Systematic Decomposition of the MJO and its Northern Hemispheric Extra-Tropical Response into Rossby and Inertio-Gravity Components

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Outline

1) MJO

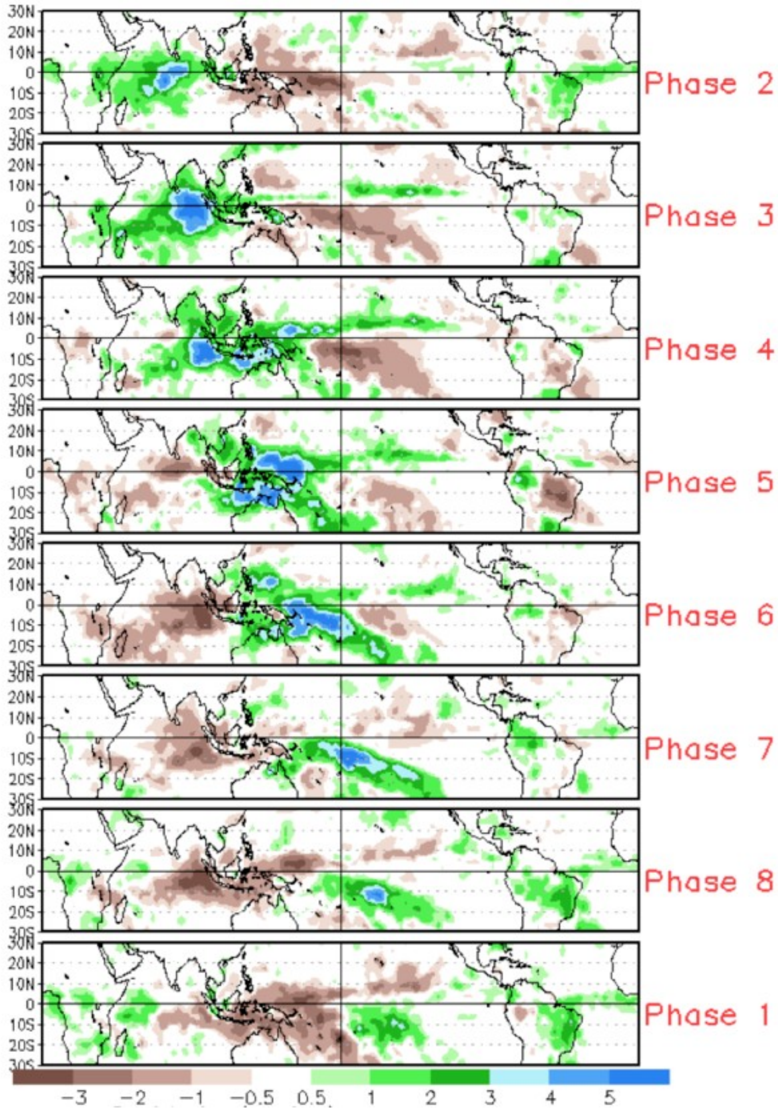
2) Normal Mode Functions

3) Climatology

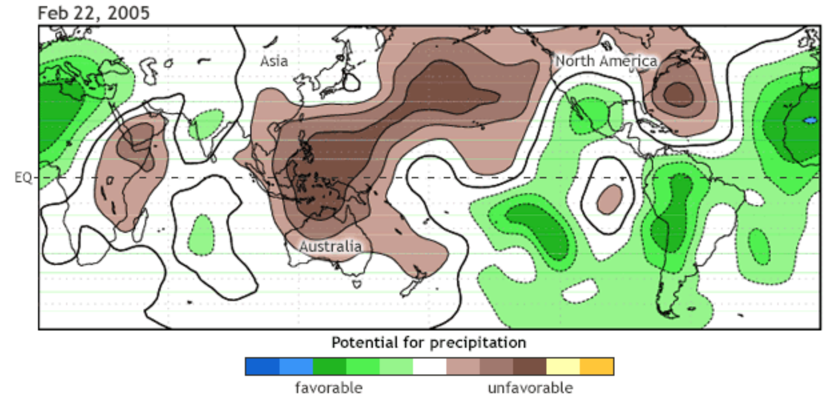
4) MJO decomposition

5) Summary

Madden-Julian Oscillation



Precipitation



- Eastward propagating at 4-8 m/s
- 30-60 day oscillation

Source:NOAA

Madden-Julian Oscillation

Impacts of the MJO:

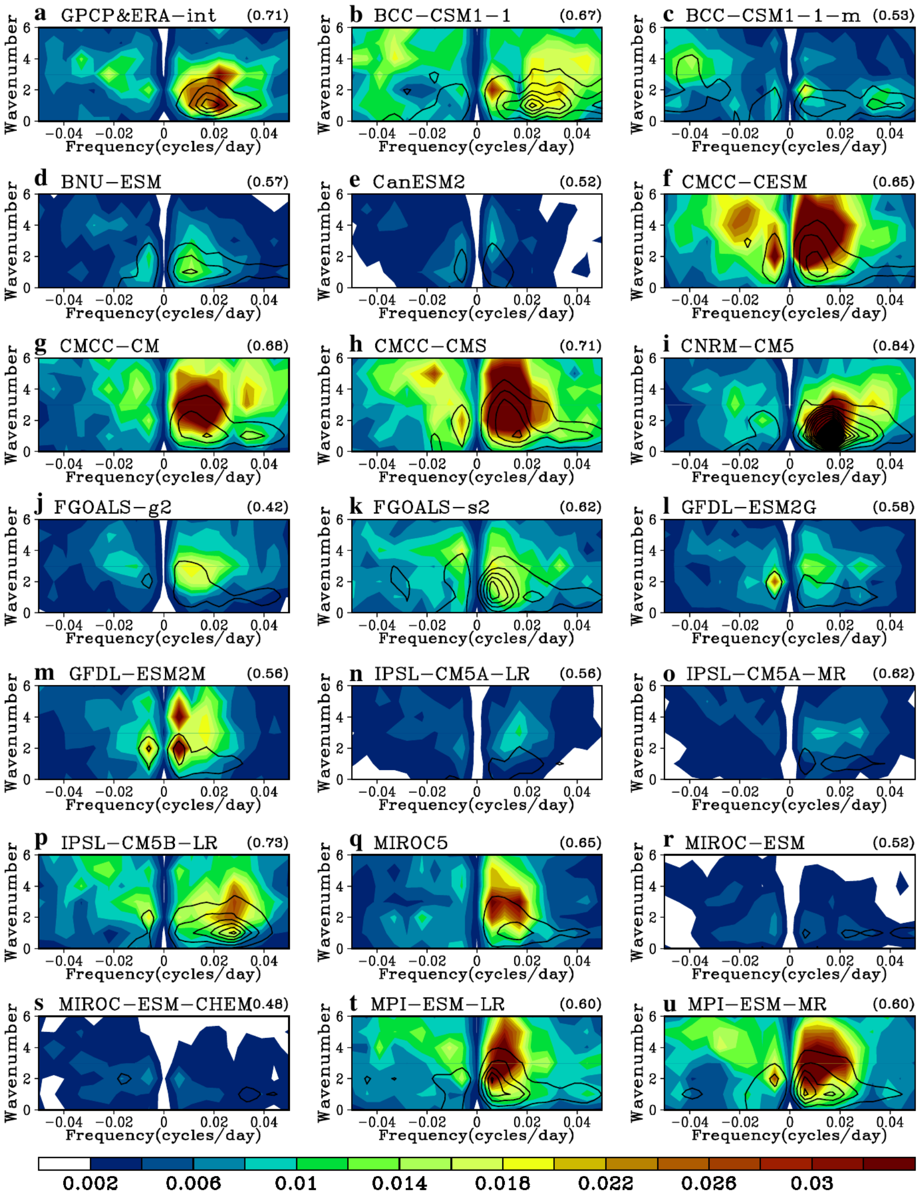
- North Atlantic weather regimes
- North Atlantic weather forecasts
- Tropical cyclones
- Tornado outbreaks
- North American west coast winter precipitation
- North American east coast cold air outbreaks
- ...

Madden-Julian Oscillation

MJO in CMIP5 climate models

Precipitation: Colors
850hPa U-Wind: Contours

The MJO is the **"Holy Grail"** of climate research



Ahn et al. 2017

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Normal Mode Decomposition

Geosci. Model Dev., 8, 1169–1195, 2015
www.geosci-model-dev.net/8/1169/2015/
doi:10.5194/gmd-8-1169-2015

Geoscientific Model Development
Open Access

Normal-mode function representation of global 3-D data sets: open-access software for the atmospheric research community

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[3]University of Tsukuba, Center for Computational Sciences, Tsukuba, Japan

Based on earlier work by Kasahara in the 1970s.

Normal Mode Decomposition

Linearized primitive equations:

$$\frac{\partial u'}{\partial t} - 2\Omega v' \sin(\varphi) = -\frac{g}{a\cos(\varphi)} \frac{\partial h'}{\partial \lambda},$$

$$\frac{\partial v'}{\partial t} + 2\Omega u' \sin(\varphi) = -\frac{g}{a} \frac{\partial h'}{\partial \varphi},$$

$$\frac{\partial}{\partial t}\left[\frac{\partial}{\partial \sigma}\left(\frac{g\sigma}{R\Gamma_0} \frac{\partial h'}{\partial \sigma}\right)\right] - \nabla \cdot V' = 0.$$

Normal Mode Decomposition

Separation into vertical and horizontal structure functions:

$$[u', v', h']^{\mathrm{T}}(\lambda, \varphi, \sigma, t) = [u, v, h]^{\mathrm{T}}(\lambda, \varphi, t) \times G(\sigma)\,.$$

$$\frac{\mathrm{d}}{\mathrm{d}\sigma}\left(\frac{\sigma}{S}\frac{\mathrm{d}G}{\mathrm{d}\sigma}\right) + \frac{H_*}{D}G = 0\,,$$

$$\frac{\partial}{\partial t}\boldsymbol{W} + \mathbf{L}\boldsymbol{W} = 0\,,$$

where $\boldsymbol{W}$ denotes the vector dependent variable

$$\boldsymbol{W} = (\widetilde{u}, \widetilde{v}, \widetilde{h})^{\mathrm{T}}$$

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Normal Mode Decomposition

Horizontal Structure equations

$$\frac{\partial u}{\partial t} - 2\Omega \sin\phi \, v = -\frac{g}{a\cos\phi}\frac{\partial h}{\partial \lambda},$$

$$\frac{\partial v}{\partial t} + 2\Omega \sin\phi \, u = -\frac{g}{a}\frac{\partial h}{\partial \phi},$$

$$\frac{\partial h}{\partial t} + \frac{D}{a\cos\phi}\left[\frac{\partial u}{\partial \lambda} + \frac{\partial}{\partial \phi}\left(v\cos\phi\right)\right] = 0.$$

Normal Mode Decomposition

H is eigenfunction of **L**

$$\mathbf{L}\,\mathbf{H}_l = i\upsilon_l\,\mathbf{H}_l\ ,$$

Hough harmonic functions

$$\mathbf{H}_n^k(\lambda,\phi) = \Theta_n^k(\phi)\exp(ik\lambda).$$

$$\Theta_n^k(\phi) = \begin{pmatrix} U(\phi) \\ -iV(\phi) \\ Z(\phi) \end{pmatrix},$$

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Normal Mode Decomposition

Advantage of this approach:

- Mass and wind fields are in balance

Normal Mode Decomposition

Solving $$\frac{\partial}{\partial t}\boldsymbol{W} + \mathbf{L}\boldsymbol{W} = 0\,,$$

leads to two dispersion relationships

- first kind: west- and eastward Inertio-Gravity waves
  - inertial terms dominate Coriolis terms
  - unbalanced flow

$$\nu = \frac{-k}{2n(n+1)} \pm \left(-\frac{k^2}{4n^2(n+1)^2} + \frac{n(n+1)}{\frac{4a^2\Omega^2}{gD}} \right)$$

Normal Mode Decomposition

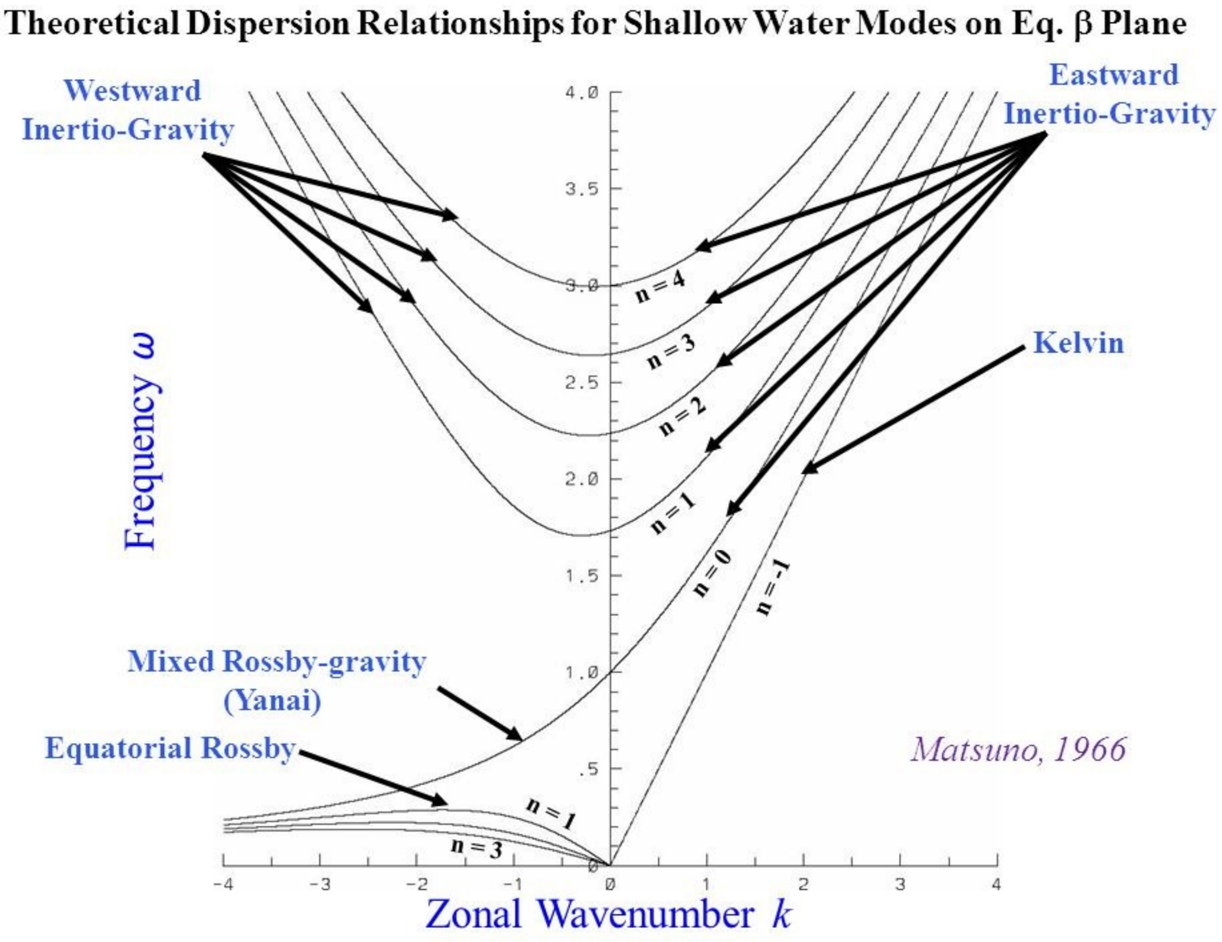
Solving $$\frac{\partial}{\partial t}\boldsymbol{W} + \mathbf{L}\boldsymbol{W} = 0\,,$$

leads to two dispersion relationships

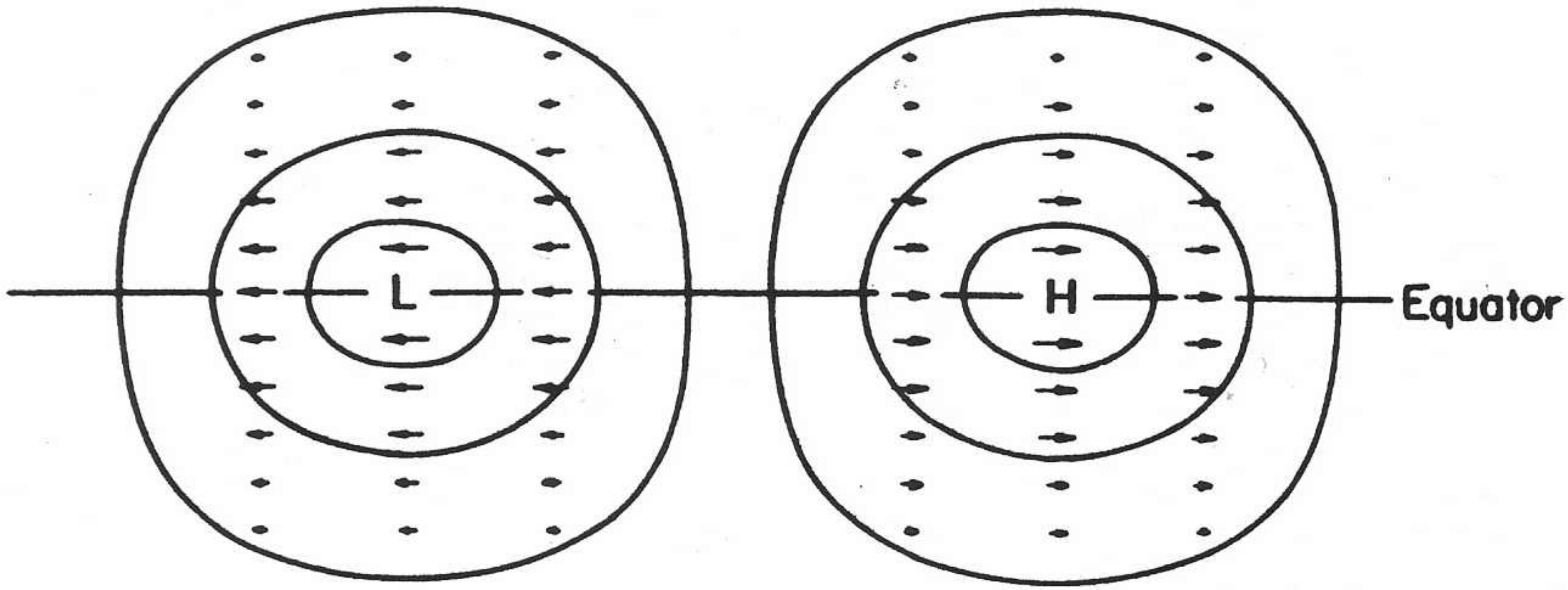
- second kind: westward Rossby-Haurwitz waves
  - Coriolis terms dominate
  - balanced flow

$$\nu = \frac{-2\Omega k}{n(n+1)}$$

Equatorial Waves



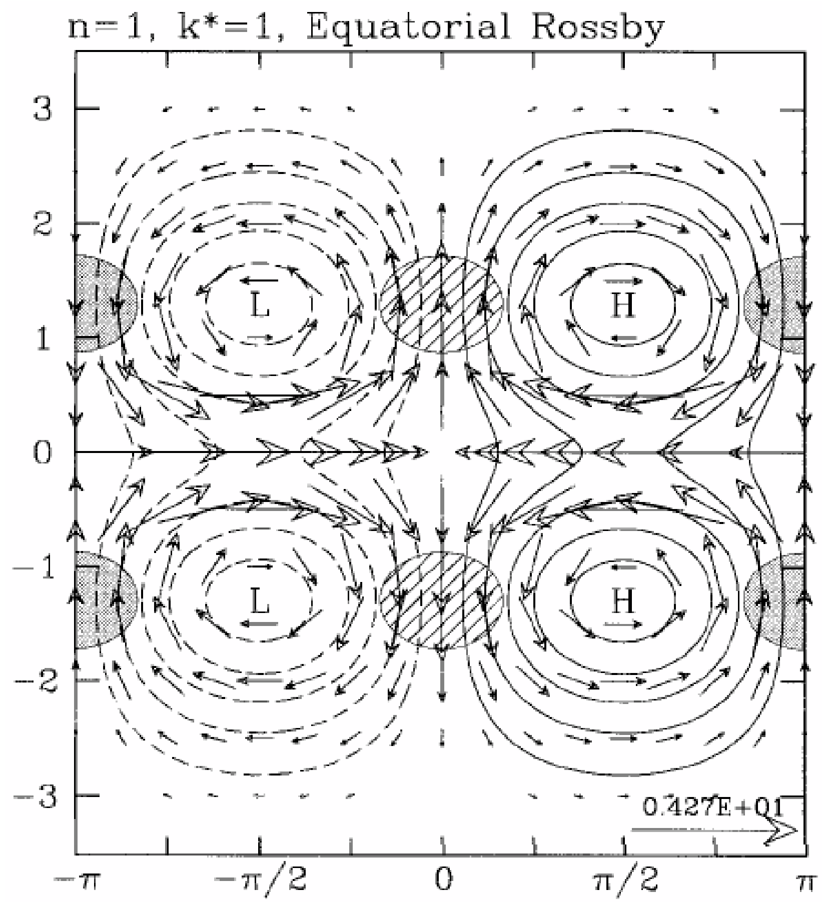
Kelvin Wave



'ig. 11.15 Plan view of horizontal velocity and height perturbations associated with an equatorial Kelvin wave. (Adapted from Matsuno, 1966.)

- Non-dispersive
- Balances Coriolis forces against a wave-guide

Equatorial Rossby Wave



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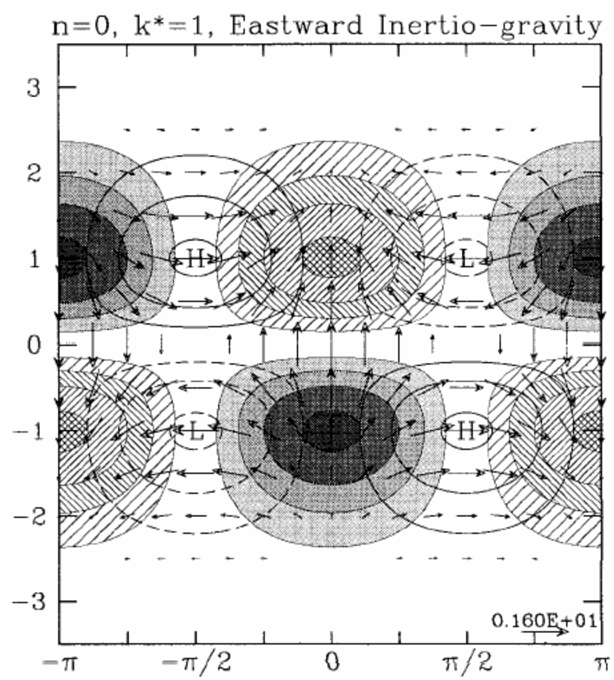
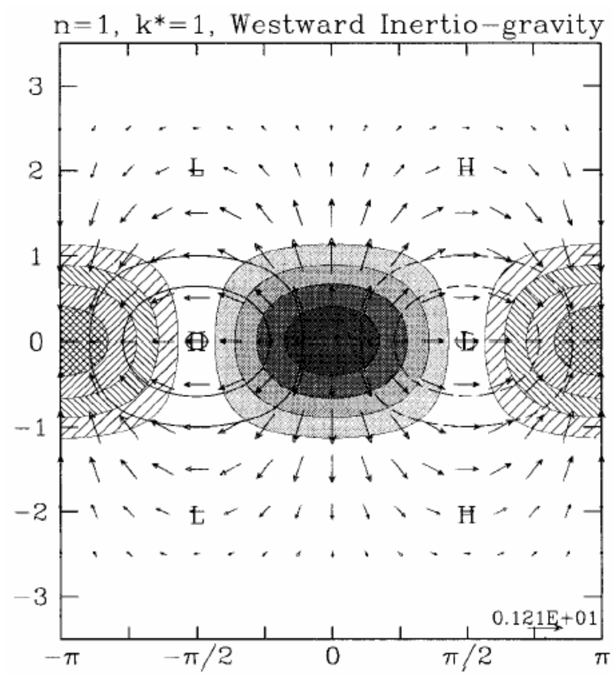
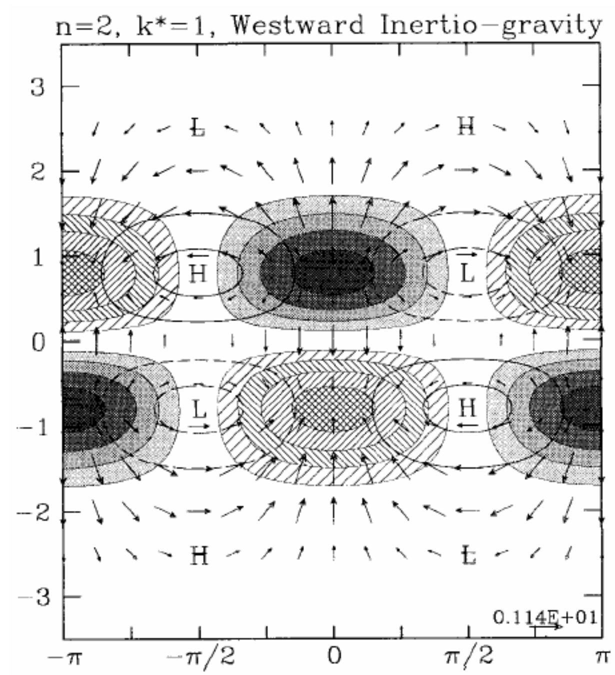
Inertio-Gravity Wave







Gravity waves which are affected by Coriolis force

Climatology

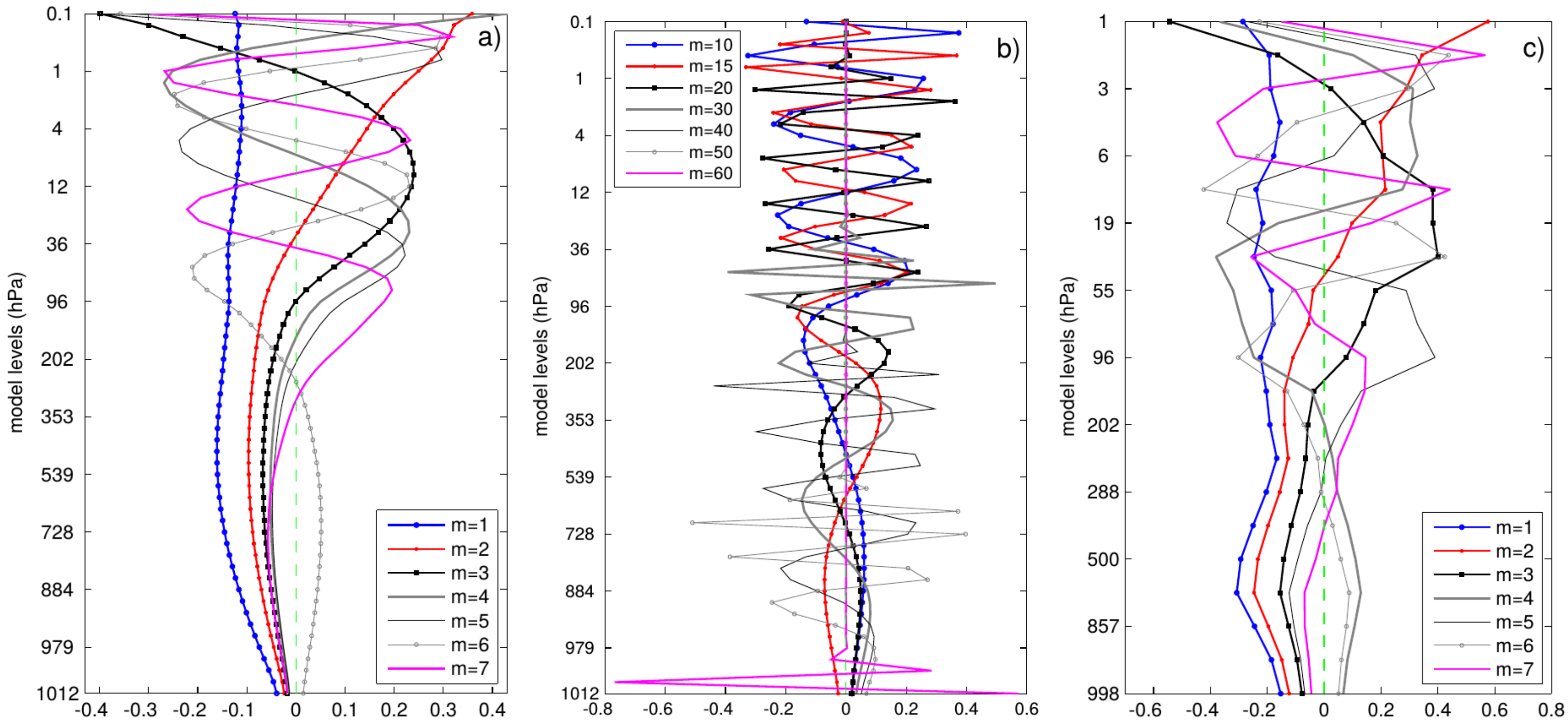
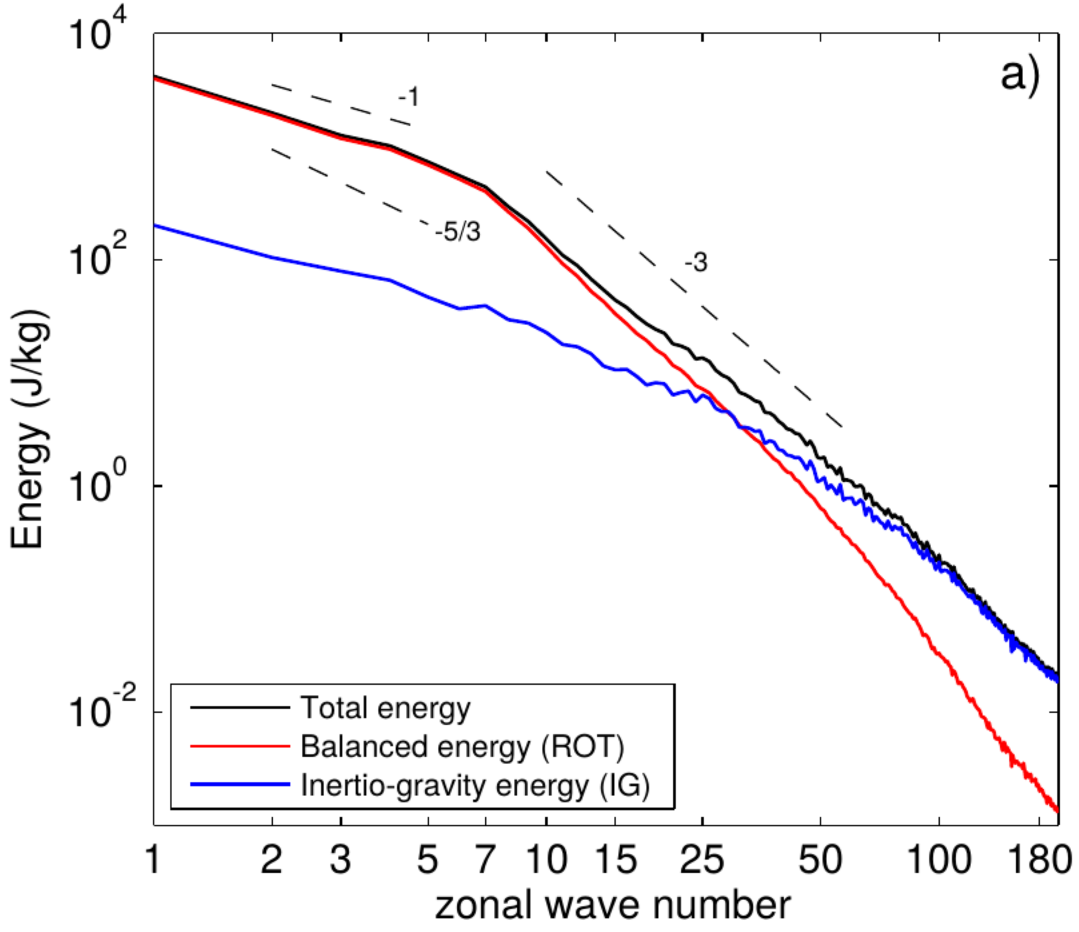
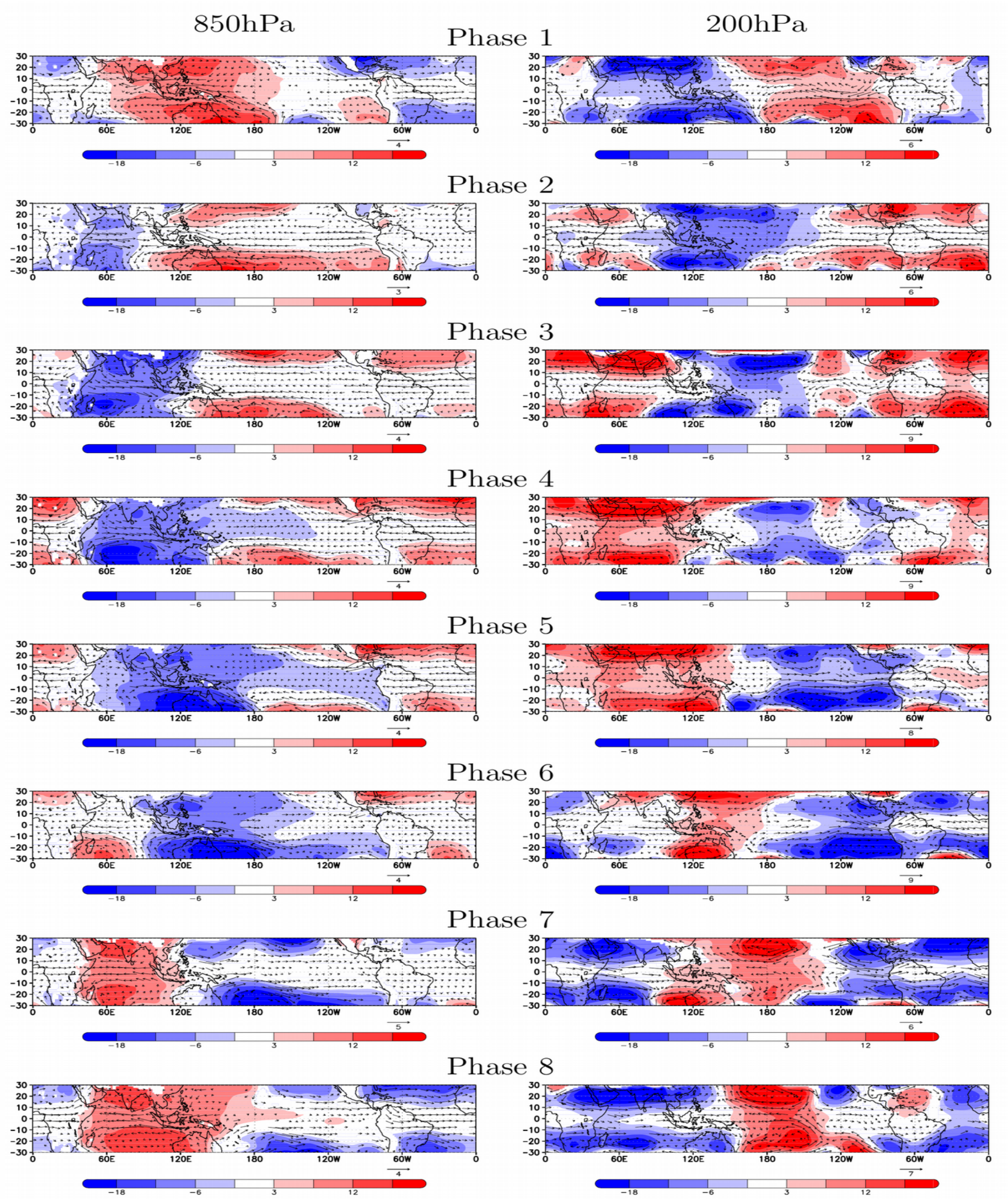


Figure 4. Vertical structure functions for **(a)** the first seven vertical modes and **(b)** modes 10, 15, 20, 30, 40 50 and 60, derived using the 60 model levels of ERA Interim; **(c)** same as **(a)** but for the 21 model levels closest to the standard 21 pressure levels.

Climatology



MJO: Rossby Flow



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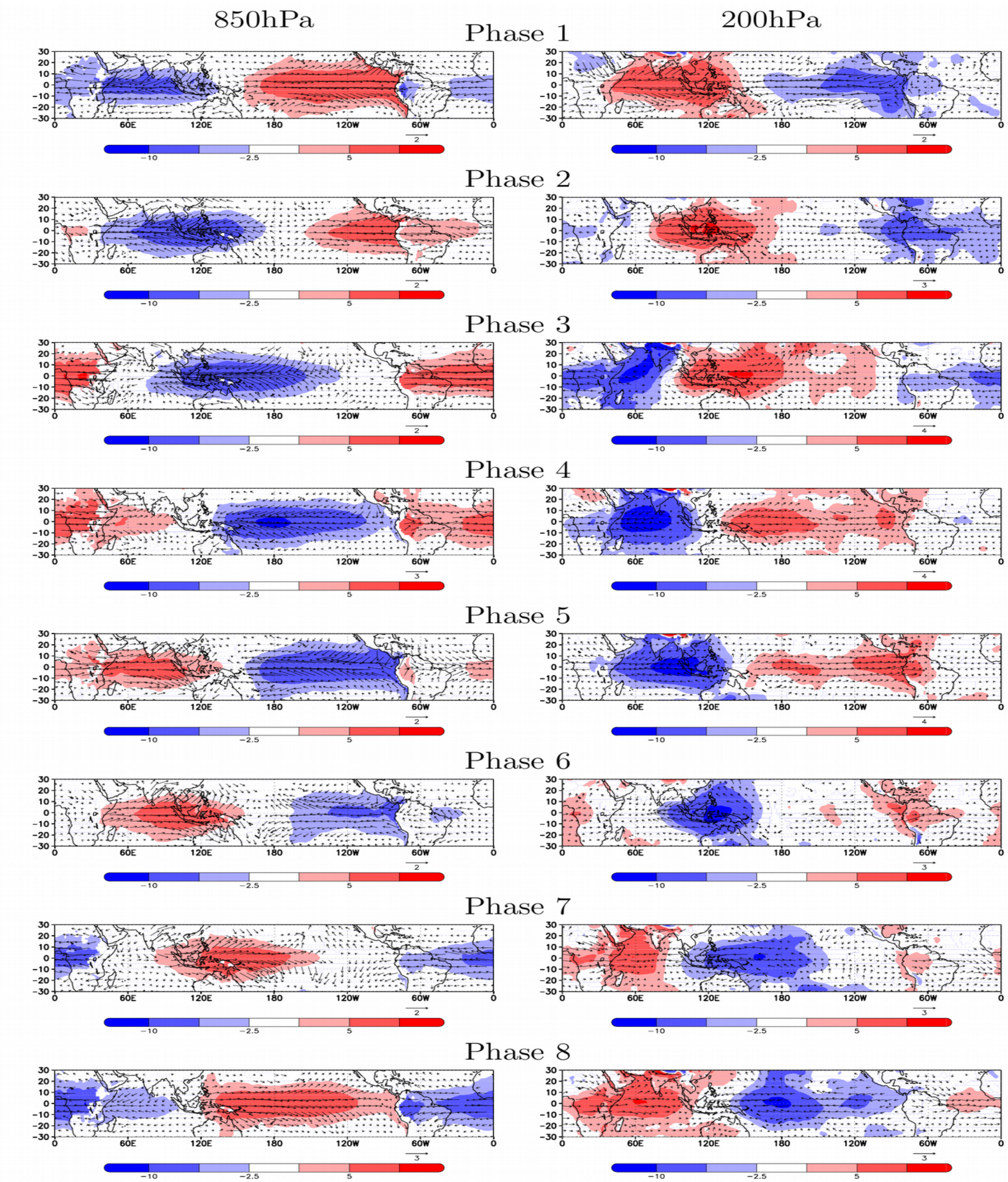
MJO: Inertio-Gravity Flow



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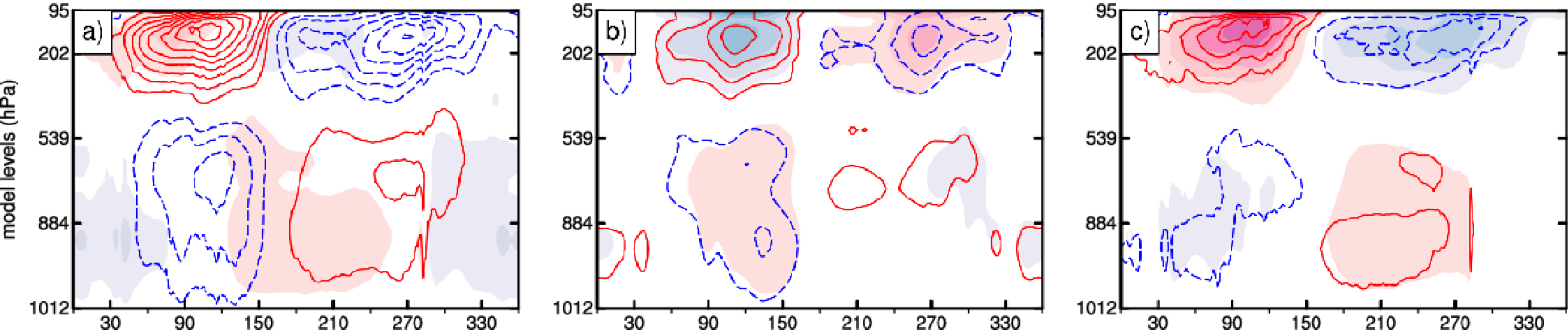
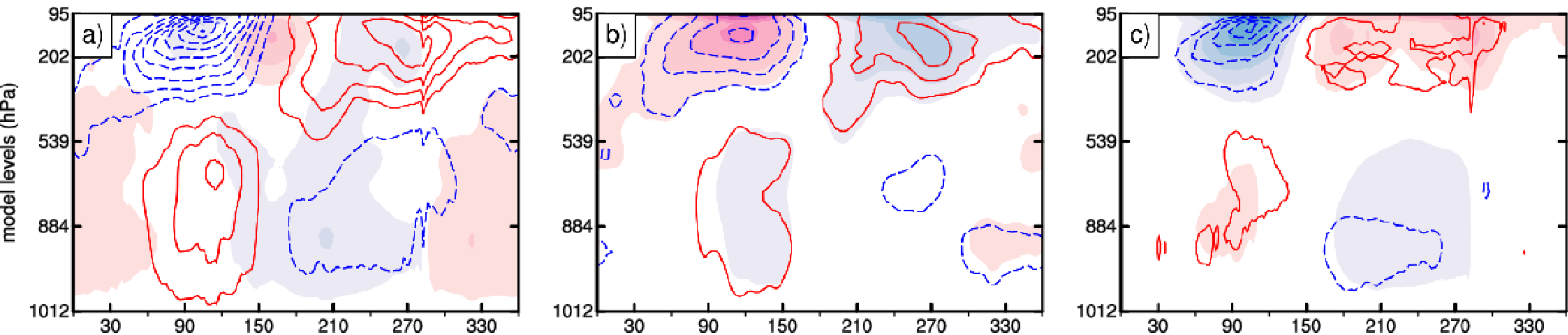
MJO

Total Balanced Unbalanced

Phase 1



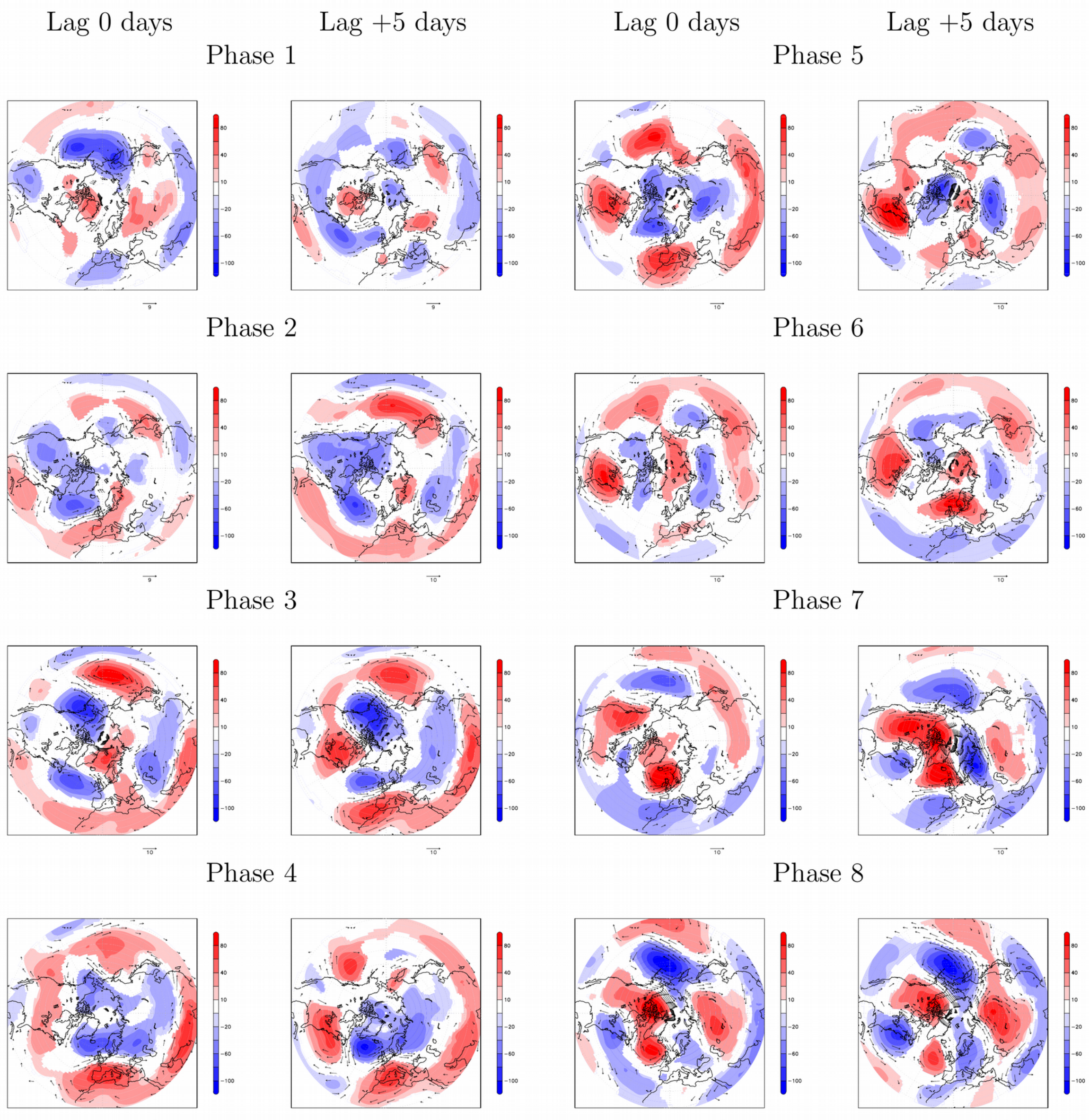
Phase 5



Contours correspond to the zonal winds every 0.5 m/s (blue for negative and red for positive speeds) and shades to the geopotential height (in meters).

MJO: Extra-Tropics

Rossby Flow



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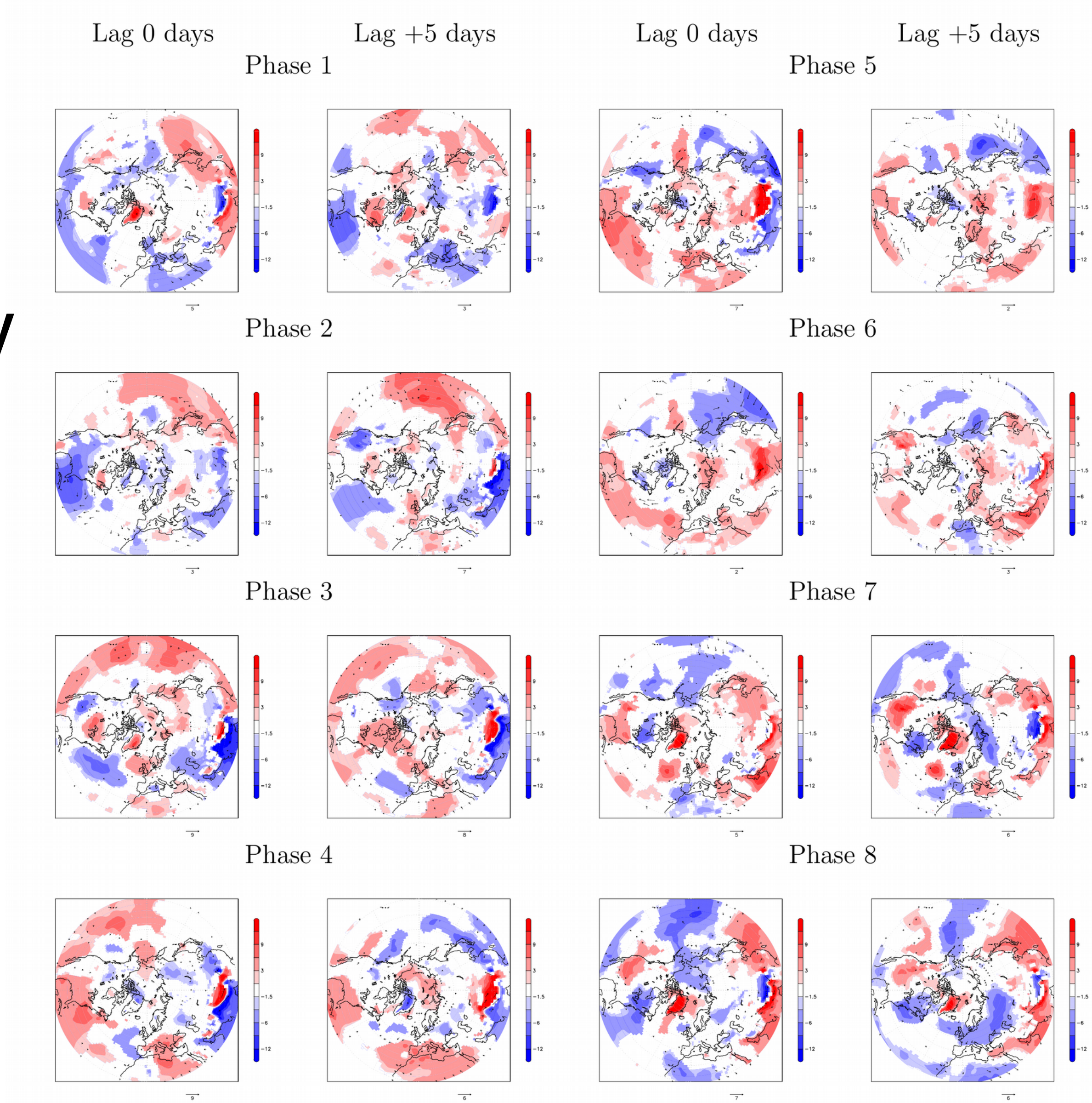
MJO: Extra-Tropics

Inertio-Gravity



Summary

- New tool to decompose flow fields into Rossby and Inertio-Gravity components
- Major IG MJO component is the Kelvin mode
- Rossby flow is more dominant for MJO
  - Rossby components 93% of kinetic energy
  - IG components: 7% of kinetic energy
- IG flow propagates also into the extra-tropics

Reference:

Franzke, C., D. Jelic, S. Lee and S. Feldstein, 2018: Systematic Decomposition of the MJO and its Northern Hemispheric Extra-Tropical Response into Rossby and Inertio-Gravity Components. Q. J. Roy. Meteorol. Soc., submitted.