Linkages Between Tropopause Polar Vortices and the Great Arctic Cyclone of August 2012

Daniel Keyser, Kevin A. Biernat, and Lance F. Bosart

Department of Atmospheric and Environmental Sciences

University at Albany, SUNY

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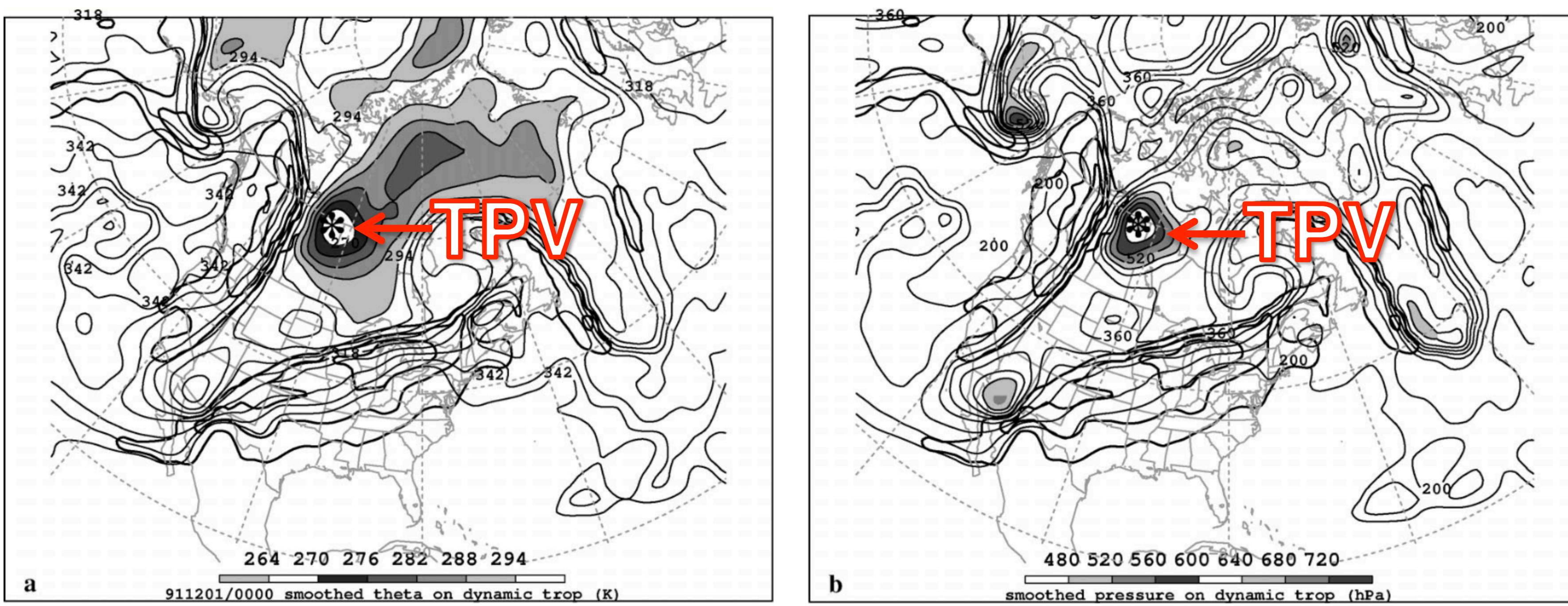
What are Tropopause Polar Vortices (TPVs)?

- 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).

Motivation

- TPVs may interact with and strengthen jet streams, and act as precursors to the development of intense Arctic cyclones (e.g., Simmonds and Rudeva 2012, 2014)

- Arctic cyclones may be associated with strong surface winds and poleward advection of warm, moist air, contributing to reductions in Arctic sea-ice extent (e.g., Zhang et al. 2013)

- Heavy precipitation, strong surface winds, and large waves due to Arctic cyclones may pose hazards to ships moving through open passageways in the Arctic Ocean

The Great Arctic Cyclone of August 2012 (AC12)

- AC12 formed over Siberia on 2 August 2012 and tracked northeastward into the Arctic, reaching a minimum central sea level pressure (SLP) of 966.4 hPa at 1800 UTC 6 August in the CFSR (Simmonds and Rudeva 2012)

- AC12 led to reductions in Arctic sea-ice extent during a time in which sea ice was thin and sea-ice volume was well below normal (Zhang et al. 2013)

- Strong surface winds associated with AC12 helped to break up the thin sea ice (e.g., Parkinson and Comiso 2013)

The Great Arctic Cyclone of August 2012 (AC12)

- According to Zhang et al. (2013), sea-ice volume decreased twice as fast as normal during AC12 due to melting of the bottom and perimeter of ice floes

- Simmonds and Rudeva (2012) and Yamazaki et al. (2015) found that a TPV played an important role in the life cycle of AC12

Outline

- Identification and synoptic examination of three TPVs, a predecessor surface cyclone, and AC12

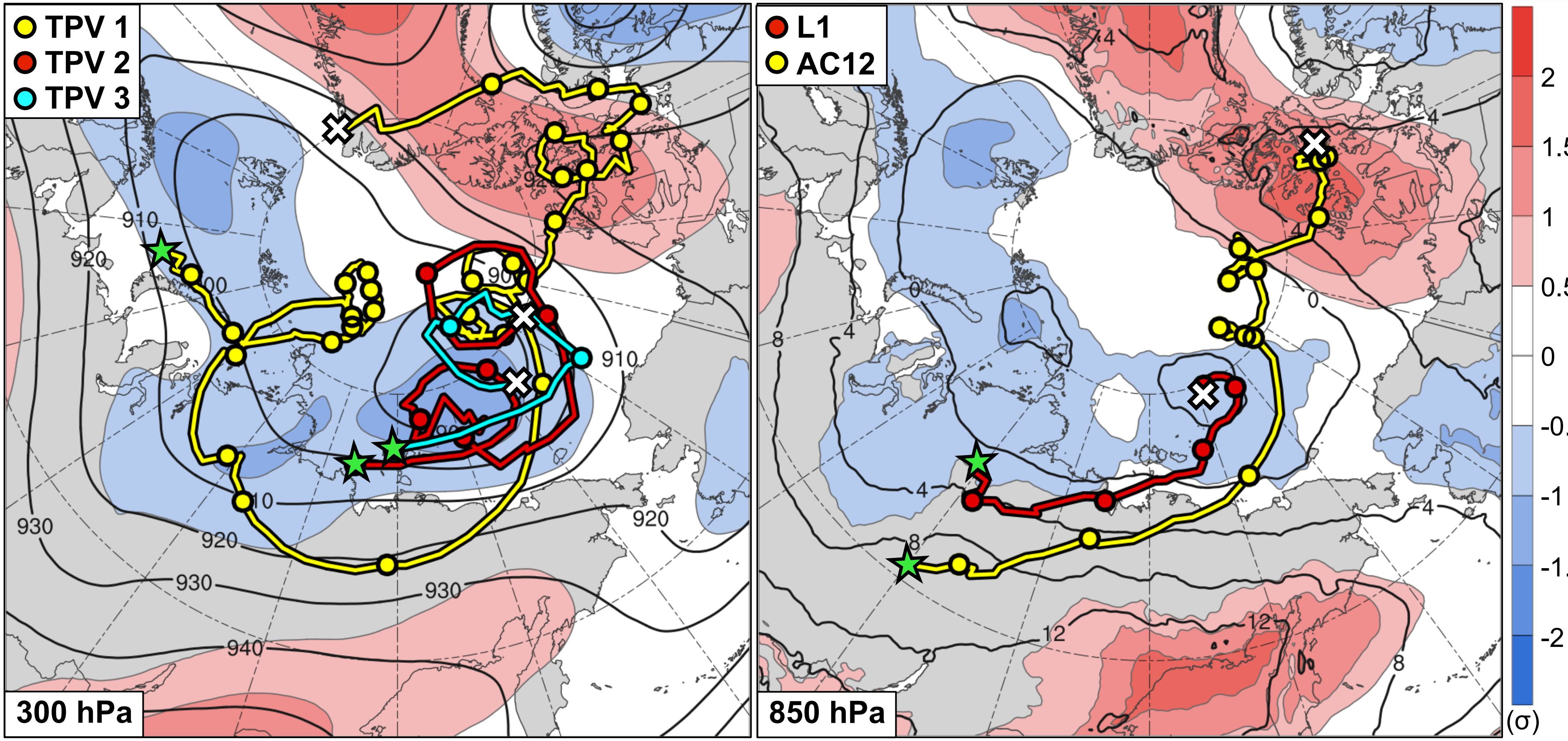
- Impact of AC12 on Arctic sea-ice extent

Data and Methods

- Data:
  - 0.3° ERA5 (Hersbach and Dee 2016)
- Utilized TPV tracking algorithm developed by Nicholas Szapiro and Steven Cavallo to identify and track TPVs of interest for AC12
- Manually tracked the predecessor surface cyclone and AC12 by following the locations of minimum SLP

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

TPV and Surface Cyclone Tracks



Feature	Genesis	Lysis	Lifetime
TPV 1	23 July	19 Aug	~27 d
TPV 2	3 Aug	9 Aug	6 d
TPV 3	4 Aug	6 Aug	~3 d
L1	31 July	5 Aug	~5 d
AC12	2 Aug	15 Aug	~13 d

★ Genesis ✖ Lysis ○ 0000 UTC positions

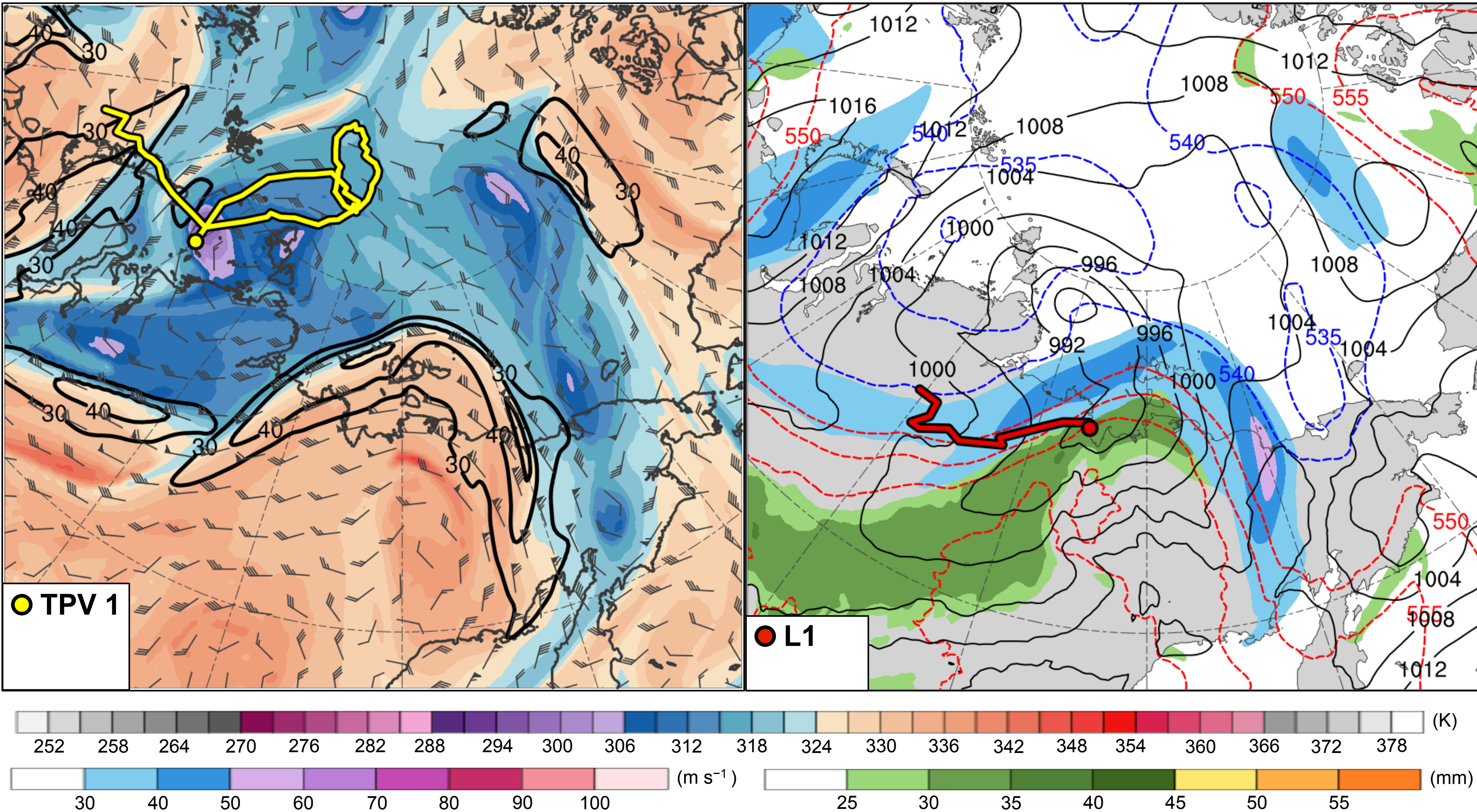
1–7 Aug 2012 time-mean (left) 300-hPa geopotential height (dam, black) and standardized anomaly of 300-hPa geopotential height (σ, shaded); (right) 850-hPa temperature (°C, black) and standardized anomaly of 850-hPa temperature (σ, shaded)

TPV and Surface Cyclone Tracks

- TPV 1 is the longest-lived of the three TPVs and corresponds to the TPV shown in previous studies to play an important role in the evolution of AC12
- TPV 2 and TPV 3 are shorter-lived TPVs that play supporting roles in the evolution of AC12
- L1 is the predecessor cyclone that merges with AC12
- AC12 is the main cyclone of interest and has a lifetime of ~13 days
- TPV 1 and AC12 track in a region of tropospheric-deep baroclinicity over Siberia

Synoptic Evolution

0000 UTC 2 Aug 2012

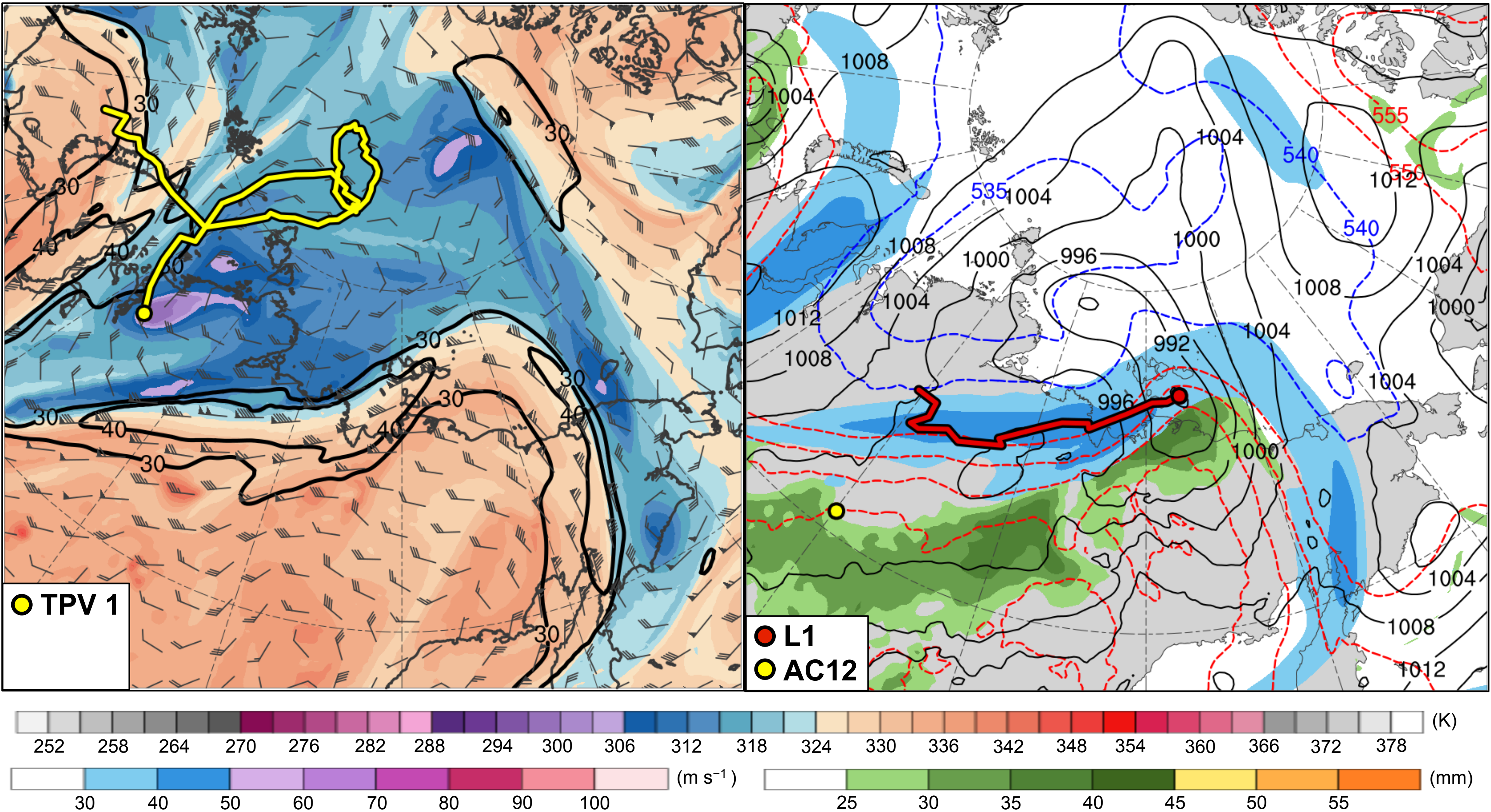


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 30 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Synoptic Evolution

1200 UTC 2 Aug 2012



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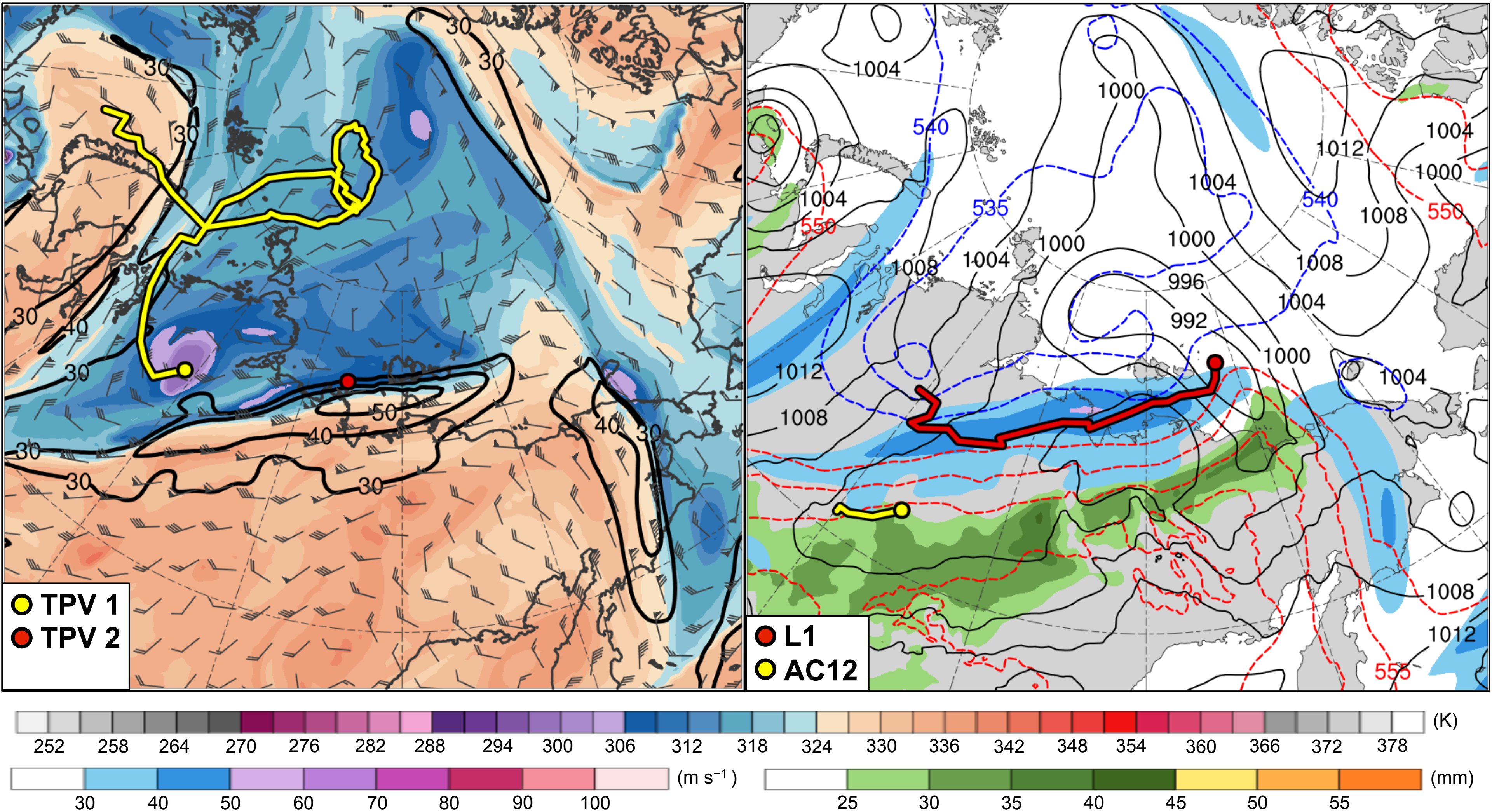
Synoptic Evolution

0000 UTC 3 Aug 2012



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Synoptic Evolution

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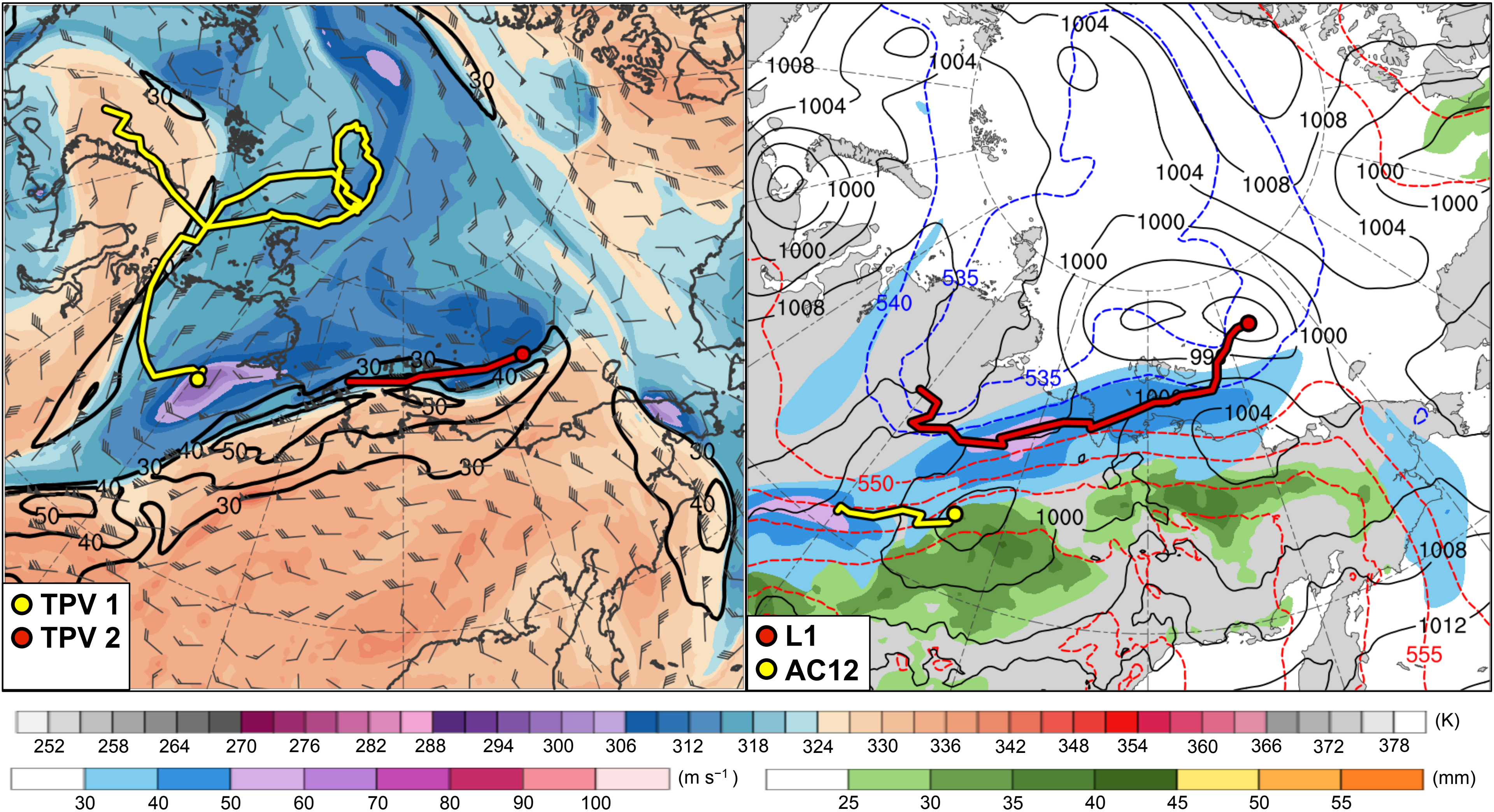

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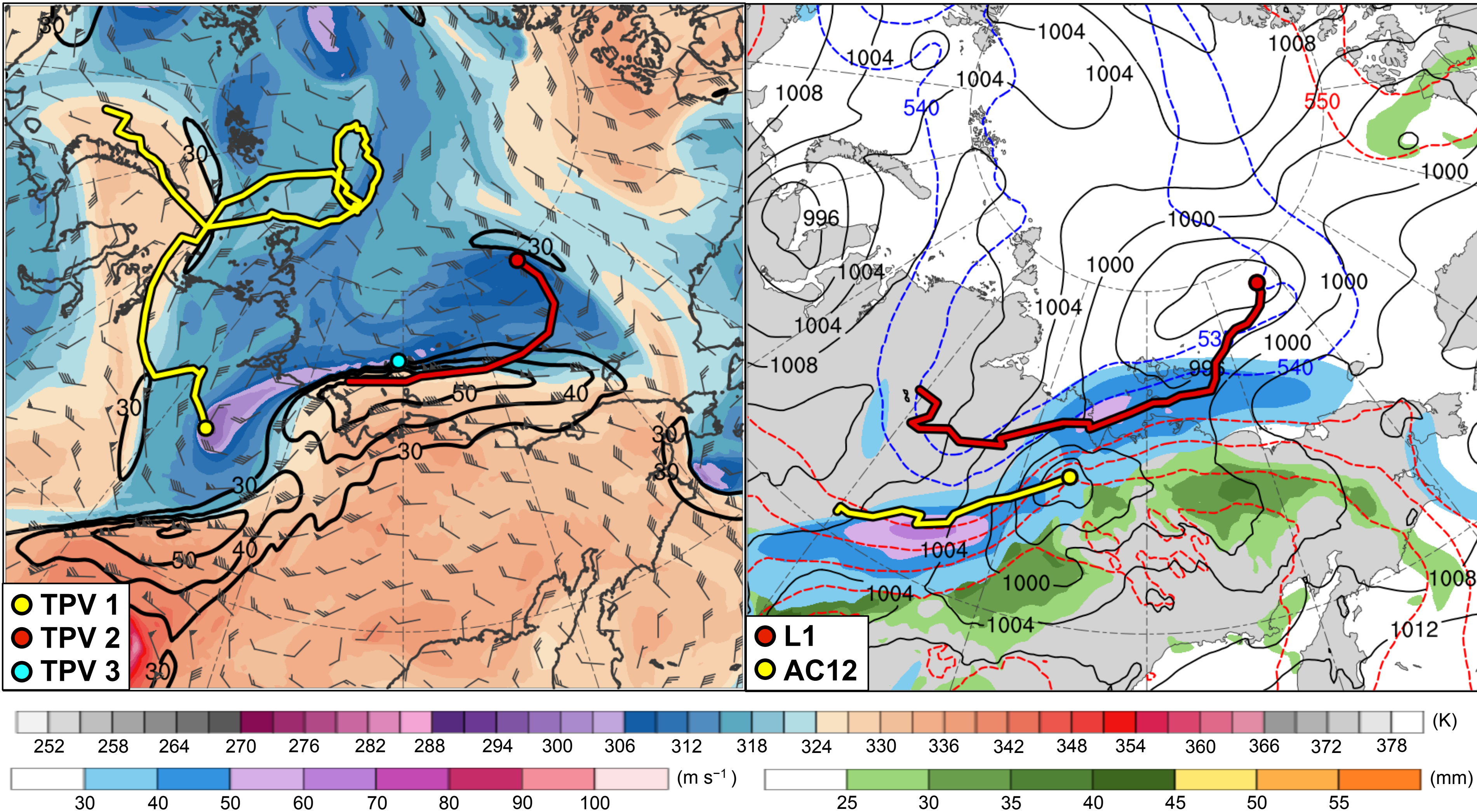
Synoptic Evolution

0000 UTC 4 Aug 2012



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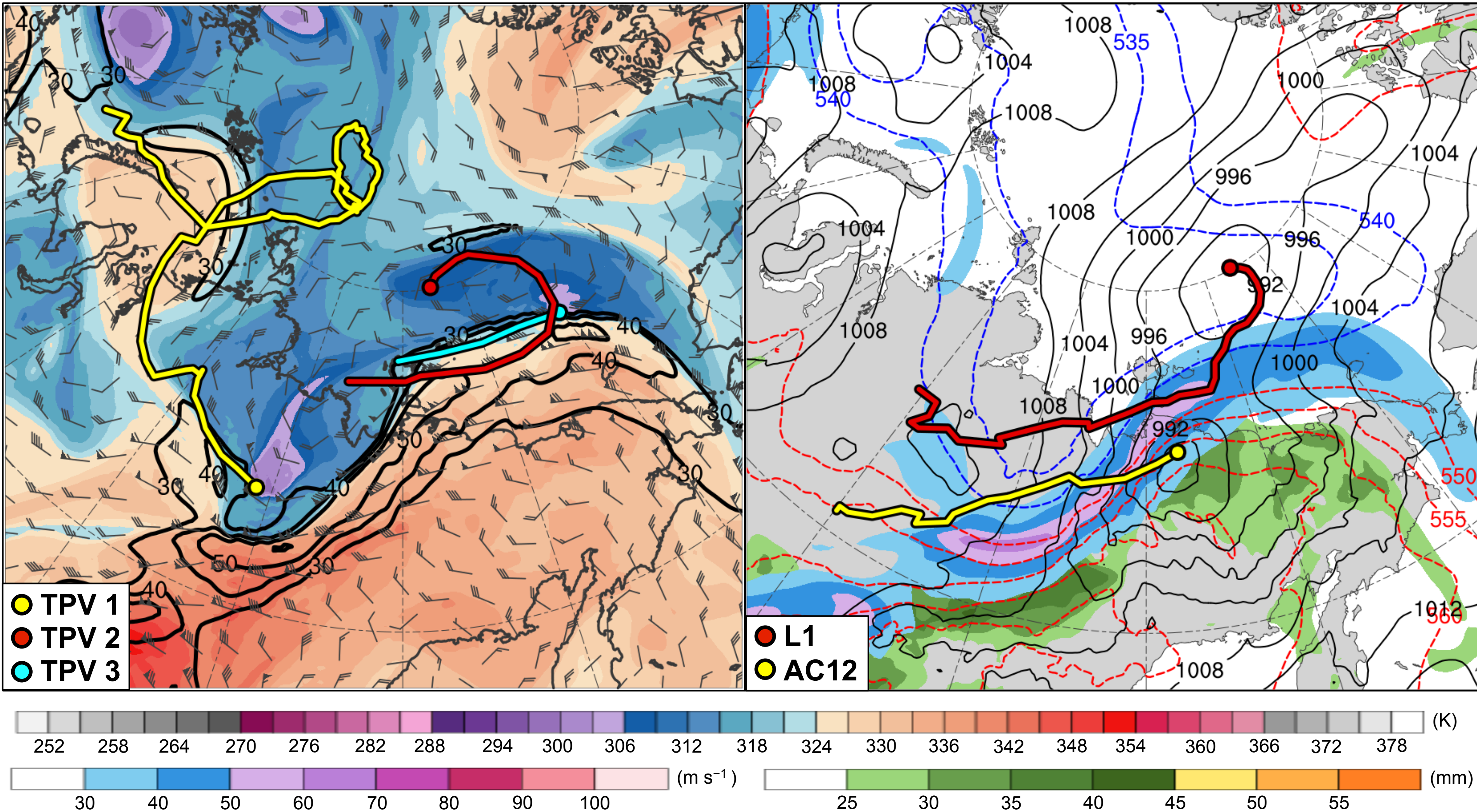

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Synoptic Evolution

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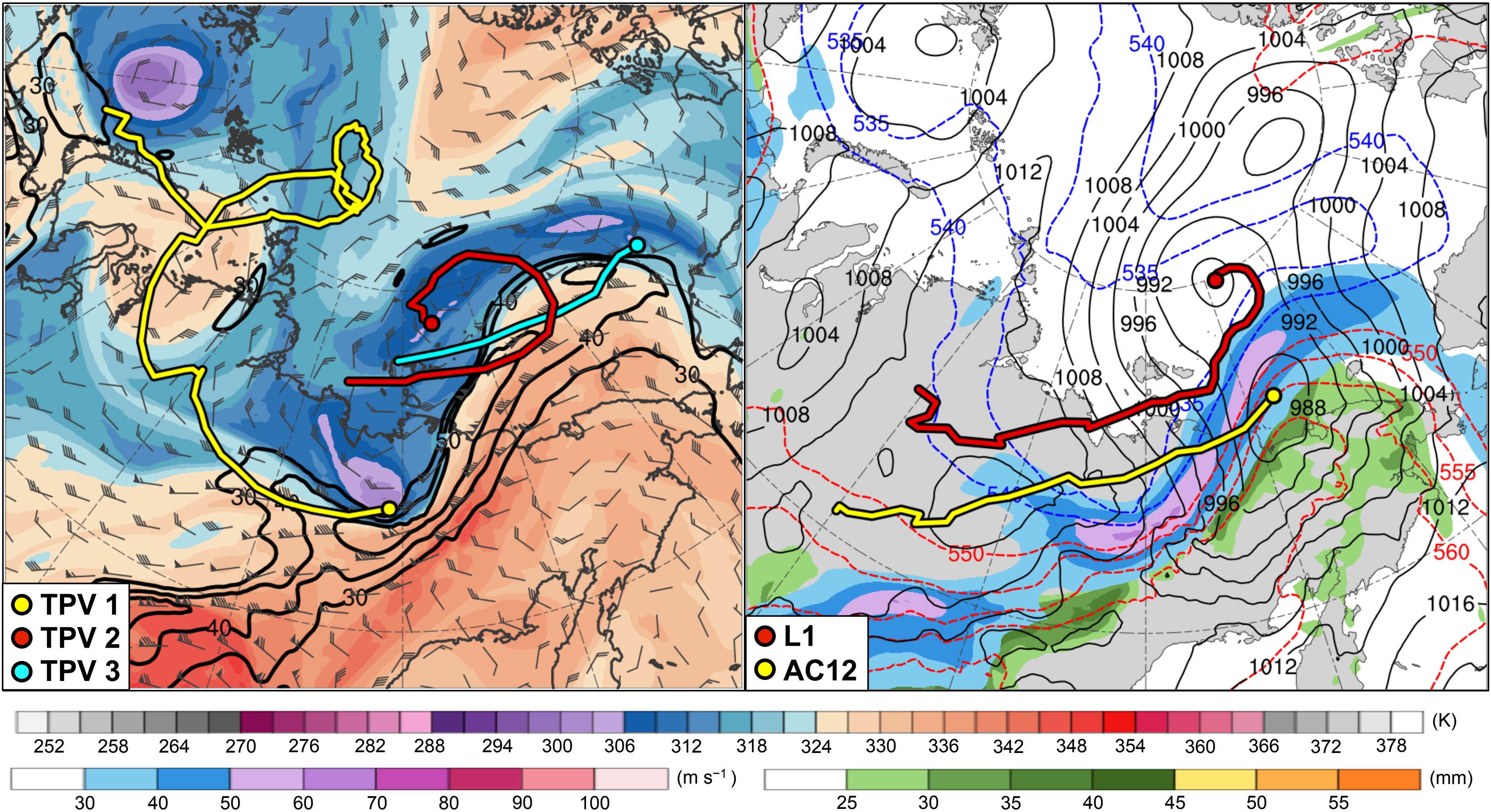

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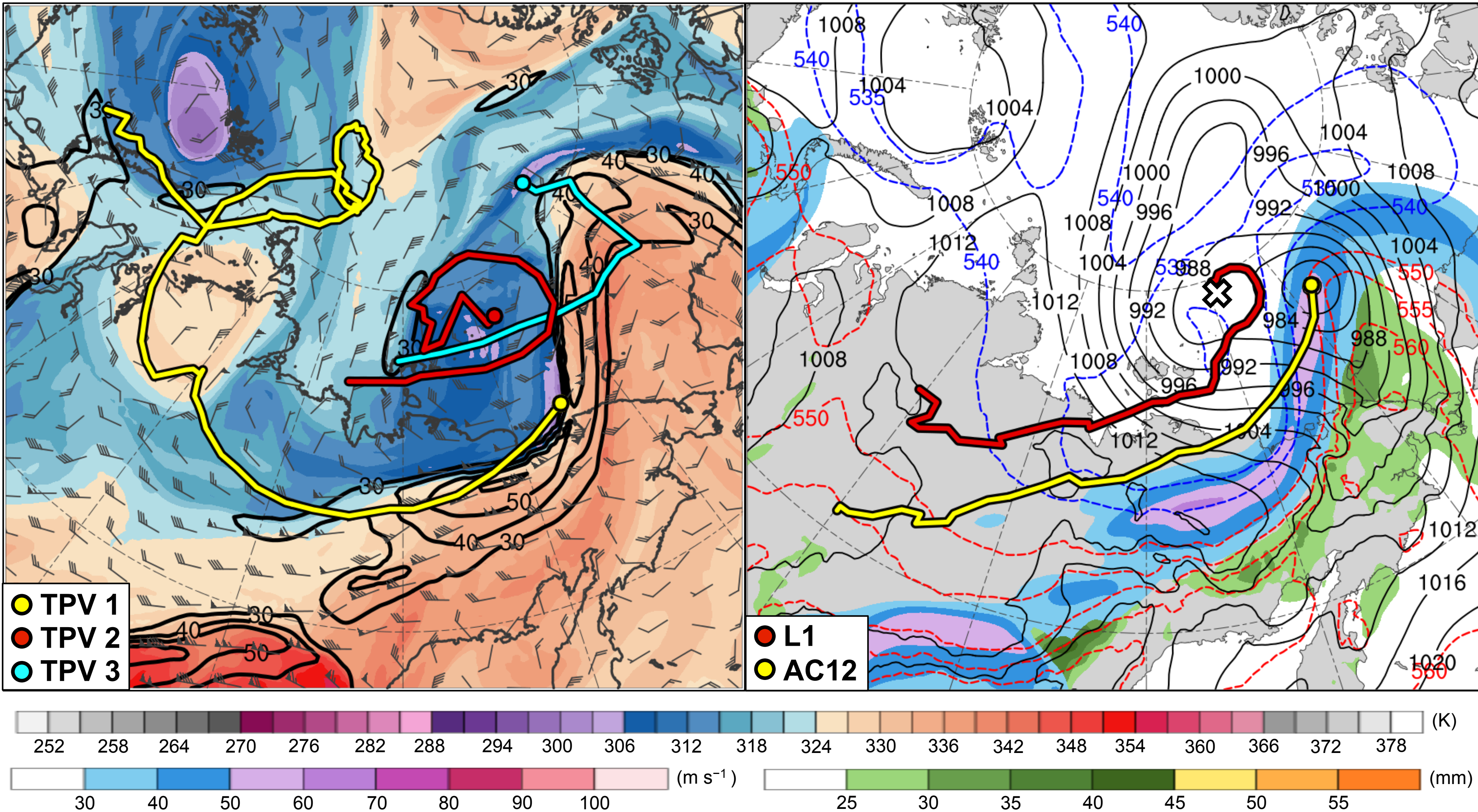

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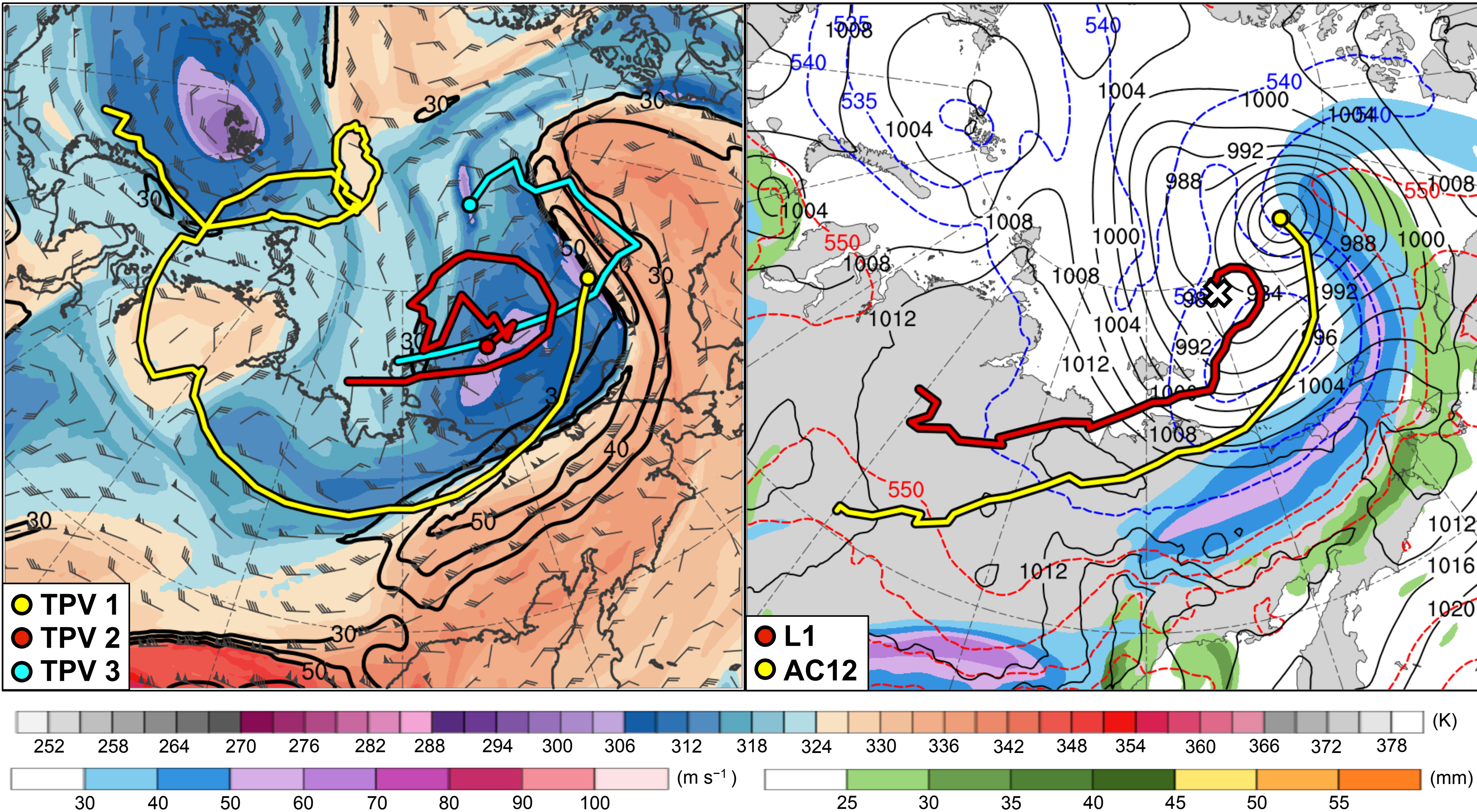

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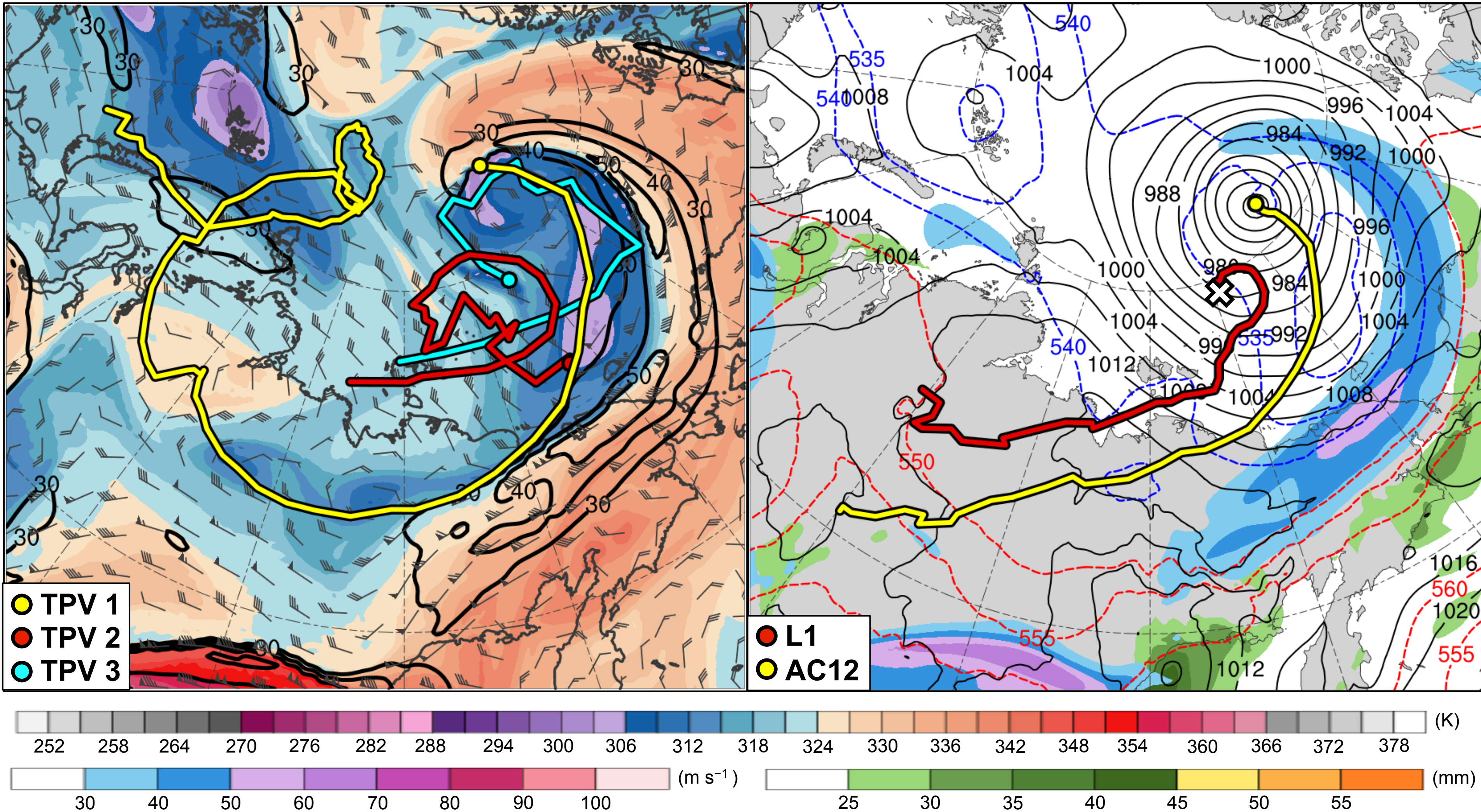

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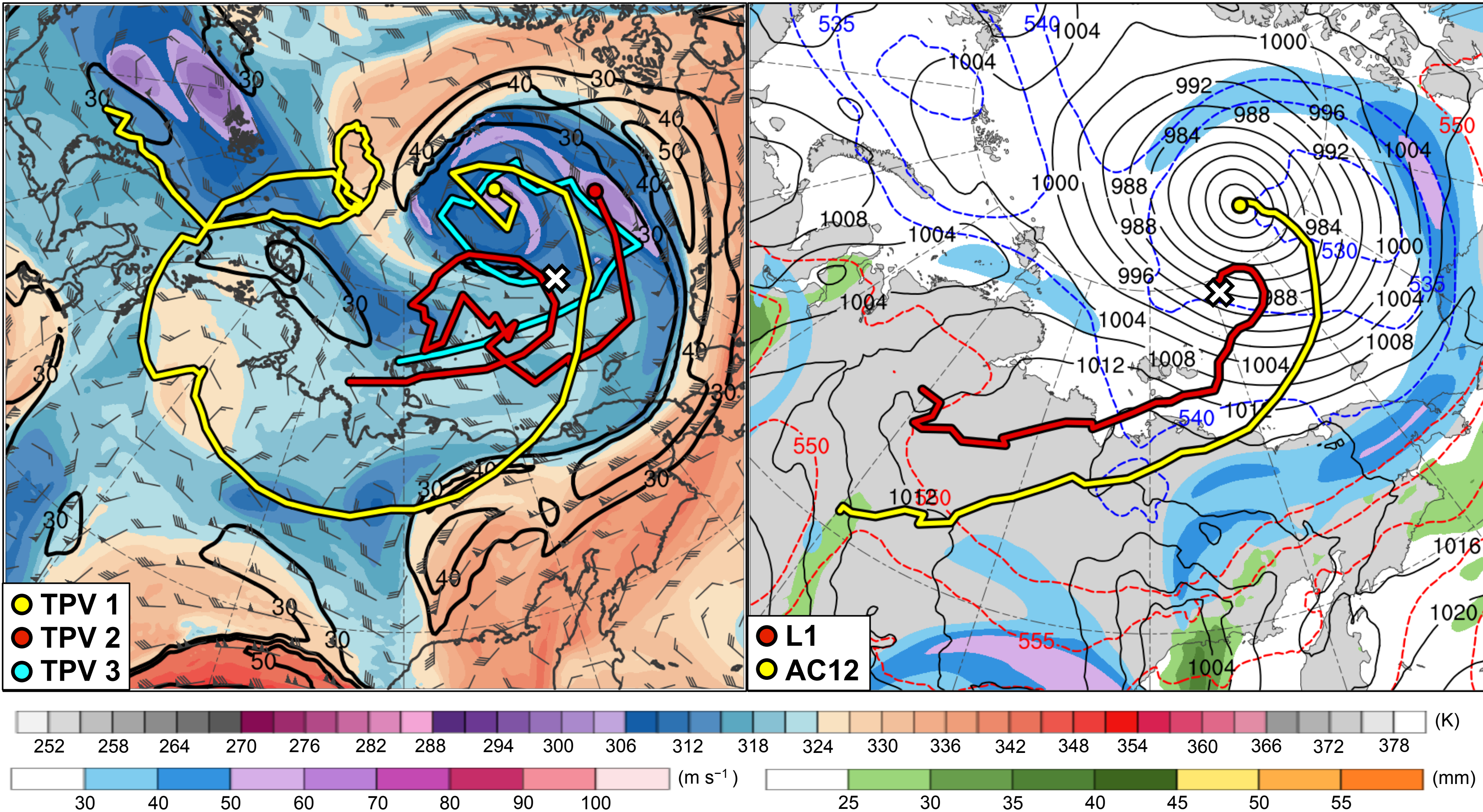
Synoptic Evolution

0000 UTC 7 Aug 2012



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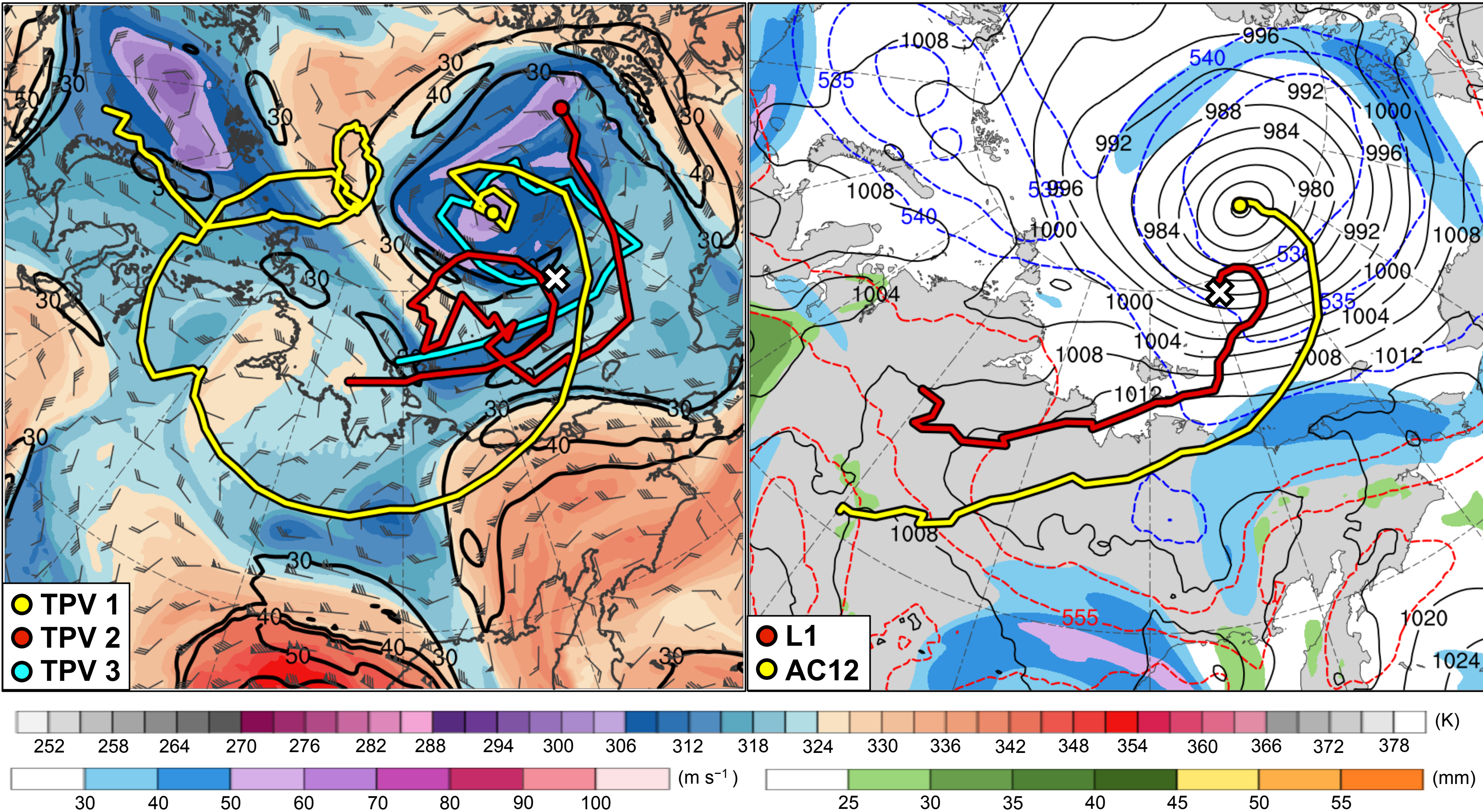
Synoptic Evolution

1200 UTC 7 Aug 2012



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Synoptic Evolution

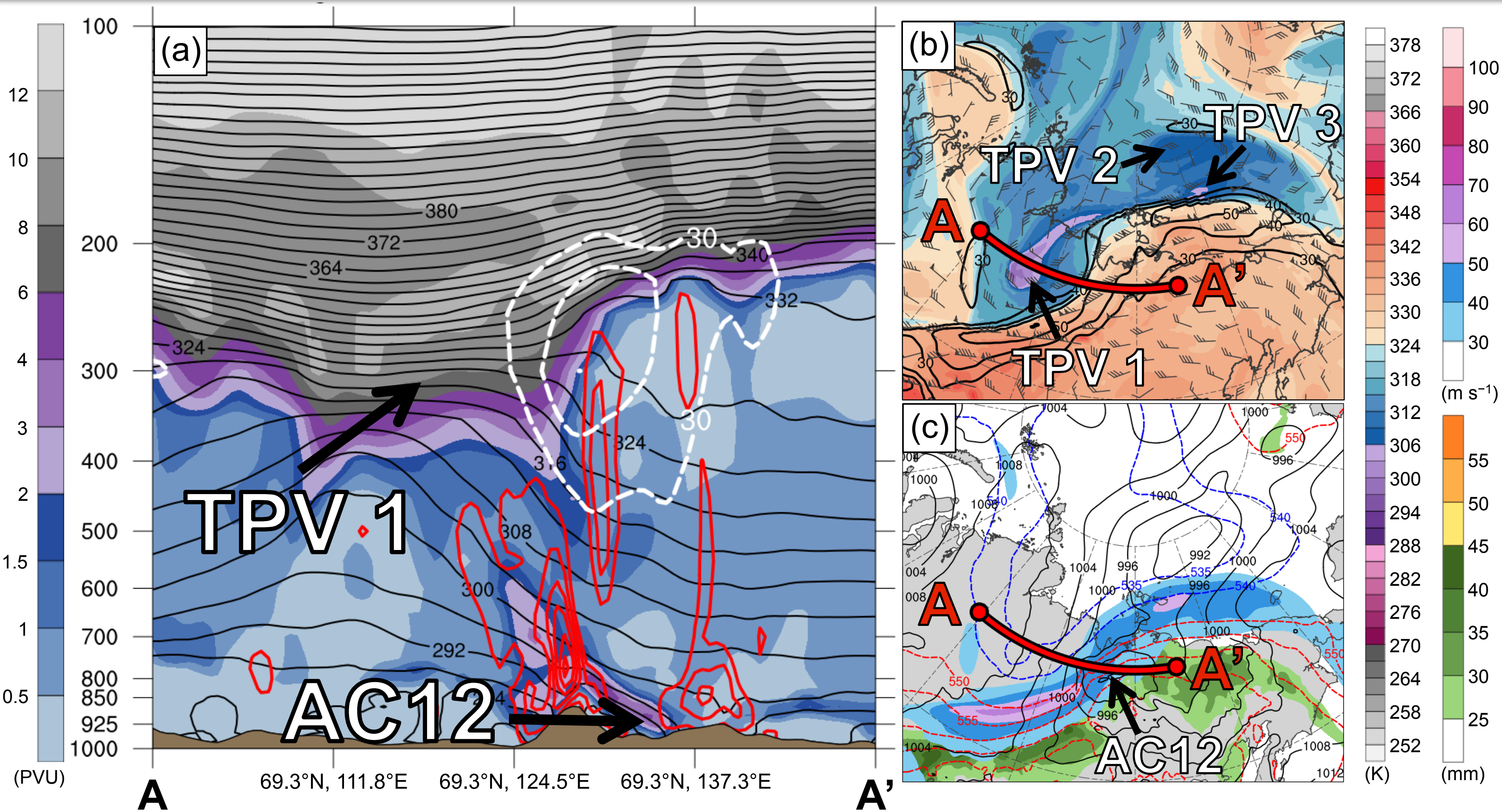
- TPV 1 approaches and interacts with AC12 in a region of strong baroclinicity, likely supporting the development of AC12 through baroclinic processes
- TPV 2 forms at 0000 UTC 3 Aug east of TPV 1, and TPV 3 forms at 0000 UTC 4 Aug by splitting off from TPV 1
- TPV–jet interactions involving TPV 1, TPV 2, and TPV 3 likely contribute to the formation of a dual-jet configuration and jet coupling over AC12 during 3–4 Aug
- Upper-level divergence associated with the jet coupling, as well as forcing for ascent associated with TPV 1, likely support the intensification of AC12

Synoptic Evolution

- L1 interacts and merges with AC12 on 5 Aug, which may further support the intensification of AC12
- AC12 becomes positioned in the left exit region of a jet streak located between TPV 1 and a downstream ridge by 0000 UTC 6 Aug and continues to intensify
- AC12 attains peak intensity of 962.3 hPa at 1000 UTC 6 Aug in the ERA5 and becomes vertically aligned with TPV 1 by 1200 UTC 6 Aug
- AC12 and TPV 1 then meander slowly in tandem over the Arctic, while AC12 slowly weakens

Cross Sections

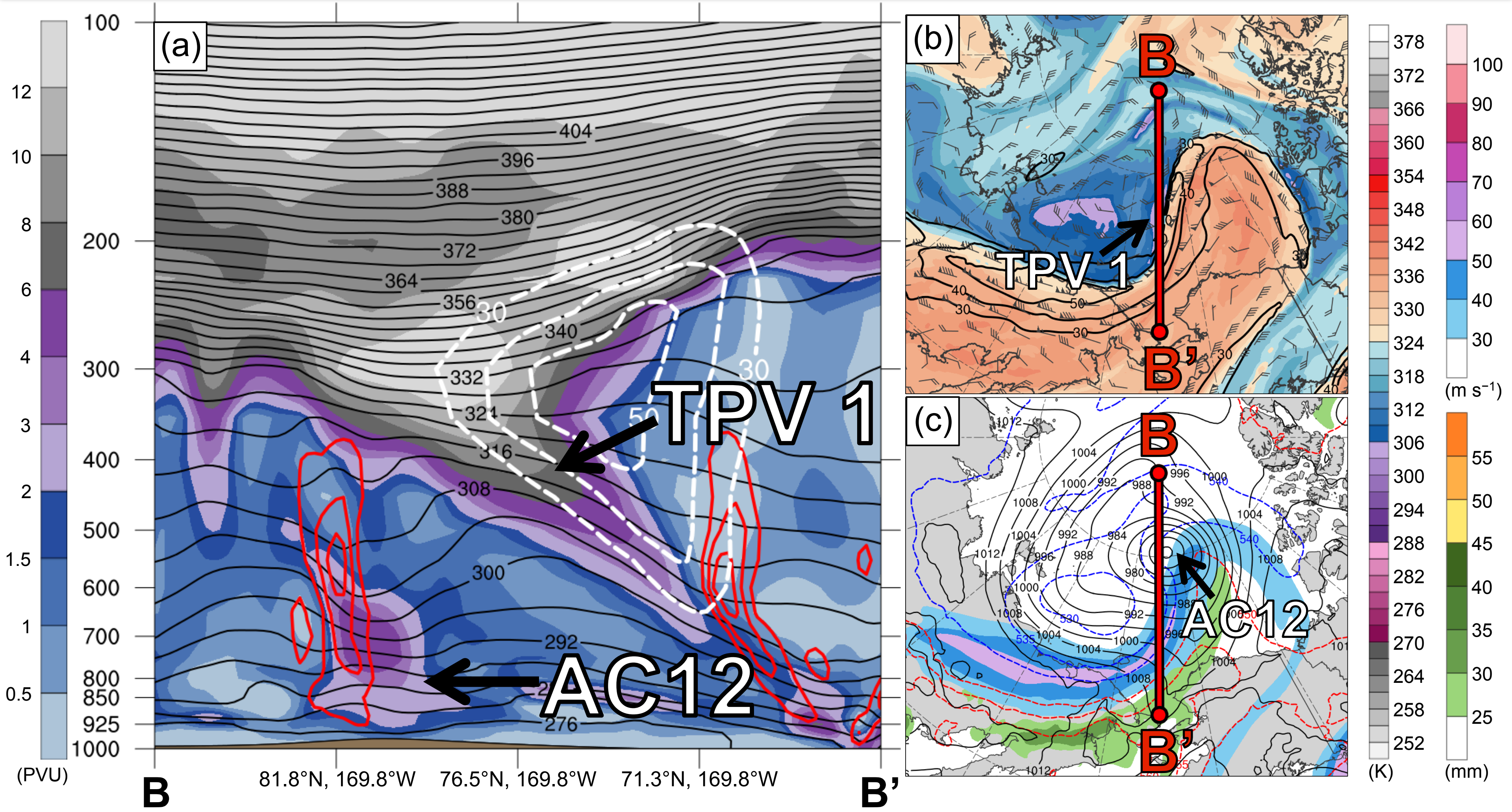
0600 UTC 4 Aug 2012



(a) PV (PVU, shaded), θ (K, black), ascent (red, every 3 × 10^{-3} hPa s^{-1}), and wind speed (dashed 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) 250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

Cross Sections

0000 UTC 6 Aug 2012



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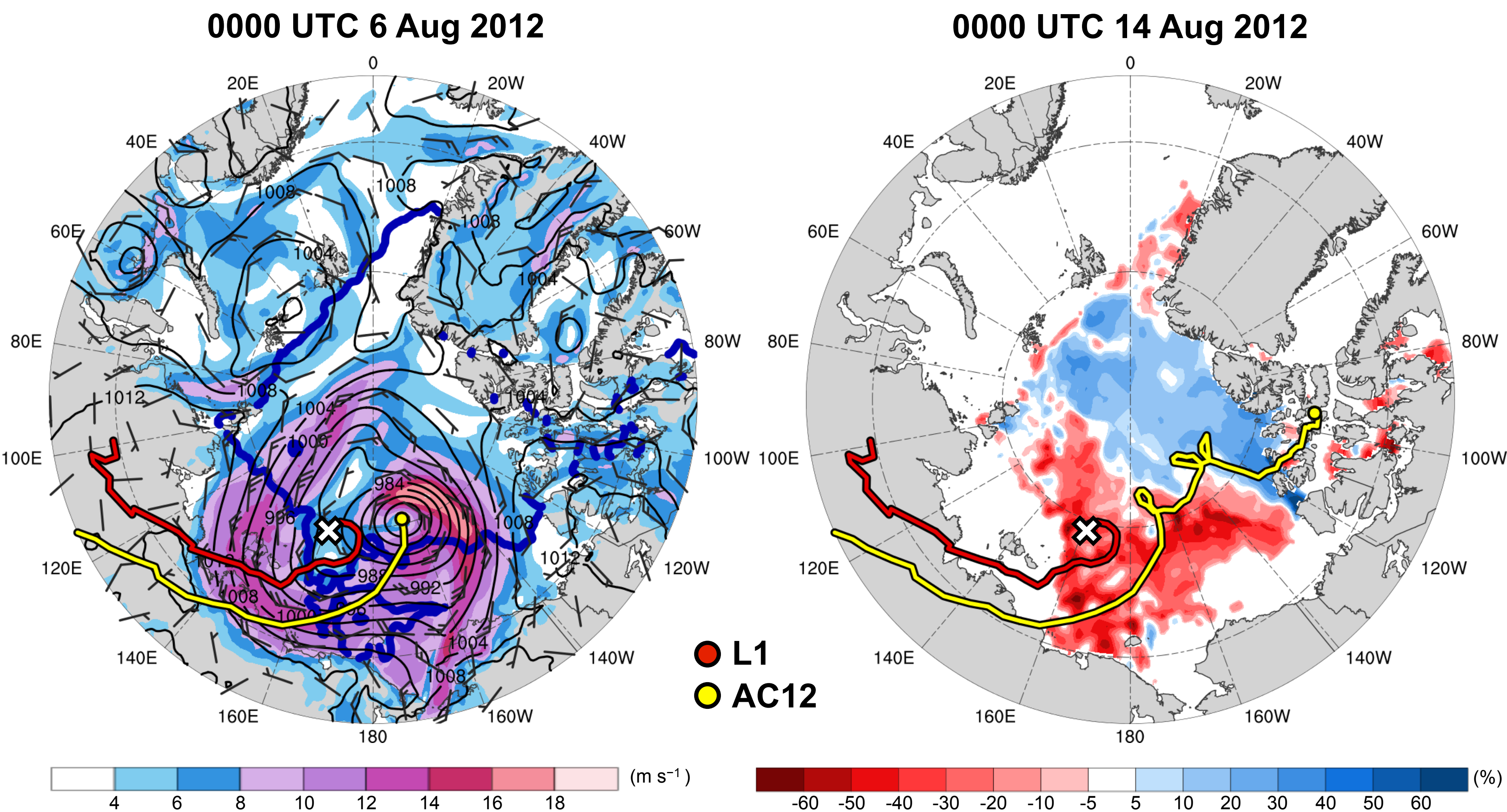
Cross Sections

- TPV–jet interactions involving TPV1, TPV 2, and TPV 3 likely contribute to the dual-jet configuration and jet coupling over AC12 at 0600 UTC 4 Aug
- Jet coupling likely supports the relatively strong low-level ascent over and near AC12
- Latent heating related to the low-level ascent in the presence of warm, moist air likely contributes to the formation of a potential vorticity (PV) tower associated with AC12

Cross Sections

- By 0000 UTC 6 Aug, the depth of the PV tower associated with AC12 has increased
- The increase in the depth of the PV tower likely is a manifestation of the contribution of latent heating to the intensification of AC12

Reduction in Arctic Sea Ice



SLP (hPa, black); 10-m wind speed (m s^{-1}, shaded) and wind (m s^{-1}, black barbs), and 20% contour of sea-ice concentration (thick blue)

Change in sea-ice concentration (%, shaded) during 0000 UTC 2–0000 UTC 14 Aug 2012

Reduction in Arctic Sea Ice

- AC12 is associated with an expansive field of relatively strong winds
- The relatively strong southerly winds to the east of the center of AC12 are approximately perpendicular to the sea-ice edge, likely helping to move and break up the thin sea ice
- AC12 meanders slowly over the Arctic, leading to a prolonged impact on the sea ice, as illustrated by the relatively large reduction in sea-ice concentration northeast of Siberia

Conclusions

- TPV 1 approaches and interacts with AC12 in a region of strong baroclinicity, likely supporting the development of AC12 through baroclinic processes
- TPV–jet interactions involving TPV 1, TPV 2, and TPV 3 likely contribute to the formation of a dual-jet configuration and jet coupling over AC12
- Latent heating related to low-level ascent in the presence of warm, moist air in region of jet coupling likely contributes to the formation of the PV tower associated with AC12

Conclusions

- The increase in the depth of the PV tower associated with AC12 likely is a manifestation of the contribution of latent heating to the intensification of AC12
- L1 interacts and merges with AC12, which may further support the intensification of AC12
- After attaining peak intensity, AC12 meanders slowly over the Arctic, where its expansive surface wind field contributes to reductions in Arctic sea-ice extent