Ocean Water Vapor and Cloud Burden Trends Derived from the Topex Microwave Radiometer

Shannon Brown, Shailen Desai, Stephen Keihm, Wenwen Lu
Jet Propulsion Laboratory
Pasadena, CA
Shannon.T.Brown@jpl.nasa.gov

Christopher Ruf
University of Michigan
Ann Arbor, MI

***Abstract*—An end-of-mission recalibration effort was recently completed for Topex Microwave Radiometer to generate climate data records of precipitable water vapor and cloud liquid water for 1992-2005. The TMR climate data is analysed for trends. The global trend in precipitable water vapor is found to be 0.9 ± 0.06 mm/decade. Regional precipitable water vapor trends are found to be highly correlated with regional sea surface temperature trends. The cloud liquid water trends are observed to be generally negative outside the tropics and positive in the tropics.**

Keywords-water vapor trend, cloud liquid water trend, TMR, microwave radiometer

I. Introduction

The Topex Microwave Radiometer (TMR), which is included on the Topex/Poseiden oceanography satellite, is dedicated to measuring the integrated water vapor content of the atmosphere. TMR is nadir pointing and measures the radiometric brightness temperature (T_B) at 18.0, 21.0 and 37.0 GHz. This satellite was decommissioned in January of 2006, but has left an unprecedented 13-year time series of integrated water vapor measurements over the ocean. This extraordinarily long time series of global measurements from a single instrument presents an ideal opportunity to derive a water vapor climatology that is complementary to existing products and will make an important contribution to our understanding of water vapor's role in the Earth climate system. With this in mind, an effort was undertaken to minimize systematic calibration errors present in the data, resulting in a high quality and reliable climate data record. The recent completion of this effort affords the opportunity to observe decadal trends in water vapor both globally and regionally.

II. TMR Observations

The TMR flew in a 10-day non-sun-synchronous exact repeat orbit with an inclination of about 66°. One advantage of the Topex orbit is that the TMR observations are not aliased with respect to local solar time. TMR sampled the atmosphere in the nadir direction along the spacecraft ground track with a 45 km footprint. A complete description of the TMR instrument can be found in [1] and [2]. A description of the TMR geophysical retrieval algorithms can be found in [3]. The water vapor retrieval algorithm is a log-linear regression algorithm with coefficients that are stratified by wind speed and water vapor. The cloud liquid water algorithm is a polynomial combination of the three TMR channels.

III. Global Trends

The TMR climate record data is filtered for land, sea ice and nominal instrument state. A cos(latitude) weighting is applied to each observation in a 10-day repeat cycle. These weighted observations are then averaged for the latitude ranges 60S-60N, 0-60N, 0-60S, and 20S-20N. These data are then averaged monthly. The annual signal is removed from the data by subtracting the monthly mean of the entire dataset from each month.

Three different levels of cloud/rain filtering were used when computing the water vapor averages. The first filter is cloud liquid water (CLW) < 300 microns, which should throw out all observations in rain. The second is CLW < 600 microns, which may include some rain contaminated observations. The third is CLW < 1000 microns, which will include greater than 99% of the otherwise unflagged observations. The water vapor trends were found to be almost insensitive to the CLW filtering, so the remainder of the analysis is done using the CLW<1000 filter. The averages of CLW include all data in which CLW < 1000 microns.

Figure 1 shows the cloud liquid water trends derived from TMR from September 1992 through October 2005 and Figure 2 shows the precipitable water vapor trends for the same time period. The monthly mean computed from the entire TMR dataset is subtracted from the monthly averages to remove the annual signal. The four panels shown are for zonal averages 60S-60N, 20S-20N, 0-60N, and 0-60S. A linear least squares line is fit to the data and the trends are shown in Table I. The water vapor trends for each zonal region are positive. The global precipitable water vapor trend from 1992-2005 is found to be 0.9 ± 0.06 mm/decade. Only the tropical and northern hemisphere cloud liquid water trends are statistically significant at 2.34 ± 1.33 microns/decade and 2.59 ± 1.19 microns/decade, respectively.

The strong 1997/98 El Nino/La Nina is evident in the water vapor and cloud liquid water trends for the southern hemisphere. An increase in the tropical cloud liquid water is

The work described in this article was performed as the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

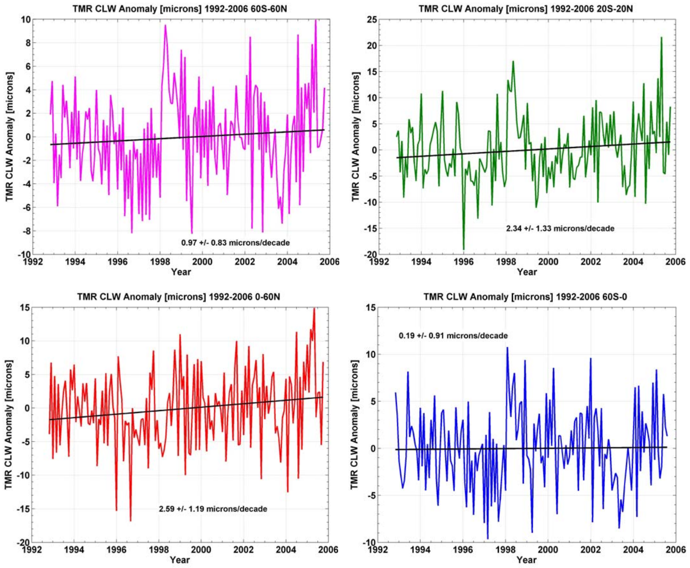

Figure 1. TMR integrated cloud liquid water trends from 1992 to 2006 for 60S-60N (top left), 20S-20N (top right), 0-60N (bottom left) and 60S-0 (bottom right).

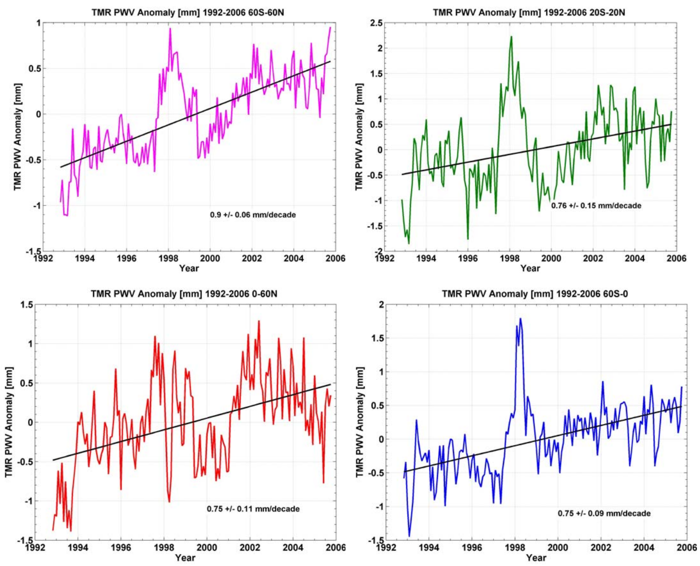

Figure 2. TMR precipitable water vapor trends from 1992 to 2006 for 60S-60N (top left), 20S-20N (top right), 0-60N (bottom left) and 60S-0 (bottom right).

observed during the first half of 1998. A significant increase in tropical precipitable water vapor is observed beginning in the last half of 1997 and continuing through the first half of 1998. A strong increase in the tropical precipitable water vapor is observed from 1999 to 2002. The observed global precipitable water vapor trends from TMR are found to be in excellent agreement with those derived from SSM/I over the same time period [4] (see Fig. 10).

IV. Regional Trends

Maps of integrated water vapor and cloud liquid water, and their trends, are generated from the TMR climate records. The

TABLE I. Integrated Water Vapor and Cloud Liquid Water Linear Trends Derived from TMR for 1992-2005

Water Vapor Trends [mm/decade]			
60S-60N	***20S-20N***	***60S-0***	***0-60N***
0.90 ± 0.06	0.76 ± 0.15	0.75 ± 0.09	0.75 ± 0.11
Cloud Liquid Water [microns/decade]			
60S-60N	***20S-20N***	***60S-0***	***0-60N***
0.97 ± 0.83	2.34 ± 1.33	0.19 ± 0.91	2.59 ± 1.19

data is first averaged on a 2.5° by 2.5° latitude/longitude grid for each 10-day Topex repeat cycle. Data is flagged for land, sea ice and nominal instrument state. For each grid box, outliers are thrown out by removing all data greater than 3-sigma from the mean of that grid box. This typically removed 1-2 cycle averages from the 478 total cycles. This data was then averaged to form the climatology of a given variable for the entire TMR record from 1992-2005. A trend is also computed at each grid box. This is done by first removing the monthly mean for each month for a given grid box. A linear regression is then fit to these data to determine the trend. The regional trend data is smoothed using a 2-D cosine taper smoothing function over a 5x5 grid box area (filtering for land). The water vapor trends are shown in Figure 3 (in %/decade). The cloud liquid water trends are shown in Figure 4.

It is apparent that there are significant regional trends in PWV. Large positive trends are observed in the tropical western Pacific and the North Atlantic oceans. Large negative trends are observed in the eastern Pacific near 15 degrees north and south latitude. A regional SST trend map, shown in Figure 5, is acquired from the Goddard Institute from Space Studies (GISS) surface temperature analysis data set [5]. The regional water vapor trends are strongly correlated with the regional SST trends, as one might expect.

[6] derives a simple relationship between SST and integrated water vapor as

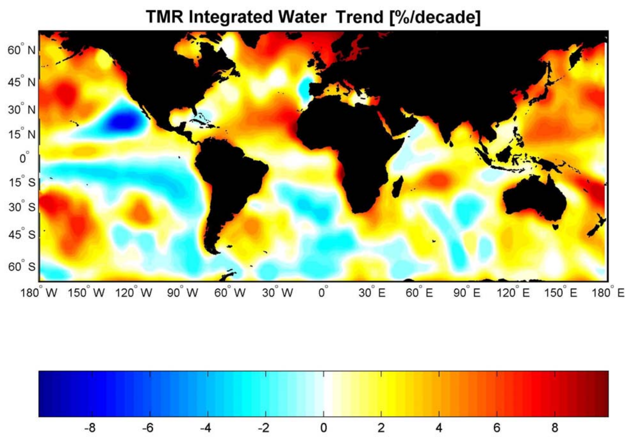

Figure 3. TMR regional precipitable water vapor trends in %/decade from September 1992 – October 2005.

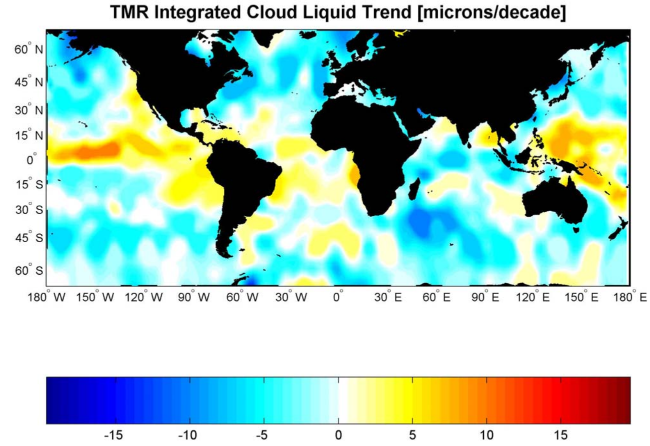

Figure 4. TMR regional integrated cloud liquid water trends in %/decade from September 1992 – October 2005.

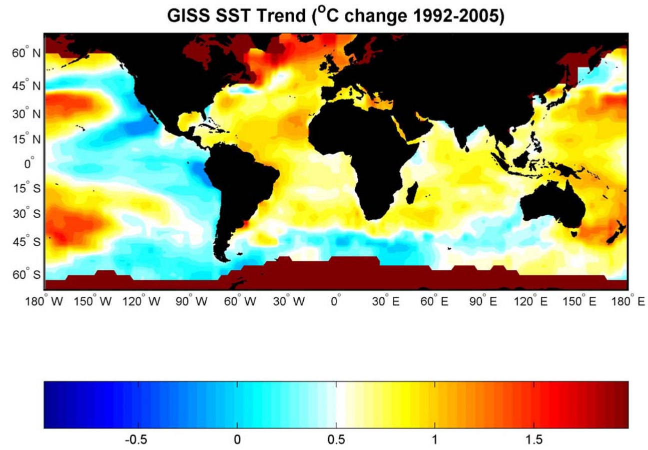

Figure 5. SST trend acquired from the GISS surface temperature analysis

$$w = 10.82\left(\frac{RH}{1+\lambda}\right)e^{a(SST-288)} \tag{1}$$

where RH is the relative humidity at the surface, λ is the ratio of the pressure scale height to the water vapor scale height, $a \approx 0.064K^{-1}$ is a constant found in an approximation to the Clausius-Clapeyron equation, and SST is the sea surface temperature in (K). From (1), we get

$$\frac{\Delta w}{w} = a\Delta SST = 0.064\Delta SST \tag{2}$$

In [6], it was found that (1) best fit observed data for SSTs greater than 15°C. A plot of Δw/w versus ΔSST is shown in Figures 5 and 6 for all SSTs and for SSTs > 15 °C, respectively. The values determined for *a* by least-squares regression are 0.05 for the all SST case and 0.06 for the SST > 15 °C case. The correlation coefficient for the first case is 0.46 and it is 0.36 for the second case.

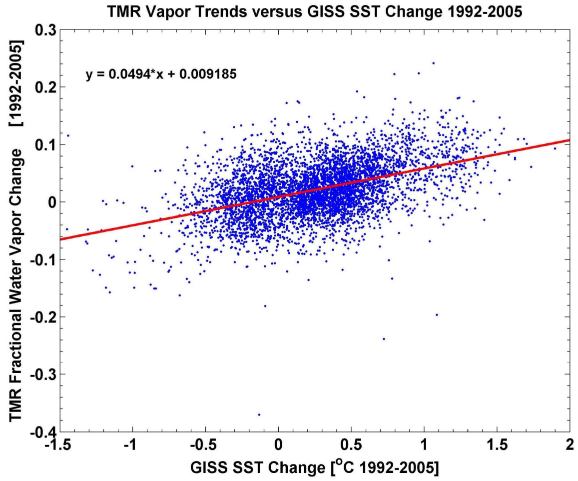

Figure 6. TMR fractional water vapor change versus SST change 1992-2005 for all SST.

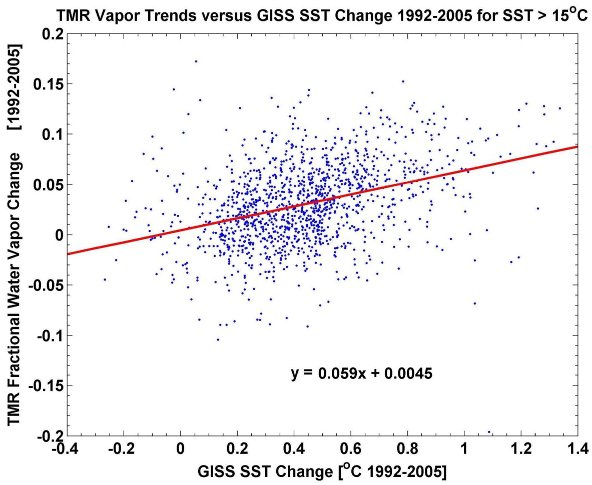

Figure 7. TMR fractional water vapor change versus SST change 1992-2005 for SST > 15 C.

The cloud liquid water trends are observed to be positive at about 5-10 microns/decade in the equatorial Pacific. Other regions are observed to have a negative trend from 5-10 microns/decade. Additional work is being done to determine whether the cloud liquid water trends are due to increased cloud frequency or due to thicker clouds.

V. Conclusions

The Topex Microwave Radiometer was decommissioned in January 2006, but left 13 years of continuous observations. An end-of-mission recalibration effort was recently completed, yielding a high quality TMR climate record of precipitable water vapor and cloud liquid water. This dataset is analysed to observe the trends from 1992-2005. It is found that the global precipitable water vapor trend is positive at 0.9 ± 0.06 mm/decade. Maps of regional water vapor trends are generated and it is shown that the correlation between sea surface temperature trends and water vapor trends follows a simple relationship derived from the Clausius-Clapeyron equation.

The cloud liquid water trends are observed to be generally negative outside the tropics and positive in the tropics.

REFERENCES

[1] Ruf, C.S., S. Keihm and M. Janssen. 1995. TOPEX/Poseidon Microwave Radiometer (TMR). I. Instrument description and antenna temperature calibration. *IEEE. Trans. Geosci. Rem. Sens.* 33(1). 125-137.

[2] Janssen, M. C. Ruf. and S. Keihm. 1995. TOPEX/Poseidon Microwave Radiometer (TMR). II. Antenna pattern correction and brightness temperature algorithm. *IEEE. Trans. Geosci. Rem. Sens.* 33(1). 138-146.

[3] Keihm, S., M. Janssen, and C. Ruf. 1995. and TOPEX/Poseidon microwave radiometer (TMR). III. Wet troposphere range correction algorithm and pre-launch error budget. *IEEE. Trans. Geosci. Rem. Sens.* 33(1). 147-161.

[4] Trenberth, K., J. Fasullo, and L. Smith. 2004. Trends and variability in column-integrated atmospheric water vapor. *Climate Dynamics.* 24. 741-758.

[5] GISTEMP - http://data.giss.nasa.gov/gistemp/maps/

[6] Stephens, G. 1990. On the Relationship between Water Vapor over the Oceans and Sea Surface Temperature. *J. of Climate*. vol 3. pp. 634-645.