The Passive Microwave Water Cycle Product:

Closing the Water Cycle over the Ocean Using a Constellation of Satellites

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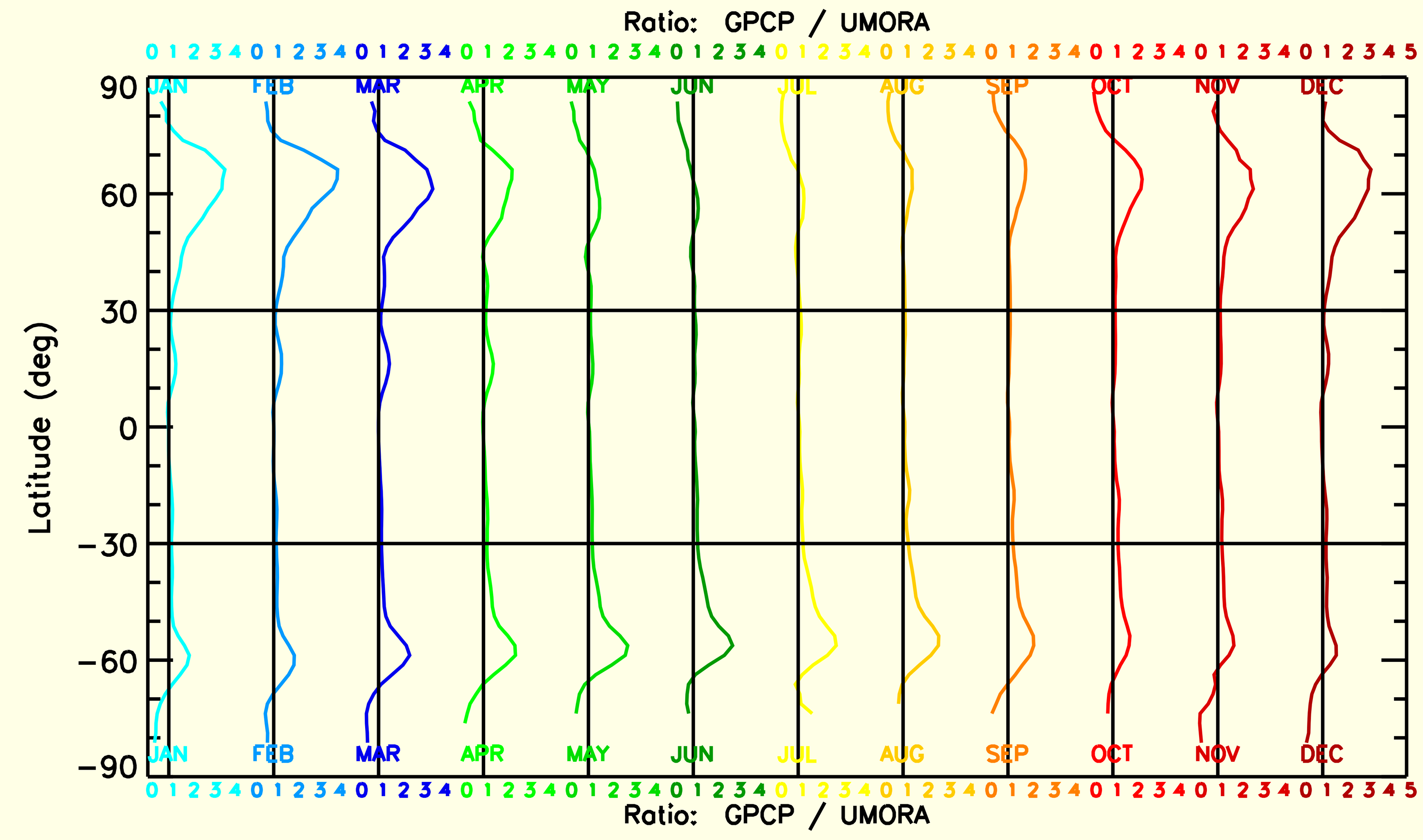
STATUS: We are in the final stages of completing our Passive Microwave Water Cycle Product (PMWC) for NEWS. The purpose of this product is a full characterization of the atmospheric branch of the water cycle over the global oceans using accurately intercalibrated passive microwave data. The product is a monthly, 0.25-degreee product spanning the last 20 years: 1987-2007. The product contains six maps: water vapor transport zonal component (*u*) and meridional component (*v*), water vapor transport divergence (*D*), evaporation (*E*), precipitation (*P*), and water vapor (*WV*). Working on this product has generated many science questions that are discussed below.

The Seasonal Cycle in Precipitation

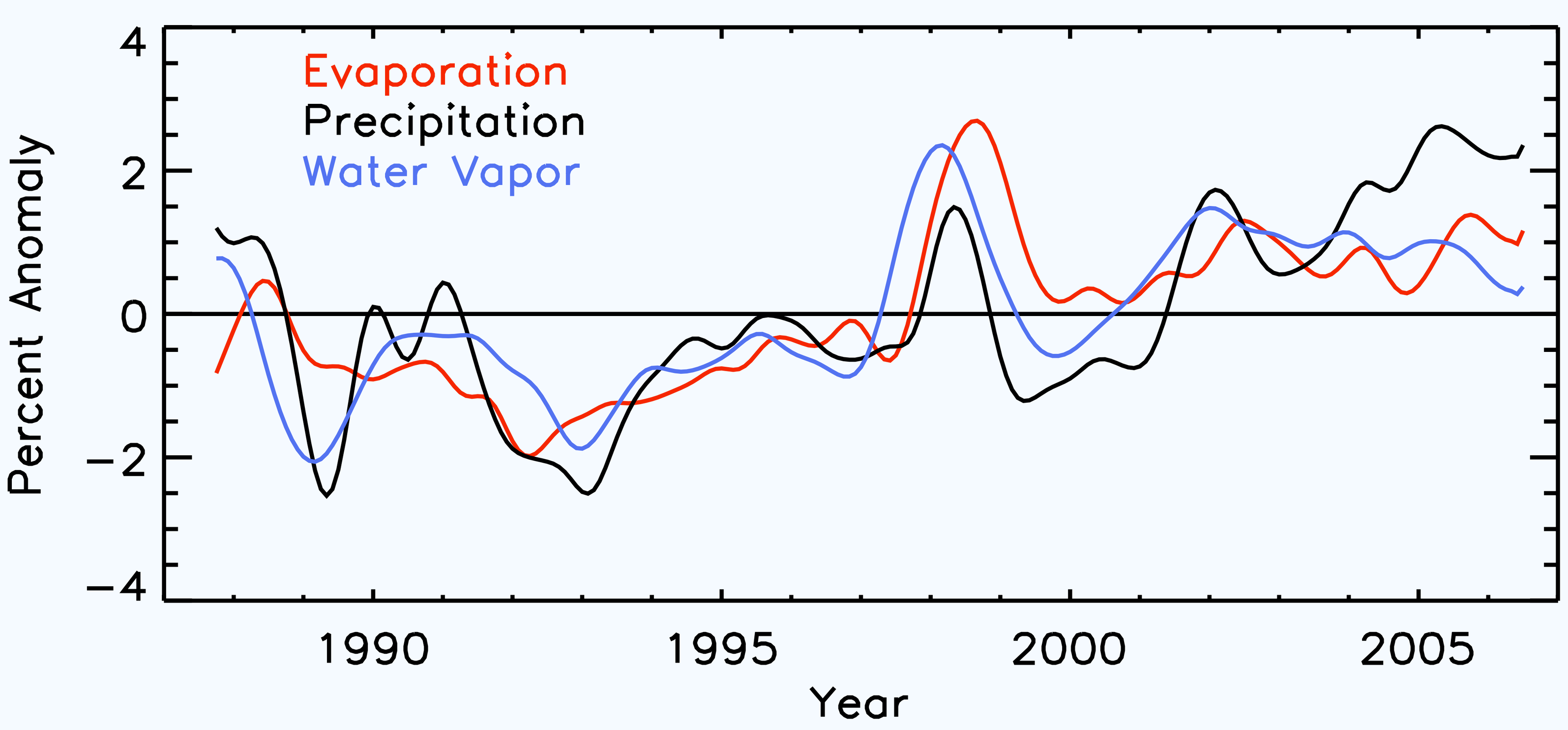
Using hydrological balance as an indirect validation technique (Wentz et al., *Science*, 13 July 2007), we found that the current version of our rain rates (UMORA V6 SSM/I) are about 18% too low globally. We believe this underestimation is located in the extratropics. In the *Science* paper, whose results are shown and discussed below, a static (time-independent), latitude-dependent adjustment was applied to our UMORA (Unified Microwave Ocean Retrieval Algorithm) rain rates.

This discrepancy led us to collaborate with George Huffman to understand the differences between UMORA rain rates and GPCP rain rates. The figure shows that the ocean only, zonal average ratio of GPCP to UMORA exhibits little signal in the tropics, but a strong signal in the extratropical wintertime hemisphere. Applying this latitude-dependent seasonal adjustment removes the 18% annual-average global bias. The strong wintertime signal suggests that UMORA underestimation may be due to a lack of sensitivity to frozen precipitation or assumptions about the vertical rain profile. We are currently collaborating with Grant Petty (University of Wisconsin-Madison) to determine the physical basis for this discrepancy and the relative contribution of frozen precipitation to the global water cycle.



Water Cycle Balance and Trends

Parameter	Mean	Std. Dev.	Trend
Evaporation	961 mm/year	1.1%	1.3%/decade
Precipitation	950 mm/year	1.4%	1.4%/decade
Water Vapor	28.5 mm	1.0%	1.2%/decade



Hydrologic balance gives that over the globe, on monthly time scales, precipitation should equal evaporation. The table confirms that our estimates of global precipitation and evaporation match to within 1%. Evaporation was calculated using our passive microwave wind speed retrievals, Reynolds SST, an ICOADS climatology of relative humidity, an air-sea temperature climatology from the Hadley Center's nighttime marine air temperatures, and the bulk formula from the NCAR CAM 3.0. Land evaporation is assumed to be a static average value (note that only 14% of the global evaporation is from the land). Precipitation over land is filled with GPCP.

The figure shows that anomaly time series of global-average precipitation and evaporation exhibit a strong correlation with over-ocean total water vapor. The relative time lags between water vapor, precipitation, and evaporation are due to the strong relationships between SST and vapor; and between evaporation and wind.

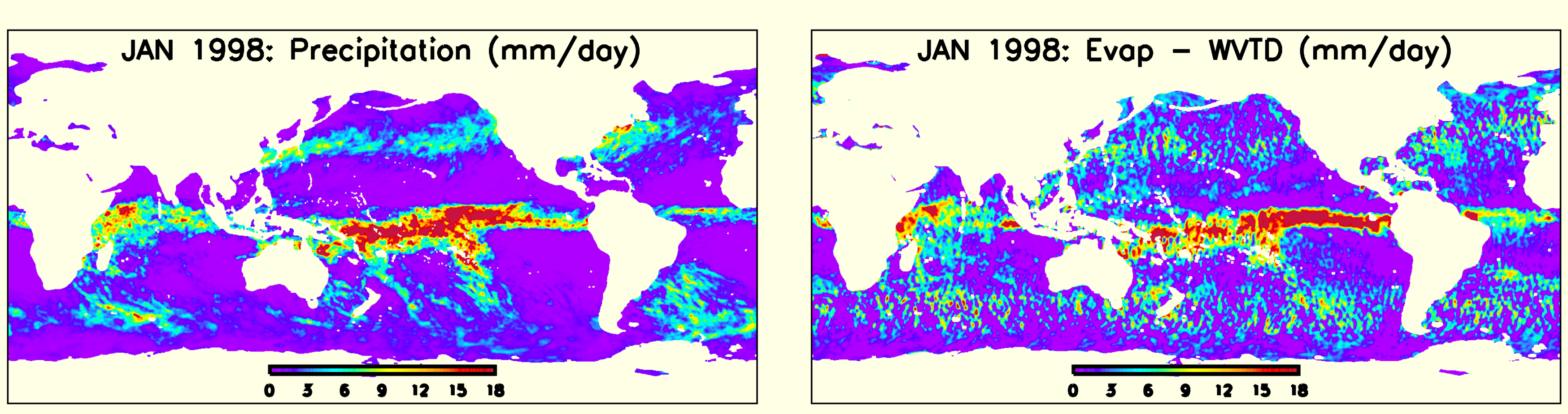
Our water vapor retrievals display a trend of 7%/K as the world warms, which is consistent with the Clausius-Clapeyron (C-C) relationship. Climate models also show this. We found that our precipitation and evaporation measurements also increase at the C-C rate (Wentz et al., *Science*, 13 July 2007). This is in contrast with climate models that predict a muted response of precipitation to global warming with rates between 1 to 3 %/K. We are currently investigating the implications of these results in terms of the global energy balance. A study published two weeks after our *Science* paper (Zhang et al., *Nature*, 26 July 2007) found that in situ GHCN precipitation measurements agree with our results.

Calculating Water Vapor Transport Divergence

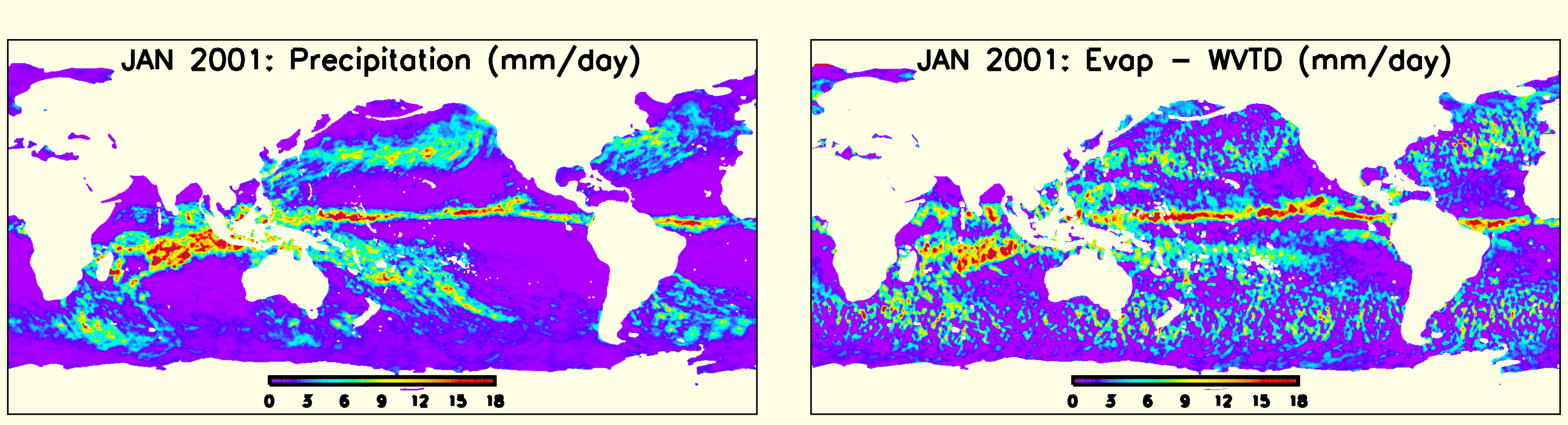
Hydrologic balance gives that at a particular location, on monthly time scales, precipitation should be equal to evaporation minus water vapor transport divergence. The maps for January 1998 and 2001 show that the circulation changes associated with ENSO are indeed consistent with changes in the distribution of precipitation in the tropics.

Our water vapor transport estimates leverage the results of two NASA DISCOVER projects. The first project, led by Remote Sensing Systems, provides time-organized water vapor fields from passive microwave sensors (http://www.discover-earth.org/). The second project, led by Joe Ardizzone, uses our passive microwave wind speed retrievals to create wind vectors using a variational method (http://sivo.gsfc.nasa.gov/oceanwinds/). Their Level 2.5 dataset is organized by sensor type and contains data voids where there are no satellite data or where rain contamination exists. Their Level 3.0 dataset contains four spatially-complete, time-organized maps per day. We found that the water vapor transport in and around raining areas is crucial to obtaining accurate water vapor transport divergence maps. Thus, we use the Level 3.0 dataset.

We used NCEP wind and relative humidity fields to determine the relationship between the surface wind vector and the water vapor transport vector. We developed both a "climatological adjustment" technique, somewhat similar to Liu and Tang (2005); and a "gradient adjustment" technique that uses the spatial structure of the retrieved wind field itself to determine the vertical wind shear. We found that a blend of these two techniques performs best. Unavoidable small random errors in the water vapor transport create large errors in the divergence. We developed a statistical "divergence stabilization" technique that mitigates these errors.



El Niño



La Niña