# The Passive Microwave Water Cycle Product:

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


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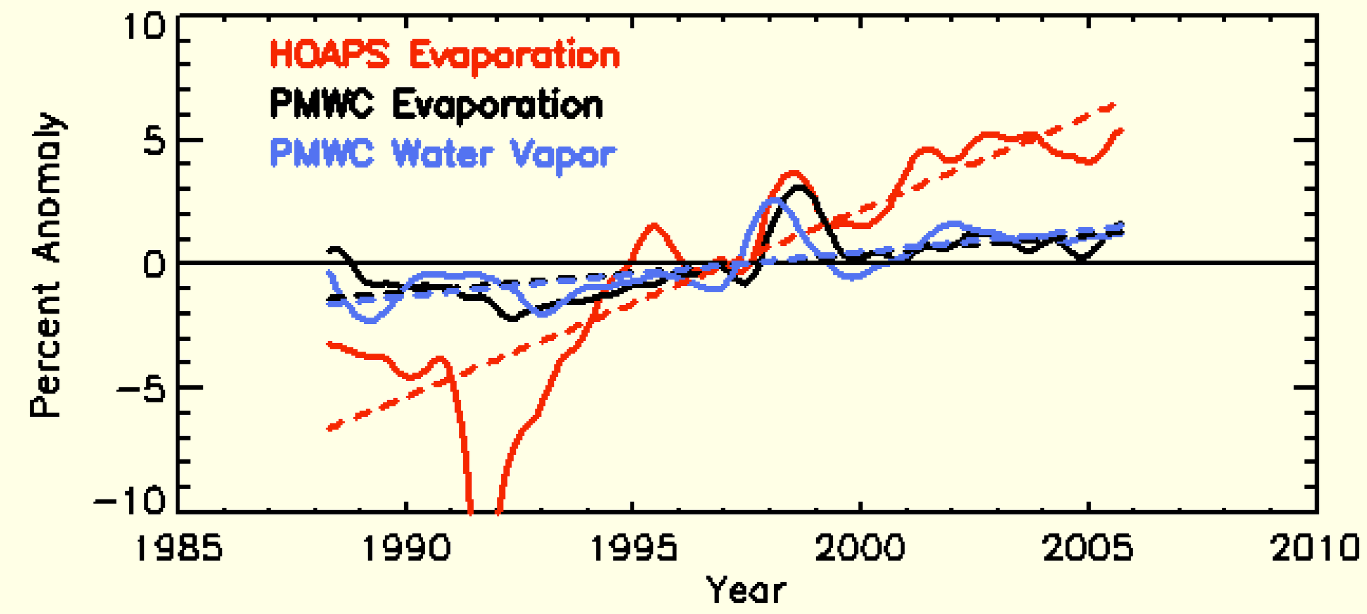
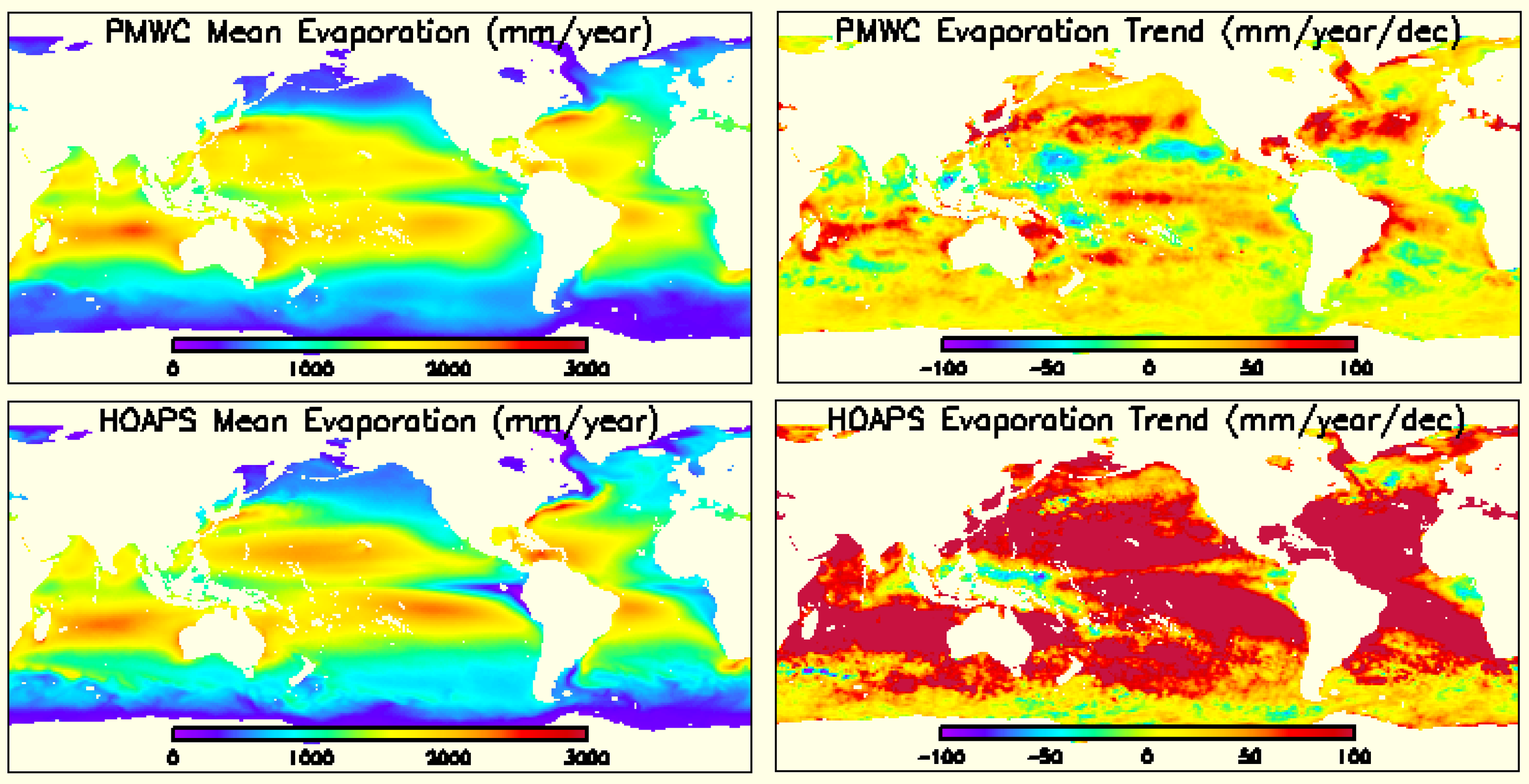
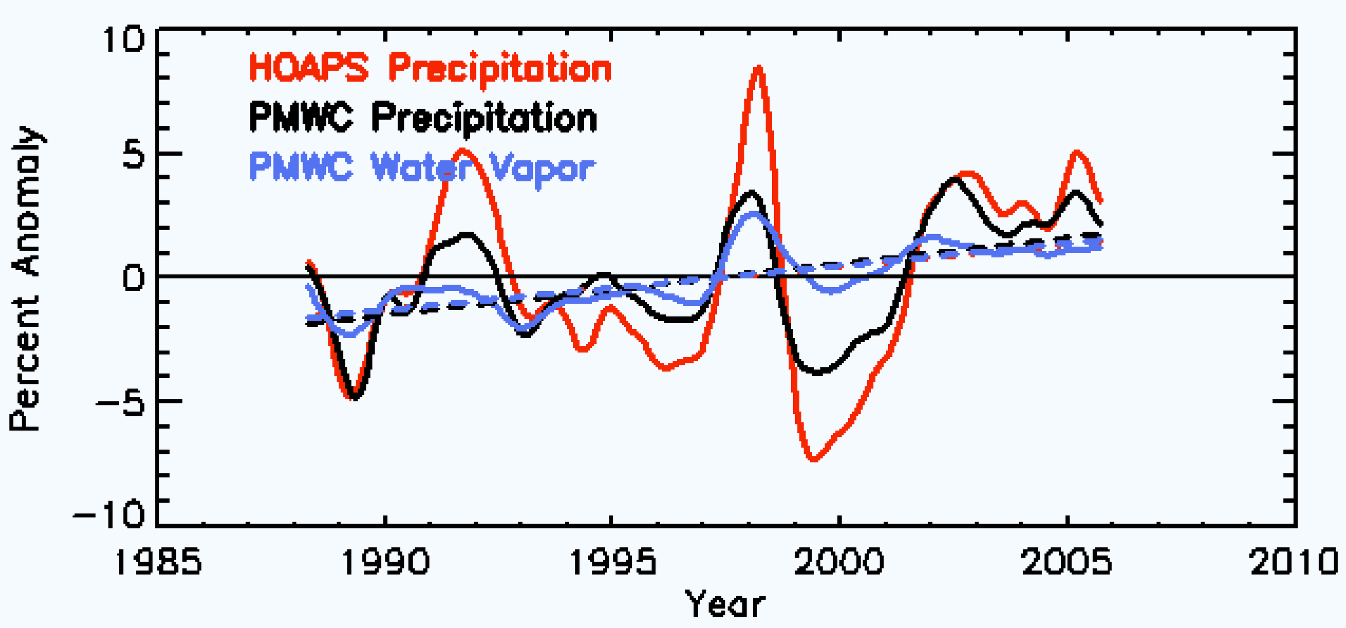
## Evaporation

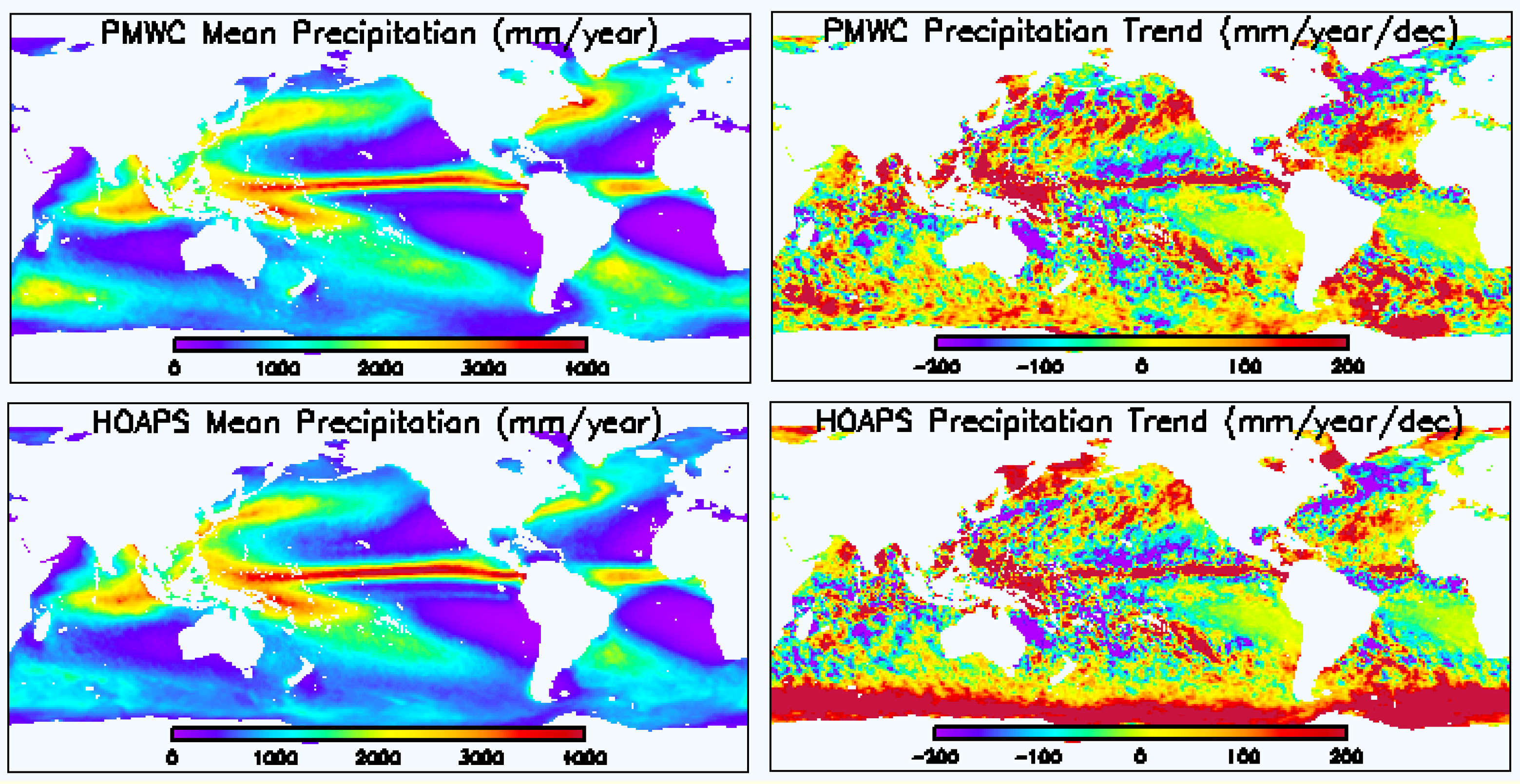
Evaporation is calculated using a bulk aerodynamic formula. The calculation is driven mostly by the surface wind speed and the sea surface temperature. Surface wind speed comes from our passive microwave satellite retrievals. Sea surface temperature is taken from Reynolds, because C-band measurements (needed for cold water SST) are only available since 2002. The evaporation calculation is driven secondarily by the surface relative humidity and the air-sea temperature difference. We believe these parameters probably have little, if any, long-term trend over time; so we use values from monthly climatological maps. The maps were created using ICOADS relative humidity and Hadley Center marine air temperatures. Our Version-01a PMWC product also applies a small annual adjustment to the satellite winds in order to bring the winds into agreement with buoys winds. The adjustments are less than 0.1 m/s and have no net effect on the overall trend. The small adjustments do make an important contribution to the interannual variability of the time series. Our evaporation calculations follow the same procedures as Wentz et al., (*Science*, 13 July 2007).

Our PMWC evaporation is compared with HOAPS to the right. The comparisons are limited by the availability of the HOAPS data: 1988-2005. The HOAPS evaporation trend (red line) is about one order of magnitude larger than the PMWC trend (black line). The PMWC evaporation trend (black line) has roughly the same relative magnitude as the water vapor trend (blue line). Mean maps of evaporation show roughly similar spatial patterns with HOAPS and PMWC, however HOAPS is higher in the subtropics. Trend maps of evaporation show that the HOAPS trend is larger almost everywhere.




## Precipitation

Precipitation is calculated using the latest version of our intercalibrated passive microwave rain rates (Hilburn and Wentz, *J. Appl. Meteor. Climatol.*, March 2008). The diurnal cycle of rain over the ocean is smaller than over land, but it is not negligible, and failure to account for the different satellite local crossing times will yield inconsistencies on the order of 1-3%. The rain rates are adjusted to represent the daily average rain rate with a static, global value for each satellite platform. The rain rates are then adjusted to represent precipitation (rain + snow), since conventional passive microwave observations are not sensitive to frozen precipitation. The adjustments are a function of latitude and time-of-year. The adjustments reach as large as a factor of 3, and only occur in the winter hemisphere poleward of 30 degrees latitude. The net effect of the rain-to-precipitation adjustment is an increase in the global-ocean-average of 18%.

Our PWMC precipitation is compared with HOAPS to the left. HOAPS and PMWC have roughly the same trend over time, and these trends are similar to the water vapor trend. Comparing the precipitation trends with the evaporation trends shows that HOAPS trends are severely out-of-balance, while the PMWC product is hydrologically balanced. Note that the PMWC estimates of evaporation and precipitation rely on independent physical principles. HOAPS precipitation has larger interannual variability than PMWC. The increasing trend in PMWC precipitation is due to increases in heavy rain. Mean maps of precipitation show that PMWC is somewhat larger in the extratropics compared to HOAPS. This is evidence of our rain-to-precipitation adjustment. While PMWC and HOAPS have similar global-ocean-average precipitation trends, the trend maps show that HOAPS has somewhat smaller trends over the tropics and a very large trend over the whole Southern Ocean.

## Water Vapor, Transport, and Divergence

Water vapor estimates come directly from our satellite retrievals, which have a trend of slightly more than 1%/decade over the last 20 years. Water vapor transport is calculated using water vapor and the surface wind vector, which comes from the Level 2.5 Atlas/Ardizzone winds. Their product uses our passive microwave wind speed retrievals to create wind vectors using a variational method (*http://sivo.gsfc.nasa.gov/oceanwinds/*). The surface wind vectors are adjusted to represent water vapor transport vectors using two steps. The first step is a climatological increase of the speed and anticyclonic rotation of the direction as a function of latitude. The adjustment is based on NCEP and increases the speed from 1 to 1.75 times and rotates the direction from 0 to 18 degrees anticyclonically as latitude goes from equator to pole. More complicated climatological corrections - including zonal asymmetry - yield odd east-west Pacific artifacts in the transport due to mismatch between satellite and model hydrological cycles. Realize that any sort of climatological adjustment is inherently large scale, and has very little effect on the transport divergence. Thus, the second step involves adjusting the transport vectors to minimize the difference between the transport divergence and E-P. This depends (weakly) on some assumptions about evaporation and precipitation over land. We assume constant values as in Wentz et al., (2007), and further versions of the product would benefit from using over-land products. The large map to the right shows the magnitude of the adjustment, which mostly serves to rotate the direction of the vectors (with a median value of 12 degrees).

Our PMWC water vapor transport and divergence products are compared with Tim Liu's NEWS transport product on the right. The comparisons are limited by the availability of LIU: the tropical ocean equatorward of 30 degrees latitude for the time period 2000-2005. The time series show some interesting behavior. For the zonal component (U), LIU has a trend roughly 12 times larger than the water vapor trend, while PMWC has a trend roughly 4 times larger. For the meridional component (V), LIU has a trend roughly the same as vapor, while the PMWC trend is near zero. For the transport divergence, LIU has a trend about half as large as the PMWC trend, which is nearly equal to the E-P trend. Interannual variability in divergence for LIU is very different than PMWC. The water vapor transport speed histogram shows that LIU and PMWC have similar transport speeds except at low vapors. Remember that these results are for the tropical ocean only. The directional histogram shows that directions are most different at low vapors.