Diagnosing ocean eddy heat and salt fluxes from satellite altimetry and Argo profile data

Oleg Melnichenko[1] (oleg@hawaii.edu), and Angel Amores[2]

[1] IPRC/SOEST, University of Hawaii, Honolulu, Hawaii, [2] Mediterranean Institute for Advanced Studies, Balearic Islands, Spain

OSTST 2017

Introduction

Surface kinetic energy in the ocean is dominated by mesoscale variability or eddies [Ferrari and Wunsch, 2009; Chelton et al., 2011]. Eddies play an important role in the ocean transport of heat, salt, and other properties. Despite their importance, eddy transports remain poorly characterized, mainly due to difficulties in gathering observations on mesoscale time and space scales. Most studies represent only limited geographic regions where adequate observations exist, or rely on the outputs of ocean general circulation models. Ocean models, however, may have their own biases and uncertainties, arising from misrepresented physics, limited resolution, errors in boundary conditions, errors in the forcing fields, etc [Jane and Marotzke, 2002]. For consistent description, direct estimates of the eddy fluxes from observations are much needed. In this regard, the assessment of the roles played by coherent mesoscale eddies, which are abundant worldwide in the ocean and which account for most of kinetic energy of the ocean circulation, is of primary interest.

In this study, transport properties of mesoscale eddies in various parts of the world ocean are diagnosed from a synergistic use of satellite altimetry data and in-situ temperature and salinity profiles collected by Argo floats. The goal is to (i) provide a systematic description and characterization of the eddy transport of heat and salt in the word ocean estimated from satellite and in-situ observations and (ii) diagnose the mechanisms responsible for these transports (**work in progress**).

Data and Method

3-D eddy composite analysis

Data: Aviso sea level anomaly (SLA) maps; global mesoscale ocean eddy data set from satellite altimetry by Chelton et al. (2011); Argo temperature/salinity profiles quality-controlled as described in Amores et al. (2017)

Method: In the composite analysis of in-situ data, the mean vertical structure of mesoscale eddies in a given geographical area is reconstructed by synthesizing all available profile data in the framework of the eddy tracking technique (Qiu and Chen, 2005; Chaigneau et al., 2011; Castelao, 2014; Amores et al., 2017): (1) The World Ocean is divided into geographic bins; (2) Within each bin, we search for Argo profiles concurrent with eddies detected in SLA and compose them relative to the eddy centroids; (3) Temperature, salinity and dynamic height anomalies are computed relative to Argo climatology: (4) All the parameters are interpolated into a regular grid (referenced to the eddy centroid) by fitting a truncated Fourier series in 2D. Eddy velocities are computed from the gridded dynamic height anomaly. At the end of this step, a 3D composite eddy structure is reconstructed in the upper ocean layer in each geographic bin and according to the eddy polarity. An example of a composite anticyclonic eddy reconstructed in the South Indian Ocean is shown in Figure 1.

Example: 3-D structure of a composite anticyclonic eddy in the south Indian Ocean (27-17ºS, 70-90ºE)

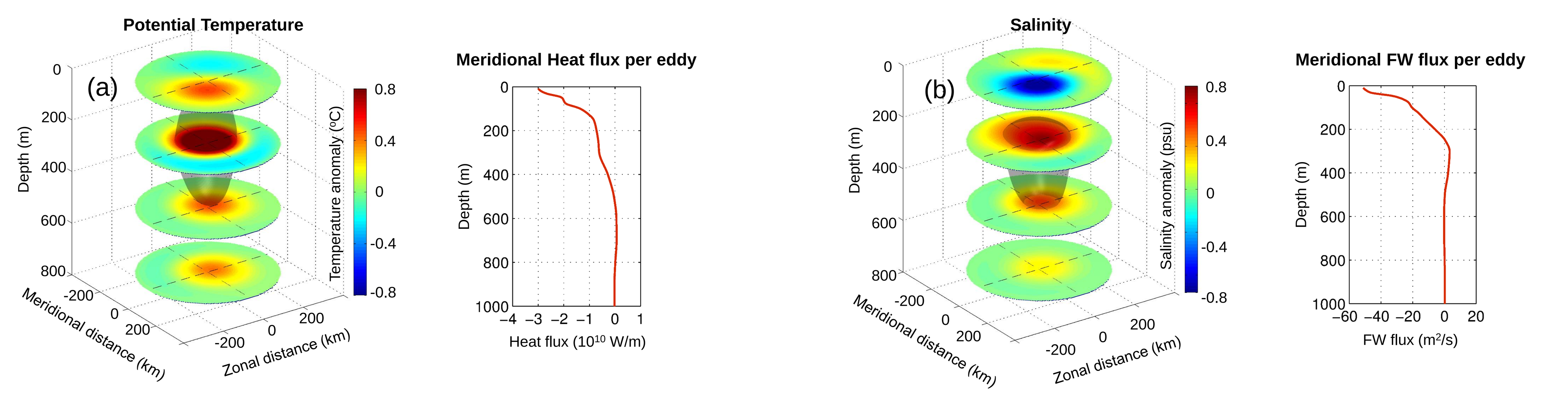

Figure 1. 3-D structure of a composite anticyclonic eddy in the south Indian Ocean (27-17ºS, 70-90ºE): (a) potential temperature anomaly (ºC), and (b) salinity anomaly (psu). The iso-surfaces are 0.5ºC and 0.06 psu, respectively. The horizontal slices are shown at 5 depths: 10, 150, 300, 450 and 600 m. **The vertical profiles of the corresponding eddy heat and FW fluxes are computed according to Eq. (1).**

(a) $$F_y^{\theta} = \rho_0 C_p \int_{-L}^{L} \langle v' \rangle \langle \theta' \rangle dx$$

(b) $$F_y^{FW} = -\frac{1}{S_0} \int_{-L}^{L} \langle v' \rangle \langle S' \rangle dx \qquad (1)$$

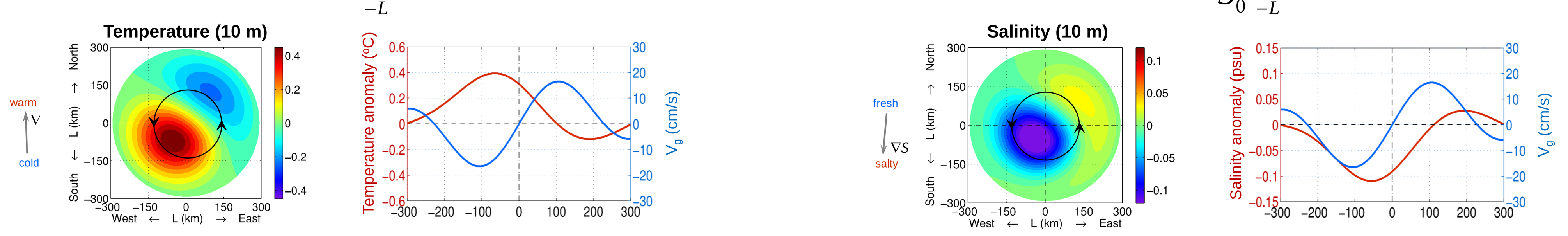

Figure 2. Horizontal structure of (a) temperature and (b) salinity anomaly at 10 m depth associated with the composite anticyclonic eddy in the south Indian Ocean shown in Figure 1. Zonal sections are through the eddy centroid (dy=0). The directions of time-mean, large-scale SST and SSS gradients are shown schematically by arrows on the left side of the corresponding panel. Owing to the phase shifts between eddy-induced pressure and T (S) anomalies, eddies produce net heat (salt) flux in the corresponding layer.

The eddy flux across a zonal section in the ocean (where the eddy composites were reconstructed; we use 4º-latitude bins) is computed by taking into account the average number of eddies present simultaneously along the section.

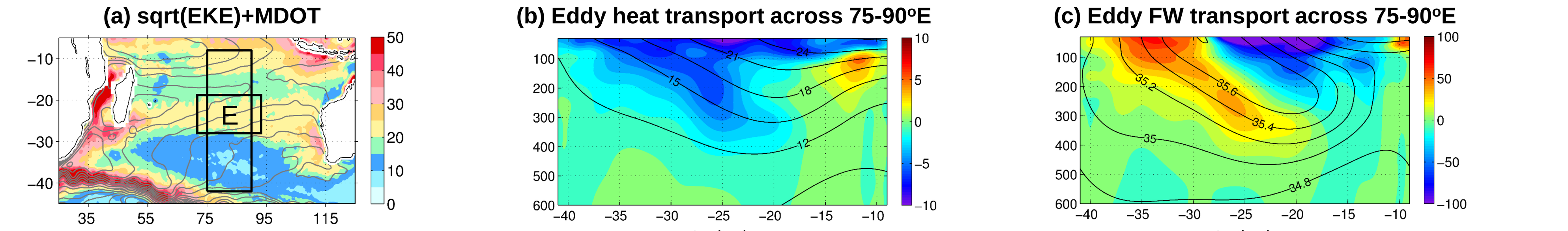

Figure 3. (a) RMS eddy velocity variability (color; cm/s) and mean dynamic topography (contours); (b) Eddy heat transport (10^{10} W/m) across 75-90ºE (black box in (a)); (c) Eddy freshwater transport (m^2/s) across 75-90ºE (black box in (a)).

Heat and freshwater transport by mesoscale eddies

North Pacific Subtropical Gyre

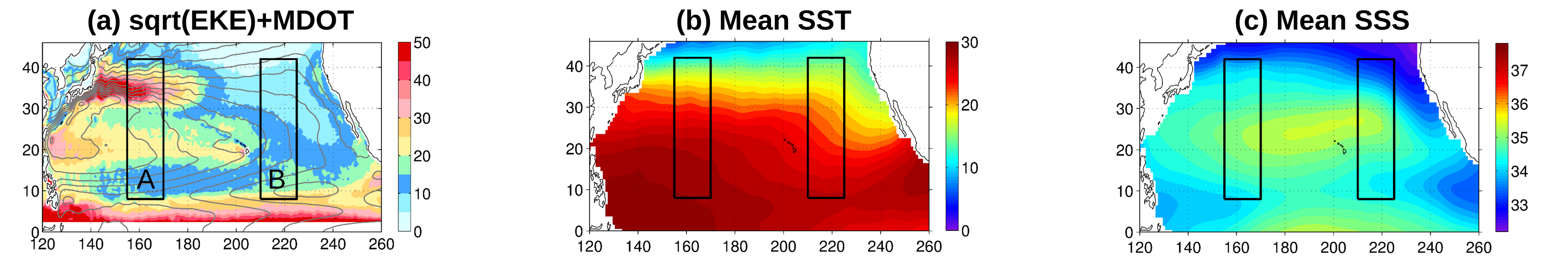

Figure 4. Background: (a) RMS eddy velocity variability (color; cm/s) and mean dynamic topography (contours); (b) Annual mean SST (ºC); and (c) Annual mean SSS. The black boxes indicate the areas over which the meridional eddy heat and FW fluxes are estimated.

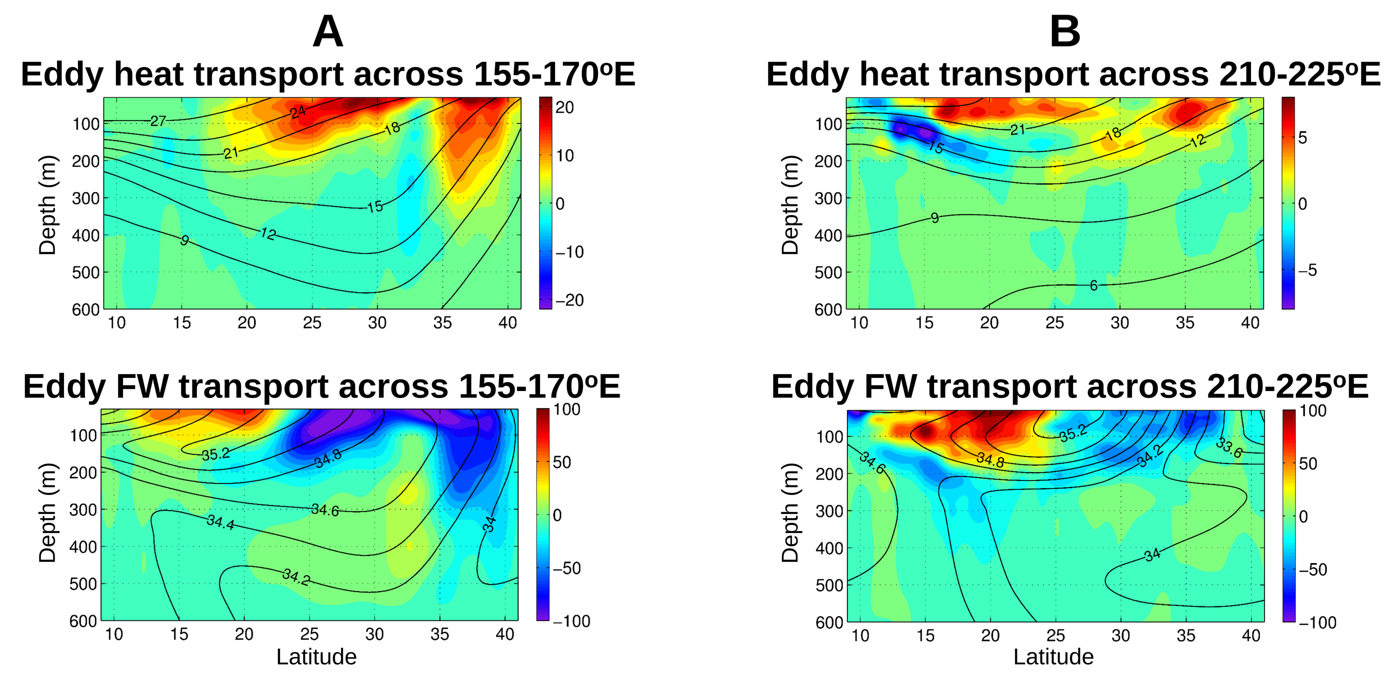

Figure 5. (A) Eddy heat (10^{10} W/m) and freshwater (m^2/s) transport across 155-170ºE in the North Pacific (box A in Fig. 4a). Contours are climatological mean temperature and salinity, respectively. (B) The same as in A but for the zonal band 210-225ºE (Box B in Fig. 4a). **The eddy fluxes are not negligible in gyre interiors. In the vertical, the fluxes are largely confined to the upper 300 m with a clear signature of subducting water.**

Near-Global

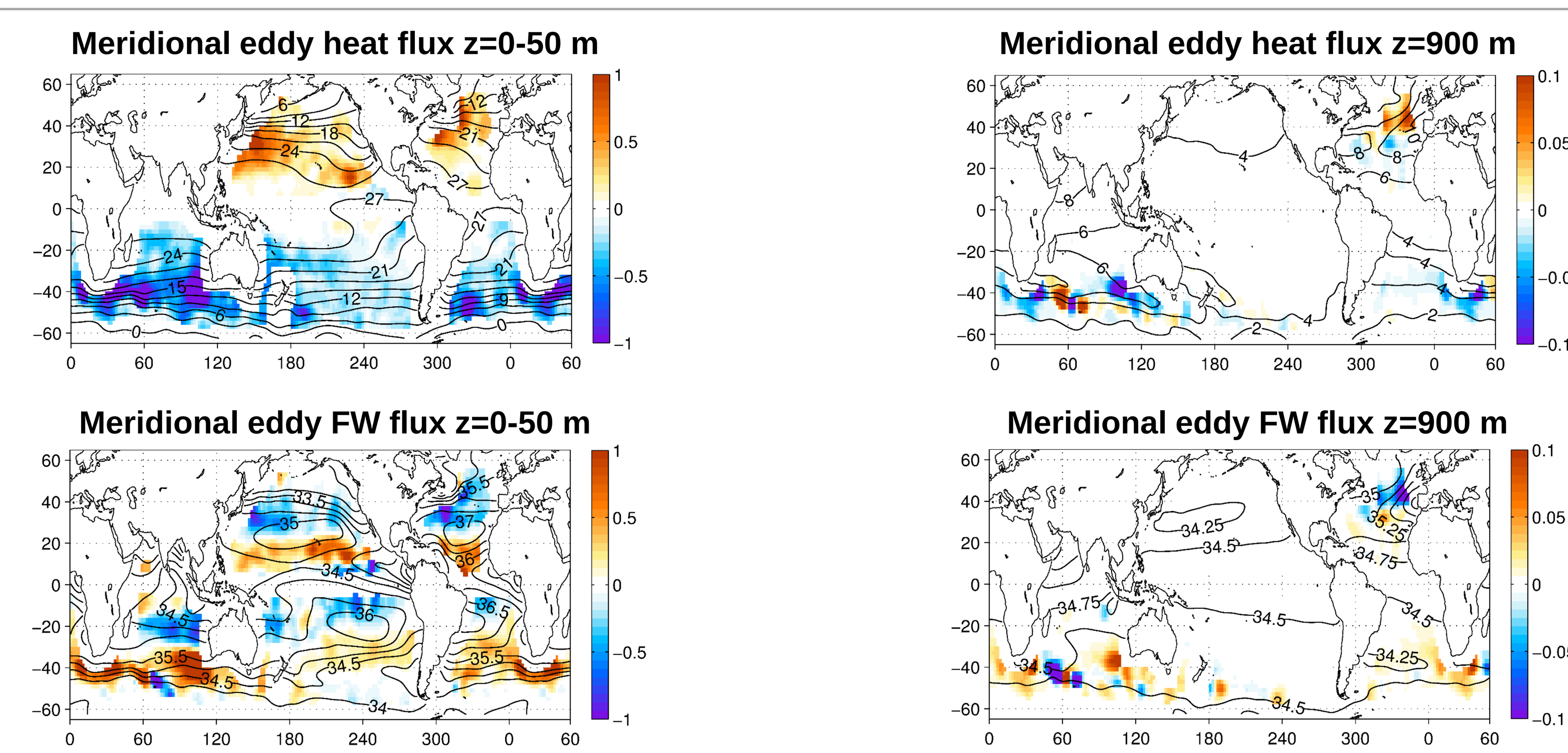

Figure 6. Upper: Meridional eddy heat flux ($<\rho C_p v'T'>$; 10^5 W/m^2) in the upper ocean 50 m layer (left) and at depth 900 m (right) evaluated from the composite analysis of Argo profile data and statistics of eddy trajectories in SLA. Lower: The same as upper, but for the meridional eddy FW flux (10^{-4} m^3/s).

Summary

Transport properties of coherent mesoscale eddies in various parts of the world ocean have been diagnosed from a synergistic use of satellite altimetry data and in-situ temperature and salinity profiles collected by Argo floats. We focus is on the eddy stirring and elucidate the mechanisms by which westward propagating eddies provide meridional transport of heat and salt.

The eddy transports are expectedly strong in the western boundary currents and in the Southern Ocean along the Antarctic Circumpolar Current (ACC). The transports are generally weak, but not negligible in gyre interiors. In the vertical, the eddy heat and salt transports are surface-intensified and confined mainly to the upper ~300 m layer, but their distribution with depth is not homogeneous throughout the ocean. In the Kuroshio extension (KE) region, for example, the eddy heat transport is poleward everywhere in the surface layer above the thermocline, but oppositely signed relative to the jet's axis in a deeper layer between approximately 300-800 m, where the transport is poleward on the northern side of the jet and equatorward on its southern side. Relatively strong eddy transports at depth are also observed in the ACC, particularly in the Indian sector, and in the subtropical North Atlantic at the level of the Mediterranean Water (MW) at around 1000 m depth. The latter exemplifies the role of eddies in MW spreading.

Acknowledgements. This research was supported by NASA PO grant NNX13AM86G and grant NNX17AH26G. Additional support is provided by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) through its sponsorship of the International Pacific Research Center. Argo data were collected and made freely available by the International Argo Program and the national programs that contribute to it (http://www.argo.ucsd.edu). We thank D. Chelton for the eddy dataset (downloaded from http://cioss.coas.oregonstate.edu/eddies/nc_data.html) and N. Maximenko for fruitful discussions.