Phenomenological and Predictability Studies of the Structure and Evolution of Arctic Cyclones and Tropopause Polar Vortices

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Project Objective

- This project addresses three research topics concerned with improving prediction of Arctic cyclones and related phenomena.

- This project is expected to contribute to advances in the understanding and prediction of tropopause polar vortices (TPVs) and Arctic cyclones on synoptic-to-subseasonal time scales.

- This project is being conducted by the PI (Lance Bosart), Co-PI (Dan Keyser), and two DAES graduate students (Kevin Biernat and Mansour Riachy) in collaboration with Steven Cavallo, Jim Doyle, Andrea Lang, and Ryan Torn.

Research Topics

1. The role of longitudinally localized incursions of warm, moist air from middle latitudes in disrupting the tropospheric polar vortex and in reconfiguring the large-scale baroclinicity over the Arctic.

2. The influence of reconfigurations of large-scale baroclinicity, high-latitude ridge amplification and blocking, sea ice and snow cover boundaries, and radiative processes on the genesis and evolution of TPVs and Arctic cyclones.

Research Topics

3. The dependence of predictability horizons of TPVs and Arctic cyclones on model uncertainty on synoptic-to-subseasonal time scales as determined through the synoptic evaluation of the forecast skill of deterministic and ensemble prediction systems.

Research Topics #1 and #2

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

- The Contributions of Tropopause Polar Vortices and Remnant Tropical Moisture from Tropical Storm Alberto to the Development of Two Intense Arctic Cyclones in June 2018

Great Arctic Cyclone of August 2012

1) Background

- The Great Arctic Cyclone of August 2012 (hereafter AC12) formed over Siberia on 2 August 2012 and tracked northeastward into the Arctic, reaching a minimum central sea level pressure (SLP) of 962.3 hPa at 1000 UTC 6 August in the ERA5

- Strong surface winds and waves associated with AC12 helped break up thin Arctic sea ice and contributed to increased upward ocean heat transport and bottom melting of ice, with sea-ice volume decreasing twice as fast as normal during AC12

Great Arctic Cyclone of August 2012

1) Background

- This presentation examines linkages between TPVs and AC12, and the impact of AC12 on Arctic sea-ice extent

Great Arctic Cyclone of August 2012

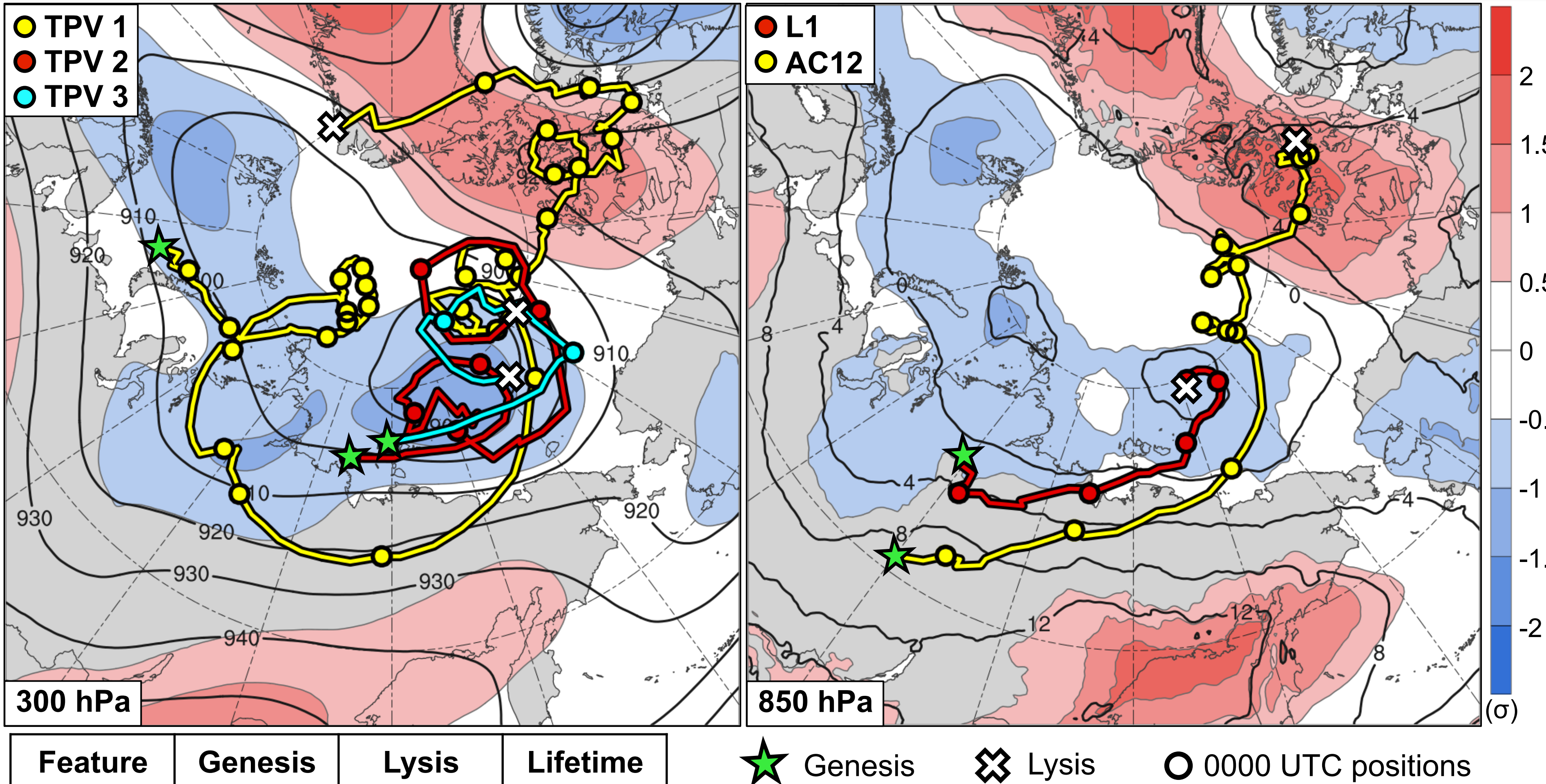
2) Data and Methods

- Data: ERA5 gridded to 0.3° horizontal resolution

- Utilized TPV tracking algorithm (Szapiro and Cavallo 2018) to identify and track TPVs of interest for AC12

- Manually tracked a predecessor surface cyclone (L1) and AC12 by following the locations of minimum SLP

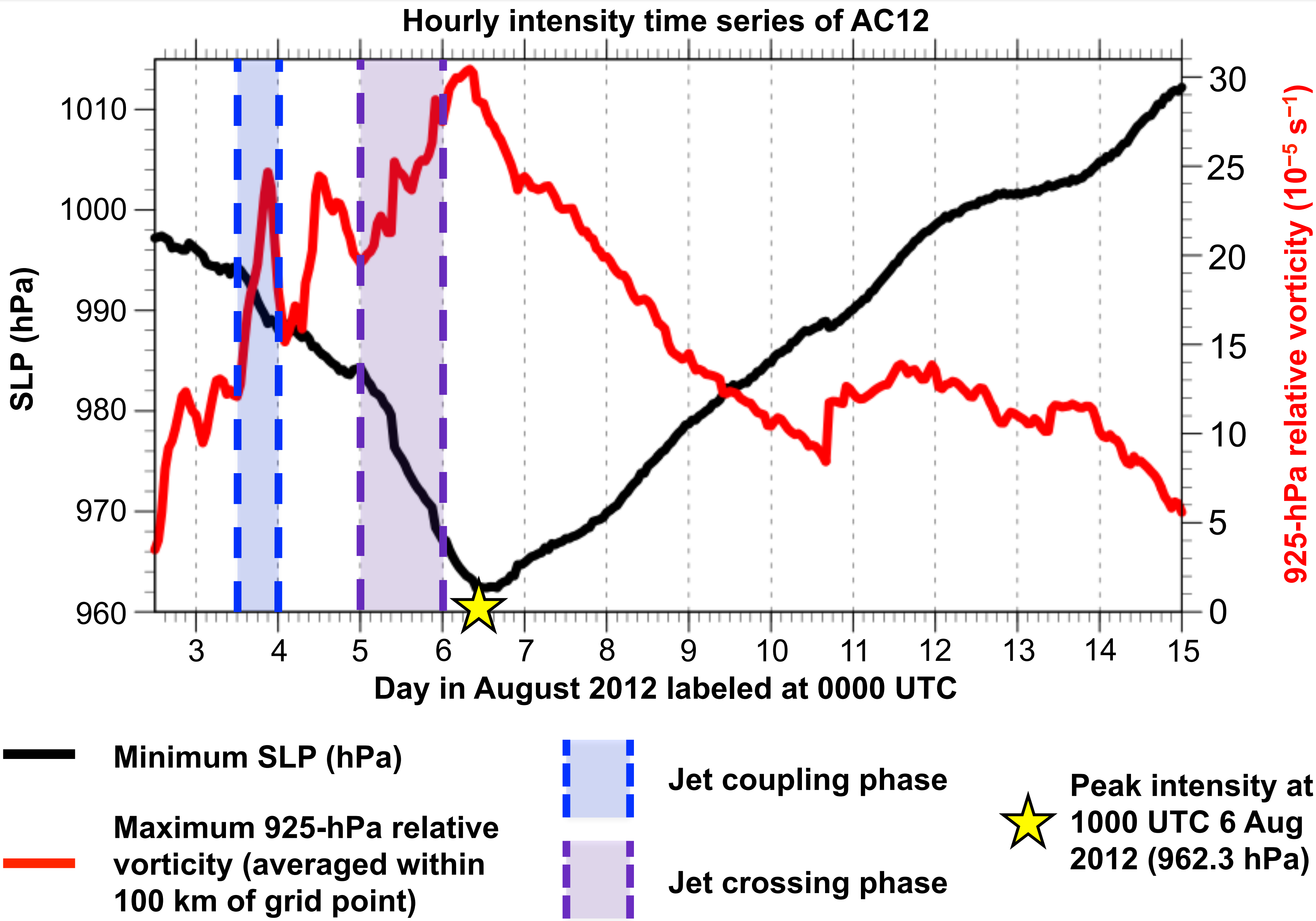
3) Track and Intensity



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

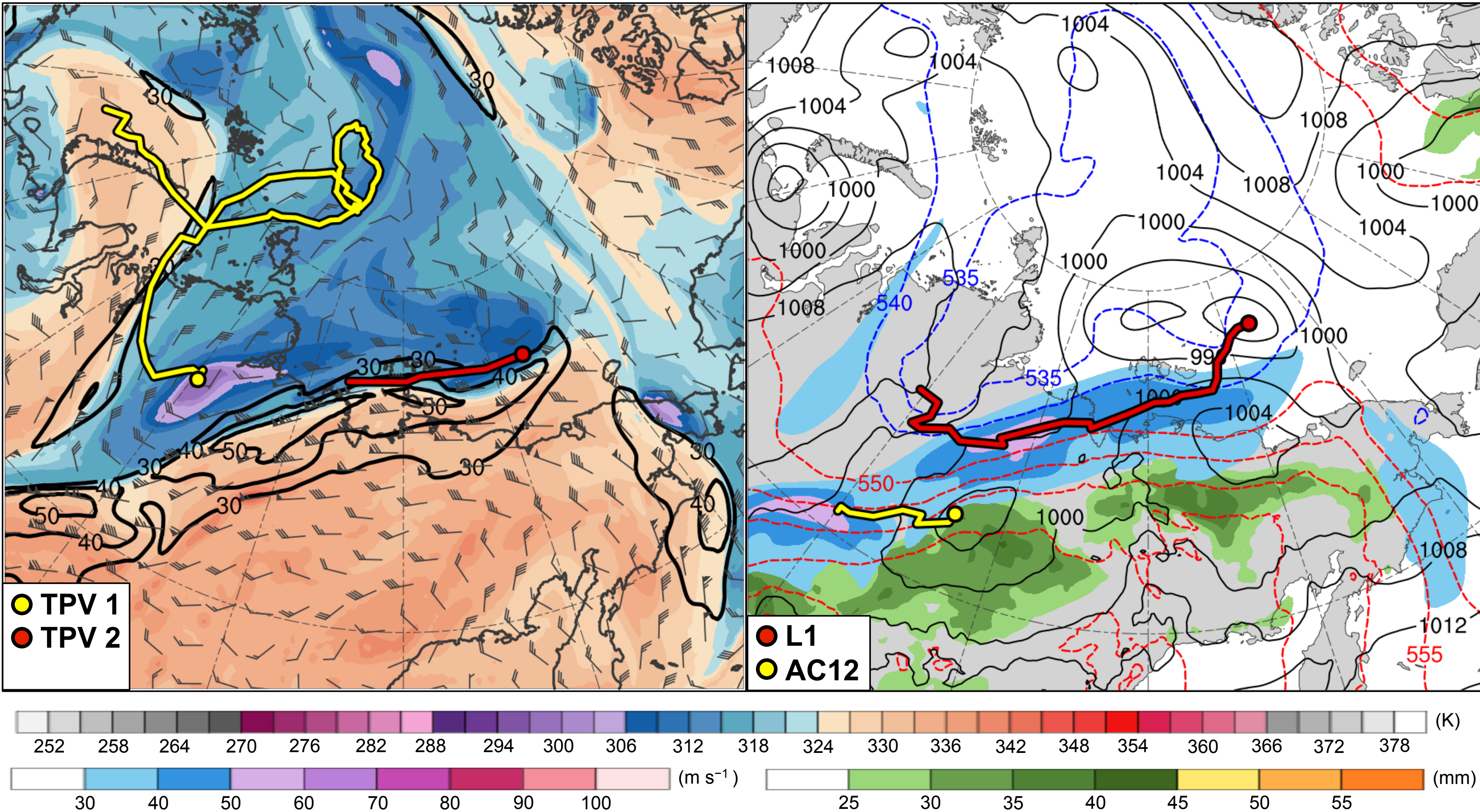
1–7 Aug 2012 time-mean (left) 300-hPa geopotential height (dam, black) and standardized geopotential height anomalies (σ, shaded); (right) 850-hPa temperature (°C, black) and standardized temperature anomalies (σ, shaded)

3) Track and Intensity



4) Synoptic Evolution

1200 UTC 3 Aug 2012

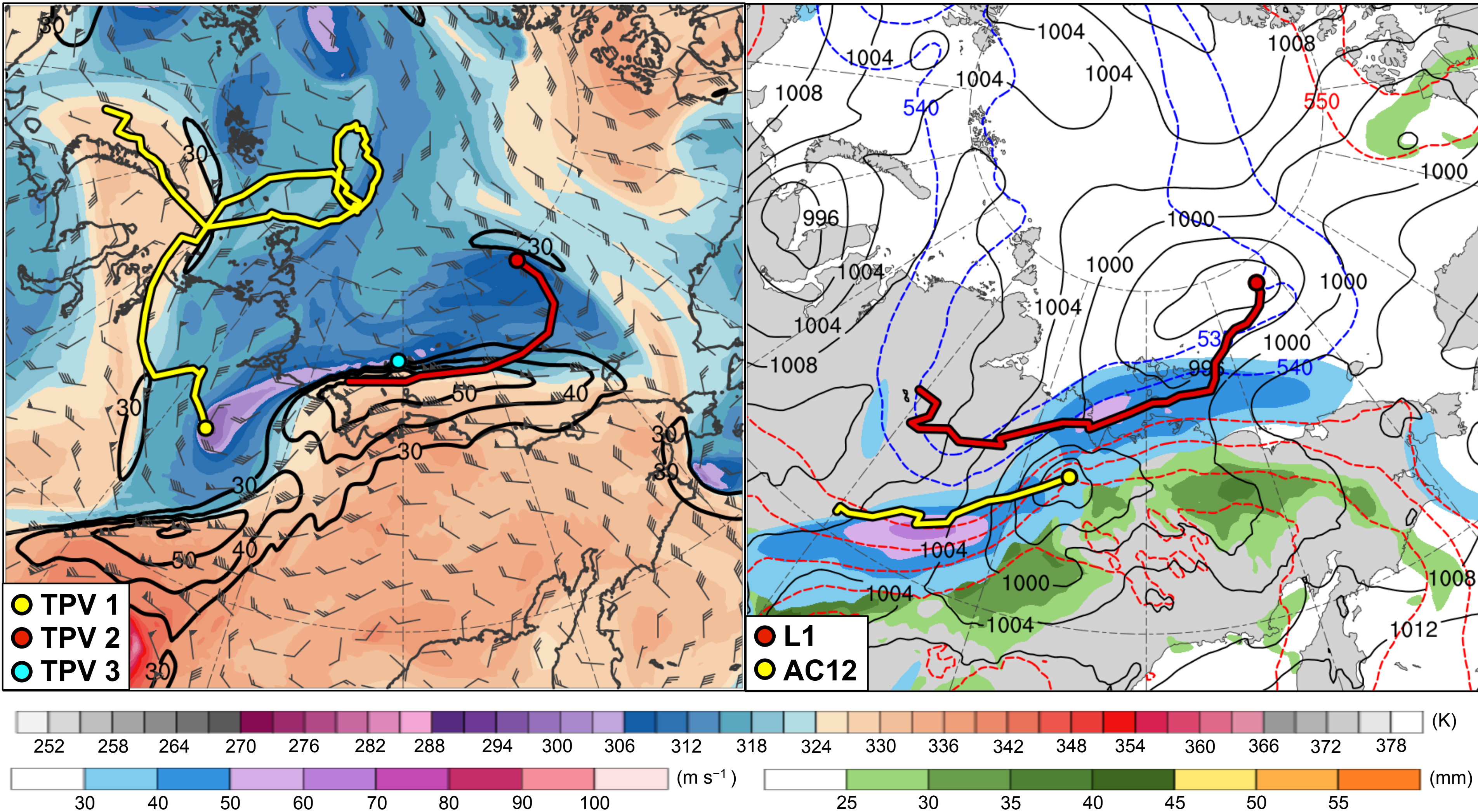


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 30 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

4) Synoptic Evolution

0000 UTC 4 Aug 2012



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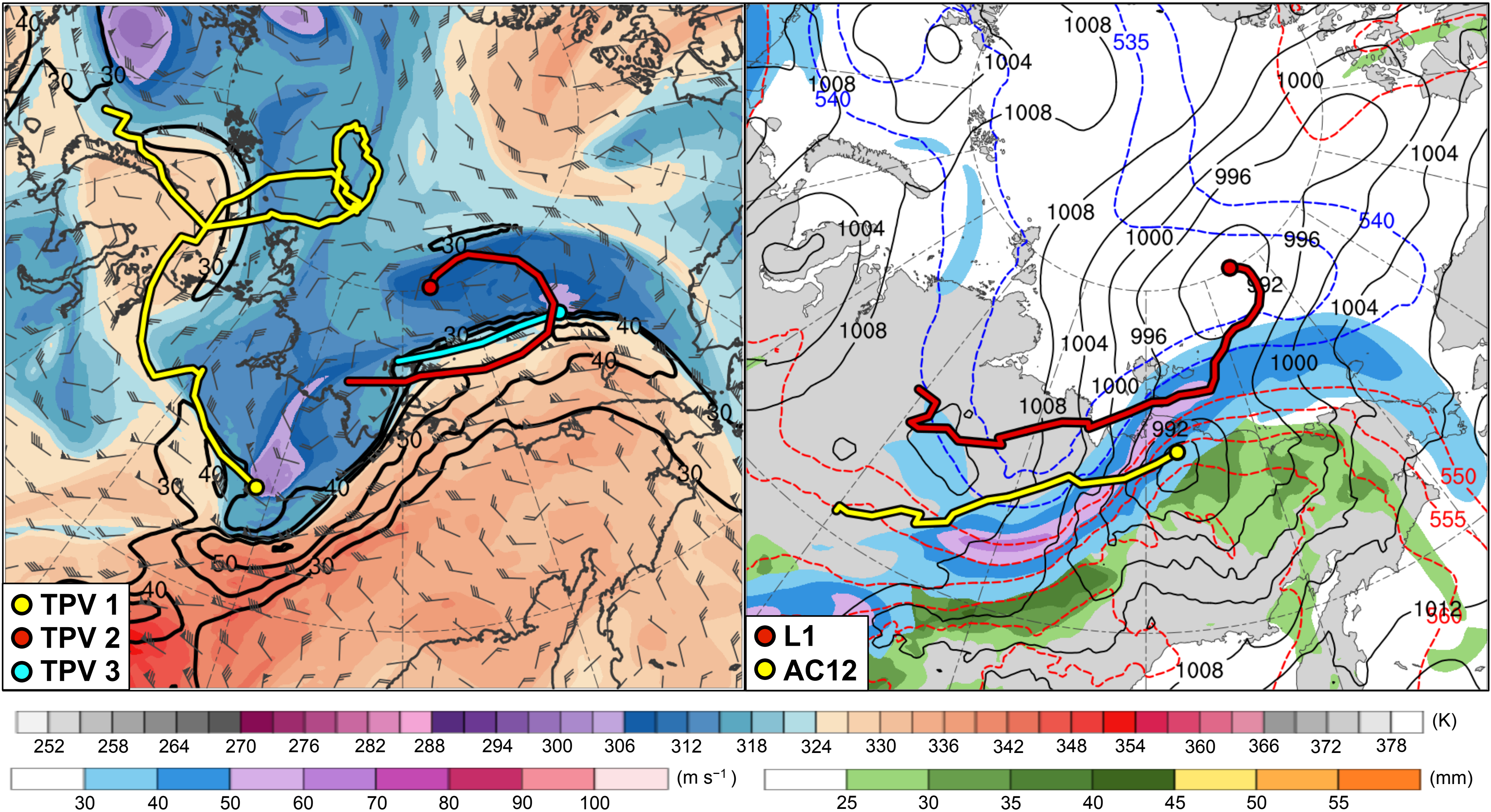
4) Synoptic Evolution

1200 UTC 4 Aug 2012



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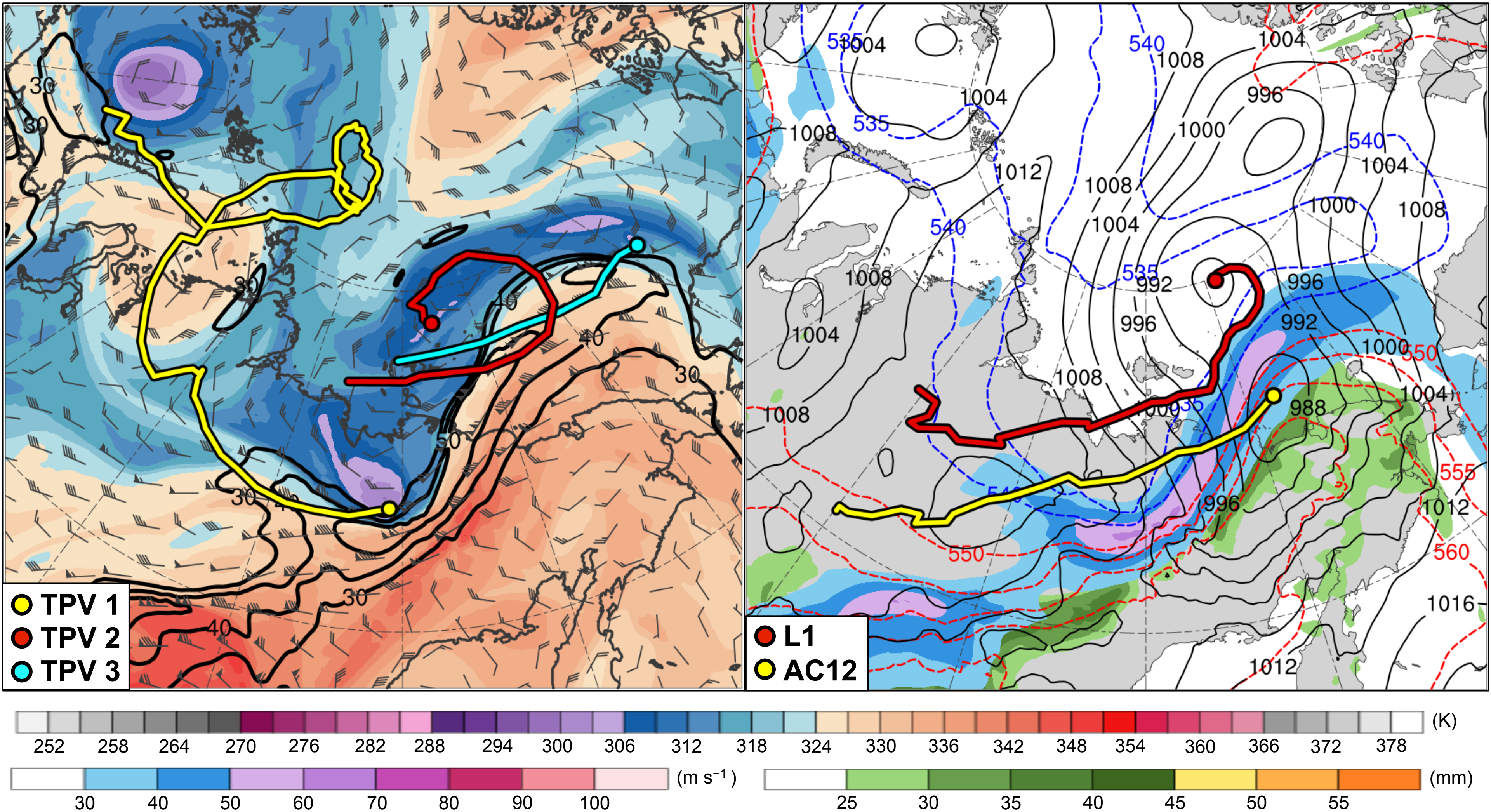
4) Synoptic Evolution

0000 UTC 5 Aug 2012



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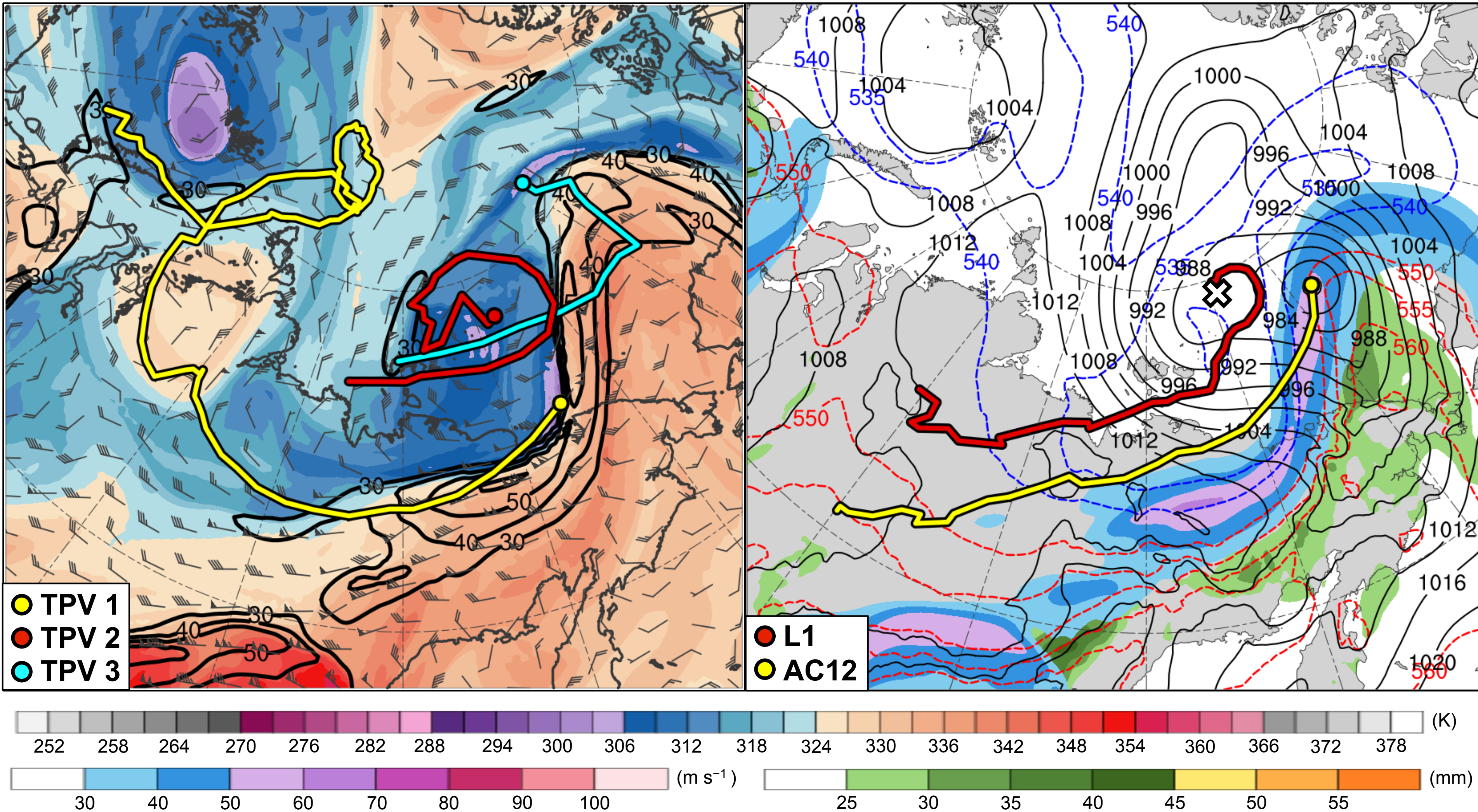
1200 UTC 5 Aug 2012



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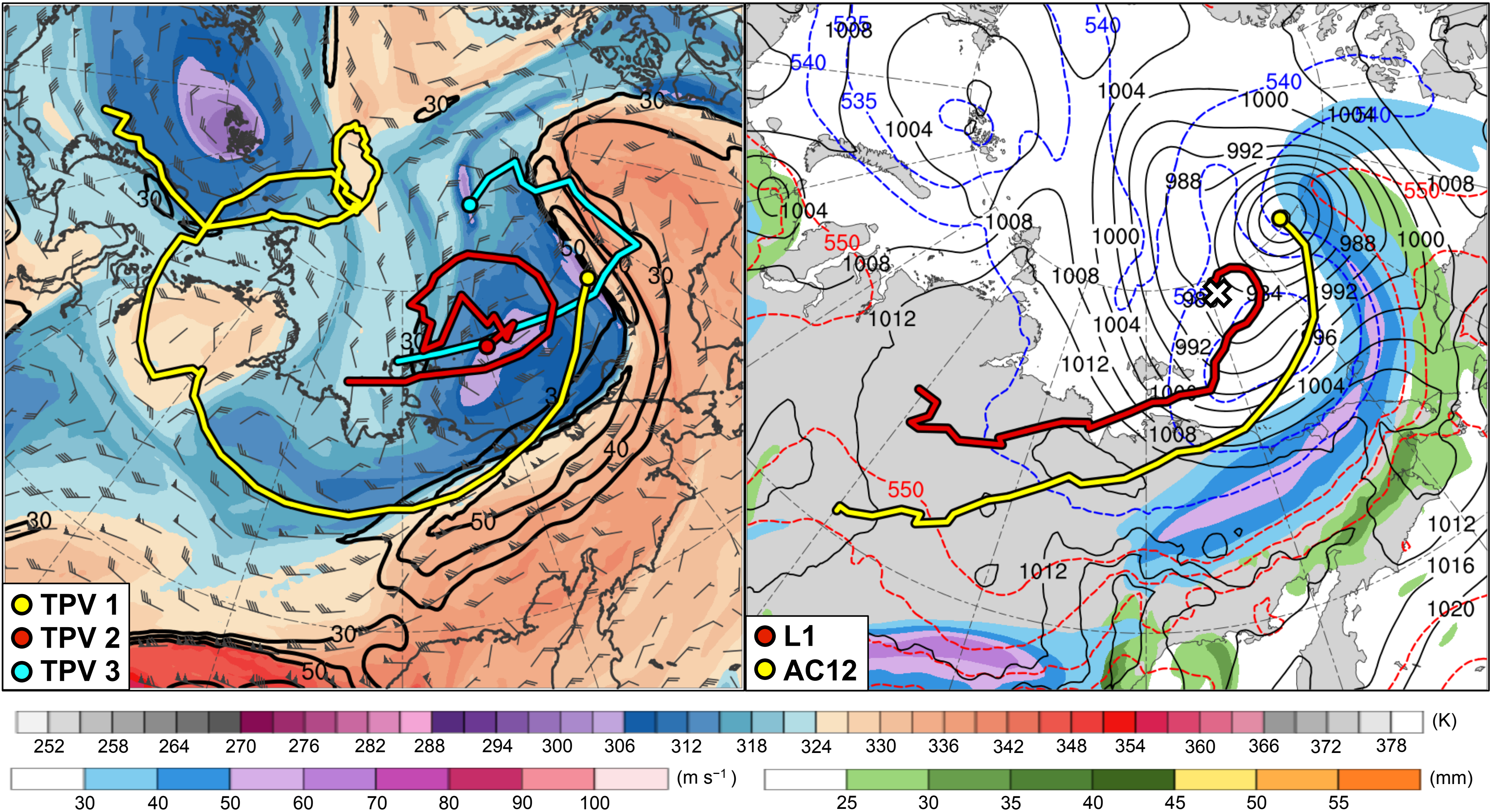
4) Synoptic Evolution

0000 UTC 6 Aug 2012



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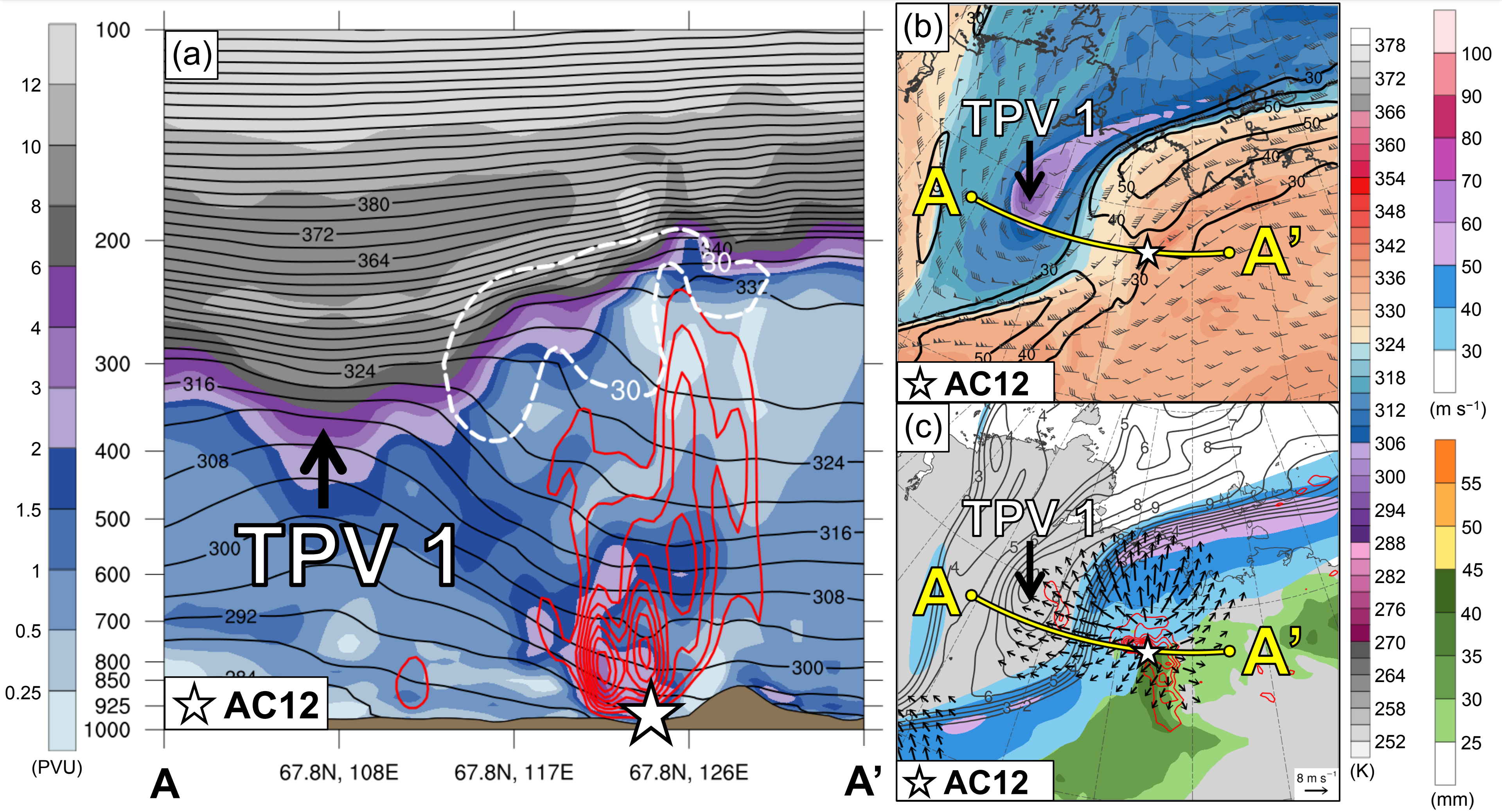
300-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

5) Cross Sections

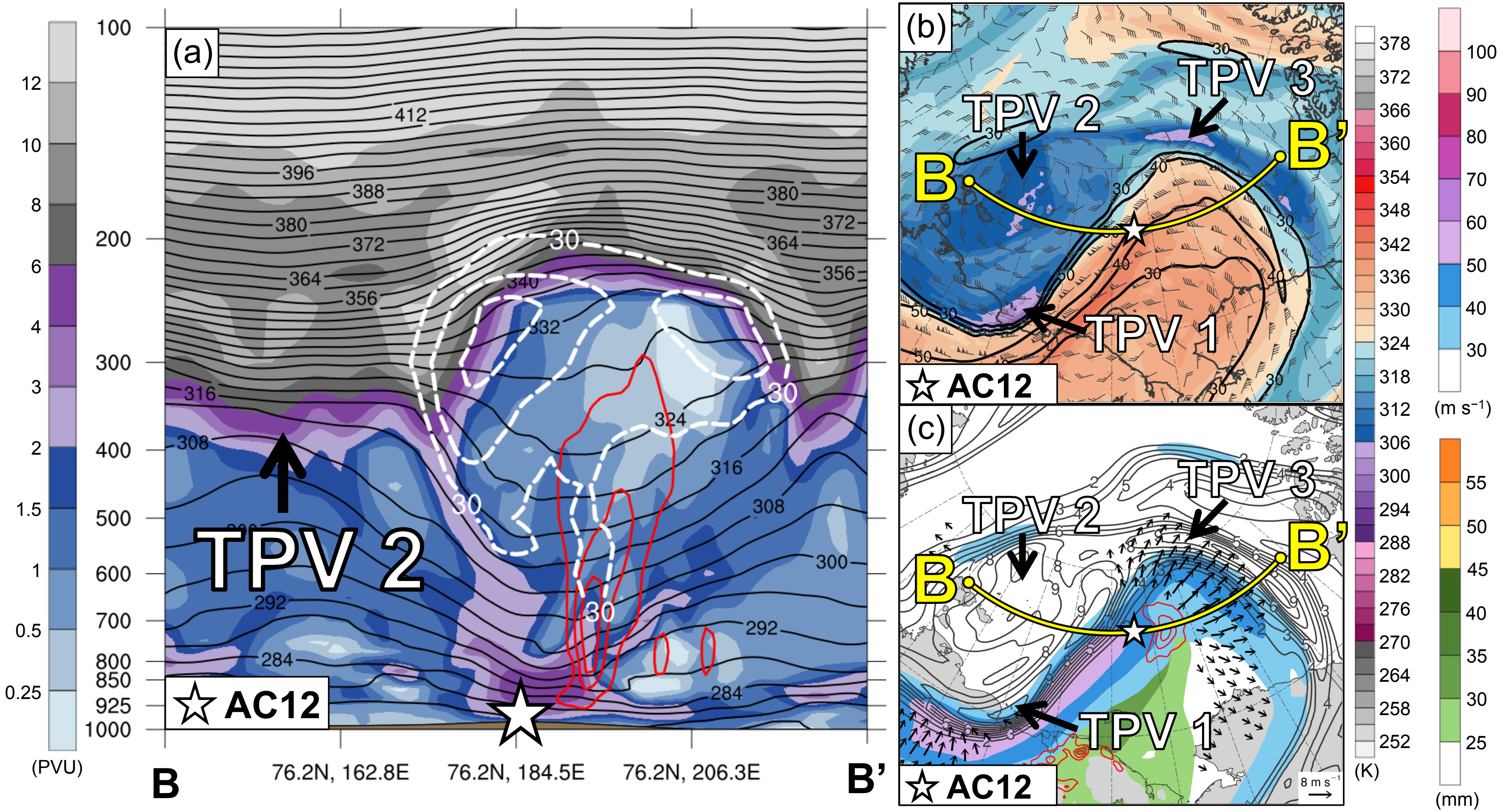
2100 UTC 3 Aug 2012



(a) PV (PVU, shaded), θ (K, black), ascent (red, every 5×10^{-3} hPa s^{-1}), and wind speed (white, every 10 m s^{-1} starting at 30 m s^{-1}); 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) 350–250-hPa PV (PVU, gray) and irrot. wind (m s^{-1}, vectors), 300-hPa wind speed (m s^{-1}, shaded), 800–600-hPa ascent (every 5×10^{-3} hPa s^{-1}), and PW (mm, shading)

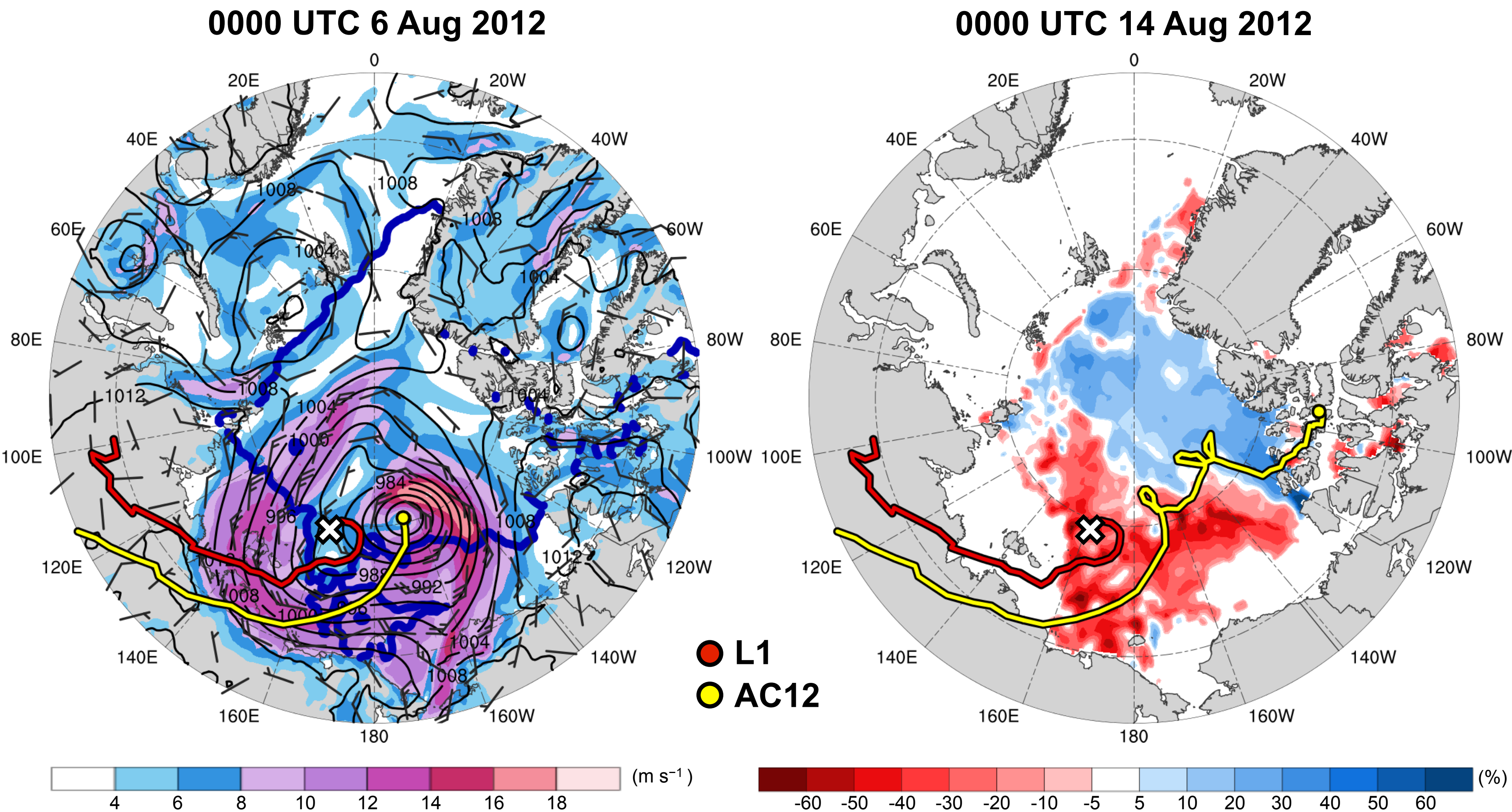
5) Cross Sections

1200 UTC 5 Aug 2012



(a) PV (PVU, shaded), θ (K, black), ascent (red, every 5 × 10^{-3} hPa s^{-1}), and wind speed (white, every 10 m s^{-1} starting at 30 m s^{-1}); 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) 350–250-hPa PV (PVU, gray) and irrot. wind (m s^{-1}, vectors), 300-hPa wind speed (m s^{-1}, shaded), 800–600-hPa ascent (every 5 × 10^{-3} hPa s^{-1}), and PW (mm, shading)

6) Impacts of AC12 on 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

Great Arctic Cyclone of August 2012

7) Summary

- 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 (jet coupling phase)

Great Arctic Cyclone of August 2012

7) Summary

- 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 a PV tower associated with AC12 and concomitant intensification of AC12

  – Interaction between TPV 1 and PV tower likely supports the intensification of AC12

- Cold air advection in the wake of L1 helps maintain the strong baroclinicity in the vicinity of AC12, which, along with interaction between L1 and AC12, may further support the intensification of AC12

Great Arctic Cyclone of August 2012

7) Summary

- Most rapid intensification of AC12 occurs on 5 Aug 2012, when AC12 crosses from the warm side to the cold side of a strong upper-level jet streak (jet crossing phase)
  - Latent heating may contribute to PV tower associated with AC12 and intensification of AC12 during jet crossing phase, though this contribution may be smaller than that during jet coupling phase
- Widespread, relatively strong surface winds associated with AC12 contribute to reductions in Arctic sea-ice extent as AC12 meanders slowly over the Arctic

Two Intense Arctic Cyclones in June 2018

1) Background

- Arctic cyclone 1 (AC1) formed along an old cold frontal boundary northeast of the Caspian Sea, moved poleward, performed a cyclonic loop with a subsequent Arctic cyclone (AC2) near the north coast of Russia, and eventually merged with AC2 over the Arctic Ocean

- AC2 formed via lee cyclogenesis east of Greenland, and may have had some “DNA” (i.e., vorticity) from the remnants of Tropical Storm (TS) Alberto, which moved poleward across the central U.S. and northeastern Canada

Two Intense Arctic Cyclones in June 2018

1) Background

- The comparative rarity of two sequential intense Arctic cyclones that interacted with one another, one of which (AC2) may have had antecedent DNA from TS Alberto, motivates this presentation

Two Intense Arctic Cyclones in June 2018

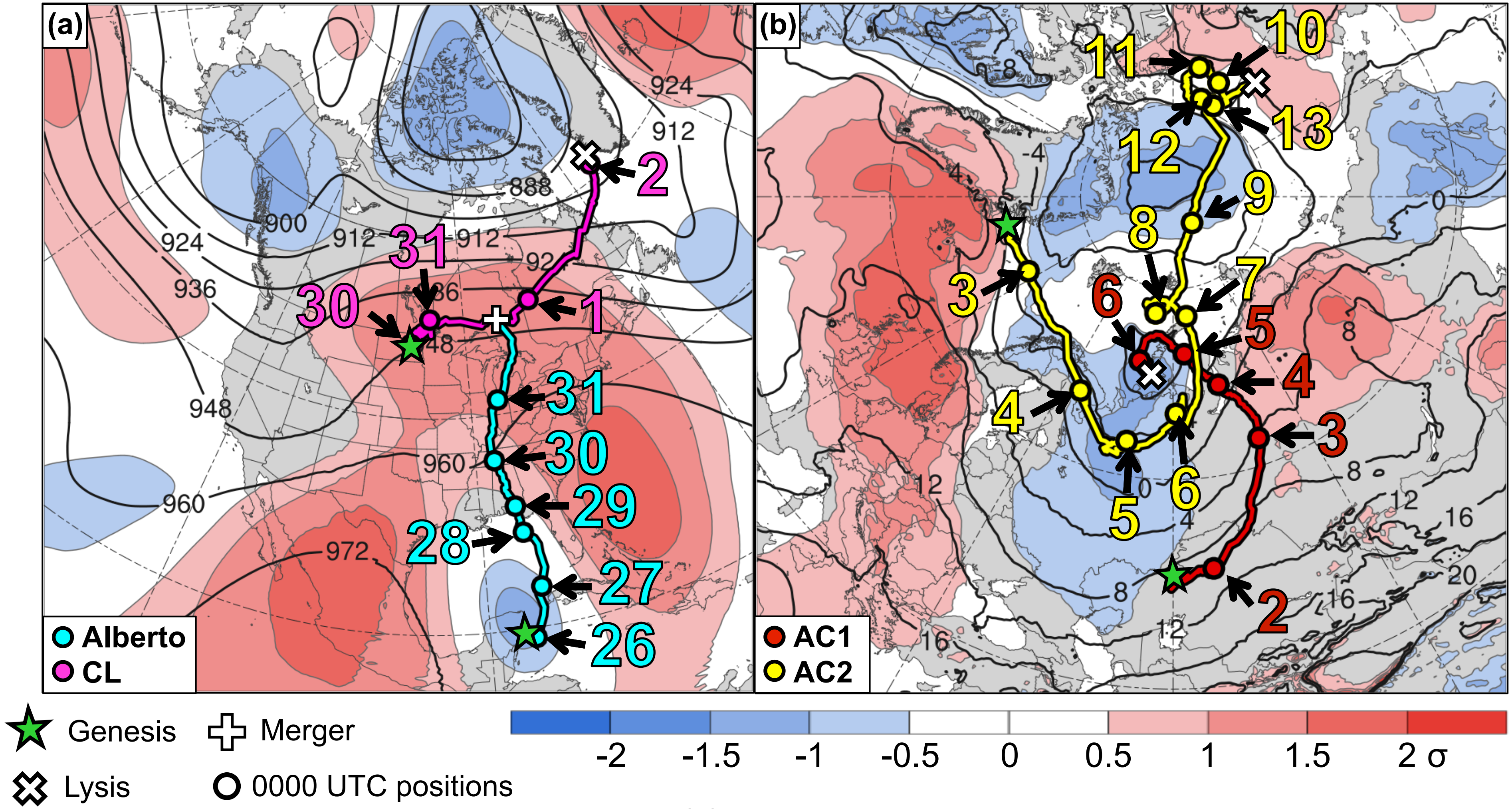
2) Data and Methods

- Data: ERA5 gridded to 0.25° horizontal resolution for all fields, with ERA-Interim 1979–2010 mean and standard deviation of selected fields for calculation of standardized anomalies

- Manually tracked AC1, AC2, and a Canadian low (CL) by following the locations of minimum SLP

- Tracked TS Alberto using National Hurricane Center positions of TS Alberto during 1500 UTC 25 May–0600 UTC 29 May 2018 and remnants of TS Alberto using ERA5 afterward

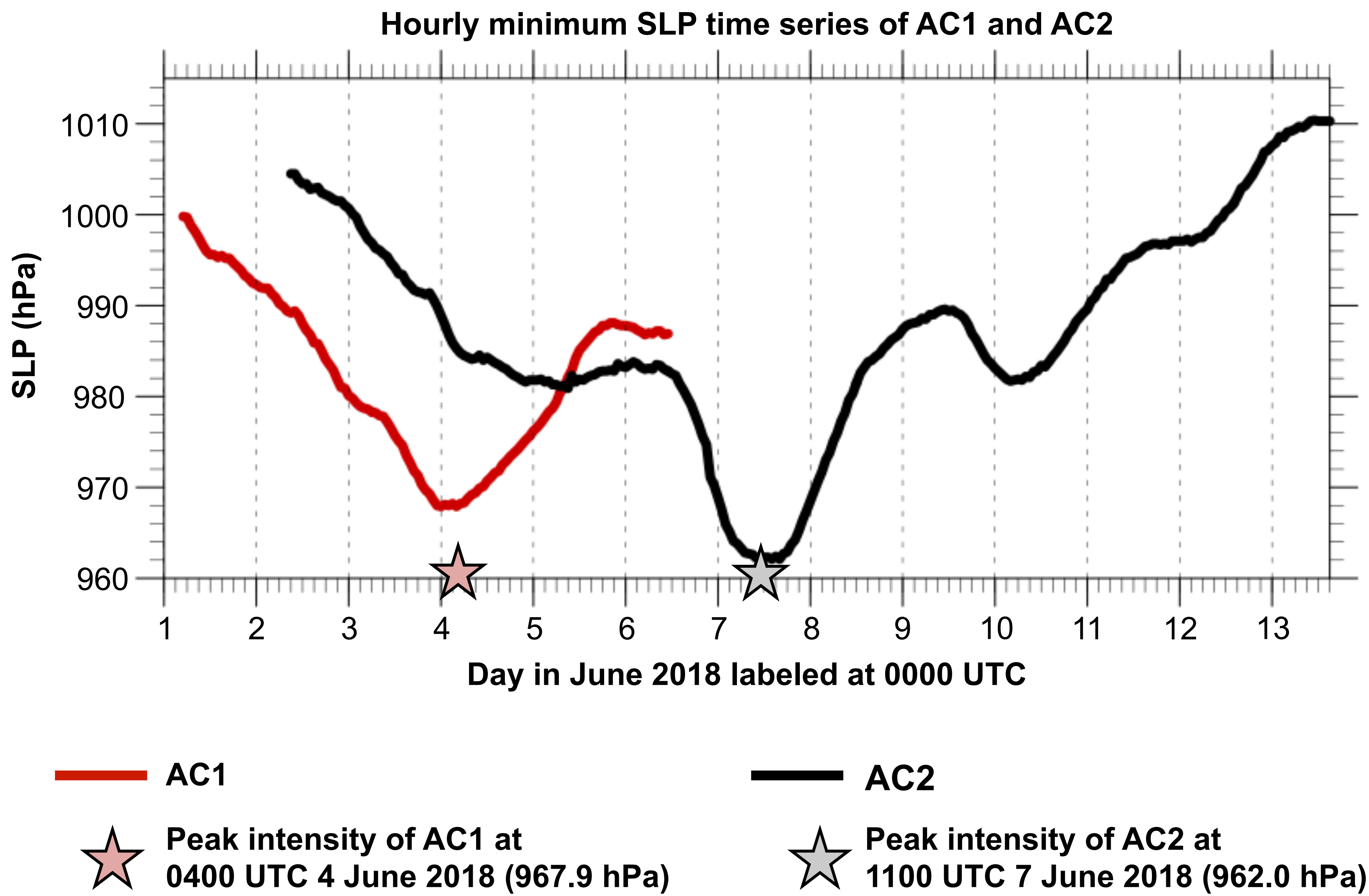
3) Track and Intensity



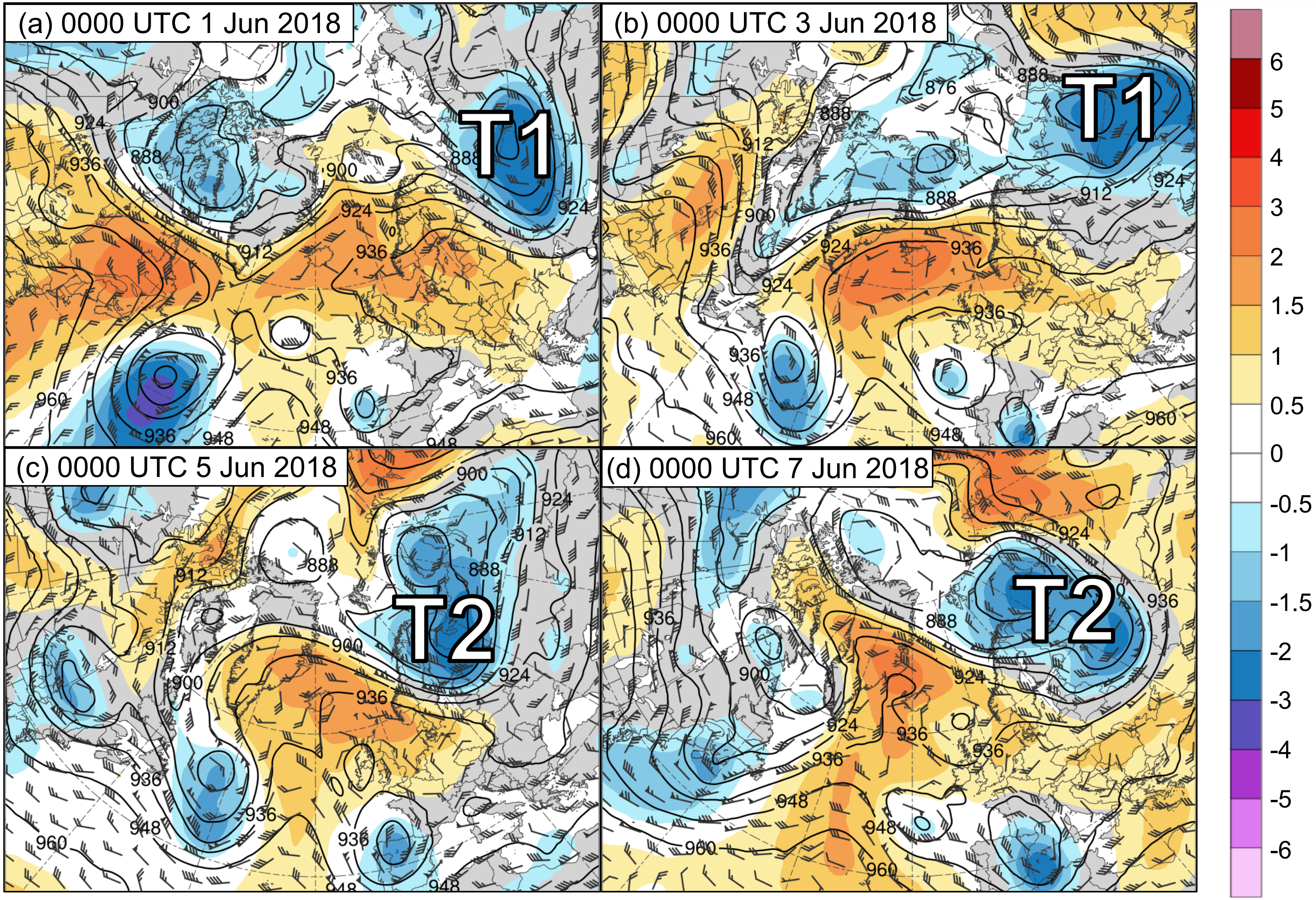
Cyclone	Genesis	Lysis	Lifetime
AC1	1 June 2018	6 June 2018	~5 d
AC2	2 June 2018	13 June 2018	~11 d

(a) 26 May–1 June 2018 time-mean 300-hPa geopotential height (dam, black) and standardized geopotential height anomalies (σ, shaded); (b) 1–7 June 2018 time-mean 850-hPa temperature (°C, black) and standardized temperature anomalies (σ, shaded).

3) Track and Intensity



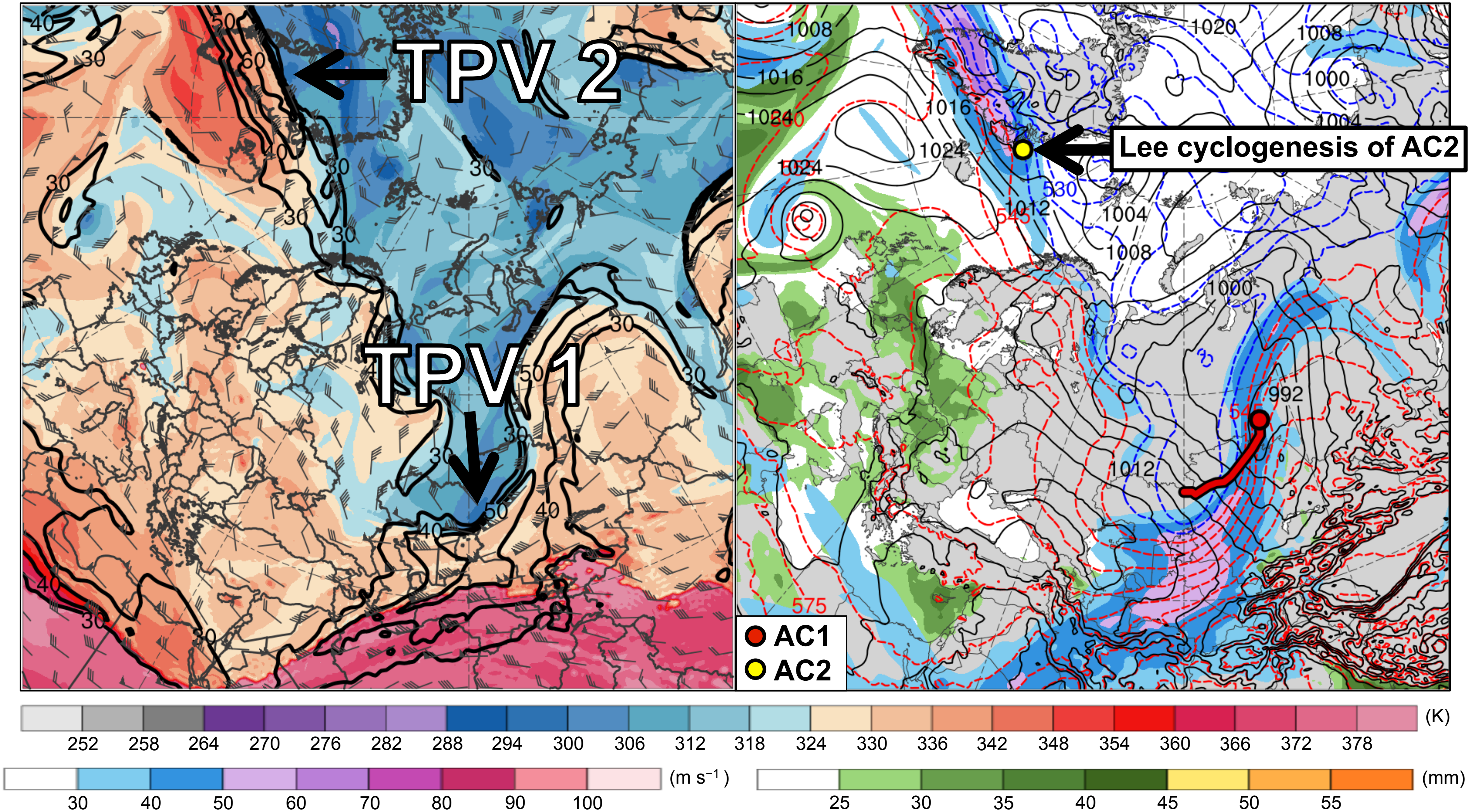
4) Large-Scale Flow Evolution



300-hPa geopotential height (dam, black), winds (m s^{-1}, flags and barbs), and standardized geopotential height anomalies (σ, shaded)

5) Synoptic Evolution

1200 UTC 2 June 2012



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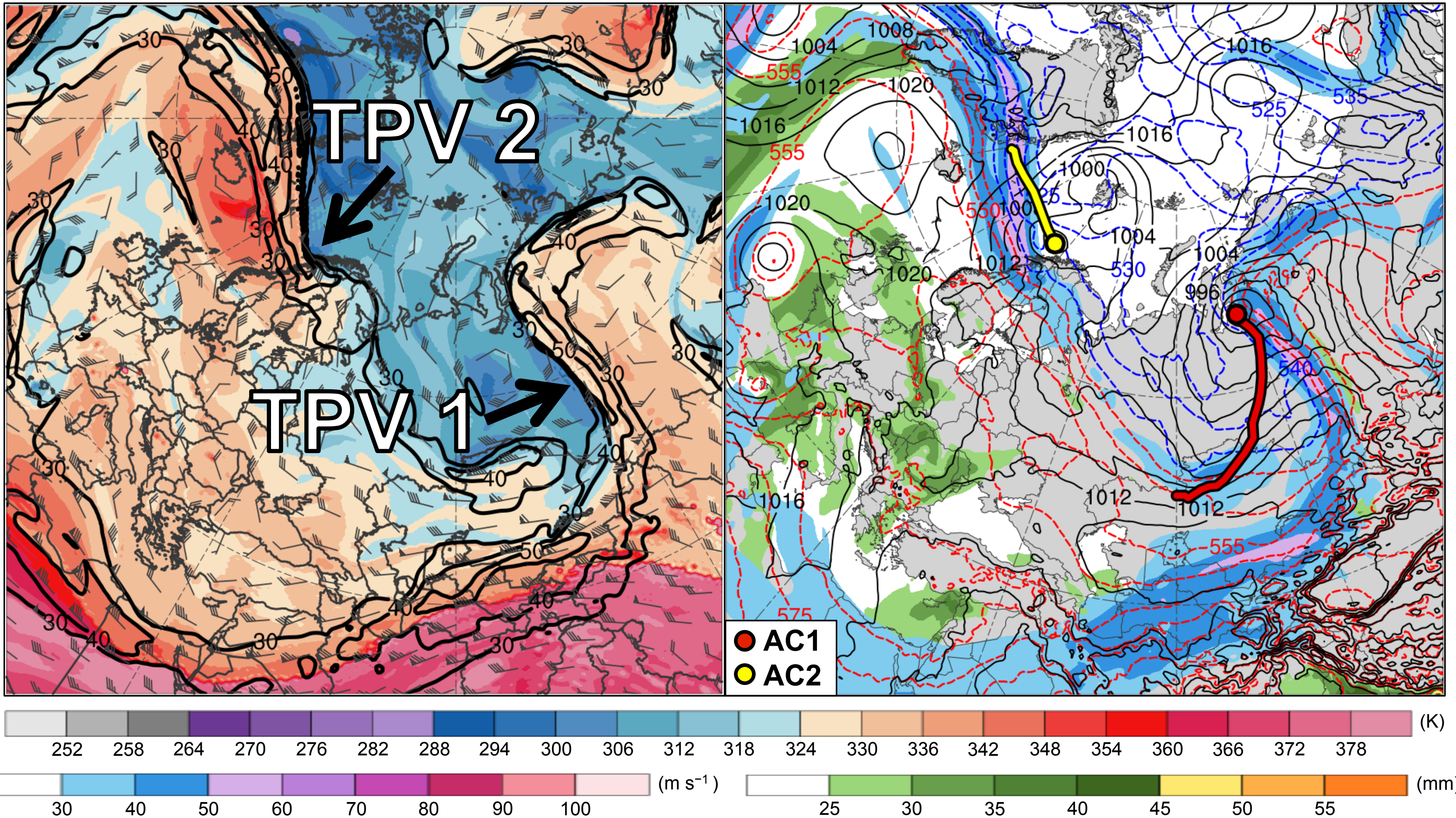
300-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

5) Synoptic Evolution

1200 UTC 3 June 2012



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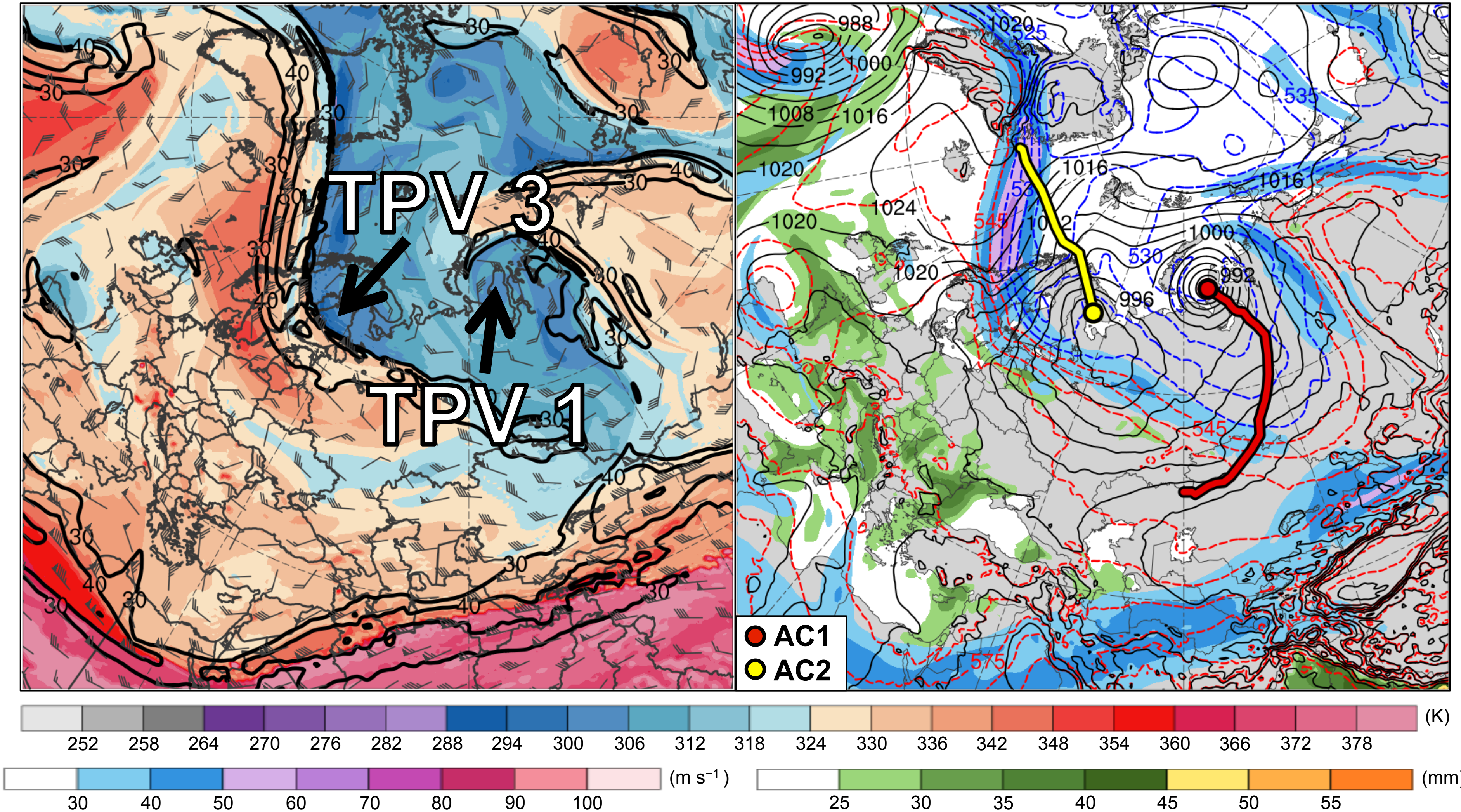
5) Synoptic Evolution

1200 UTC 4 June 2012



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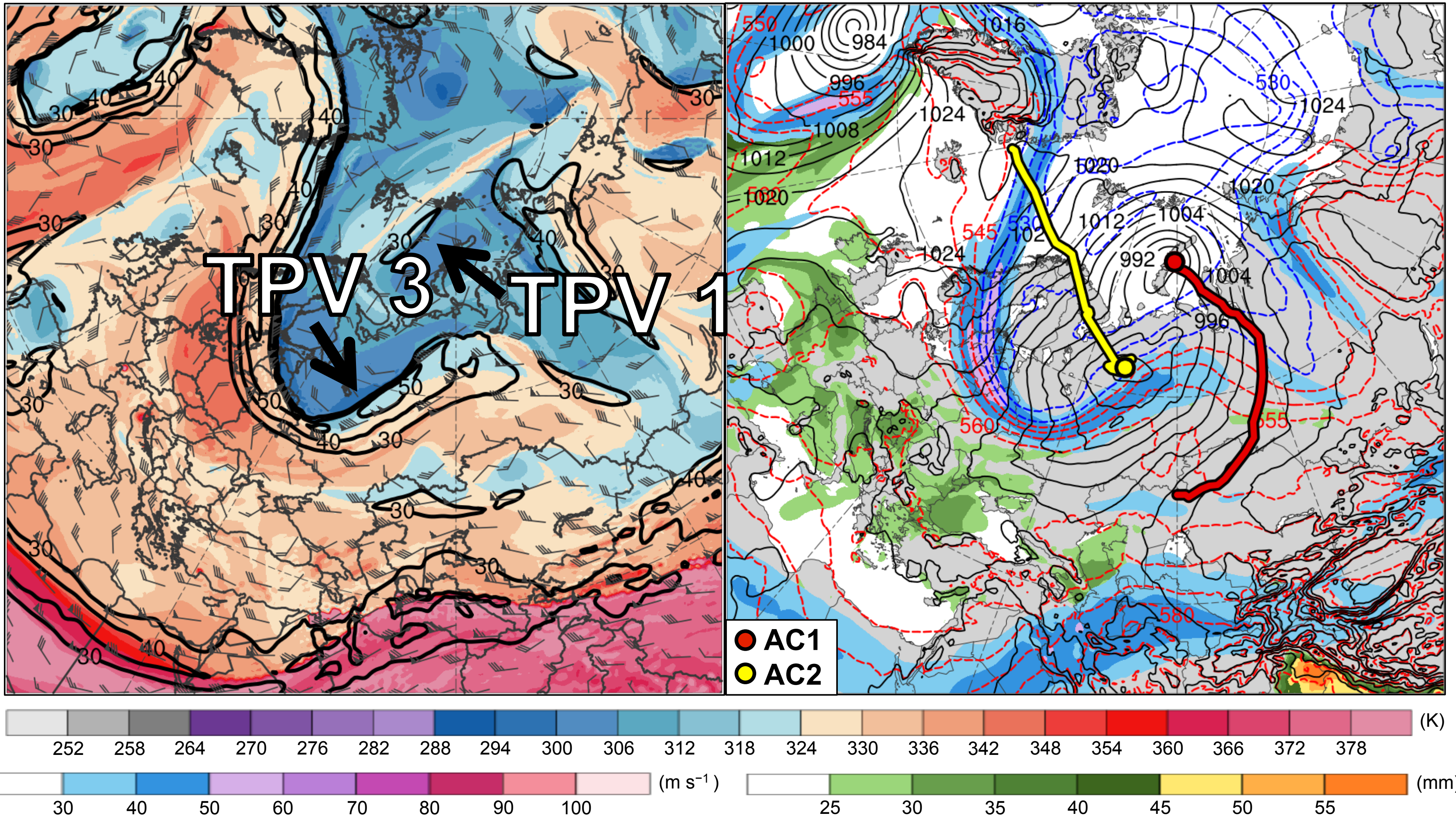
5) Synoptic Evolution

1200 UTC 5 June 2012



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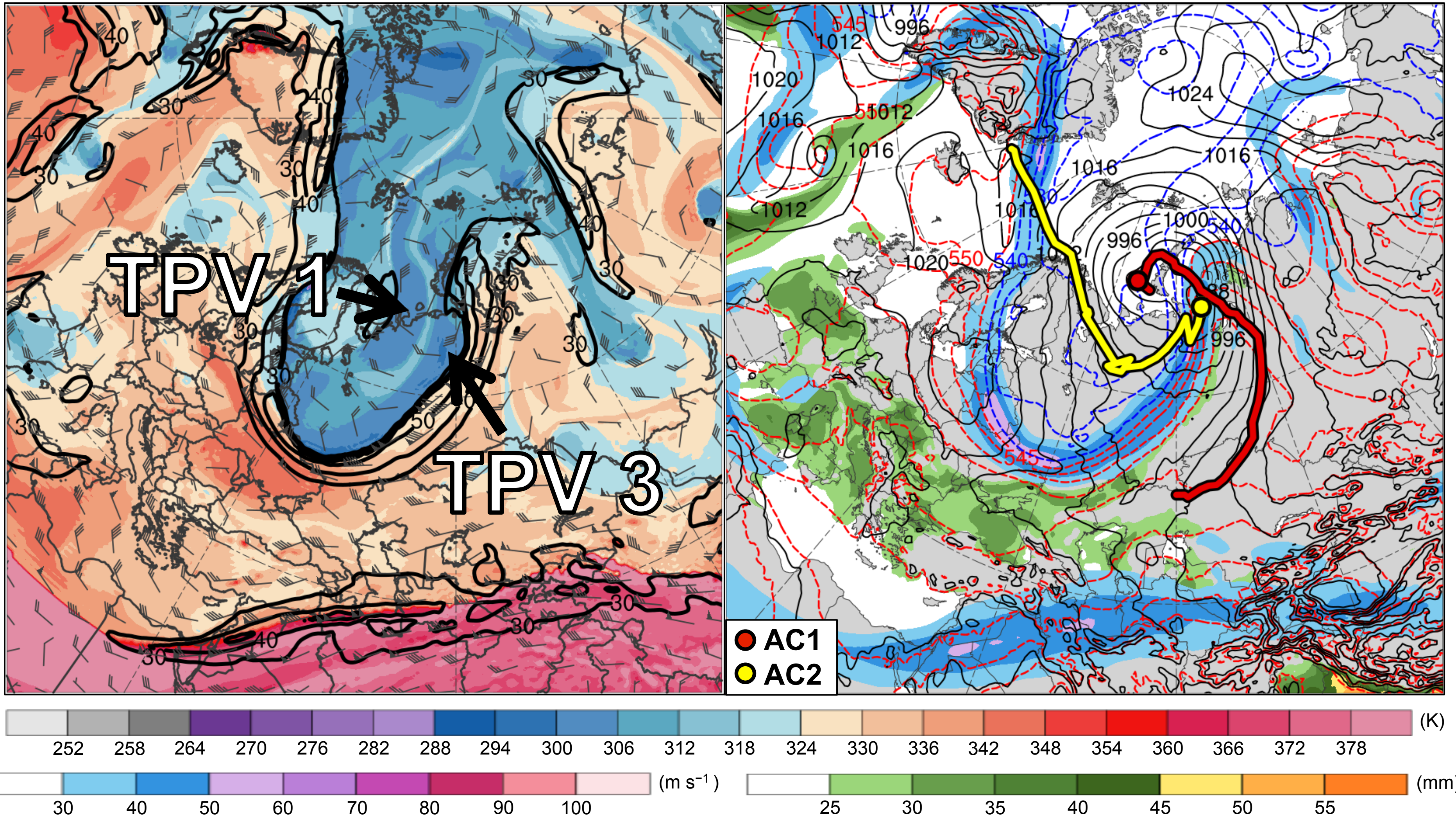
300-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

5) Synoptic Evolution

1200 UTC 6 June 2012



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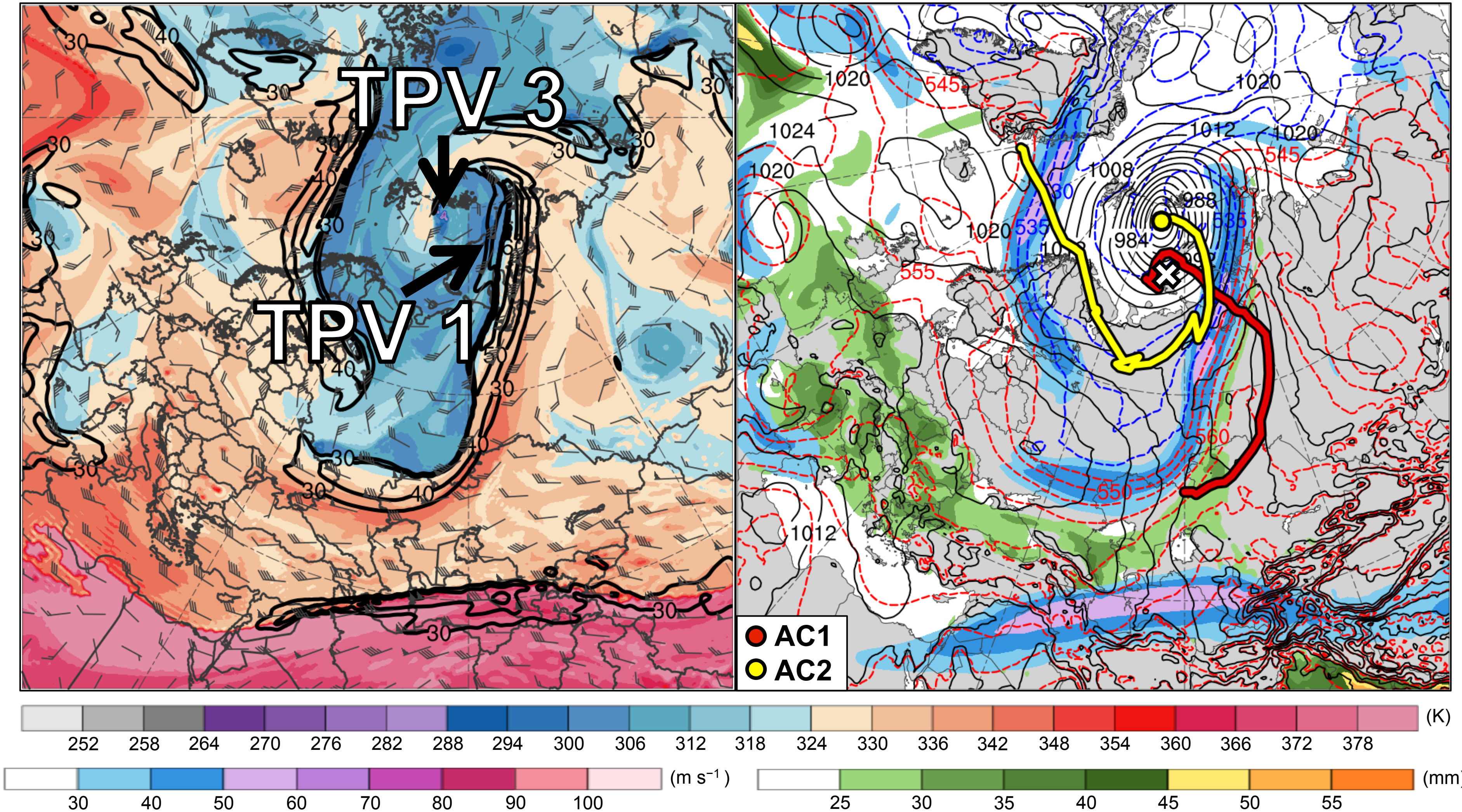
300-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

5) Synoptic Evolution

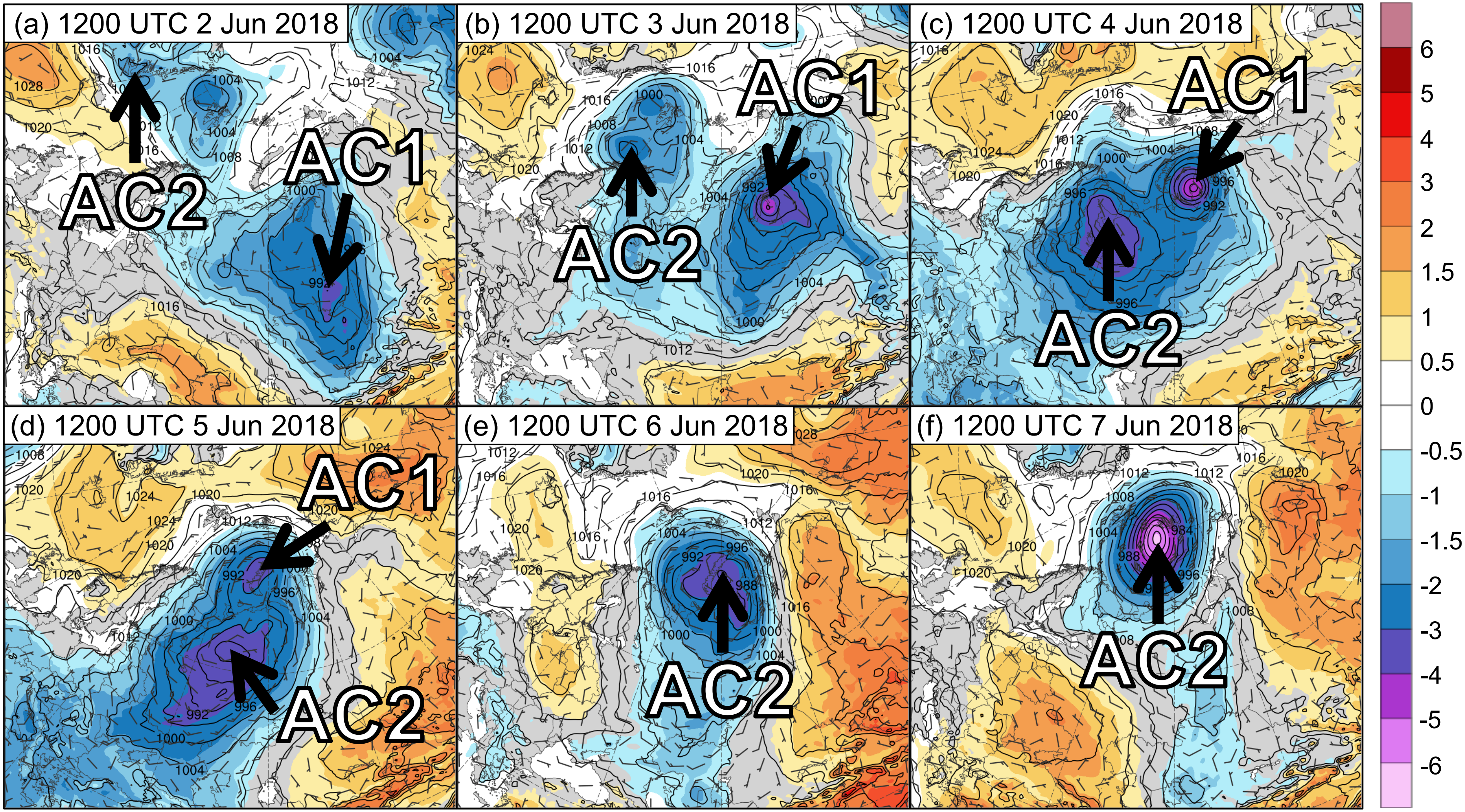
1200 UTC 7 June 2012



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

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

6) Interactions between Arctic Cyclones



SLP (hPa, black), 10-m winds (m s^{-1}, flags and barbs), and standardized SLP anomalies (σ, shaded)

Two Intense Arctic Cyclones in June 2018

7) Discussion

- Remnants of TS Alberto are absorbed into the cyclonic/ frontal region of CL over southern Canada

- CL moves northeastward, weakens over the Davis Strait, and redevelops as a lee cyclone (AC2) east of Greenland

- Successive deep troughs over Eurasia in early June that form in response to cyclonic wave breaking foster development of AC1 and AC2

- AC1 forms near the Caspian Sea along a trailing cold front, moves northeastward, deepens, and reaches the Kara Sea

Two Intense Arctic Cyclones in June 2018

7) Discussion

- AC2 intensifies as an ordinary baroclinic cyclone over northwestern Europe in conjunction with a strong jet stream

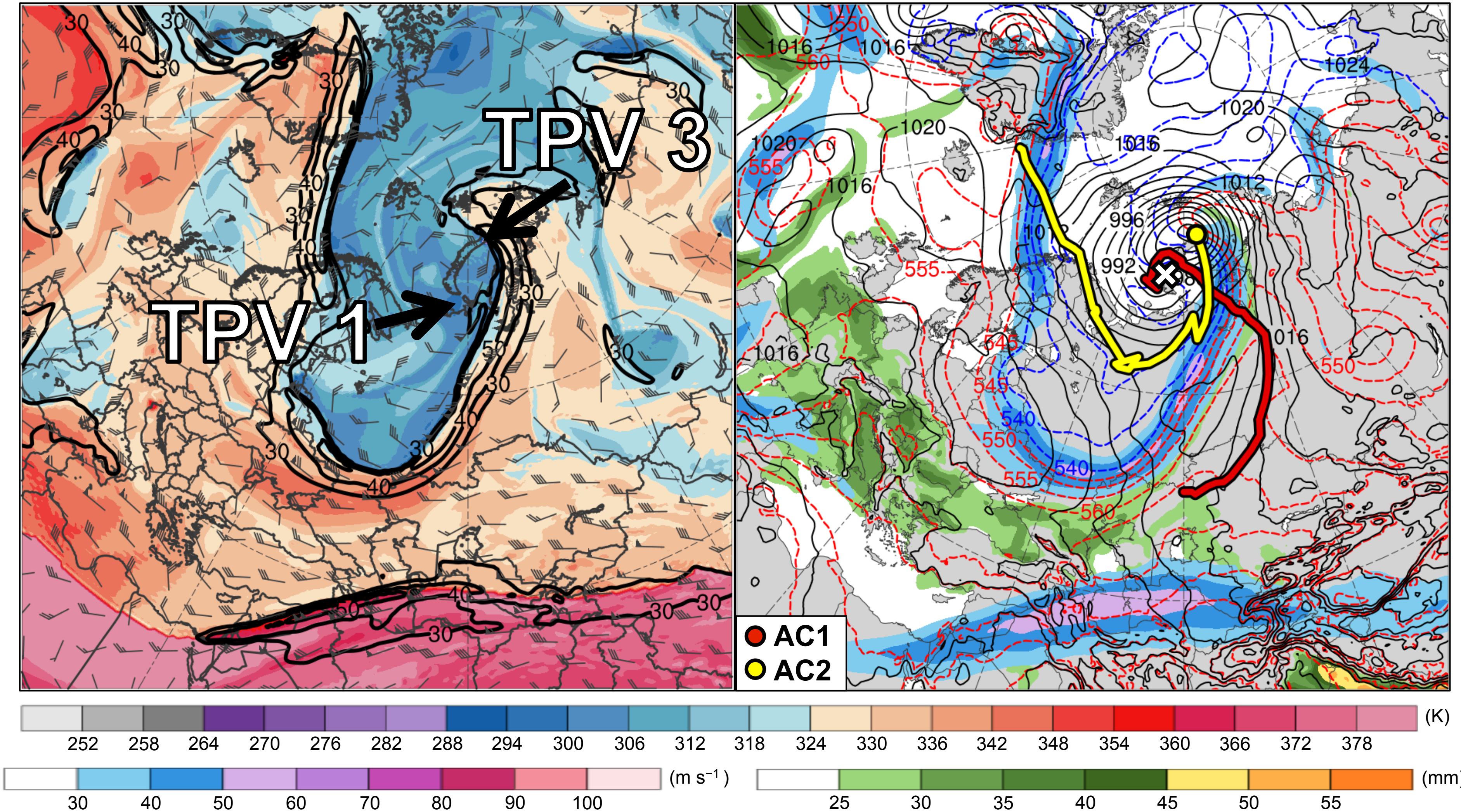
- TPVs embedded within deep troughs likely contribute to rapid deepening of AC1 and AC2 in the left exit region of a jet streak

- AC2 interacts and merges with AC1 and becomes the dominant cyclone, with a peak intensity of 962 hPa and a standardized SLP anomaly of $< -6\ \sigma$

Extra Slide

5) Synoptic Evolution

0000 UTC 7 June 2012



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