3.1 Temperature/salinity products

Argo floats record T/S at a relatively fine vertical resolution (typically 1-5 dbar in the upper ocean and coarser resolution at depth), from 2000 dbar to the sea surface. These measurements of T and S are then stored in a file for that particular float at that particular location and time. Thus, it is not straightforward to obtain, for example, T and S in a specific region (covered by several floats) or at a location over a specific time range. This project will help users by creating binned T/S data that is further interpolated onto a vertical and horizontal grid. Since some users prefer to do their own interpolation, we propose two different products: one gridded vertically at standard depths and the other gridded horizontally. In each case the data set will be in NetCDF format and will include, besides the data, latitude, longitude, time, depth of measurement, and a flag indicating the region (*e.g.,* marginal seas and subbasins will have a different ID). The dataset will be constructed so that future data can be concatenated onto the end (rather than users having to replace the entire file during every update).

Argo-derived *in situ* temperature will be used along with salinity to compute potential temperature and potential density. T/S/ρ will then be interpolated to standard depth levels (Levitus, 1982) for the first data product. This product is designed for modelers, who typically want a vertically gridded product to validate their model or use for assimilation. The second product will include an interpolation to a horizontal grid, nominally on a 1x1 degree grid. These products will be based on 10-day downloads of the profile and trajectory files from the US GDAC.

Additionally, derived quantities of mixed layer depth (MLD), based on a temperature criterion (Kara et al., 2000a) and barrier layer thickness (BLT) based on a density criterion (Kara et al. 2000b) will be produced from the above T/S/ρ data.

3.2 Absolute dynamic height and absolute geostrophic velocities

Dynamic height (DH) or geopotential height is defined as DH = $\int_{p1}^{p2} \delta(T,S,p)\cdot dp$, where

$\delta(T, S, p) = \alpha\ (T,S,p) - \alpha\ (0^0C, 35psu, p)$ is an anomaly of specific volume α. DH can be used as a streamfunction to determine the geostrophic velocity shear $\Delta\mathbf{V}$ at level p_1 relative to p_2 :
$\mathbf{f} \times \Delta\mathbf{V} = - g\nabla(DH)$, where **f** is an upward looking inertial frequency vector and g is the acceleration due to gravity. Traditionally, to obtain the estimate of absolute geostrophic velocity one uses the so-called dynamical method assuming a no-motion at the reference level p_2. Although the intensity of currents usually does decay with depth, the "no-motion level" does not exist in reality. Fortunately, an alternative approach is possible. DH can be interpreted as a quantity proportional to the pressure associated with the geostrophic current, and **the absolute dynamic height** (ADH) at level p can be defined as ADH = SSH - $\int_{0}^{p} \delta(T,S,p)\cdot dp$, where SSH is the sea surface height (aka dynamic ocean topography at the sea surface). At the sea surface ADH is equal to SSH. The latter is the deviation of the shape of the ocean surface from the Earth's geoid due to the ocean dynamics, and it was poorly known until recently. Maximenko and Niiler (2005) (see also, Niiler et al., 2003; Maximenko and Niiler, 2006) combined the data of Lagrangian near-surface drifters, satellite altimetry and wind to downscale the improved mean dynamic ocean topography (MDOT)

computed by V. Zlotnicky (NASA/JPL) based on the GRACE (Gravity Recovery And Climate Experiment mission) gravity model. Map of this MDOT is shown in Fig.3 and data can be obtained at `http://apdrc.soest.hawaii.edu/projects/DOT/` . Instantaneous SSH will be calculated by combining the MDOT with the sea level anomaly (SLA) data gridded and distributed in near-realtime and delay (improved) modes by the Aviso (CLS, France; Aviso, 1996). The SLA is on the 1/3-degree Mercator grid, and maps are computed weekly with the optimal interpolation technique described by Ducet et al. (2000). A simple procedure will be applied to convert the Aviso SLA into anomalies relative to 1992-2002, the period, for which MDOT of Maximenko and Niiler (2005) is defined. We will not use the absolute sea level distributed by Aviso along with anomalies, as it is based on Rio and Hernandez (2004) MDOT. The latter has been computed with statistical methods as a synthesis of different kinds of data, one of which was dynamic height from CTD profiles relative to 1000m. Therefore, Rio and Hernandez MDOT is based on an implicit assumption of "no-motion level" and is not appropriate for our study of the ocean structure at intermediate depths.

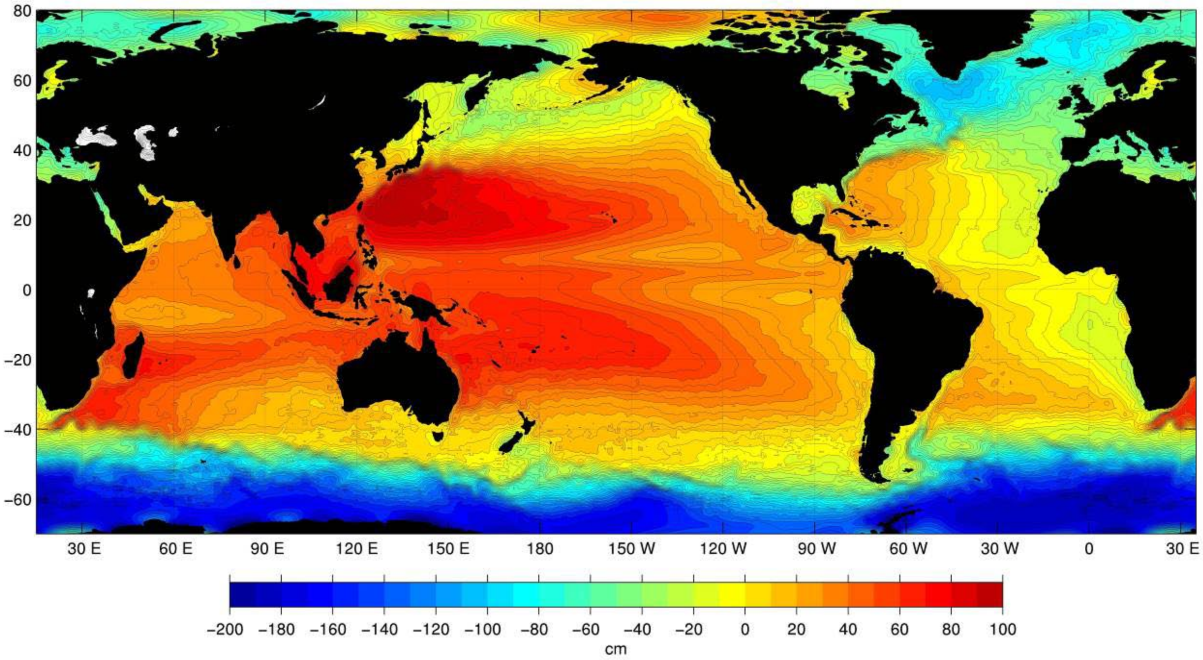

Figure 3. 1992-2002 mean dynamic ocean topography of Maximenko and Niiler (2005) available at `http://apdrc.soest.hawaii.edu/projects/DOT/` . Also included in the National Geographic Atlas of the World, 8th Ed.

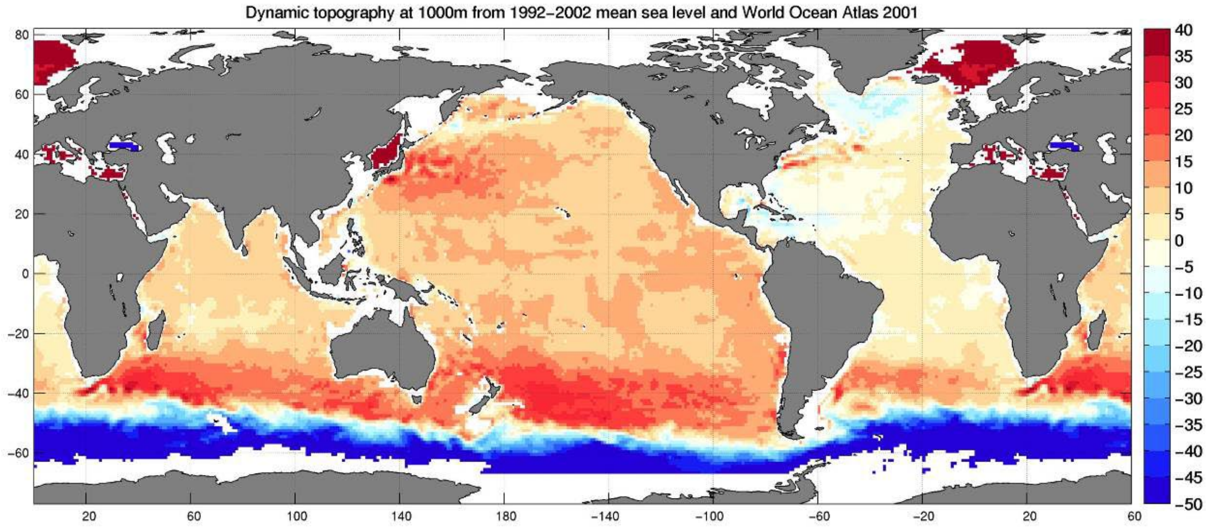

Figure 4. Absolute mean dynamic height at 1000m calculated from the MDOT in Fig. 3 and World Ocean Atlas 2001. Units are dyn.cm.

Fig. 4 shows the mean absolute dynamic height at 1000m depth calculated from the World Ocean Atlas 2001 (WOA) by referencing it to MDOT of Maximenko and Niiler (2005). It can be viewed as a streamfunction of geostrophic circulation at this depth, whose map reveals a system of relatively large-scale mid-latitude gyres and deep-penetrating jets, such as the Gulf Stream, Kuroshio, and Antarctic Circumpolar Current with the associated signal of many tens of dynamic centimeters. This map contains large uncertainties on the large scale due to the vague definition of the "mean" in WOA and on the mesoscale due to the poor spatial resolution of WOA. Both uncertainties will be significantly reduced in the proposed project.

While vertical excursions of Argo floats are preprogrammed, their horizontal displacements are completely due to ocean currents. The latter are known to be remarkably geostrophic away from lateral, bottom and surface boundaries. This allows us to convert the deep (parking level) velocities estimated with the technique described by Yoshinari et al. (2006) into estimates of horizontal gradient vector of ADH and to use them as extra observations. In fact, addition of these two components at every cycle of the float virtually triples the amount of effective observations of the ADH at the parking depth, and will allow us to increase special resolution from 2-3 to 1-1½ degrees. To extrapolate values of ∇(ADH) vertically we will use a simple model of vertical structure.

Yu et al. (2006) showed that much of vertical structure of low-frequency variability in an advanced OGCM is successfully described by the local first baroclinic mode. Chen et al. (2007) showed using Argo profiles and trajectories in the Kuroshio Extension that as much as "86% of the total variance resides in the first baroclinic mode and 6% in the second baroclinic mode". Many studies combining altimetry with profiles (*e.g.,* Roemmich and Gilson, 2001; Willis et al., 2003; Willis, 2004) have also found that the two datasets greatly compliment each other and reveal deep signal remarkably coherent with its expression at the surface. As deep Argo velocities are measured not at the locations of profiles but between them, to assess the structure of vertically coherent modes in the vicinity of every grid point we will select a cluster of the nearest profiles. The differences between the profiles (at least three profiles are needed) will then be used to calculate the vertical structure of the two-dimensional vector of ∇(ADH). Thus defined, ∇(ADH) corresponds to relatively large horizontal scale, while values of ∇(ADH) derived from the Argo velocities at the parking level correspond to smaller scale. We will assume that vertical structure is universal throughout both scales and will do a vertical expansion of ∇(ADH) “observed” at the parking depth by adjusting (rotating and scaling) the vertical profile obtained on the previous step. Misfit between thus-deduced ∇(ADH) at the sea surface and ∇(SSH) will be used to estimate maximum error.

For every 10-day period the ADH will be interpolated three-dimentionally with the variational method described in one the following sections. Gridded ADH will then be used to calculate absolute geostrophic velocities at latitudes higher than 3^0.

3.3 Other products

In addition to the gridded and vertically interpolated products described in the previous sections we will release

- *in situ* velocity data at the sea surface and at the parking depth calculated from the float trajectories on every cycle;
- profiles used for vertical extrapolation of ∇(ADH).

The full set of the products will be sufficient for the advanced user to be able to reproduce our results or to help develop alternative techniques of data analysis and gridding.

Also, we will calculate and publish new gridded climatological datasets and assessments of the seasonal cycle and interannual changes based of the short period of the Argo observations. These climatologies will be compared with the results of other scientists, *e.g.*, Willis (2006).

3.4 Near-realtime data updates and distribution

As a result of this project a (quasi-)automated system will be developed at the APDRC/IPRC that will allow 10-daily, near-realtime updates of all products at minimal cost to institutional funds. All the products will be freely available on the APDRC servers. Bugs in the original data, detected during this project and/or reported by the users of our products, will be documented and forwarded to the specific DACs hosting the problematic data. Climatologies and past data will be recomputed when/if the original data are significantly improved by DACs. Periodic updates will also be done as the “delayed” Argo (*i.e.*, more thoroughly quality-controlled) data become available.

4. Mapping technique

A variational analysis technique will be used to interpolate temperature, salinity and absolute dynamic topography onto a three-dimensional spatial grid. The cost function

$$J = W_1 \cdot J_1 + W_2 \cdot J_2 + W_3 \cdot J_3 + W_4 \cdot J_4$$

will include members penalizing in the three-dimensional space domain the following deviations:

J_1: Deviation of the gridded T/S/ADH from the corresponding collocated profile data.

J_2: Deviation of gradient of the gridded ADH from the gradient value assessed from collocated data. The latter values at the parking level will be deduced from the float velocities through geostrophic equations and extrapolated in vertical as described in Section 3.2.

J_3: Deviation of tilts of the isotherm and isohaline from the tilt of the isopycnal (*i.e.*, variations of water properties on the isopycnal will be discouraged). Compressibility of the sea water will be taken into account.

J_4: Non-smoothness as characterized by the harmonic or biharmonic operator.

The solution minimizing the costfunction J is controlled by relative values of the weights W_i , not by the weights themselves. It can be shown that J_1 is more significant at large scale and J_2 is more significant at small scale. The ratio W_1/W_2 sets the threshold scale, on which both terms are equally significant. The threshold will be set equal to 2-3 degrees latitude/longitude. W_3 will be large for T and S and equal to zero for ADH. W_4 will be set small enough to only suppress the noise on the grid scale.

The calculations will start with the analysis of the local vertical structure of ∇(ADH) and errors of the simple vertical model. The model will be used to extrapolate the gradient of ADH vertically, and the errors will be accounted while defining the weights W_2.

Next, gridded ADH will be computed by minimizing the costfunction J. Temperature and salinity will be interpolated using the dynamical information of the shape of isopycnals assessed from the gridded ADH and locally linearized equation of state of seawater. Absolute geostrophic velocities will be derived from ADH by differentiating in the horizontal direction.

As a separate task, MLD and BLT will be interpolated horizontally with the cost function consisting only of terms J_1 and J_4.

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