
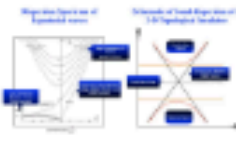
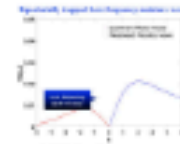



Topological Structure of Moist Equatorial Waves



Topological Structure of Moist Equatorial Waves
Karthikey Mamidi, Vincent Mathew
Department of Physics, School of Physical Sciences, Central University of Kerala, India

<p>Introduction</p> <ul style="list-style-type: none"> Topology and symmetries have an emerging guiding principles to predict and harness the propagation of waves in various physical systems. Be it quantum particles (such as electrons) or classical waves (mechanical waves), these concepts have so far been mostly explored in idealized systems, in which the wave dynamics is wave-normal based. 	<p>Motivation of the study</p> 	<p>Moist Equatorial Waves</p> 	<p>Conclusion</p> <ul style="list-style-type: none"> In conclusion, we confirmed our calculations towards the identified variation of various parameters in the barotropic model. Following the previous work by Delplace et al. (2017), we have shown that barotropic model calculations are complex and all the eigenmodes are spatially trapped. However, barotropic model doesn't affect the topological behaviour of equatorial waves.
<p>Equatorial Waveguide</p> 	<p>Theoretical Description</p> <p>We consider the equations of the one-layer shallow water model in the absence of dissipation on the equatorial barotropic ($\bar{u} = \bar{v} = \bar{w} = 0$), with zonal ($x$) and meridional ($y$) directions ($\mathbf{X} = (x, y)$).</p> $\partial_t \mathbf{v} + (\mathbf{v} \cdot \nabla) \mathbf{v} + f \hat{n} \times \mathbf{v} = -\nabla \theta \quad (1.1)$		<p>References</p> <ol style="list-style-type: none"> Delplace, P., Monin, J.B., Silvestre, A. Topological origin of equatorial waves. <i>Science</i> 358, 1075-1077 (2017). Kane, C.L. & Mele, E.J. Quantum spin Hall effect in graphene. <i>Phys. Rev. Lett.</i> 95, 220601 (2005). G.N. Kladov, M. C. Wheeler, P. T. Heaton, E. H. Smead, P. E. Roundy. Convectively coupled equatorial waves. <i>Phys. Rev. Lett.</i> 95, 220601 (2005). doi:10.1103/PhysRevLett.95.220601 S. M. Z. Hasan, C. L. Kane. <i>Colloquium</i>

This website uses cookies to ensure you get the best experience on our website. [Learn more](#)

Accept

Karthikey Mamidi, Vincent Mathew

Department of Physics, School of Physical Sciences, Central University of Kerala, India

PRESENTED AT:

AGU FALL MEETING
New Orleans, LA & Online Everywhere
13-17 December 2021

Poster Gallery
brought to you by
WILEY



INTRODUCTION

- Topology and symmetries have as compelling guiding principles to predict and harness the propagation of waves in various physical systems.
- Be it quantum particle (such as electrons) or classical waves (mechanical waves), these concepts have so far been mostly explored in idealized systems, in which the wave dynamics is conservative.
- Very recently, the equatorial wave systems have been described from a topological point of view by Delplace et. al (2017).
- It was shown that the emergence of unidirectional edge waves (Yanai and Kelvin waves) can be attributed to the topological bound states.
- An f-plane model is used to connect the topological invariants, the Chern numbers, to the existence of these modes
- Topology guarantees the existence of equatorial Yanai and Kelvin waves, obviating the need to carry out the classic but more complex calculation on the equatorial beta-plane.
- We have extended this analysis by incorporating a beta plane model thereby including the Earth's sphericity from beginning.
- Equatorial beta plane model renders the Poincare and Rossby waves also equatorially trapped. Further, the effect of moisture balance on the topology of the equatorial waveguide is examined.

Equatorial Waveguide

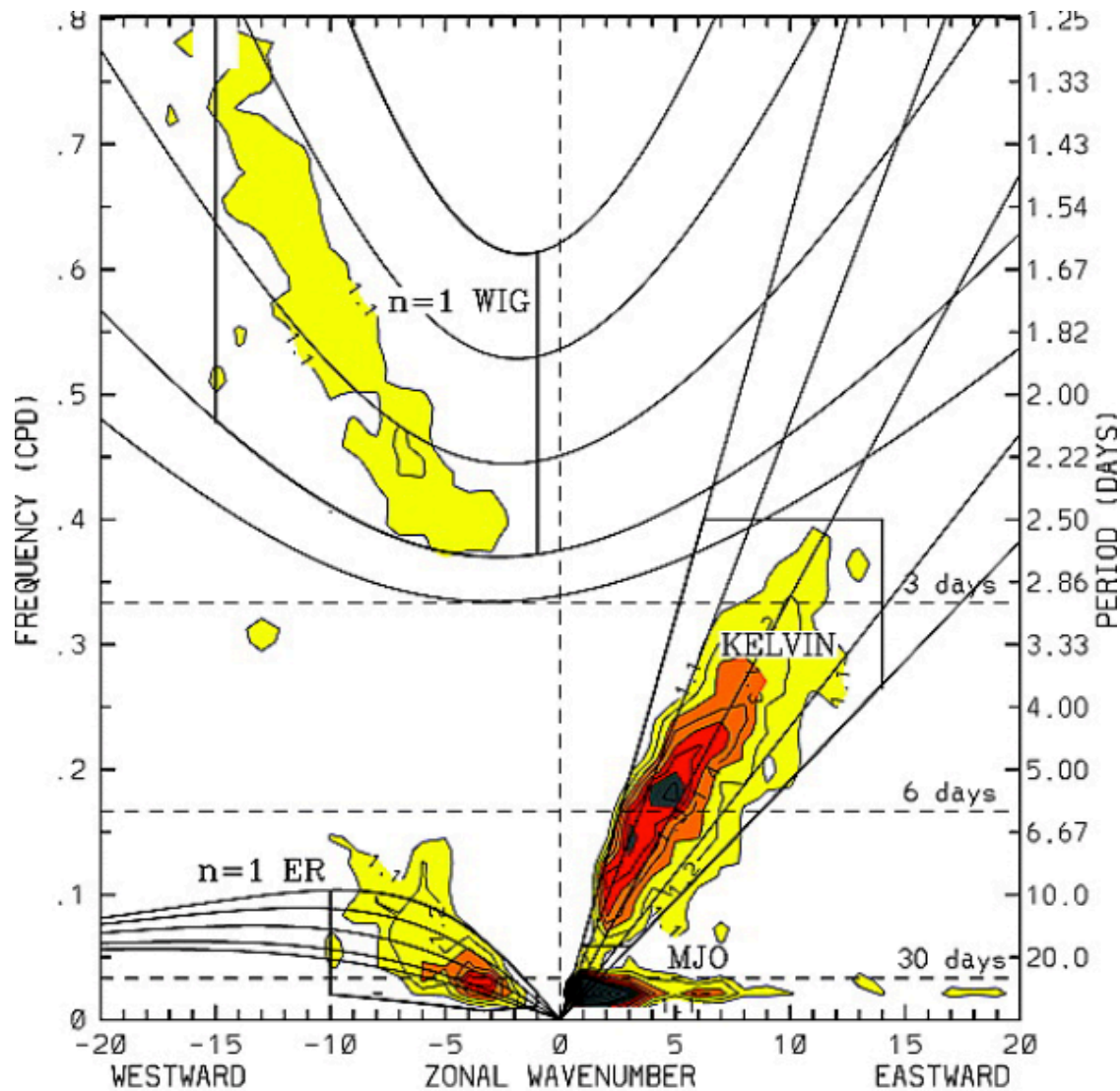
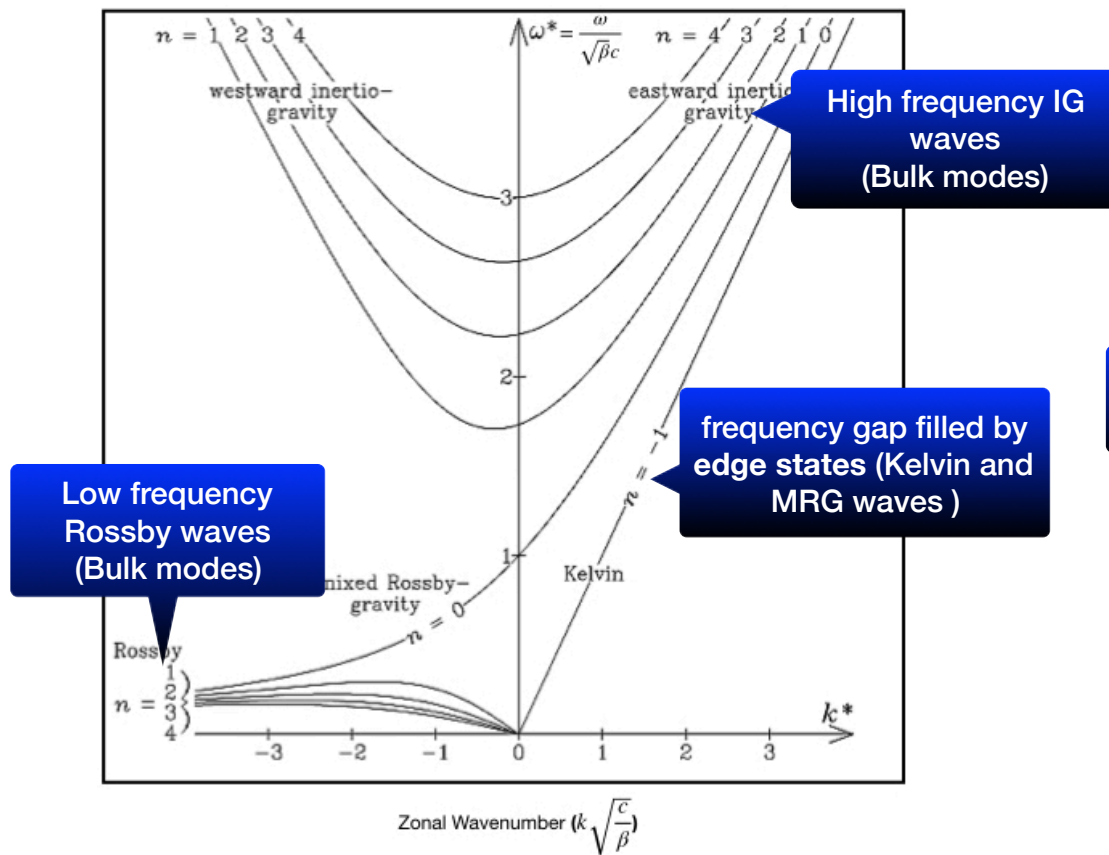


Figure 1 : Observed wavenumber–frequency spectrum of the equatorial symmetric component of brightness temperature⁴

- ▶ The flow in the tropical atmosphere is characterized by a perturbation in rainfall and cloud distribution.
- ▶ These perturbations are the manifestations of equatorial waves.
- ▶ Several authors suggested that these equatorial waves are the significant physical processes within the tropics, which play a crucial role in the large-scale dynamics.

Motivation of the study

Dispersion Spectrum of Equatorial waves



Schematic of band dispersion of a 2-D Topological Insulator

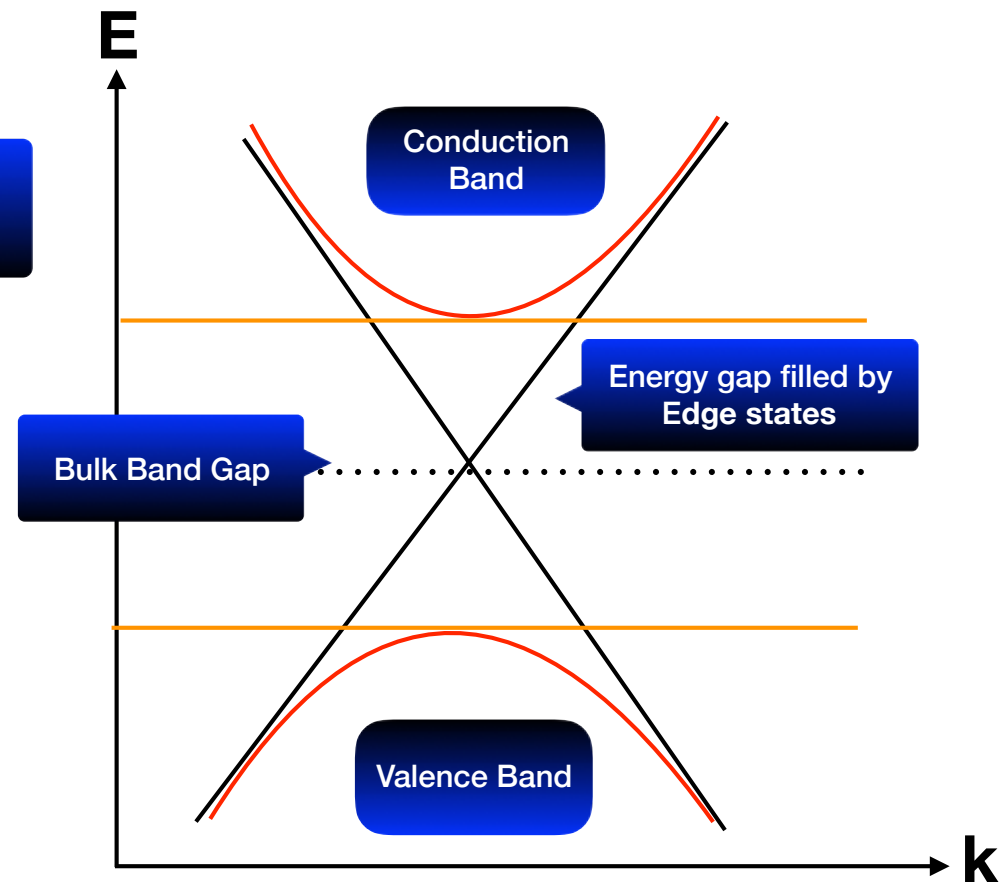
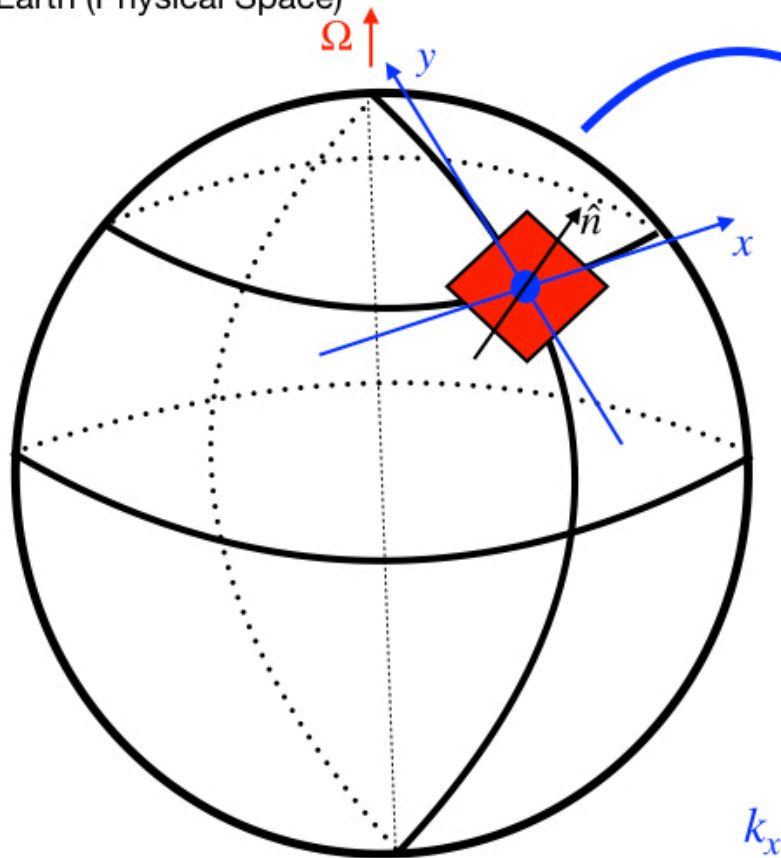
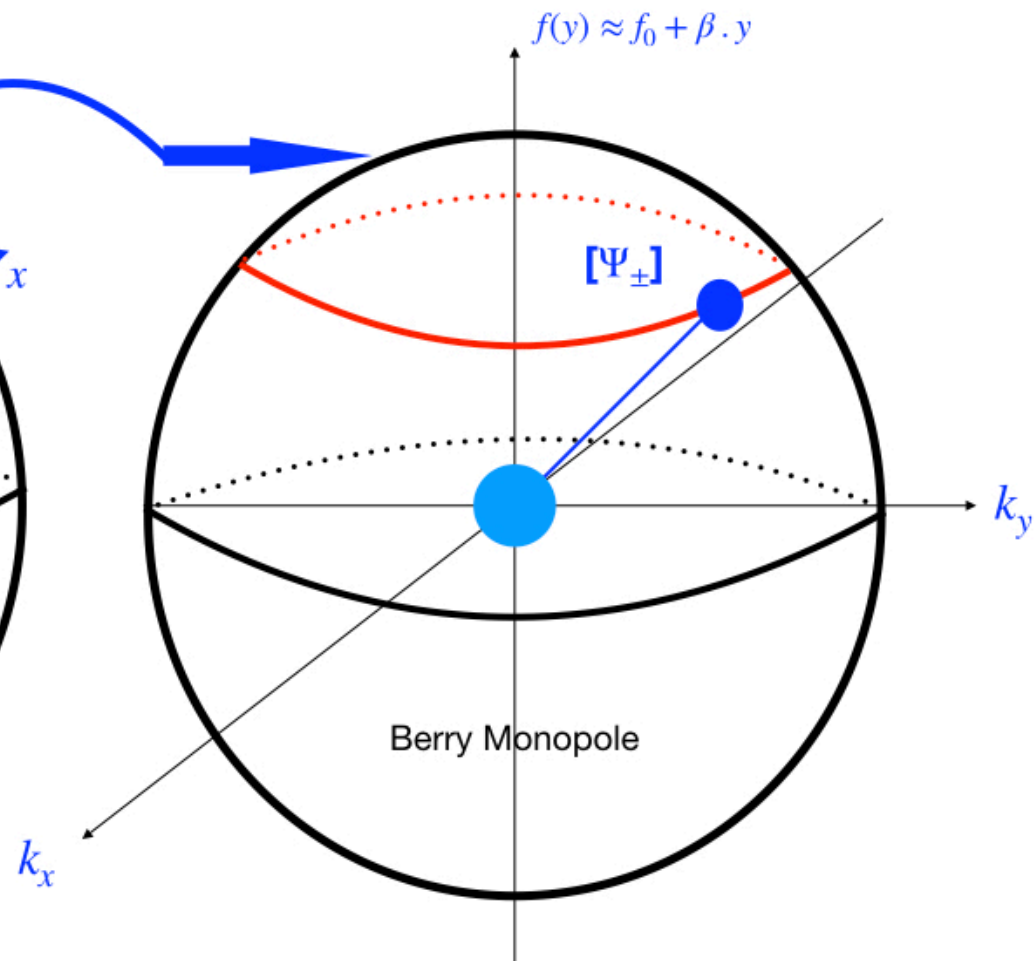


Figure 2 : Comparison of Equatorial waves (Classical Waves) with the Band Structure (Quantum Waves) of the Topological Insulator

Earth (Physical Space)



(a) beta-plane geometry on a rotating planet



(b) Corresponding Parameter space (k_x, k_y, f)

Theoretical Description

- We consider the equations of the one-layer Shallow water model in the absence of **dissipation** on the equatorial beta-plane ($f = f_0 + \beta y$), with zonal (x) and meridional (y) directions $\{\mathbf{X} = (x, y)\}$.

$$\partial_t \mathbf{v} + (\mathbf{v} \cdot \nabla) \mathbf{v} + f \hat{n} \times \mathbf{v} = - \nabla \theta \quad (1.a)$$

$$\partial_t \theta + \nabla \cdot (\mathbf{v} \theta) = 0 \quad (1.b)$$

- The velocity field is described by $\mathbf{V}(\mathbf{x}, t) = (u(\mathbf{x}, t), v(\mathbf{x}, t))$, and here $\nabla = (\partial/\partial x, \partial/\partial y)$, and \hat{n} is the unit vector in the vertical direction, and θ is the potential temperature perturbation.
- We non-dimensionalised and linearised the above equation of motion at ($u = 0$ and $\theta = \hat{\theta}$) and We look for the solution (Eigen modes) in the form of a wave (Planar wave), with amplitudes of the fields ($\zeta(x, y, t) = \zeta(y)e^{i(\omega t - k_x x - k_y y)}$).

Resultant eigenvalue equation

$$\frac{\partial u}{\partial t} + f v + \frac{\partial \theta}{\partial x} = 0$$

$$\frac{\partial v}{\partial t} - f u + \frac{\partial \theta}{\partial y} = 0$$

$$\frac{\partial \theta}{\partial t} + \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = 0$$



$$\omega \begin{pmatrix} \hat{\theta} \\ \hat{u} \\ \hat{v} \end{pmatrix} = \begin{pmatrix} 0 & k_x & k_y \\ k_x & 0 & -if \\ k_y & if & 0 \end{pmatrix} \begin{pmatrix} \hat{\theta} \\ \hat{u} \\ \hat{v} \end{pmatrix}$$

Where $(f = f_0 + \beta y)$

By rearranging the above linear eigenvalue equation
The dynamical system becomes

$$i\partial_t \Psi = \mathbf{H}\Psi \quad (2)$$

Where $\Psi = (\mathbf{v}, \theta)$ and \mathbf{H} is the Hermitian operator

In a Quantum mechanical context it can be referred as a Hermitian system and can easily applied to the Conservative systems (idealized physical systems in which the wave amplitude is neither attenuated nor amplified)

The time reversal symmetry is broken due to non-zero Coriolis parameter and this broken symmetry generates the gaps in the wave spectrum¹

$$t \rightarrow -t, x' \rightarrow x, \theta \rightarrow \theta, u \rightarrow -u$$

Diagonalization of equation (2) leads to three eigenmodes $\omega_0 = 0$,

$\omega_{\pm} = \pm \sqrt{k^2 + f^2}$, where $k^2 = k_x^2 + k_y^2$ and corresponding **three** eigenvectors
(wave bands)

$$\Psi_+(k_x, k_y, f) = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{k}{\sqrt{k^2 + f^2}} \\ \frac{k_x}{k} - i \frac{fk_y}{k\sqrt{k^2 + f^2}} \\ \frac{k_y}{k} + i \frac{fk_x}{k\sqrt{k^2 + f^2}} \end{pmatrix} \quad \Psi_-(k_x, k_y, f) = \Psi_+(-k_x, -k_y, f) \quad \Psi_0(k_x, k_y, f) = \frac{1}{\sqrt{k^2 + f^2}} \begin{pmatrix} f \\ ik_y \\ -ik_x \end{pmatrix}$$

- We now consider an atmospheric component of the model that describes the dynamics of anomaly circulation of the lower troposphere, represented by the Linear shallow water equations describing the horizontal structure of the first baroclinic wave motion on an equatorial β -plane, along with vertically integrated moisture equation.
- We non-dimensionalize the governing equations using the spatial, temporal and potential temperature scales defined by

$$[L_0] = \left\{ \frac{C_0}{\beta} \right\}^{1/2} \quad [T_0] = \left\{ \frac{1}{C_0 \beta} \right\}^{1/2} \quad \text{and} \quad [\theta_0] = H \frac{d\bar{\theta}}{dz}$$

$$\frac{\partial u}{\partial t} + \epsilon^* u + f v + \gamma \frac{\partial \theta}{\partial x} = 0 \quad (3.a)$$

$$\frac{\partial v}{\partial t} + \epsilon^* v - f u + \gamma \frac{\partial \theta}{\partial y} = 0 \quad (3.b)$$

$$\frac{\partial \theta}{\partial t} + \gamma \left[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right] - \eta B s = 0 \quad (3.c)$$

$$\frac{\partial s}{\partial t} + \Gamma_q \left[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right] + \Lambda u + B s = 0 \quad (3.d)$$

$$\text{where, } \Gamma_q = \frac{H}{\bar{q}} \frac{d\bar{q}}{dz}$$

Resultant eigenvalue equation

$$\omega \begin{pmatrix} \hat{\theta} \\ \hat{u} \\ \hat{v} \\ \hat{s} \end{pmatrix} = \begin{pmatrix} 0 & \gamma k_x & \gamma k_y & i\eta B \\ \gamma k_x & i\epsilon^* & -if & 0 \\ \gamma k_y & if & i\epsilon^* & 0 \\ 0 & \Gamma_q k_x + i\Lambda & \Gamma_q k_y & iB \end{pmatrix} \begin{pmatrix} \hat{u} \\ \hat{v} \\ \hat{\theta} \\ \hat{s} \end{pmatrix}$$

Again by rearranging the above linear eigenvalue equation
The dynamical system becomes

$$i\partial_t \Psi = \hat{H} \Psi$$

Where $\Psi = (\mathbf{v}, \theta, s)$ and \hat{H} is the **Non-Hermitian** operator

The parameters Λ : the non-dimensional values of evaporation- wind feedback component. Γ_q represents the strength of moisture convergence. B and γ represents, the moisture relaxation timescale and temperature scale respectively. ϵ^* represents the Rayleigh damping parameter.

Equatorially trapped Low-frequency moisture waves

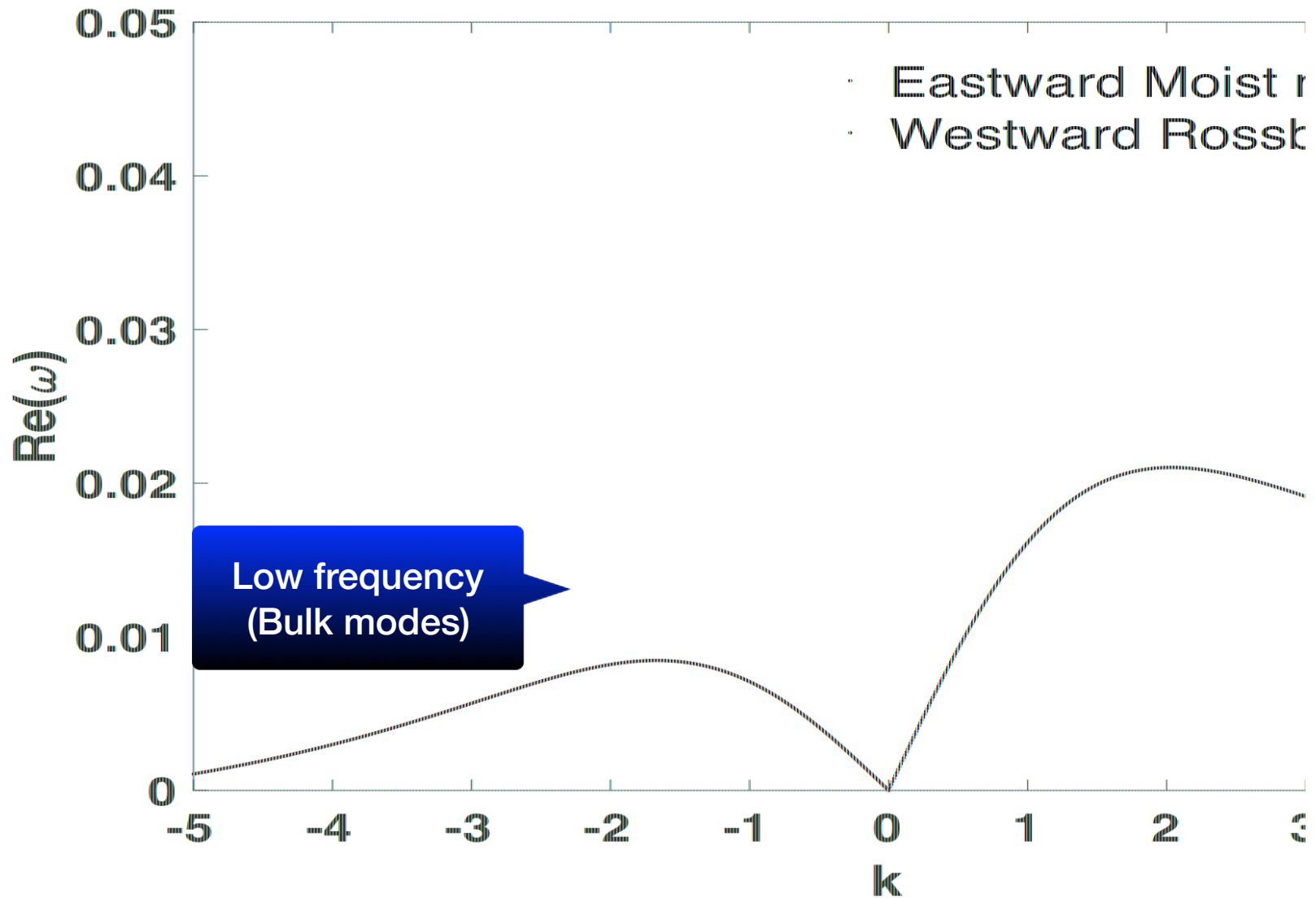


Figure 4 : Dispersion Relation (low frequency modes only)

CONCLUSION

- In conclusion, we continued our calculations towards the latitudinal variation of coriolis parameter i.e., beta-plane model.
- Following the previous work by Delplace et. al. (2017), we have shown that beta-plane model calculations are complex and all the eigenmodes are equatorially trapped. However, beta-plane model doesn't affect the topological behaviour of equatorial waves.
- We further incorporated vertically integrated moisture equation along with the momentum damping into the shallow water system, and we have seen that a new eastward propagating low-frequency mode, identified to be MJO emerges.
- However, in contrast with the dry shallow water system, incorporation of moisture and damping makes the system non-Hermitian.
- Understanding the topological properties of non-Hermitian Hamiltonian in continuum system is still an open area.

REFERENCES

1. Delplace, P., Marston, J.B. &Venaille, A. Topological origin of equatorial waves. *Science* 358, 1075-1077 (2017).
2. Kane, C.L. & Mele, E.J. Qunatum spin hall effect in graphene. *Phys. Rev. Lett.* 95, 226801 (2005).
4. G. N. Kiladis, M. C. Wheeler, P. T. Haertel, K. H. Straub, P. E. Roundy, Convectively coupled equatorial waves. *Rev. Geophys.* 47, RG2003 (2009). doi:10.1029/2008RG000266.
3. M. Z. Hasan, C. L. Kane, Colloquium: Topological insulators. *Rev. Mod. Phys.* 82, 3045–3067 (2010). doi:10.1103/RevModPhys.82.3045.
4. T. Matsuno, Quasi-geostrophic motions in the equatorial area. *J. Meteorol. Soc. Japan Ser. II* 44, 25 (1966).
5. Gong, Z. et al. Topological phases of non-Hermitian systems. *Phys. Rev. X* 8, 031079(2018).

AUTHOR INFORMATION

Kartheek Mamidi, and Vincent Mathew

Department of Physics, School of Physical Sciences, Central University of Kerala, India