HYBRID DECADE-MEAN GLOBAL SEA LEVEL WITH MESOSCALE RESOLUTION

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ABSTRACT

Improved global mean sea level is obtained by combining two datasets: large-scale mean sea level based on measurements of twin-satellite mission GRACE and mesoscale sea level tilt derived from the momentum balance as seen in drifter, satellite altimeter and wind data. Hybrid product reveals complex structures of main currents even after averaging over 10 years and shows their places in the large-scale near-surface circulation.

INTRODUCTION

Shape of the sea level determines geostrophic currents in the upper ocean, which play important role in the global circulation. Before the beginning of satellite altimetry, direct observations of the sea level on large scales were not available. Indirect techniques (such as the dynamical method) were based on assumptions (such as the assumption of no-motion level), which are not acceptable any more by many modern studies. Even after accuracy of satellite altimeter reached a few centimeters, extraction of the signal related to ocean dynamic is still a challenge. Indeed, absolute sea level deviates from the Earth’s ellipsoid by up to 100 meters due to gravitational anomalies and only by up to 2 meters due to the ocean currents. Decades of satellite and in situ gravity measurements produced multiple models of the Earth's equipotential surface (geoid), but even most advanced of them, such as EGM96 (Lemoine et al., 1998) contained large-scale errors reaching 1 meter in some areas. Recently released GRACE (Gravity Recovery and Climate Experiment Mission) Gravity Model 01 (GGM01, http://www.csr.utexas.edu/grace) corrected that error (Showstack, 2002) and allowed more accurate estimate of the large-scale geostrophic circulation (Tapley et al., 2003). Based on this model, a number of improved models of the mean sea level were released by different institutions, varying in the used ensembles of satellites and in the employed techniques. General for all these models is their coarse spatial resolution not exceeding a few hundred kilometers. This limitation is clearly set by the design of the GRACE, whose satellites are orbiting the Earth at altitude of 485 km.

Independently, Niiler et al. (2003) developed the technique for computation of the mean sea level based on joint analysis of drifter, satellite altimeter and wind data. Their dynamically balanced sea level exhibits excellent accuracy on mesoscale, but may contain significant systematic errors accumulated during integration of pressure gradient over large scales.

In this work we combine the data of the large-scale mean sea level computed at the NASA Jet Propulsion Laboratory (JPL) using GGM01 with the data of mesoscale dynamical sea level gradient to obtain the product equally confident on the broad range of spatial scales.

METHODS AND RESULTS

Estimate of the mean gradient of sea level $\nabla\langle h\rangle$ can be obtained (Niiler et al., 2003) as

$$\underline{\boldsymbol{G}} = -(d\mathbf{V}/dt + \mathbf{f}\times\mathbf{V})/g - \nabla h' + (\partial\tau/\partial z)/(\rho_0 g), \qquad (1)$$

where **V** is the horizontal velocity vector, **f** is the Coriolis parameter vector, g is the gravitational constant, h' is the temporal anomaly of the sea level and the rightmost term describes the vertical divergence of horizontal stress due to vertical viscosity, mainly related to the Ekman dynamics. Acceleration and Coriolis terms are calculated from trajectories of the Surface Velocity Program (SVP) drifters having large drogues attached at 15m depth, gradient of sea level anomaly is derived from the sea level anomaly maps provided by the Aviso (1996) and $\partial\tau/\partial z$ term is computed from the NCAR/NCEP reanalysis wind at 10m level using simple parameterizations of Ekman currents. Niiler et al. (2003) used Ekman parameterization suggested by Ralph and Niiler (1999; hereafter, RN99) that was derived for the mean wind and currents in the low-latitude Pacific Ocean. Largest errors in the mean sea level of Niiler et al. (2003) are on the large scale and are mainly due to errors in the Ekman formula.

In the present work improvement has been achieved using the mean sea level $\langle h\rangle_{JPL}$ provided by JPL (courtesy of Victor Zlotnicki) in two steps: first, Ekman parameterization was improved and, second, data of the sea level and its tilt were combined. Following RN99 we assumed linear relation between the mean NCEP wind and mean $\partial\tau/\partial z$, and new Ekman formula was obtained by transforming equation (1) and substituting $\underline{\boldsymbol{G}}$ by the values from the JPL sea level. Resultant formula differs significantly from RN99, especially at high latitudes. Unlike RN99, the angle between mean Ekman velocity at 15m and mean NCEP wind varies (decreases) with latitude. However, correction of the mean Ekman parameterization had a limited effect on the improvement of the global sea level. More detailed study revealed other unaccounted factors playing important roles, such as a non-linearity to the wind speed, seasonal differences, dependence on frequency and variations in longitude.

Eventually, hybrid mean sea level $\langle h\rangle_H$ was calculated by minimizing the cost function

$$F = \int \{ W_1\cdot(\langle h\rangle_H - \langle h\rangle_{JPL})^2 + W_2\cdot(\nabla\langle h\rangle_H - \underline{\boldsymbol{G}})^2 \}ds, \qquad (2)$$

where integration is over the World Ocean area covered by data. Qualitatively, the meaning of this technique is that $\langle h\rangle_{JPL}$ sets the sea level difference between two distant locations and $\underline{\boldsymbol{G}}$ defines positions and relative sharpness of sea level fronts between them. Weights W_1 and W_2 were selected to set the scale separating influences of the two datasets at 1000 km.

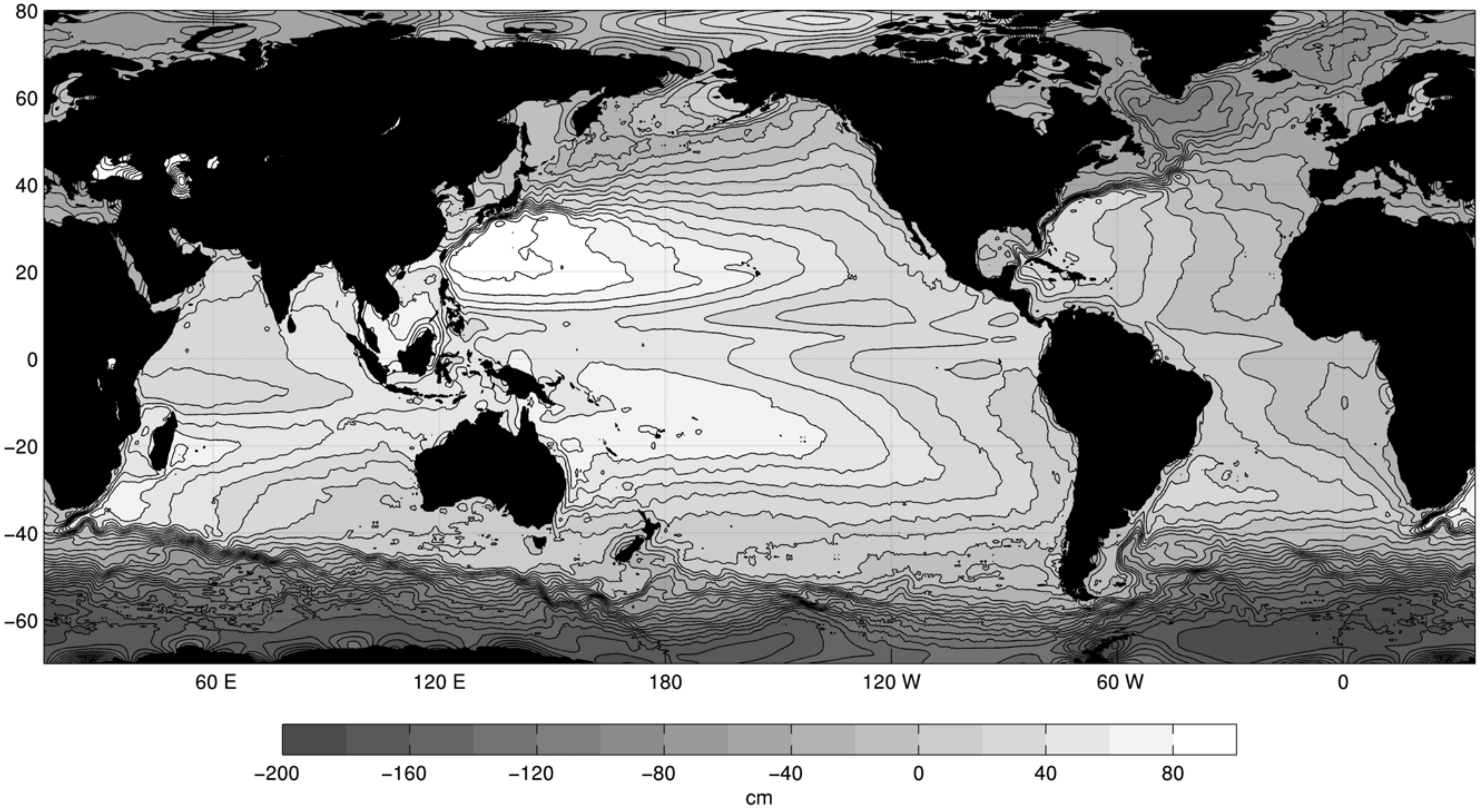

Figure 1. Hybrid 1992-2002 mean absolute sea level. Contour interval is 10 cm.

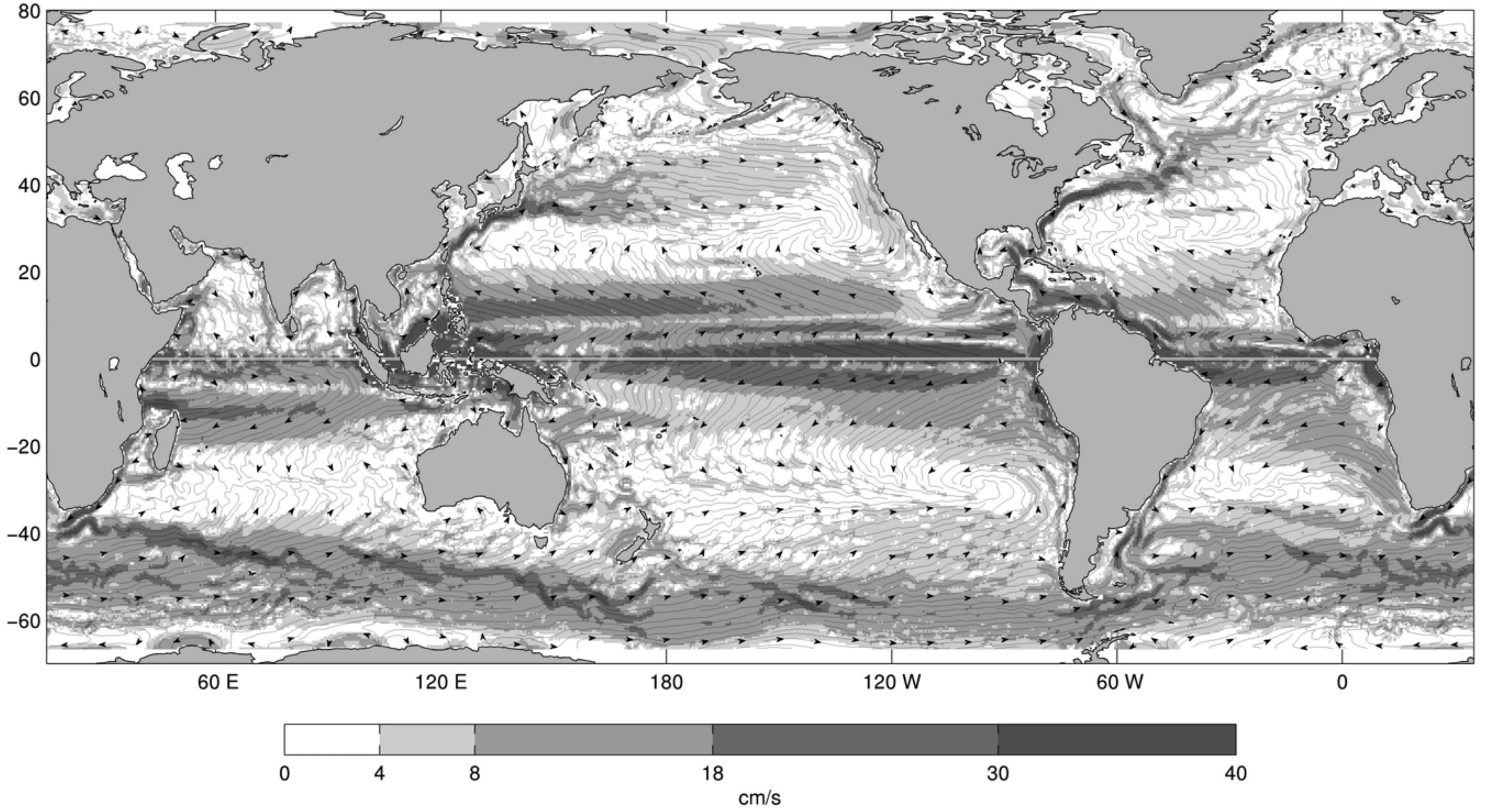

Figure 2. Streamlines and magnitude (gray colors) of the full 1992-2002 mean velocity at 15m depth.

Result of this computation on 0.5-degree grid is shown in Figure 1. Importantly, this mean sea level has a clear definition of the "mean" as a time average over the period of 1992-2002. While large-scale pattern shown in Fig.1 is in complete agreement with the JPL dataset, it contains much greater details of most of oceanic currents, such as quasi-stationary meanders and eddies, complex multi-jet structure of the Southern Ocean and remarkably clear signature of such relatively weak jets as the Azores Current.

We are now able to calculate mean circulation at 15m depth as a superposition of its two principal components: geostrophic and Ekman velocities. Figure 2 showing streamlines overlaid on the gray-colored magnitude of the full velocity agrees well with mean trajectories of the drifters collected in course of the Surface Velocity Program. Digital data of the mean sea level, geostrophic and Ekman velocities are available on request from the authors.

ACKNOWLEDGMENTS

This research was supported by NASA grant No.NNG04GH81G and by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) through its sponsorship of the International Pacific Research Center. The SVP drifter data are processed and distributed by the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML). Sharon Schneider corrected the error in the drifter data due to the down-wind slip and calculated NCEP wind vectors at drifter locations. The authors thank Victor Zlotnicky for providing them with the data of the JPL mean sea level based on GGM01. IPRC/SOEST contribution 338/6608.

REFERENCES

Archiving, Validation, and Interpretation of Satellite Oceanographic Data (Aviso). 1996. In *Aviso Handbook for Merged TOPEX/Poseidon products*, 3rd ed., Toulouse, France.

Lemoine et al., 1998. The development of the joint NASA GSFC and NIMA geopotential model EGM96, NASA TM-1998-206861.

Niiler, P. P., N. A. Maximenko, and J. C. McWilliams. 2003. Dynamically balanced absolute sea level of the global ocean derived from near-surface velocity observations, *Geophys. Res. Lett.*, 30(22), 2164, doi:10.1029/2003GL018628.

Ralph, E. A., and P. P. Niiler. 1999. Wind driven currents in the tropical Pacific, *J. Phys. Oceanogr.*, 29, 2121-2129.

Showstack, R. 2002. GRACE mission promises improved maps of Earth gravity, *Eos Trans. AGU*, 83(14), 158, doi:10.1029/2002EO000103.

Tapley, B. D., D. P. Chambers, S. Bettadpur, and J. C. Ries. 2003. Large scale ocean circulation from the GRACE GGM01 Geoid, *Geophys. Res. Lett*, 30(22), 2163, doi:10,1029/2003GL018622.