Blocking Diversity: Distinct Roles of Diabatic Heating

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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

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

Daniel Steinfeld1, Michael Sprenger2, Urs Beyerle2, and Stephan Pfahl3

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

Daniel Steinfeld1, Maxi Boettcher1, Richard Forbes2, and Stephan Pfahl3

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

S. Pfahl1, C. Schwierz2, M. Croci-Maspoli2, C. M. Grams1 and H. Wernli1

Role of latent heat release in atmospheric blocks

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

Take away:
- Moist related diabatic processes are important, overall exerting a positive effect on the formation and intensification of blocks.
We hypothesize that:
• The role of diabatic heating (from moist processes) is distinct among different types of blocks.

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)

<table>
<thead>
<tr>
<th></th>
<th>Occurrence (1980-2022)</th>
<th>Duration</th>
<th>Strength (local wave activity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole blocks</td>
<td>784</td>
<td>9.3 days</td>
<td>84 (m/s)</td>
</tr>
<tr>
<td>Ridge blocks</td>
<td>1470</td>
<td>8.8 days</td>
<td>60 (m/s)</td>
</tr>
</tbody>
</table>

For ridge blocks:
- Occur downstream to the storm tracks.

For dipole blocks:
- Occur along the storm tracks, upstream to the ridge blocks.
- More ridge blocks than dipole blocks.
- Dipole blocks are stronger and more persistent.
Distinct horizontal structure of diabatic heating

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.

Liu and Wang (submitted)
From MERRA2

Shading: $\frac{dT}{dt_{moist}}$
Contours: Z500
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:

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

Moist process $\rightarrow$ Diabatic heating $\rightarrow$ QGPV changes $\rightarrow$ LWA changes

\[
\frac{\partial T}{\partial t}_{\text{moist}} \quad \frac{dq}{dt}_{\text{moist}} \quad \frac{\partial A \cos \phi}{\partial t}
\]
From thermodynamics to dynamics contribution

Residual Method (Neal et al., 2022)

LWA tendency residual

LWA in 2021 Pacific Northwest Heat Wave

Diabatic heating source

2021 June Block region (North East Pacific)
We directly calculate the moist-induced LWA tendency based on diabatic heating.
Distinct horizontal patterns of moist-induced LWA

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

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.

Liu and Wang (submitted) From MERRA2

Shading: $\frac{\partial LWA}{\partial t}$
Contours: $LWA$
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

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

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.

Color: domain averaged moist-induced LWA tendency

Liu and Wang (submitted)
From MERRA2
Distribution of persistence effect

Persistence effect is very robust.

Persistence effect is relatively moderate.

Distribution of west-east gradient of moist-induced LWA tendency

For ridge blocks (1470 events):
- Persistence effect is very robust.

For dipole blocks (784 events):
- Persistence effect is relatively moderate.

Liu and Wang (submitted)
From MERRA2
Geographic features of persistence effect

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

Dipole blocks dominate Northwest Atlantic and Northwest Pacific

Negative effect from diabatic heating

Reduced blocking frequency at Northwest Atlantic and Northwest Pacific
A new insight to assess the future projection of blocks

Geographic features of ridge blocks

Ridge blocks dominate Northeast Atlantic and Northeast Pacific

Role of diabatic heating in ridge blocks

Positive effect from diabatic heating

Future projection of blocking frequency

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

Rigid top $\omega = 0$

Vorticity equation

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

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

Continuity equation

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

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

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

Hydrostatic balance

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