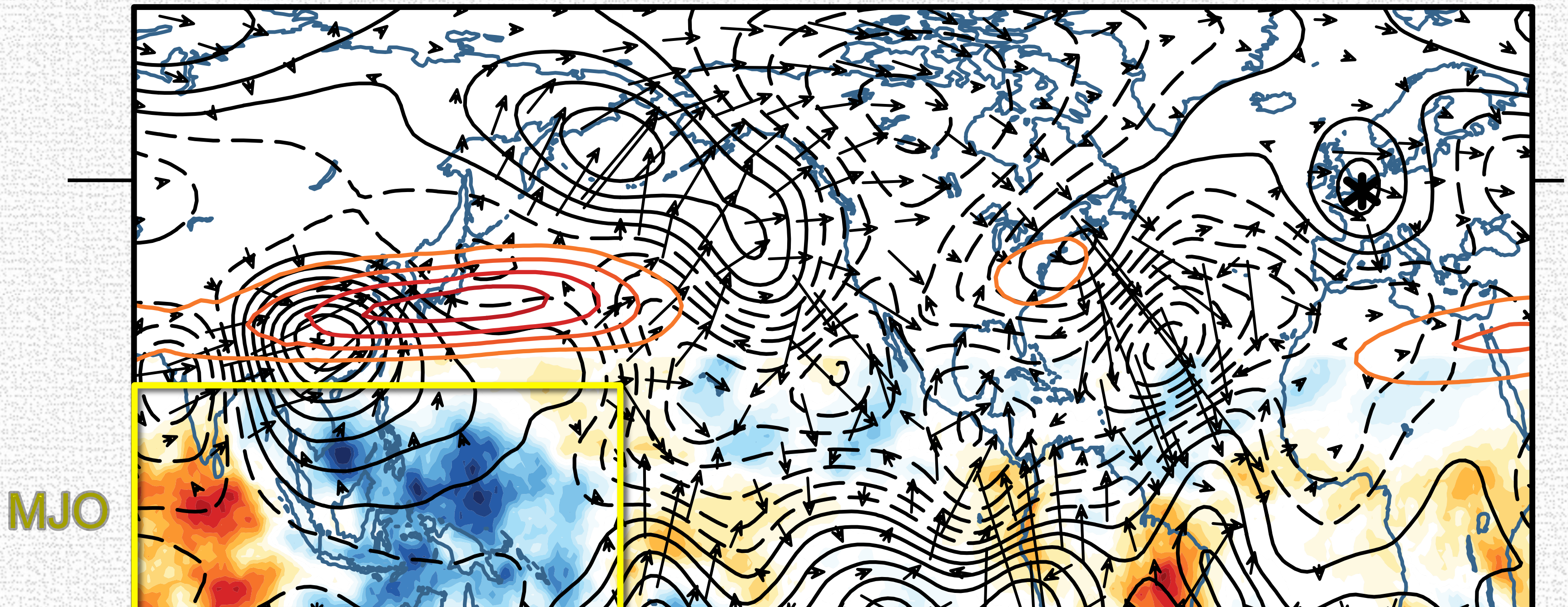
THE ROLE OF TROPICAL-EXTRATROPICAL INTERACTIONS ON THE OPTIMAL GROWTH OF MADDEN-JULIAN OSCILLATION EVENTS



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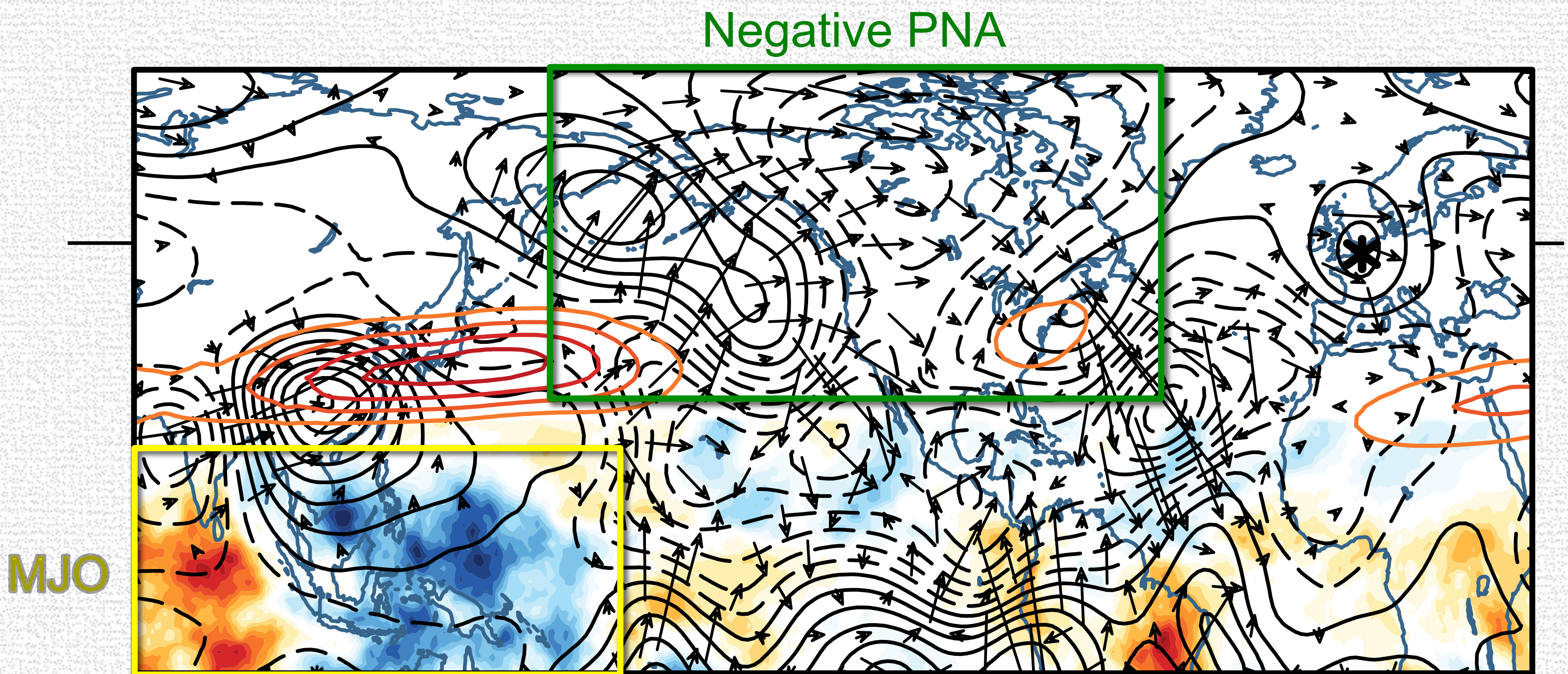
THE ROLE OF TROPICAL-EXTRATROPICAL INTERACTIONS ON THE OPTIMAL GROWTH OF THE PACIFIC-NORTH AMERICAN PATTERN



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Data

- ERA-Interim reanalysis:
  - 200-hPa and 850-hPa streamfunction (15°N – 90°N)
  - Vertically integrated apparent heat source (Q1; Yanai et al. 1973) 20°S – 15°N
- NOAA Optimum Interpolation Sea Surface Temperature (OISST) dataset (20°S – 15°N)
- Pentad (5-day) anomalies
- December – February (DJF)
- Range: December 1982 – February 2015
- Daily NOAA/NCEP Climate Prediction Center (CPC) PNA index

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Linear Inverse Modeling (LIM)

$$d\mathbf{x}/\mathbf{dt} = \mathbf{Lx} + \zeta$$

State of system — Dynamics (arrow to $\mathbf{L}$) — Noise

$$\mathbf{x}(t) = \begin{bmatrix} \mathbf{SST} \\ \mathbf{Q1} \\ \mathbf{\Psi}_{200} \\ \mathbf{\Psi}_{850} \end{bmatrix}$$

LIM approximates the evolution of a dynamical system by a multivariate linear model

Linear Inverse Modeling (LIM)

$$dx/dt = \mathbf{L}\mathbf{x} + \zeta$$

State of system — Dynamics — Noise

$$\mathbf{x}(t) = \begin{bmatrix} \mathbf{SST} \\ \mathbf{Q1} \\ \mathbf{\Psi}_{200} \\ \mathbf{\Psi}_{850} \end{bmatrix}$$

- The forecast, x(τ), is the solution to the homogeneous part:

$$\mathbf{x}(\tau) = \mathbf{e}^{\mathbf{L}\tau}\mathbf{x}(\mathbf{0})$$

Linear Inverse Modeling (LIM)

$$d\mathbf{x}/\mathbf{dt} = \mathbf{Lx} + \zeta$$

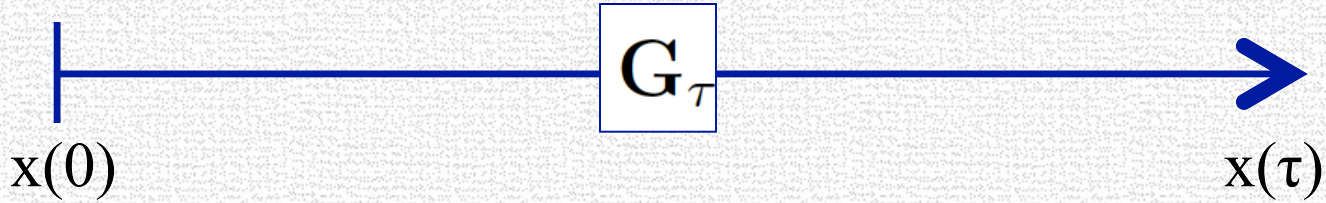
State of system (↑ $\mathbf{x}$) · Dynamics (↑ $\mathbf{L}$) · Noise (↑ ζ)

$$\mathbf{x}(\mathrm{t}) = \begin{bmatrix} \mathbf{SST} \\ \mathbf{Q1} \\ \mathbf{\Psi}_{200} \\ \mathbf{\Psi}_{850} \end{bmatrix}$$

- The forecast, x(τ), is the solution to the homogeneous part:

$$\mathbf{x}(\tau) = \mathbf{e}^{\mathbf{L}\tau}\mathbf{x}(\mathbf{0}) = \mathbf{G}_\tau \mathbf{x}(\mathbf{0})$$

$$\mathbf{G}_\tau = C_\tau / C_0$$



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Linear Inverse Modeling (LIM)

$$d\mathbf{x}/\mathbf{dt} = \mathbf{Lx} + \zeta$$

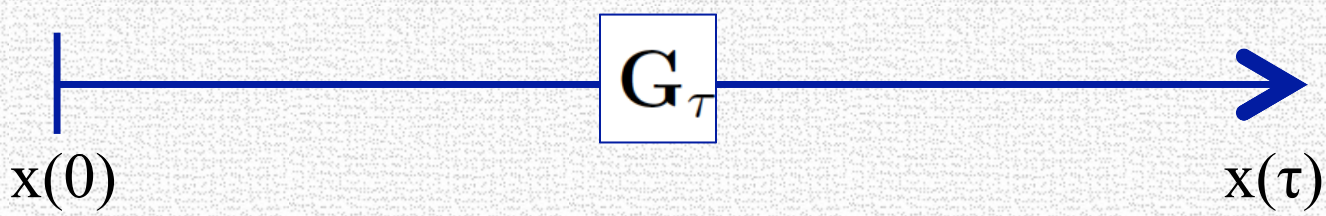
- $d\mathbf{x}$: State of system
- $\mathbf{L}$: Dynamics
- ζ: Noise

$$\mathbf{x}(t) = \begin{bmatrix} \mathbf{SST} \\ \mathbf{Q1} \\ \mathbf{\Psi_{200}} \\ \mathbf{\Psi_{850}} \end{bmatrix}$$

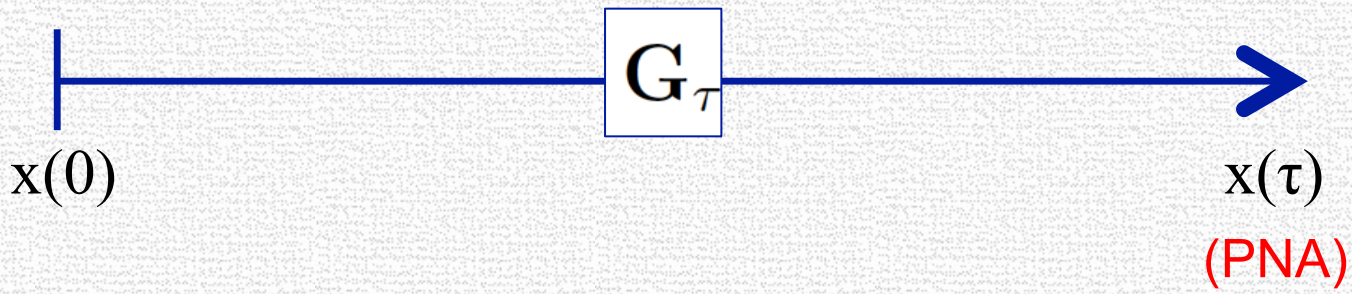
- The forecast, x(τ), is the solution to the homogeneous part:

$$\mathbf{x}(\tau) = \mathbf{e}^{\mathbf{L}\tau}\mathbf{x}(\mathbf{0}) = \mathbf{G}_\tau \mathbf{x}(\mathbf{0})$$

$$\mathbf{L} = \ln(\mathbf{G}_\tau)/\tau \qquad \mathbf{G}_\tau = C_\tau / C_0$$



Growth towards the MJO



- We can estimate an optimal initial condition (**p**) by maximizing growth in the direction of a chosen norm (**N**) by solving the eigenvalue problem:

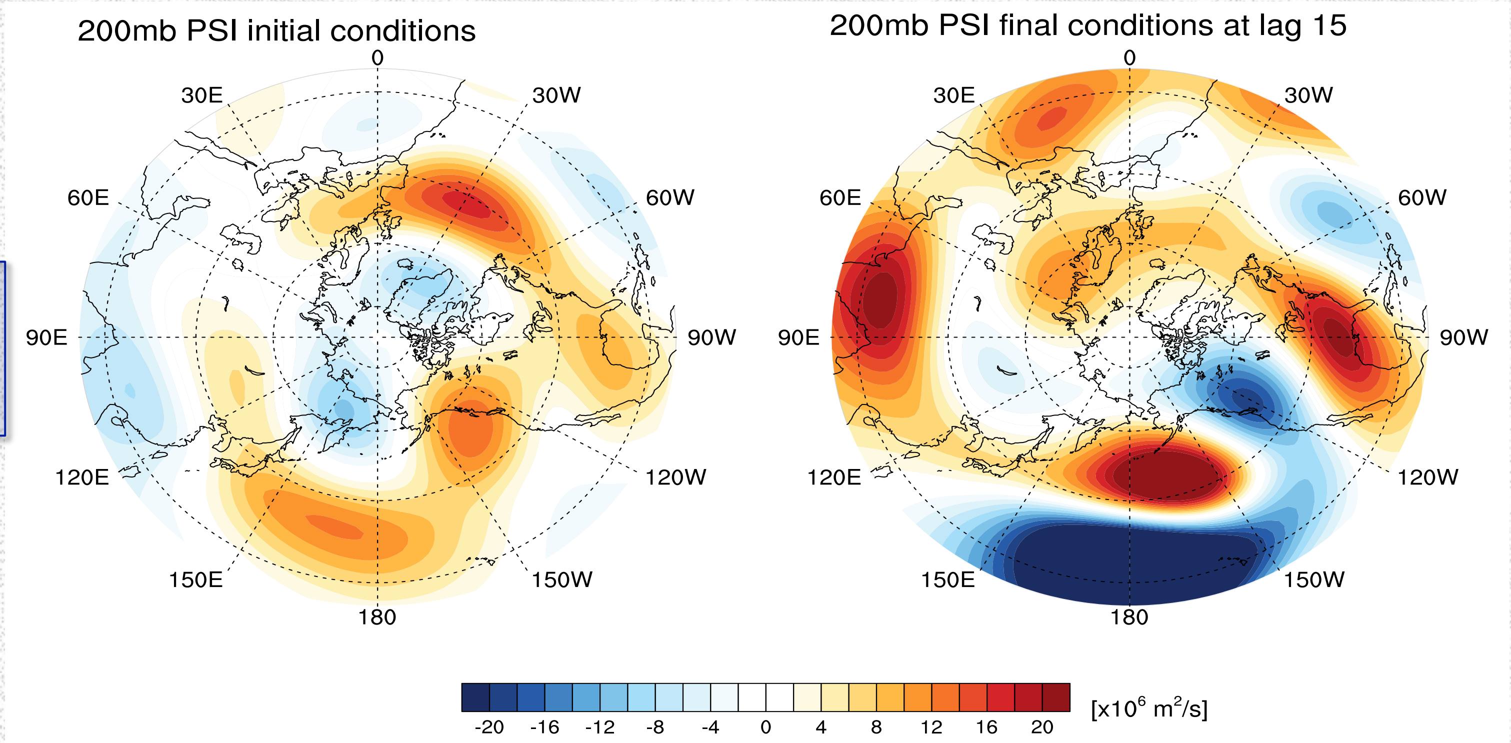
$$G_\tau^T \mathbf{N} G_\tau \mathbf{p} - \mu(\tau)\mathbf{p} = \mathbf{0}$$

norm (PNA) — eigenvector — growth

Initial condition

Final PNA pattern

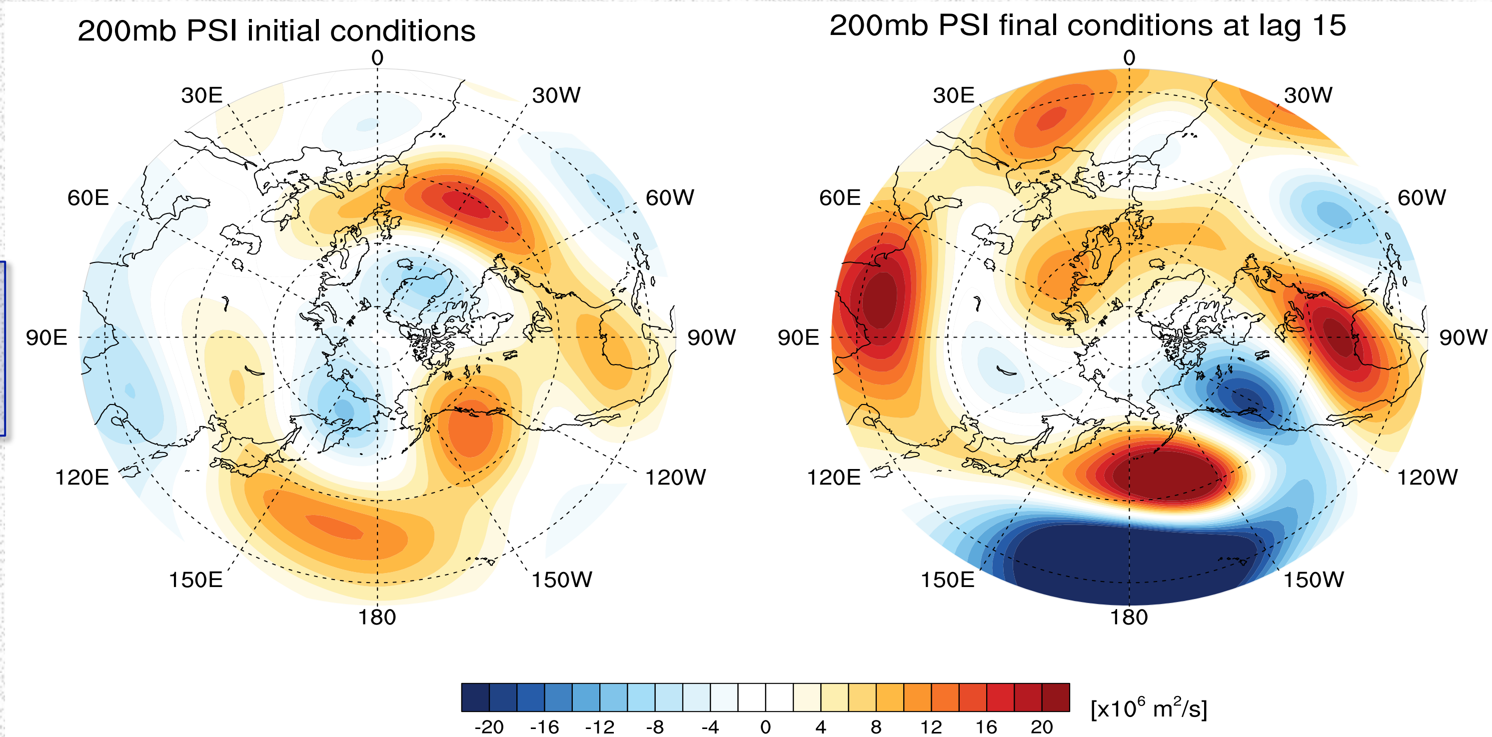
200-hPa streamfunction



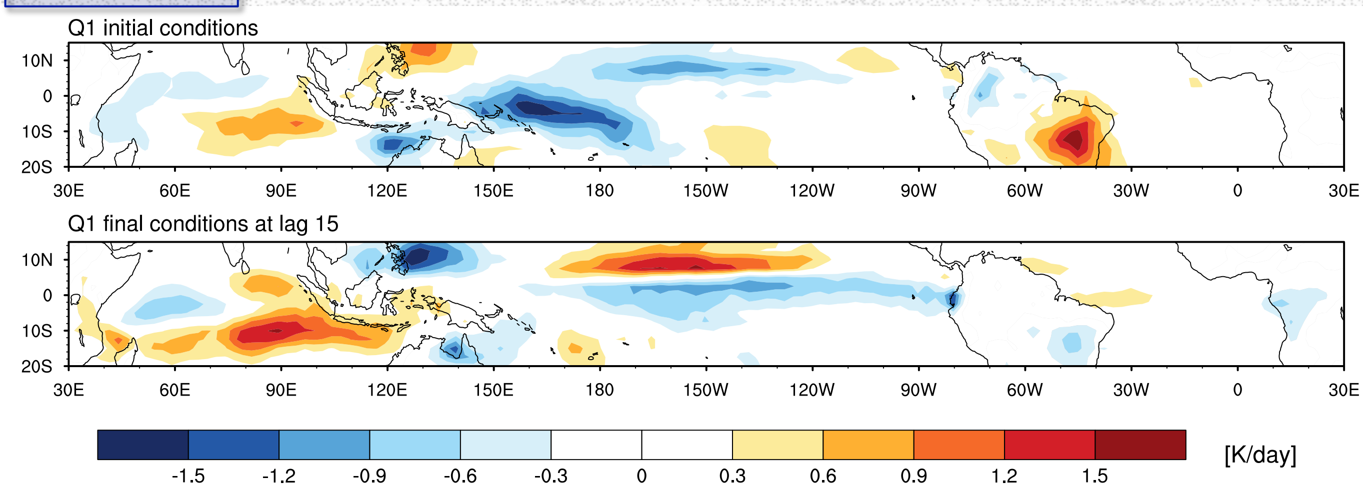
Initial condition

Final PNA pattern

200-hPa streamfunction



Q1



Initial condition

Final condition

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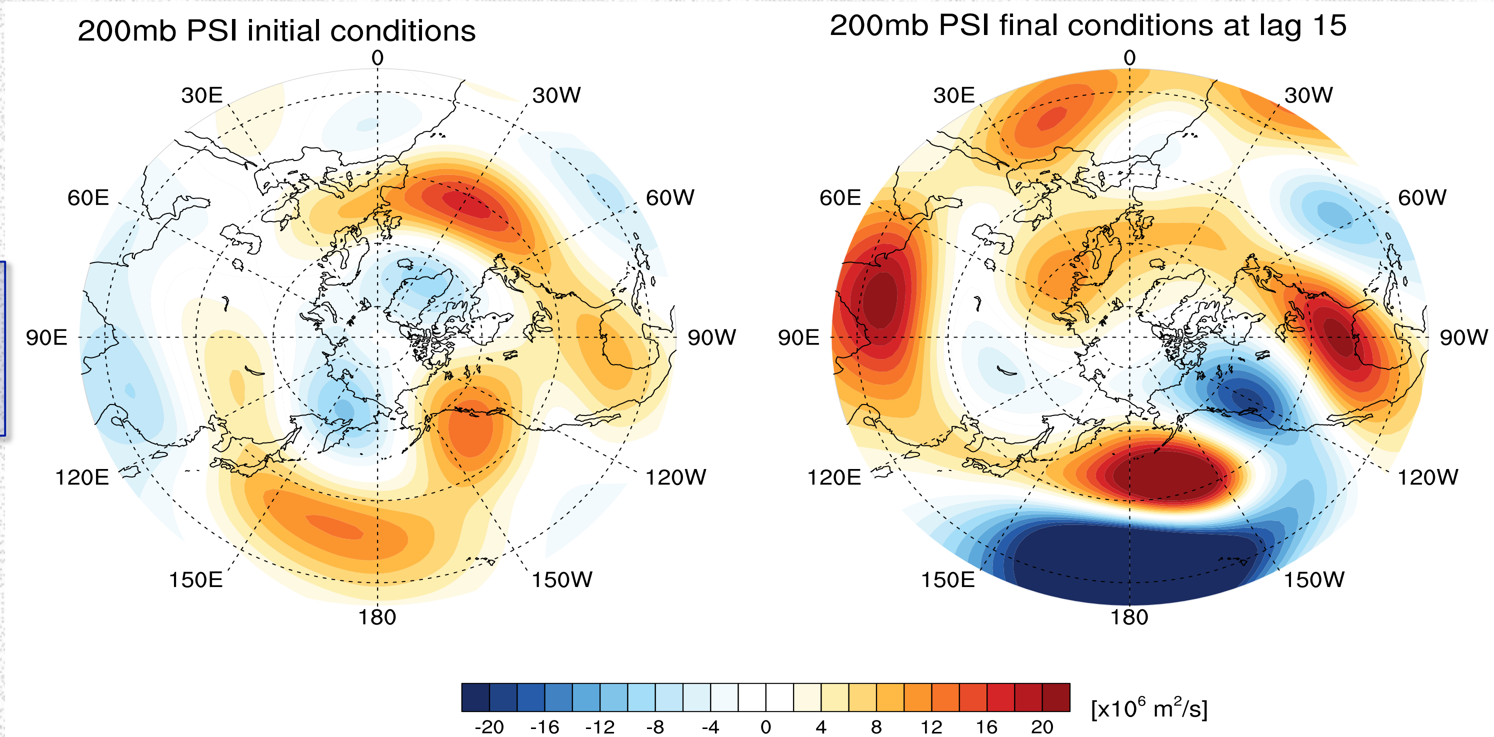
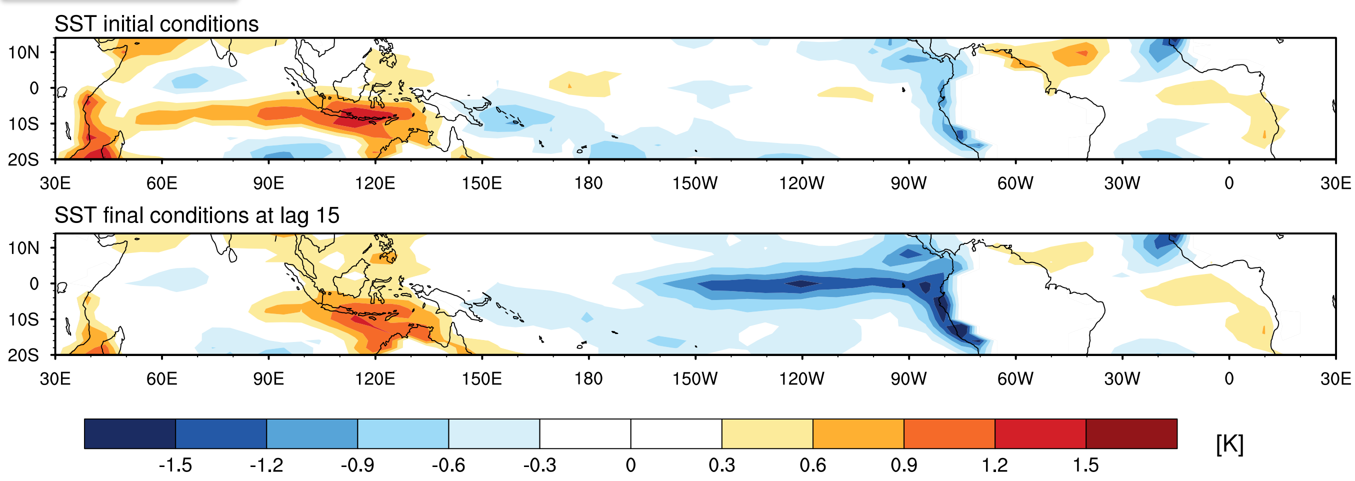
Initial condition

Final PNA pattern

200-hPa streamfunction



SST

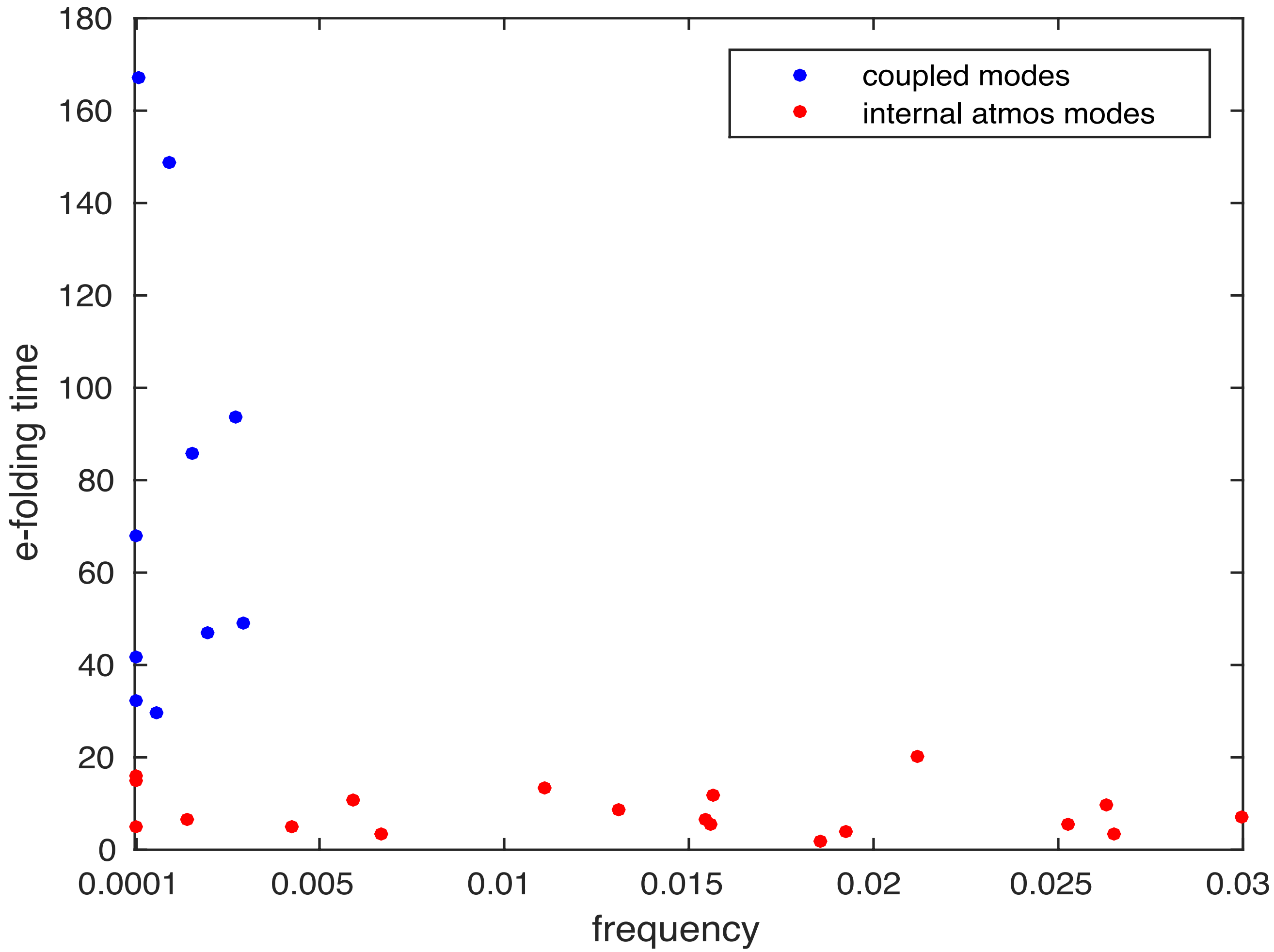


Initial condition

Final condition

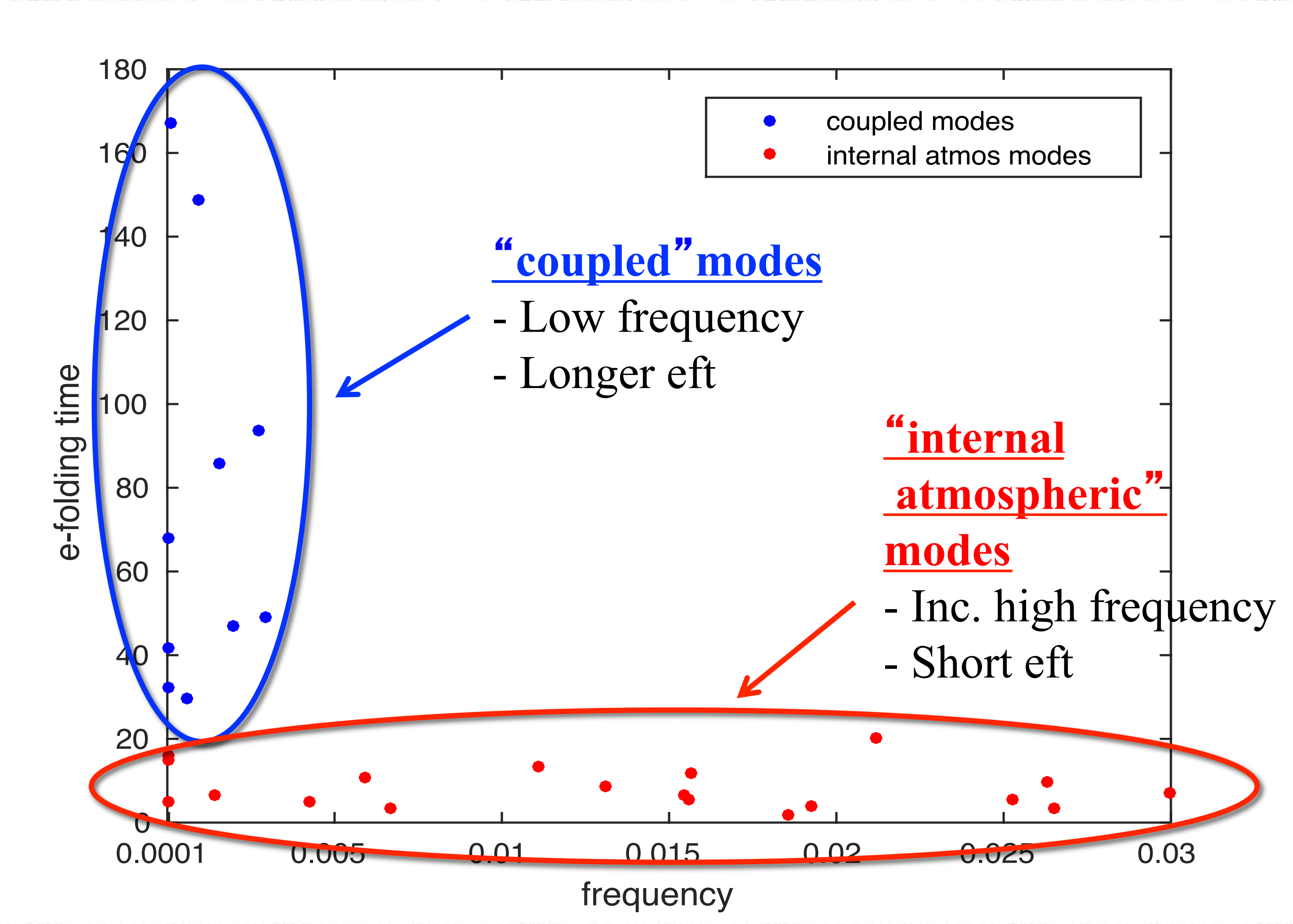
Two eigenspaces of L

Recall: $\mathbf{L} = \mathbf{ln}(\mathbf{G}_\tau)/\tau$ $\mathbf{G}_\tau = C_\tau / C_0$



Two eigenspaces of L

Recall: $\mathbf{L} = \ln(\mathbf{G}_\tau)/\tau$ $\mathbf{G}_\tau = C_\tau / C_0$

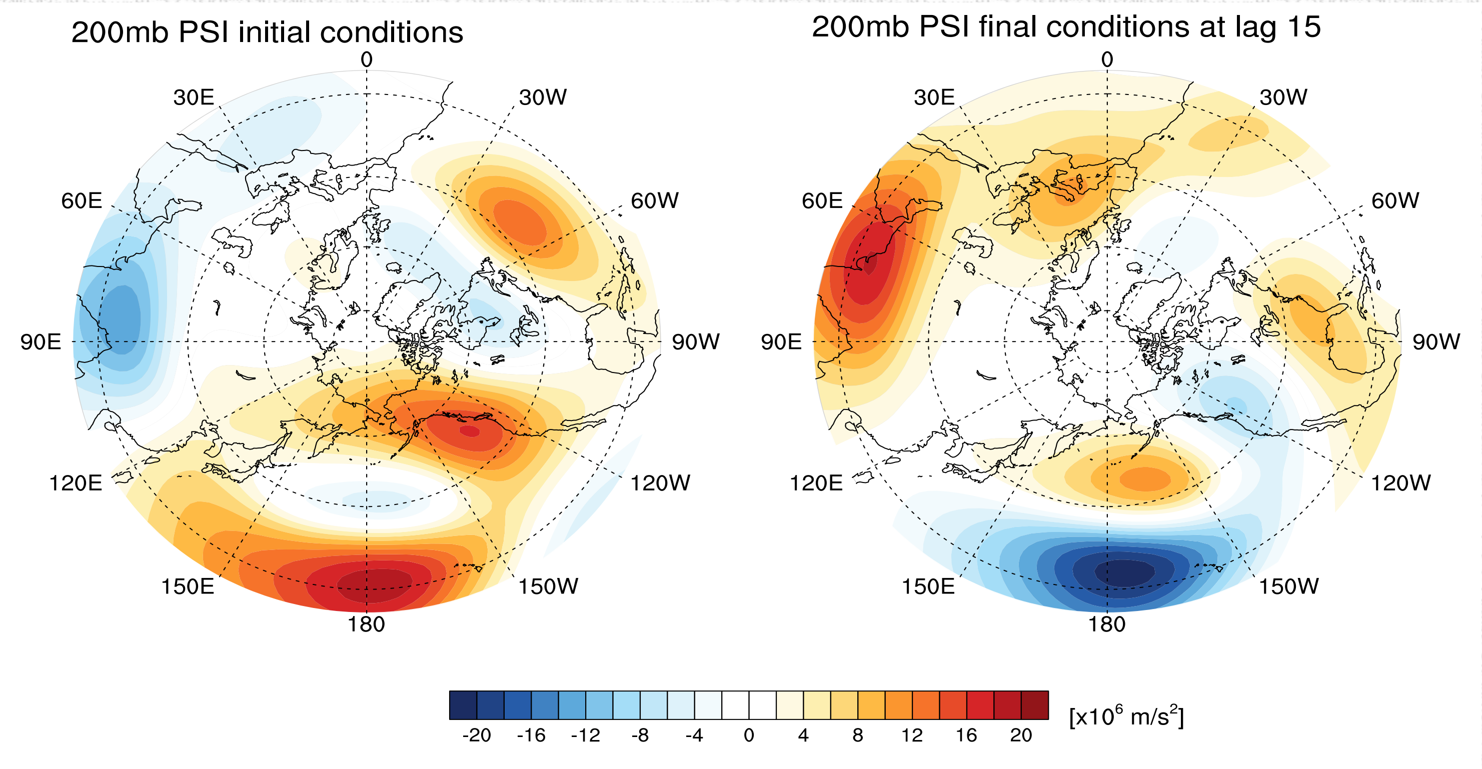


Uncoupled LIM

200-hPa streamfunction

Initial Condition

Final PNA pattern

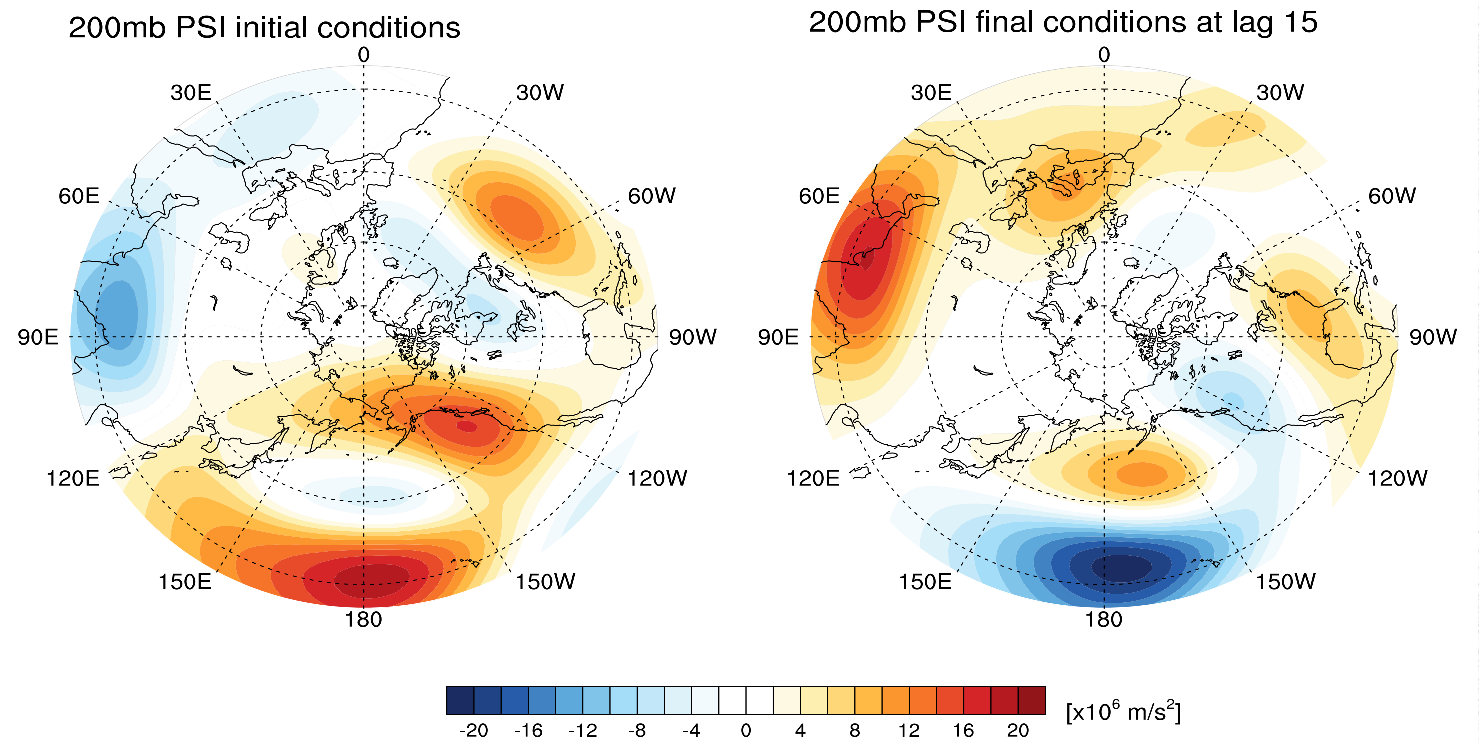


Uncoupled LIM

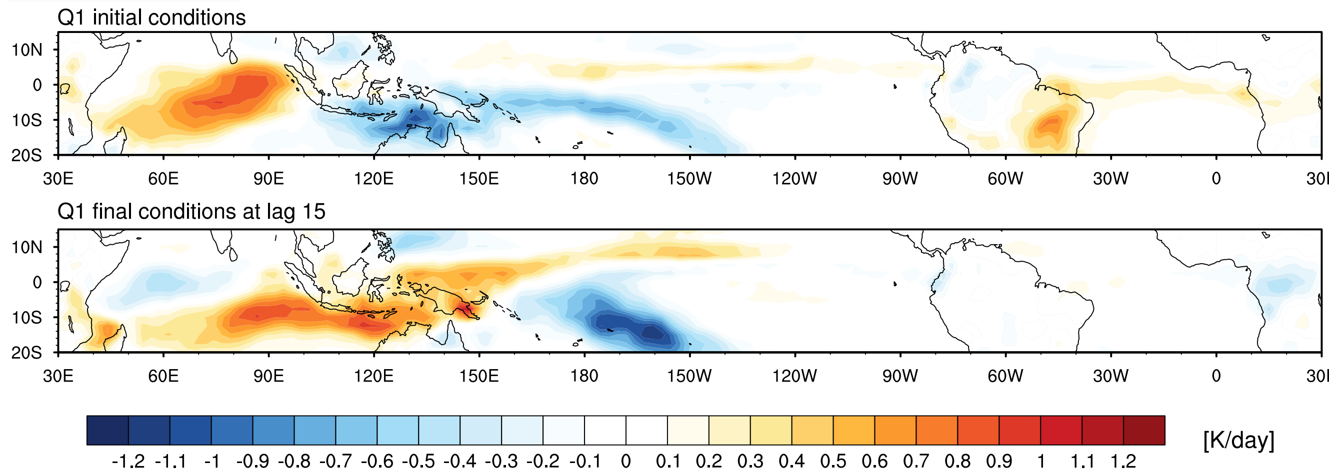
200-hPa streamfunction

Initial condition

Final PNA pattern



Q1



Initial condition

Final condition

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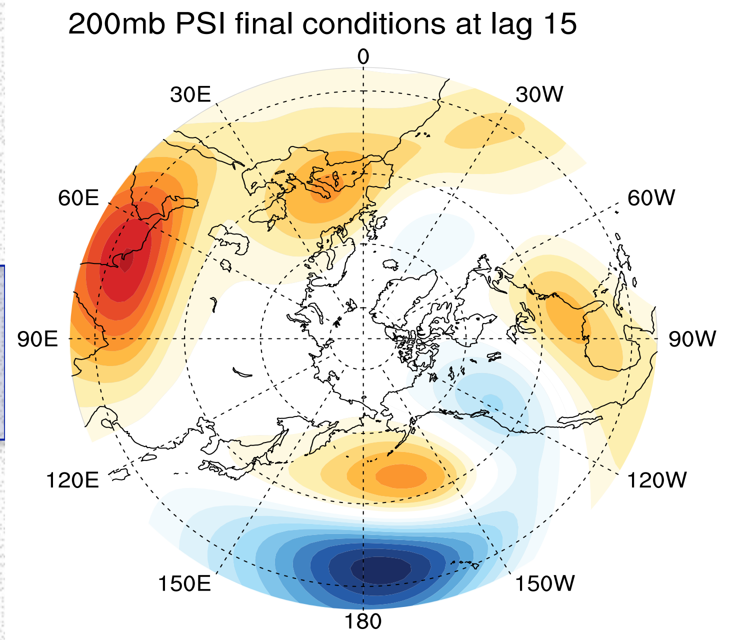
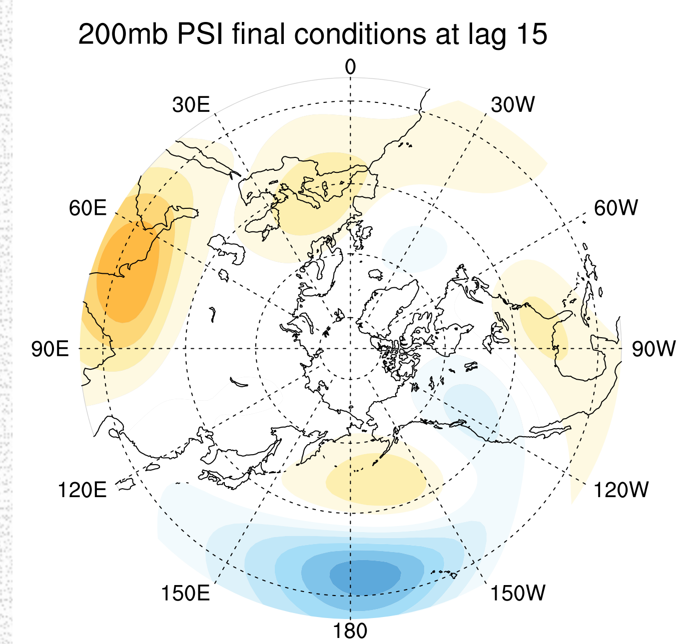
Tropical initial conditions removed

200-hPa streamfunction

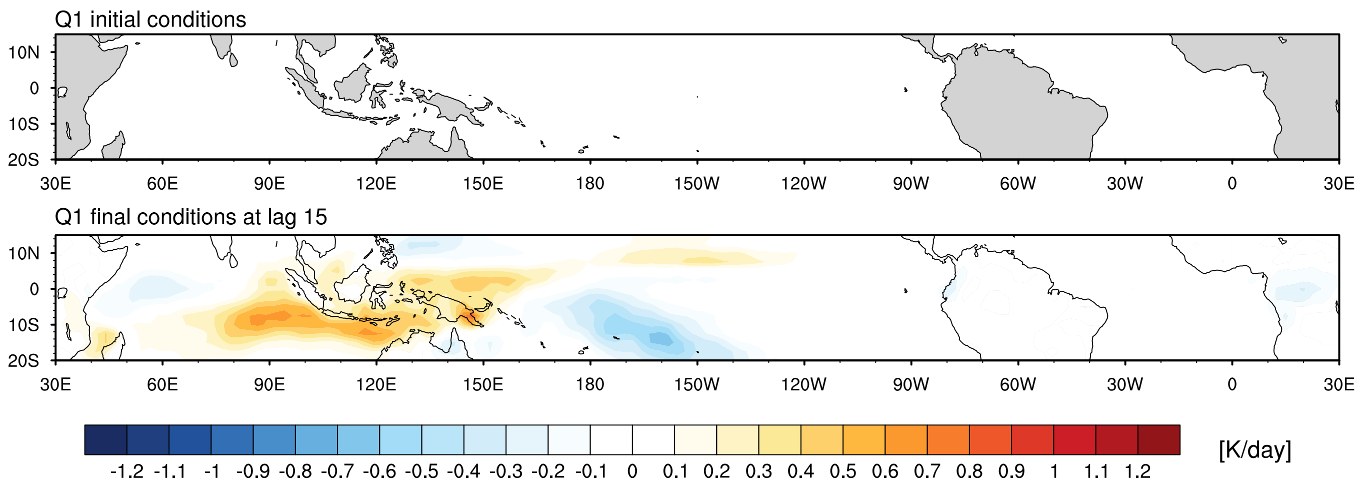
Unmodified **p** final PNA



Modified **p** final PNA



Q1



Initial condition

Final condition

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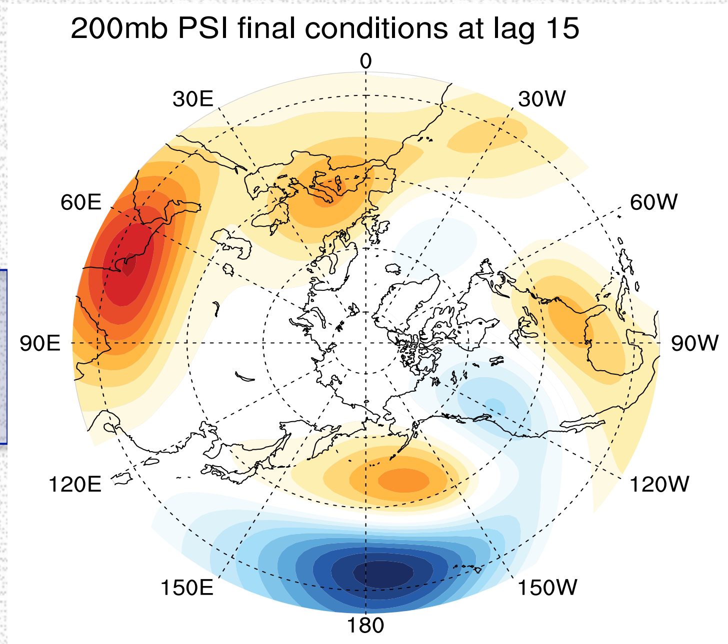
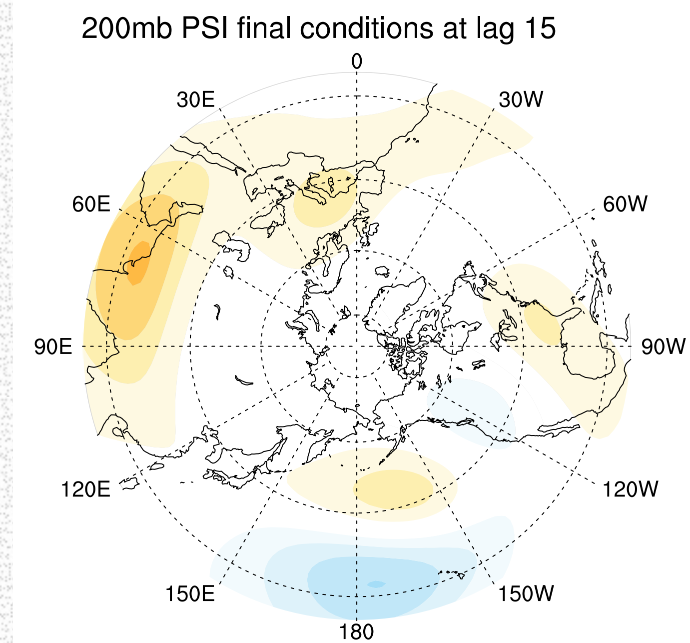
Extratropical initial conditions removed

200-hPa streamfunction

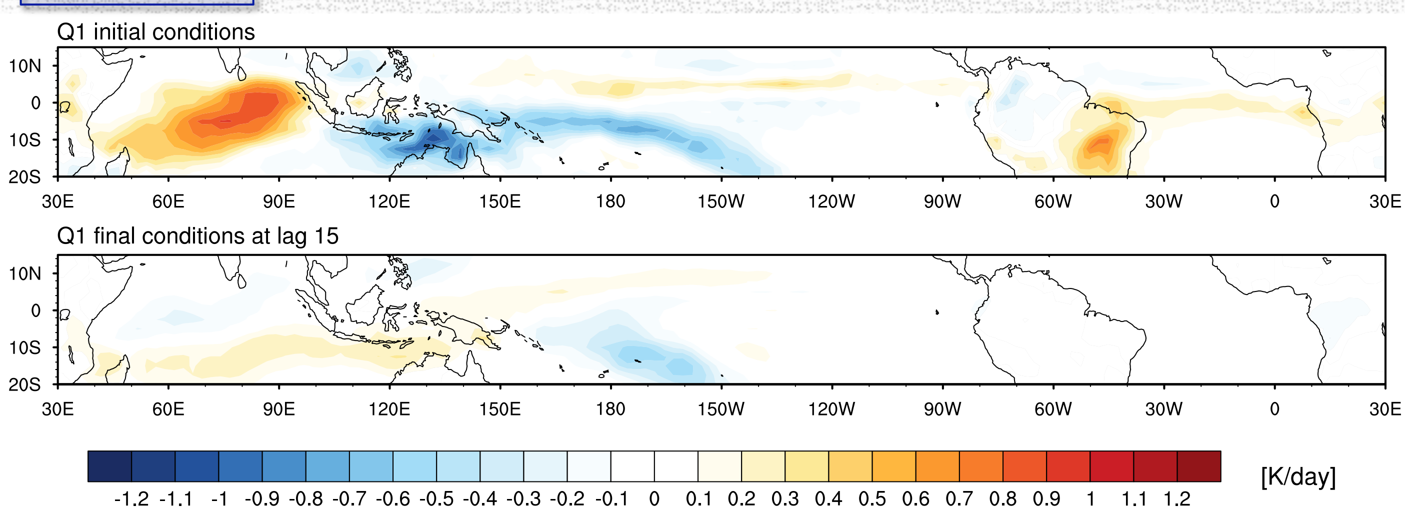
Unmodified **p** final PNA



Modified **p** final PNA



Q1



Initial condition

Final condition

Summary

- Linear inverse modeling (LIM) is used to examine the optimal conditions that lead to PNA pattern growth.
- Unfiltered LIM: suppressed tropical heating in the SPCZ, ENSO-related heating, and MJO-like heating in the east Indian Ocean optimally lead to PNA pattern growth.
- An uncoupled LIM is developed to examine PNA growth outside of ENSO. Optimal PNA growth is from MJO anomalous heating over the east Indian Ocean and suppressed heating over the Maritime continent and SPCZ.
- In the extratropics, the optimal initial condition agree with previous studies, including an anticyclonic anomaly over the East Pacific that retrogrades, becoming part of the PNA pattern.
- Modifying the initial conditions suggest both tropical heating and the extratropical circulation are important for PNA pattern growth in the uncoupled LIM.