# Northern Hemisphere Winter Blocking: Differing Onset Mechanisms across Regions

Zhuo Wang

University of Illinois at Urbana-Champaign, Urbana, Illinois

*Acknowledgements: Dr. Doug Miller*

*Miller, D. E., and Z. Wang, 2022: Northern Hemisphere Winter Blocking: Differing Onset Mechanisms across Regions. J. Atmos. Sci., 79, 1291–1309, https://doi.org/10.1175/JAS-D-21-0104.1.*

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

NOAA MAPP
Modeling, Analysis, Predictions, and Projections

# Outline

- Introduction
- Evolution of blocking structure in different regions
- Blocking onset mechanisms in different regions
- Summary

# How is blocking formed?

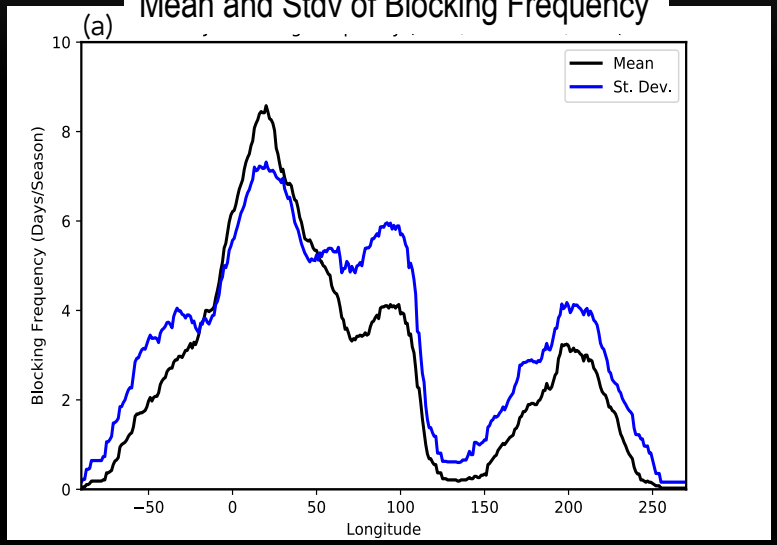
- Mechanisms for blocking onset
  - planetary theory:  emphasizes large-scale Rossby waves (Austin, 1980) excited by tropical precipitation anomalies (e.g., Cassou et al., 2005), extratropical SSTA (Peings and Magnusdottir, 2014), topographic forcing (Charney and DeVore, 1979), or Rossby waves arising from internal atmospheric dynamics (Swanson, 2001).
  - local theory: emphasizes enhanced transient activity (Nakamura and Wallace 1990; Nakamura and Huang, 2018; Luo and Zhang, 2020), isentropic PV advection (Nakamura, 1994; Nakamura et al., 1997), and latent heat release (Pfahl et al., 2015; Steinfeld and Pfahl, 2019).
- These mechanisms are not mutually exclusive as the dominant mechanisms may vary for different regions (Nakamura et al., 1997).
  - Drouard and Woollings (2018) provided evidence for different onset mechanisms over three Eurasian sectors during the summer season.

# Motivating Question

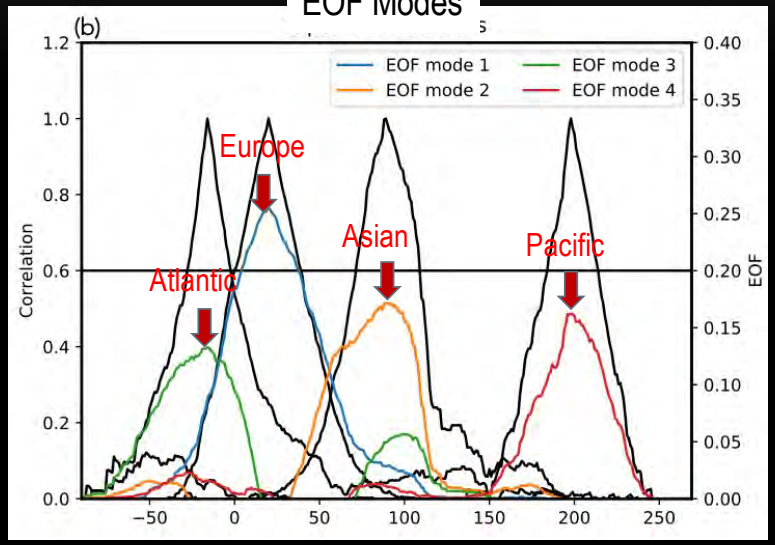
- *How do the winter blocking onset mechanisms vary from region to region?*
  - More specifically, we are interested in the roles of multi-scale interaction, Rossby wave breaking, and diabatic heating.
  - We will focus on the boreal winter, hemispheric-scale

# Selection of Blocking Sectors

Mean and Stdv of Blocking Frequency




EOF Modes



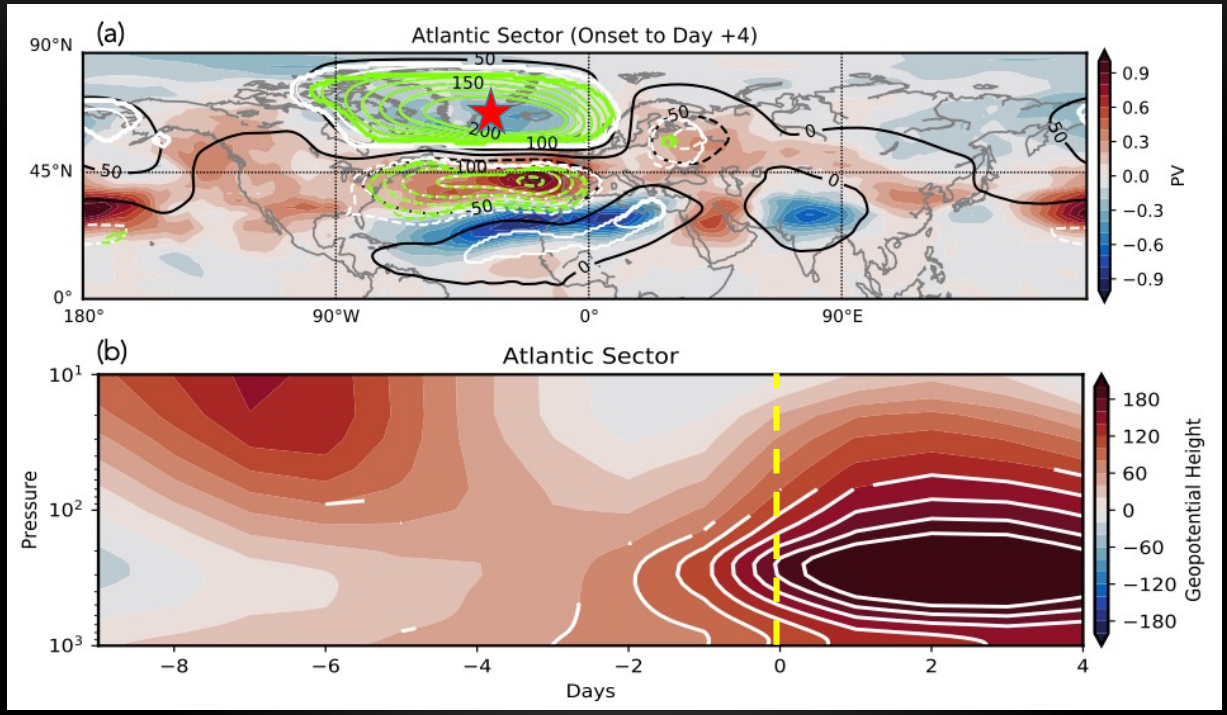

- Blocking is detected following the algorithm by Masato et al. (2013) using the ERAI reanalysis 1979-2016.
- Four Blocking Sectors (from left to right in panel b): an Atlantic sector (EOF3), a Europe sector which is close in location to the primary peak (EOF1), an Asian sector (EOF2), and a Pacific sector (EOF4).

# Evaluation of Blocking Structure

# Atlantic Sector: H (contours) and PV (shading)

Composite (Day0–Day 4)

Time-Height Cross section of H




---- H500
t-test significance
field significance
Shading: 350-K PV

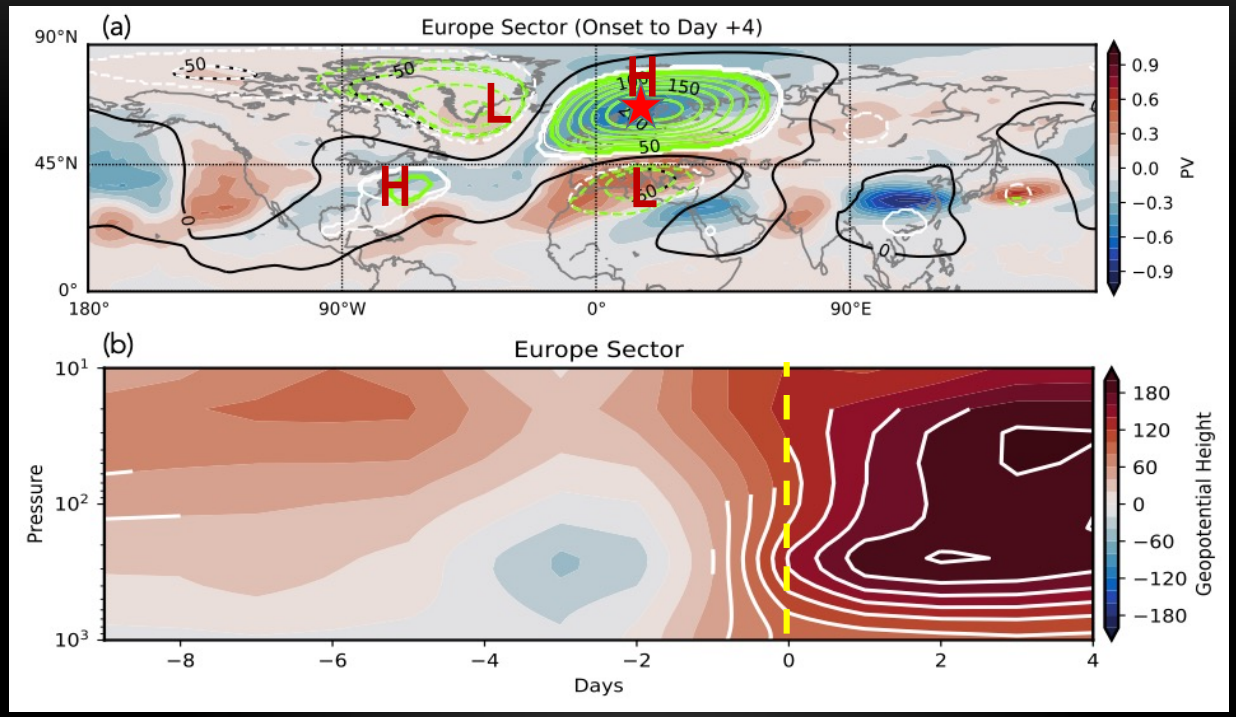
t-test significance
Shading: H

- The Atlantic sector blocks are characterized by a classic negative phased North Atlantic Oscillation
- Significant positive anomalies are evident several days prior to onset and increase steadily – a gradual buildup process for onset

# Europe Sector: H (contours) and PV (shading)

Composite (Day0–Day 4)

Time-Height Cross section of H




---- H500
---- t-test significance
---- field significance
Shading: 350-K PV

---- t-test significance
Shading: H

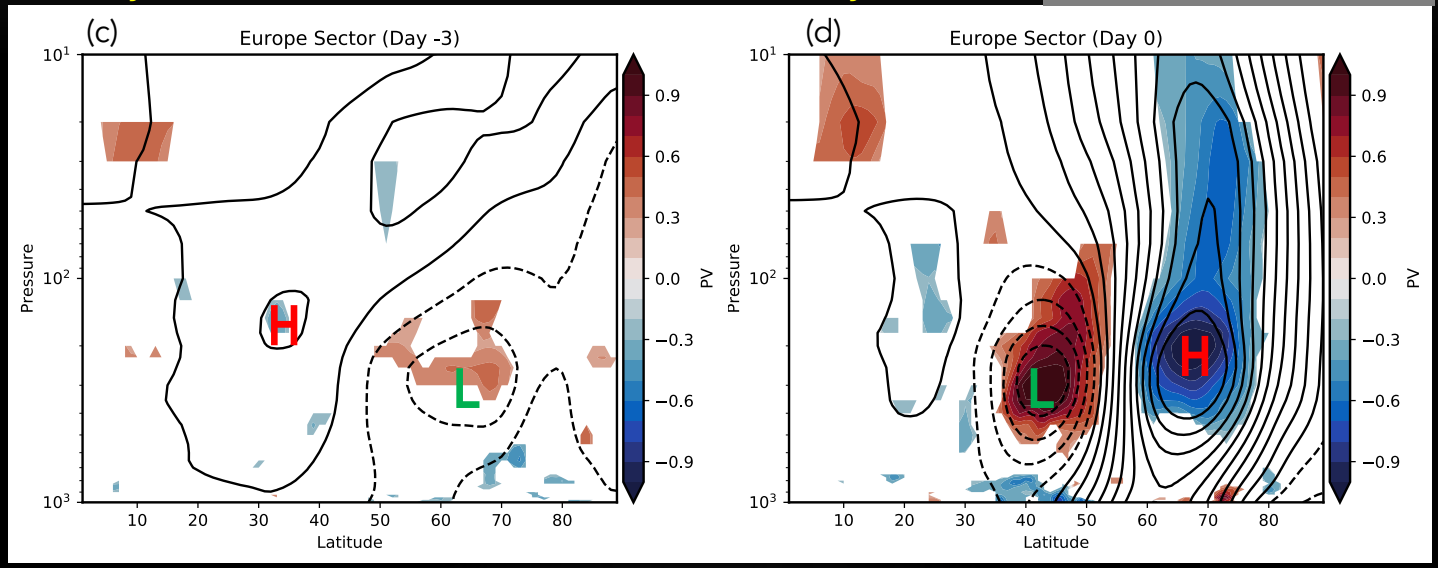
- Blocking over the Europe sector is manifested as Scandinavian blocking within a quadrupole structure.
- Europe sector blocking onset is preceded by weak negative H anomalies from the troposphere to the lower stratosphere, and positive anomalies rapidly develop less than two days prior to blocking onset – an abrupt onset

# H and PV: Latitude-pressure cross sections

(averaged over blocking sector)

H: contours
Significant PV': shading

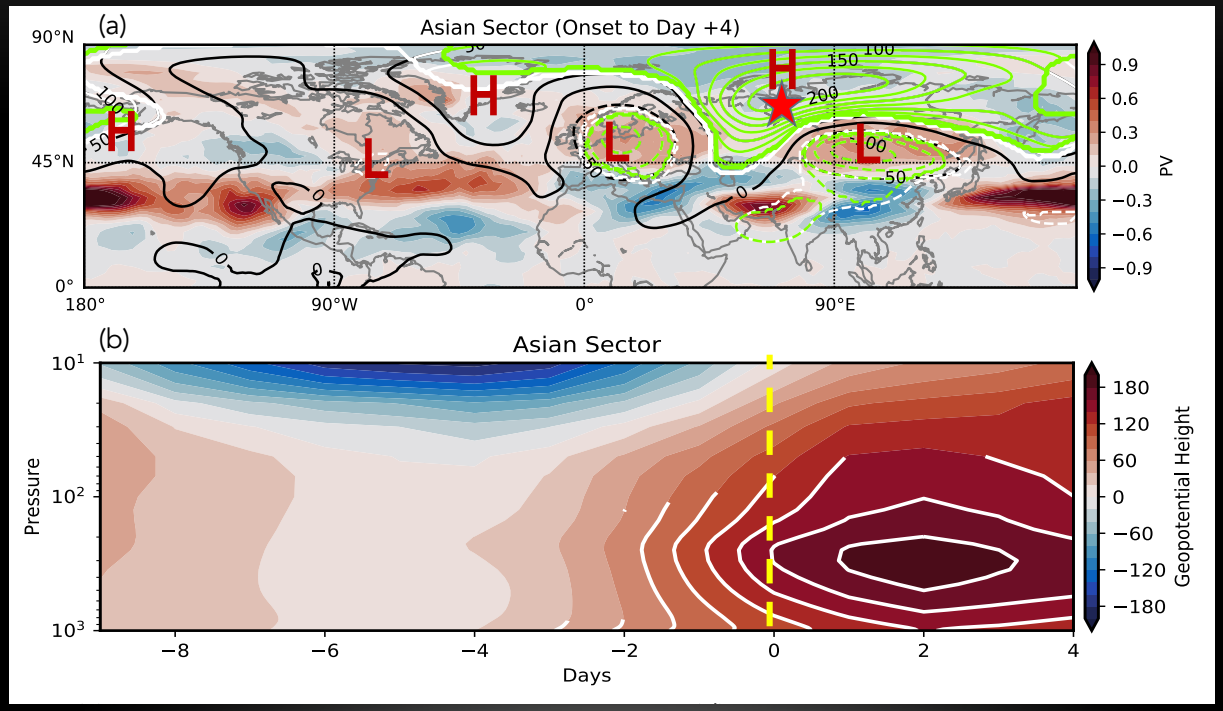
**Day -3** **Day 0**




- Weak, negative height anomalies are present on Day 3, and significant PV anomalies are hardly discernable.
- As shown later, RWB plays a major role in the onset of Europe blocking, and the strong influence by high- and intermediate-frequency PV flux interactions may contribute to the abruptness of the blocking onset in this sector.

# Asian Sector: H (contours) and PV (shading)

Composite (Day0–Day 4)




---- H500
t-test significance
field significance
Shading: 350-K PV

Time-Height Cross section of H

t-test significance
Shading: H

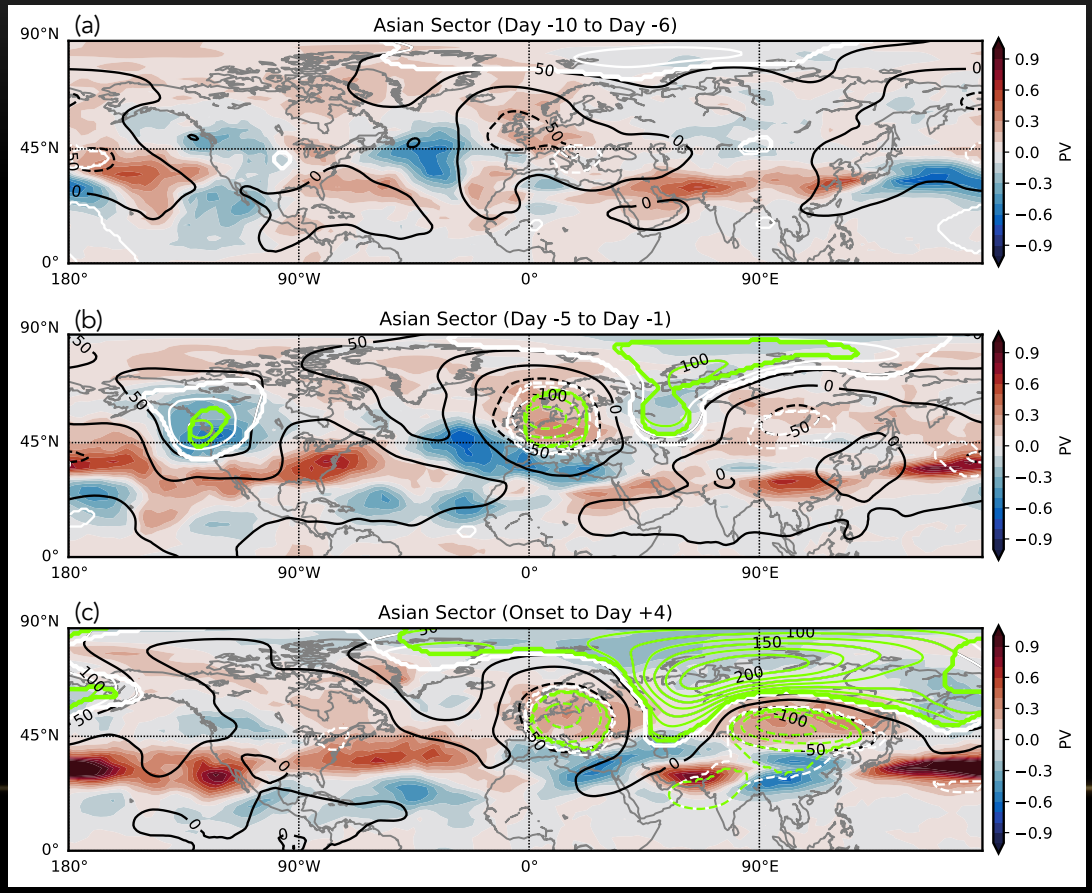
- Asian sector blocks are characterized by a circumglobal stationary wavetrain.
- Significant positive geopotential height anomalies are present over the Asian sector at day -3 and steadily strengthen throughout blocking development.

# Asian Sector: 500-hPa H and PV

Day -10 to Day -6

Day -5 to Day -1

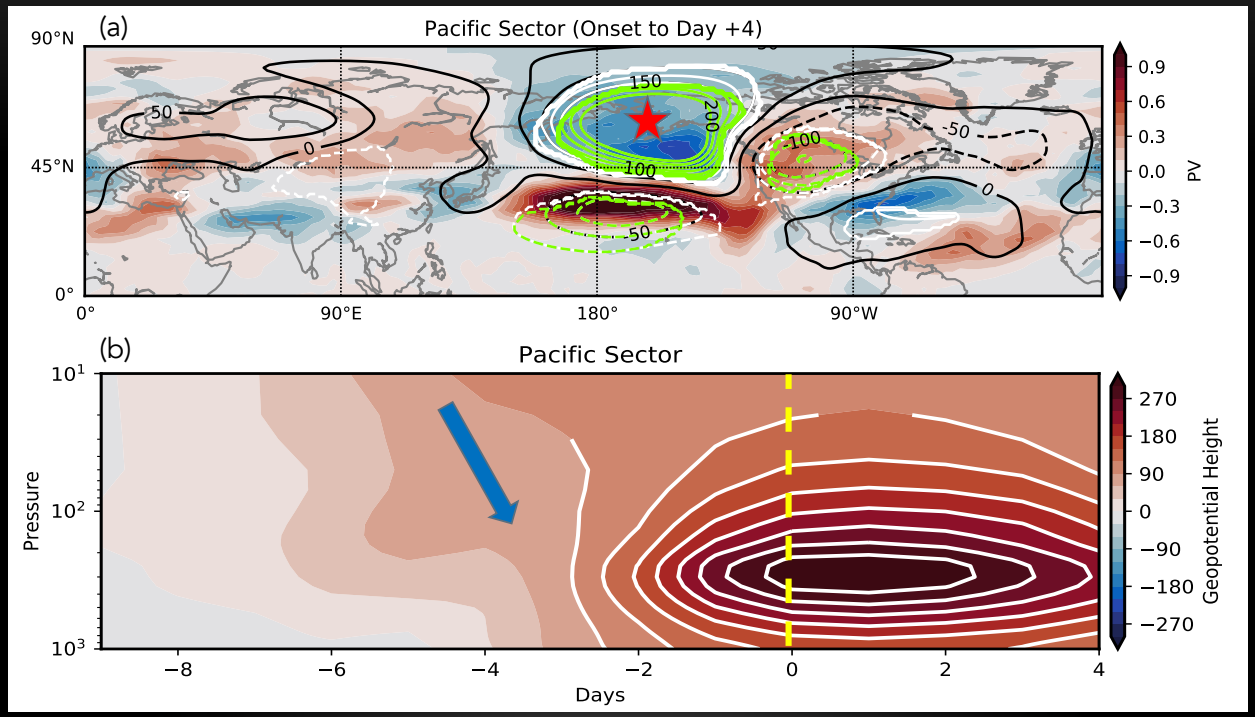
Day 0 to Day +4



# Pacific Sector: H (contours) and PV (shading)

Composite (Day0–Day 4)

Time-Height Cross section of H




- The Pacific sector blocks are characterized by a strong Alaskan ridge, as part of a wave train pattern. Wave signals are weak and most insignificant west of the North Pacific.
- There is a gradual buildup of geopotential height anomalies, and positive anomalies in the stratosphere show a slight downward propagation prior to blocking onset.

# Physical Mechanisms involved in Blocking Development

# Multi-scale Interaction

- A total anomaly field is defined with respect to the climatological seasonal cycle.
- The anomaly field is decomposed into 3 frequency bands (Rennert and Wallace 2009):
  - high (<= 6 days): eastward propagating baroclinic waves
  - intermediate (6 days < period <= 30 days): Rossby wave trains oriented along a great circle route
  - low (> 30 days): represent planetary scale teleconnection patterns

# PV Budget Analysis

- To investigate the role of multi-scale interaction in blocking onset, we employed the PV budget equation

$$\frac{\partial q}{\partial t} = -\nabla \cdot (\mathbf{V}q) - \frac{\partial \omega q}{\partial p} - g(\zeta + f)\frac{\partial \dot{\theta}}{\partial p} + R$$

- To examine the scale interactions, a variable is decomposed into four terms. For example

$$q = q_c + q_{LF} + q_{IF} + q_{HF}$$

- where the subscript c denotes the climatological seasonal cycle, LF, IF and HF represents the low-frequency, intermediate-frequency and high-frequency components, respectively.
- The horizontal PV flux term can be expanded into 16 terms. It was found that the terms associated with the $q_c$ or $\boldsymbol{V_c}$ are negligible compared to the other flux terms. We thus have the following approximation:

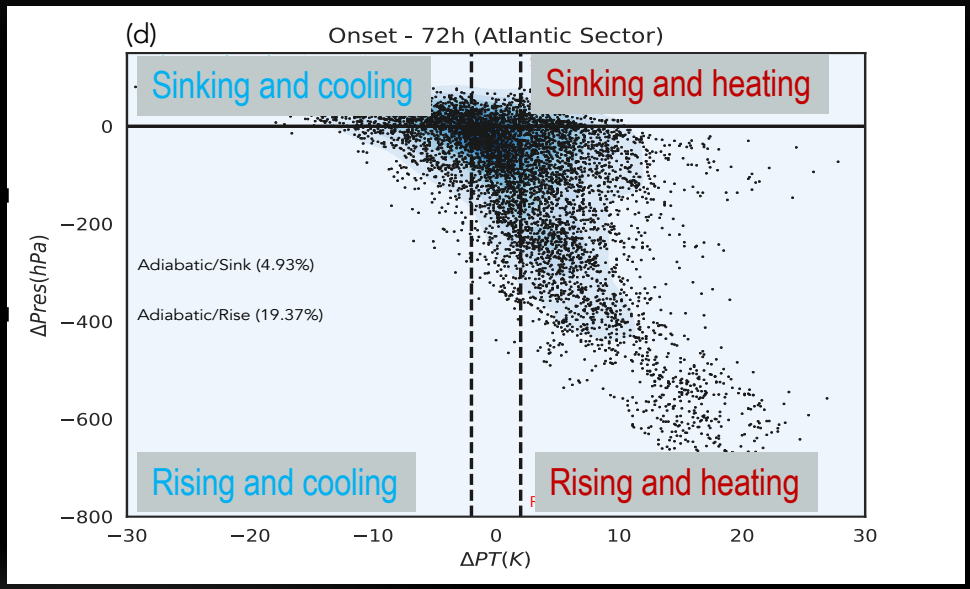
$$\overline{\partial q\ /\ \partial t} = -\nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}}$$

$$-\nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \nabla \cdot \overline{\boldsymbol{V}_{LF} q_{LF}} - \partial \overline{\omega q}/\partial p - \overline{g(\zeta + f)\frac{\partial \dot{\theta}}{\partial p}} + \bar{R}$$

# Backward Trajectory Analysis

- Trajectory analysis is carried out using the HYSPLIT model
- Parcel evolution is then analyzed in the dP-d(theta) space.

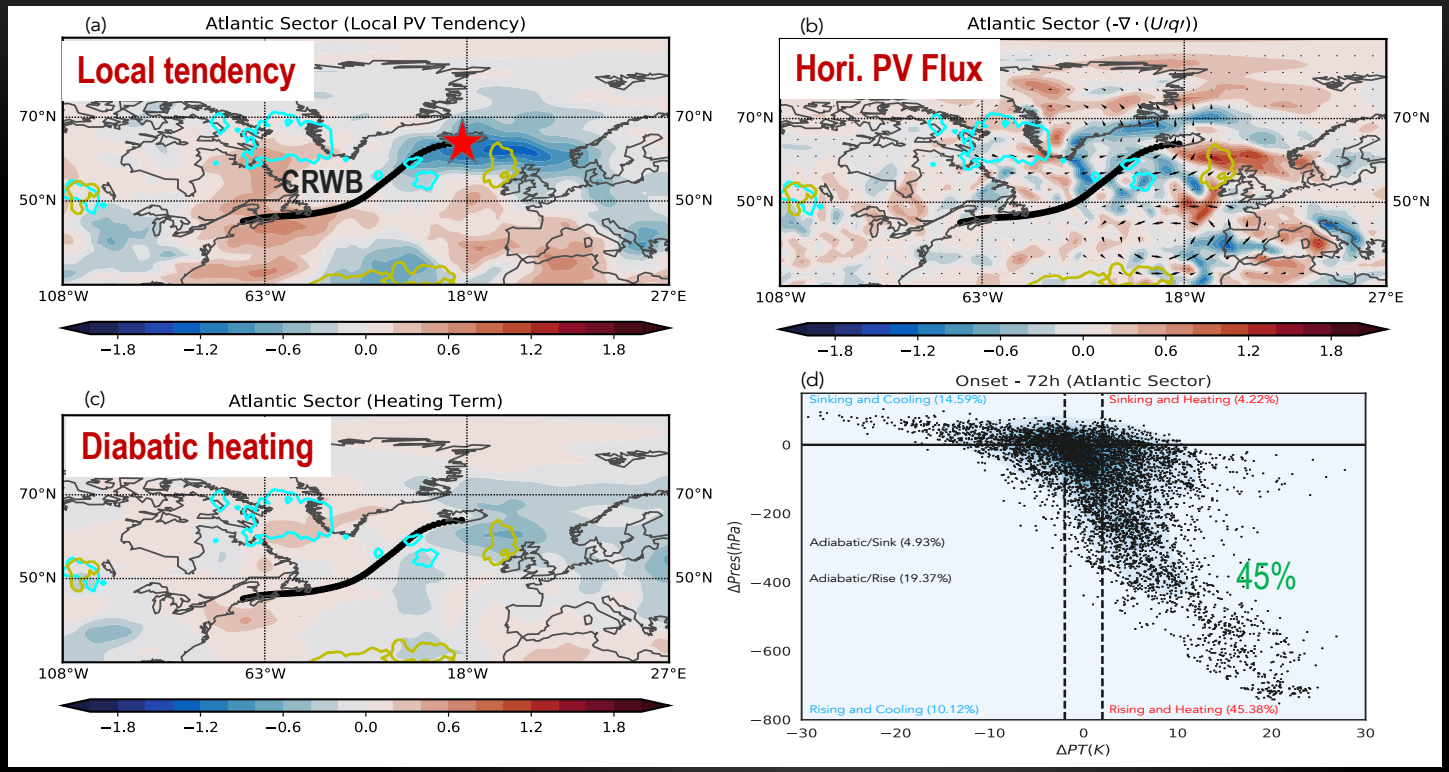
**dP-d(theta) space:**




**dP**

**d(theta)**

# Atlantic Sector: PV budget and Trajectory Analysis




anticyclonic RWB

cyclonic RWB

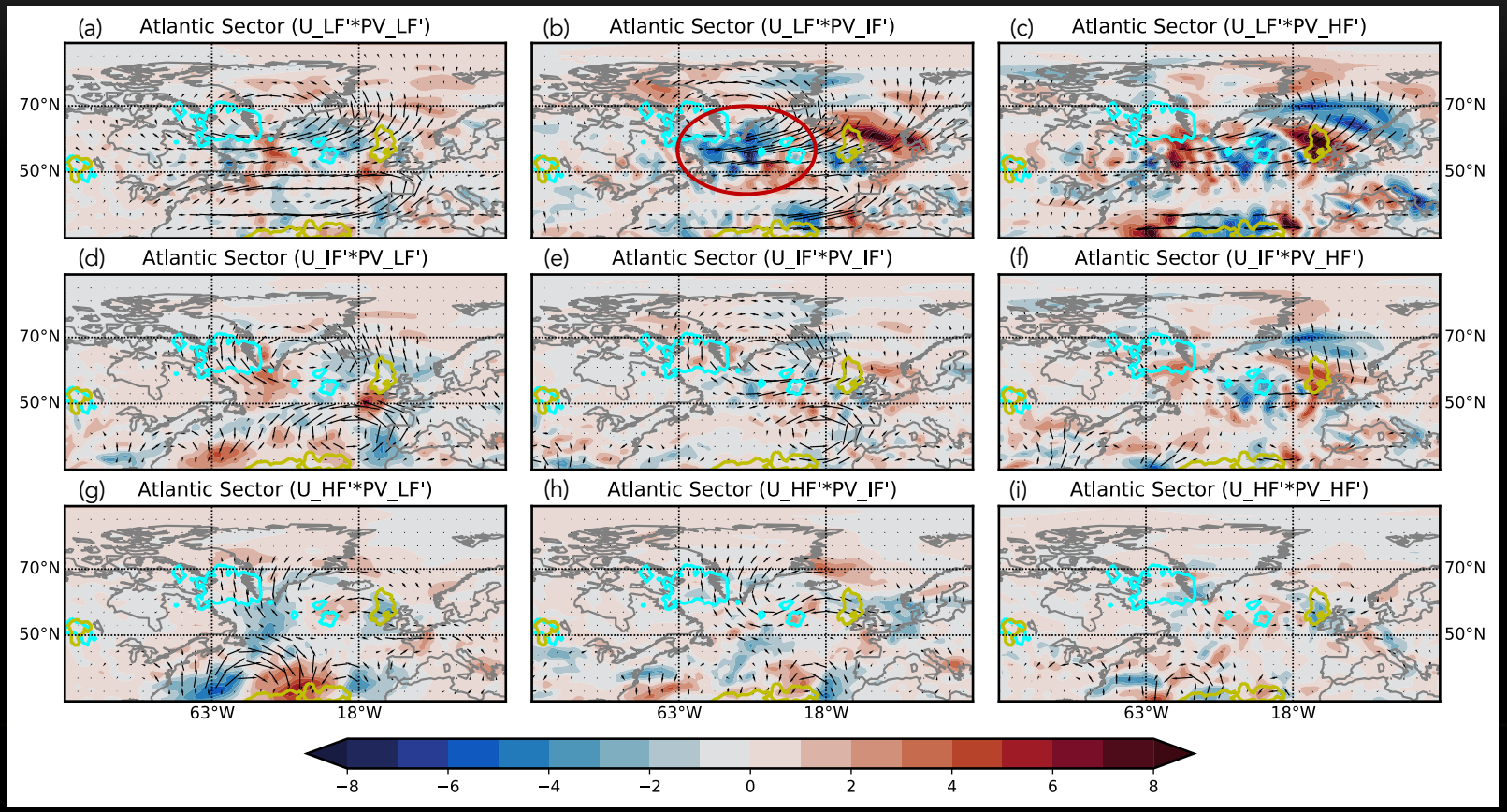
**Shading: PV budget**

45% of parcels experience ascent and heating within 3 days prior to blocking onset

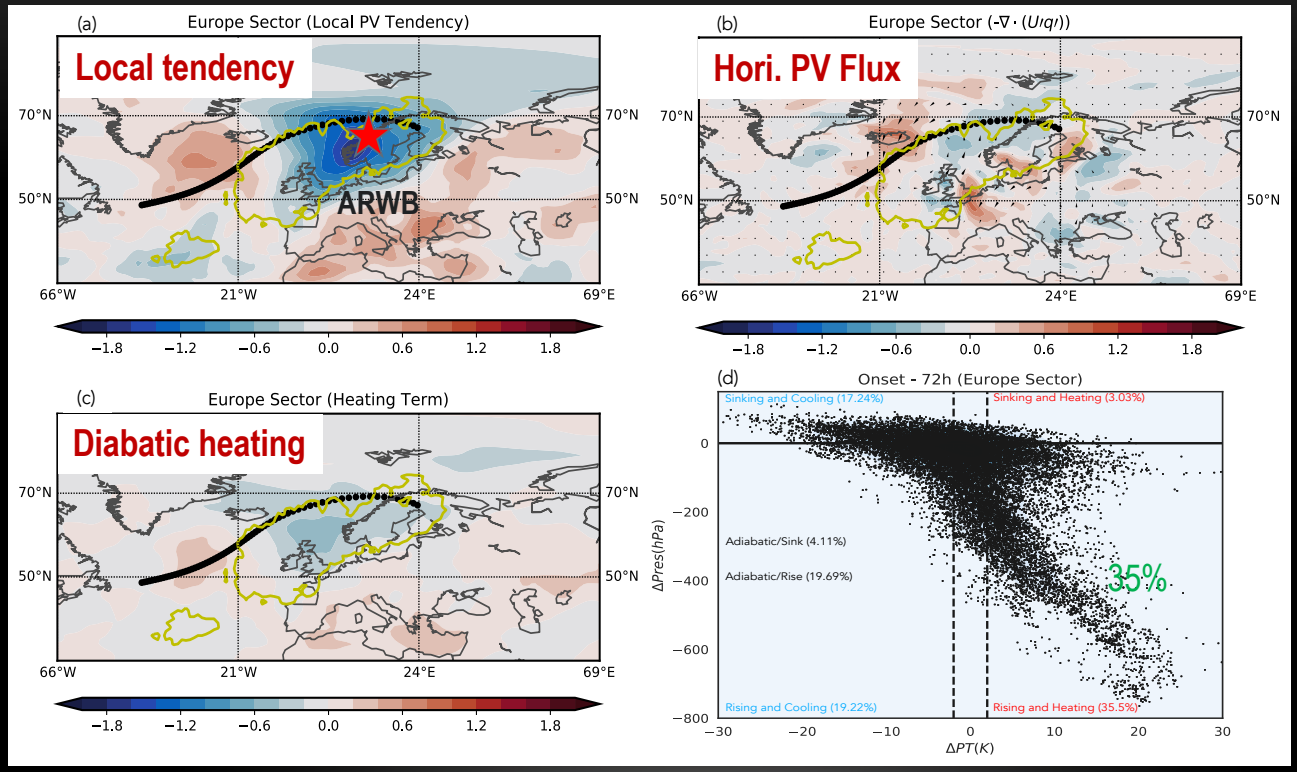
The negative PV tendency associated with the blocking development is partly contributed by diabatic heating east of Iceland and is associated with PV-flux divergence in the west.

Enhanced cyclonic RWB is present west of Greenland.

# Atlantic Sector: 200-hPa horizontal PV flux decomposition



# Europe Sector: PV budget and Trajectory Analysis

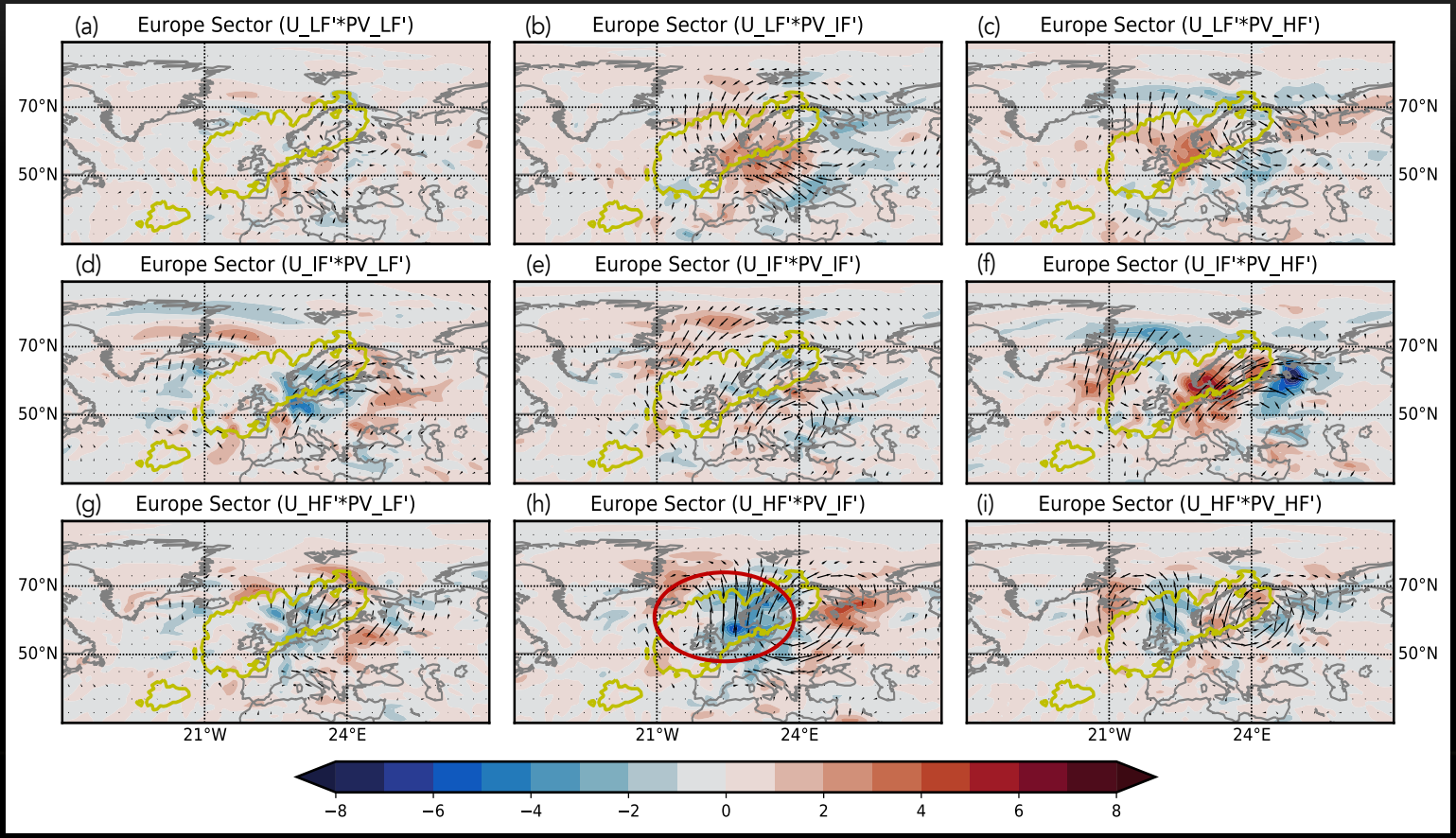



**anticyclonic RWB**
**cyclonic RWB**
**Shading: PV budget**

~35% of parcels experience diabatic heating and ascent within 3 days before onset

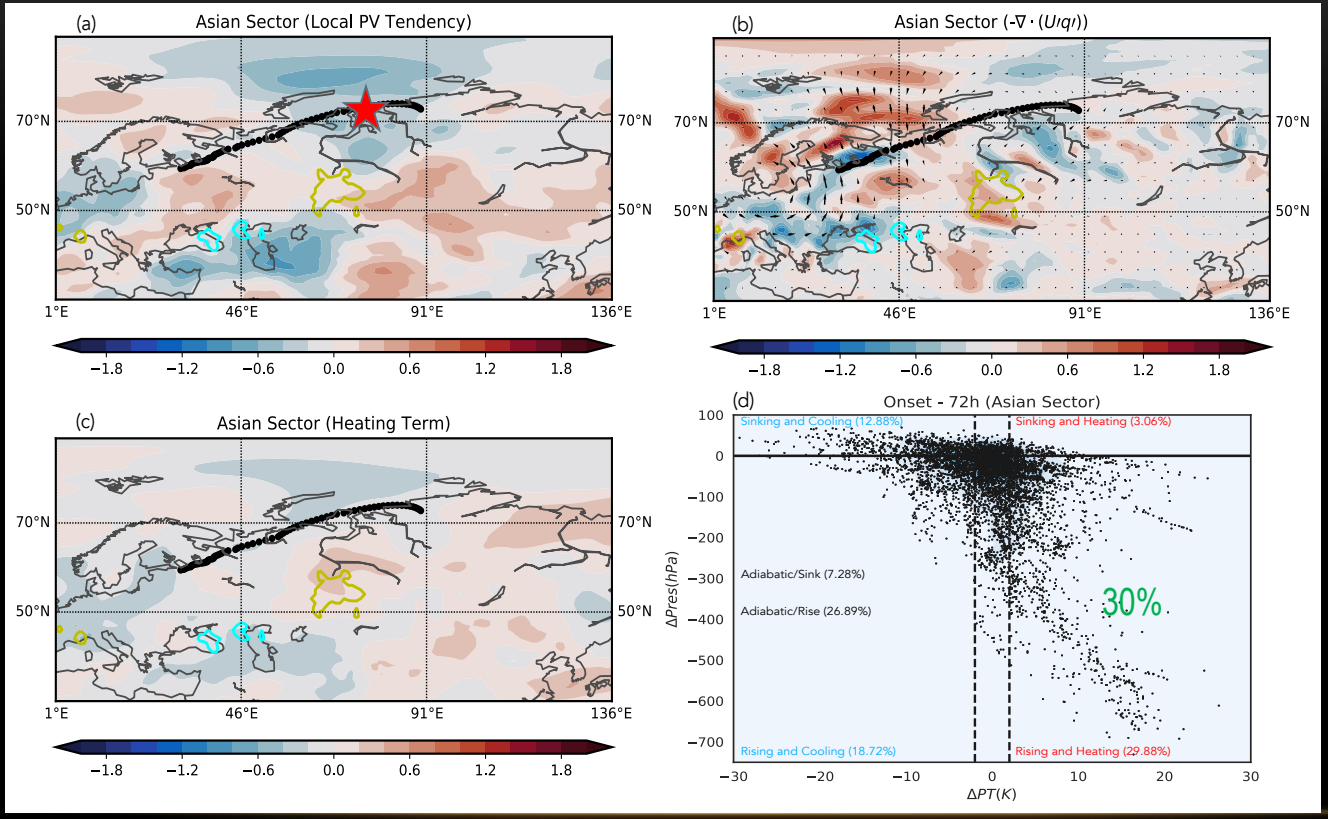
The negative PV tendency is associated with an extensive region of enhanced anticyclonic RWB, PV flux divergence and negative diabatic PV tendency.

# Europe Sector: 200-hPa horizontal PV flux decomposition




The strongest contribution arises from the transport of intermediate-frequency PV by the high-frequency winds

# Asian Sector: PV budget and Trajectory Analysis



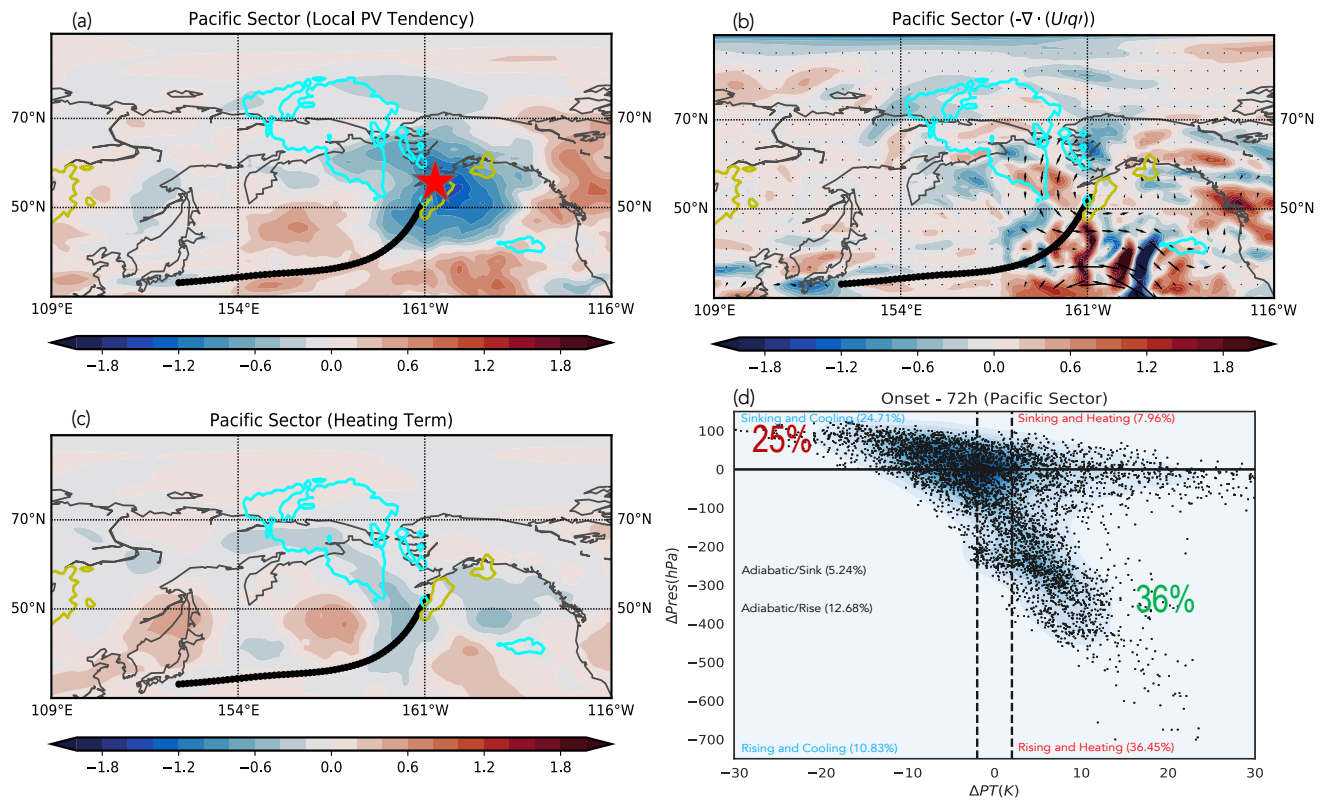

anticyclonic RWB

cyclonic RWB

**Shading: PV budget**

The circumglobal stationary wave is associated with moderate negative tendencies north of 70°N.
RWB signals are nearly absent, and the PV anomalies related to the diabatic heating term are the weakest of all sectors

# Pacific Sector: PV budget and Trajectory Analysis




anticyclonic RWB

cyclonic RWB

**Shading: PV budget**

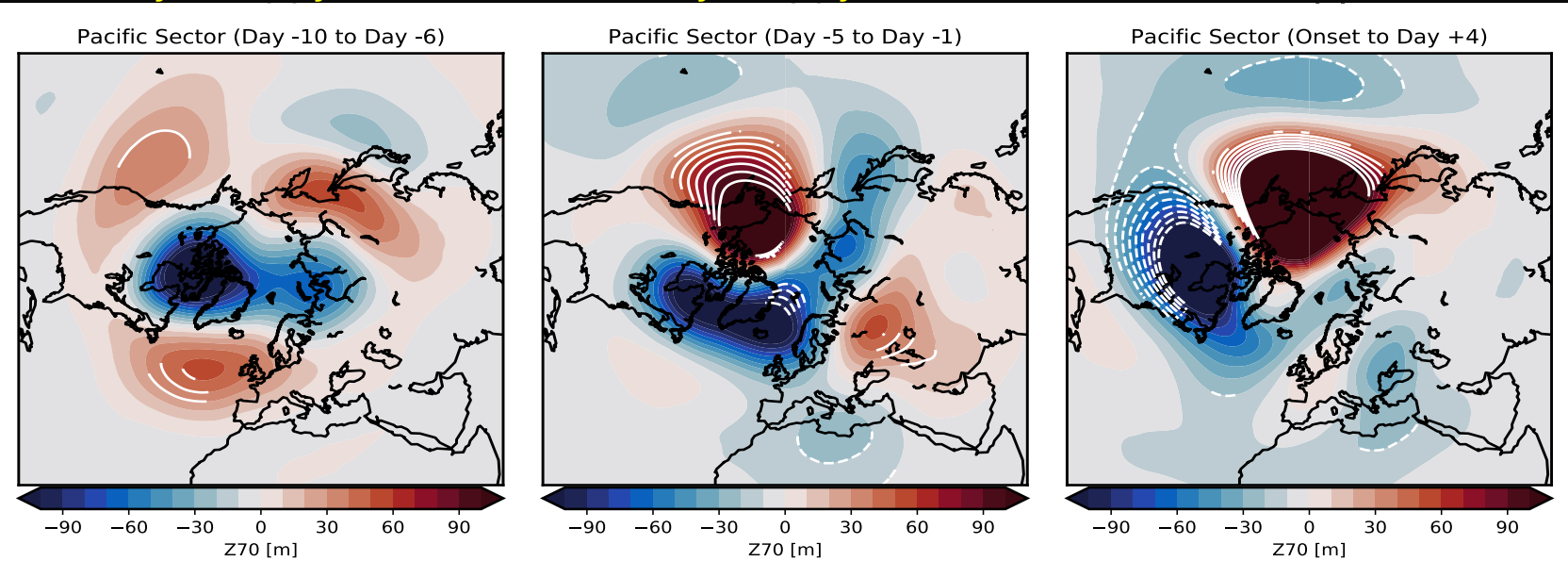
The Pacific blocks contain the largest percentage of parcels that experience sinking and cooling (~25%).

Cyclonic wave breaking (blue contour) is dominant over the North Pacific.

Neither the horizontal flux term or heating term can explain the large negative PV tendency in the blocking region, and it is due to the vertical PV transport term related to potential stratospheric precursors.

# Pacific Sector: Composite anomalies of 70-hPa H

**Day -10 to Day -6** | **Day -5 to Day -1** | **Day 0 to Day +4**




Stratospheric polar vortex is displaced 10 days prior to the blocking onset, and significant positive Z70 anomalies are located over the North Pacific from Day -5 to Day 5, indicating the possible influence of stratospheric precursors on blocking development.

# Summary

- Atlantic blocks are dominant by the low-frequency flow evolution that resembles the negative phase of the North Atlantic Oscillation and are influenced by cyclonic RWB west of Greenland.
- Europe blocks develop rapidly, mainly attributed to strong anticyclonic RWB and interaction between high- and intermediate-frequency flow.
- Asian blocks are fixated within a stationary wave train and do not have strong PV or RWB features.
- The Pacific blocks are influenced by stratospheric processes.
- Diabatic heating plays an important role in blocking onset over the Atlantic, Europe, and Pacific sectors, while Asian blocking is dominated by adiabatic processes.
- Given the different mechanisms for different blocking sectors, the future changes of blocking may be different across sectors. Another interesting question is whether different onset mechanisms imply different levels of predictability.

Thanks!