Generation of equatorial Kelvin, Yanai and short Rossby waves near a western boundary

Dennis W. Moore[1], Hristina G. Hristova[2,1], Theodore S. Durland[3], Julian P. McCreary, Jr.[4]

(1) NOAA/Pacific Marine Environmental Laboratory, (2) Joint Institute for Marine and Atmospheric Research, University of Hawai'i, (3) Oregon State University, (4) SOEST, University of Hawai'i

In short

This poster presents a numerical exploration of waves on an equatorial beta-plane in a rectangular basin whose boundaries intersect the equator at an arbitrary angle. The waves are forced by a pressure source on the western boundary northeast of the equator, started from rest and spun up numerically.

At the 2015 AOFD meeting we presented a similar problem where we choose a forcing frequency for which the only modes with real wavenumber were the Equatorial Kelvin Waves and the Equatorial Mixed Rossby-Gravity (Yanai) Waves. The non-dimensional frequencies were between 1-√1/2 and 1+√1/2 , or approximately 0.3 and 1.7 (dimensional periods 5.5 and 31.4 days).

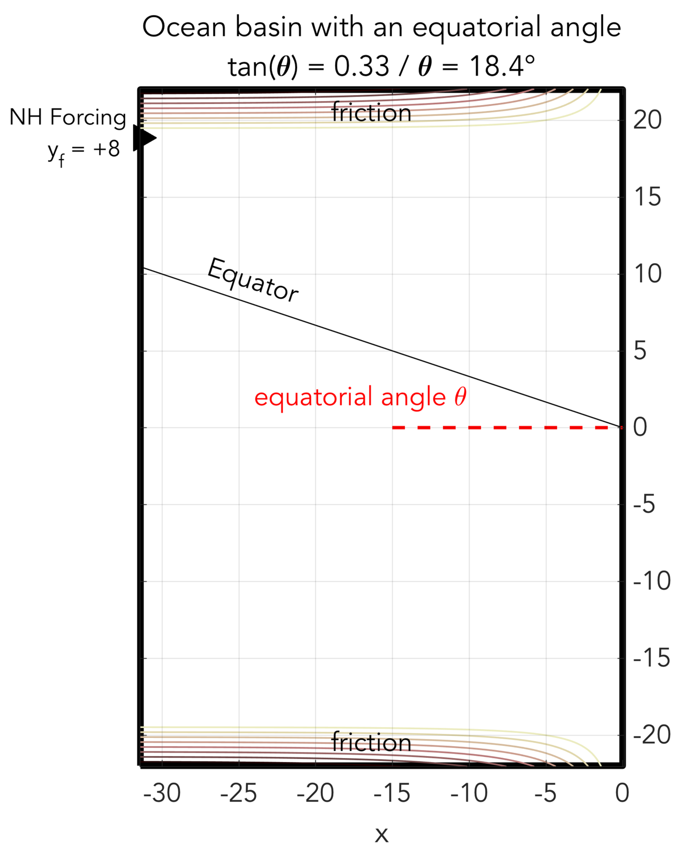
In this study, we lowered the forcing frequency slightly to 0.25 (dimensional period 37 days), so that n=1 short and long Rossby waves with pressure and zonal velocity symmetric about the equator and meridional velocity anti-symmetric about the equator are also possible.

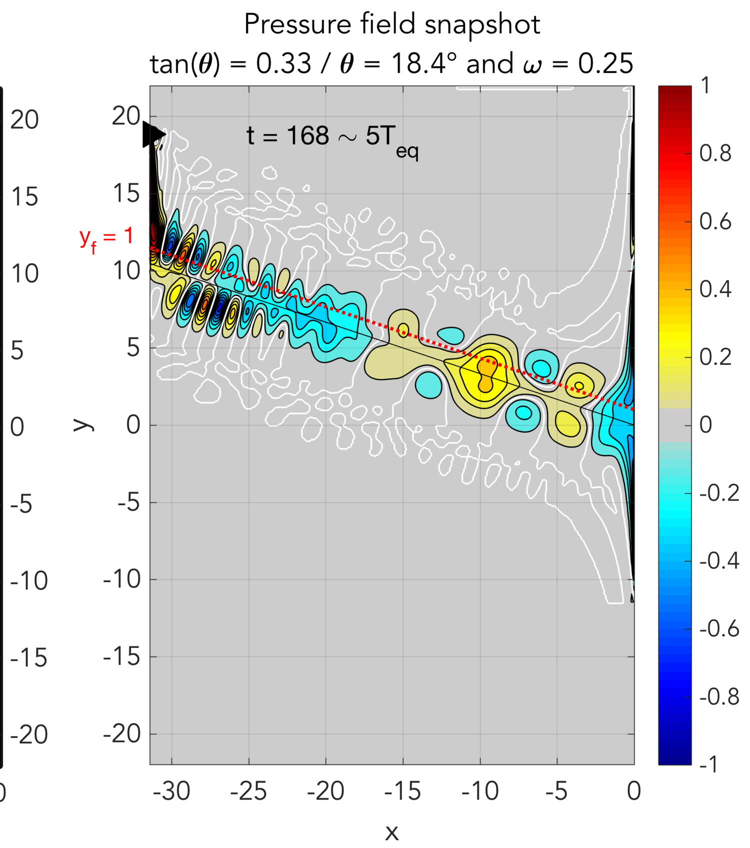
The availability of Rossby modes with real wavenumber changes the character of the energy partition on the eastern boundary, as well as the length of time it takes to reach a quasi-steady state. All the unusual energy partition results when the only propagating modes are Kelvin and Yanai waves change when short and long Rossby waves come into play.

1. Background

We consider the following scenario:

- The ocean basin is of rectangular shape with equator that is inclined at an angle θ with respect to the north and south walls.
- A coastal Kelvin wave is generated on the western boundary in the northern hemisphere (NH) by specifying an oscillating pressure point at a given frequency ω.
- The latitude of the forcing corresponds to 8 deformation radii off the equator, so it is poleward of the critical latitude for the frequencies explored here.
- We do a spin-up type of calculation: starting from an initial state of rest, we look at the equatorial signal generated when the western boundary coastal disturbance reaches the equator.
- The calculations are run for time 30 times T_{eq} where T_{eq} is the time it takes an equatorial Kelvin wave (the fastest wave in the system) to go across the basin.
- Friction near the northern and southern boundaries of the domain prevents waves from wrapping around the closed basin.



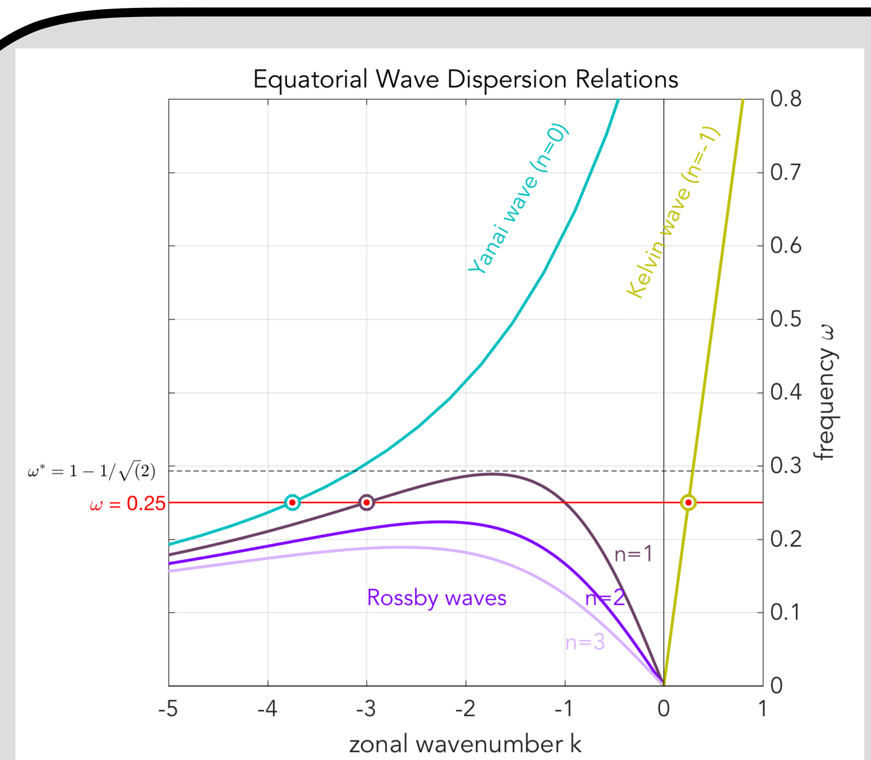


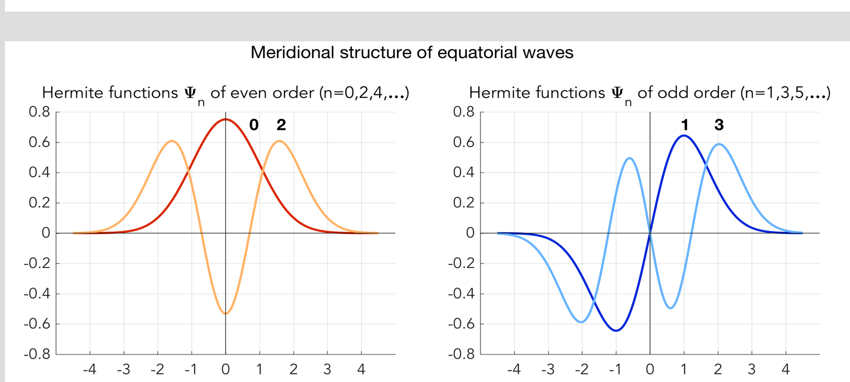
Case setup:

- equatorial angle θ = 18.4° (tanθ = 1/3)
- frequency of forcing ω = 0.25 (dimensional period 37 days)
- cross-basin width along the equator L_{eq} = 33.1 (dimensional 11,000km)
- crossing-time for an equatorial Kelvin wave T_{eq} = 33.1 (dimensional 50 days)

- Notations and nondimensionalization:
  - We use (x,y) for the coordinates in the computational domain (with tilted equator), and (x_f,y_f) for the geographic East/North coordinates.
  - Typical values used for nondimensionalization: c = 2.7 m/s, β = 2.3x10^{-11} 1/s
  - Lengths are scaled with the equatorial Rossby deformation radius $(c/\beta)^{1/2}$ ~340 km (3 degrees).
  - Time is scaled with the equatorial time scale $(c\beta)^{-1/2}$ ~1.5 days.

Equatorial Wave Theory





For frequencies above the threshold ω*, the only equatorial waves with real wavenumber are the Kelvin and Yanai waves:

- **Kelvin wave**

$$k = \omega$$

v = 0
u = p symmetric (~Ψ₀)

- **Yanai wave**

$$k = \omega - \frac{1}{\omega}$$

v symmetric (~Ψ_0)
u = p anti-symmetric (~Ψ_1)

For frequencies below the threshold ω*, in addition there are short and long Rossby waves with real wavenumbers. In particular, for ω = 0.25 only the n=1 mode Rossby wave is excited:

- **Rossby wave (n=1)**

$$\omega = -\frac{k}{k^2+2n+1}$$

v anti-symmetric (~Ψ_1)
u, p symmetric (~Ψ_0, Ψ_2)

u: zonal velocity, v: meridional velocity, p: pressure

2. Results: Wave generation for ω = 0.25 (with n=1 Rossby wave)

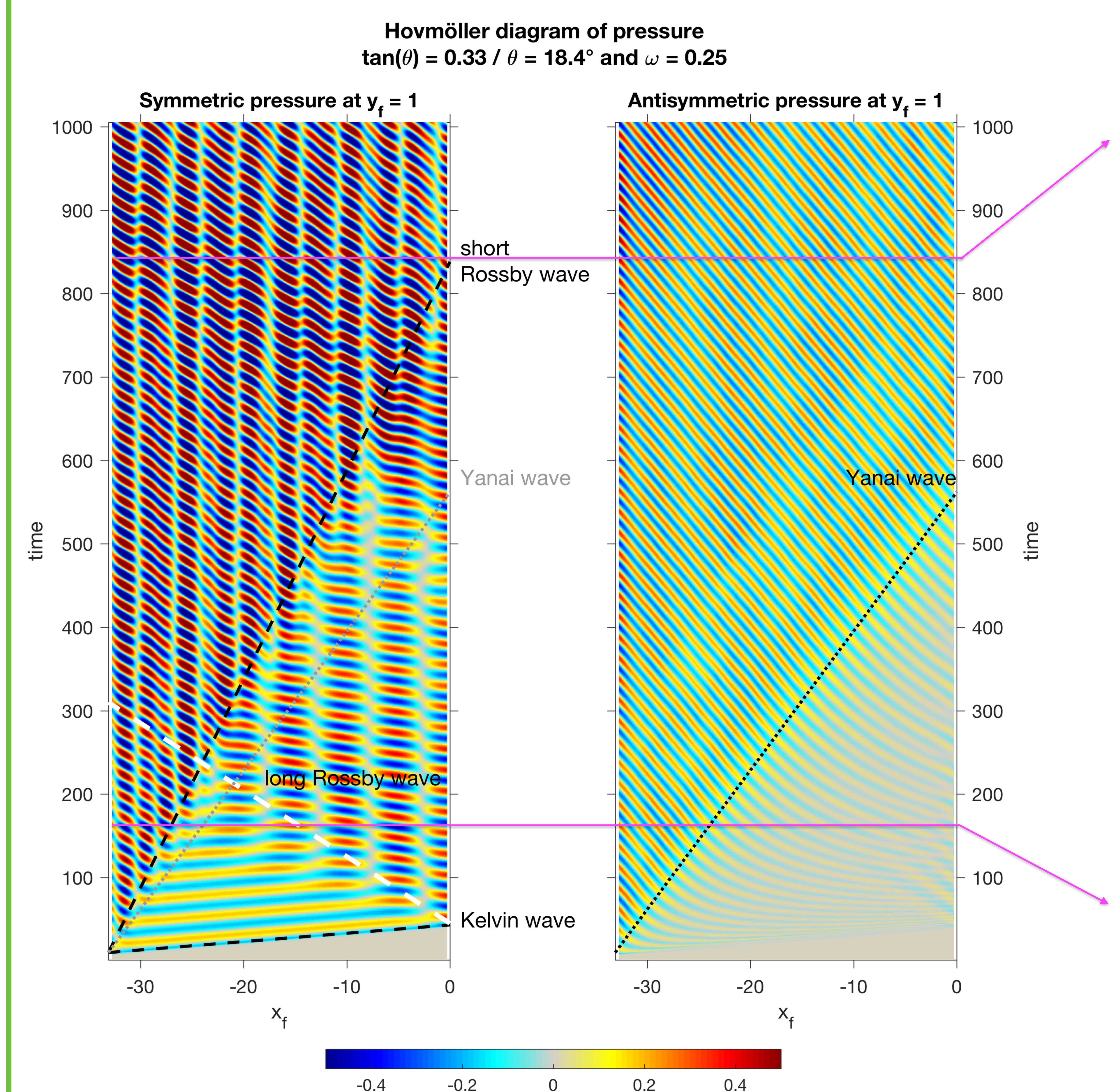
ω = 0.25	wavelength	phase speed	group speed	
Kelvin wave	25.1	1	1	
Yanai wave	1.7	-0.07	0.06	
Rossby wave (n=1)	2.1	-0.08	0.04	(short)
	6.3	-0.25	-0.12	(long)

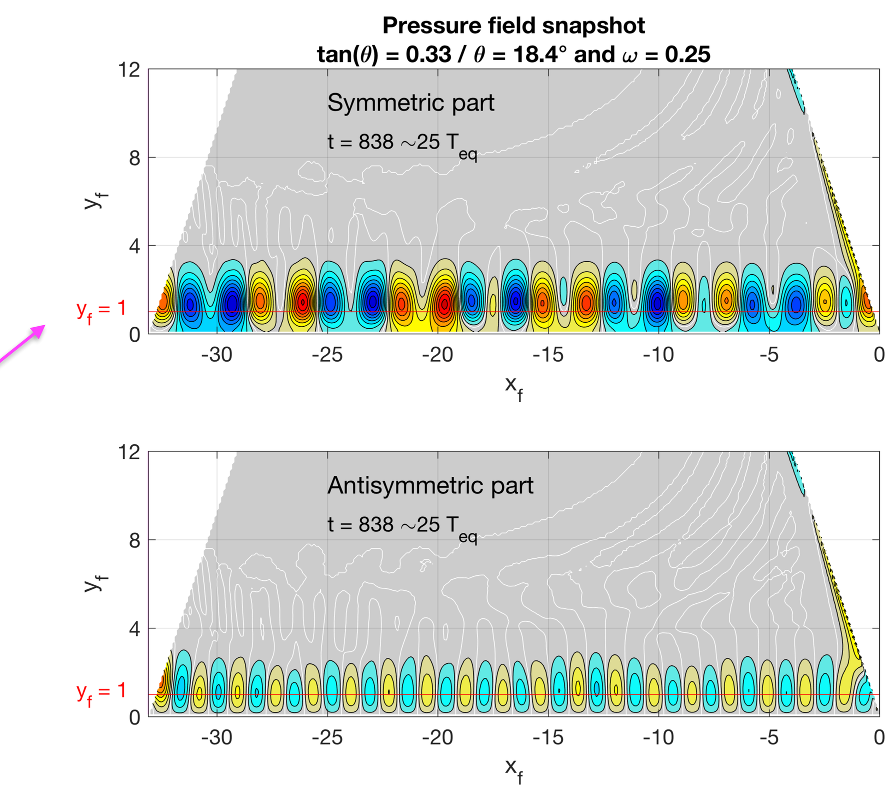
For ω = 0.25 (dimensional period = 37 days), the coastal disturbance generates a short Rossby wave (n=1), in addition to the Kelvin and Yanai waves.

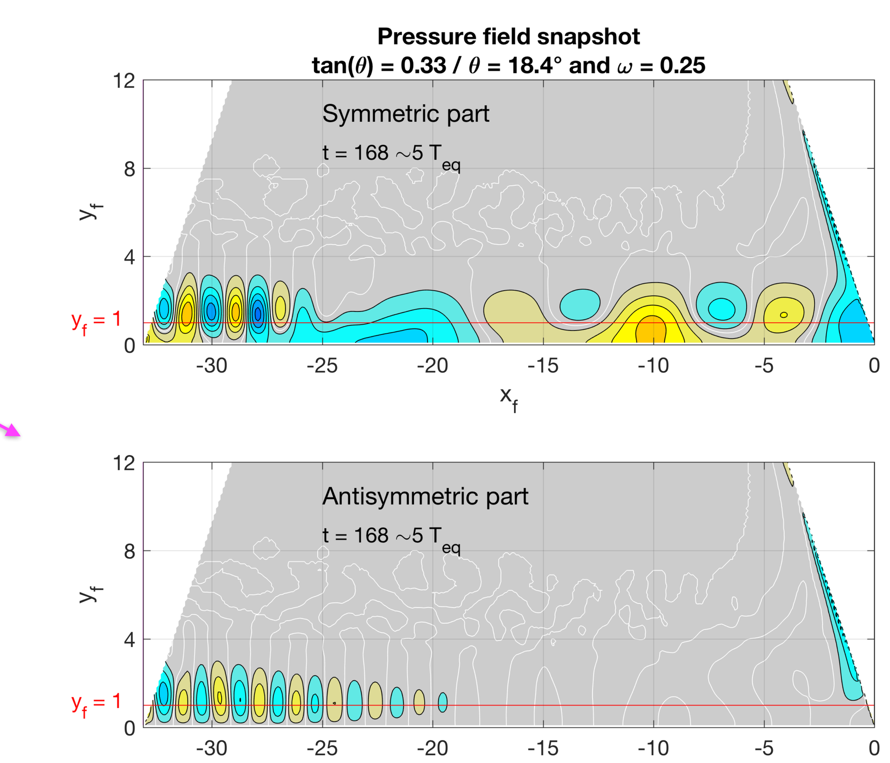
At this lower frequency,

- The wavelength for the Kelvin wave is much larger than that of the Yanai and short Rossby waves.
- The Kelvin wave has a eastward phase speed, while both the Yanai wave and Rossby waves have westward phase speeds.
- The group velocity for the Rossby and Yanai waves is much slower than that for the Kelvin wave (so the signal remains confined near the western wall).

Upon reaching the eastern boundary, part of the energy goes into generating poleward coastal Kelvin waves, but a fraction is also reflected back west along the equator through a long Rossby wave (westward group speed).







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