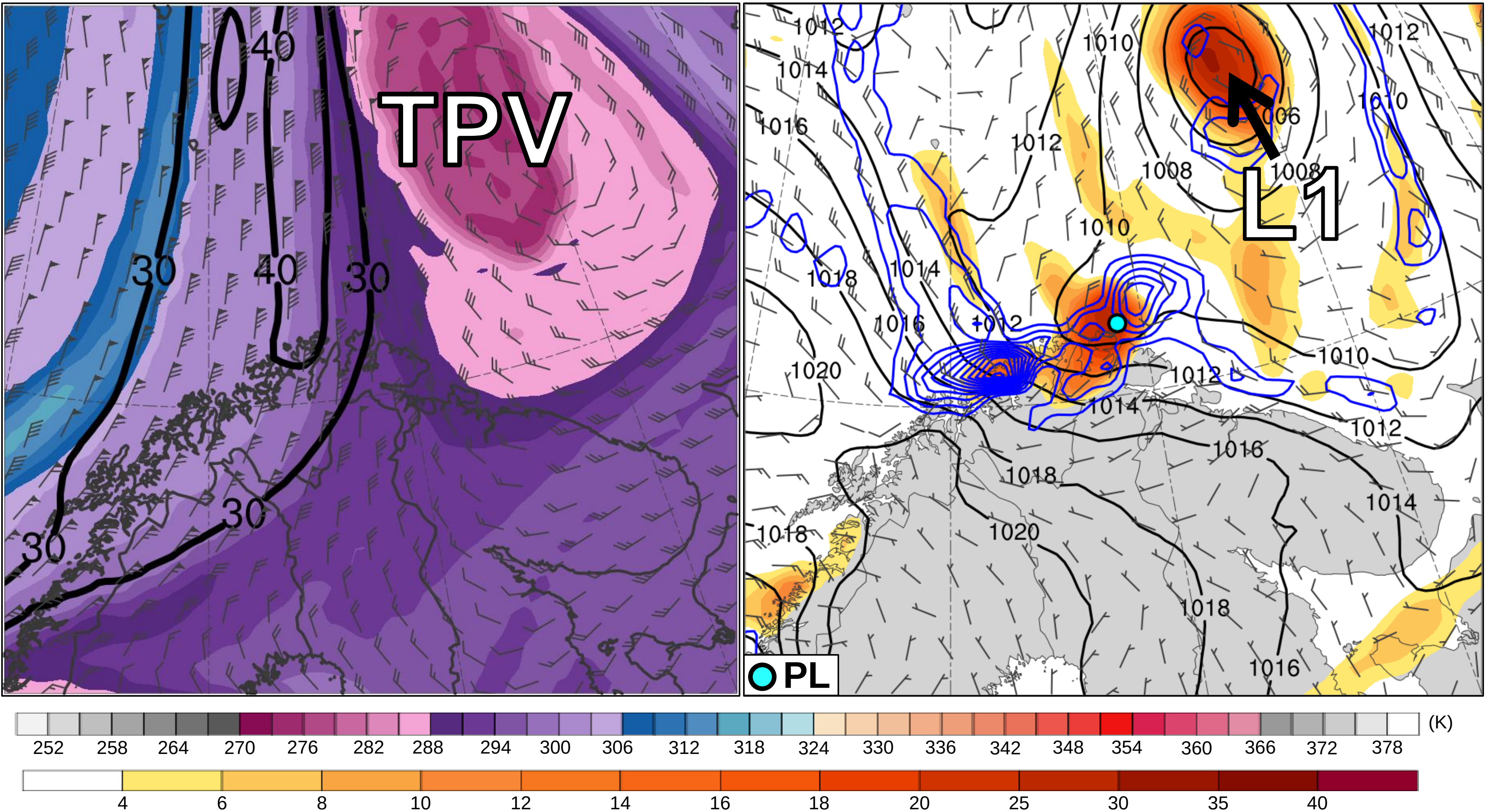


Feature	Genesis	Lysis	Lifetime
PL	10 Feb	11 Feb	18 h
TPV	31 Jan	20 Feb	20 d

Tracks of (a) polar low and (b) TPV, and 10–11 Feb 2011 time-mean (a) 850-hPa temperature (K, black) and standardized temperature anomalies (σ, shaded), and (b) 300-hPa geopotential height (dam, black) and standardized geopotential height anomalies (σ, shaded).

Mesoscale Evolution

1800 UTC 10 Feb 2011

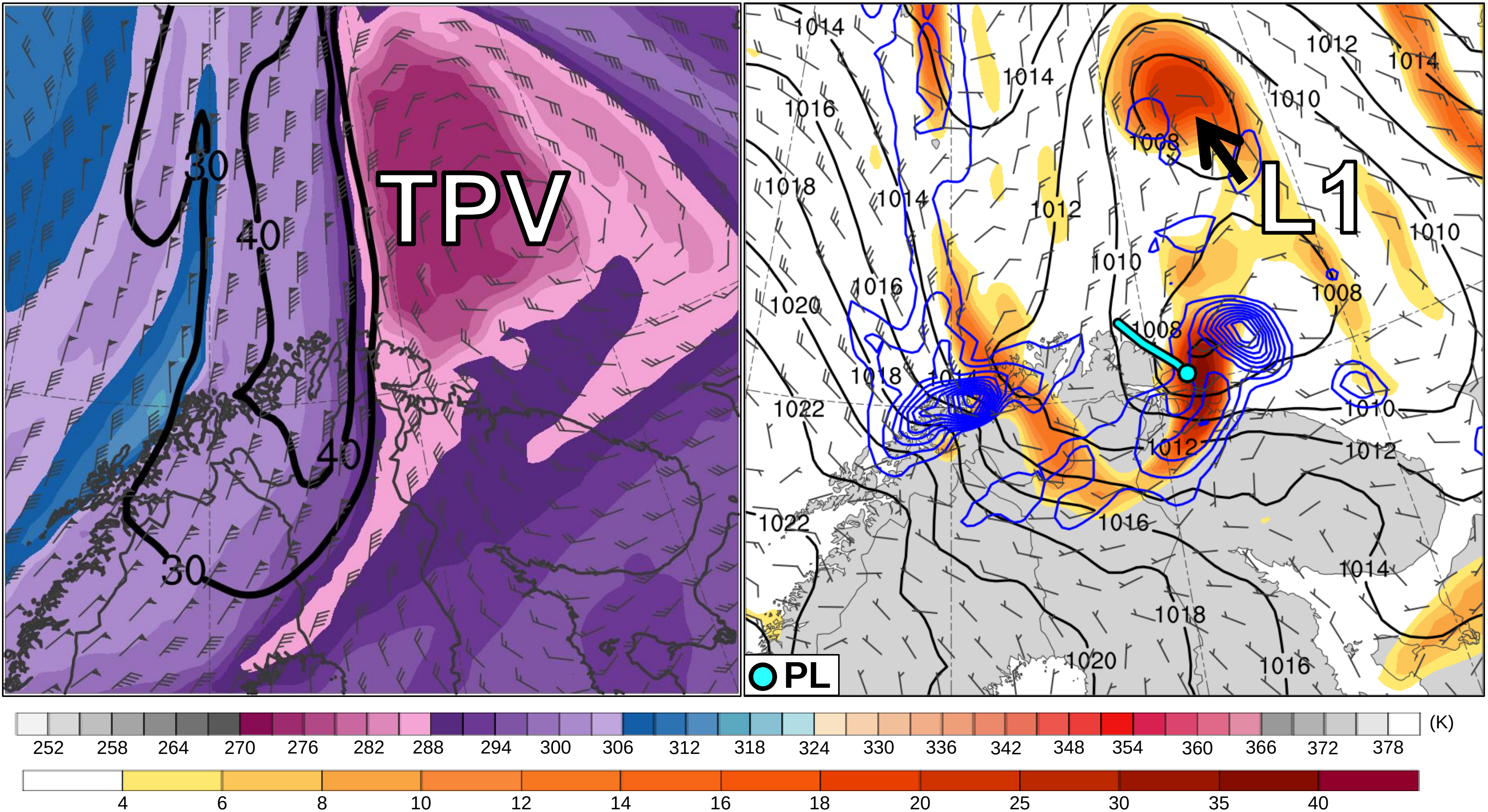


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 30 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

850-hPa relative vorticity (10^{-5} s^{-1}, shaded), 850–600-hPa ascent (blue, every 2.5 × 10^{-3} hPa s^{-1}), SLP (hPa, black), and 10-m wind (m s^{-1}, barbs)

Mesoscale Evolution

0000 UTC 11 Feb 2011



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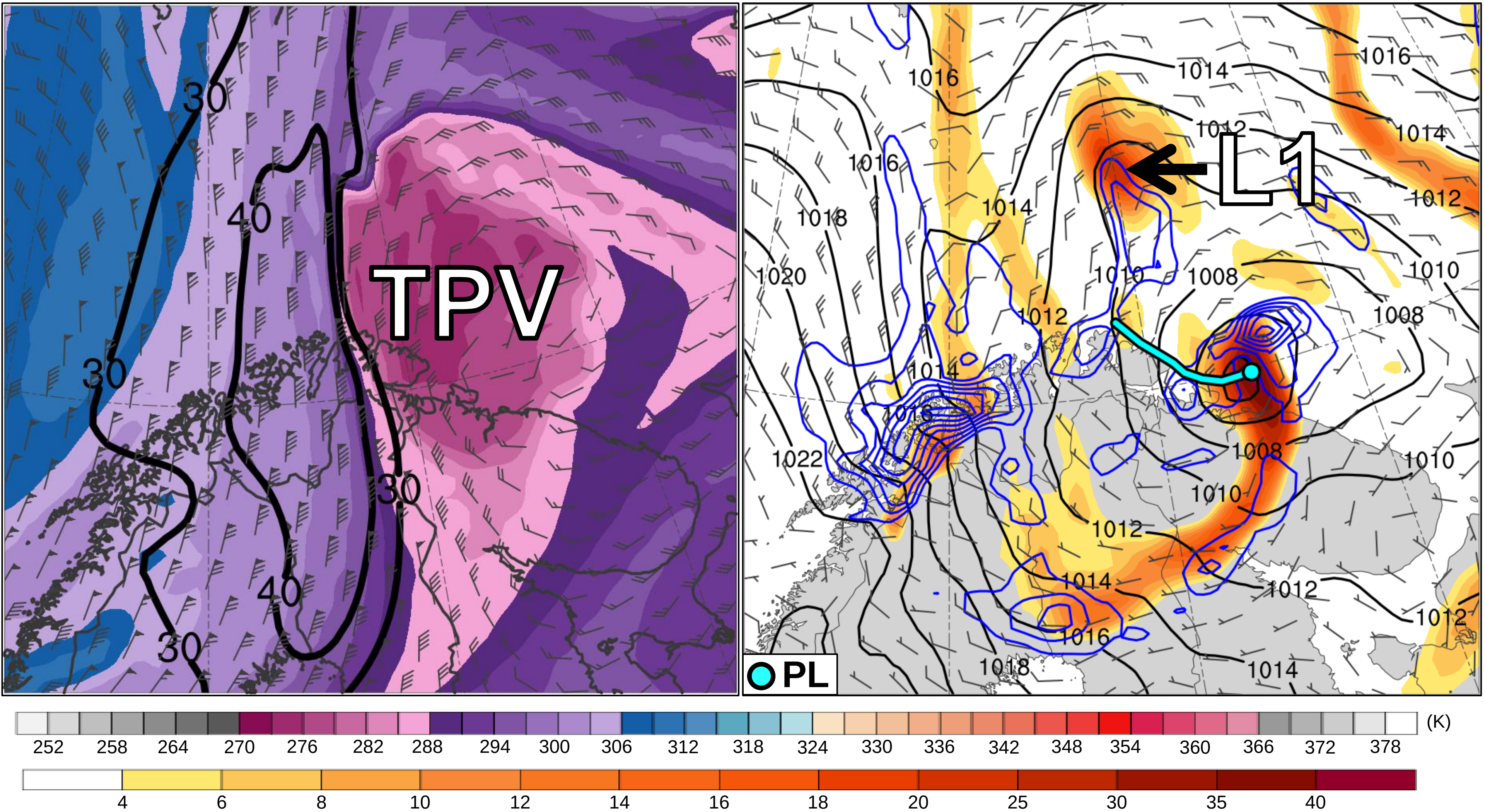
Mesoscale Evolution

0600 UTC 11 Feb 2011



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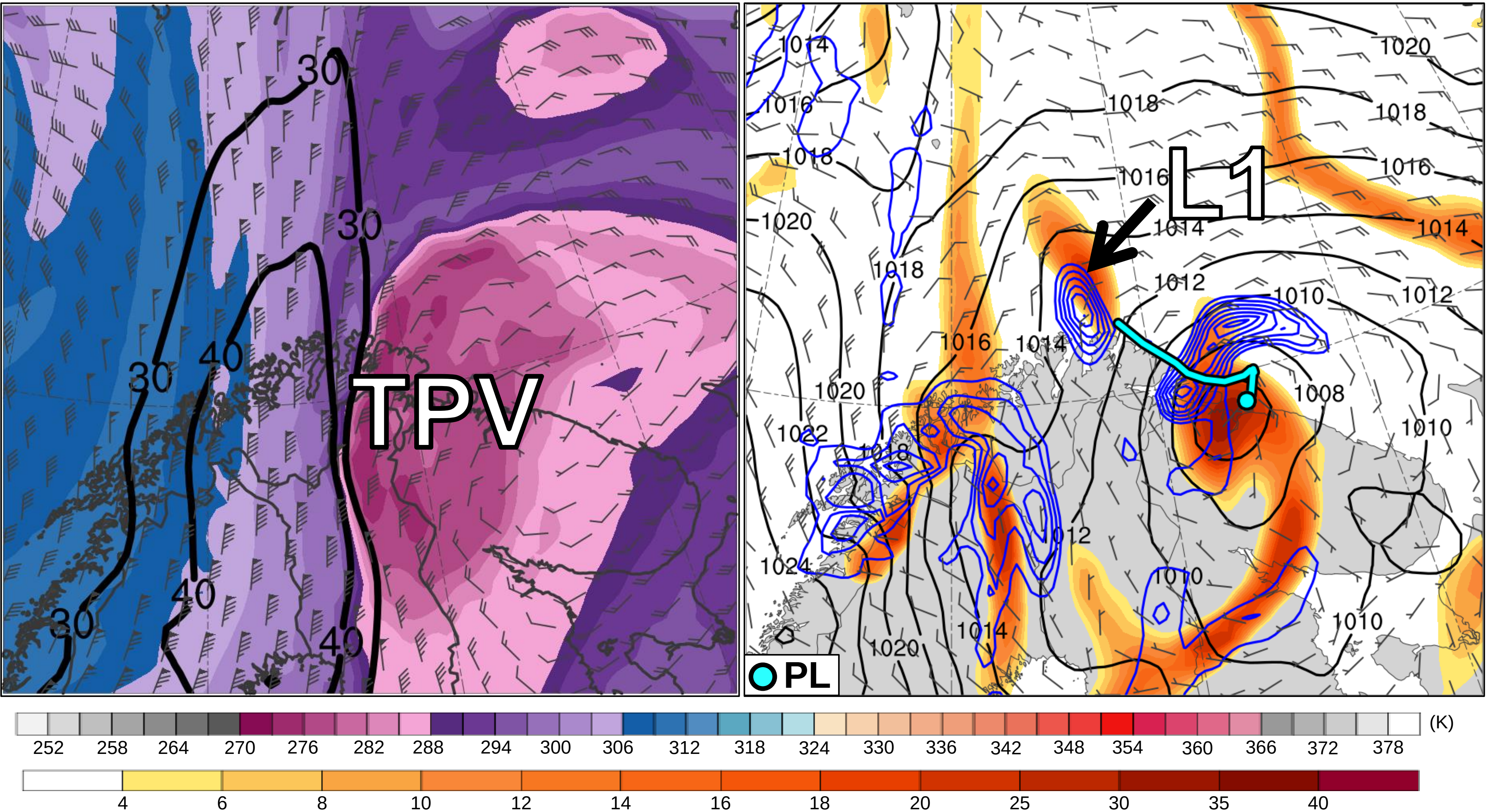
Mesoscale Evolution

1200 UTC 11 Feb 2011



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850-hPa relative vorticity (10^{-5} s^{-1}, shaded), 850–600-hPa ascent (blue, every 2.5 × 10^{-3} hPa s^{-1}), SLP (hPa, black), and 10-m wind (m s^{-1}, barbs)

Summary

- The evolution of the polar low appears to be related to the interaction between the TPV and a tropospheric-deep baroclinic zone

- Forcing for ascent associated with the TPV and a favorable thermodynamic environment likely support the intensification of the polar low

Outline

- Analyze the evolution of a polar low linked to a TPV
- **Investigate factors influencing the predictability of the evolution of the polar low**

Evaluating Forecast Skill of the Polar Low

- Use ECMWF Ensemble Prediction System (EPS; Buizza et al. 2007) from TIGGE (Bougeault et al. 2010) initialized at 1200 UTC 9 February 2011
  - 30 h prior to genesis of polar low
  - Downloaded at 0.5° horizontal resolution
- Use ERA5 regridded to 0.5° horizontal resolution as verification

Evaluating Forecast Skill of the Polar Low

- Assess forecast skill of polar low in terms of a metric combining track error and intensity error of polar low

- Calculate metric by adapting methodology used by Lamberson et al. (2016) to evaluate forecast skill of a strong extratropical cyclone

- Calculate track error and intensity error every 6 h from 1800 UTC 10 Feb 2011 to 1200 UTC 11 Feb 2011 for each member

Evaluating Forecast Skill of the Polar Low

- Calculate track error as the distance between the location of the polar low in ERA5 and in each member
  - Location of the polar low corresponds to location of the maximum value of 850-hPa relative vorticity of the polar low
- Calculate intensity error as the absolute difference in intensity of the polar low in ERA5 and in each member
  - Intensity of the polar low corresponds to the maximum value of 850-hPa relative vorticity of the polar low

Evaluating Forecast Skill of the Polar Low

- Average errors over time and rank members 1–51 for both track and intensity, with 1 corresponding to member with lowest average error
- Add track error rank to intensity error rank to determine a combined track and intensity error rank for each member
- Subdivide members into two groups: one containing the eight most accurate members and one containing the eight least accurate members in terms of combined track and intensity error rank

Calculating Normalized Composite Differences

- Calculate normalized composite differences between the most accurate and least accurate groups for selected quantities following Lamberson et al. (2016)

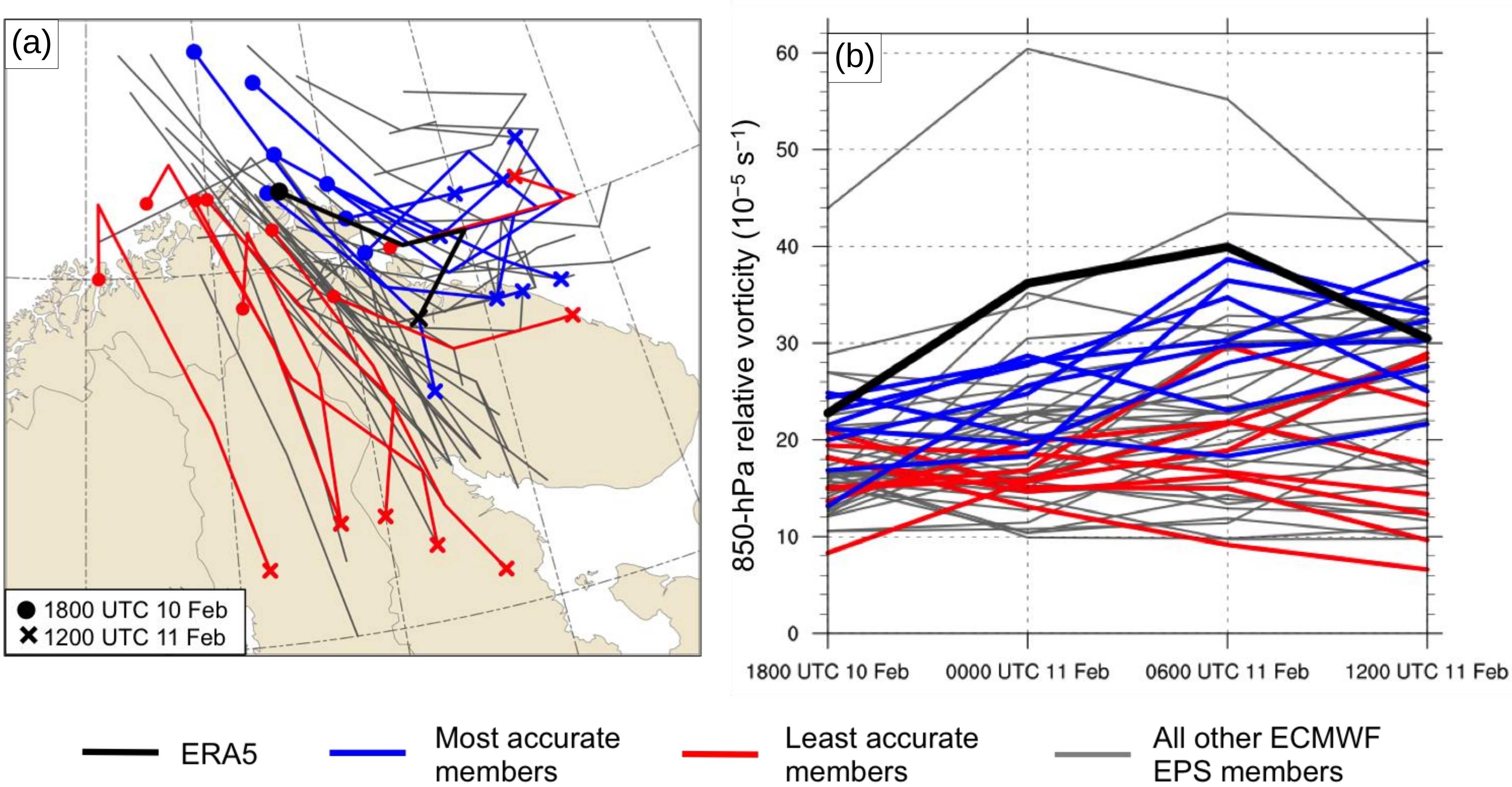
$$\Delta x_i = \frac{\bar{\mathbf{x}}_i^{\,most\ accurate} - \bar{\mathbf{x}}_i^{\,least\ accurate}}{\sigma_{x_i}}$$

$\bar{\mathbf{x}}_i^{\,most\ accurate}$ = mean of the *i*th state variable for most accurate members

$\bar{\mathbf{x}}_i^{\,least\ accurate}$ = mean of the *i*th state variable for least accurate members

σ_{x_i} = ensemble standard deviation of $\mathbf{x}_i$ computed for all members

Track and Intensity



(a) Track and (b) intensity of 850-hPa relative vorticity maximum (10^{-5} s^{-1}) associated with polar low, every 6 h during 1800 UTC 10–1200 UTC 11 Feb 2011.

Composite Differences

1800 UTC 10 Feb 2011 (30 h)

Ensemble mean

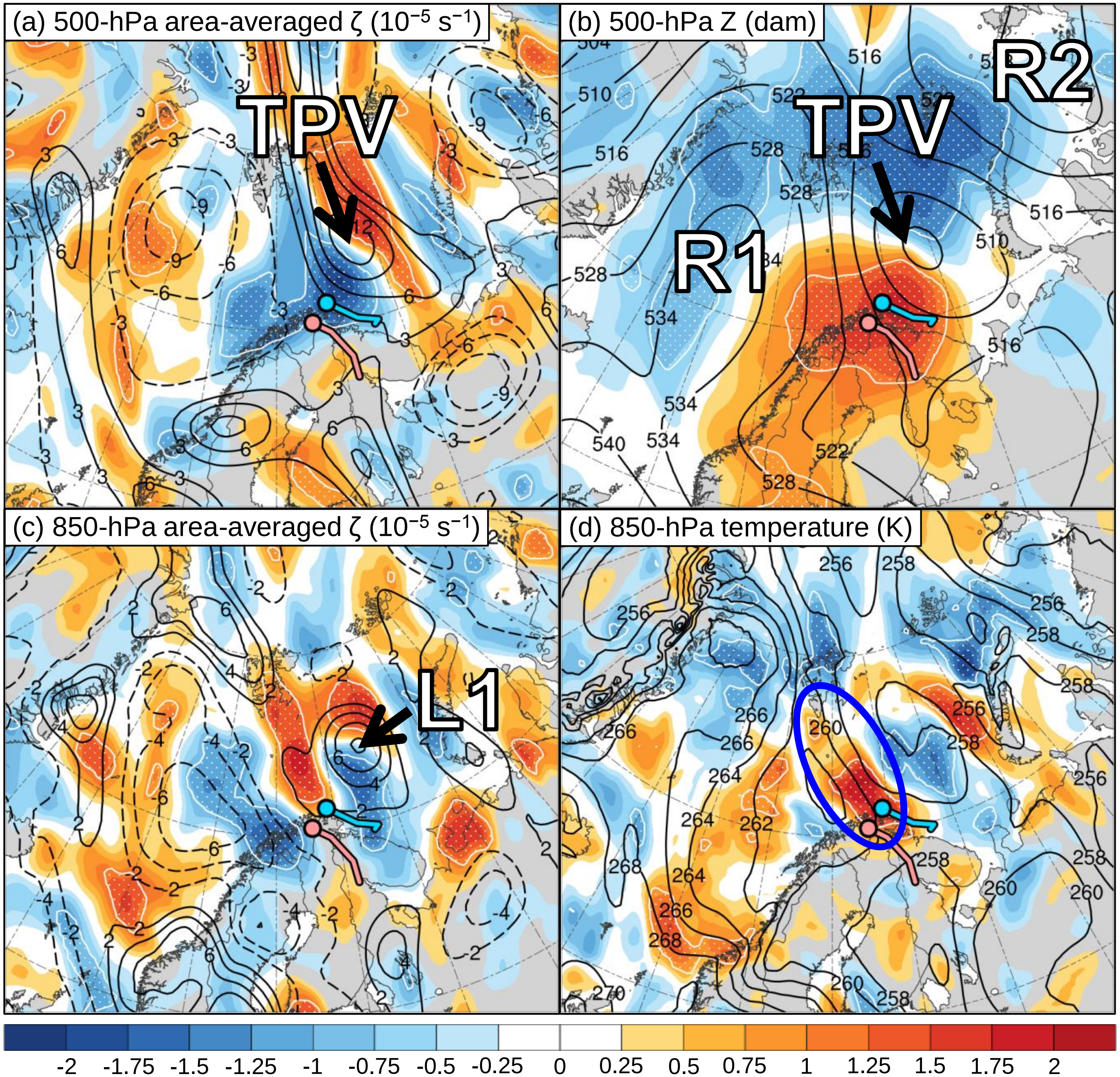
shading: normalized composite differences (σ; most accurate group minus least accurate group)

stippling: statistically significant differences between groups at 95% confidence level according to a two-sided Student's *t* test

Mean position of PL in most accurate group*

Mean position of PL in least accurate group*

***Track:** 1800 UTC 10–1200 UTC 11 Feb 2011



Summary

- Composite differences between the most and least accurate groups suggest that the TPV and L1 are positioned farther northeastward and the baroclinic zone is positioned farther eastward in the most accurate group
  - These position differences may be tied to the ridges flanking the TPV (R1 and R2) being less amplified and R1 extending farther eastward in the most accurate group
  - These position differences likely contribute to the farther northeastward track of the polar low in the most accurate group

Summary

- The more conducive thermodynamic environment for polar low development in the most accurate group likely contributes to the polar low being stronger in the most accurate group

Questions? *Email: kbiernat@albany.edu*

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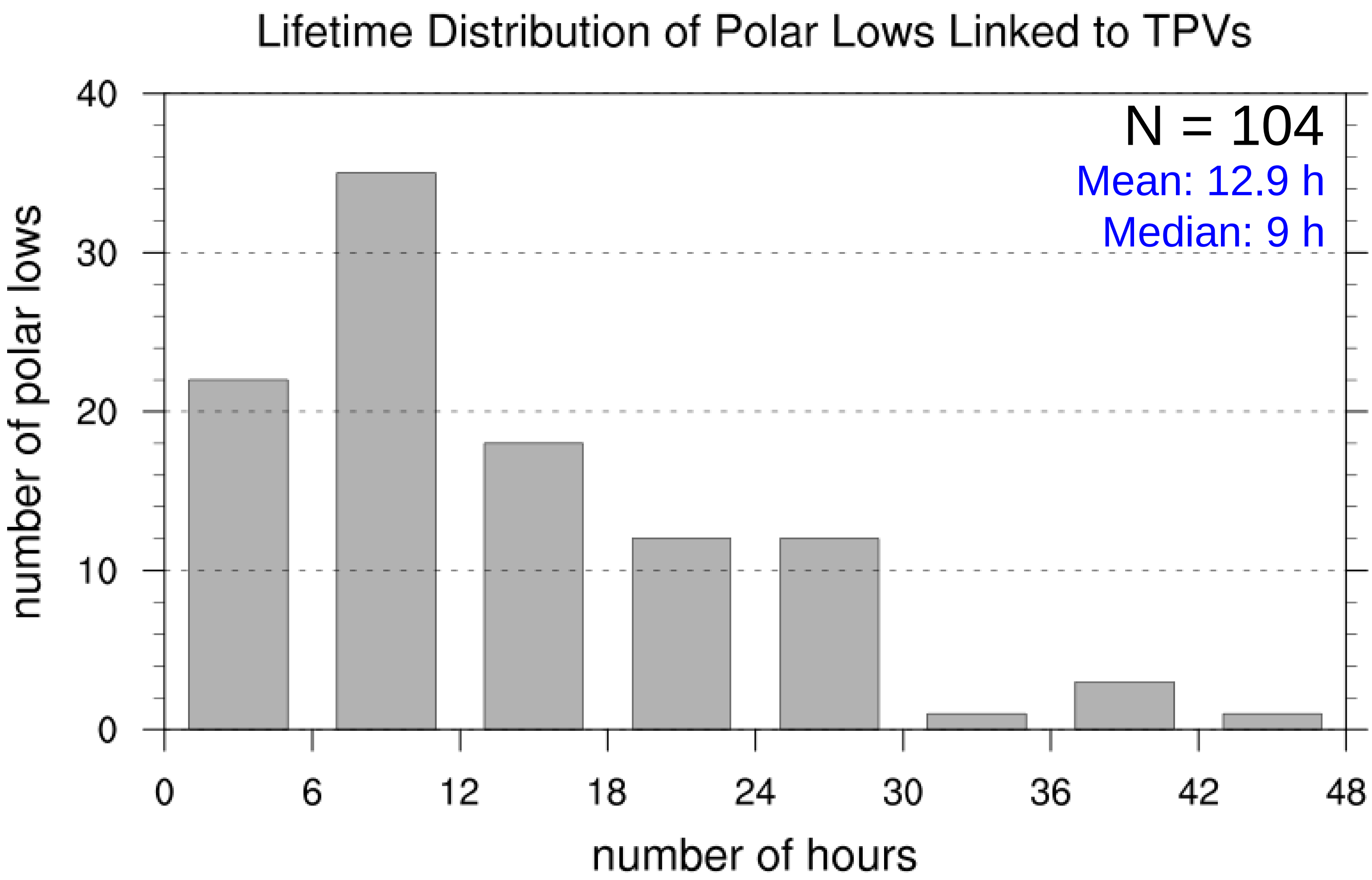
Supplementary Figures

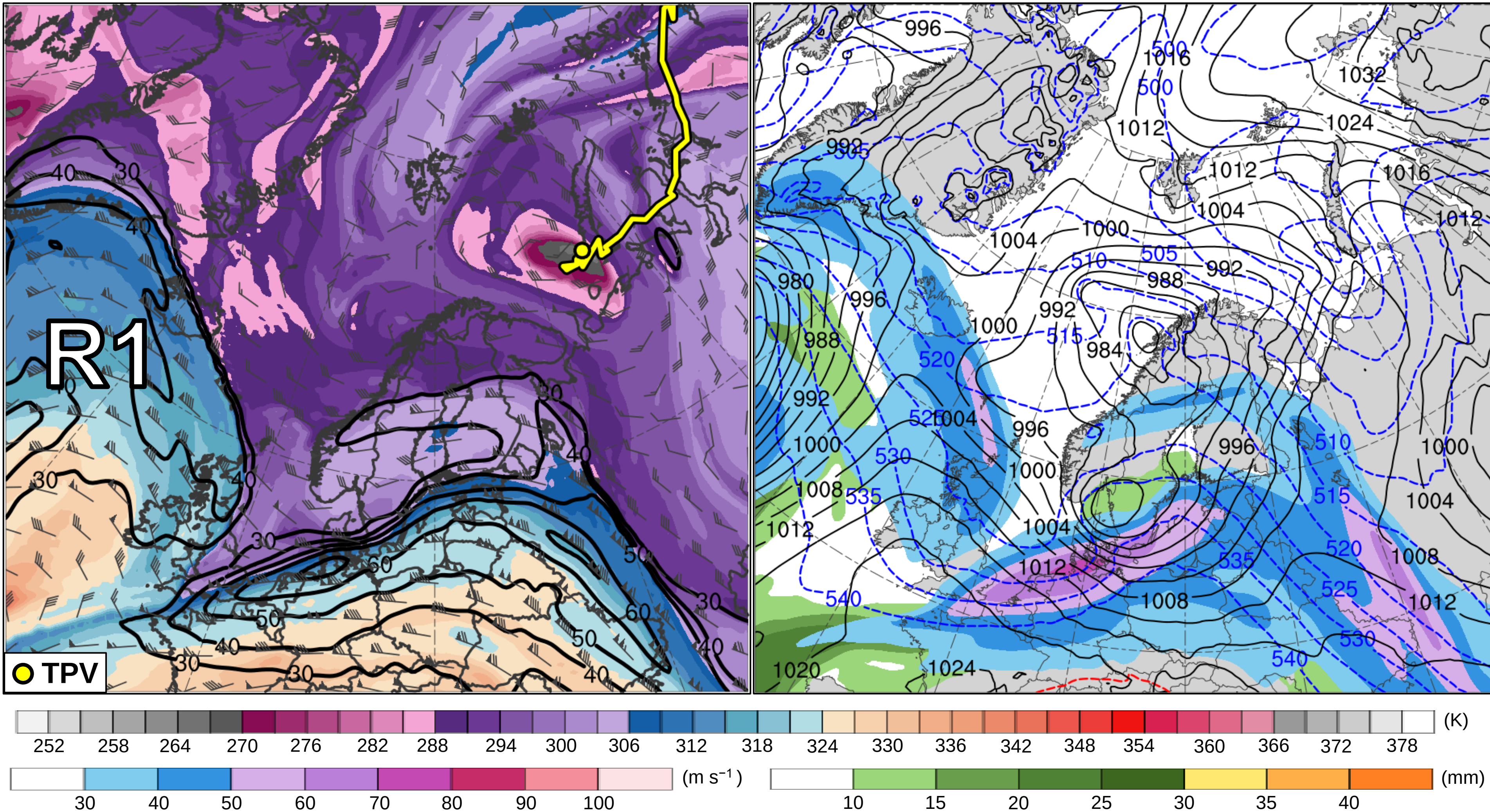
Climatology of Polar Lows Linked to TPVs



Lifetime distribution of polar lows linked to TPVs, with lifetime in number of hours.

Synoptic Evolution

0000 UTC 8 Feb 2011

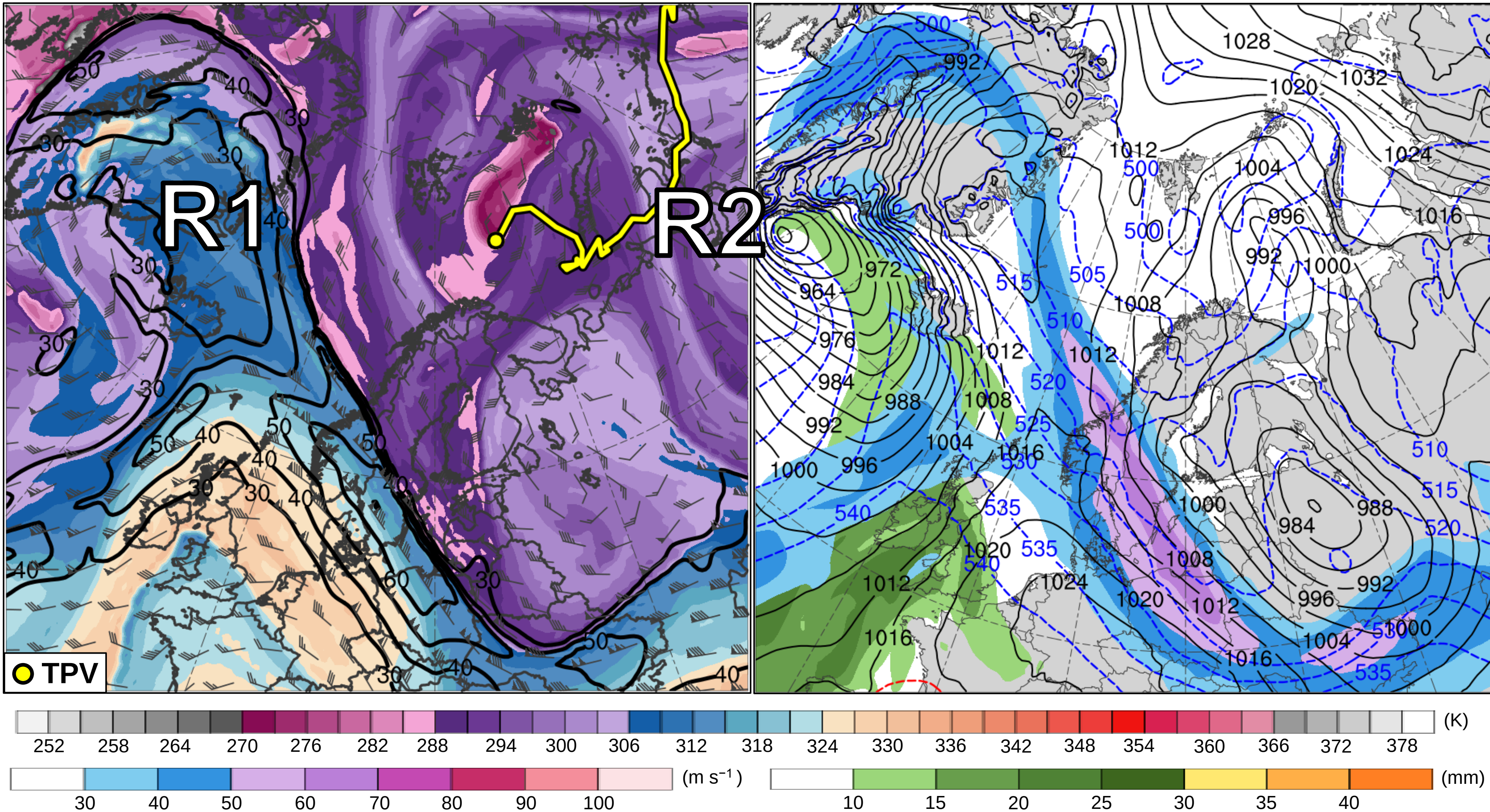


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 30 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

Synoptic Evolution

0000 UTC 9 Feb 2011



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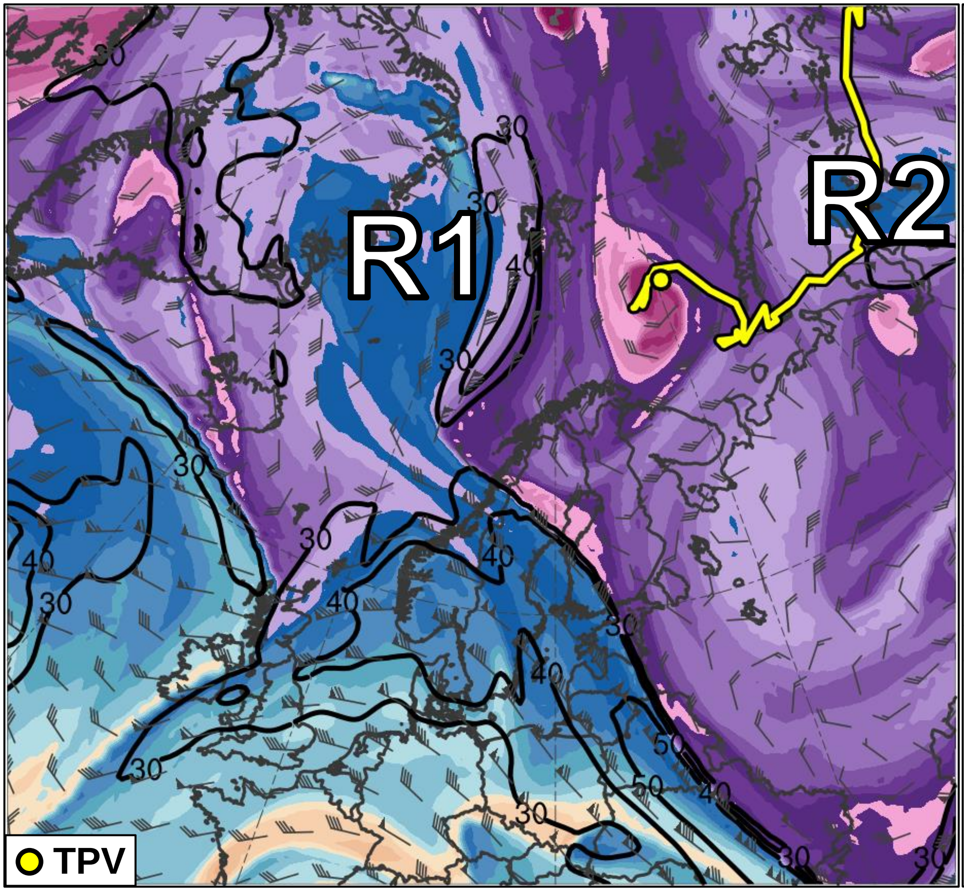
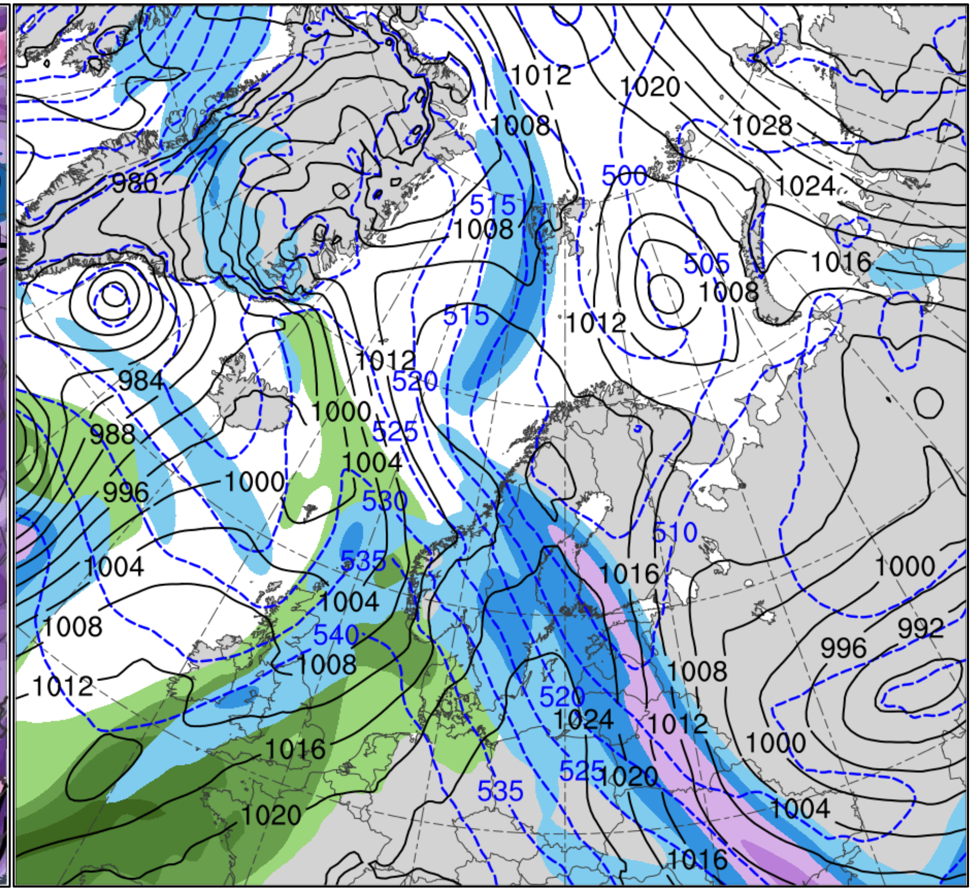
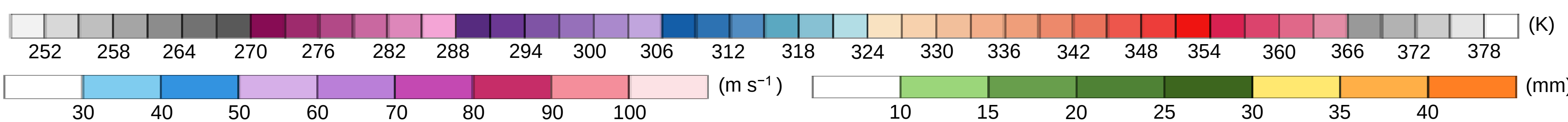
Synoptic Evolution

0000 UTC 10 Feb 2011







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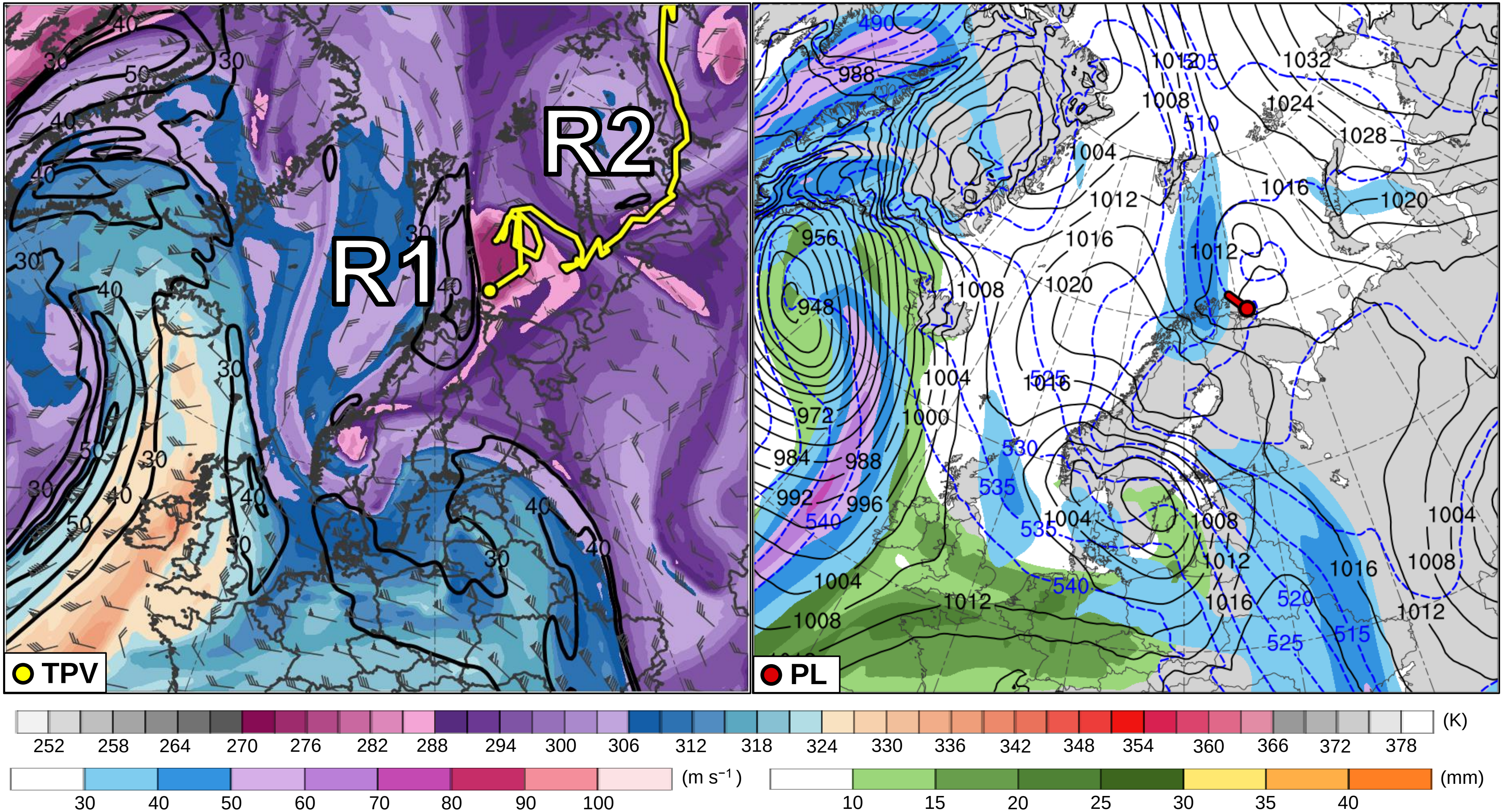
Synoptic Evolution

0000 UTC 11 Feb 2011



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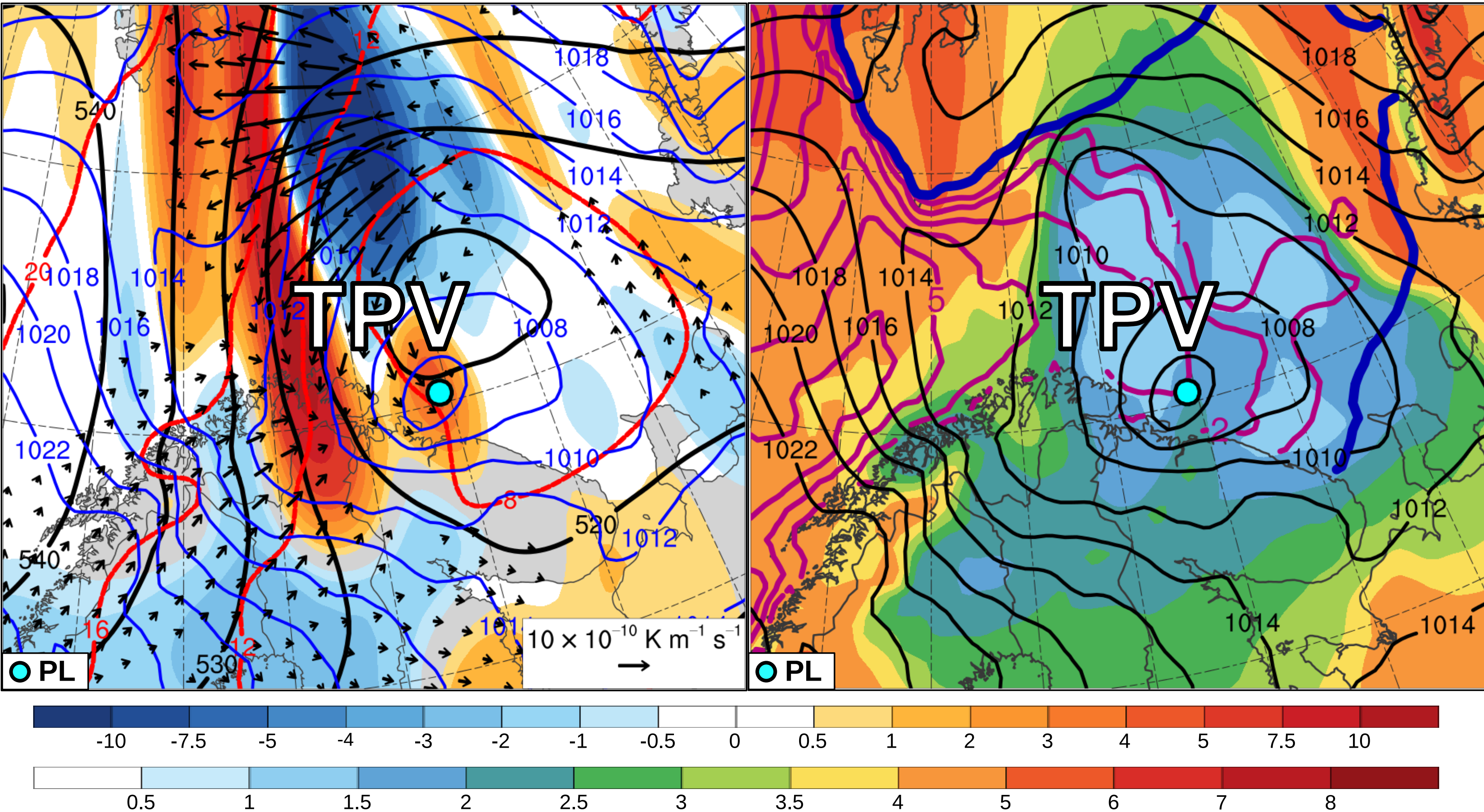
300-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

Favorable Conditions

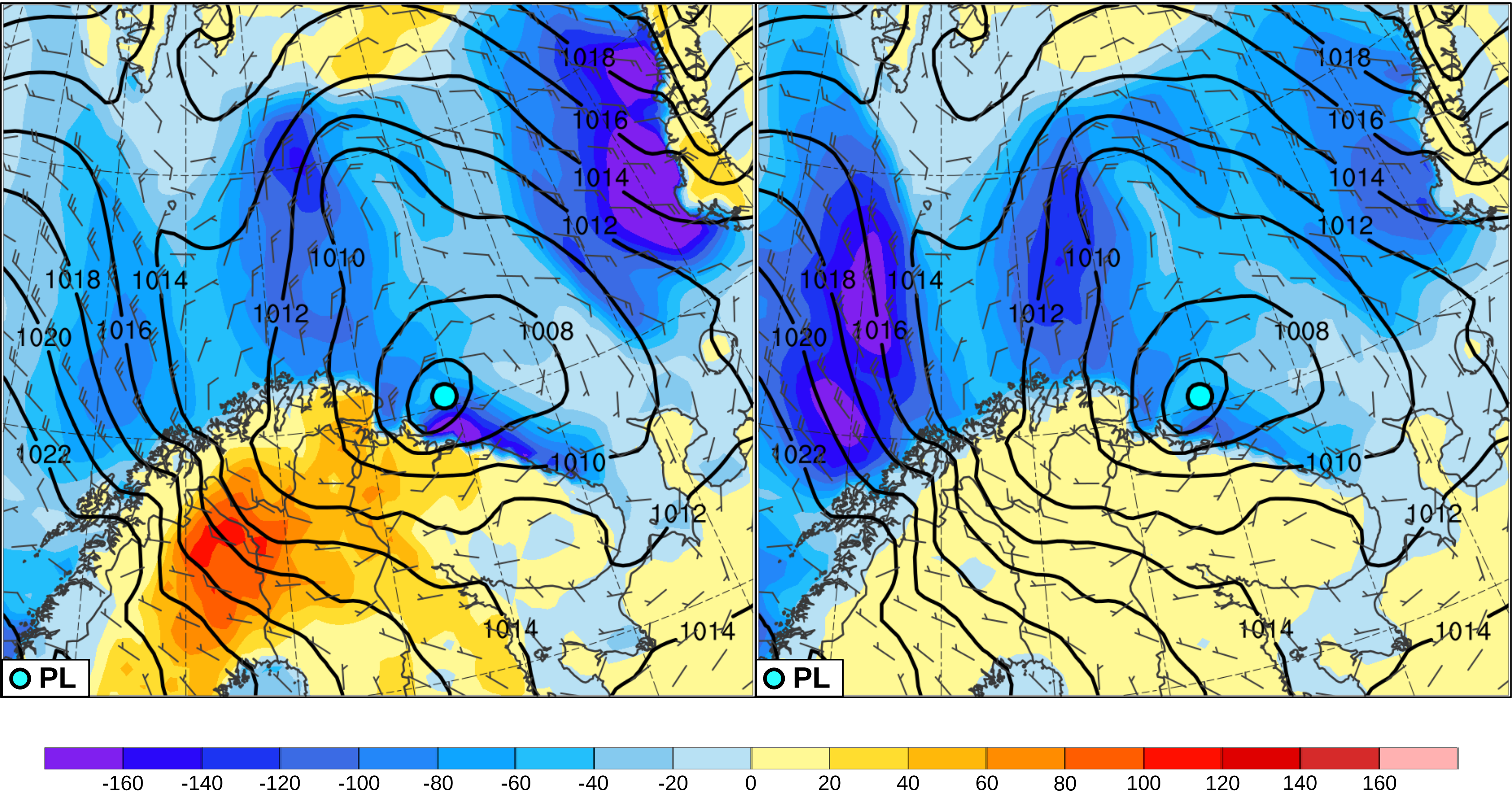
0300 UTC 11 Feb 2011



SLP (hPa, blue); 600–400-hPa **Q** (K m^{-1} s^{-1}, vectors), **Q** forcing for vertical motion (10^{-17} Pa^{-1} s^{-3}, shaded), θ (°C, red), and geopotential height (dam, black)	900–600-hPa static stability [K (100 hPa)$^{-1}$, shaded], SLP (hPa, black), SST (°C, purple), and 20% contour of sea-ice concentration (thick blue)

Favorable Conditions

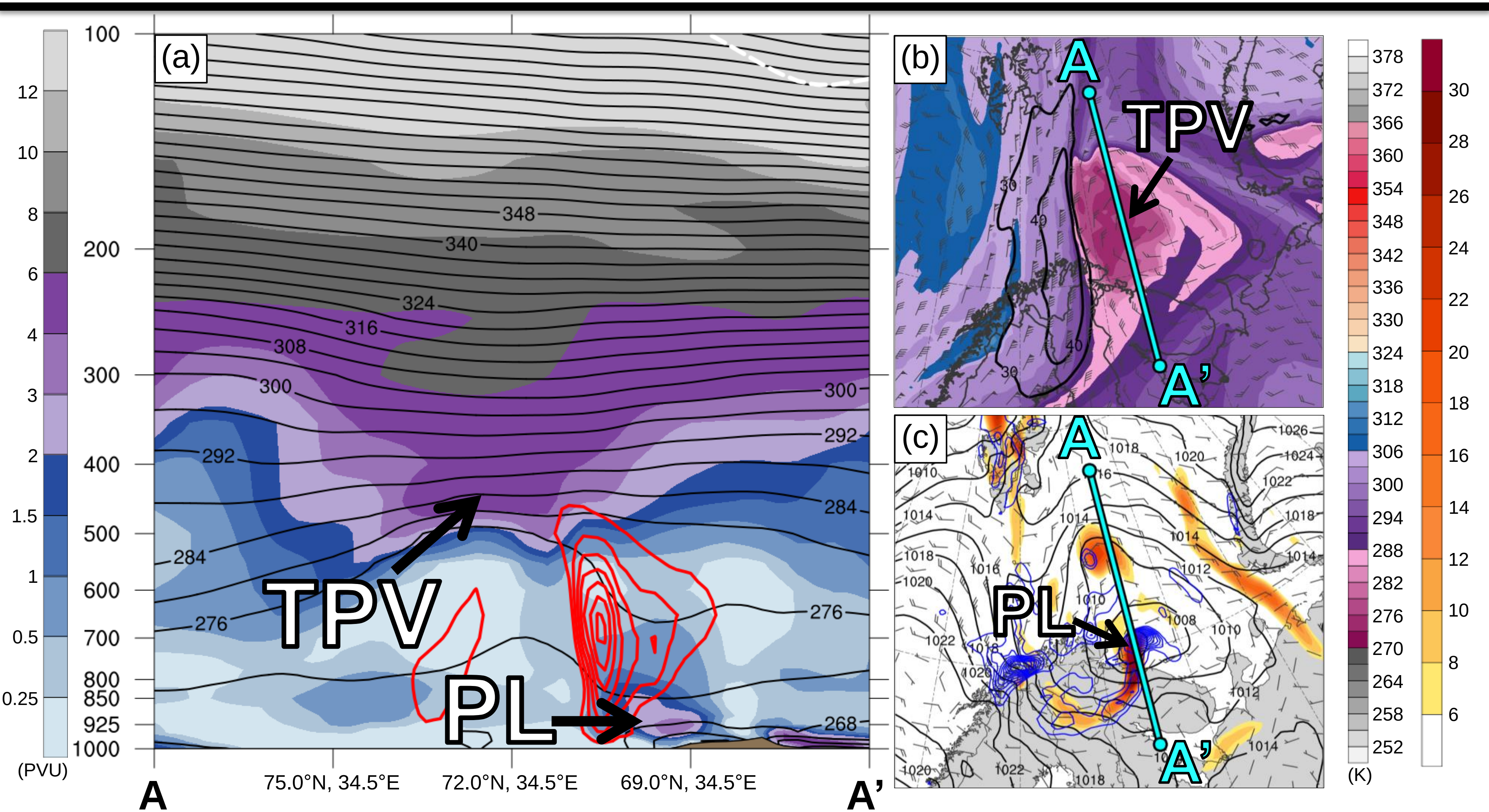
0300 UTC 11 Feb 2011



Sensible heat flux [W m^{-2}, shaded], SLP (hPa, black), and 10-m wind (m s^{-1}, barbs)	Latent heat flux [W m^{-2}, shaded], SLP (hPa, black), and 10-m wind (m s^{-1}, barbs)

Cross Sections

0300 UTC 11 Feb 2011



(a) PV (PVU, shaded), θ (K, black), ascent (red, every 2.5 × 10^{-3} hPa s^{-1}), and wind speed (white, every 10 m s^{-1} starting at 30 m s^{-1}); (b) DT (2-PVU surface) θ (K, shaded), wind speed (black, every 10 m s^{-1} starting at 30 m s^{-1}), and wind (m s^{-1}, flags and barbs); (c) 850-hPa relative vorticity (10^{-5} s^{-1}, shaded), 850–600-hPa ascent (blue, every 2.5 × 10^{-3} hPa s^{-1}), SLP (hPa, black), and 10-m wind (m s^{-1}, barbs)

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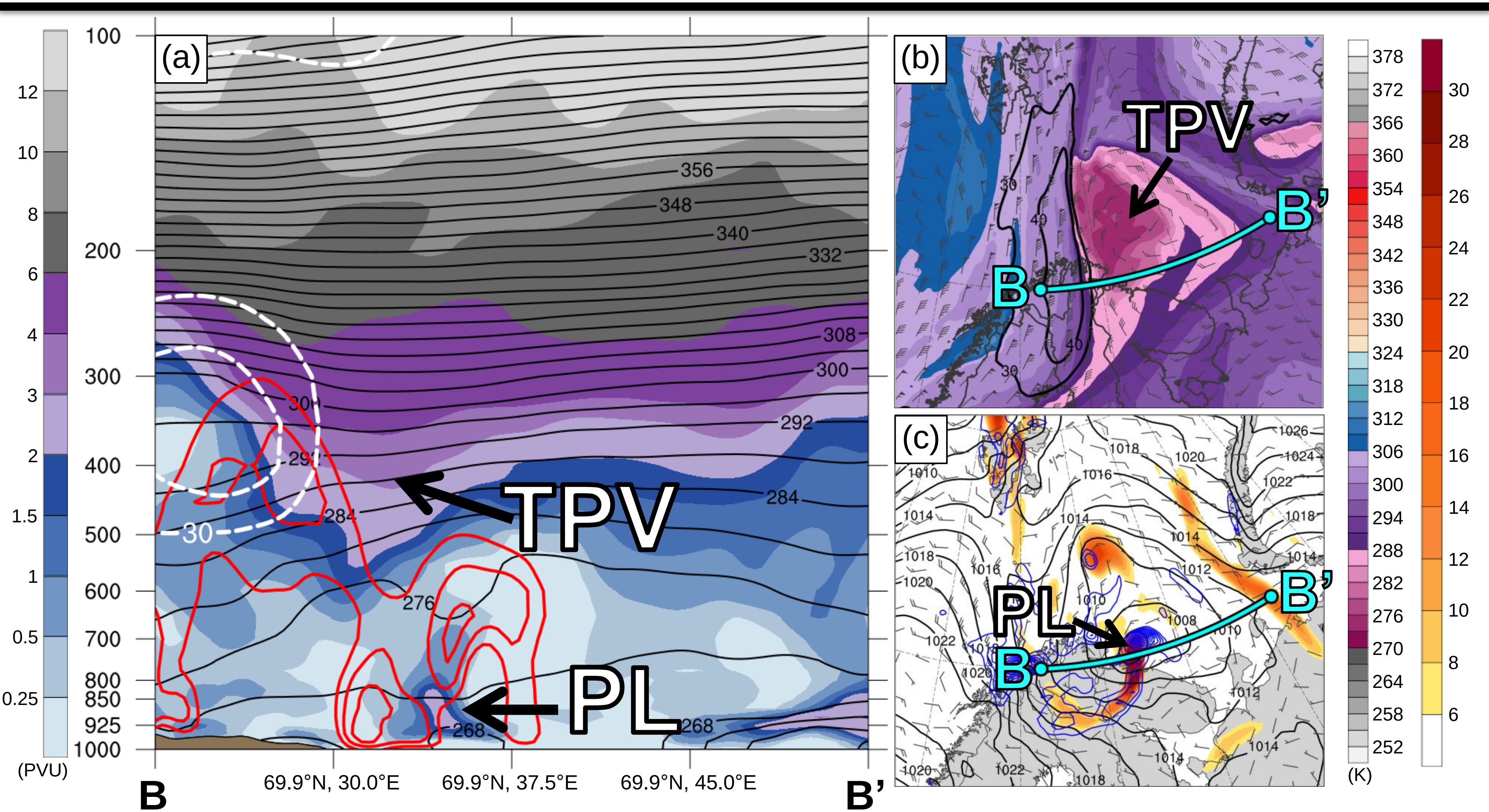

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