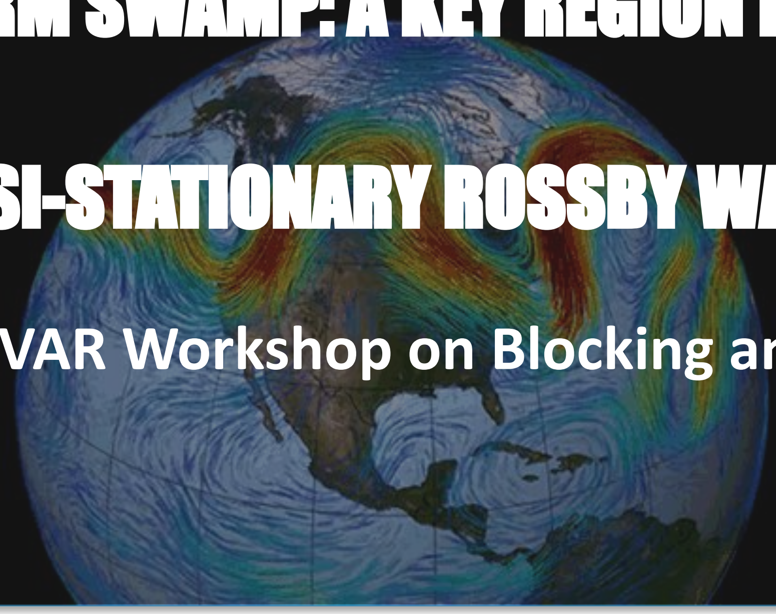
STORM SWAMP: A KEY REGION FOR CONCURRENT BLOCKING AND HEAT WAVE EVENTS WITH QUASI-STATIONARY ROSSBY WAVES AMPLIFICATION



US CLIVAR Workshop on Blocking and Extreme Weather in a Changing Climate, 2024

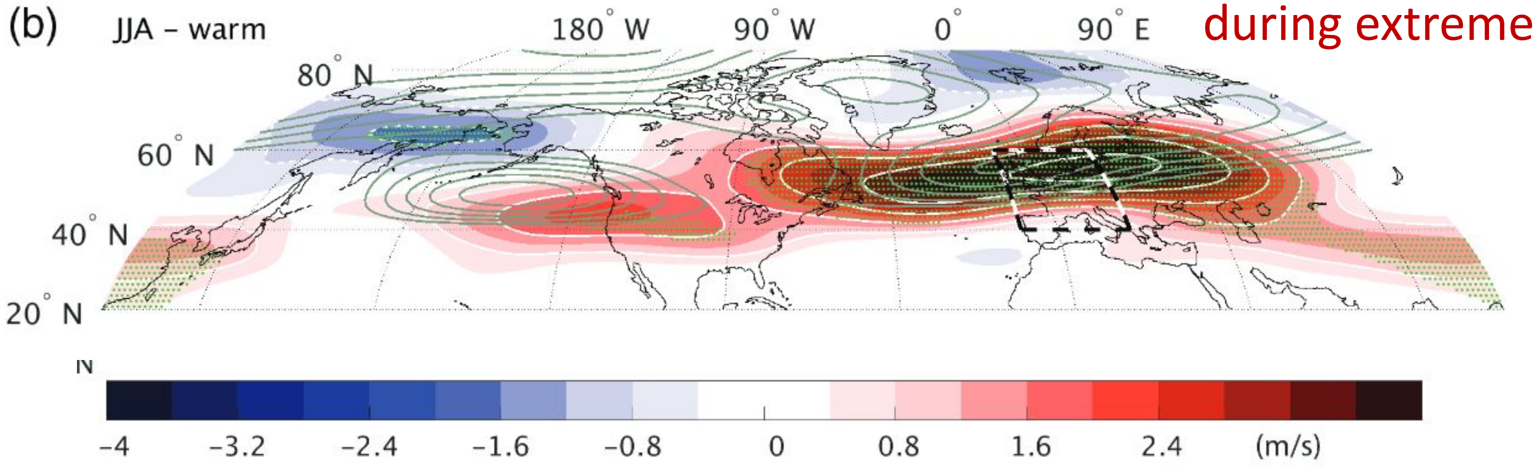
Valentina Castañeda, Lei Wang
Earth, Atmospheric and Planetary Sciences
Purdue University

Department of Earth, Atmospheric, and Planetary Sciences

INTRODUCTION: ROSSBY WAVES, BLOCKING AND HEATWAVES

AMPLIFIED ROSSBY WAVES AND **EXTREME HEAT**:

RWP anomalous amplitude during extreme heat

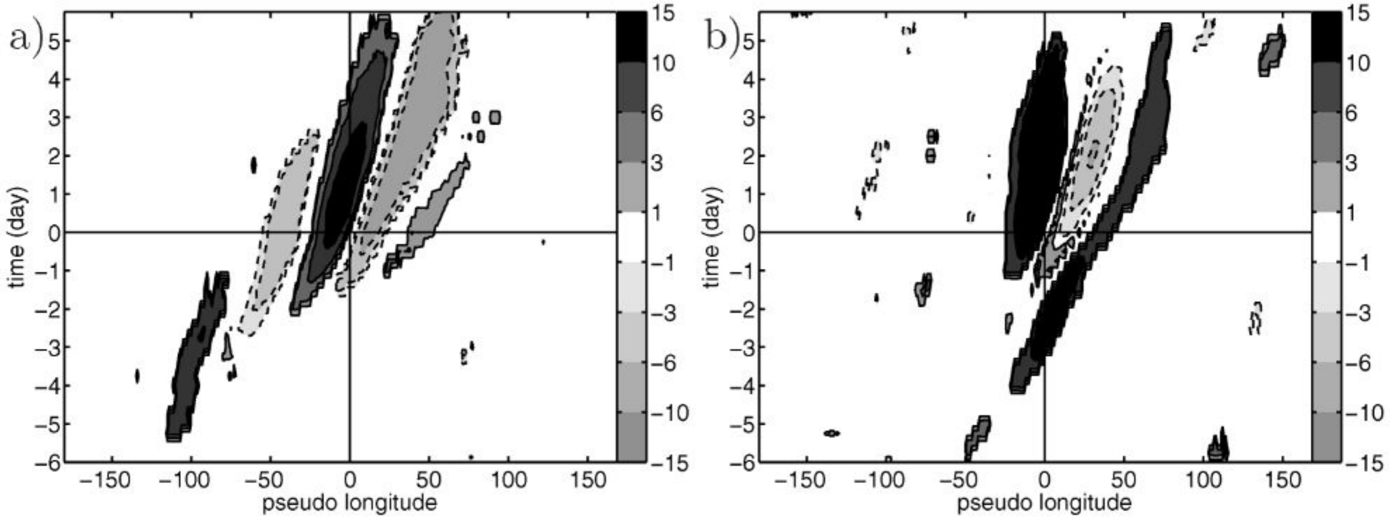


Wolf et. al., (2018).

ROSSBY WAVES AND **BLOCKING EVENTS**:

Pacific Blocking

Atlantic Blocking



Altenhoff et. al., (2016).

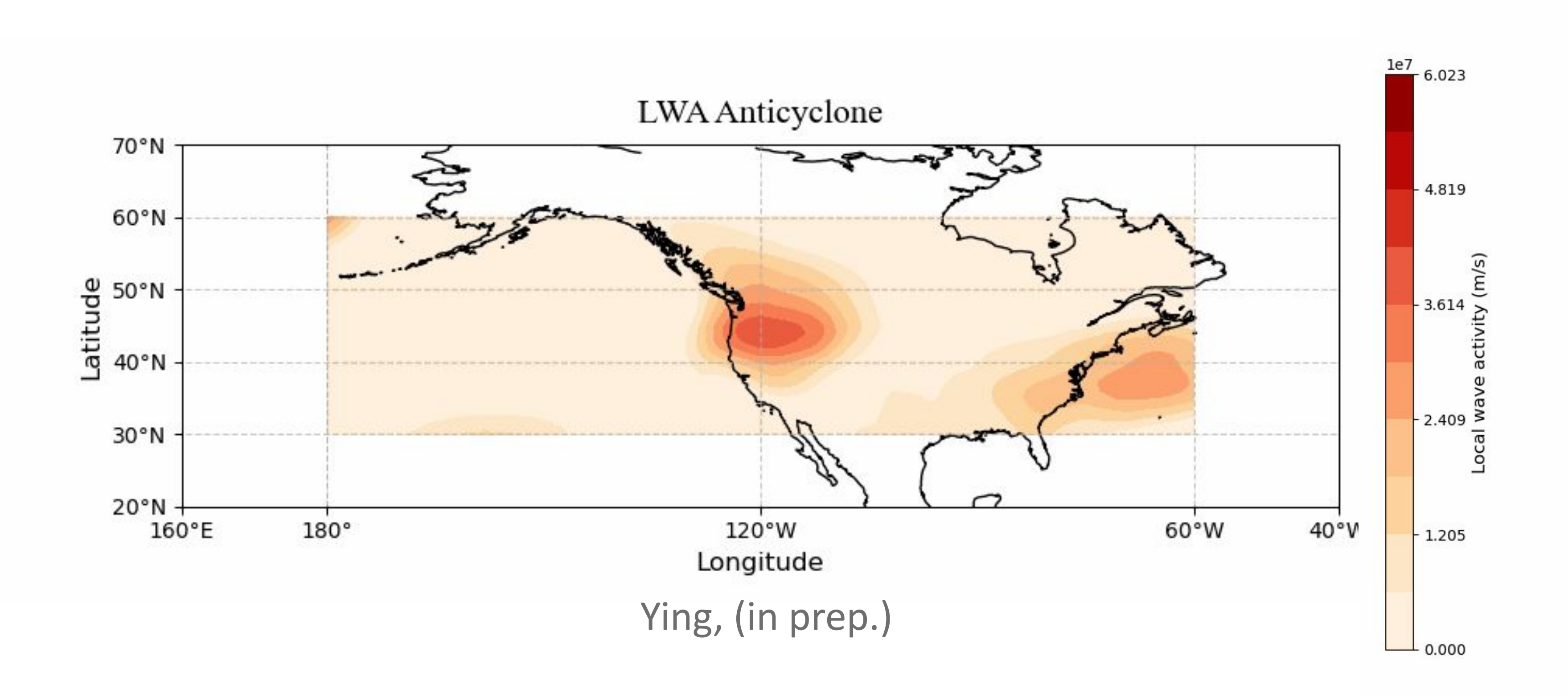
HEATWAVES AND BLOCKING DETECTION

BLOCKING:

At least 5 consecutive days following:

1. LWA to identify strong wave events
2. Pass through LWA threshold
3. Track wave events with max point
4. Max. distance: 10° lon and 5° lat.

From ***Martineau et al. 2017***



Ying, (in prep.)

HEATWAVES AND BLOCKING DETECTION

HEATWAVES:

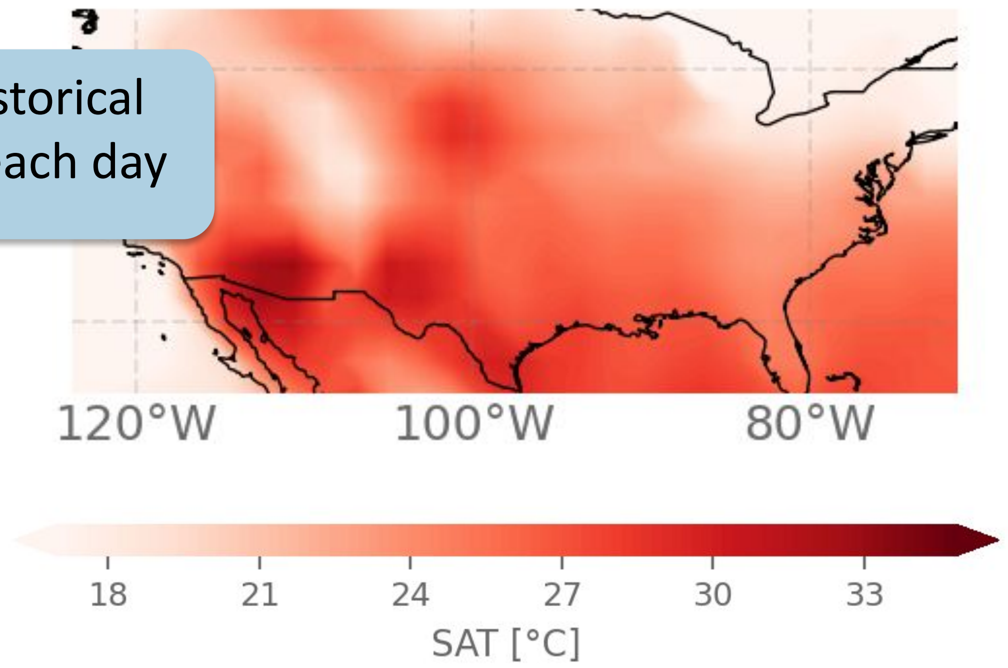
At least 5 consecutive days following:

1. More than 5% of US has daily surface air temperature exceeding a **threshold**
2. Track wave events with max point
3. Max. distance: 5° lon and 5° lat.

From ***Teng et al. 2013***

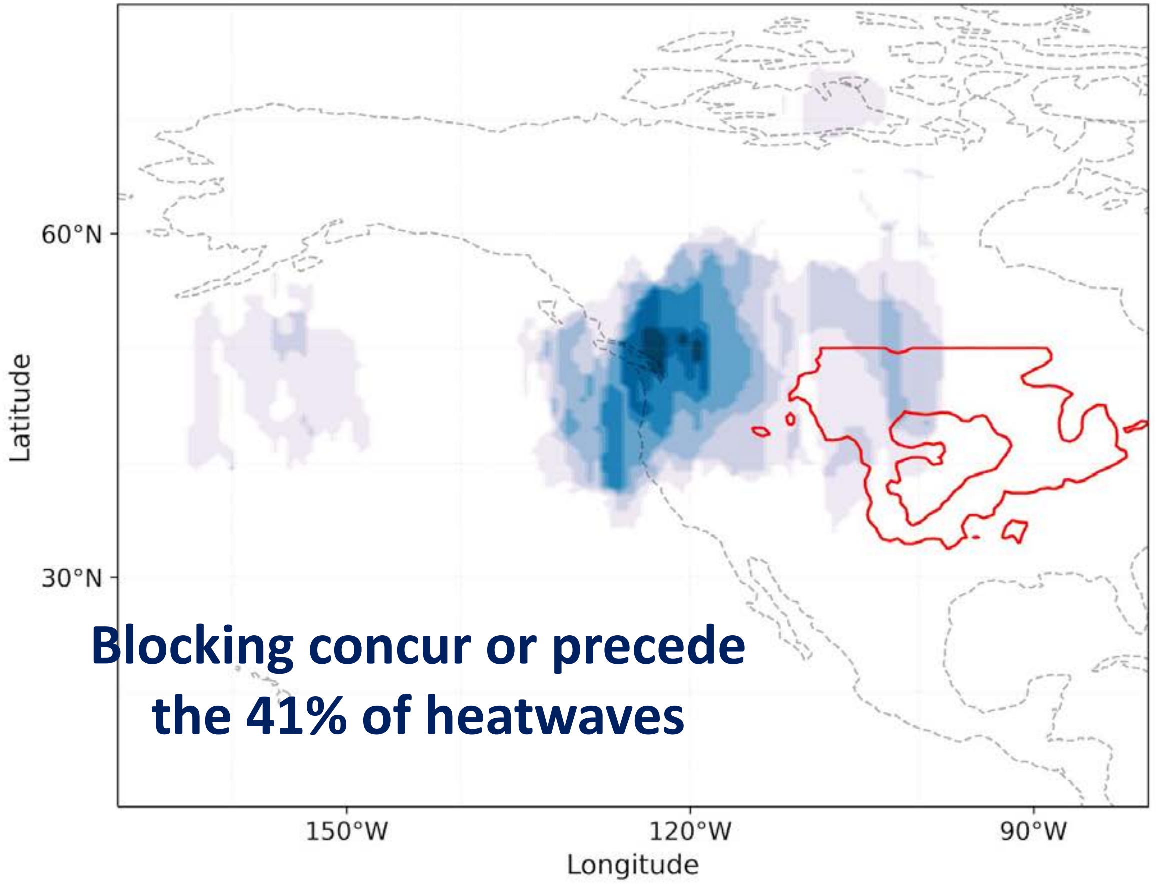
97.5% of the historical climatology for each day

Example: threshold for 06-14



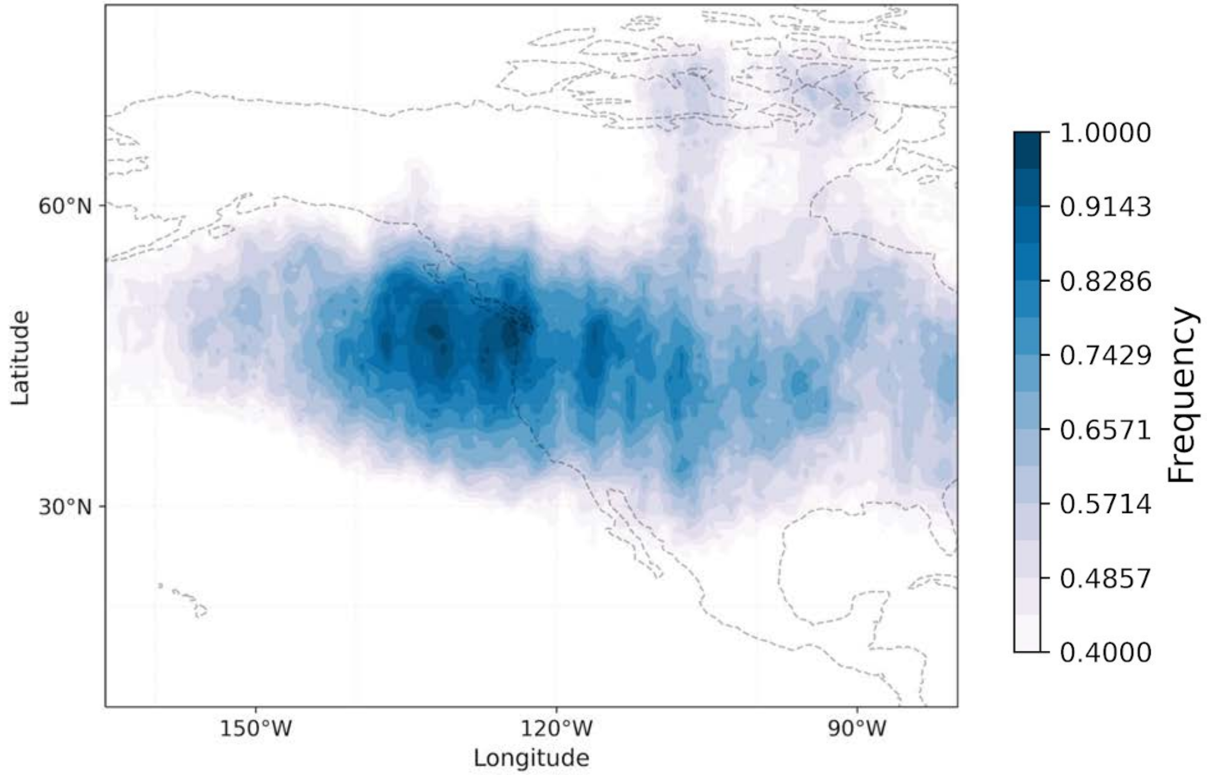
BLOCKING AND HEATWAVES FROM REANALYSIS

Blocking events preceding or concurring with heatwaves



Blocking concur or precede the 41% of heatwaves

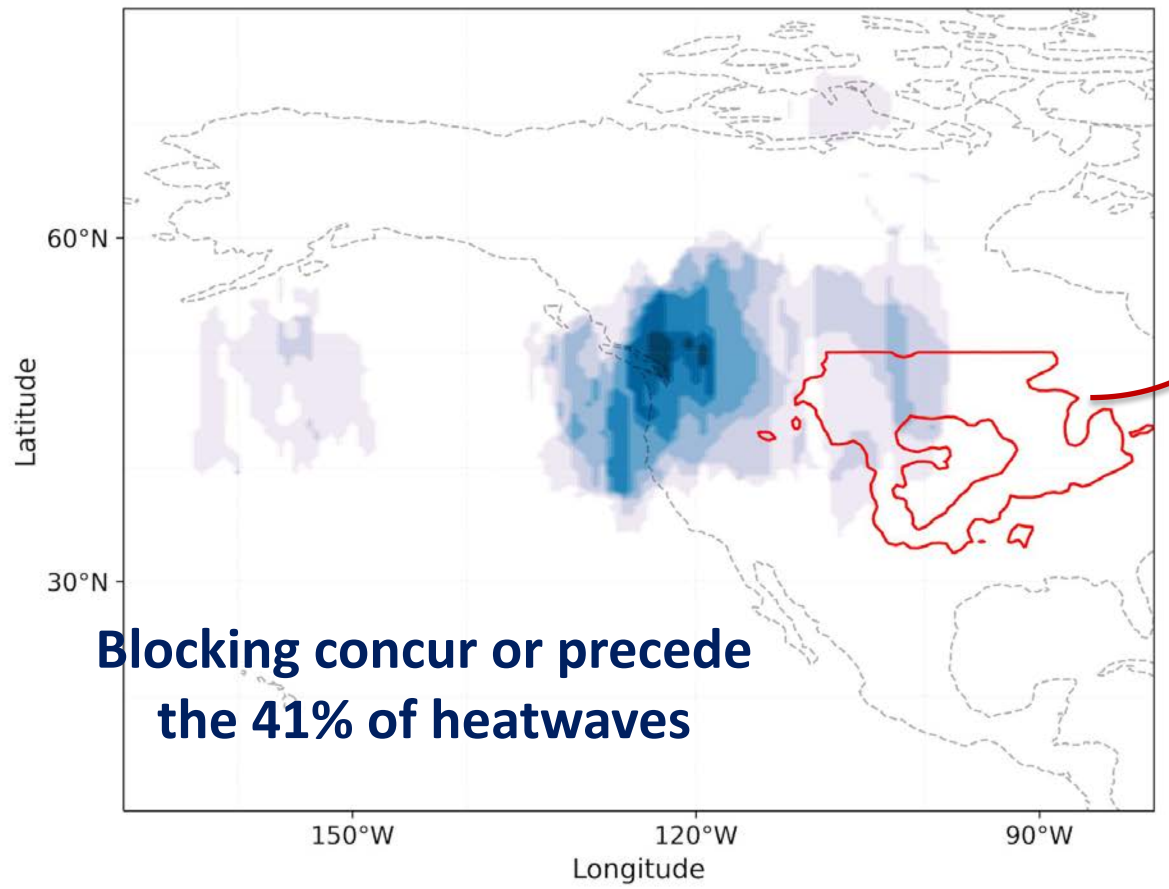
Blocking events during JJA



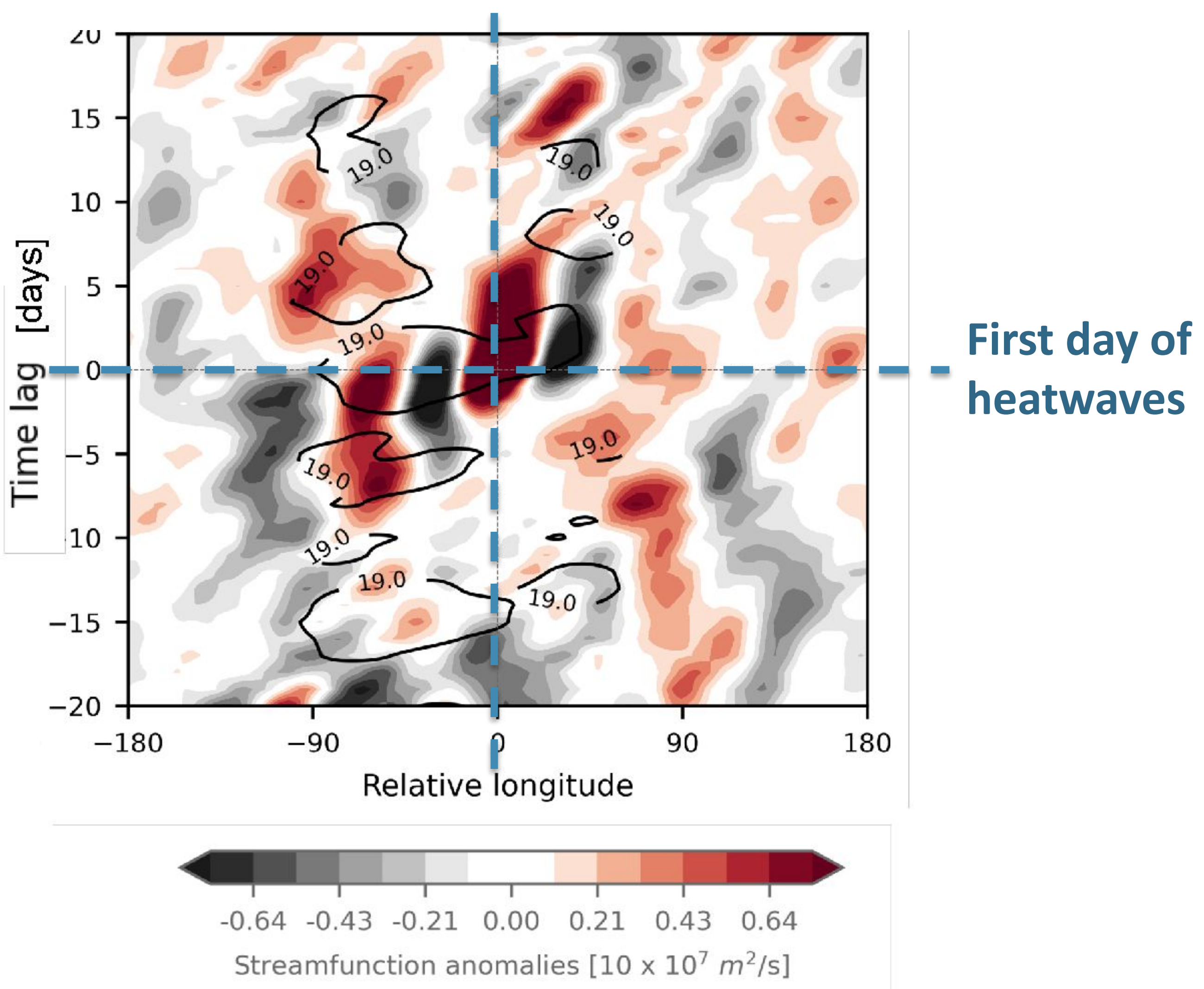
Castañeda and Wang (in prep.)

BLOCKING AND HEATWAVES FROM REANALYSIS

Blocking events preceding or concurring with heatwaves



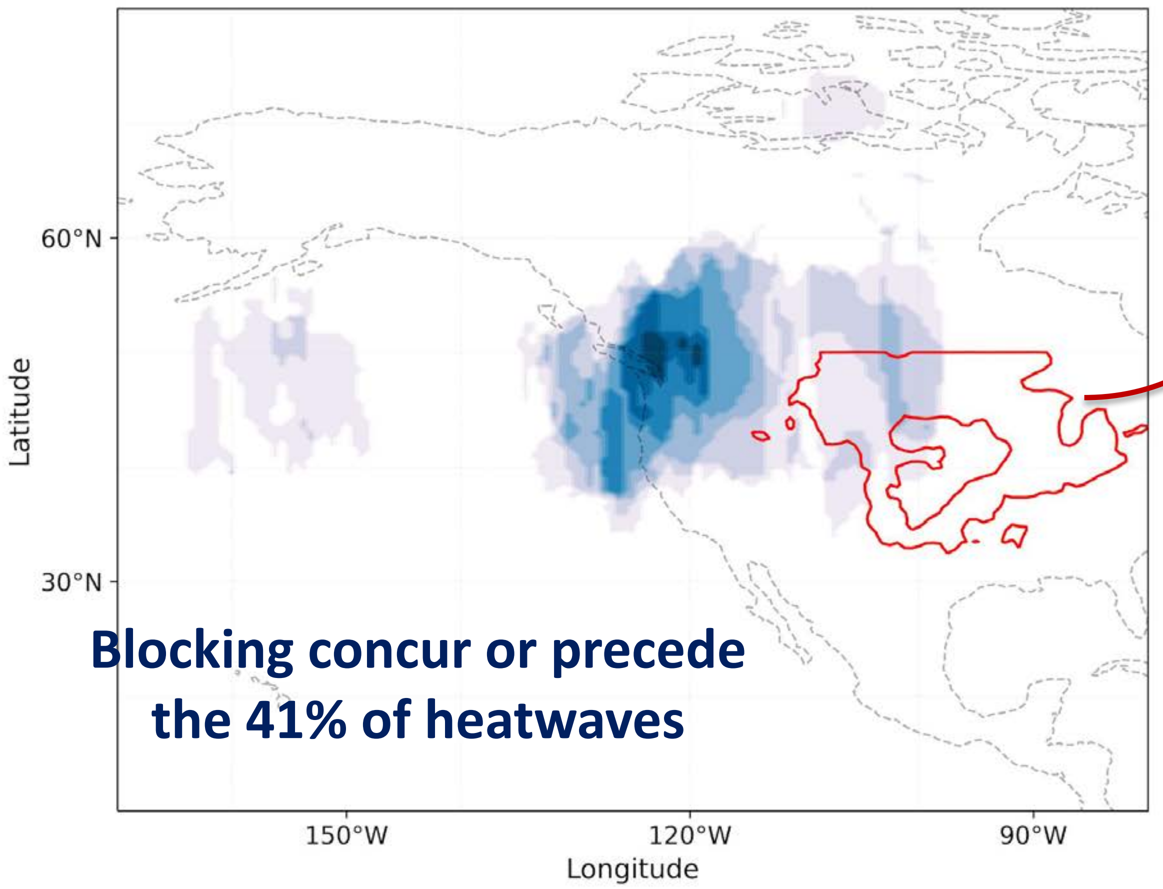
Associated Rossby wave pattern: WAVENUMBER 5



Castañeda and Wang (2024)

BLOCKING AND HEATWAVES FROM REANALYSIS

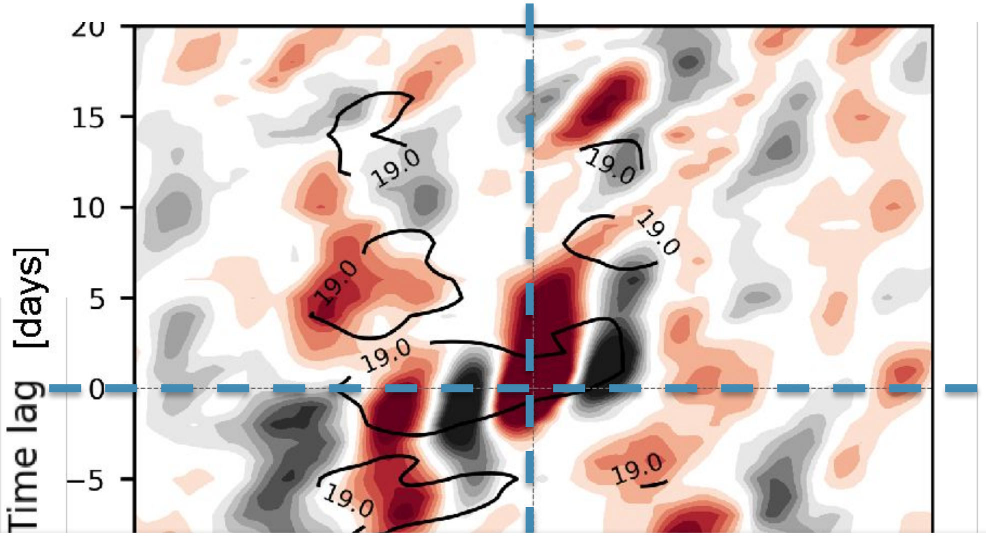
Blocking events preceding or concurring with heatwaves



Blocking concur or precede the 41% of heatwaves

Associated Rossby wave pattern: WAVENUMBER 5

Center of US heatwaves



First day of heatwaves

JGR Atmospheres

Research Article | Open Access

The Role of Climatological State in Supporting US Heat Waves Through Rossby Waves Packets

Valentina Castañeda, Lei Wang

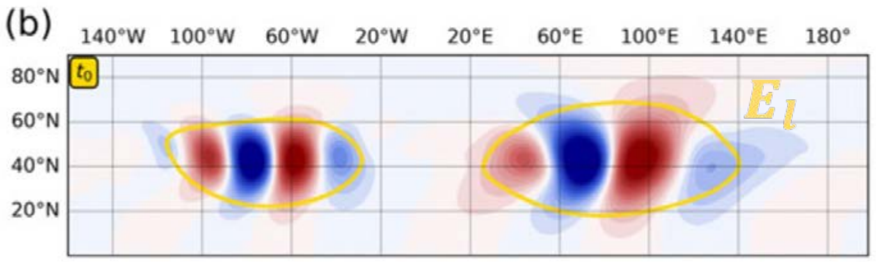
First published: 17 February 2024 | https://doi.org/10.1029/2023JD039212

SECTIONS PDF TOOLS SHARE

METHODS: RWP DIAGNOSIS

- **Rossby wave packet envelope**

RWP amplitude



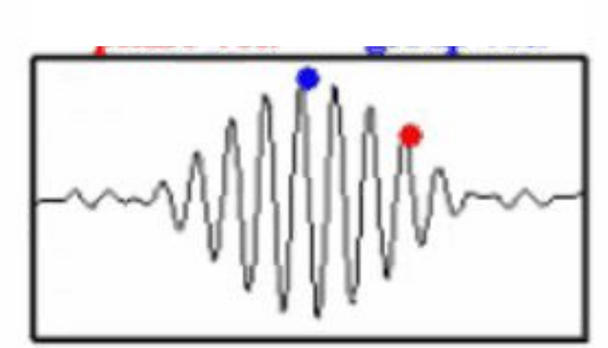
Example from Fragkoulidis, 2020

$$A_{v'_\ell} = |A_{v'_\ell}|\, e^{i\mathrm{Arg}\{A_{v'_\ell}\}} = E_\ell\, e^{i\Phi_{v'_\ell}}$$

$$E_\ell = |A_{v'_\ell}|$$

Zimin, 2003

- **Phase speed**
- **Group velocity**



$$c_p = \frac{\omega_{v'_\ell}}{k_{v'_\ell}},$$

$$\text{where} \quad \omega_{v'_\ell} = -\frac{\partial \Phi_{v'_\ell}}{\partial t}, \quad \text{and}$$

$$k_{v'_\ell} = \frac{1}{a\cos\phi}\frac{\partial \Phi_{v'_\ell}}{\partial \lambda}.$$

Fragkoulidis, 2019

- **Waveguide**

Quasi-geostropic Potential Vorticity

$$\frac{d_1}{dt}q = 0$$

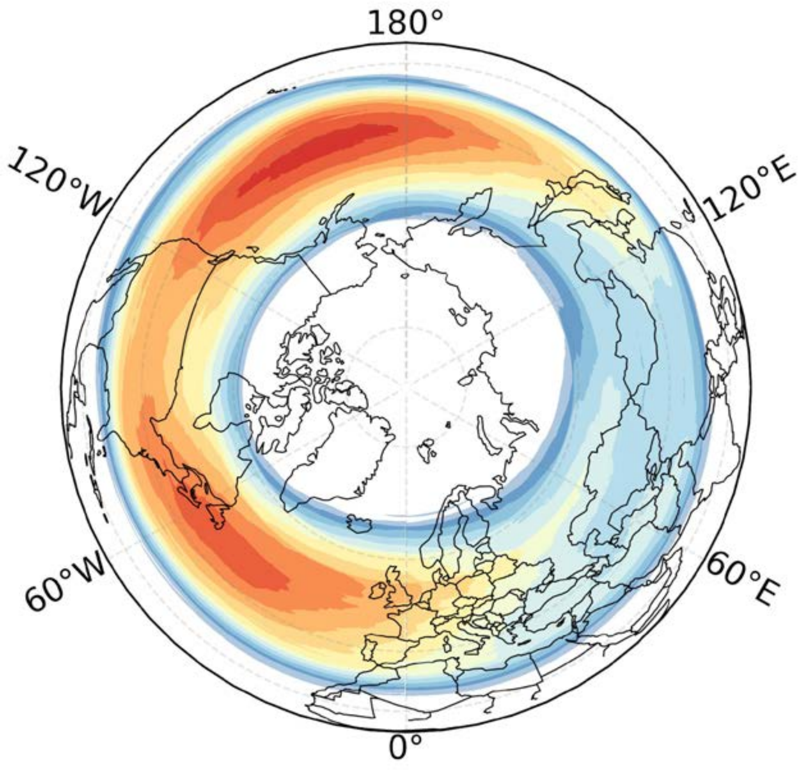
$$q = \beta y + \nabla_H^2\psi + e^{z/H}\frac{\partial}{\partial z}\left(\frac{f_0^2 e^{-z/H}}{N^2}\frac{\partial \psi}{\partial z}\right)$$

$$\frac{d_g}{dt} = \frac{d_1}{dt} = \frac{\partial}{\partial t} - \frac{\partial \psi}{\partial y}\frac{\partial}{\partial x} + \frac{\partial \psi}{\partial x}\frac{\partial}{\partial y}$$

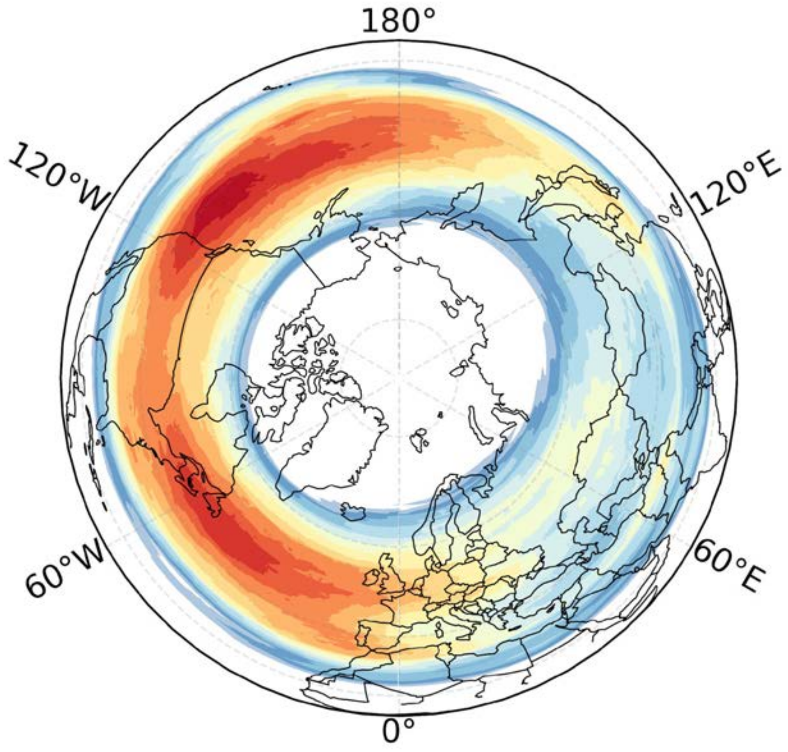
RWP PRECEDING THE EVENTS

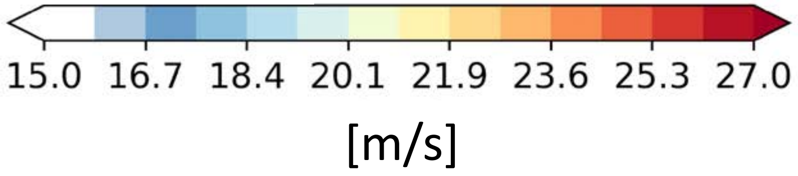
RWP ENVELOPE

SEASONAL MEAN

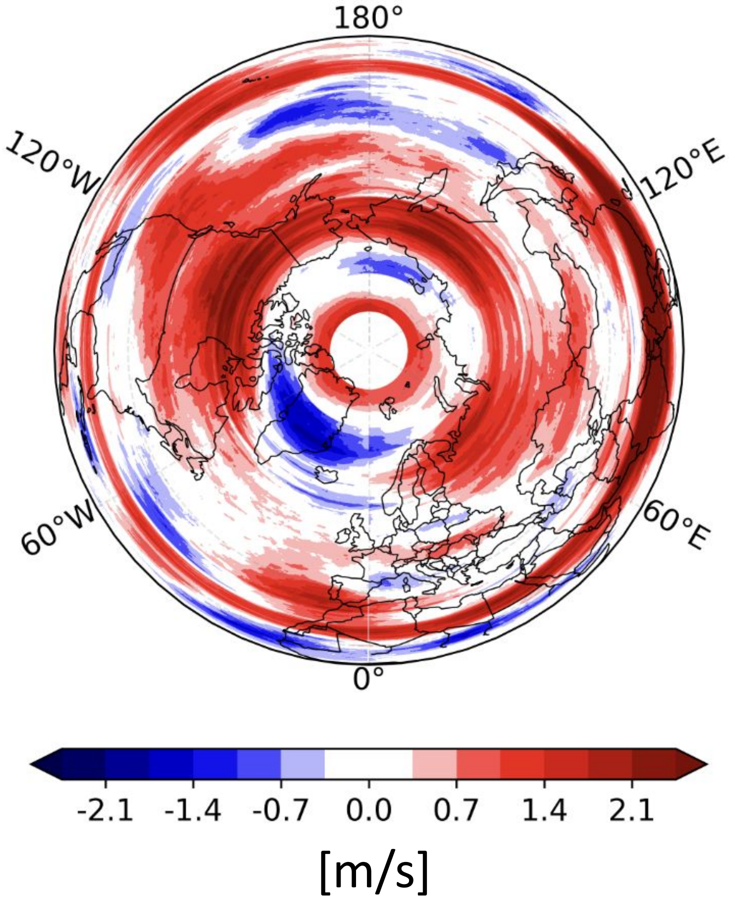


MEAN OF ALL 15 DAYS PRIOR HEATWAVES





DIFFERENCE



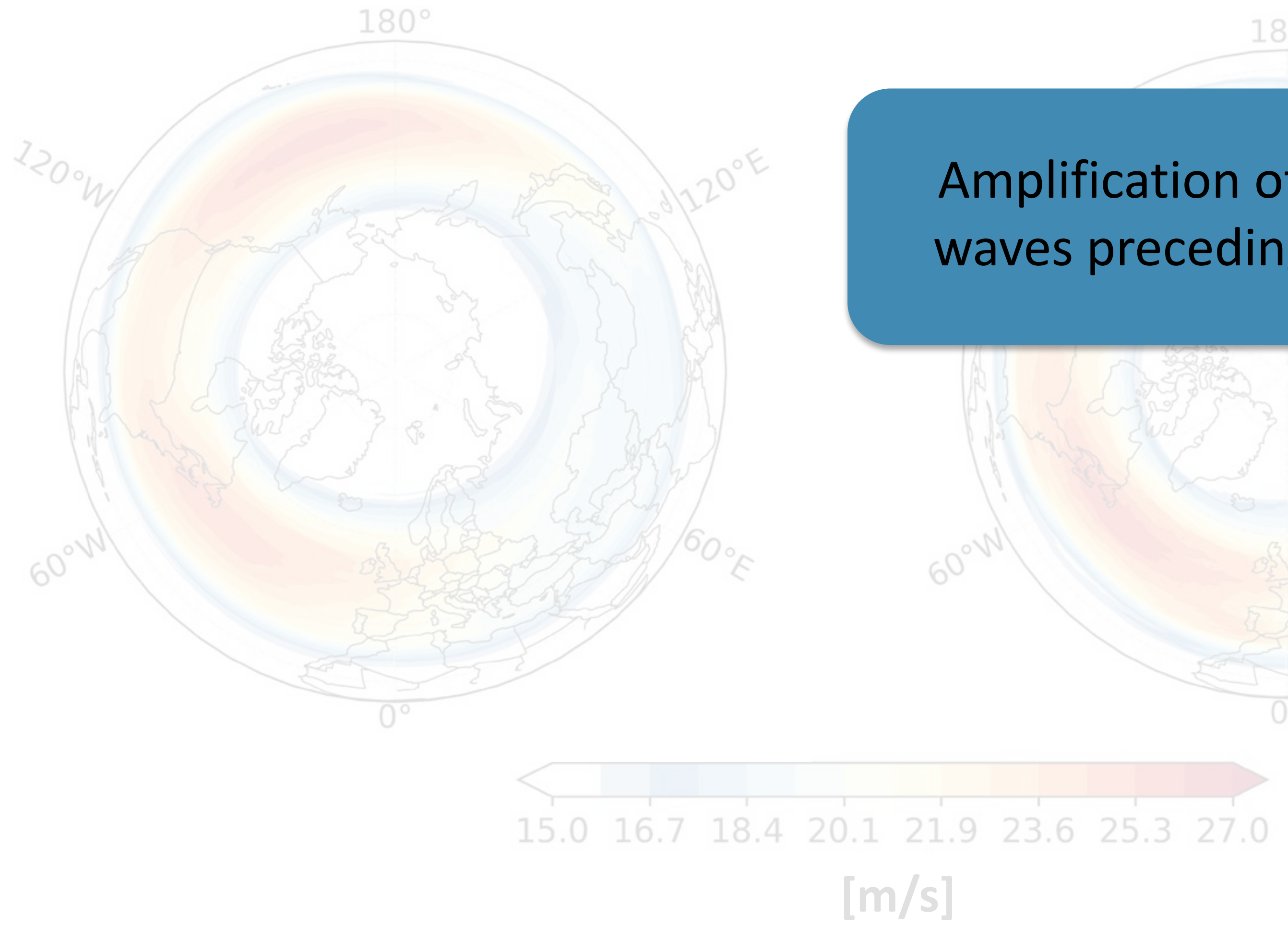
Castañeda and Wang (in prep.)

RWP PRECEDING THE EVENTS

RWP ENVELOPE

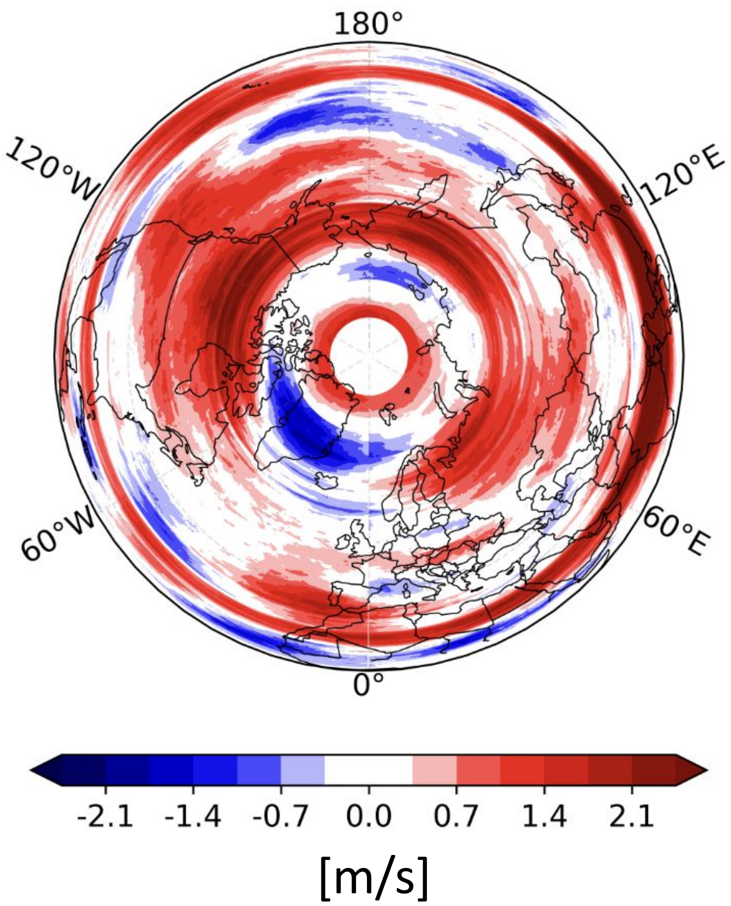
SEASONAL MEAN

MEAN OF ALL 15 DAYS PRIOR HEATWAVES



Amplification of the Rossby waves preceding the events

DIFFERENCE



What is the role of basic states providing favorable dynamic conditions for high-amplitude RWPs on blocking and heatwaves statistics?

HEATWAVES VS. NON HEATWAVES

Gradient of QGPV (waveguide)

Evolution

Day -20

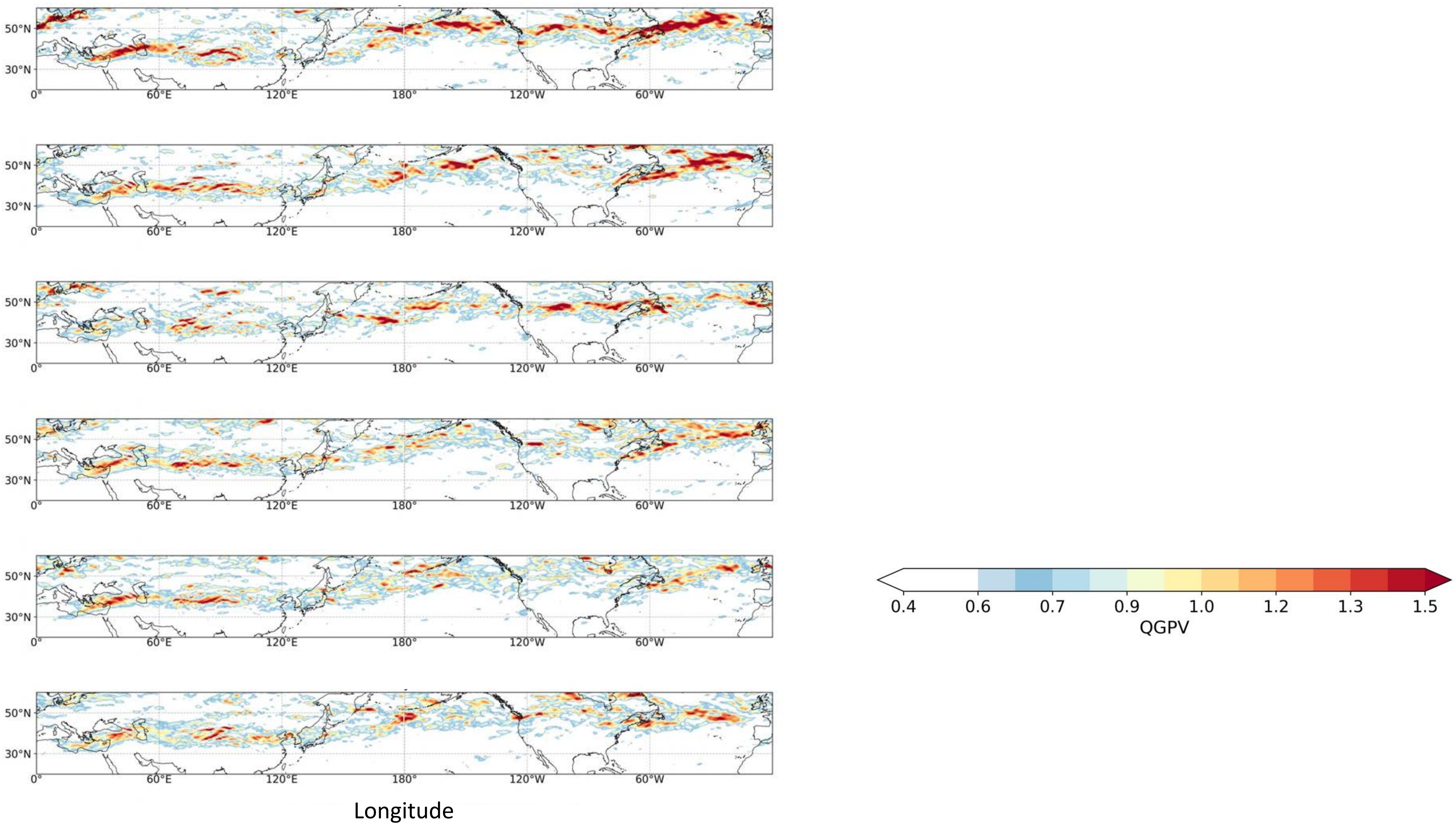
Day -15

Day -10

Day -5

First day of US heatwaves

Day 5



HEATWAVES VS. NON HEATWAVES

Gradient of QGPV (waveguide)

Evolution

Day -20

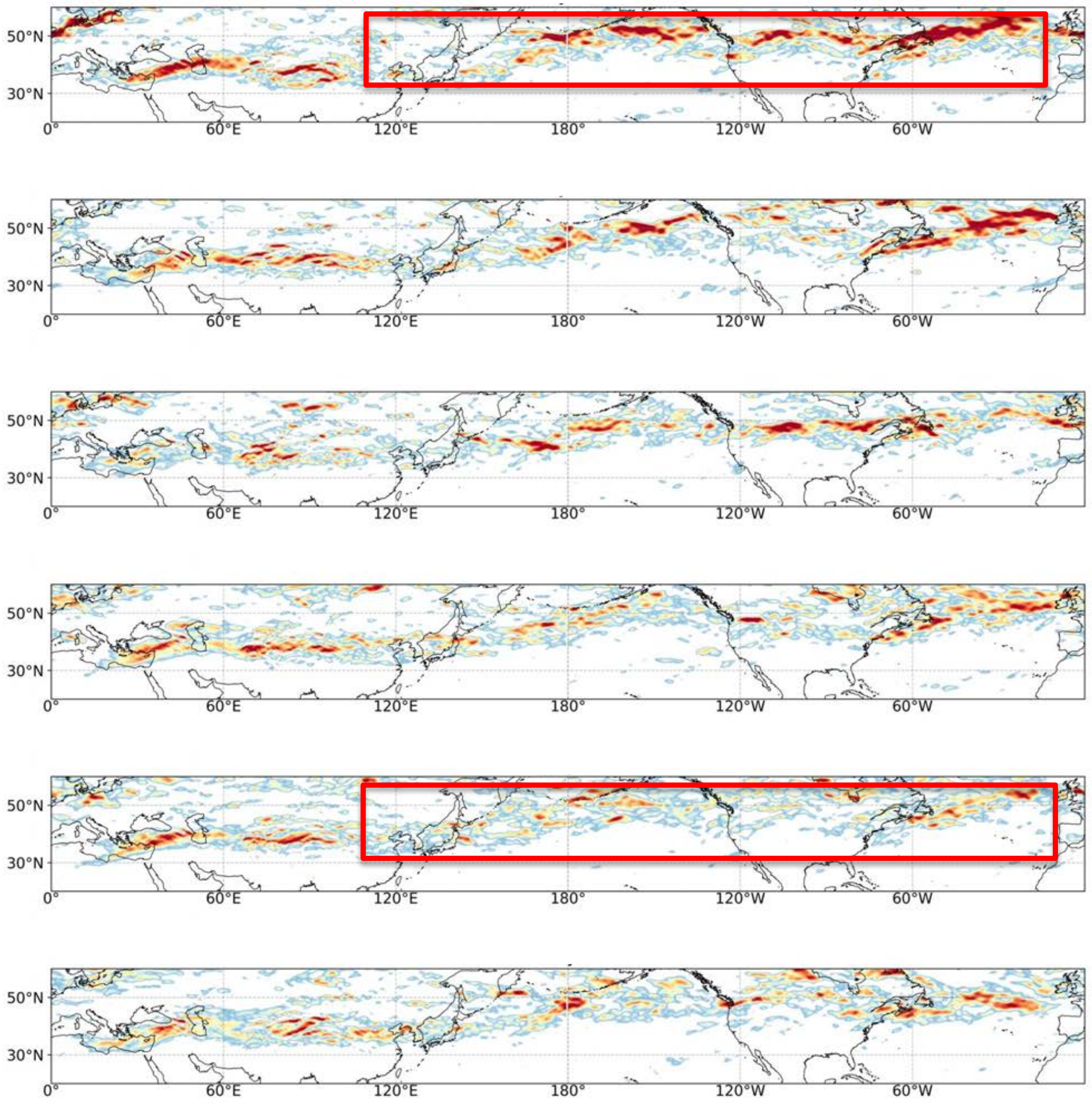
Day -15

Day -10

Day -5

First day of US heatwaves

Day 5



Longitude

Weaker waveguides
□ (?) □ heatwaves

DATA AND METHODS: MODEL

- **Dry dynamical core proposed by Held and Suarez, 1994.**

Simple Newtonian relaxation

$$\frac{\partial T}{\partial t} = \frac{T - T_{eq}}{\tau}$$

$$T_{eq(N+1)} = T_{eq(N)} - \frac{2}{3}(T_{(N)} - T_R),$$

$$N = 1, 2, 3...$$

Chang, 2006

- **Idealized** model: No diurnal cycles, no seasonal cycles, no topography
- Isolates the **dry dynamics**

DATA AND METHODS: EXPERIMENTS

- **Dry dynamical core proposed by Held and Suarez, 1994.**

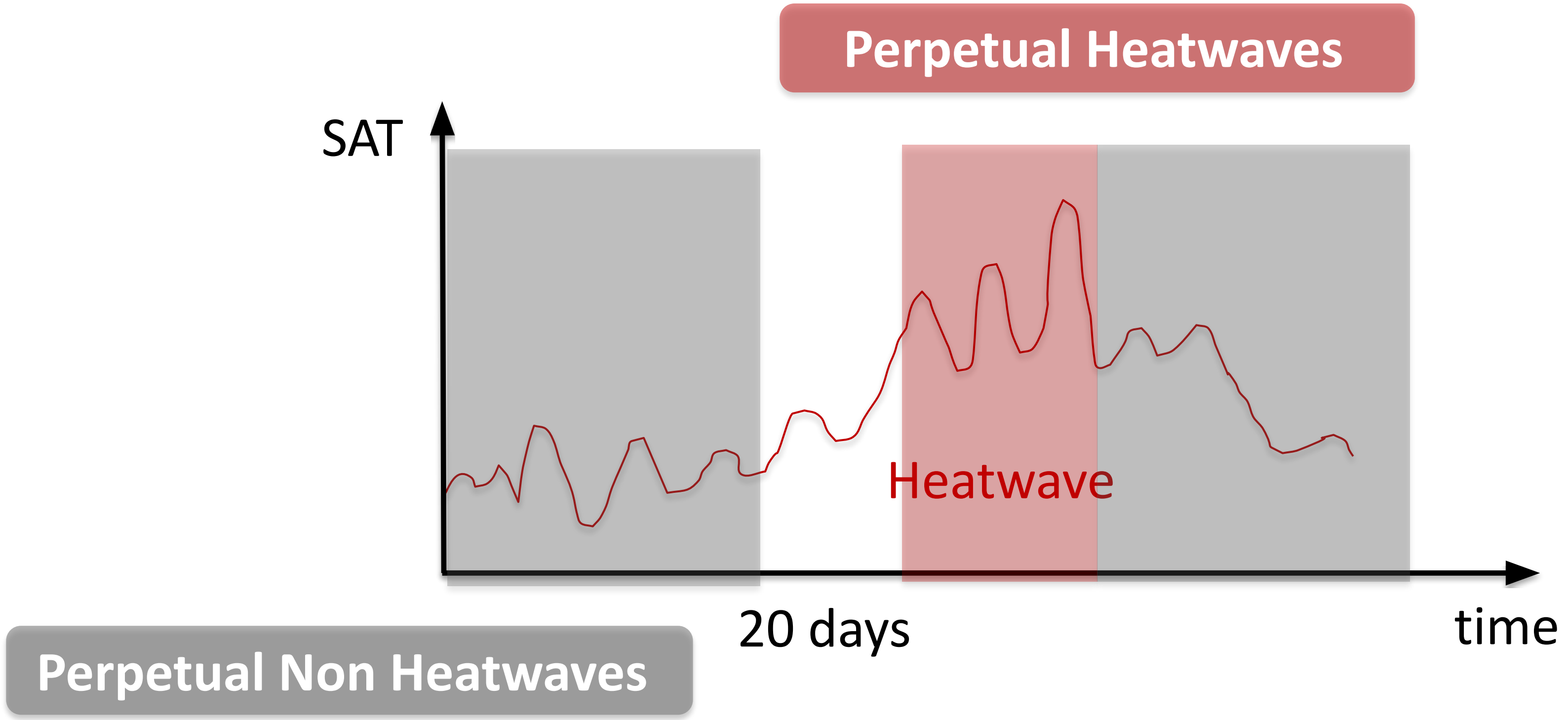
Simple Newtonian relaxation

$$\frac{\partial T}{\partial t} = \frac{T - T_{eq}}{\tau}$$

$$T_{eq(N+1)} = T_{eq(N)} - \frac{2}{3}(T_{(N)} - T_R),$$

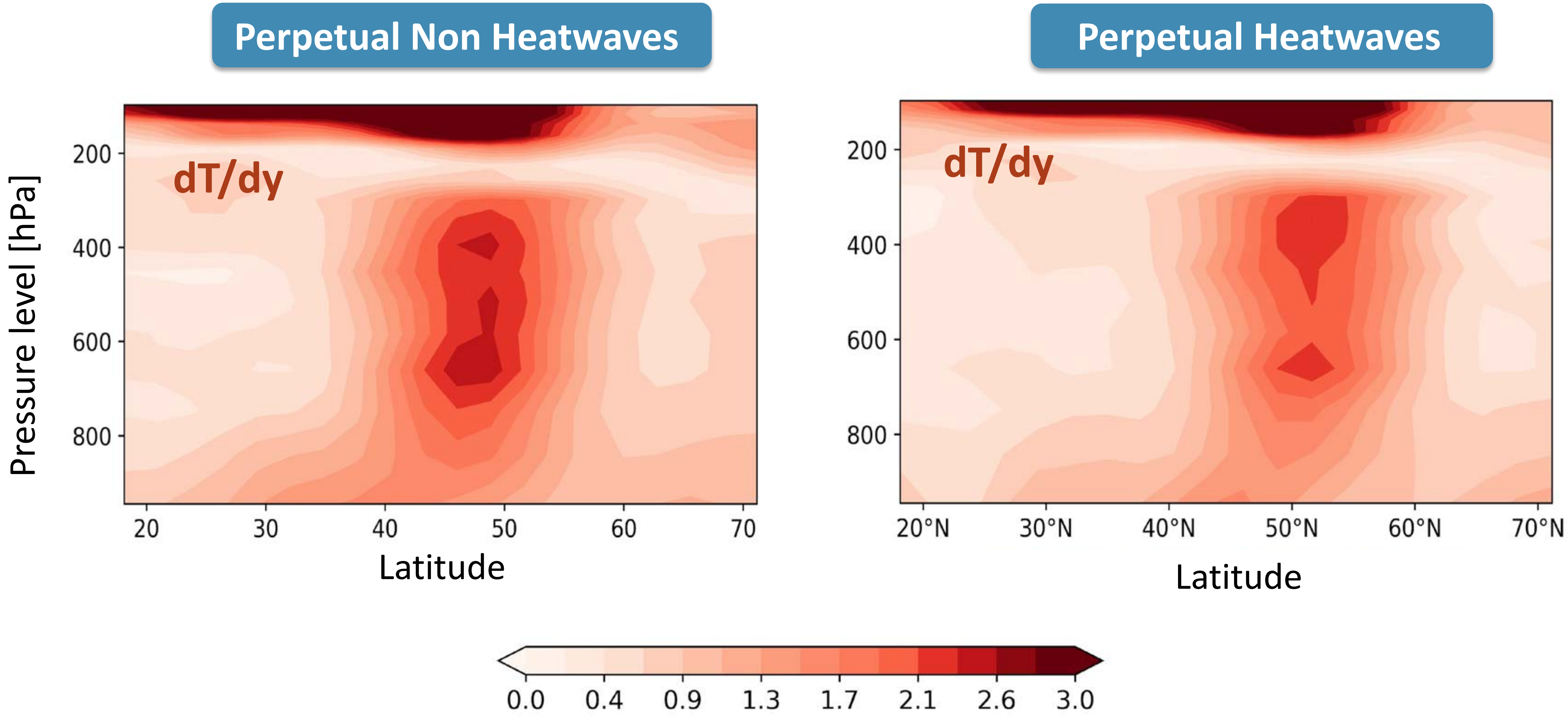
$$N = 1, 2, 3...$$

Chang, 2006



PURDUE UNIVERSITY

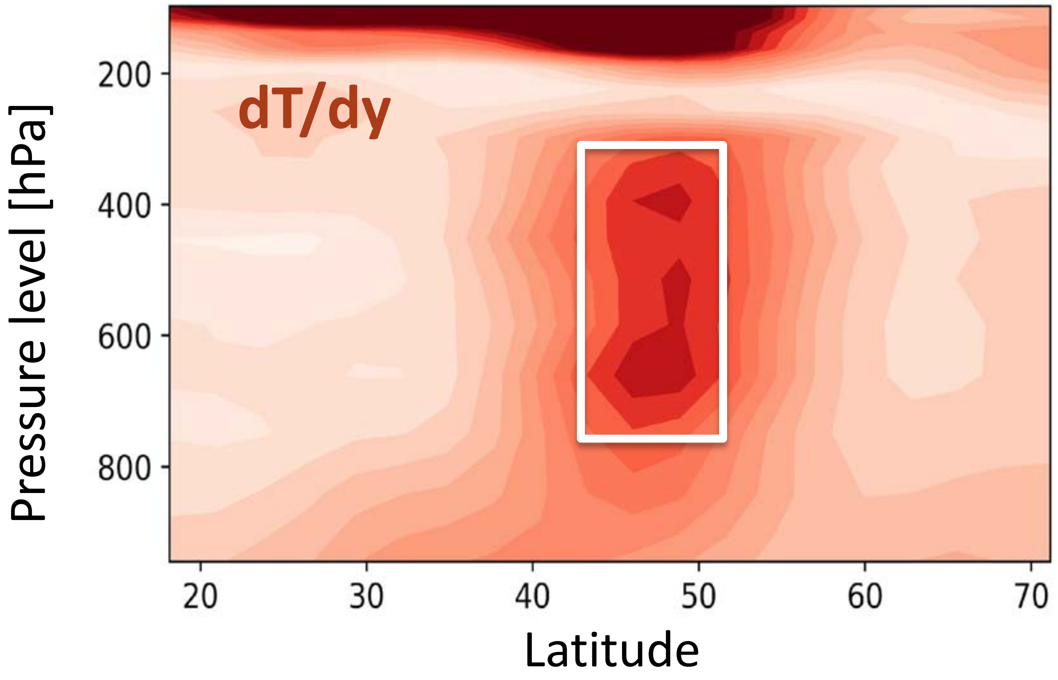
BASIC STATES - EXPERIMENTS



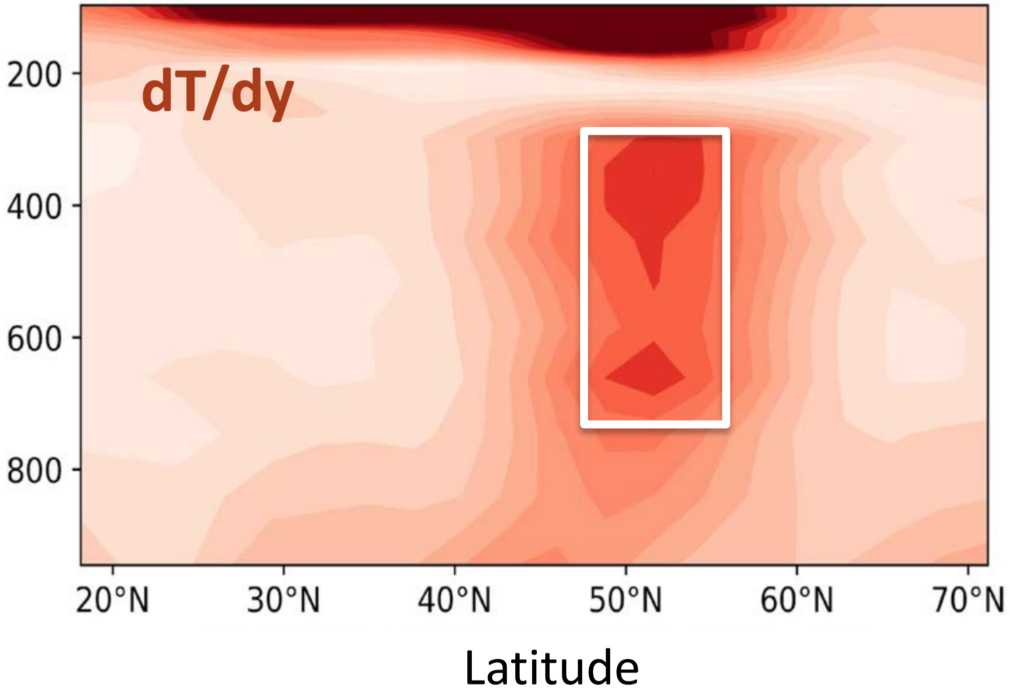
PURDUE UNIVERSITY

BASIC STATES - EXPERIMENTS

Perpetual Non Heatwaves



Perpetual Heatwaves



Lower **meridional temperature gradients**

BASIC STATES - EXPERIMENTS

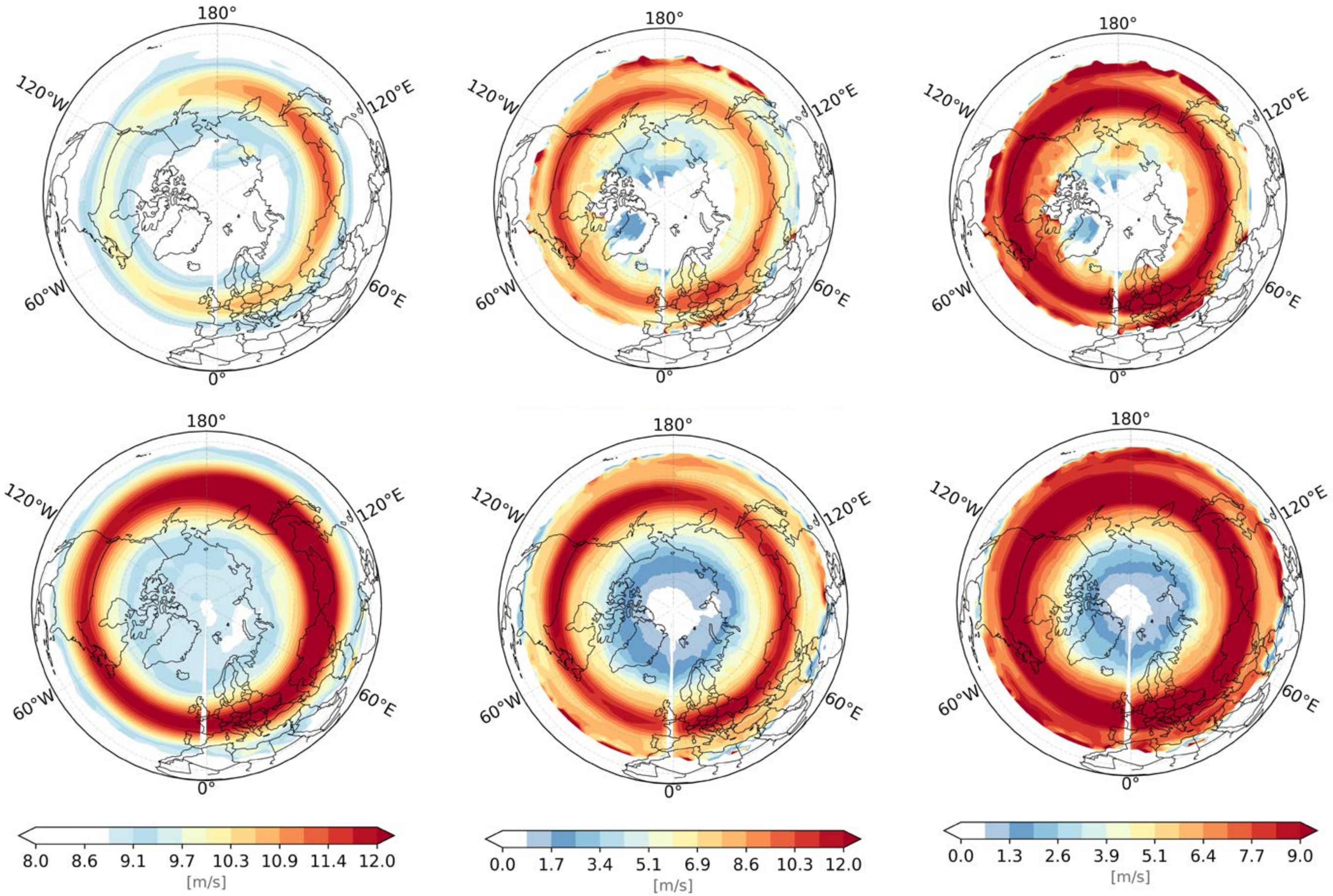
ENVELOPE | **GROUP VELOCITY** | **PHASE SPEED**

Perpetual Heatwaves

Seasonal mean

Perpetual Non Heatwaves

Seasonal mean



PURDUE UNIVERSITY

BASIC STATES - EXPERIMENTS

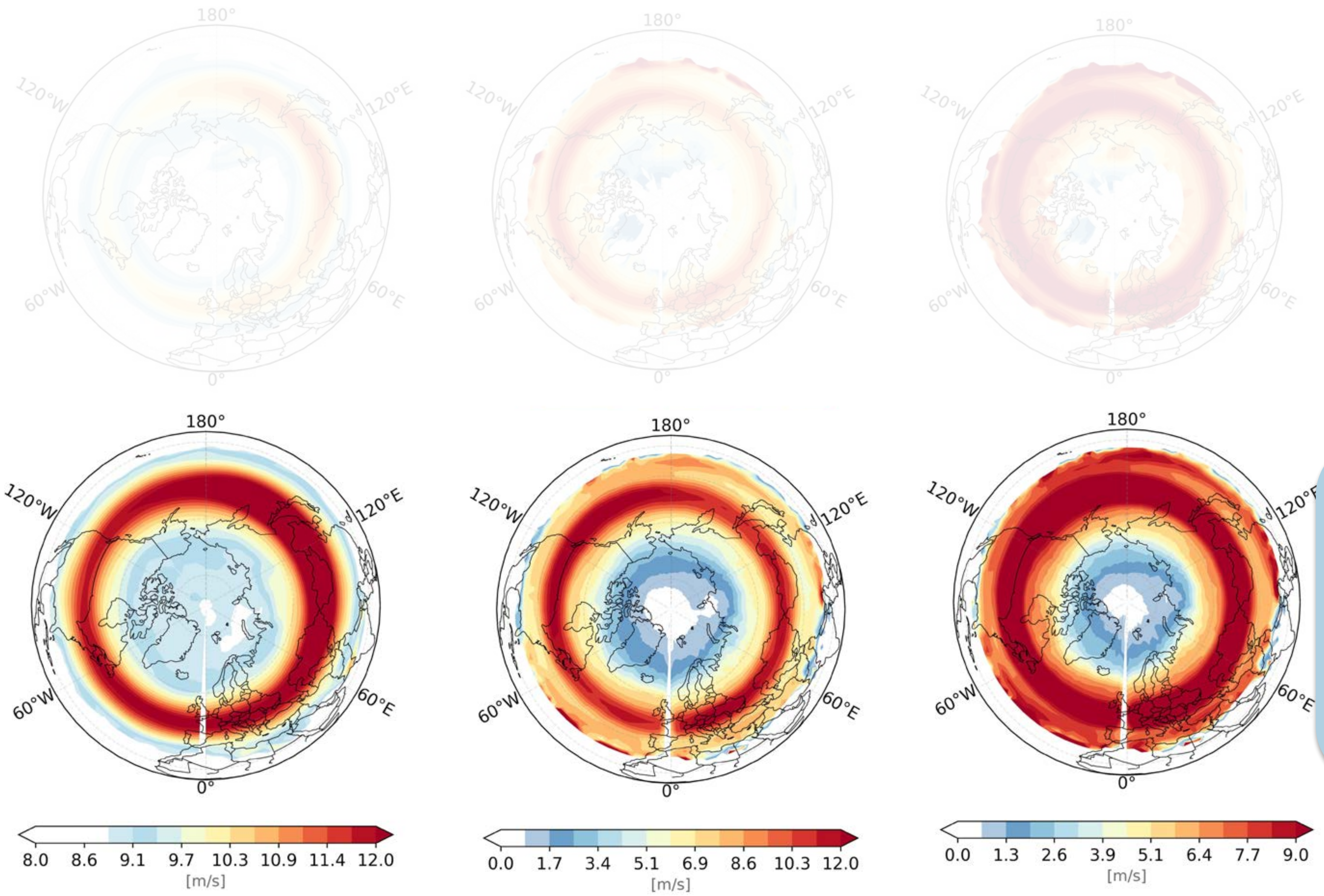
ENVELOPE | GROUP VELOCITY | PHASE SPEED

Perpetual Heatwaves

Seasonal mean

Perpetual Non Heatwaves

Seasonal mean



Very fast propagation not optimal for providing conditions for heatwaves

PURDUE UNIVERSITY

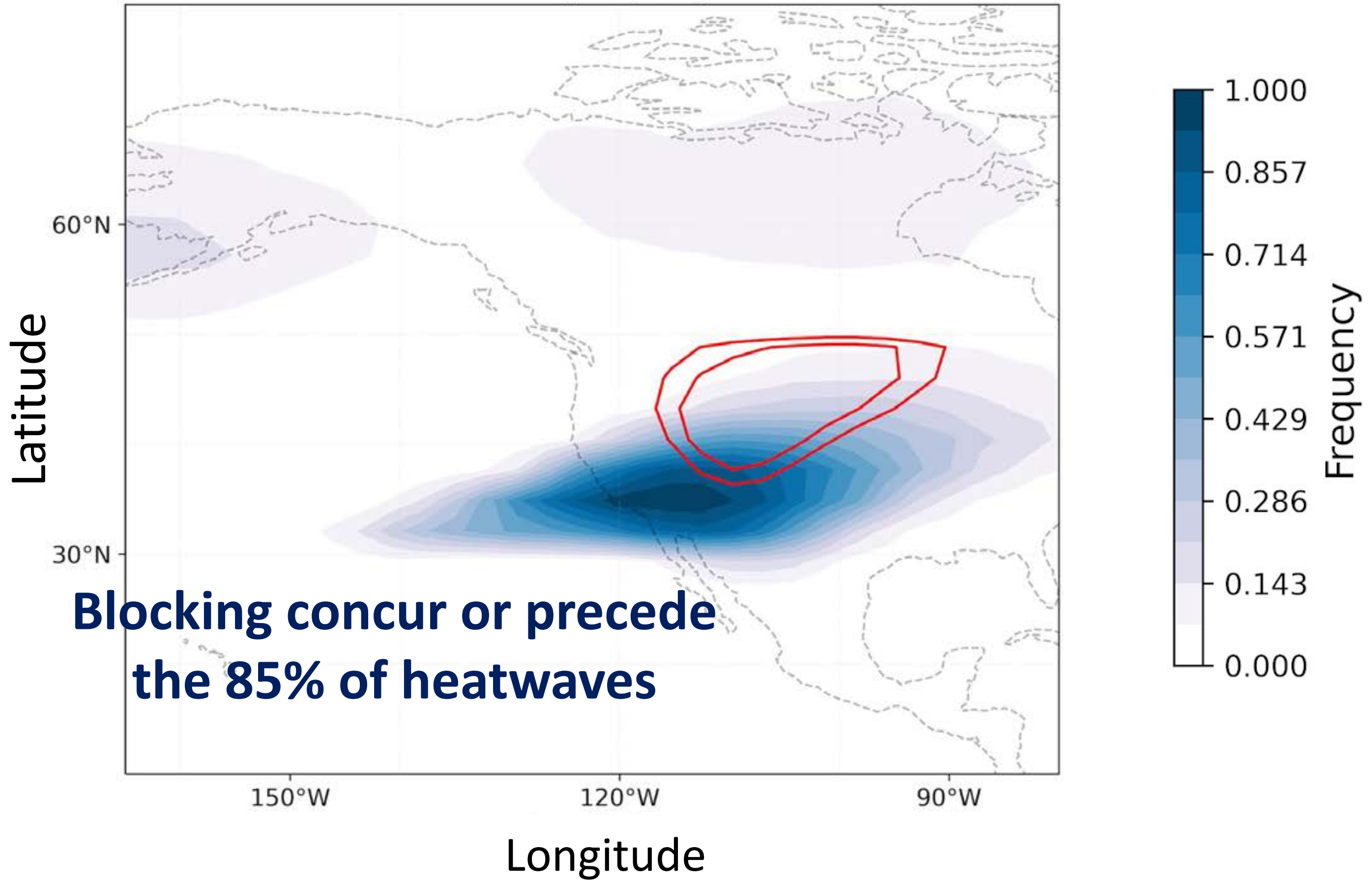
RESULTS: HEATWAVES AND BLOCKING FROM THE EXPERIMENTS

Blocking events preceding or concurring with heatwaves:

Perpetual Non Heatwaves

No events

Perpetual Heatwaves



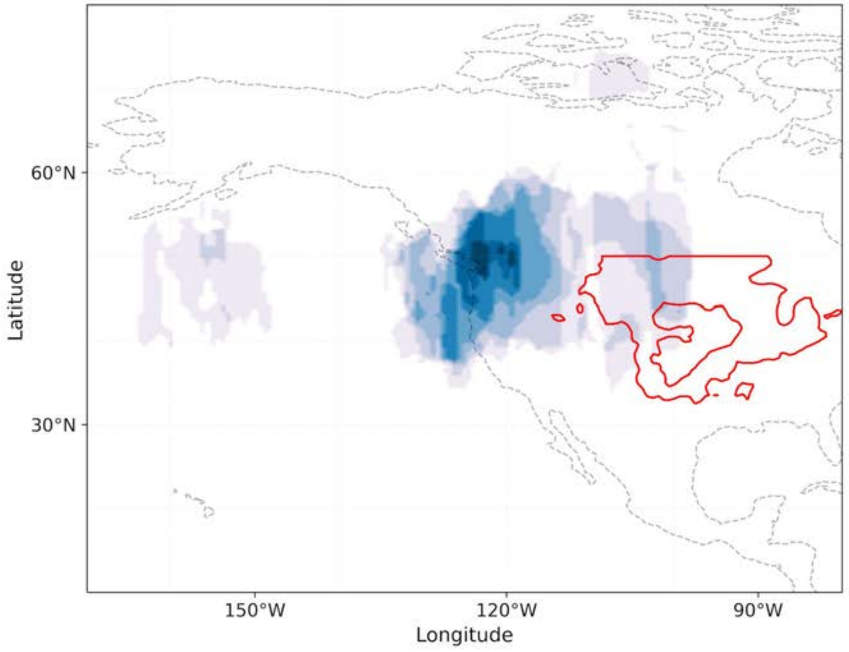
Blocking concur or precede the 85% of heatwaves

PURDUE UNIVERSITY

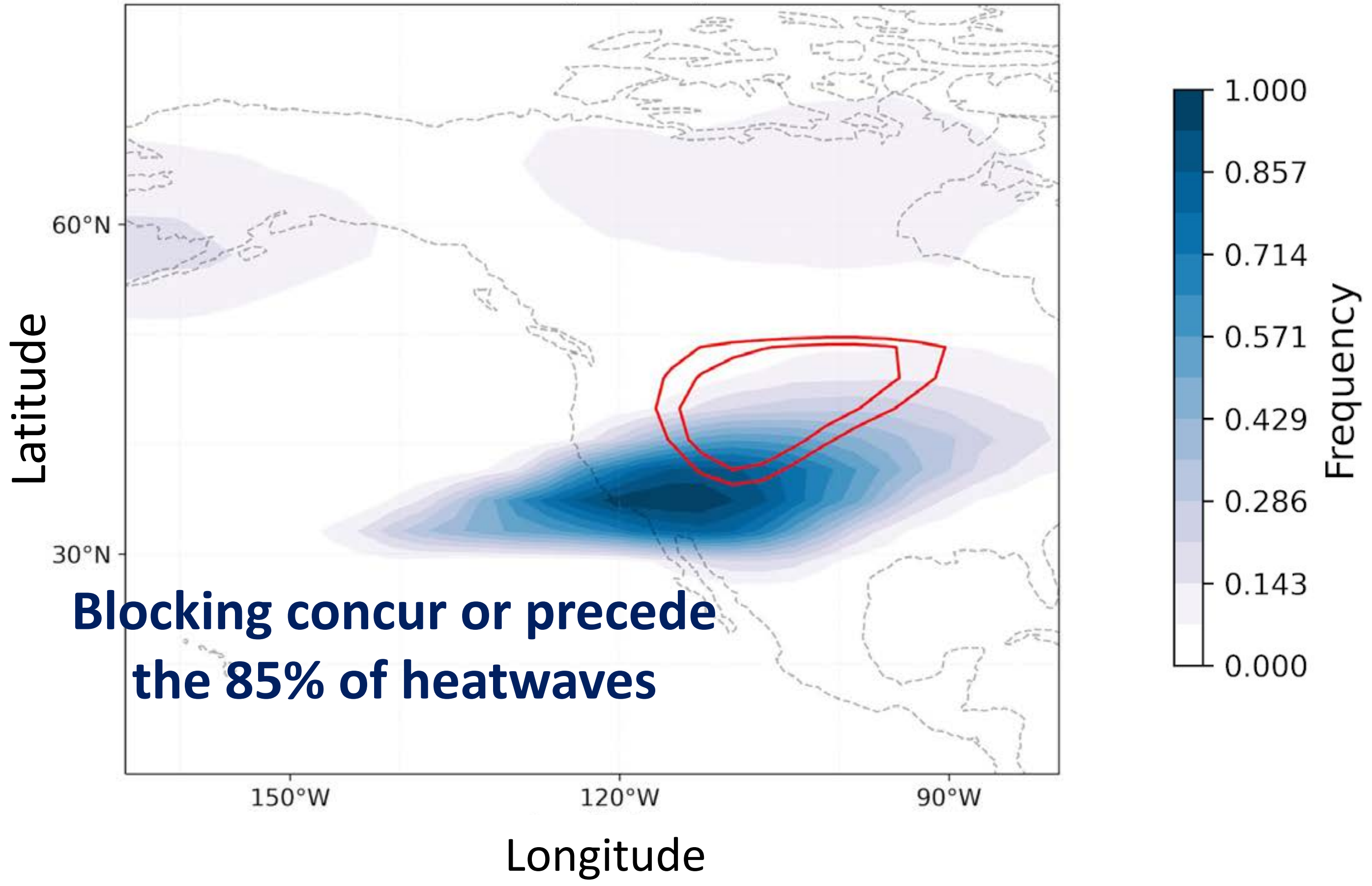
RESULTS: HEATWAVES AND BLOCKING FROM THE EXPERIMENTS

Blocking events preceding or concurring with heatwaves:

Dry core resemble the concurrence and location of heatwaves and blocking events



Perpetual Heatwaves



Blocking concur or precede the 85% of heatwaves

Castañeda and Wang (in prep.)

PURDUE UNIVERSITY

RESULTS: PERPETUAL HEATWAVE EXPERIMENT

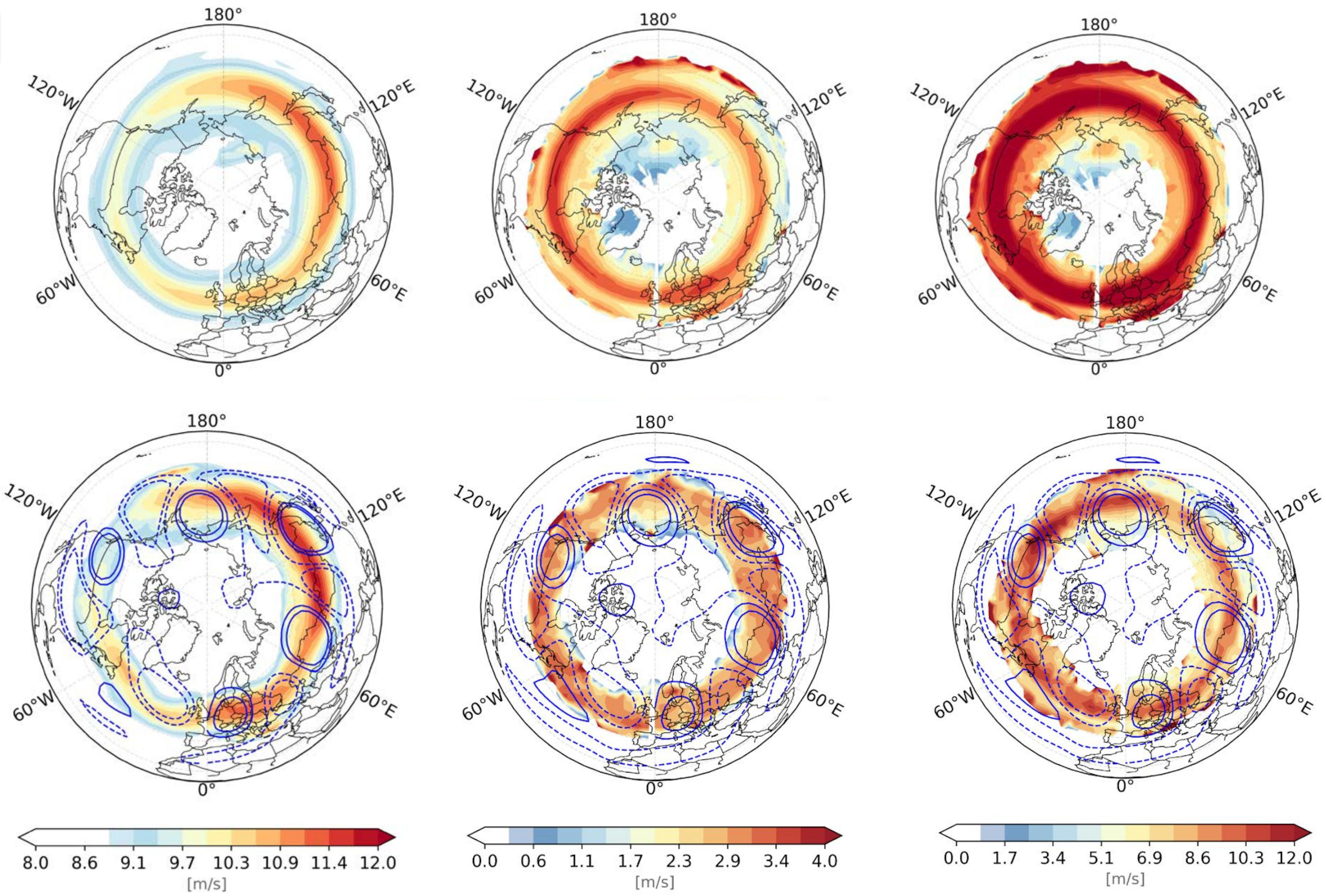
RESULTS: PERPETUAL HEATWAVE EXPERIMENT

ENVELOPE | **PHASE SPEED** | **GROUP VELOCITY**

Perpetual Heatwaves

Seasonal mean

Mean of all 15 days prior heatwaves



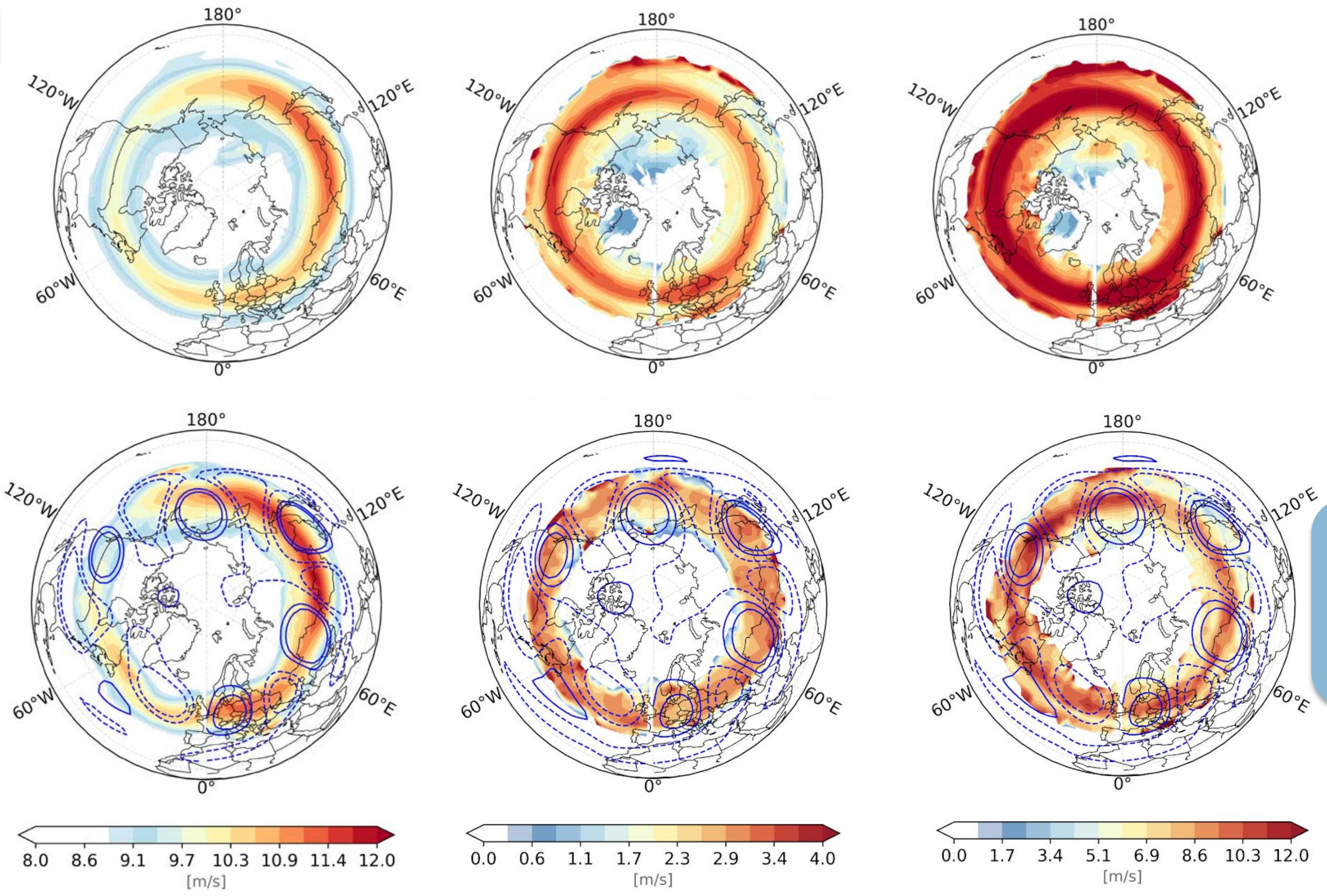
RESULTS: PERPETUAL HEATWAVE EXPERIMENT

ENVELOPE | **PHASE SPEED** | **GROUP VELOCITY**

Perpetual Heatwaves

Seasonal mean

Mean of all 15 days prior heatwaves



Wavenumber 5

Lower Cp and Cg

Amplified RWP

HEATWAVES VS. NON HEATWAVES

Gradient of QGPV (waveguide)

Evolution

Day -20

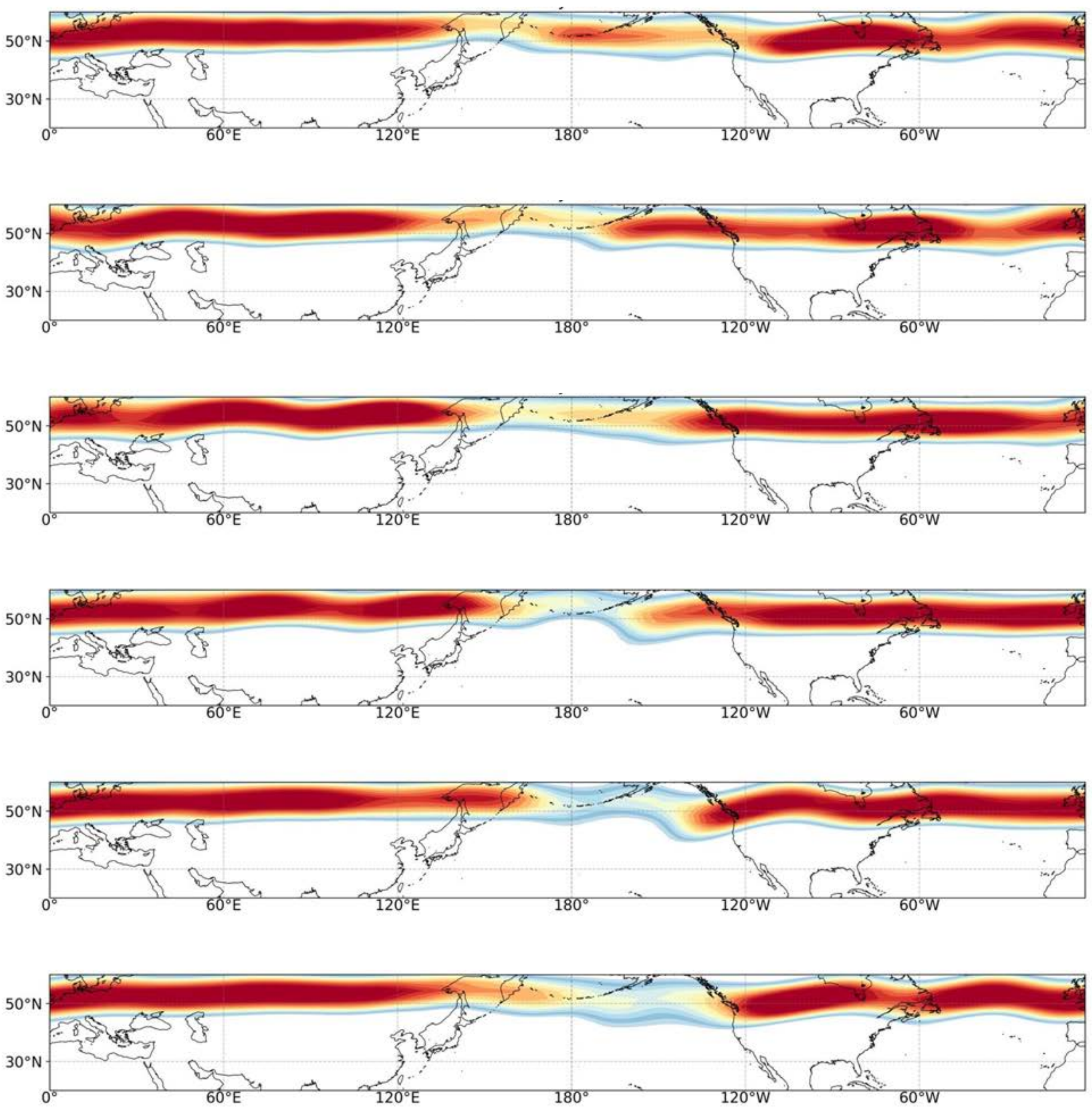
Day -15

Day -10

Day -5

First day of US heatwaves

Day 5



Longitude

Weaker waveguides
□ heatwaves

HEATWAVES VS. NON HEATWAVES

Gradient of QGPV (waveguide)

Evolution

Day -20

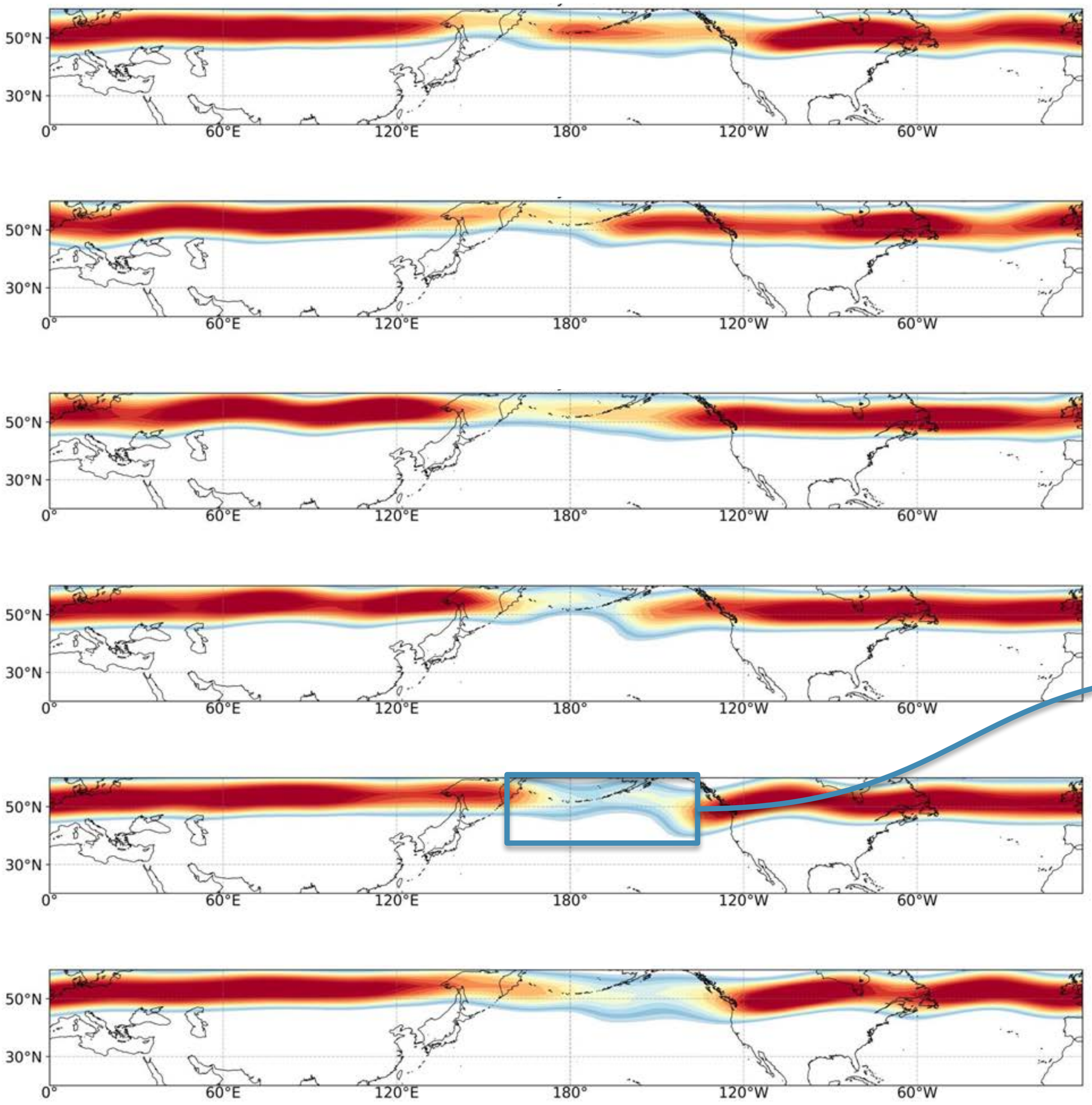
Day -15

Day -10

Day -5

First day of US heatwaves

Day 5

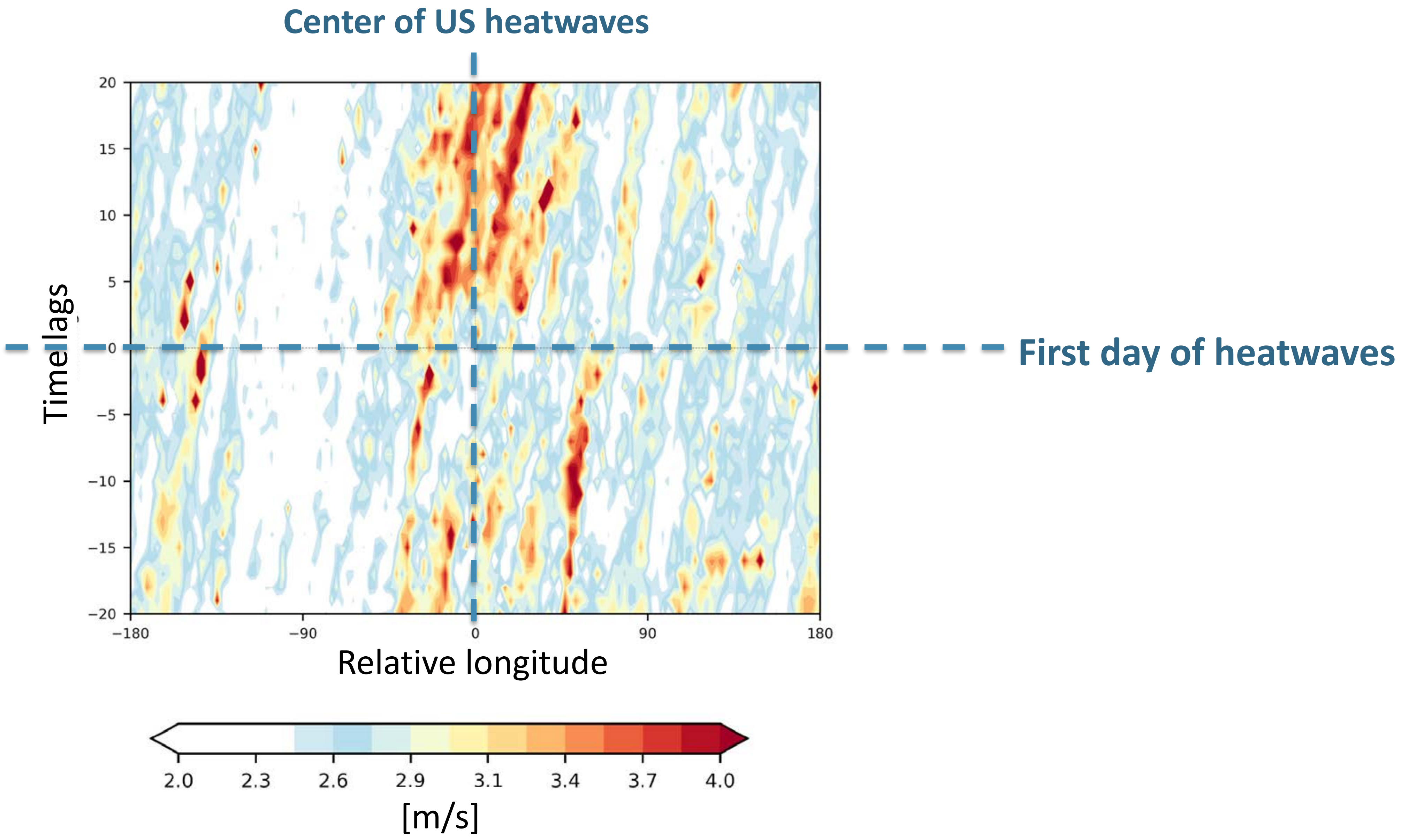


Longitude

"Swamp" of the storm track: reduction of the PV gradients (no waveguide)

RESULTS: PERPETUAL HEATWAVE EXPERIMENT

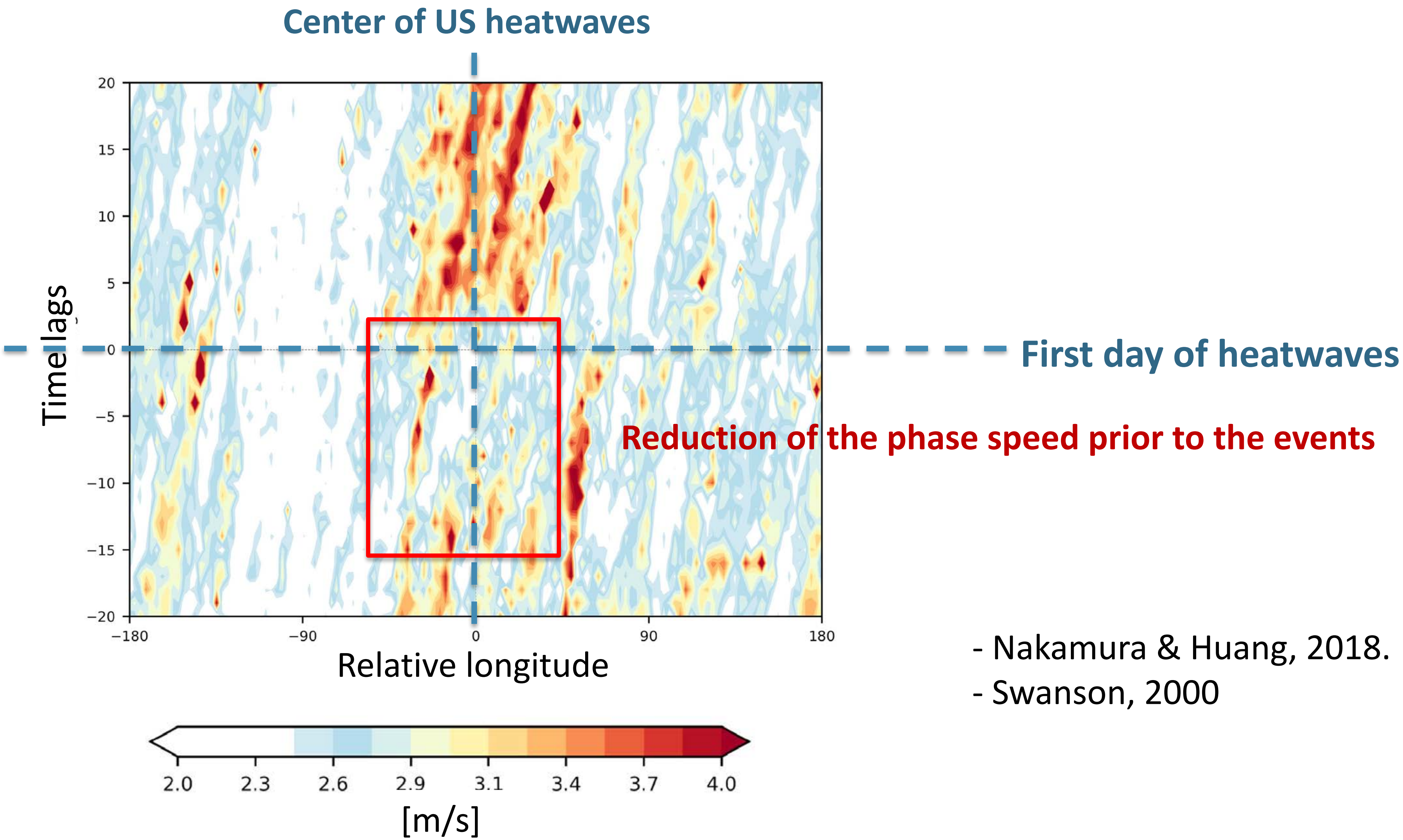
Hövmoller diagram for the **phase speed**:



Castañeda and Wang (in prep.)

RESULTS: PERPETUAL HEATWAVE EXPERIMENT

Hövmoller diagram for the **phase speed**:



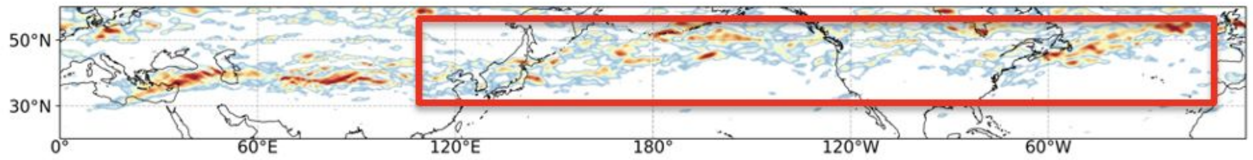
- Nakamura & Huang, 2018.
- Swanson, 2000

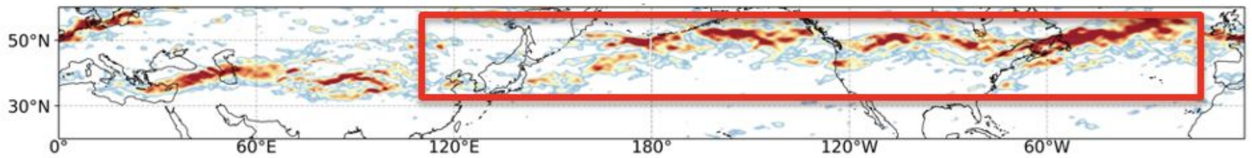
Castañeda and Wang (in prep.)

PURDUE UNIVERSITY

SUMMARY

1. The background state during heat waves days is characterized by weaker QGPV gradients at preferred regions.





2. This background state acts as as waveguide for the RWP propagation and formation of the “Storm Swamp”

3. The ”storm swamp” provides favorable dynamical conditions for blocking and heatwaves in the US
    - Amplified RWPs
    - Reduced phase speed

4. The dry dynamics are able to reproduce the heatwaves, blocking events and the fundamental mechanism