An Intraseasonal Mode of Atmospheric Variability Relevant to the U.S. Extreme Precipitation in Boreal Summer: Dynamic Origin and East Asia Connection

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Hydrological extremes

- **Hydrological extremes include both extreme precipitation events and drought events.**




Impacts of hydrological extremes

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- **Many regions in the world suffer from these events.**

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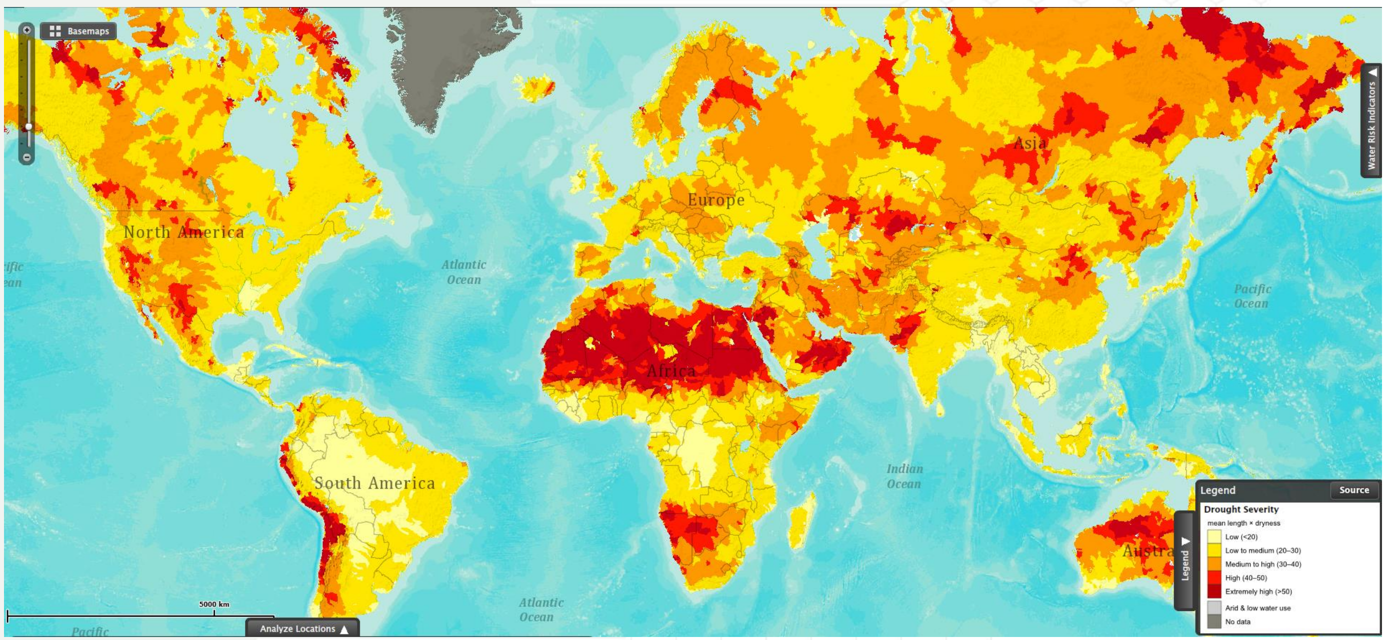

Impacts of hydrological extremes

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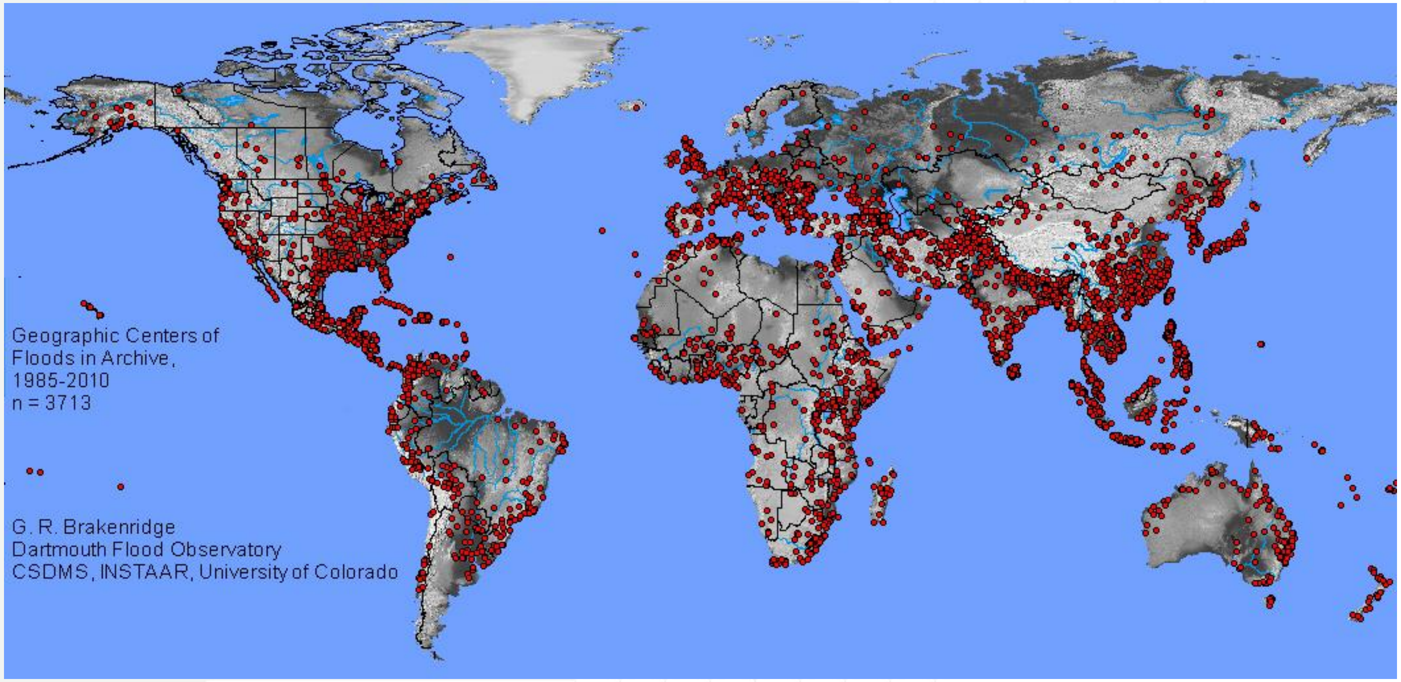
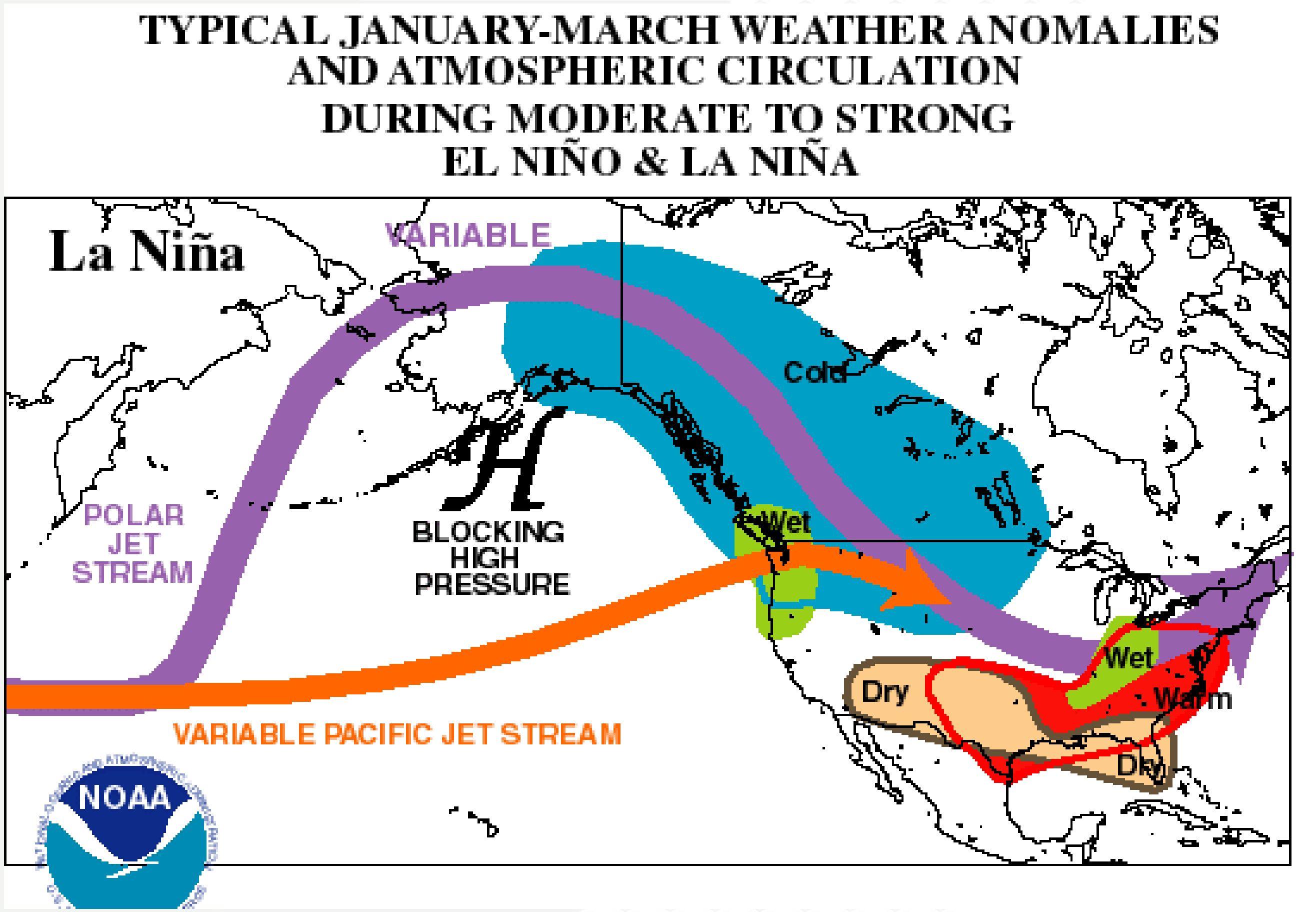


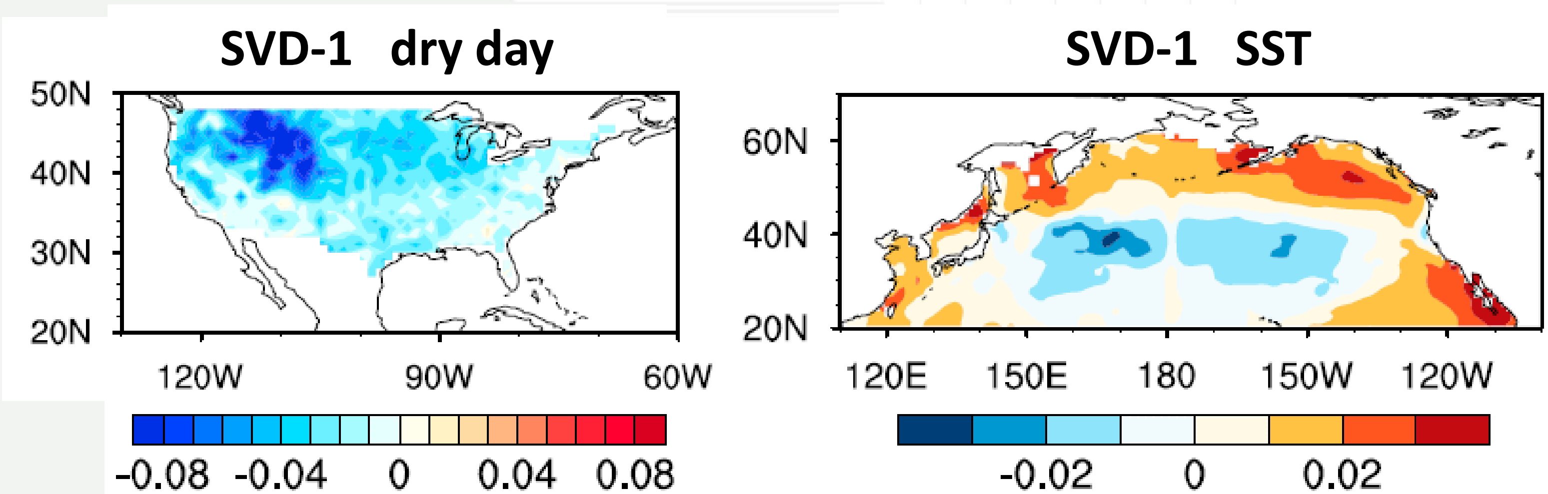
Potential influences on U.S. hydrological extremes

➢ **ENSO effect in winter**



Potential influences on U.S. hydrological extremes

➢ **PDO/ENSO effect in summer**



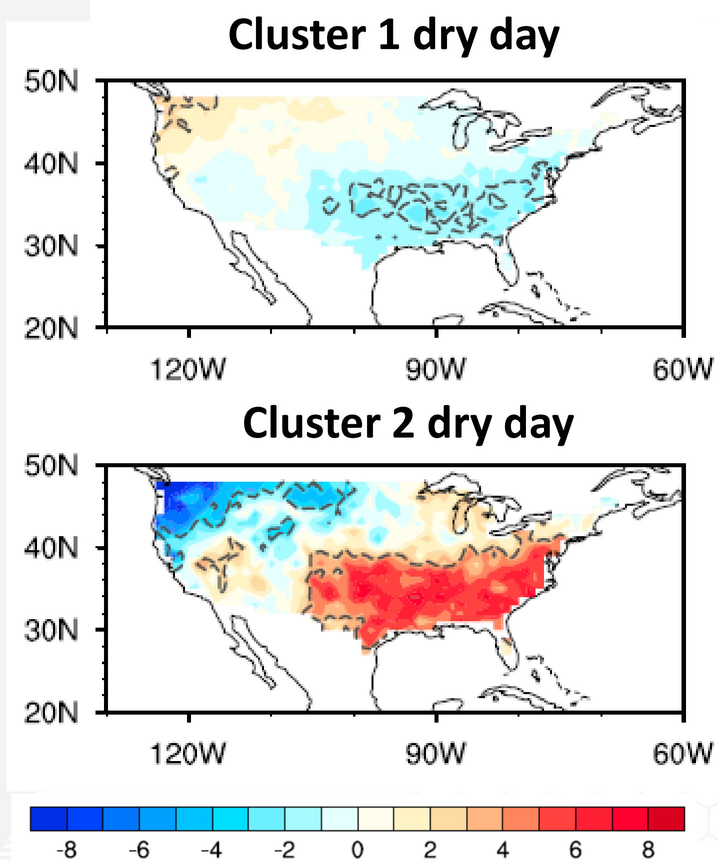
More precipitation

Positive PDO phase

——*Zhao et al. 2017*

Potential influences on U.S. hydrological extremes

➢ **Precipitation in summer beyond PDO/ENSO effect**



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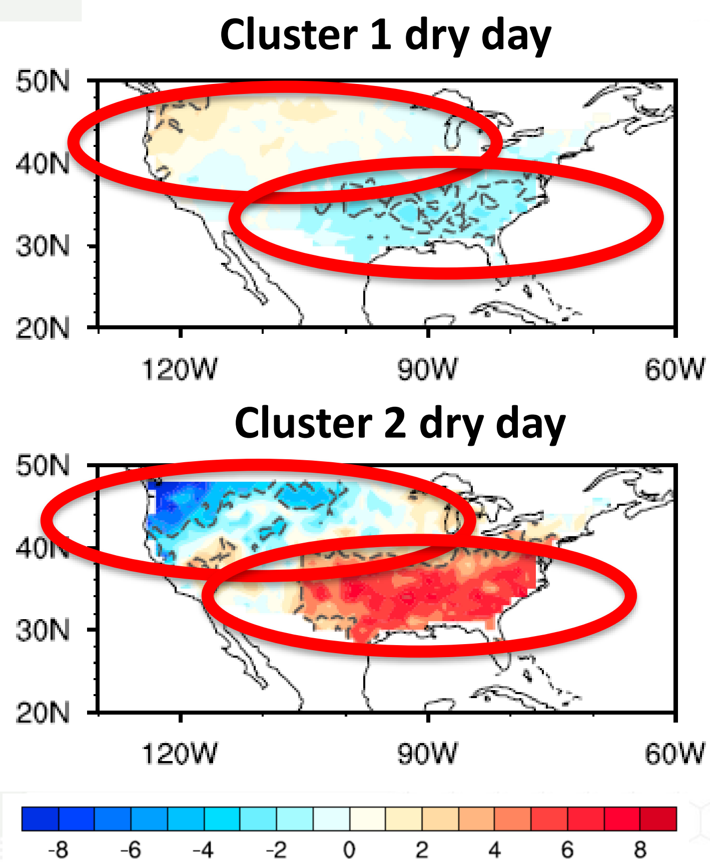
Potential influences on U.S. hydrological extremes

- Precipitation in summer beyond PDO/ENSO effect



Dipole structure

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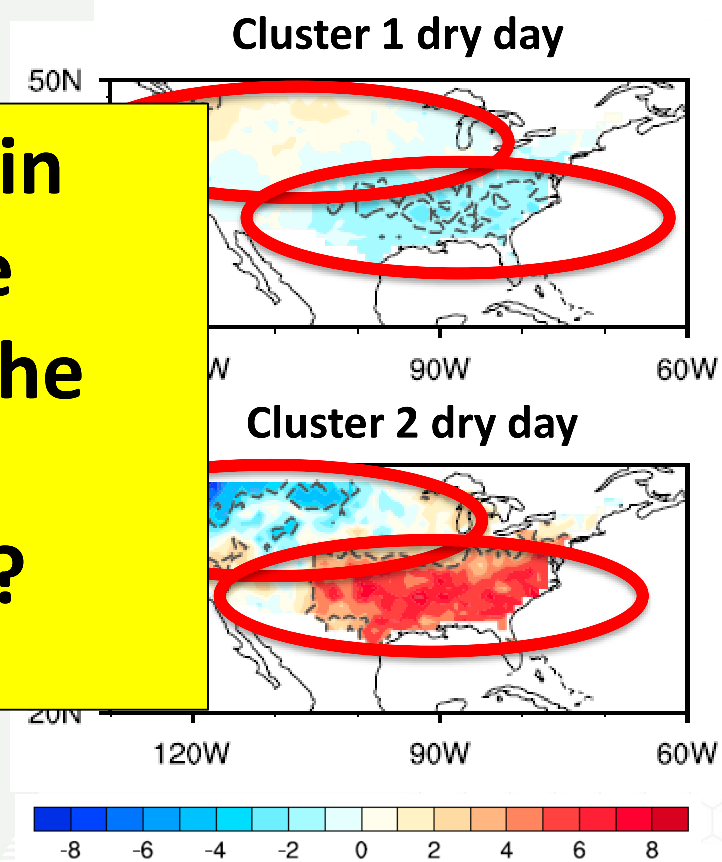
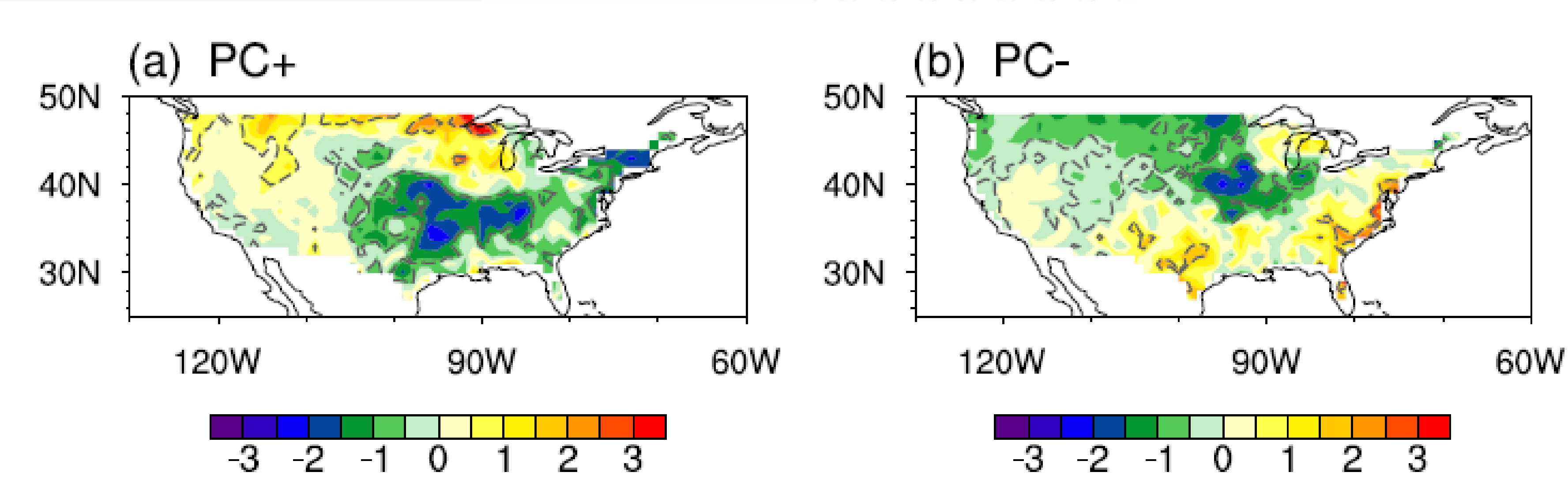


Dynamic origin for the dipole structure of the U.S. summer precipitation?

Datasets

- Geopotential height and zonal and meridional winds (NCEP-NCAR Reanalysis; 2.5° ×2.5°)
- Precipitation (NOAA CPC unified gauge-based analysis of daily precipitation; 1° ×1°)
- Cloud liquid and ice water (NASA MERRA Reanalysis; 1° ×1°)
- CMIP5 model outputs (CCSM4 and GFDL-CM3)
- Study period: boreal summer (JJA) of 1950-2016

Precipitation associated with an intraseasonal mode in summer



——*Zhao et al. 2018*

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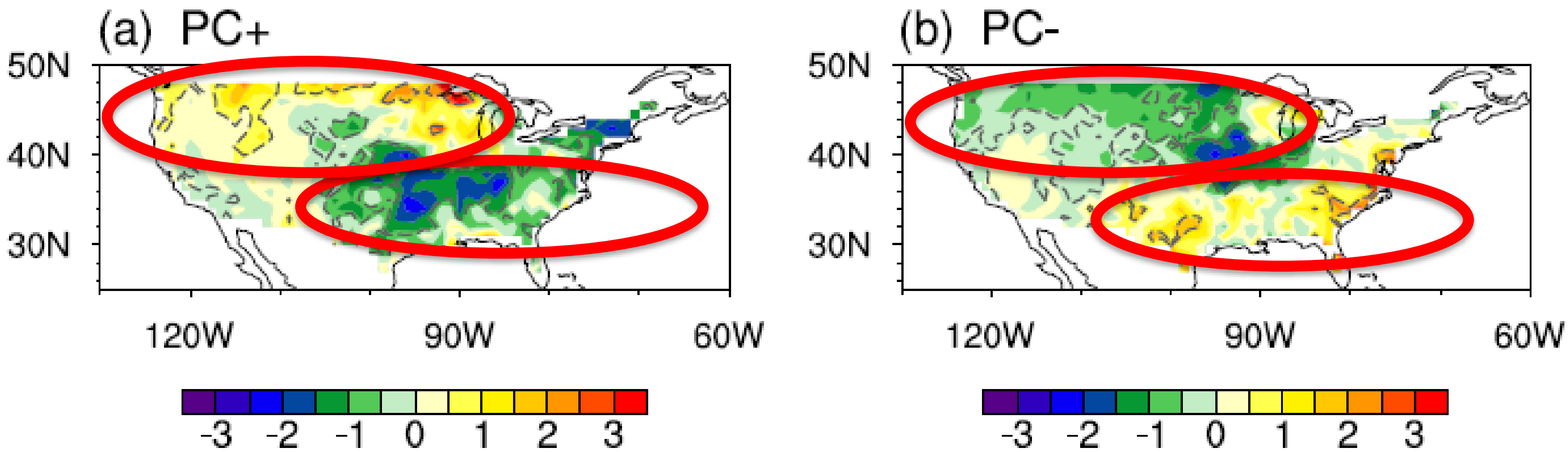
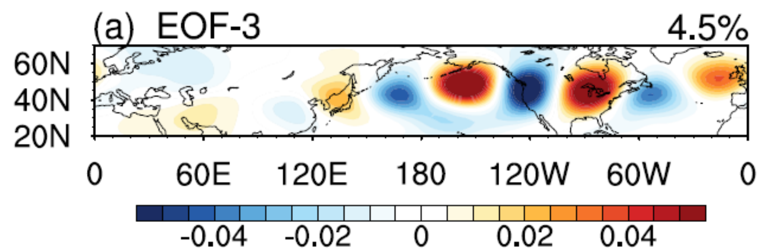
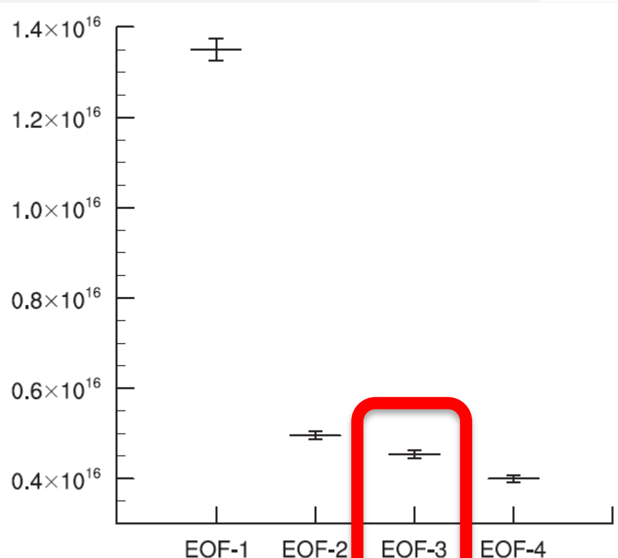


NW-SE oriented dipole structure

An intraseasonal mode

The third EOF mode (EOF-3) of the 10–90 day filtered daily streamfunction at 250 hPa during summer





Statistically distinct according to North et al. (1982)

——*Zhao et al. 2018*

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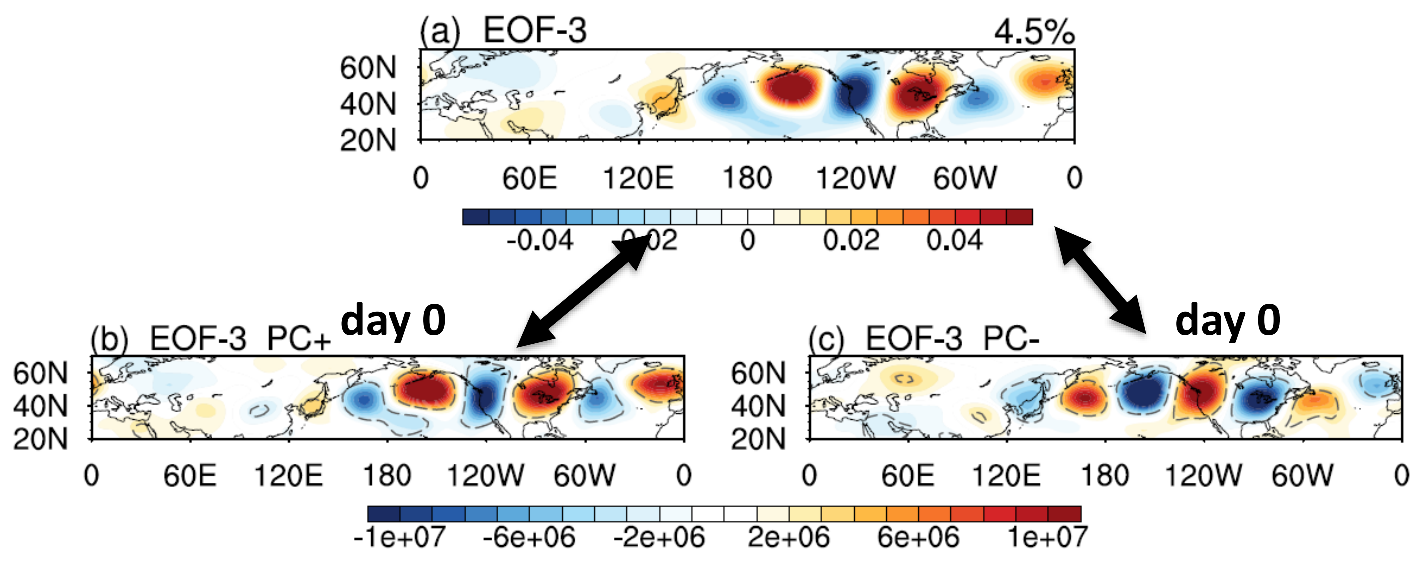

The same as EOF-3 mode

Opposite phase (sign)

An intraseasonal mode

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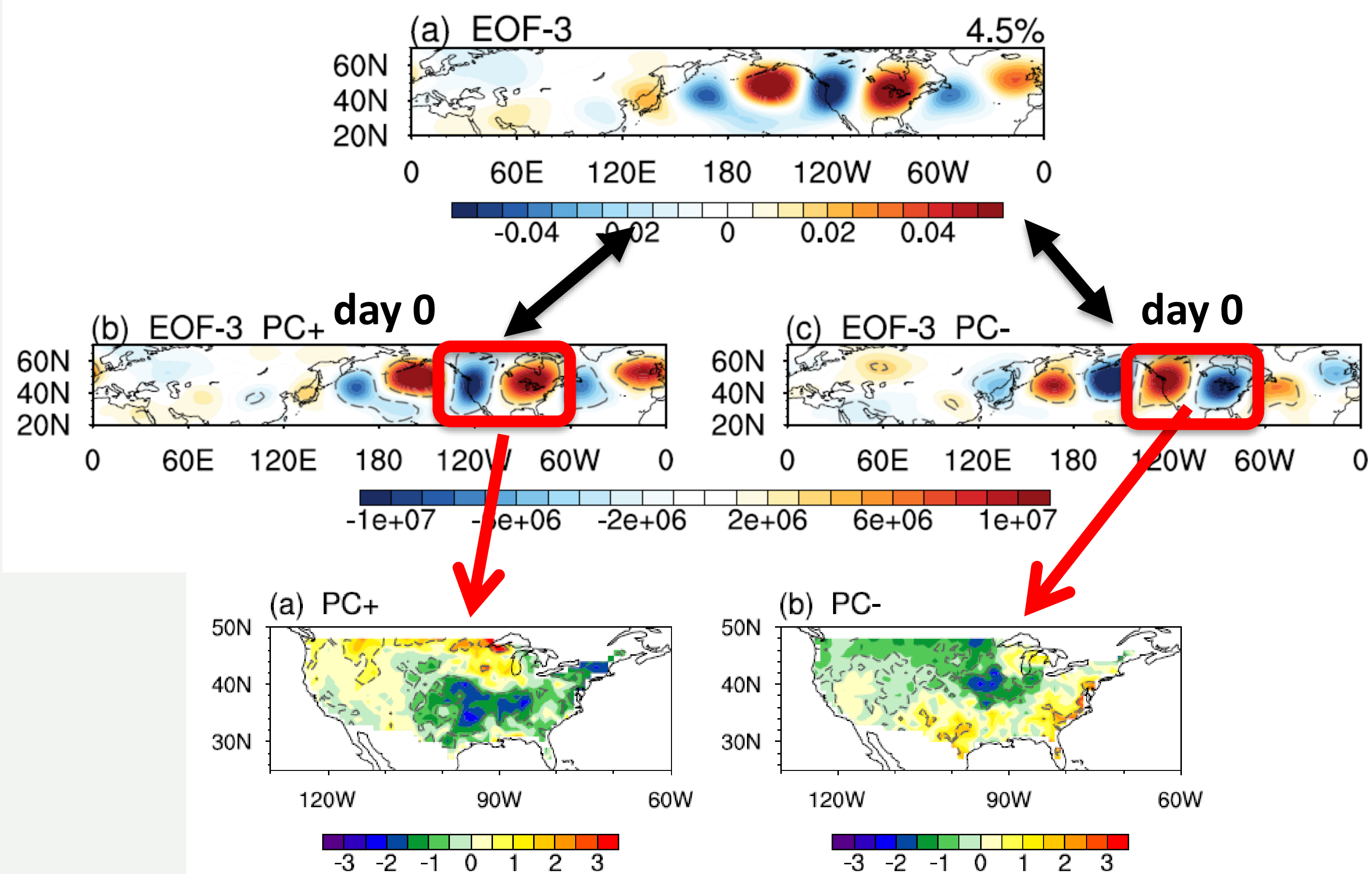

An intraseasonal mode

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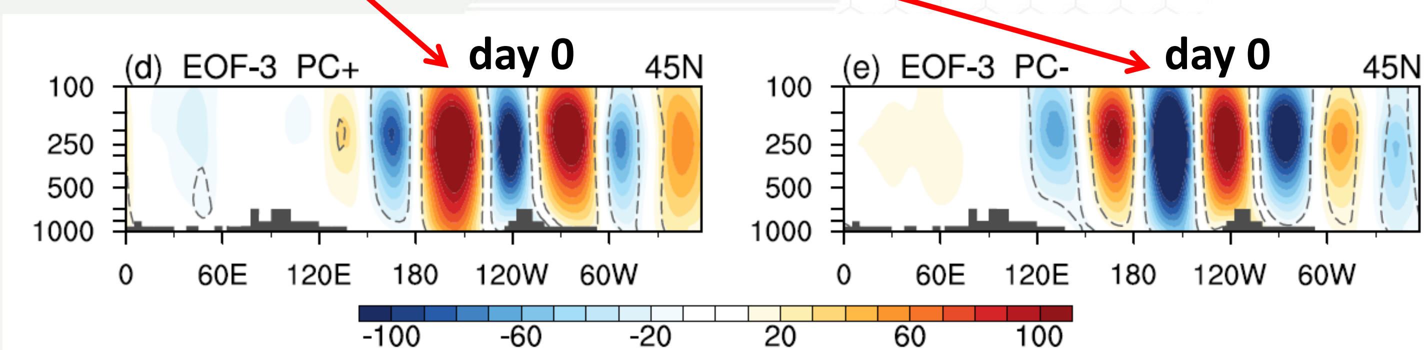
Barotropic structure (NO vertical tilt)



An intraseasonal mode

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√ barotropic model

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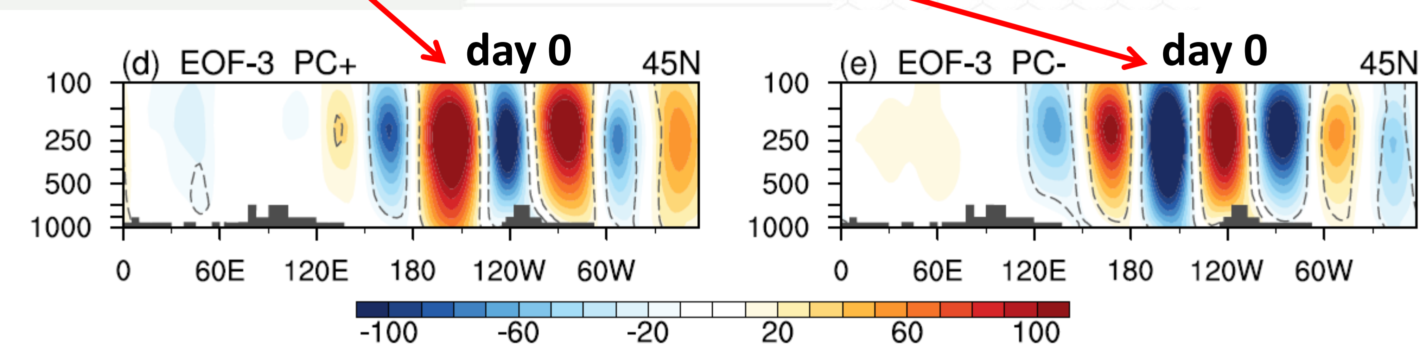


Nonmodal instability analysis

- **Nonmodal instability analysis in this study is applied to seek initial perturbation that grows fastest over a specified time interval τ given certain background flow.**
- **The disturbance with the fastest growth from initial perturbation is called an optimal mode.**
- **Auto-correlation analysis of PC time series of EOF-3 shows that a proper value of τ to be considered is 5-10 days.**

——*Mak 2011; Zhao et al. 2018*

Nonmodal instability analysis

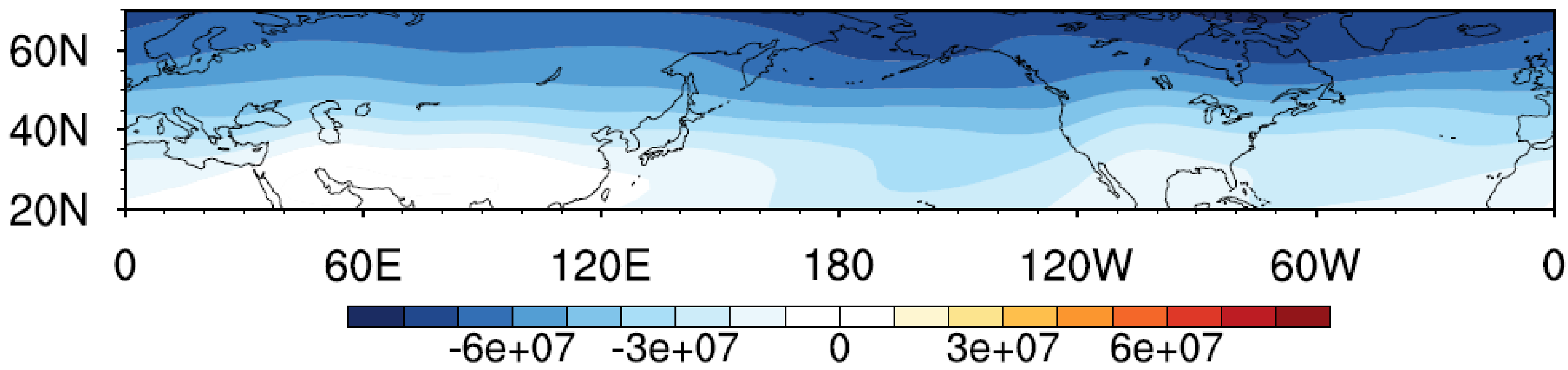
- **barotropic model**

250 hPa

$$\frac{\partial \nabla^2 \psi}{\partial t} = \frac{1}{r^2 \cos\varphi}\left(\frac{\partial \psi}{\partial \varphi}\frac{\partial \nabla^2 \psi}{\partial \lambda} - \frac{\partial \psi}{\partial \lambda}\frac{\partial \nabla^2 \psi}{\partial \varphi}\right) - \frac{2\Omega}{r^2}\frac{\partial \psi}{\partial \lambda}$$

Background flow for nonmodal instability analysis

250 hPa summer mean streamfunction (1950-2016)



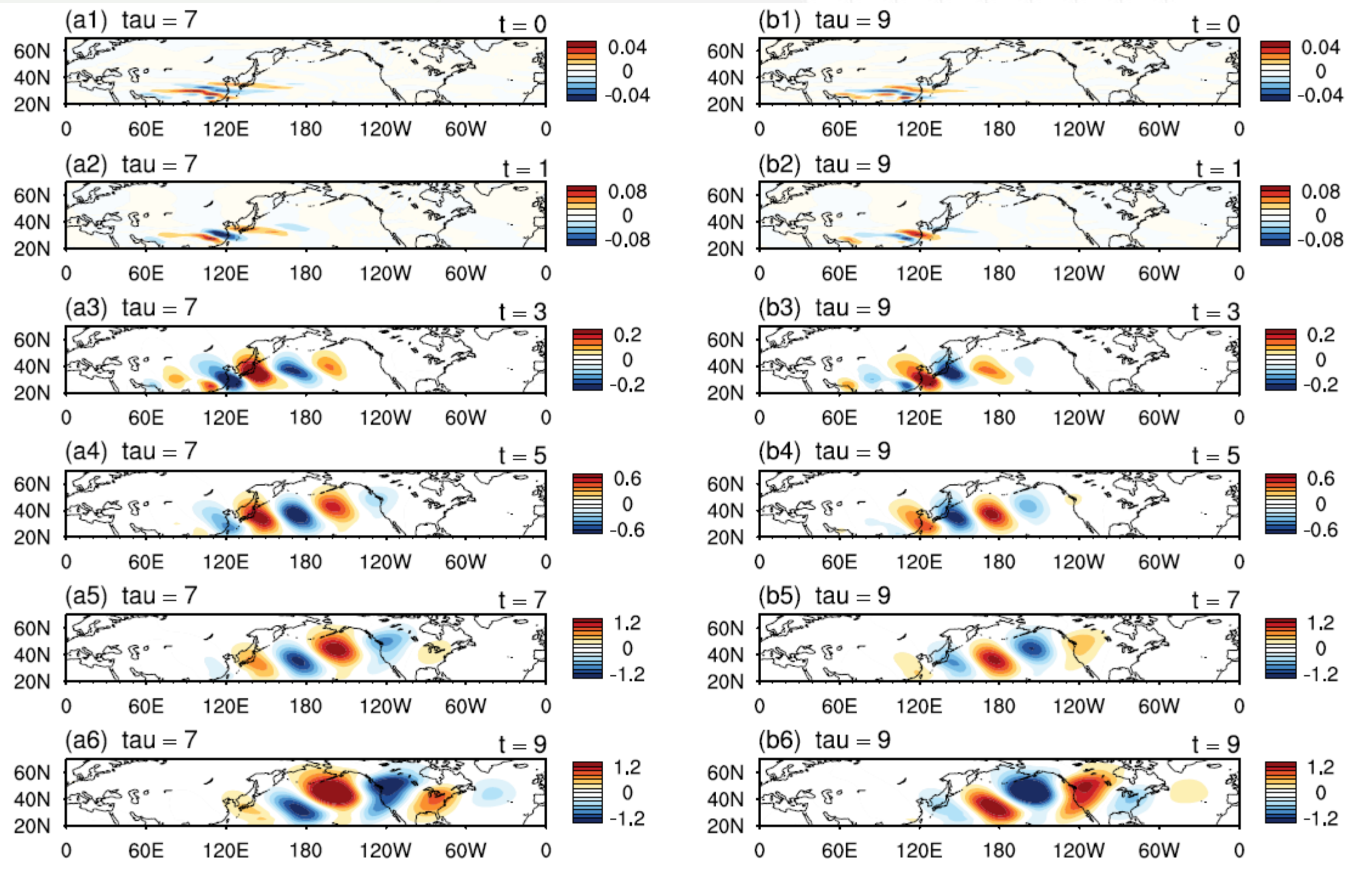
The Input data

Optimal modes resembling EOF-3

Time evolution map of optimal modes obtained from nonmodal instability analysis

——*Zhao et al. 2018*

τ = 7 days **τ = 9 days**



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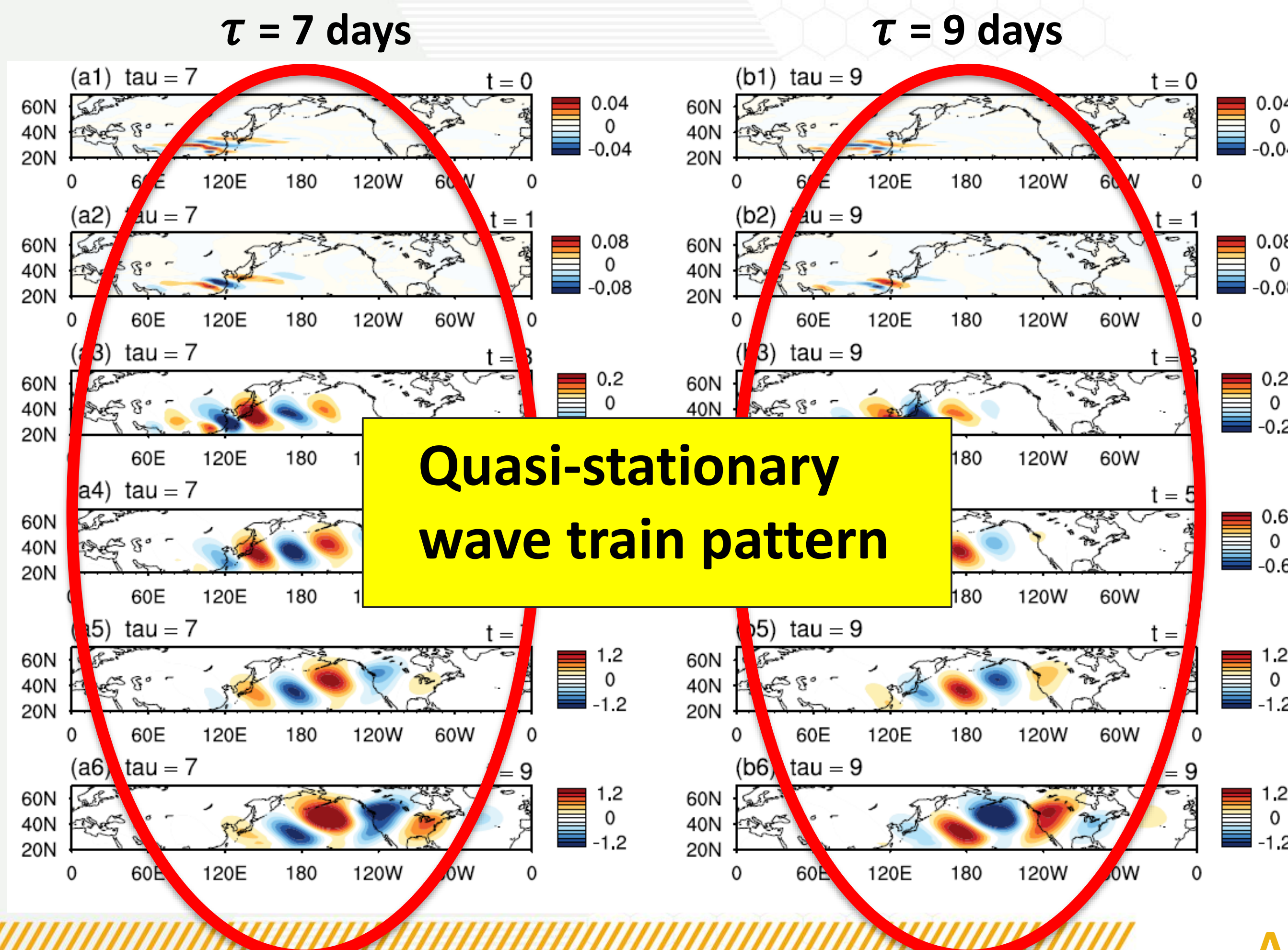

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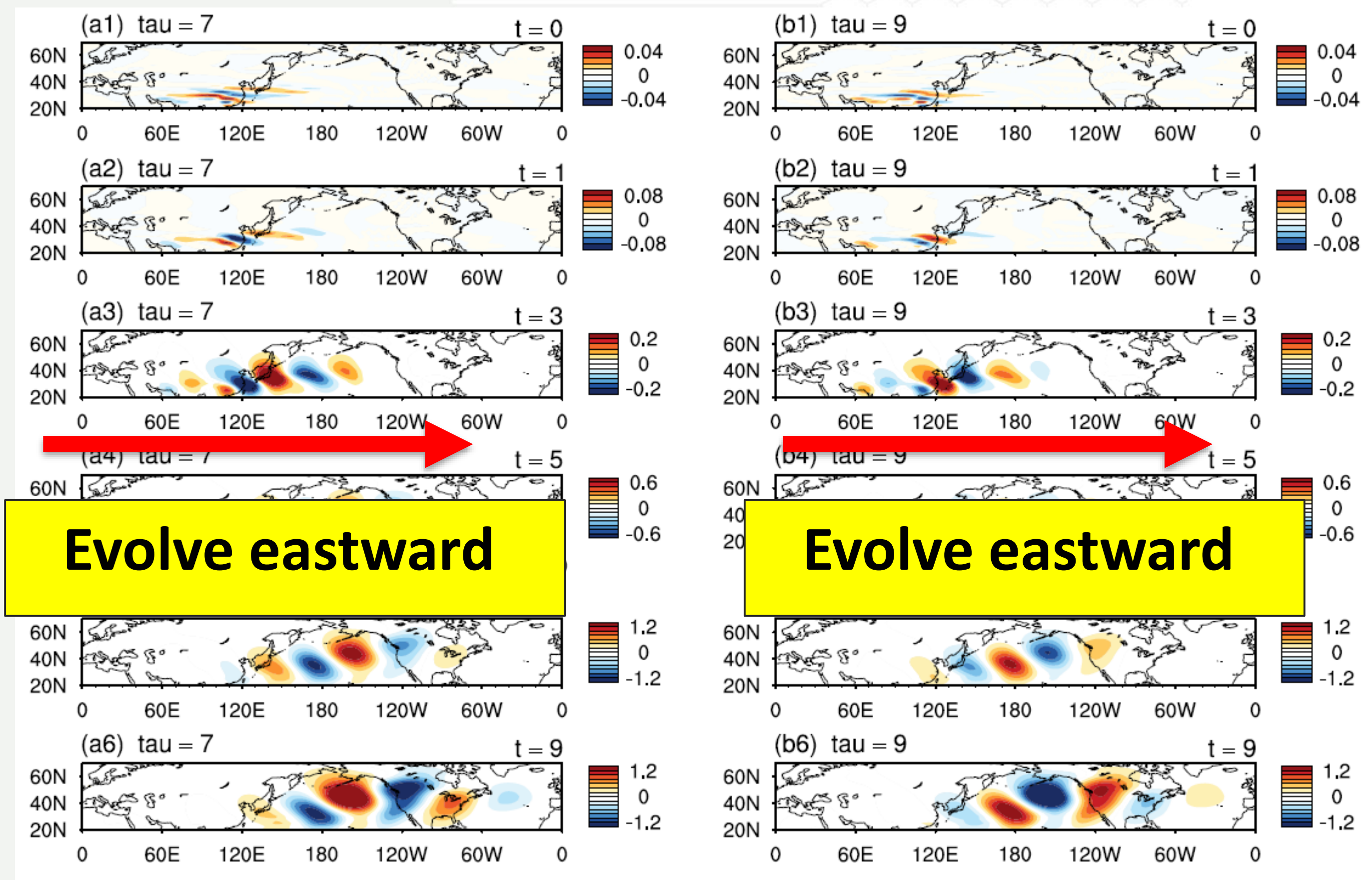

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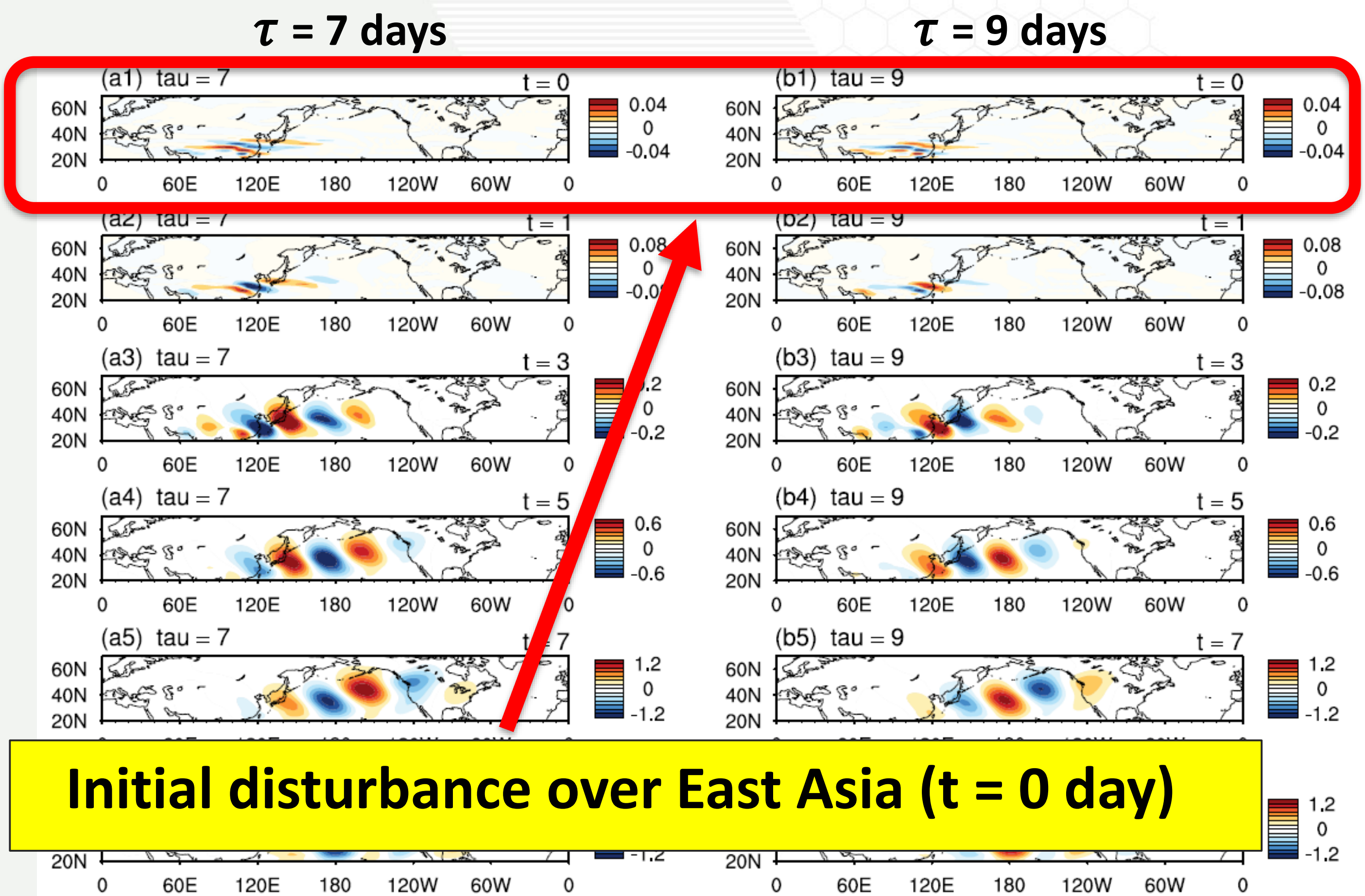
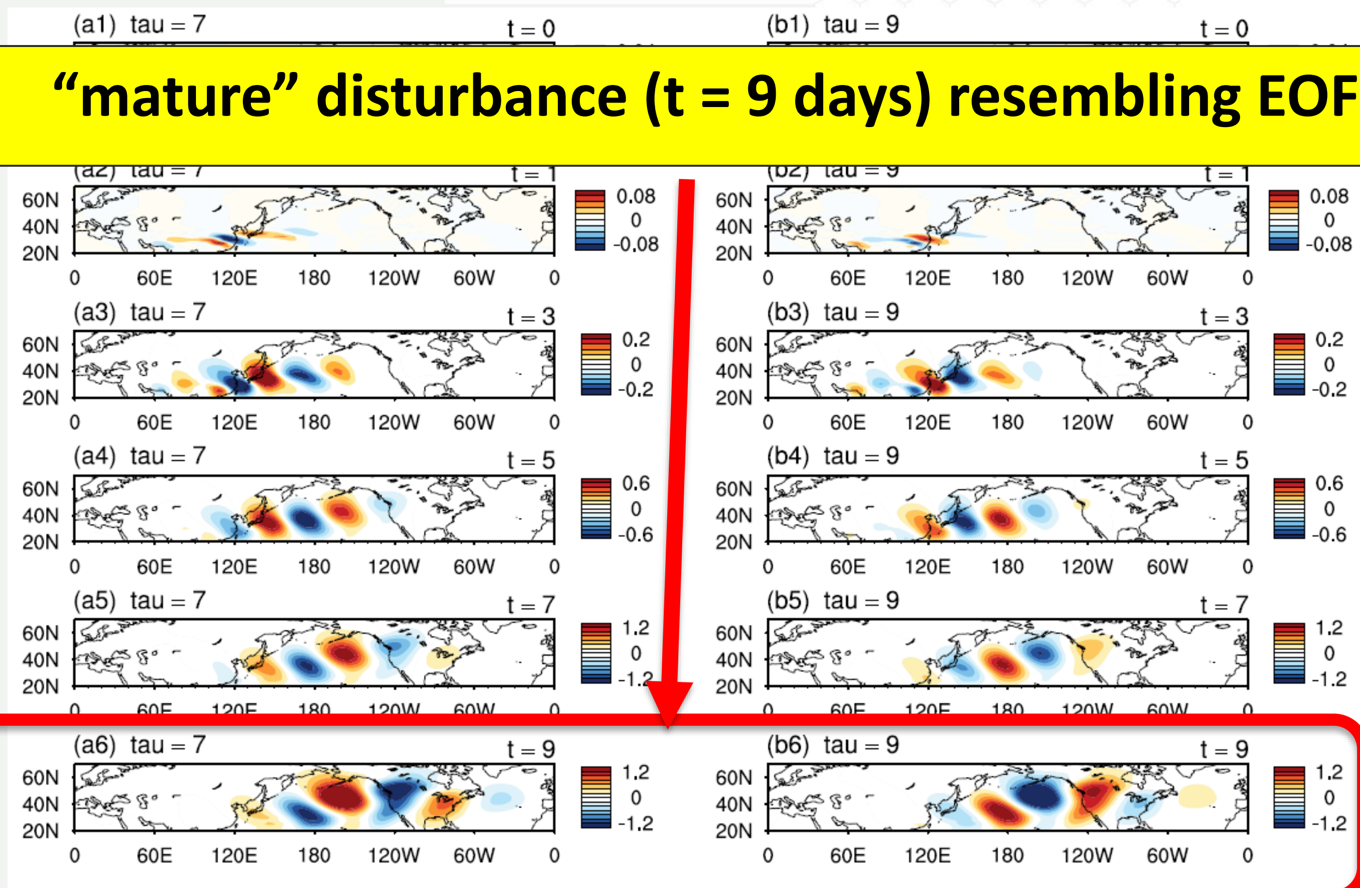


Optimal modes resembling EOF-3

Time evolution map of optimal modes obtained from nonmodal instability analysis

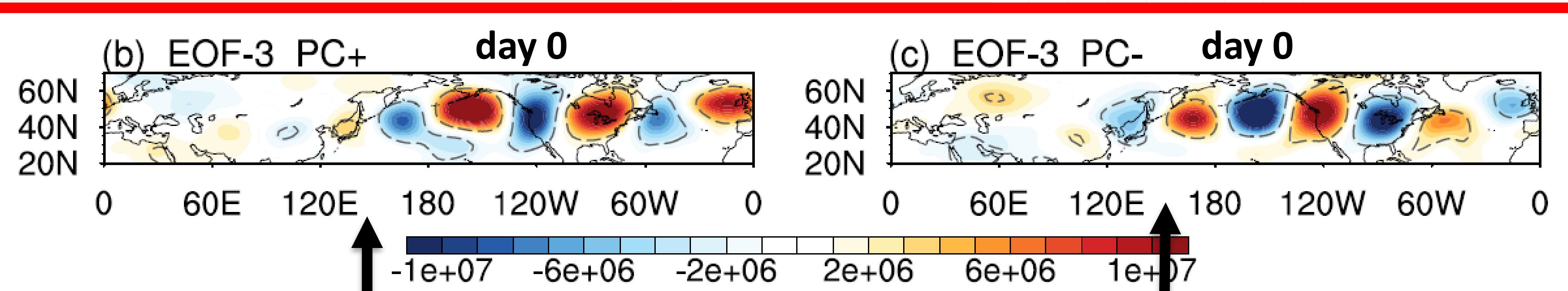
τ = 7 days τ = 9 days

"mature" disturbance (t = 9 days) resembling EOF-3



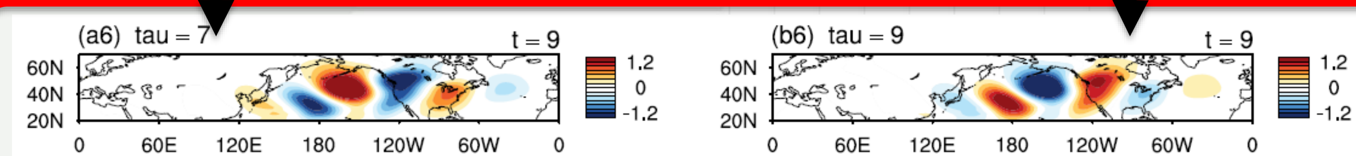
Optimal modes resembling EOF-3

similar !



τ = 7 days

τ = 9 days

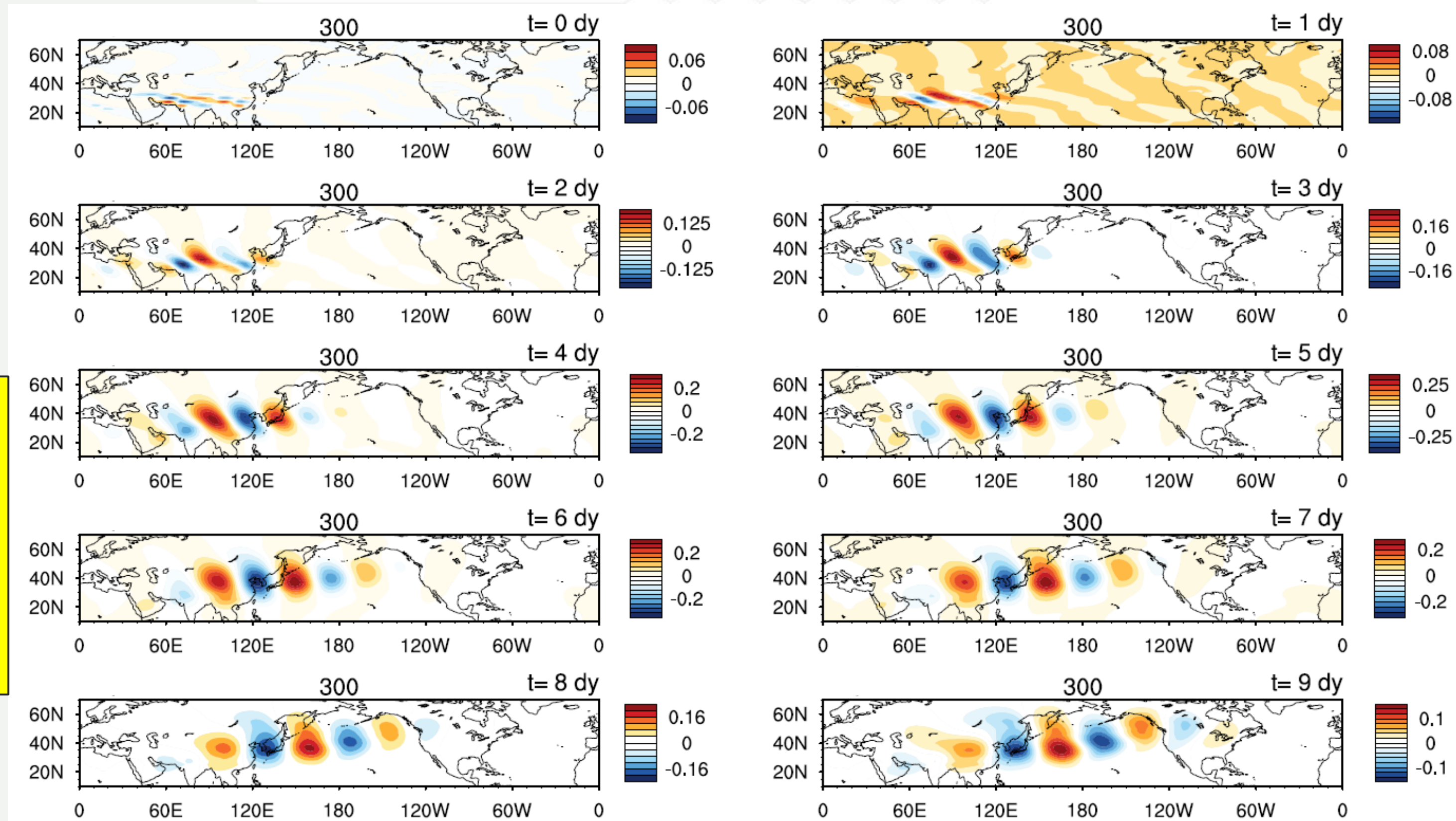


Optimal modes in two-level QG model

Georgia Tech

Time evolution map of optimal modes obtained from nonmodal instability analysis

τ = 5 days   Upper level (300 mb)

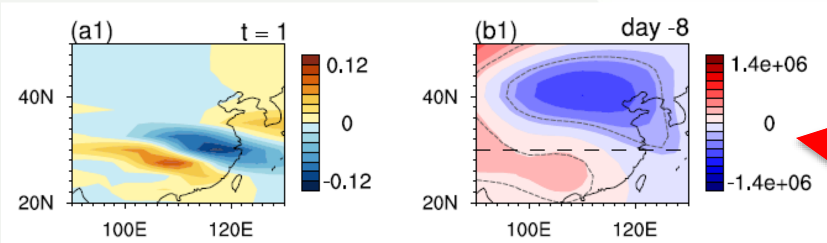


The scale of the wave is smaller than that for barotropic model.

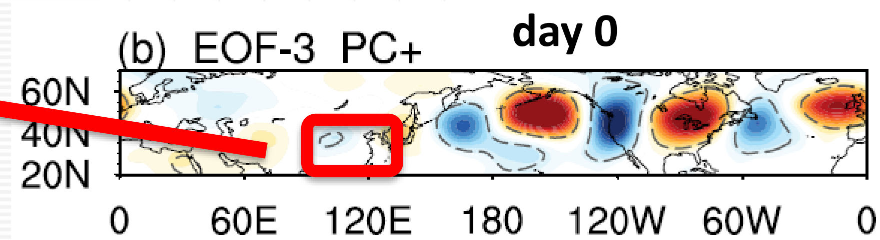
Initial disturbance for EOF-3 and optimal mode

Optimal mode
τ = 7 days

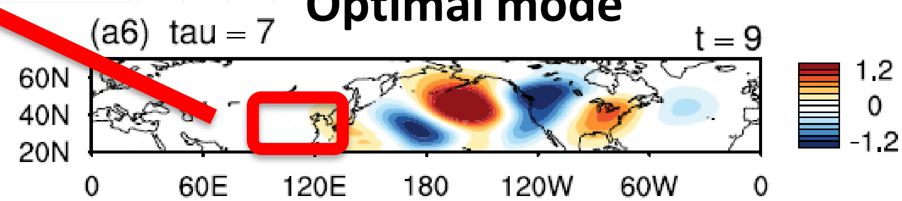
EOF-3 PC+ events



day 0



Optimal mode



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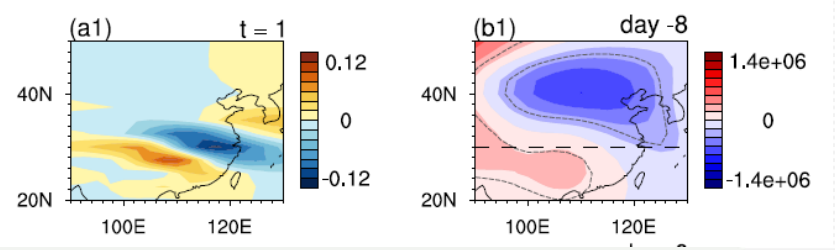


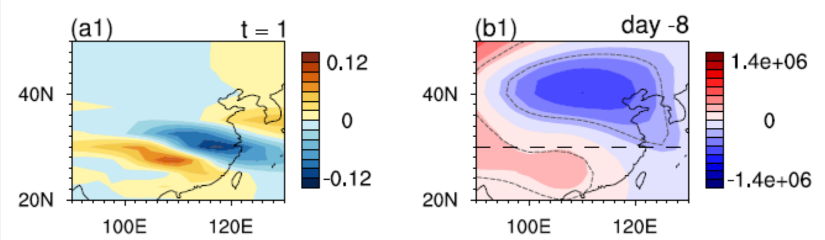
Dipole structure

Around initial disturbance (day -8 / t = 1 day)

Examine external forcing for initial disturbance

Optimal mode
τ = 7 days

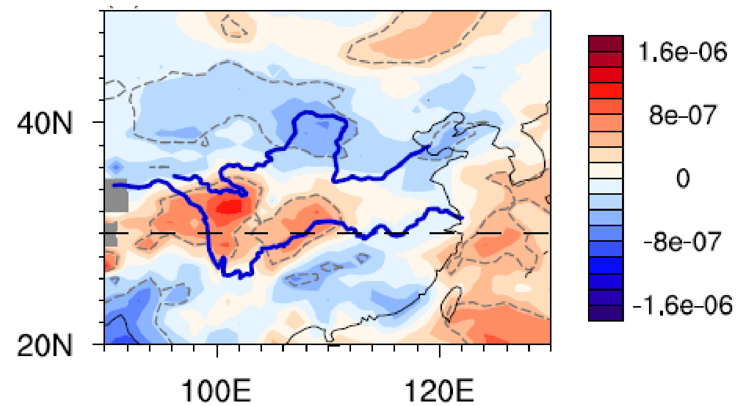
EOF-3 PC+ events



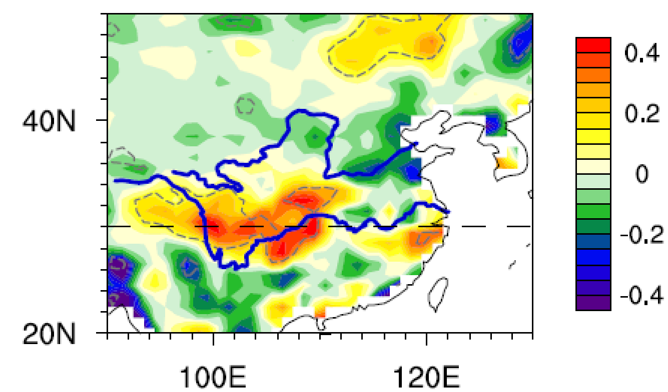
Around initial disturbance (day -8 / t = 1 day)

——*Zhao et al. 2018*

cloud water (day -8)



precipitation (day -8)



Examine external forcing for initial disturbance

Optimal mode
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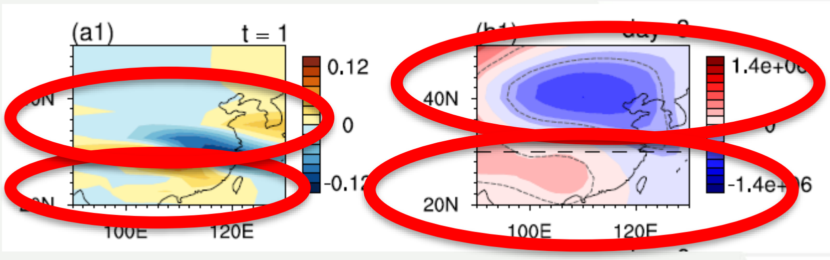
EOF-3 PC+ events



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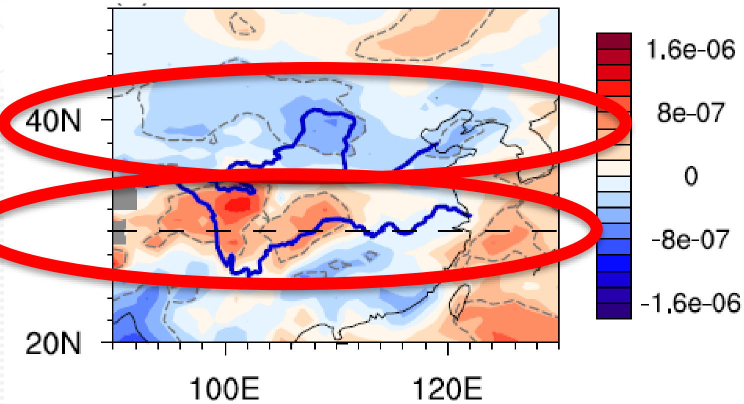

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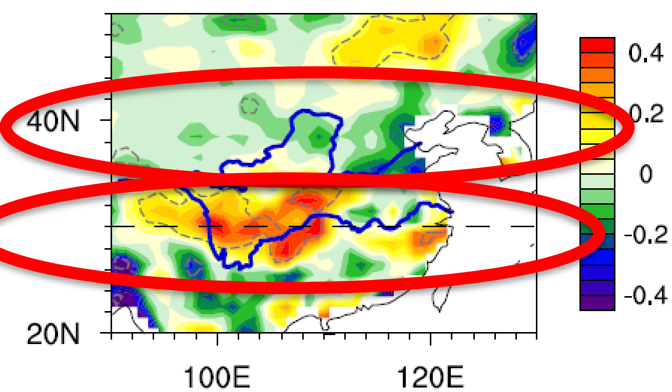

Examine external forcing for initial disturbance

Optimal mode
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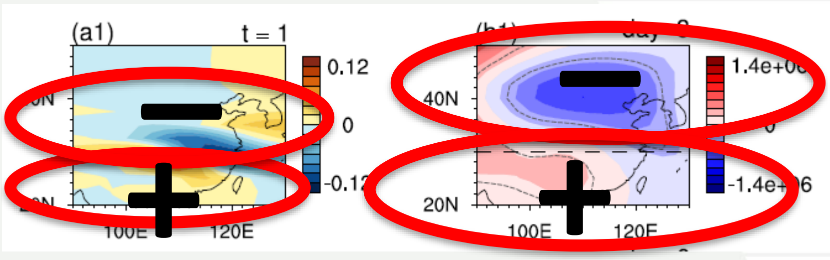
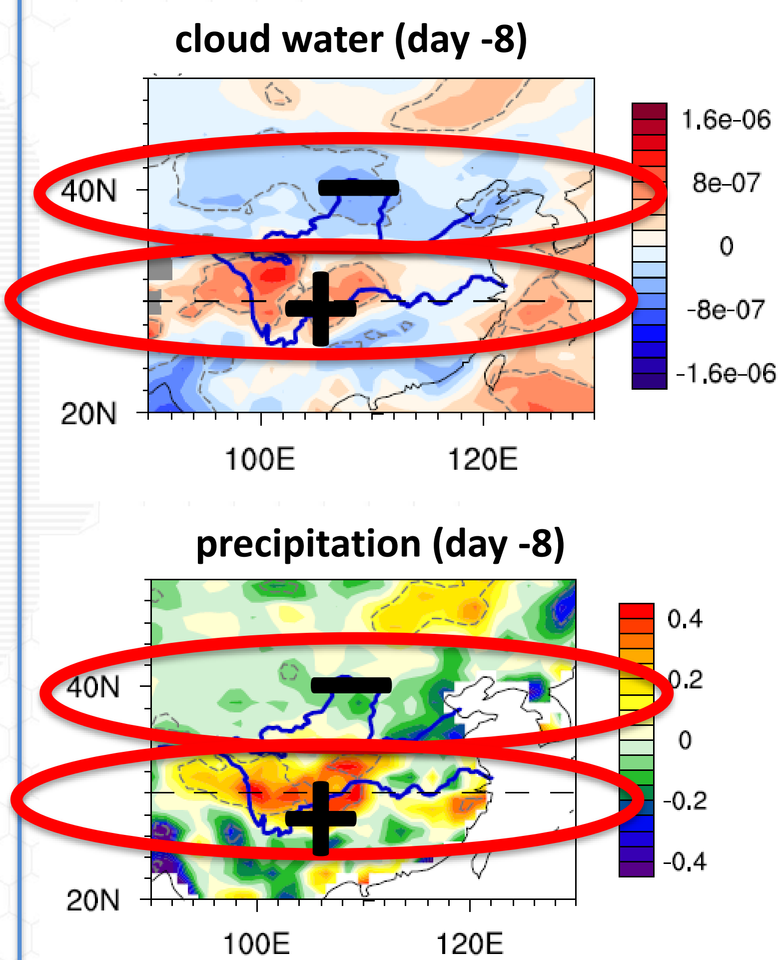




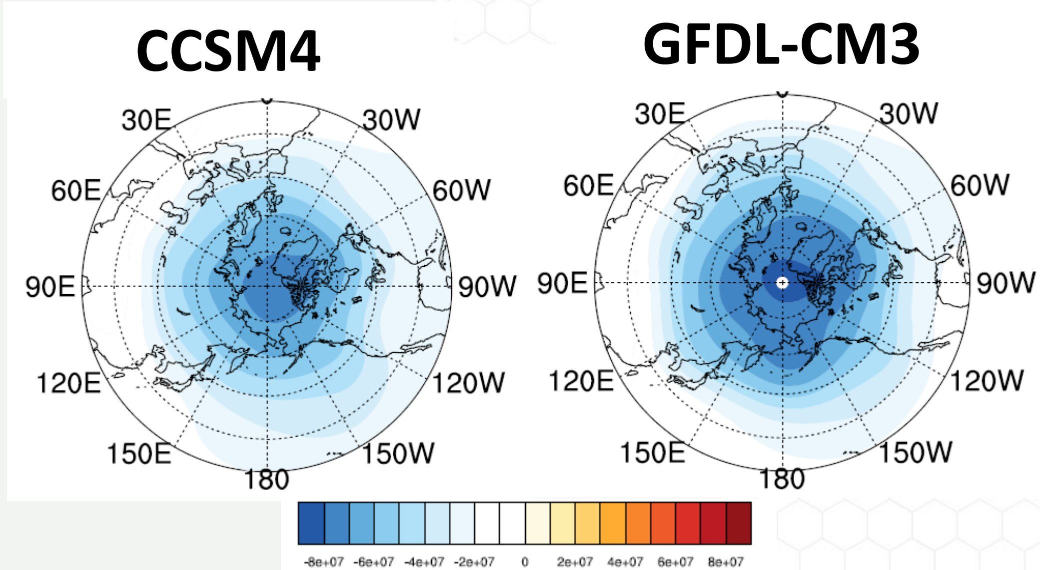
Positive (negative) anomaly of cloud water/precipitation can trigger upper-level ridge (trough) through releasing more (less) latent heat.

Hydrological cycles of East Asia and North America

These results suggest the existence of an important connection between the hydrological cycles of East Asia and North America, which is dynamically intrinsic to the boreal summer upper tropospheric flow.

CMIP5 models representation of background flow

model background flow (summer mean streamfunction)



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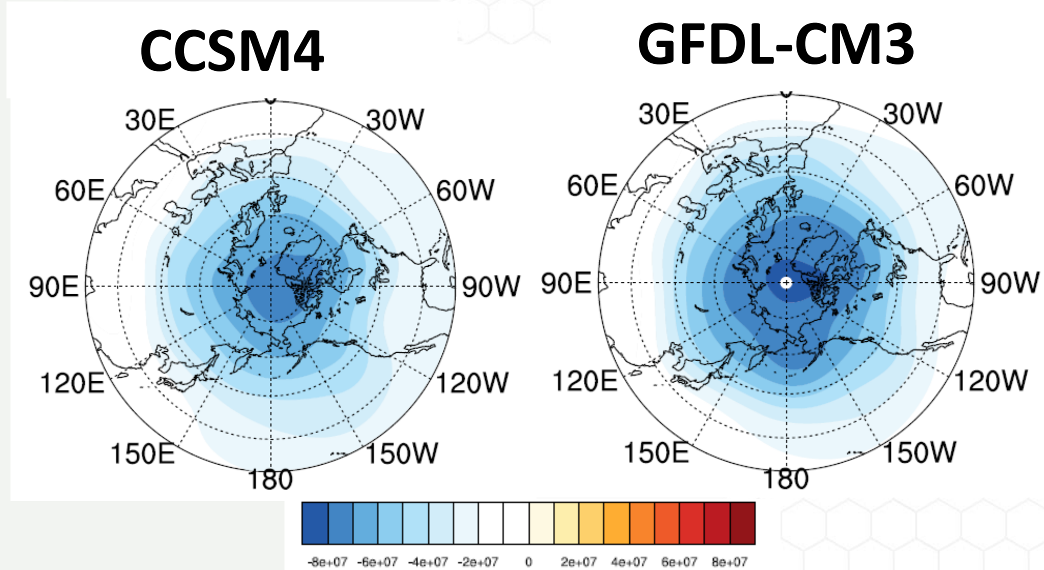
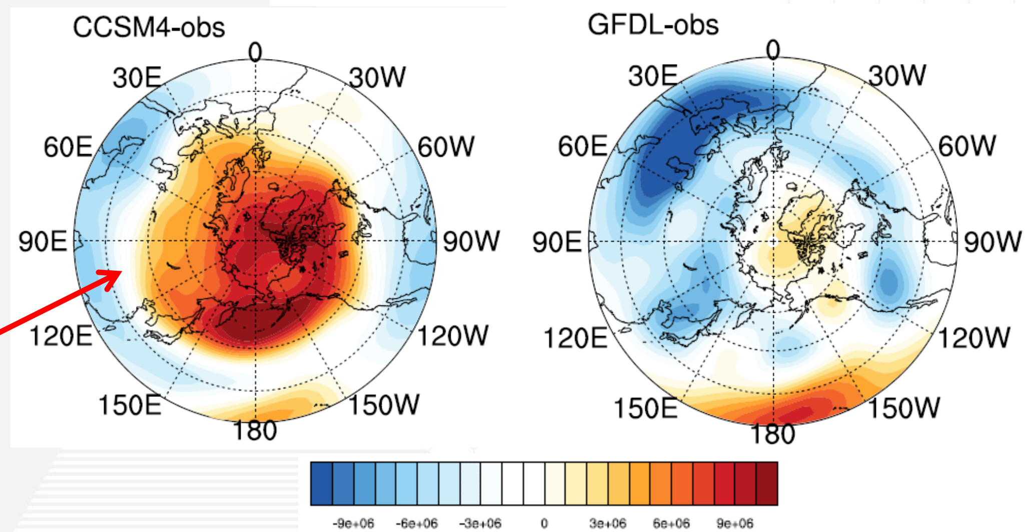


model bias



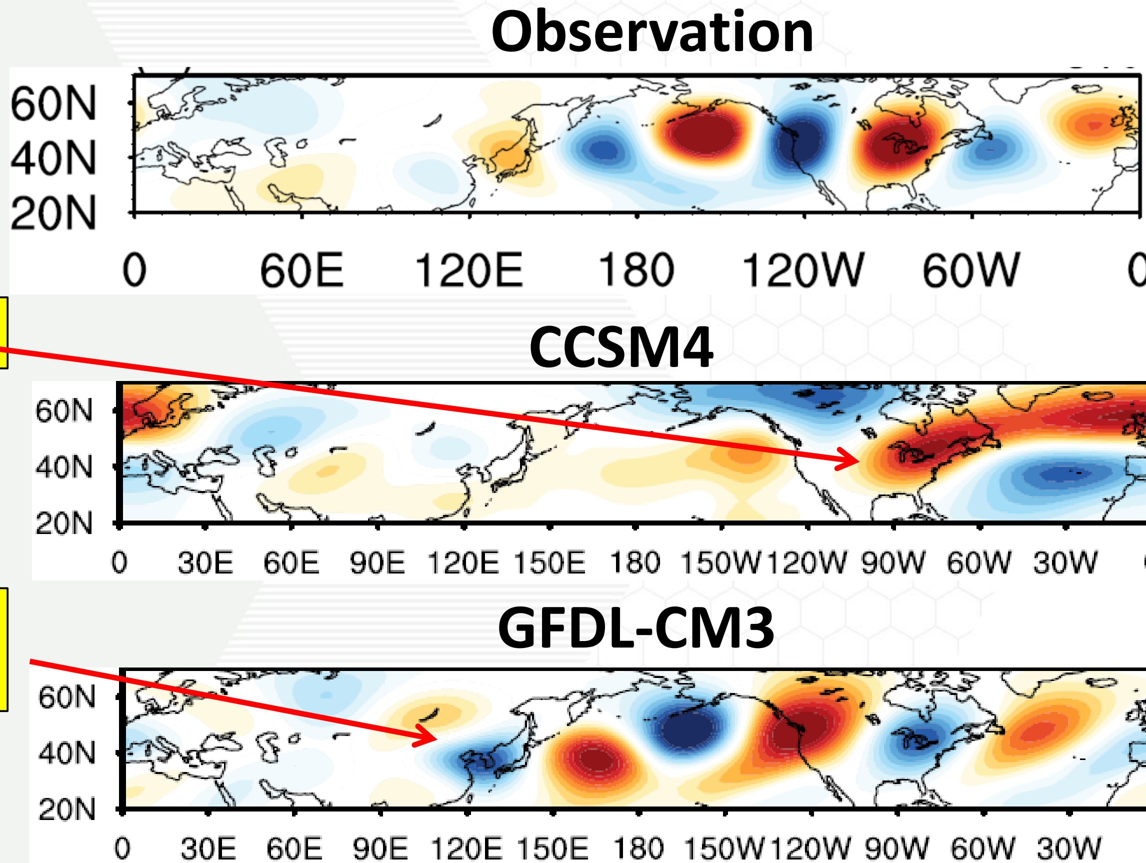
Largely overestimated by CCSM4!

small

CMIP5 models representation of EOF-3

Shift to North Atlantic!

Wave train pattern well simulated by GFDL model

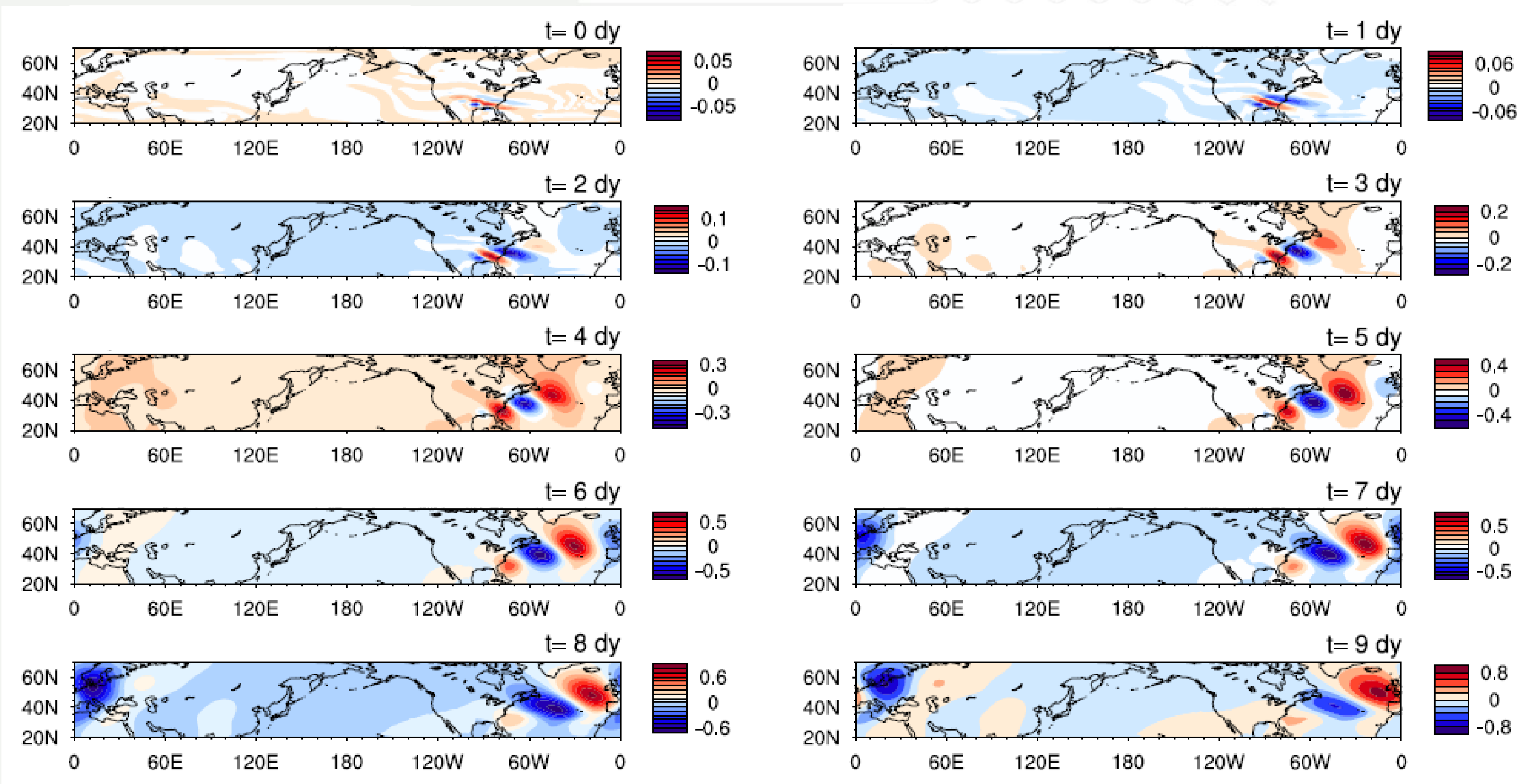


CMIP5 models representation of optimal mode

CCSM4 τ = 6 days

Shift to North Atlantic !

Time evolution map of optimal modes obtained from nonmodal instability analysis

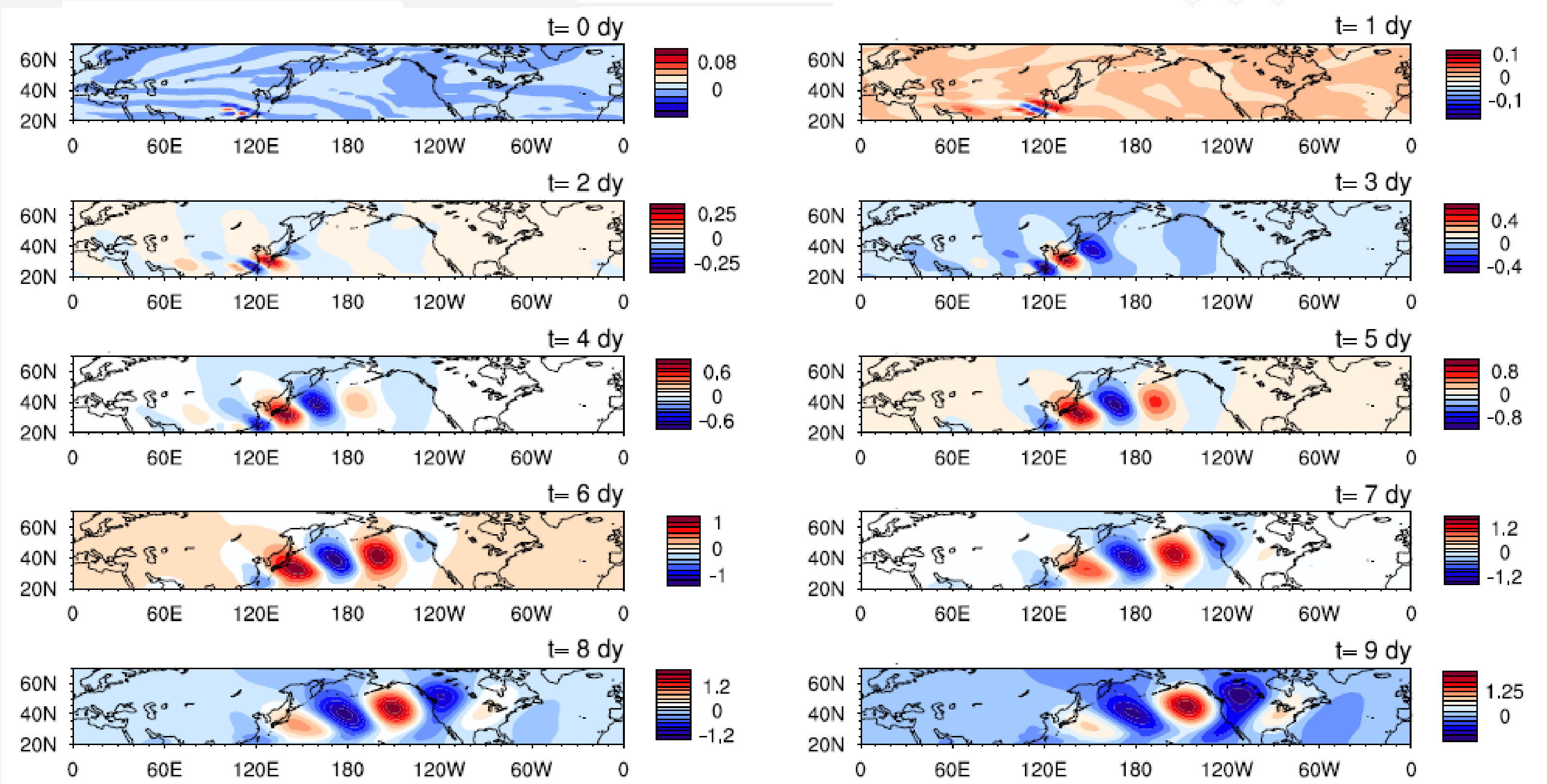


CMIP5 models representation of optimal mode

GFDL-CM3 τ = 6 days

Good performance!

Time evolution map of optimal modes obtained from nonmodal instability analysis



Take-home message

- The U.S. hydrological extremes in summer are closely tied to East Asian monsoonal rainfall.
- The connection between the water cycles of East Asia and North America in summer can be understood in terms of optimally excited disturbances in a summer background flow.
- Future changes in summer background flow could have direct implications for regional hydroclimate variability at subseasonal timescales.

THANKS!