Frequency dependent wind-driven currents from drifters in the Southern Ocean

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1. What's in this poster?

- The goal of this study is to study the wind-driven Ekman-like component of surface velocities as observed by drifters in the Southern Ocean.

$$\mathbf{U}_{\text{drifter}} = \mathbf{U}_{\text{ageostrophic}} + \mathbf{U}_{\text{geostrophic}} + \text{Noise}$$

- Box 2 presents the data used for this study.
- Box 3 presents the rotary spectral analysis.
- Box 4 presents our coherence squared estimates between wind stress and ageostrophic velocities. The drifter wind slip issue is also addressed.
- Box 5 shows how a vertical eddy viscosity can be estimated when our results are fitted to a simple extended Ekman theory.

3. Rotary Spectral Analysis

Spectral analysis

For a vector time series $\mathbf{U}$, the normalized double-sided spectrum is:

$$S(\omega^{\pm}) = \left\langle \tilde{\mathbf{U}}\tilde{\mathbf{U}}^{*} \right\rangle / \omega_r,$$

where $\tilde{\cdot}$ designates the Fourier transform, * the complex conjugate and $\langle\cdot\rangle$ the ensemble average. $\omega_r = 2\pi/40$ radian cycle per day is the pulsation resolution for this study.

For the Southern Hemisphere positive frequencies correspond to anticyclonic motions (dashed curves) and negative frequencies to cyclonic motions (solid curves).

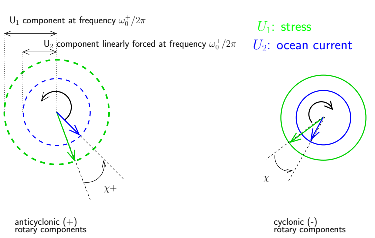
Cross-Spectral analysis

The **coherence squared** γ^2 and the **coherence phase** χ between two vector time series $\mathbf{U}_1$ and $\mathbf{U}_2$ are:

$$\gamma^2(\omega^{\pm}) = \frac{\left|\left\langle \tilde{\mathbf{U}}_1\tilde{\mathbf{U}}_2^{*}\right\rangle\right|^2}{\left\langle \tilde{\mathbf{U}}_1\tilde{\mathbf{U}}_1^{*}\right\rangle \left\langle \tilde{\mathbf{U}}_2\tilde{\mathbf{U}}_2^{*}\right\rangle}, \quad \chi(\omega^{\pm}) = \arctan\left[\frac{\mathcal{I}\left(\left\langle \tilde{\mathbf{U}}_1\tilde{\mathbf{U}}_2^{*}\right\rangle\right)}{\mathcal{R}\left(\left\langle \tilde{\mathbf{U}}_1\tilde{\mathbf{U}}_2^{*}\right\rangle\right)}\right].$$

Coherence squared gives an estimation of the linear relationship between $\mathbf{U}_1$ and $\mathbf{U}_2$ as a function frequency. Coherence squared is reduced by noise.

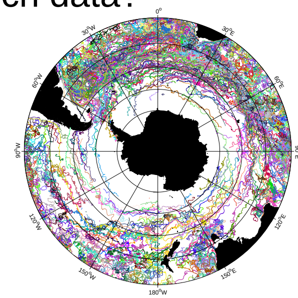
In rotary analysis, the coherence phase gives the angular separation between the two vectors. Our convention is such that a positive phase means that $\mathbf{U}_1$ is to the left of $\mathbf{U}_2$.



Transfer function

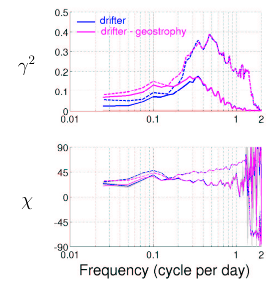
The transfer function $\mathbf{H}(\omega) = \frac{\left\langle \tilde{\mathbf{U}}_1\tilde{\mathbf{U}}_2^{*}\right\rangle}{\left\langle \tilde{\mathbf{U}}_2\tilde{\mathbf{U}}_2^{*}\right\rangle}$ gives the response of $\mathbf{U}_2$ to the forcing by $\mathbf{U}_1$ in terms of gain and phase.

2. Which data?



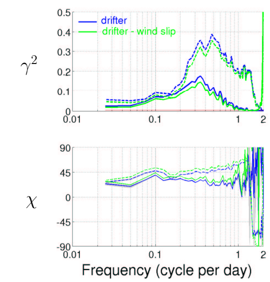
- 10,431 40-day time series of drifter position and velocity were obtained from a total of 875 drifter trajectories collected over a 13 year period as part of the WOCE Surface Velocity Program. Time series overlap by 20-days. These segments were binned in 2° latitude bands. The individual trajectories are plotted above.
- Merged T/P-ERS maps of sea level anomalies from AVISO at 7-day intervals are used to derive geostrophic current anomalies at the surface. A mean sea level from hydrography [*Gouretski and Jancke, 1998*] and hence a mean sea surface geostrophic velocity is added. Geostrophic velocities were interpolated in time and space at each drifter location.
- Ageostrophic velocities are estimated by subtracting geostrophic velocities from drifter velocities.
- ECMWF 10-m wind fields at 6-hour intervals are used to derive wind stress at the ocean surface [*Smith, 1980*]. The wind stress is interpolated in time and space at the drifter locations.

4. Coherence between Wind Stress and Surface Ageostrophic Velocities



Example with data in the 44-46°S band. Coherence squared and coherence phase between drifter velocities and wind stress and between ageostrophic velocities (drifter - geostrophy) and wind stress

- Subtracting geostrophic velocities from the drifter velocities increases the coherence with wind stress for low frequency motions.



Example with data in the 44-46°S band. Coherence squared and coherence phase between drifter velocities and wind stress and between drifter velocities corrected for wind slip and wind stress.

- The wind-slip is the direct action of the surface on the drifter's surface transmitting float. It adds an erroneous downwind component of the ocean surface velocity.

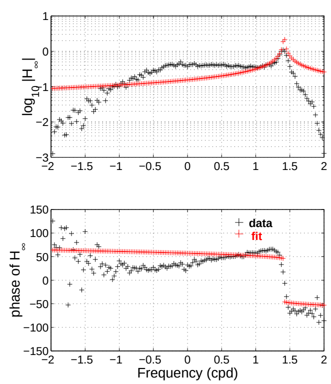
The main features of these plots are 1) higher coherence squared in the anticyclonic domain at subinertial frequencies, 2) an ocean velocity vector to the left of the stress vector, 3) a phase jump at the local inertial frequency. This is in agreement with an extended Ekman theory presented by Gonella (1971) .

5. Estimating vertical eddy viscosity from an extended Ekman theory?

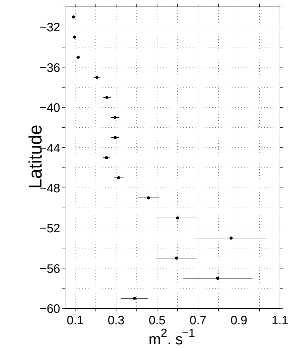
- The coherence analysis shown in box 4 suggests an Ekman-like response of the ocean surface layer dependent on frequency. Following Ekman theory, Gonella (1971) gives the transfer function between wind stress $\mathbf{T}$ and surface ageostrophic velocities $\mathbf{U_a}$ for an infinite depth, homogeneous ocean, with constant vertical eddy viscosity ν:

$$\mathbf{H}_{\infty}(\omega, z) = \frac{\tilde{\mathbf{U}}_{\mathbf{a}}\,\tilde{\mathbf{T}}^{*}}{\tilde{\mathbf{T}}\,\tilde{\mathbf{T}}^{*}} = \frac{1}{\rho\nu}\frac{e^{z\sqrt{i\left(\frac{\omega+f}{\nu}\right)}}}{\sqrt{i\left(\frac{\omega+f}{\nu}\right)}}$$

- Fitting the experimental complex transfer function to this model gives estimates of ν across latitudinal bands of the Southern Ocean.



Experimental transfer function and fit for data within the 44-46°S band. $\nu = 0.25\ \mathrm{m^2.s^{-1}}$ is found for this latitudinal band.



Vertical eddy viscosity estimates in the Southern Ocean. Error bars are one standard deviation obtained by bootstrapping.
Previous estimates of vertical eddy viscosity vary greatly according to datasets and techniques.
High values from 48°S to 60°S suggest higher momentum input from the stronger winds and more vertical stirring.

ECMWF winds provided by the Data Support Section of the Scientific Computing Division at NCAR.

For further information and handouts see http://www-pord.ucsd.edu/~selipot.