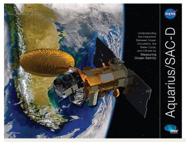

Session: C14
Poster: T22B

Salinity and Water Cycle; Air-sea freshwater balance

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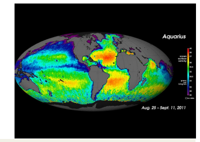

Abstract

More than three-fourths of the global water cycle consists of the annual rainfall and evaporation freshwater exchange between the ocean and atmosphere. The water cycle is expected to intensify in a warmer climate, with shifting large-scale rainfall and drought patterns. Ocean salinity variations in recent decades provide a clear indicator of such changes and offer a key index for monitoring future climate variability related to the hydrologic cycle. In this sense, the ocean behaves like a rain gauge. This simple idea will also contribute to resolving the major discrepancies among rainfall climatologies. Addressing these problems requires a full understanding of complex upper ocean processes such as mixing and advection that balance the net freshwater flux at the surface. In this paper, we explore the current understanding of the upper ocean and atmospheric freshwater budgets, and the gaps between them. The global surface salinity measurement system, including both in situ instruments and satellites, along with regional upper ocean process studies, will advance these studies. Lastly, we offer a preliminary budget calculation using the new Aquarius/SAC-D satellite salinity data (**See also Poster T23A**).

Salinity as the ocean indicator of trends in the global water cycle

A key climate question for society is whether the water cycle is presently changing. The exponential dependence of the vapor pressure of water on temperature suggests that a one degree C increase in mean surface temperature could result in a 7% increase in the vapor carrying capacity of the atmosphere (Schmitt, 2008). There may be compensating effects in the atmosphere to mitigate such a strong response but the size of any response is of intense interest. Oceanographic data on salinity provides a very distinct message on trends in the water cycle. A variety of studies dating back many years has documented variability and trends in surface salinity, (Brewer et al, 1983; Curry et al, 2003; Freeland et al, 1997; Boyer et al, 2005; Gordon and Giulivi, 2008) with the overall result coming down firmly in support of a strengthening of the water cycle. The most recent and complete summary of this intensification is by Durack and Wijffels (2010). They quantify the fifty-year trends in global surface salinity and show a salinification of the subtropical gyres, and freshening of tropical and high latitude rainfall regions and a growing contrast between an increasingly salty Atlantic and an increasingly fresh Pacific. This salinity contrast is the prime reason that the Atlantic supports a meridional overturning circulation (MOC) and the Pacific does not, or more succinctly, the lower surface salinity of the North Pacific, due to high precipitation rates, inhibits deep convection in the Pacific (Warren, 1983; Emile-Geay, et al, 2003). The observed increasing salt contrasts serve as the best indication yet of an intensifying water cycle. This is to be expected, since the water cycle is predominantly an ocean-atmosphere phenomenon, and the terrestrial portion is small by comparison (Schmitt, 1995).

Using the ocean as a rain gage; a trial balance of surface fluxes

Using the ocean to trace climatologic changes in the global water cycle requires a significant reduction of the present uncertainties in both the atmospheric and oceanic limbs of the marine freshwater (Lagerloef et al, 2010). This begins with a simplified salt budget equation for the surface mixed layer is given by Eq (1). This analysis covers years 2005-2008 using global satellite evaporation (E) and Precipitation (P) fields and ocean data from Argo ocean buoy data to extract the surface salinity S and the mixed layer depth H. For the surface velocity fields, we used the satellite-based OSCAR data derived from sea surface height and vector wind data with linear geostrophic and Ekman dynamics (Dohan and Maximenko, 2010). P and E fields are respectively from the GPCP and OAFlux data sets Yu and Weller (2007), and, for comparison, the separate satellite based Passive Microwave Water Cycle (PMWC) dataset (Hilburn, 2009).

$$\frac{\partial S}{\partial t} + \vec{U} \bullet \nabla S = \frac{S(E-P)}{H} + mixing\ processes \qquad (1)$$

Figure 1

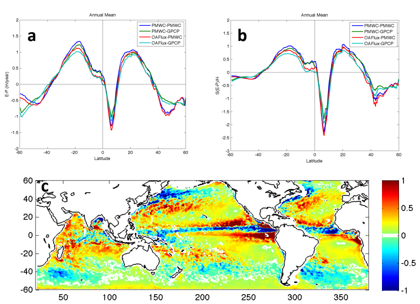

Figure 2

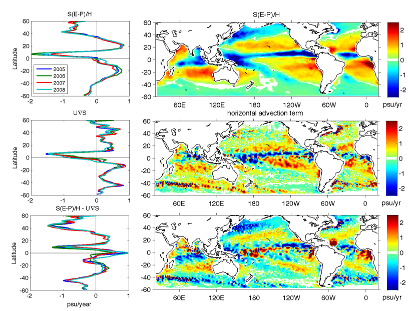

Figure 3

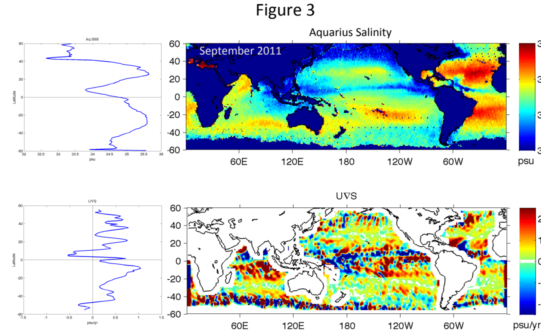

Figure 1a illustrates the uncertainty range of the the zonal averaged E-P using the four combinations in the GPCP (P only), OAFlux (E only) and PMWC (P & E) data sets. Figure 1b is S(E-P)/H; the corresponding salinity tendency term in Eq. (1). Although the spread among the S(E-P)/H estimates appears to be much less than the scale of the meridional variations, the zonal averages obscure most of the detail. The difference map of S(E-P)/H from PMWC minus that from the OAFlux-GPCP combination (Figure 4c) reveals considerable spatial structure to the bias between the respective flux fields, particularly in the eastern tropical Pacific and tropical Atlantic, where it exceeds 1 psu/year equivalent. This is several orders of magnitude larger than the salinity climate trends noted above, indicating that the ocean is a potential gage to reduce the uncertainty of E-P estimates. The job is not so easy however. The remaining terms in (1), which are all oceanographic, must be resolved to much better accuracy to identify the errors among the various atmospheric E-P analyses. Major enhancements in the global salinity observing system may now make this possible.

To illustrate, we explore the trial balance between the middle two terms of (1): Horizontal advection and air-sea freshwater flux. Figure 2 (top) shows the 4-year average (2005-2008) S(E-P)/H map and the zonal average for each year using GPCP (P) and OAFlux (E). The interannual variability, especially in the tropics, is comparable to the variations among the different E-P analyses in the previous figure. The surface horizontal divergence term (Figure 2, middle) bears many large scale similarities to the net E-P map in the tropics, and zonal averages of the two terms have similar magnitude. Generally, the evaporation-dominated regions are partially compensated by salinity divergence (or equivalently freshwater convergence), while the narrow tropical rain-dominated band is largely compensated by salinity convergence (freshwater divergence). In the higher latitude zones, however, the picture appears quite different; the surface layer salinity divergence remains >0 at all latitudes (zonal average) outside of the tropics, and does not appear to compensate for the net precipitation.

The difference calculation, (Figure 2, bottom) accounts for unknown bias errors in these two terms, the four-year salinity trend (relatively small and not shown) and the unknown mixing process. We interpret much of the difference pattern to represent the mixing processes, and note particularly that the magnitude is about the same as the other two terms. This term is strongly negative poleward of 30° latitude in both hemispheres. In these regions, mixing processes evidently must offset both excess precipitation and horizontal salinity divergence. The zonal average differences in the tropics result because the two terms are slightly offset in latitude, and where vertical processes must also play a role as part of the complex tropical circulation and overturning cells.

Satellite salinity data are now becoming available with much higher spatio/temporal resolution than resolved by Argo and other in situ salinity measurements. Aquarius has been operating for two months and still requires considerable calibration and validation. Figure 3a is a recently derived September 2011 mean Aquarius salinity map (courtesy F.Wentz and the Aquarius algorithm team). Figure 3b is the salt divergence term as in Fig. 2b showing similar structure large scal patter, though many smaller scale differences. As the calibratin and validation of Aquarius data improves with time, it will be possible to document the salinity, salt advection and E-P co-variability. The key oceanographic challenge will be resolving the ocean mixing processes to gain closure of Eq.(1).

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