Southern Ocean eddies & their role in ocean mixing

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Summary : Our Jason-II proposal continues our on-going investigations of Southern Ocean **meso-scale processes**, and their role in

- the dynamics of the ACC,
- stirring and mixing
- the formation and modification of mode and intermediate waters,
- the transport and diffusion of heat and other tracers.

Eddy stirring and mixing in the Southern Ocean

Filament structures between mesoscale eddies are very important for ocean stirring and mixing, and in the vertical exchange of properties between the surface and subsurface layers (heat, nutrients, carbon, etc). The position of these small-scale structures can be identified using Finite Size Lypanov Exponentss (FSLE). These fine-scale FSLE structures (2 10 km) have been calculated from 15 years of altimetric geostrophic currents by D'Ovidio, 2008.

Stirring rates have been calculated from these FSLEs, and are correlated with eddy statistics such as EKE and eddy diffusion.

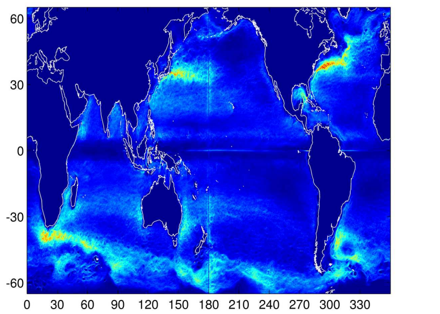


Figure 1. (a) 2003-2006 average of the stirring rates derived from FSLEs over the global oceans, calculated from AVISO surface geostrophic velocities. Although FSLEs are calculated from the mesoscale (100 km resolution) geostrophic velocities, their patterns are well correlated with the finer-scale tracer field..

See Poster : D'Ovidio et al: Stirring in the Southern Ocean

Eddy diffusion in the Southern Ocean

Studies of the mechanisms acting on the formation of deep winter mixed layers in the Southern Ocean show that eddy diffusion becomes important in certain key areas (see Figure 1). Eddy diffusion coefficients have been calculated from 15 years of surface drifters, and also altimetric geostrophic currents, providing similar results. This suggests that the statistical eddy diffusion coefficients are dominated by mesoscale eddies.

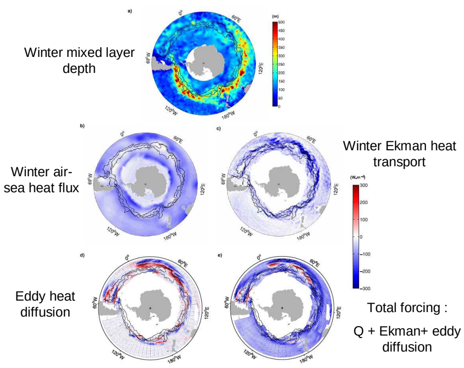


Figure 2. (a) Winter mixed layer depth in the Southern Ocean from Argo and ship data, (b) climatological winter air-sea heat exchange, (c) Ekman heat advection, (d) eddy heat diffusion in the mixed layer and (e) the total of these three components. Contours represent the mean ACC fronts (PF, SAF and SAF-N). Sallee et al., GRL, 2008.

See Poster : Sallee et al: An estimate of Lagragian eddy statistics and diffusion in the mixed layer of the Southern Ocean

Internal mixing vs surface forcing for SAMW modification in the Southern Ocean

The sources and pathways of **mode waters** entering the subtropical gyre of the Indian Ocean are examined. A lagrangian analysis is performed on an eddy resolving model of the Southern Ocean (DRAKKAR, ¼° Mercator grid), where we trace the subducted mode water's pathways, identify their formation regions, and trace back whether their source waters come from the Atlantic, Pacific or Indian sectors of the Southern Ocean. We also quantify how the mode water characteristics are modified after subduction, due to internal mixing effects.

Figure 3. Lagrangian particle analysis of SAMW (density class 26.4 – 26.8) for waters formed in the Indian sector of the Southern Ocean, which then exit north at 30°S in the Indian Ocean. Maps show the SAMW characteristics at the location where these waters subducted (base of the mixed layer). a) volume transport of particles in 10^{-4} m²/s, b) mixed layer depth, in 10^2m, c) month, d) potential density in kg.m³/s, e) temperature in °C, f) salinity. Lower panels s how the upstream and downstream lagrangian pathways for these source waters formed between g) 20-90°E, h) 90-125°E, and i) 125-155°E.

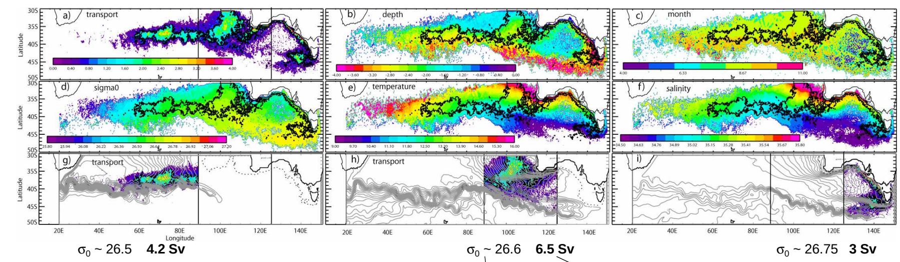
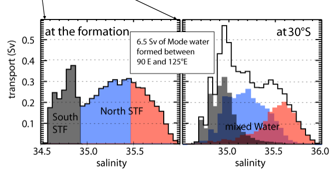


Figure 4. Zoom on the salinity caracteristics of the 6.5 Sv of particles formed between 90°E – 125°E (see panel h). Left panel : at their formation site. Right panel: at 30°S. Total transpor t and density range remains the same. Isopycnal mixing **AFTER** subduction has changed their water mass characteristics – eddy mixing effects?



Koch-Larrouy et al;, 2008. Paper in preparation

EKE response to Southern Ocean climate modes

Interannual variations in Southern Ocean eddy kinetic energy (EKE) are investigated using 14 years of altimetric data. Circumpolar averages show a peak in EKE from 2000-2002, 2-3 years after the peak in the Southern Annular Mode (SAM) index. Although the SAM forcing is in phase around the circumpolar band, we find the EKE response varies regionally. The strongest EKE is in the Pacific, with energy peaks occurring progressively later towards the east. This may be due to the presence of two climate modes – SAM and ENSO. When strong positive SAM events coincide with La Nina periods, as in 1999, anomalous meridional wind forcing is enhanced in the south Pacific Ocean, contributing to the observed increase in EKE 2-3 years later. When positive SAM events coincide with El Nino periods, as in 1993, the climate modes are in opposition, leading to a weaker EKE response during the mid 1990s.

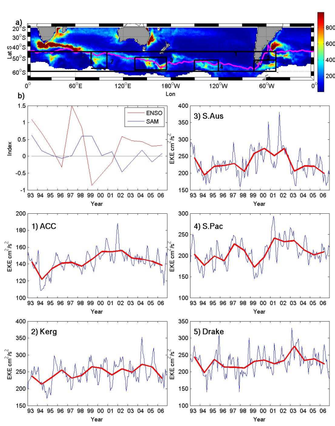


Figure 5. a) EKE averaged over 14 years in the Southern Ocean, in cm2s-2. White lines limit the 5 regions analysed. The mean SAF-N position is in magenta. b) Upper left panel : annual mean SAM (blue) and ENSO (red) indices. Other panels show monthly (blue) and annual (red) mean EKE from 1993-2009 for the 5 regions: 1) ACC region from 45-60°S, 0-315°E; 2) downstream of Kerguelen Plateau; 3) SW of Australia; 4) at the mid-Pacific Fracture Zone; 5) downstream of Drake Passage.

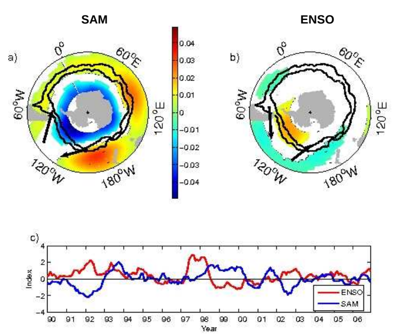


Figure 4 Regression of a) SAM and b) ENSO indices onto sea level pressure in the Southern Ocean. Black arrows indicate the direction of the wind anomalies in the south Pacific.

C) Temporal evolution of the SAM and ENSO indices from 1990 - 2007.

Paper submitted : Morrow and Pasquet, Eddy response to Southern Ocean climate modes, submitted, 2008

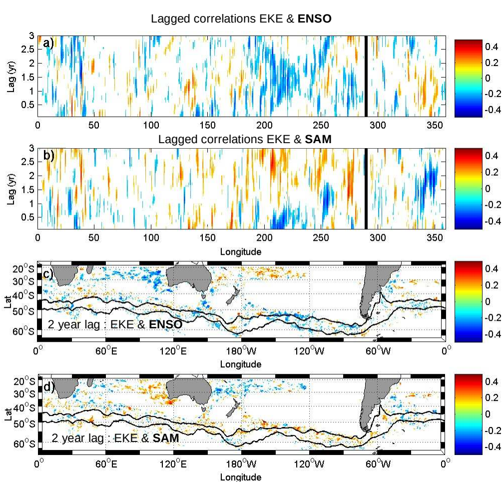


Figure 6. Lagged correlations between the monthly EKE time series and a) ENSO and b) SAM indices, for each point in longitude along the mean position of the SAF-N (y-axis). Lags range from 0-3 years (x-axis). Drake Passage is marked by the black vertical line. Spatial distribution of the 2 year lagged correlation from monthly EKE with c) ENSO and d) SAM indices. The thin black contour lines show the SAF-N and the PF, after Sallee et al. (2008a). Only EKE values > 80 cm2s-2and significant at the 95% level are shown.

Further Information

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