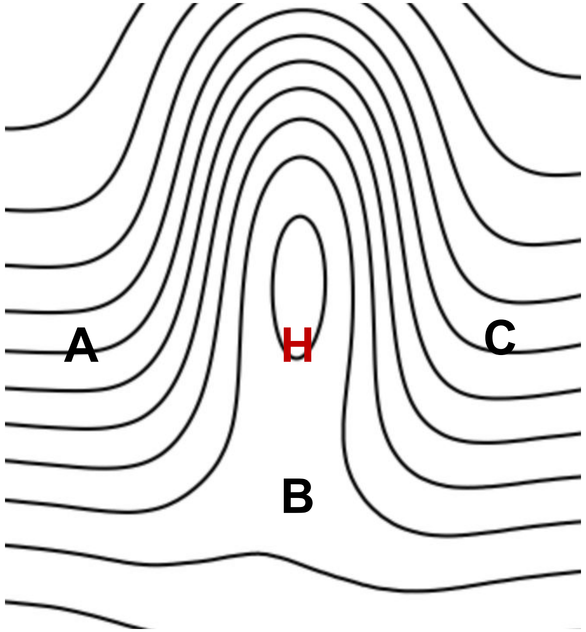
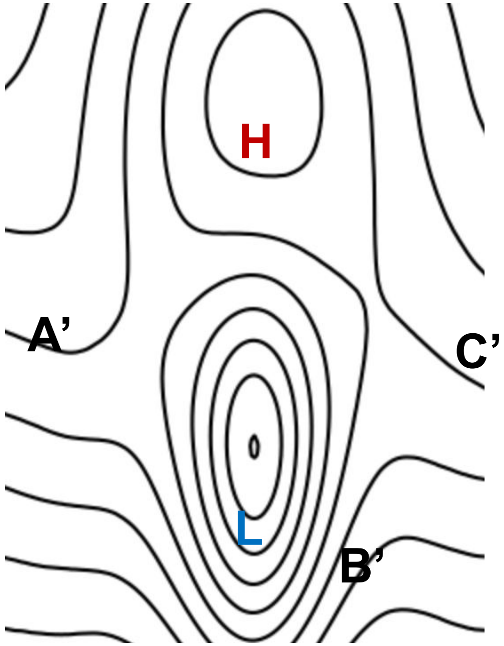
Blocking Diversity: Distinct Roles of Diabatic Heating

Zhaoyu Liu, Lei Wang



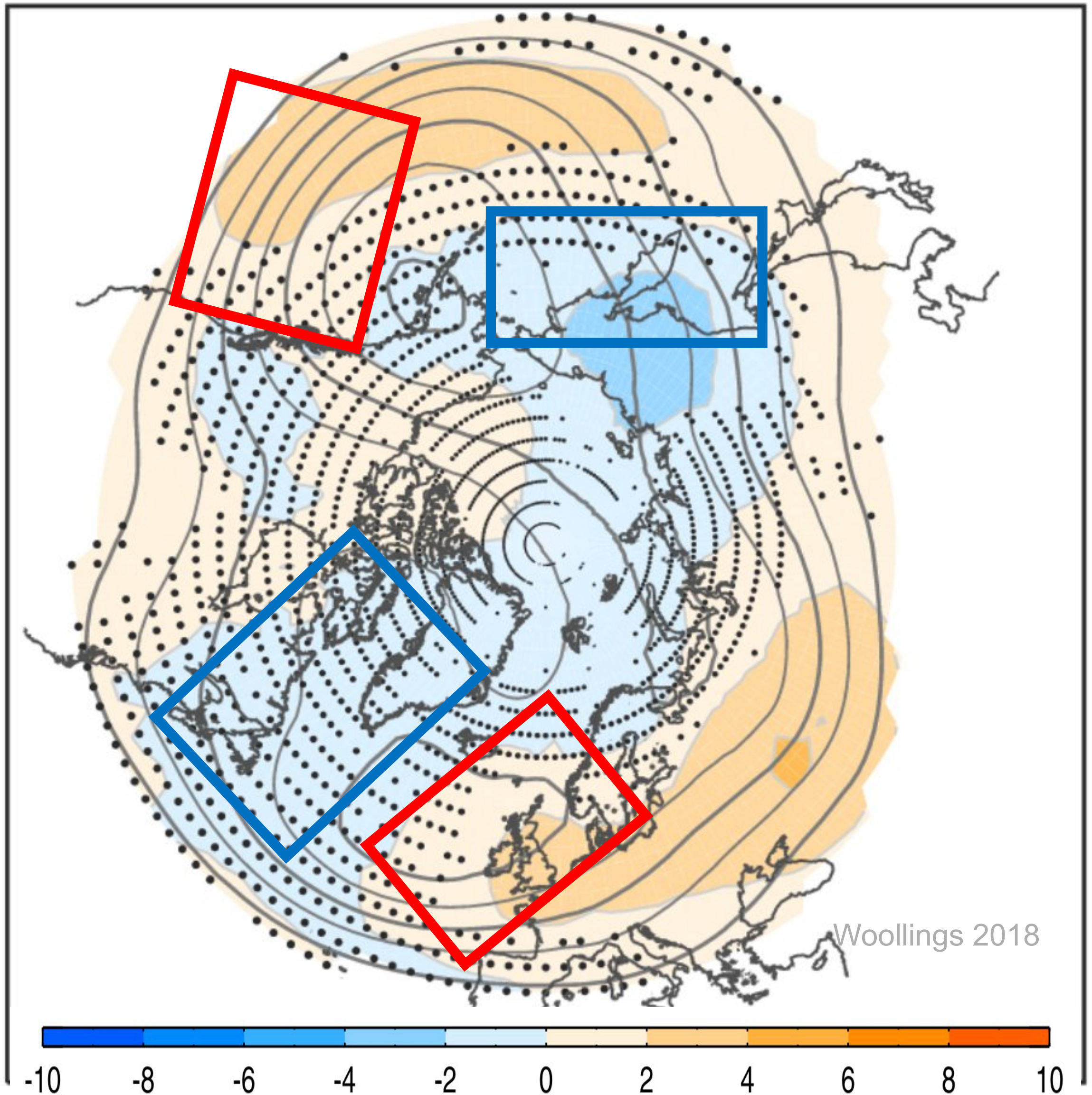


Question:

- Where does diabatic heating (due to moist processes) occur?
- Is diabatic heating playing the same role in these two types of blocks?

Future projection of blocking frequency

Future projection of blocking frequency (DJF)



In the warmer climate, blocking frequency

- Decreases at Northwest Pacific and Northwest Atlantic.
- Increases at Northeast Pacific and Europe.

How can we understand this change?

Why blocks response differently across different regions?

Role of latent heat release in atmospheric blocks

LETTER

Response of moist and dry processes in atmospheric blocking to climate change

Daniel Steinfeld[1,2,*], Michael Sprenger[2], Urs Beyerle[2] and Stephan Pfahl[3]

The 2021 Pacific Northwest Heat Wave and Associated Blocking: Meteorology and the Role of an Upstream Cyclone as a Diabatic Source of Wave Activity

Emily Neal[1], Clare S. Y. Huang[1], and Noboru Nakamura[1]

USA

ions that led to the extreme heat in
heat was preceded by an upper-level
tudes. A heat-trapping stable stratification
es significantly. An upper-tropospheric
of Alaska initiated the block formation.
c source associated with this storm
eam, whose convergence over Canada
ve activity budget predicts a 41 percent
ck when the upstream diabatic source is

The role of latent heating in atmospheric blocking dynamics: a global climatology

Daniel Steinfeld[1] · Stephan Pfahl[1,2]

Received: 14 November 2018 / Accepted: 31 July 2019 / Published online: 7 August 2019

he mid-latitude weather variability, but the different processes
lly understood. This study investigates the role that diabatic pro-
ascending airstreams, play in the dynamics and spatio-temporal
logical analysis. The results show that the formation and (re-)
eating connected to upstream baroclinic developments. While
en individual blocking events and different regions, in particu-
lly most important during onset and in more intense and larger
ocking life cycle, associated with a series of transient cyclones
ast onset and fluctuation in intensity and size) and low-frequency

The sensitivity of atmospheric blocking to upstream latent heating – numerical experiments

Daniel Steinfeld[1], Maxi Boettcher[1], Richard Forbes[2], and Stephan Pfahl[3]

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Importance of latent heat release in ascending air streams for atmospheric blocking

S. Pfahl[1★], C. Schwierz[2], M. Croci-Maspoli[3], C. M. Grams[1] and H. Wernli[1]

Atmospheric blocking is a key component of extratropical weather variability[1] and can contribute to various types of extreme weather events[2–5]. Changes in blocking frequencies due to Arctic amplification and sea ice loss may enhance extreme events[6,7], but the mechanisms potentially involved in such changes are under discussion[8–11]. Current theories for blocking are essentially based on dry dynamics and do not directly take moist processes into account[12–17]. Here we analyse a 21-year climatology of blocking from reanalysis data with a Lagrangian approach, to quantify the release of latent heat in clouds along the trajectories that enter the blocking systems. We show that 30 to 45% of the air masses involved in Northern Hemisphere blocking are heated by more than 2 K—with a median heating of more than 7 K—in the three days before their arrival in the blocking system. This number

role of wave breaking[16] and the isentropic advection of air with low potential vorticity (PV) into the blocking region[12–15]. All these theories are essentially based on dry atmospheric dynamics, and diabatic processes have been considered only in an indirect way, for example, through the triggering of Rossby waves by tropical convection[13]. There are only few studies pointing to direct diabatic effects on blocking: substantial diabatic contributions to the intensification of two blocking systems in the Southern Hemisphere have been identified in ref. 20, whereas diabatic effects have been found to be of secondary importance for blocking formation over Siberia in ref. 21. Backward trajectory calculations from North Atlantic blockings during selected winters presented in refs 22,23 indicate that latent heating is often involved in the upward transport of air with low PV into the upper-tropospheric blocking. In this study, again a combined PV and Lagrangian approach is used to

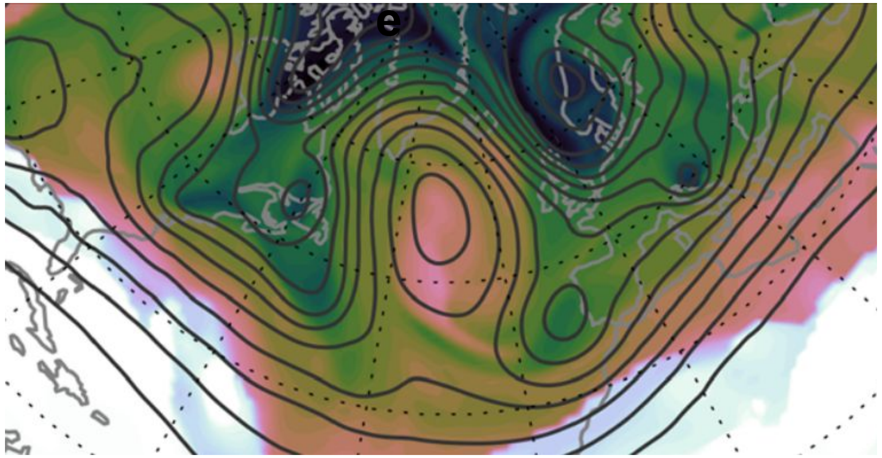
Take away:

- Moist related diabatic processes are important, overall exerting a positive effect on the formation and intensification of blocks.

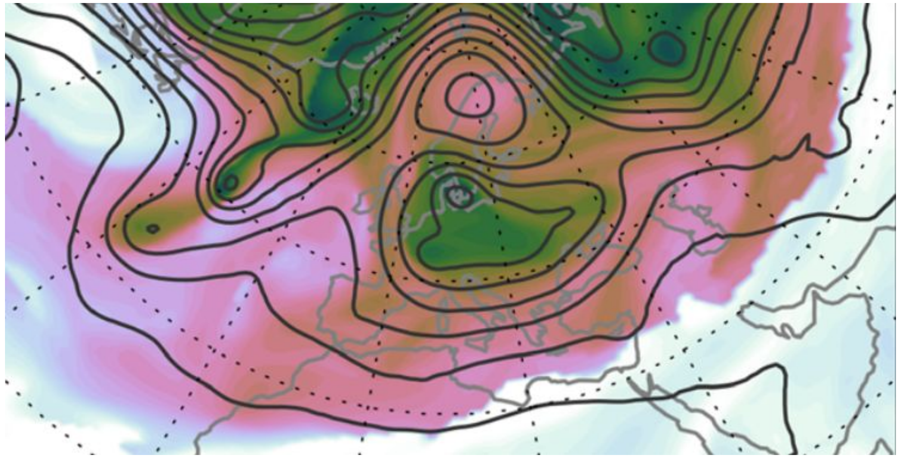
Hypothesis and Method

We **hypothesize** that:
- The role of diabatic heating (from moist processes) is distinct among different types of blocks.

Ridg
e

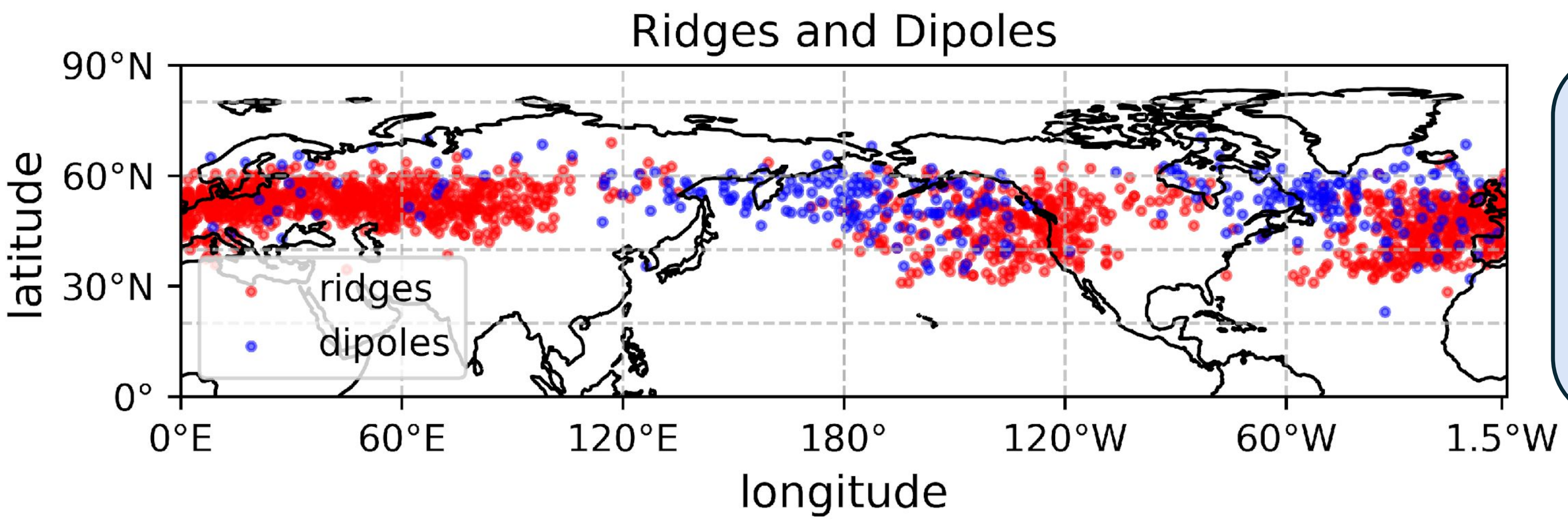


Dipole



Methods:
- We use MERRA2 reanalysis product from 1980-2022, also CAM simulations with fixed SST.
- We use **local wave activity framework** to detect different types of blocks:
    - Ridge blocks only include **anticyclonic** local wave activity .
    - Dipole block include **both cyclonic and anticyclonic** local wave activity.
- We use the budget of local wave activity to quantify the contribution from diabatic processes.

Blocking Diversity (Basic Features)



For ridge blocks:

- Occur downstream to the storm tracks.

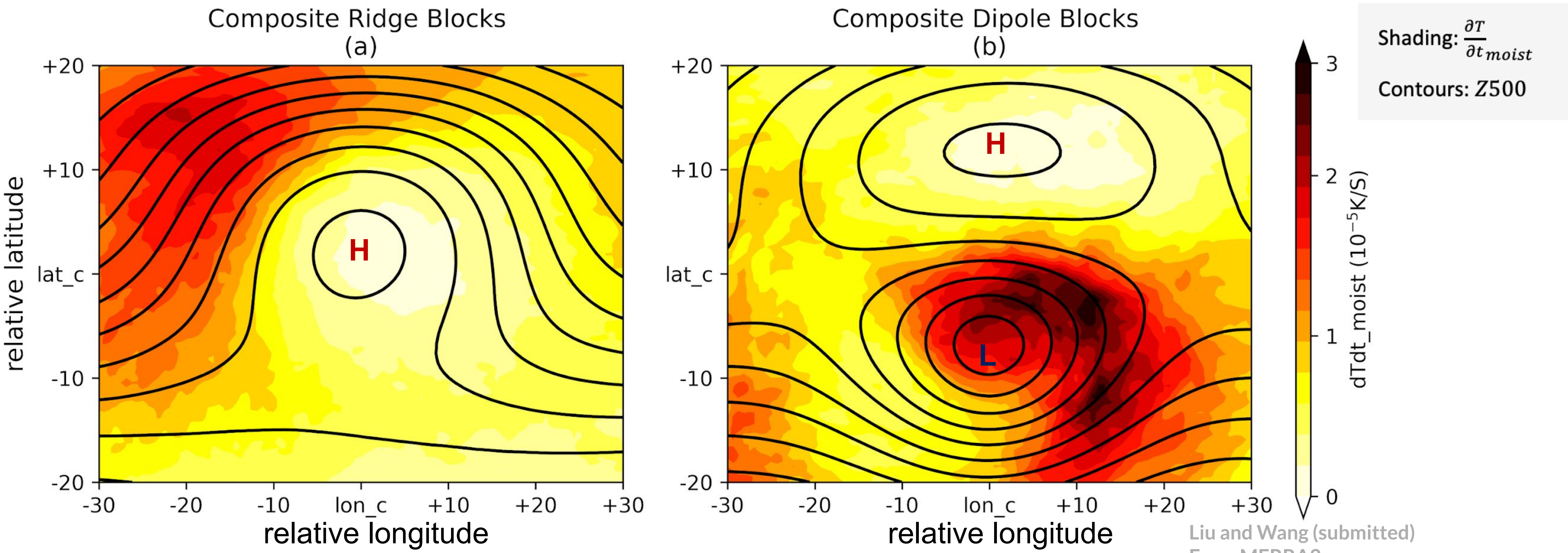
For dipole blocks :

- Occur along the storm tracks, upstream to the ridge blocks .

	Occurrence (1980-2022)	Duration	Strength (local wave activity)
Dipole blocks	784	9.3 days	84(m/s)
Ridge blocks	1470	8.8 days	60 (m/s)

- More ridge blocks than dipole blocks.
- Dipole blocks are stronger and more persistent.

Distinct horizontal structure of diabatic heating



Liu and Wang (submitted)
From MERRA2

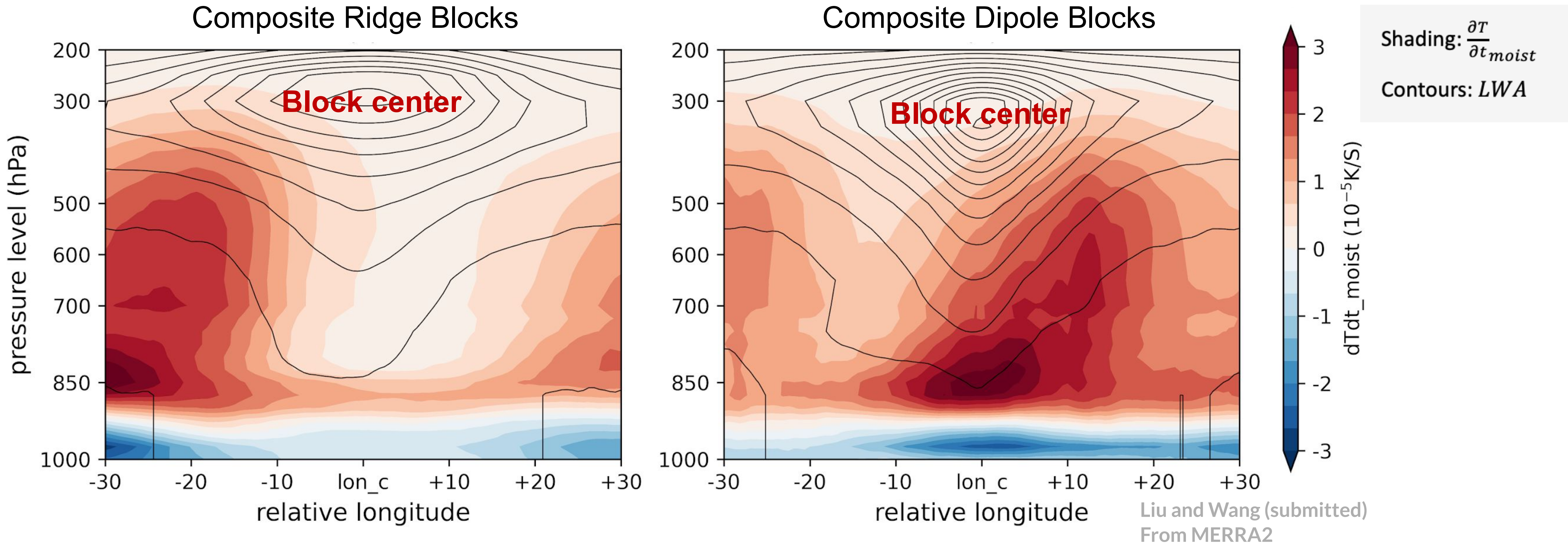
For ridge blocks:

- Diabatic heating occurs upstream to the block.

For dipole blocks:

- Diabatic heating primarily occurs within the cut low, South and downstream to the center of block.

Distinct vertical structure of diabatic heating



For ridges:

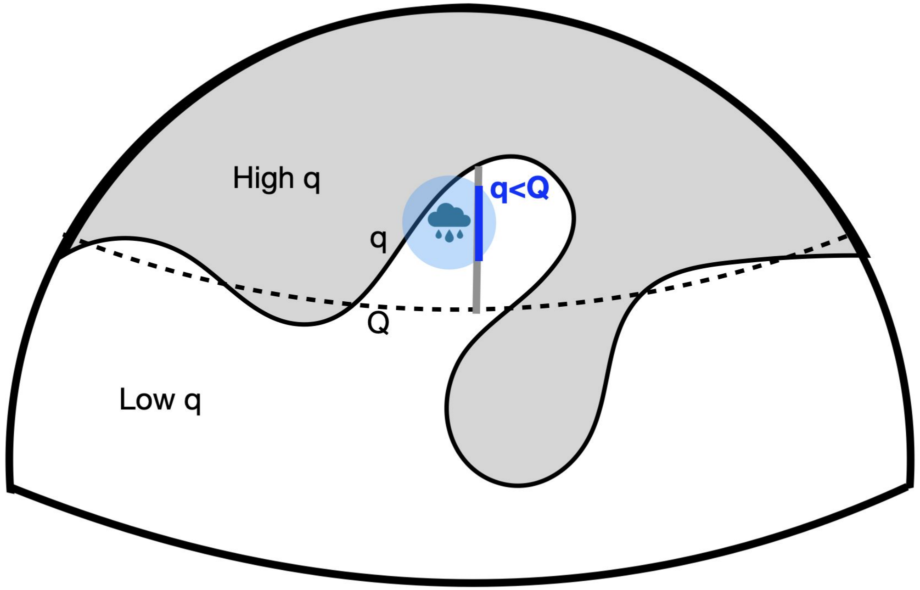
- Diabatic heating occurs upstream, and tends to stabilize the stratification.

For dipoles:

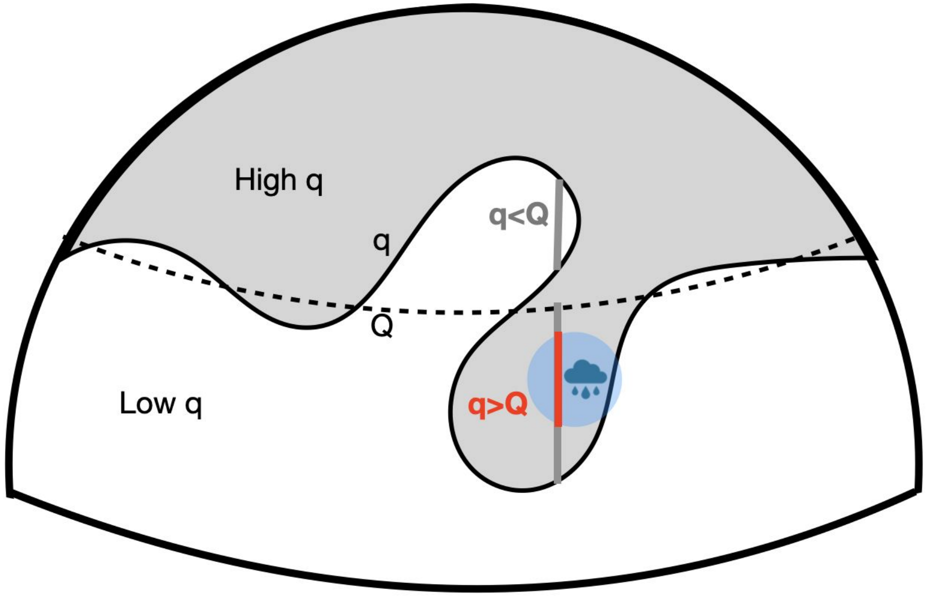
- Diabatic heating centers at lower levels, and tends to destabilize the stratification.

From thermodynamics to dynamics contribution

Moisture-induced LWA Tendency



Moisture-induced LWA Tendency



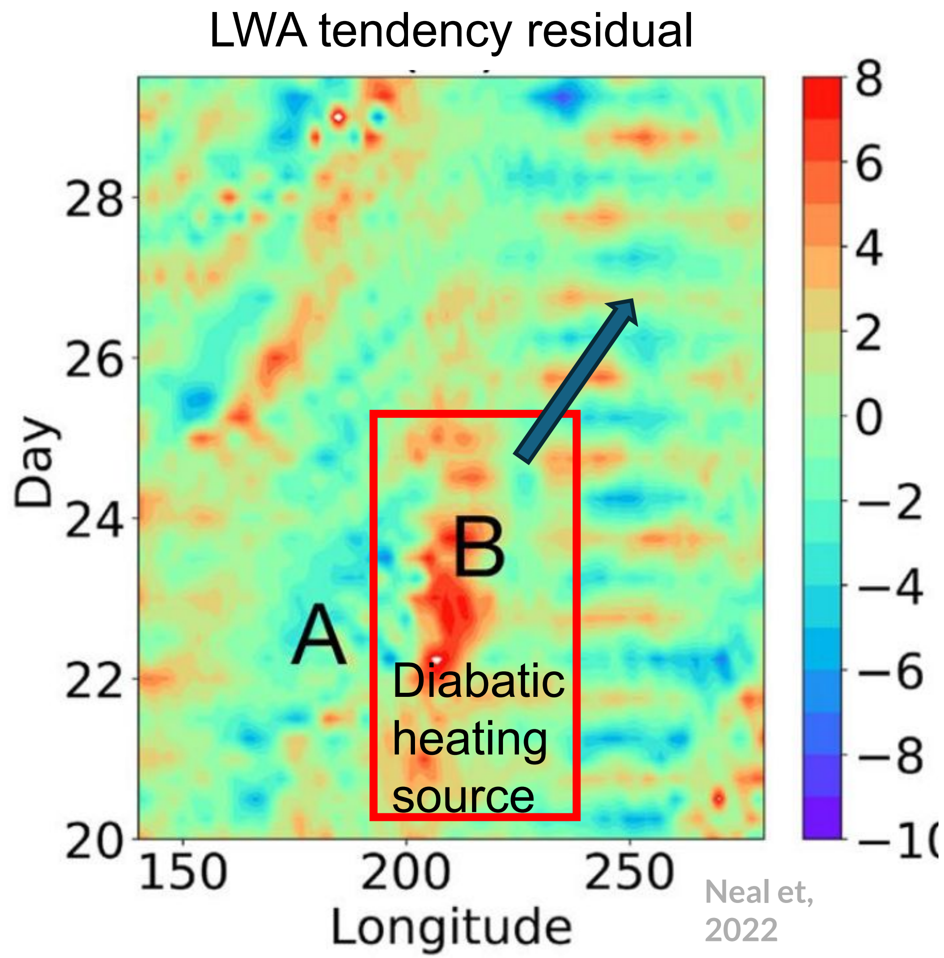
Translation from thermodynamics contribution to dynamics contribution:

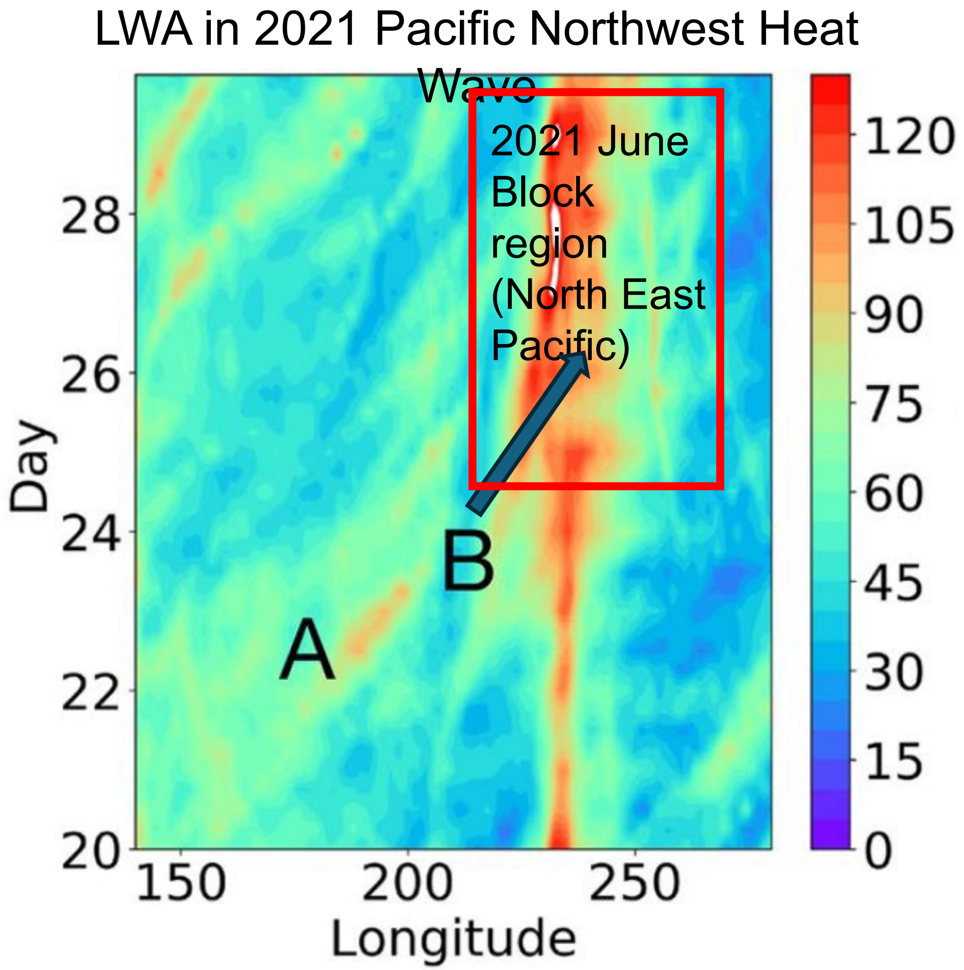
$$\frac{\partial A\cos\phi}{\partial t}_{moist} \approx= -a\int_0^{\Delta\phi} f_0 e^{\frac{z}{H}} \frac{\partial}{\partial z}\left(e^{-\frac{z}{H}} \frac{\partial T}{\partial t}_{moist} \frac{e^{\kappa\frac{z}{H}}}{\frac{\partial\theta_0}{\partial z}} \right) \cos(\phi+\phi')\, d\phi'$$

Moist process → **Diabatic heating** $\frac{\partial T}{\partial t}_{moist}$ → **QGPV changes** $\frac{dq}{dt}_{moist}$ → **LWA changes** $\frac{\partial A\cos\phi}{\partial t}$,

From thermodynamics to dynamics contribution

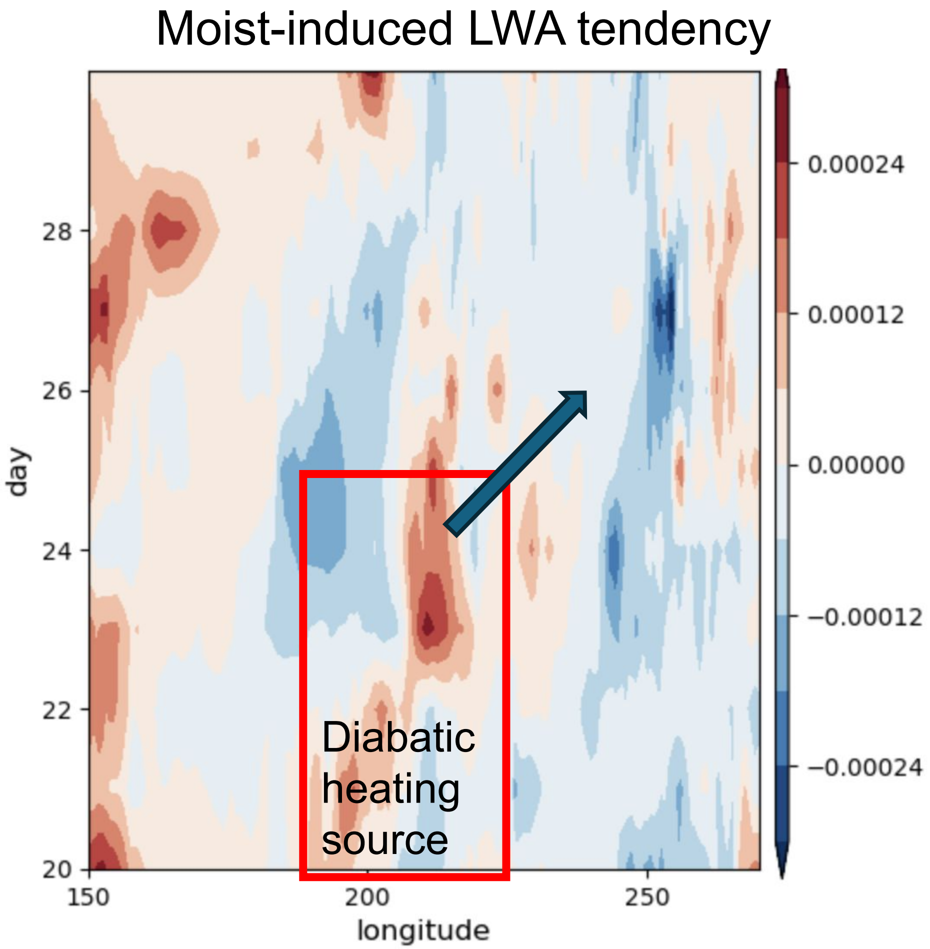
Residual Method (Neal et al., 2022)

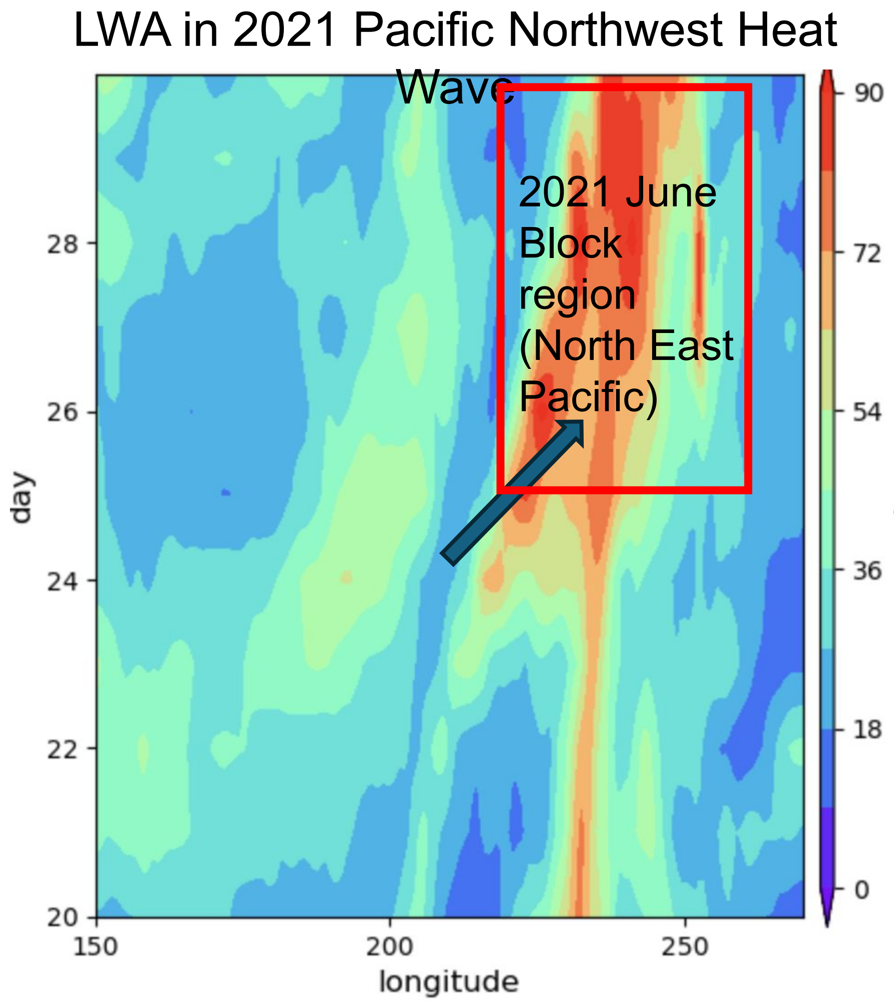




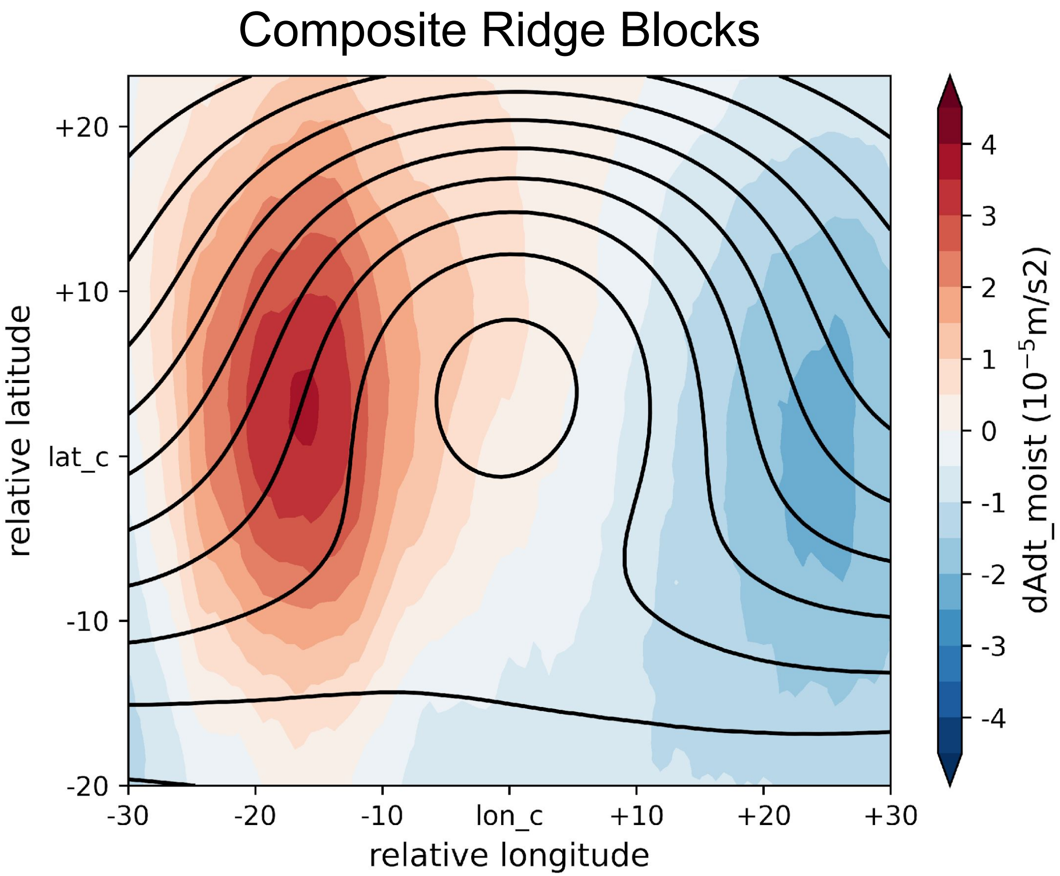
From thermodynamics to dynamics contribution

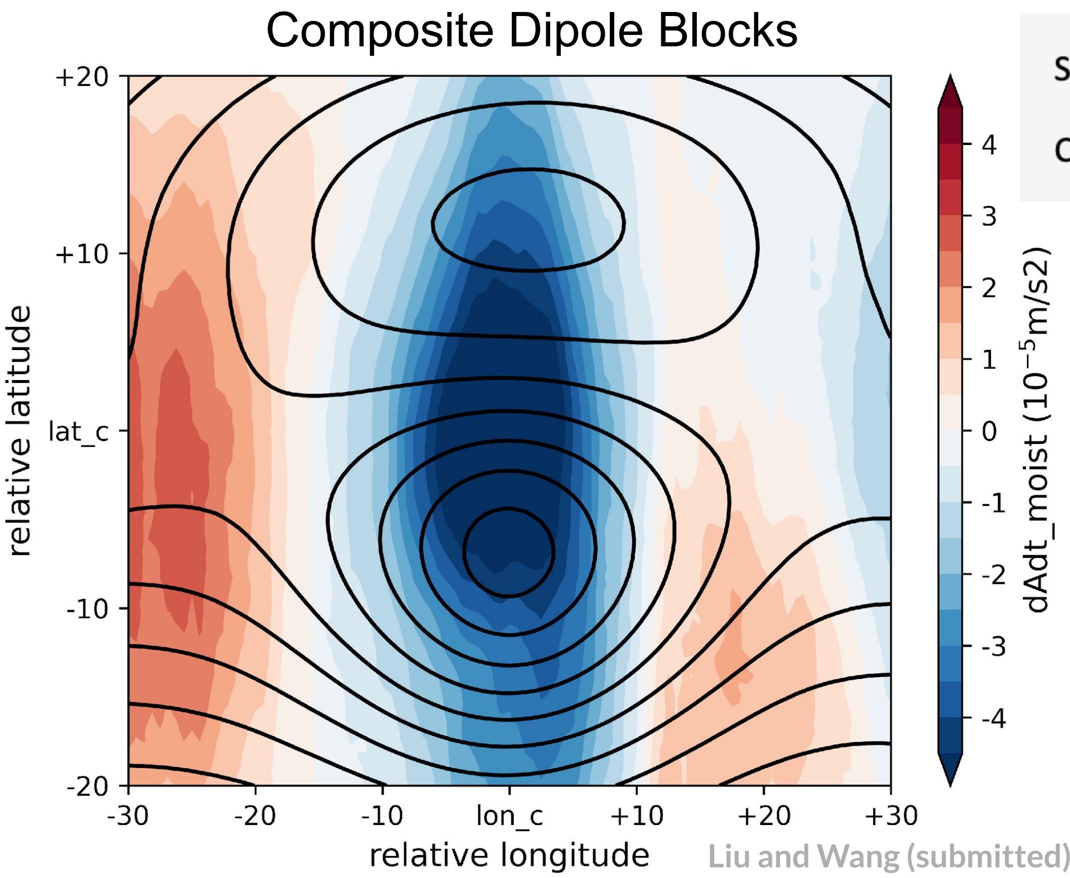
We directly calculate the moist-induced LWA tendency based on diabatic heating





Distinct horizonal patterns of moist-induced LWA





Shading: $\frac{\partial A\cos\phi}{\partial t}_{moist}$

Contours: $Z500$

Liu and Wang (submitted)
From MERRA2

For ridges:

- Weak intensification at the center.
- Strong upstream wave activity enhancement (persistence effect) helps to maintain the block.

For dipoles:

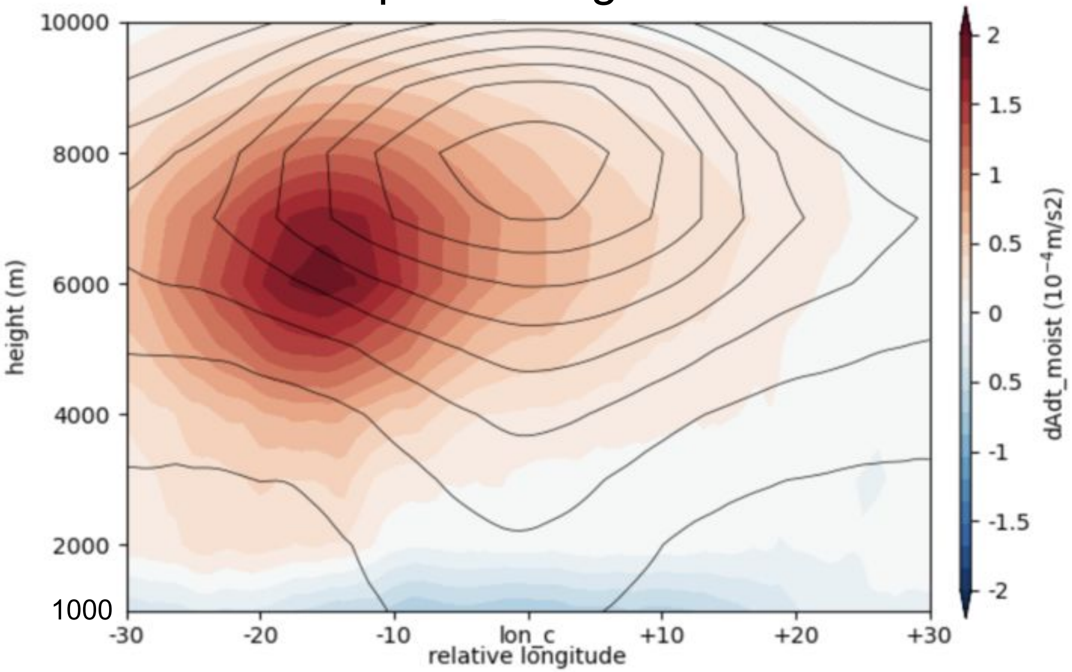
- Strong dampening effect at the center.

Distinct vertical pattern of moist-induced LWA tendency

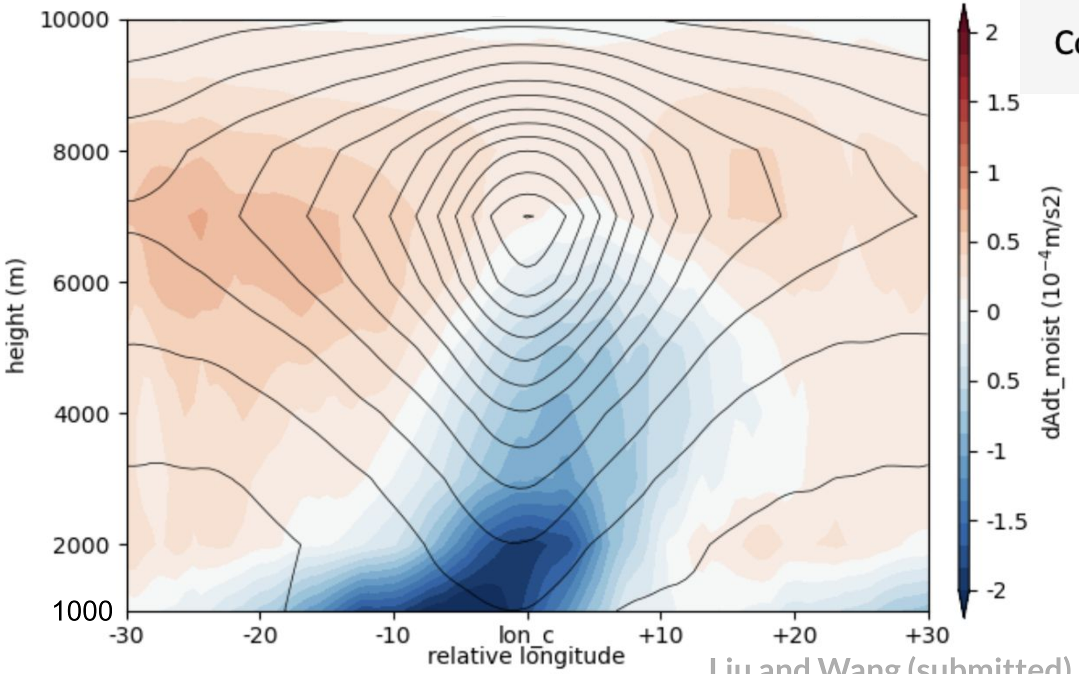
Shading: $\frac{\partial A cos\phi}{\partial t}_{moist}$

Contours: LWA

Composite Ridge Blocks



Composite Dipole Blocks



Liu and Wang (submitted)

From MERRA2

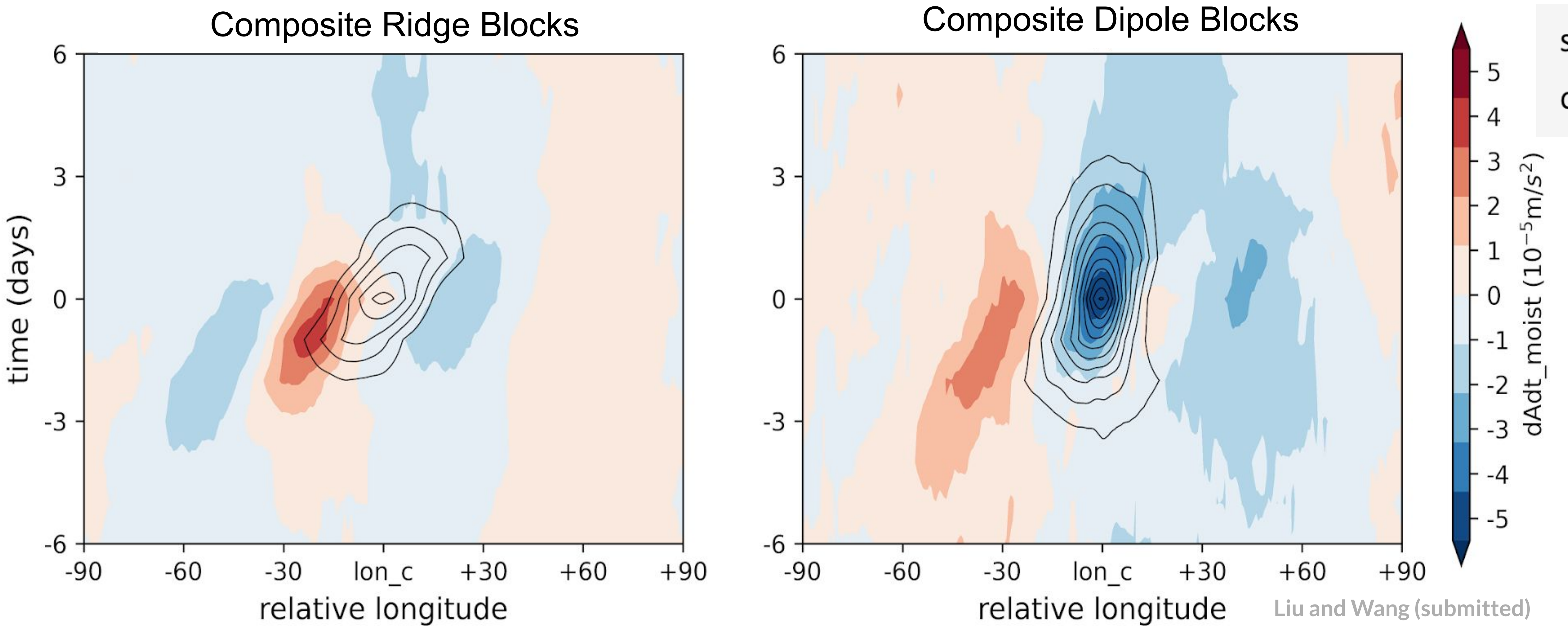
For ridges:

- The upstream enhancement maximizes on 6-7km.

For dipoles:

- The dampening effect centers at lower levels, but can extend to the middle troposphere.

Hovmoller diagram of moist-induced LWA tendency



Shading: $\frac{\partial A cos\phi}{\partial t}_{moist}$

Contours: LWA

Liu and Wang (submitted)
From MERRA2

For ridge blocks:

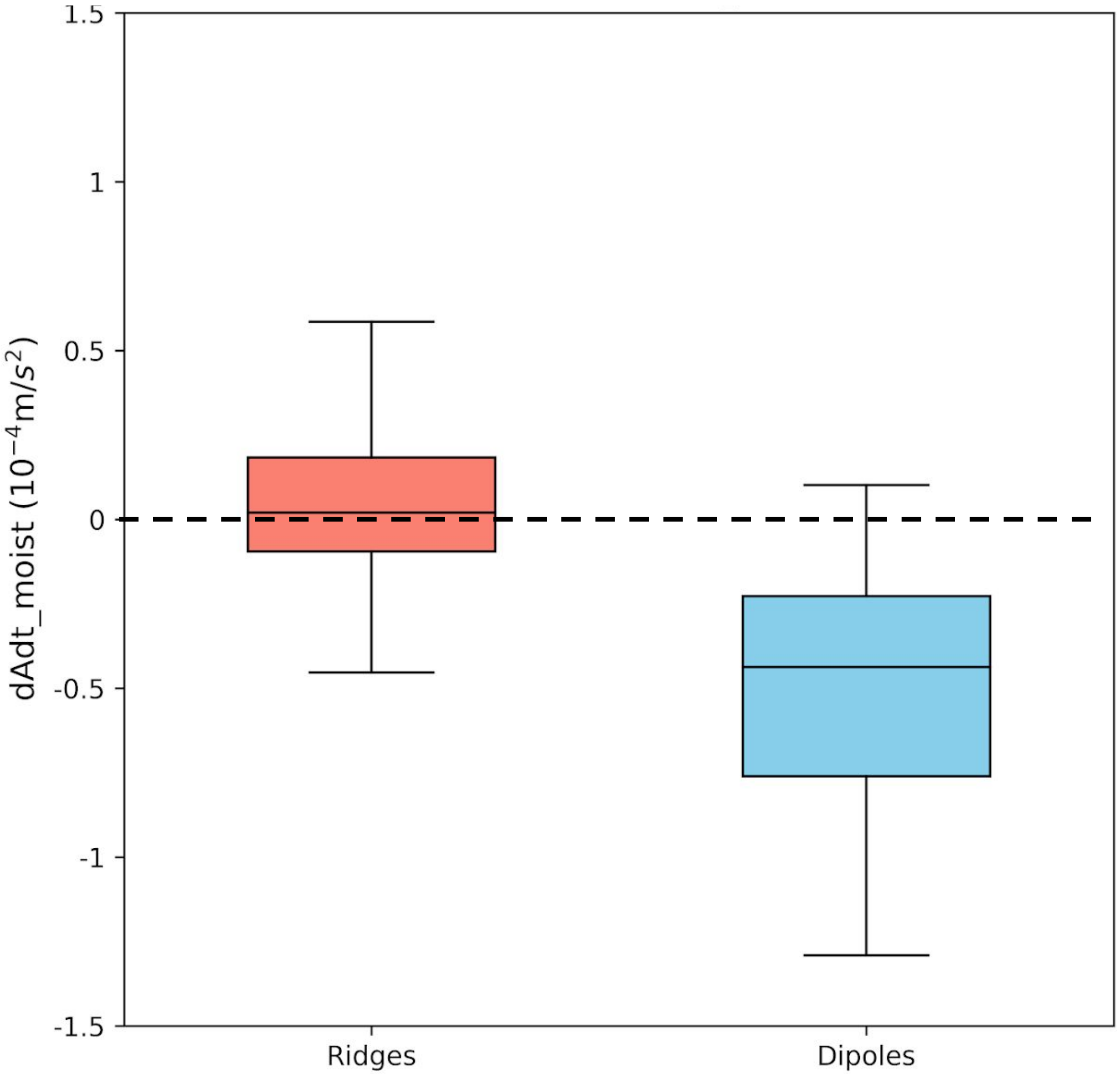
- The role of moist processes are more important before or in the early stage of the block.

For dipole blocks:

- The dampening effect by moist processes can last throughout the entire blocking lifecycle.

Distribution of dampening/intensification effect

Distribution of domain averaged moist-induced LWA tendency



For ridge blocks (1470 events):

- Block amplitude could be either enhanced or reduced.
- But the overall changing is relatively weak.

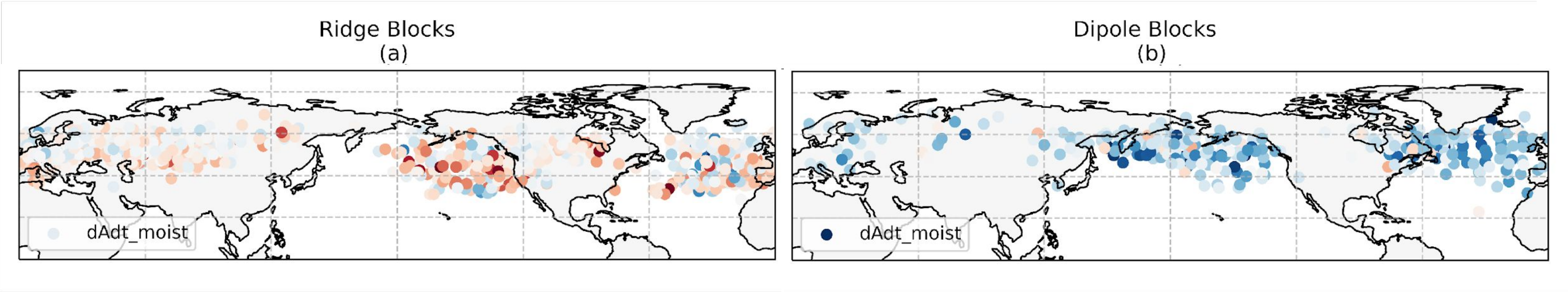
For dipole blocks (784 events):

- Dampening effect is robust for most blocks.

Box: 25th - 75th interquartile

Whisker: 5th - 95th interquartile

Geographic features of intensification/damping effect



Liu and Wang (submitted)

From MERRA2

Color: **domain averaged moist-induced LWA tendency**   -ve … +ve

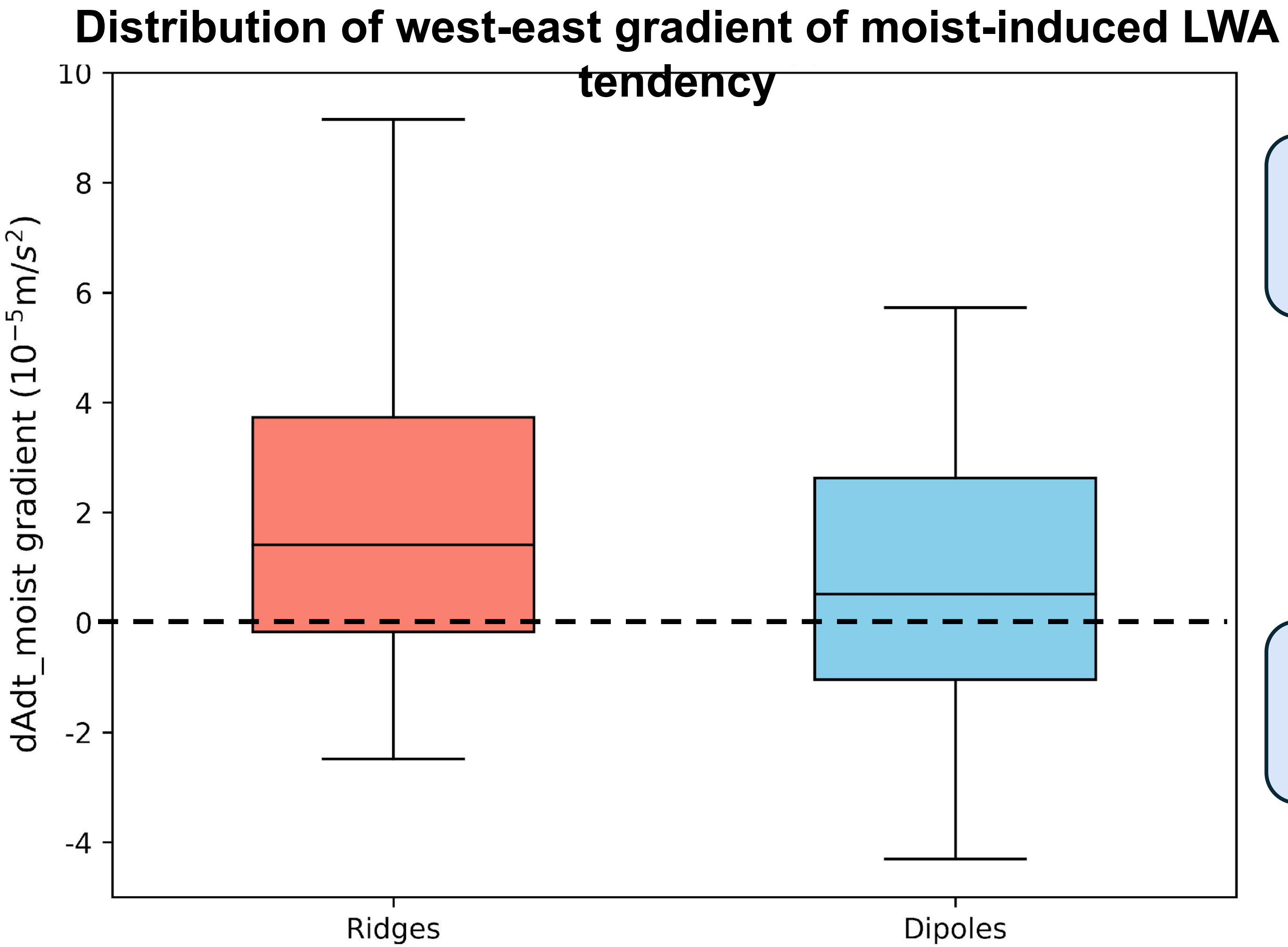
For ridge blocks (1470 events):

- Blocks could be either enhanced or reduced.
- More enhancement over the Northeast Pacific.

For dipole blocks (784 events):

- Most blocking events are featured by robust dampening effect.

Distribution of persistence effect



Liu and Wang (submitted)
From MERRA2

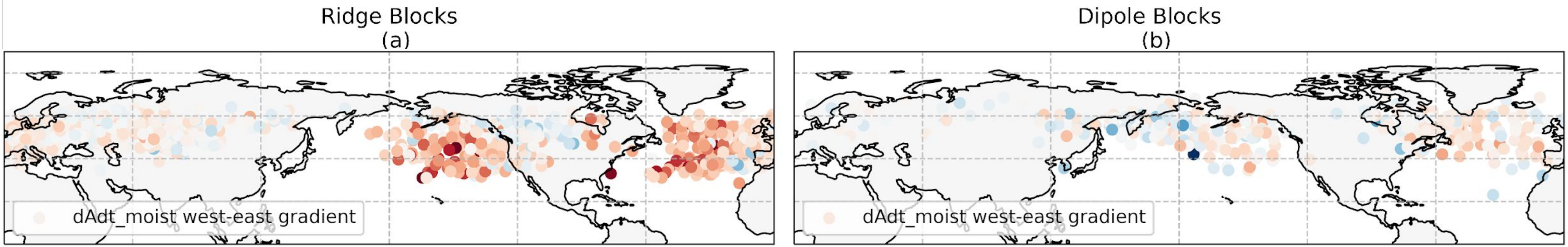
For ridge blocks (1470 events):

- Persistence effect is very robust.

For dipole blocks (784 events):

- Persistence effect is relatively moderate.

Geographic features of persistence effect



Liu and Wang (submitted)
From MERRA2

Color: **west-east gradient of moist-induced LWA tendency**

-ve +ve

For ridges (1470 events):

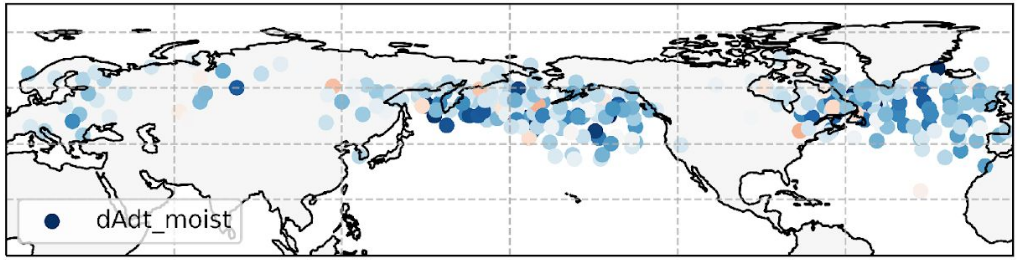
- Robust persistence effect for most blocking events over the oceans.

For dipoles (784 events):

- Relatively weak persistence effect.

A new insight to assess the future projection of blocks

Geographic features of dipole blocks



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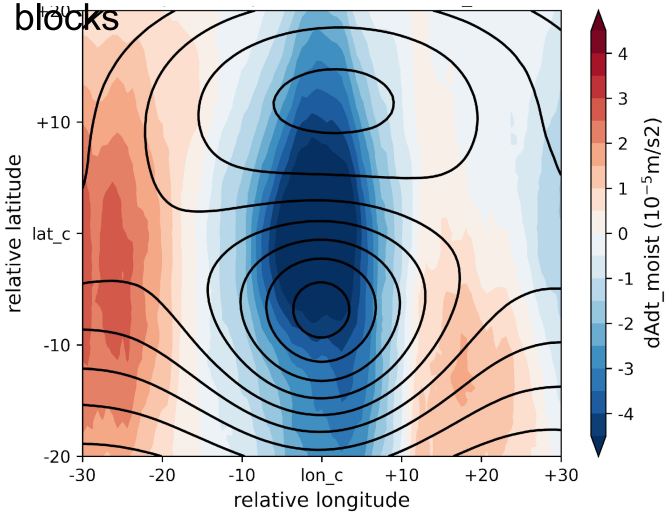
Role of diabatic heating in dipole blocks



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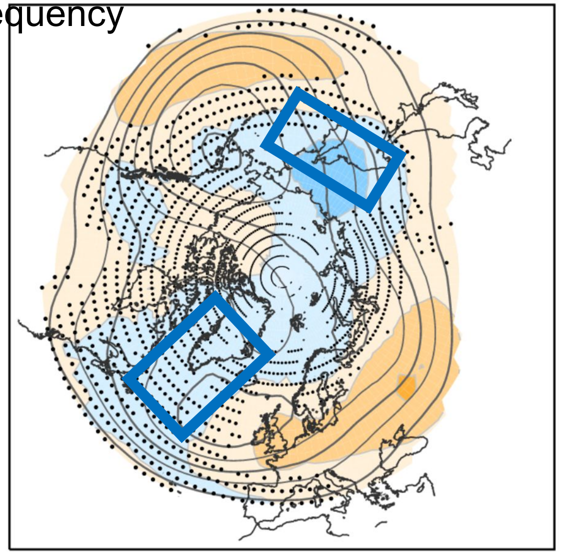
Future projection of blocking frequency



Dipole blocks dominate Northwest Atlantic and Northwest Pacific

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Negative effect from diabatic heating

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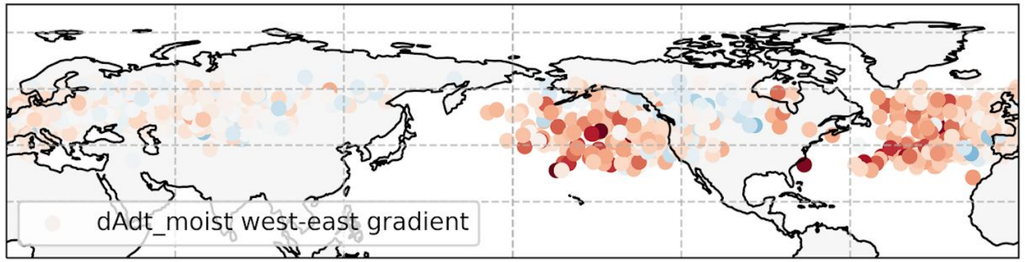
Reduced blocking frequency at Northwest Atlantic and Northwest Pacific

A new insight to assess the future projection of blocks

Geographic features of ridge blocks



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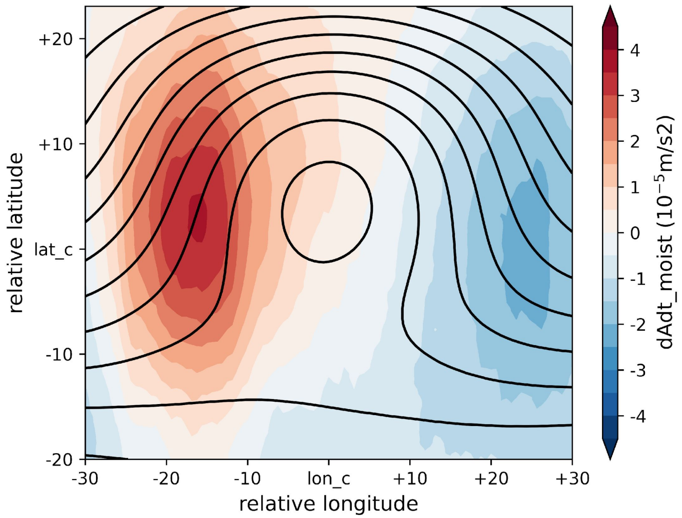
Role of diabatic heating in ridge blocks



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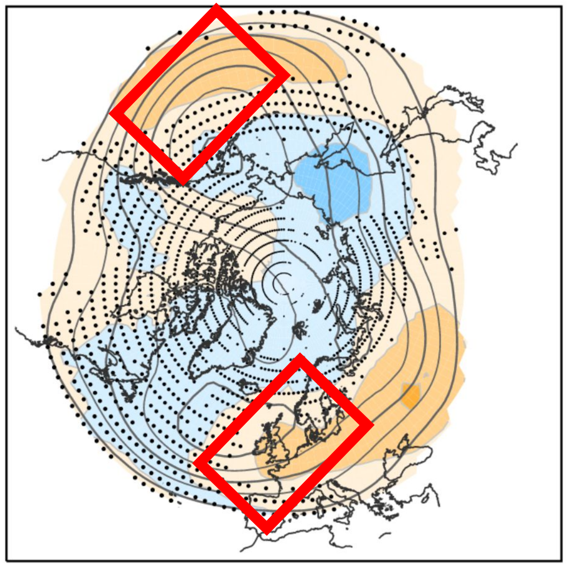
Future projection of blocking frequency



Ridge blocks dominate Northeast Atlantic and Northeast Pacific

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Positive effect from diabatic heating

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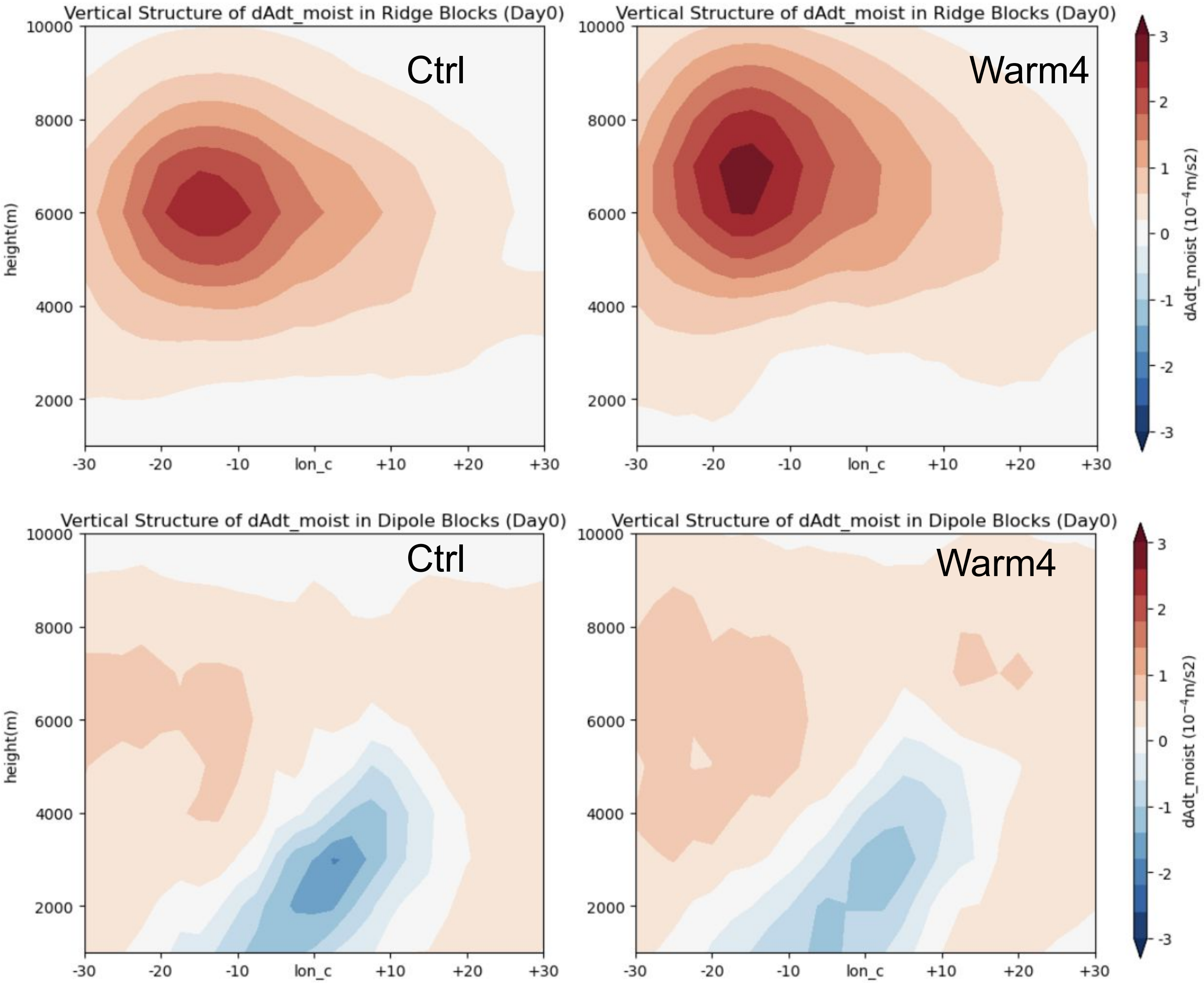
Increased blocking frequency at Northeast Atlantic and Northeast Pacific

CAM simulation with uniformly increased SST



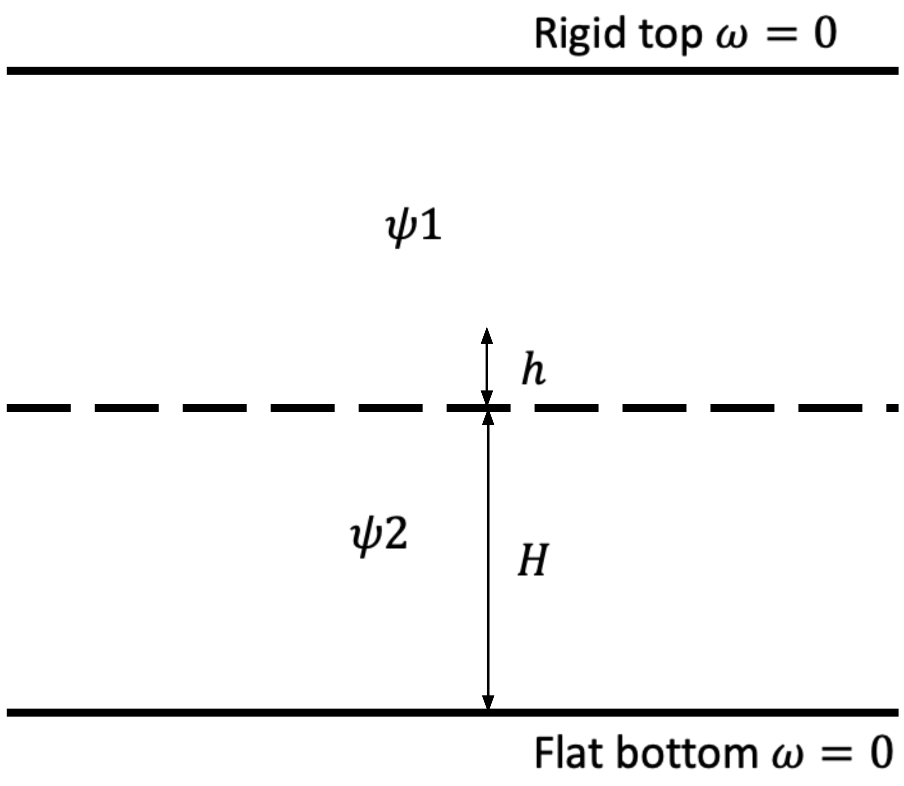
For ridges:

- In a warming climate, we find a stronger and higher upstream enhancement.

For dipoles:

- In a warming climate, we find the damping effect is reduced.

Two-layer QG model



$$\frac{D_1}{Dt}(\nabla^2\psi_1 + \beta y) - f_0 D = F_1$$

$$\frac{D_2}{Dt}(\nabla^2\psi_2 + \beta y) + f_0 D = F_2$$

Vorticity equation

$$\frac{D_i h_i}{Dt} + HD = -(-1)^i S$$

Continuity equation

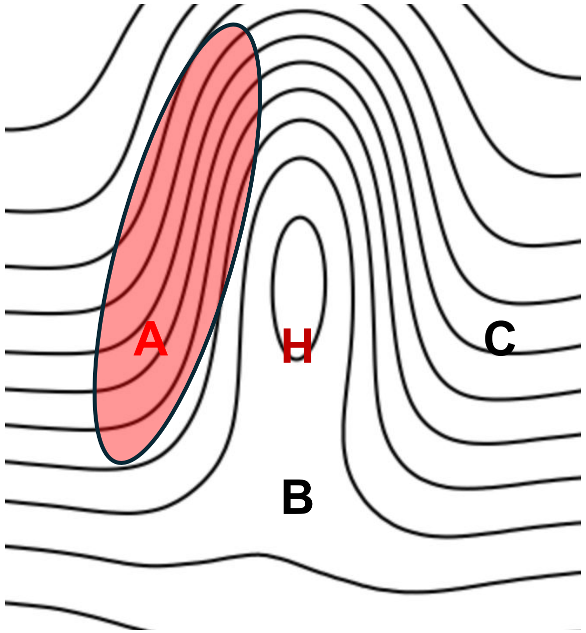
$$\boldsymbol{S} = \frac{(\boldsymbol{LP} - \boldsymbol{R})\boldsymbol{H}}{\boldsymbol{C_p \delta\theta}}$$

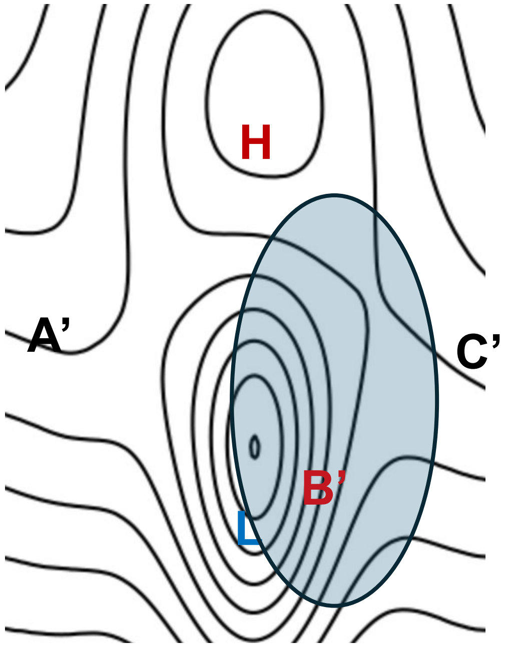
S is the mass exchange from the lower to the upper layer

$$f_0(\psi_1 - \psi_2) = \mathrm{g}\frac{\boldsymbol{\delta\theta}}{\theta_0}h$$

Hydrostatic balance

Conclusion and Discussion





For ridge blocks:

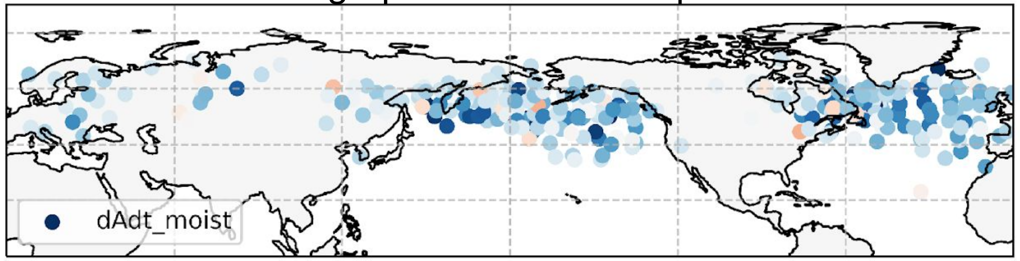
- Diabatic heating occurs upstream to the block (A’).
- Diabatic heating enhances the upstream wave activity, conducive to the persistence of blocks.

For dipole blocks:

- Diabatic heating occurs within the cut low (B’)
- Diabatic heating exerts a strong dampening effect that can directly reduce the amplitude of blocks.

Conclusion and Discussion

Geographic features of dipole blocks



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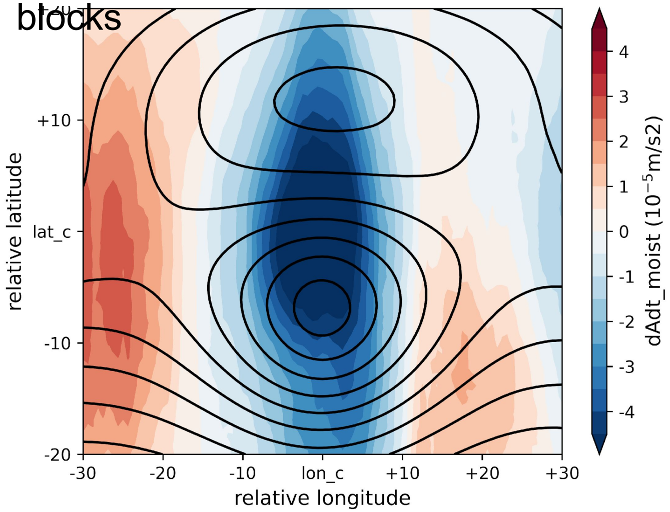
Role of diabatic heating in dipole blocks



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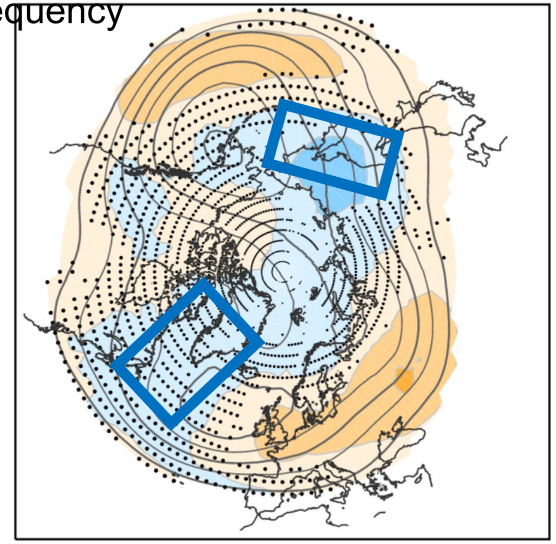
Future projection of blocking frequency



The distinct geographic features of ridge blocks and dipole blocks, together with distinct roles of diabatic heating, help to assess the future projection of blocking events.

Citation:

Liu and Wang: Blocking Diversity: Distinct Roles of Diabatic Heating (submitted)