Inter-Calibration of SSM/I F13, SSM/IS F16, and WindSat
A Holistic Approach

Frank J. Wentz and the RSS Team
Remote Sensing Systems, Santa Rosa, CA

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Physical Oceanography & Earth System Data Records

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The Problem

**Volume:** Nearly 100 satellite-years of observations from Microwave Radiometers.

**Calibration:** Each sensor has its own unique set of Sensor Calibration Problems

**Precision:** High precision required for Climate Studies

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**Satellite Microwave Radiometers**

- F08
- F10
- F11
- F13
- QuikSCAT
- WindSat
- F14
- F15
- F16
- F17
- AMSR-E
Holism (from ὅλος holos, a Greek word meaning all, entire, total) is the idea that all the properties of a given system (physical, biological, chemical, social, economic, mental, linguistic, etc.) cannot be determined or explained by its component parts alone. Instead, the system as a whole determines in an important way how the parts behave.

Consistency is the steadfast adherence to the same principles, course, form, etc.
Basic Elements of Producing Earth Science Data Records

**Climate Constraints**
Hydrologic Balance: Evaporation = Precipitation
Constant Relative Humidity (Clausius–Clapeyron)

**Direct Validation of Geophysical Retrievals**
Ocean Buoys (SST, wind, rain)
Radiosondes and GPS (vapor)
Satellite Radars (wind)

**Sensor Calibration**
Pointing Errors (geolocation)
Attitudes Errors (roll, pitch, yaw)
Along-Scan biases
Sun Intrusion in Hot Loads
Emissive Antennas
Antenna Pattern Correction (spillover, cross pol)

**Radiative Transfer Model (RTM) & Retrieval (RTM⁻¹)**
EP ➔ RTM ➔ TA ➔ RTM⁻¹ ➔ EP
Methodology: Continuous Updating and Reprocessing

Validation $\rightarrow$ **EP Adjustments** *(i.e., clear sky bias, high vapor bias)*

$\downarrow$

Geophysical Retrievals

$\rightarrow$ **Retrieval Algorithm**

$\leftarrow$ **Automatic**

$\rightarrow$ **Radiative Transfer Model**

Simulated Antenna Temperatures

$\downarrow$

**Calibration** $\rightarrow$ **RTM Adjustments**

Sensor Adjustments

$\rightarrow$ **Sensor Antenna Temperatures**

**Cycle Time** $\approx \frac{1}{2}$ Year
Climate Constraint: Constant Relative Humidity

Nearly all climate models predict a near constant Relative Humidity with global warming. This means total water vapor will increase with rising air temperatures at a rate ≈ 7%/K.

- Original MSU air temperatures showed little warming while SSM/I water vapors showed significant moistening.
- This contradiction was due to errors in the original calibration of MSU.
- Results here show with proper calibration MSU air temperature and SSM/I water vapors agree.
- The “MSU controversy” was resolved.

Figure from: Wentz and Schabel: Nature, 403, 2000, Precise climate monitoring using complementary satellite data sets.
Climate Constraint: Evaporation = Precipitation

On global, monthly time scales, Evaporation must equal Precipitation
(Variability in storage term is extremely small)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation</td>
<td>961 mm/yr</td>
<td>10.1 mm/yr (1.1%)</td>
<td>12.6 mm/yr/decade (1.3%/decade)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>950 mm/yr</td>
<td>12.7 mm/yr (1.3%)</td>
<td>13.2 mm/yr/decade (1.4%/decade)</td>
</tr>
<tr>
<td>Total Water</td>
<td>28.5 mm</td>
<td>0.292 mm (1.0%)</td>
<td>0.354 mm/decade (1.2%/decade)</td>
</tr>
</tbody>
</table>

Figure from: Wentz, Ricciardulli, Hilburn, Mears: Science, July 13, 2007, How Much More Rain Will Global Warming Bring?
Climate Constraint: Radiative Cooling Limit on Evaporation

Nearly all climate models predict an enhanced radiative cooling that is balance by an increase in latent heat from precipitation

<table>
<thead>
<tr>
<th>Climate Models</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wentz et al., Science, July 13, 2007:</td>
<td>4 mm/year/decade</td>
</tr>
<tr>
<td>Yu and Weller, BAMS, Vol 88, No 4, April 2007:</td>
<td>13 mm/year/decade (C-C rate)</td>
</tr>
<tr>
<td>Hamburg Ocean Atmos. Parameters &amp; Fluxes</td>
<td>very large</td>
</tr>
</tbody>
</table>

Explanation of Christy Result

Found a trend in the Tropical Air-Sea Temperature Difference: -0.1 K/decade (1979-1999)

Used to support their MSU Lower Tropospheric Temperature Retrieval, which indicated:
In the tropics, the troposphere is not warming as fast as the surface.
(Later was found to be incorrect)

From the standpoint of evaporation:
A trend of -0.1 K/decade in the air-sea temperature difference would greatly increase the trend in global evaporation
Geophysical Validation: Wind Speed (1)

There are ample *in situ* and radar winds to validate MW radiometer wind retrievals.
New Results for WindSat Wind Retrievals Versus Other Wind Speed Datasets
Individual overpasses: RMS variation of SSMI minus buoy difference = 1.0 m/s
Monthly Averages: RMS variation of SSMI minus buoy difference = 0.1 m/s (lag-1 correlation =0.46)
Estimate error bar is 0.05 m/s/decade at 95% confidence
SSM/I trend minus the buoy trend is 0.02 m/s/decade.
Yearly corrections (0.05-0.10 m/s) are applied to SSMI winds
These results indicate we are doing better than 0.1 K/decade

Figure from: Wentz, Ricciardulli, Hilburn, Mears: *Science*, July 13, 2007, How Much More Rain Will Global Warming Bring?
Bias (SSMI minus GPS) = -0.07 mm
Std. Dev. = 1.9 mm
Num Obs = 53,730
Credit: Carl Mears (to be published)
Distinguishing Sensor Errors from RTM Errors

Same $\Delta T_a$ (simulated minus measured) plotted versus different parameters

Same color scale: $\Delta T_a$ goes from -3K to +3K

- RTM Error Diagnostics
- Sensor Calibration Error Diagnostics

- Sun intruding into hot load

Y=Wind, X=SST
Y=Wind, X=Vapor
Y=Vapor, X=SST

Y=Orbit Position, South Pole to South Pole, X=Orbit number (5 years)
STEP-1: All Level-1 (NASA) or TDR (DMSP) datasets are reversed engineered back to radiometer counts

STEP-2: Apply a completely **consistent** set of Level-1 Routines to produce calibrated antenna temperatures

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Geolocation Analysis</th>
<th>Attitude Adjustment</th>
<th>Along-Scan Correction</th>
<th>Absolute Calibration</th>
<th>Hot Load Correction</th>
<th>Antenna Emissivity</th>
<th>Resampling Algorithm</th>
<th>Rain Threshold</th>
<th>OOB Q/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSM/I</td>
<td>NRL/RSS</td>
<td>No</td>
<td>Yes</td>
<td>APC</td>
<td>Yes</td>
<td>0</td>
<td>Opt. Intrep.</td>
<td>0.18 mm</td>
<td>Ocean RTM</td>
</tr>
<tr>
<td>TMI</td>
<td>Goddard</td>
<td>Dynamic</td>
<td>Yes</td>
<td>TA Offsets</td>
<td>No</td>
<td>3.5%</td>
<td>Opt. Intrep.</td>
<td>0.18 mm</td>
<td>Ocean RTM</td>
</tr>
<tr>
<td>AMSR-E</td>
<td>RSS</td>
<td>Fixed</td>
<td>Yes</td>
<td>APC</td>
<td>Yes</td>
<td>0</td>
<td>Opt. Intrep.</td>
<td>0.18 mm</td>
<td>Ocean RTM</td>
</tr>
<tr>
<td>AMSR-A</td>
<td>RSS</td>
<td>Dynamic</td>
<td>Yes</td>
<td>APC</td>
<td>Yes</td>
<td>0</td>
<td>Opt. Intrep.</td>
<td>0.18 mm</td>
<td>Ocean RTM</td>
</tr>
<tr>
<td>WindSat</td>
<td>NRL/RSS</td>
<td>Fixed</td>
<td>Yes</td>
<td>APC</td>
<td>Yes</td>
<td>0</td>
<td>Earth-Grid Weighted Average</td>
<td>0.18 mm</td>
<td>Ocean RTM</td>
</tr>
<tr>
<td>SSMIS</td>
<td>RSS</td>
<td>No</td>
<td>Yes</td>
<td>APC</td>
<td>Yes</td>
<td>1 - 4% Note: 1</td>
<td>Opt. Intrep.</td>
<td>0.18 mm</td>
<td>Ocean RTM</td>
</tr>
</tbody>
</table>

Note 1: Over 19 – 92 GHz
Version – 7

100 Satellite-Years of Earth System Data Records
Consistently Processed with Common Algorithms

The Products

- SST (not all sensors)
- Wind Speed
- Columnar Water Vapor
- Columnar Liquid Water
- Rain Rate

The Sensors

- SSM/I: F08, F10, F11, F13, F14, F15
- SSM/IS: F16, F17, F18
- TMI
- AMSR-E and AMSR-A
- WindSat

Availability

Backbone: F13, WindSat, F16&17 undergoing final beta testing
Will be made publicly available April 2010.

Remaining Sensors will be made publicly available end of 2010.

Products will be hosted at www.remss.com