Linkages Between Tropopause Polar Vortices and the Development of Cold Air Outbreaks over Central and Eastern North America

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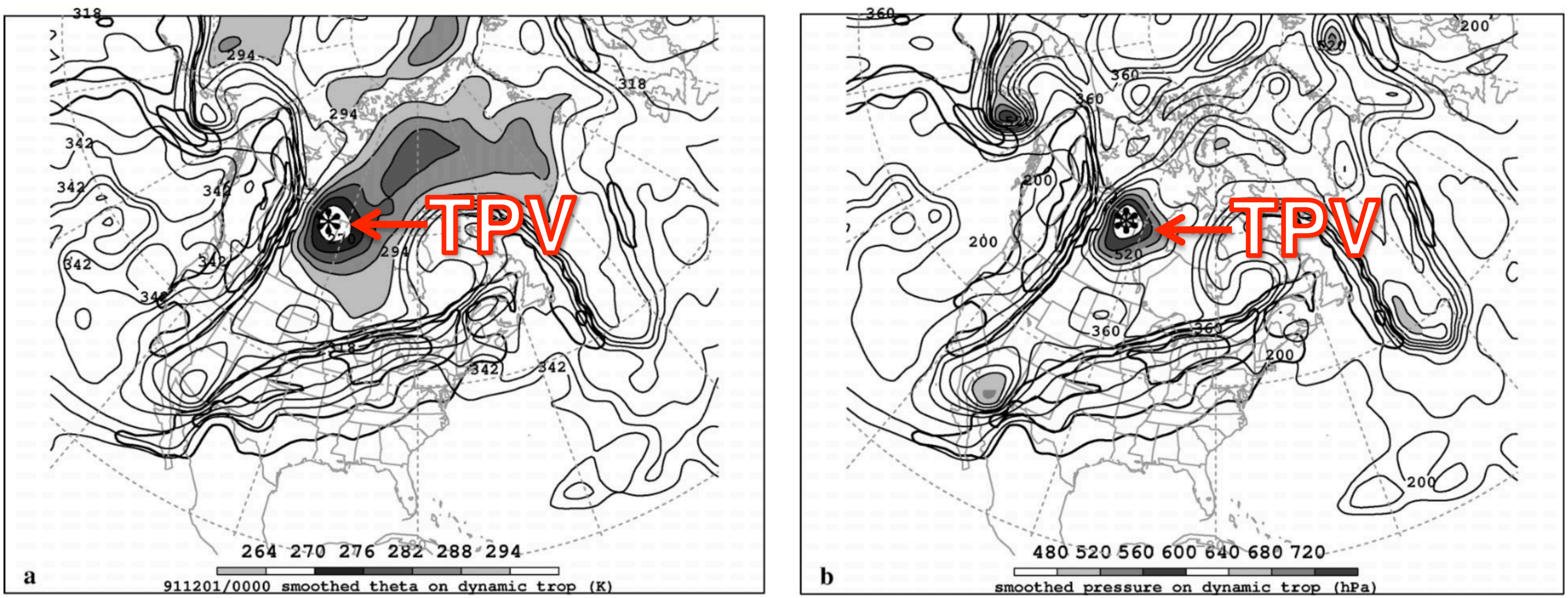
What are Tropopause Polar Vortices (TPVs)?

- 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 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 intense midlatitude cyclones

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- Arctic air surges that accompany TPVs as they are transported into middle latitudes may lead to widespread cold air outbreaks (CAOs)

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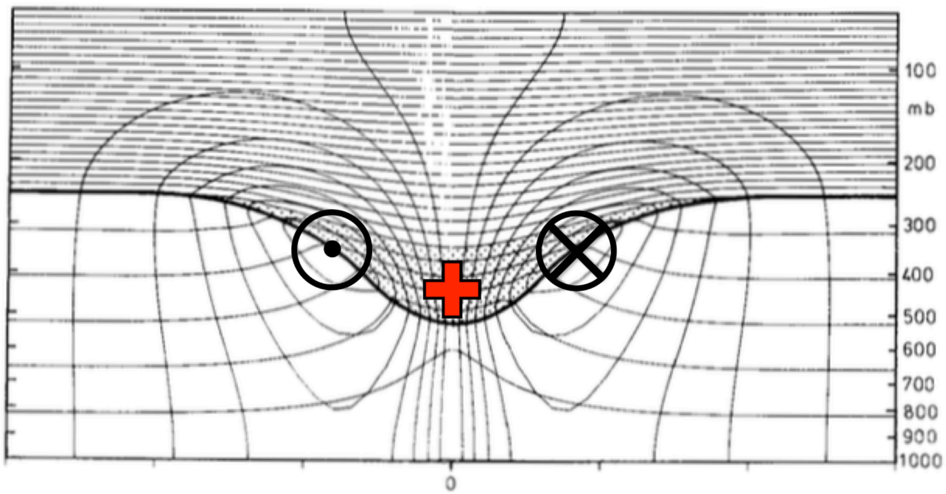
- Arctic air surges that accompany TPVs as they are transported into middle latitudes may lead to widespread cold air outbreaks (CAOs)
- CAOs may lead to significant socioeconomic impacts, posing a hazard to society, agriculture, and infrastructure

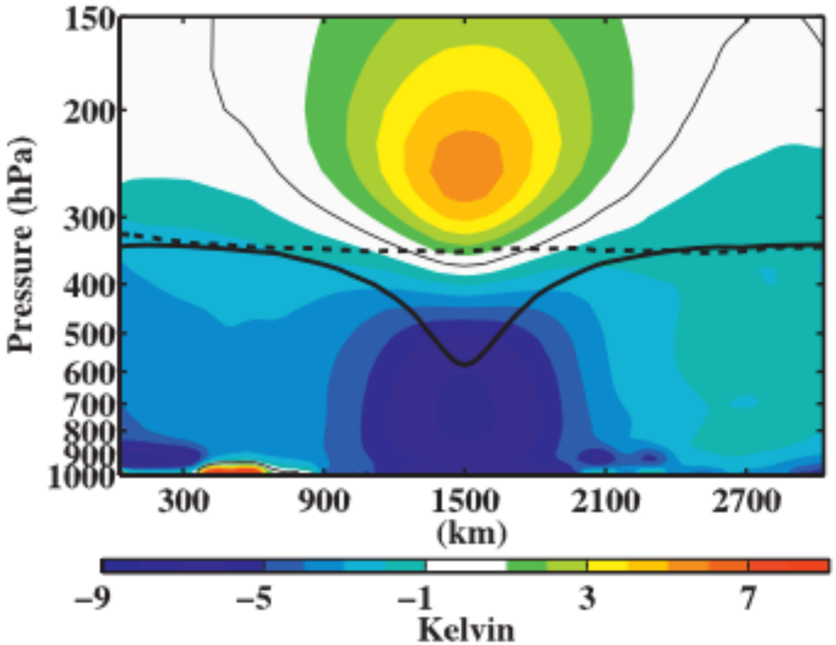
Background

Hoskins et al. (1985)



Cross section of circularly symmetric cyclonic flow induced by simple isolated upper-level cyclonic PV anomaly (stippled region and red plus symbol). The thick line represents the tropopause and the solid contours represent potential temperature (every 5 K) and azimuthal wind velocity (every 3 m s^{-1}). Figure 15 and caption adapted from Hoskins et al. (1985, section 3).

Cavallo and Hakim (2010)

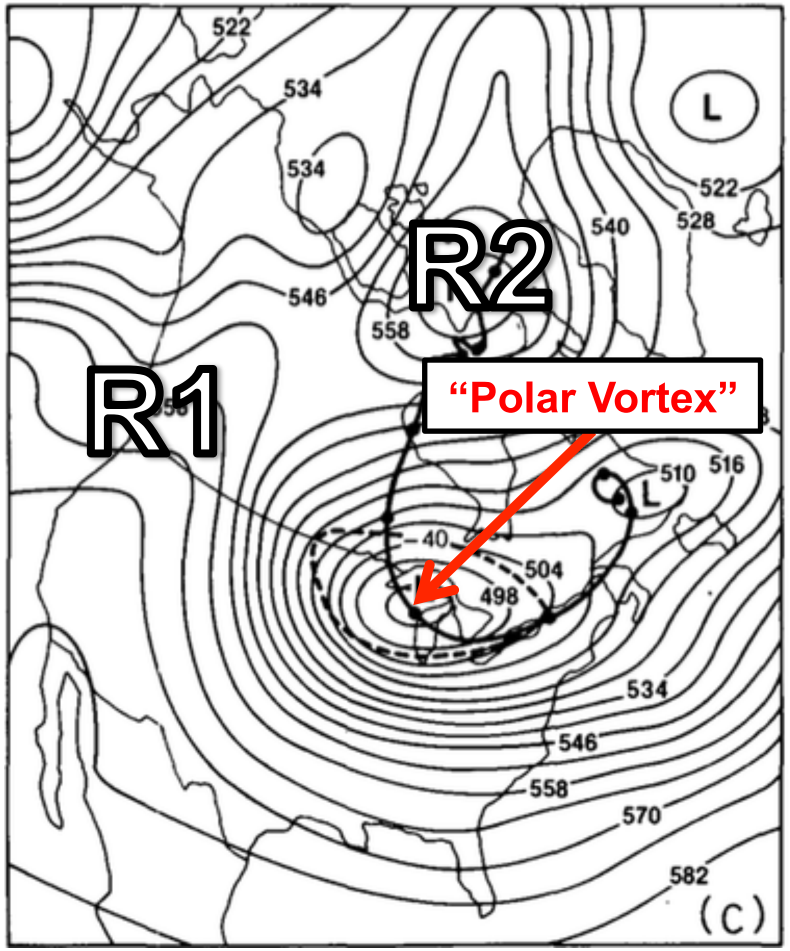


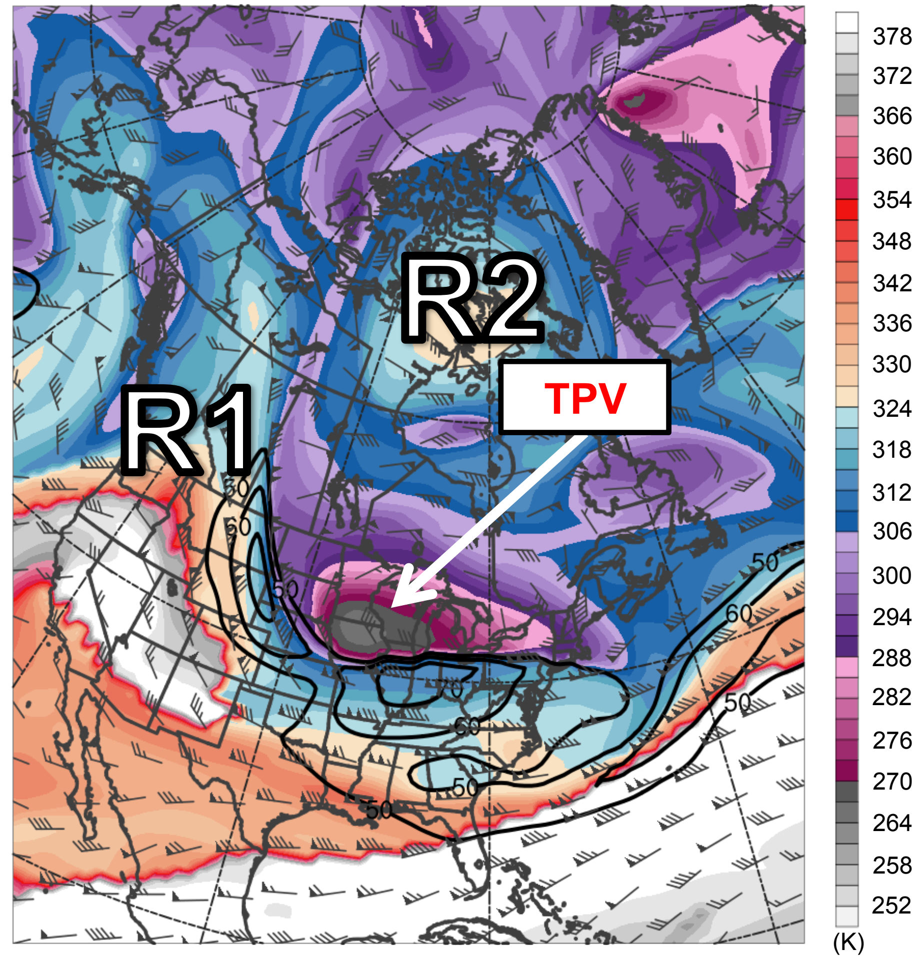
Composite west-to-east cross-TPV section of anomalous temperature (K). Thick solid black contour is the composite tropopause, thick dashed black contour is the background tropopause, and thin solid contour is the 0 contour. Figure 9 and adapted caption from Cavallo and Hakim (2010).

Background

Shapiro et al. (1987)

0000 UTC 20 January 1985





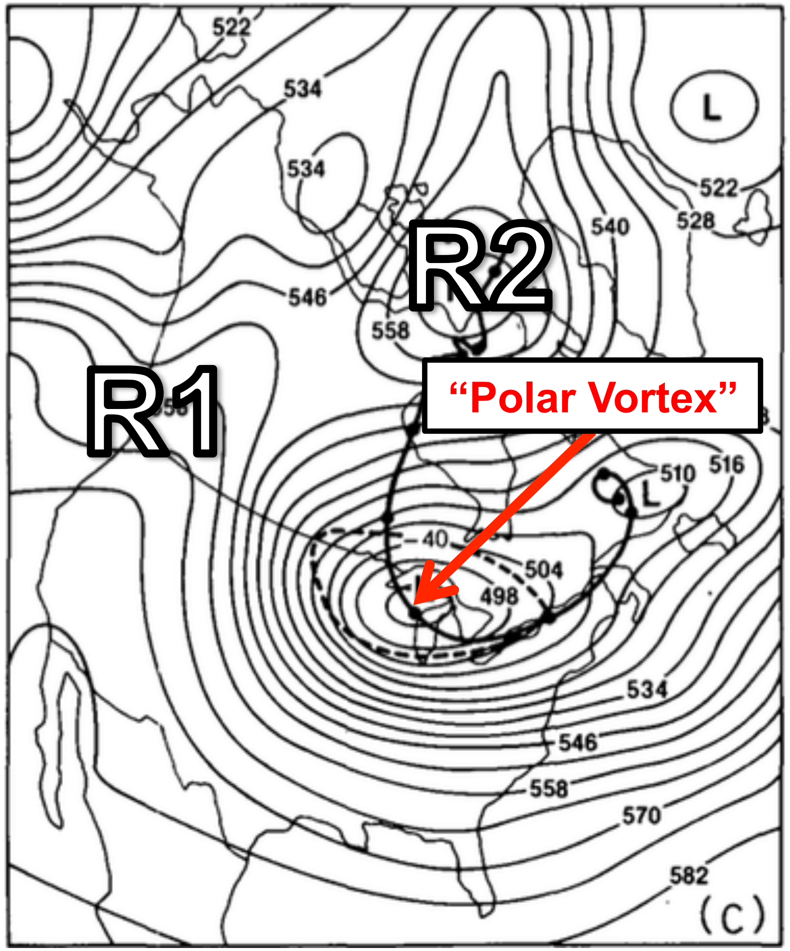
500-hPa geopotential height (black, every 6 dam) and −40°C isotherm (dashed contour); track of polar vortex from 0000 UTC 12 January to 0000 UTC 24 January 1985 (heavy black). Figure 5 and caption adapted from Shapiro et al. (1987).

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

Background

Shapiro et al. (1987)

0000 UTC 20 January 1985



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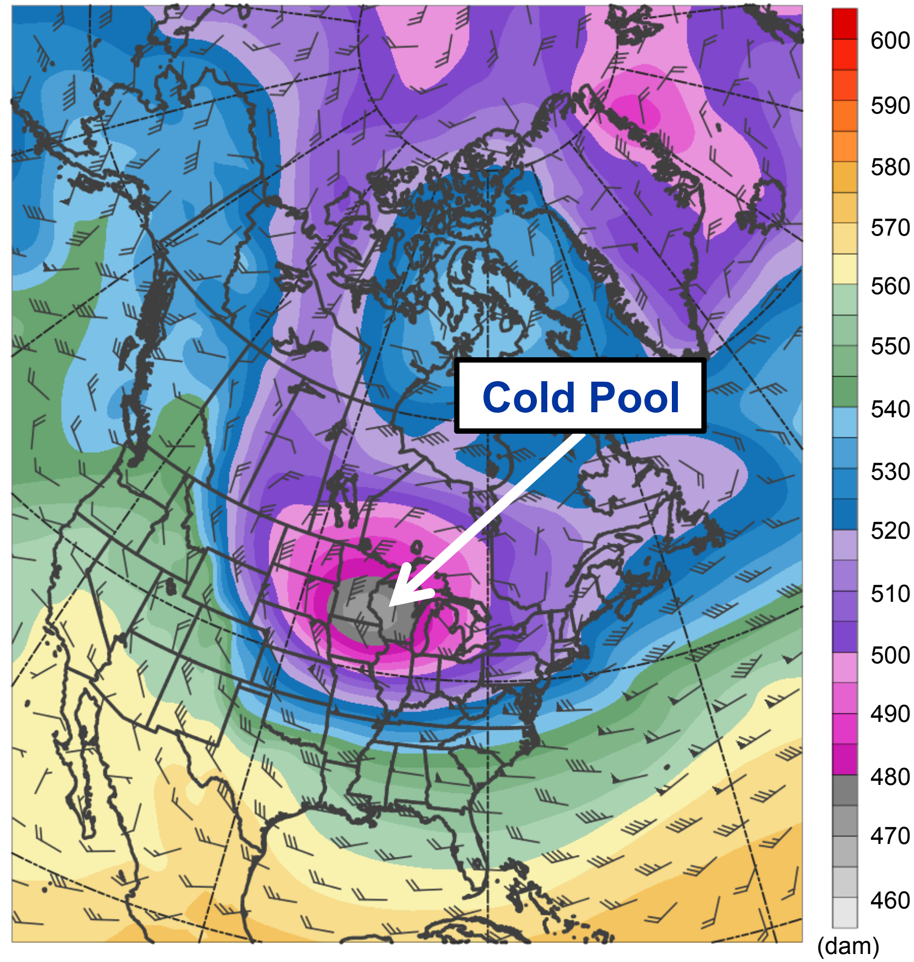
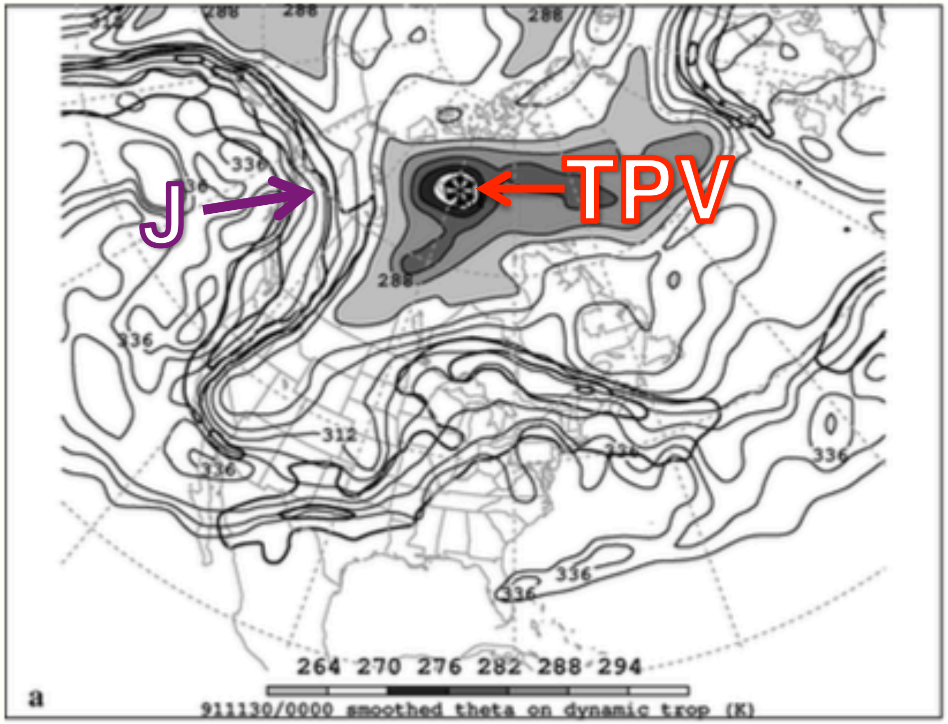


1000–500-hPa thickness (dam, shaded) and 700-hPa wind (m s^{-1}, flags and barbs).
Data source: ERA-Interim.

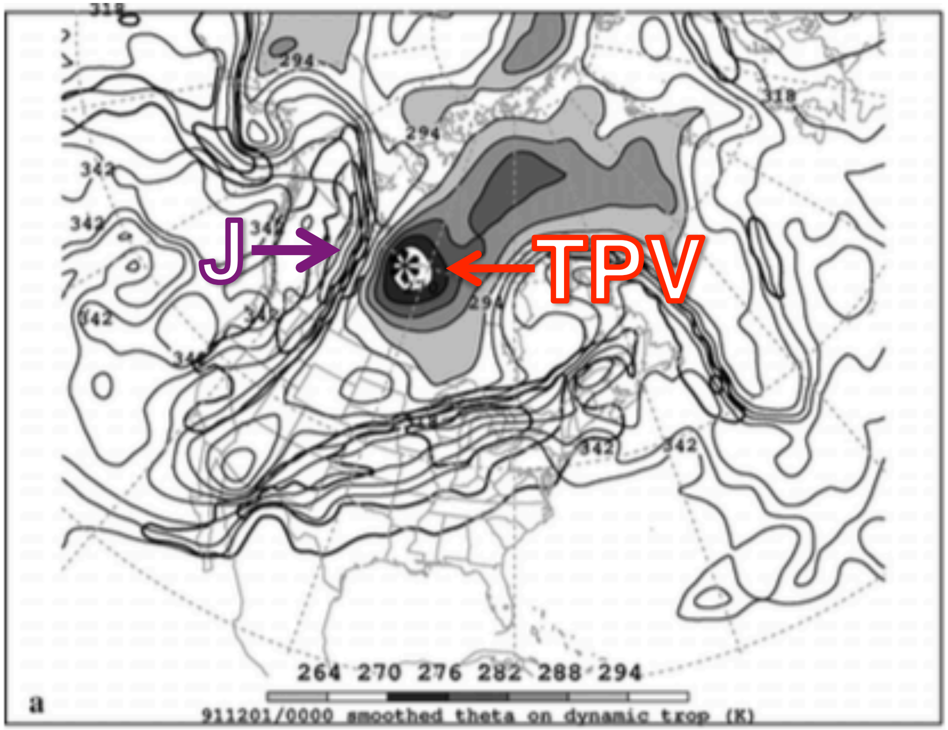
Background

- TPV–jet interaction may lead to the formation and intensification of jet streaks

0000 UTC 30 November 1991



0000 UTC 1 December 1991



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). Figures 10 and 11 and captions adapted from Pyle et al. (2004).

9–14 January 1982 CAO

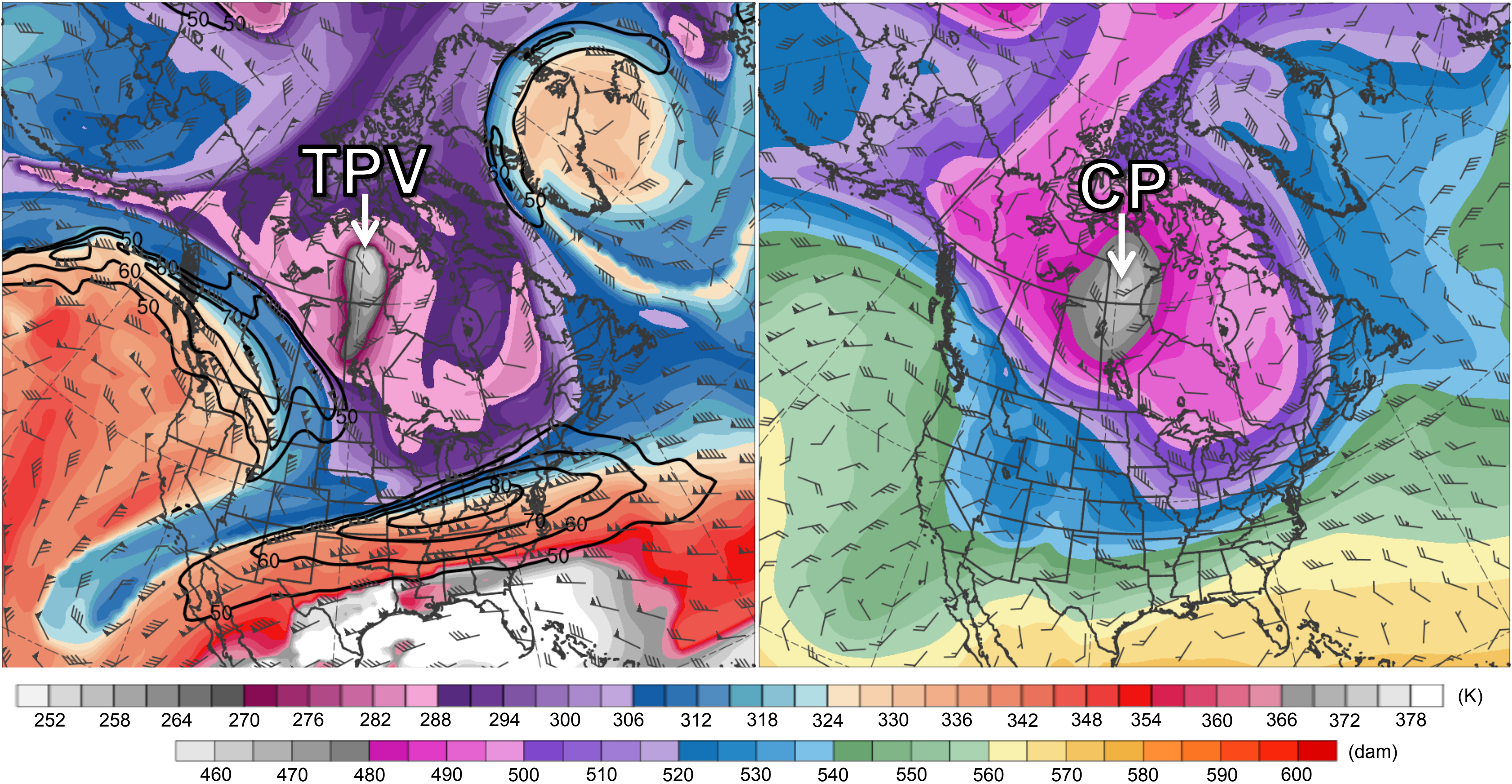
- According to NOAA NCEI, contributed to cost of 1.7 billion dollars, after 2017 consumer price index adjustment, and 85 deaths (https://www.ncdc.noaa.gov/billions/)

- Lead to widespread record low temperatures over the central and eastern U.S. (Wagner 1982)
  - All-time record low of −32.2°C (−26°F) in Chicago, IL on 10 January 1982
  - All-time record low of −17.2°C (1°F) in Augusta, GA on 11 January 1982

9–14 January 1982 CAO

0000 UTC 8 Jan 1982

Data Source: ERA-Interim

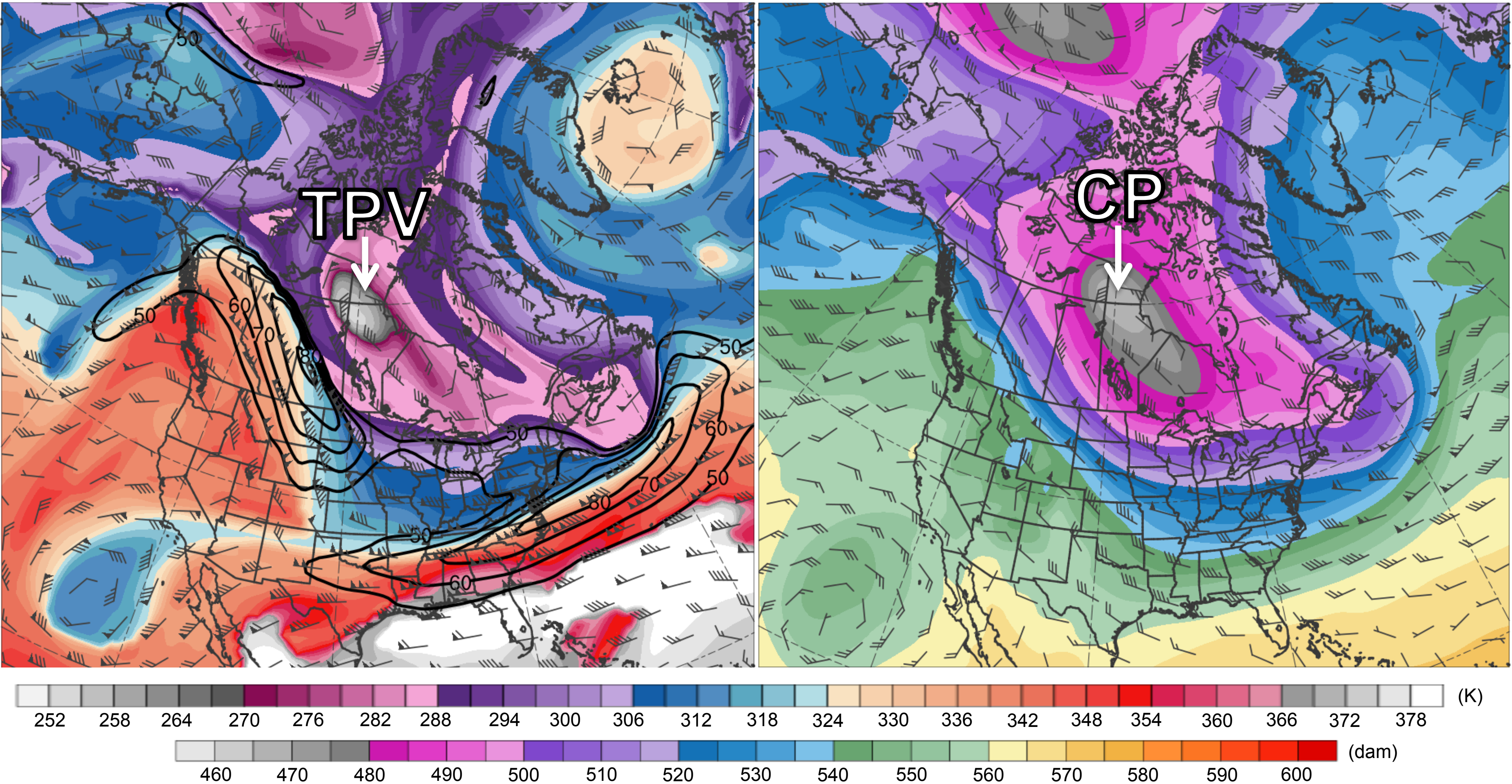


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface	1000–500-hPa thickness (dam, shaded) and 700-hPa wind (m s^{-1}, flags and barbs); CP denotes “cold pool”

9–14 January 1982 CAO

0000 UTC 9 Jan 1982

Data Source: ERA-Interim



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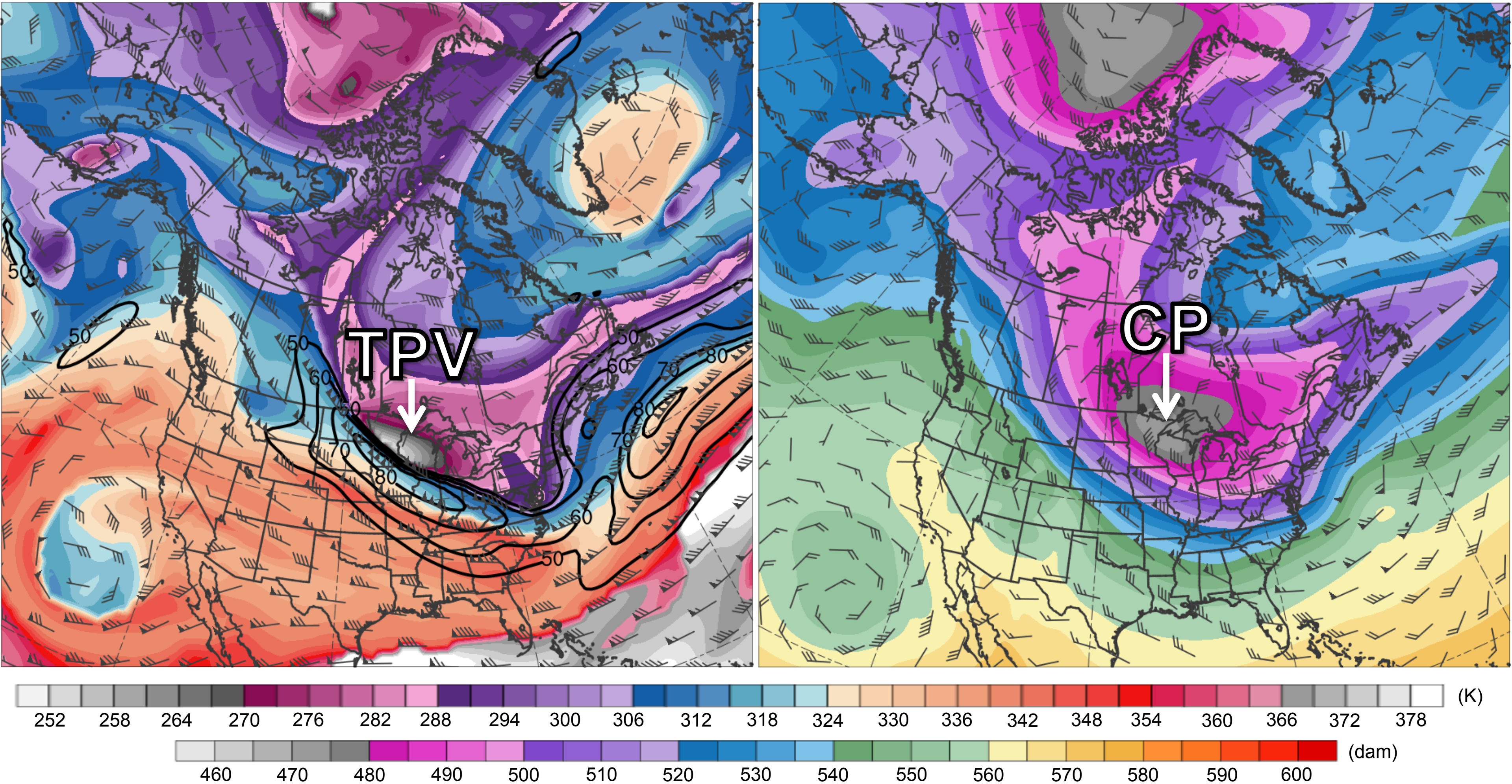
9–14 January 1982 CAO

0000 UTC 10 Jan 1982

Data Source: ERA-Interim



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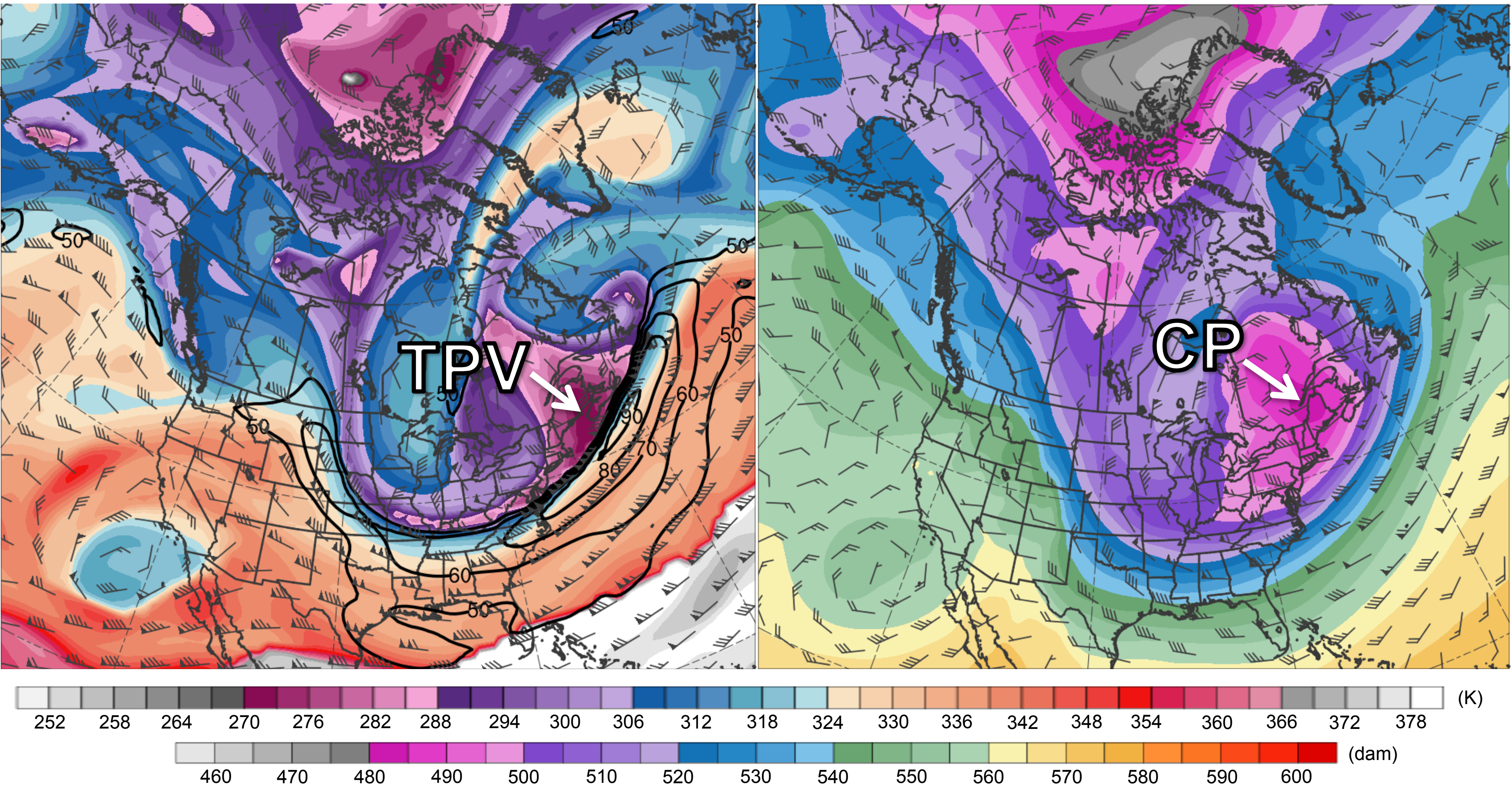
9–14 January 1982 CAO

0000 UTC 11 Jan 1982

Data Source: ERA-Interim



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Research Objectives

- Investigate the equatorward transport of TPVs and cold pools to middle latitudes

- Investigate the dynamical linkages between TPVs, cold pools, and CAOs

Outline

- TPV and cold pool tracking
- TPV and cold pool climatologies
- Identification of CAOs
- Identification of CAOs linked to cold pools
- Identification of cold pools associated with TPVs
- Identification of CAOs that are linked to cold pools associated with TPVs
- Examination of 9–14 January 1982 CAO

TPV Tracking

- Data:
  - 0.5° ERA-Interim (Dee et al. 2011)
  - 1979–2015, every 6 h
- Utilized TPV tracking algorithm developed by Nicholas Szapiro and Steven Cavallo to identify and track TPVs
  - Input variables: potential temperature, relative vorticity, and wind on 2-PVU surface
  - Potential temperature minima on 2-PVU surface tracked spatially and temporally to create TPV tracks

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

Cold Pool Tracking

- Modified TPV tracking algorithm by changing input variables to identify and track cold pools
  - Input variables: 1000–500-hPa thickness and thermal vorticity, and 700-hPa wind
  - 1000–500-hPa thickness minima tracked spatially and temporally to create cold pool tracks

Filtering TPV and Cold Pool Tracks

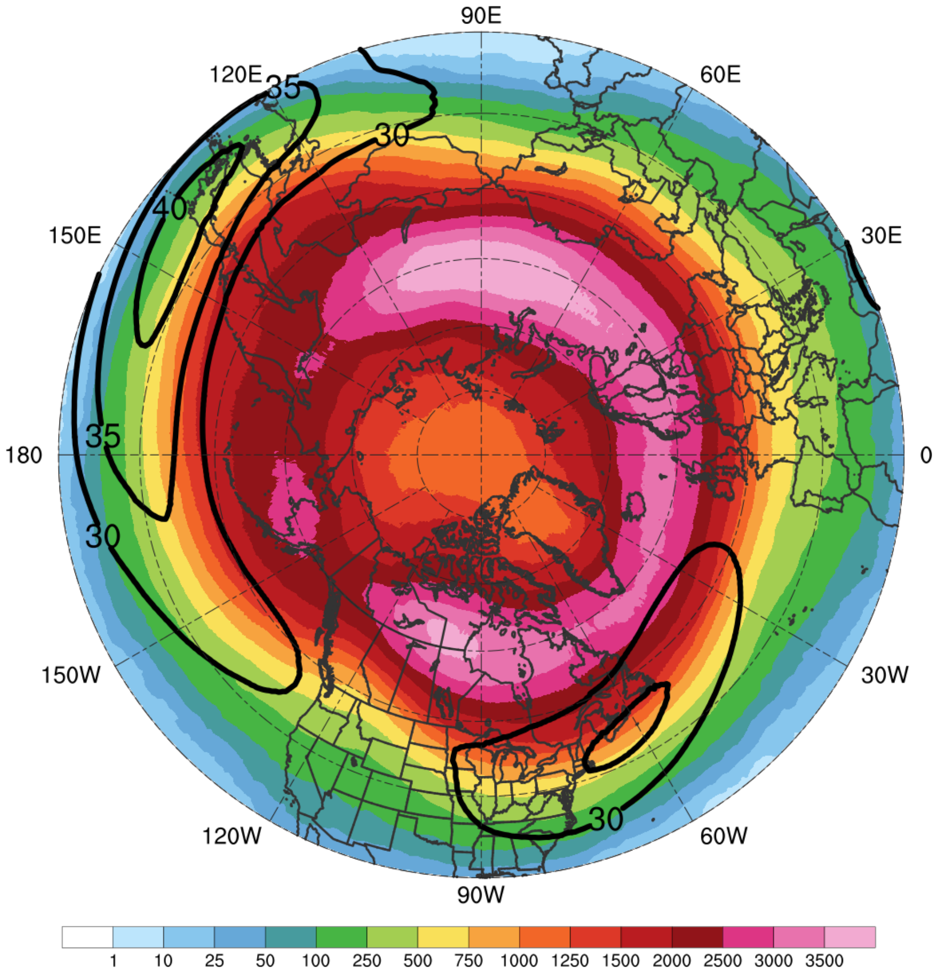
- TPVs must last at least 2 days and spend at least 6 h poleward of 60°N (adapted from criteria of Cavallo and Hakim 2010)

- Cold pools must last at least 2 days and spend at least 6 h poleward of 60°N

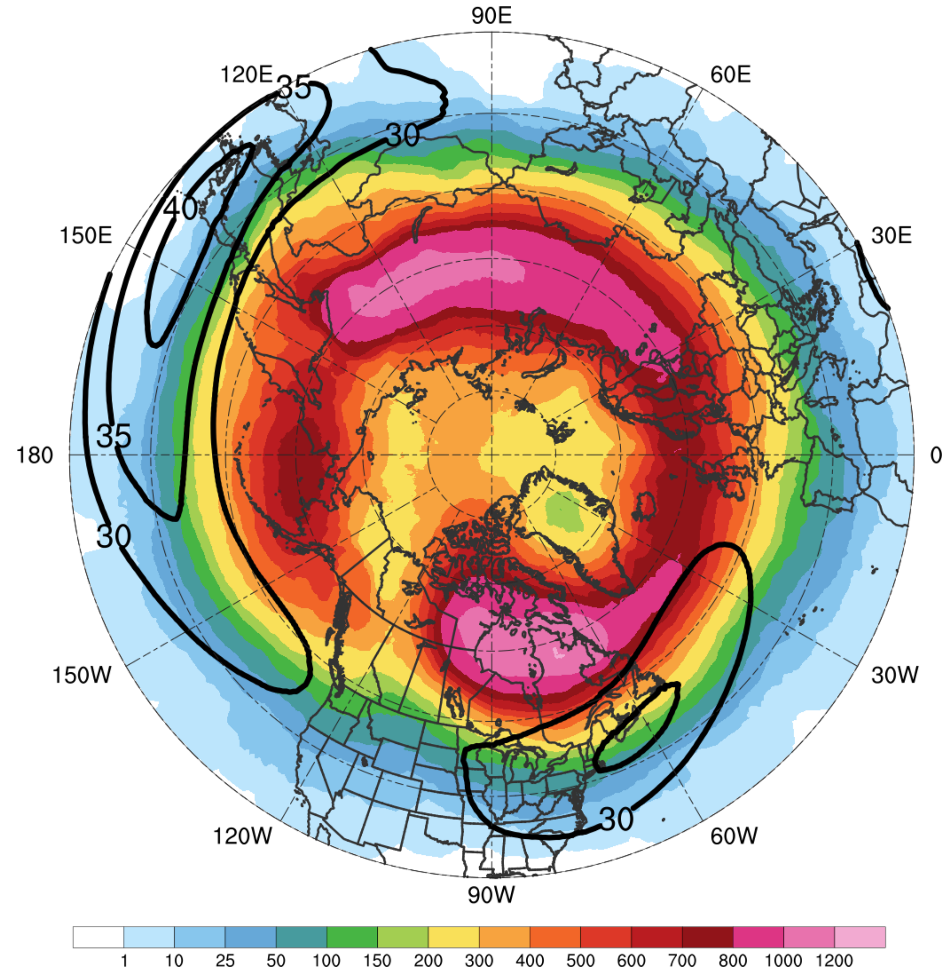
- Focus on TPVs and cold pools transported from high latitudes to middle latitudes
  - Require that TPVs and cold pools in high latitudes move equatorward of 60°N

TPV and Cold Pool Track Density

TPVs Transported to Middle Latitudes
(N = 25,085; avg. of ~678 per yr)



Cold Pools Transported to Middle Latitudes
(N = 8,395; avg. of ~227 per yr)



Total number of unique TPVs (left) and cold pools (right) within 500 km of each grid point (using a 0.5° grid) for TPVs and cold pools that move equatorward of 60°N during 1979–2015. Also, 1979–2015 mean wind speed (black, every 5 m s^{-1} starting at 30 m s^{-1}) on 2-PVU surface

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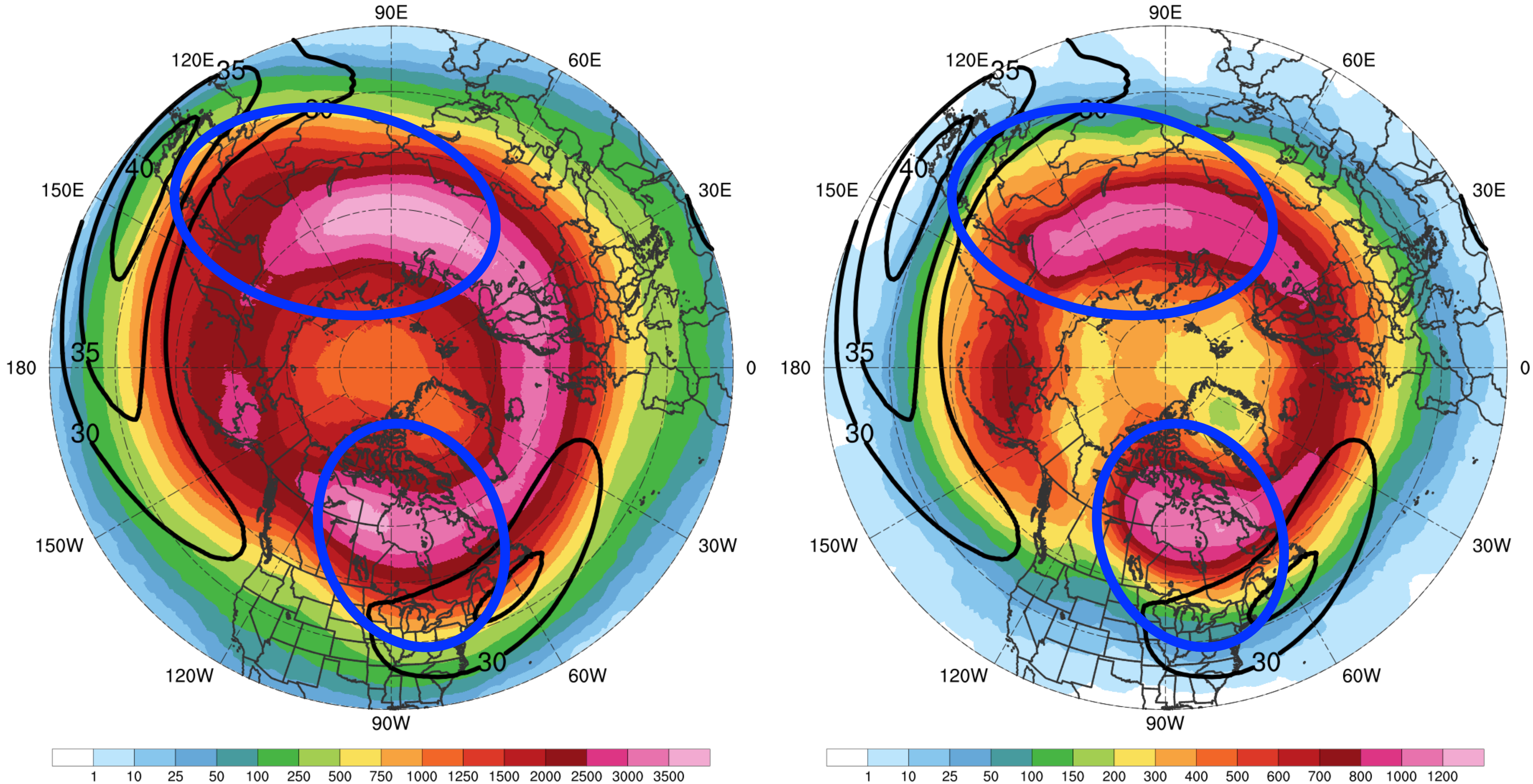

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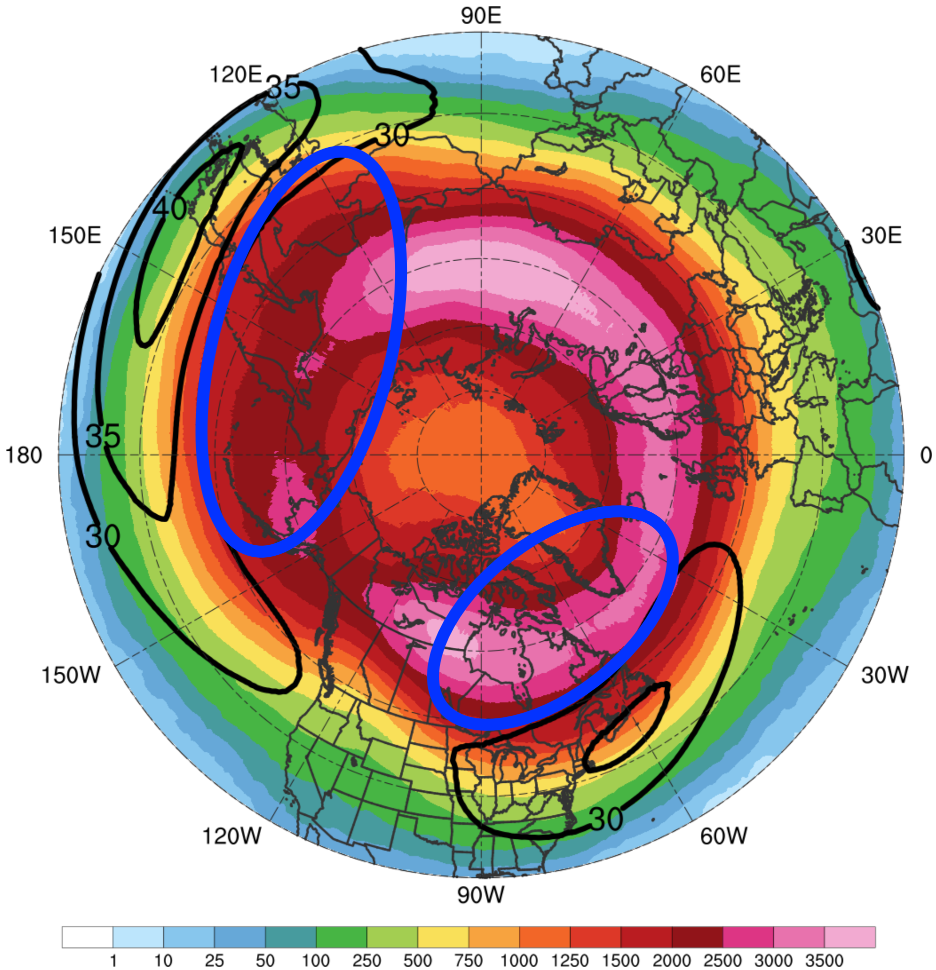

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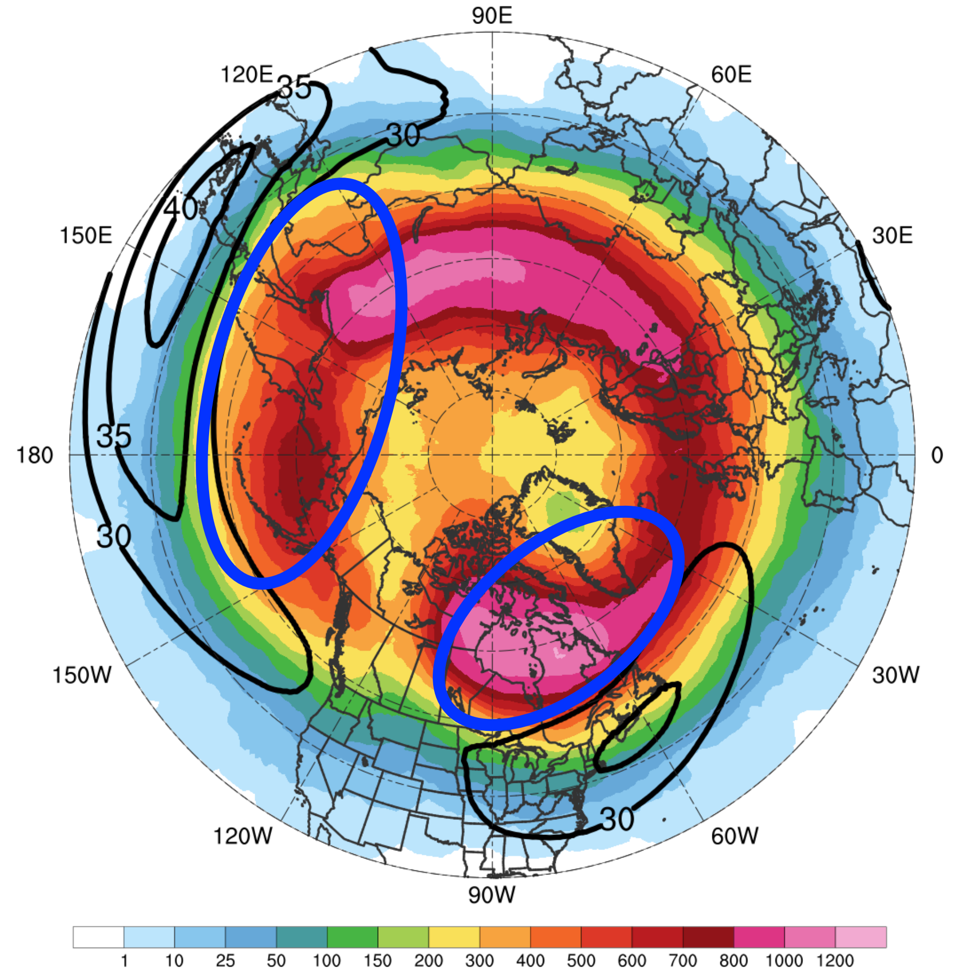

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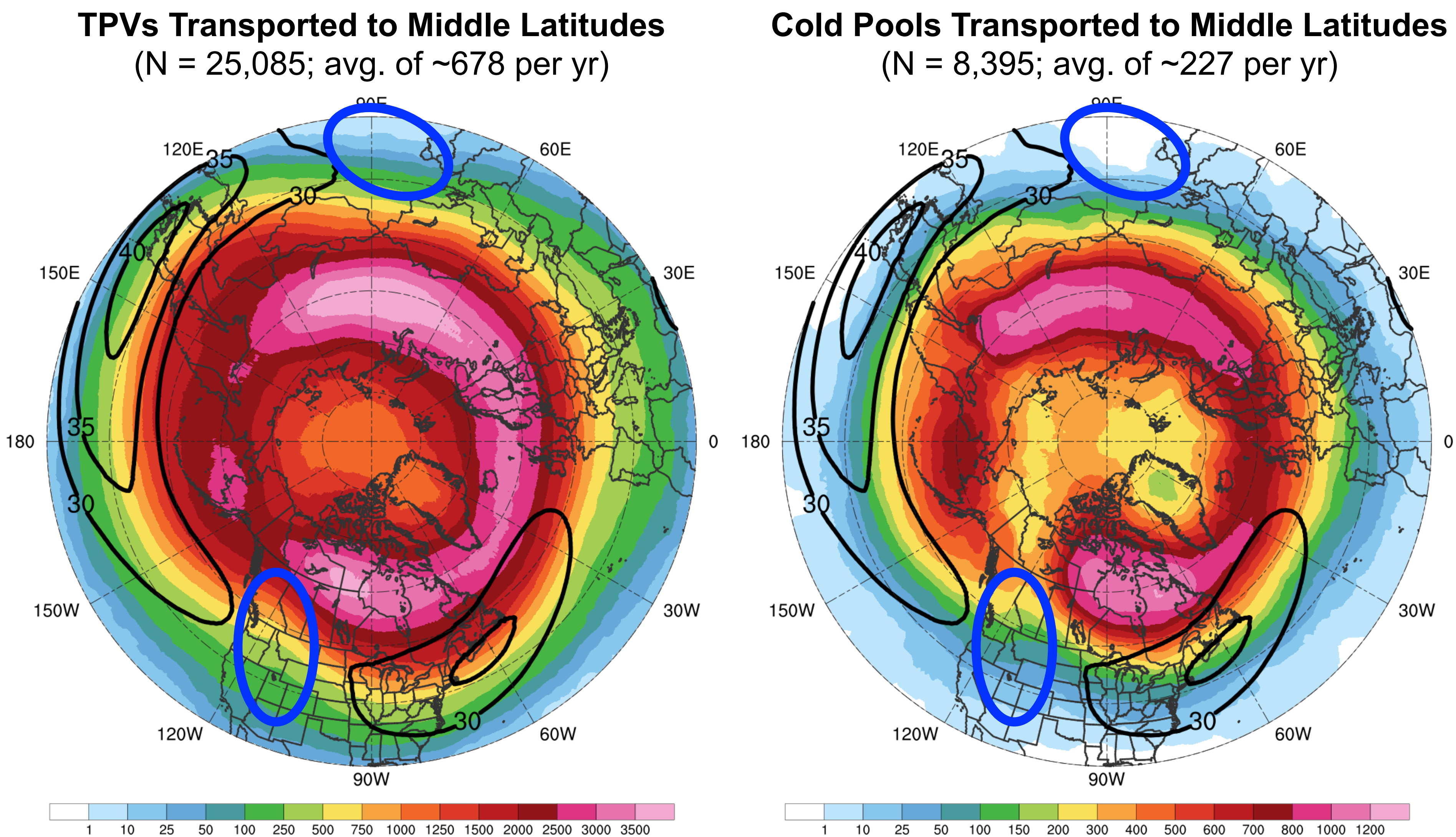

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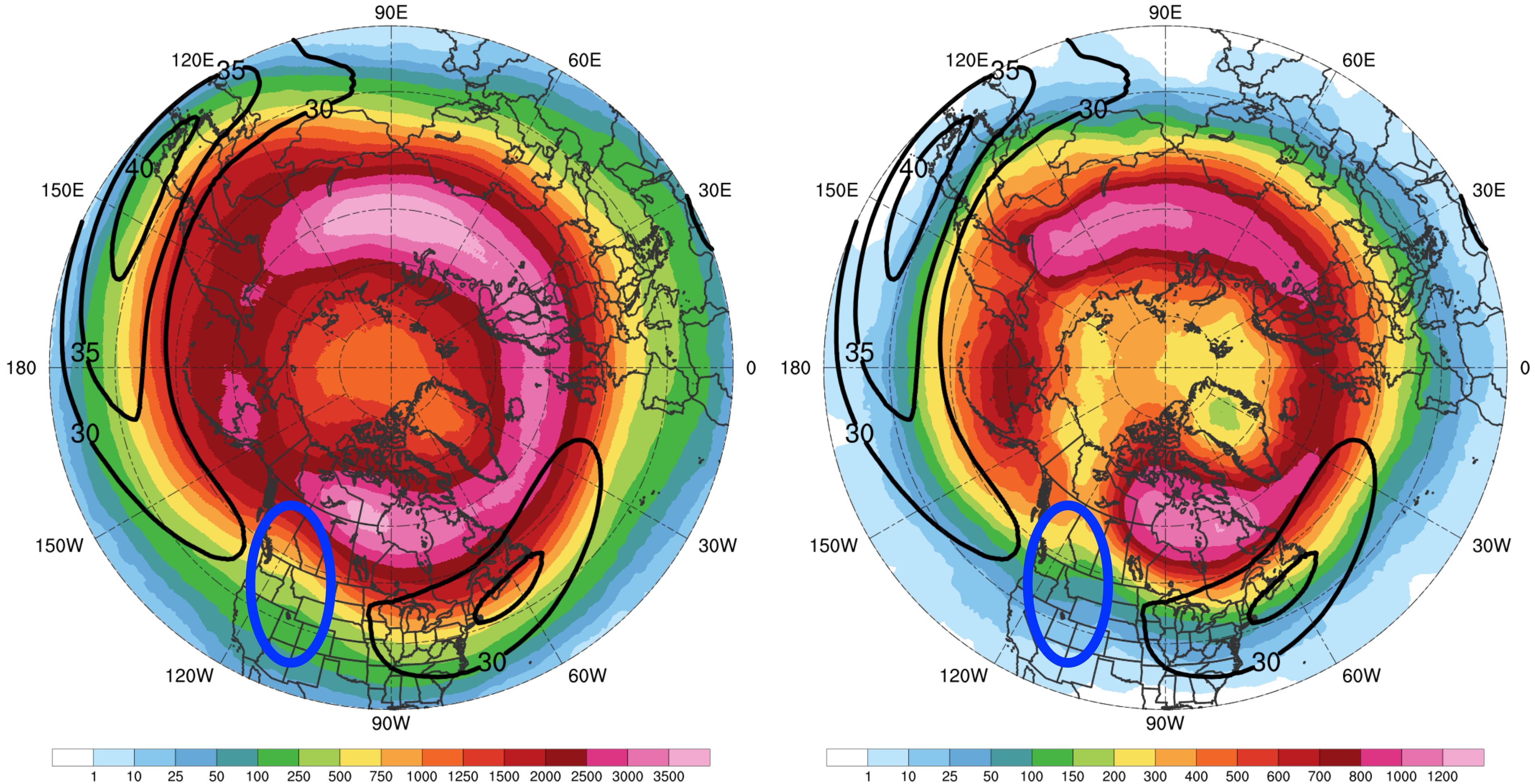

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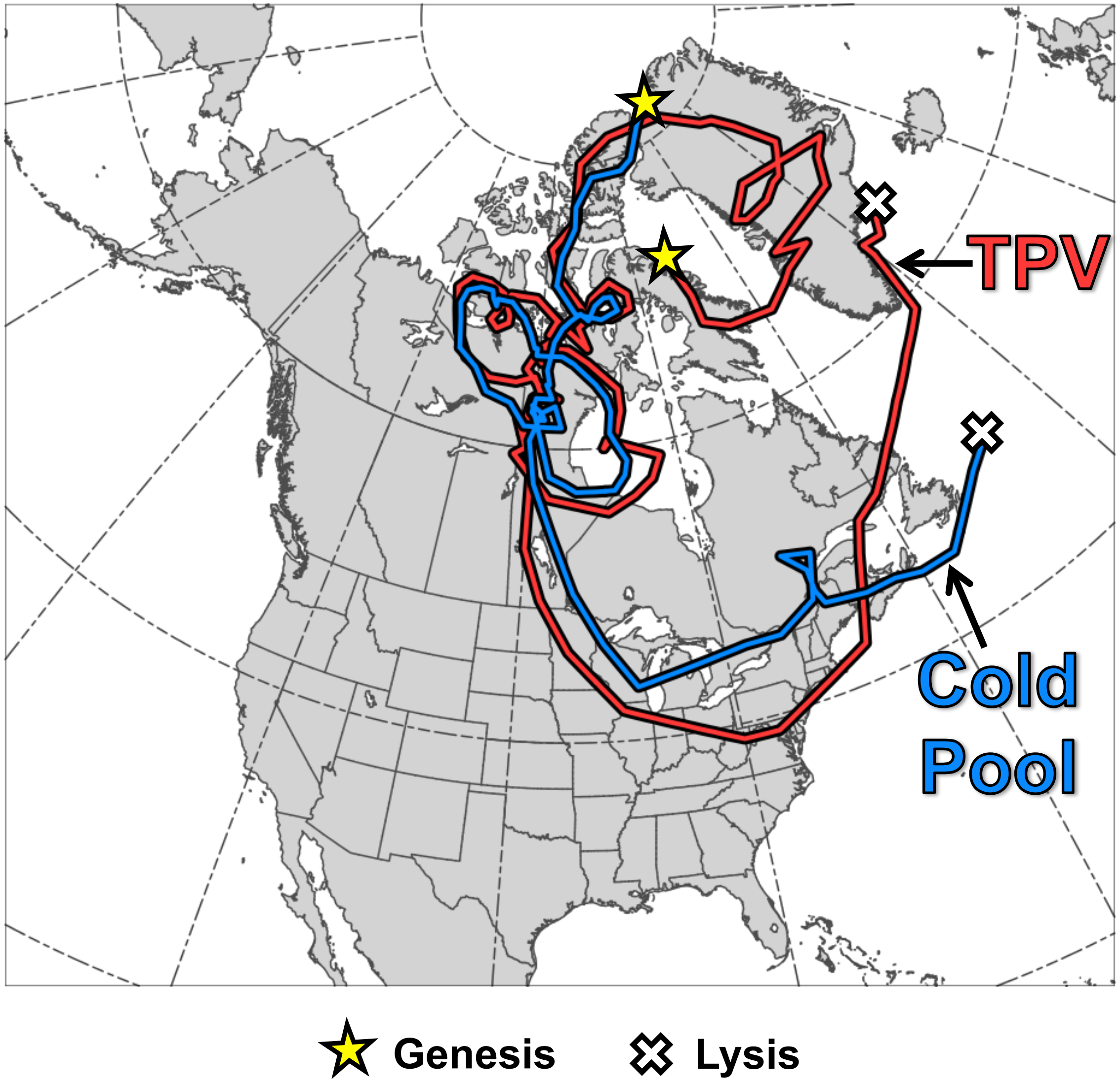
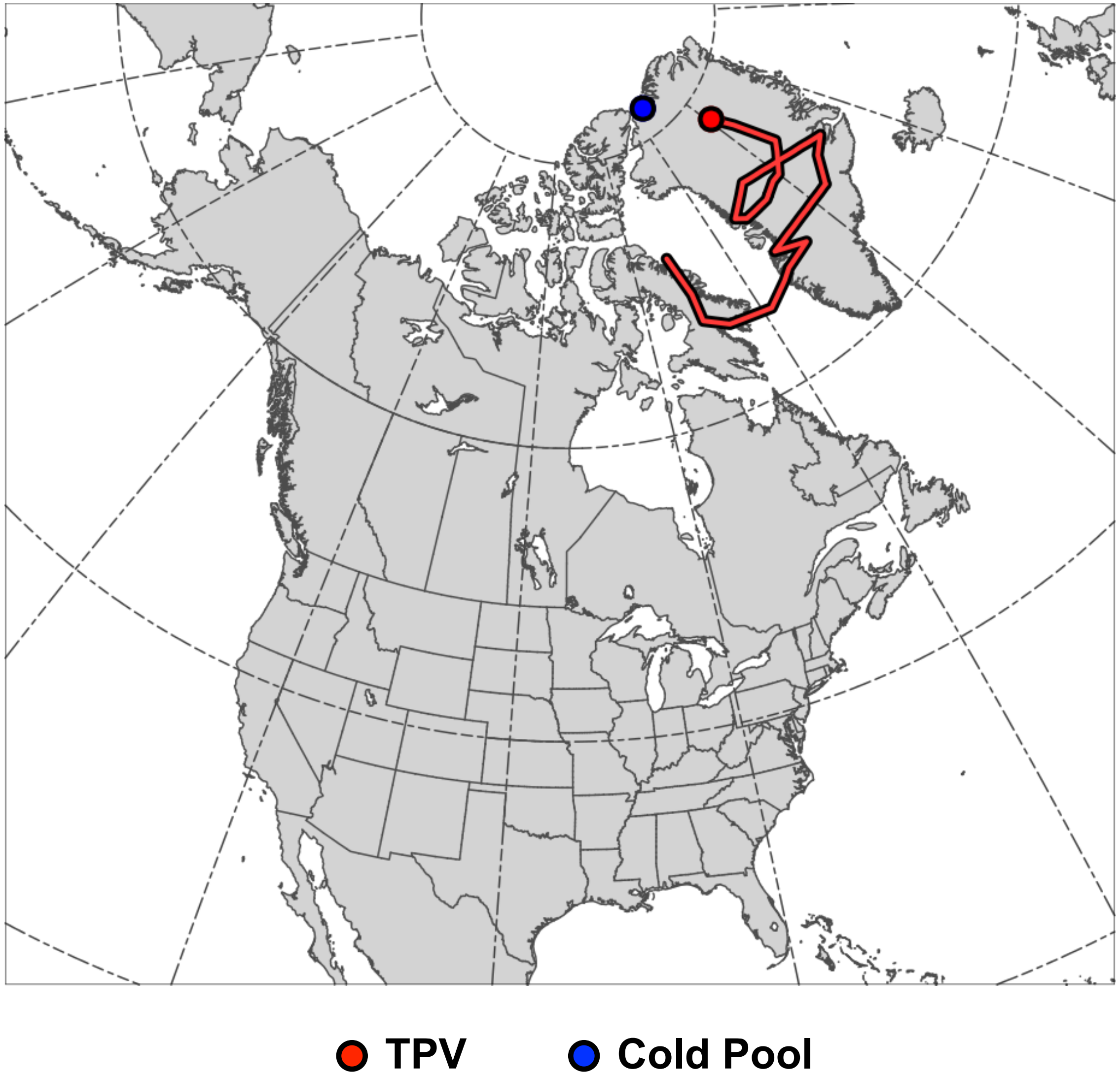
Tracks for Jan 1982 CAO



- **TPV Track:**
  - **Genesis:** 0600 UTC 15 Dec 1981
  - **Lysis:** 0000 UTC 13 Jan 1982
  - **Lifetime:** ~29 days
- **Cold Pool Track:**
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 21 Dec 1981



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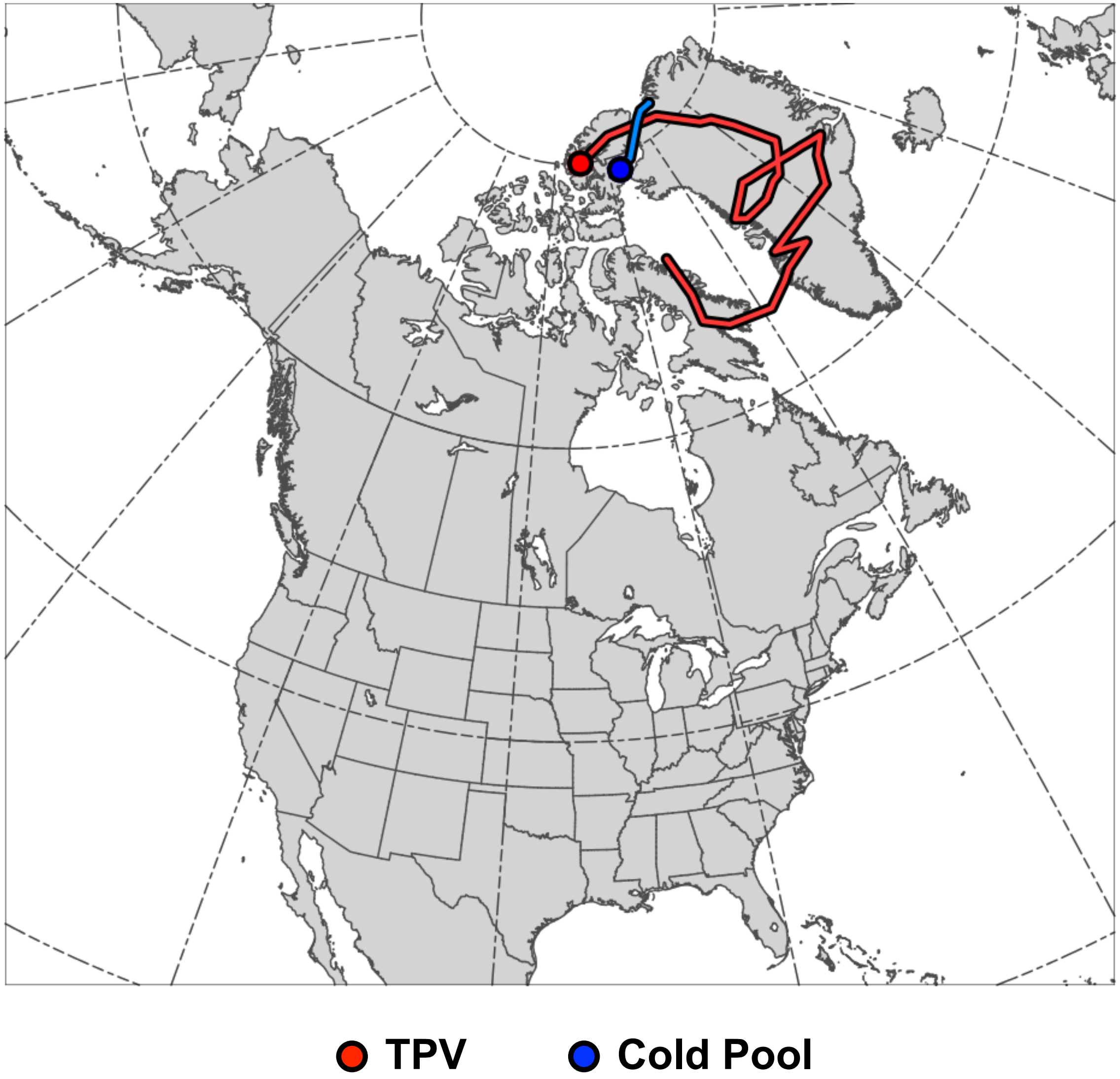
  - **Lifetime:** ~29 days
- **Cold Pool Track:**
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 22 Dec 1981



- **TPV Track:**
  - **Genesis:**
    0600 UTC 15 Dec 1981
  - **Lysis:**
    0000 UTC 13 Jan 1982
  - **Lifetime:**
    ~29 days
- **Cold Pool Track:**
  - **Genesis:**
    1800 UTC 20 Dec 1981
  - **Lysis:**
    1800 UTC 13 Jan 1982
  - **Lifetime:**
    ~24 days

Tracks for Jan 1982 CAO

0000 UTC 23 Dec 1981

TPV   Cold Pool

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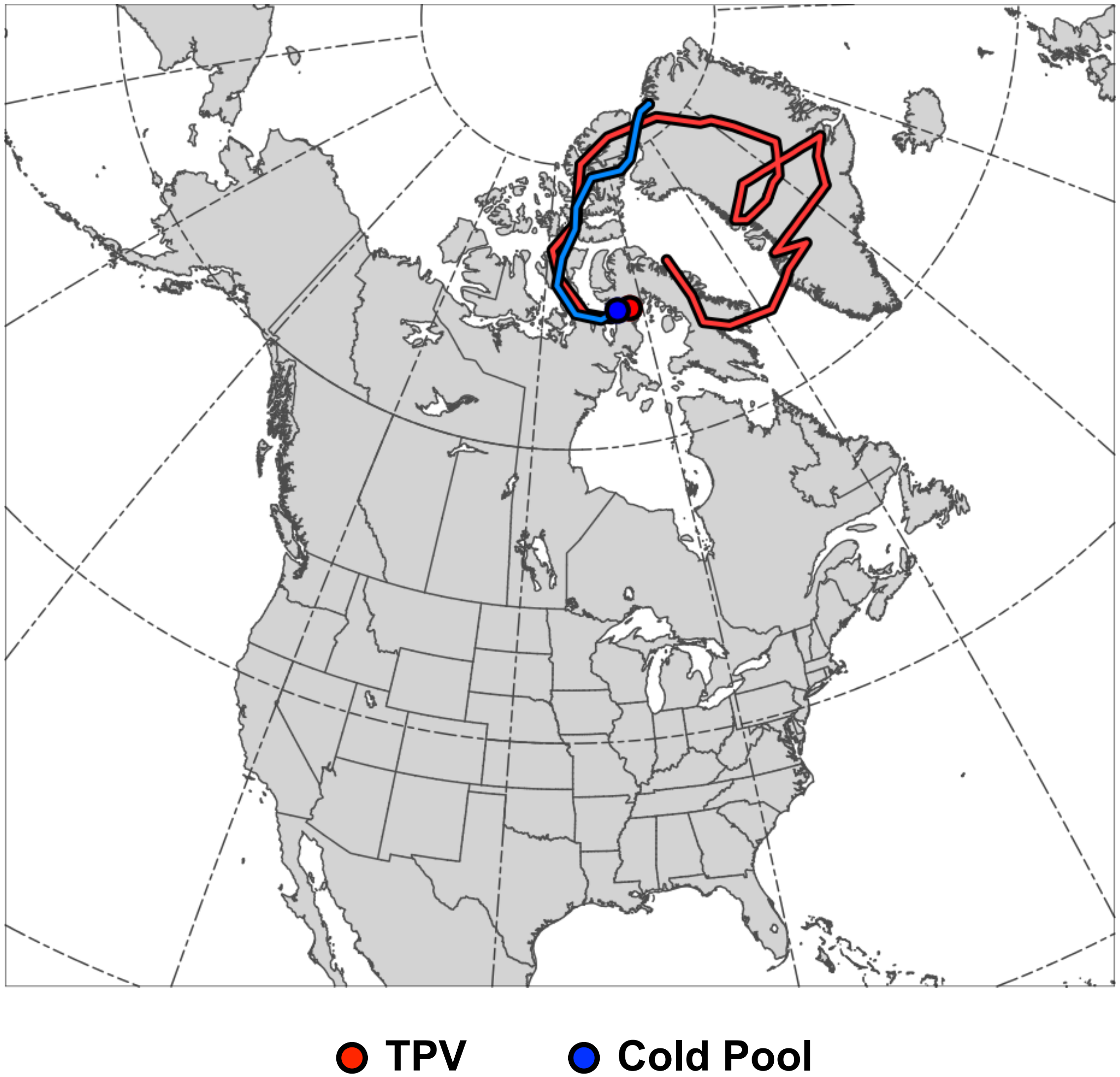
Tracks for Jan 1982 CAO

0000 UTC 24 Dec 1981



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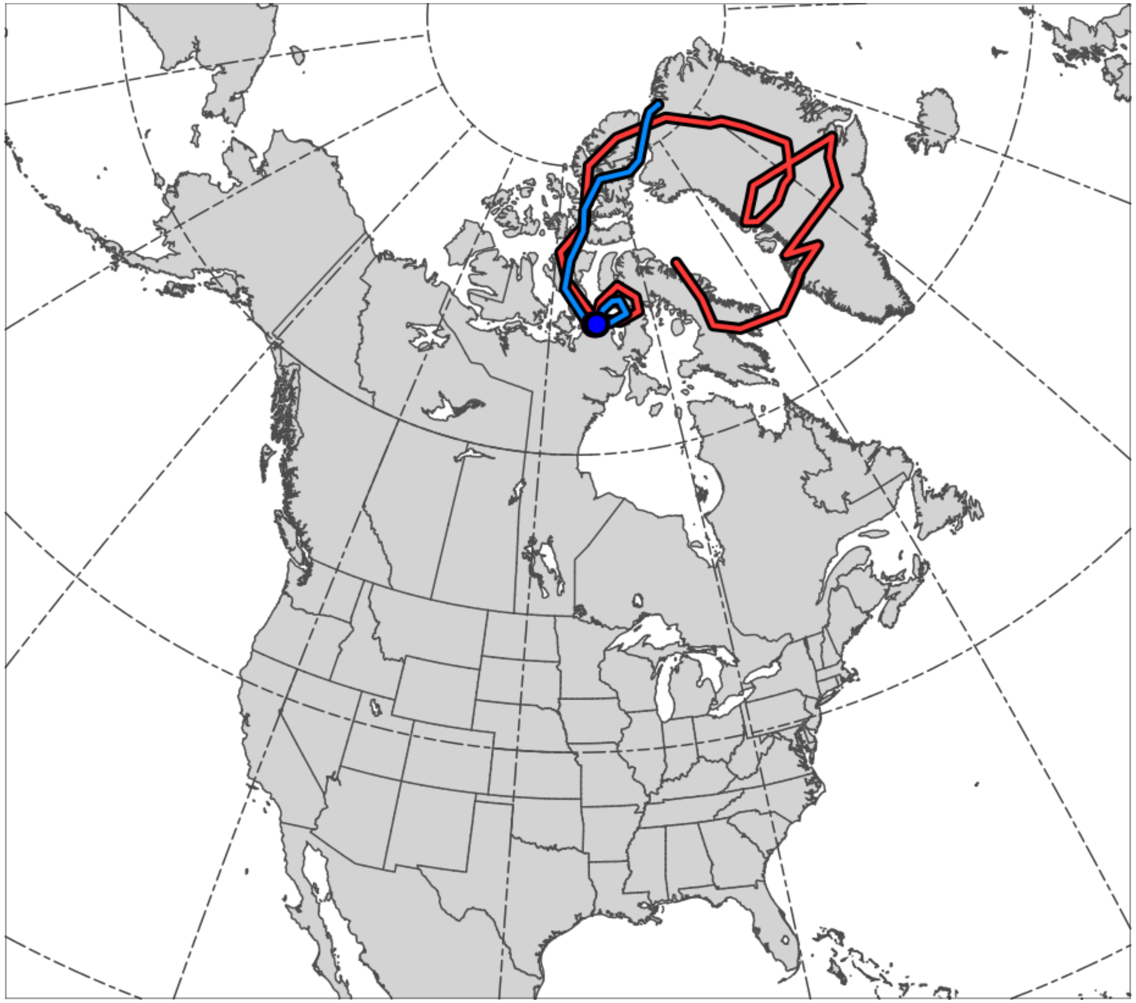
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 25 Dec 1981



TPV Cold Pool

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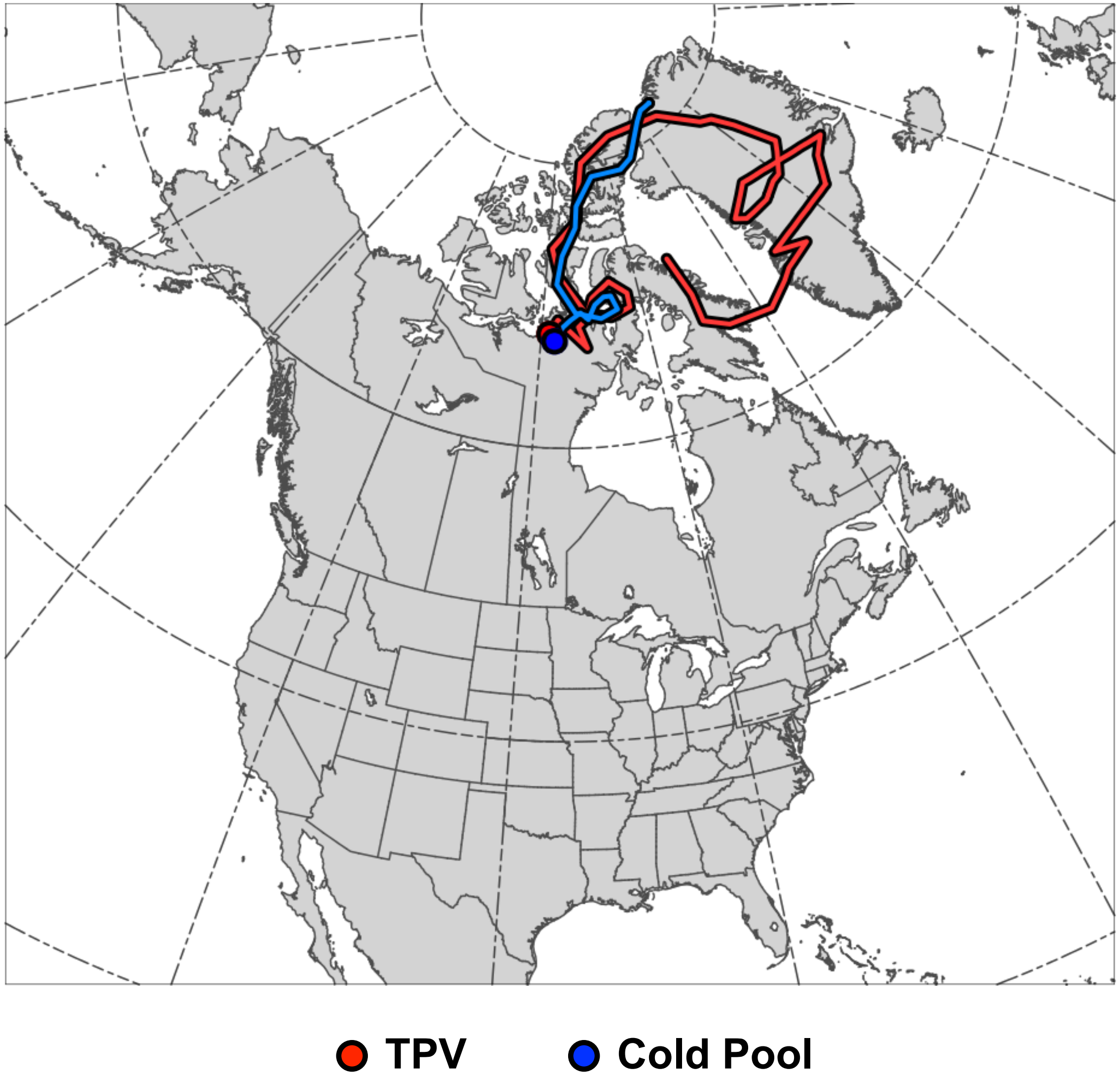
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 26 Dec 1981



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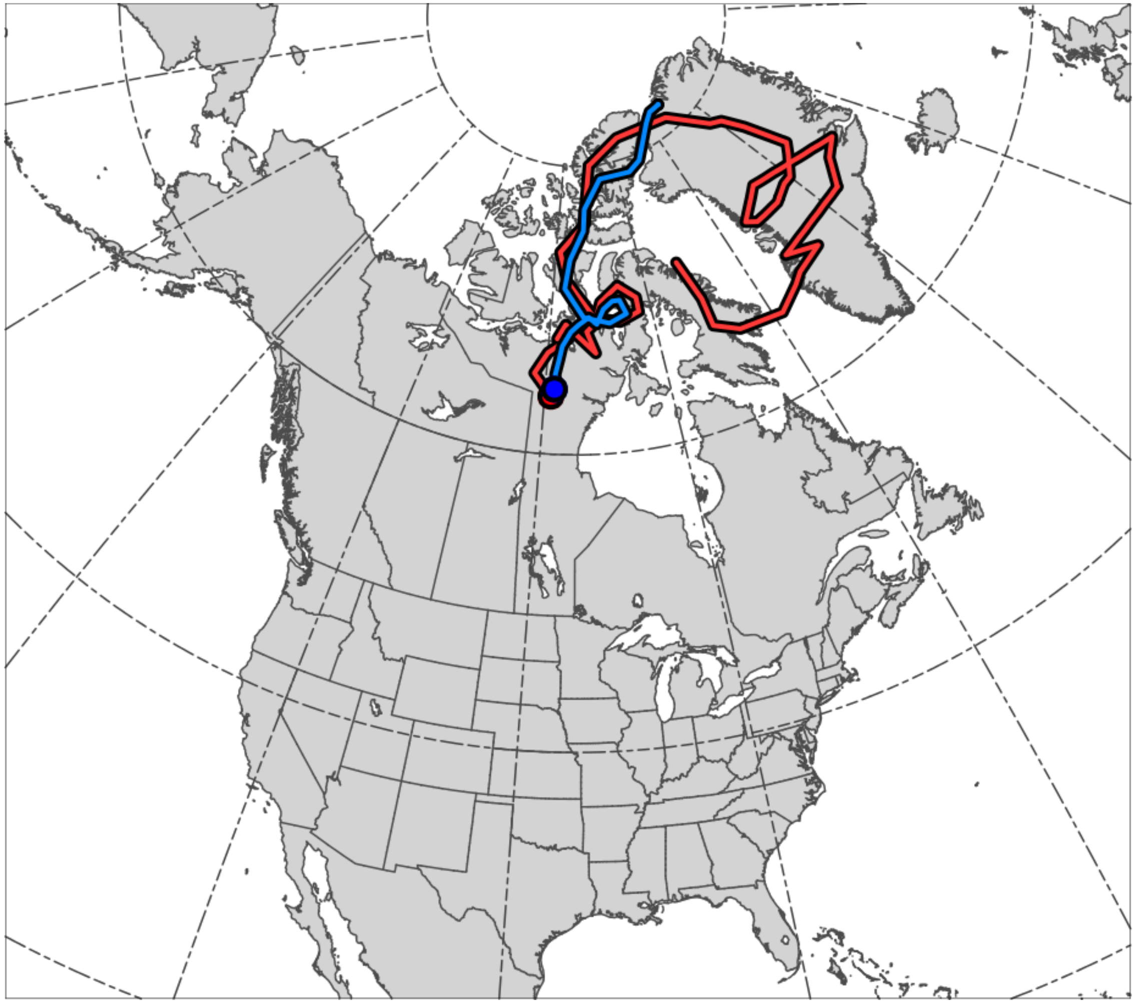
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 27 Dec 1981



● TPV ● Cold Pool

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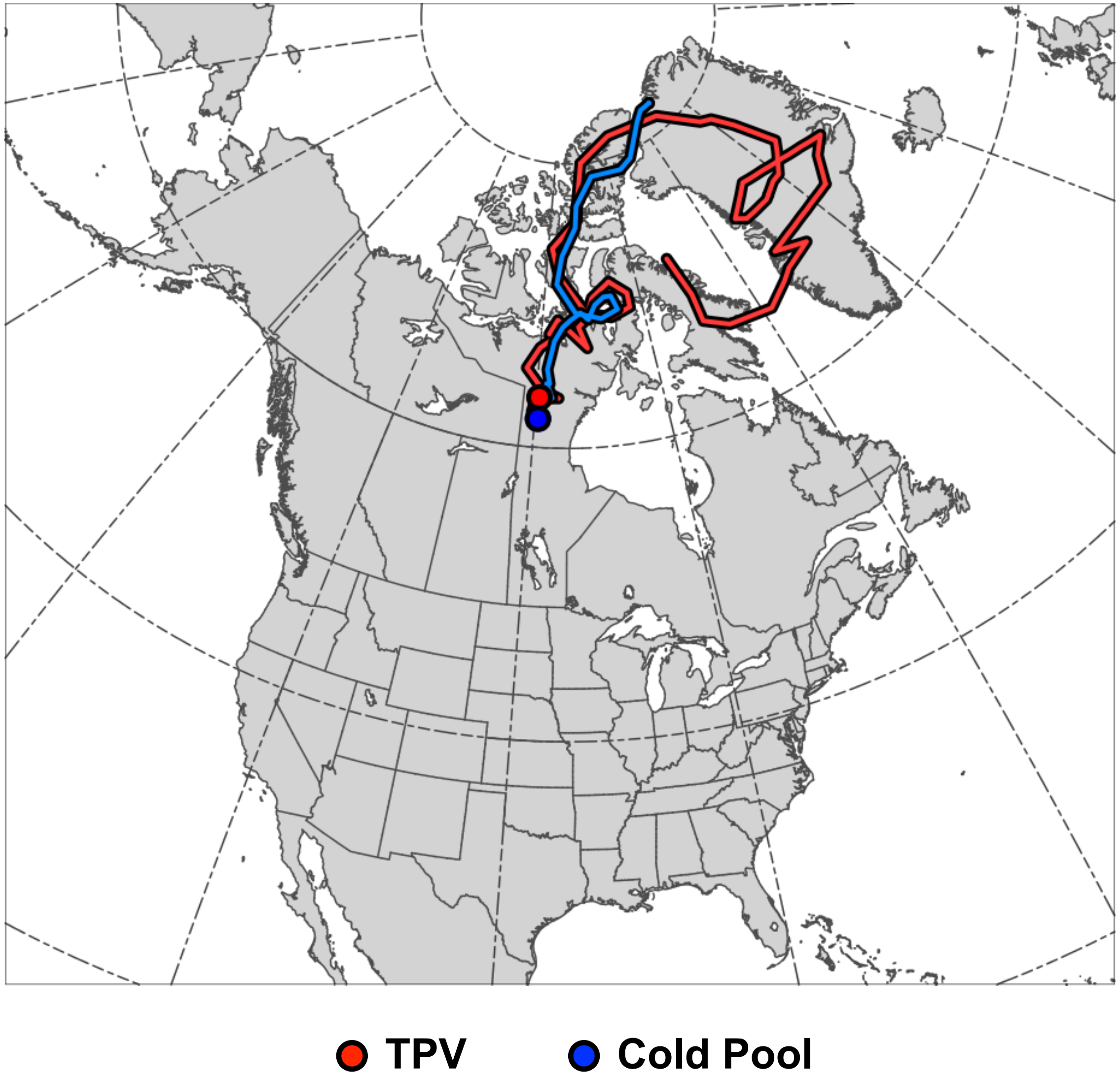
Tracks for Jan 1982 CAO

0000 UTC 28 Dec 1981



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    1800 UTC 20 Dec 1981
  - **Lysis:**
    1800 UTC 13 Jan 1982
  - **Lifetime:**
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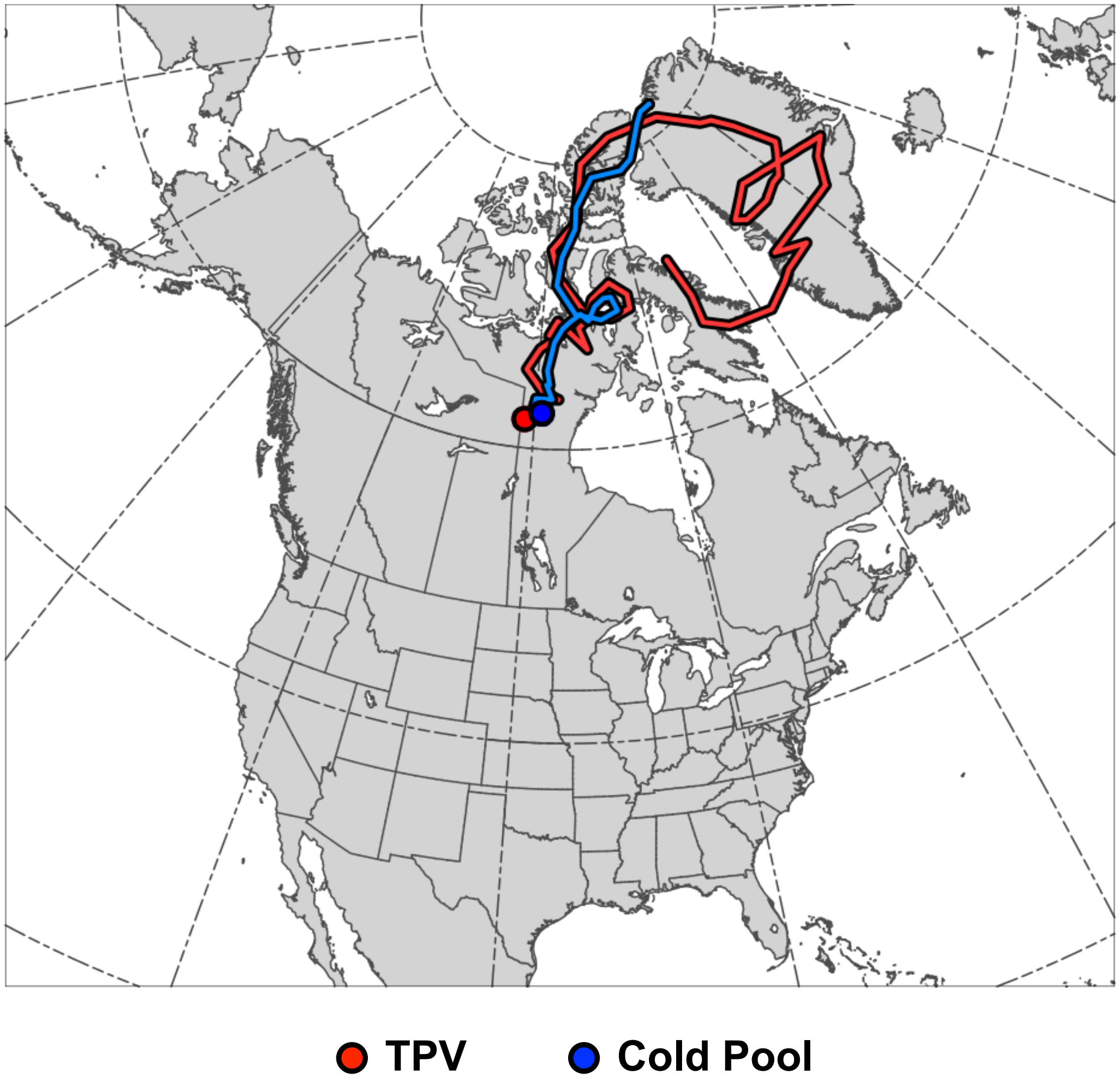
Tracks for Jan 1982 CAO

0000 UTC 29 Dec 1981



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- **Cold Pool Track:**
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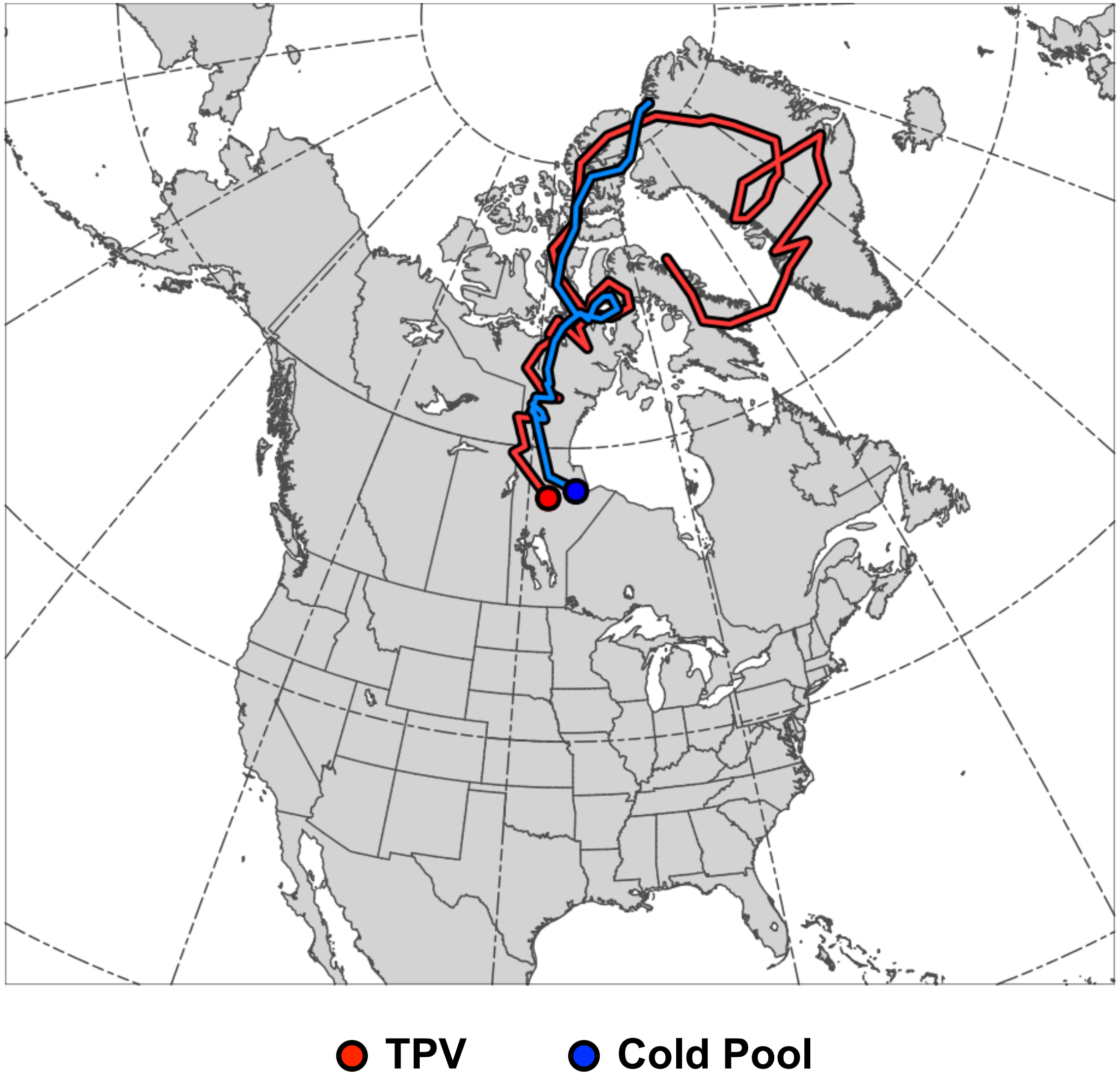
Tracks for Jan 1982 CAO

0000 UTC 30 Dec 1981



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- **Cold Pool Track:**
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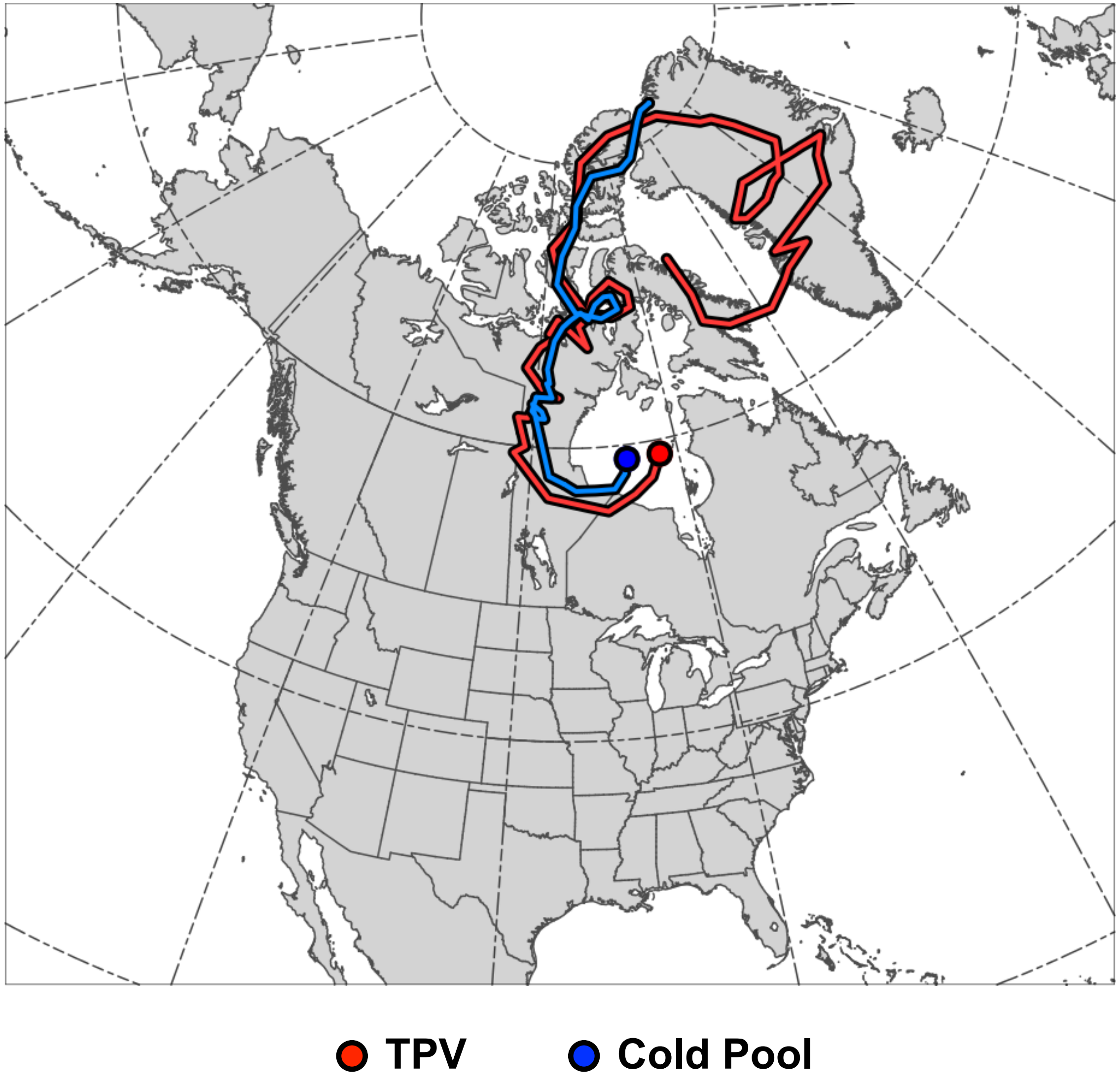
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 31 Dec 1981



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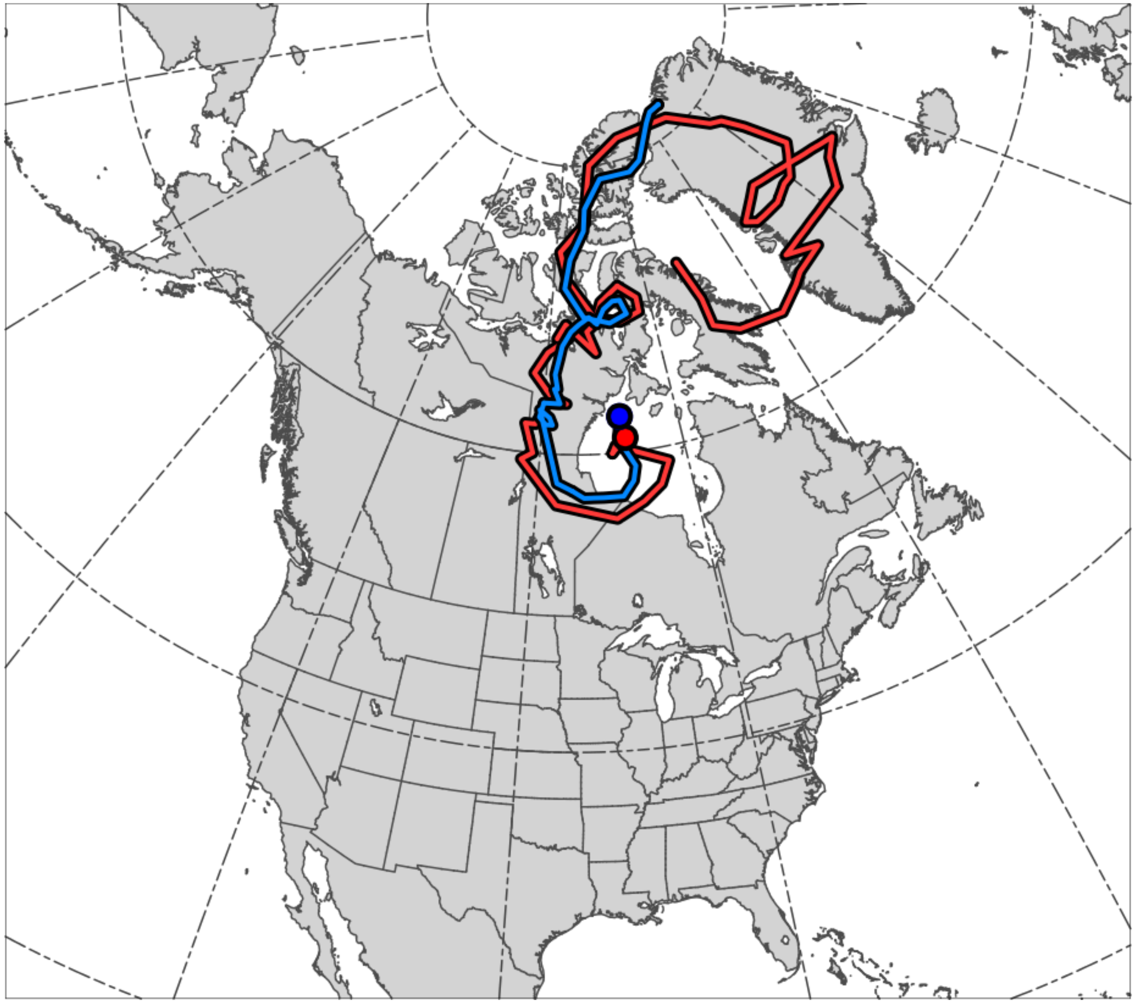
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 1 Jan 1982



TPV Cold Pool

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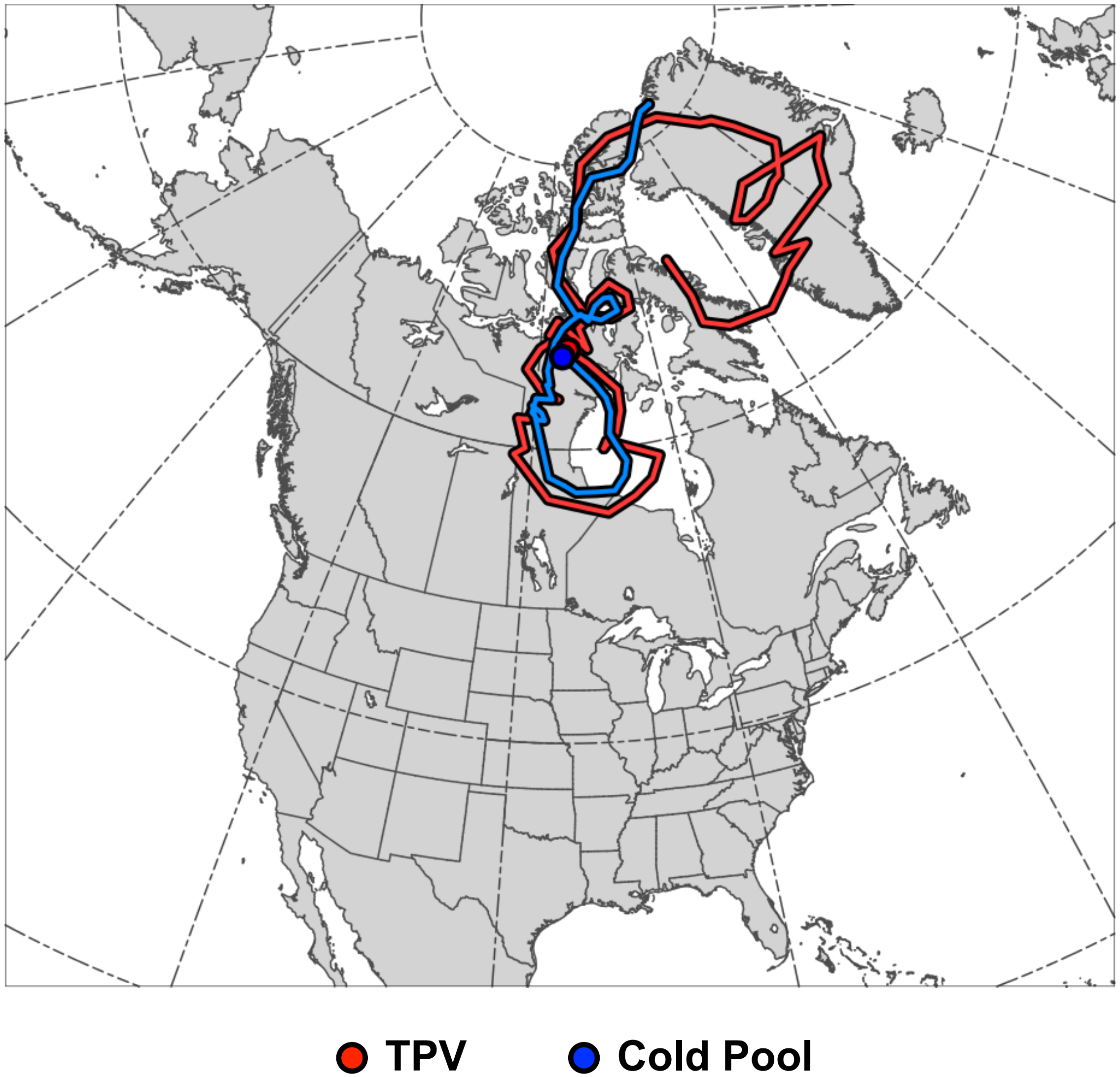
Tracks for Jan 1982 CAO

0000 UTC 2 Jan 1982



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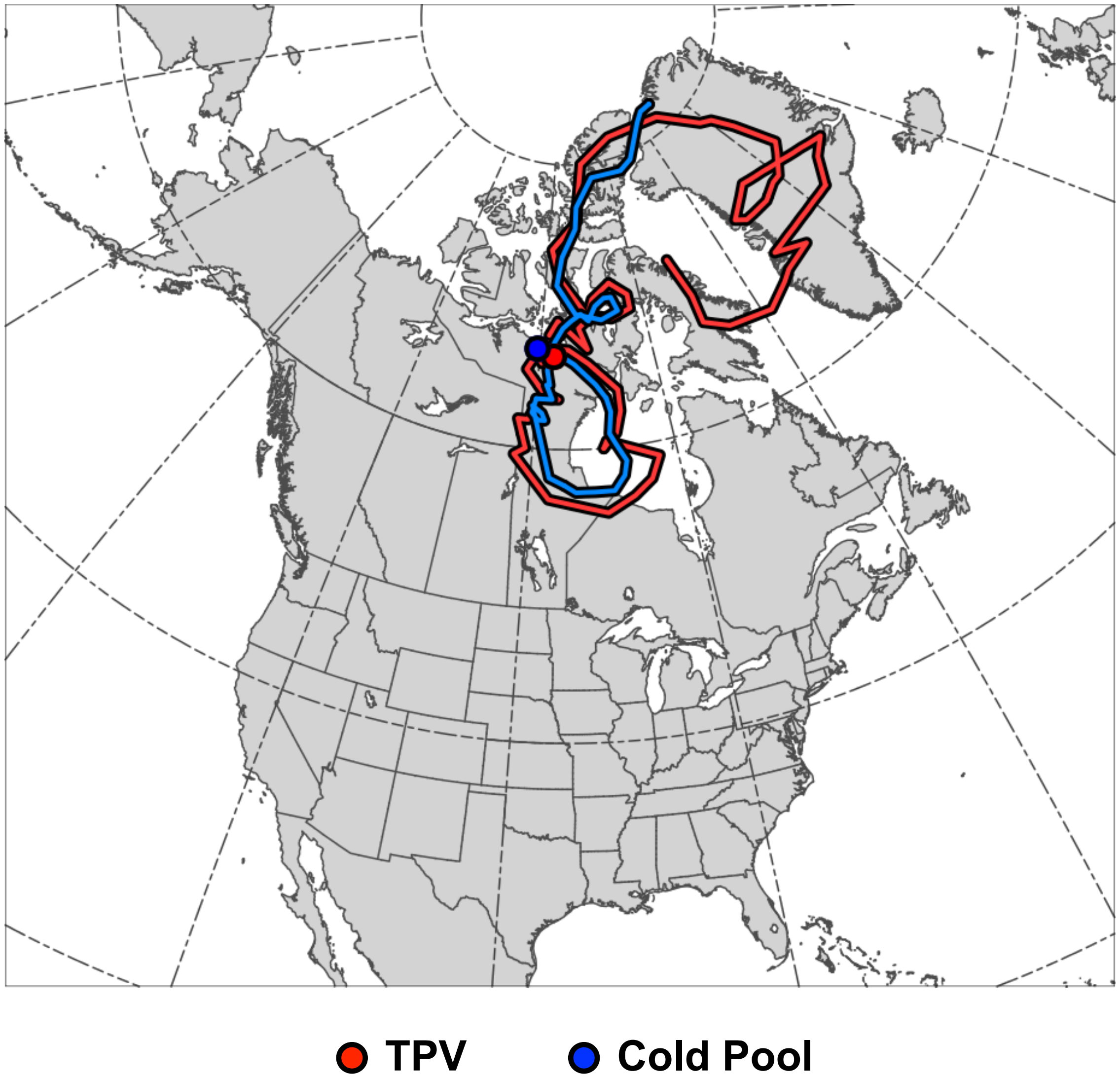
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 3 Jan 1982



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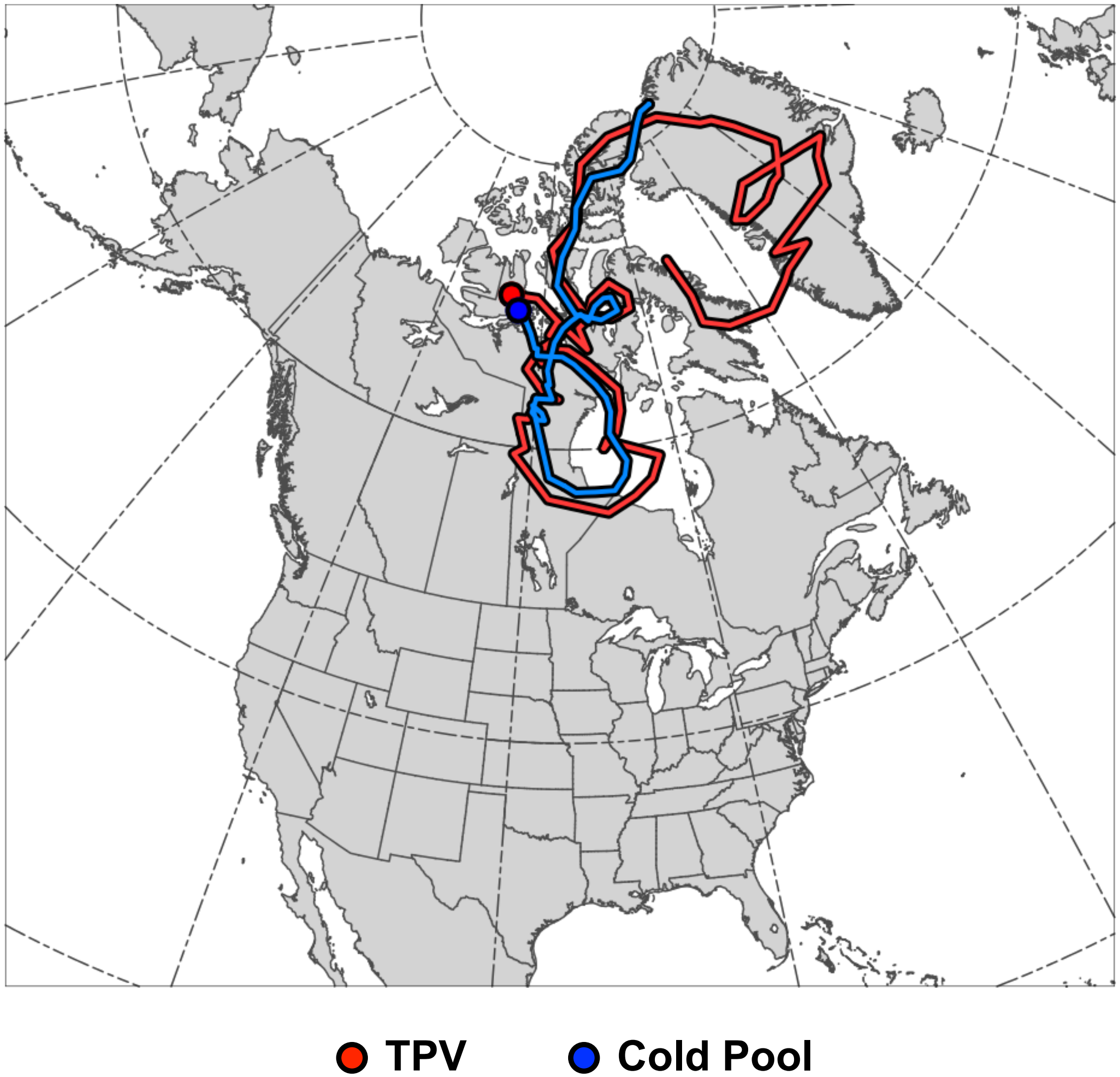
Tracks for Jan 1982 CAO

0000 UTC 4 Jan 1982



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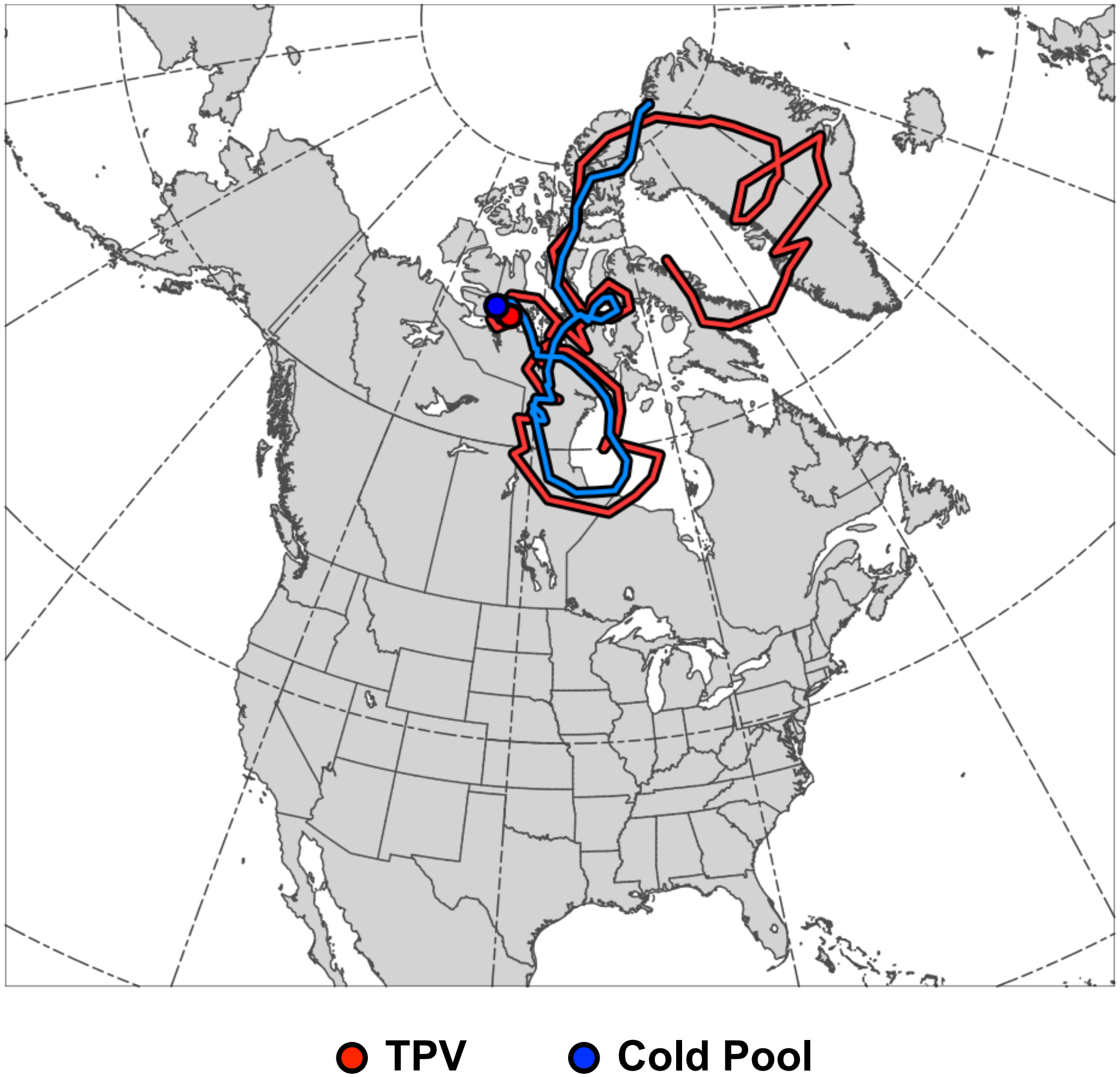
Tracks for Jan 1982 CAO

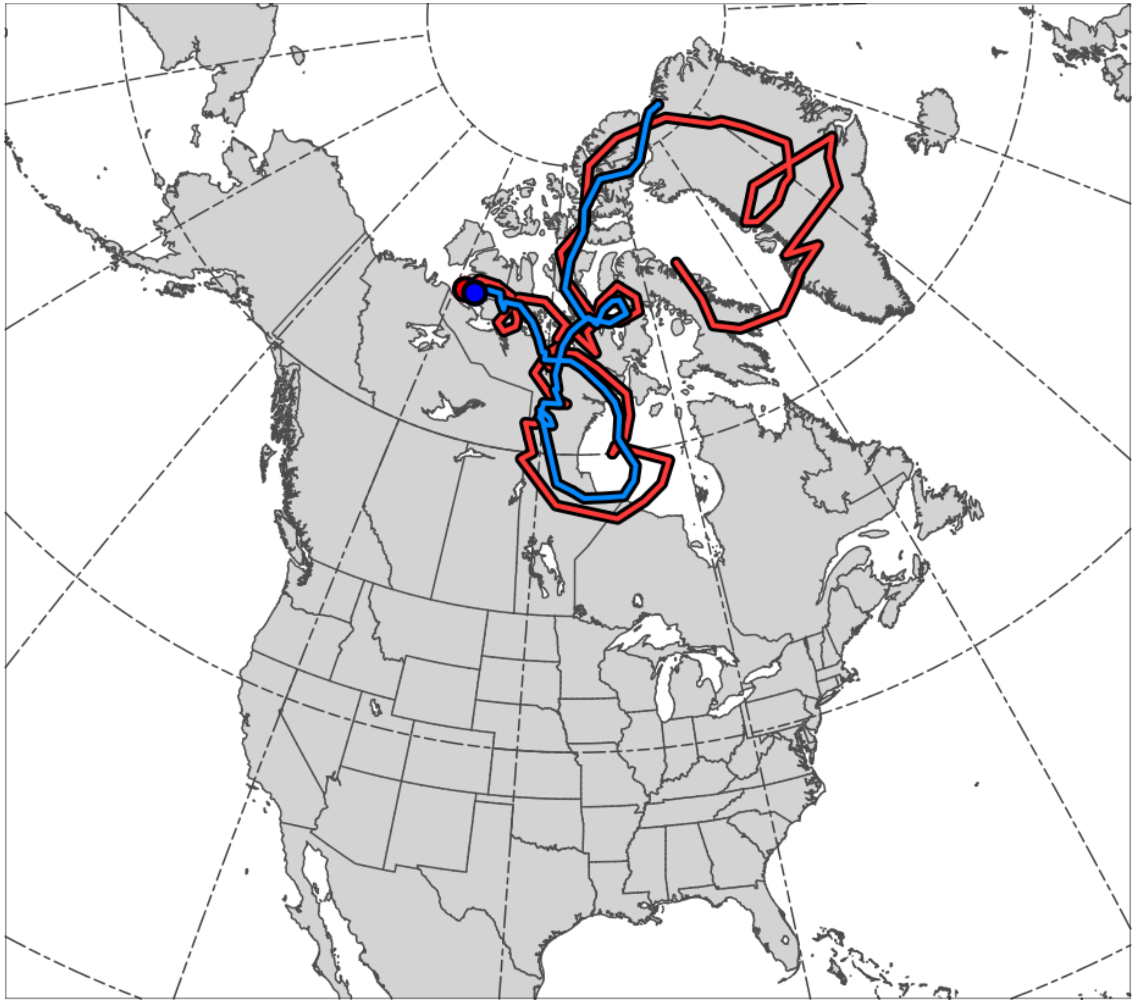
0000 UTC 5 Jan 1982



- **TPV Track:**
  - **Genesis:** 0600 UTC 15 Dec 1981
  - **Lysis:** 0000 UTC 13 Jan 1982
  - **Lifetime:** ~29 days
- **Cold Pool Track:**
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 6 Jan 1982



TPV   Cold Pool

- **TPV Track:**
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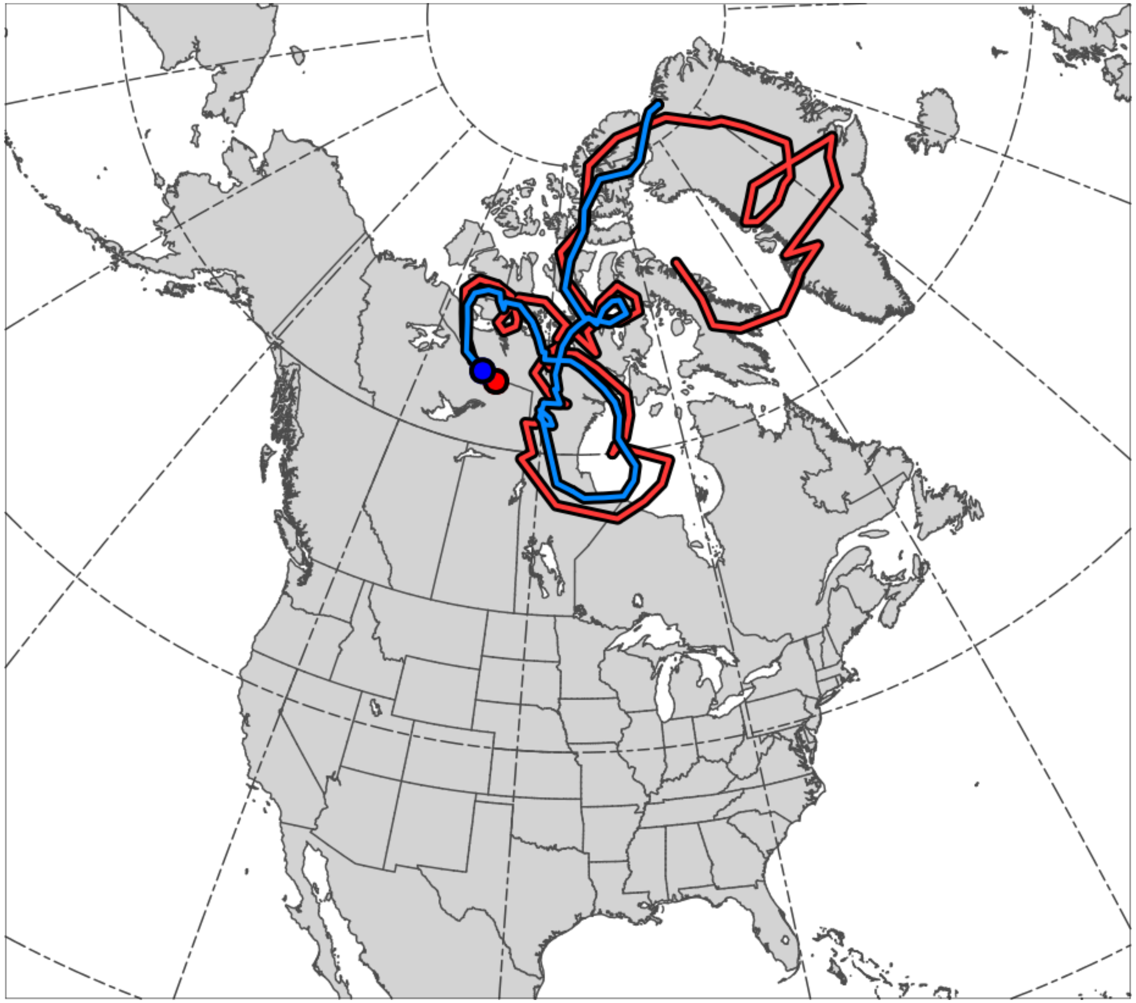
  - **Lysis:** 0000 UTC 13 Jan 1982
  - **Lifetime:** ~29 days

- **Cold Pool Track:**
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 7 Jan 1982



TPV   Cold Pool

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  - **Lysis:** 0000 UTC 13 Jan 1982
  - **Lifetime:** ~29 days
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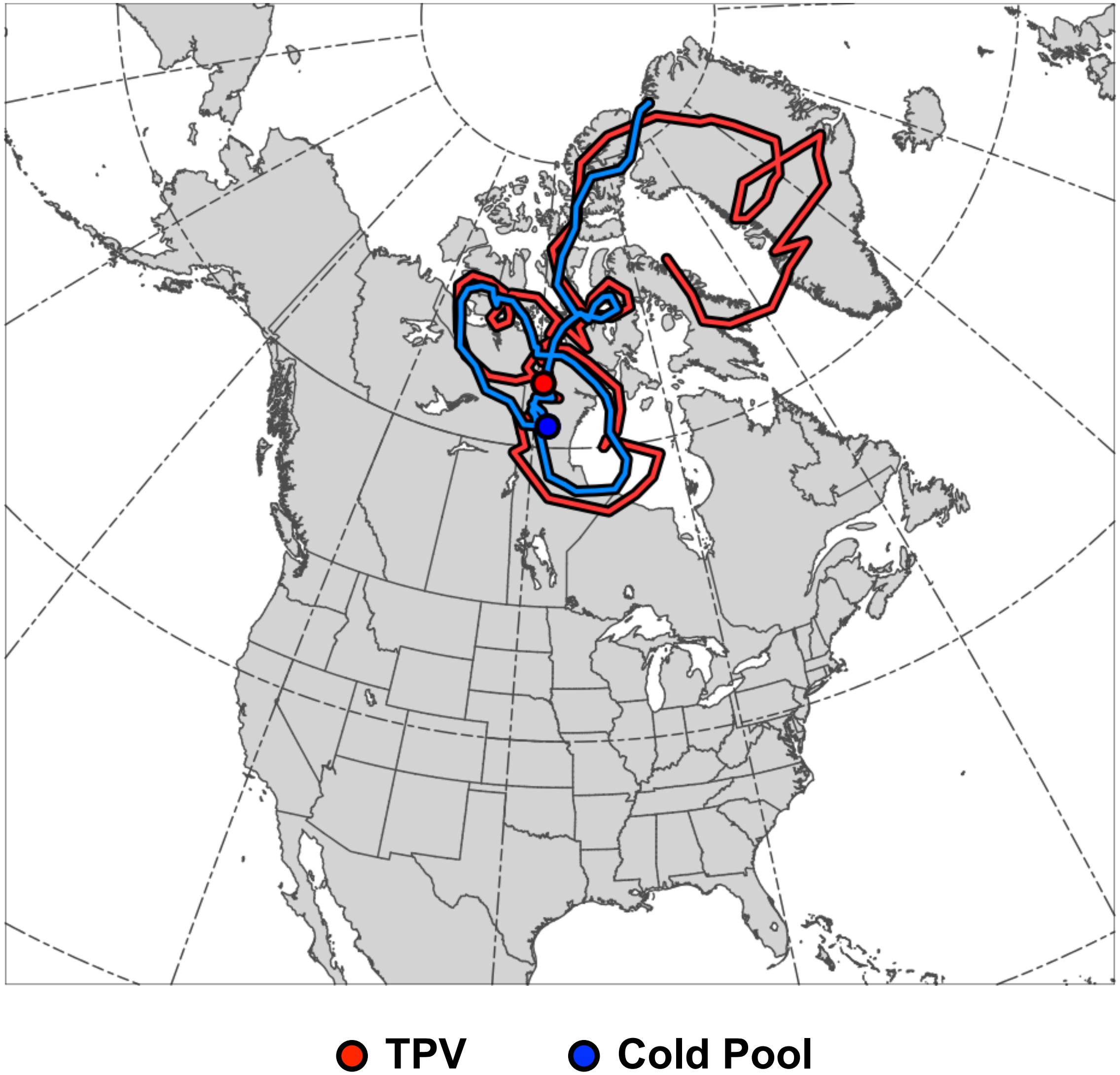
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 8 Jan 1982



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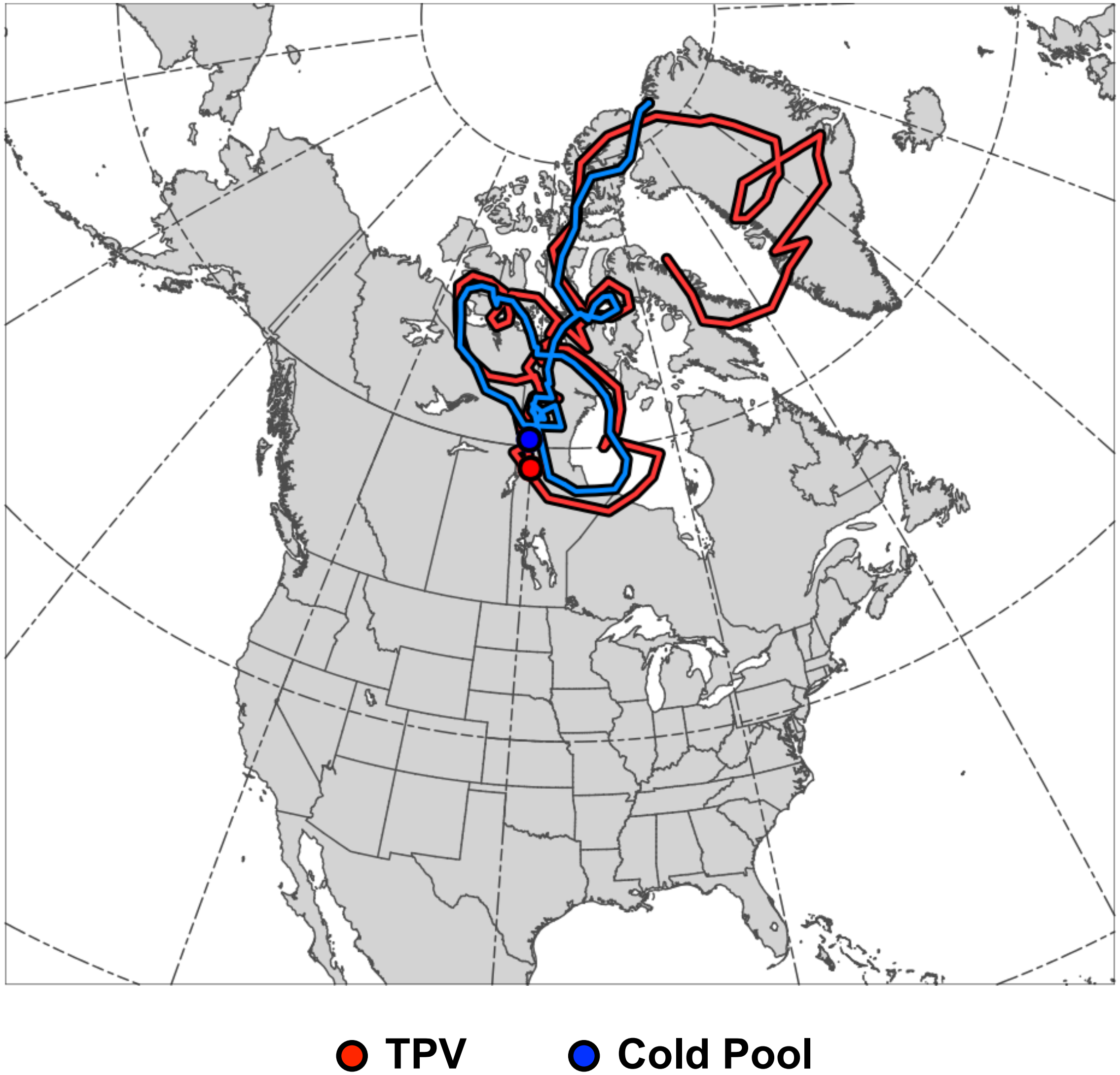
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 9 Jan 1982



- **TPV Track:**
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  - **Lifetime:** ~29 days
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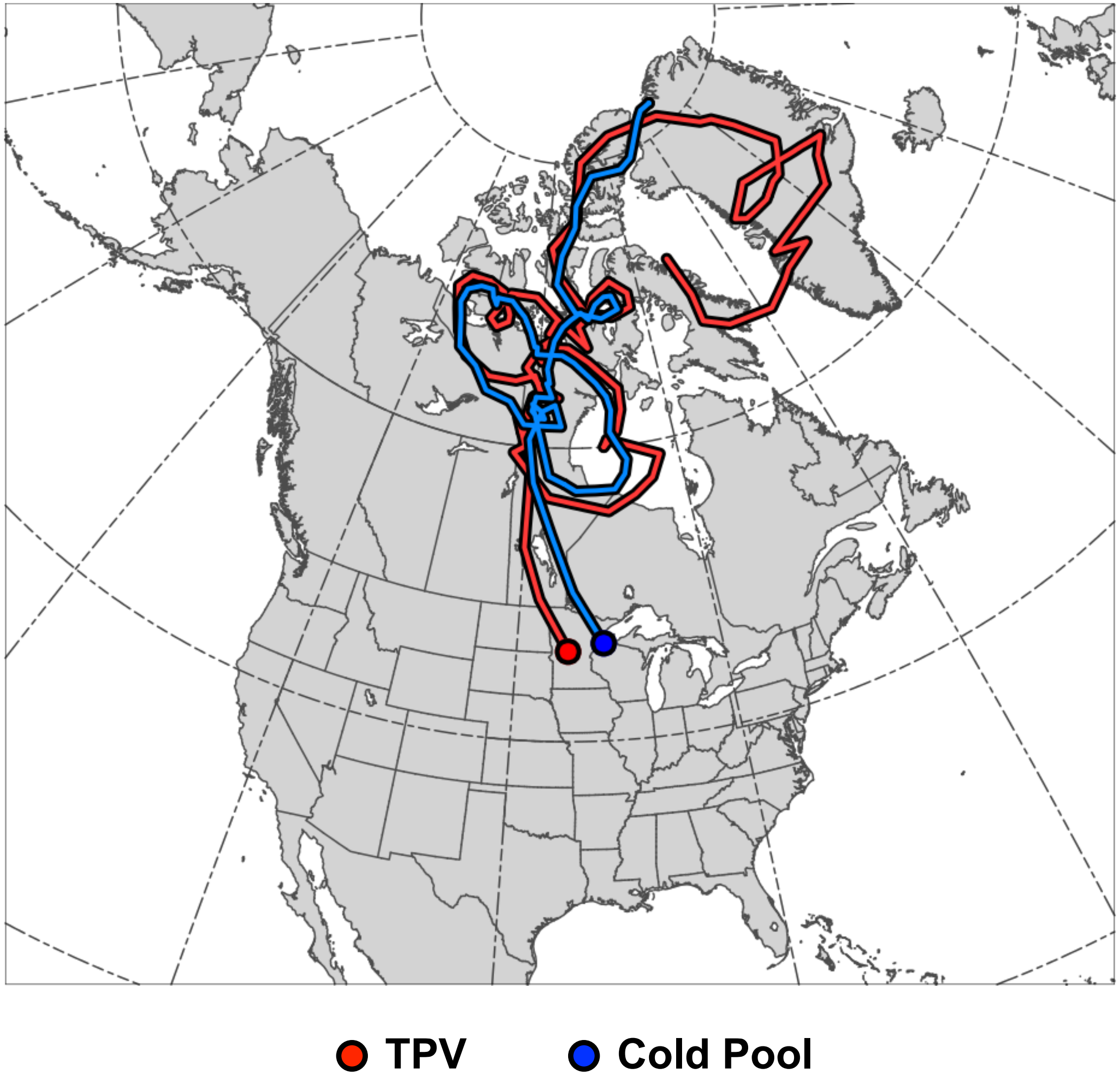
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 10 Jan 1982



- **TPV Track:**
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  - **Lysis:** 0000 UTC 13 Jan 1982
  - **Lifetime:** ~29 days
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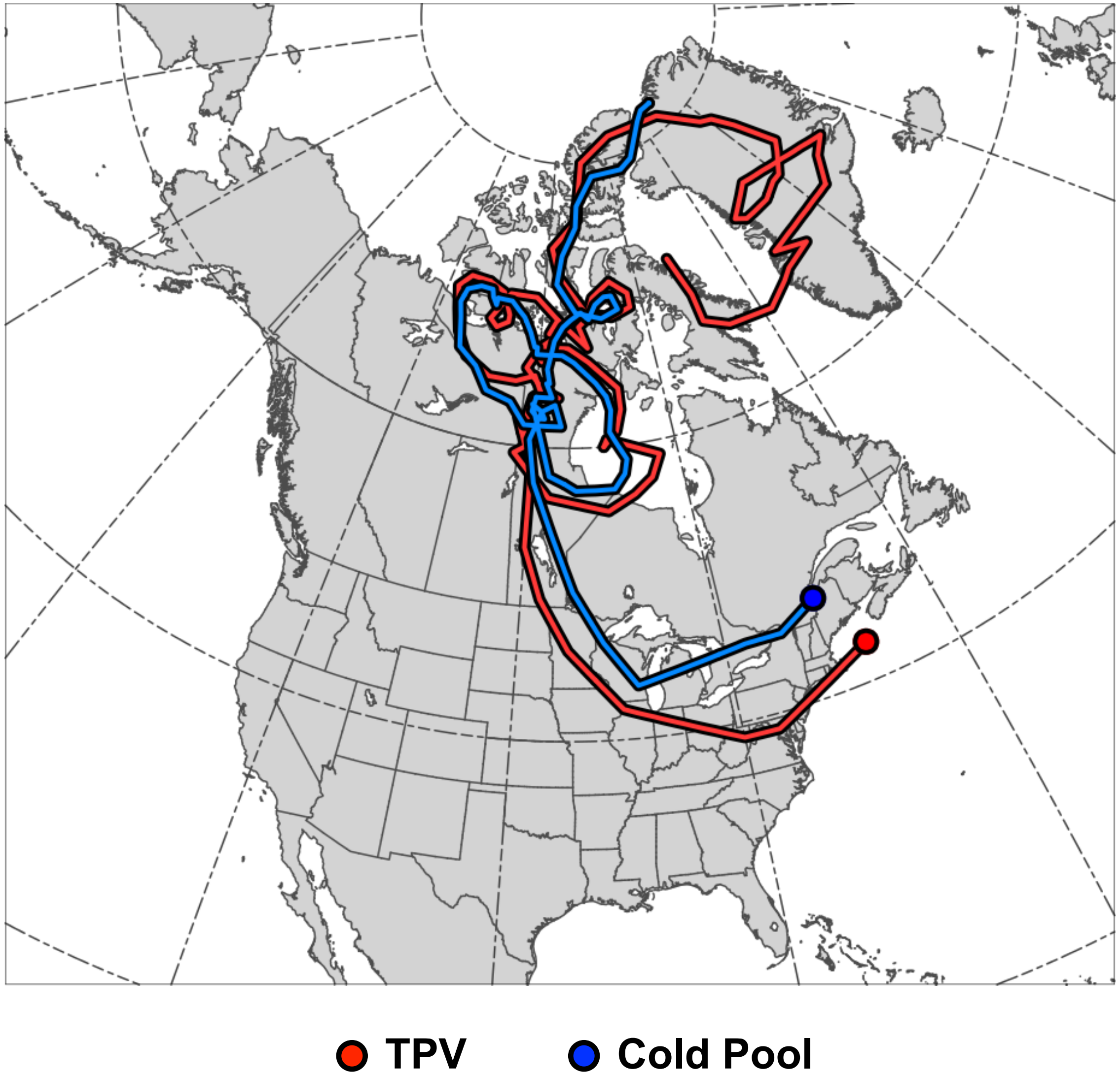
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

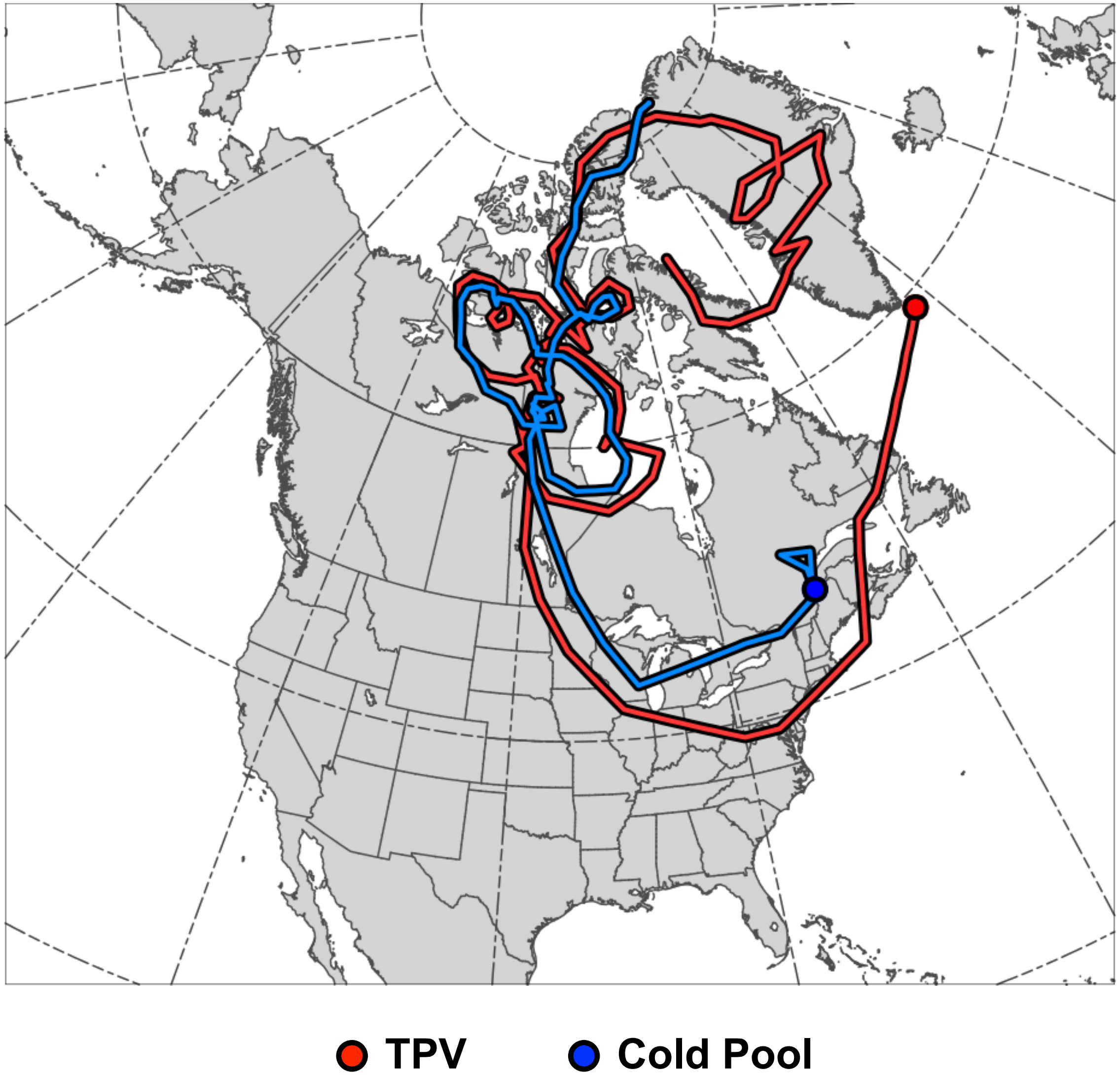
0000 UTC 11 Jan 1982



- **TPV Track:**
  - **Genesis:** 0600 UTC 15 Dec 1981
  - **Lysis:** 0000 UTC 13 Jan 1982
  - **Lifetime:** ~29 days
- **Cold Pool Track:**
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

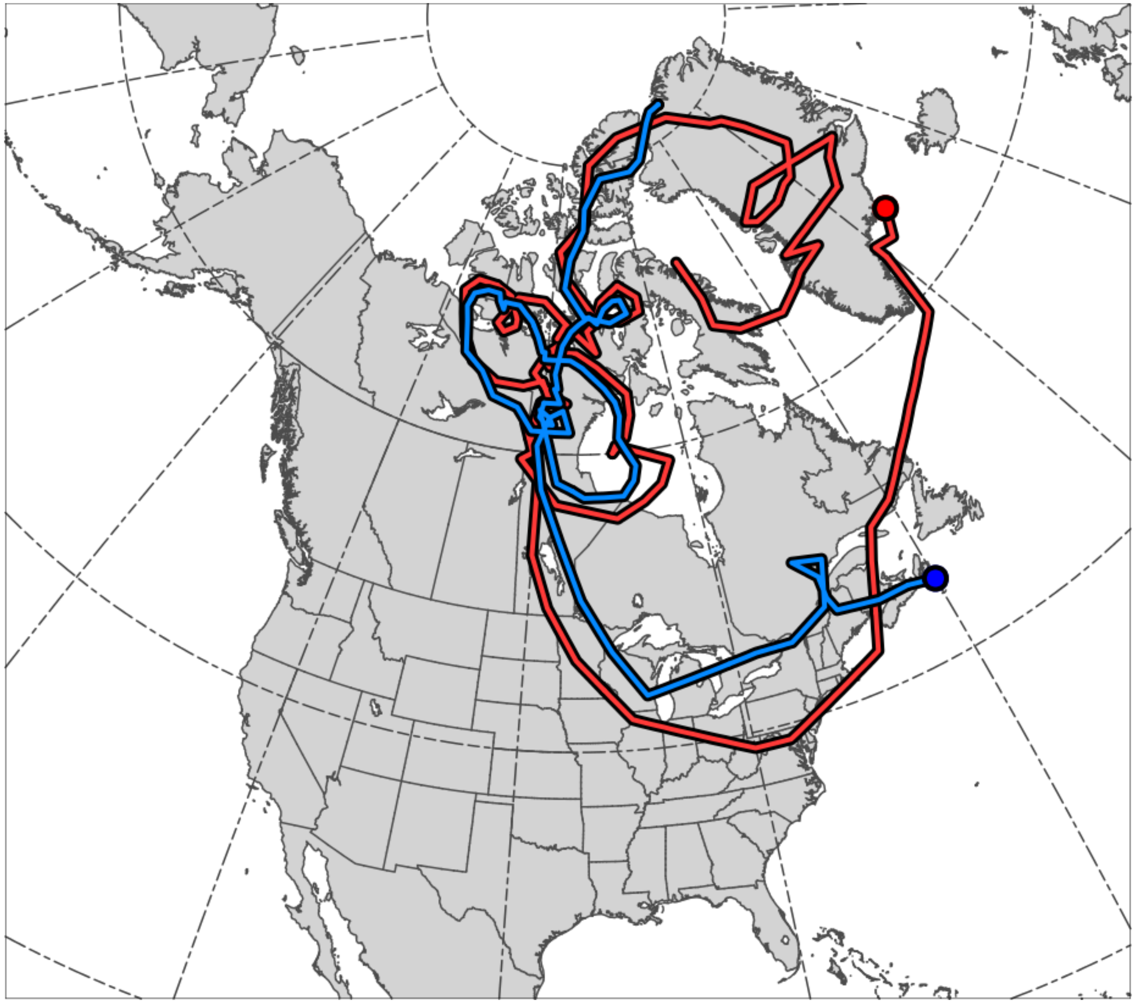
0000 UTC 12 Jan 1982



- **TPV Track:**
  - **Genesis:** 0600 UTC 15 Dec 1981
  - **Lysis:** 0000 UTC 13 Jan 1982
  - **Lifetime:** ~29 days
- **Cold Pool Track:**
  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

Tracks for Jan 1982 CAO

0000 UTC 13 Jan 1982



TPV   Cold Pool

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  - **Lifetime:** ~29 days
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  - **Genesis:** 1800 UTC 20 Dec 1981
  - **Lysis:** 1800 UTC 13 Jan 1982
  - **Lifetime:** ~24 days

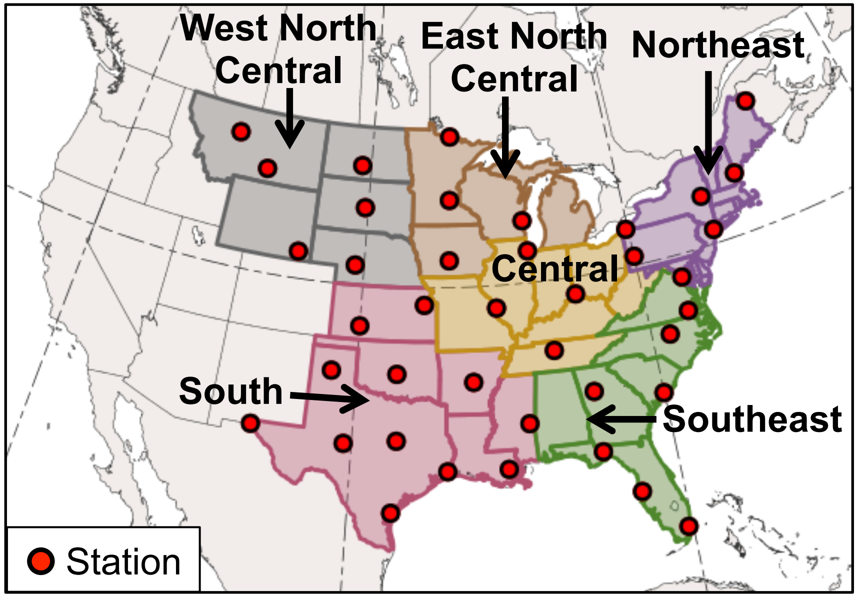
CAO Identification

- Regional CAOs are identified using CAO climatology created by Murphy (2017)
- **Dataset:** Global Historical Climatology Network-Daily minimum temperature data
- **Period of study:** 1979–2015

CAO Identification

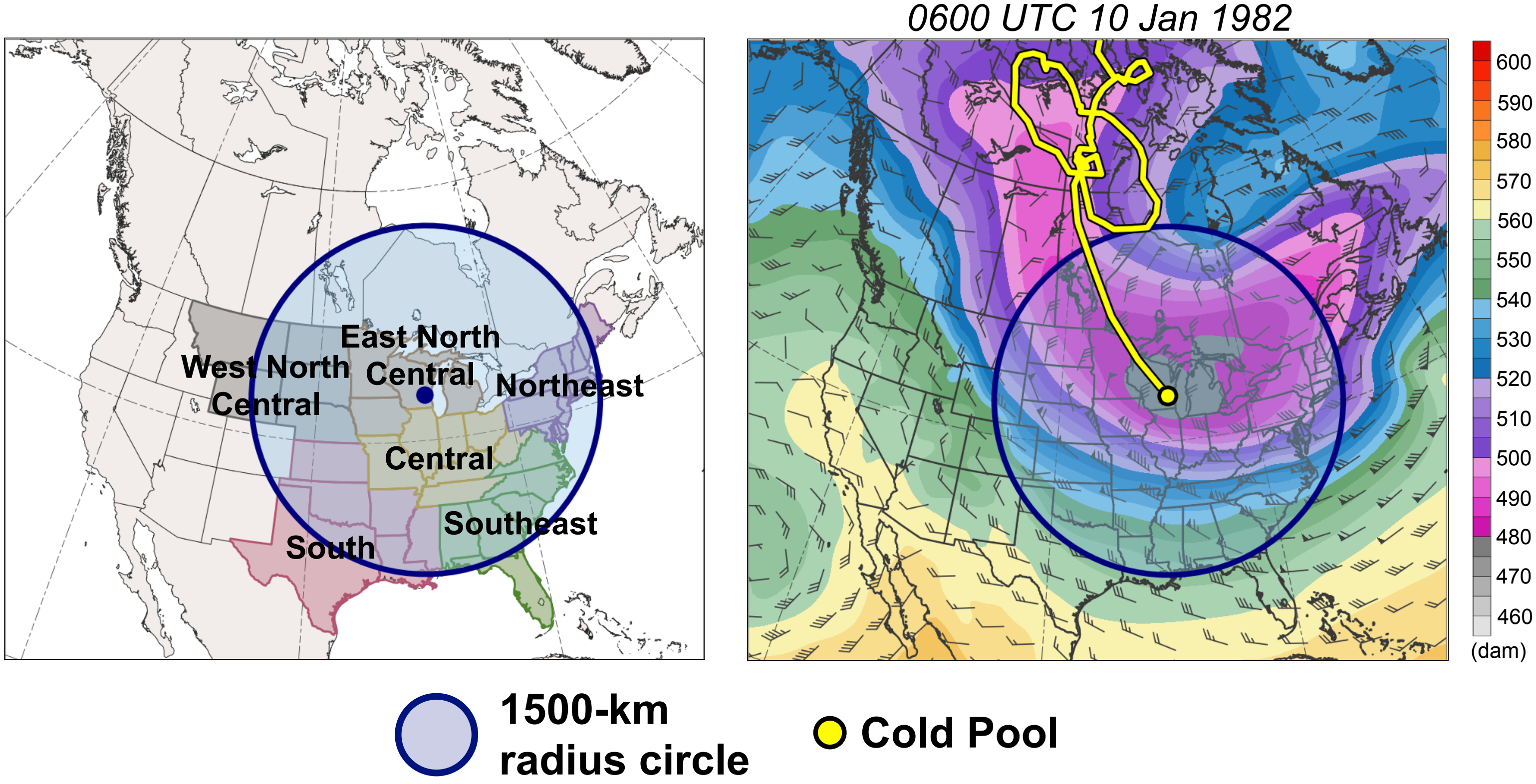
- **Regions studied:** Six NCEI climate regions encompassing central and eastern U.S. are examined (regions are color shaded in map below)

- **Regional CAO Definition:**
  - Two or more stations within a NCEI climate region experience three or more consecutive days where minimum temperatures fall below the 31-day centered moving average of the 5th percentile minimum temperature for those days and share at least one overlapping day

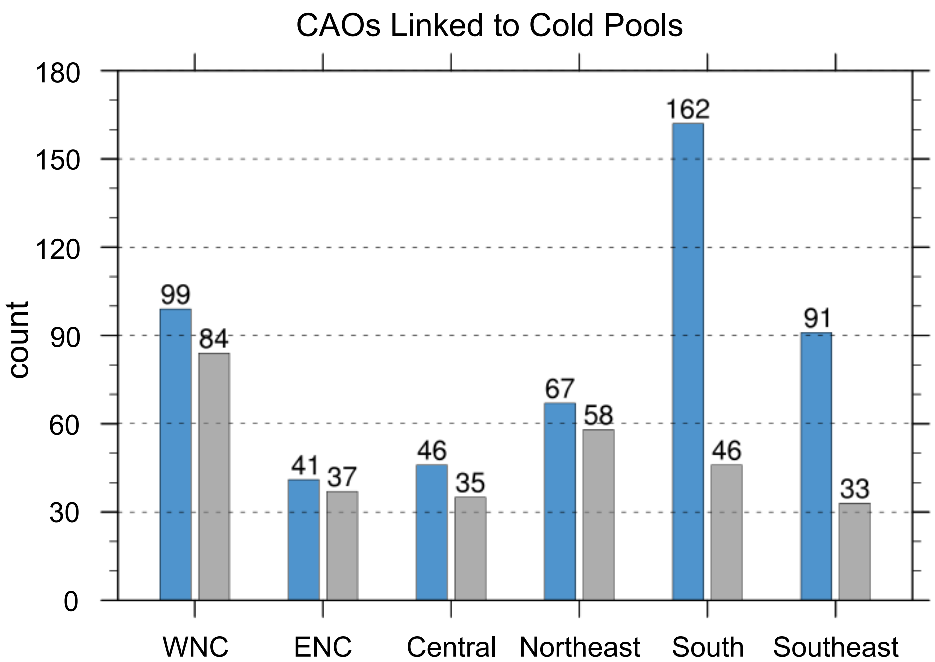


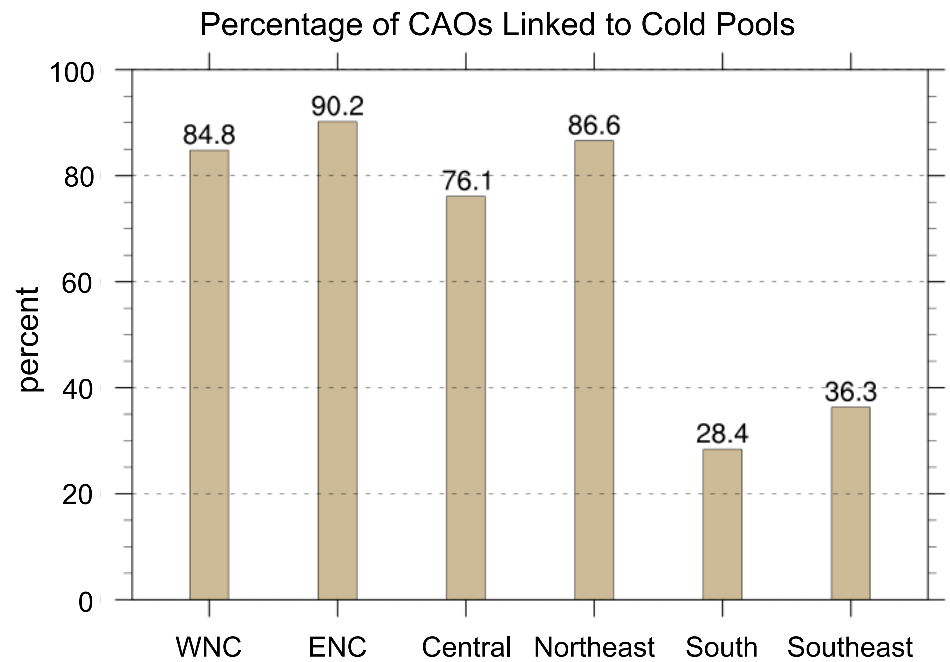
CAOs Linked to Cold Pools

- **Identification of CAOs linked to cold pools:**
  - Circle of radius 1500 km surrounding 1000–500-hPa thickness minimum of a cold pool must overlap at least one grid point (using a 0.5° grid) of region for at least one time stamp (6 h interval) during CAO



CAOs Linked to Cold Pools

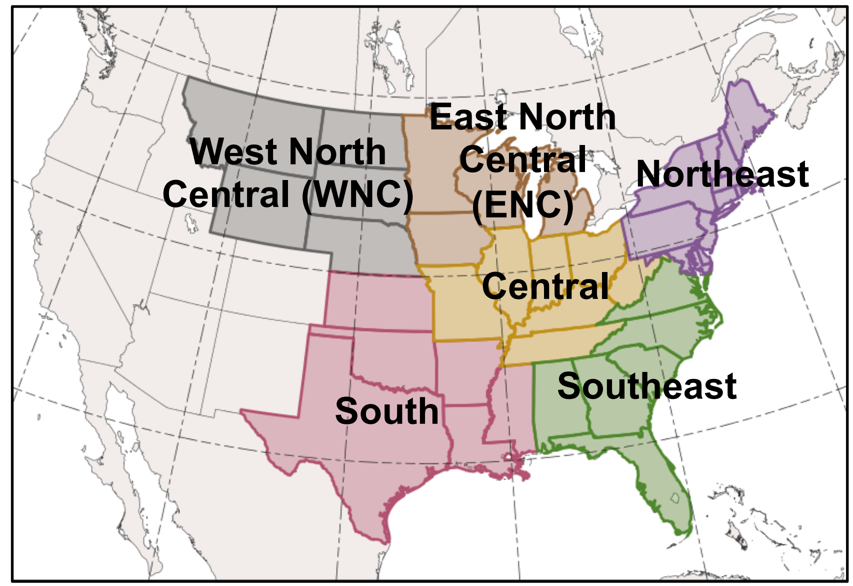




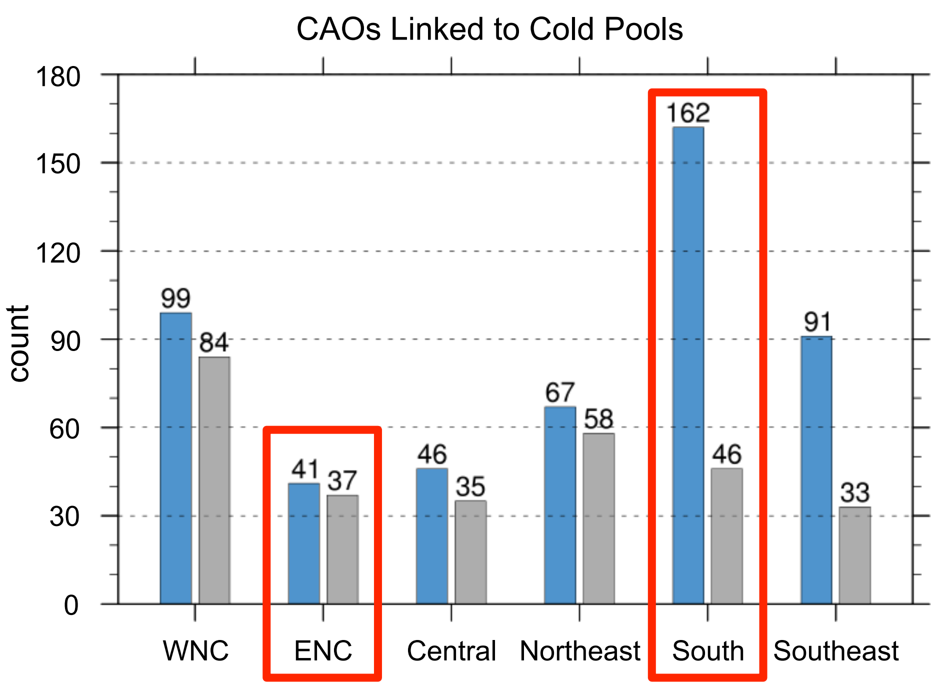
Total number of CAOs

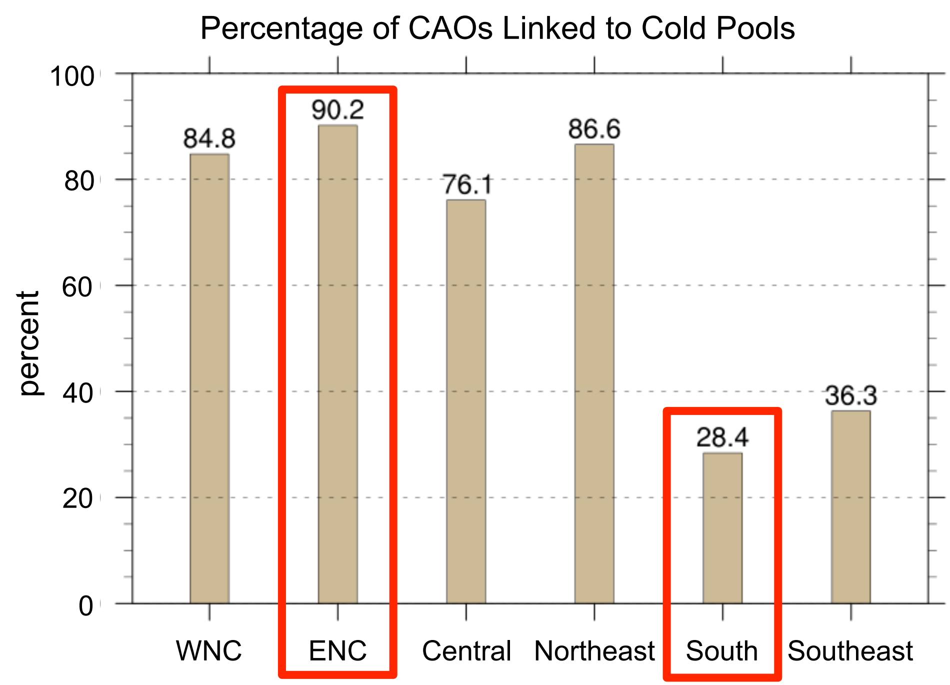
Number of unique CAOs linked to at least one cold pool

Percentage of unique CAOs linked to at least one cold pool [(gray/blue) × 100]



CAOs Linked to Cold Pools

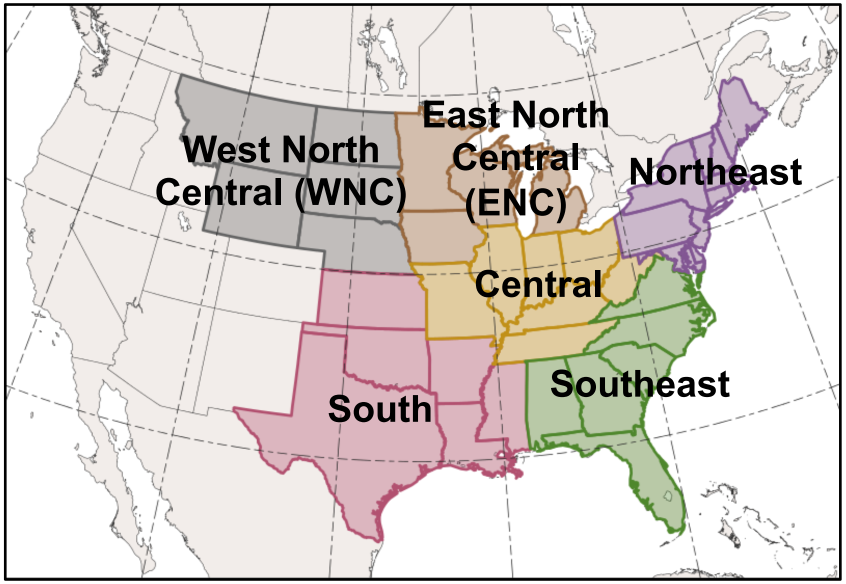




Total number of CAOs

Number of unique CAOs linked to at least one cold pool

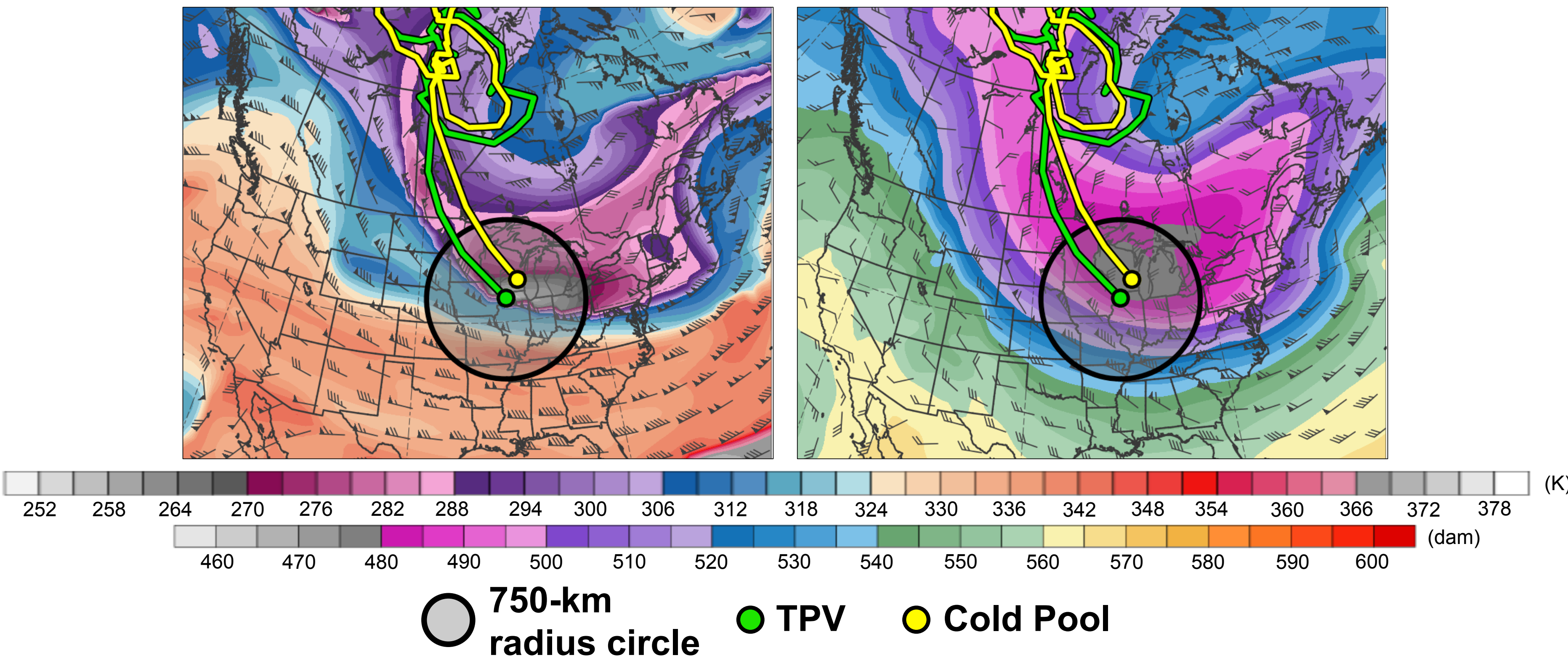
Percentage of unique CAOs linked to at least one cold pool [(gray/blue) × 100]



Cold Pools Associated with TPVs

- **Identification of cold pools associated with TPVs:**
  - Centers of TPVs and cold pools must be located within 750 km of each other for at least two consecutive days to be identified as a match

0600 UTC 10 Jan 1982



Cold Pools Associated with TPVs

- 6,288 out of a total of 8,395 cold pools, or 74.9%, match with at least one TPV

- 6,510 out of a total of 25,085 TPVs, or 26.0%, match with at least one cold pool

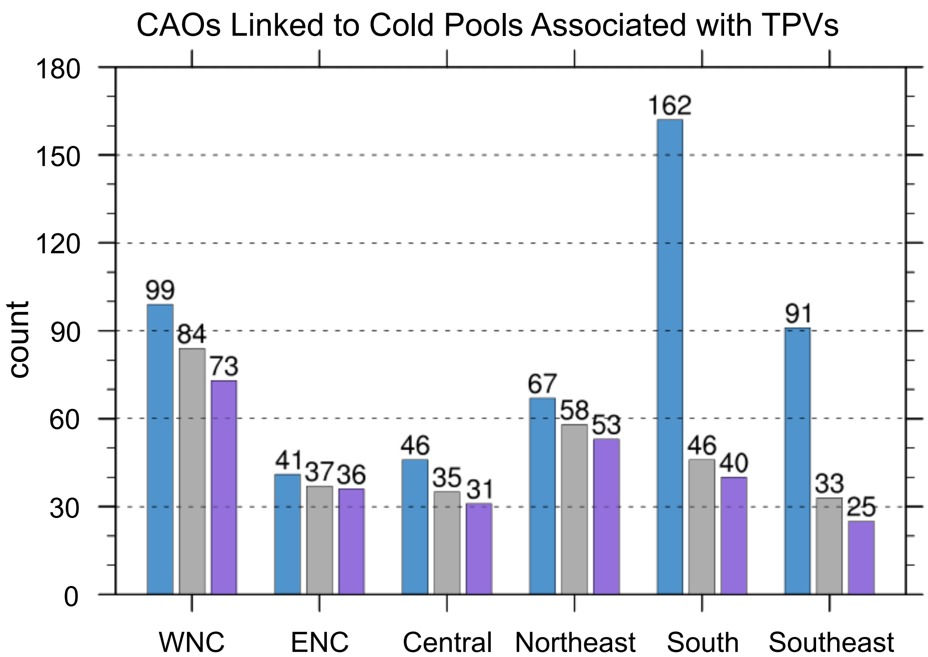
Cold Pools Associated with TPVs

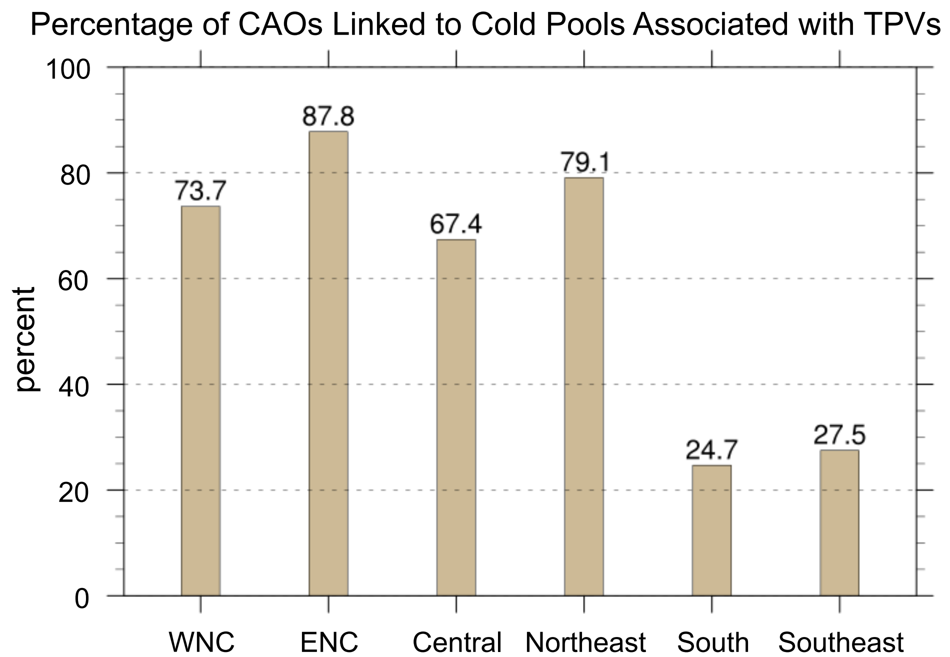
- 6,288 out of a total of 8,395 cold pools, or 74.9%, match with at least one TPV
- 6,510 out of a total of 25,085 TPVs, or 26.0%, match with at least one cold pool
- TPVs may not match with cold pools because:
  - TPVs may be too small or too weak to be associated with trackable cold pools
  - TPVs may be associated with thickness troughs that are not trackable
  - TPVs may match with cold pools not meeting latitude criteria

CAOs Linked to Cold Pools Associated with TPVs

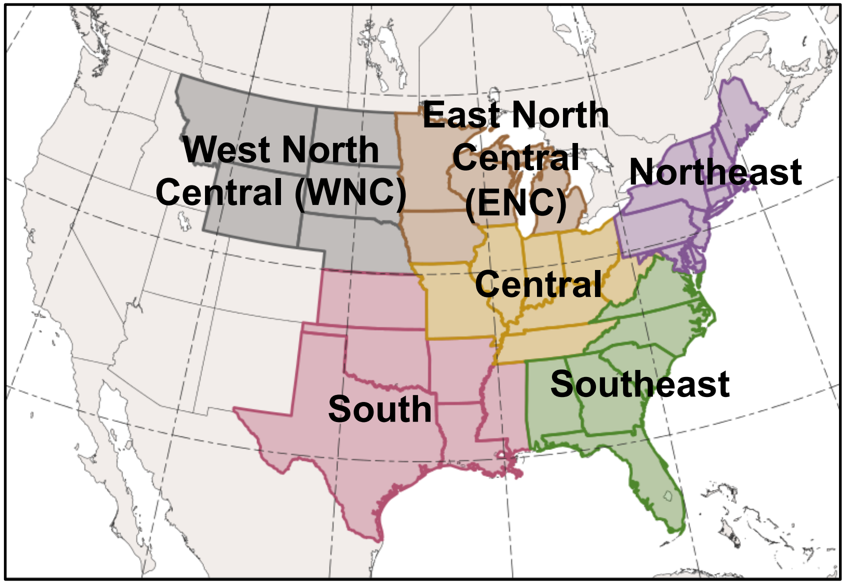
- CAOs that are linked to cold pools associated with TPVs can now be identified

CAOs Linked to Cold Pools Associated with TPVs



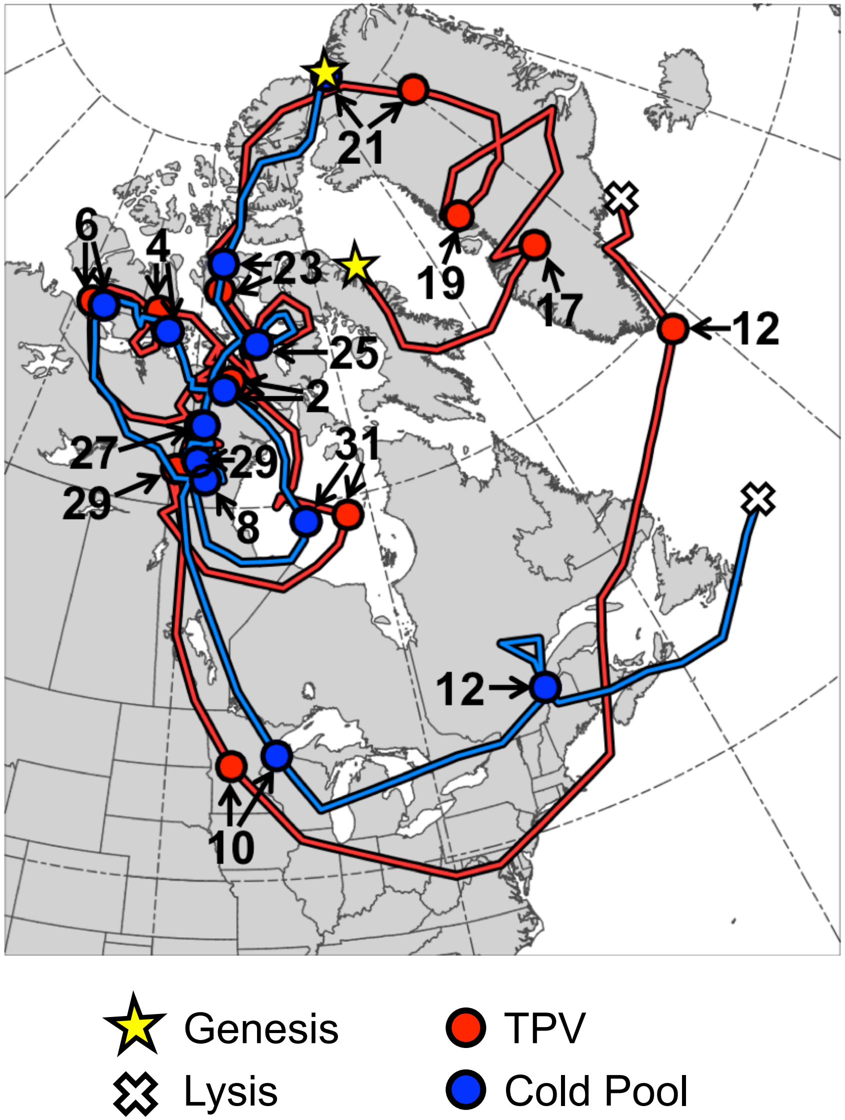


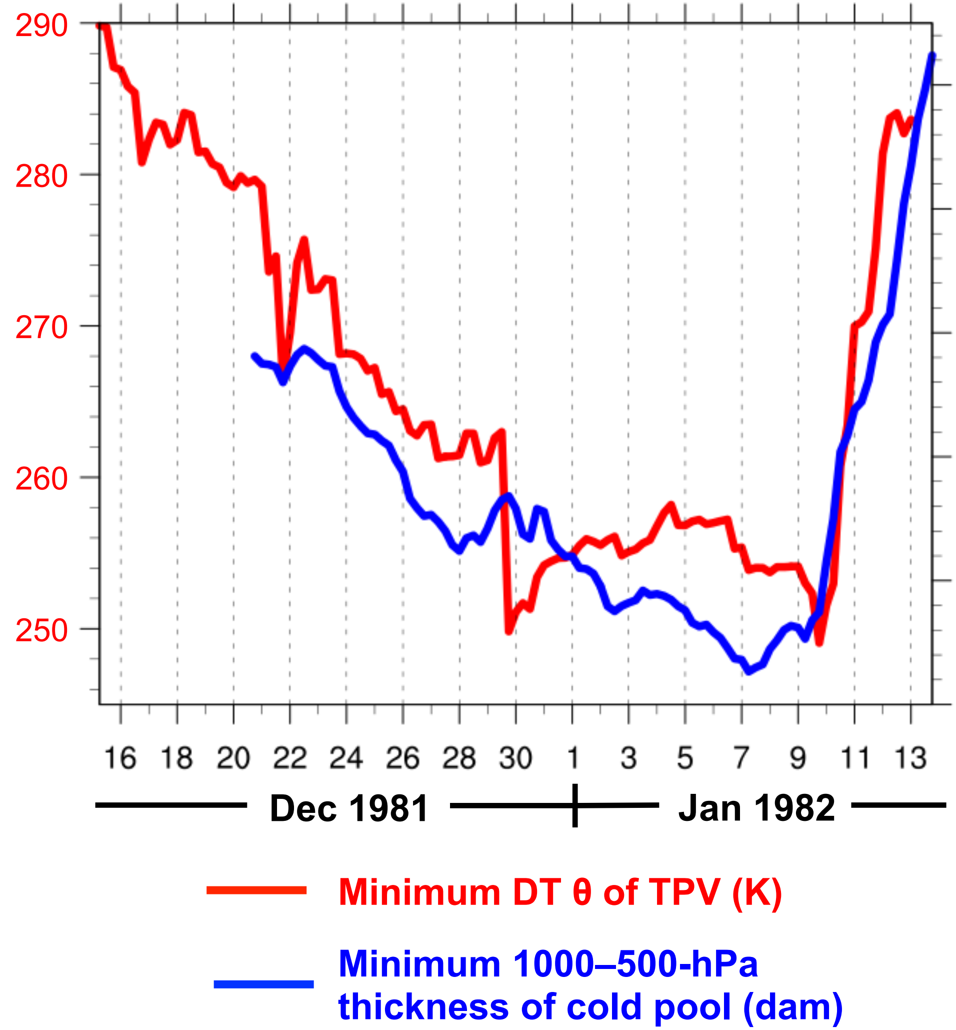
- Total number of CAOs
- Number of unique CAOs linked to at least one cold pool
- Number of unique CAOs linked to at least one cold pool associated with TPVs
- Percentage of unique CAOs linked to at least one cold pool associated with TPVs [(purple/blue) × 100]



Examination of January 1982 CAO

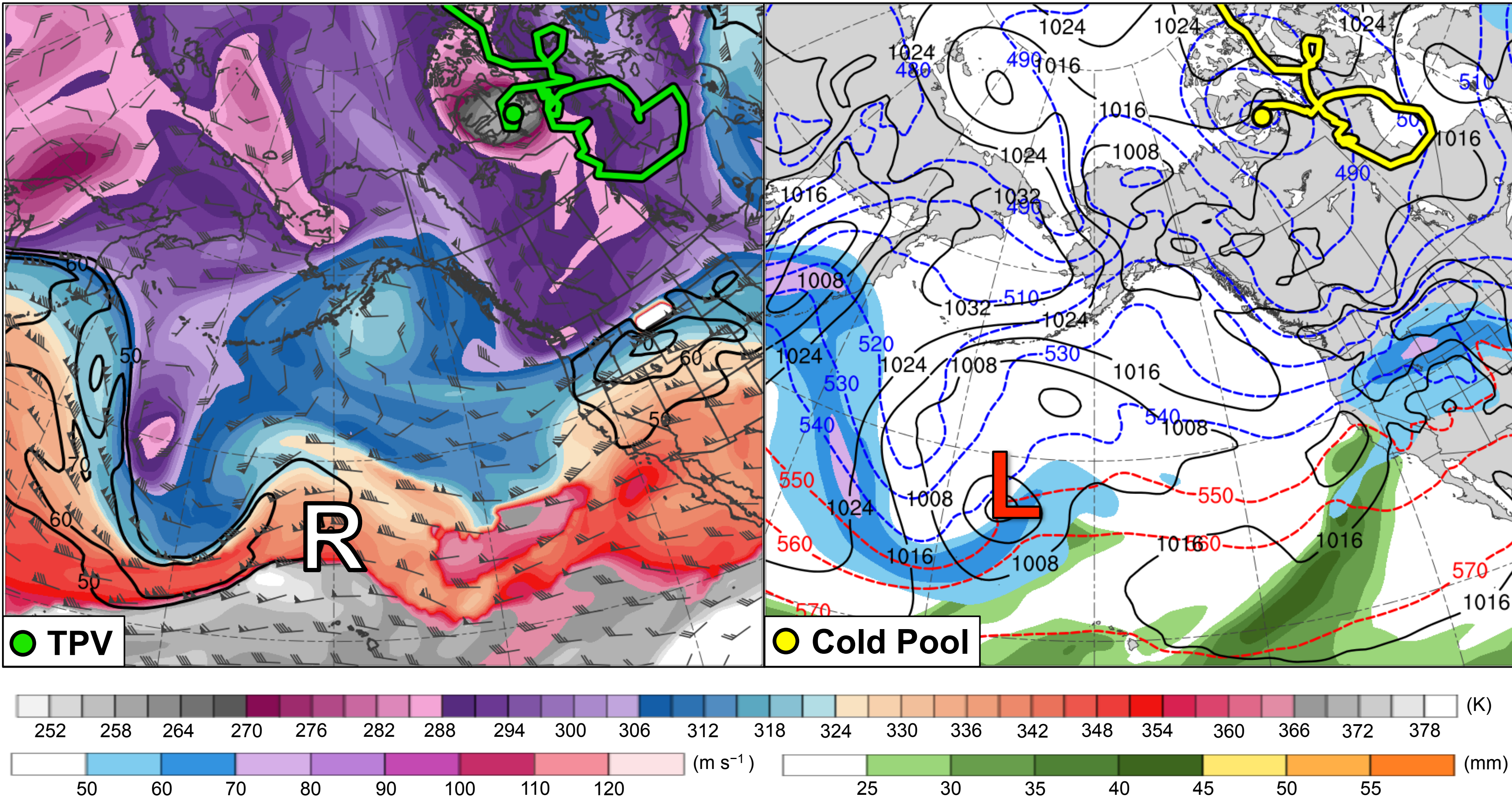
TPV and Cold Pool Track and Intensity





Ridge Amplification

0000 UTC 5 Jan 1982

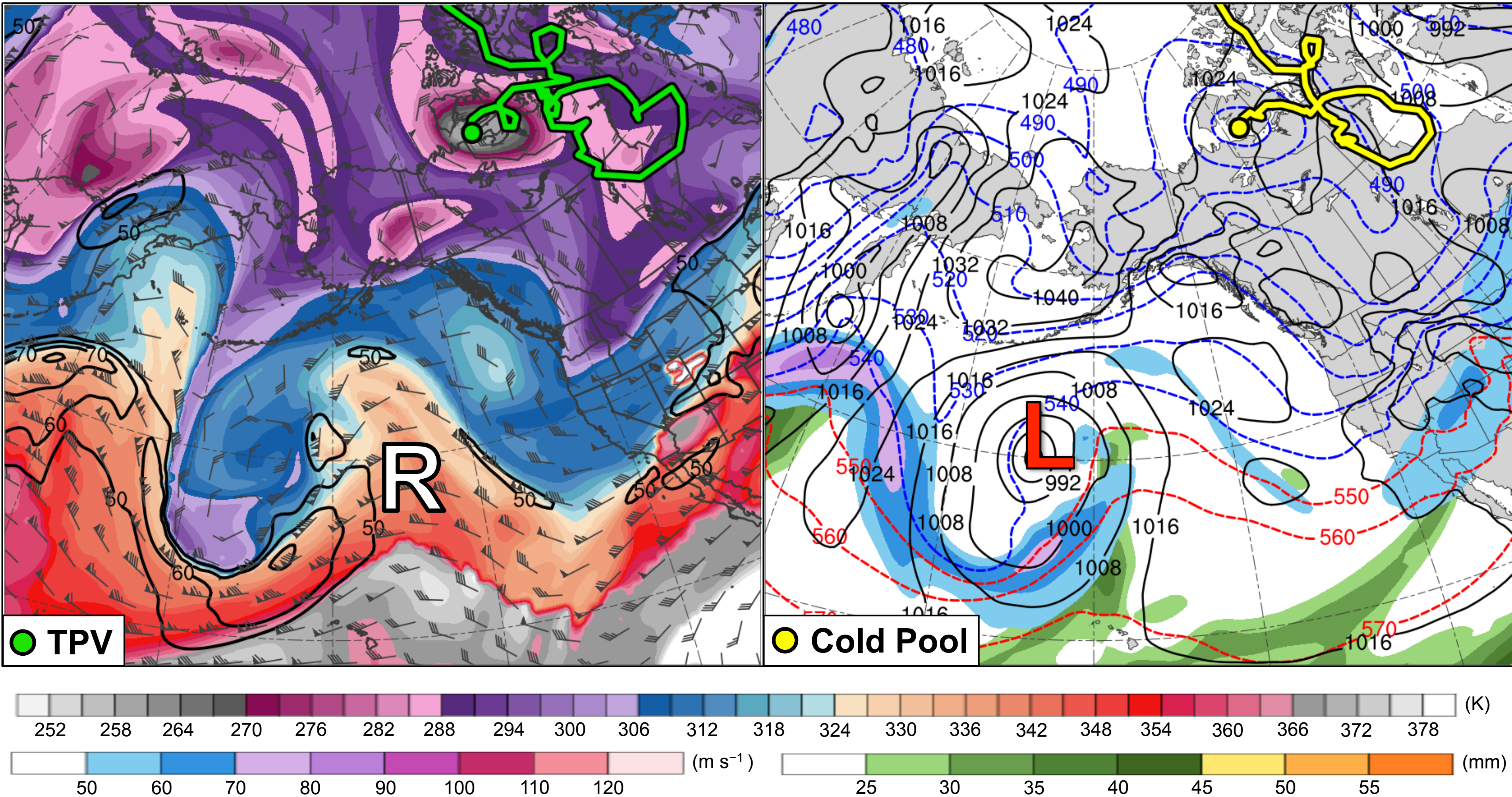


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Ridge Amplification

0000 UTC 6 Jan 1982

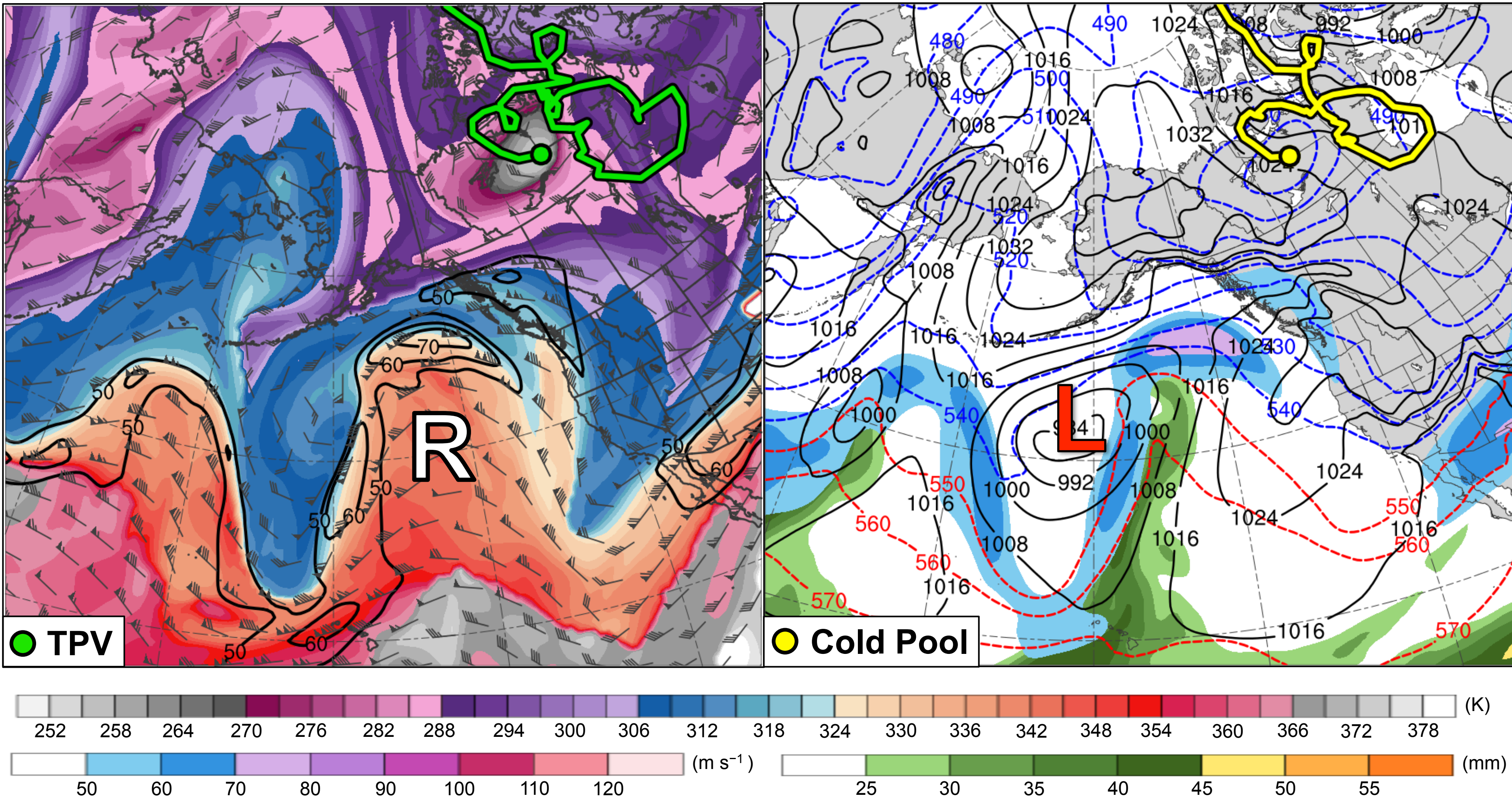


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Ridge Amplification

0000 UTC 7 Jan 1982

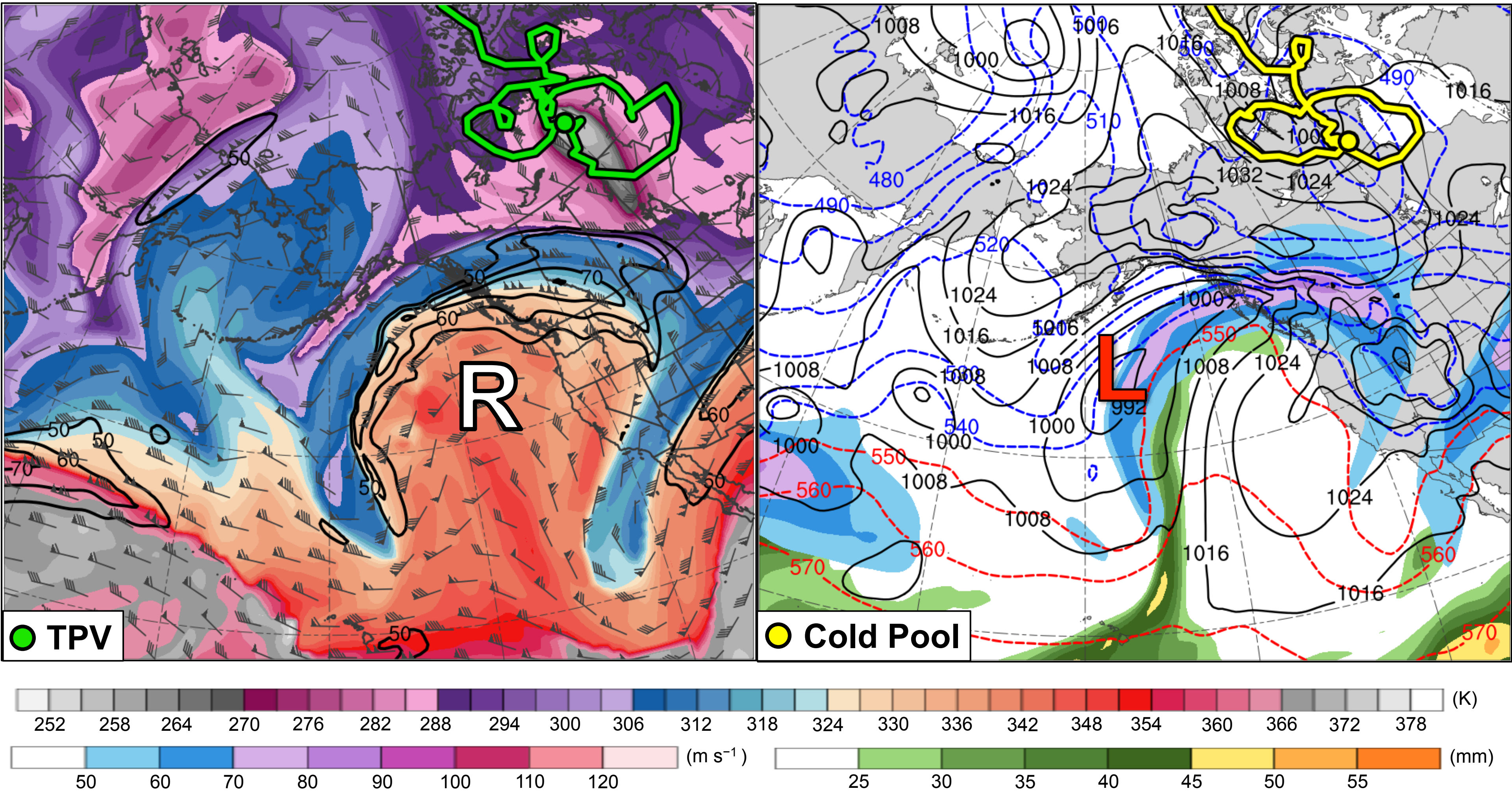


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Ridge Amplification

0000 UTC 8 Jan 1982



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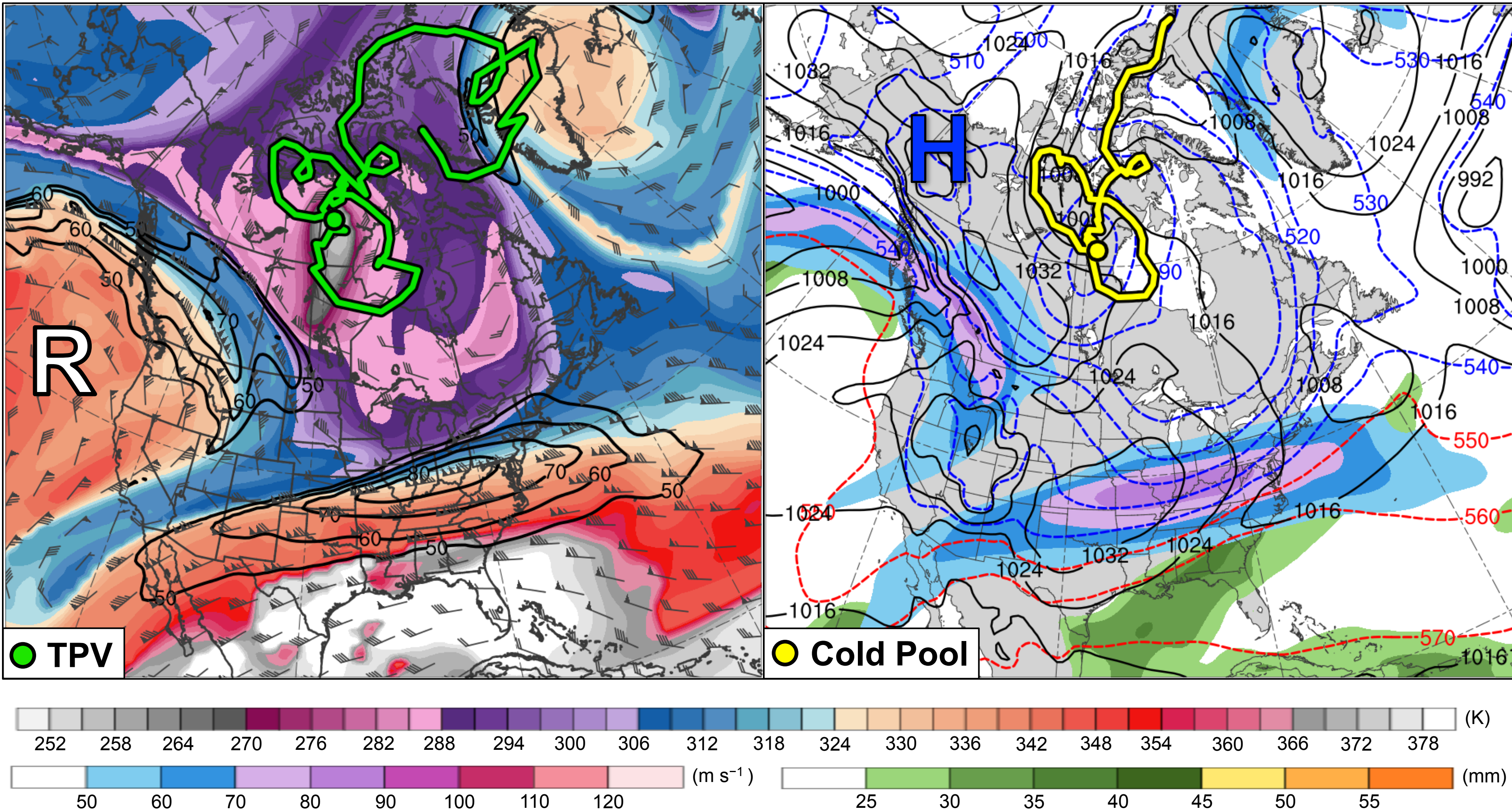
250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), PW (mm, shaded)

CAO Development

0000 UTC 8 Jan 1982



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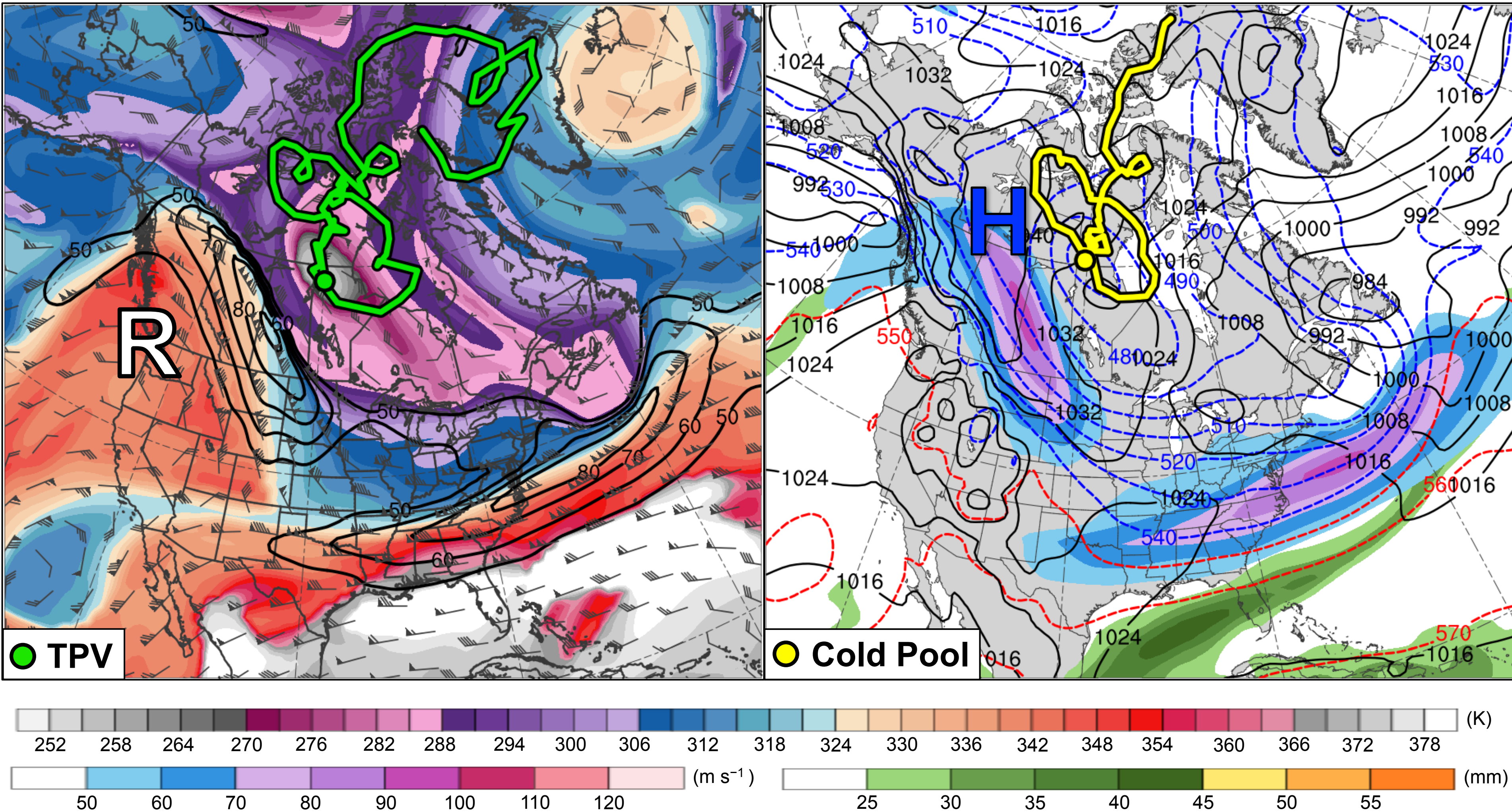
250-hPa wind speed (m s^{-1}, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), PW (mm, shaded)

CAO Development

0000 UTC 9 Jan 1982



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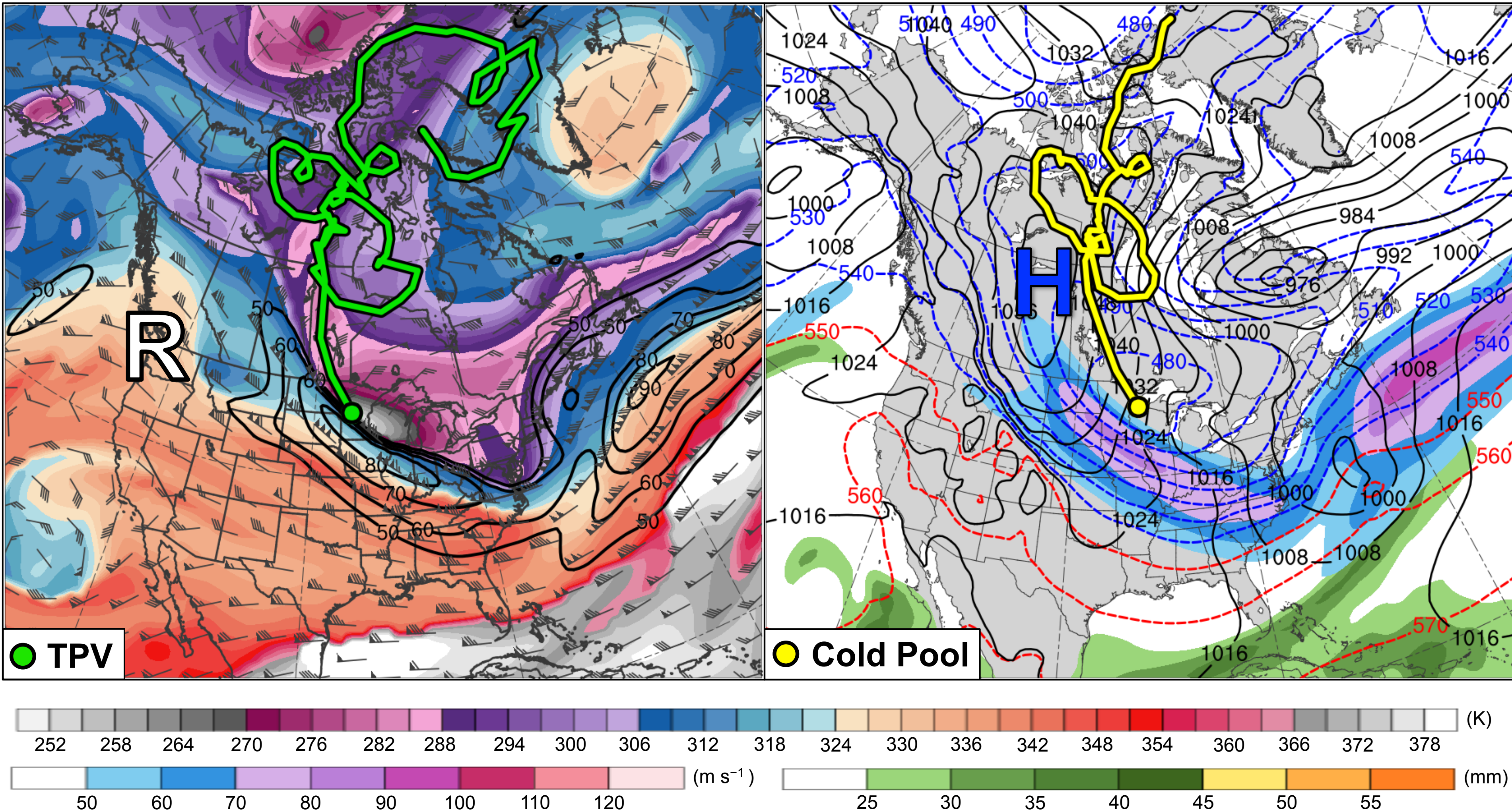
CAO Development

0000 UTC 10 Jan 1982

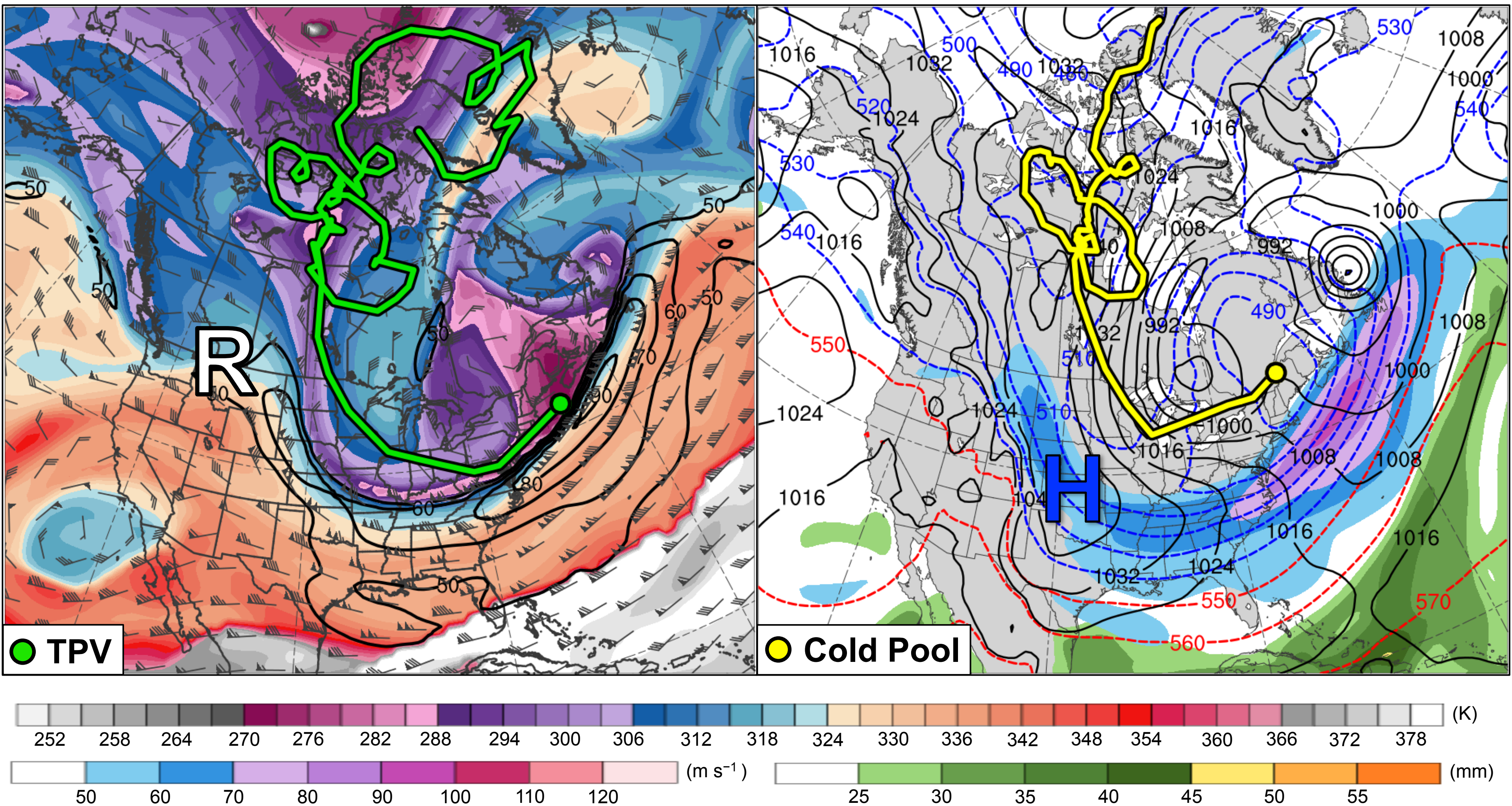


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

CAO Development

0000 UTC 11 Jan 1982

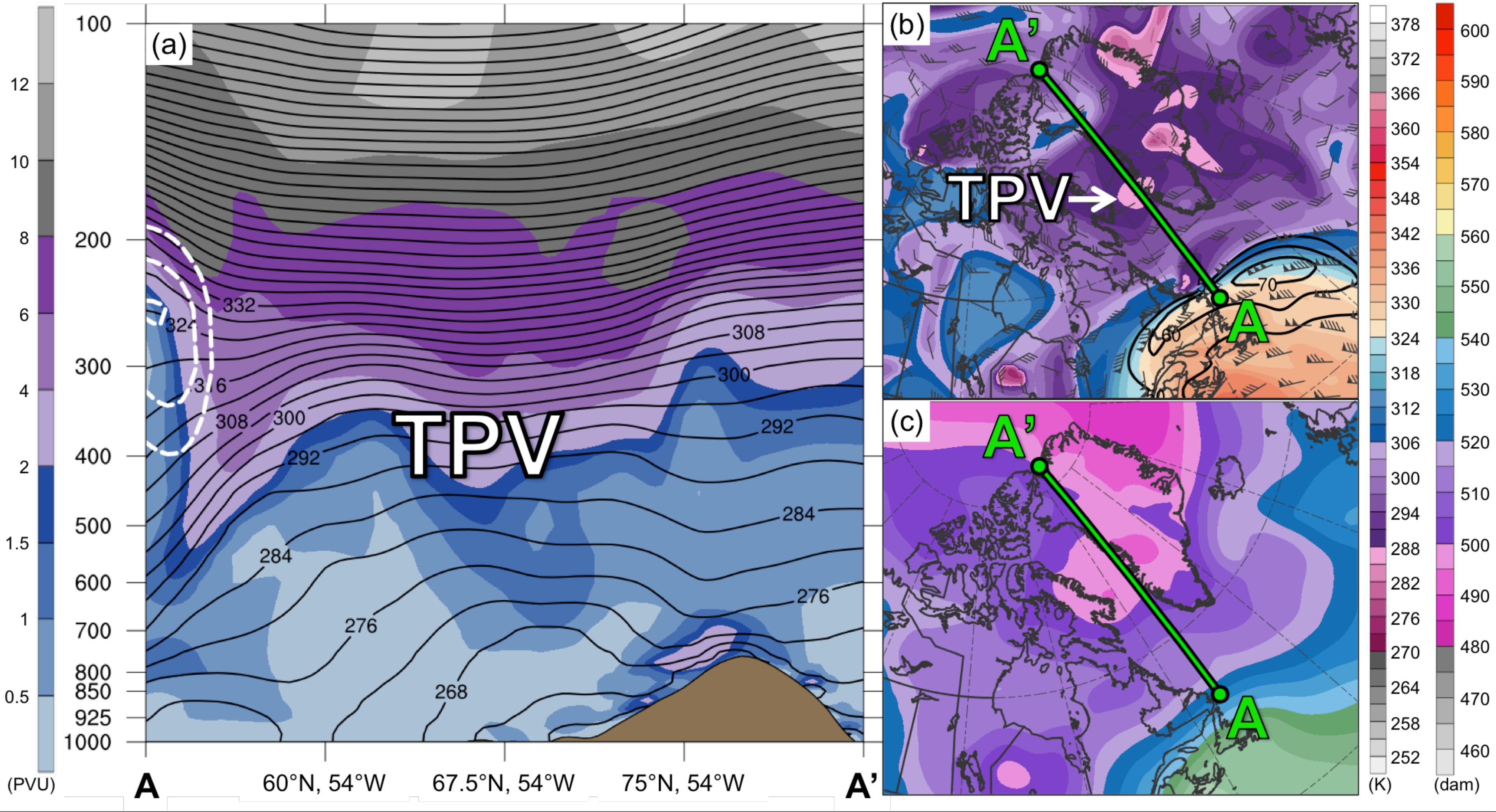


Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 50 m s^{-1}), and wind (m s^{-1}, flags and barbs) on 2-PVU surface

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

Cross Sections

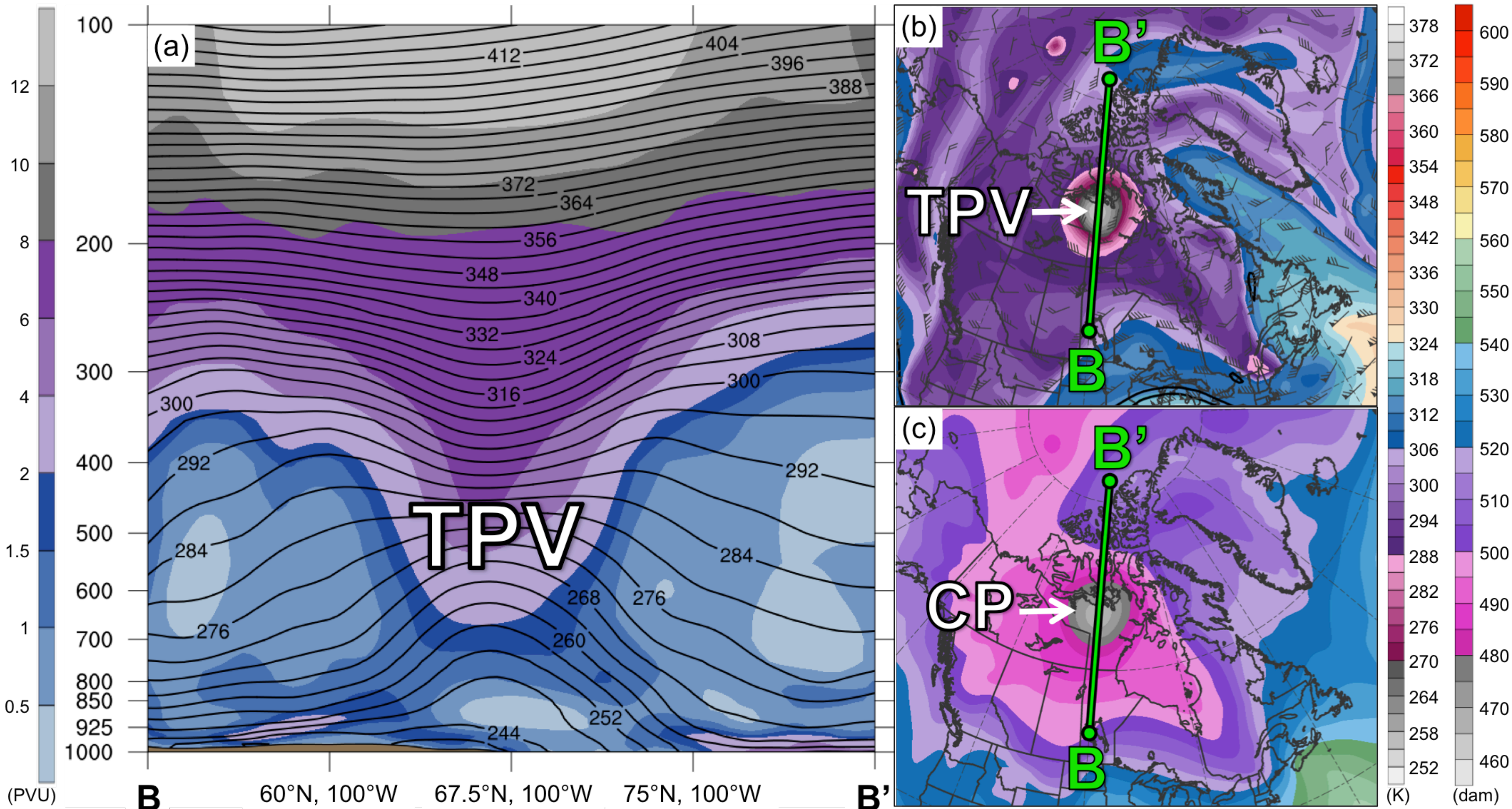
1200 UTC 16 Dec 1981



(a) PV (PVU, shaded), θ (K, black), and wind speed (dashed white, m s^{-1});
(b) DT (2-PVU surface) θ (K, shaded), wind speed (black, m s^{-1}), and wind (m s^{-1}, flags and barbs);
(c) 1000–500-hPa thickness (dam, shaded)

Cross Sections

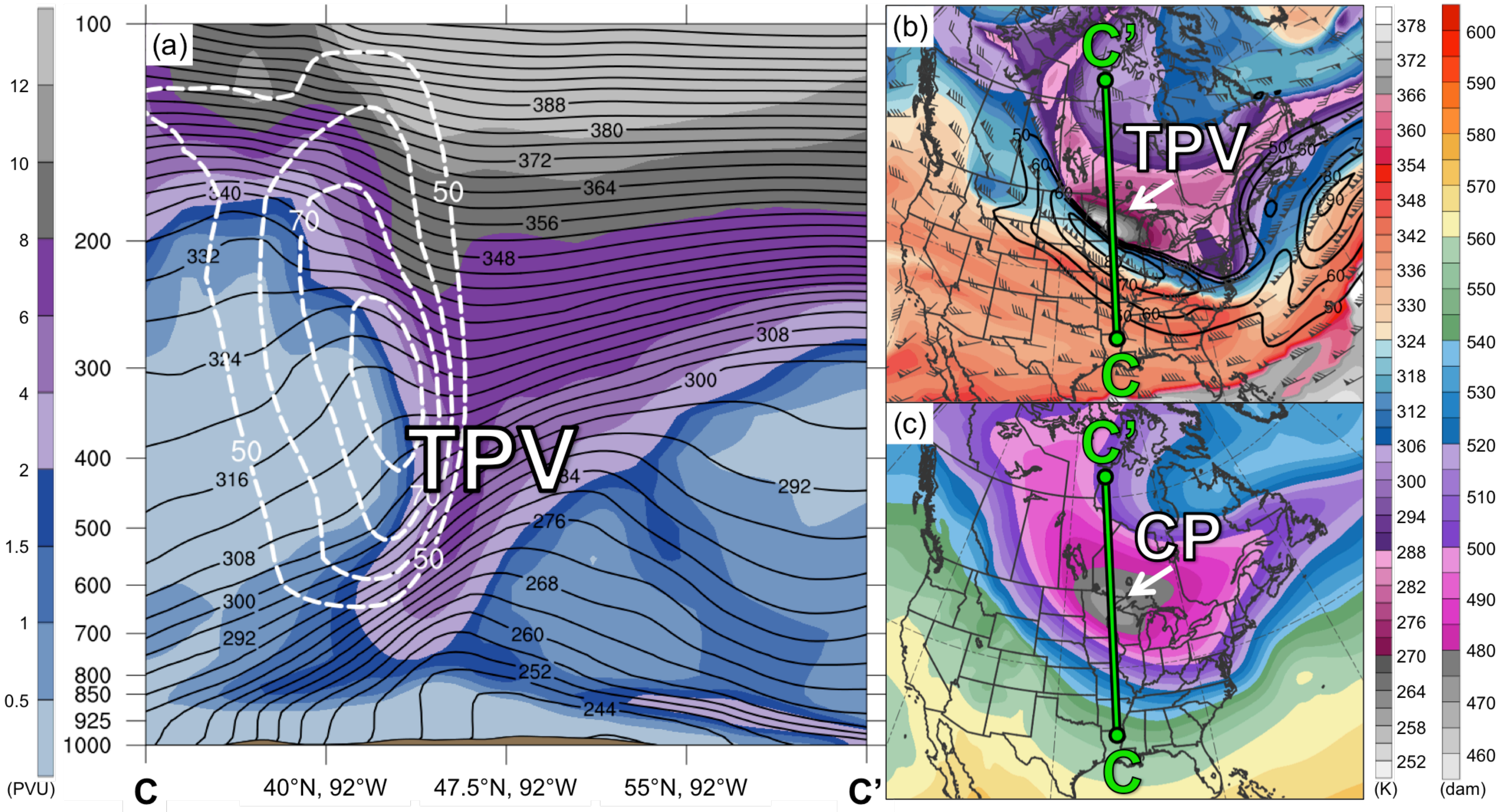
1200 UTC 2 Jan 1982



(a) PV (PVU, shaded), θ (K, black), and wind speed (dashed white, m s^{-1});
(b) DT (2-PVU surface) θ (K, shaded), wind speed (black, m s^{-1}), and wind (m s^{-1}, flags and barbs);
(c) 1000–500-hPa thickness (dam, shaded)

Cross Sections

0000 UTC 10 Jan 1982



(a) PV (PVU, shaded), θ (K, black), and wind speed (dashed white, m s^{-1});
(b) DT (2-PVU surface) θ (K, shaded), wind speed (black, m s^{-1}), and wind (m s^{-1}, flags and barbs);
(c) 1000–500-hPa thickness (dam, shaded)

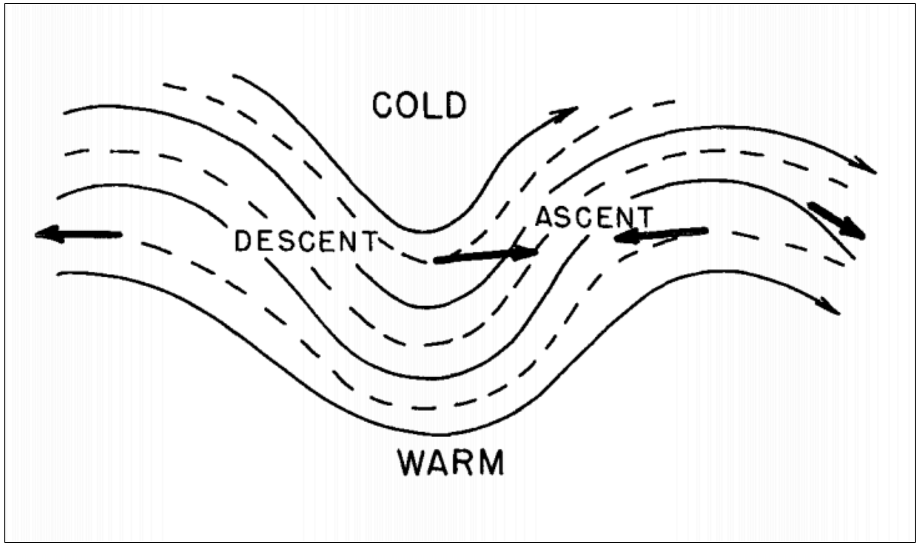
TPV–jet Interaction and Surface Anticyclogenesis

- As jet streak strengthens over western North America during TPV–jet interaction, surface anticyclone strengthens and expands in left entrance region of jet streak

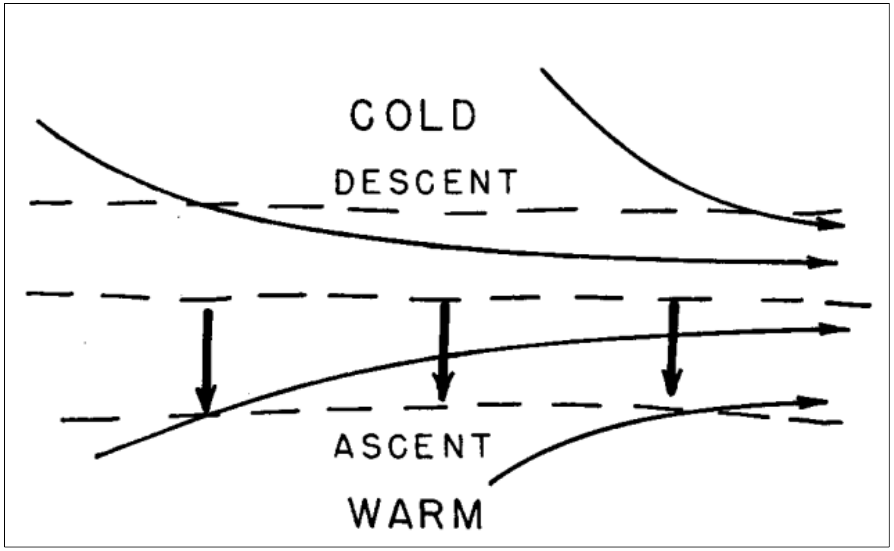
- Does TPV–jet interaction play a role in surface anticyclogenesis?

Q-vector Diagnosis

Sanders and Hoskins (1990)



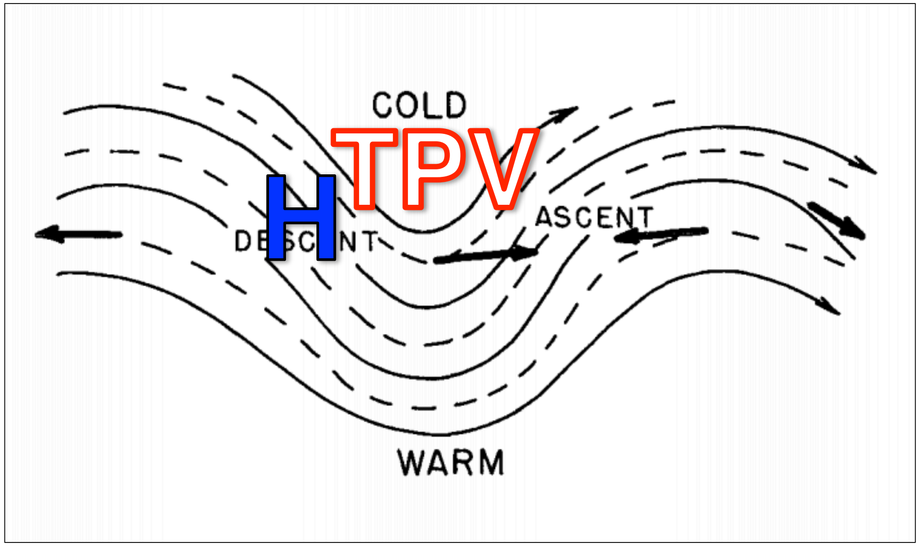
Idealized pattern of upper-level geopotential height contours (solid) and isotherms (dashed) for a train of equivalent-barotropic troughs and ridges, with Q-vectors overlaid. Figure 4 and caption adapted from Sanders and Hoskins (1990).



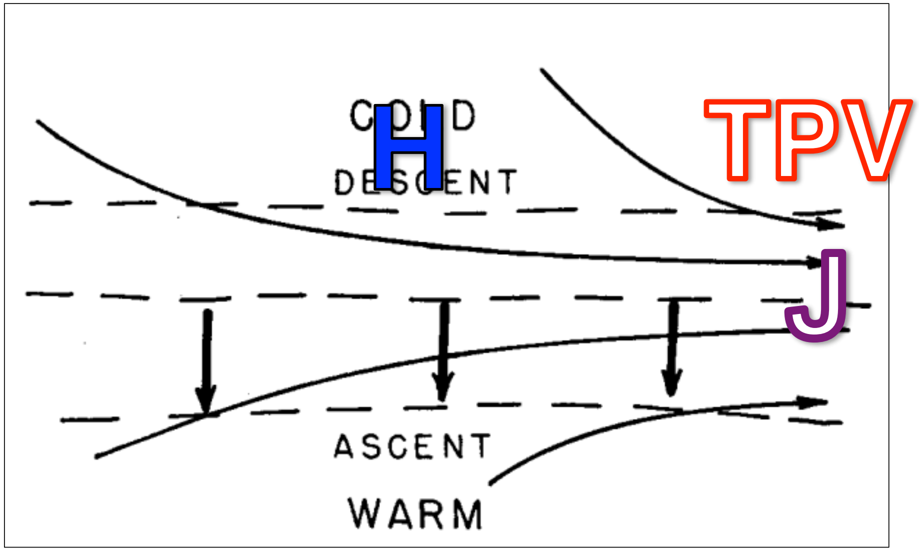
Idealized pattern of confluent frontogenesis corresponding to an entrance region of a jet. Solid lines are contours of low-level geopotential height and dashed lines are contours of lower-tropospheric thickness, with Q-vectors overlaid. Figure 5 and caption adapted from Sanders and Hoskins (1990).

Q-vector Diagnosis

Sanders and Hoskins (1990)



Idealized pattern of upper-level geopotential height contours (solid) and isotherms (dashed) for a train of equivalent-barotropic troughs and ridges, with Q-vectors overlaid. Figure 4 and caption adapted from Sanders and Hoskins (1990).



Idealized pattern of confluent frontogenesis corresponding to an entrance region of a jet. Solid lines are contours of low-level geopotential height and dashed lines are contours of lower-tropospheric thickness, with Q-vectors overlaid. Figure 5 and caption adapted from Sanders and Hoskins (1990).

- How does TPV–jet interaction influence Q-vector forcing for descent and forcing for anticyclogenesis?

Q-vector Diagnosis

- Diagnose Q-vector forcing for vertical motion during TPV–jet interaction

- Q-vectors in pressure coordinates calculated following Hoskins and Pedder (1980):

$$\boldsymbol{Q} = -\left(\frac{\partial \mathbf{V}_g}{\partial x} \cdot \nabla_p \theta\right)\boldsymbol{i} - \left(\frac{\partial \mathbf{V}_g}{\partial y} \cdot \nabla_p \theta\right)\boldsymbol{j}$$

- Q-vectors separated into across-isentrope (**Q**$_n$) and along-isentrope (**Q**$_s$) components following Keyser et al. (1992) as follows:

$$\boldsymbol{Q}_n = \left[\boldsymbol{Q} \cdot \left(-\frac{\nabla\theta}{|\nabla\theta|}\right)\right]\left(-\frac{\nabla\theta}{|\nabla\theta|}\right)$$

$$\boldsymbol{Q}_s = \left(\frac{\boldsymbol{Q}\cdot(\boldsymbol{k} \times \nabla\theta)}{|\nabla\theta|}\right)\left(\frac{\boldsymbol{k} \times \nabla\theta}{|\nabla\theta|}\right)$$

Q-vector Diagnosis

- Q-vector forcing for vertical motion associated with $\mathbf{Q}_n$ and $\mathbf{Q}_s$ calculated by adapting Q-vector form of QG omega equation in pressure coordinates from Hoskins and Pedder (1980)

$$\left(\sigma\nabla_p^2 + f_0^2 \frac{\partial^2}{\partial p^2}\right)\omega = -2h\left(\nabla_p \cdot \boldsymbol{Q}_n\right)$$

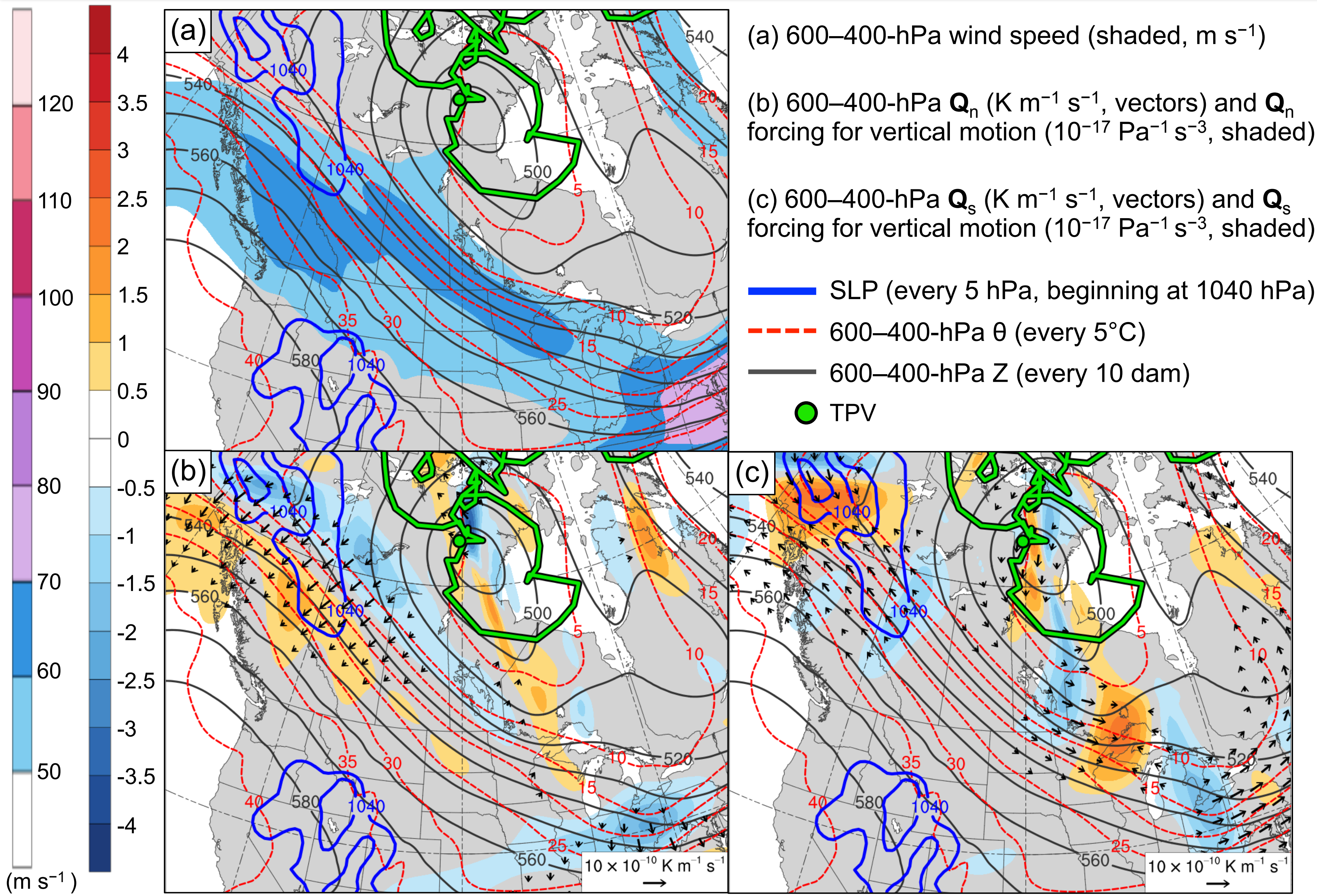
$$\left(\sigma\nabla_p^2 + f_0^2 \frac{\partial^2}{\partial p^2}\right)\omega = -2h\left(\nabla_p \cdot \boldsymbol{Q}_s\right)$$

where $h = (\rho\,\theta)^{-1}$, or equivalently, $h = \frac{R}{p_o}\left(\frac{p_0}{p}\right)^{c_v/c_p}$

- Q-vector components and respective forcings for vertical motion averaged over 600–400-hPa layer

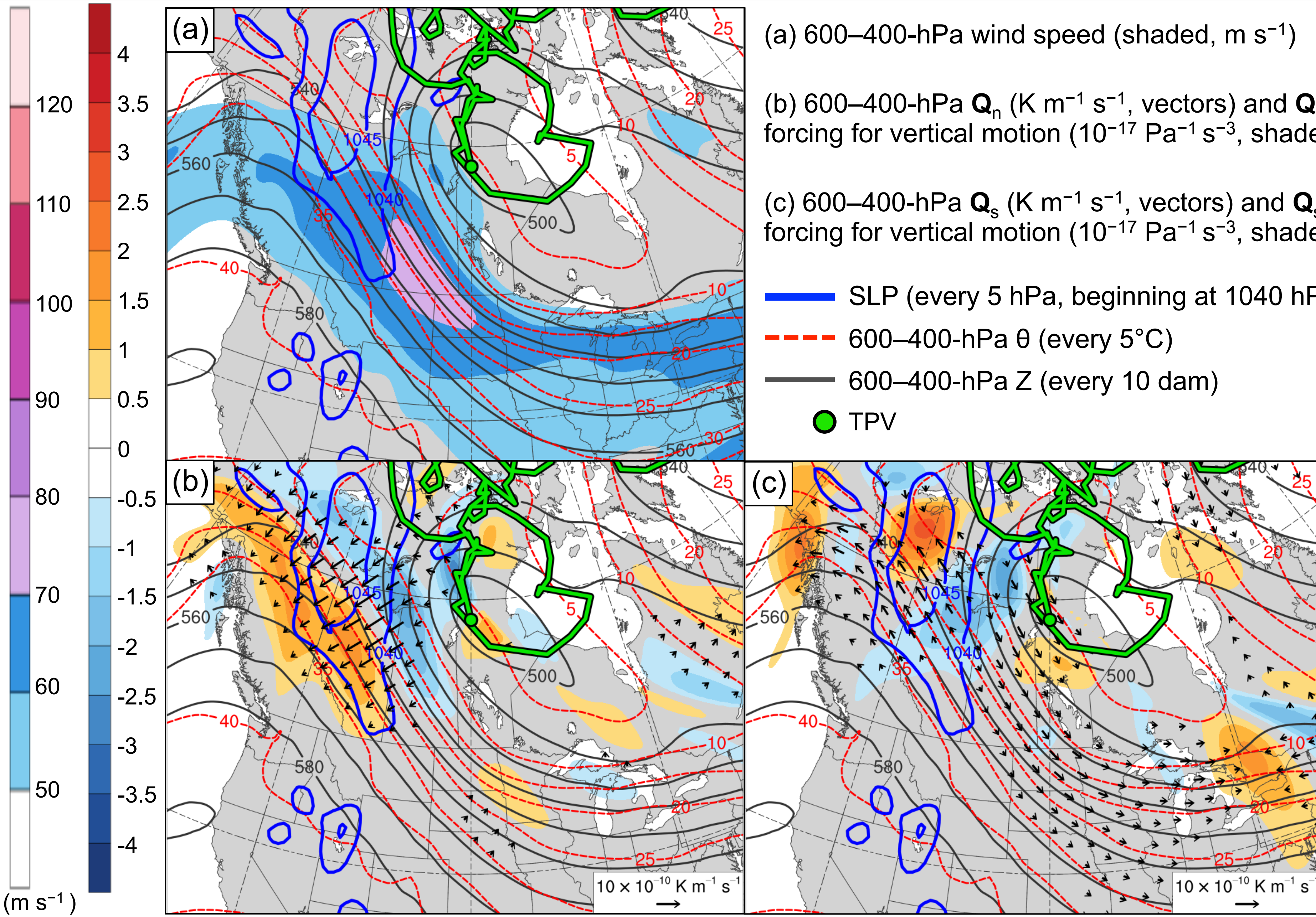
Q-vector Diagnosis

1200 UTC 8 Jan 1982



Q-vector Diagnosis

0000 UTC 9 Jan 1982



(a) 600–400-hPa wind speed (shaded, m s^{-1})

(b) 600–400-hPa $\mathbf{Q}_n$ (K m^{-1} s^{-1}, vectors) and $\mathbf{Q}_n$ forcing for vertical motion (10^{-17} Pa^{-1} s^{-3}, shaded)

(c) 600–400-hPa $\mathbf{Q}_s$ (K m^{-1} s^{-1}, vectors) and $\mathbf{Q}_s$ forcing for vertical motion (10^{-17} Pa^{-1} s^{-3}, shaded)

SLP (every 5 hPa, beginning at 1040 hPa)

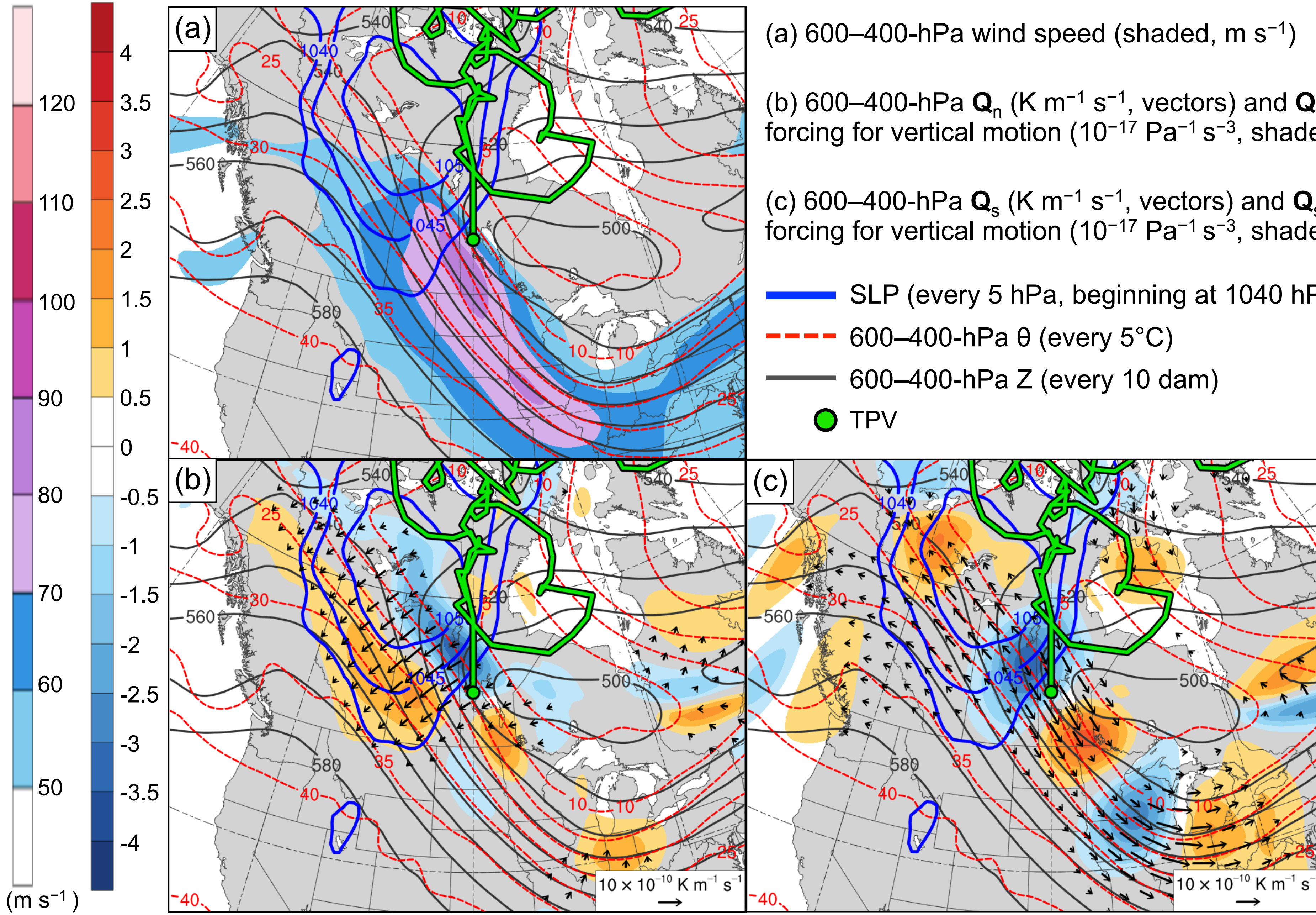
600–400-hPa θ (every 5°C)

600–400-hPa Z (every 10 dam)

TPV

Q-vector Diagnosis

1200 UTC 9 Jan 1982



(a) 600–400-hPa wind speed (shaded, m s^{-1})

(b) 600–400-hPa $\mathbf{Q}_n$ (K m^{-1} s^{-1}, vectors) and $\mathbf{Q}_n$ forcing for vertical motion (10^{-17} Pa^{-1} s^{-3}, shaded)

(c) 600–400-hPa $\mathbf{Q}_s$ (K m^{-1} s^{-1}, vectors) and $\mathbf{Q}_s$ forcing for vertical motion (10^{-17} Pa^{-1} s^{-3}, shaded)

SLP (every 5 hPa, beginning at 1040 hPa)

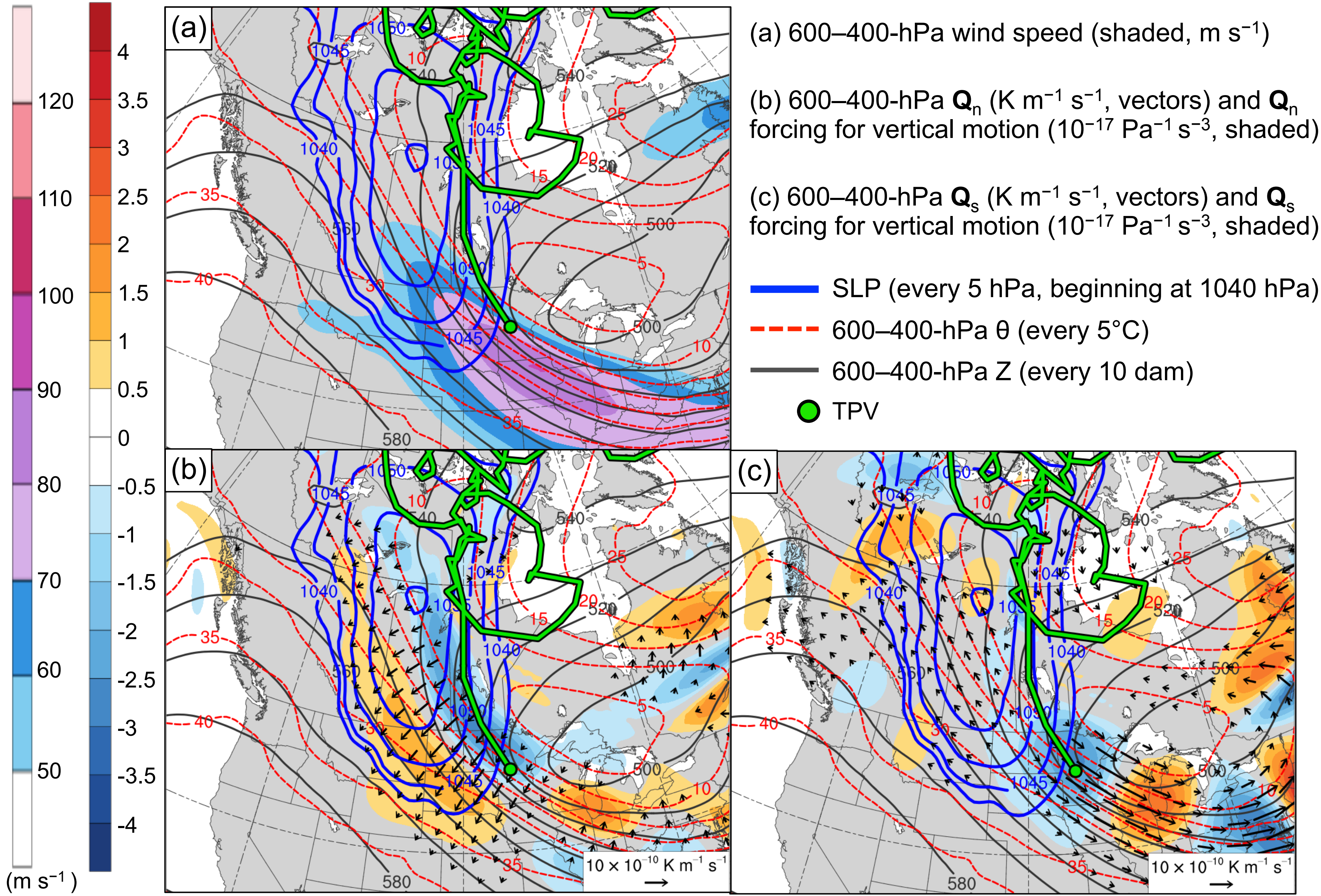
600–400-hPa θ (every 5°C)

600–400-hPa Z (every 10 dam)

TPV

Q-vector Diagnosis

0000 UTC 10 Jan 1982



Conclusions

- Central and eastern North America and Siberia and eastern Asia are preferred corridors for the equatorward transport of TPVs and Cold Pools
- ~85–90% of CAOs over northern regions of the U.S. are linked to cold pools
- ~74–88% of CAOs over northern regions of the U.S. are linked to cold pools associated with TPVs

Conclusions

- Large spatial overlap and temporal coincidence of TPV and cold pool in Jan 1982 CAO case suggests a dynamical linkage between the TPV and cold pool
- As TPV strengthens and becomes better defined, the cold pool does as well, further illustrating a dynamical linkage between the TPV and cold pool
- This dynamical linkage demonstrates that
  - The influence of TPVs can extend through the depth of the troposphere and over a widespread geographical area
  - The equatorward transport of TPVs can lead to CAO development

Conclusions

- TPV plays central role in development of January 1982 CAO given that
  - The TPV is associated with a cold pool that moves in tandem with TPV into the U.S. during the time of the occurrence of the CAO
  - The TPV via TPV–jet interaction may help to strengthen the strong surface anticyclone that helps transport cold air from the cold pool associated with the TPV equatorward
- Improved understanding of TPVs and their equatorward transport may lead to improved understanding of CAOs

Thank you!

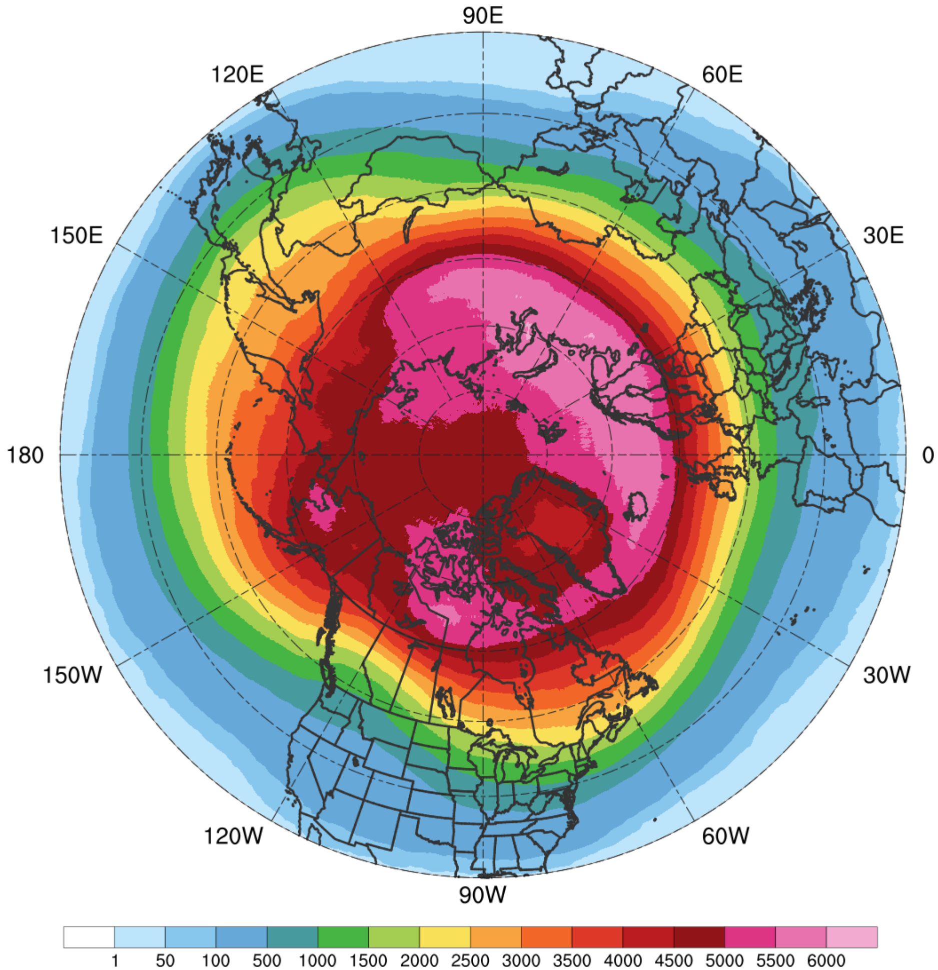
- Lance and Dan
- DAES Faculty
- Support Staff
- Fellow graduate students
- ES 234
- My Family

Extra Slides

TPV and Cold Pool Track Density

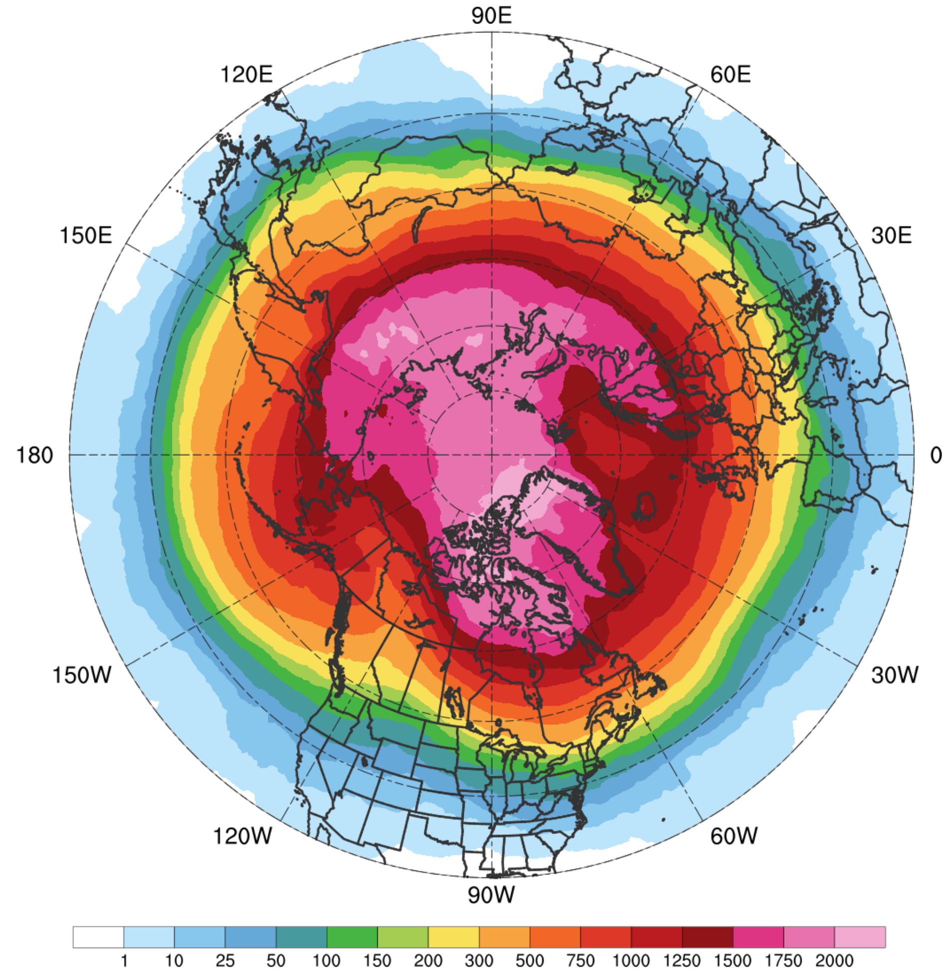
All TPVs

(N = 58,563; avg. of ~1,583 per yr)



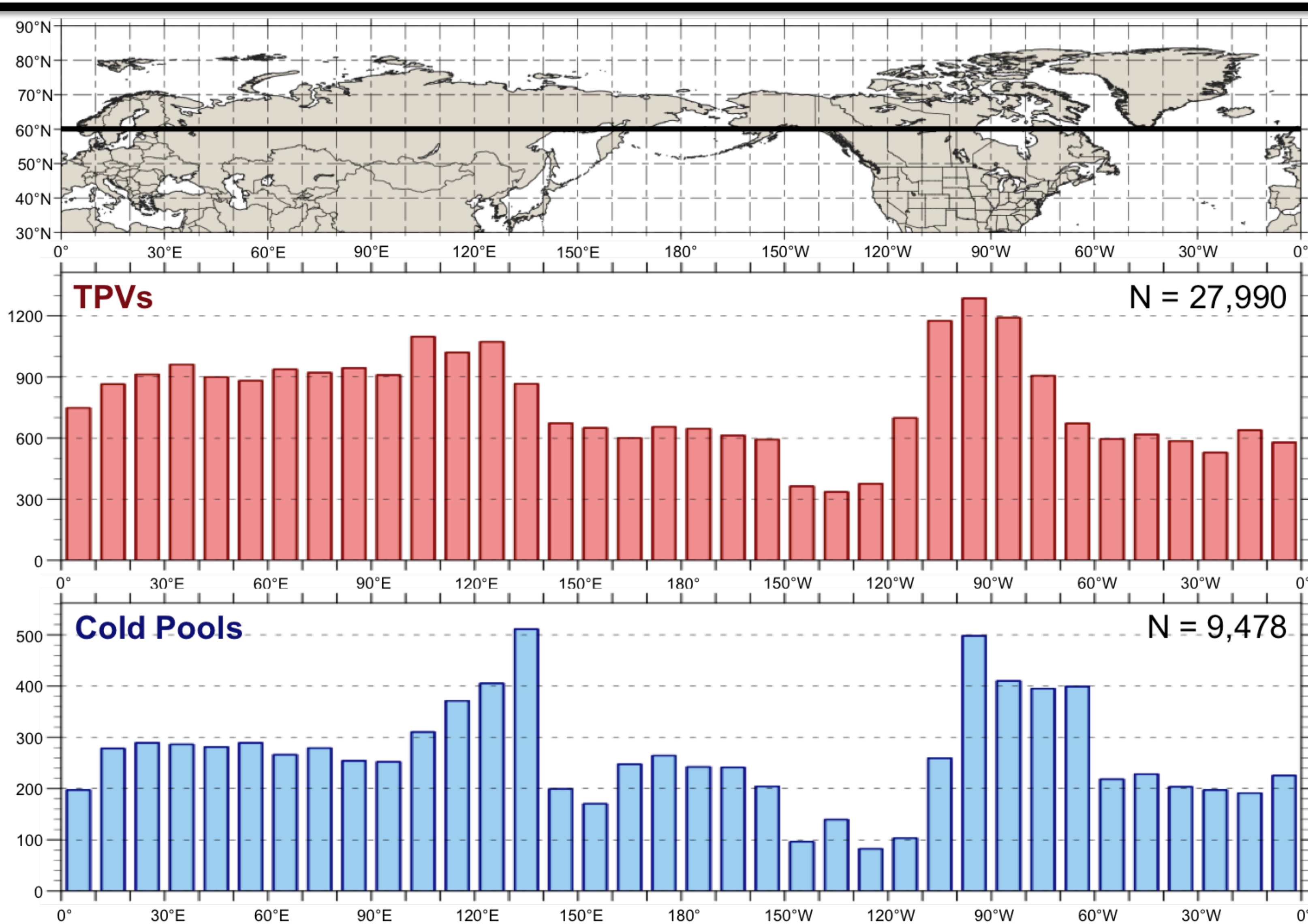
All Cold Pools

(N = 23,045; avg. of ~623 per yr)



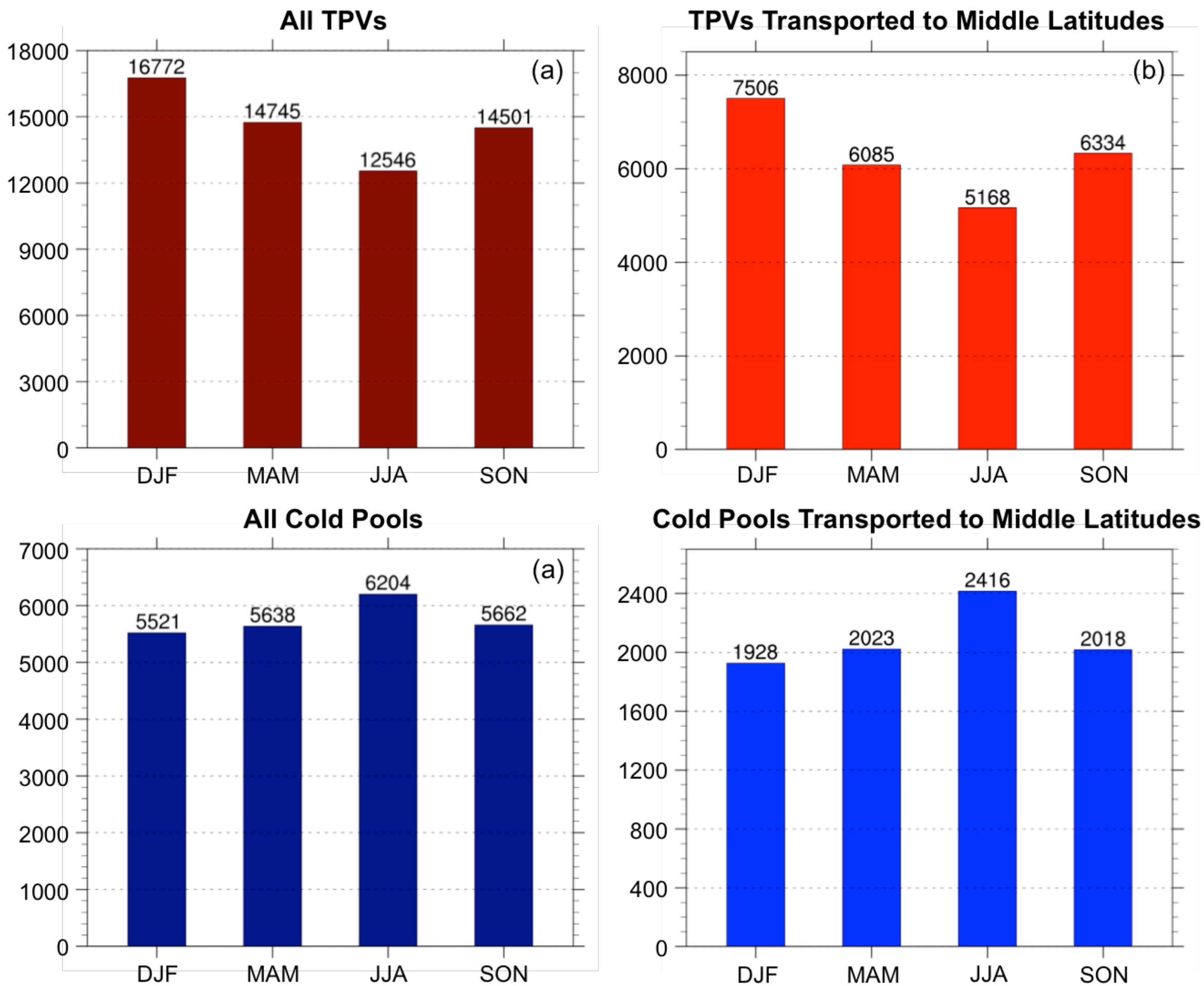
Total number of unique TPVs (left) and cold pools (right) within 500 km of each grid point (using a 0.5° grid) for all TPVs and cold pools during 1979–2015

Equatorward Transport of TPVs and Cold Pools



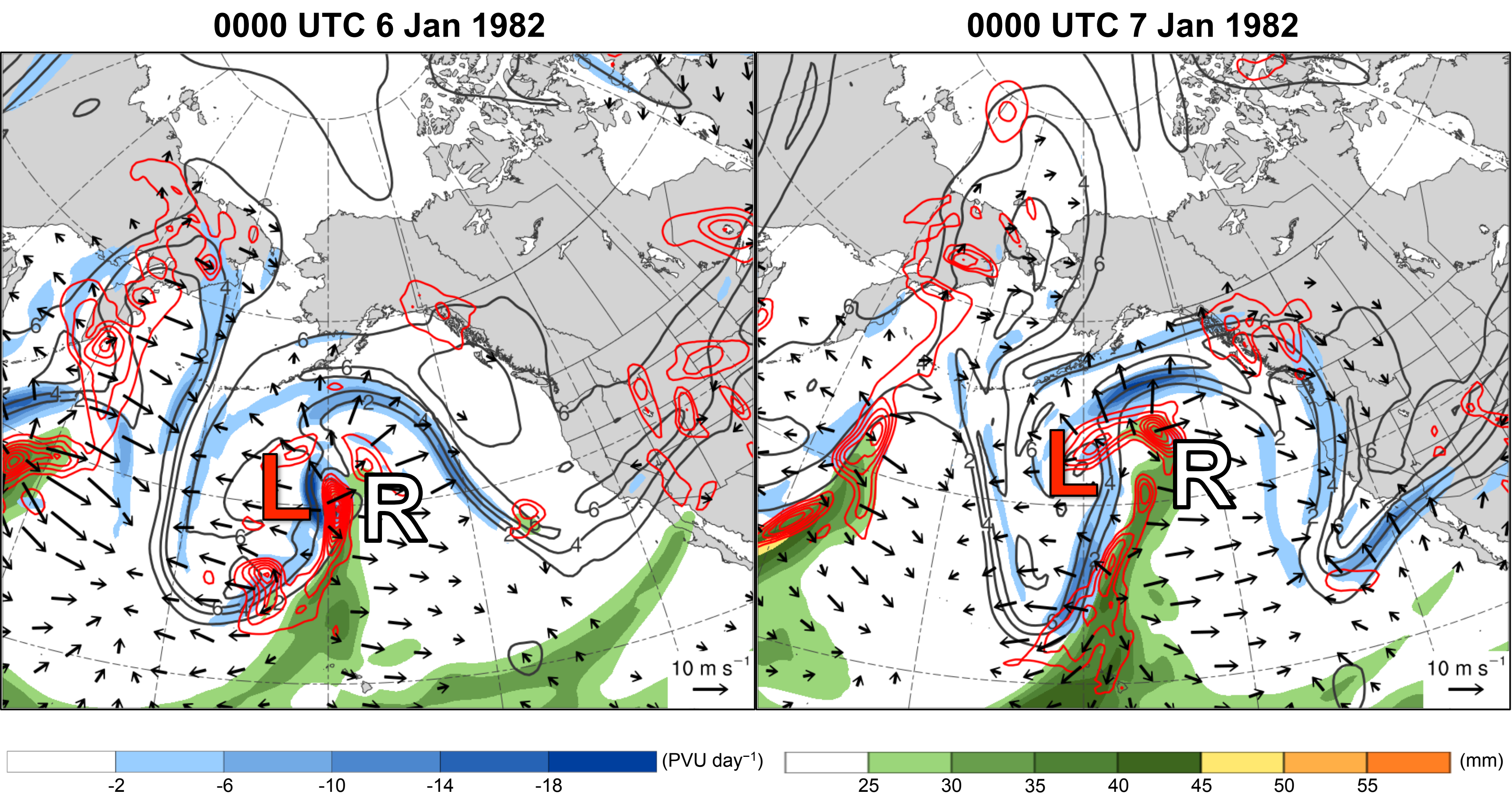
Histograms showing total number of instances in which a TPV (red) and cold pool (blue) is transported equatorward of 60°N (black line on map) for each 10° longitude bin globally during 1979–2015. A TPV and cold pool can be counted more than once if it crosses equatorward of 60°N after returning poleward of 60°N

Seasonal Variability



(a) Total number of TPVs per season, (b) total number of TPVs transported to middle latitudes (equatorward of 60°N) per season, (c) total number of cold pools per season, and (d) total number of cold pools transported to middle latitudes (equatorward of 60°N) per season, normalized to a 91.25-day season

Ridge Amplification



PW (mm, shaded), 600–400-hPa ascent (red, every 2.5 × 10^{-3} hPa s^{-1}), and 300–200-hPa PV (PVU, gray), irrotational wind (m s^{-1}, vectors), and negative PV advection by the irrotational wind (PVU day^{-1}, shaded)