Ocean Influence on Terrestrial Water Balance

W. Timothy Liu and Xiaosu Xie

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, w.t.liu@jpl.nasa.gov

With the short resident time of water in the atmosphere, the excess of evaporation over precipitation from the ocean is transported through the atmosphere and deposits as excess of precipitation over evaporation on land and returns to the ocean through river discharge. We have characterized such linkage using space observation through integrated moisture transport derived from spacebased measurements.

1 Integrated Moisture Transport

The integrated moisture transport is

$$\Theta = \int_0^{p_s} q\mathbf{u}dp \quad (1) \qquad W = \frac{1}{g}\int_0^{p_s} qdp \quad (2)$$

where p_s is the surface pressure, q and u are the specific humidity and wind vector at a certain level.

- **Θ can be viewed as the column of water vapor W advected by an effective velocity ue, so that ue= Θ /W, where ue is the depth-averaged wind velocity weighted by humidity and is related to winds at the surface and above the boundary layer.**
- **Statistical models have been developed and estimate Θ, using cloud drift winds at 850 mb, scatterometer vector winds at the surface, and W from microwave radiometers.**
- **Xie et al. (2008) showed that Θ derived from their statistical model agree with Θ derived from 90 rawinsonde stations from synoptic to seasonal timescales and from equatorial to polar oceans.**
- **Hilburn (2010) found very good agreement between this data set and data computed from Modern Era Retrospective-analysis for Research and Applications (MERRA) over the global ocean.**
- **The Θ data were further validated through mass balance of oceans and continents, using the Gravity Recovery and Climate Experiment (GRACE) to monitor the water storage change ∂M/∂t and climatological river discharge, R, (Dai and Trenbeth 2002), as shown from Liu and Xie (2014).**
- **Data starting from July 1999 at 0.5 degree and daily resolution have been produced.**

2. Water Balance over South American continent

With climatological river discharge R from the whole continent removed from Θ integrated across the entire continental coastline, the residue agrees, both in phase and in magnitude, with area sum of mass change ∂M/∂t (Liu et al. 2006).

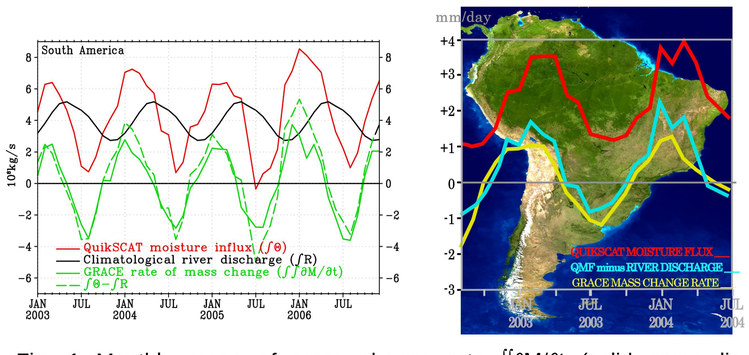

Fig. 1 Monthly mean of mass change rate ∫∫∂M/∂t (solid green line), climatological river discharge ∫R (solid black line), total moisture transport across coastline into the continent ∫Θ (red line), and ∫Θ-∫R (dashed green line) over South America.

3 Sahel

The integrated moisture transport enables us to combine the effect of onshore flow at the surface and offshore transport aloft. The results demonstrate the depth-integrated moisture advection across the west coast from the Atlantic ocean is in-phase with the annual and inter-annual variation of Sahel rainfall, but is two months out-of-phase with rainfall in the southern region around the Gulf of Guinea (Liu et al. 2012).

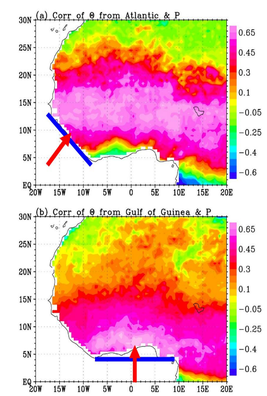

Fig. 2 The temporal correlation coefficient between precipitation measured by TRMM and the on-shore components (normal to simplified coast line shown) of Θ from (a) the Atlantic and (b) the Gulf of Guinea.

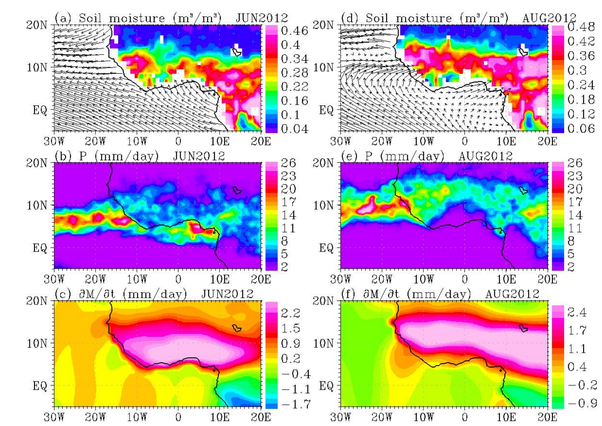

Fig. 3 Maps of (a) soil moisture from Aquarius and Θ, (b) rain, and (c) ∂M/∂t for June 2012. (d)-(f) are the same as (a)-(c), except for August 2012.

In June, moisture from the Gulf of Guinea causes increase of rainfall and water storage in the south. In August, moisture from Atlantic increases precipitation and water storage in Sahel.

4 India Subcontinent

We show that the difference between integrated moisture transported in from the Arabian Sea and out to the Bay of Bengal is largely deposited as rain over land during the summer monsoon. We explained that the extreme hot and dry weeks in Central India before summer monsoon onset that cause human life and economic hardships occur when moisture is drawn out to the Bay of Bengal before they can be replenished from the Arabian Sea.

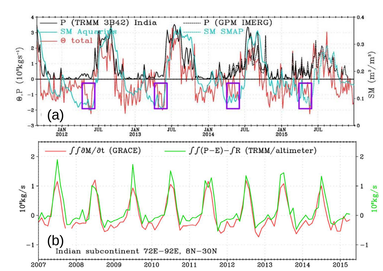

Fig. 4 (a) Time series of spatially integrated precipitation (black) and averaged soil moisture (cyan), over land bounded by 72ºE-85ºE and 10ºN-30ºN, and net moisture transport Θ (red) from ocean to land integrated along coastline. (b) Time series of integrated mass change rate, ∫∫∂M/∂t, from GRACE (red) and ∫∫P-E - ∫R (green), derived from TRMM and altimeter data.

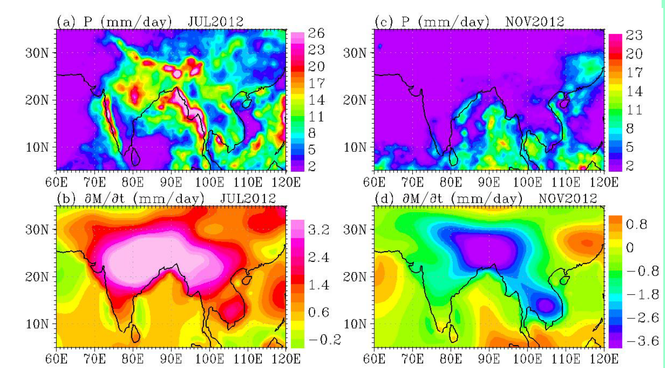

Fig. 5 Maps of (a) rain, and (b) ∂M/∂t for July 2012. (c)-(d) are the same as (a)-(b), except for November 2012. **Water storage increases in July due to monsoon rainfall and increase of river discharge reduces water storage in November.**

Reference

Dai, A., and K. E. Trenberth, 2002: Estimates of freshwater discharge from continents: Latitudinal and seasonal variations. J. Hydrometeorol., 3, 660-687.

Hilburn, Kyle A., 2010, Intercomparison of water vapor transport datasets, presented at 17th Conference on Satellite Meteorology and Oceanography and 17th Conference on Air-Sea Interaction, Annapolis, MD.

Liu, W. T., X. Xie, W. Tang, and V. Zlotnicki, 2006: Spacebased observations of oceanic influence on the annual variation of South American water balance. Geophys. Res. Lett., 33, L08710, doi:10.1029/2006GL025683.

Liu, W. T., X. Xie, and K. B. Katsaros, 2012: Observtion of oceanic origin of Sahel precipitation from space, Remote Sensing of Environment, 123, 593-599

Liu, W.T. and X. Xie, 2014: Ocean-atmosphere water flux and evaporation, Encyclopedia of Remote Sensing. E. Njoku (ed.), Springer-Verlag Berlin Heidelberg, 480-489. DOI: 10.1007/SpringerReference_327186.

Liu, W.T., and Xie, 2017: Premonsoon Drought in India Observed from Space. J. Hydrometeor., 18, 683-692. DOI: 10.1175/JHM-D-16-0014.1

Xie X., W.T. Liu, and B. Tang, 2008: Spacebased estimation of moisture transport in marine atmosphere using support vector machine, Rem. Sens. Environment, doi:10.1016/j.rse.2007.09.003.