Pre-Monsoon Drought in India Observed from Space

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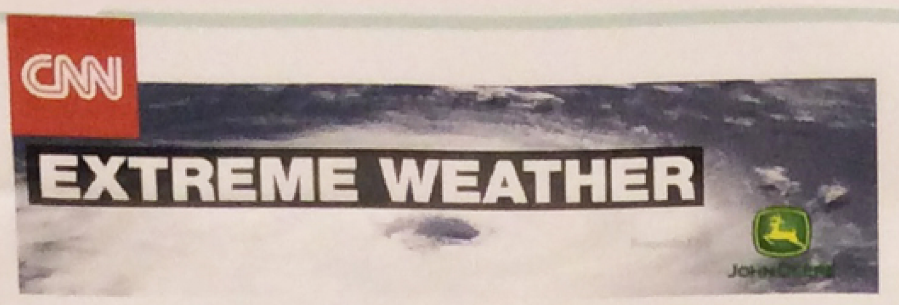
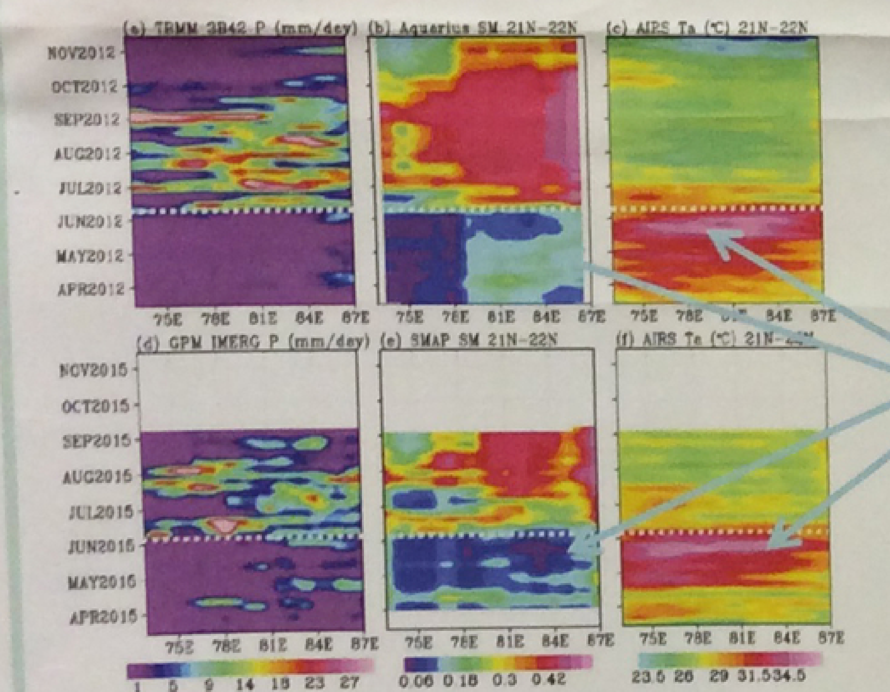


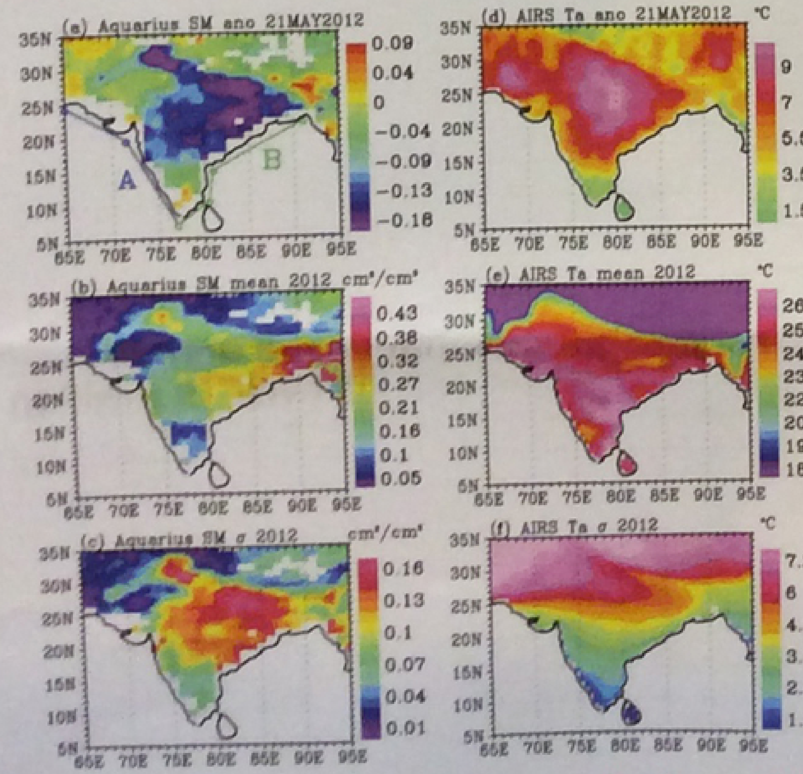
India heat wave kills 2,330 people as millions wait for rain

By Hilary Whiteman, CNN Updated 12:17 AM ET, Tue June 2, 2015 | Video Source: CNN

- There have been anecdotic descriptions of extreme dry and hot weather before summer monsoon that causes economic hardship and human suffering in India, but little documentation on the severity and postulation on the scientific reason.
- Are they results of human anxiety caused by delays of monsoon onset?
- 3 years of Aquarius soil moisture are used with rain from TRMM-replaced by SMAP and GPM in 2015 for characterization

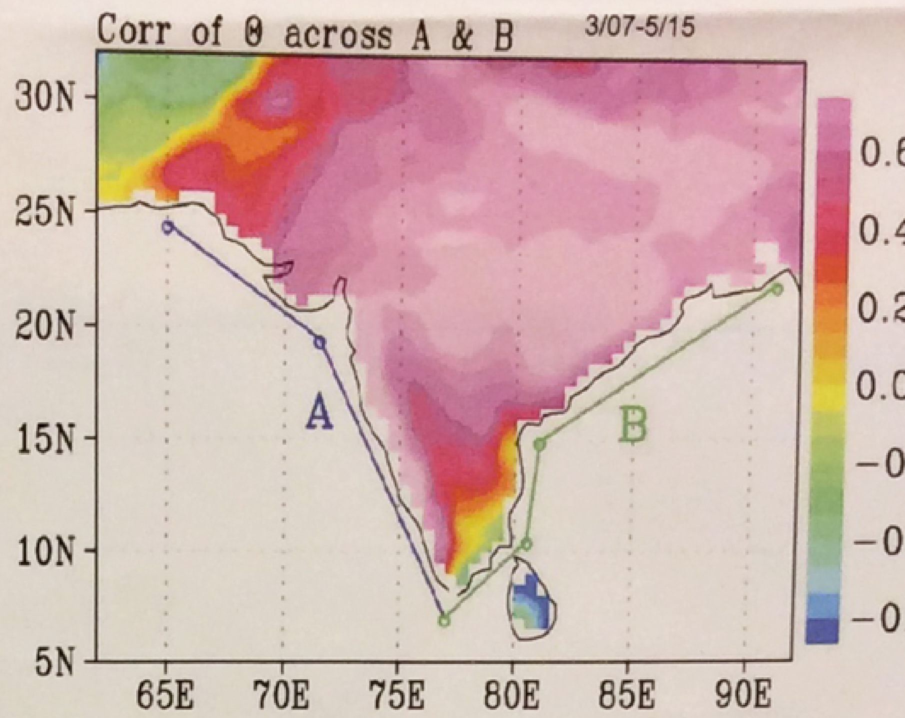
Pre-Monsoon Drought and Heat Waves in India





Geographical variation of drought and heat wave. (a) Soil moisture anomaly (deviation from annual mean) for the 5-day average from May 21-25, 2012, (b) annual mean of 2012, and (c) standard deviation of 2012. (d)-(f) are the same as (a)-(c), except for air temperature.

Using moisture transport to represent monsoon



The water balance equation is

$$\frac{\partial W}{\partial t} + \nabla \bullet \Theta = E - P$$

where

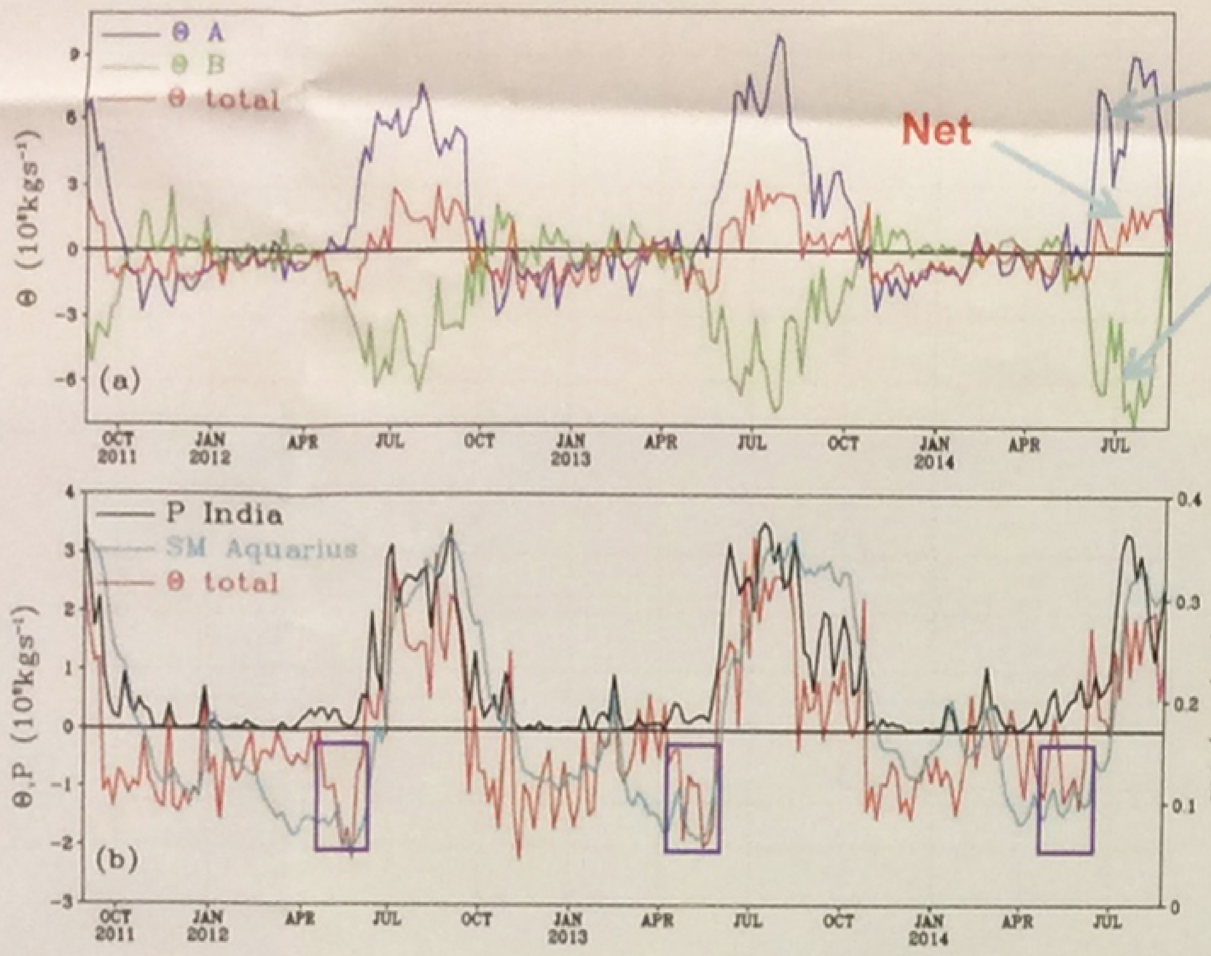
$$\Theta = \frac{1}{g}\int_0^{p_o} qU dp$$

$$W = \frac{1}{g}\int_0^{p_o} q dp$$

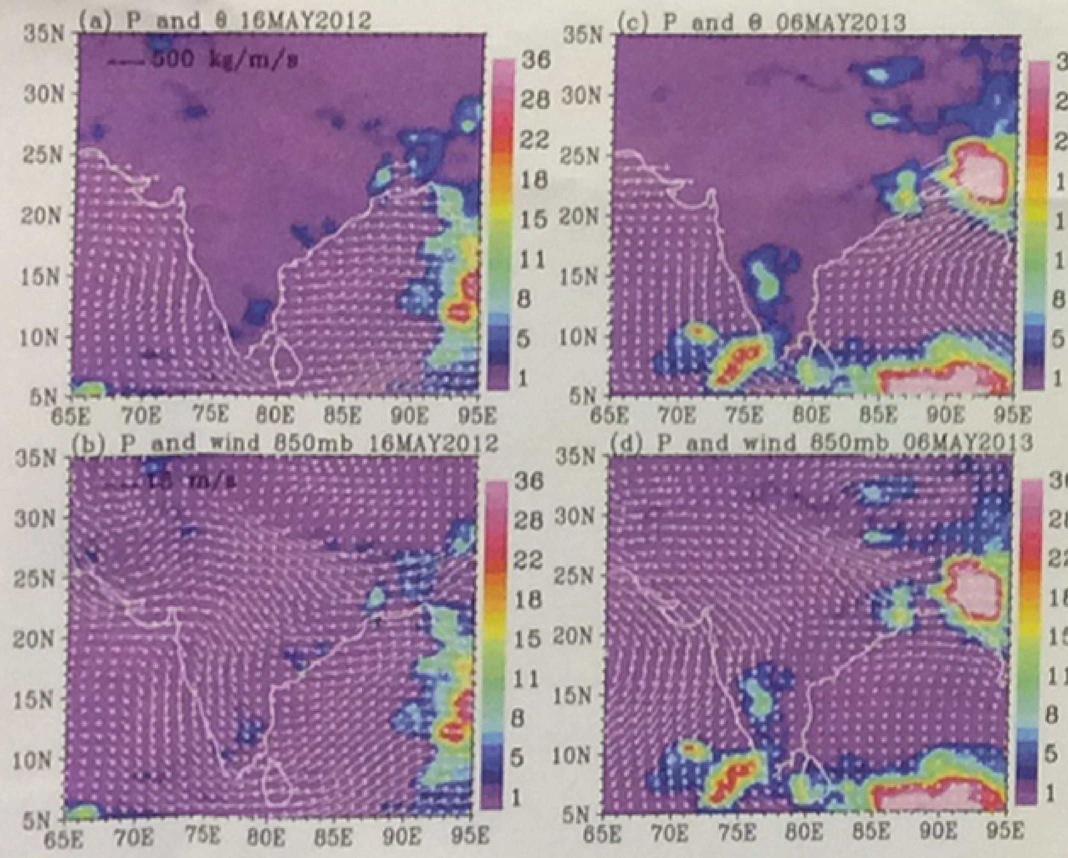
Θ is the moisture transport integrated over the depth of the atmosphere. W is the total precipitable water. q and U are the specific humidity and wind vector at a certain level. E and P are evaporation and precipitation.

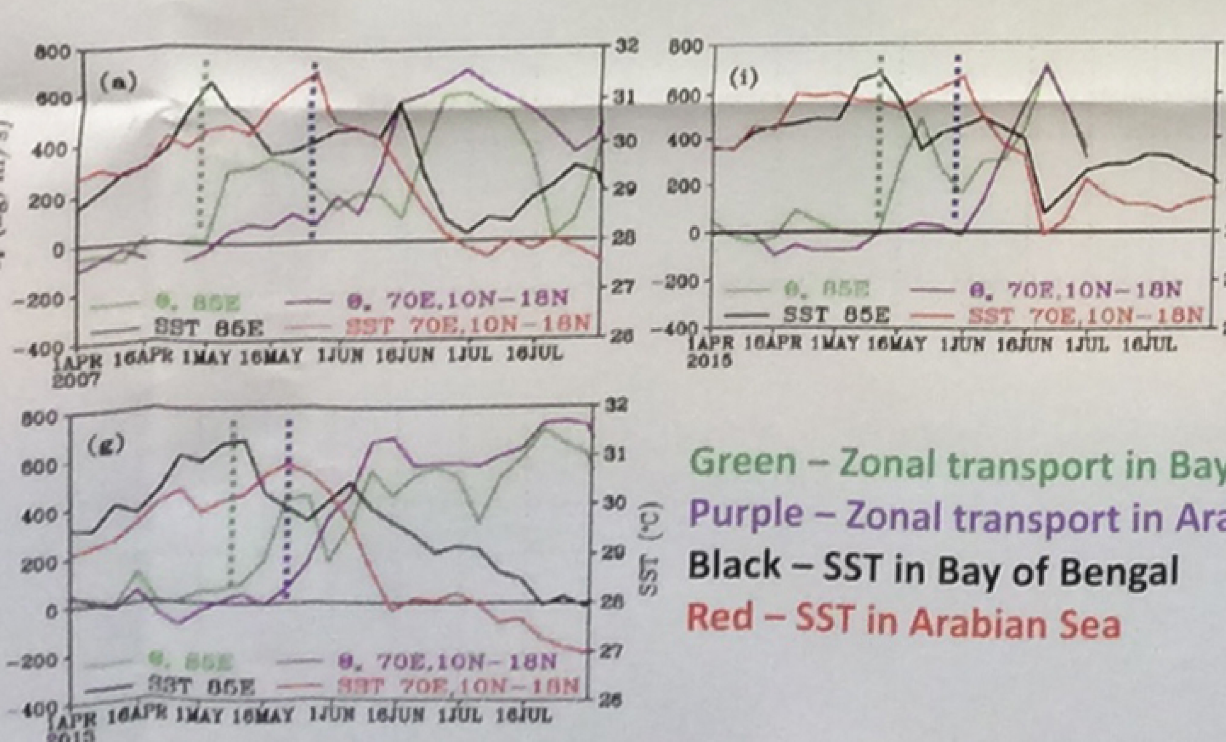
Θ is equivalent to column water vapor W advected by Ue. Ue is the depth-averaged wind weighted by humidity
Before 2005, Ue is related to Un only. From 2005, we use support vector regression to relate Ue to wind at two levels:
1. U_N: scatterometer surface wind stress
2. U_{850mb}: cloud drift wind (free-stream wind)

- Xie et al. [2008] showed the model-derived Θ agree with Θ from 90 rawinsonde stations from synoptic to seasonal time scales and from equatorial to polar oceans.
- Hilburn [2010] found very good agreement between this data set and data computed from MERRA over the global ocean.
- Liu et al. 2006] showed closure of the terrestrial water balance in South America.
- Liu et al. [2012] demonstrated the significance of Θ in affecting rainfall in West Africa where the surface winds are in different direction from winds aloft.
- Liu and Xie [2014] (Encyclopedia of Remote Sensing) summarized validation and application, showing water balance over global ocean and major continents



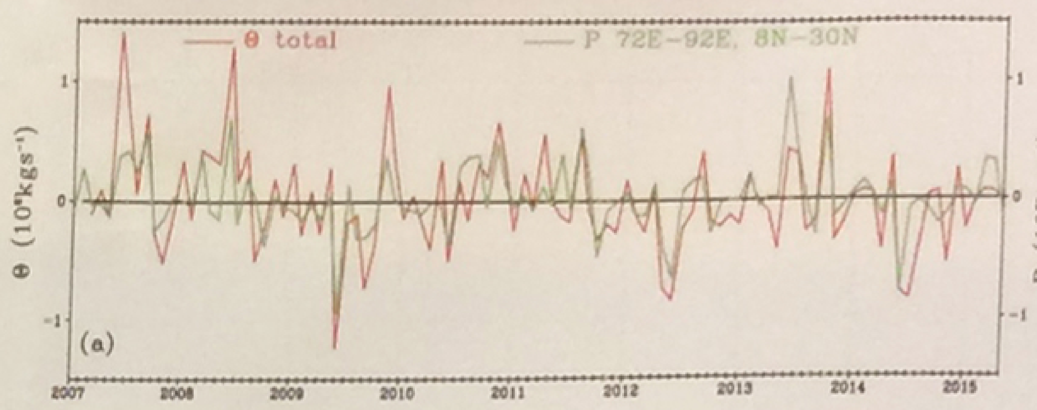
Indian Monsoon as described by integrated moisture transport (Θ). Net moisture input falls out as rain. Drought occurs during short periods when moisture input is negative. Moisture is sucked out to Bay of Bengal before it can be replenished from Arabian Sea.





Summer monsoon starts at the peak of SST rise, in both Arabian Sea and Bay of Bengal. Bay of Bengal changes earlier than Arabian Sea.

Interannual anomalies (with 9-year annual cycle removed)



Large positive (2007, 2008, 2013) and negative (2009, 2012, 2014) anomalies in June signify early and late monsoon onsets

Summary

- L-band radiometers allow us to characterize pre-monsoon drought (PMD).
- PMD is an annual occurrence, may be amplified by interannual variation of monsoon onset but not driven by it.
- It occurs when moisture advects out to Bay of Bengal earlier than coming in from Arabian Sea.
- Southwest summer monsoon starts earlier in Bay of Bengal and sucks air out of India, replaced by air from the northwest desert before monsoon moisture comes from Arabian Sea.
- Summer monsoon is found to start at the peak of sea surface temperature (SST) rise in both Arabian Sea and Bay of Bengal.
- SST rise precedes monsoon onset in Bay of Bengal, allowing early warning of drought and mitigating human and economic adversaries.
- Ocean currents that cause annual temperature and salinity cycle in Arabian Sea and Bay of Bengal are not driven by local monsoon.
- How they are remotely generated remain unclear.
- We are examining river discharges (from land surface model and altimeter), evapotranspiration over land, mass changes over land and ocean (GRACE). The water budget and deviation from closure would shed new lights on the linkage of ocean and terrestrial water cycles.