A 25-YEAR SATELLITE MICROWAVE MEAN TOTAL PRECIPITABLE WATER DATA SET FOR USE IN CLIMATE STUDY

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Abstract

We have created a merged, 1-degree total precipitable water (TPW) data set constructed using the version-7 (V7) passive microwave geophysical ocean products publicly available from Remote Sensing Systems (www.remss.com). The TPW values are retrieved from SSM/I F08 through F15, SSMIS F16 and F17, AMSR-E, and WindSat brightness temperatures. This work highlights the construction of the merged 1-degree product and description of product contents. The data set was released in January 2013 in netCDF format and is accessible by FTP (ftp.remss.com/vapor), OpenDAP, and the web. The product is updated monthly and will continue for as long as microwave satellite radiometers are in operation. We will add TMI, F18 and AMSR2 data to the product in the coming year.

WHAT IS CLIMATE QUALITY?

This 25-year satellite microwave mean total precipitable water data set is constructed using carefully intercalibrated and consistently processed data from a series of DMSP platform SSM/I and SSMIS radiometers, the Aqua AMSR-E data, and the Coriolis WindSat data. The individual satellite data have been processed by Remote Sensing Systems (RSS) [Wentz and Meissner, 2000, 2007] and are publicly available as Version-7 data [Hilburn, et al., 2010]. No TMI data are used at this time as they have not yet been processed into V7 data. We expect to add TMI, F18 SSMIS, AMSR2, and GMI data as they become available in 2014. The V7 data have been amply tested and validated and are suitable for climate study. The process of merging these data into one TPW product was explored to determine the effect the product creation would have on overall TPW trends. In order to produce a suitable climate product, it is necessary to be sure the following requirements have been met:

- all instruments must be intercalibrated at the brightness temperature level
- data must be processed with a consistent algorithm and approach
- differences in instrument design (channel frequencies, footprint sizes) must be taken into account
- product generation must reduce alteration and not introduce sampling biases

To make the climate product described in this document, we asked four separate scientists to use the RSS V7 microwave data and construct a product. These products were then compared by looking at difference maps, vapor time series, and vapor trends. The different methodologies are summarized in Table 1. From this activity, we found that geographic sampling has a significant effect on global trends derived from each product and that construction decisions were important to the resulting product quality. Figure 1 shows the time series of TPW for each of the 4 products both before and after we requiring the same grid cells be included in each product (thereby unifying the construction decisions that had geographic effects).

Instrument	Details	Scientist 1	Scientist 2	Scientist 3	Scientist 4
F08	Start/Stop	Jul 87 - Dec 91	Jul 87 - Dec 91	Jul 87 - Dec 91	Jul 87 - Dec 91
	Omitted	Dec 87	2 cases of bad regional data in 87	none	none
F10	Start/Stop	Mar 91 - Oct 97	Dec 90 – Nov 97	Dec 90 – Dec 96	Dec 90 – Nov 97
	Omitted	Dec 90, Jan 91, Apr 91, Aug 91, Sep 91, Nov 97	4 cases of bad regional data in 93,94,96	none	none
F11	Start/Stop	Jan 92 - Apr 2000	Dec 91 – May 00	Dec 92- Apr 00	Dec 91 – May 00
	Omitted	Dec 91, Apr 96, Mar 97, Apr 97	4 cases of bad regional data in 94	none	none
F13	Start/Stop	May 95 - Oct 09	May 95 – Nov 09	May 95 – Nov 09	May 95 – Oct 09
	Omitted	None	none	none	none
F14	Start/Stop	May 97 - Jul 08	May 97 – Sep 08	May 97- Aug 08	May 97 – Jul 08
	Omitted	None	none	none	none
F15	Start/Stop	Jan 2000 - Jun 06	Dec 99 - Aug 06	Dec 99- Sep 06	Dec 99 – May 06
	Omitted	Dec 99	Aug 05 d1-7,Jul 05 d29,region specific	none	none
F17	Start/Stop	Dec 06 - Jun 12	Dec 06 – Jun 12	Dec 06 - Jun 12	not used
	Omitted	None	none	none	
AMSR-E	Start/Stop	Jun 02 - Sep 11	Jun 02 – Oct 11	not used	not used
	Omitted	None			
WindSat	Start/Stop	Feb 03 - Jun 12	Feb 03 – Jun 12	not used	not used
	Omitted	Feb-Jun 05, Jun/Jul 07, Jun 08	none		
Min Obs Req		per satellite	112	5	variable capability
Extra Rain Flag	use +1 cell check	No	yes	no	no
Ice Removal	remove ice present	Yes	yes, extended 1 cell	no	yes, > 1%
AverageMethod	bucket vs individual	avg by instrument first, then bucket	bucket	bucket	bucket
Mean Vapor	global (1 std dev)	28.5 (0.6)	28.37 (0.6)	28.18 (0.6)	28.62 (0.5)
Vapor Trend	percent/decade	1.89	1.66	1.24	1.33

Table 1: **Four approaches used to construct a microwave radiometer water vapor data set. Each specified distinct boundaries on instruments, and used different construction decisions (bottom of table). Despite using high-quality, consistently processed, intercalibrated ocean data, the mean vapor and global trends varied much more than expected, demonstrating that construction decisions that alter sampling have a large effect on trends.**

PRODUCT CONSTRUCTION METHODOLOGY

The 25-year product was constructed using the simplest methods possible while imposing strict Q/C requirements that omitted data not suitable for climate study. We used only RSS Version-7 water vapor values in making this product. The data are from all SSM/I instruments, the F16 and F17 SSMIS, AMSR-E and WindSat. First, we created monthly TPW maps for each satellite. We used a 1x1 degree grid on which we calculated mean values. These interim individual satellite files contained mean vapor, number of observations, number of ice observations and a quantity we call the mean-day-of-month. We only calculated a mean vapor value if the number of observations in the grid cell was greater than 160, the number of ice observations was less than 30, and the mean-day-of-month was with 6 days of the center of the month. There were a few satellites that failed to meet these requirements (F08 for Jan 1988 and Oct 1990 and F10 for Dec 1991) but that were used anyhow as they were the only satellite data available and were needed to preserve the time series.

In the second step, we used a drop-in-the-bucket simple method to combine the individual instrument maps into the final merged product. Post-hoc corrections were applied to AMSR-E and WindSat to account for remaining small offsets (shown in Figure 1). We determined that these offsets may be needed to compensate for two factors: time-of-measurement effects and variations in the calibration datasets used. The AMSR-E measurements are at 1:30pm/1:30am local time while the majority of the remaining radiometers measure in a 6 am-10am / 6pm - 10 pm window. Also, AMSR-E and WindSat were calibrated with only rain-free data as opposed to using all data (both rain-free and rainy) for the intercalibration process. This slight difference in calibration may account for why AMSR-E and

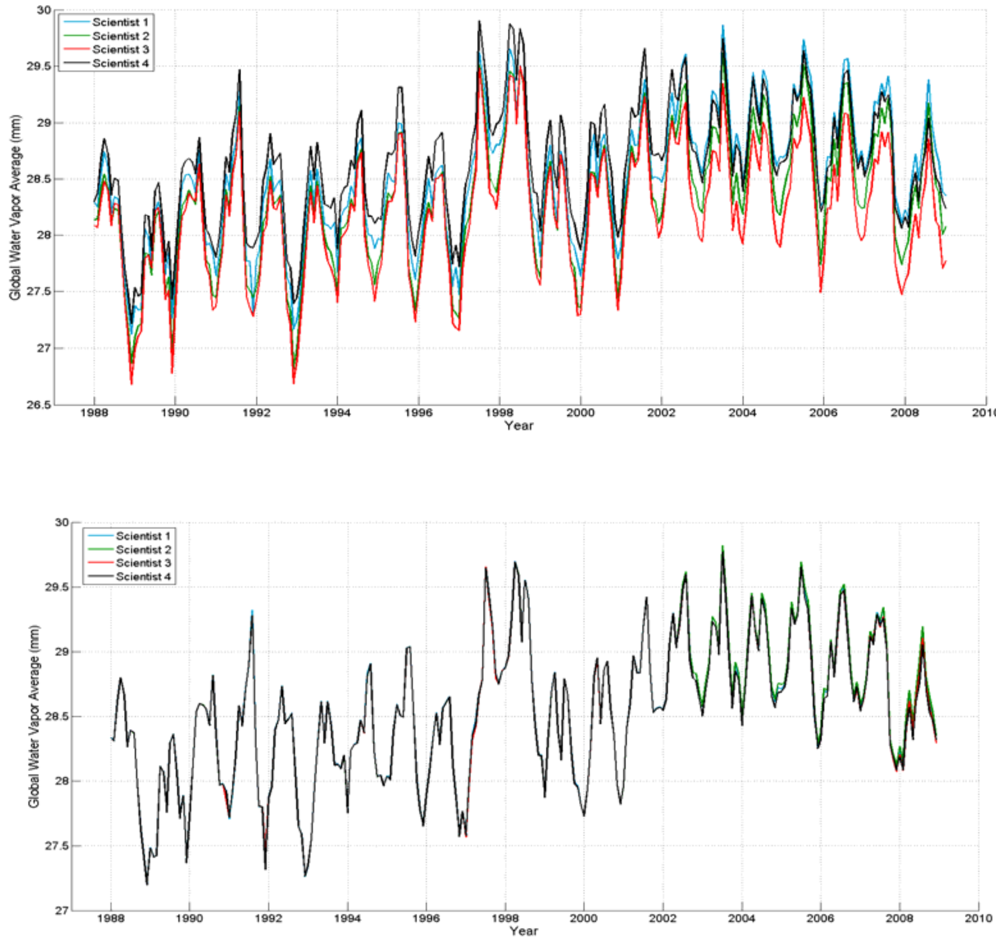

Figure 1: **Water vapor time series of four different vapor data sets constructed from the same source data using different construction methodologies. Plots shown are before (top) and after (bottom) requiring the same grid cell sampling in the calculations. This requirement unified all decisions that affected geographical sampling (such as rain flagging, ice flagging, and what data were used/excluded). Differences in the top plot vary by as much as 0.5 mm. The remaining small differences visible after 2002 in the bottom plot are due to AMSR-E and WindSat offsets as described in the text.**

WindSat are slightly different from SSM/I and SSMIS. To merge all vapor values into one product, however we need to account for these differences whatever the reason for the existence, so we apply small post-hoc corrections to AMSR-E (-0.2 mm) and WindSat (-0.05 mm) data prior to merging. We examined the differences created by using a simple additive offset or a more complicated multiplicative correction. The difference was negligible so we used the simpler additive correction in product production. The post-hoc correction was applied to every water vapor value for a given satellite prior to merging in the second step.

A 10-year climatology was calculated for 1988 to 2007. We will recalculate the climatology every 10 years with the next recalculation to be completed in 2017. These 12 monthly climatology maps were used to calculate TPW anomaly maps included in the data set. We update the product monthly, adding the data for the last month to the time series.

DATA PRODUCT CONTENTS AND ACCESS

The 25-year merged mean TPW file is available from Remote Sensing Systems as a single netCDF file with CF-compliant metadata. In addition, individual monthly files (as opposed to one complete data set) can be obtained from the NASA Global Hydrology Resources Center (GHRC DAAC). A full description of the data product is at both locations and read routines in IDL, Matlab and Python are provided to users. We have developed a browse environment for this data product. The environment allows the user to switch between monthly mean vapor plots, anomaly plots, the 12-month climatology and the TPW trend. The 'Get Data' button connects the user to the ftp server for data file download. One can access the interface at http://images.remss.com/cdr/climate_data_record_browse.html

The netCDF file contains mean TPW values on a 1-degree grid, a 12-month TPW climatology, monthly anomalies, a TPW trend map, and a time-latitude (hovmoeller) plot. In addition we include which satellites were used in the mean calculation, a single value for each month global mean precipitable water anomaly (60S to 60N), and a tropical mean TPW value (20S to 20N). An example of the monthly mean TPW for January 2008 and the global TPW trend map are shown in Figure 2.

The product contains data for the global oceans at 1-degree spatial resolution and represents monthly means for January 1988 to the date of the most recent processing. The product is updated monthly. There are no data values in regions of land, persistent ice, and coastal areas. TPW is reported in kg per square meter (kg/m-2) where 1 kg/m-2 is equivalent to 1 millimeter (mm). Valid TPW values range from 0 to 75 kg/m-2. Temporal coverage for this data set is monthly maps from Jan 1988 through to the present.

The product file is re-created every month by the 15th adding the previous month's value. The number of months in the data file will continue to increase until there are no more satellite radiometer instruments in operation.

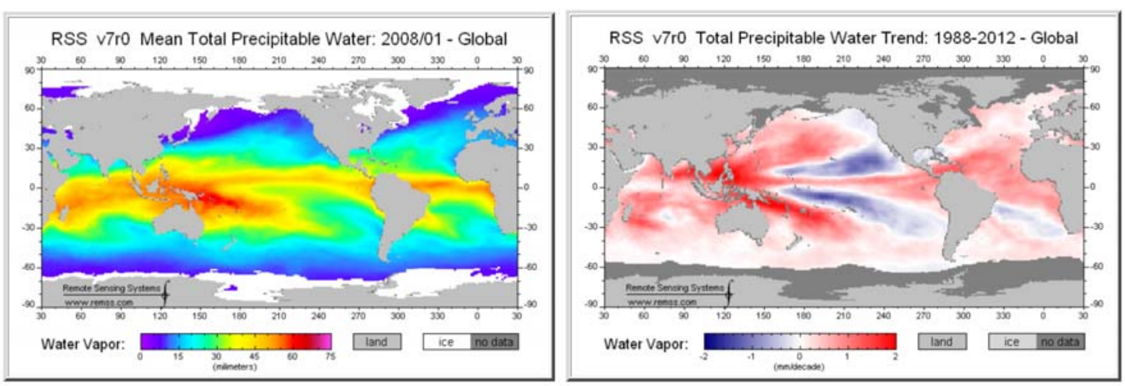

Figure 2: **Example of the mean TPW map for January 2008 and the Global TPW trend map for 1988 - 2012.**

MERGED PRODUCT QUALITY

The microwave radiometer data were carefully intercalibrated at the brightness temperature level and the V7 ocean products produced using a consistent methodology for all sensors. Water vapor is a particularly robust ocean parameter to retrieve from radiometer observations due to the strong spectral signature in the radiometer frequency measurements. Comparisons with small-island radiosonde measurements and GNSS (GPS) water vapor data demonstrate root-mean-square errors of ~1.0 mm. We find GNSS values are in better agreement with V7 water vapor values than with previous RSS data versions. This quality carries through to our data product. Figure 3 shows the agreement of each instrument water vapor data to the mean product. The average difference is less than 0.1 mm.

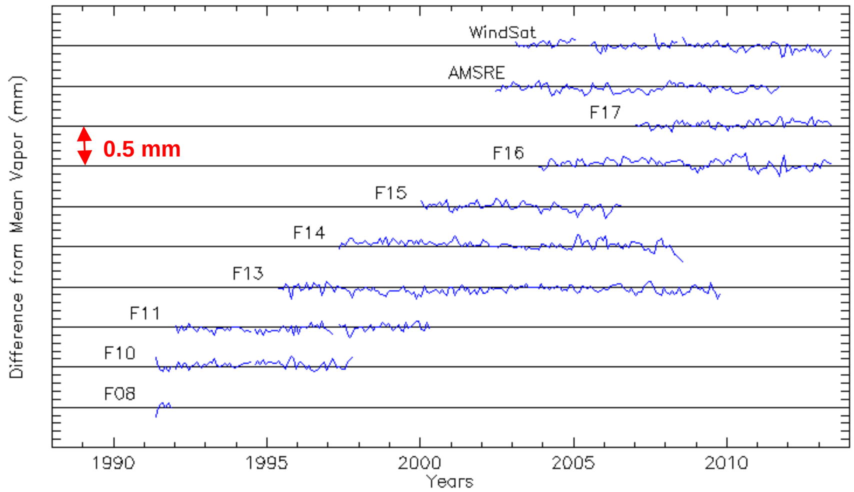

Figure 3: **Agreement of TPW measurements from 10 microwave radiometers. The average difference is less than 0.1 mm (kg/m-2)**

RECOMMENDATIONS FOR MAKING A CLIMATE DATA SET

From our work in developing this product we have created a list of recommended procedures to use in climate quality microwave product development. These are merely recommendations that we have found useful in this analysis.

Use intercalibrated data: We suggest itercalibrating on the brightness temperature level and then consistently processing throughout the instrument operation period. The intercalibration between different types of instruments such as SSM/I and AMSR-E requires a more careful process in which channel frequencies and footprint sizes are taken into consideration and accounted for. We use a radiative transfer model [

Use a minimum number of observations: The minimum number of observations for each data product grid cell is determined by the time period covered. Determination of this minimum number requires analysis of the instrument availability and geophysical parameters that could affect the product.

Remove ice: Especially important in microwave radiometer data is the presence of ice. Icebergs calve from the ice edges and move rapidly through grid cells, causing ephemeral effects on the data product. Ice needs to be calculated separately from data counts. One must set the minimum percentage of time that ice is present in such a way that the trends derived from the climate product are not affected.

Keep it simple: If any adjustments are needed to bring the measurements into alignment due to un-accounted-for factors, use simple additive adjustments rather than complicated multiplicative corrections. The outcome is often the same and the simpler method is easier to implement.

Use a two-step process: When using data from multiple satellites create the monthly products from each satellite first applying strict quality control measures and then merge the monthly products to create the merged product and climatology. The minimum number of observations and the presence of ice are applied to each individual satellite monthly product prior to combined product creation.

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