Observations of Eddy - Internal Wave Interactions in the Tropics

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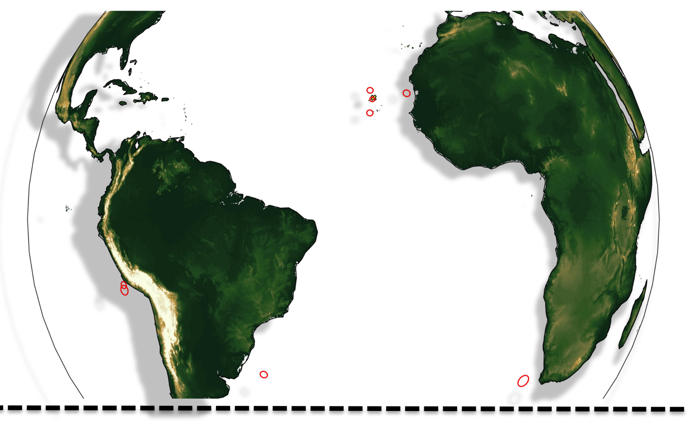
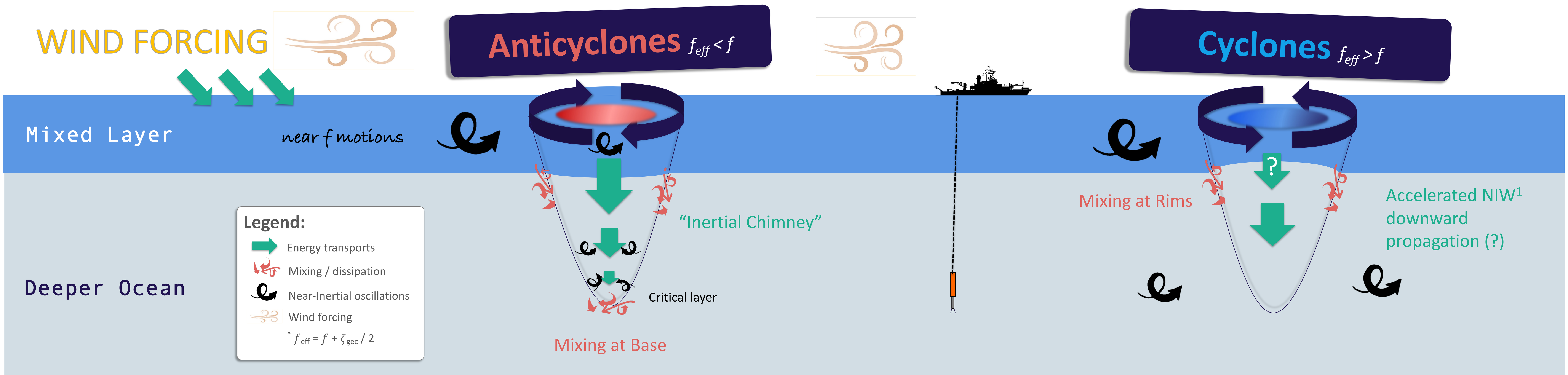
Why?

- **Energy transports:** Quantification of pathways into the deep ocean for mixing **&** Mixed Layer budget
- **Local mixing:** → Nutrient transport → Biological productivity/diversity
- **Model performance**: Supplementing parameterization schemes



Schematic



Exemplary ADCP Transects

Accumulation of NIW[1]

- Well expressed, coherent eddies in the offshore ETNA[3] are often **Anticyclones** or ACME[4]
- Internal Wave (NIW) packages converge at the base of **Anticyclones**, irrespective of their extent (in depth and radius)
- Increased shear in parallel to low stratification (→ low Richardson numbers) enhances probability of turbulence and mixing especially at **critical layers**
- In the **cyclonic** case, enhanced shear and probable accumulation at eddy rims and higher Richardson numbers within the core

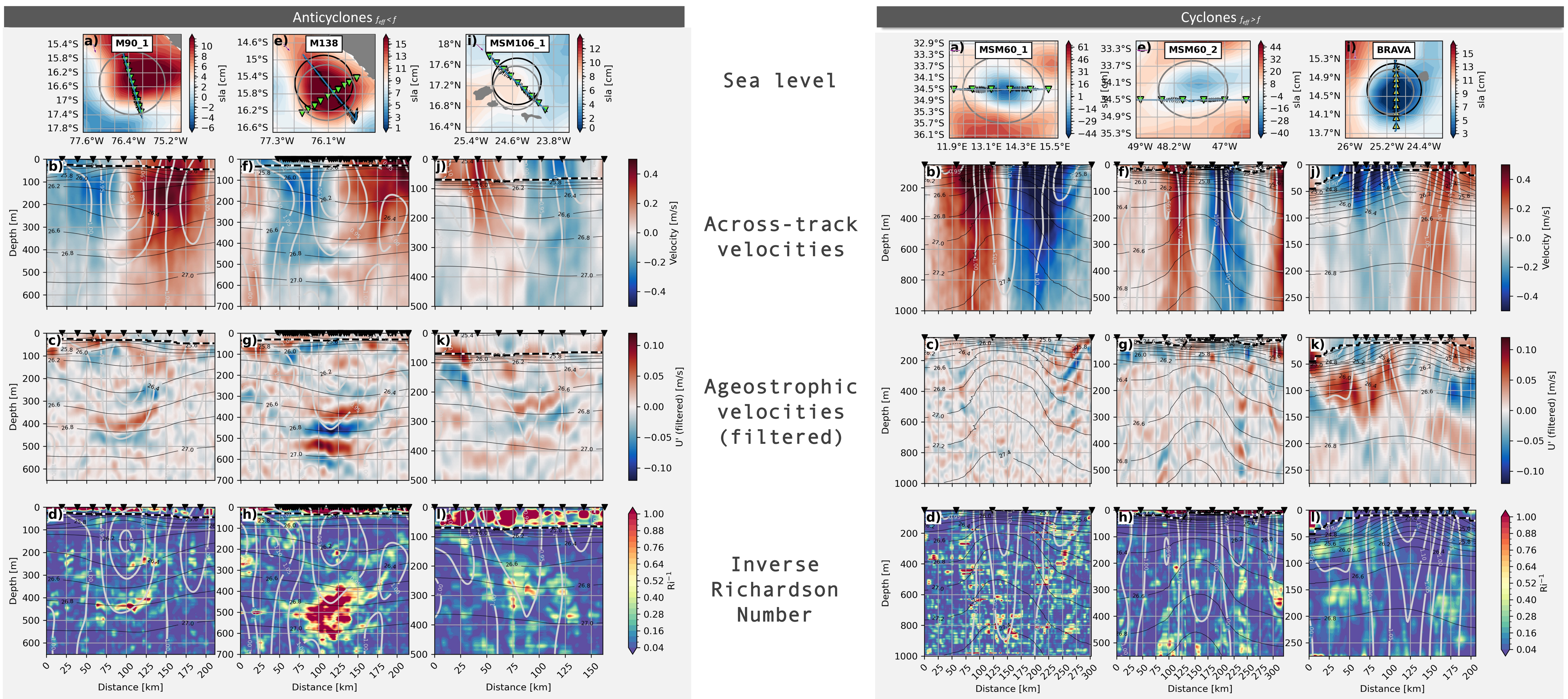


Figure 1 & 2 Exemplary ADCP[2] transects (either 38kHz or 75kHz system) through 3 Anticyclones (to the left, labeled M90_1,M138,MSM106_1) and 3 Cyclones (to the right, labeled M60_1,M60_2,BRAVA). Each column belongs to a eddy. The first row shows the sea level anomaly (CMEMS[4]), second the "raw" across-ship velocities, including potential density anomalies in black and contour lines of the ratio f_{eff}/f in grey (1.0 is equivalent to an inferred relative vorticity ζ_{geo} = 0). Third and fourth row are organized as the second, but for filtered velocities (2nd order Butterworth filter with critical wavelengths of 300m in the vertical and 5km in horizontal) and for the Richardson number. All fields were gridded by Gaussian mapping. Note the alignment of internal wave structures (third row) and low Richardson numbers (fourth row) with contour lines of f_{eff}/f

Microstructure

- Microstructure measurements reveal most direct picture of TKE[5] dissipation
- Relatively enhanced mixing at eddy rims
- Turbulence correlates with larger-scale (300m) geostrophic shear

Turbulence at eddy rims

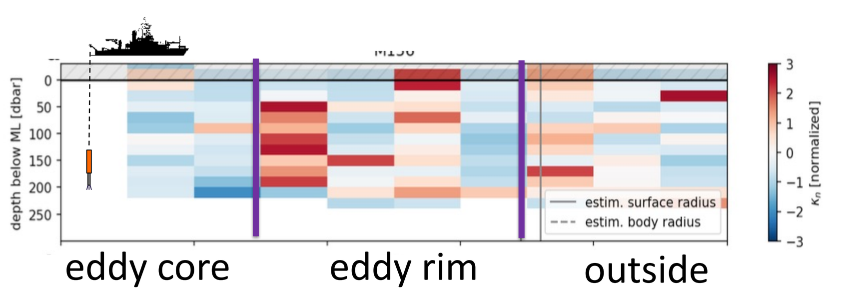


Figure 3 Compilation of Microstructure measurements in vicinity of a Cyclone (Meteor cruise M156) with diffusivity displayed against depth below the mixed layer and distance to the estimated center of the cyclone. For visualization, dissipation values were normalized by the standard deviation for each depth bin, such that values at different distances are relative to each other.

Geostrophic shear → Mixing?

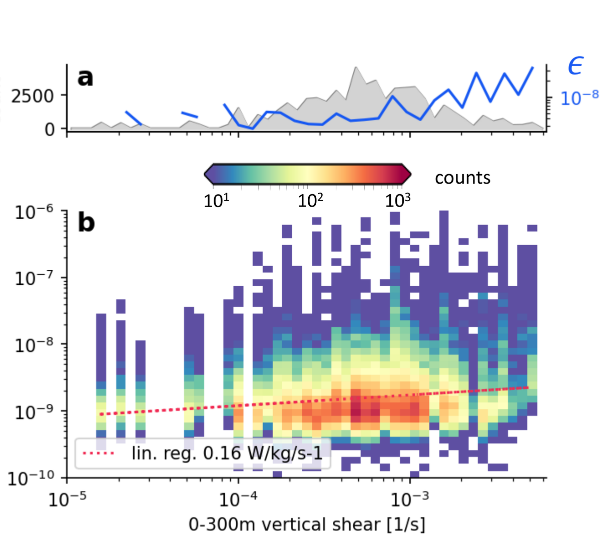


Figure 4 Microstructure measurements of cruises M156 and M160 displayed against "geostrophic shear" (upper 300m linear fit of velocities). Upper row: Count of measurements (grey shaded) and 90% percentiles of each bin (blue line). Lower row: the actual heatmap for TKE dissipation.

Rotary spectra

Downward propagation in Cyclones?

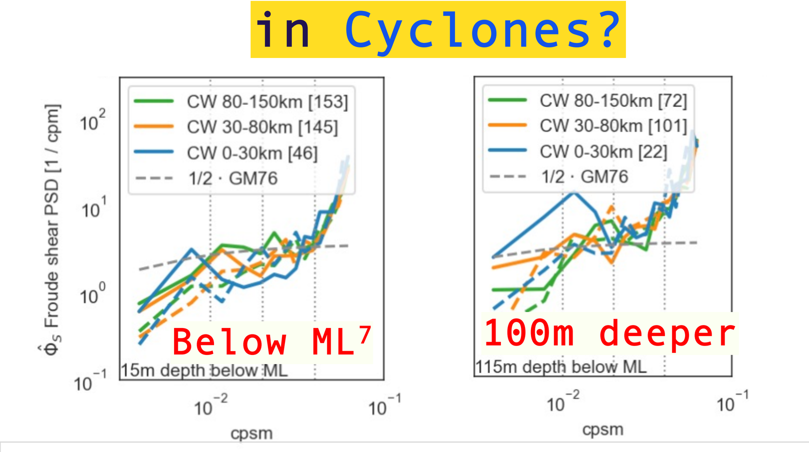


Figure 5 Vertical wave number rotary spectra of velocity shear from ADCP, normalized by buoyancy. Shear levels for the core (blue), the rim (orange) and outside (green), referenced to the canonical Garrett-Munk level (grey dashed). Solid lines: Clockwise rotation with depth (dashed → Anticlockwise). Left: For water column of 256m directly below the ML. Right: Analogue, but 100m deeper. 8m ADCP bin res.

Mooring

Detected NIW-frequencies

- Eddy composites from CVOO[6] long-term mooring (@ 17.61°N 24.25°W from 2006 to 2023)
- Elevated NIW energy close to center of **Anticyclones**
- No clear signal for **Cyclones**

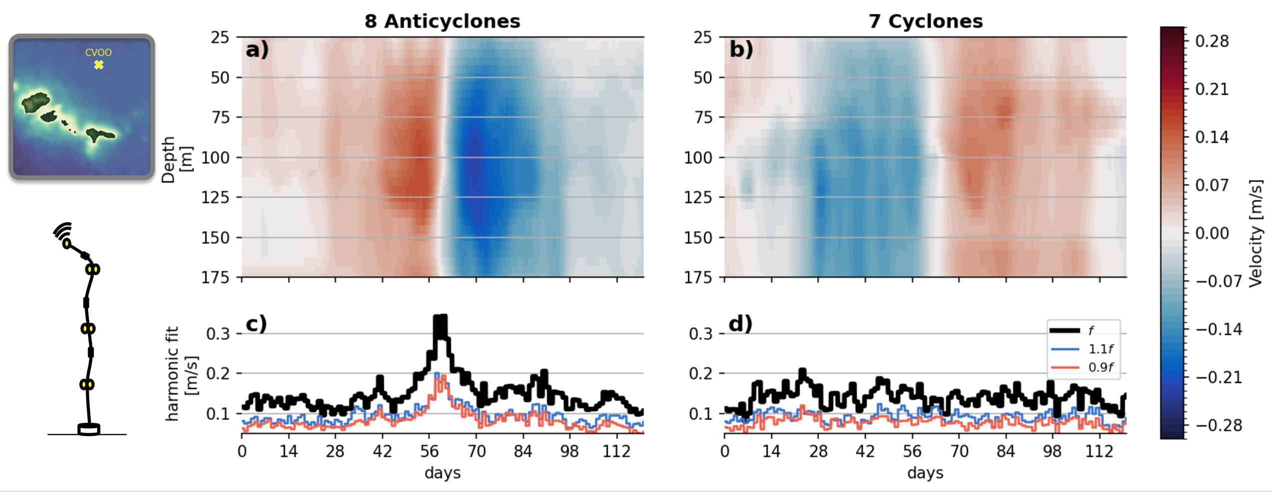


Figure 6 Composite of Anticyclones (left) and Cyclones (right) from moored ADCP. Upper row: Mean of smoothed across-drift velocities against time (in days). Lower row: Amplitudes of 5-day harmonic fits of Coriolis frequency f (black) or 1.1 f (blue) and 0.9f (red) with 4 days overlap against time. Note the clear peak at about 60 days in the anticyclonic case. "Eddy-pass-times" were hand-picked according to signatures in sea level (satellite) and ADCP velocities.

Take Home Messages

- Accumulation of NIW energy at the eddy base, likely enhancing mixing is a common observed feature in **Anticyclones**
- Enhanced mixing at the rim of strong (**Anti**)-**Cyclones**, where geostrophic shear is high
- Mesoscale eddies effectively reorganize the internal wave field

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Sharing is encouraged

Contact | References | Abbreviations | Miscellaneous

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[1]Near inertial Waves (waves with frequencies "near", or slightly above the Coriolis frequency f. * f_{eff} The "effective" Coriolis frequency is the altered lower bound in the frequency spectrum of internal waves due to the additional geostrophic background vorticity ζ_{geo} induced by e.g., mesoscale eddies or fronts. [2]ADCP: Vessel-Mounted Acoustic Doppler Current Profilers measure ocean velocities in the water column. [3]ETNA: Eastern Tropical North Atlantic [4]ACME: Anticyclonic mode water eddy. [4]CMEMS Copernicus Marine Data Service dataset *cmems_obs-sl_glo_phy-ssh_my_allsat-l4-duacs-0.25deg_P1D*. [5]Dissipation of Turbulent Kinetic Energy reflect the final path of the Energy Cascade towards actual mixing. [6]CVOO: Cape Verde Ocean Observatory. [7]ML: Mixed relative. Depth is relative to Mixed layer Depth (MLD)

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