Forecast Skill of the Development of a Strong Extratropical Cyclone Linked to Tropopause Polar Vortices

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ATM 621: Structure and Dynamics of Extratropical Cyclones

Project Proposal

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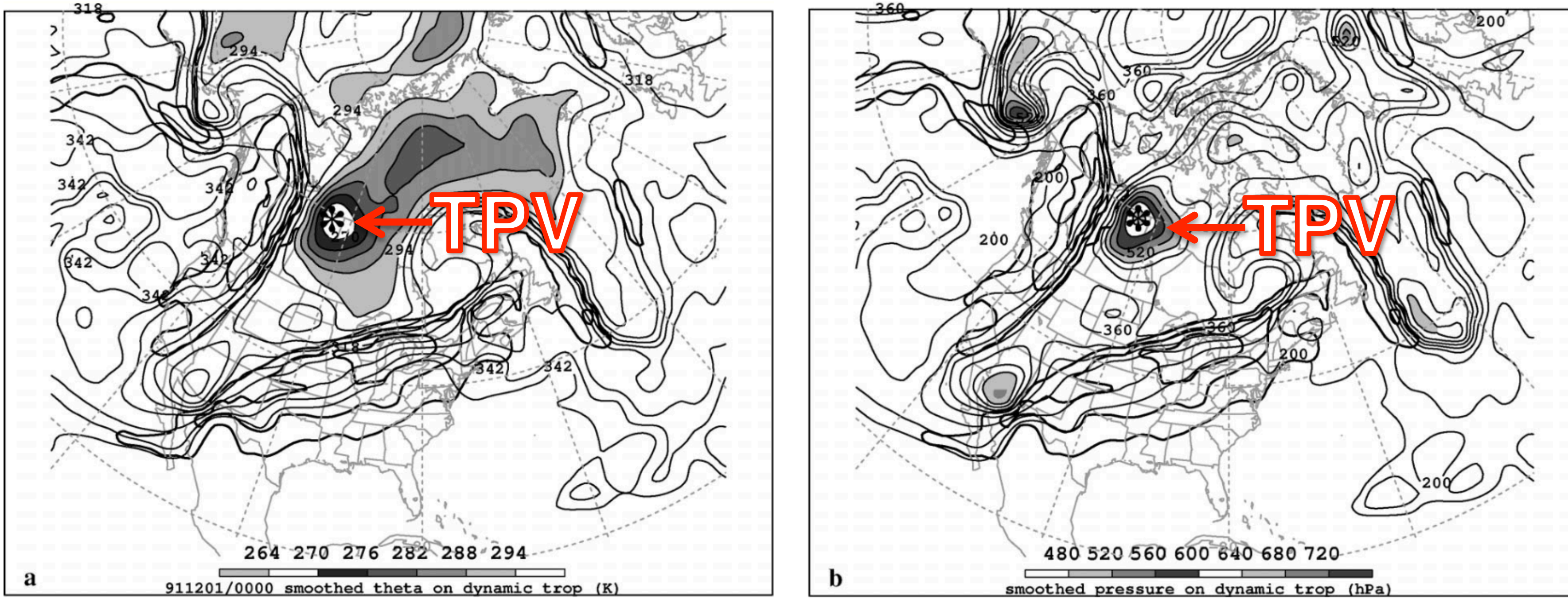
What are Tropopause Polar Vortices (TPVs)?

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



(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 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 midlatitude jet streams, and act as precursors to development of strong extratropical cyclones (ECs)

- Lower-tropospheric cold pools that many accompany TPVs can further enhance baroclinicity throughout troposphere, providing additional dynamical support for development of strong ECs

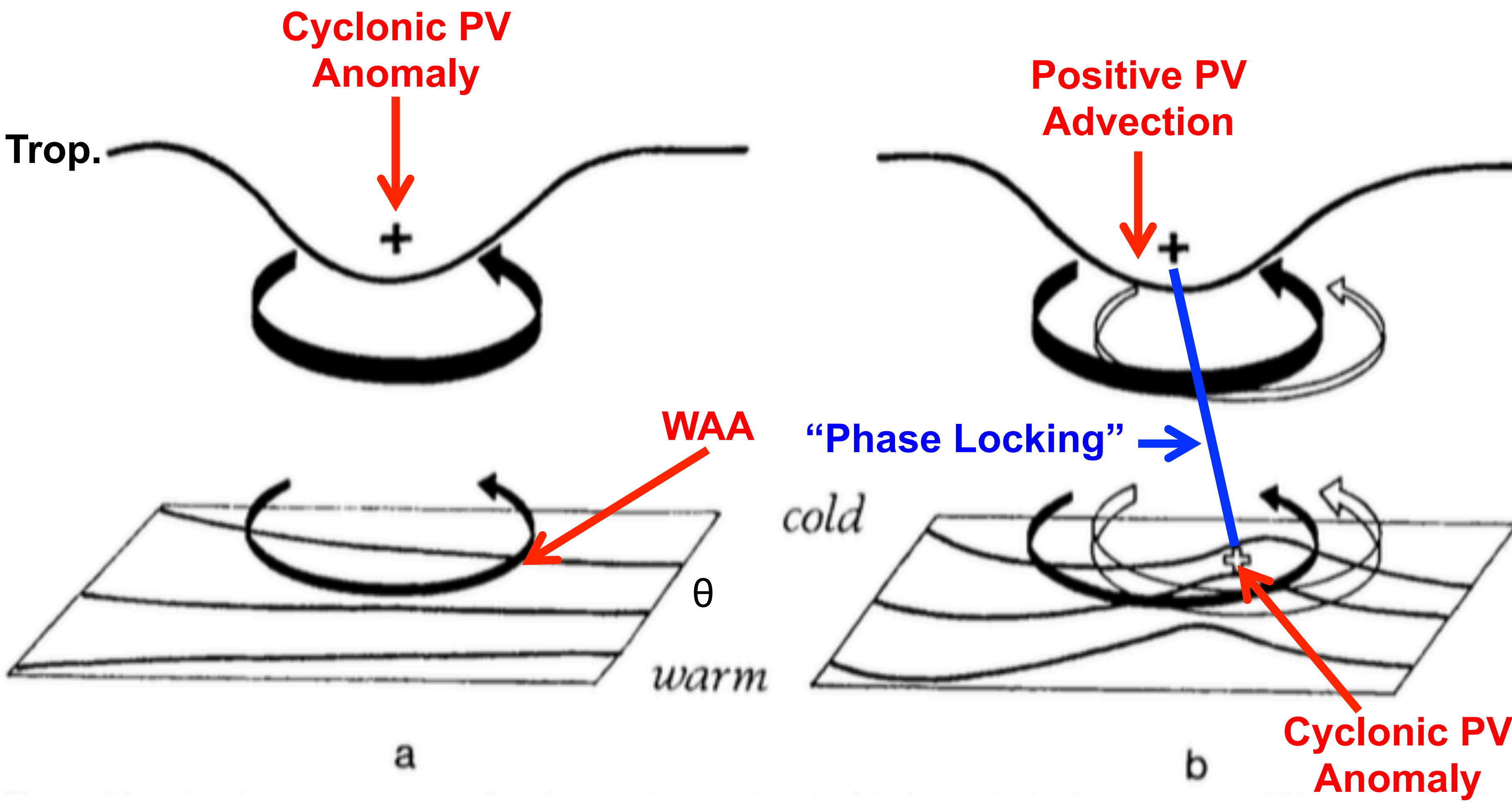
- Strong ECs may lead to extreme weather events (EWEs) associated with heavy precipitation and strong winds that can pose hazards to life and property

Research Goal

- Investigate how the forecast skill of a strong EC linked to TPVs is related to the forecast skill of the TPVs and their interaction with the large-scale flow and one another

Literature Review

Cyclonic PV Anomalies and Cyclogenesis Hoskins et al. (1985)

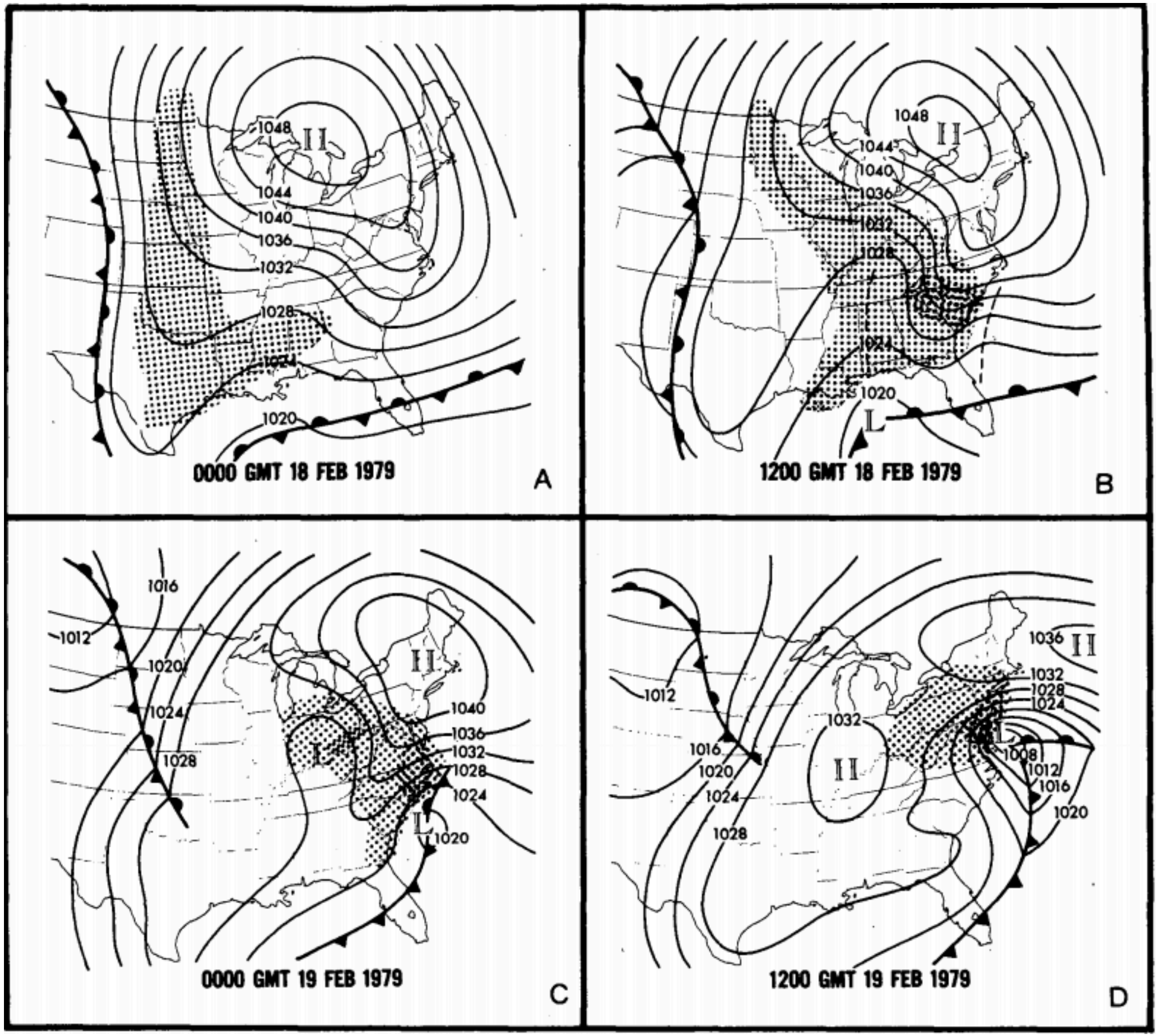


$t = t_0$

$t = t_0 + \Delta t$

Presidents' Day Storm of 1979

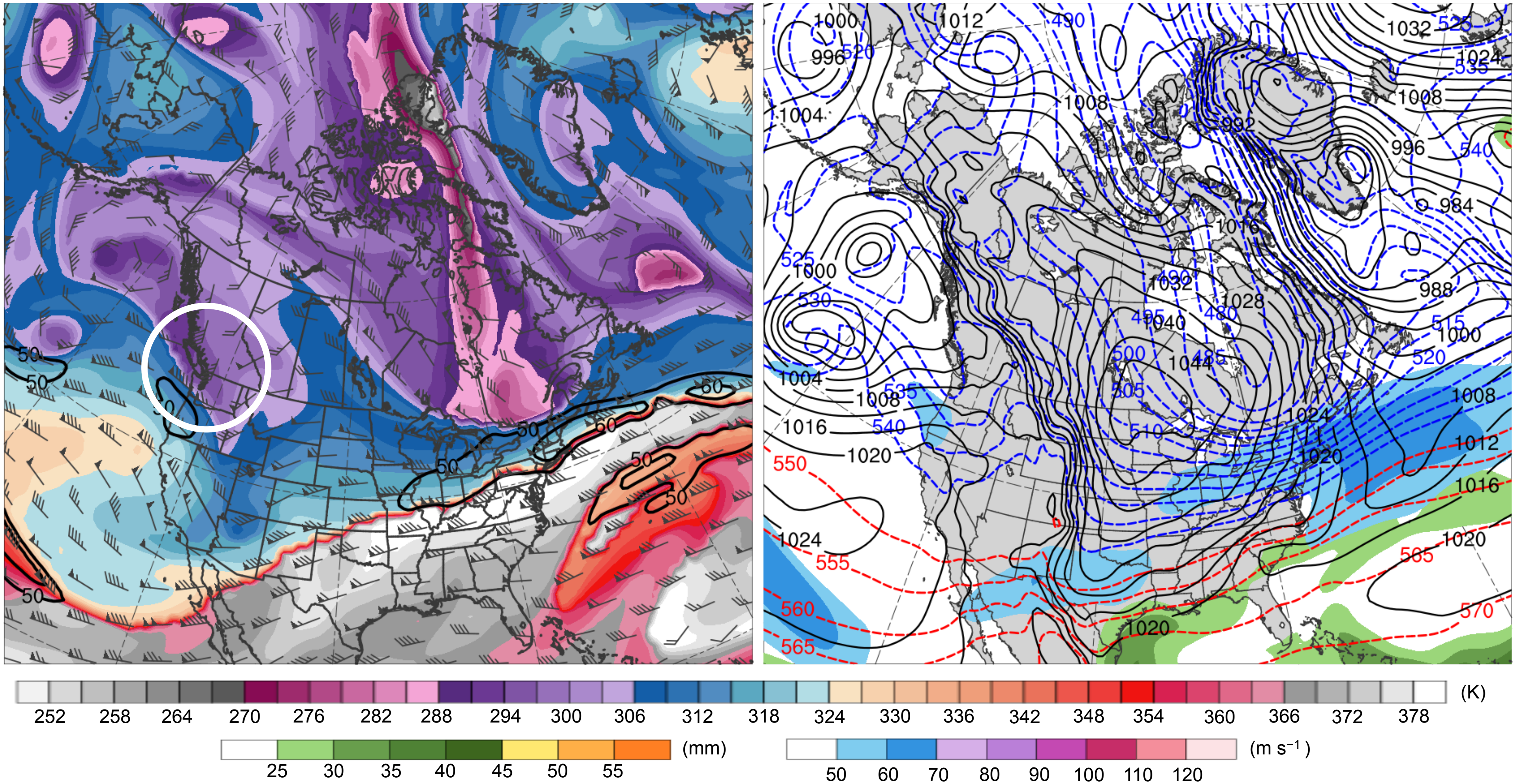
Uccellini et al. (1985)



Sea level pressure (mb) and surface frontal analyses for (a) 0000 GMT 18 Feb, (b) 1200 GMT 18 Feb, (c) 0000 GMT 19 Feb, and (d) 1200 GMT 19 Feb 1979. Shading represents precipitation; dark shading indicates moderate-to-heavy precipitation. Dashed line in (b) denote inverted and coastal troughs. Adapted from Fig. 1 in Uccellini et al. 1985.

Presidents' Day Storm of 1979 0000 UTC 17 Feb 1979

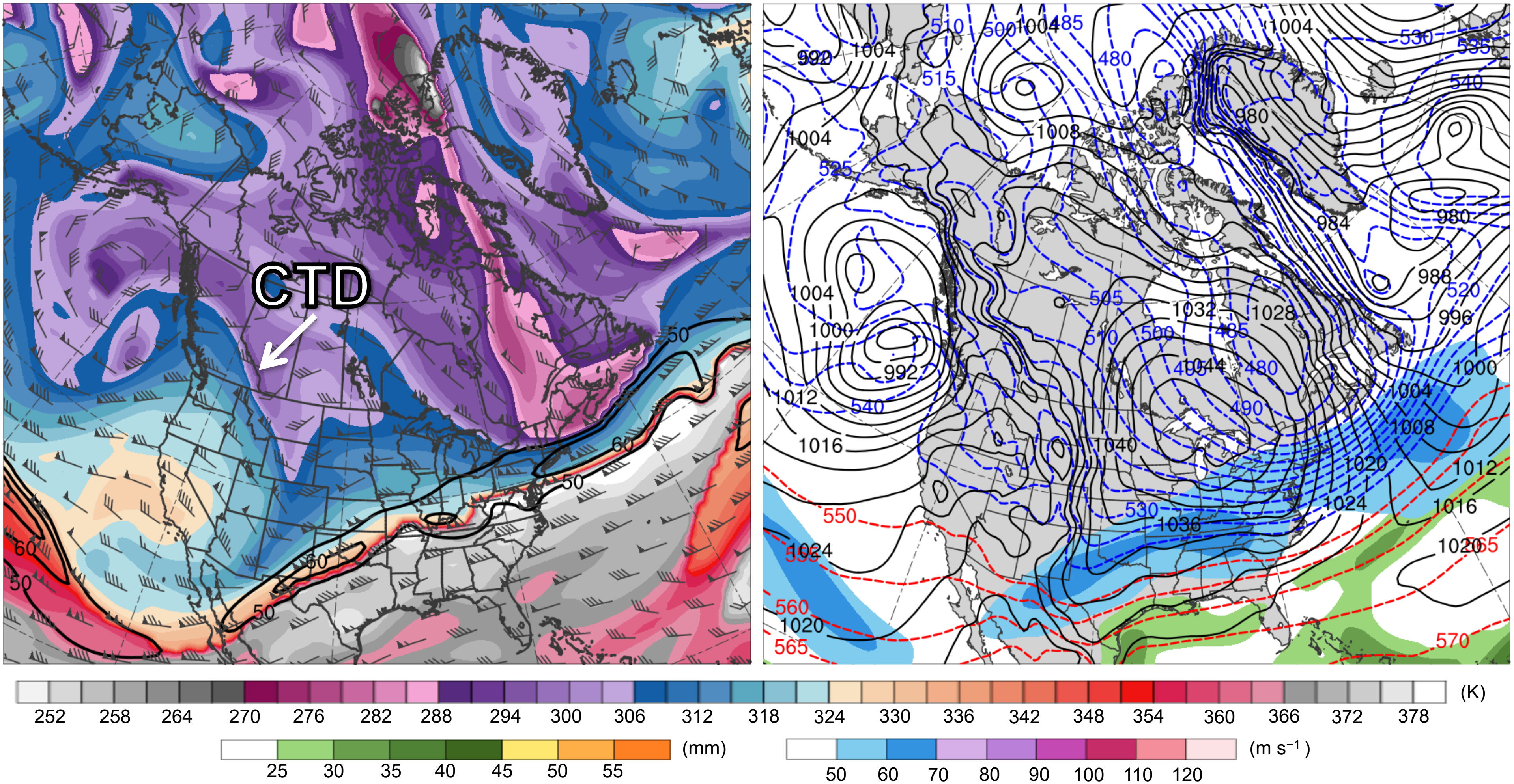
Data Source: 0.5° ERA-Interim



Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 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), MSLP (hPa, black), PW (mm, shaded)

Presidents’ Day Storm of 1979 1200 UTC 17 Feb 1979

Data Source: 0.5° ERA-Interim



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Presidents' Day Storm of 1979 0000 UTC 18 Feb 1979

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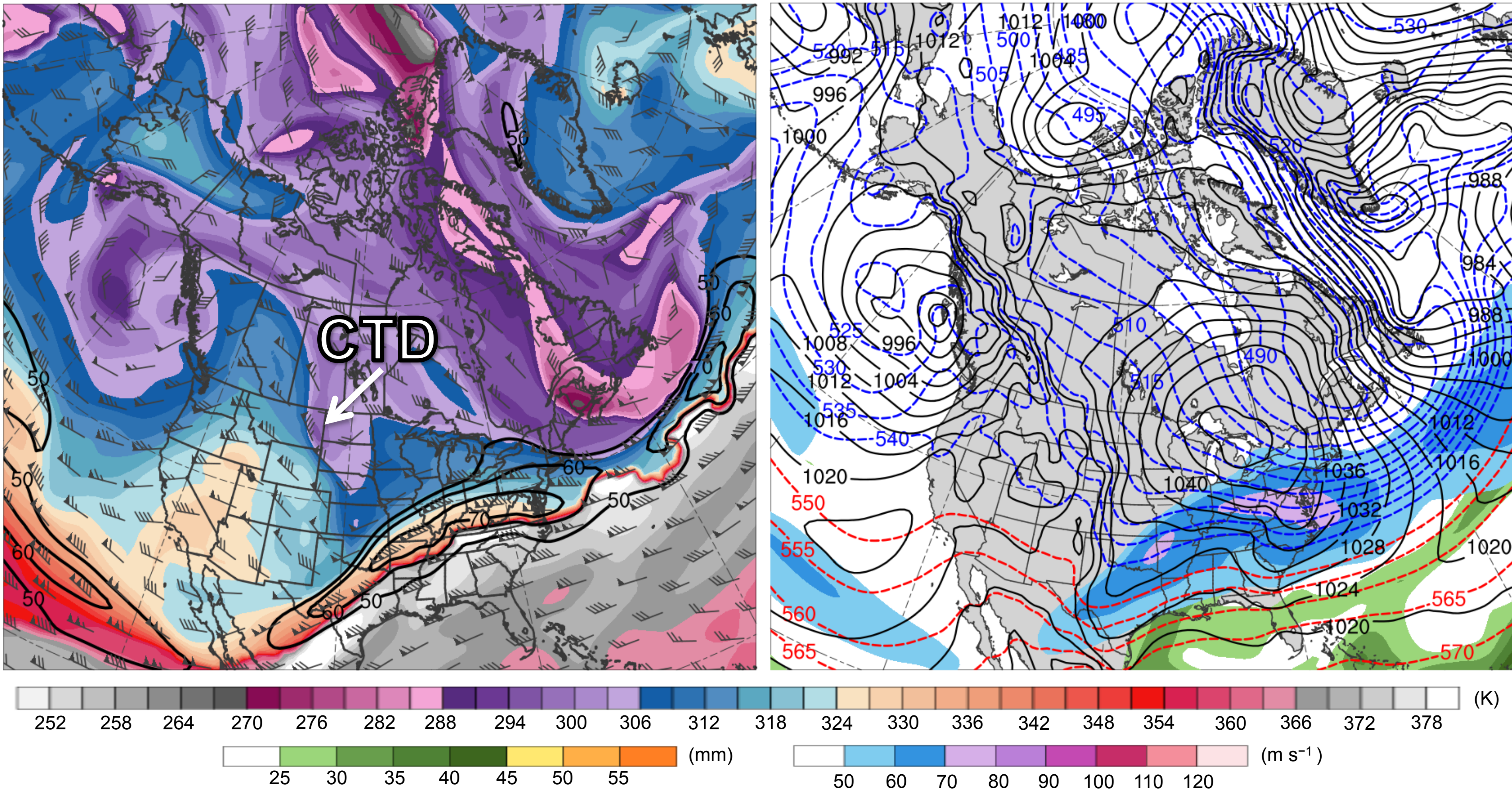

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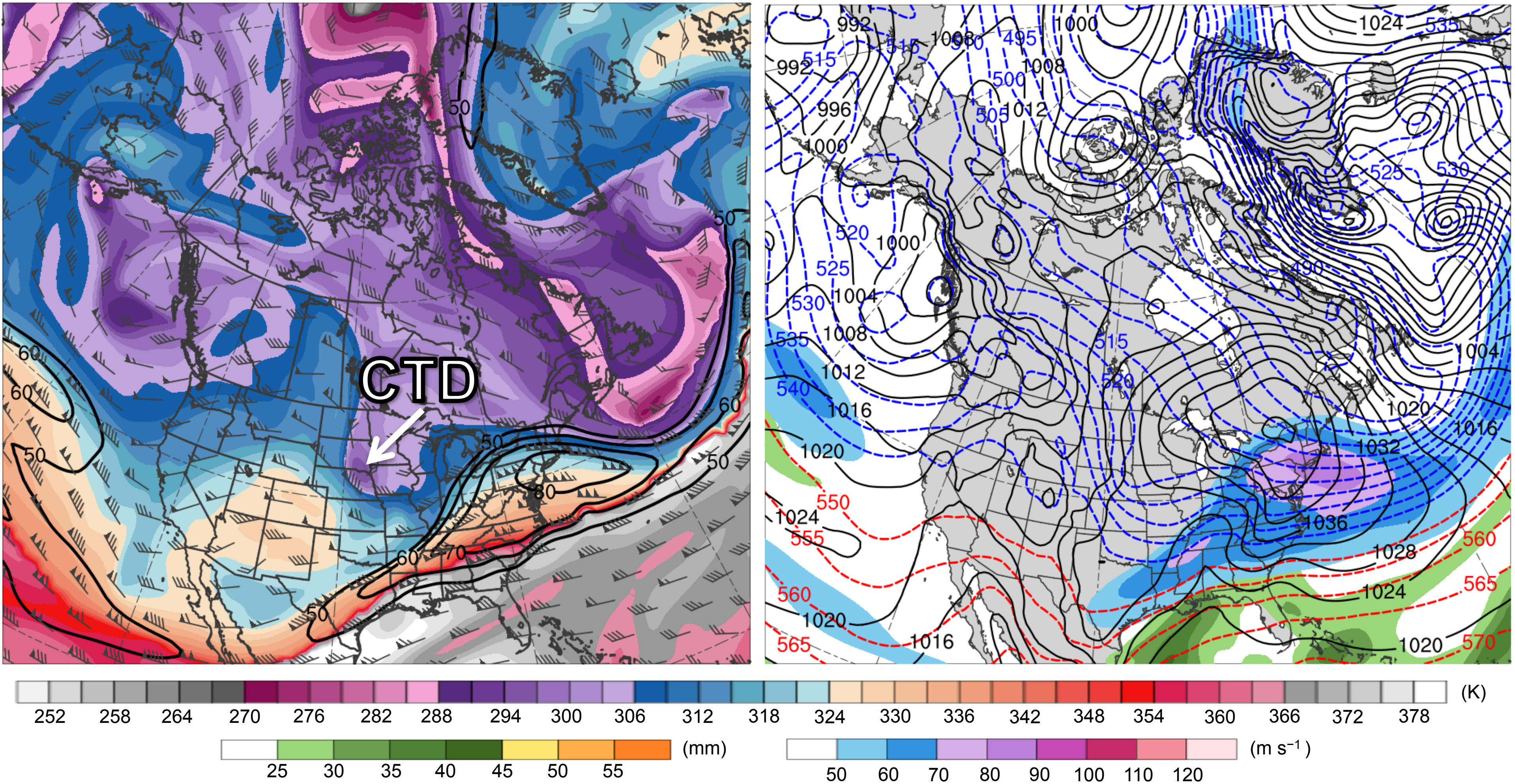
Presidents' Day Storm of 1979 1200 UTC 18 Feb 1979

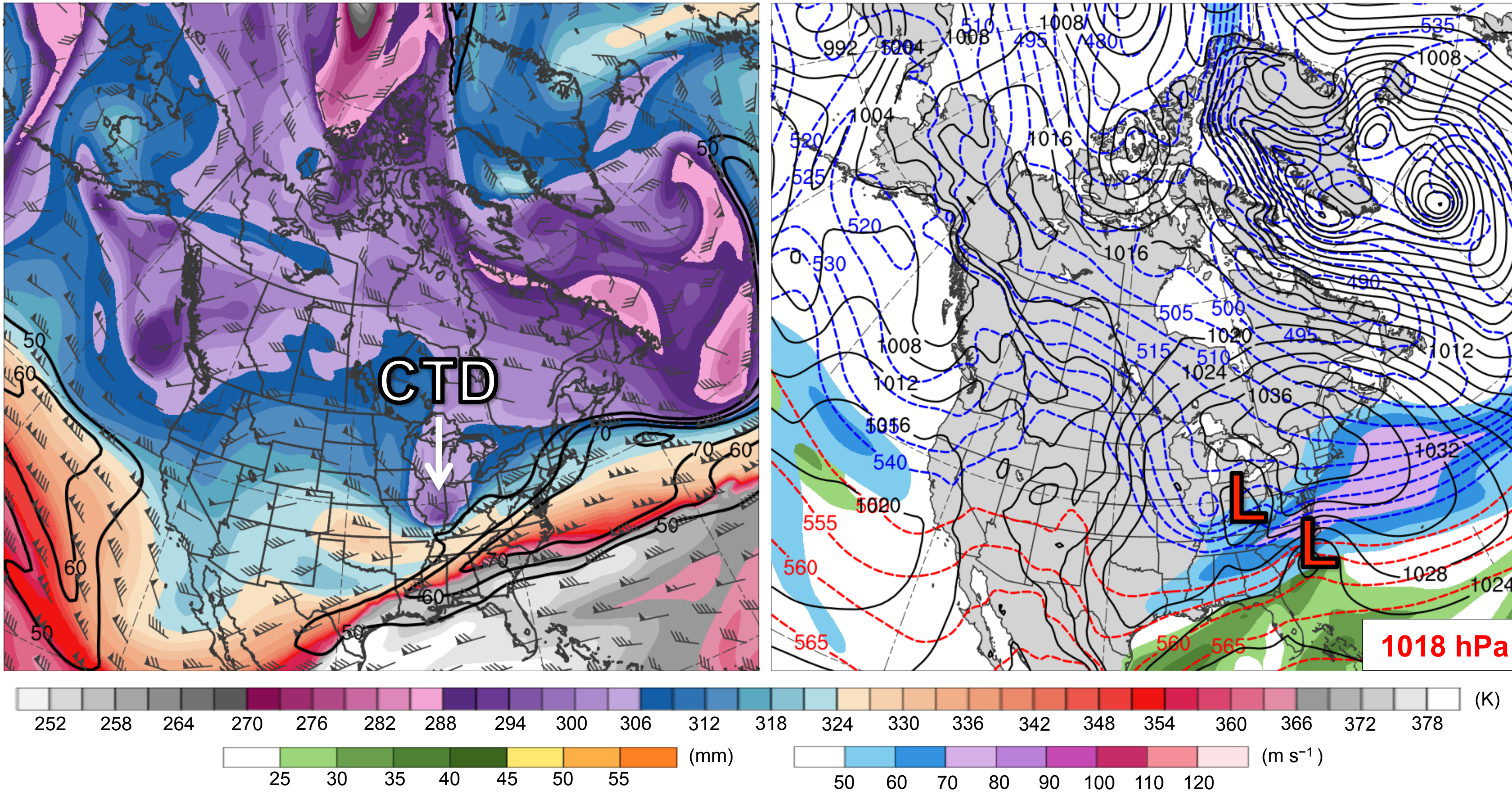
Data Source: 0.5° ERA-Interim



Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 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), MSLP (hPa, black), PW (mm, shaded)

Presidents' Day Storm of 1979 0000 UTC 19 Feb 1979

Data Source: 0.5° ERA-Interim



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Presidents' Day Storm of 1979 1200 UTC 19 Feb 1979

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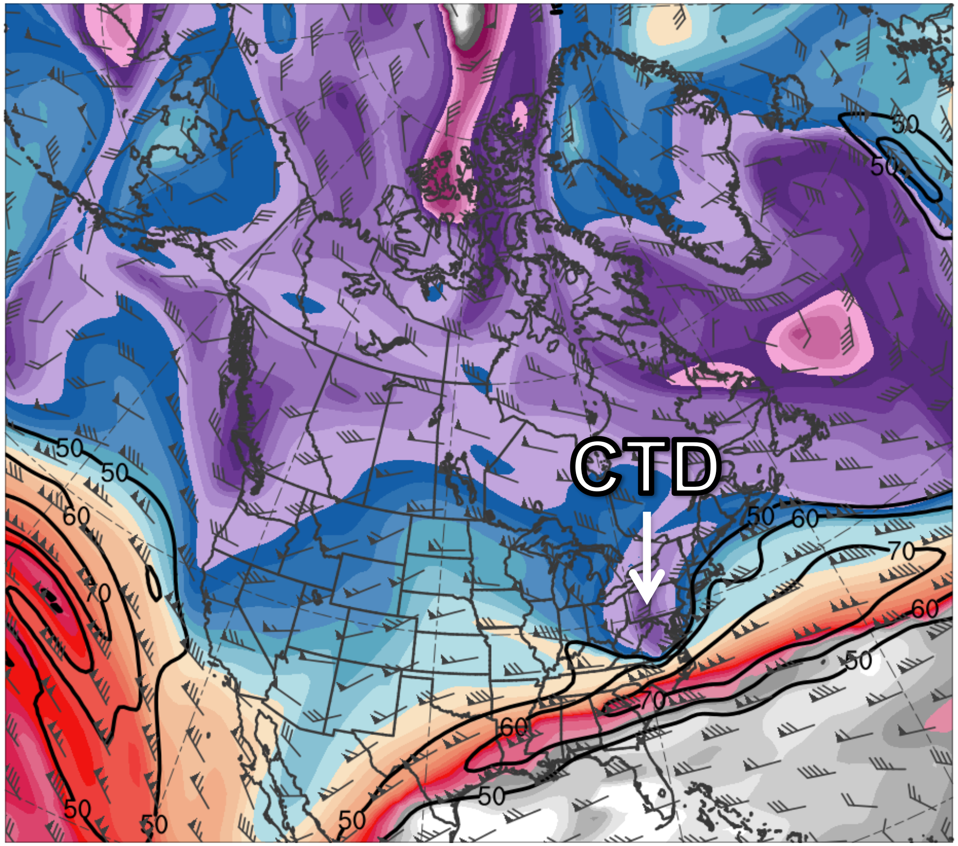

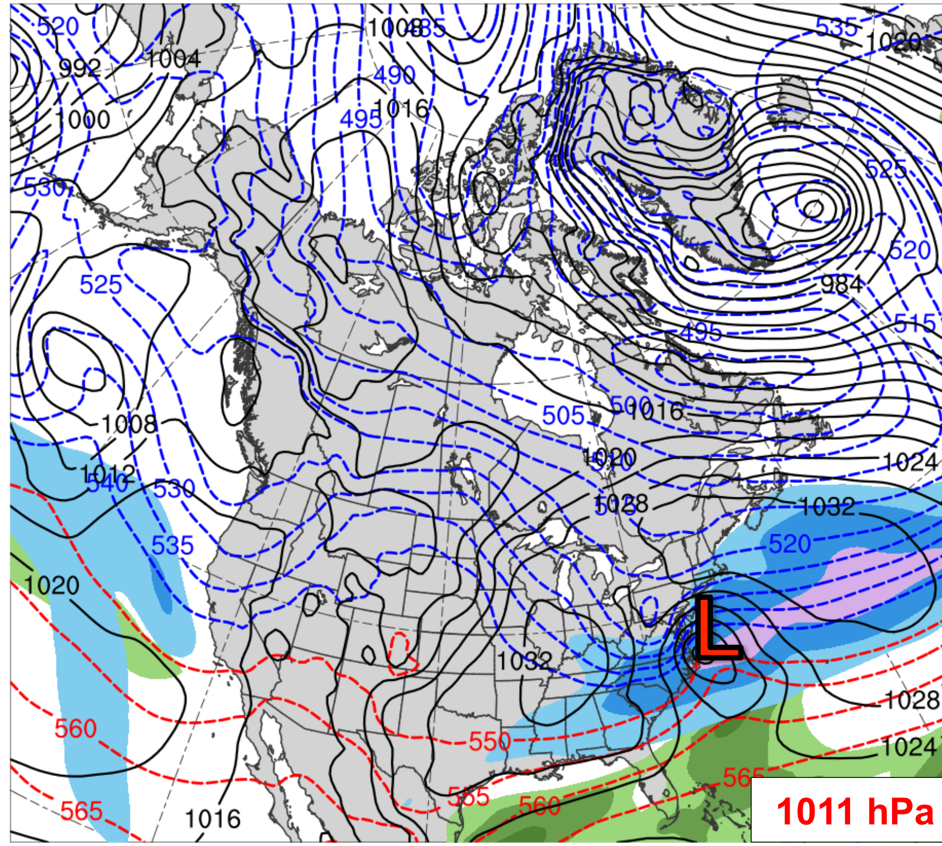

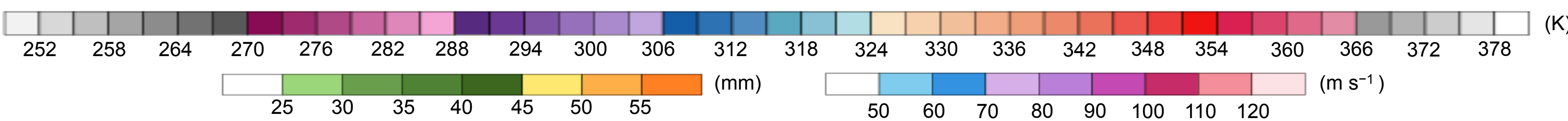

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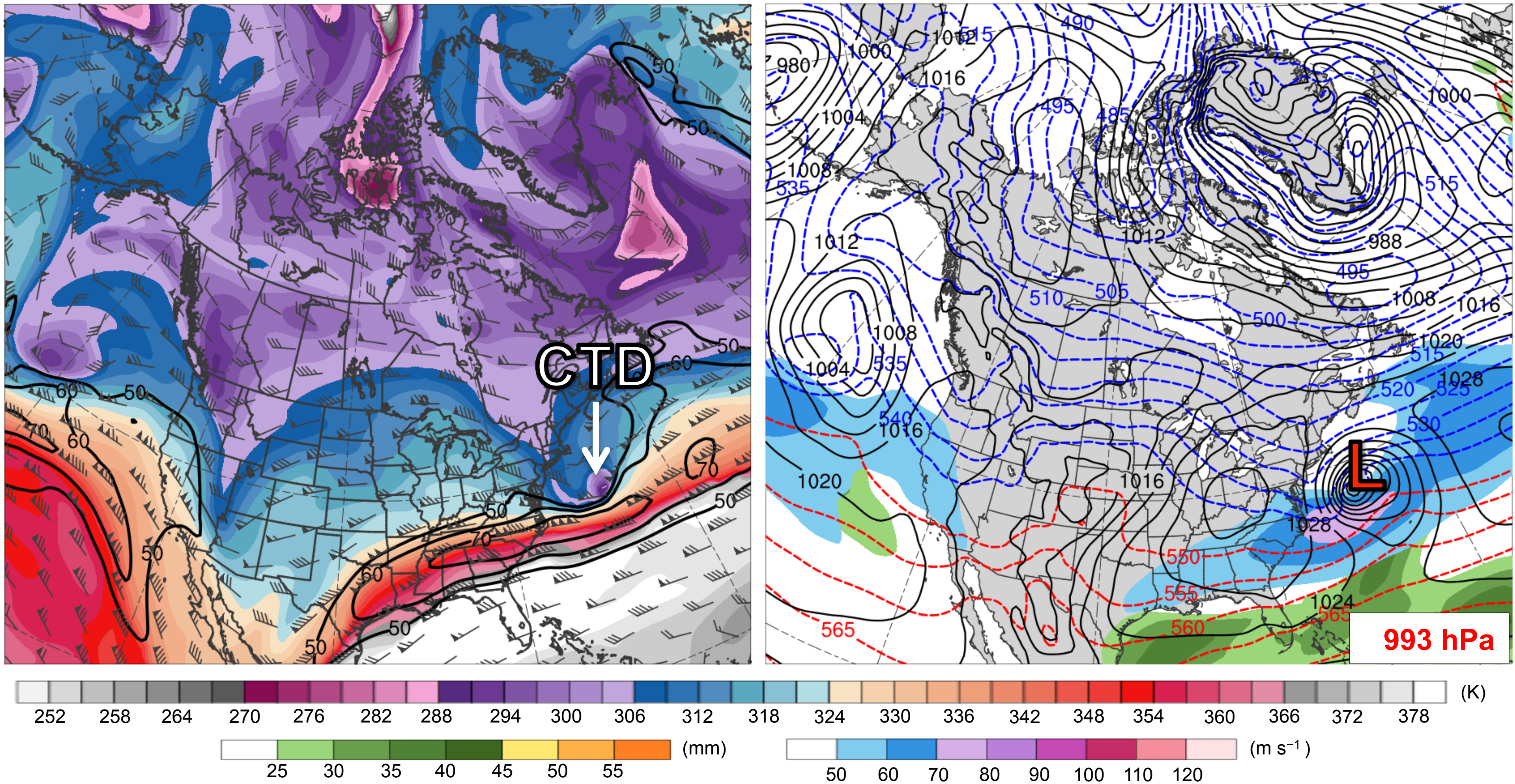
Presidents' Day Storm of 1979 0000 UTC 20 Feb 1979

Data Source: 0.5° ERA-Interim



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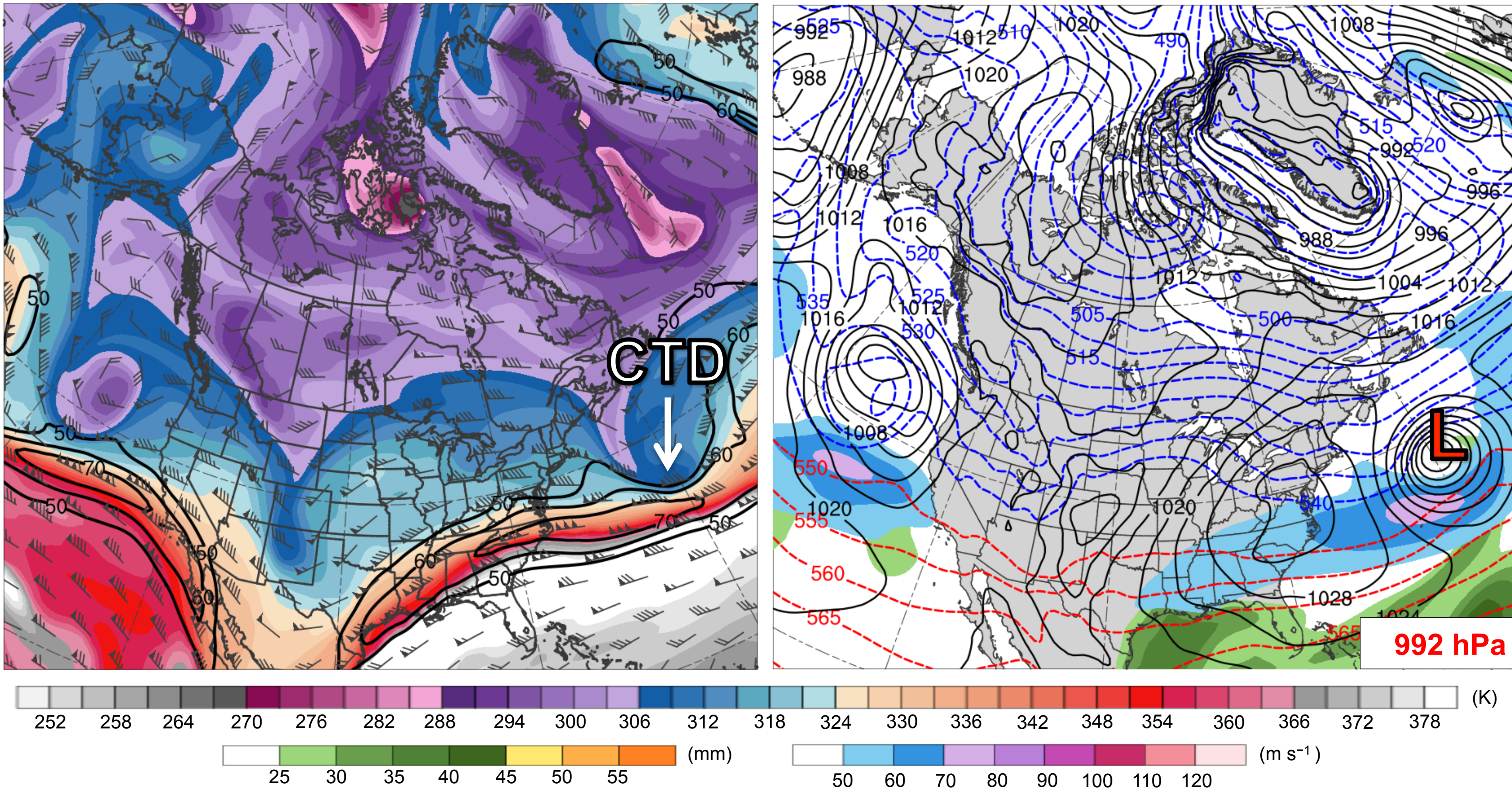

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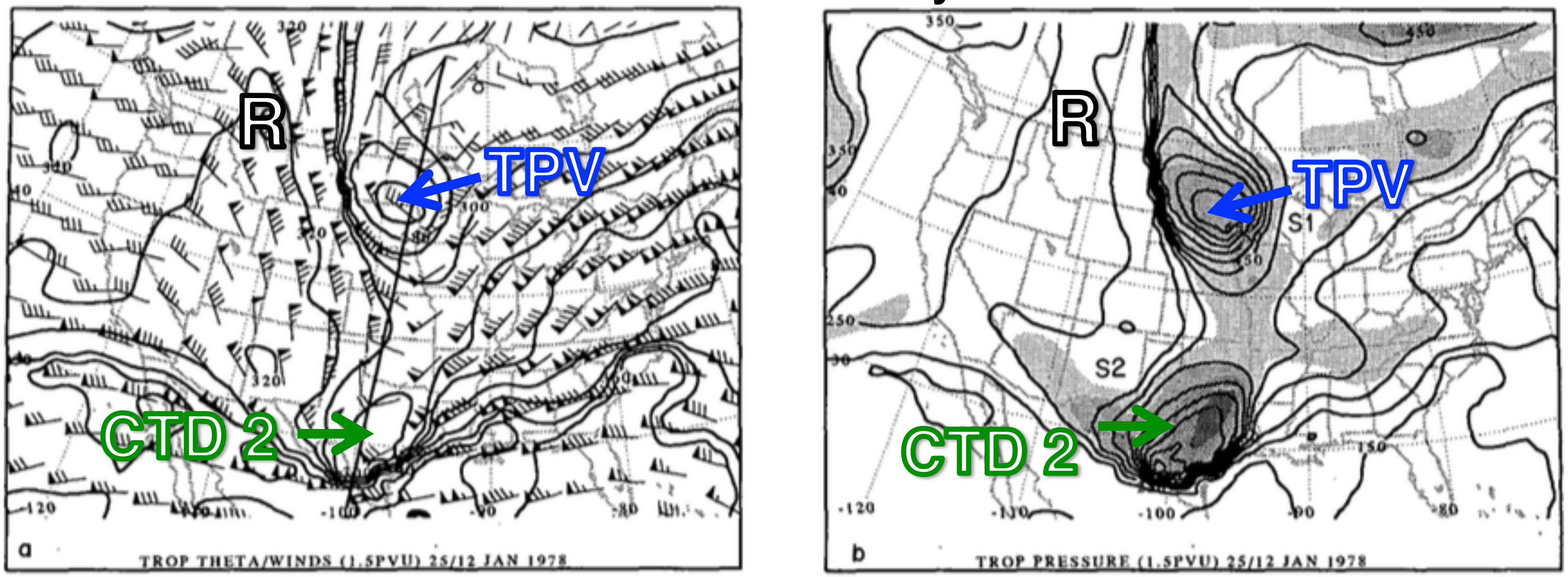
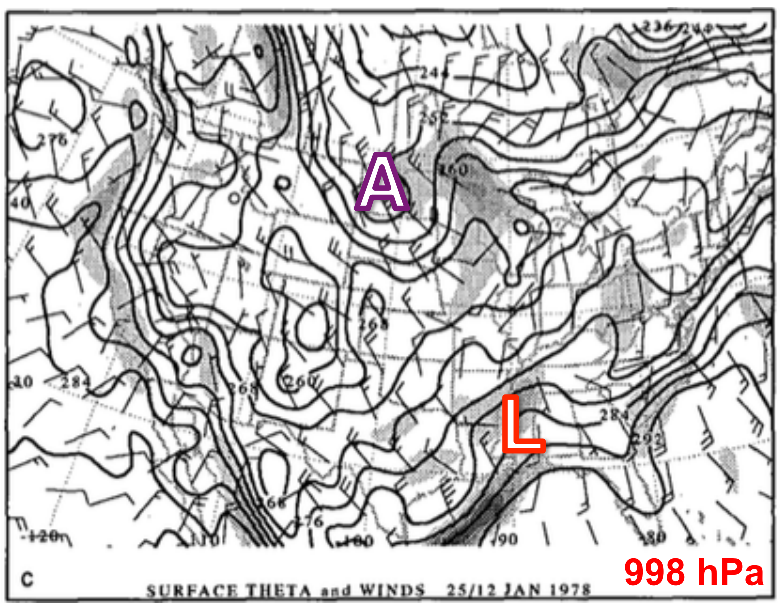
1978 Cleveland Superbomb

Hakim et al. (1995, 1996)

1200 UTC 25 January 1978



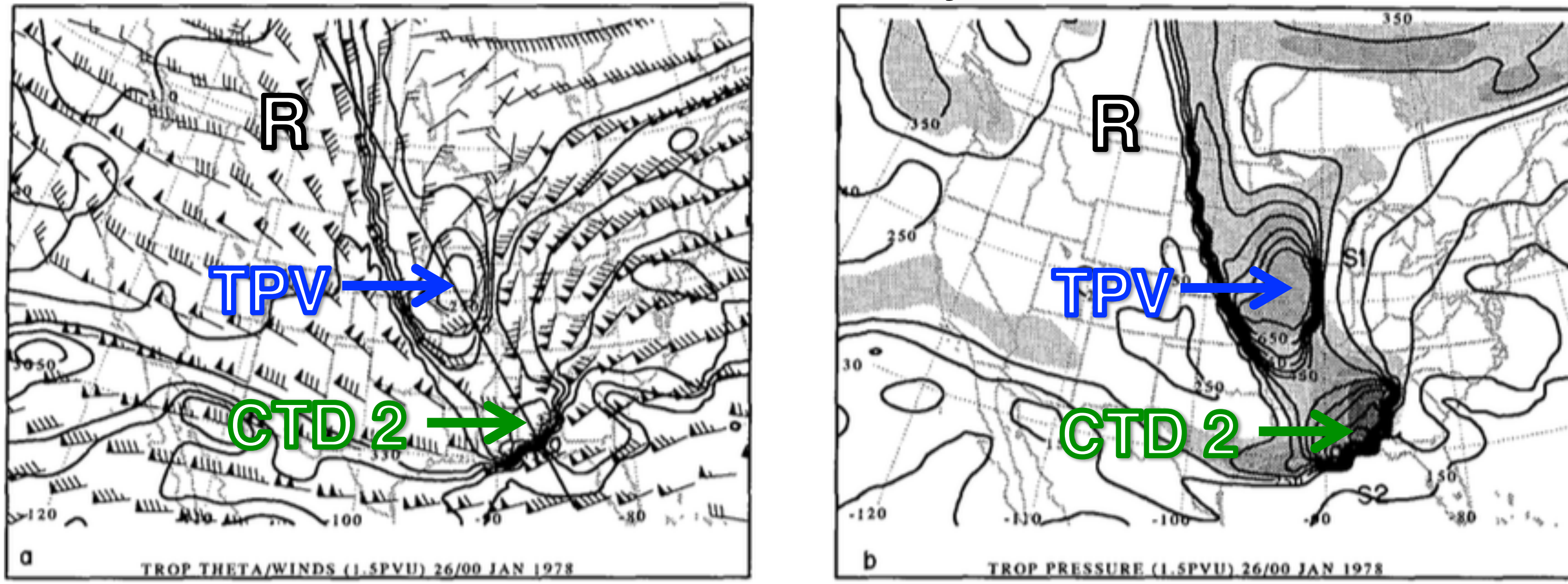


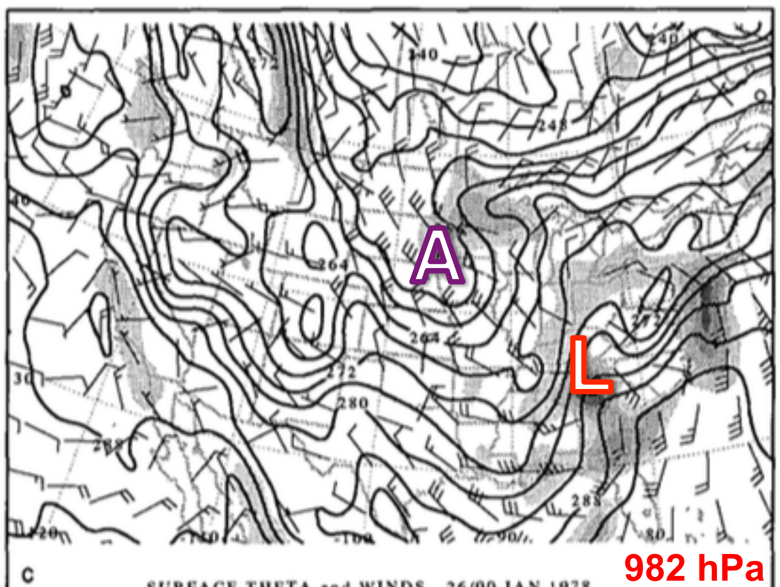
(a) Dynamic tropopause (DT; 1.5 PVU) potential temperature (black contours, every 10 K) and wind (flags and barbs, m s^{-1}); (b) DT pressure (black contours, every 50 hPa) and relative vorticity (shaded every 2×10^{-5} s^{-1} for values greater than 4×10^{-5} s^{-1}); (c) surface potential temperature (black contours, every 4 K) and relative vorticity (shaded every 2×10^{-5} s^{-1} for values greater than 2×10^{-5} s^{-1}). Adapted from Fig. 6 in Hakim et al. (1995).

1978 Cleveland Superbomb

Hakim et al. (1995, 1996)

0000 UTC 26 January 1978



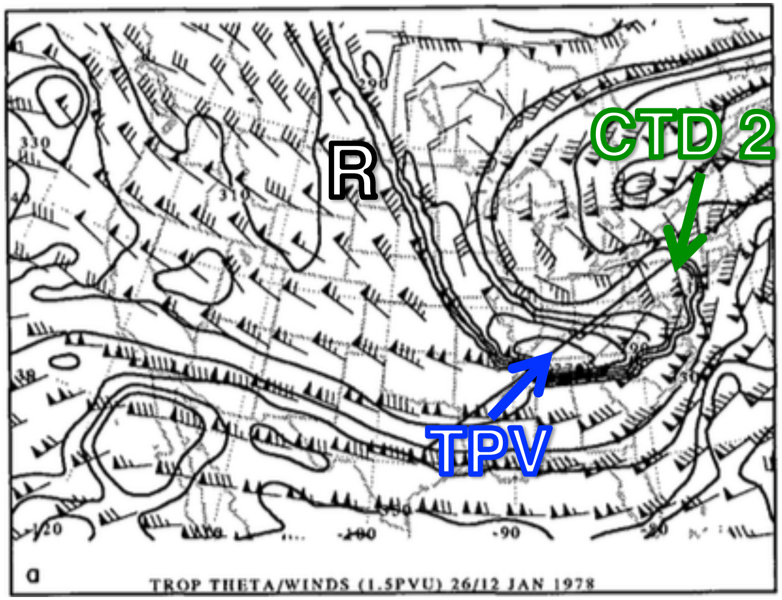


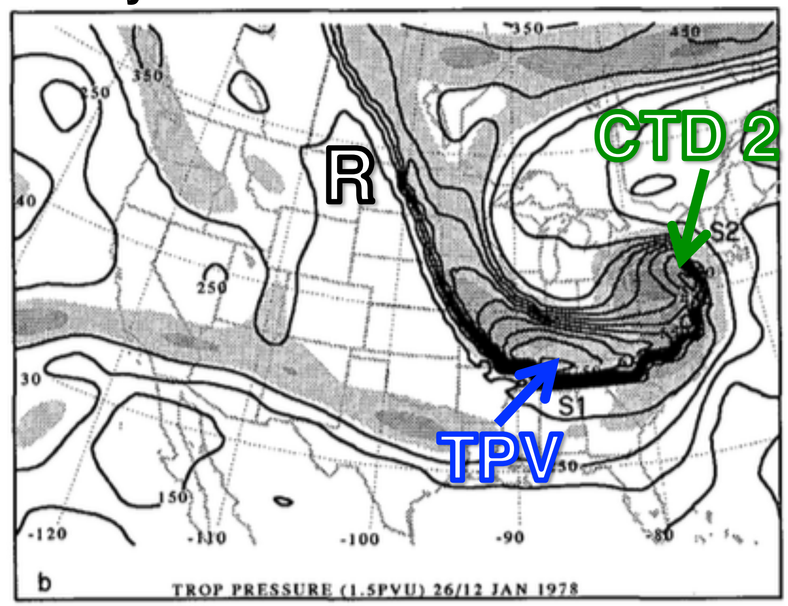
(a) Dynamic tropopause (DT; 1.5 PVU) potential temperature (black contours, every 10 K) and wind (flags and barbs, m s^{-1}); (b) DT pressure (black contours, every 50 hPa) and relative vorticity (shaded every 2×10^{-5} s^{-1} for values greater than 4×10^{-5} s^{-1}); (c) surface potential temperature (black contours, every 4 K) and relative vorticity (shaded every 2×10^{-5} s^{-1} for values greater than 2×10^{-5} s^{-1}). Adapted from Fig. 8 in Hakim et al. (1995).

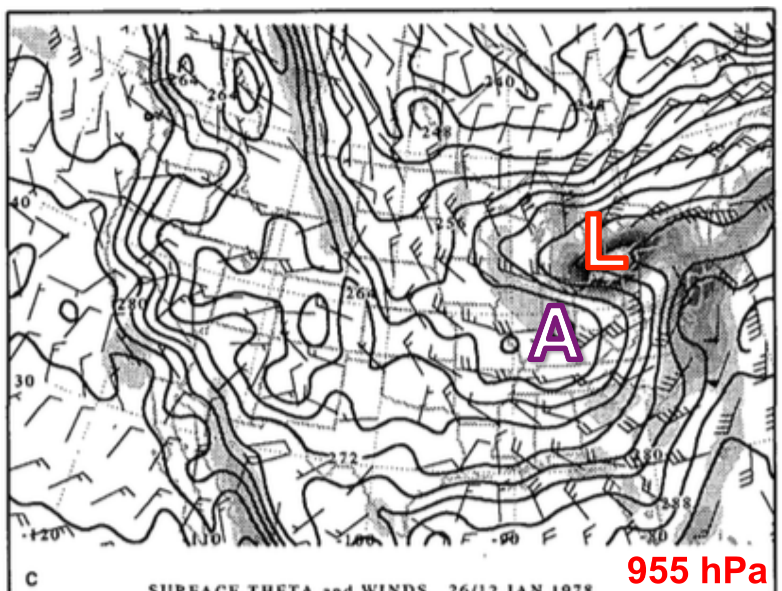
1978 Cleveland Superbomb

Hakim et al. (1995, 1996)

1200 UTC 26 January 1978







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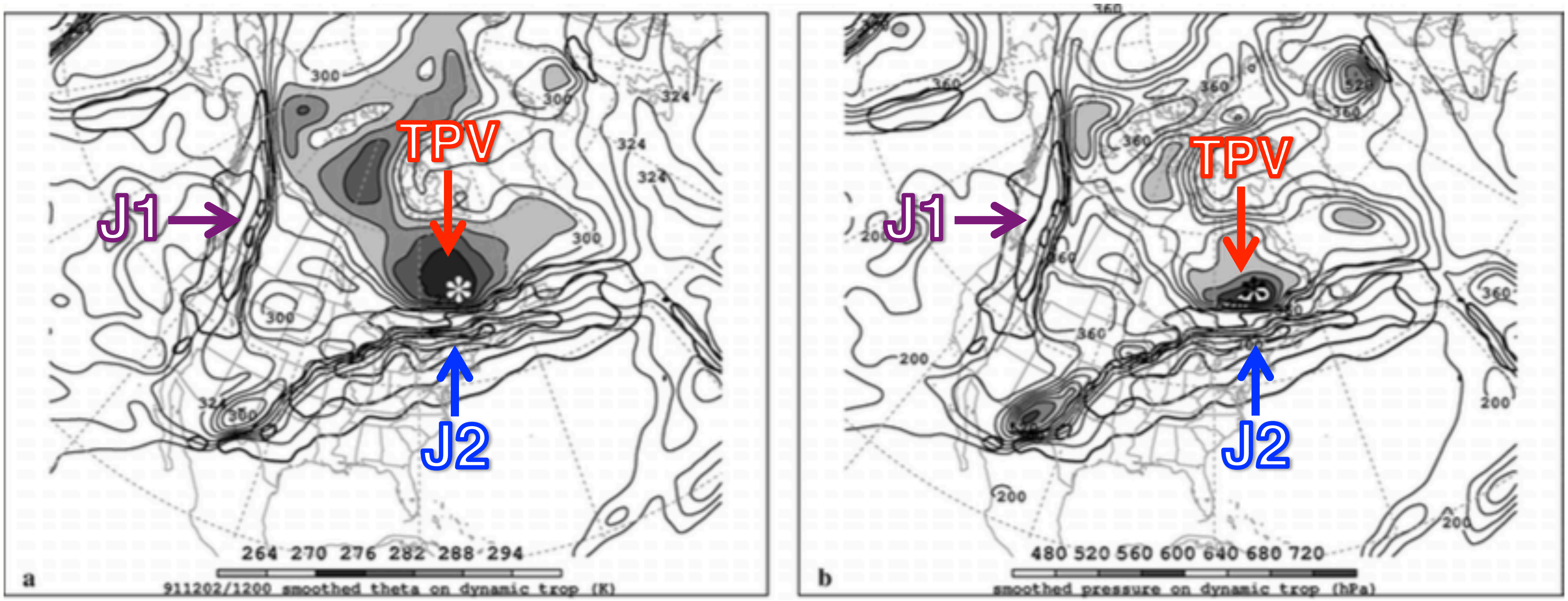
TPV–Jet Interaction

Pyle et al. (2004)

- TPV/CTD–jet interactions may lead to formation or intensification of a jet streak
- Strengthening ageostrophic circulations associated with strengthening jet streaks may play important roles in the development of tropopause folds and vertical motion patterns that may aid in cyclogenesis.

1200 UTC 2 December 1991



(left) DT (1.5-PVU surface) wind speed (every 15 m s^{-1} starting at 50 m s^{-1}, thick contours) and potential temperature (K, thin contours and shading); (right) same as left except DT pressure (hPa, thin contours and shading).
Adapted from Fig. 12 in Pyle et al. (2004).

CAOs and ECs

- Konrad and Colucci (1989) studied 17 strong cold air outbreak (CAOs) over North America and found that rapid cyclogenesis tended to follow the strongest CAOs

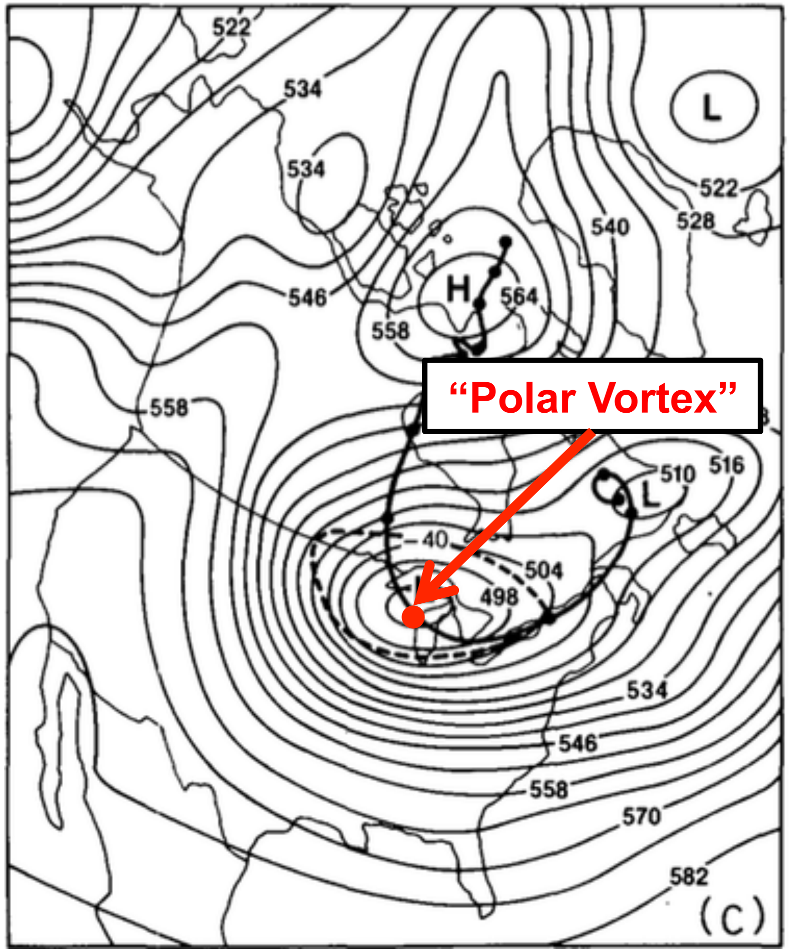
TABLE 1. Temperature, spatial and cyclogenesis characteristics for 17 strong cold air outbreaks.

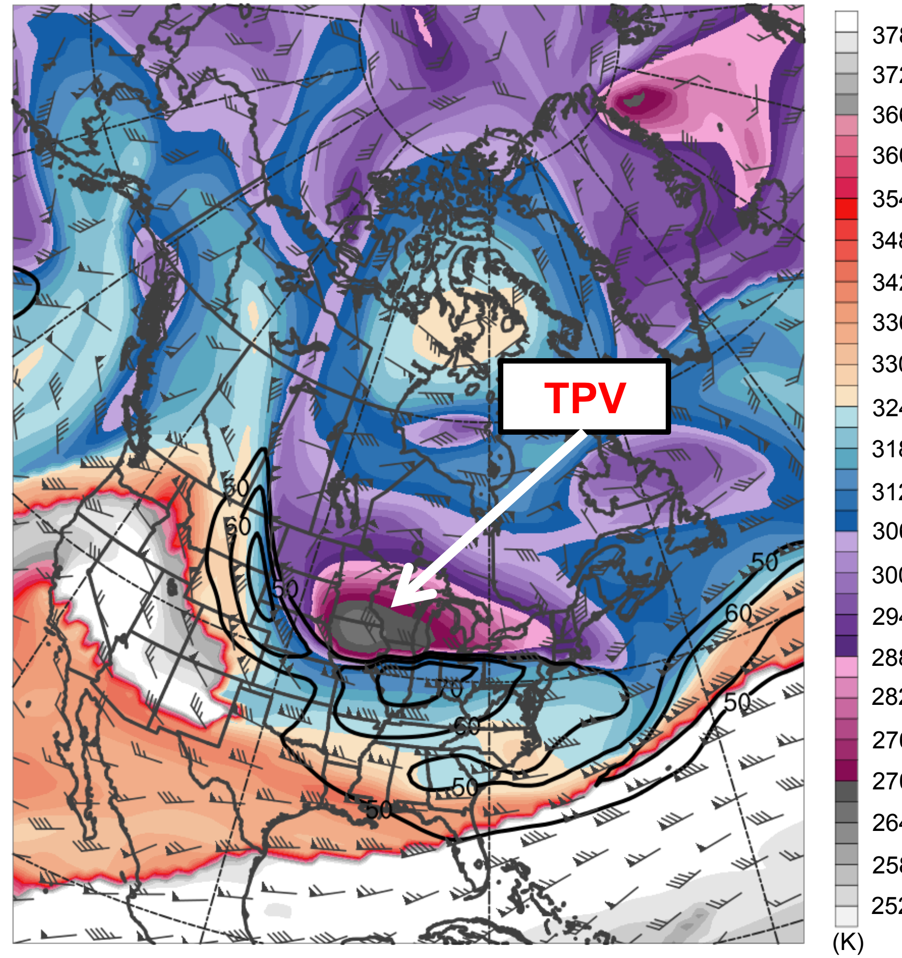
Outbreak		Regional minimum 850 mb temperature (°C)	Cyclogenesis rate (bergerons)		Spatial scale longitude
Number	Date		Preceding	Following	
1	25/12/83	−20.4	NONE	2.4	30
2	10/1/82	−19.2	0.5	2.5	30
3	21/1/85	−17.9	0.3	2.3	43
4	17/1/82	−17.0	0.4	NONE	22
5	17/1/77	−16.5	NONE	1.5	32
6	26/12/85	−15.8	0.2	1.5	29
7	3/1/79	−15.6	0.2	0.9	18
8	25/12/80	−14.9	NONE	1.3	32
9	10/1/78	−14.9	1.5	NONE	33
10	29/1/77	−14.9	1.0	NONE	25
11	12/1/81	−14.7	NONE	2.2	45
12	2/2/76	−14.5	2.4	NONE	14
13	11/1/77	−14.2	1.0	NONE	19
14	21/12/76	−14.1	0.9	NONE	21
15	18/1/76	−13.8	NONE	1.4	22
16	26/12/77	−13.7	0.9	NONE	20
17	21/1/84	−13.5	NONE	NONE	30

Jan 1985 TPV and CAO

Shapiro et al. (1987)

0000 UTC 20 January 1985





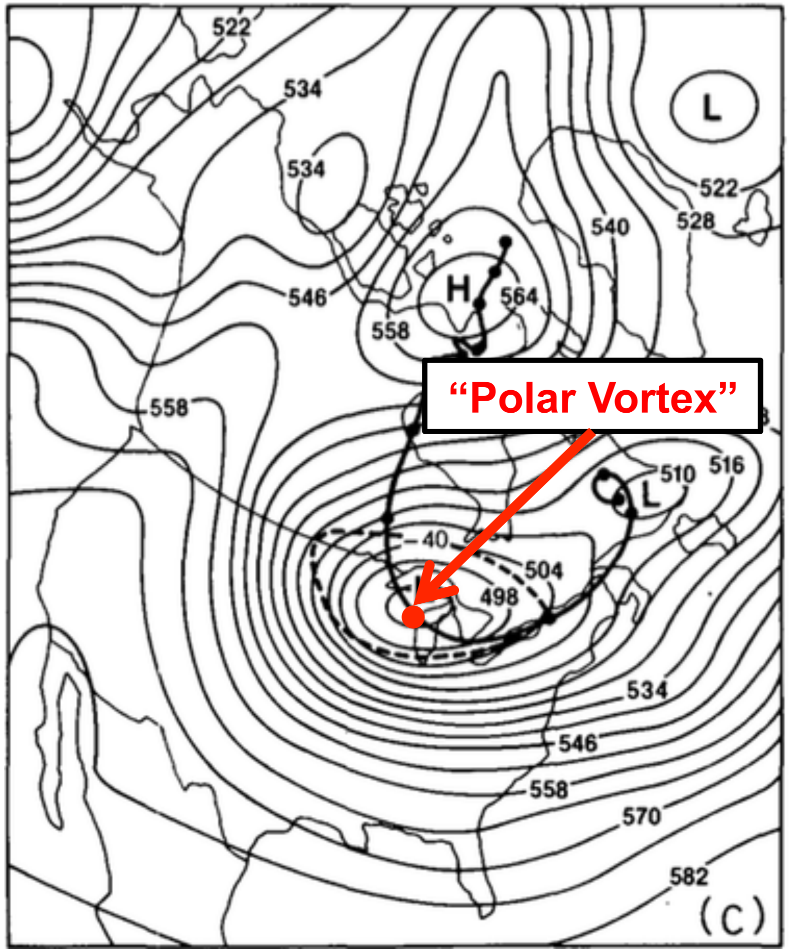
500-hPa geopotential height (black, every 6 dam) and −40°C isotherm (dashed contour); track of polar vortex from 0000 UTC 12 January to 0000 UTC 24 January 1985 (heavy black). Adapted from Fig. 5 in Shapiro et al. (1987).

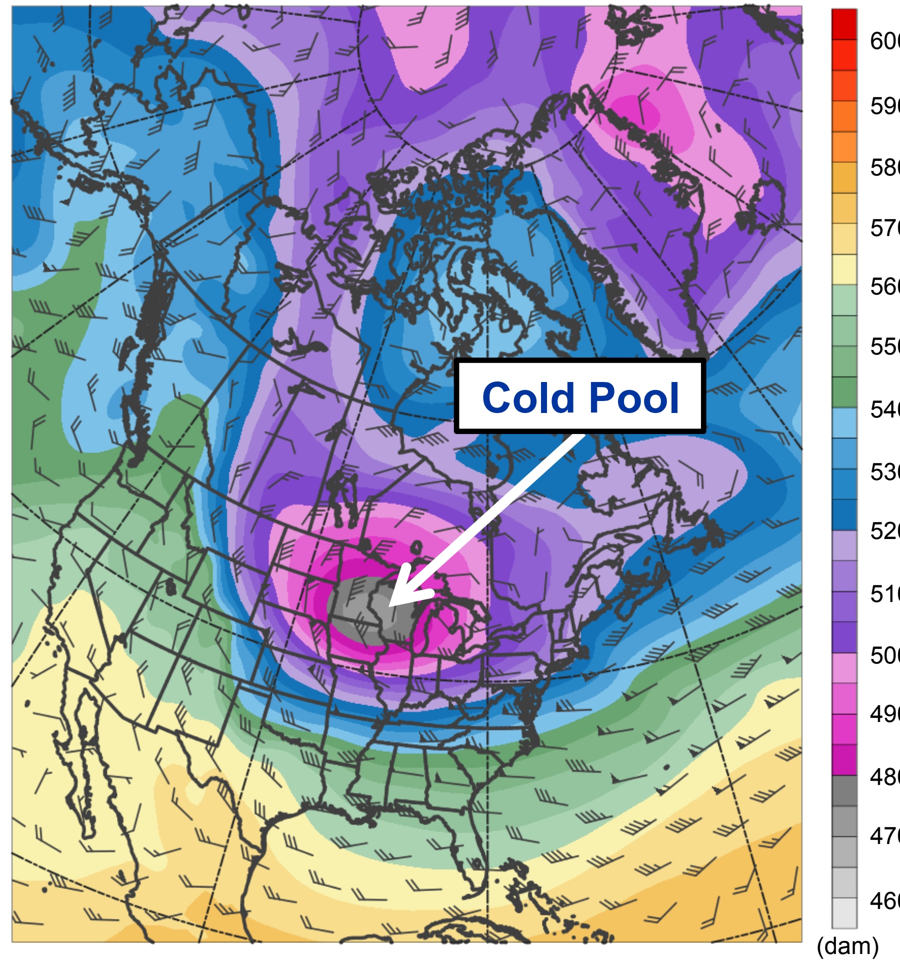
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, barbs) on 2-PVU surface. Data source: ERA-Interim.

Jan 1985 TPV and CAO

Shapiro et al. (1987)

0000 UTC 20 January 1985





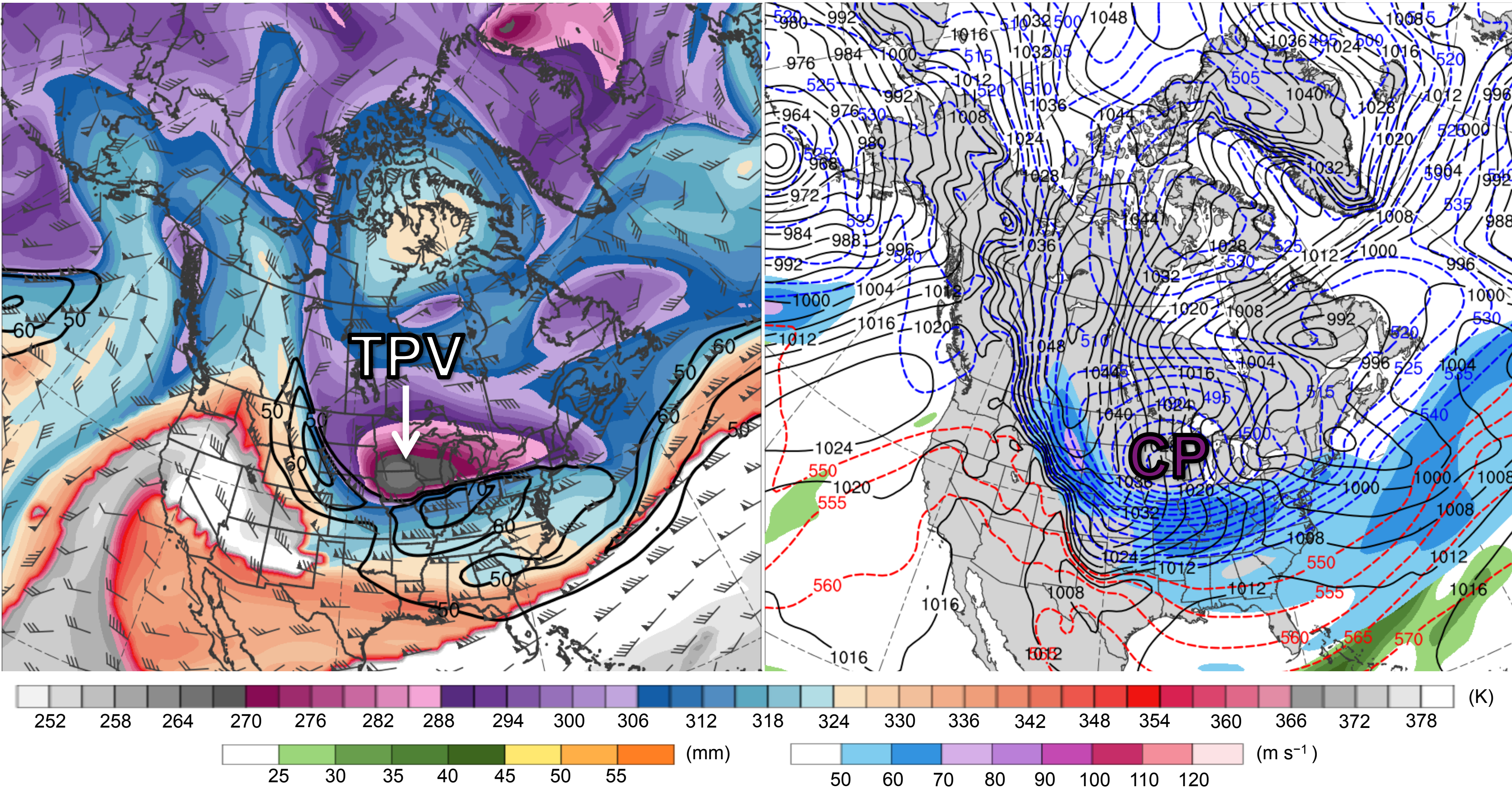
500-hPa geopotential height (black, every 6 dam) and −40°C isotherm (dashed contour); track of polar vortex from 0000 UTC 12 January to 0000 UTC 24 January 1985 (heavy black). Adapted from Fig. 5 in Shapiro et al. (1987).

1000–500-hPa thickness (dam, shaded) and 700-hPa wind (m s^{-1}, flags and barbs). Data source: ERA-Interim.

Jan 1985 TPV and CAO

0000 UTC 20 Jan 1985

Data Source: 0.5° ERA-Interim

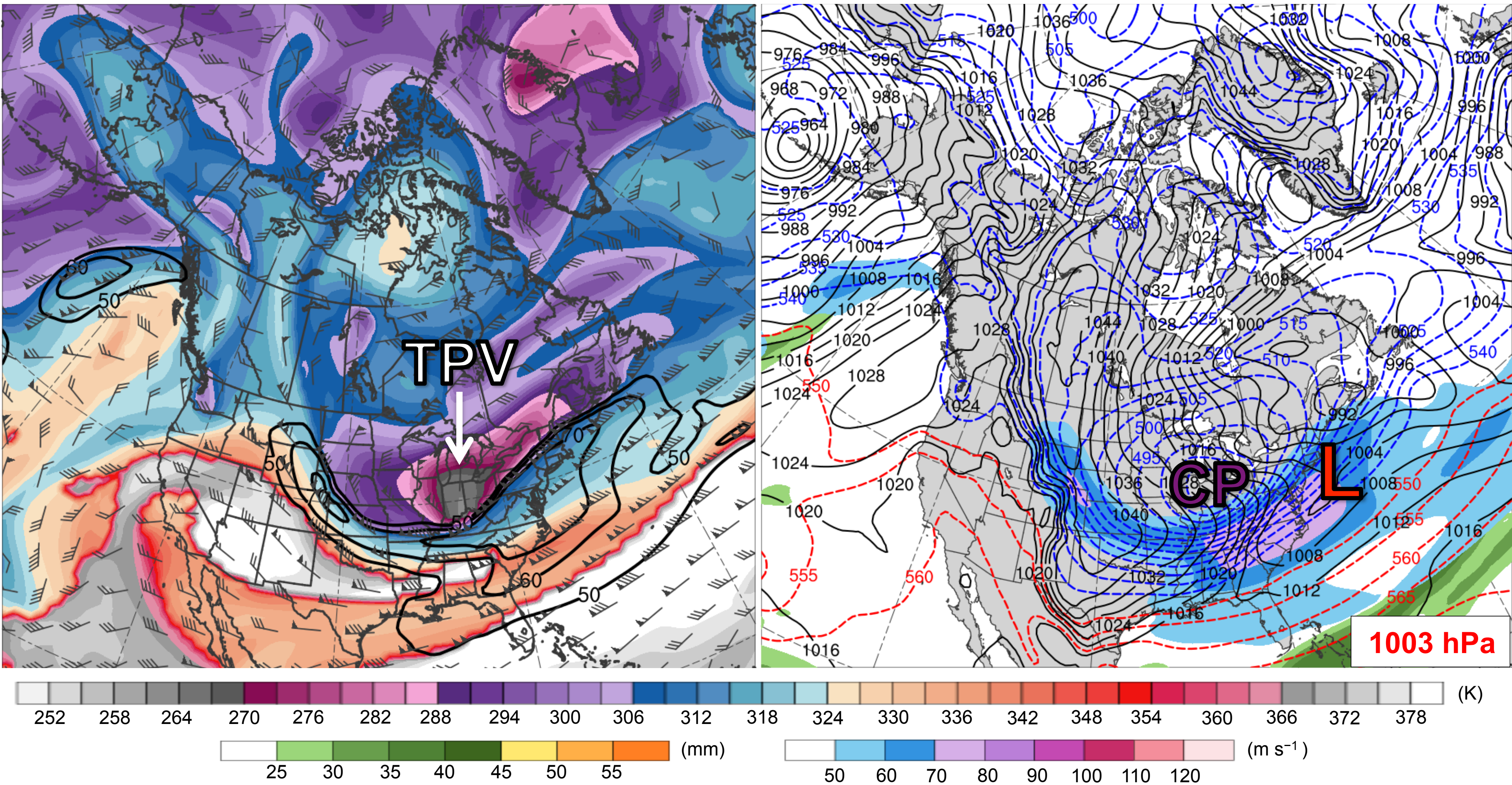


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Jan 1985 TPV and CAO

1200 UTC 20 Jan 1985

Data Source: 0.5° ERA-Interim



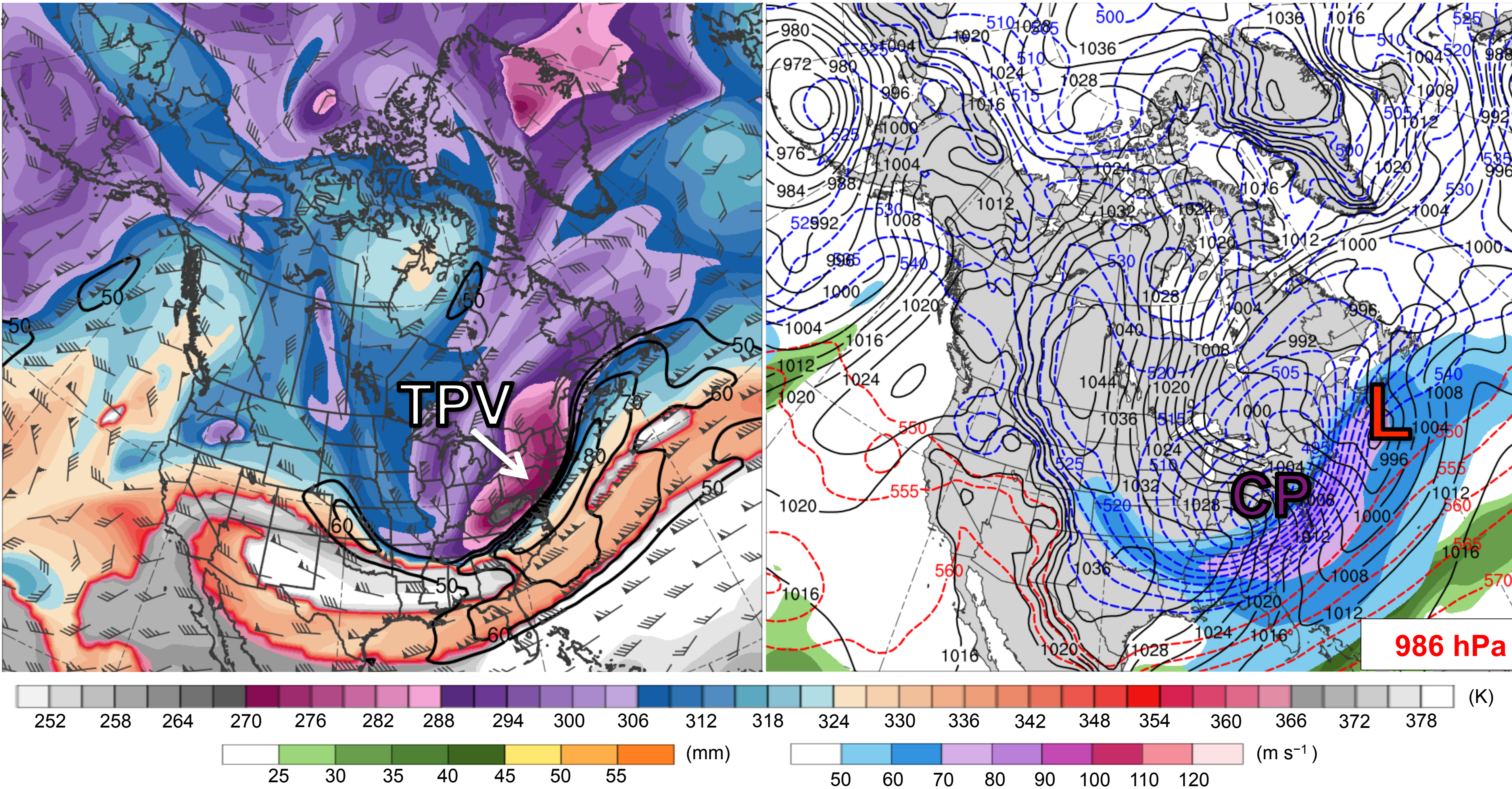
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Jan 1985 TPV and CAO

0000 UTC 21 Jan 1985

Data Source: 0.5° ERA-Interim



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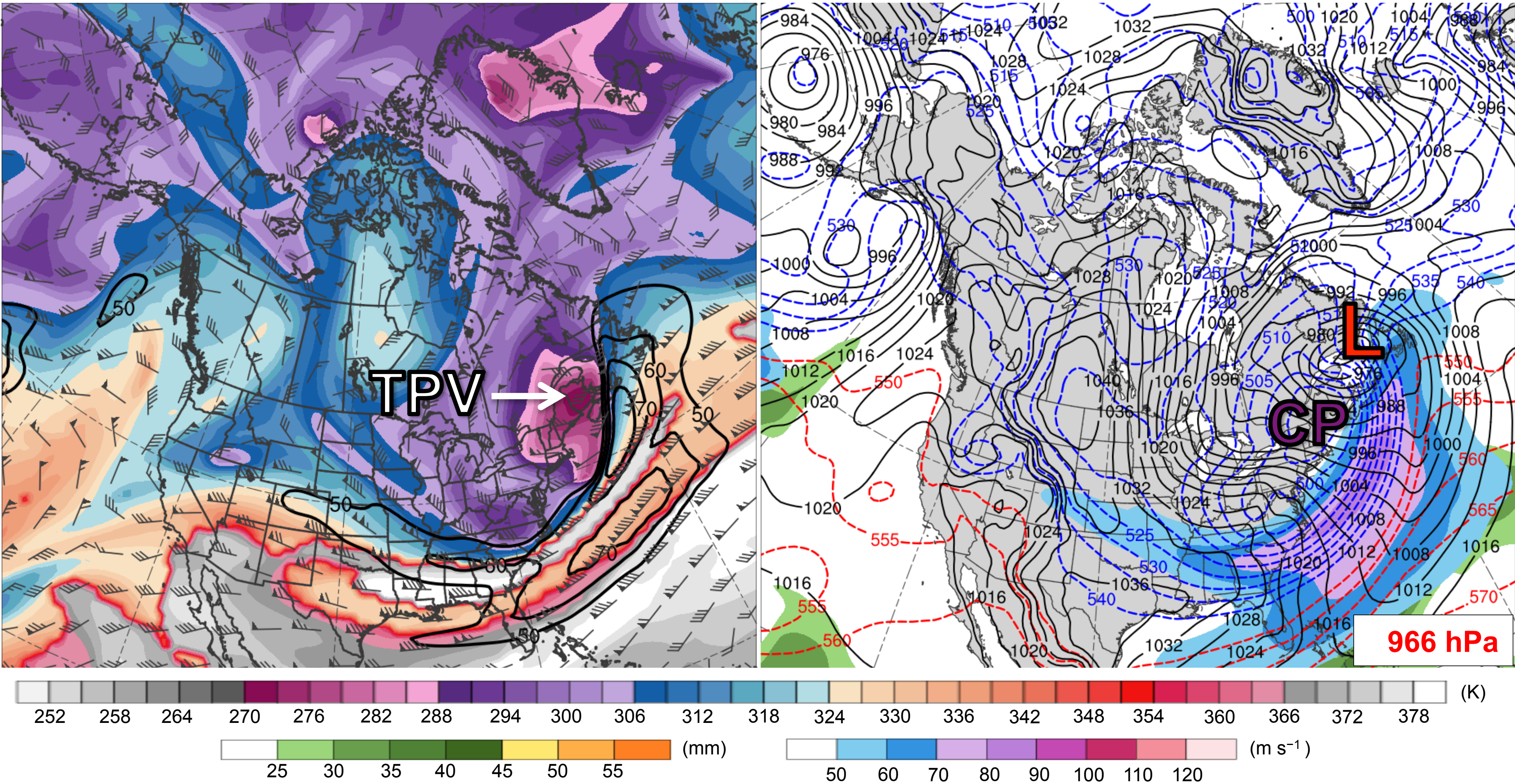
Jan 1985 TPV and CAO

1200 UTC 21 Jan 1985

Data Source: 0.5° ERA-Interim



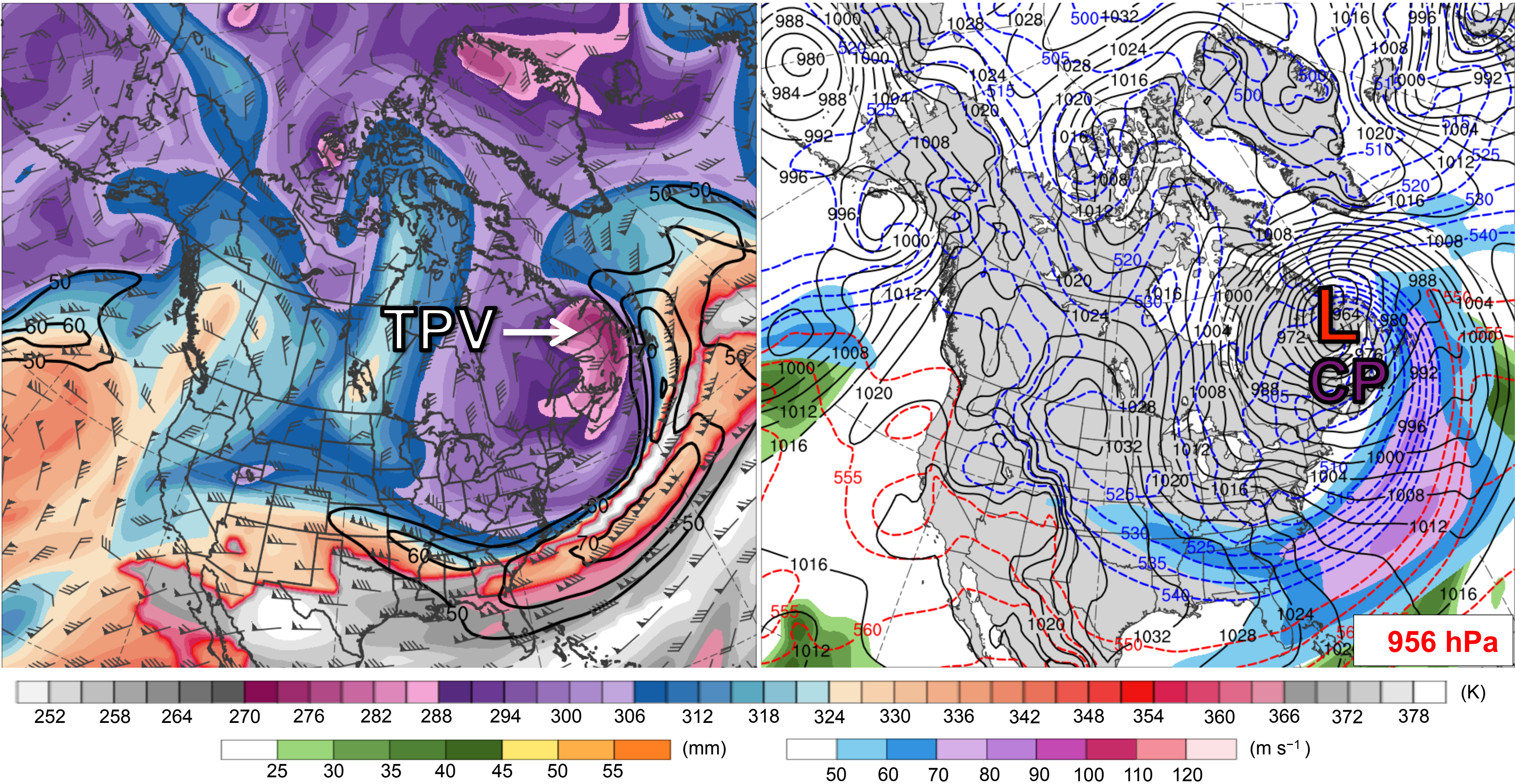
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Jan 1985 TPV and CAO

0000 UTC 22 Jan 1985

Data Source: 0.5° ERA-Interim

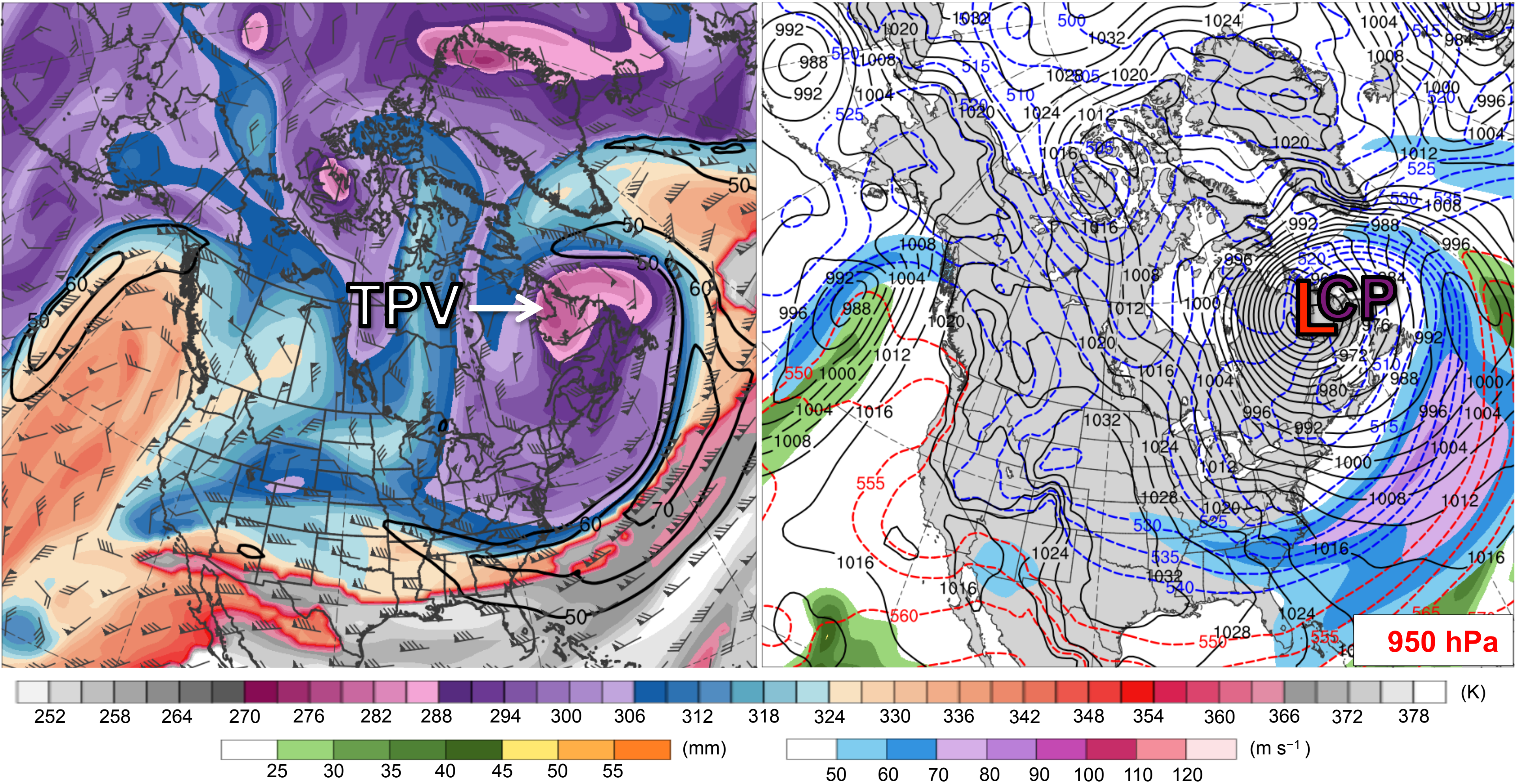


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Jan 1985 TPV and CAO

1200 UTC 22 Jan 1985

Data Source: 0.5° ERA-Interim



Potential temperature (K, shaded), wind speed (black, every 10 $m\ s^{-1}$ starting at 50 $m\ s^{-1}$), 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), MSLP (hPa, black), PW (mm, shaded)

Hypotheses

- Forecast errors of strong ECs linked to TPVs originate from misrepresentation of the track of the TPVs, as well as misrepresentation of the interaction of the TPVs with the large-scale flow

- Forecasts with lower forecast skill of strong ECs linked to TPVs are associated with larger TPV track errors and larger errors in the interaction of the TPVs with the large-scale flow compared to forecasts with higher forecast skill

Research Plan

- Evaluate forecast skill of a strong EC linked to TPVs
- **Case:** An EC that explosively deepened during 30–31 December 1996 near Labrador
- **Case Motivation:**
  - EC's development likely influenced by two TPVs that interact with and strengthen a jet streak as well as interact with one another
  - EC was identified in Alicia Bentley's climatology of ECs leading to EWEs over central and Eastern North America

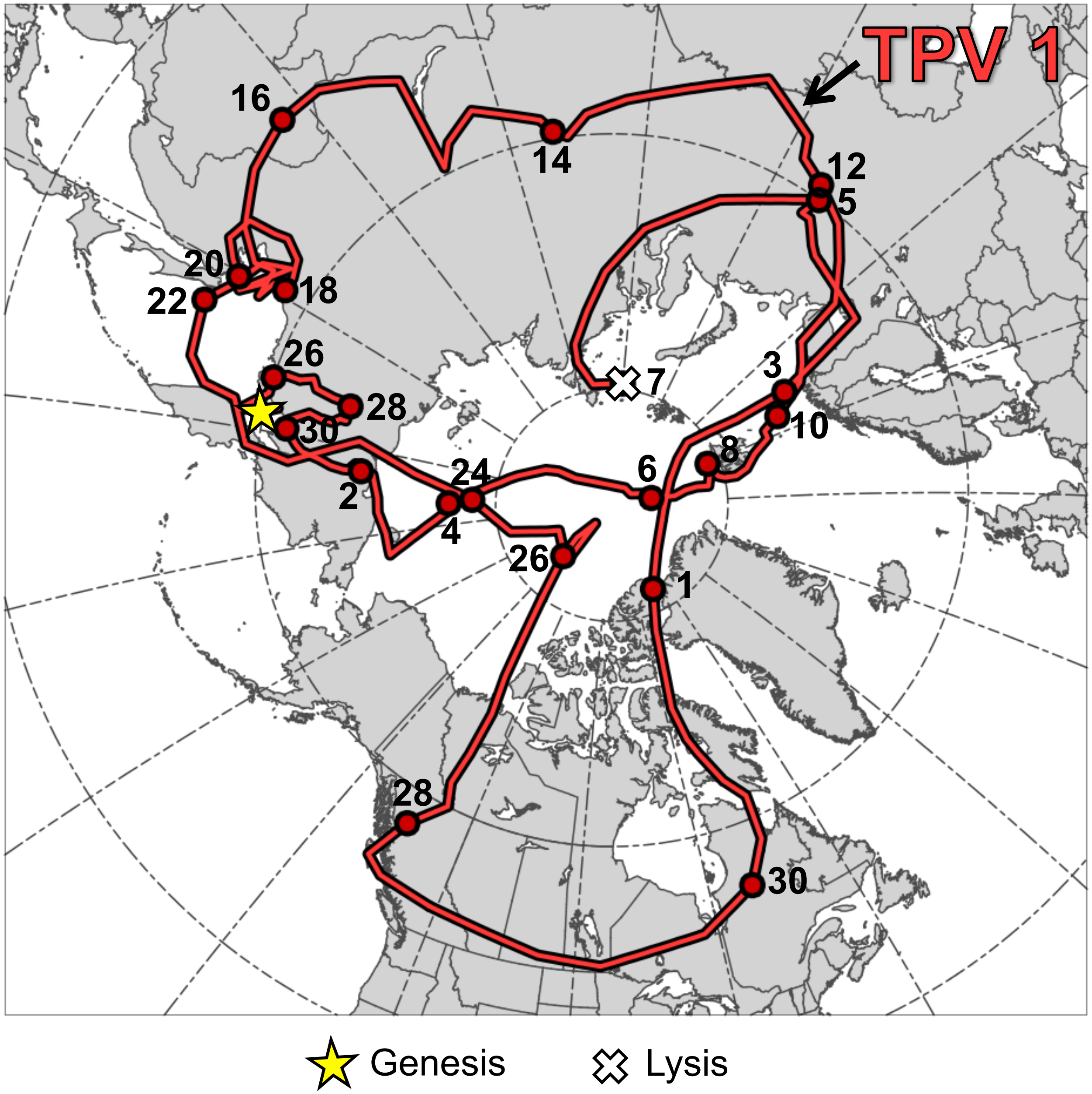
Research Plan

- Use ERA-Interim (Dee et al. 2011) to evaluate synoptic evolution of EC and TPVs

- TPVs and cold pools identified objectively for ERA-Interim by utilizing an adapting a TPV tracking algorithm developed by Nicholas Szapiro and Steven Cavallo
  - TPVs and cold pools must last at least 2 days and spend at least 6 h poleward of 60°N (adapted from criteria of Cavallo and Hakim 2010)

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

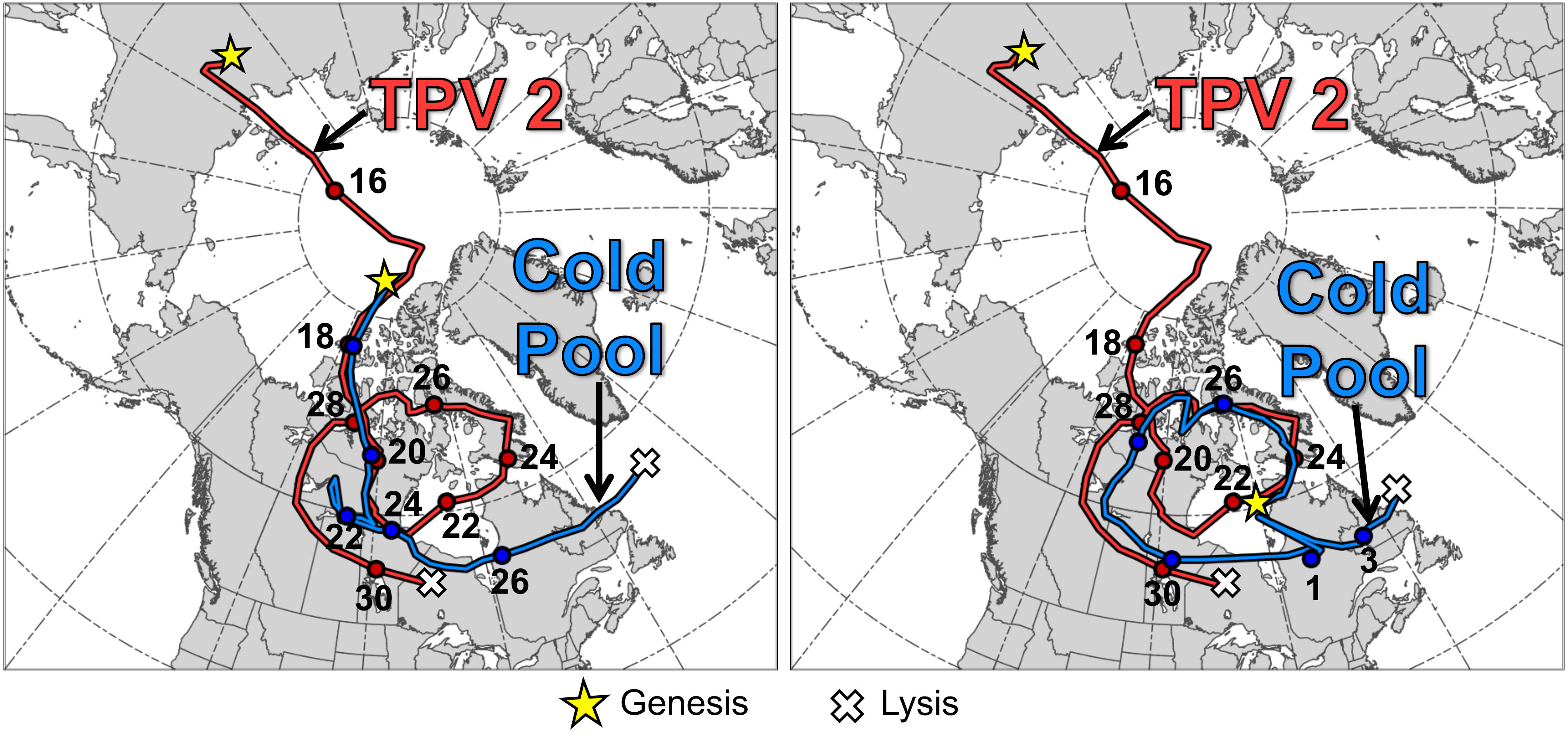
TPV and Cold Pool Tracks



TPV 1 Track

- **Genesis:**
  0600 UTC 24 Nov 1996
- **Lysis:**
  0000 UTC 7 Jan 1997
- **Lifetime:**
  44 days

TPV and Cold Pool Tracks



TPV 2 Track

- **Genesis:**
  0600 UTC 14 Dec 1996
- **Lysis:**
  0600 UTC 30 Dec 1996
- **Lifetime:**
  ~16 days

Cold Pool Track (left)

- **Genesis:**
  1200 UTC 17 Dec 1996
- **Lysis:**
  1800 UTC 27 Dec 1996
- **Lifetime:**
  ~10 days

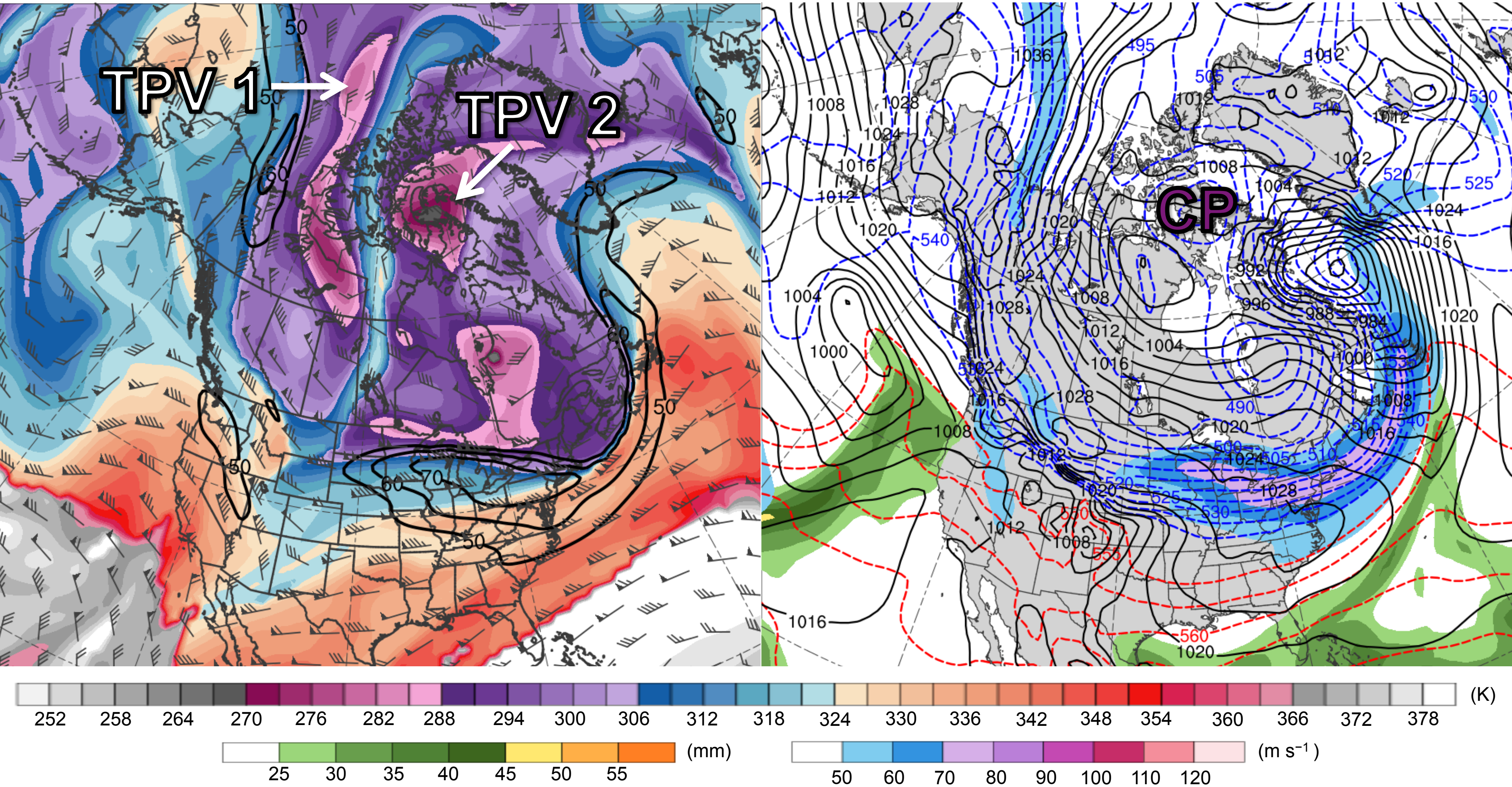
Cold Pool Track (right)

- **Genesis:**
  1200 UTC 22 Dec 1996
- **Lysis:**
  1800 UTC 3 Jan 1997
- **Lifetime:**
  ~12 days

Synoptic Analysis

0000 UTC 26 Dec 1996

Data Source: 0.5° ERA-Interim

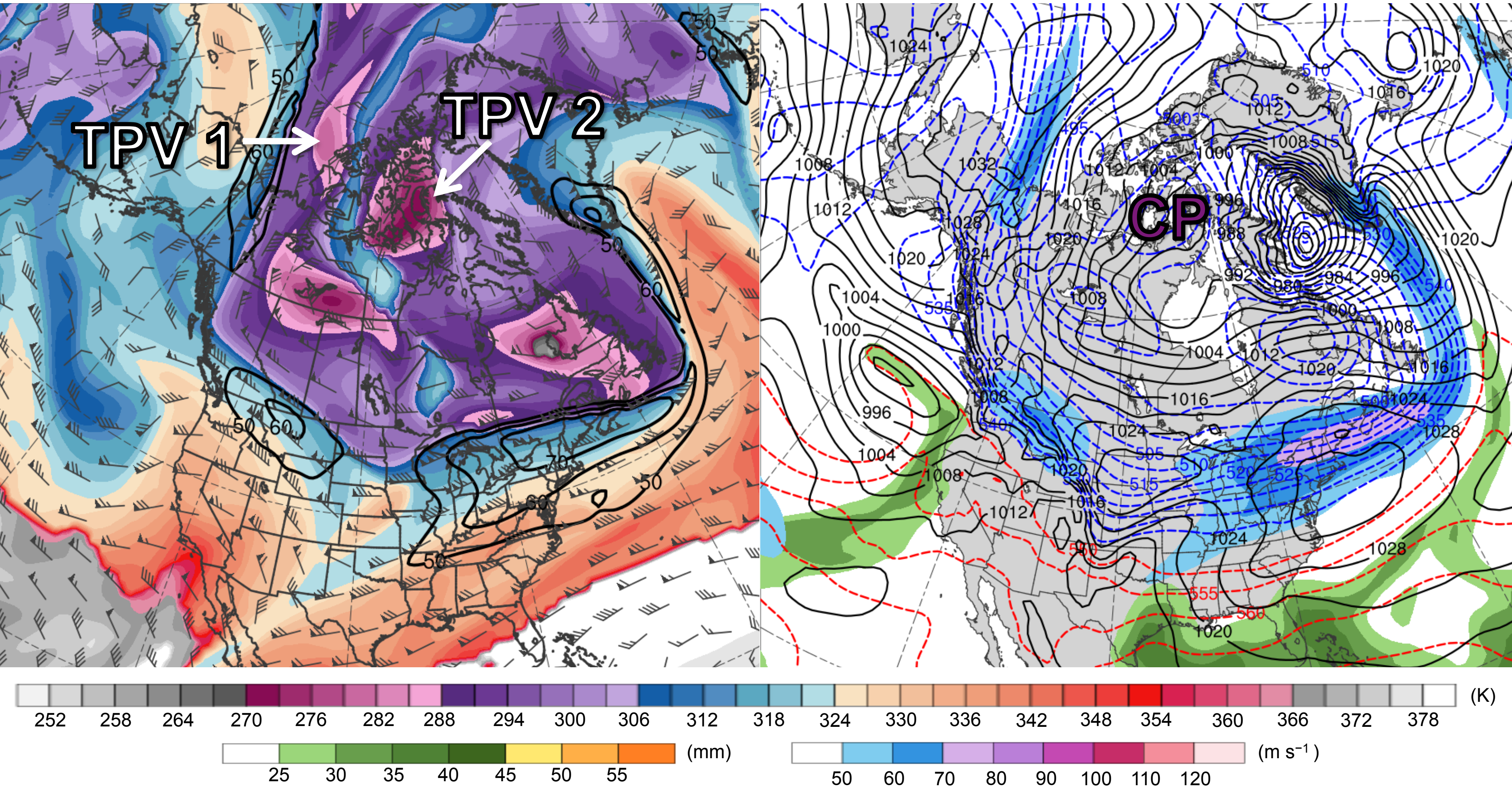


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Synoptic Analysis

1200 UTC 26 Dec 1996

Data Source: 0.5° ERA-Interim



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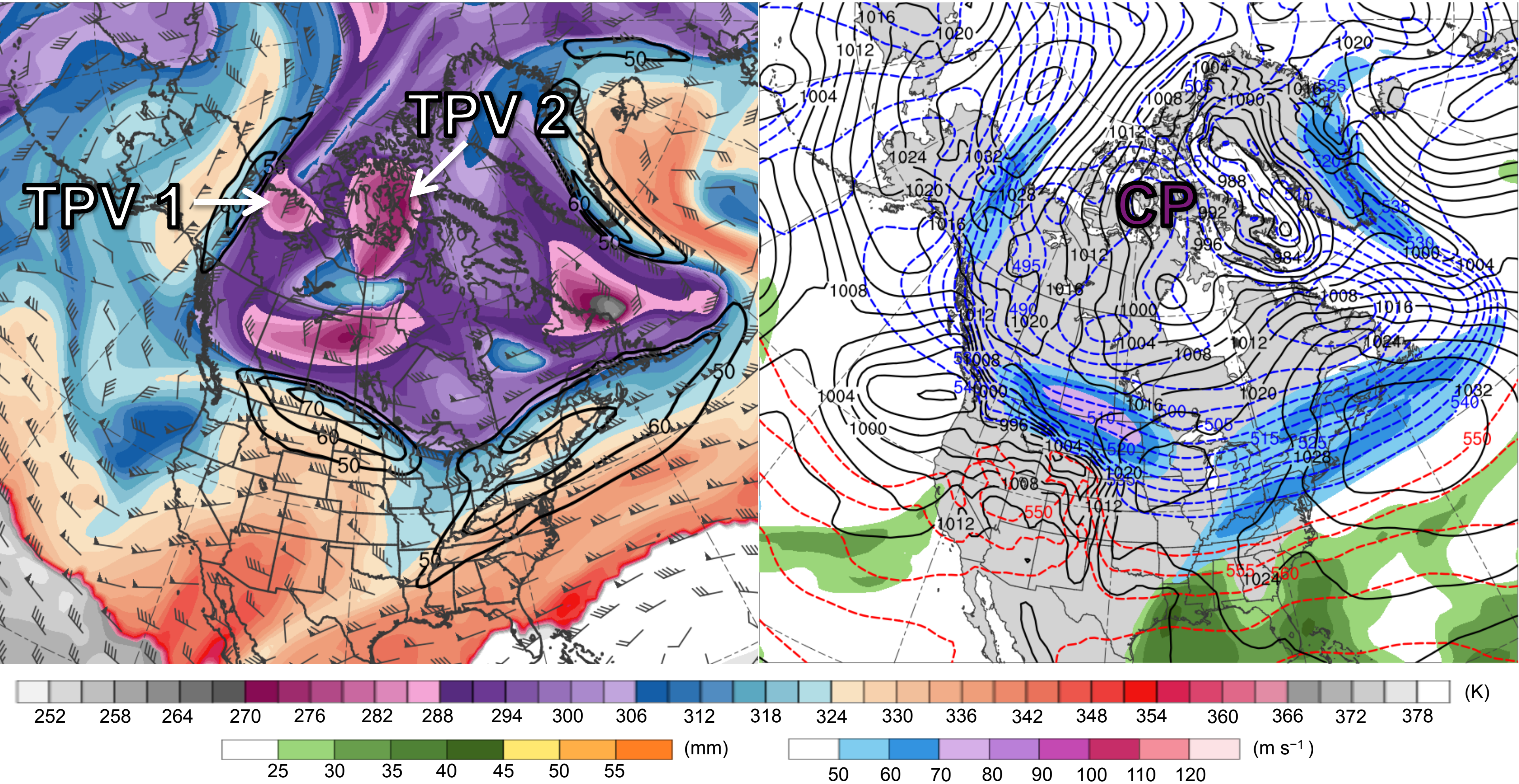
Synoptic Analysis

0000 UTC 27 Dec 1996

Data Source: 0.5° ERA-Interim



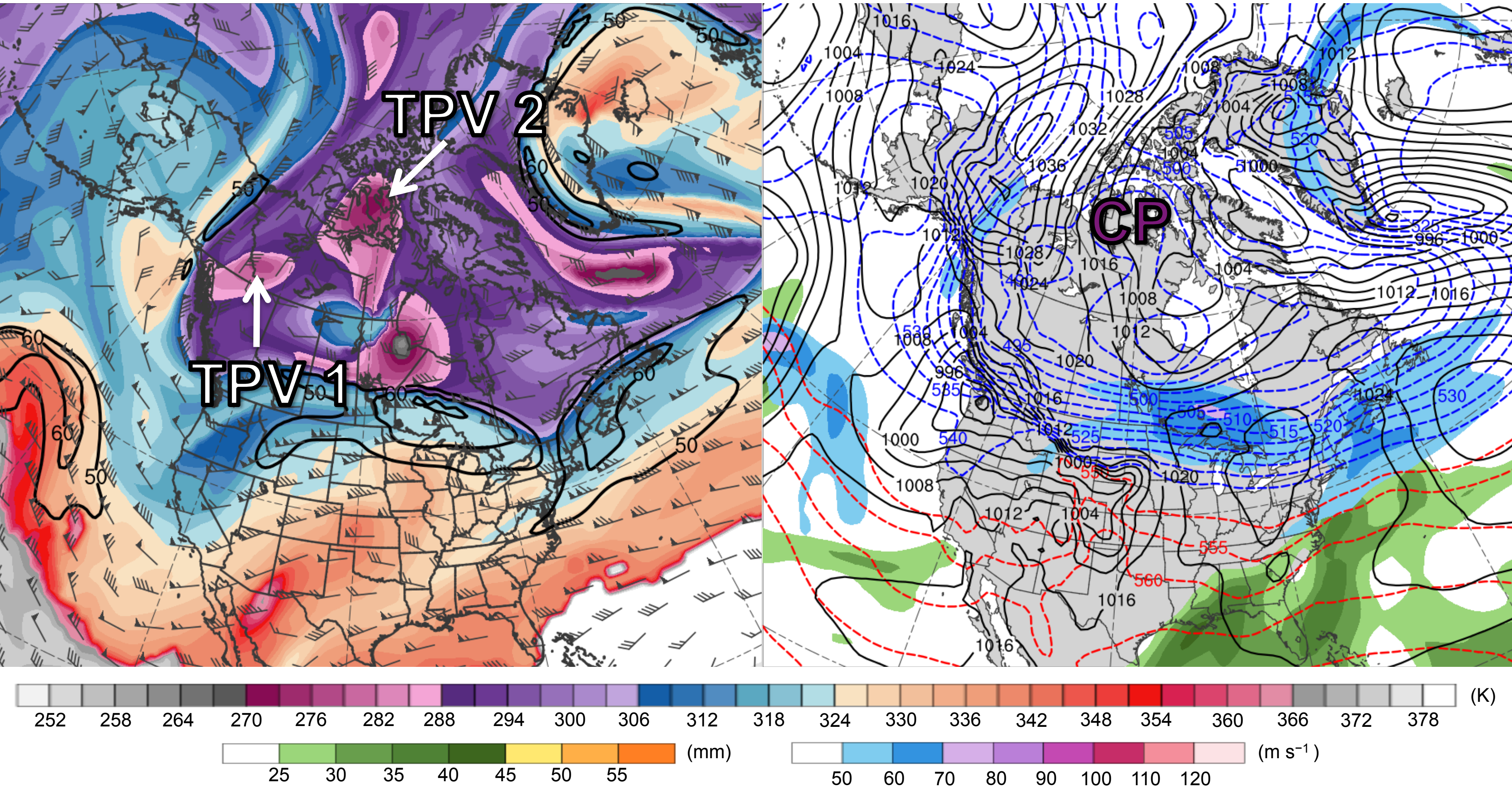
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Synoptic Analysis

1200 UTC 27 Dec 1996

Data Source: 0.5° ERA-Interim

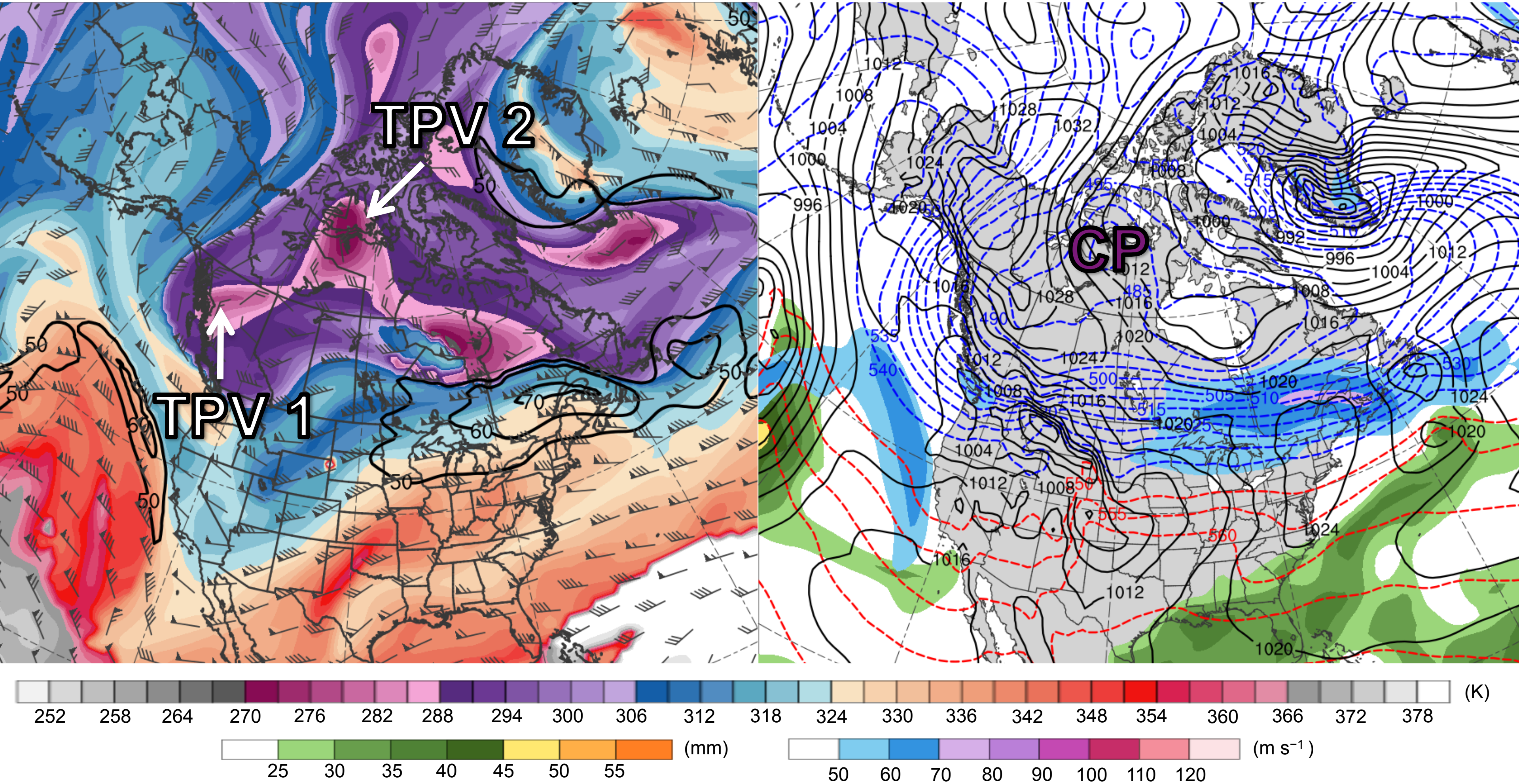


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Synoptic Analysis

0000 UTC 28 Dec 1996

Data Source: 0.5° ERA-Interim

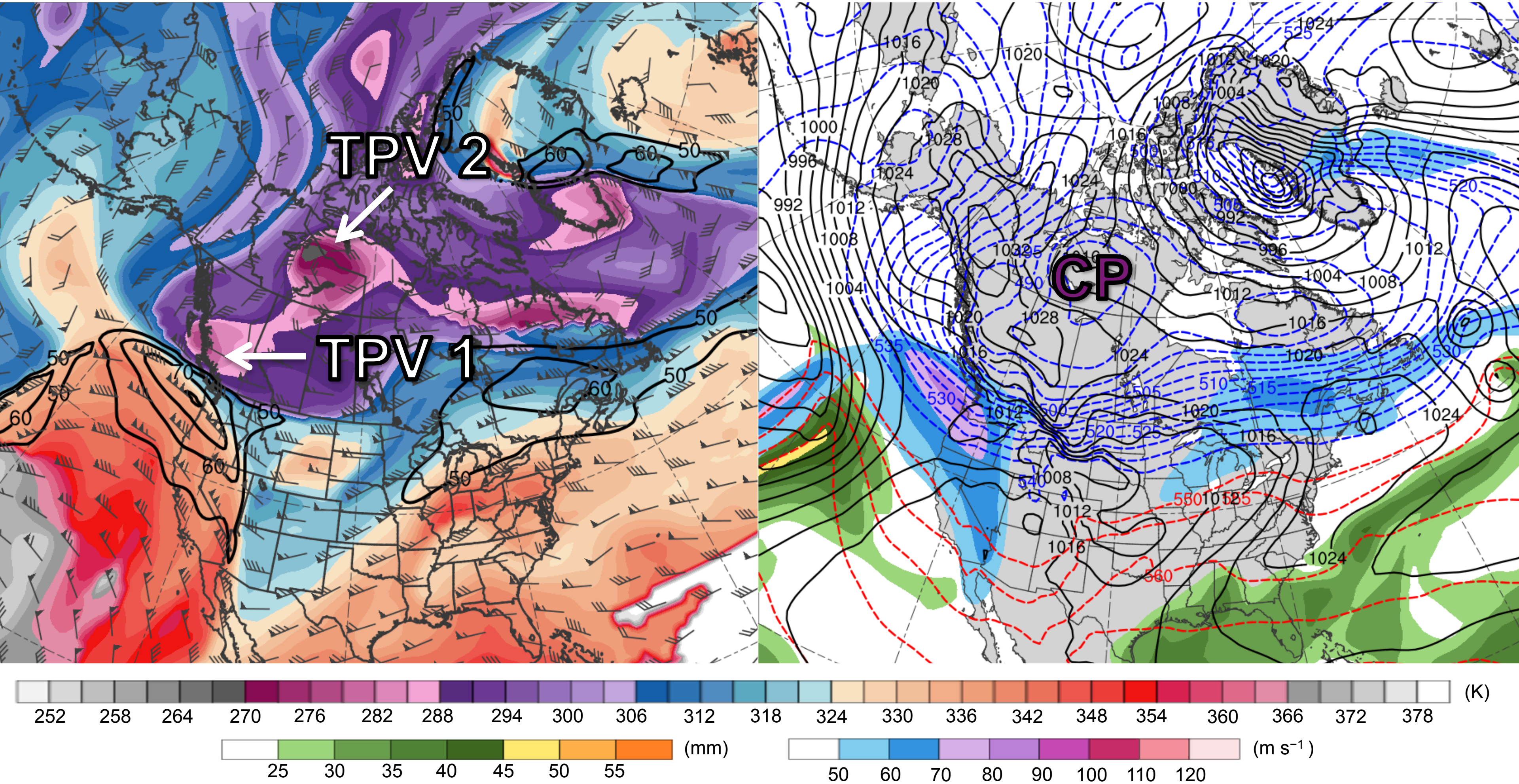


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Synoptic Analysis

1200 UTC 28 Dec 1996

Data Source: 0.5° ERA-Interim

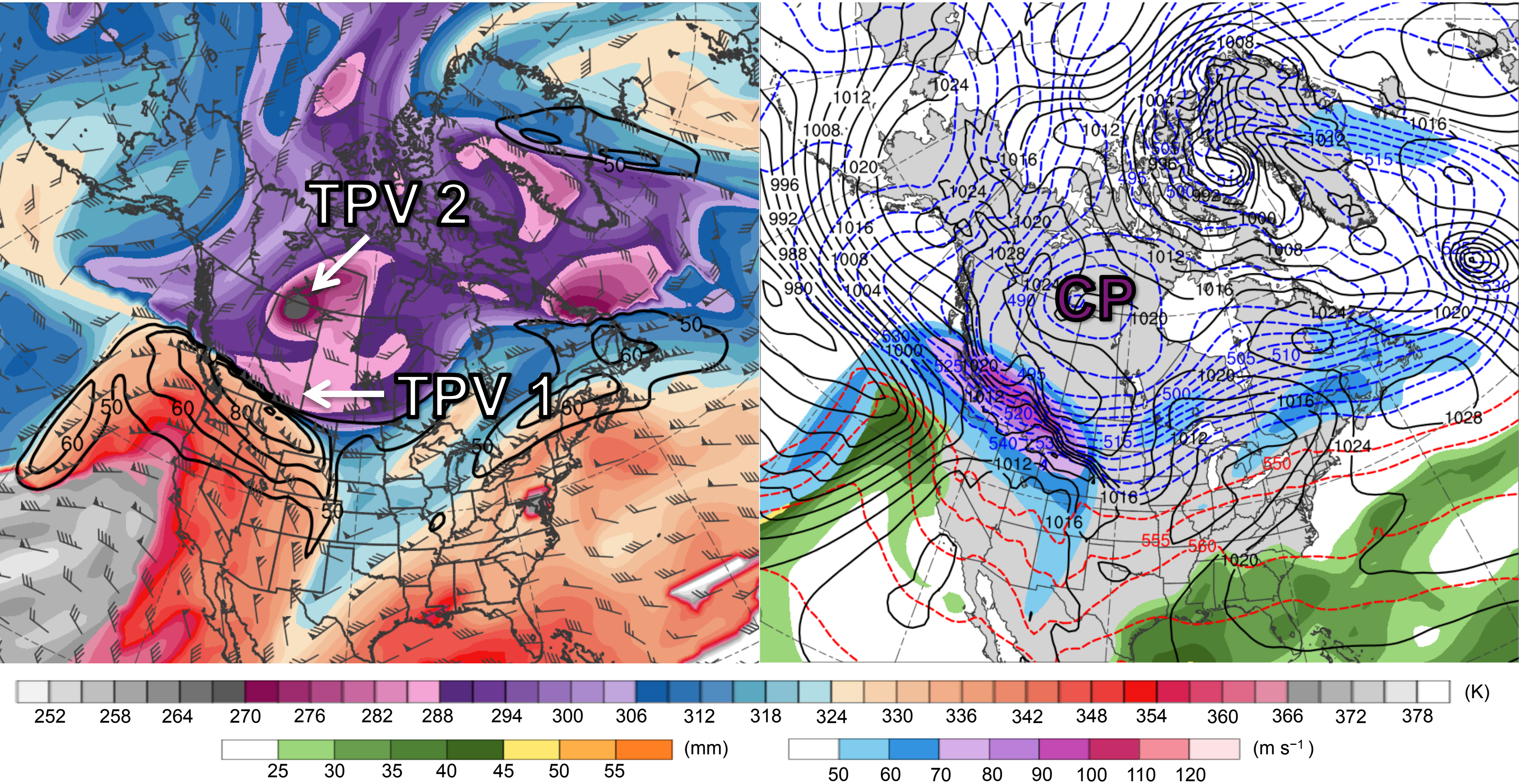


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Synoptic Analysis

0000 UTC 29 Dec 1996

Data Source: 0.5° ERA-Interim

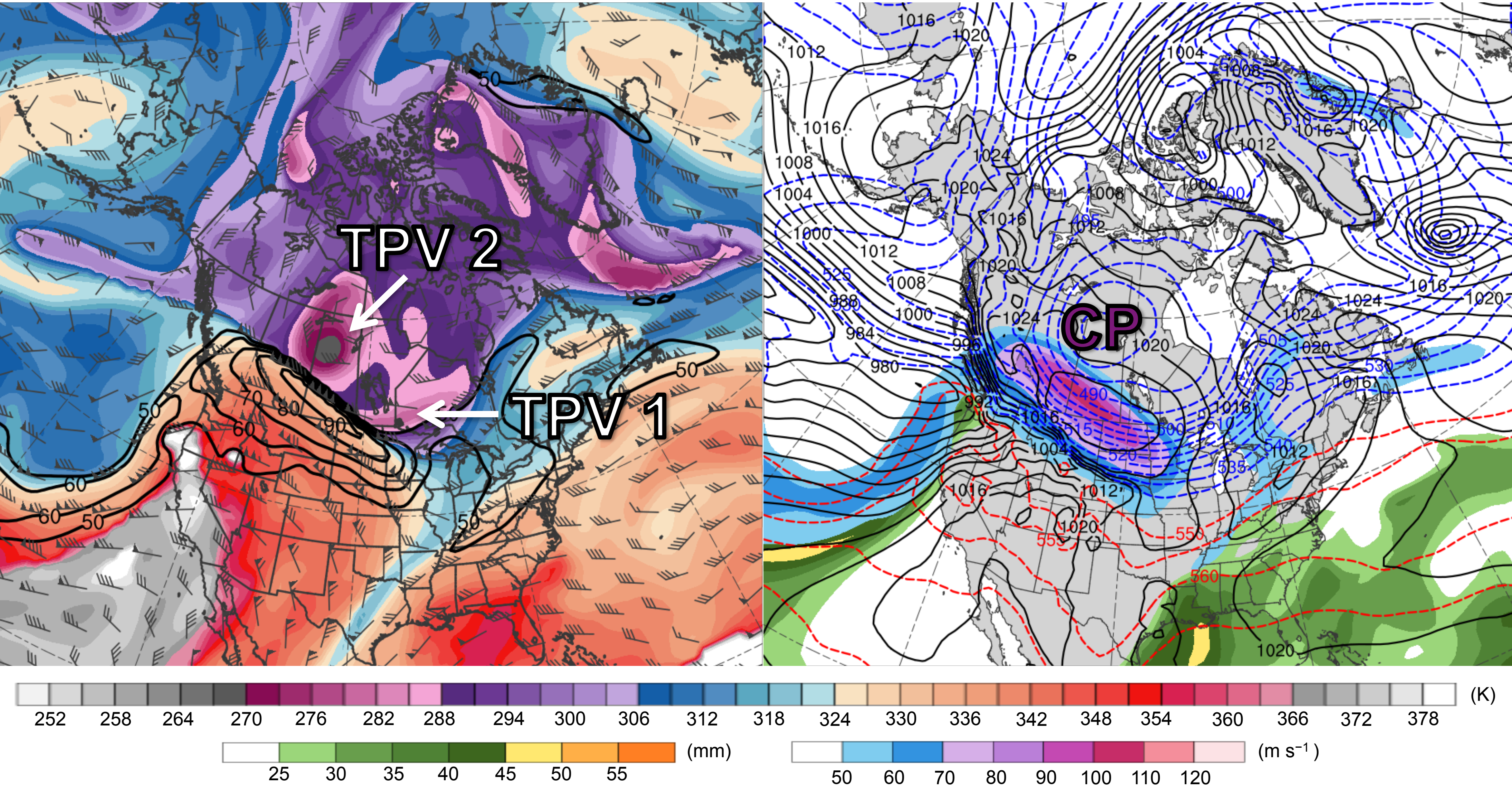


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Synoptic Analysis

1200 UTC 29 Dec 1996

Data Source: 0.5° ERA-Interim



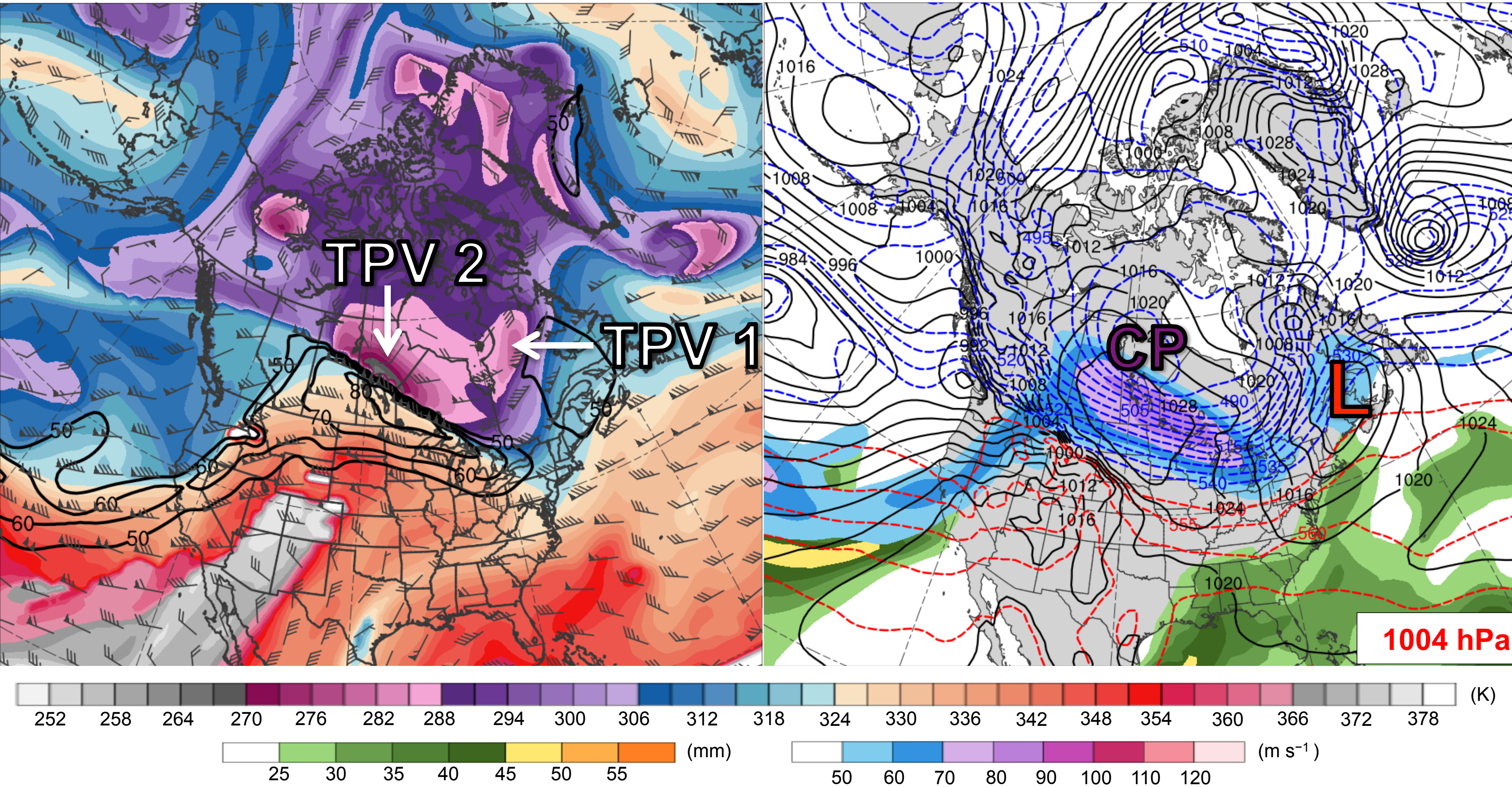
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Synoptic Analysis

0000 UTC 30 Dec 1996

Data Source: 0.5° ERA-Interim



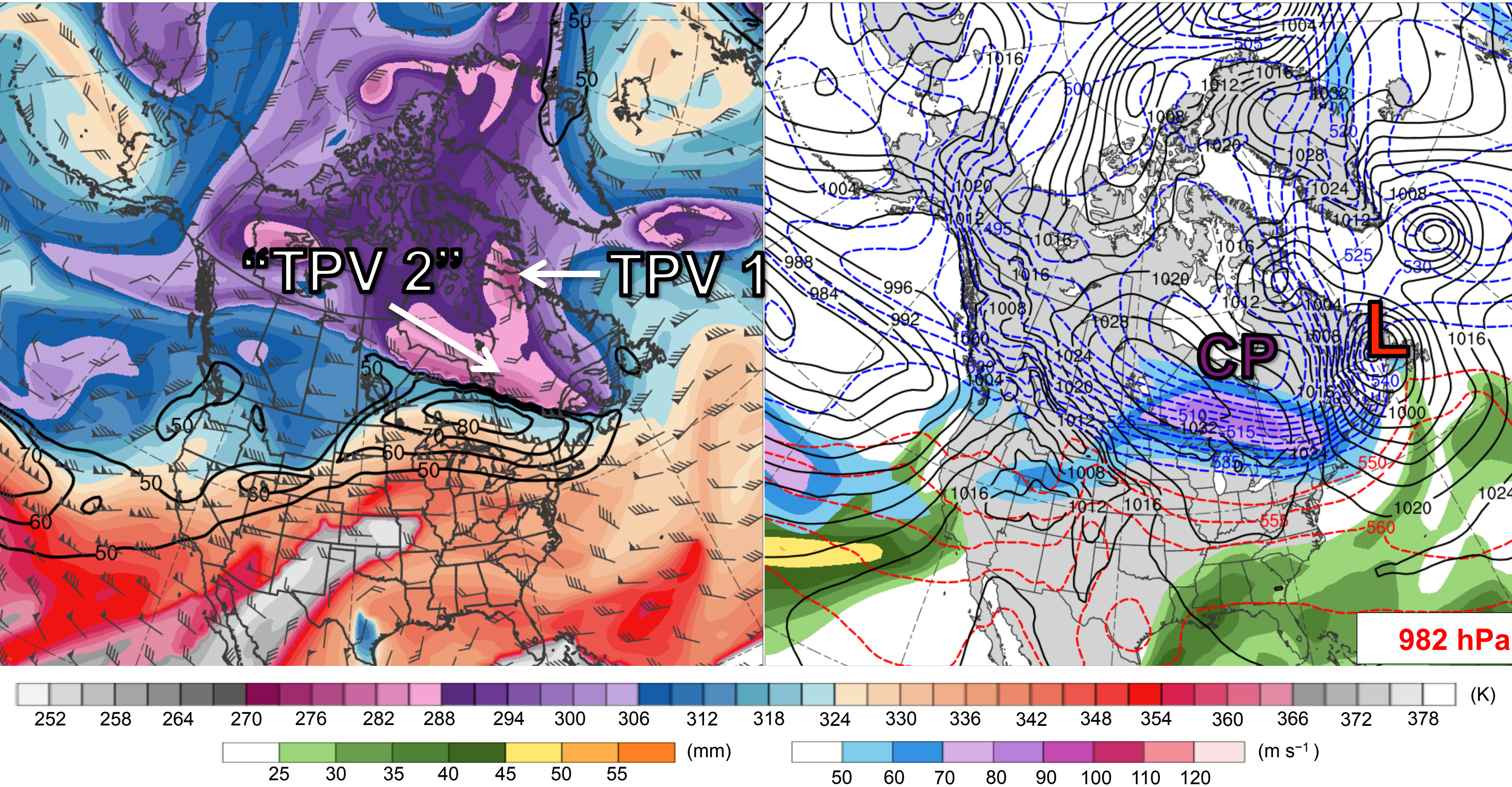
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Synoptic Analysis

1200 UTC 30 Dec 1996

Data Source: 0.5° ERA-Interim



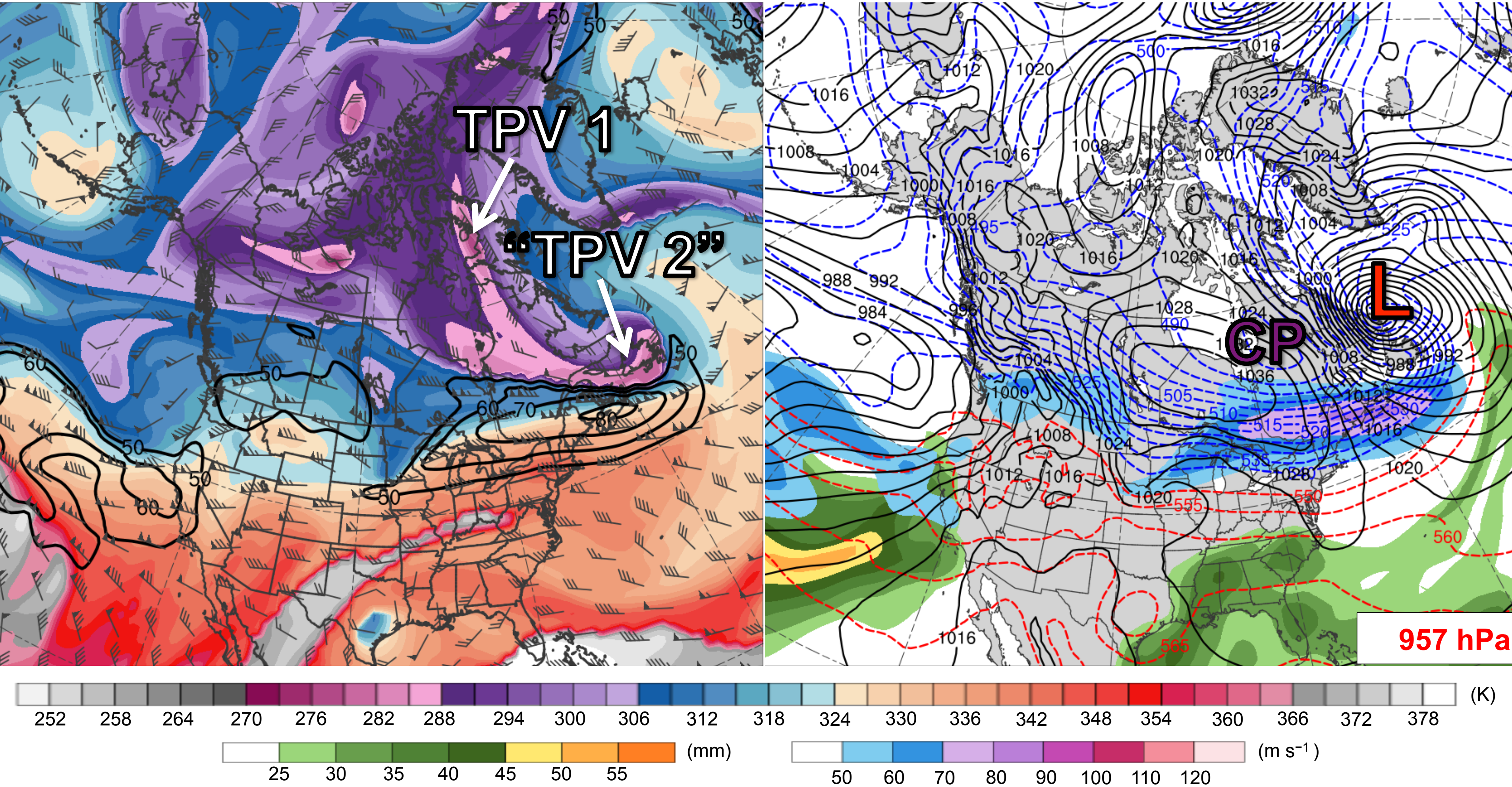
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Synoptic Analysis

0000 UTC 31 Dec 1996

Data Source: 0.5° ERA-Interim

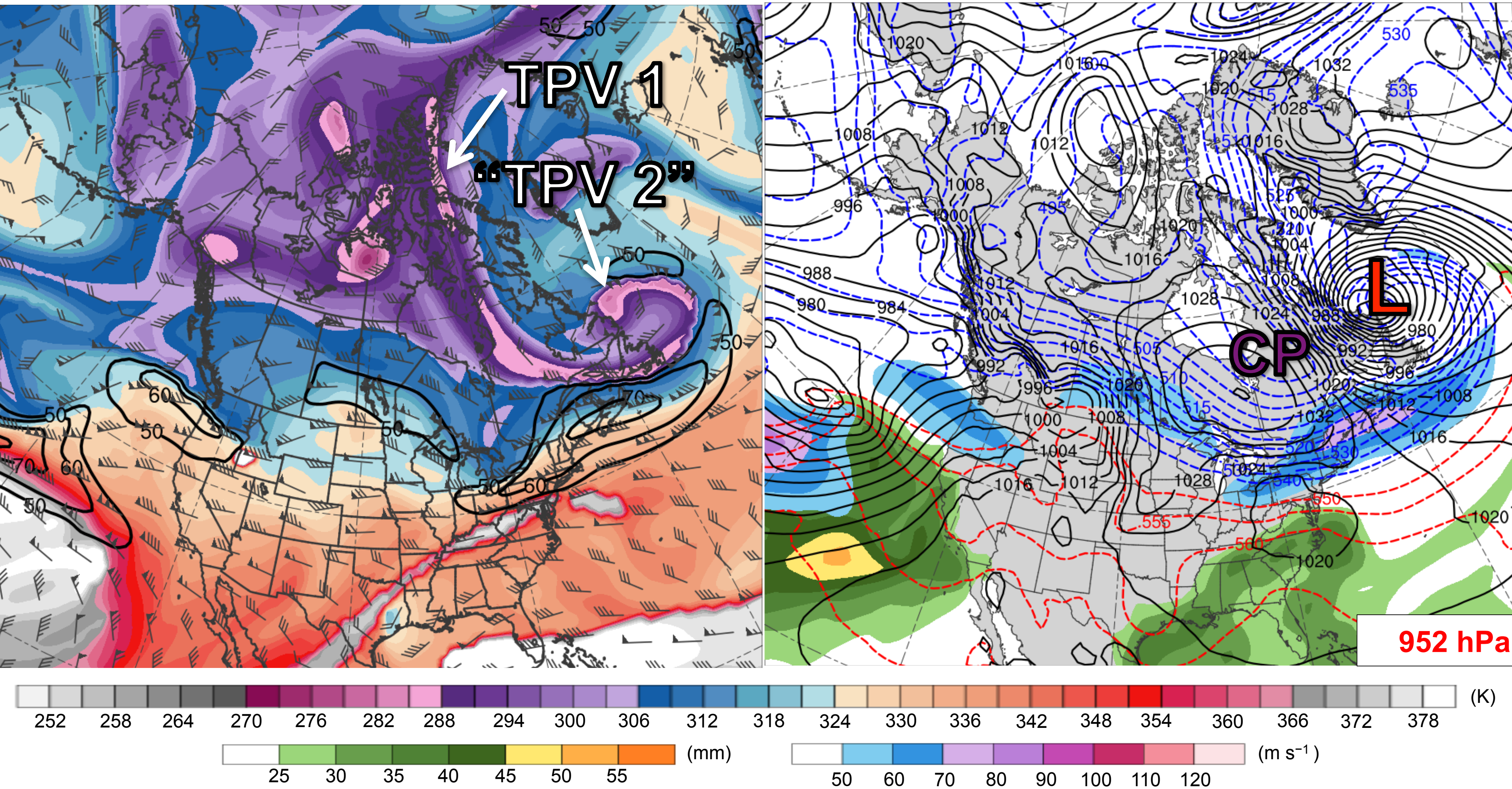


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Synoptic Analysis

1200 UTC 31 Dec 1996

Data Source: 0.5° ERA-Interim

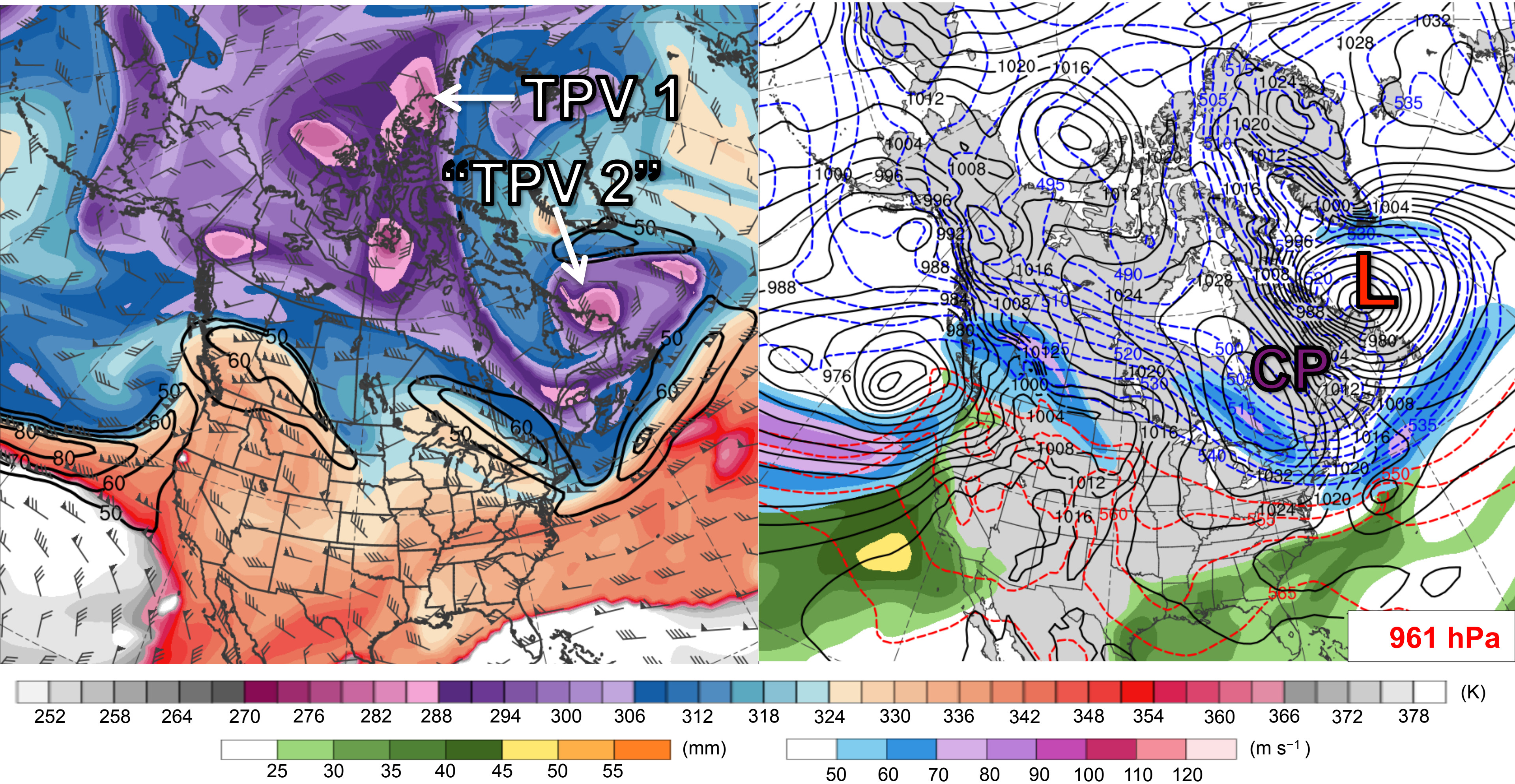


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Synoptic Analysis

0000 UTC 1 Jan 1997

Data Source: 0.5° ERA-Interim



Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 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), MSLP (hPa, black), PW (mm, shaded)

Evaluation of Forecast Skill

- Evaluate forecast skill of EC using version 2 of ESRL/PSD Global Ensemble Forecasting System (GEFS) reforecast dataset (Hamill et al. 2013)
  - Available once daily (0000 UTC) at 1° horizontal resolution
- Use GEFS ensemble forecasts initialized at 0000 UTC 26 Dec 1996, 5.5 days prior to time of maximum intensity of EC in ERA-Interim
- Use ERA-Interim regridded to 1° horizontal resolution as verification

Evaluation of Forecast Skill

- Forecast skill of EC is assessed in terms of a metric combining forecast track and intensity error of EC
- Metric calculated by adapting methodology of Lamberson et al. (2016) to rank ensembles by forecast accuracy in terms of track and intensity error for EC Joachim (2011)
- Track and intensity error is calculated every 12 h from 0000 UTC 30 Dec 1996 to 0000 UTC 1 Jan 1997 for each GEFS member

Evaluation of Forecast Skill

- Track error for each time is calculated as the great circle distance between the location of the EC in ERA-Interim and in each GEFS member
  - Location of EC at a time corresponds to location of minimum MSLP value of EC at that time
- Intensity error for each time is calculated as the absolute difference in intensity of EC in ERA-Interim and in each GEFS member
  - Intensity of EC at a time corresponds to minimum MSLP value of EC at that time

Evaluation of Forecast Skill

- Track and intensity errors are then averaged over time, and the GEFS members are ranked 1–11 for both track and intensity, with 1 corresponding to member with lowest average error
- The track error rank is added with the intensity error rank to determine a combined track and intensity error rank for each GEFS member
- The GEFS member with the lowest and highest combined track and intensity error rank will be considered the best and worst member, respectively

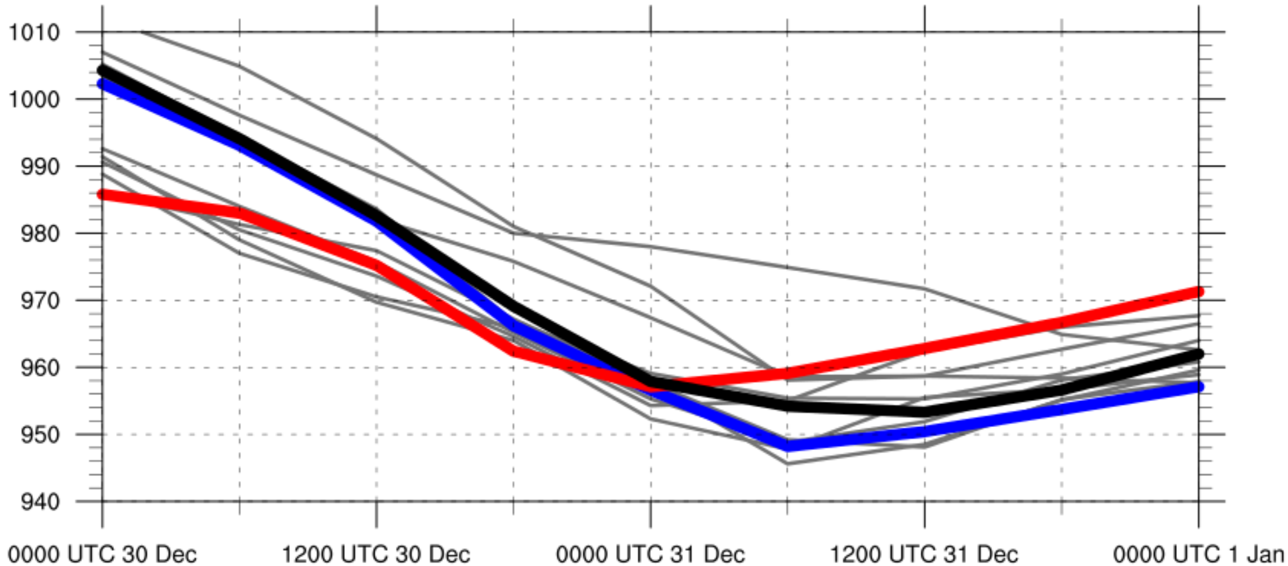
Results: GEFS Members Ranked by Skill

Member	Track error rank	Intensity error rank	Summed intensity and track error rank
8	2	2	4
6	5	1	6
2	6	3	9
5	4	6	10
9	1	9	10
1	8	4	12
4	3	11	14
7	7	7	14
3	10	5	15
Control	9	8	17
10	11	10	21

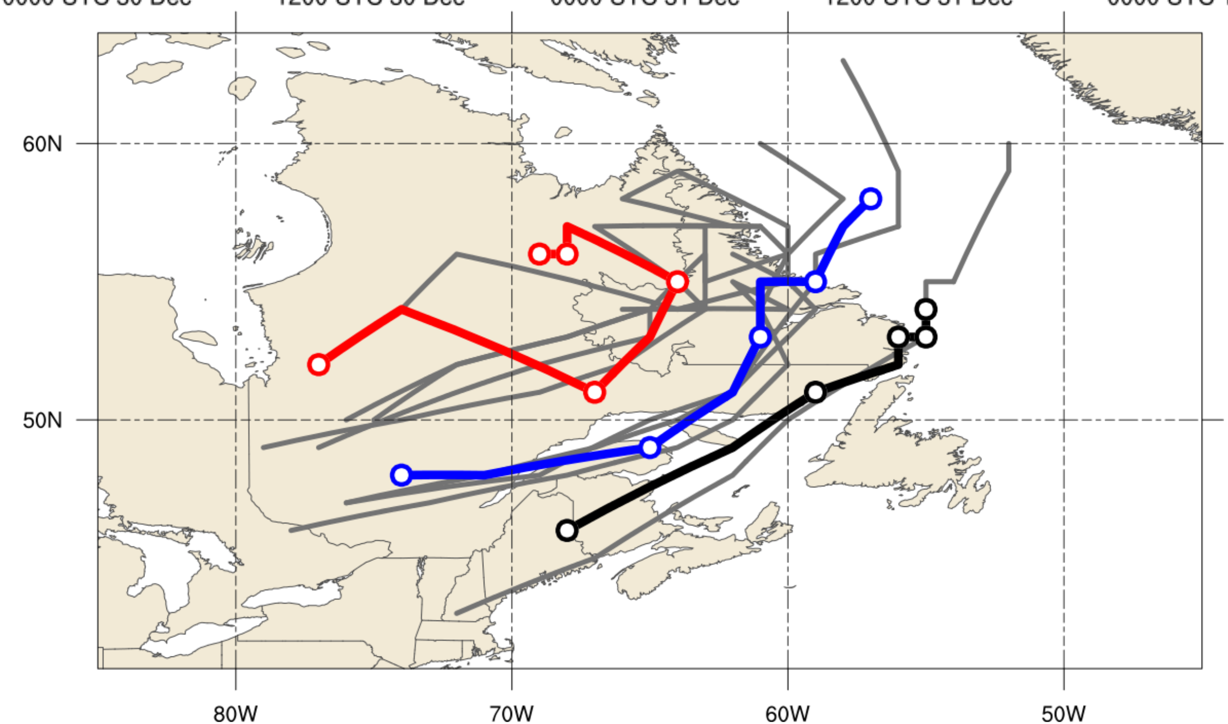
Results: GEFS Members Ranked by Skill

	Member	Track error rank	Intensity error rank	Summed intensity and track error rank
"best"	**8**	**2**	**2**	**4**
	6	5	1	6
	2	6	3	9
	5	4	6	10
	9	1	9	10
	1	8	4	12
	4	3	11	14
	7	7	7	14
	3	10	5	15
	Control	9	8	17
"worst"	**10**	**11**	**10**	**21**

Results: Comparison of Track and Intensity



Minimum sea level pressure (hPa) of EC every 6 h from 0000 UTC 30 Dec to 0000 UTC 1 Jan 1997 for **ERA-Interim**, **best GEFS member**, **worst GEFS member**, and all other GEFS members

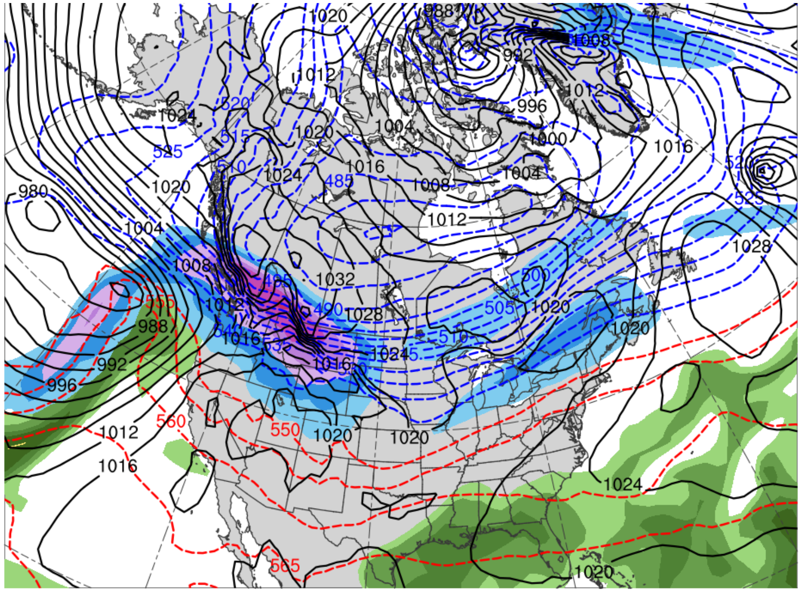


Track of EC every 6 h (circles every 12 h) from 0000 UTC 30 Dec 1996 to 0000 UTC 1 Jan 1997 for **ERA-Interim**, **best GEFS member**, **worst GEFS member**, and all other GEFS members

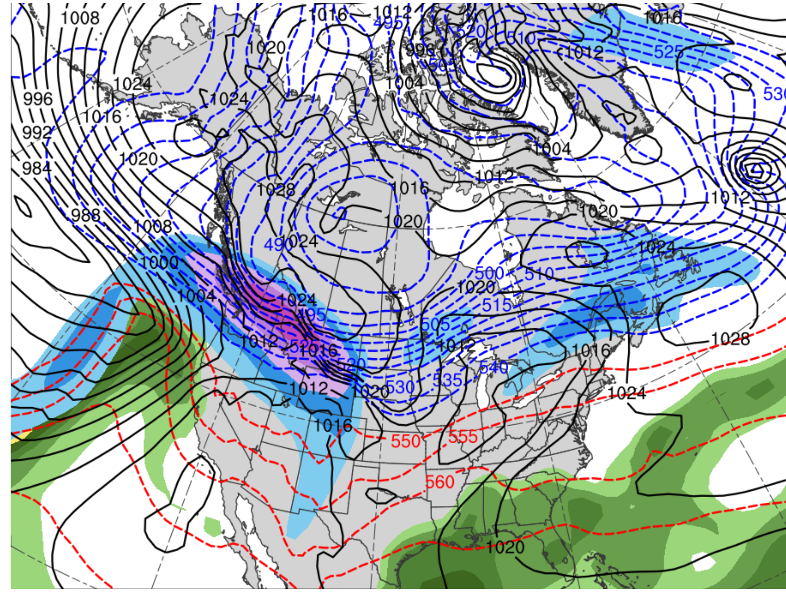
Best and Worst Comparison

0000 UTC 29 Dec 1996

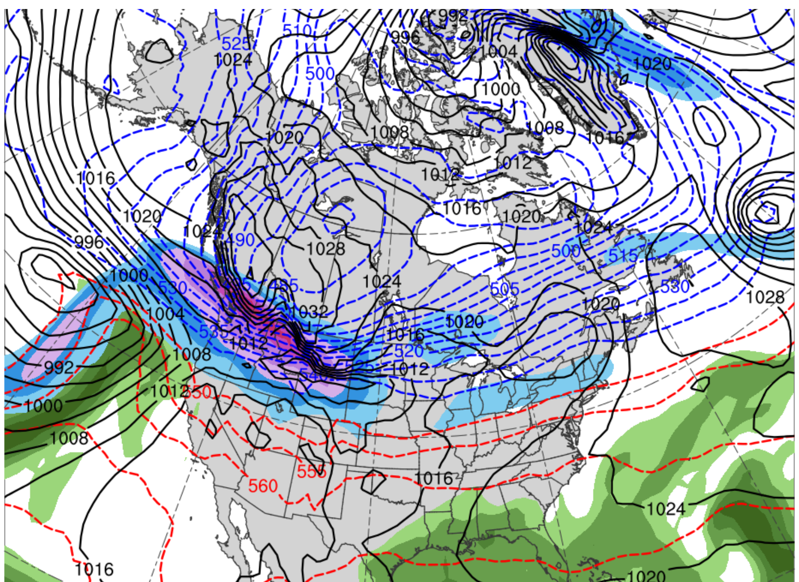
Best GEFS Member

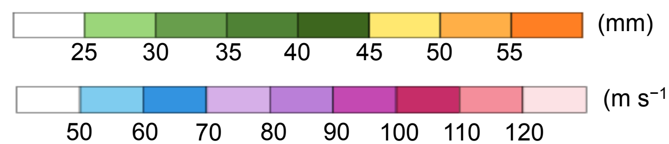


ERA-Interim



Worst GEFS Member



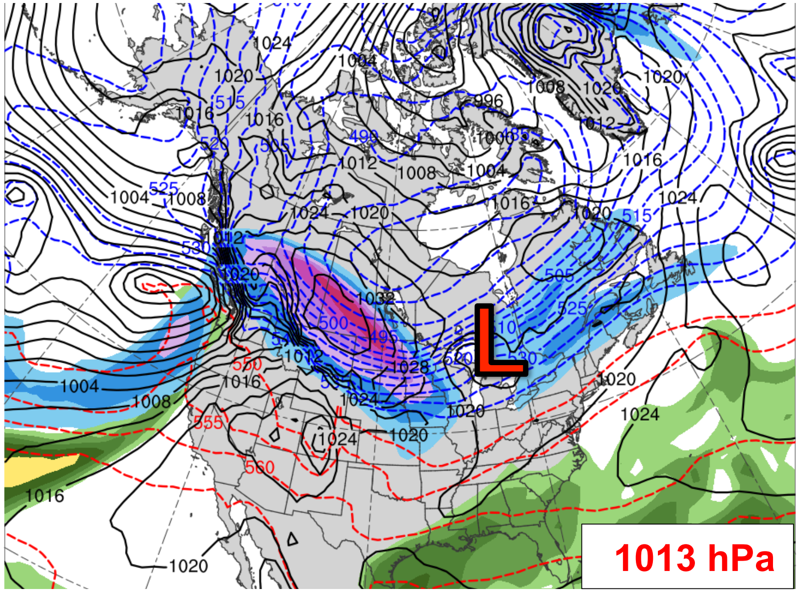


250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

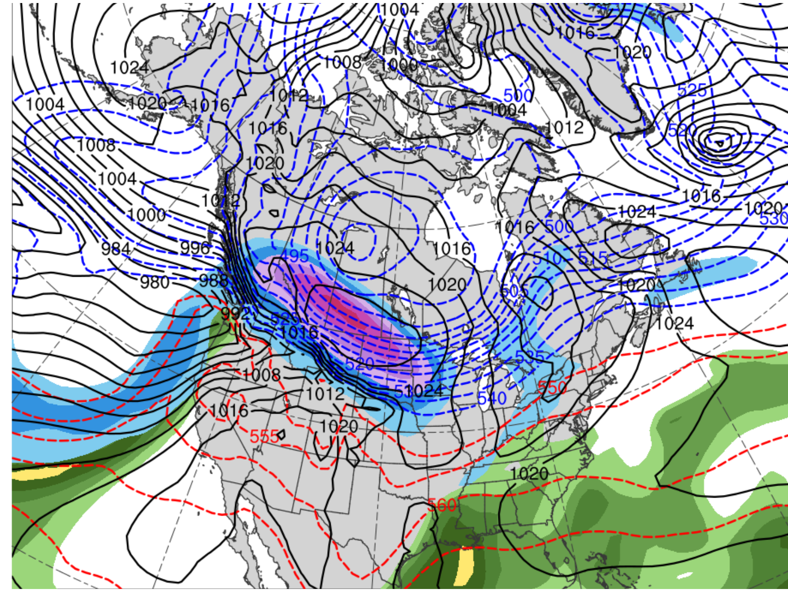
Best and Worst Comparison

1200 UTC 29 Dec 1996

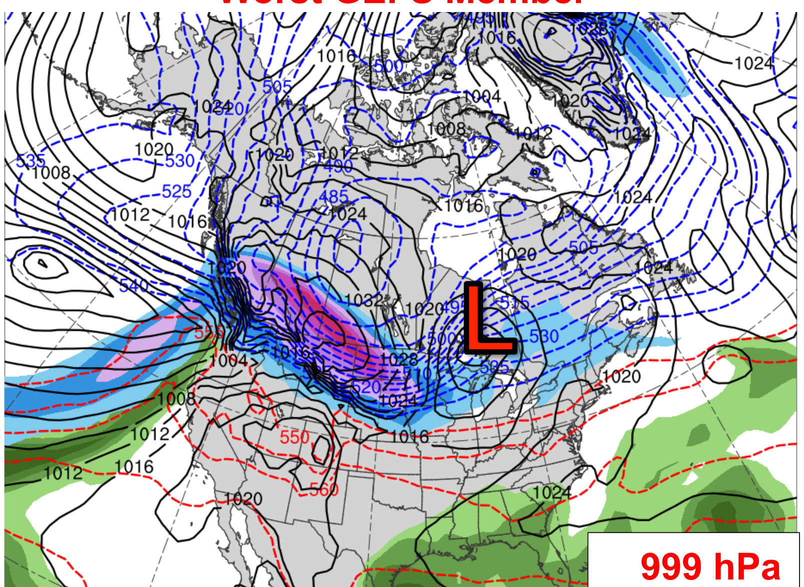
Best GEFS Member

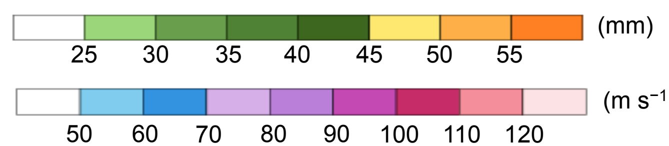


ERA-Interim



Worst GEFS Member



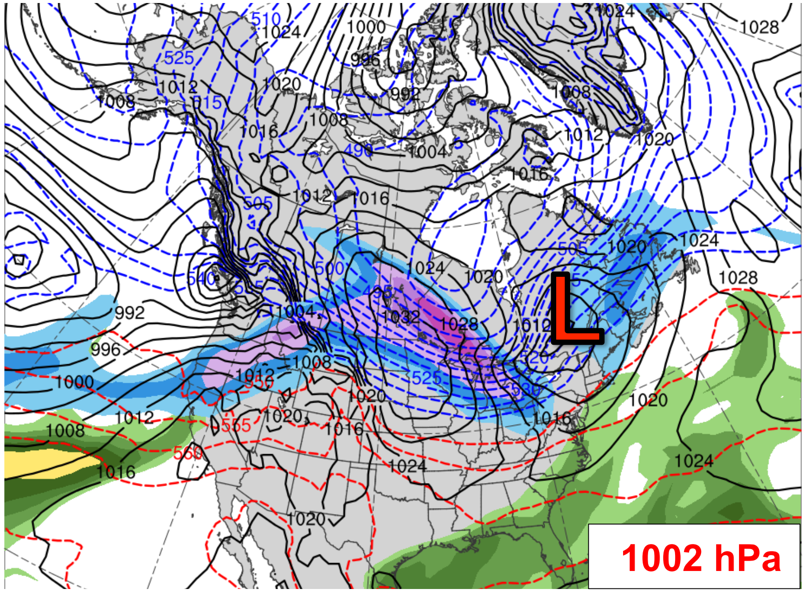


250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

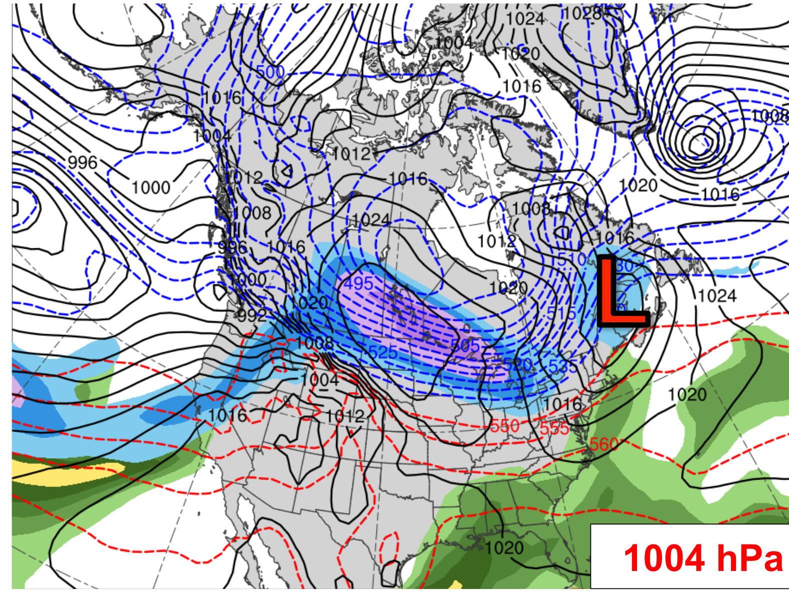
Best and Worst Comparison

0000 UTC 30 Dec 1996

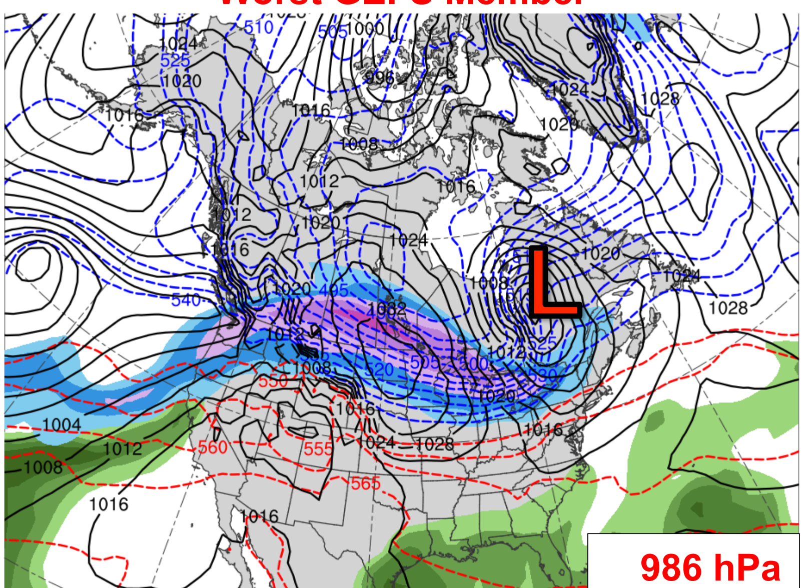
Best GEFS Member

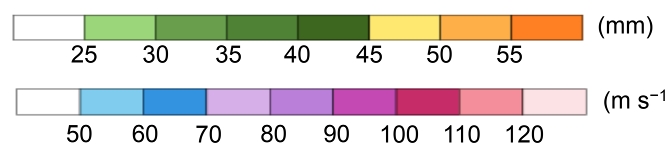


ERA-Interim



Worst GEFS Member



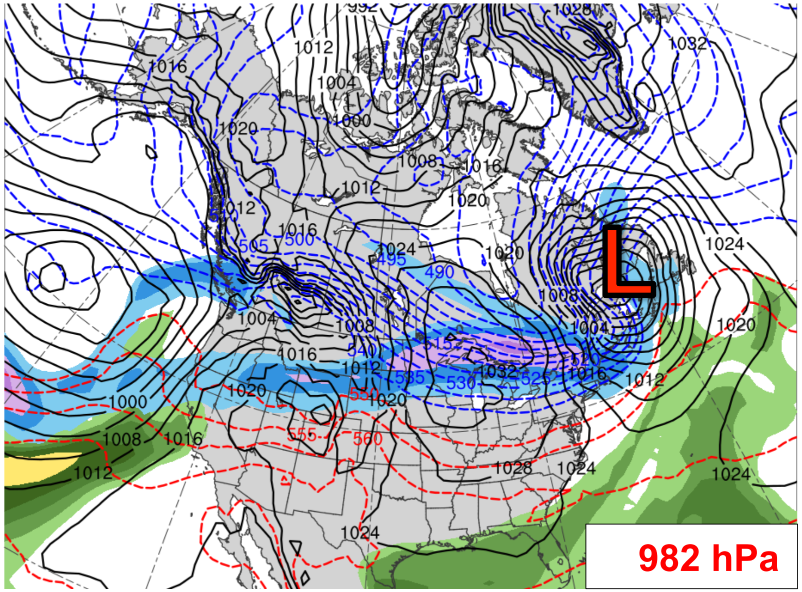


250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

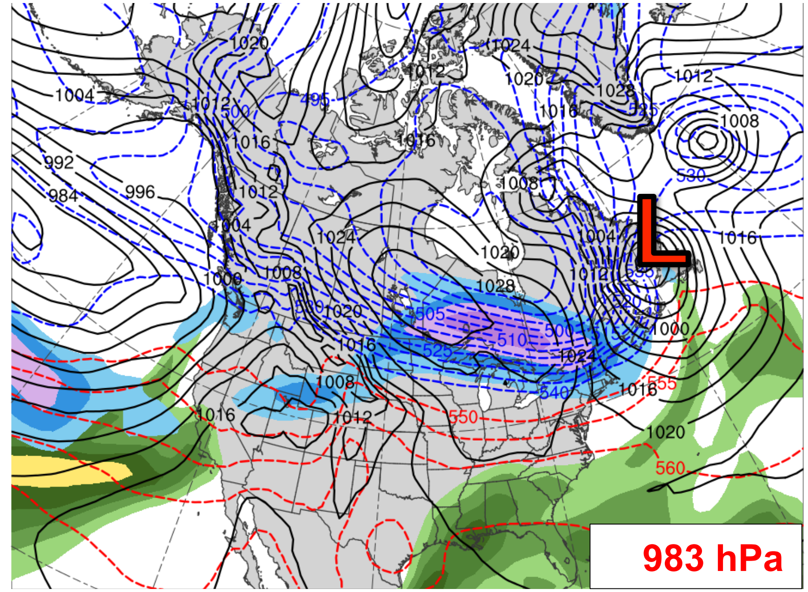
Best and Worst Comparison

1200 UTC 30 Dec 1996

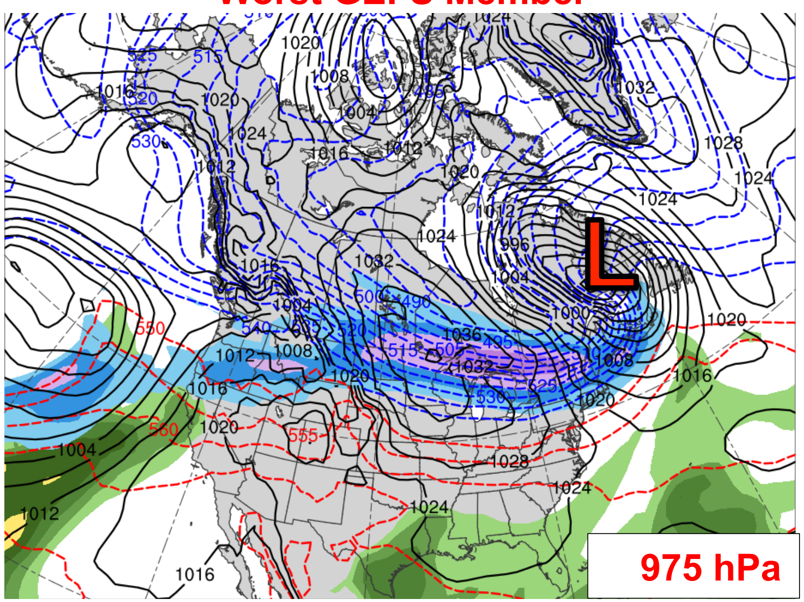
Best GEFS Member

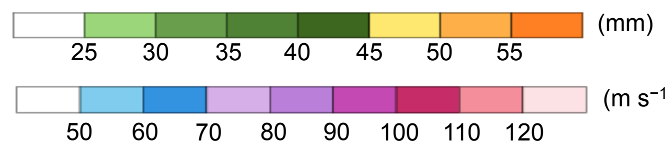


ERA-Interim



Worst GEFS Member



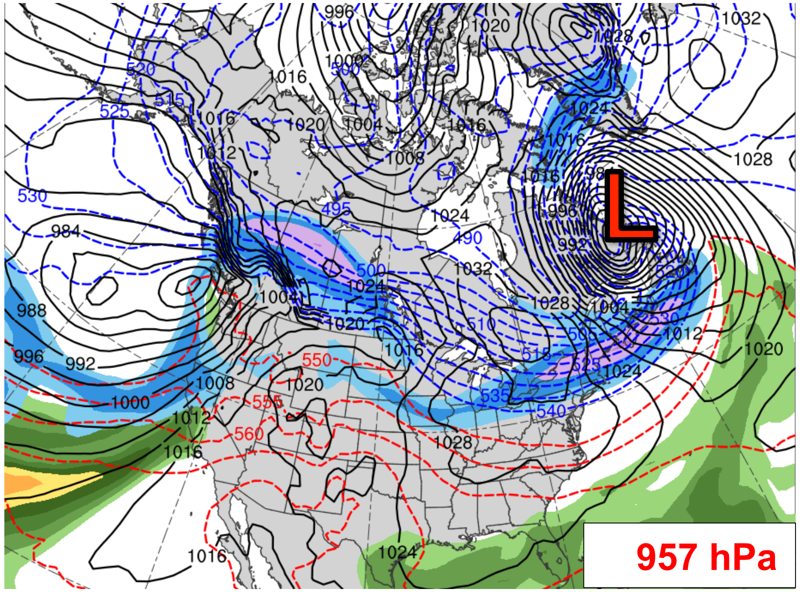


250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

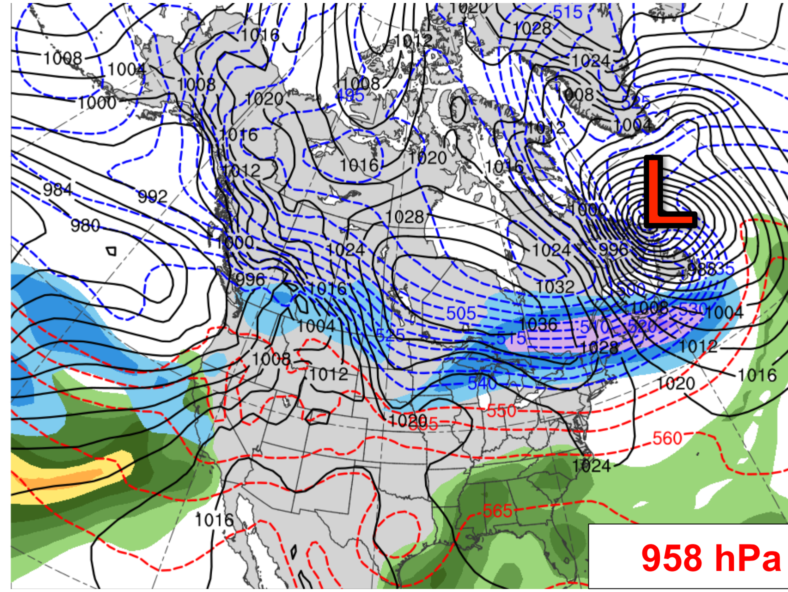
Best and Worst Comparison

0000 UTC 31 Dec 1996

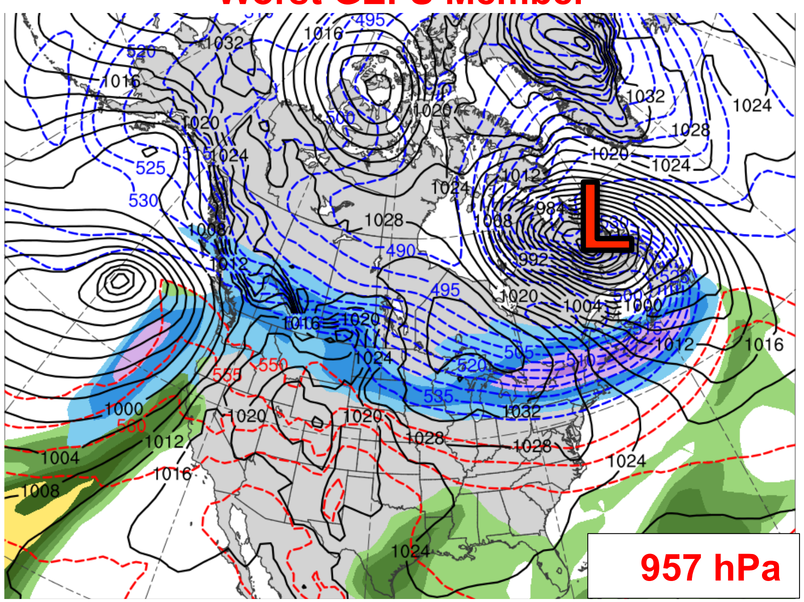
Best GEFS Member

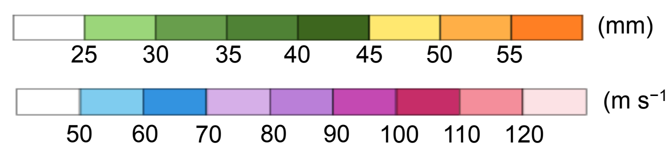


ERA-Interim



Worst GEFS Member



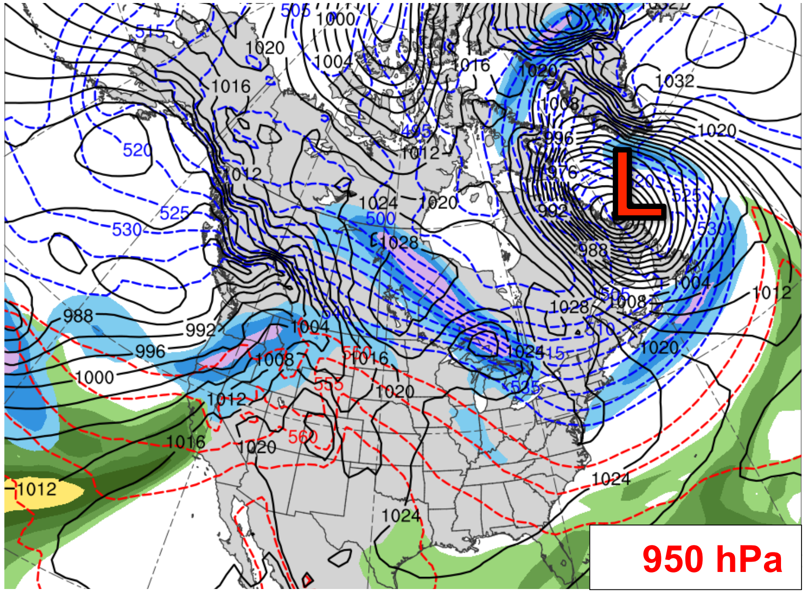


250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

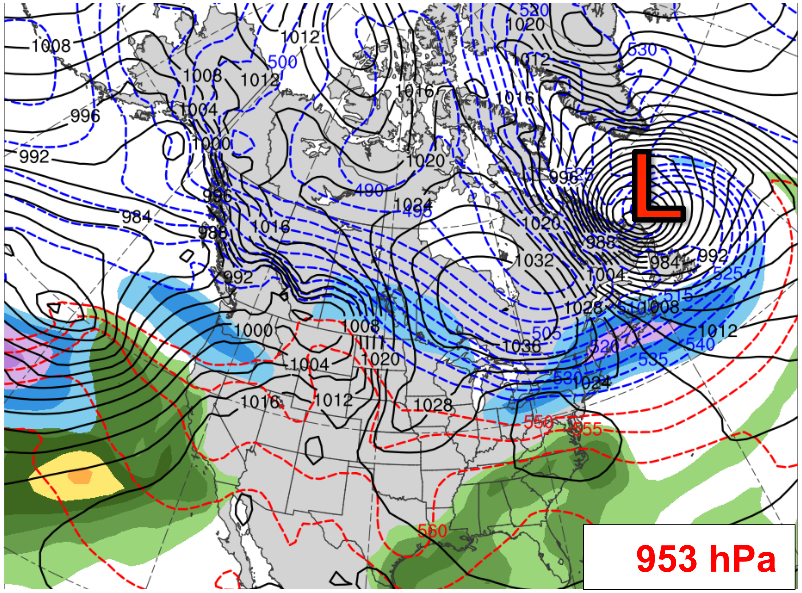
Best and Worst Comparison

1200 UTC 31 Dec 1996

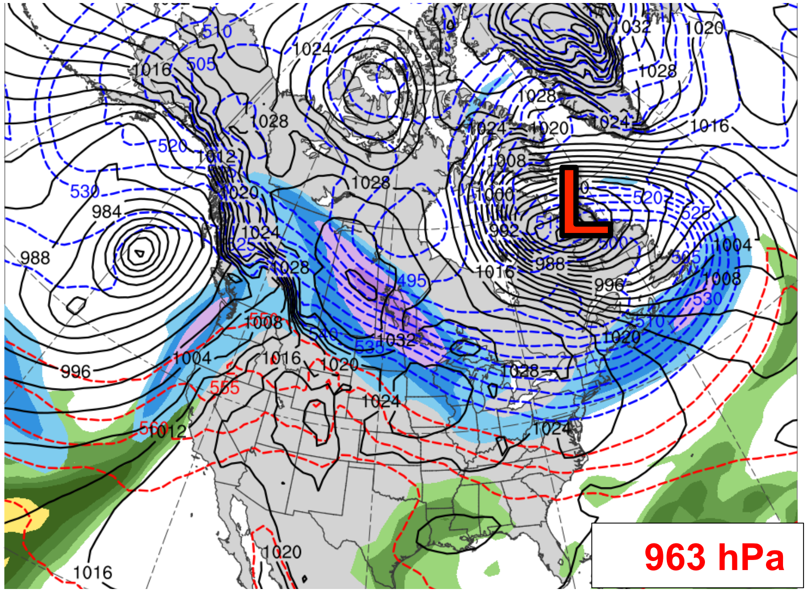
Best GEFS Member

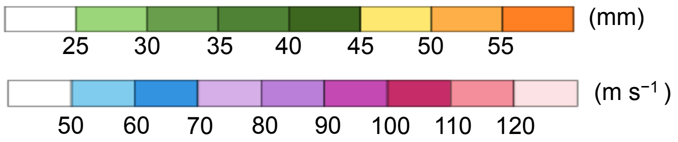


ERA-Interim



Worst GEFS Member



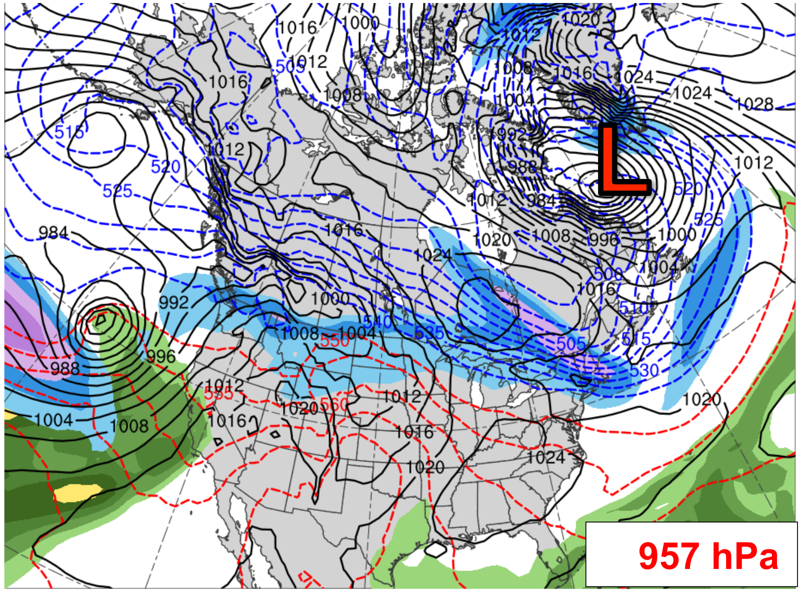


250-hPa wind speed (m s^{-1}, shaded),
1000–500-hPa thickness (dam, blue/red),
MSLP (hPa, black), PW (mm, shaded)

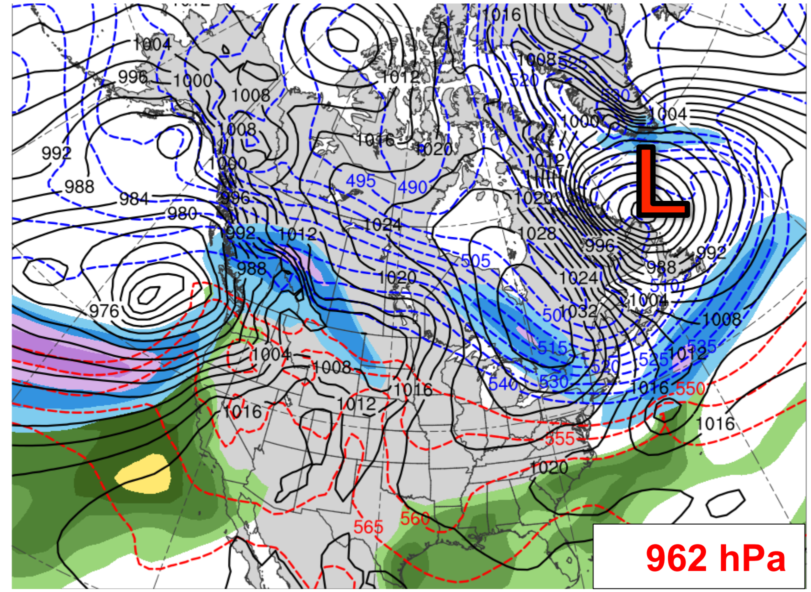
Best and Worst Comparison

0000 UTC 1 Jan 1997

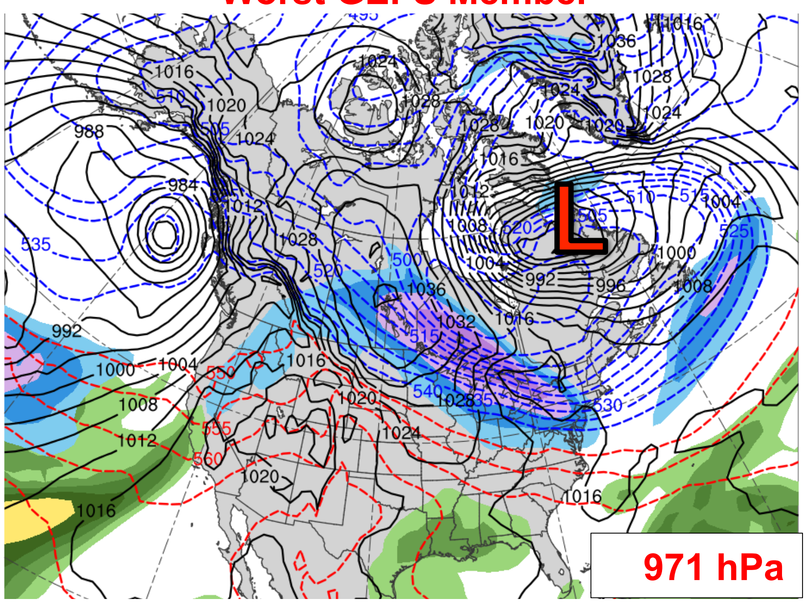
Best GEFS Member

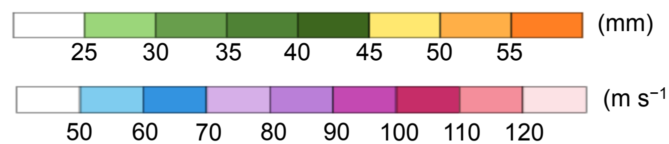


ERA-Interim



Worst GEFS Member



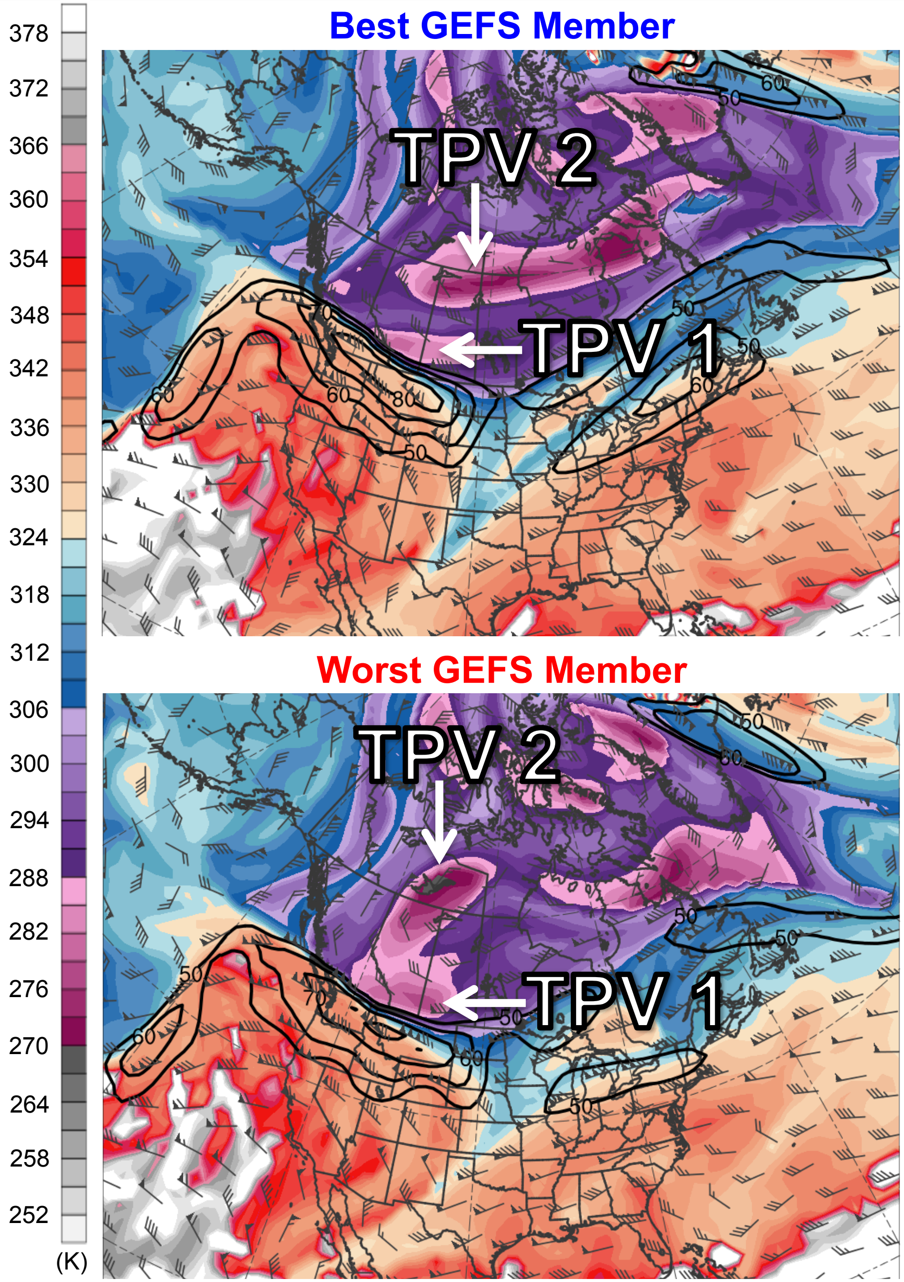


250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), MSLP (hPa, black), PW (mm, shaded)

Best and Worst Comparison

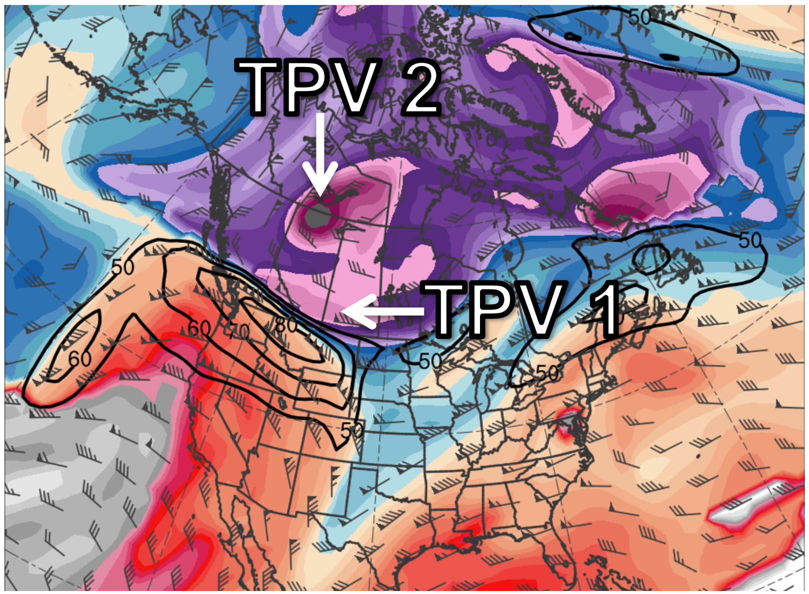
0000 UTC 29 Dec 1996

Best GEFS Member



Worst GEFS Member

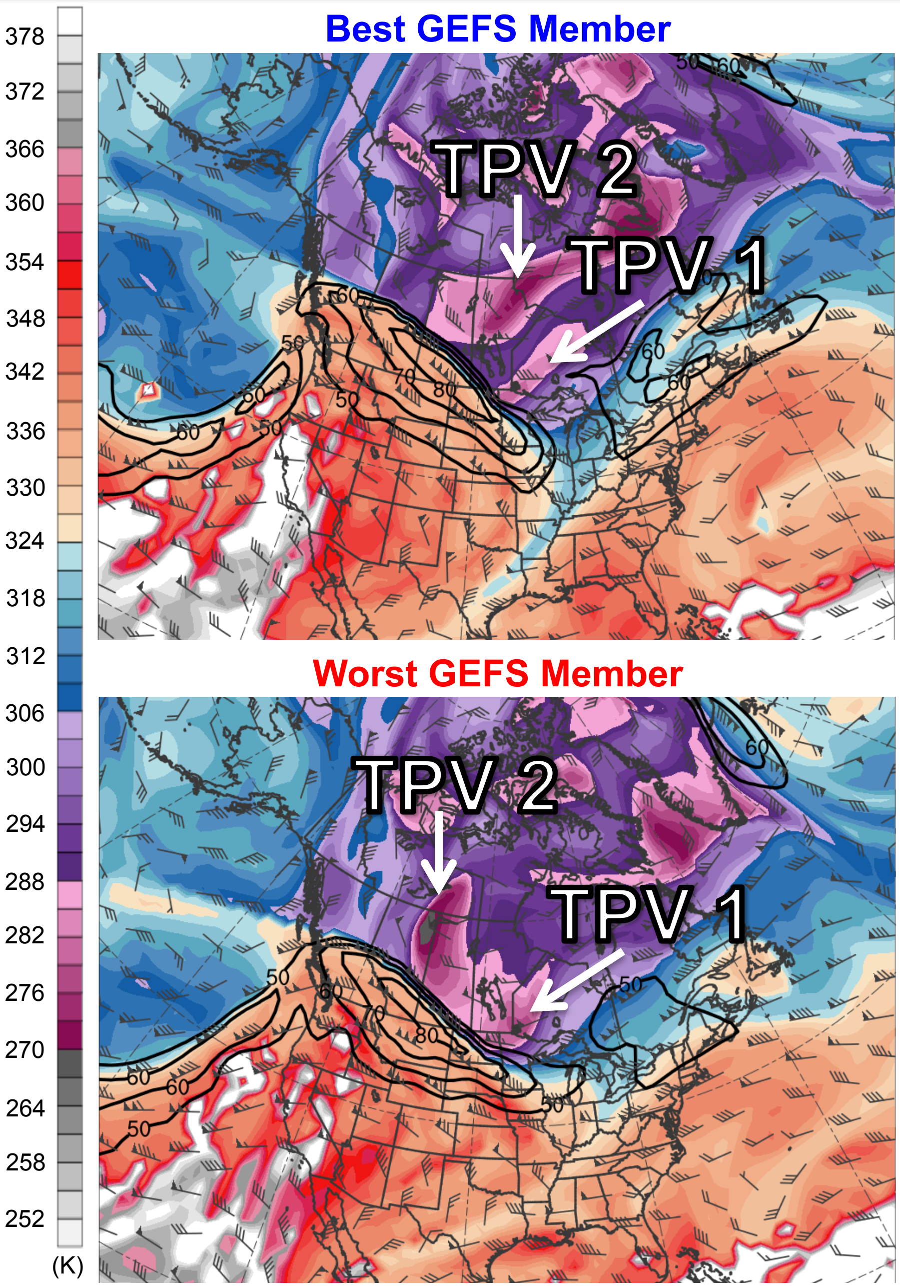
ERA-Interim

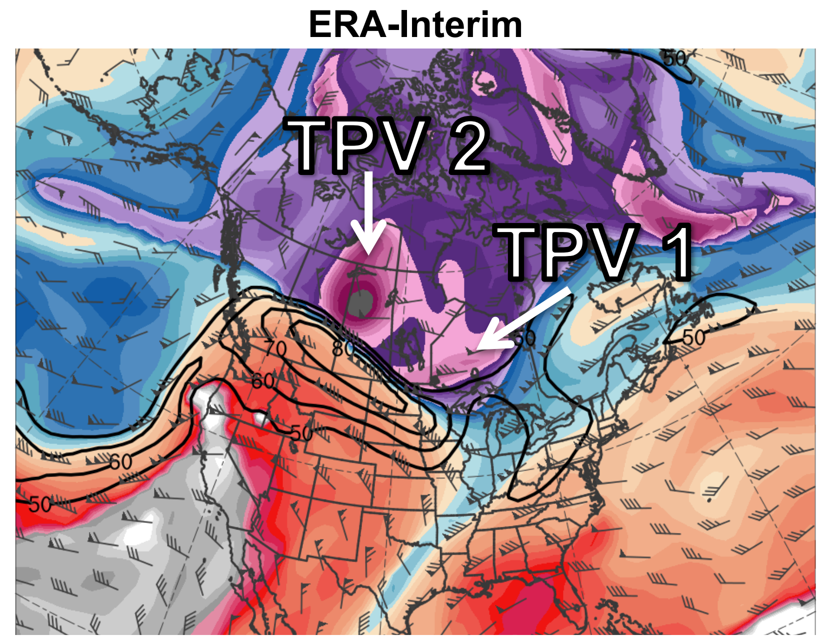


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

Best and Worst Comparison

1200 UTC 29 Dec 1996

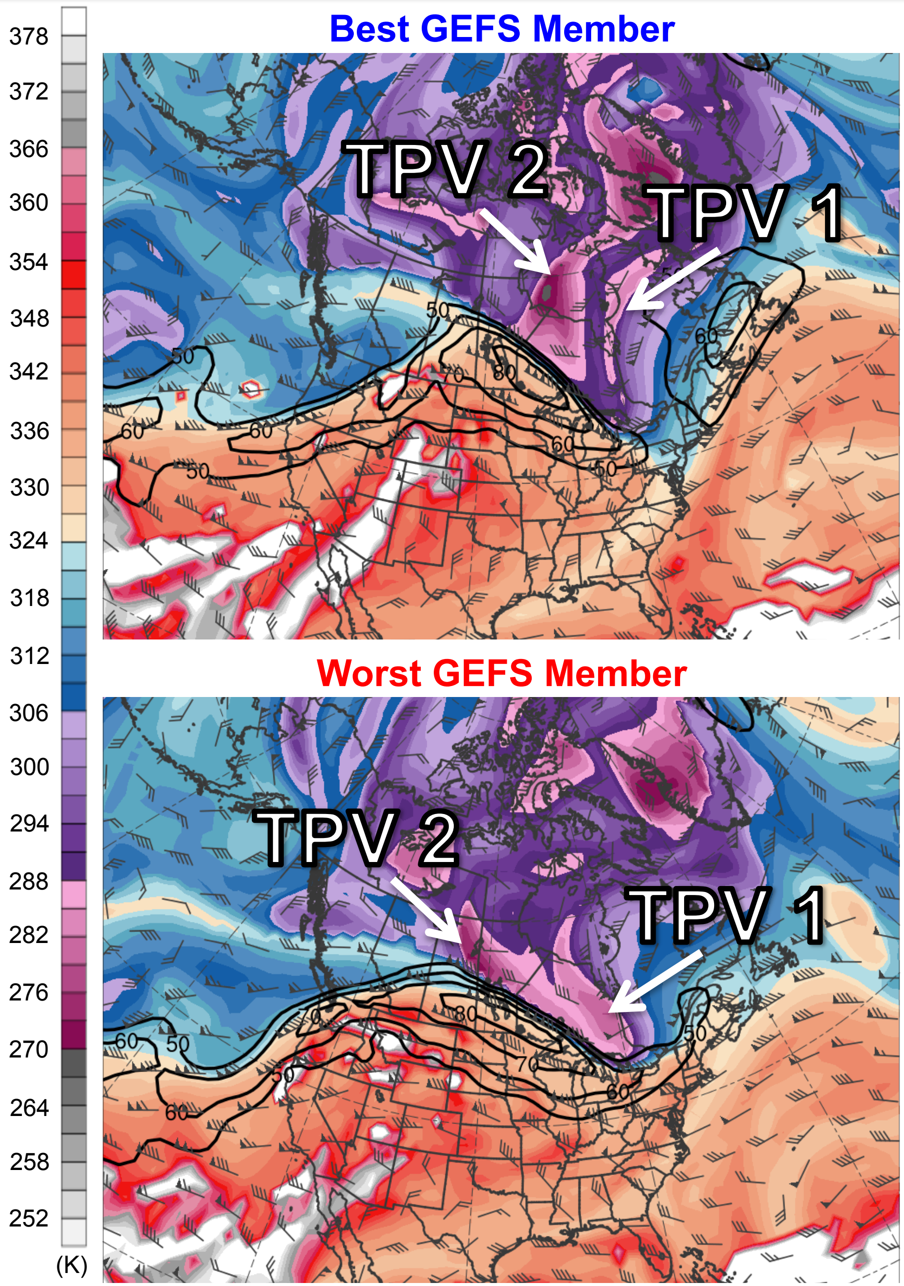


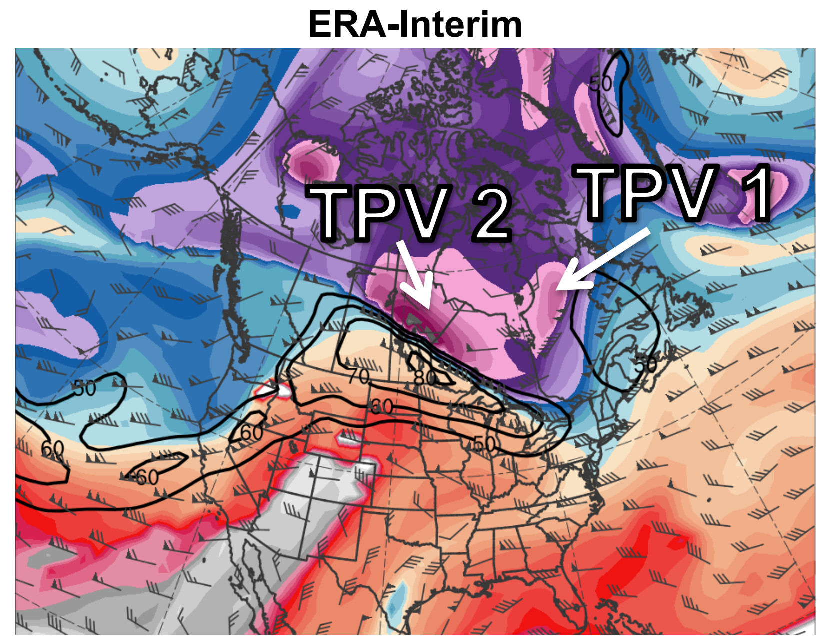


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

Best and Worst Comparison

0000 UTC 30 Dec 1996

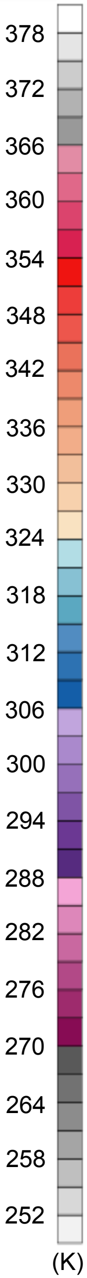




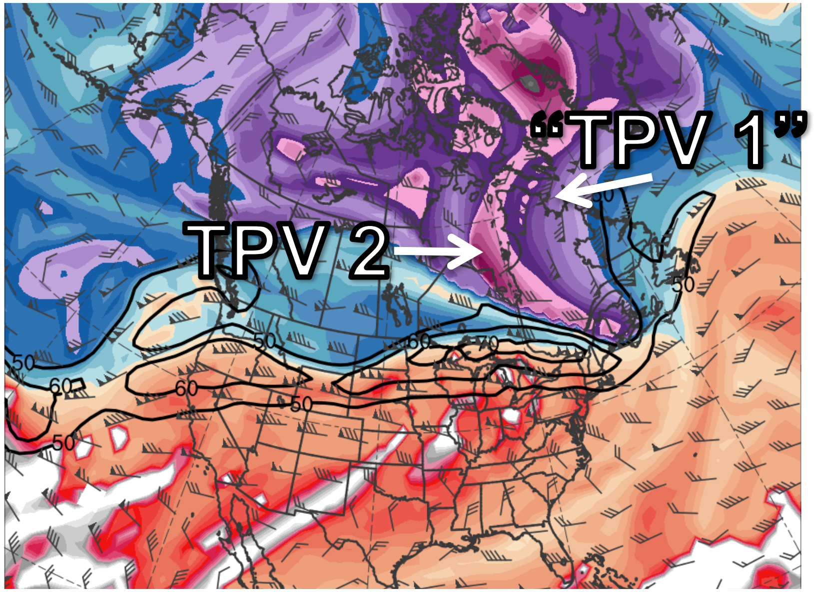
Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

Best and Worst Comparison

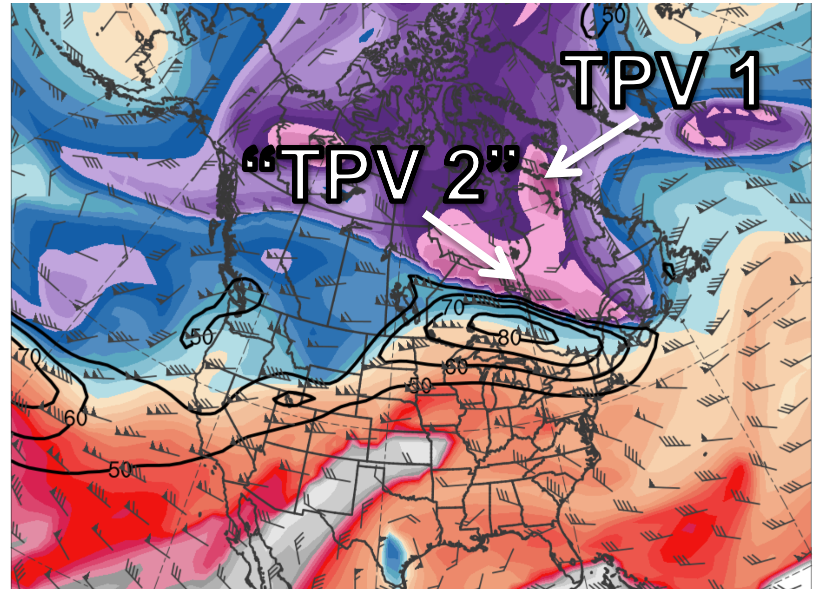
1200 UTC 30 Dec 1996



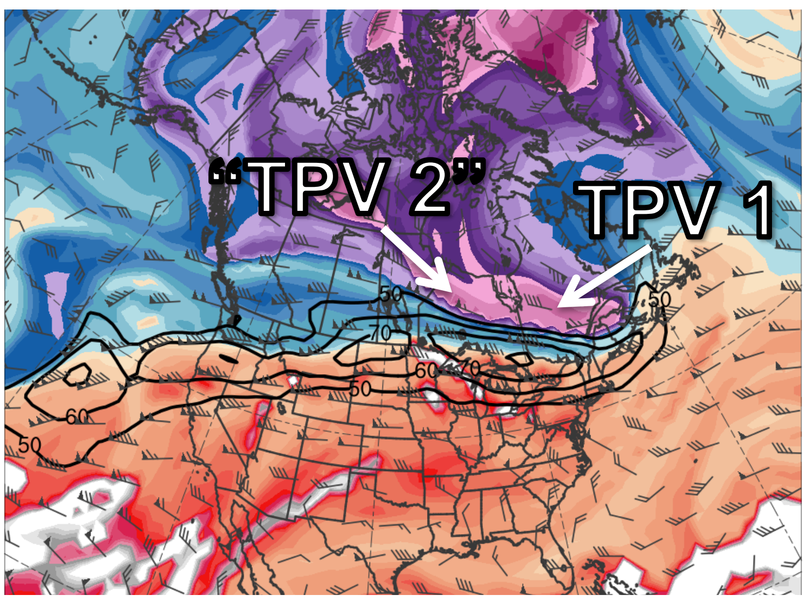
Best GEFS Member



ERA-Interim



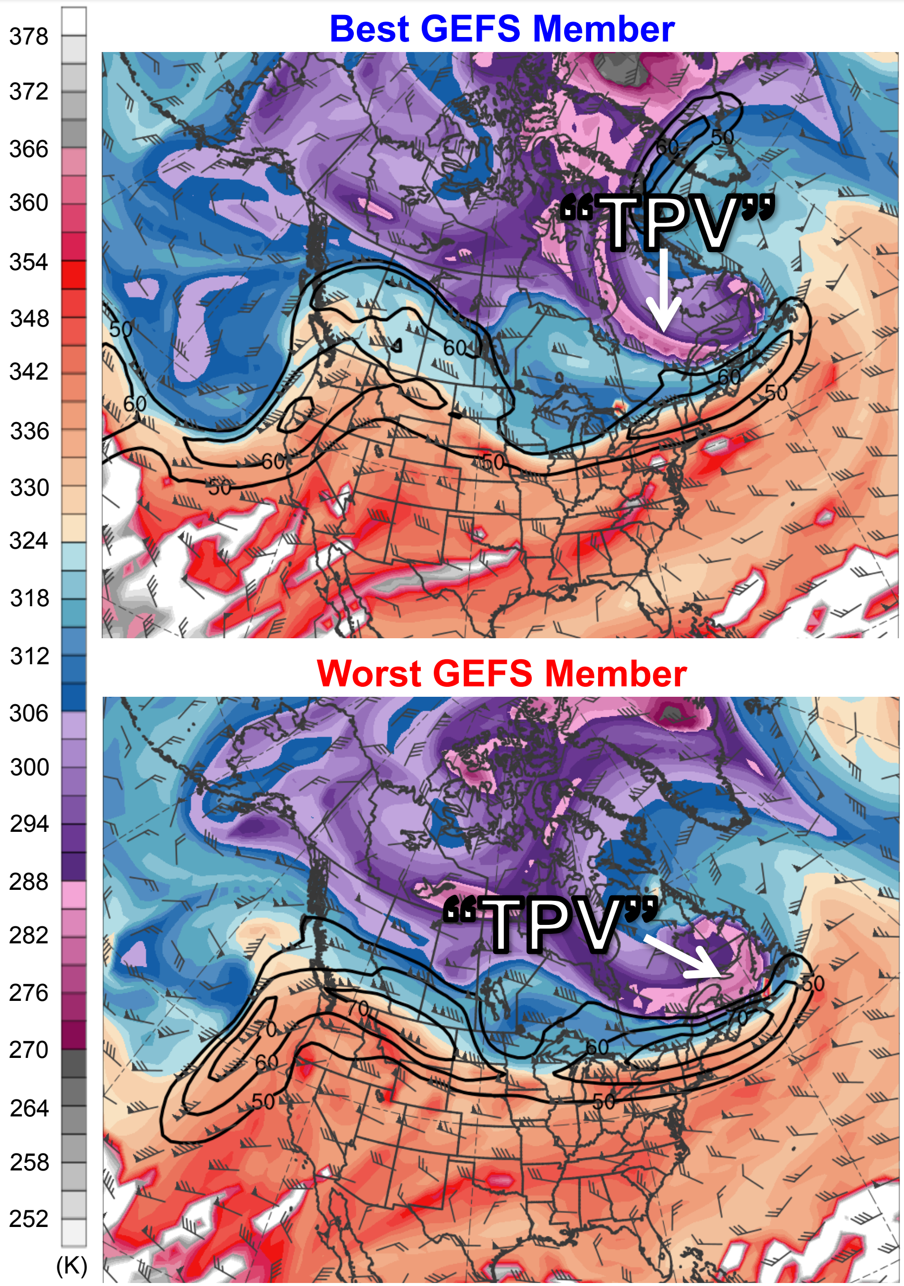
Worst GEFS Member

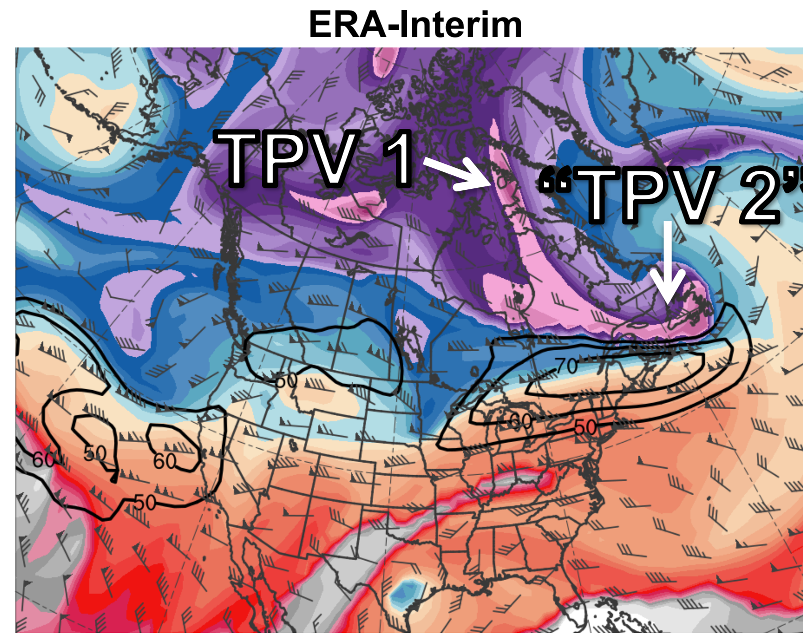


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

Best and Worst Comparison

0000 UTC 31 Dec 1996

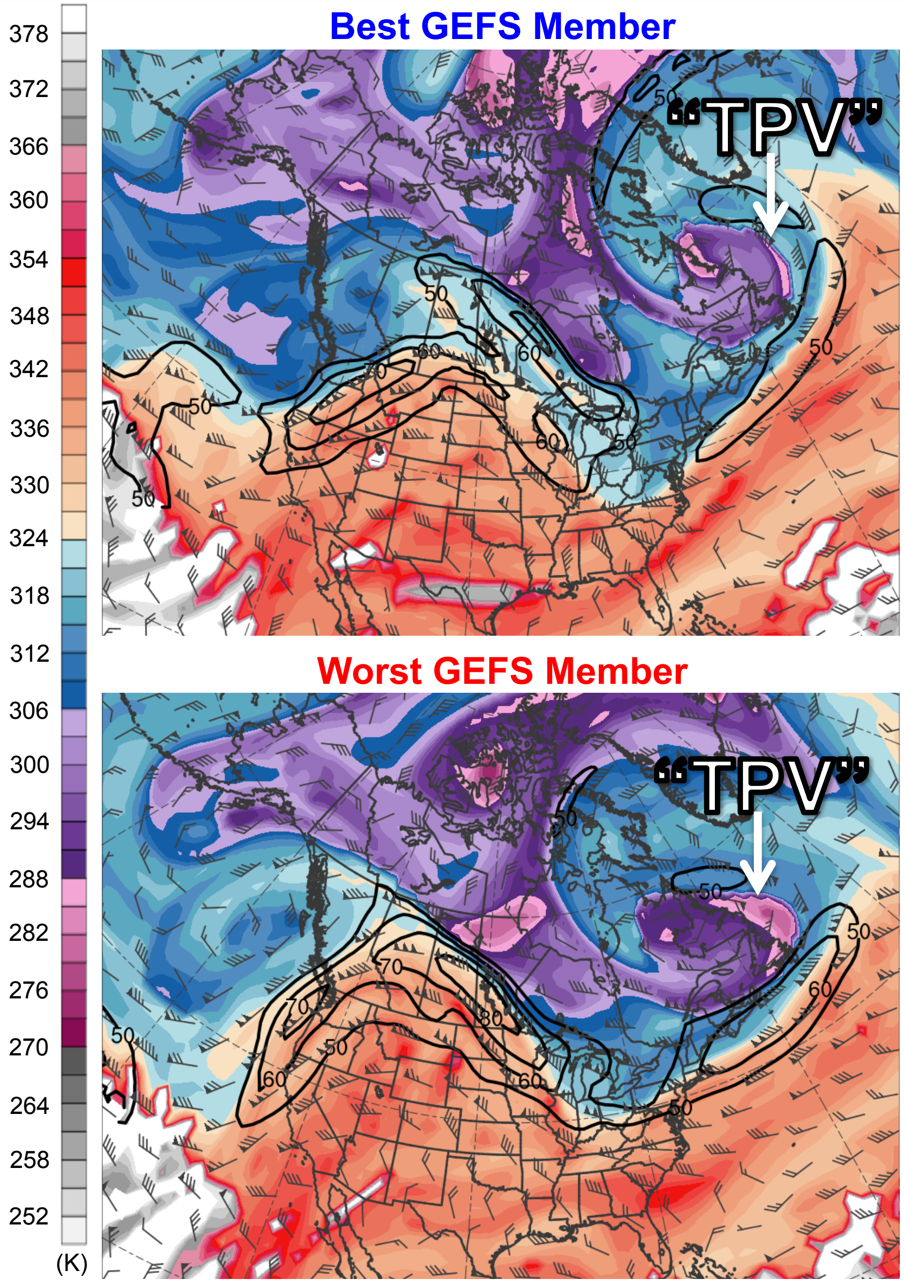


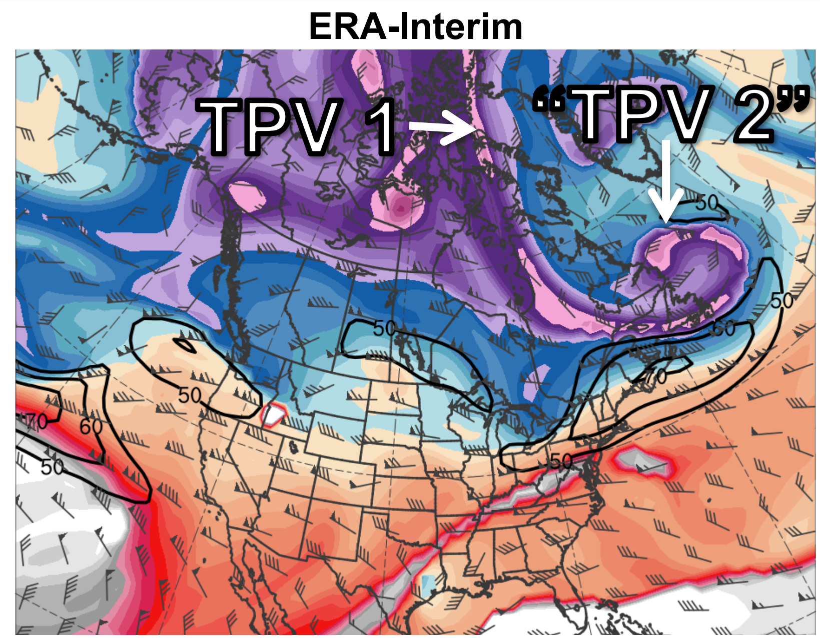


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

Best and Worst Comparison

1200 UTC 31 Dec 1996

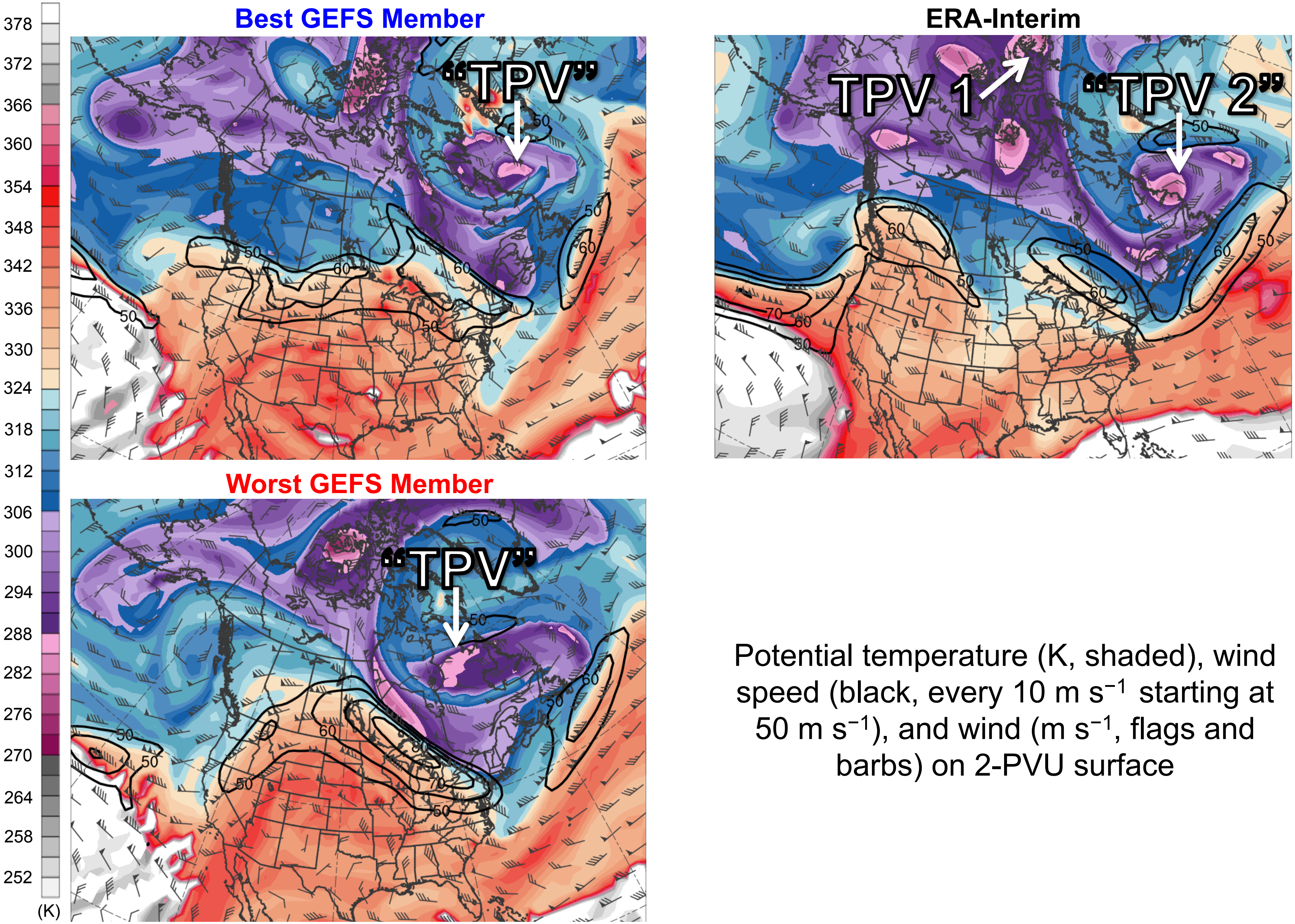




Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

Best and Worst Comparison

0000 UTC 1 Jan 1997



Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

Preliminary Conclusions

- Appears to be two overall camps in GEFS forecasts:
  - EC in forecast develops too quickly and tracks too far to northwest of actual EC track
  - EC in forecast develops more slowly like actual EC and tracks closer to actual EC track (though still a bit too far to the northwest in most cases)
- Timing of EC development and resulting EC track may be tied to location and strength of TPVs, and the degree of interaction of these TPVs with the jet and with one another
  - E.g., worst GEFS member has a stronger TPV 1 that appeares to interact more strongly with jet streak, resulting in earlier development of the EC than in ERA-Interim

Next Steps

- Calculate similar forecast skill metric for TPVs and determine the degree to which forecast skill of these TPVs is related to forecast skill of the EC
- Look more in-depth into best and worst GEFS members to better determine contributions of TPV 1 and TPV 2 to EC development and how these contributions differ from those in the ERA-Interim