A Multiscale Analysis and Predictability Study of a Polar Low Linked to a Tropopause Polar Vortex

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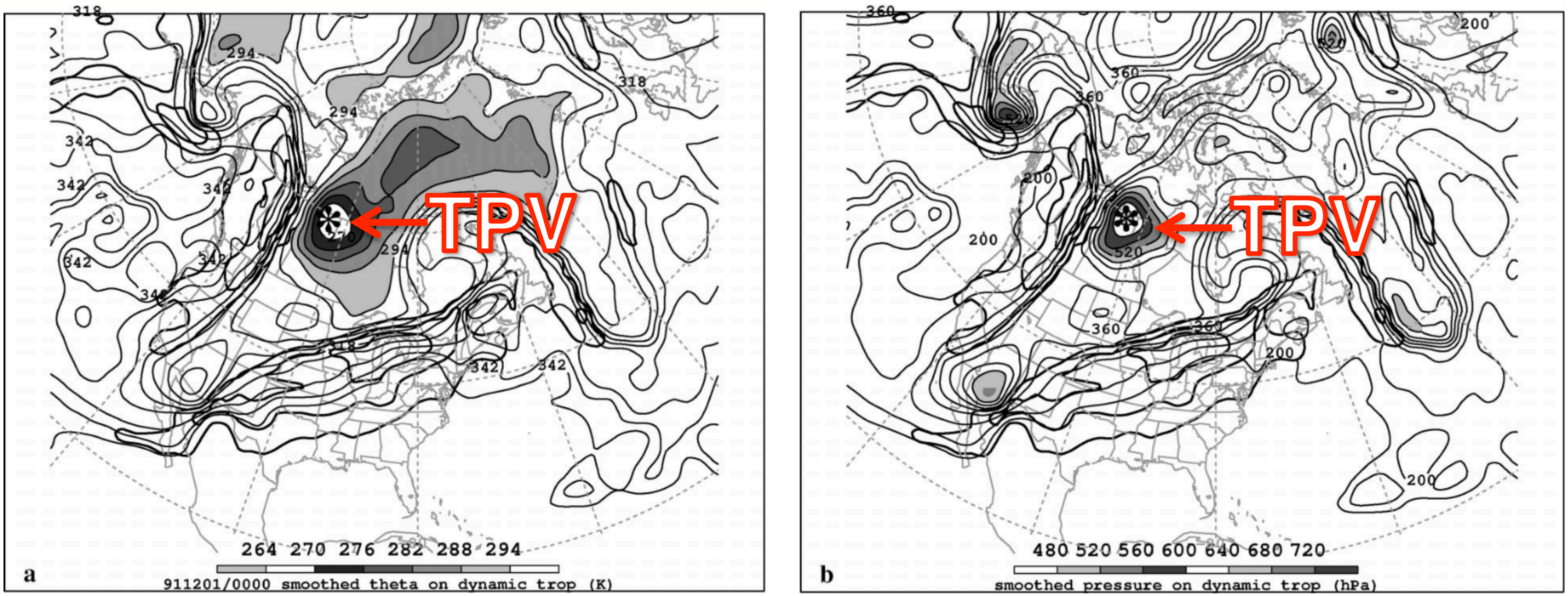
What are Tropopause Polar Vortices (TPVs)?

- 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 horizontal scales from 10s to 100s of km, short lifetimes, and rapid evolution (e.g., Rasmussen and Turner 2003)

- Polar lows often form within a cold air mass or along an Arctic front 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 to the development of polar lows (e.g. Kolstad 2011)

Outline

- **Analyze the evolution of a polar low that is 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 Sea and Barents Sea (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 to a 1979–2015 database of TPVs constructed using the ERA-Interim (Dee et al. 2011) and a TPV tracking algorithm developed by Nicholas Szapiro and Steven Cavallo

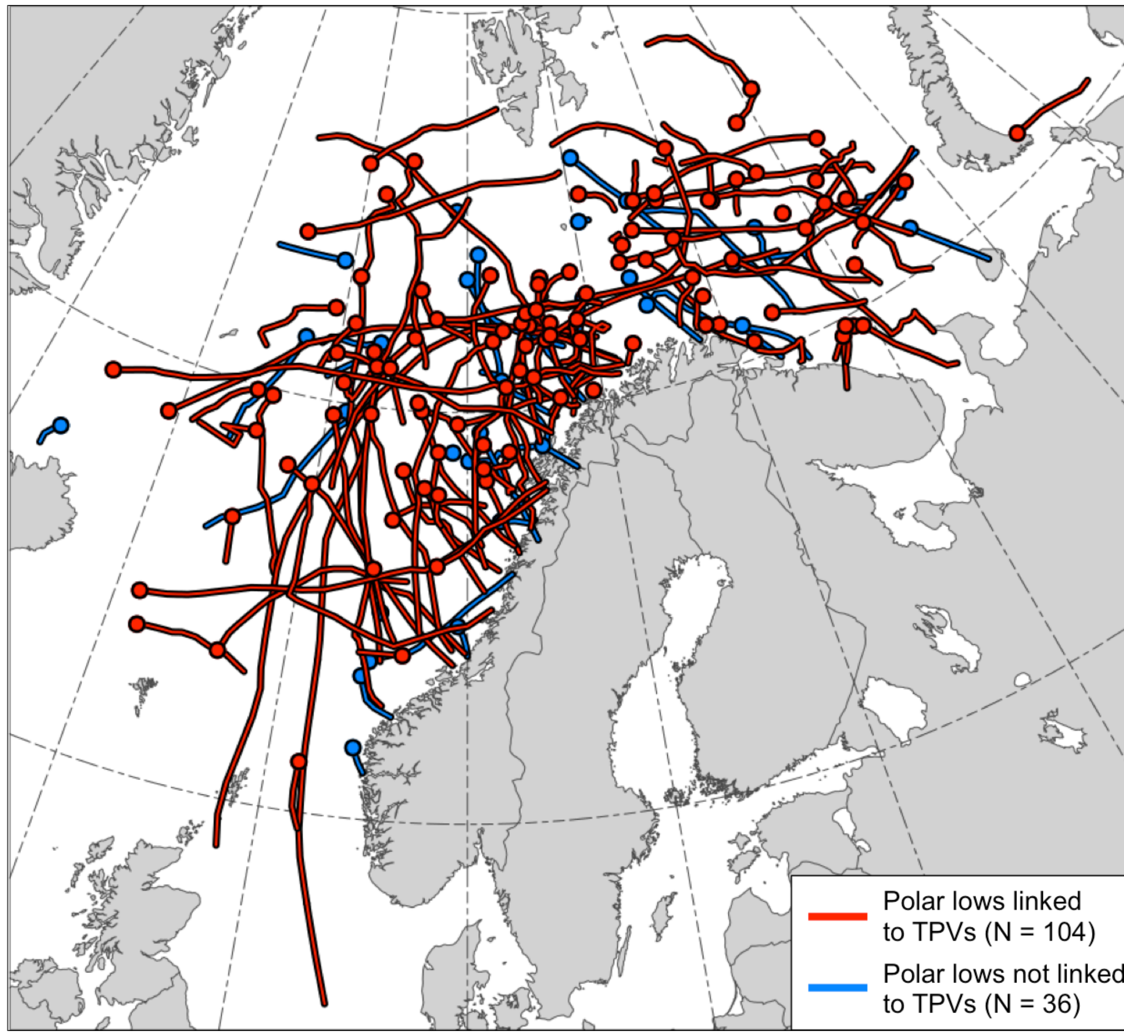
- Determine which polar lows may be linked to TPVs by requiring that a polar low be located within 500 km of at least one TPV at any point in the lifetime of the polar low

Link for Tracking Algorithm: https://github.com/nickszap/tpvTrack

Climatology of Polar Lows Linked to TPVs

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

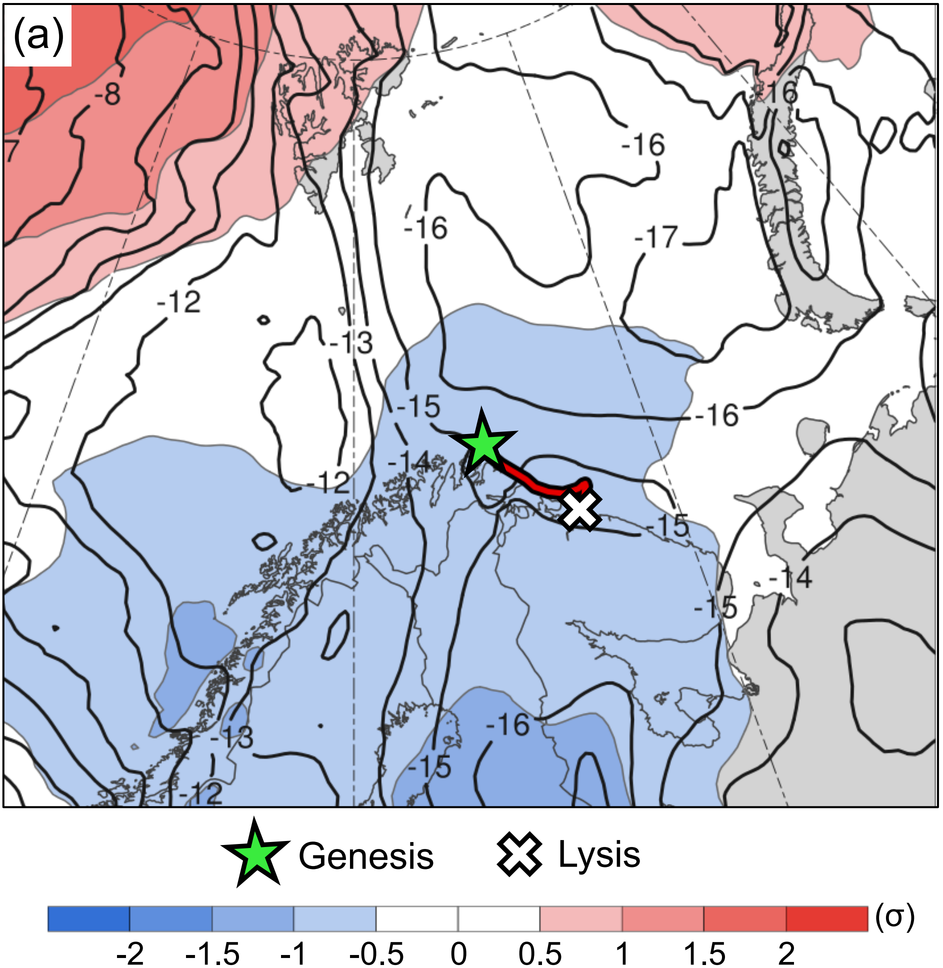
Tracks of the polar lows in the STARS database. Tracks of polar lows linked to TPVs (red) and tracks of polar lows not linked to TPVs (blue). Dots indicate the genesis locations of the polar lows.

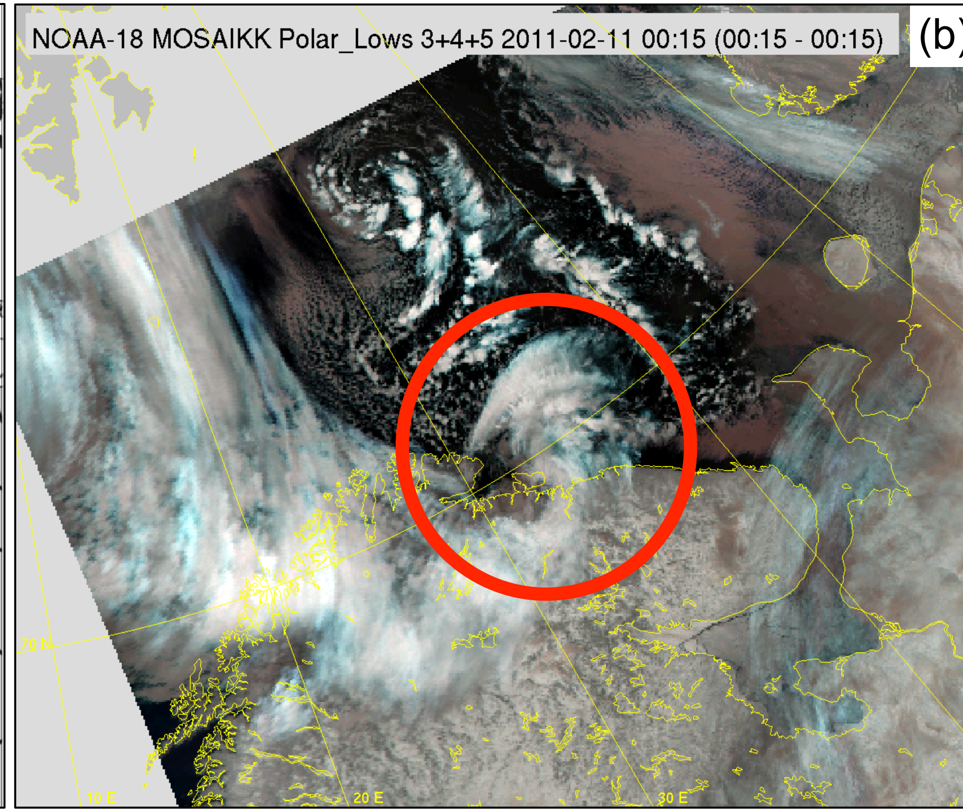


Case Selection

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

The Polar Low





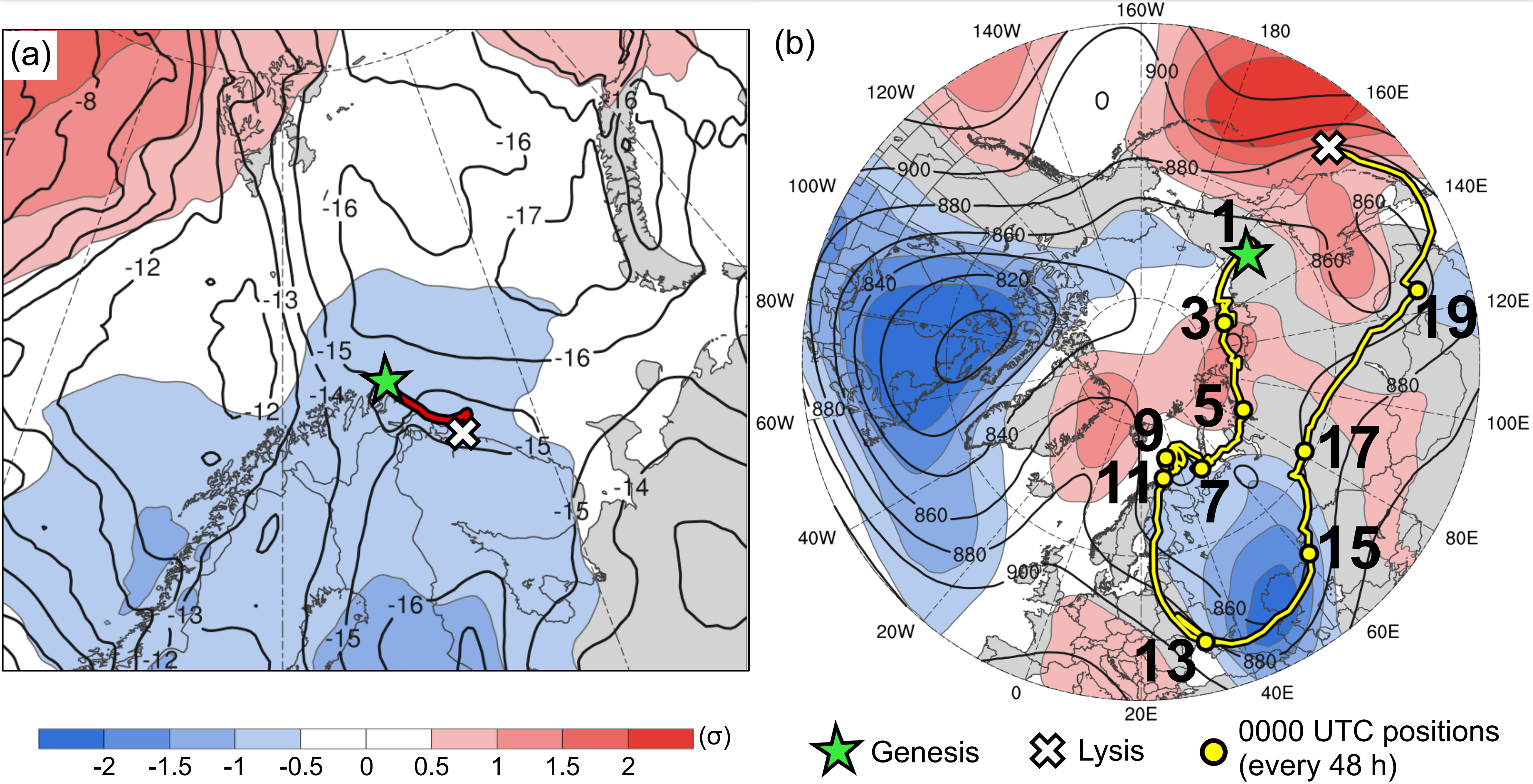
Genesis	Lysis	Lifetime
1800 UTC 10 Feb 2011	1200 UTC 11 Feb 2011	18 h

(a) Track of polar low (red) and 10–11 Feb 2011 time mean 850-hPa temperature (K) and standardized anomaly of 850-hPa temperature (σ, shaded).

(b) NOAA Advanced Very High Resolution Radiometer IR satellite image valid at 0015 UTC 11 Feb 2011. Image obtained from the STARS database.

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

The Polar Low and TPV

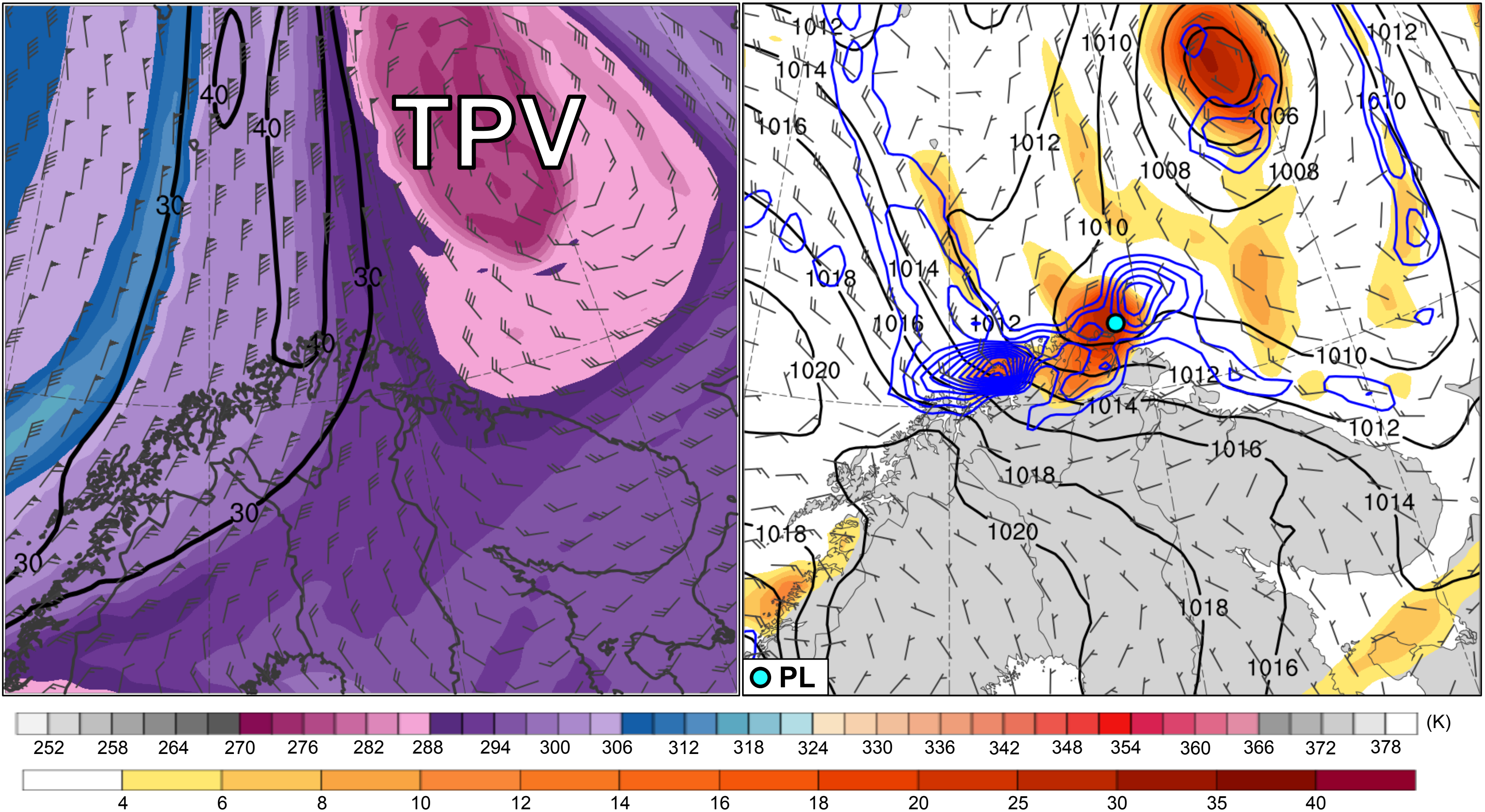


Feature	Genesis	Lysis	Lifetime
PL	10 Feb	11 Feb	18 h
TPV	31 Jan	20 Feb	20 d

Track of (a) polar low (red) and (b) the TPV linked to the polar low (yellow). Also, the 10–11 Feb 2011 time-mean (a) 850-hPa temperature (K, black) and standardized anomaly of 850-hPa temperature (σ, shaded), and (b) 300-hPa geopotential height (dam) and standardized anomaly of 300-hPa geopotential height (σ, shaded).

Mesoscale Evolution

1800 UTC 10 Feb 2011

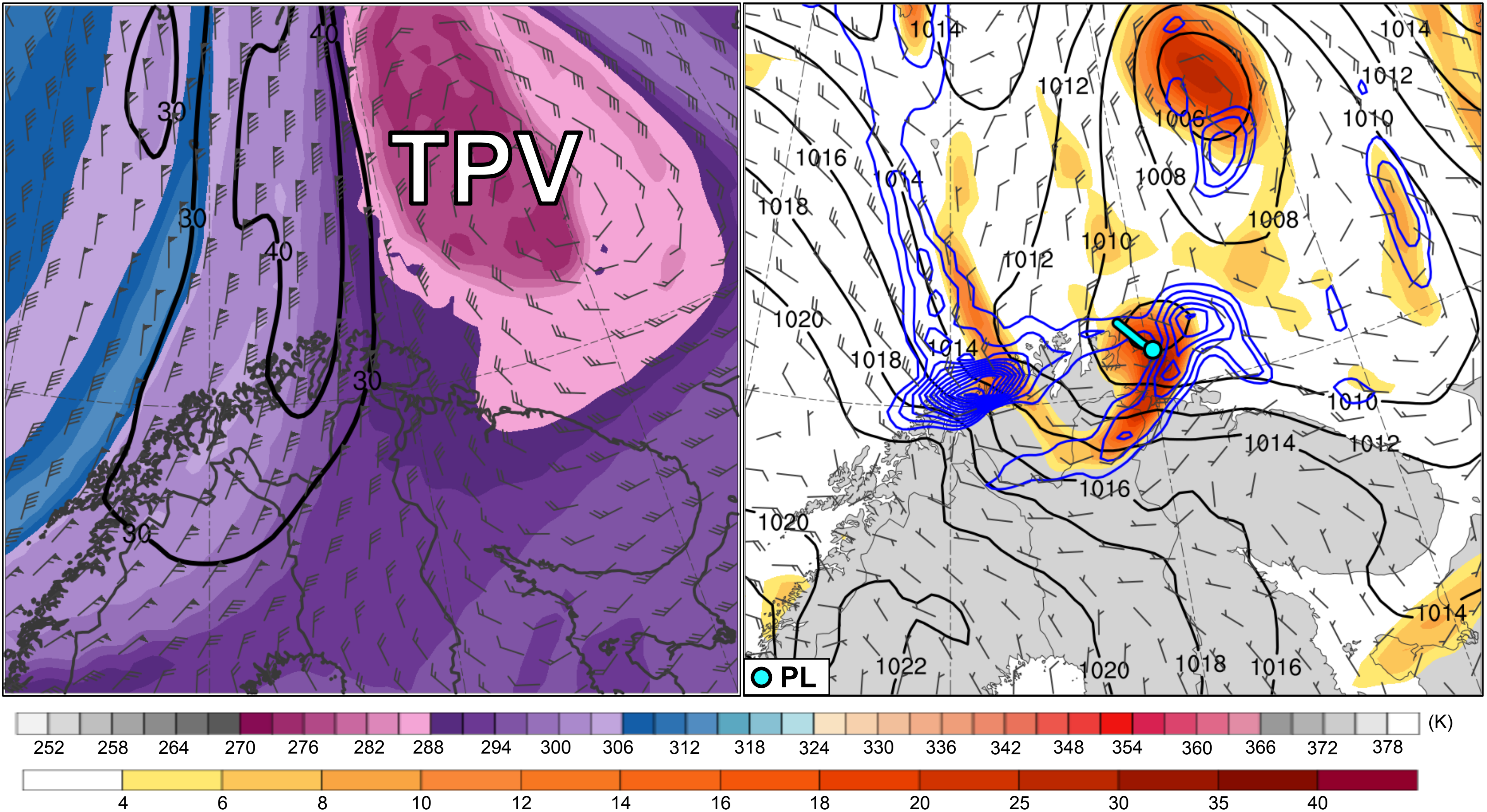


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 30 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

2100 UTC 10 Feb 2011



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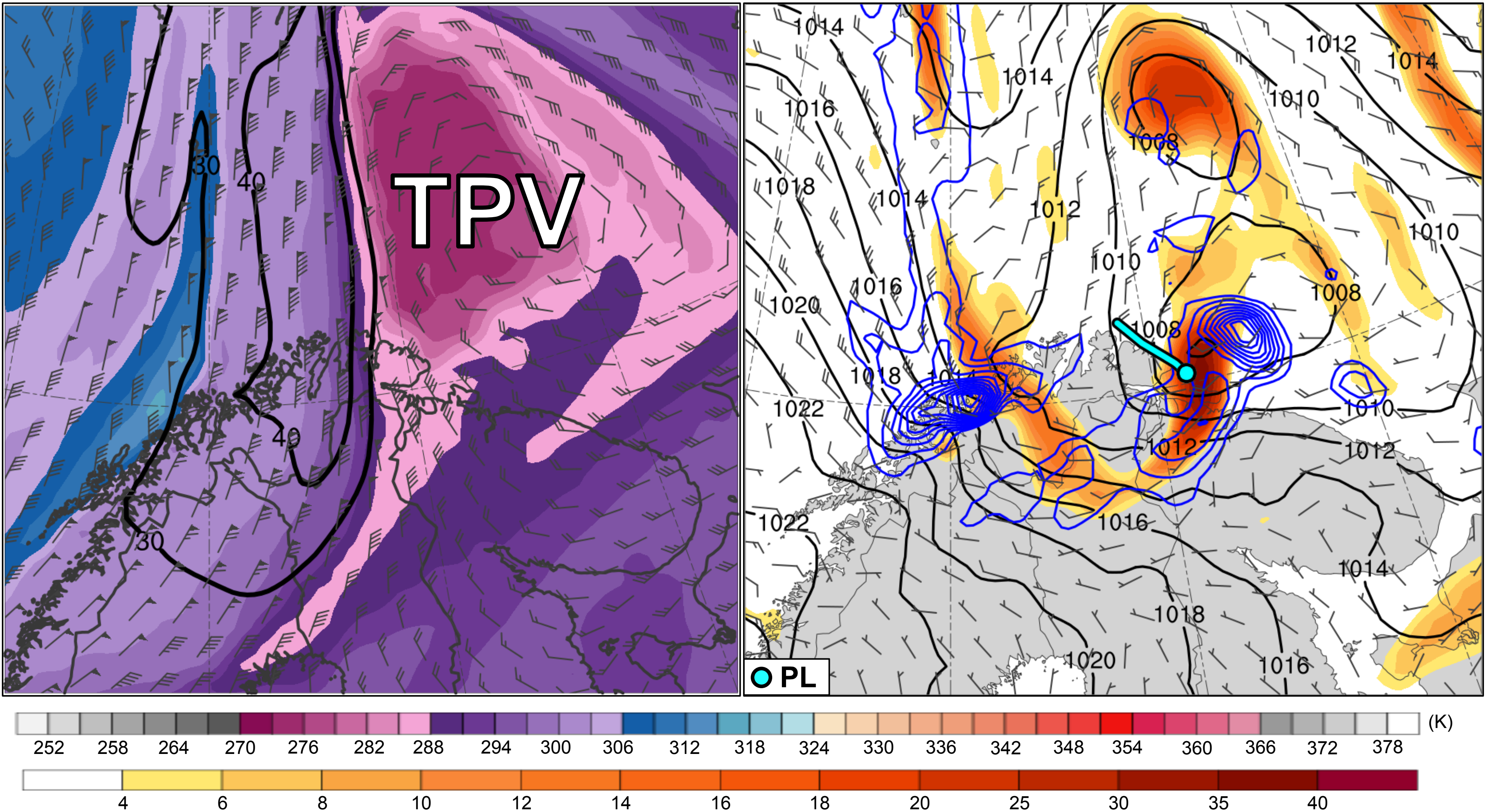
Mesoscale Evolution

0000 UTC 11 Feb 2011



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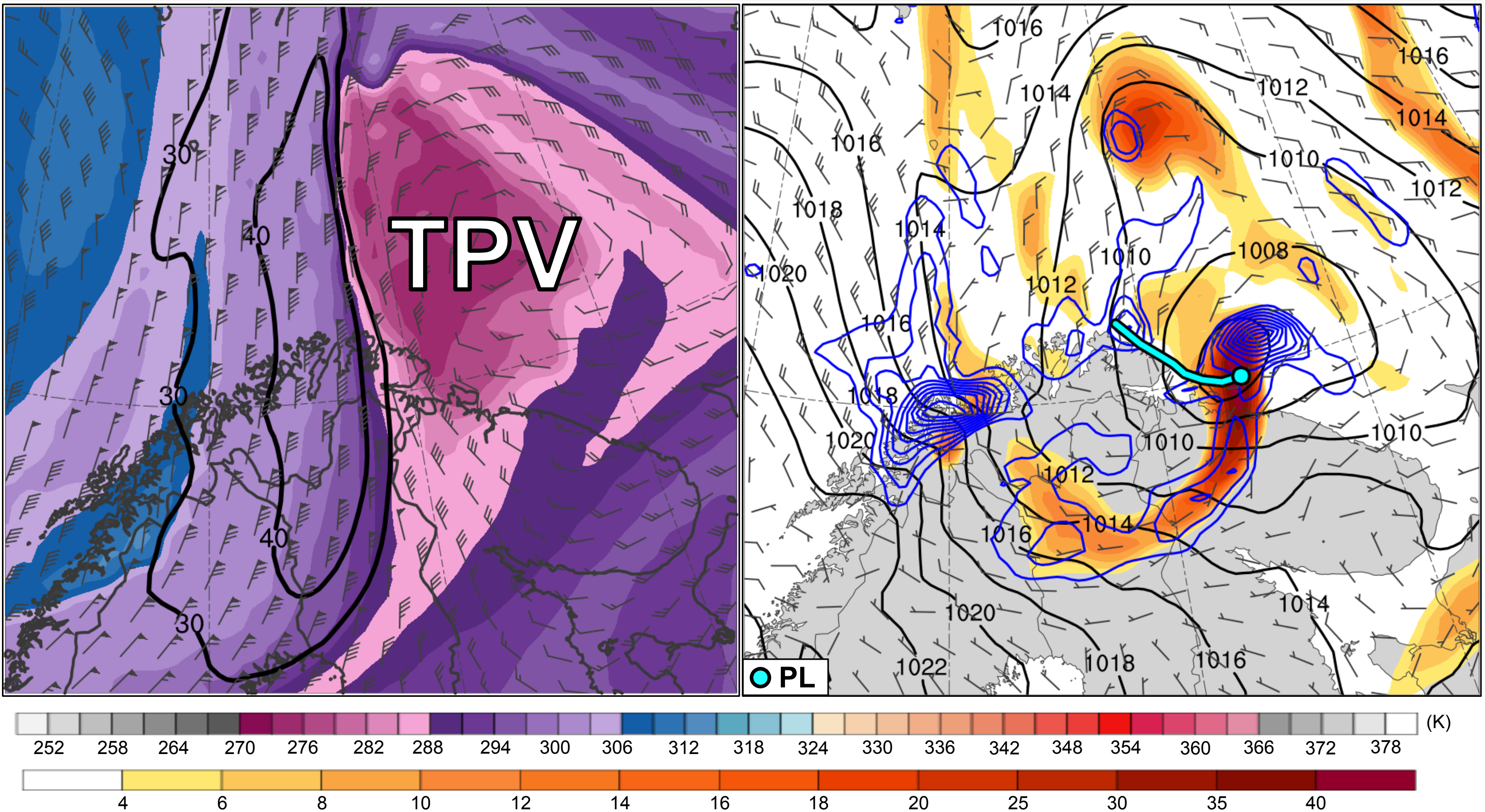
Mesoscale Evolution

0300 UTC 11 Feb 2011



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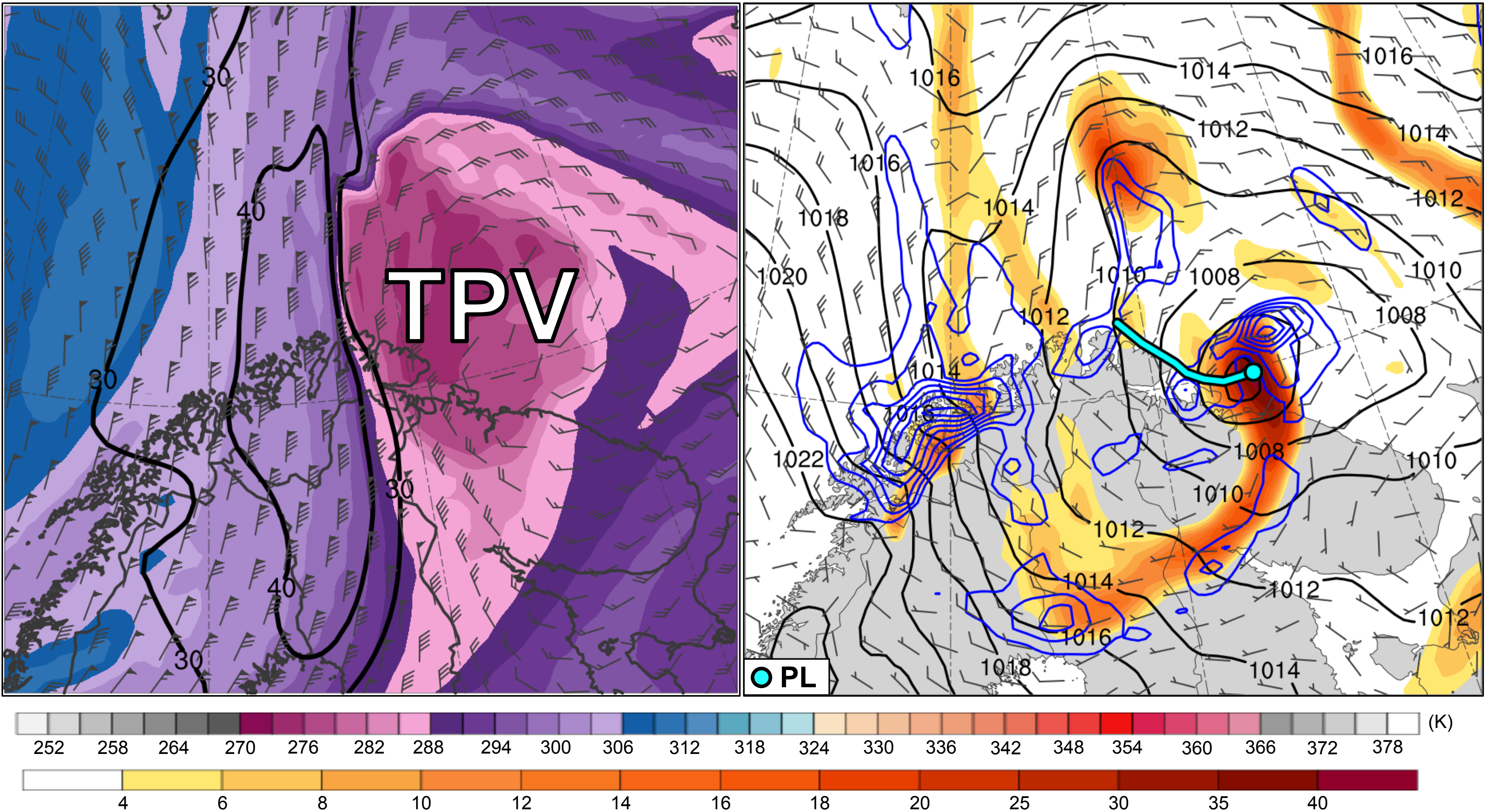
Mesoscale Evolution

0600 UTC 11 Feb 2011



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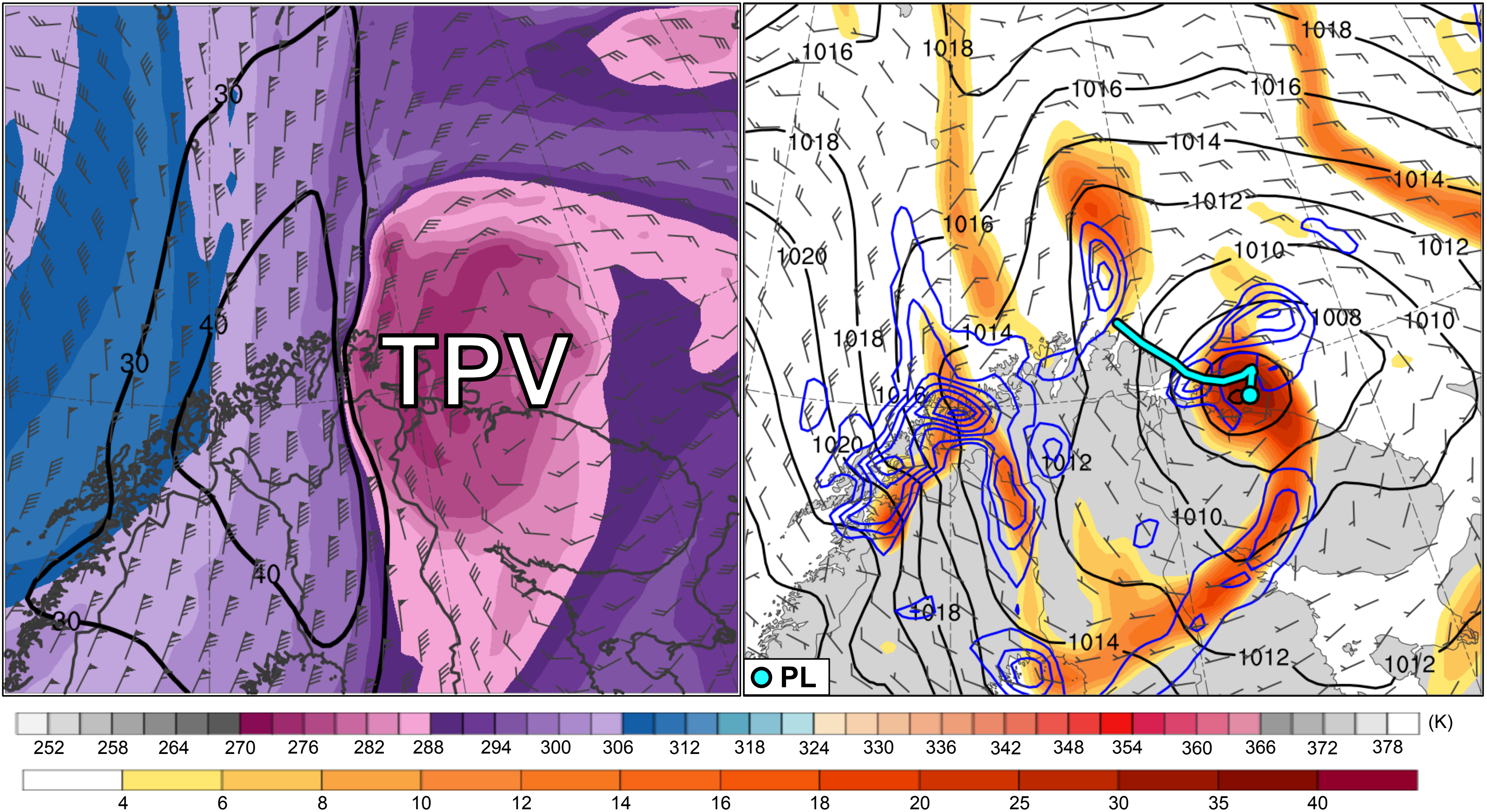
Mesoscale Evolution

0900 UTC 11 Feb 2011



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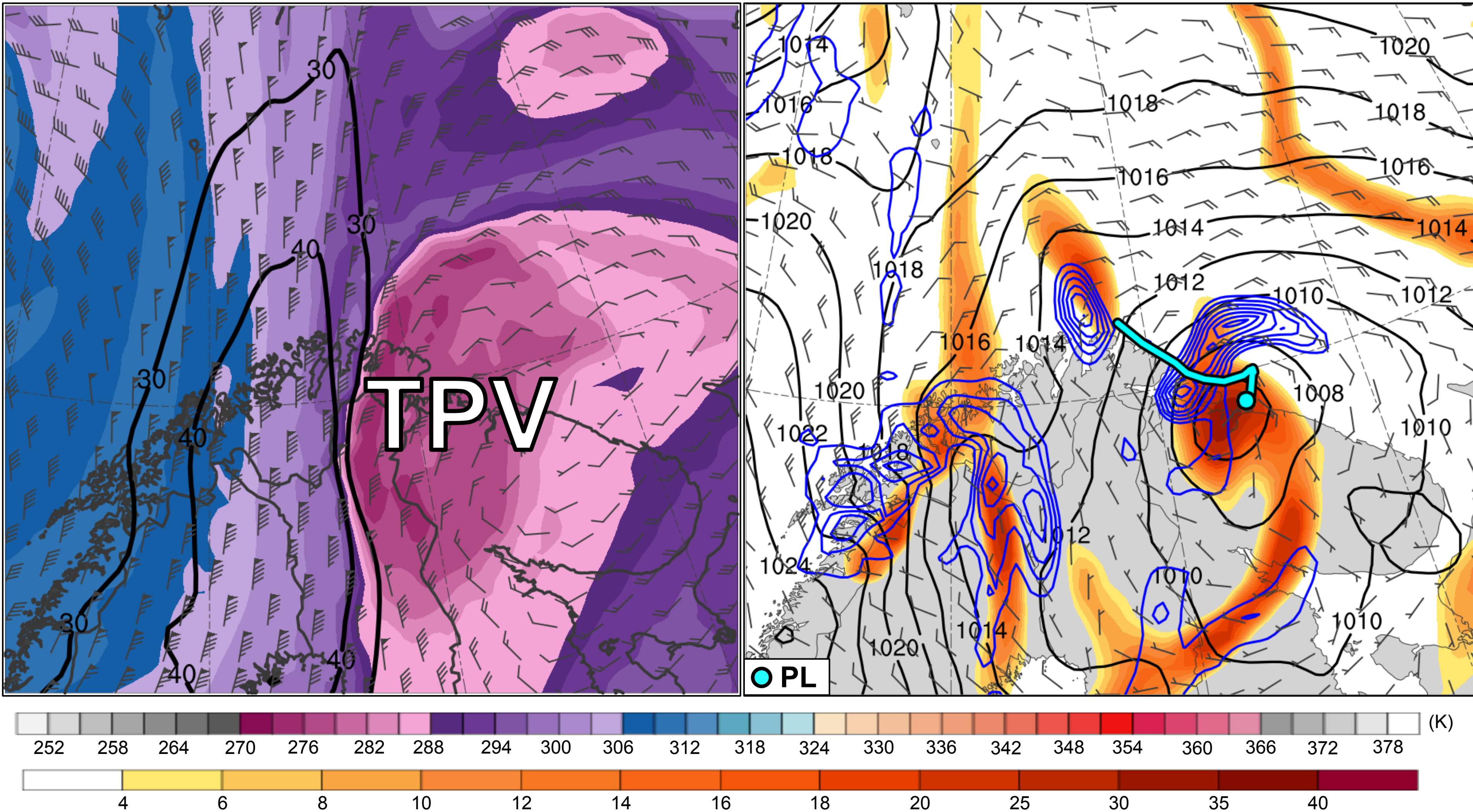
Mesoscale Evolution

1200 UTC 11 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)

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 play an important role in supporting

  - the relatively strong lower-to-midtropospheric ascent associated with the polar low

  - the intensification of the polar low

Outline

- Analyze the evolution of a polar low that is 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
  - 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)

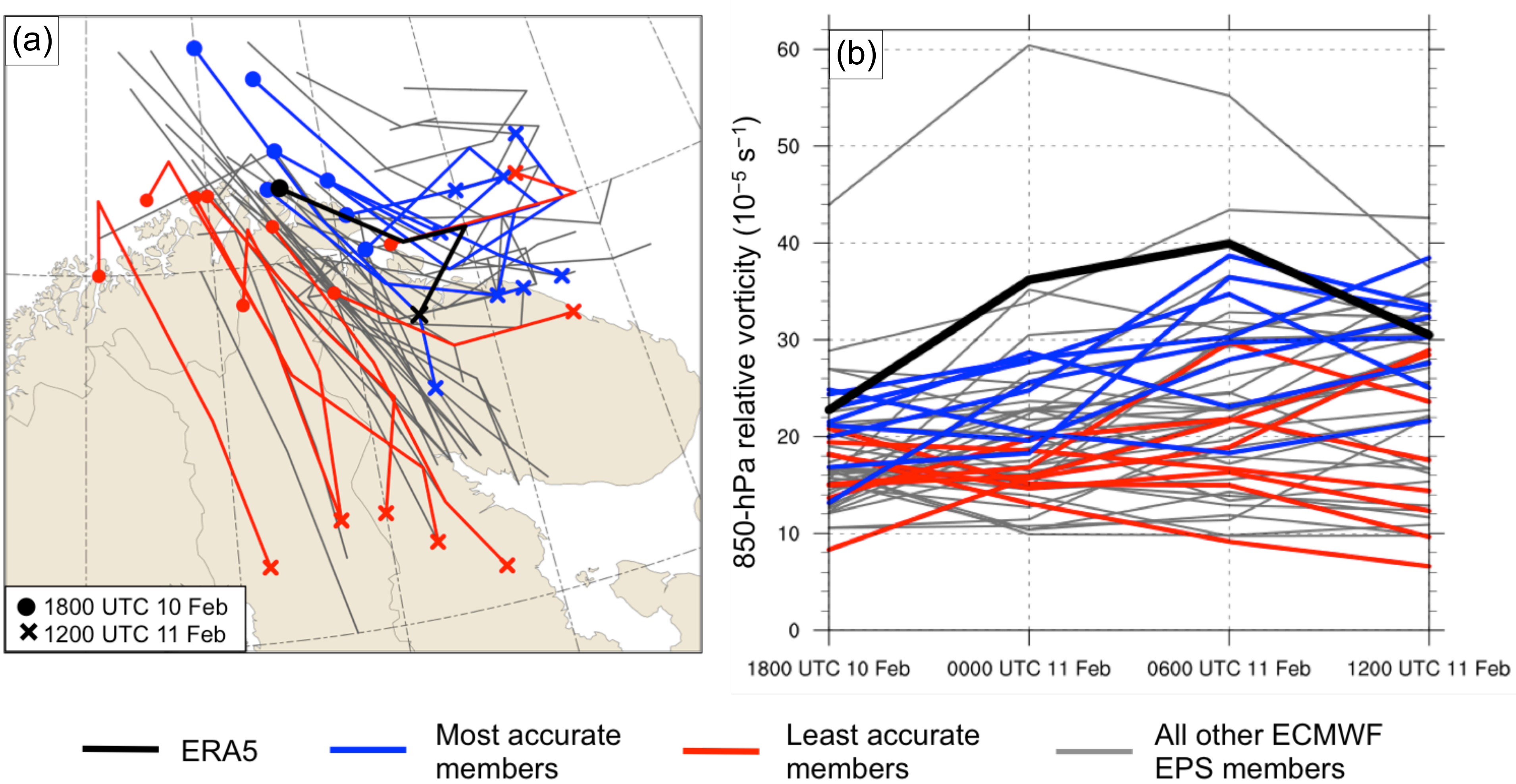
$$\Delta x_i = \frac{\overline{\mathbf{x}}_i^{\,most\ accurate} - \overline{\mathbf{x}}_i^{\,least\ accurate}}{\sigma_{x_i}}$$

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

$\overline{\mathbf{x}}_i^{\,least\ accurate}$ = 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 February 2011 for ERA5 (black), most accurate members (blue), least accurate members (red), and all other ECMWF EPS members (gray)

Composite Differences

1800 UTC 10 Feb 2011 (30 h)

Ensemble mean

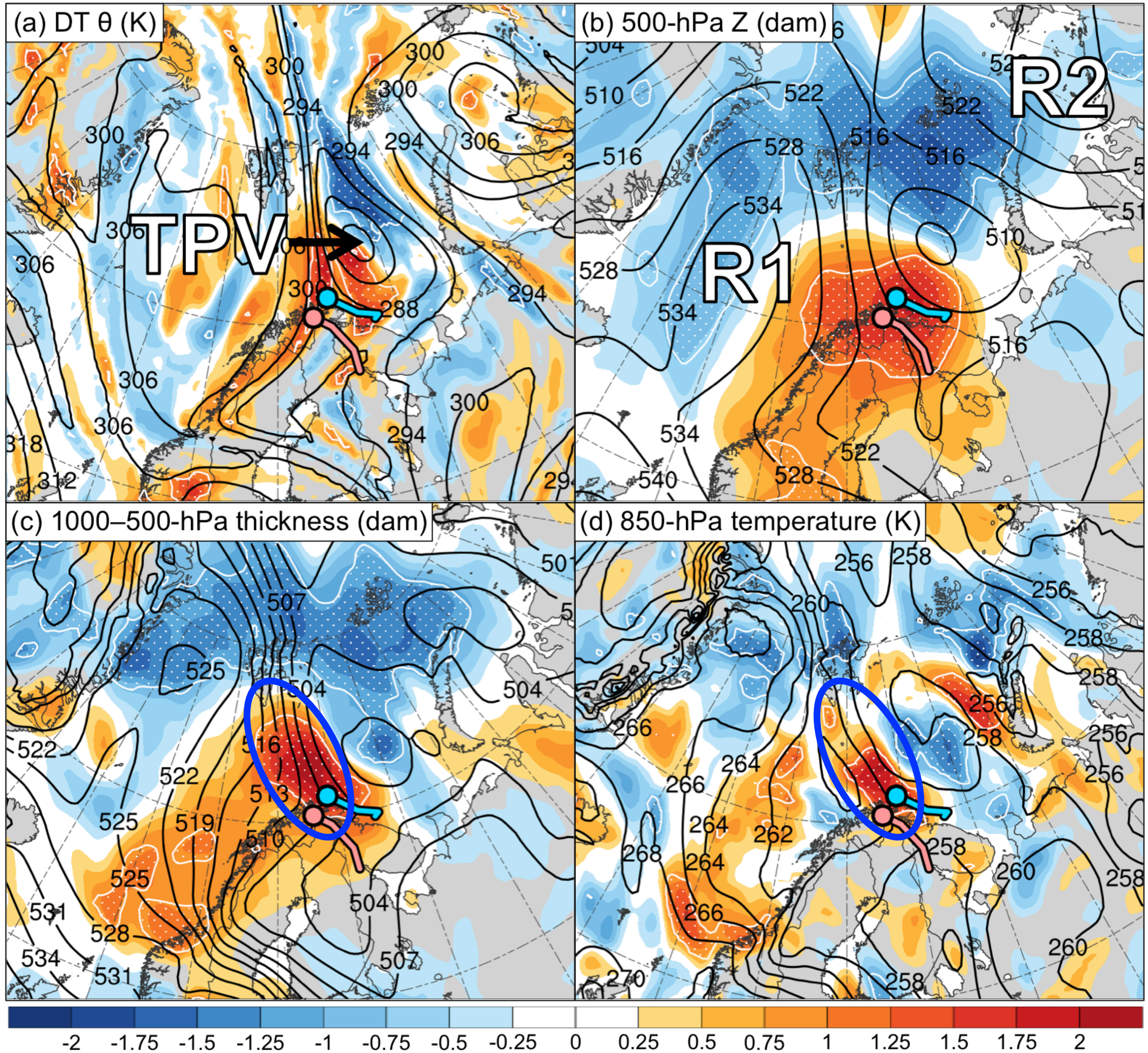
shading: normalized composite differences (most accurate minus least accurate; units: standardized anomaly)

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*

*Corresponding line shows mean track of PL from 1800 UTC 10 to 1200 UTC 11 Feb 2011



Summary

- Composite differences between the most accurate and least accurate groups suggest that the TPV is positioned farther northward and the tropospheric-deep baroclinic zone farther eastward in the most accurate group
  - The differences in position of the TPV and baroclinic zone likely contribute to the farther northward and eastward track of the polar low in the most accurate group
- The more conducive thermodynamic environment for polar low development in the most accurate group may contribute to the polar low being stronger in the most accurate group

Conclusions

- The results of this study show that
  - The interaction between a TPV and a tropospheric-deep baroclinic zone is shown to play an important role in the evolution of a polar low
  - Forecast differences in the positions of the TPV and the baroclinic zone are shown to contribute to significant forecast differences in the track and intensity of the polar low

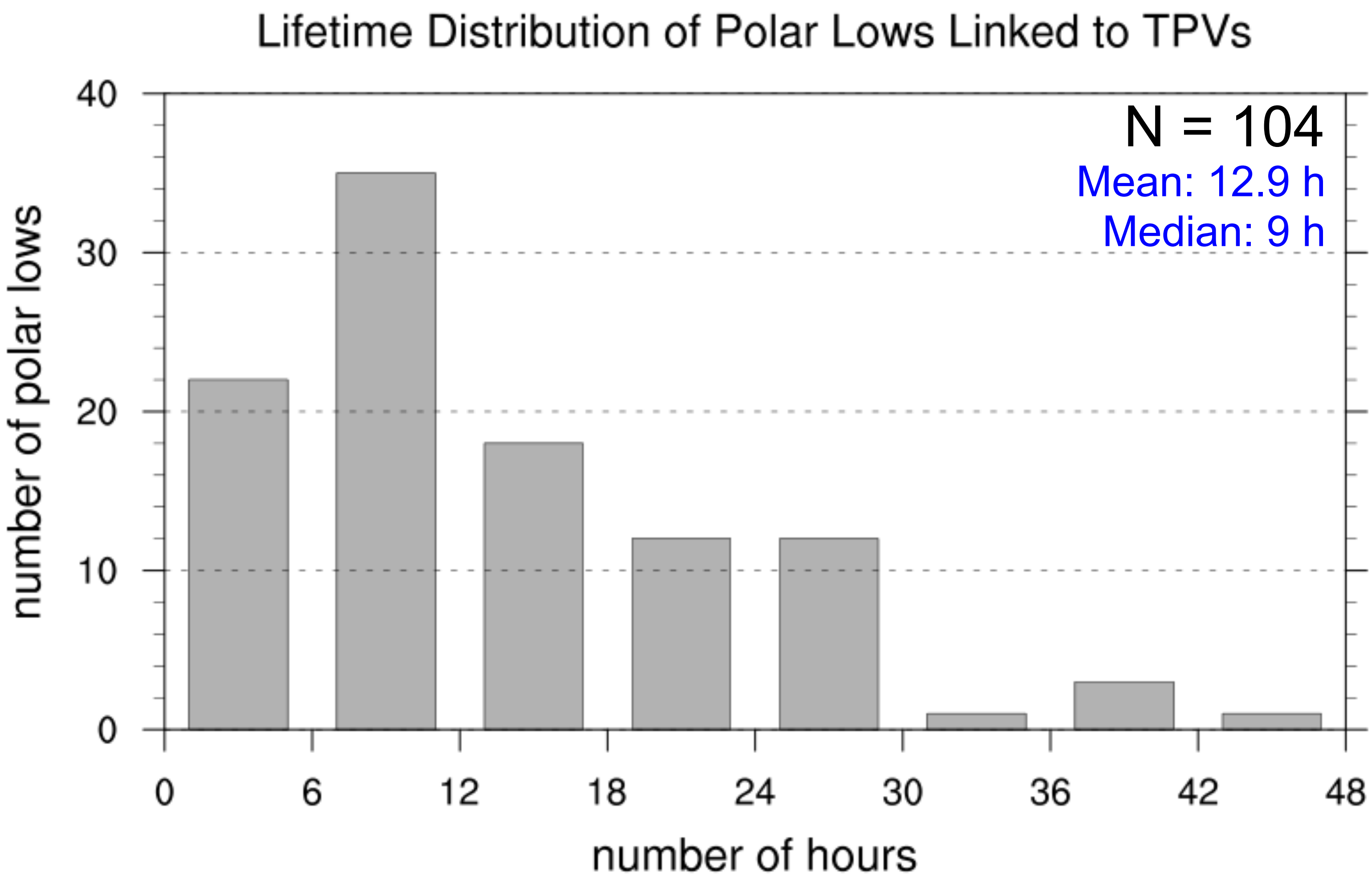
Questions? *Email: kbiernat@albany.edu*

- The results of this study show that
  - The interaction between a TPV and a tropospheric-deep baroclinic zone is shown to play an important role in the evolution of a polar low
  - Forecast differences in the positions of the TPV and the baroclinic zone are shown to contribute to significant forecast differences in the track and intensity of the polar low

Acknowledgments
Jeremy Berman

Supplementary Figures

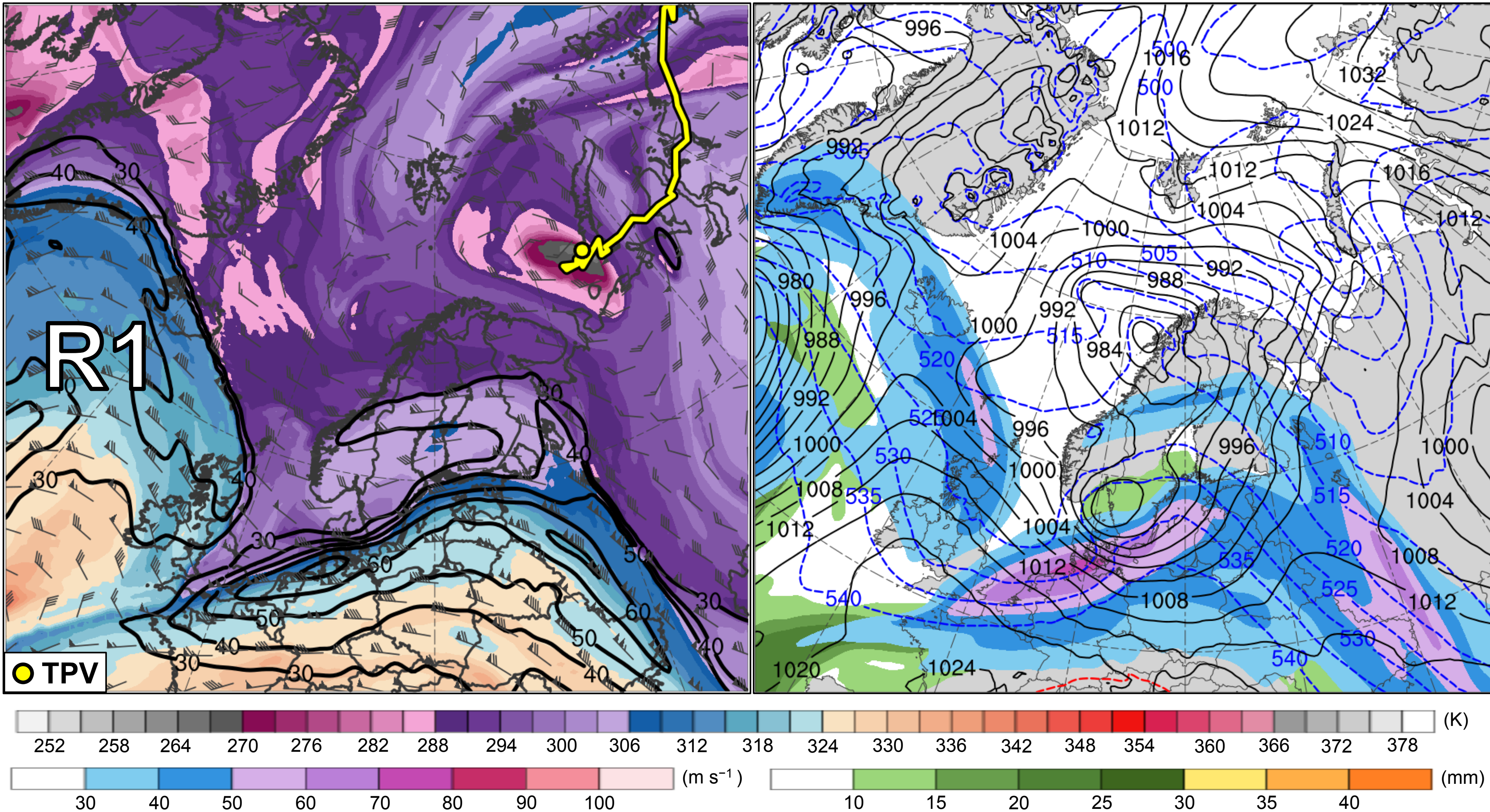
Climatology of Polar Lows Linked to TPVs



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

Synoptic Evolution

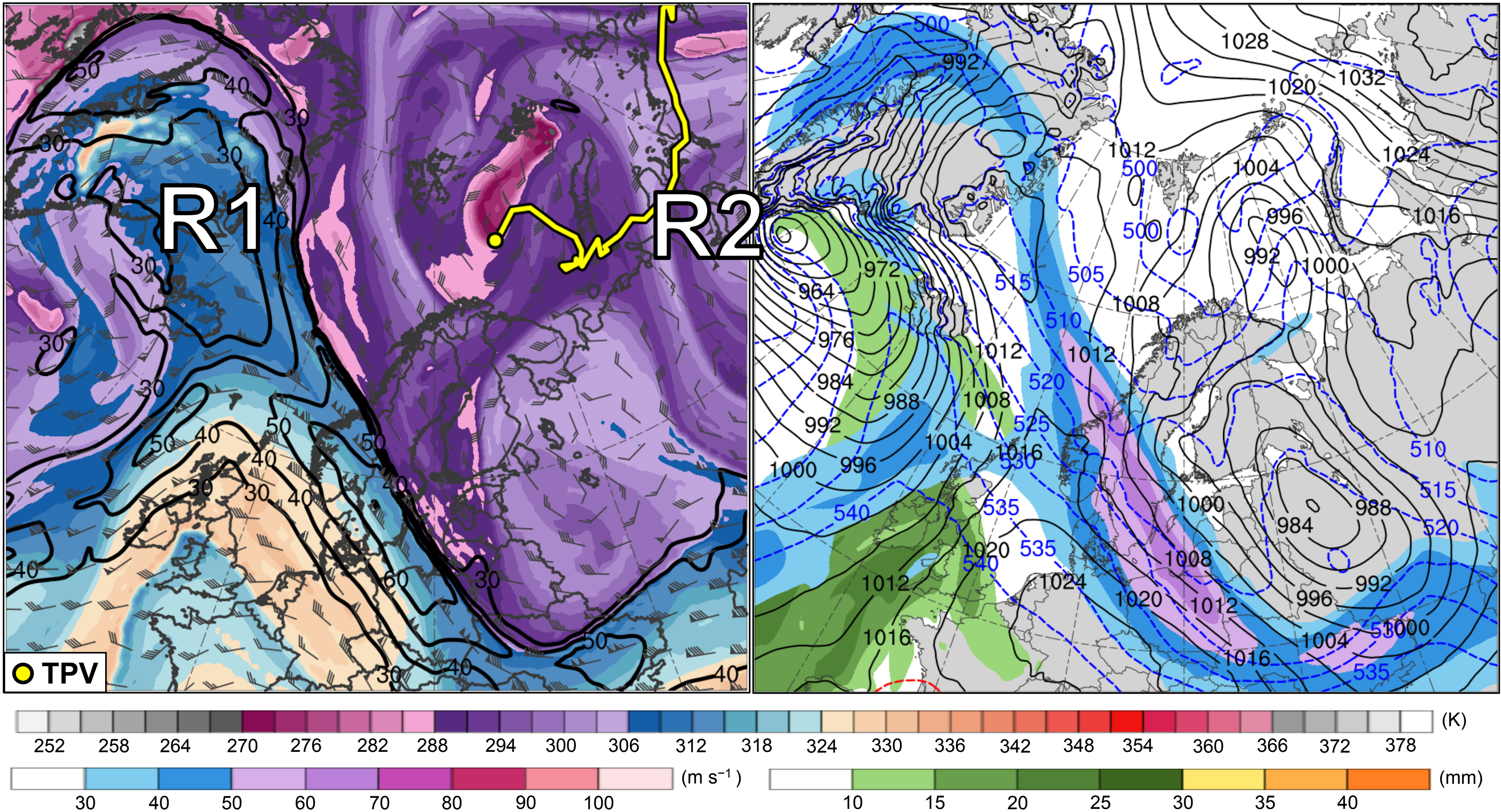
0000 UTC 8 Feb 2011



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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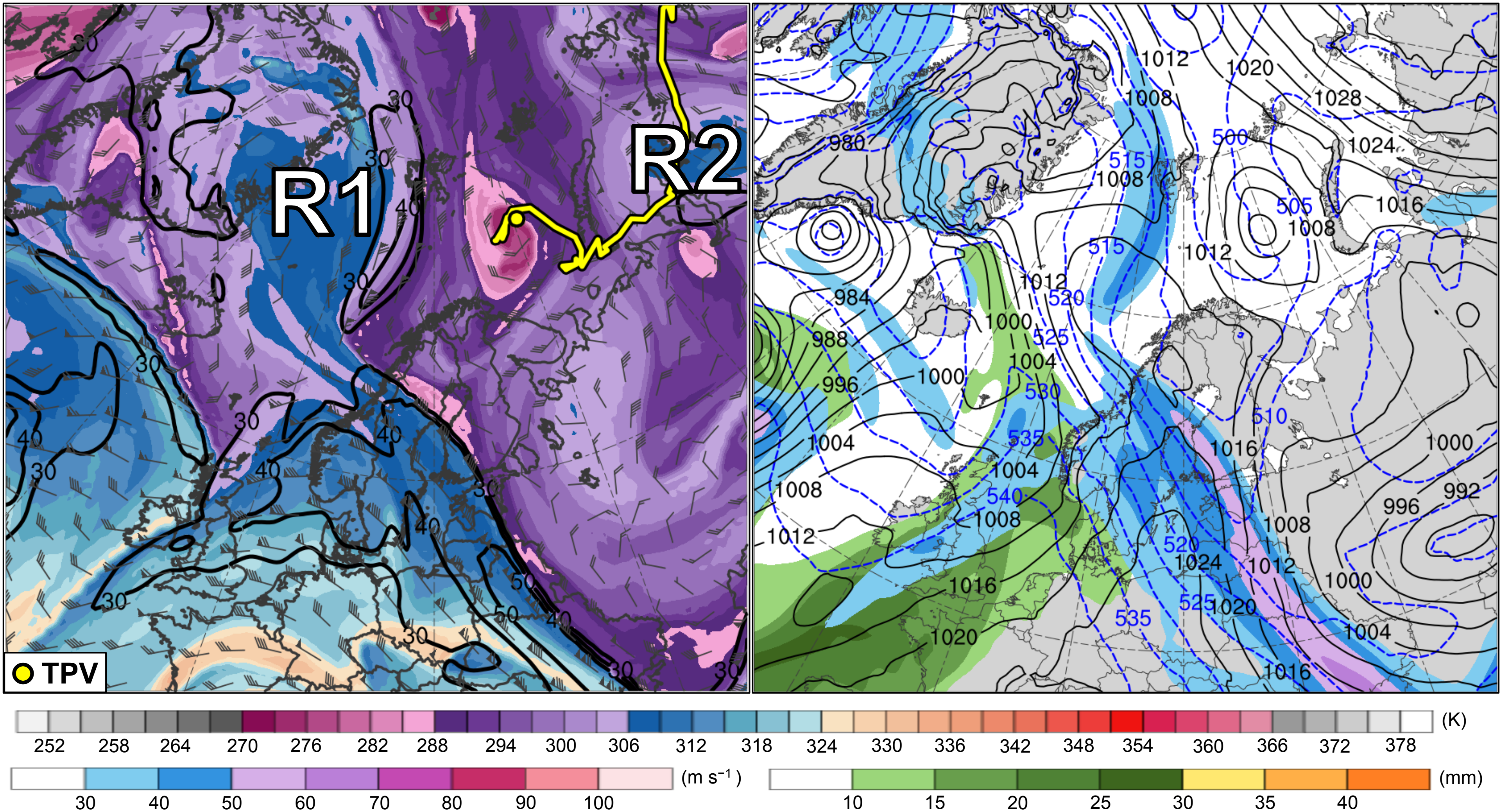
Synoptic Evolution

0000 UTC 10 Feb 2011



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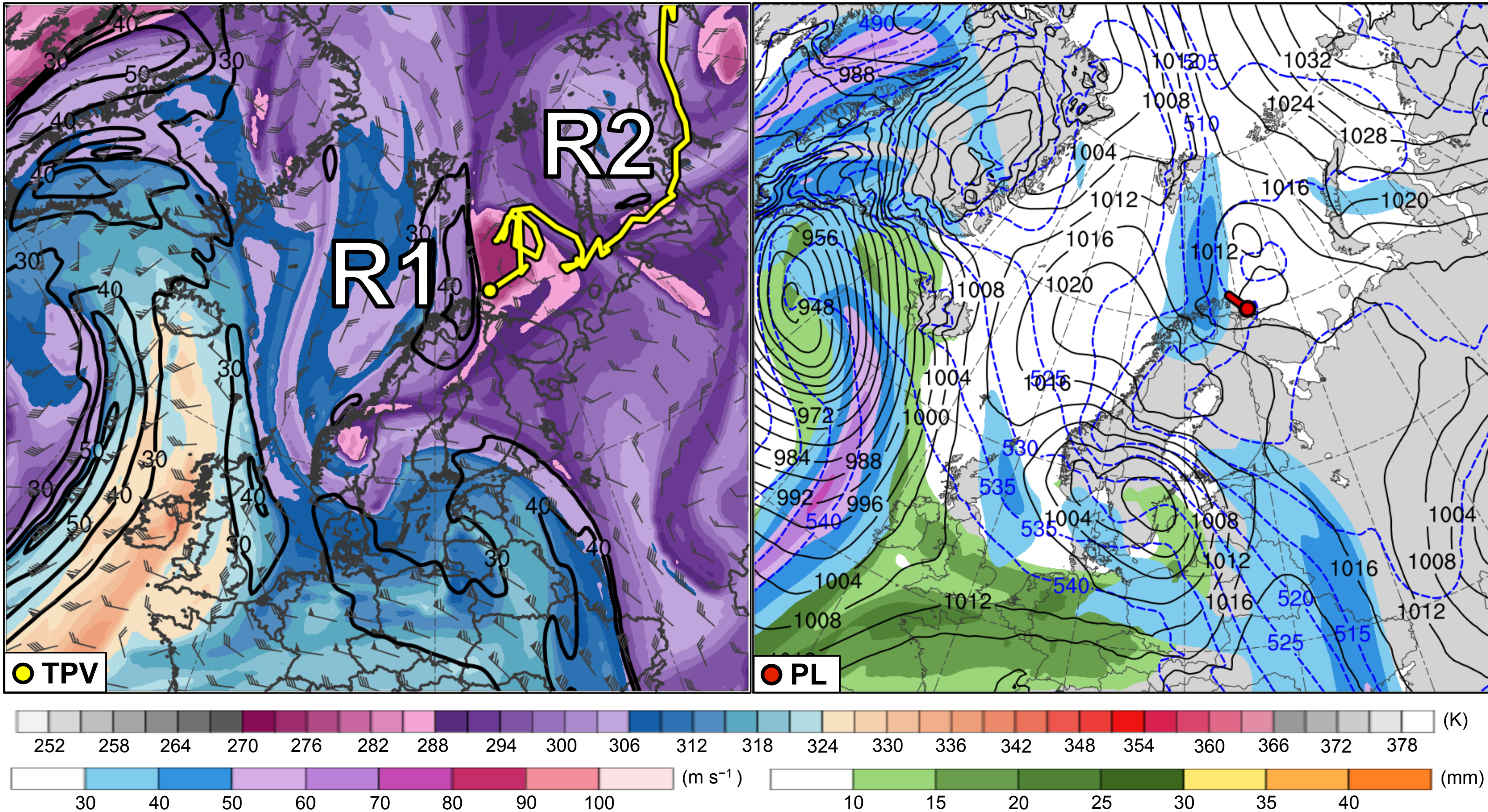
Synoptic Evolution

0000 UTC 11 Feb 2011



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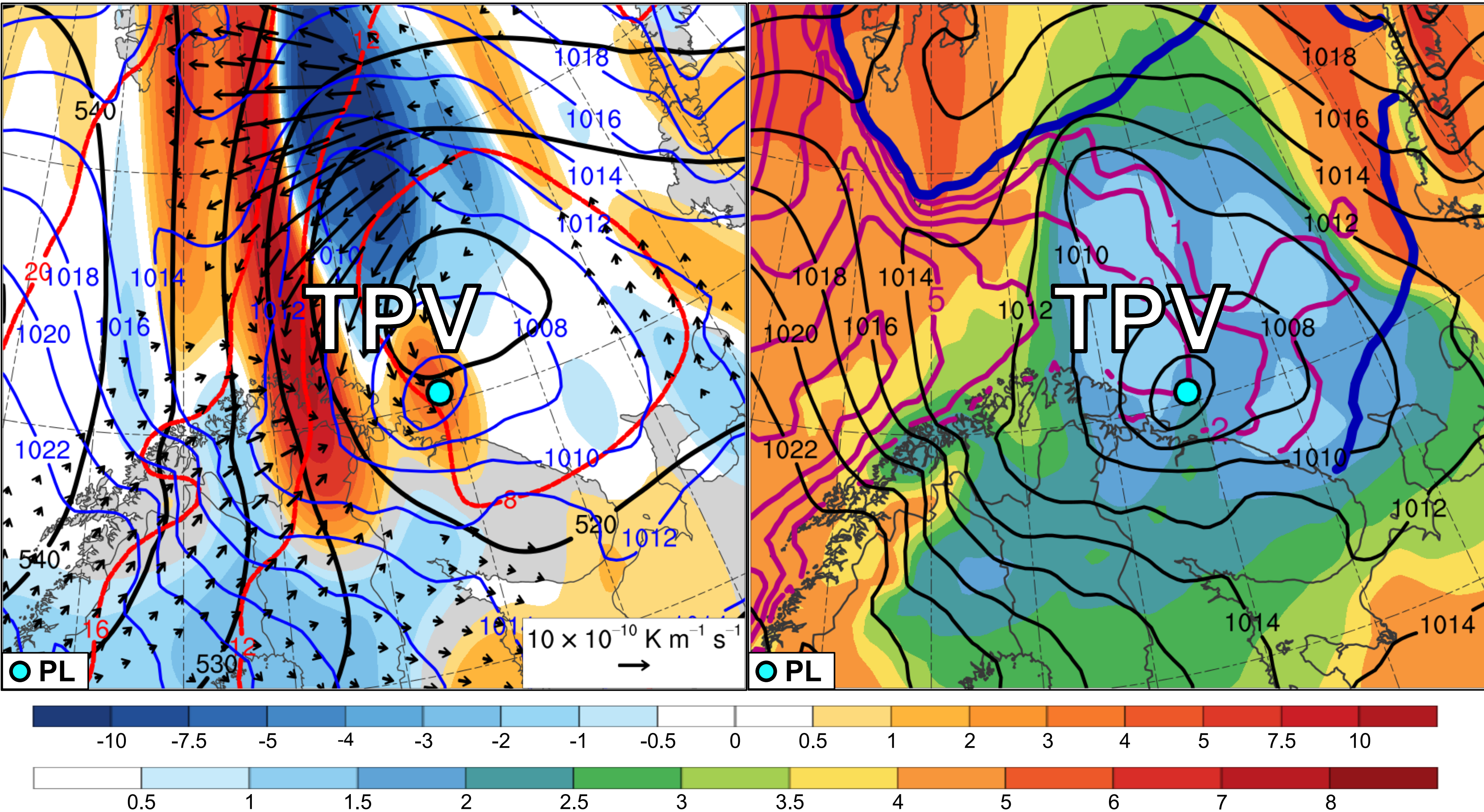
Favorable Conditions

0300 UTC 11 Feb 2011

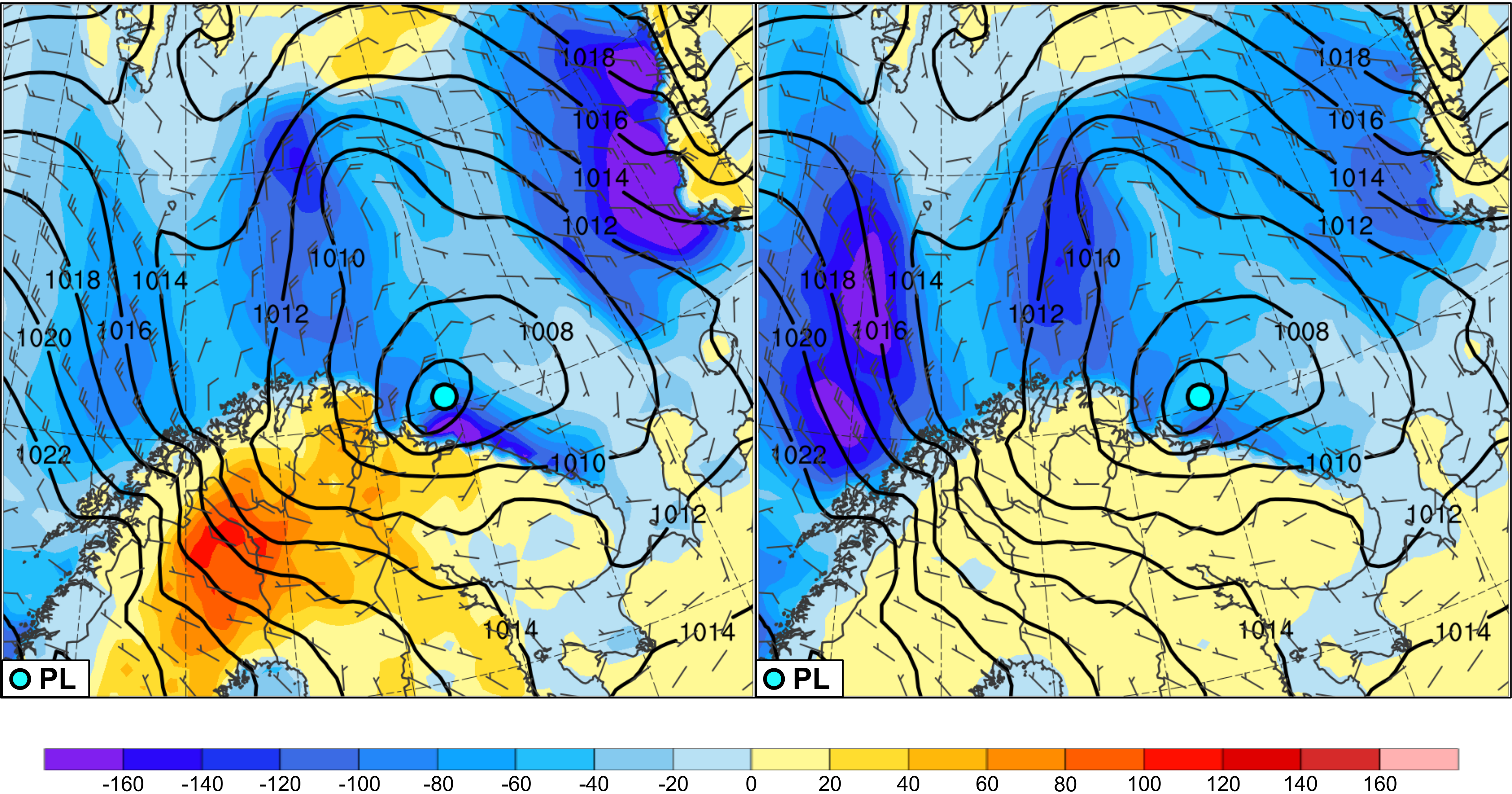


SLP (hPa, blue); 600–400-hPa **Q** (K m^{-1} s^{-1}, vectors), **Q** forcing for vertical motion (10^{-17} Pa^{-1} s^{-3}, shaded), θ (°C, red), and geopotential height (dam, black)

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

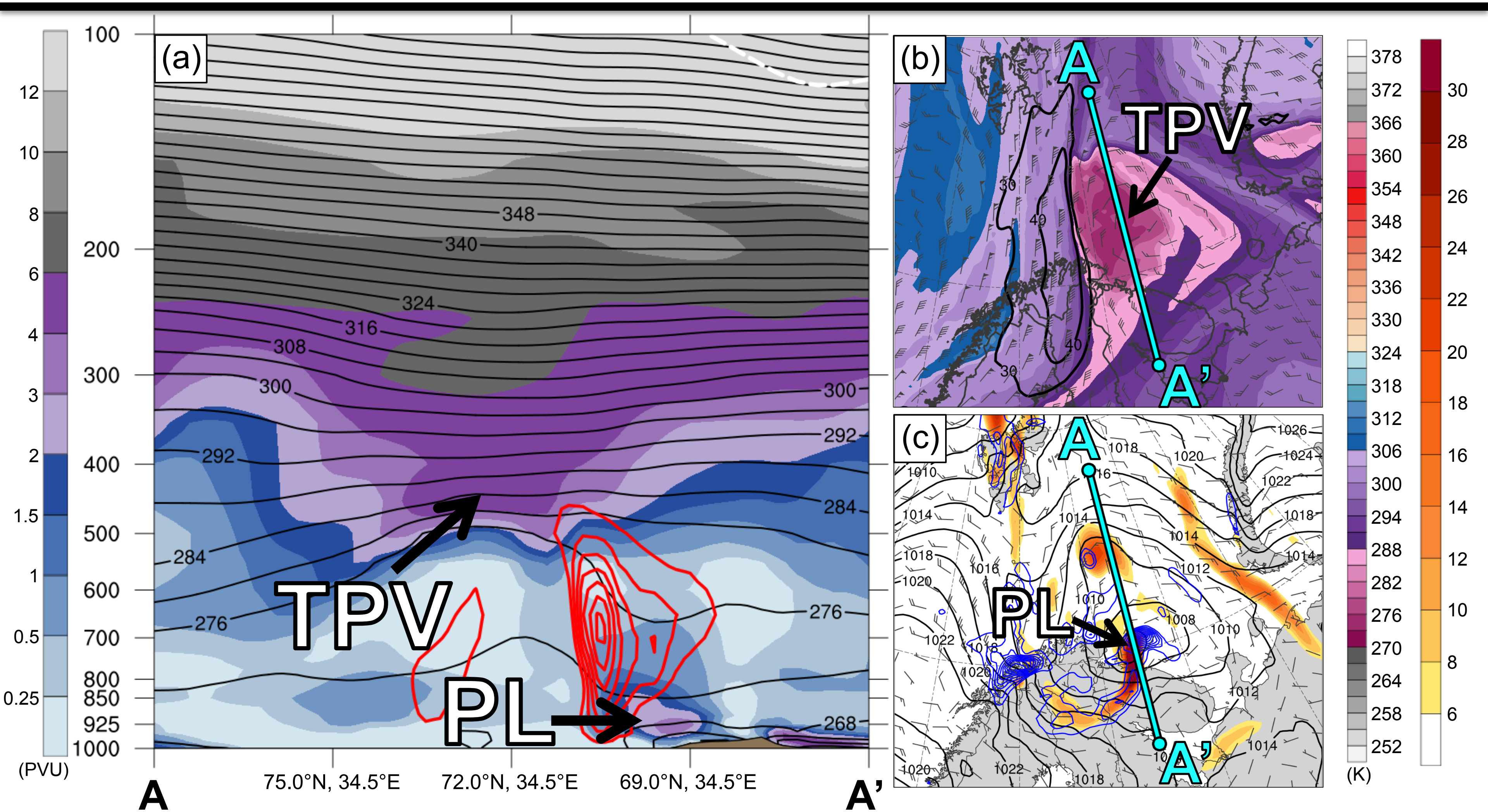
0300 UTC 11 Feb 2011



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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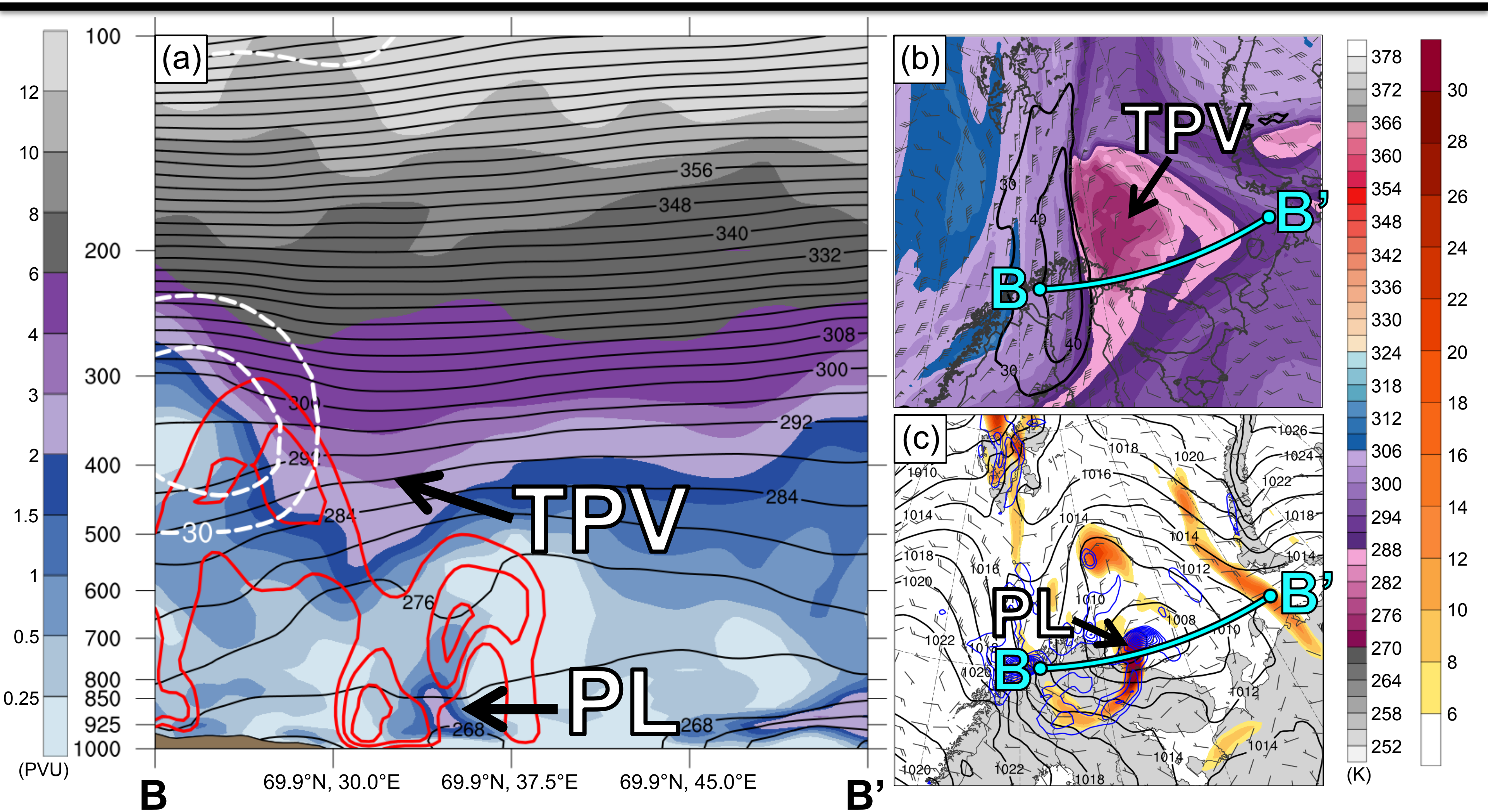

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Most Accurate Members

Track error rank, intensity error rank, and combined track and intensity error rank for the eight ensemble members in the most accurate group.

Member	Track error rank	Intensity error rank	Combined track and intensity error rank
15	1	2	3
16	5	3	8
41	8	8	16
6	10	7	17
39	16	9	25
1	15	12	27
8	17	10	27
3	2	27	29

Least Accurate Members

Track error rank, intensity error rank, and combined track and intensity error rank for the eight ensemble members in the least accurate group.

Member	Track error rank	Intensity error rank	Combined track and intensity error rank
45	39	32	71
47	30	42	72
9	45	28	73
36	49	24	73
42	38	37	75
5	51	34	85
48	44	43	87
20	46	51	97

Significant Differences

Values of selected quantities for 1800 UTC 10 February–1200 UTC 11 February 2011 time period for ERA5, most accurate group, and least accurate group. The difference between the means of the most accurate and least accurate group for each quantity are shown as well, with confidence levels for the significance of the difference between the means of the most accurate and least accurate group for each quantity based on a two-sided Student's *t* test given in parentheses.

Quantity	ERA5	Most accurate	Least accurate	Difference (confidence level)
Mean Latitude (°N)	70.0	70.2 ± 0.3	68.8 ± 0.7	+1.4 (99.9%)
Mean Longitude (°E)	32.0	33.6 ± 1.7	29.5 ± 4.6	+4.1 (96.0%)
Maximum 850-hPa ζ (10^{-5} s^{-1})	39.9	33.1 ± 4.9	23.2 ± 5.0	+9.9 (99.8%)
Minimum SLP (hPa)	1004.0	1003.6 ± 2.6	1009.1 ± 3.4	−5.5 (99.7%)