Internal Baroclinic Motion along 26°N in the Atlantic: do Rossby Waves reflect off of the western boundary?

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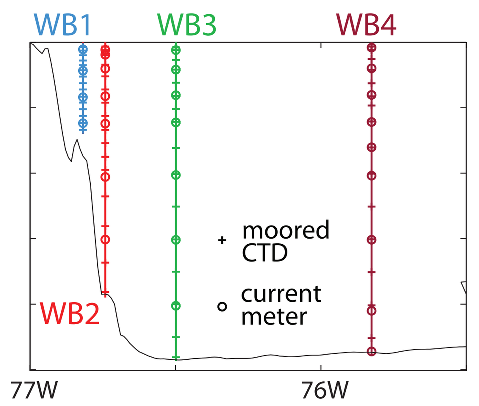
1. Introduction

Motivation The 26N overturning array measures full depth density and velocity at the western boundary. The observations contain a wealth of information about internal motion at periods of hours to years that can be used to evaluate processes that occur at the western boundary of a subtropical gyre.

Approach

1. Potential and kinetic energy levels are unambiguous descriptors of the dynamic regime.
2. Energy flux indicates wave propagation at periods from 2 hours to 2 years, spanning regimes from gravity to earth's rotation.
3. Changes between moorings of time-averaged energy indicate sources/transfers/sinks of energy.
4. The frequency distribution of energies and energy fluxes reflects the underlying wave regimes.



Geometry of the 26N array at the western boundary.

2. Methods

Start with individual instrument records (moored CTDs and current meters). For depth-integrated energy, perform trapezoidal integration to approximate:

$$PE = \int_{-H}^{0} \frac{g^2 \rho'^2}{2\rho_0 N^2}\, dz \qquad KE = \int_{-H}^{0} \frac{\rho_0}{2} u'^2\, dz$$

$$F = \int_{-H}^{0} p' u'\, dz \quad \text{where} \quad p' = g\int_{z}^{0} \rho' u'\, dz - \frac{g}{H}\int_{-H}^{0} \rho' u'\, dz$$

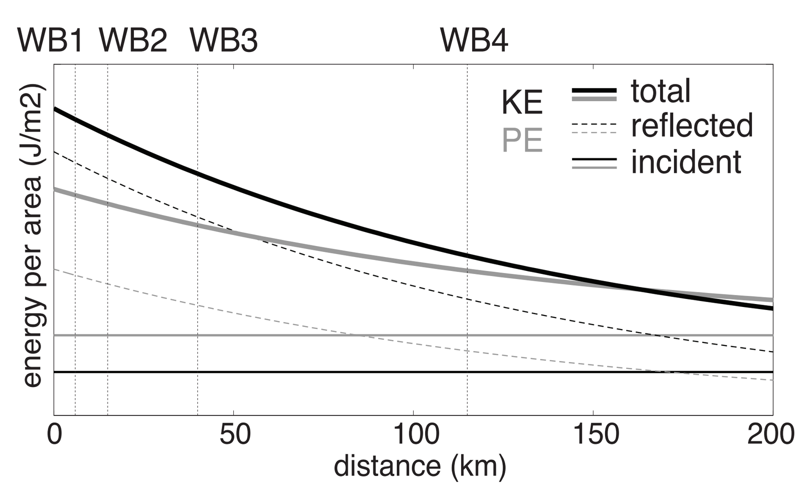
For band-passed calculations, filter single-instrument records prior to calculations.

For vertical modes, calculate linear vertical modes for a flat-bottomed motionless ocean, and fit to measurements following Szuts et al. (2012) for pressure perturbation p' and velocity perturbation u',v'. Band-pass the mode amplitudes and integrate over water column.

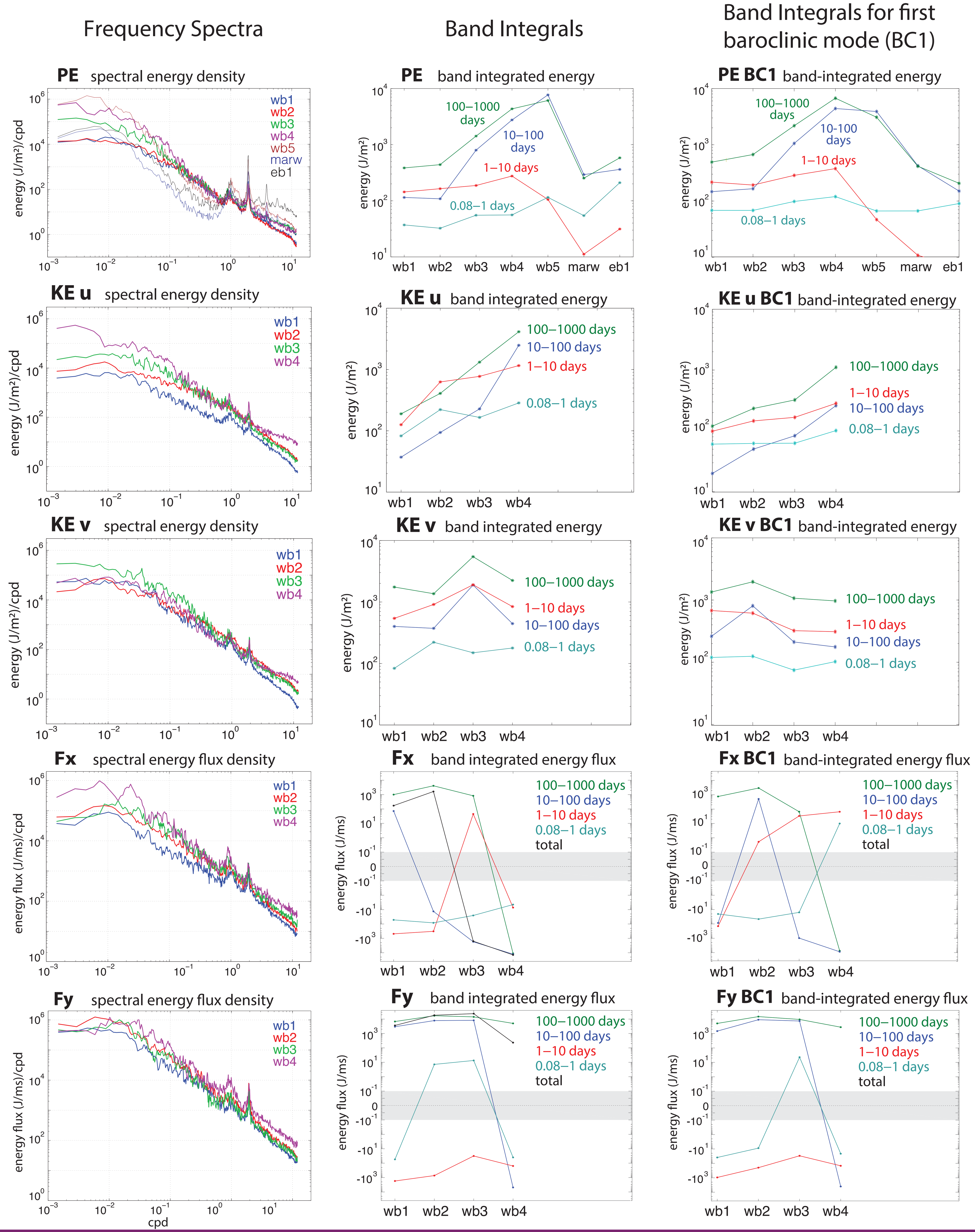
3. How do Rossby waves reflect?

The transport of energy into a western boundary be eddies and Rossby waves is central to ocean dynamics. It is unknown from observations what fraction of energy is reflect (e.g. Gill, 1982; Zhai et al., 2010), transformed into boundary waves (e.g. Johnson and Marshall, 2002), or both (Kanzow et al., 2009). An additional hypothesis is that the waves scatter in frequency and wavenumber. To determine the impact on ocean circulation, it is necessary to quantify the horizontal and vertical redistribution of energy.

For instance, at T=160 days, an incident long-wave (L=400 km) reflects into a short wave (L=219 km) with higher energy density and more kinetic energy. The sum is maximum at the coast, with the short-wave decaying offshore. Do measurements show this?



4. Data



At low frequencies, spectral PE density (far left) decreases towards the coast. Band-integrated PE (middle left) decreases toward the coast for low frequencies, but is flat and small for high frequencies. PE in BC1 mode (near left) has the same patterns as total PE.

At low frequencies, zonal KE the coast. Band-integrated KEu (middle left) decreases towards the coast at all frequencies. KEu in BC1 (near left) has a similar pattern as total KEu, except WB4 has 10x less energy at low frequencies.

In contrast to zonal KE, meridional KE (far left) decreases little towards the coast. Band-integrated KEv (middle left) is level at lower frequencies, with large values at WB3 reflecting the DWBC, and no decrease at WB1. KEv in BC1 (near left) is level, with no spike at WB3 and less energy at WB4 than total KEv.

Zonal energy flux has spectra (far left) similar to KEu, with Fx decreasing toward the coast. Band-integrated Fx (middle left) shows direction, with low frequencies having westward flux at WB3 or WB4, and eastward flux near the coast. Fx in BC1 (near left) is roughly similar to total Fx, but with variable signs.

Meridional energy flux has spectra (far left) similar to KEv, with little change towards the coast. Band-integrated Fy (middle left) is northward for low frequencies, with clear southward flux in the 1-10 day band. Fy in BC1 (near left) is roughly similar to total Fy.

5. Interpretation

The measured patterns exclude linear Rossby wave reflection:
- PE at WB5 and WB4 indicates planetary waves in 100-1000 days band: high PE, dominance of BC1 (Szuts et al., 2012), high correlation with SSH (Szuts et al., 2012; Clément et al., 2014)
- Low frequency energy flux at WB4 is westward
- Low frequencies lose energy toward the boundary, which starts between WB4 and WB3, which is 1-2 Rossby radii (Ro=45 km) from the boundary

What happens instead? These are indicators:
- Relative energy in the 1-10 day band increases toward the coast — a result of unstable turbulent motion?
- Zonal energy flux is eastward at WB1 — some reflection occurs?
- Zonal energy flux converges at WB2-WB3, in BC1 motion too — does the Deep Western Boundary Current absorb energy?
- Meridional energy flux is northward at low frequencies — a result of a convoluted coastline and large low-frequency wave lengths?
- Meridional energy flux for 1-10 days is southward — describes boundary waves (e.g. Kelvin waves), but how much energy do they gain?
- The largest amount of energy is lost from WB4 to WB3
- Meridional velocity and energy flux is controlled differently than zonal velocity and energy flux.

The Deep Western Boundary Current (core located at WB3) and the Antilles Current (core at WB1) are strong mean currents that could absorb the low frequency energy.

6. Conclusions

- PE and KEu have no near-shore maximum - Rossby wave reflection is not linear.
- PE and KEu at low frequencies (T>10 days) lose most energy from WB4 to WB3. This occurs at more than 1 Rossby radius (=45 km) from the boundary, but less than the wavelengths of Rossby waves (200+ km).
- Low frequency Fx is westward at WB4, and it converges at the boundary.
- Fy is northward at low frequencies, and is southward for T=1-10 days (including Kelvin waves)

References

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