Closing the Water Cycle Using a Constellation of Satellites

Kyle Hilburn and Frank Wentz
Remote Sensing Systems, Santa Rosa, CA, USA

2008 Spring AGU Meeting
Fort Lauderdale, Florida, USA
29 May 2008
Earth Observation with a Constellation of Radiometers

SSM/I: F13, F14, F15; TMI; AMSR-E

Remote Sensing Systems
www.remss.com
Rain Rate Intercalibration Completed

- Our new rain algorithm: **UMORA (Unified Microwave Ocean Retrieval Algorithm)** is a modification of the Wentz and Spencer (1998) approach
  - Improved beamfilling: modeling saturation and resolution dependence (removed biases among different sensors)
  - Improved rain column height: constrained to data (removed tropical biases)
  - Improved calibration: 0.05K

**F13 (green), F14 (blue), F15 (purple), AMSR-E (orange), TMI (red), Global Precipitation Climatology Project (black)**
Indirect Validation using Hydrological Consistency

- Global evaporation balances global precipitation (with a static, latitude-dependent adjustment to rain)
  - Average evaporation: 962 mm/year
  - Average precipitation: 951 mm/year
  - Imbalance on the order of 1%

- Trends in evaporation and precipitation have the same magnitude as trends in water vapor, in contrast with climate models
  - Evaporation trend: + 1.3 % / decade
  - Precipitation trend: + 1.5 % / decade
  - Water Vapor trend: + 1.4 % / decade

Climate prediction models predict a muted response by precipitation see Wentz et al., 2007, Science.
Increase in Heavy Rain

These are for global oceans, tropical oceans the same. Consistent with Trenberth.
The Hierarchical Context

- Evaporation (E)
- Precipitation (P)
- Water Vapor (V)

### The Science paper
(one-dimension: time)


Averaging over time (~month) at a particular location we have:

$$\text{div } Q = E - P$$

### Water Vapor Transport (Q) (a vector)
### Water Vapor Transport Divergence (div Q)

The next step: add 2-D space
First Approach: Feature Tracking

• Water Vapor Transport
  – Initial idea: using feature tracking to deduce the transport velocity
  – Problems with non-conservation of water vapor and the optical flow aperture problem, also issues near coastlines
  – Tested using on-orbit simulation with NCEP wind and humidity
  – Monthly average transports are ok... but the divergence field lacks proper structure
Current Approach: Using Radiometer Derived Wind Vectors

• In the process of testing feature tracking, found that the surface wind vector was highly correlated with the water vapor transport vector (as would be expected)

• Ardizzone/Atlas Winds (Level 2.5)
  – Based on our radiometer wind speeds, but assigned a direction
  – A very high quality climate data record
  – Enthusiastically recommend its use!
Trajectory Analysis with Atlas Winds

Note that particle positions (determined by Atlas winds) line-up with water vapor.
Seasonal Cycle of V-Wind and Rain

using TMI UMORA rain rates and Atlas Level-2.5 TMI winds

Rain occurs where there is convergence

Color: Meridional Wind (m/s)
Contours: Rain Rate (4, 6, 8, 10 mm/hr)
going from thin to thick

TMI: 1998-2005
What goes into PMWC Product?

- **Precipitation (Rainfall + Frozen Precip)**
  - SSM/I, TMI, and AMSR-E rain rate retrievals +
  - Diurnal and other intersatellite adjustments (UMORA paper) ^
  - Rain to precip adjustment (lat/mon climo; based on GPCP) ^

- **Evaporation**
  - Reynolds SST (X,C-band only available since 1998,2002)
    - Note: need C-band for global (warm+cold) SSTs
  - SSM/I, TMI, and AMSR-E wind speed retrievals +
  - Buoy-based wind speed adjustment (Science paper) ^
  - RH, TA-TS climatologies (Science paper)

- **((Water Vapor) Transport) Divergence**
  - SSM/I, TMI, and AMSR-E water vapor retrievals +
  - SSM/I, TMI, and AMSR-E wind vectors (Atlas L2.5) ^
  - SFC to WVT adjustment (climatology, based on NCEP)

+ RSS Product
^ Based on RSS Product
SFC to WVT Adjustment

\[ \tilde{T} = \frac{\tilde{Q}_{WVT}}{V} = \frac{\int_0^{p_s} \tilde{W} q \frac{dp}{g}}{V} \]

\[ V = \int_0^{p_s} q \frac{dp}{g} \]

Note: also use variational minimization for adjustment

Using simple latitude-dependent climatological adjustment for speed and direction based on NCEP

Anticyclonic turning with height

Surface wind vector

sea surface

Surface wind vector

WVT Vector

WAA: Veering

CAA: Backing

specific humidity

Wind Vectors
High Latitude GPCP-UMORA Differences Are Seasonal

GPCP / UMORA rain rate ratio for 1988-2005

Note that UMORA is much lower than GPCP in the winter hemisphere. The patterns are similar to Petty (1995) snow observations.
PMWC vs Liu Products

• **PMWC (Passive Microwave Water Cycle) Product**
  – Ocean only, whole globe
  – 0.25 deg, Monthly resolution
  – Available from July 1987 – December 2006
  – WVT-U, WVT-V, WVT-Div, Evap, Precip, Vapor

• **Liu Transport Product**
  – Ocean only, -30 to +30 N
  – 0.5 deg, Daily resolution
  – Available from July 1999 – December 2005
  – WVT-U, WVT-V
New PMWC V01a Dataset

- Discussion on Google Groups
- Based on collaboration with Pete Robertson
- Wentz et al (2007) wind speed adjustment
  - Based on buoys
  - Magnitudes less than 0.1 m/s
- No net effect on trend
Water Vapor Transport
All comparisons 2000-2005

P M W C

L i u

P M W C – L i u
Water Vapor Transport

WVT Speed

WVT Direction

Liu

PMWC

PMWC
Water Vapor Transport Divergence

PMWC

Evap - Precip

Evap - Precip

WVT Div

Liu

Evap - Precip

Evap - Precip

WVT Div
Precipitation Implied by Hydrological Balance

Zonal Average
2000–2005

Precipitation
Rain Rate
PMWC (Evap – WVTD)
Liu (Evap–WVTD)
Vapor and Wind Trends

**Black line: SST trend**

**Vapor Trend:**
- zonal average structure like SST

**Wind Trend:**
- latitude dependent structure different than SST

**Correlation Calculations:**

\[
\frac{d(SST)}{d(Vapor)}: \quad \text{Correlation: } R = 0.94
\]

Vapor trend:
- zonal average structure like SST

\[
\frac{d(SST)}{d(Wind)}: \quad \text{Correlation: } R = -0.28
\]

**Wind Speed**
- latitude dependent structure different than SST
Transport Trends

Black line: transport trend

Zonal Vapor Transport

Meridional Vapor Transport

(Vapor Trend Contribution) \times (Mean vapor) = (Trend in vapor transport)
Conclusions

• Intercalibration of rain rates completed
  – *JAMC* paper describes rain algorithm changes
  – Used in *Science* paper; found precipitation trends in balance with evaporation trends, but in conflict with climate models

• PMWC product available
  – Monitoring WVT with a constellation of satellites
  – Available from Kyle (hilburn@remss.com) and CREW FTP
  – PMWC and Liu transports are similar, but have some important differences
  – PMWC and Liu divergence values are different, PMWC product balances better

• Thoughts about the water cycle
  – Balancing E, P, and WVT Div is much like the vertical velocity estimation problem in meteorology
  – The 2-dim (i.e., regional) water cycle is apparently more sensitive than widely appreciated