Linking Ocean Water Balance to Land Rainfall and Climate Change

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We have produced two sets of ocean surface water flux from satellite data.

The equation of water balance in the atmospheric column is (1)

where

$$\frac{\partial W}{\partial t}+\nabla\cdot\mathbf{\Theta}=E-P=F \quad (2)$$

and (3)

$$\Theta=\int_0^{p_s} q\mathbf{u}dp$$

$$W=\frac{1}{g}\int_0^{p_s} qdp$$

is the precipitable water. In these equations, p is the pressure, p_s is the pressure at the surface, q and u are the specific humidity and wind vector at a certain level. Bold symbols represent vector quantities. F is the fresh water exchange between the ocean and the atmosphere and is the difference between E and P at the surface.

When averaging longer than synoptic time scales, the change of water storage (the first term in Eq. 1) is small and negligible. The divergence of Θ (the water transported out from the column to the surrounding atmosphere) should be equal to F. We have developed and validated method to estimate E from the radiance of microwave radiometers and also Θ from spacebased measurements of W, the surface wind vector, and the cloud drift wind (Xie et al. 2008).

Based on these data sets of PMM data, we propose to investigate the following:

1. Amplification of water cycle

Negative trend in a very narrow band of the intertropical convergence zone (ITCZ) (Fig. 1b) and positive trends in the Southern Hemisphere subtropical gyre (Fig. 1c) could be discerned (meeting 95% significance test) in the Pacific from $\nabla\cdot\Theta$. The weaker trend (failing significance test) in Northern Hemisphere subtropical gyre is harder to discern (Fig. 1a). The intensification of the southern Hadley Cell in the Pacific is more pronounced than the northern one. The precipitation data given by the Tropical Rainfall Measuring Mission (TRMM) in the Pacific ITCZ and warm pool show slight increasing trends at significance level just below 95% in Fig. 2.

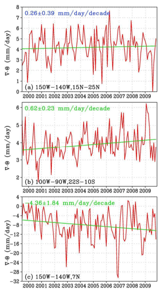

Fig. 1 Time series of $\nabla\cdot\Theta$ averaged over (a) 150ºW-140ºW, 15ºN-25ºN, (b) 100ºW-90ºW, 22ºS-10ºS, and (c) 150ºW-140ºW, 7ºN. Linear slope (green line) and standard error of the slope are marked at the top, with green color above and blue color below the 95% confidence level.

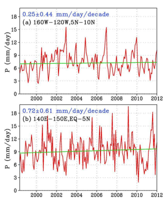

Fig. 2 Same as Fig. 1, except for time series of precipitation from TRMM 3B42 averaged over (a) 160ºW-120ºW, 5ºN-10ºN, and (b) 140ºE-150ºE, EQ-5ºN.

2. Ocean's role in continental water balance

2a Water balance over South America

Liu et al. (2006) first demonstrated the continental water balance in South America (Fig. 3b). With climatological river discharge (∫R) removed from ∫Θ across the entire continental coastline, the residue agrees, both in phase and in magnitude, with monthly rate of mass change (∬∂M/∂t). The standard deviation of the difference between ∬∂M/∂t and moisture flux-river discharge is 0.9 10^8kg/s 7% of the peak to peak variation.

On monthly time scale, the first term in Eq. (1) is small. ∫Θ should balance ∫ ∫P-E, as shown in Fig. 3. E is evapotranspiration derived by Fisher et al. (2008).

2b Interannual variations

Fig 4 shows that the interannual variations of P-E over South America are dominated by precipitation, with good agreement of the moisture flux from ocean.

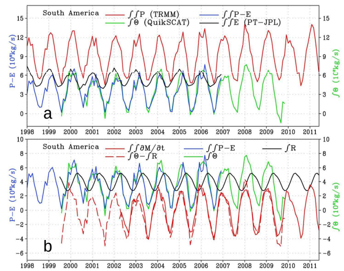

Fig. 3 Monthly time series of hydrologic parameters over South America: (a) precipitation ∬P (red), total moisture transport across coastline into the continent ∫Θ (green), evapotranspiration ∬E (black), and ∬P-E (blue), and (b) mass change rate ∬∂M/∂t (solid red line), climatological river discharge ∫R (black line), ∫Θ (green line), ∫Θ-∫R (dashed red line), ∬P-E (blue line).

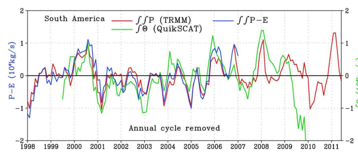

Fig. 4 Time series of P (red) and P-E (blue) integrated over South America, and integrated Θ along all coastal lines of South America (green); annual cycle was removed.

3. Ocean surface salinity budget

The equation for upper ocean salinity balance is

$$E-P=\frac{h_0}{S_0}\left(\frac{\partial S}{\partial t}+V\cdot\nabla S\right) \quad (4)$$

where V is current, S is salinity in the surface mixed layer with average depth h_0 and average salinity S_0. V is provided by the Ocean Surface Currents Analyses - Realtime (OSCAR) program. The salinity data are measured by Aquarius and Argo. E is derived from the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E, Liu and Xie 2012), and P is measured by TRMM.

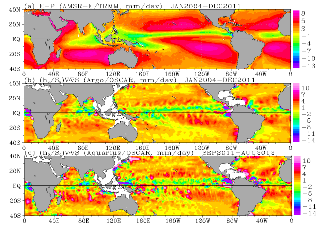

Fig. 5 (a) E-P, (b) salinity advection derived from Argo, averaged from 2004 to 2011, and (c) advection derived from Aquarius data, averaged from September 2011 to August 2012. ∂S/∂t is negligible in the long term averages. There should be a balance between E-P and advection.

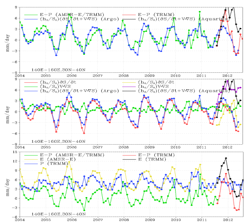

Fig. 6 Time series of each term in Equ. (1) over the Kuroshio Extension (KE, 140ºE-160ºE, 30ºN-40ºN). The last 12 months of Aquarius data are also displayed. The local change of salinity dominates over the advection. Evaporation plays a major role in the seasonal change of salinity.

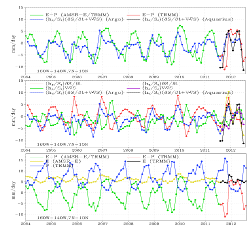

Fig. 7 Same as Fig. 6, except over the Pacific ITCZ. Different from KE, E-P over the ITCZ is dominated by precipitation and the advection is as important as the local change term. The location of salinity minimum is shifted from the maximum rainfall (not shown).

The advection calculated from Aquarius data is higher than that from Argo in the Kuroshio Extension, but there is an agreement over the ITCZ.

4. References

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