Detecting the influence of ocean process on the moisture supply for India summer monsoon from Satellite Sea Surface Salinity

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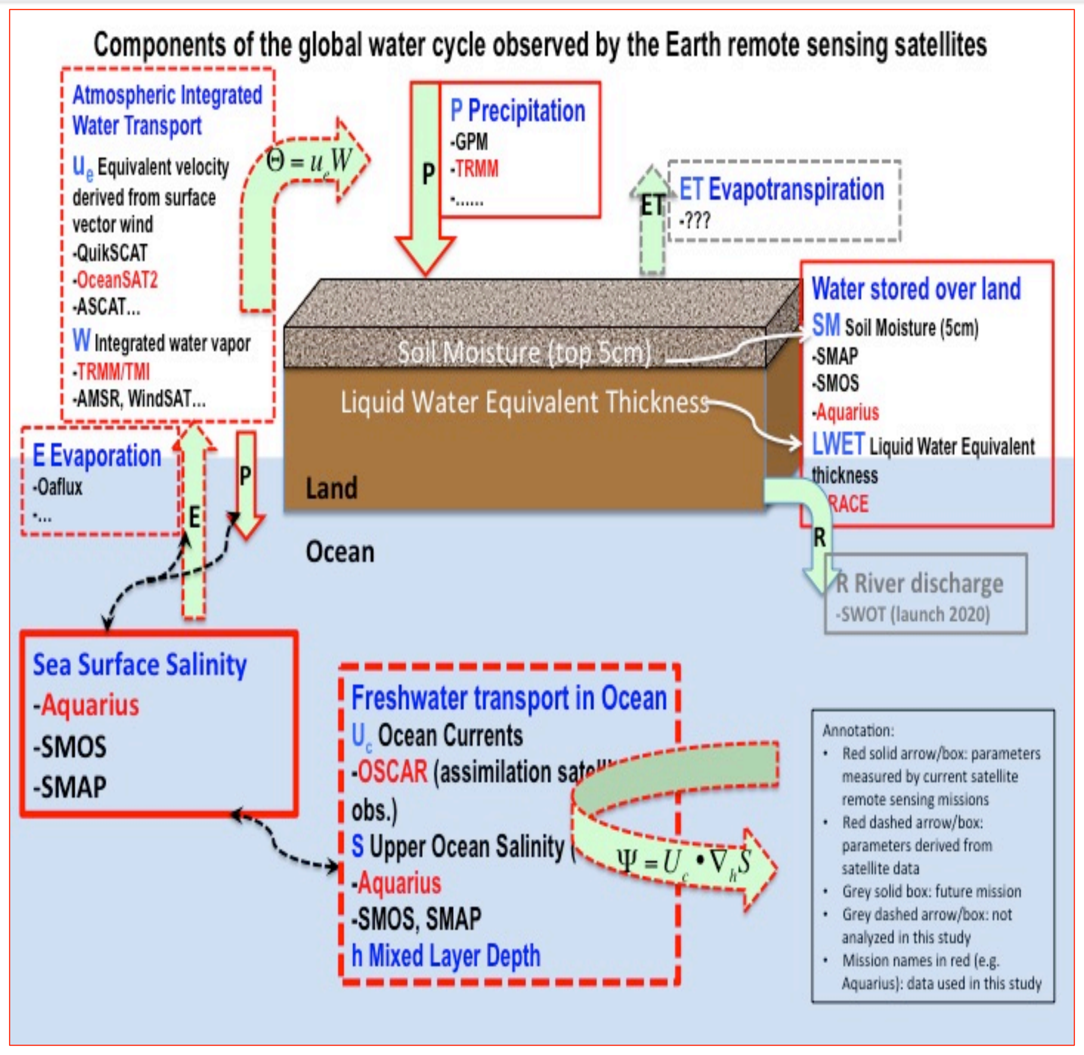
Introduction

- Freshwater exchanges at the air-sea interface fuel the global water cycle, which may be summarized as the evaporation of moisture at one place and precipitation either locally (recycled) or elsewhere, connected by the terrestrial, atmospheric and oceanic transport of water.
- The freshwater flux (F) over ocean, defined as evaporation minus precipitation, F_{E-P}, is the variable most unsatisfactorily observed, even in the current age of Earth remote sensing with multiple satellites missions devoted to observe the global water cycle.
- The spatial and temporal coverage of satellite Sea Surface Salinity (SSS) data products provide unprecedented opportunity for deriving an alternative F from ocean observations, named F_{ocean}, following the "ocean rain gauge" idea previously proposed.
- We present a case study of detecting the oceanic influence on the moisture supply for Indian summer monsoon. Using the contrast of 2012/2013 Indian summer monsoons observed over land as a reference, we identify the consistency or inconsistency of the moisture supply derived from F_{ocean} or F_{E-P} respectively.

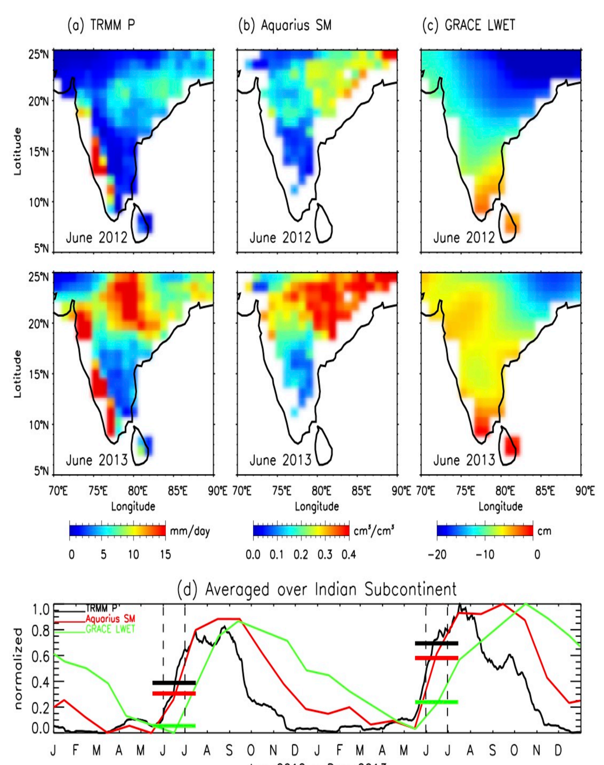


Based on the governing equation of the salt budget in the mixed layer (ML), we define the alternative E-P from the oceanic branch of the water cycle as,

$$F_{ocean} = \frac{h}{S}\left(\frac{\partial S}{\partial t} + \vec{U_c} \cdot \nabla_h S\right) + \delta$$

We will use Aquarius SSS and OSCAR currents to represent ML S and Uc, and the ML depth h derived from Argo profile. δ represents contributions from the subsurface processes, e.g. entrainment, which is small due to weak salinity gradient near ML base through year and cannot be quantified by satellite measurements (not included here).

Observed Contrast in 2012/2013 Monsoon Onsets



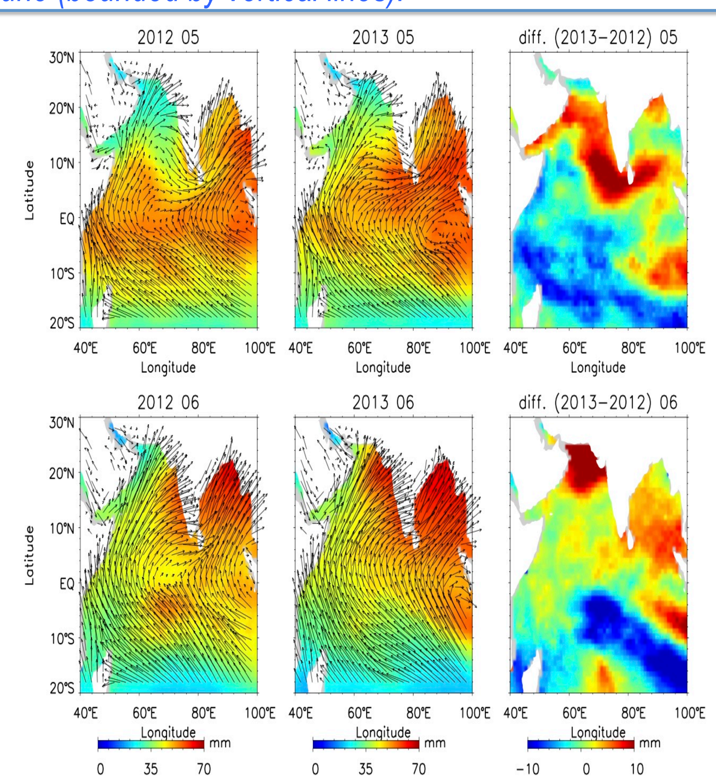
Dramatic contrast between 2012/2013 summer monsoon onsets were observed over Indian subcontinent (IS) by three satellites

- **Surface rain rate (TRMM)** The majority area of Indian subcontinent received rainfall over 10 mm/day in June 2013; **~232 km³ extra** water than June 2012.
- **Soil moisture (Aquarius)** Wet soil covered a much larger area in June 2013 with spatial distribution similar as that of rain.
- **Water storage changes (GRACE)** Although LWET (liquid water equivalent thickness) for both June of 2012 and 2013 show a decrease in water storage relative to the long time mean (negative),there was **~120 km³** more water retained in June 2013.

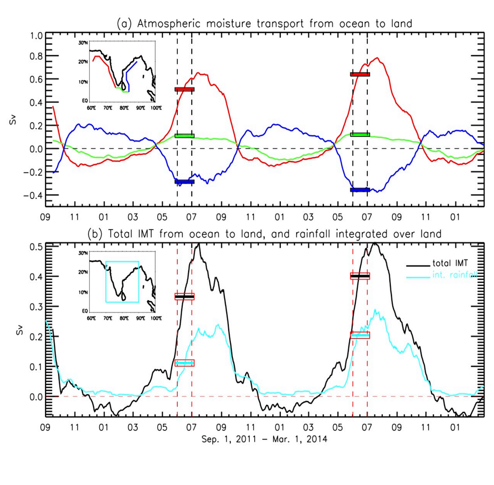
(left) (a) TRMM rain rate (P), (b) Aquarius soil moisture (SM), (c) GRACE liquid water equivalent thickness (LWET), averaged for June 2012 and 2013, respectively, and (d) the time series of normalized P, SM and EWT averaged over land in India subcontinent (70-90°E, 9-25°N). The short horizontal bars in (d) indicate the mean values of June (bounded by vertical lines).

Moisture supply surrounding Indian subcontinent

- **Surface wind (OceanSAT2)** There is no significant difference in the atmospheric circulations, as seen in the vector wind fields
- **Integrated water vapor (TRMM)** In the pre-monsoon period of 2013 the areas of positive W anomaly surrounded IS particularly from west and south along the path of monsoon moisture supply
- **Atmospheric moisture transport (OceanSAT2, TRMM)** There are **~334 km³** more water was imported through the west coast in June 2013.

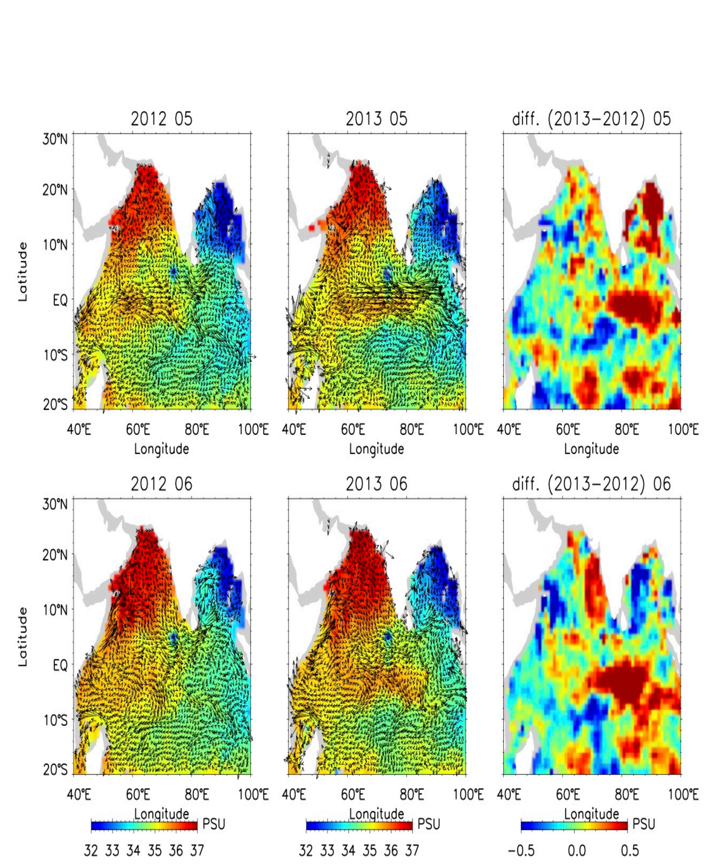


Surface wind (arrows) and integrated water vapor (color).

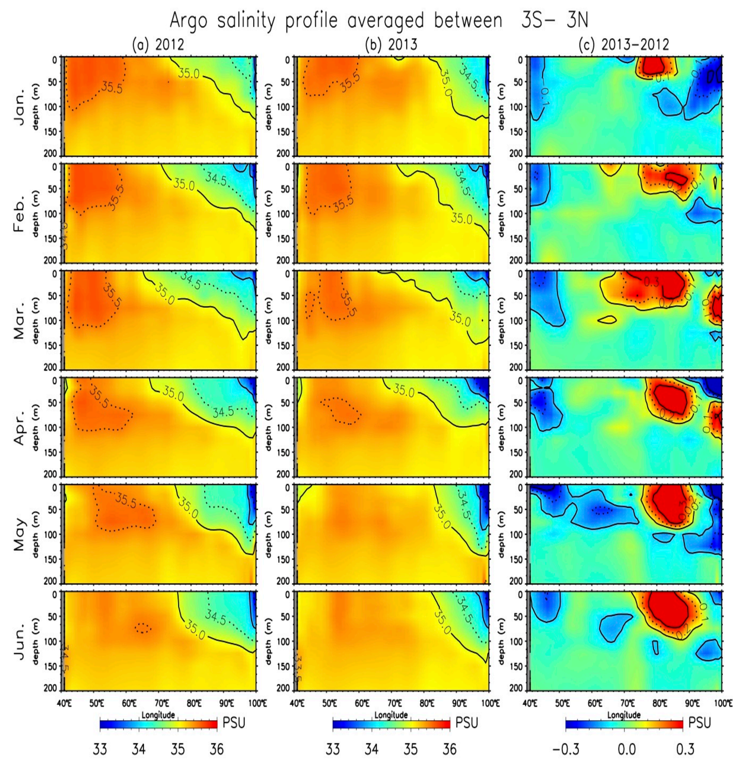


(a) Time series of the Atmospheric Integrated Moisture Transport (IMT) from ocean to land integrated along India coasts from west (red), south (green) and east (blue).
(b) Total IMT and rainfall over IS.

SSS anomaly and Ocean Process



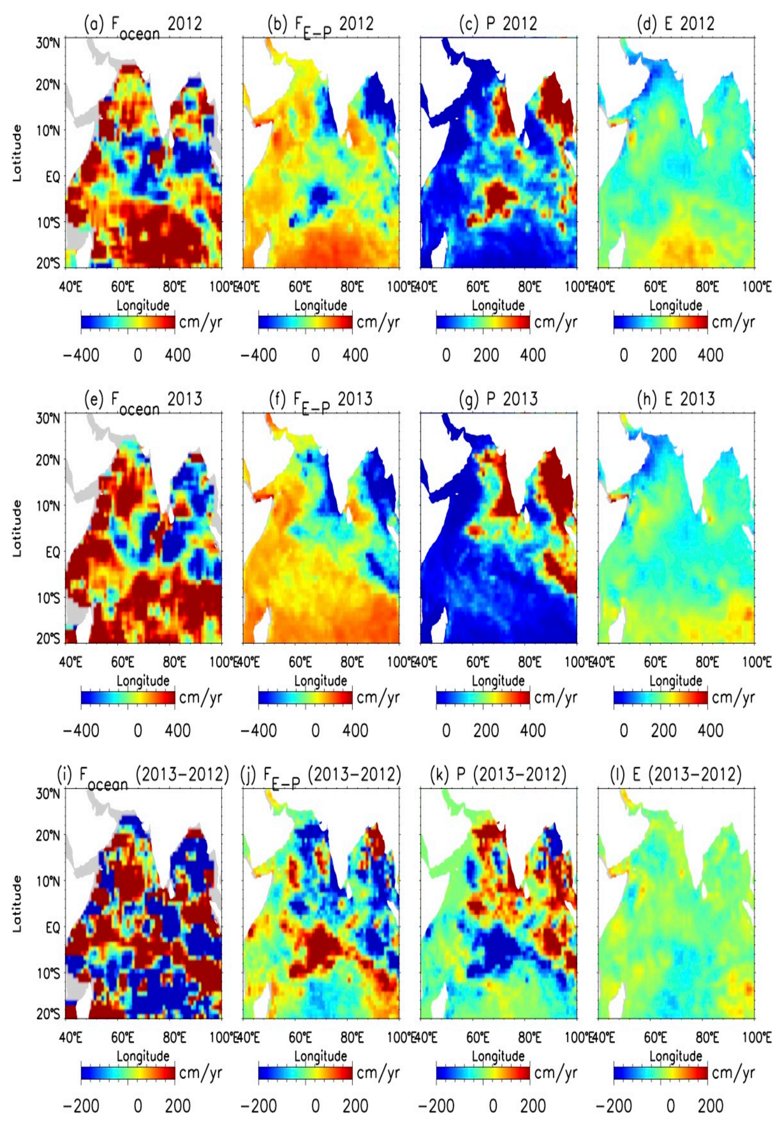
OSCAR currents(arrows) and Aquarius SSS (color).



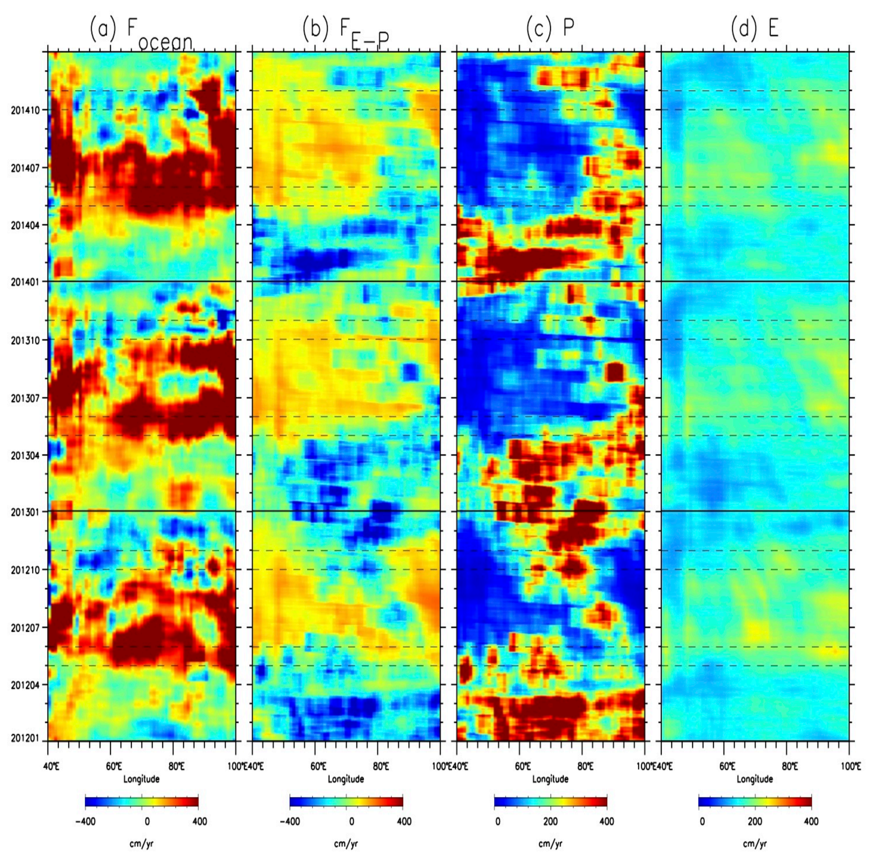
Vertical section of Argo salinity profile from surface to 200 m depth, averaged in the Indian Ocean between 3°S-3°N for each month (January to June) of (a) 2012, (b) 2013, and (c) the difference.

- Eastward equatorial "Wyrtki" **current (OSCAR)** is much strong in 2013, carries the relative saltier water far east to beyond 80°E.
- This left a significantly different footprint in **SSS (Aquarius)** between 2012 and 2013 in the equatorial IO, as well in the upper ocean salinity horizontal and temporal gradients.
- Argo salinity profiles confirmed the salinity anomaly extended down to 100m from surface

Freshwater Fluxes



The monthly average of Focean, FE-P, P and E for June 2012/2013 and the respective difference.



Longitude/time variance, averaged in the band centered at 10°S (+/- 2 degrees) for (a) F_{ocean}; (b) F_{E-P}; (c) P; (d) E.

- The mean pattern of F_{E-P} and F_{ocean} between 40°S and 40°N averaged over three years show similar large scale features.
- The freshwater exchanges integrated over the Arabian Sea area showed the difference between the two Junes derived from F_{ocean} is **444 km³**, consistent with the land reference; while that derived from F_{E-P} are **-235 km³** and **-119 km³** using P^{TRMM} or P^{GPCP}, respectively, failed to provide the extra moisture needed in 2013 season.
- The time/longitude variation along 10°S (which is known as the main source area for the Indian monsoon moisture) reveals that evaporative signal in F_{ocean} led that of F_{E-P} by about one month; suggesting the potential to improve the prediction of Indian monsoon onset by integrating the freshwater flux derived from ocean measurements.
- **With large potential to be improved (e.g. including subsurface processes), F_{ocean} (tendency+advection) delivered promising results.**

Description (All in unit km³)	June 2012	June 2013	June 2013-June2012	Satellite (observed variable)
Rainfall integrated in India Subcontinent [70-90°E, 5-25°N]	288.14	519.98	231.84	TRMM (P)
Water storage changed over India Subcontinent [70-90°E, 5-25°N]	-308.87	-189.01	119.87	GRACE (LWET)
Atmospheric moisture transport from Arabian Sea through India west coast [7-22.5°N]	1320.65	1654.92	334.28	Oceansat2 (U_W), TRMM (W)
Freshwater flux derived from F_{ocean} integrated over Arabian Sea [45-75°E, 5-25°N]	880.93	1245.79	444.86	Aquarius (SSS), OSCAR (Uc)
Freshwater flux derived from F_{E-P}^{TRMM} integrated over Arabian Sea [45-75°E, 5-25°N]	203.62	-32.37	-235.99	OAflux (E), TRMM (P)
Freshwater flux derived from F_{E-P}^{GPCP} integrated over Arabian Sea [45-75°E, 5-25°N]	310.69	191.42	-119.28	OAflux (E), GPCP (P)

Water cycle components associated with Indian summer monsoon estimated from satellite observations.

The freshwater transports in oceans, or "salty rivers", which are not as "measurable" as terrestrial rivers, may provide "predictable" information critically influencing the terrestrial water cycle.