Toward the Local Identification of Equatorial Waves

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Motivation

Equatorial waves (EWs) represent synoptic to planetary scale disturbances in the tropical atmosphere. **EWs are highly relevant in the field of tropical atmospheric circulation** to:

- Advance the **physical understanding of tropical atmospheric phenomena**, such as organized convection, cloud and precipitation variability, and high impact weather.
- **Increase the predictability of numerical weather and climate prediction models** in the tropics.

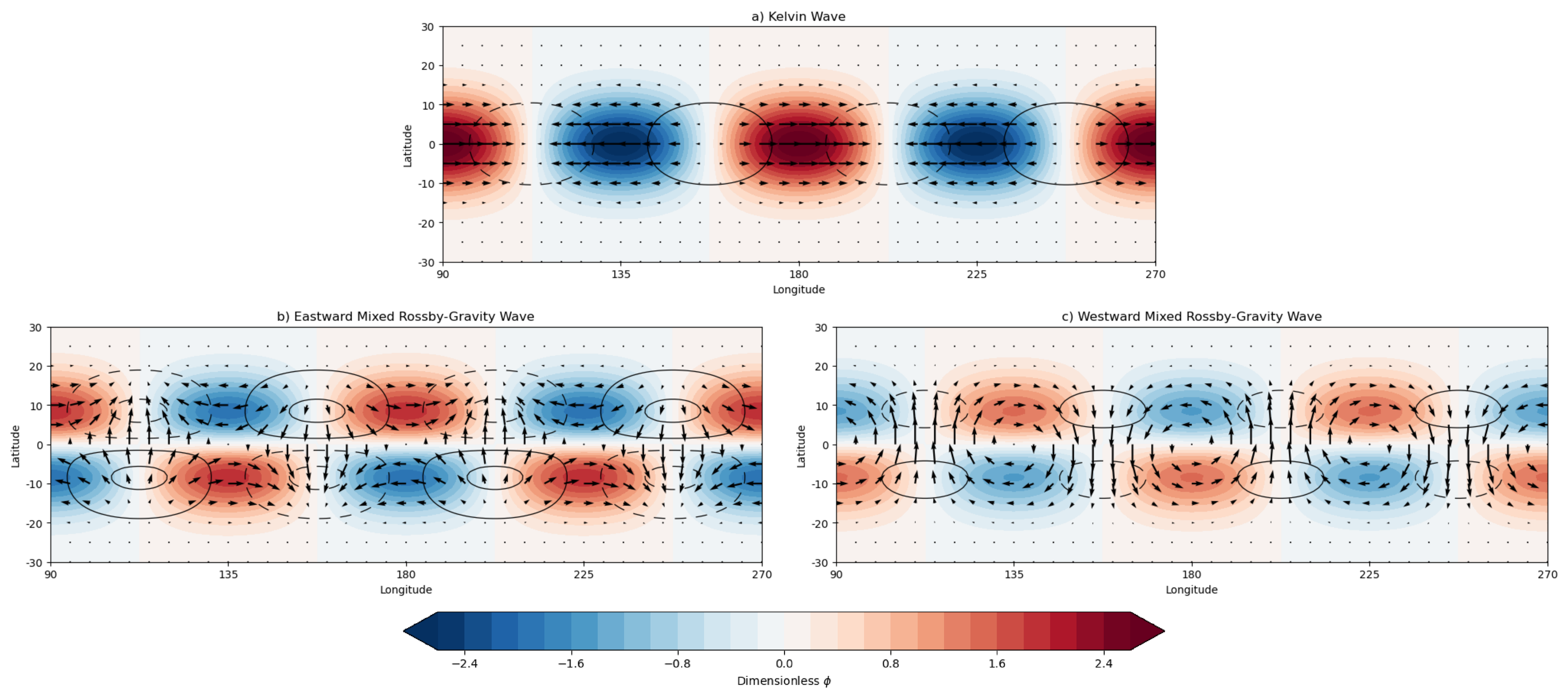

Figure 1. Horizontal structure of equatorial waves: a) Kelvin (KW), b) eastward mixed Rossby-gravity (EMRG) and c) westward mixed Rossby-gravity (WMRG). Black arrows: horizontal velocity. Color shading: geopotential perturbation. Contour lines: mass divergence (solid) and mass convergence (dashed).

Objectives

1. Develop a **technique for identifying EWs at specific longitudes**. We have been able to achieve this aim **for Kelvin (KW) and mixed Rossby-gravity (MRG) waves**.
2. Apply the Kelvin wave identification technique to **evaluate the skill of ECMWF operational forecasts at representing Kelvin waves** in the period 2015-2017.

Local Identification of Kelvin and MRG Waves

The developed local identification technique for Kelvin and MRG waves rests on the **projection of** the nondimensionalised **general circulation data vector** $\hat{\mathbf{W}} = [u, v, \phi]^T$ **onto the meridional structure of the desired EW type**.

Local Kelvin circulation field:

$$\mathbf{W}_{\mathrm{KW}}(t, \lambda, \theta) = P_{\mathrm{KW}}(t, \lambda)\,\mathbf{\Theta}_{\mathrm{KW}}(\theta)$$

Local MRG circulation field:

$$\mathbf{W}_{\mathrm{MRG}}(t, \lambda, \theta) = P_{\mathrm{EMRG}}(t, \lambda)\,\mathbf{\Theta}_{\mathrm{EMRG}}(\theta) + P_{\mathrm{WMRG}}(t, \lambda)\,\mathbf{\Theta}_{\mathrm{WMRG}}(\theta)$$

$\mathbf{\Theta}_\alpha$ - Meridional structure of EW mode of α type with fixed zonal wavenumber.

P_α - Projection of the general circulation data vector $\hat{\mathbf{W}}$ onto the $\mathbf{\Theta}_\alpha$ meridional structure.

Local vs Global Identification

The **local identification technique captures** virtually **the same Kelvin and MRG circulation fields as** the already existing **global identification** techniques.

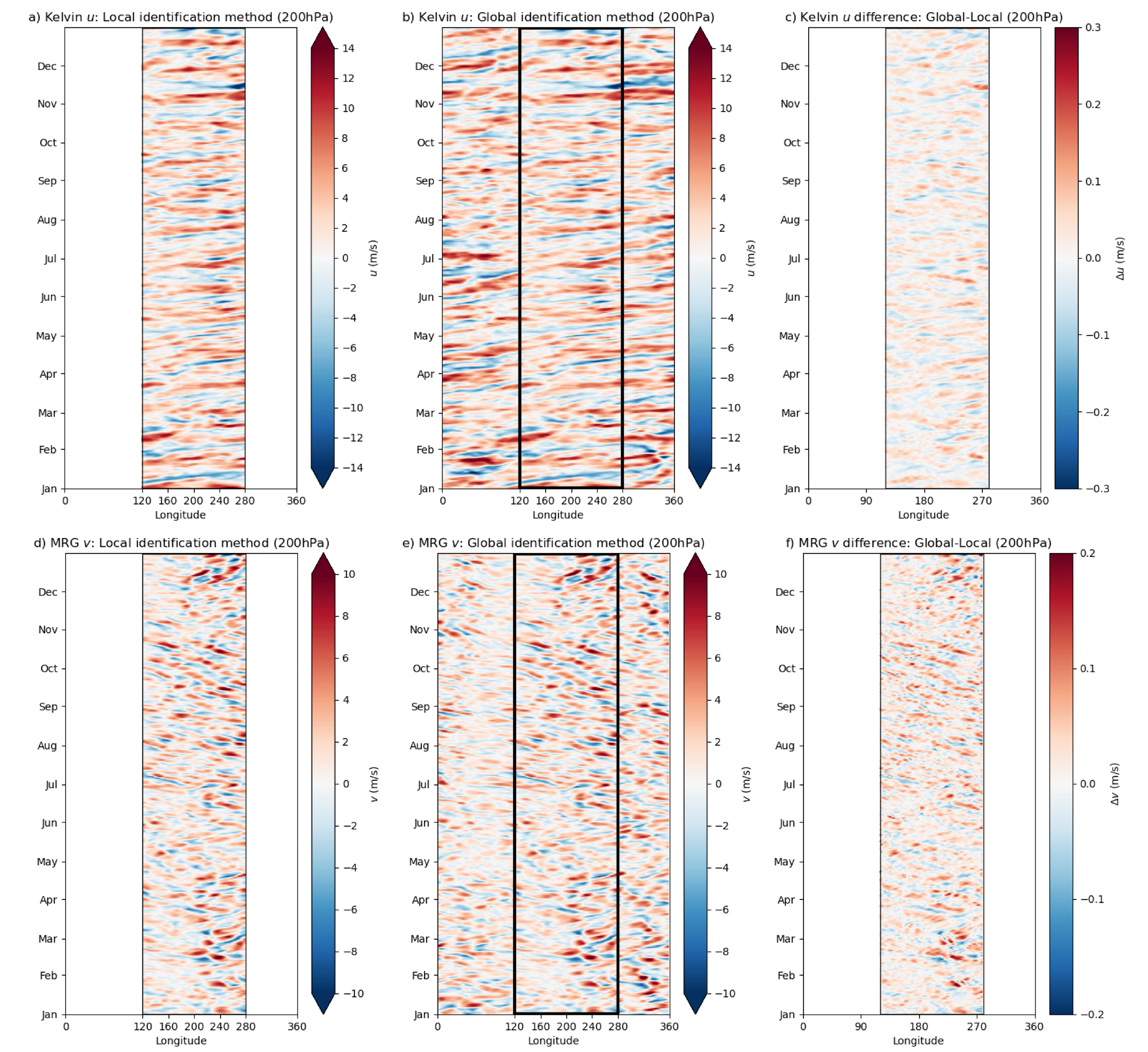

Figure 2. Local vs Global EW identification for the year 2016. a-c) Kelvin wave zonal velocity and d-f) mixed Rossby-gravity wave meridional velocity.

Kelvin Waves in Real-Time Operational Forecasts

To study Kelvin waves in real-time operational forecasts we **arrange the identified Kelvin circulation field in three distinct 90-day window types**. **Comparison between the different window types allows for** the analysis of the two error types: **model bias and edge effects of the frequency filter**.

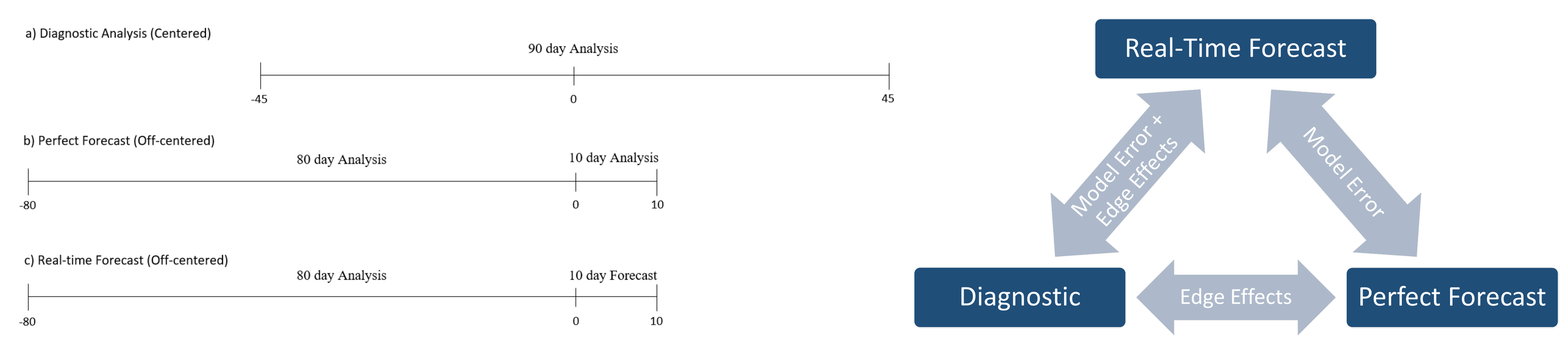

Figure 3. Left: Window types for real-time operational forecast analysis. Right: Comparison between the different window types.

ECMWF Kelvin Wave Representation: A Model Evaluation

Findings:

- The ECMWF operational forecasts shows systemic **bias in the projection signal and phase of Kelvin waves** over **Eastern Africa-Indian Ocean and Western Pacific-Central America**.
- **Until day 3 for the projection signal, and day 6 for the phase of Kelvin waves, ECMWF model error dominates** and edge effects are negligible. Edge effects are relevant for lead days thereafter.

A bias correction was applied that was able to remove the bias in the simulated Kelvin wave projection signal but not the phase.

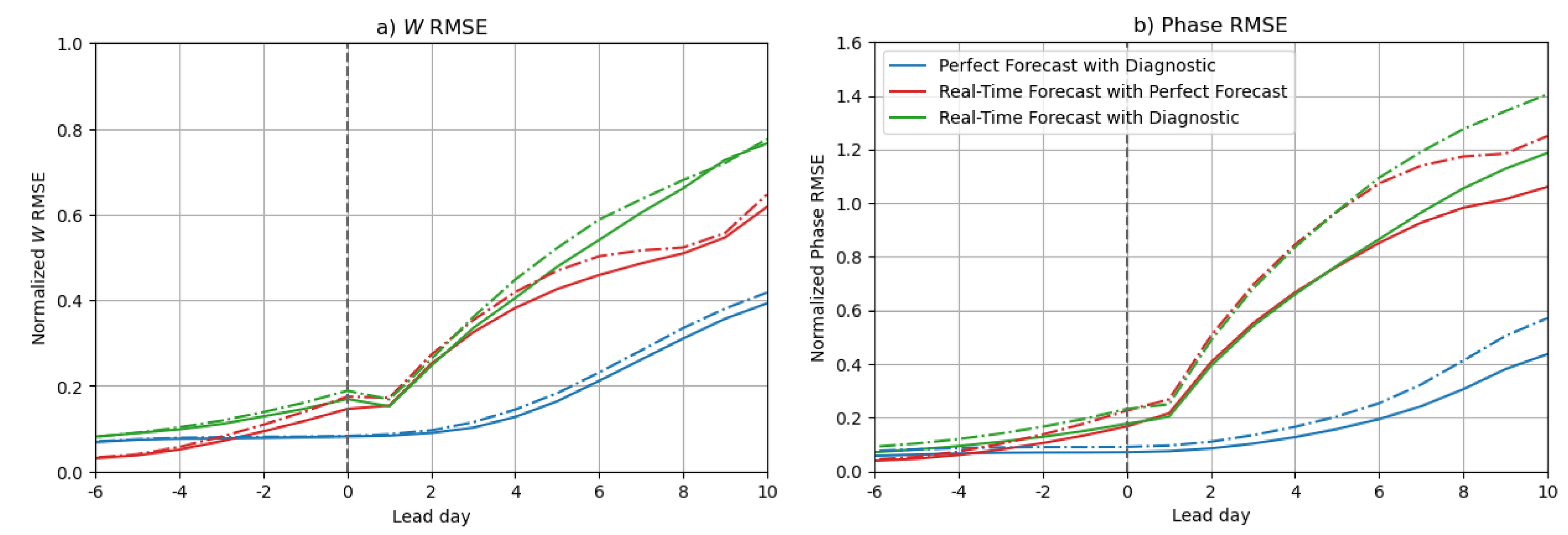

Figure 4. Visualising the importance of edge effects and model error according to forecast lead day. a) RMSE Kelvin wave projection signal and b) RMSE Kelvin wave phase. Blue: edge effects. Red: model error. Green: edge effects and model error. Solid: 850 hPa. Dashed: 200 hPa.

Local Kelvin Wave Propagation

The **propagation of Kelvin waves at a given longitude** can be visualised using amplitude-phase diagrams. The **identified Kelvin waves have a baroclinic structure in the troposphere** and in some cases the bias correction improved the ECMWF operational forecast representation of the Kelvin waves.

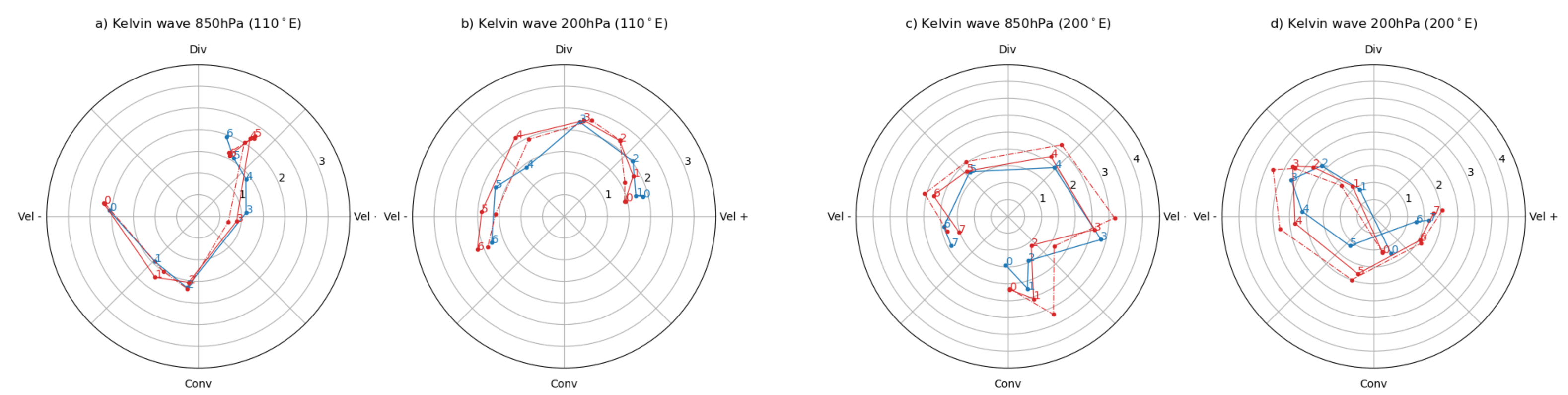

Figure 5. Local Kelvin wave propagation at certain longitudes during the period a,b) 9 - 15 December 2016 and c,d) 16 - 24 July 2016. Blue: perfect forecast. Dashed red: real-time forecast. Solid red: bias corrected real-time forecast.

Key Takeaways

- Developed a **novel identification technique for Kelvin and MRG waves in local data**.
- The identification technique requires very **low computational cost** to apply.
- The Kelvin wave identification method can be used to **evaluate Kelvin waves in real-time operational forecasts**.
- A **systemic bias in 2015-2017 ECMWF operational forecast representation of Kelvin wave signal and phase** was found.

Future Work

Extending the method to the remaining EW types: inertia-gravity and Rossby waves.

References

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