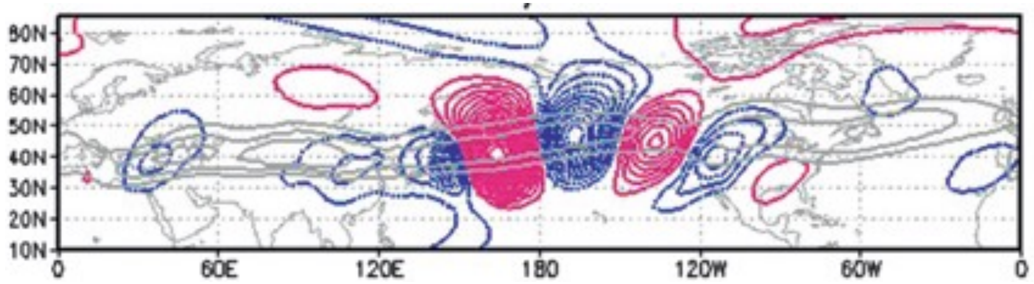
Analysis with a stationary wave model

- Question: What can we learn about the drivers of the CA flood event with an idealized simple model?
- Goal: To better understand the underlying “forcing” and gather more evidence supporting our hypothesis about the evolution of the event.

Stationary wave model



- **Dry dynamical core** of an AGCM; nonlinear and based on primitive equations with **excessive damping** to suppress transients.

Model equations: Ting and Yu (1998)

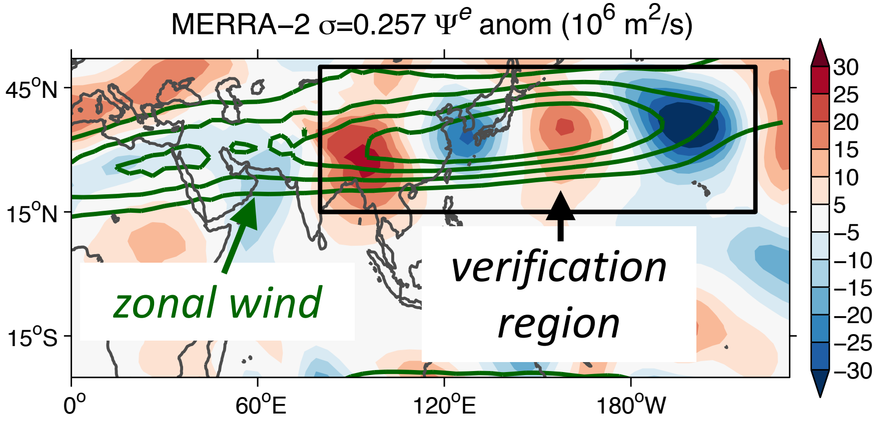
$\frac{\partial \zeta}{\partial t} = \cdots$	$\frac{\partial D}{\partial t} = \cdots$	$\frac{\partial T}{\partial t} = \cdots$	$\frac{\partial P_s}{\partial t} = \cdots$	*continuity*
vorticity	*divergence*	*temp.*	*sfc. pres.*	*hydrostatic*

- Solves for **anomalies relative to 3-D basic state** (*U, V, T, Ps*).
- **Horizontal resolution:** rhomboidal wavenumber-30 truncation
- **Vertical resolution:** 14 unevenly-spaced sigma levels
- **Steady state after about 30 days** (average of days 31-59 here)

Analysis with a stationary wave model

- In the following, the analysis procedure used to obtain a “forcing sensitivity map” is detailed for an example target circulation: the transient wave train anomaly over East Asia and the western North Pacific during Dec. 21-23, 2022.
- This wave train is referred to as the Indian Ocean Shortwave, or ISW, throughout the poster.

Question: Can we get a SWM response that resembles the Dec. 21-23 wave, and how?



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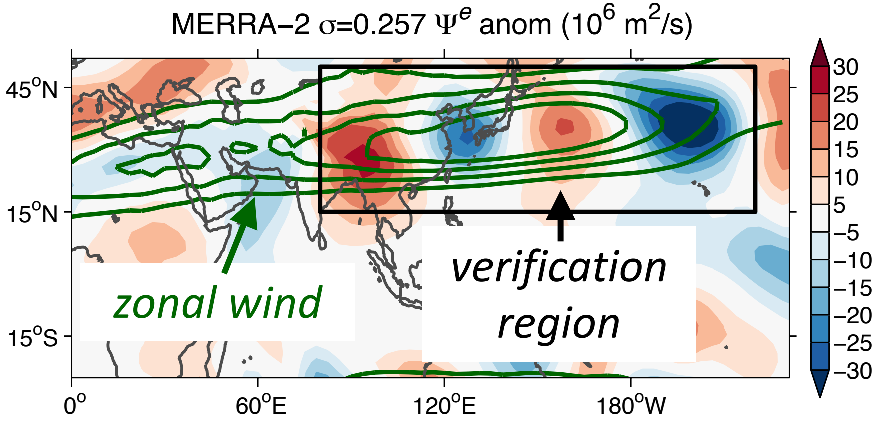

"Force" the SWM

<u>Forcing:</u> persistent anomalies in atmospheric dynamics or thermodynamics

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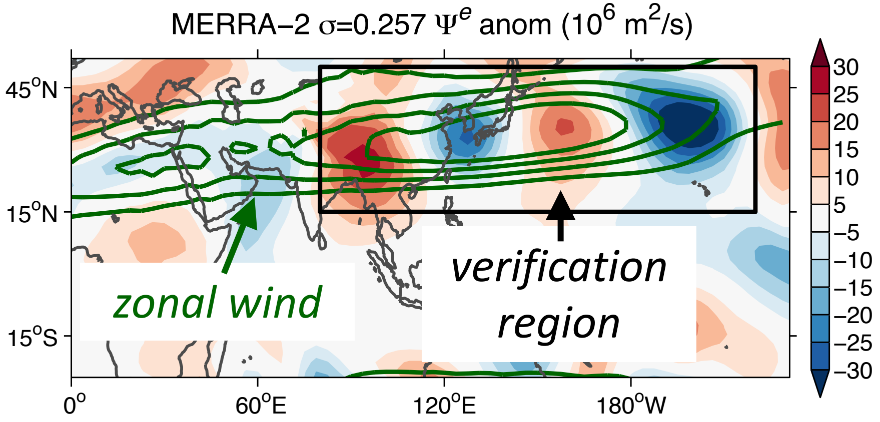

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Vorticity forcing can be important for generating such wave responses

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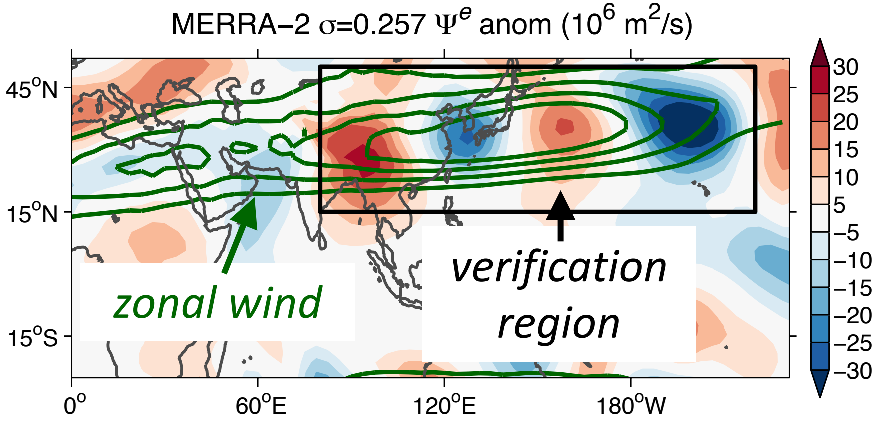

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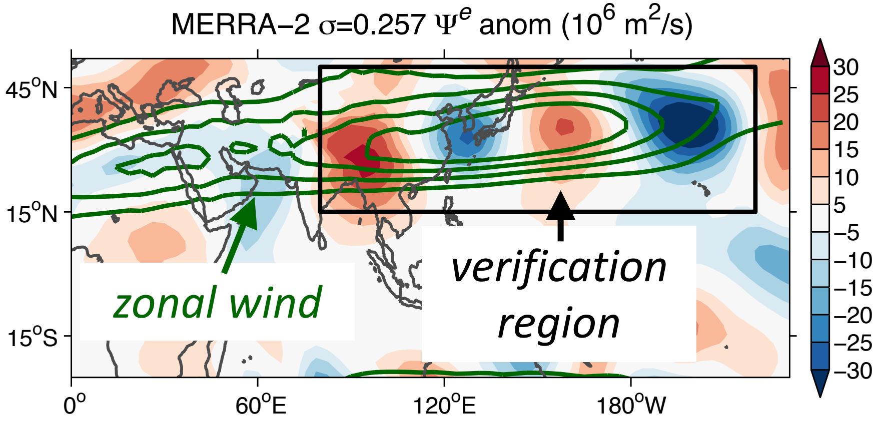
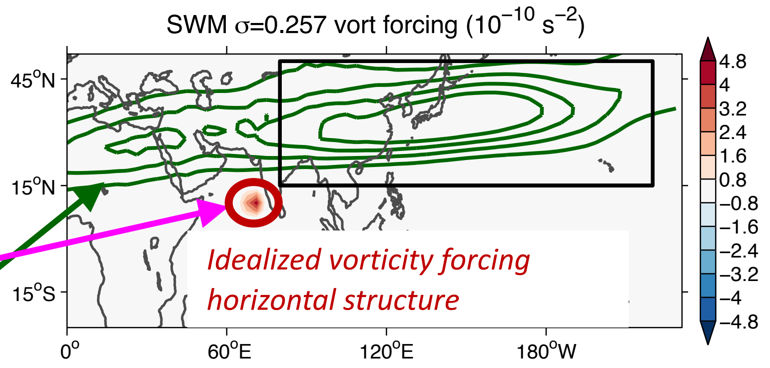
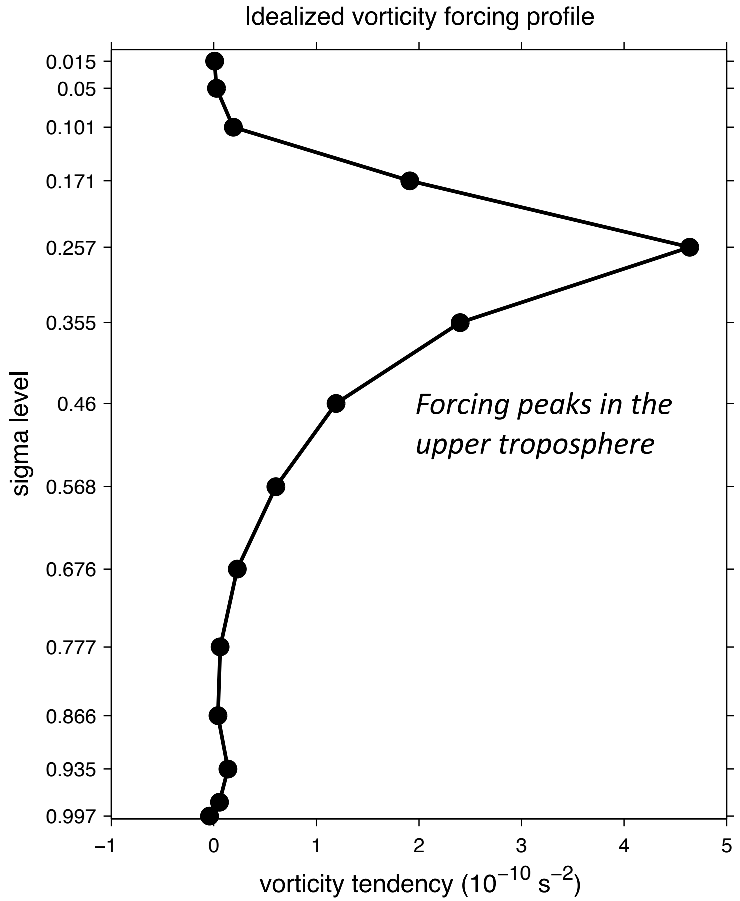


Idealized forcing experiment:

$$\frac{\partial \zeta}{\partial t} = \cdots + forcing$$

December La Nina basic state





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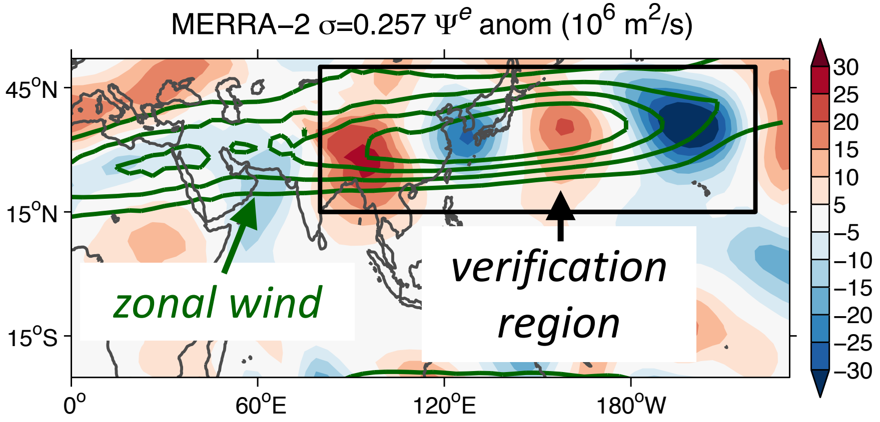

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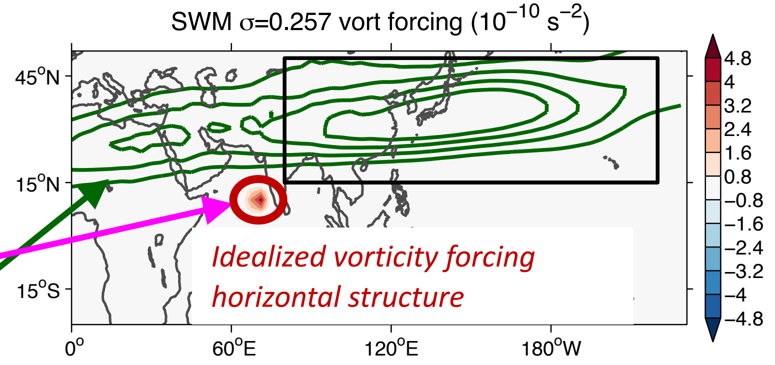

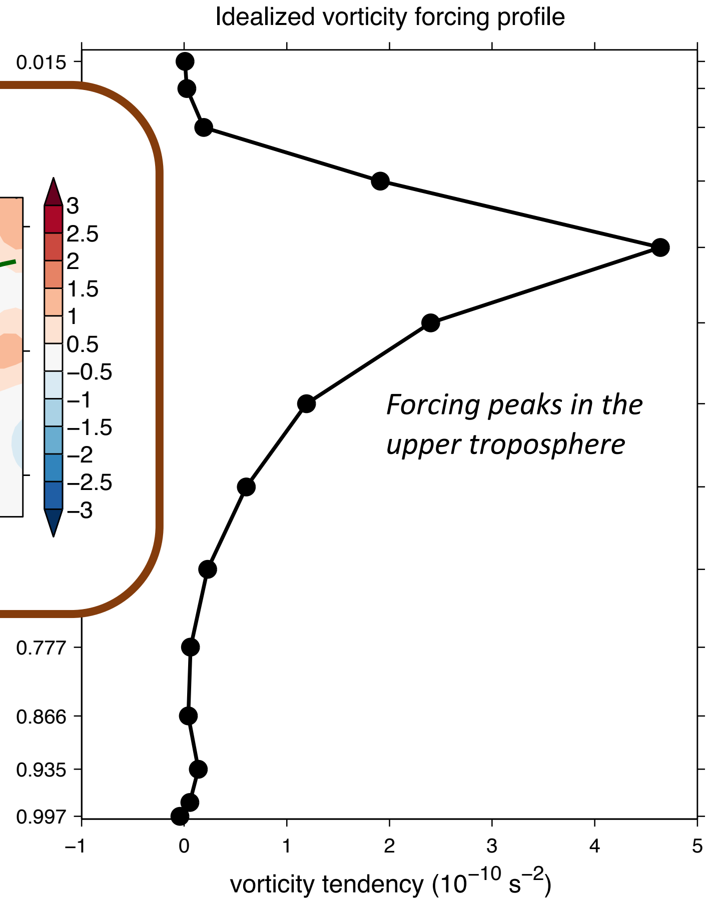

"Force" the SWM

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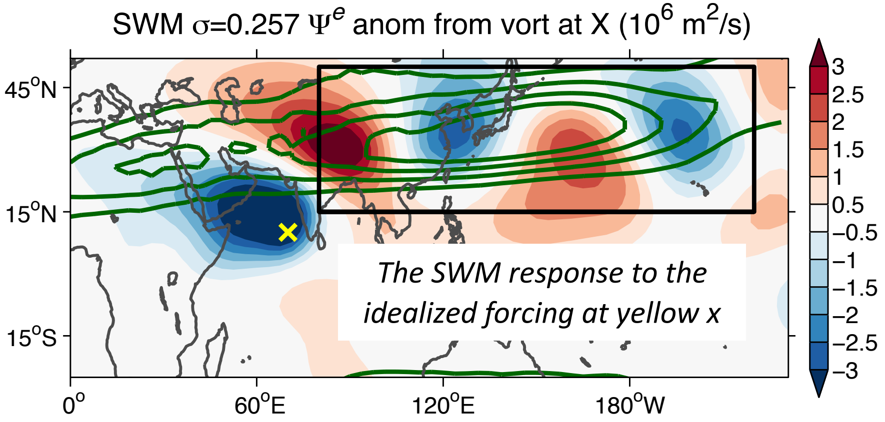

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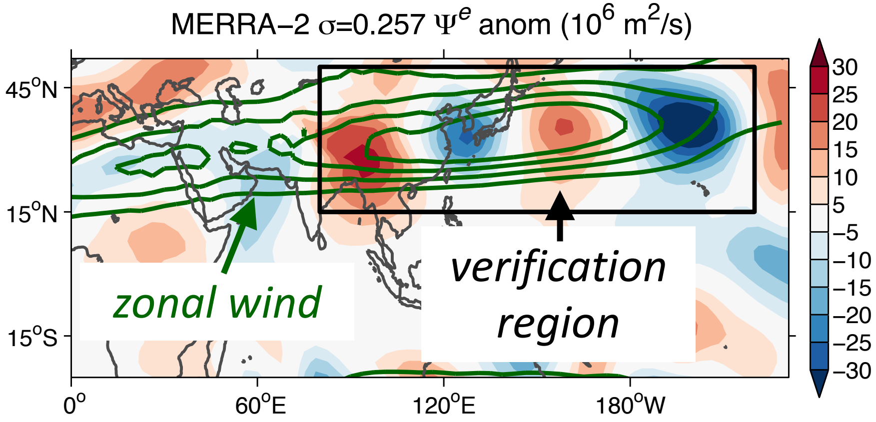

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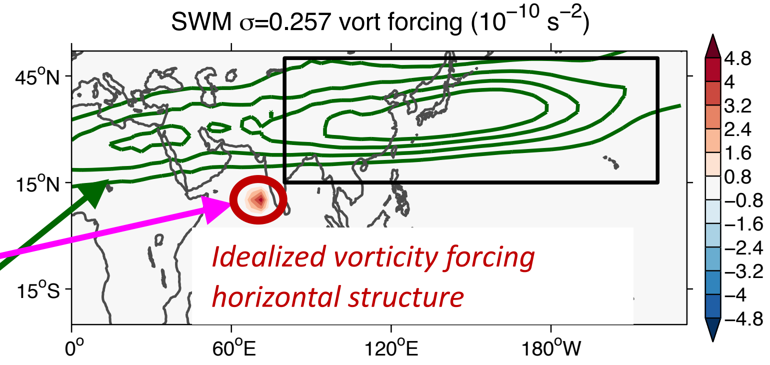

"Force" the SWM

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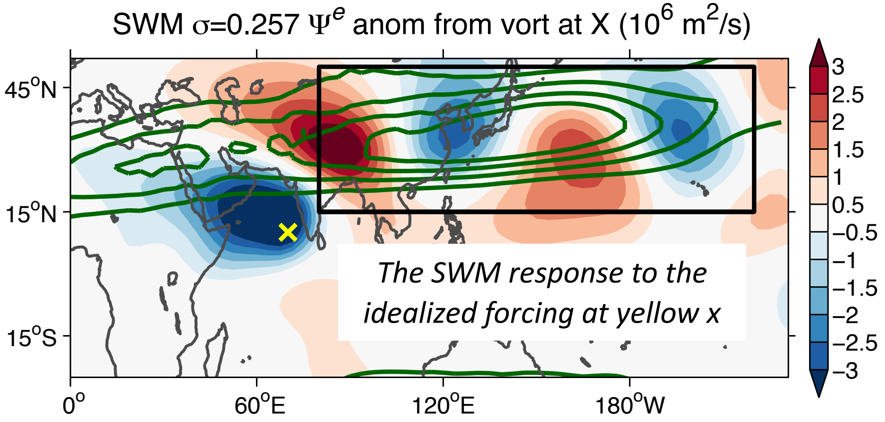
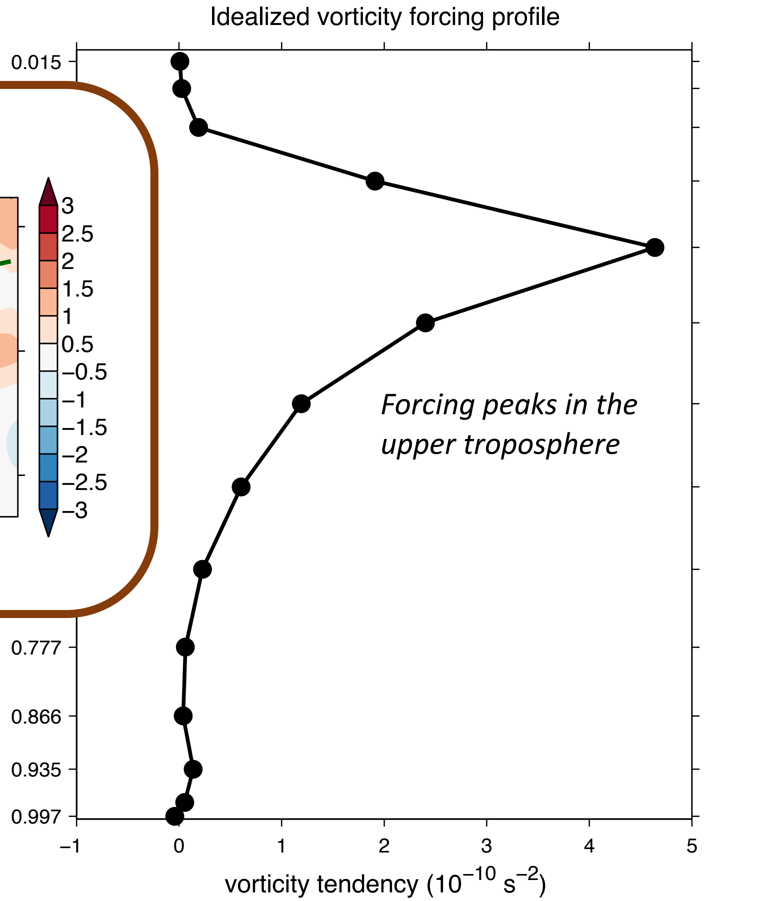




Vorticity forcing can be important for generating such wave responses

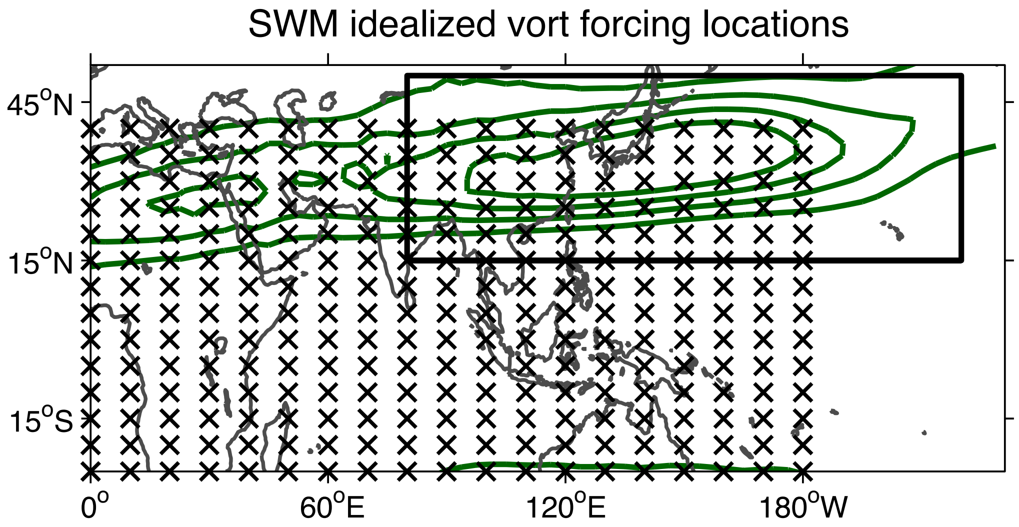
and arises from:

- *transient weather systems*
- *anomalous divergent flow, vorticity stretching, vorticity advection*

Vorticity forcing just west of India produces a wave response that resembles the observed wave

More generally, from which regions is vorticity forcing important for generating the observed wave?

1. Do the same idealized SWM experiment with vorticity forcing imposed at each of the locations marked with “x” (every 10º lon., 5º lat.):



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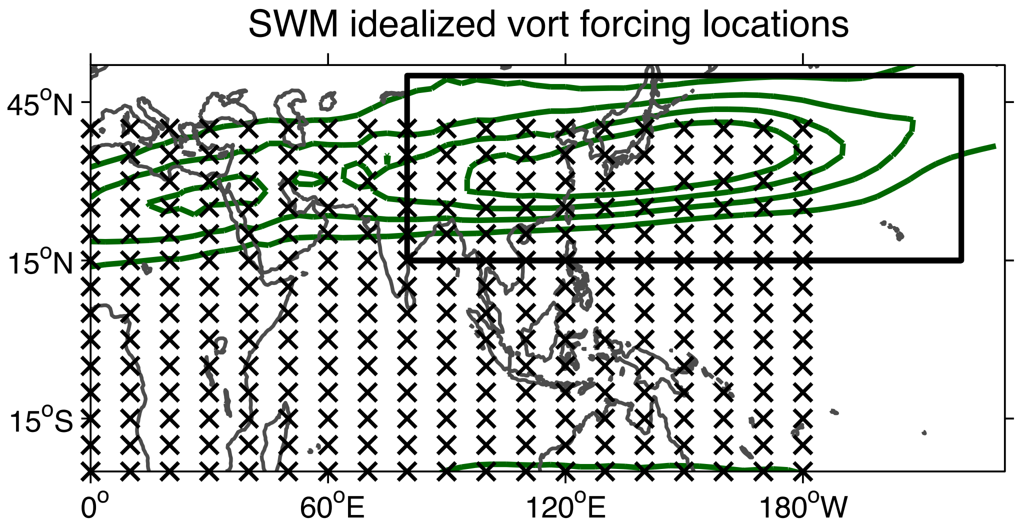

2. ~~Look at each of the 266 simulations.~~ Perform EOF analysis on the SWM responses to the different forcing locations to summarize the results.

Goal: Create a "forcing sensitivity map" for vorticity – ***highlights locations of vorticity forcing relevant for the observed wave.***

EOF analysis applied to SWM simulation eddy steam function (Ψ^e) output

$$F = \begin{bmatrix} x_{11} & x_{12} & \cdot & \cdot & \cdot & x_{1p} \\ x_{21} & + & & & & \cdot \\ \cdot & & & & & \cdot \\ \cdot & & & & & \cdot \\ \cdot & & & & & \\ x_{n1} & & \cdot & \cdot & \cdot & x_{np} \end{bmatrix}$$

A map of the **SWM response** when idealized forcing is applied at a given location

Corresponds to the **SWM response** at this grid cell when idealized forcing is applied at the different locations

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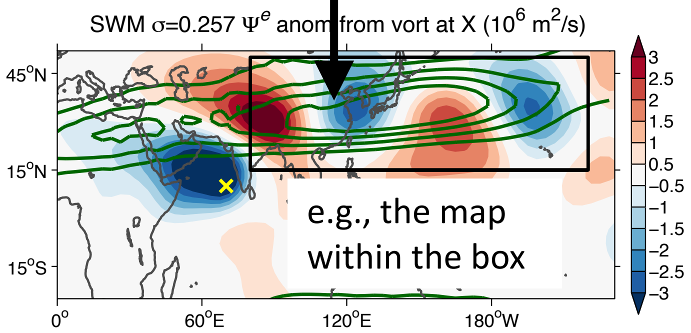

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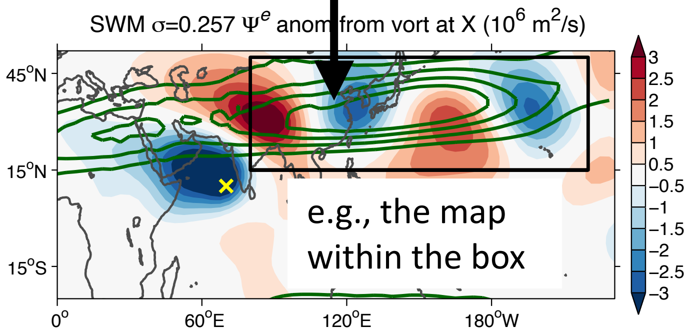

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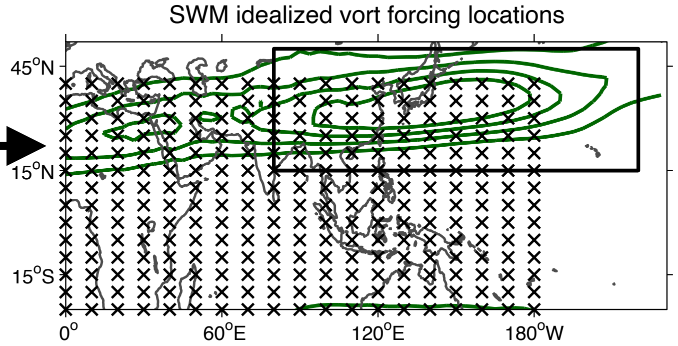

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$$C = F^T F$$

$$CE = CL$$

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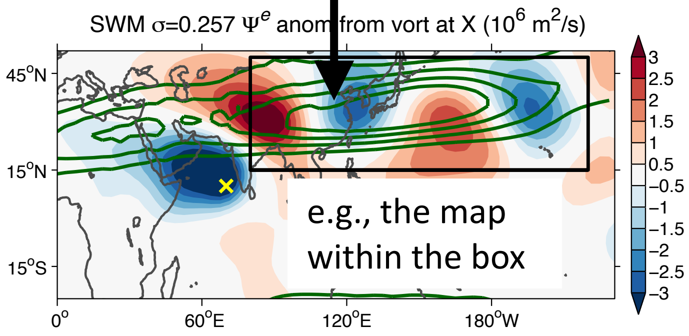

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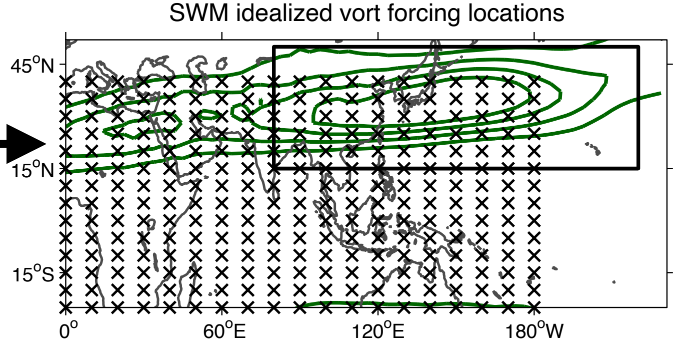

EOF analysis applied to SWM simulation eddy steam function (Ψ^e) output

$$C = F^T F$$

covariance matrix ← C

$$CE = CL$$

eigenvectors (EOFs) ← E; eigenvalues (var) ← L

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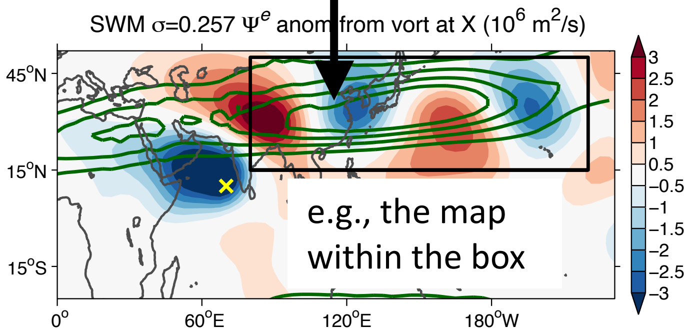

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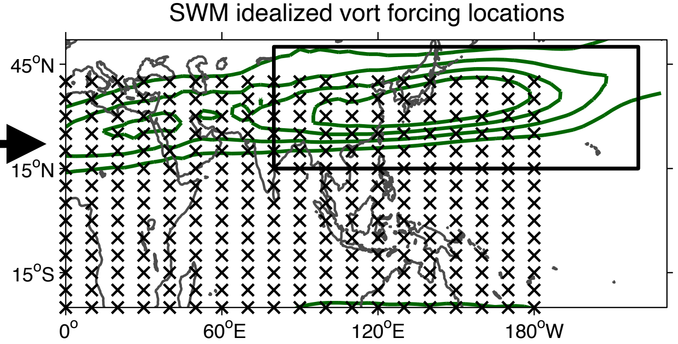

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covariance matrix ← $C = F^T F$

eigenvectors (EOFs) ← $CE = CL$ → eigenvalues (var)

EOFs (maps) represent key modes of variability across the SWM output

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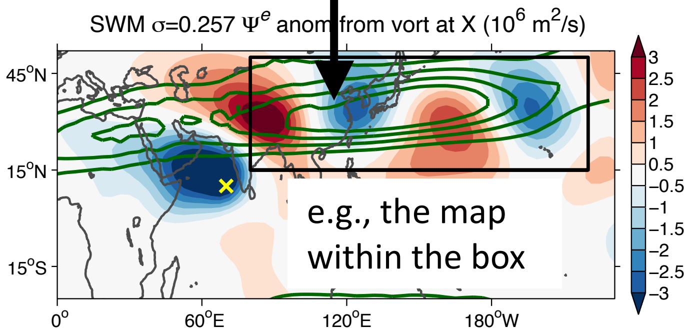
+

A map of the **SWM response** when idealized forcing is applied at a given location



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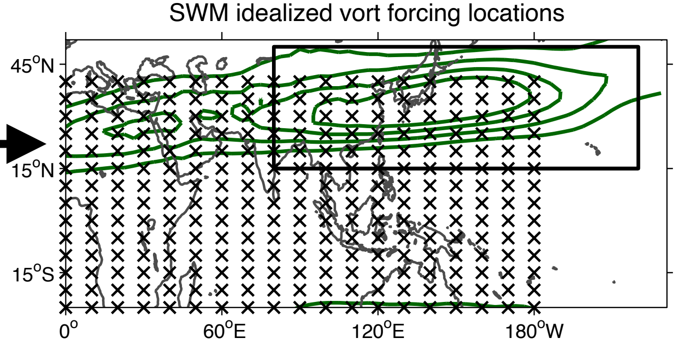

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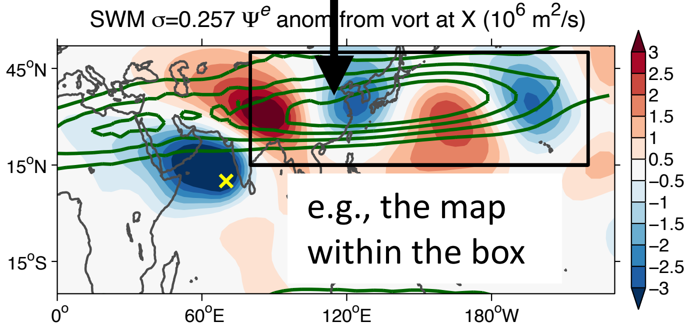

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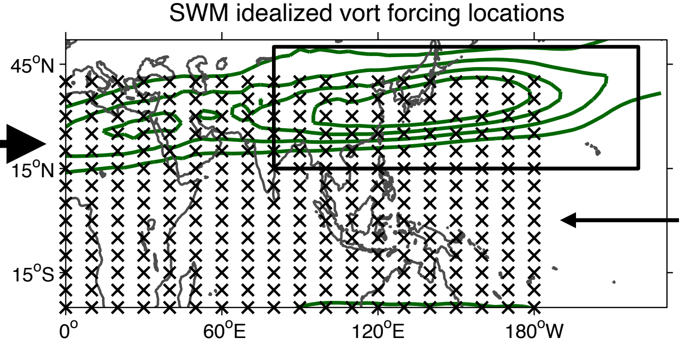
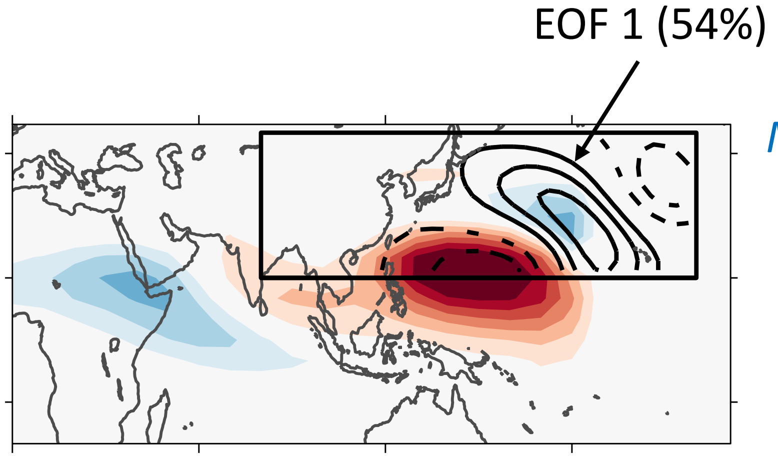


$$P = FE$$

PCs are the projections of each response onto the EOFs. They represent agreement between response and EOF. Can be displayed on a map.

The leading EOF for the 266 idealized vorticity simulations

(using December La Nina basic state)



Many SWM simulations give a response that looks like this

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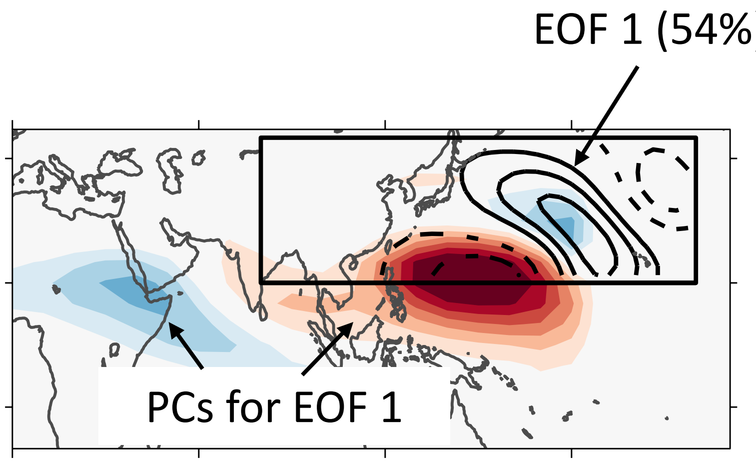


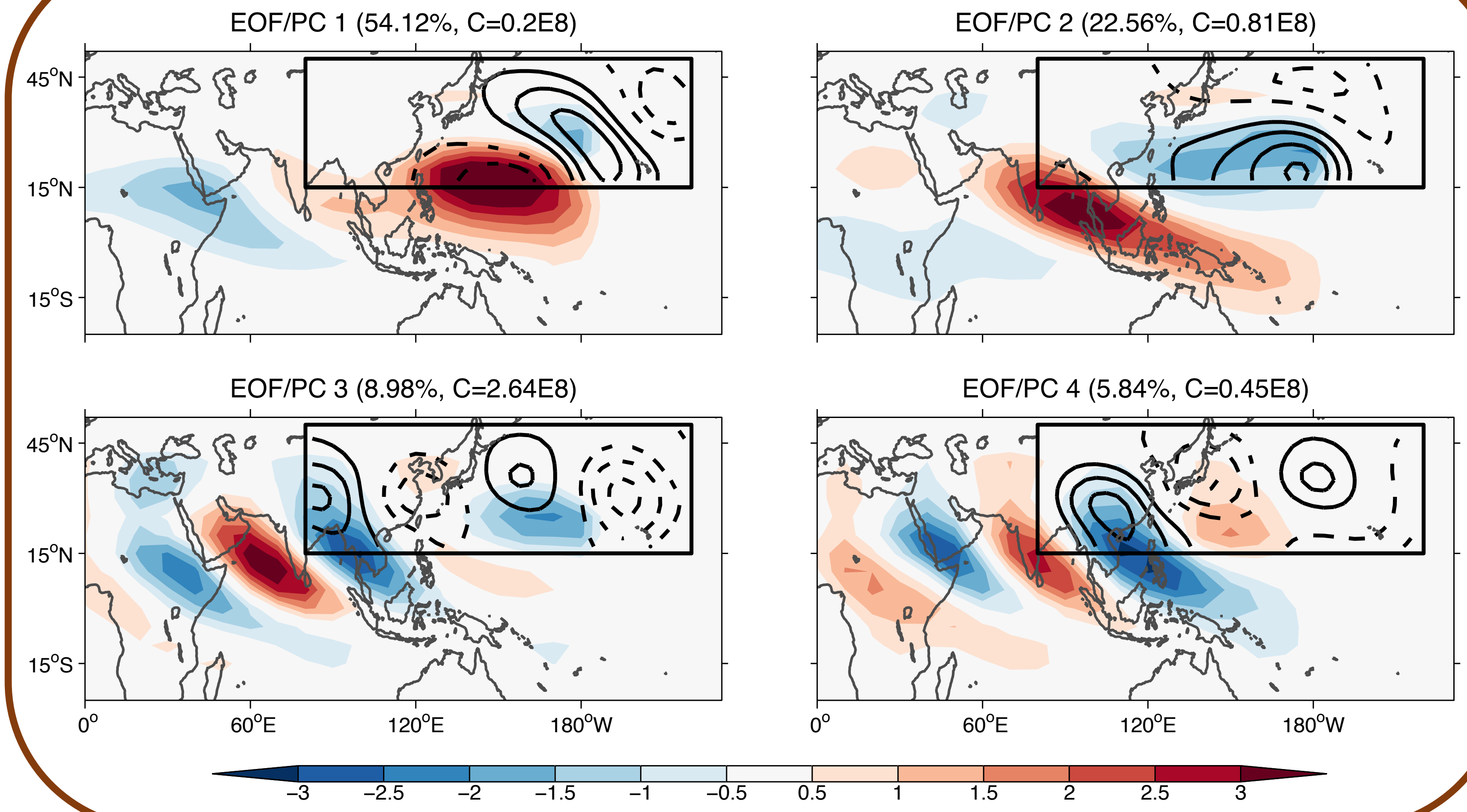
Many SWM simulations give a response that looks like this

Positive vorticity forcing over the red area gives a strong wave response that looks like this EOF (to a lesser extent, positive vorticity forcing over the blue areas generates a response that looks like this EOF but with opposite sign)

(For vorticity using December La Nina basic state)

Four leading EOFs and normalized PCs

(PCs normalized by square root of eigenvalues)



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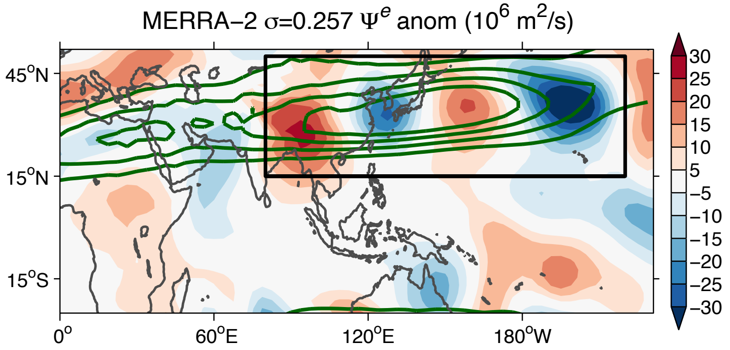

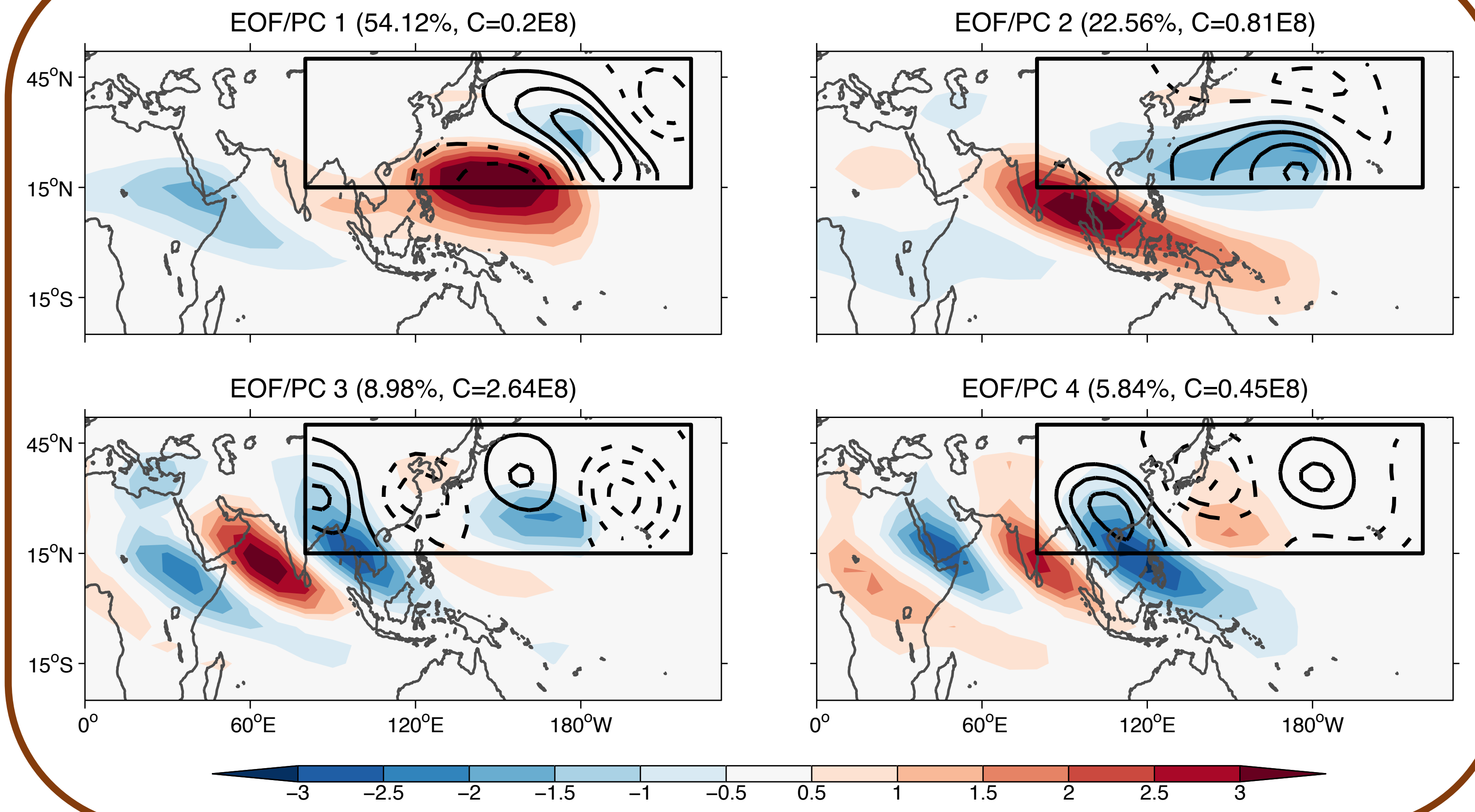

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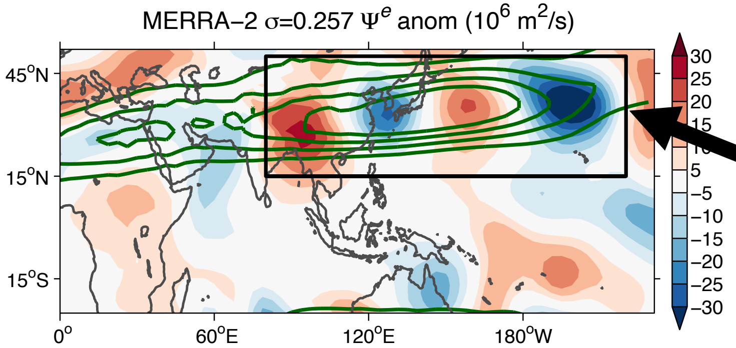

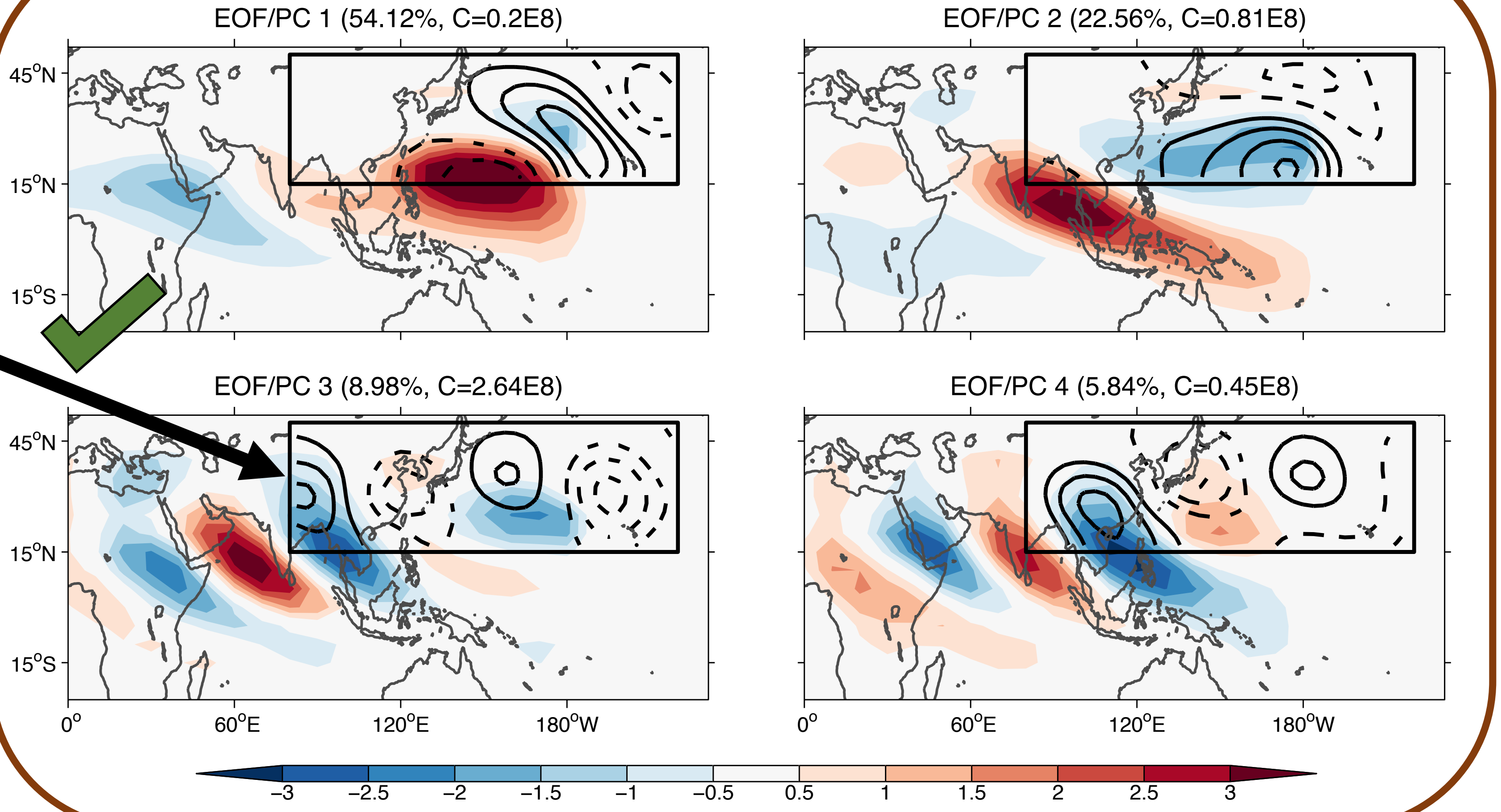

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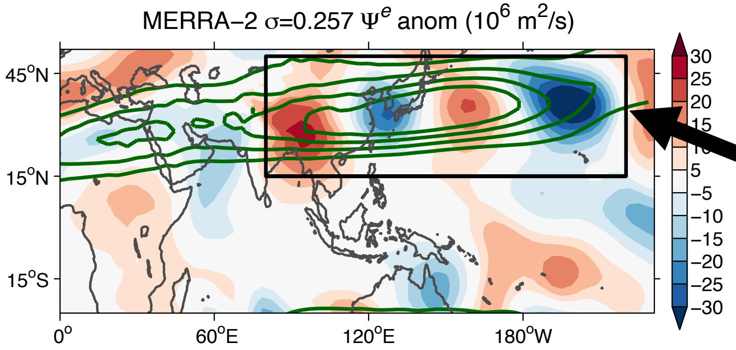

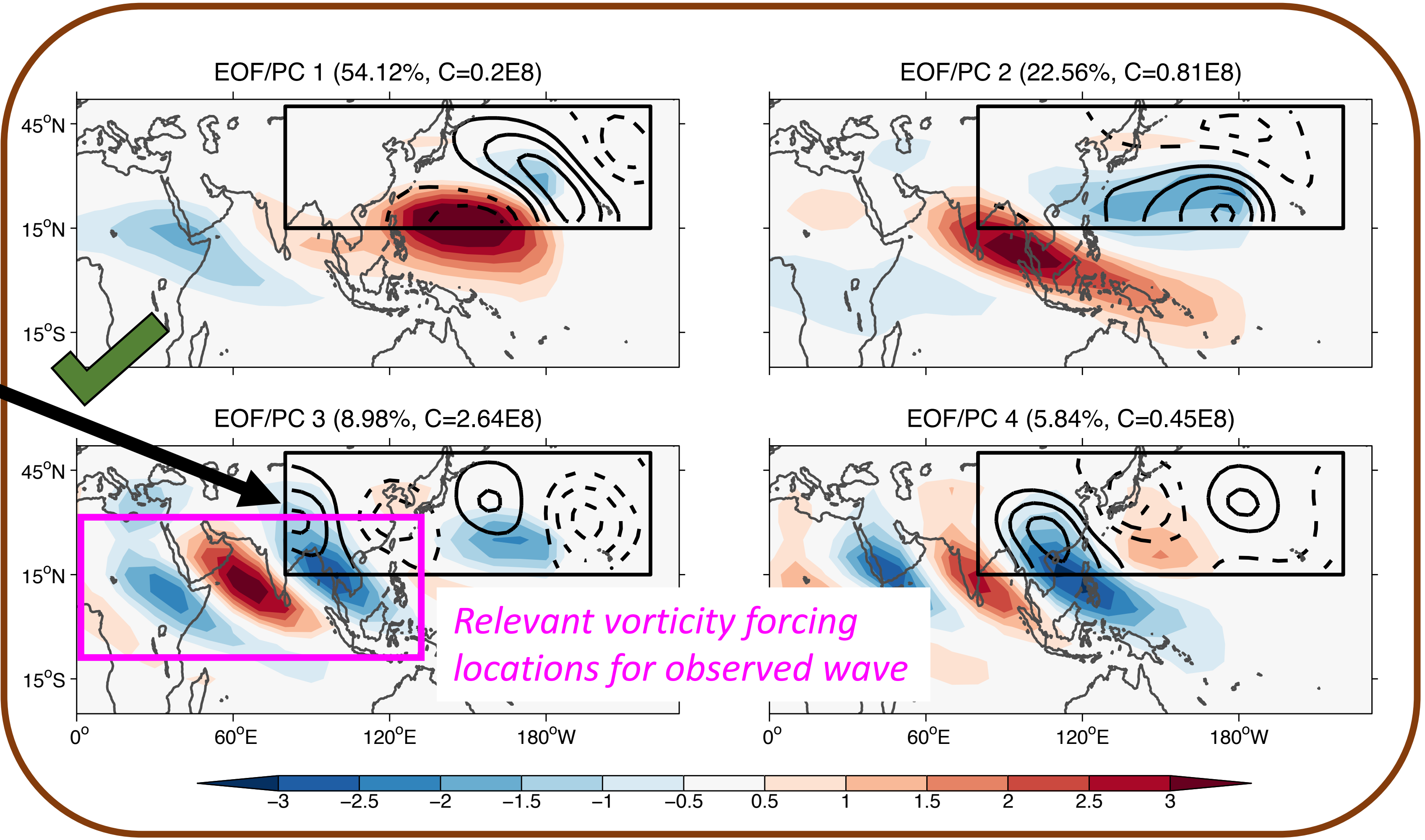

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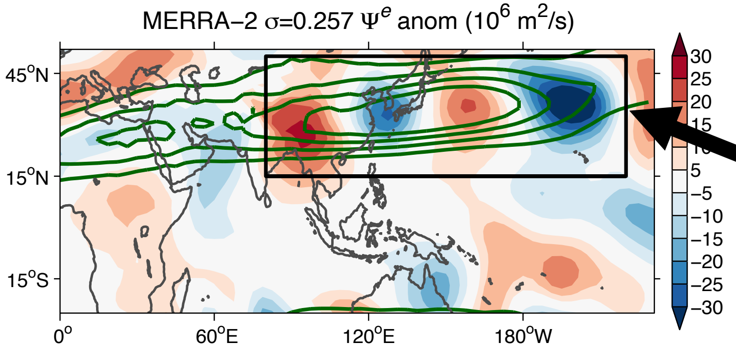
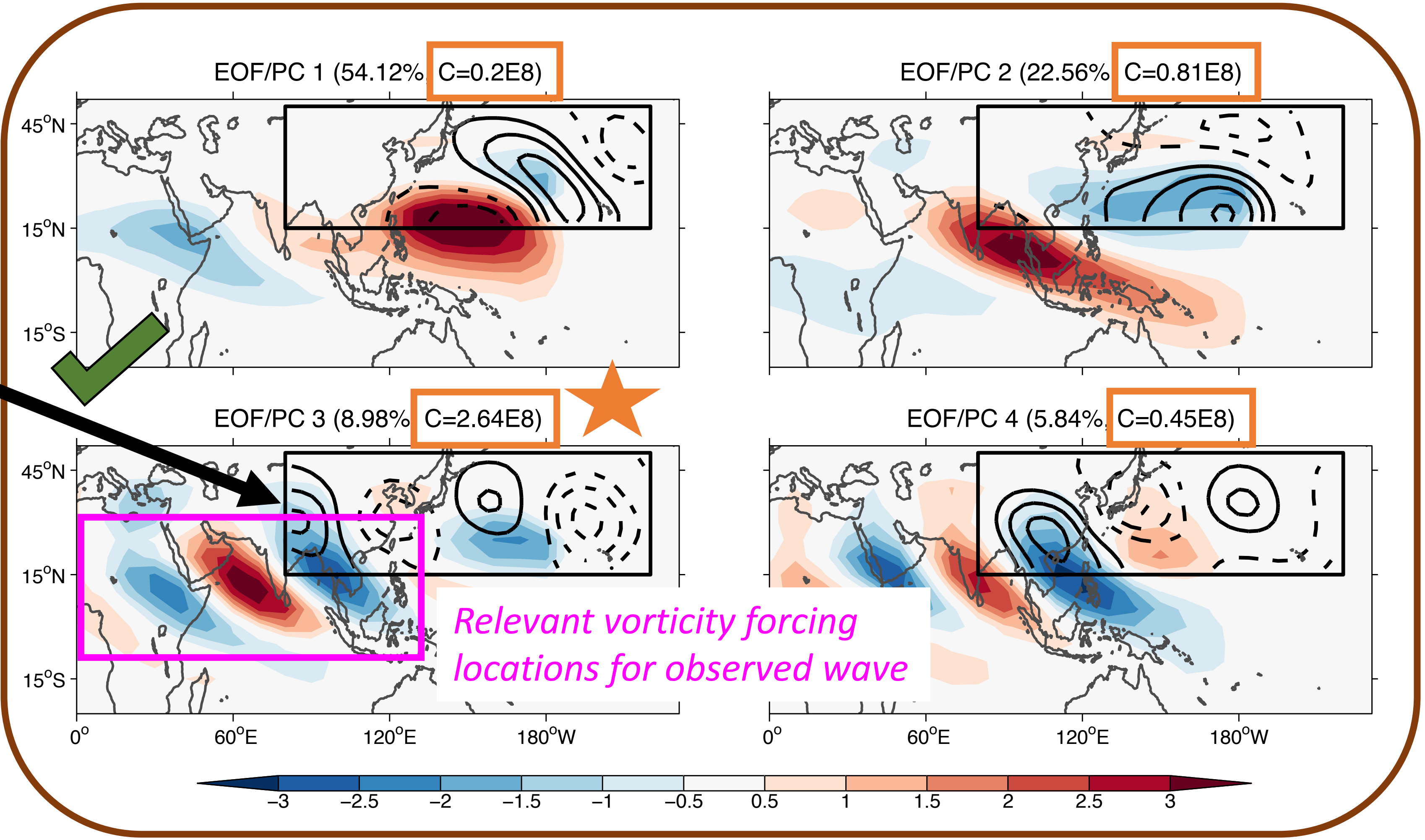


Quantify the agreement with observations: C = inner product between EOF and obs. (same as linear regression coefficient)

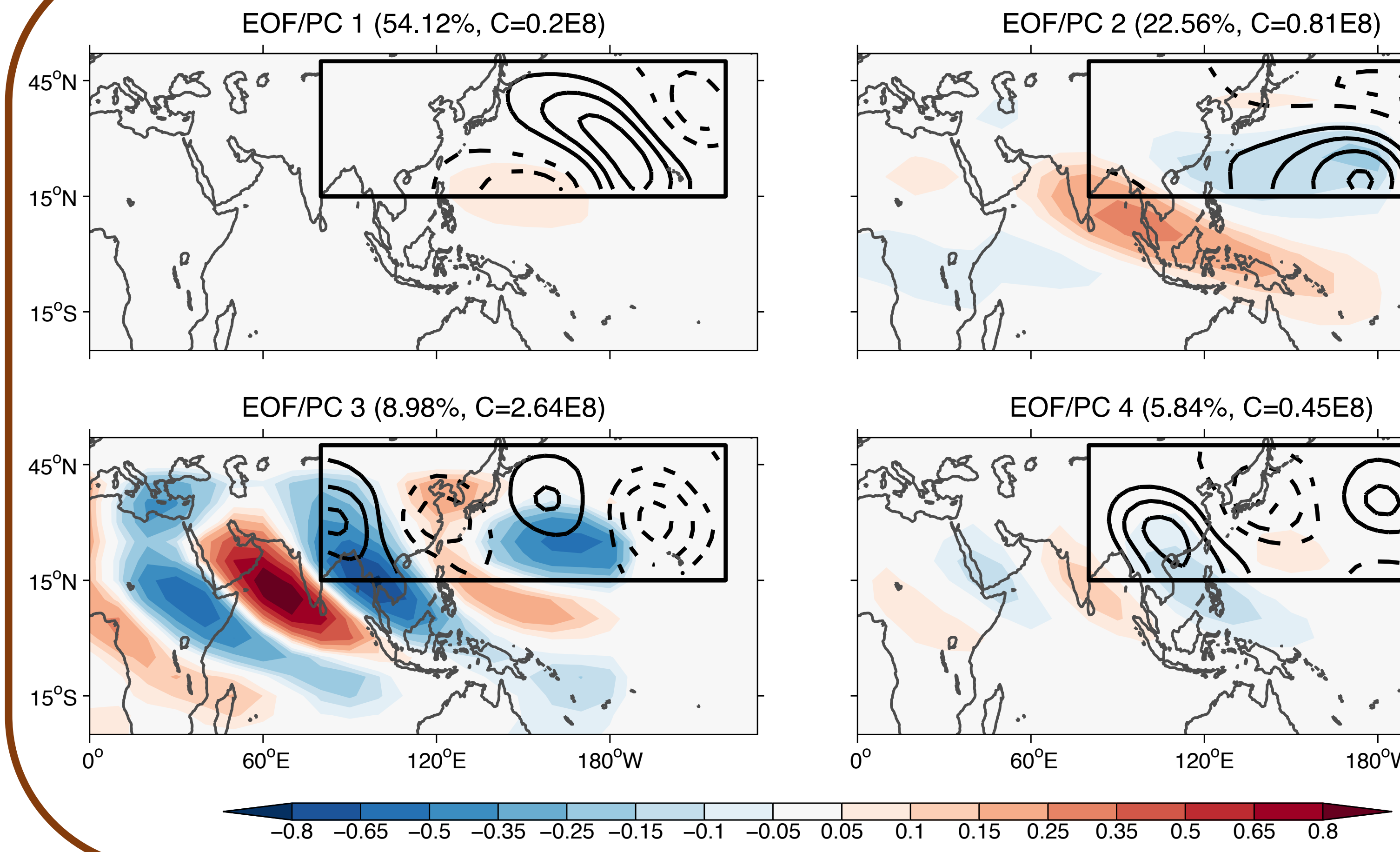
EOF 3, which looks the most like the observed wave, has the largest C value.



(For vorticity using December La Nina basic state)

Normalized PCs scaled by coefficient C

(Product divided by max value across the EOFs)



Here, the PCs are scaled by the C values, to emphasize forcing locations that would generate wave responses like the observed wave.

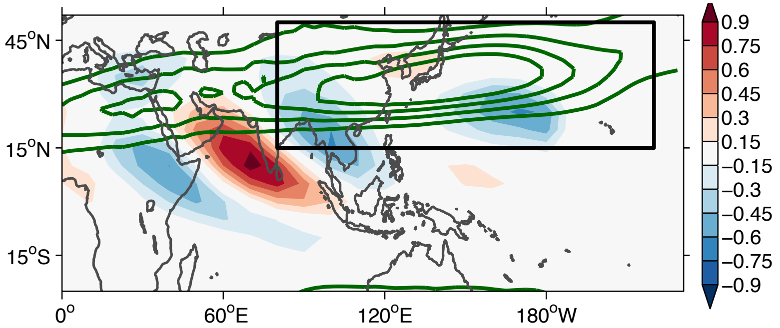
(For vorticity using December La Nina basic state)

Normalized PCs scaled by coefficient C

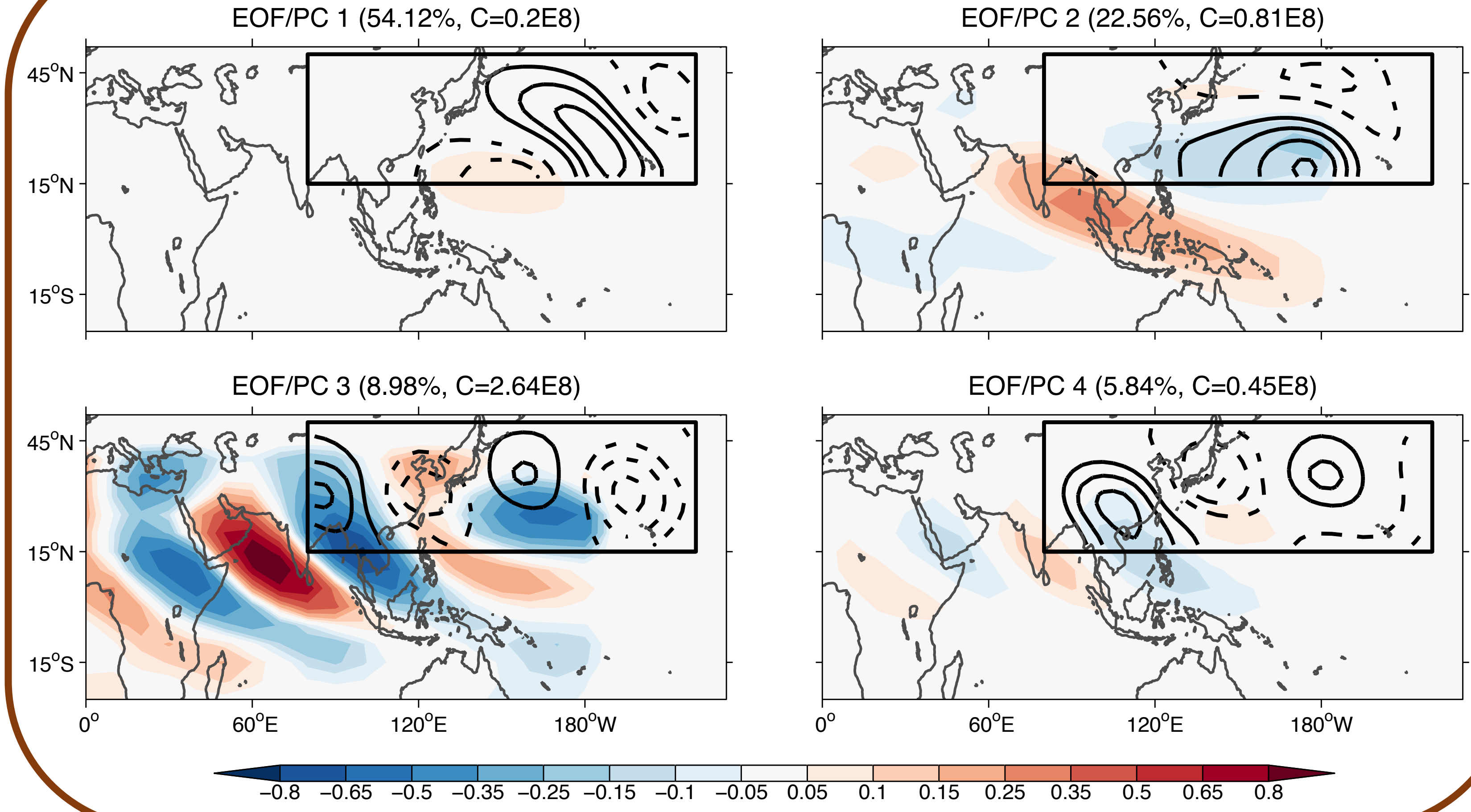
(Product divided by max value across the EOFs)

(Sum divided by max value on the map)

Add scaled PCs (1 to 4)



This is the forcing sensitivity map for vorticity



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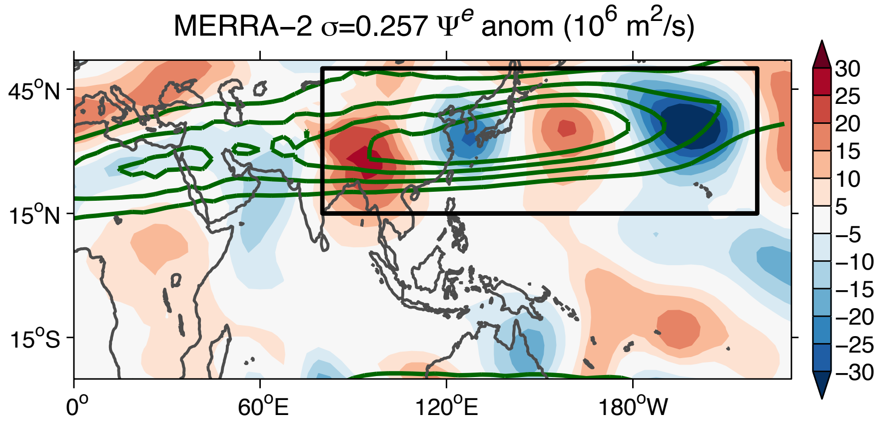
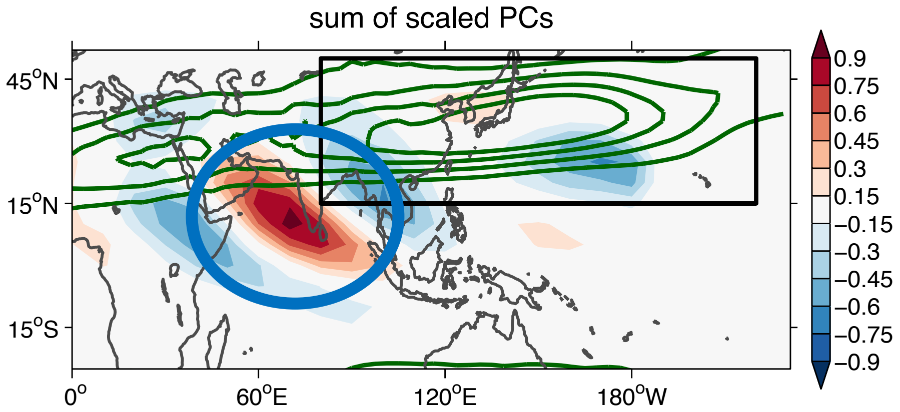


Observed wave



Forcing sensitivity map for vorticity, based on SWM

This tells us that positive vorticity forcing south/west of India would tend to produce a wave response in the SWM that resembles the observed wave on the left. Positive vorticity forcing over the blue areas would tend to produce a wave response with opposite sign.

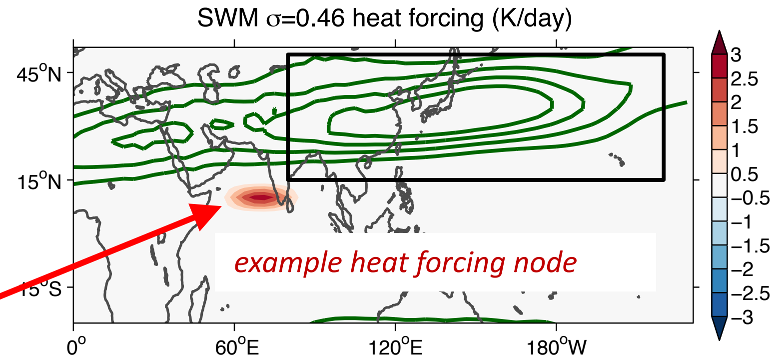
What about heat forcing?

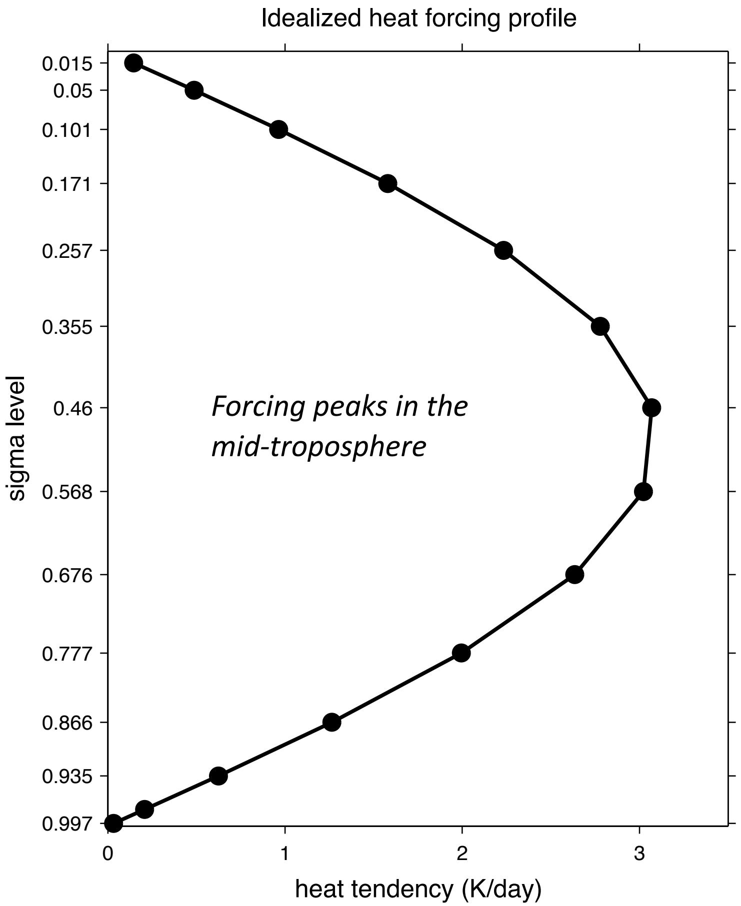
Idealized forcing experiment:

$$\frac{\partial T}{\partial t} = \cdots + forcing$$

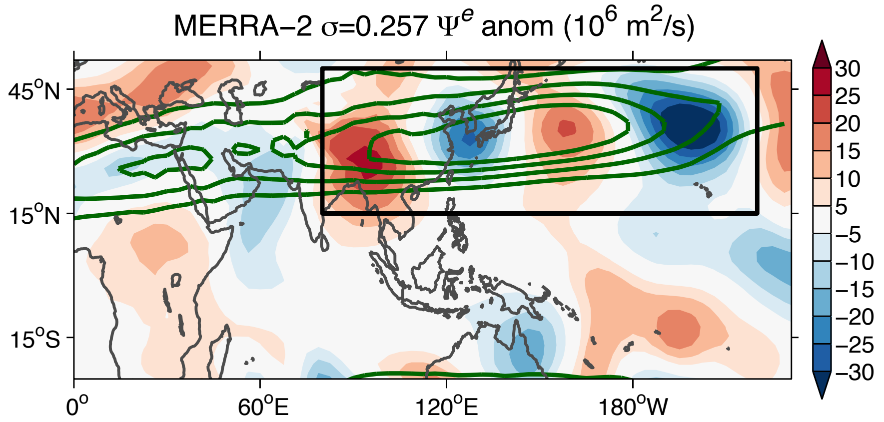
Forcing typically from diabatic heating due to positive precipitation anomalies

Repeat the same exercise as for vorticity, but with heat forcing instead.

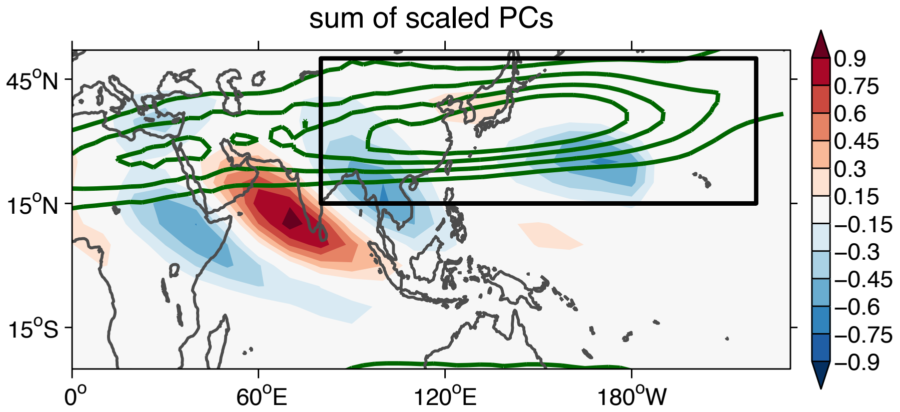




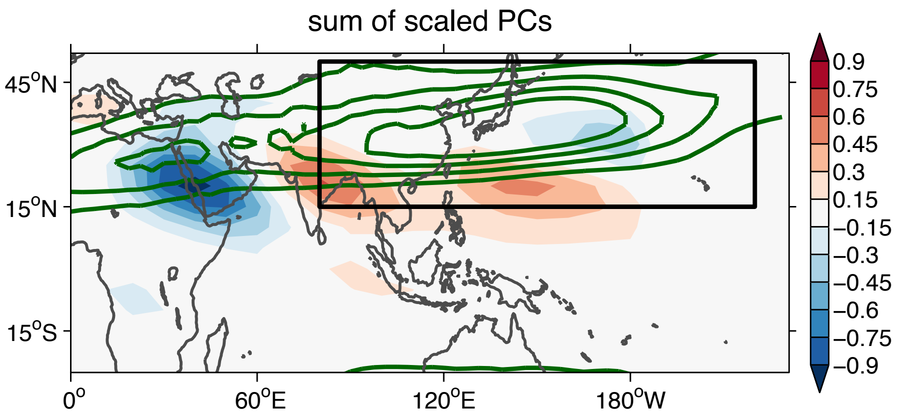
Question: Can we get a SWM response that resembles the Dec. 21-23 wave, and how?



Observed wave



Forcing sensitivity map for vorticity, based on SWM



Forcing sensitivity map for heat, based on SWM

The heat forcing sensitivity map (left) is interpreted the same way as the vorticity sensitivity map (above). In this case, heating anomalies over India or the western Pacific would tend to induce a wave response like the observed. A heat anomaly over the Red Sea would induce a wave response with opposite sign.