# Intercalibration of Passive Microwave Rain Rates

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*Remote Sensing Systems, Santa Rosa, CA, USA*

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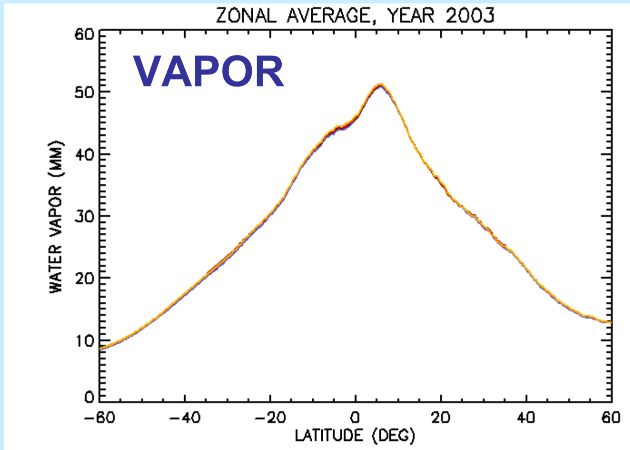
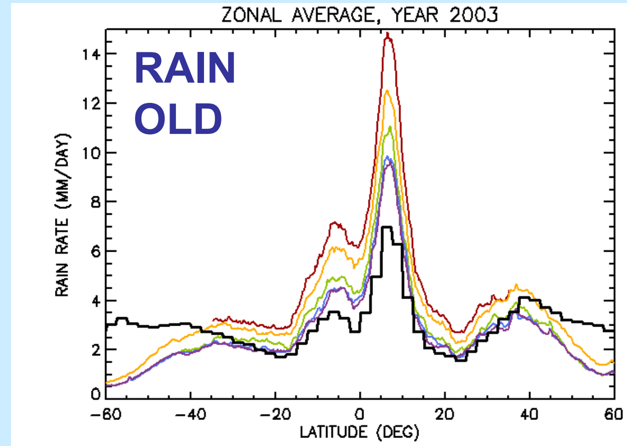
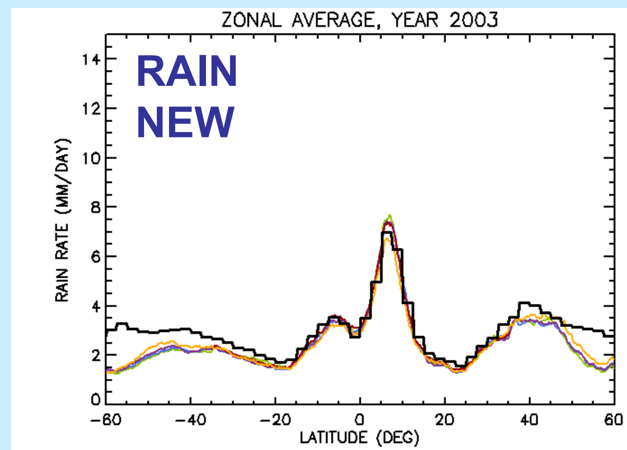
# What prompted this work?




Old rain rates disagreed by >30% and were unrealistically high in the tropics – how can vapor agree but not rain?

New rain rates agree to within 3% and most of the remaining discrepancies are due to time-of-day effects




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

# Wentz & Spencer Rain Algorithm

- Rain retrievals from all SSM/I, TMI, and AMSR over the ocean
- Passive microwave rain retrieval is inherently an *underdetermined* and *non-unique* problem
  - Our approach is not Bayesian – no database of profiles
- Dual polarization measurements are used to accurately separate the scattering and emission signals
- Emission is related to surface rain rate through three components:
  - Rain Column Height (a climatological function of SST)
  - Cloud/Rain Partitioning (a global relationship)
  - Beamfilling (a dual-frequency approach)
- Our new rain algorithm: **UMORA** (**U**nified **M**icrowave **O**cean **R**etrieval **A**lgorithm) is a modification of the Wentz and Spencer (1998) approach

# What changes did we make?

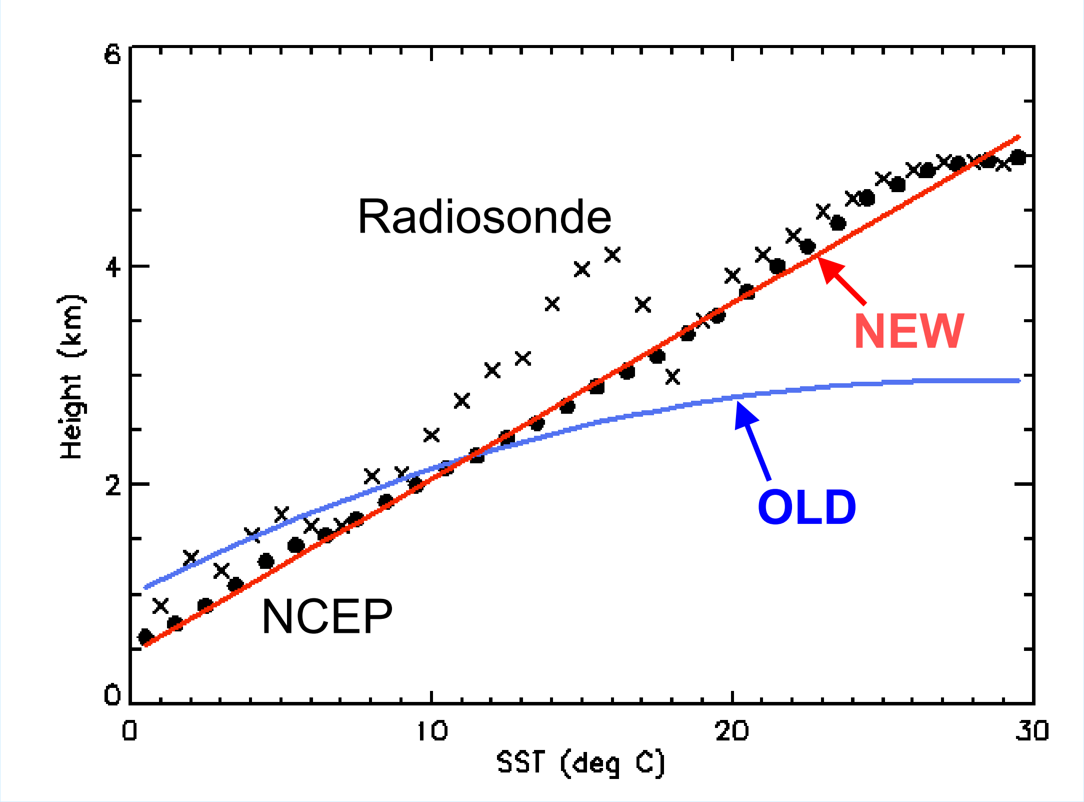
- Rain column height
  - Old Wentz and Spencer rain rates were unrealistically high in the tropics due to inappropriate rain column heights
  - Used NCEP and radiosondes to re-derive our climatological expression

- Rain/Cloud partitioning
  - Old Wentz and Spencer algorithm had the same relationship for all sensors
  - Possibly a function of resolution (larger footprint should have a lower threshold); but no changes were made because adjusting the partitioning has a small effect on average rain rate, but a large effect on rain fraction

- Non-uniform beamfilling adjustment
  - Old Wentz and Spencer rain rates did not agree among the sensors because beamfilling is a function of sensor resolution
    - Footprints: 32 km (SSM/I) vs 12 km (AMSR-E and TMI)
  - Heavy rain causes radiometer saturation, which must be modeled when using a dual-frequency approach for the beamfilling correction

- Calibration of brightness temperatures down to 0.05 K
  - Water vapor retrieval is robust, only requires calibration accuracies of 0.2 K
  - New calibration performed in order to get accurate wind trends

# Improved Rain Column Heights




**NEW HEIGHTS**

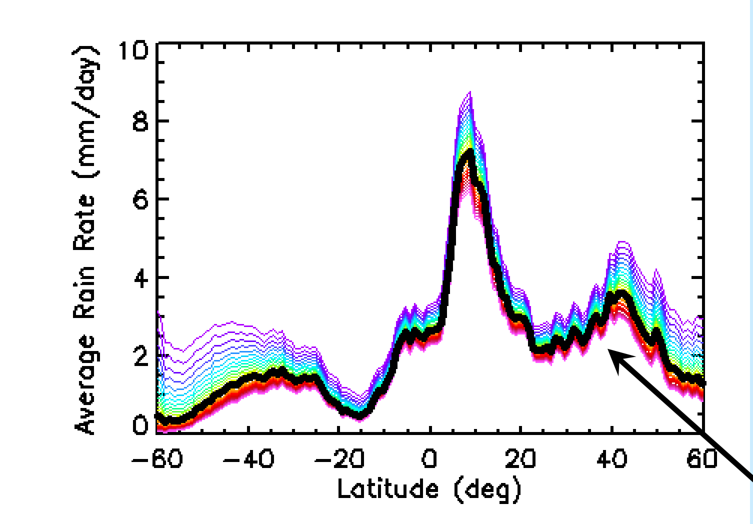
**Based on NCEP**

**Match radiosonde data in the tropics**

**A little lower in the extratropics**

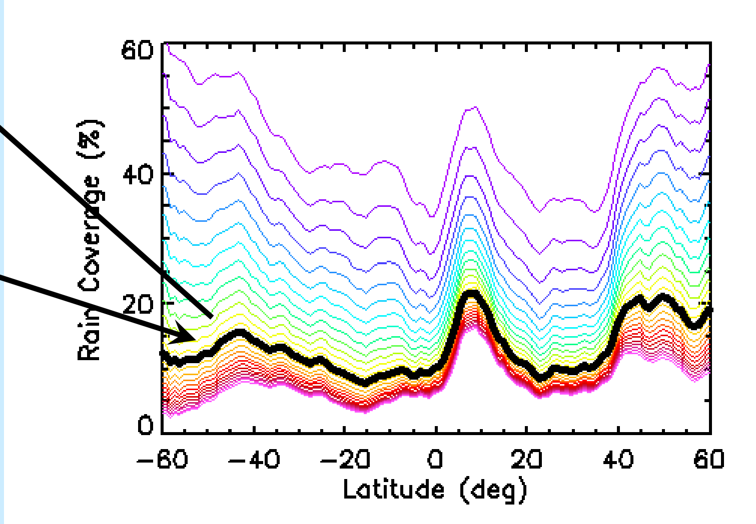
**Very few radiosondes in 10-20 deg SST regime**

# Rain/Cloud Partitioning



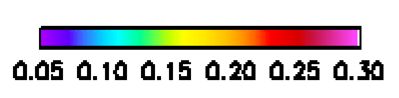

**Modest Changes**
**In Average Rain Rate**

**Large Changes**
**In Rain Fraction**

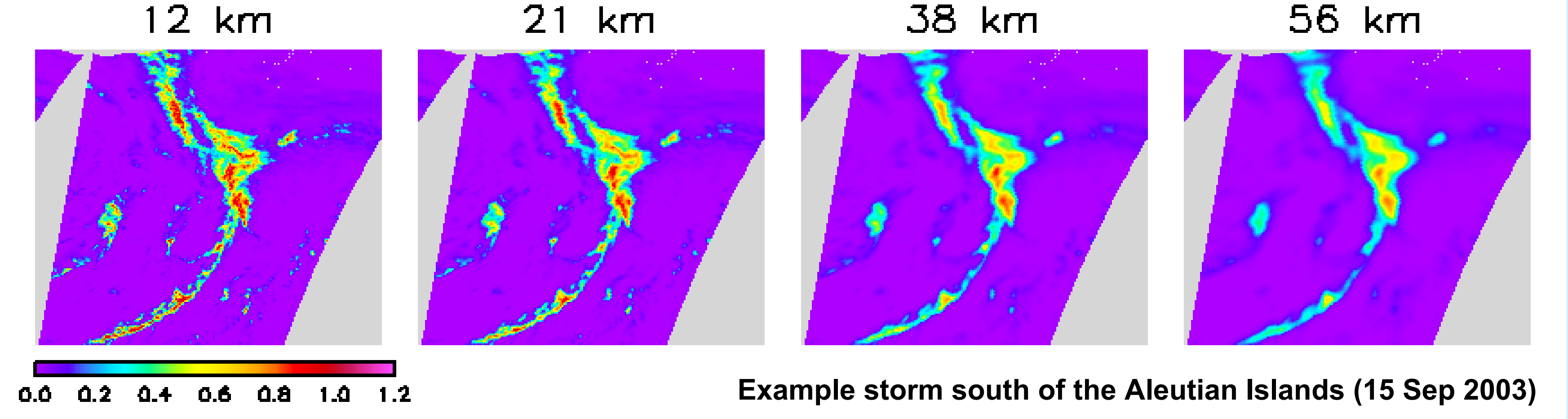



If yellow lines represent the range of believability, then adjusting this is not a good way to change the rain rate.

**Heavy Black Line: 0.18**
**columnar cloud/rain threshold**



# Using AMSR to Simulate and Model the Resolution Effect




**Example storm south of the Aleutian Islands (15 Sep 2003)**

37 GHz Attenuation:

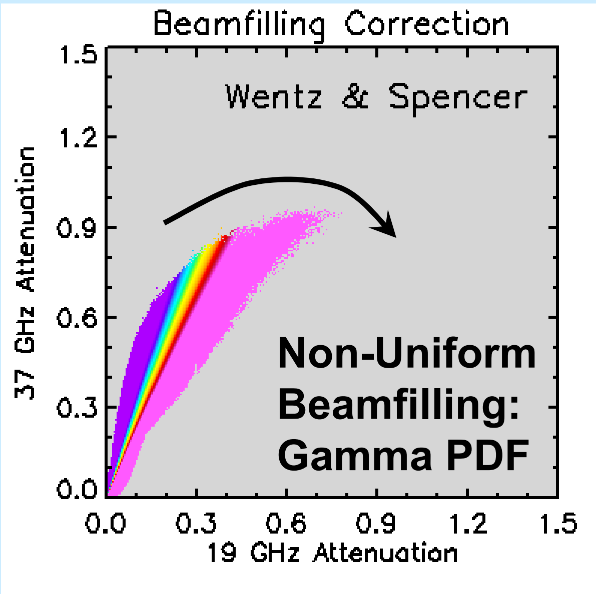
| Resolution (km) | Scene Average (non-dim) |
|---|---|
| 12 | 1.17 |
| 21 | 0.95 |
| 38 | 0.86 |
| 56 | 0.79 |

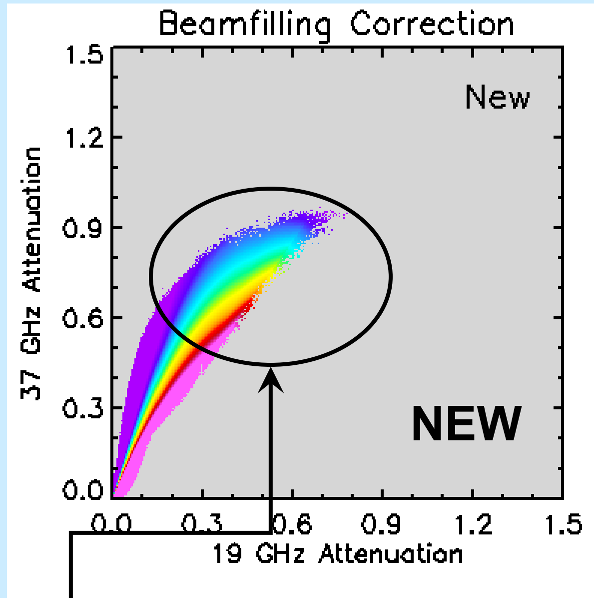
AMSR has highest resolution – use AMSR brightness temperatures, artificially resampled to lower resolutions (using OI), to get at functional relationship between resolution and biasing.

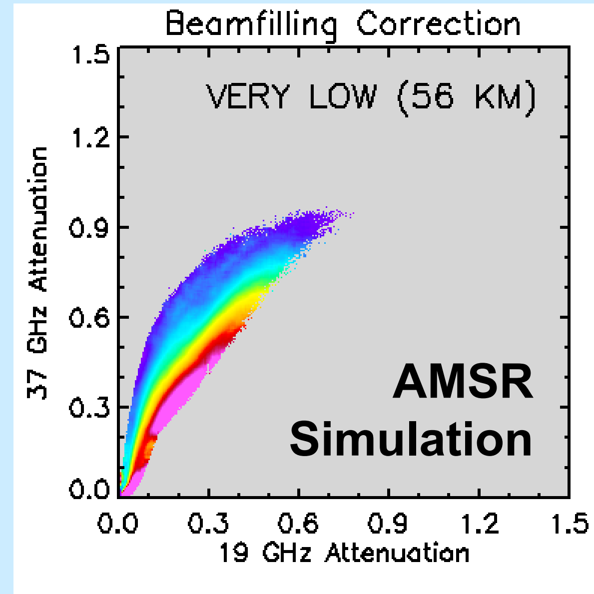
Lower resolution is not only smoothed, but the average attenuation values are biased low – this is “the beamfilling effect”.

By modeling the resolution effect we remove differences between SSM/I (~32 km), TMI and AMSR-E (~12 km).

# Modifying Wentz & Spencer



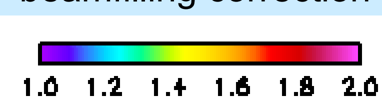




New correction also requires resolution of input attenuations

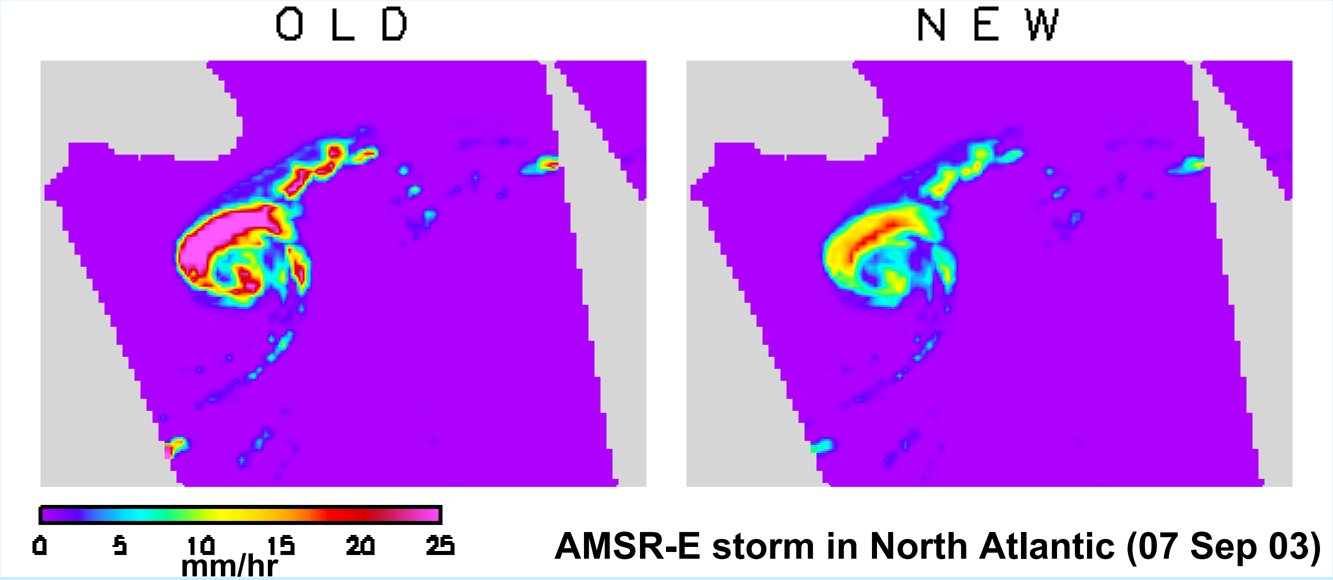
Variability of liquid water in the footprint is related to the 19-to-37 GHz attenuation ratio

In heavy rain, attenuation measurements saturate; 37 GHz saturates more quickly than 19 GHz; this saturation is now modeled and better matches AMSR simulation

Multiplicative beamfilling correction



# The Impact of Modeling Saturation




- Failure to account for the differences in saturation causes over-correction in the centers of storms and in isolated rain cells

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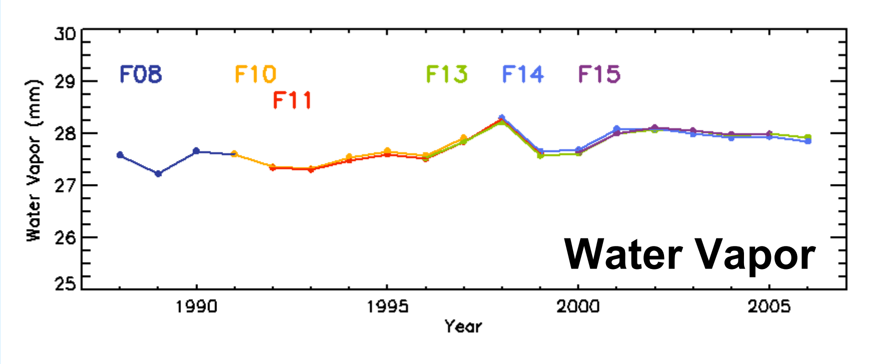
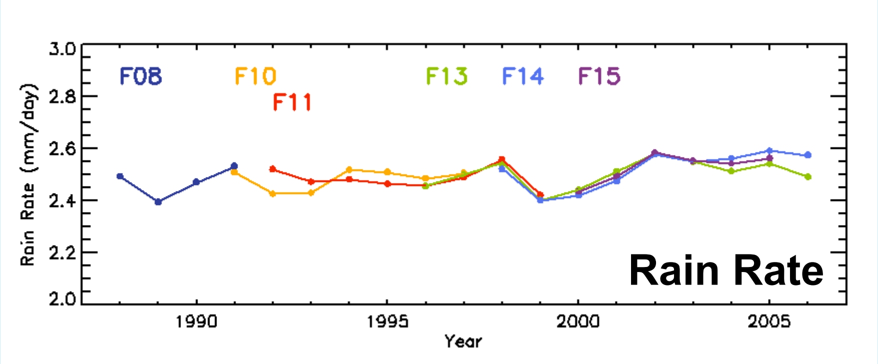
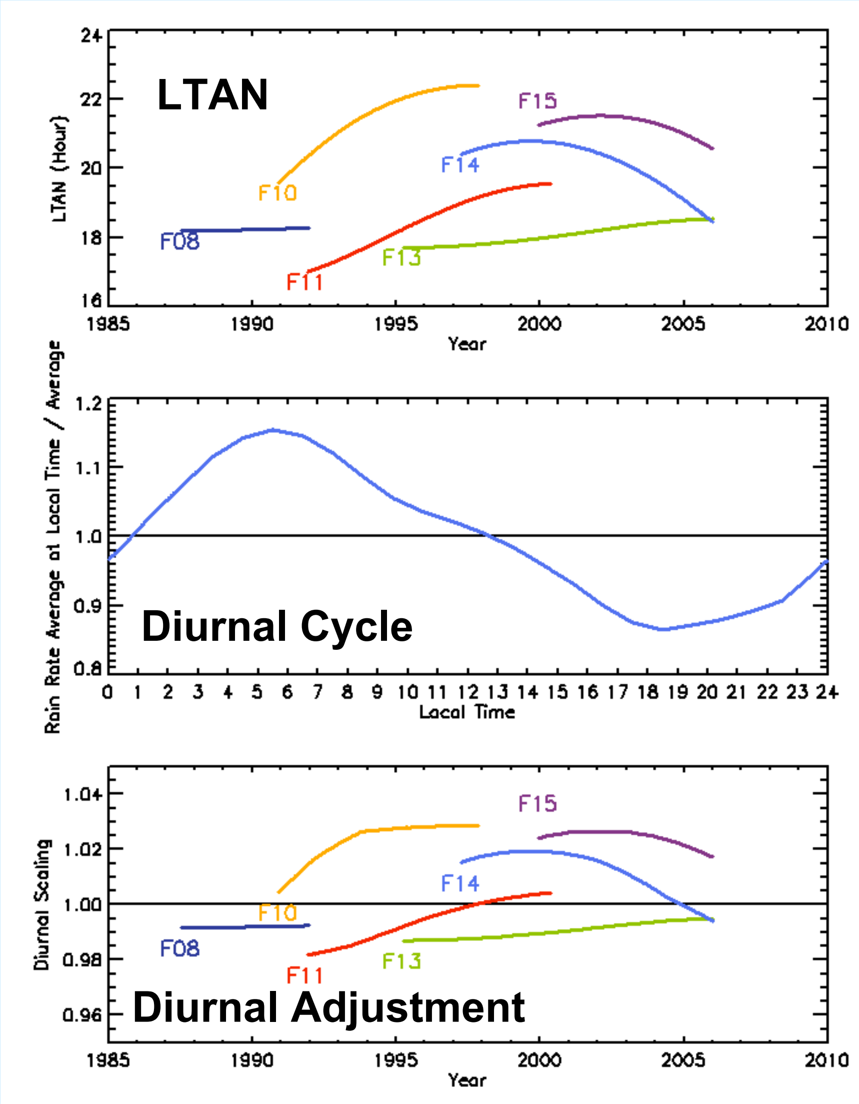
# We Now Have A Stable, Consistent 20-Year Data Record




- A stable, consistent 20-year data record for climate monitoring
- Satellites carefully intercalibrated on the brightness temperature level
- Water vapor still in excellent agreement
- Rain rates now agree to within 3% with the improved rain algorithm
- Remaining differences mostly due to time-of-day effects
  - Likely that nonlinearity and/or multiplicative errors from hot-load misspecification and/or spillover are involved for non-diurnal differences

# Time-of-day Effects are a Major Source of Intersatellite Rain Differences



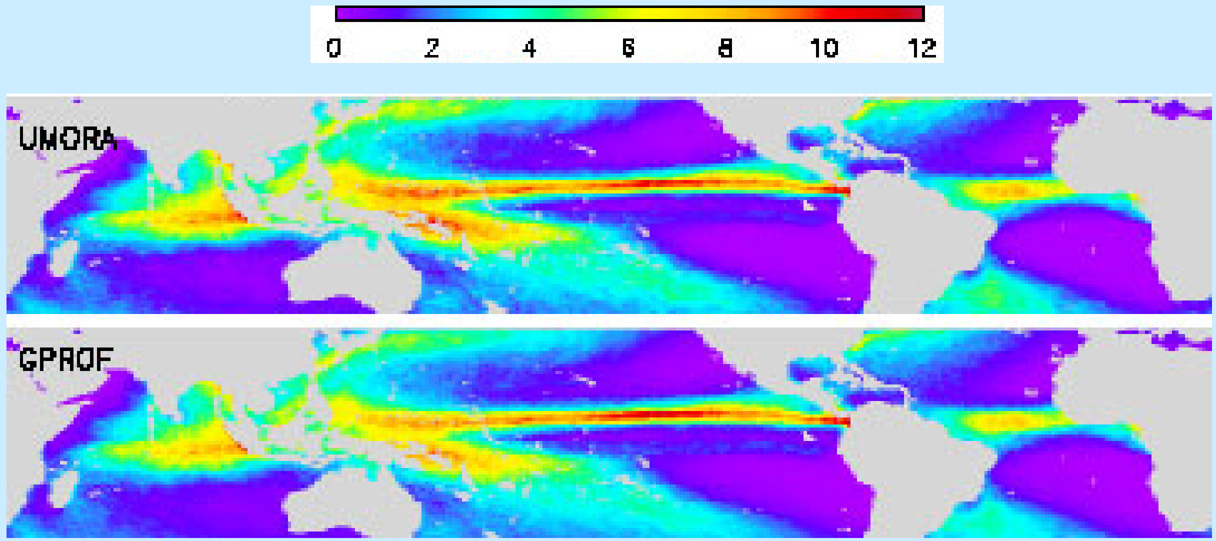

| Satellite | Diurnal Scaling | Scaling |
|---|---|---|
| F08 | 0.992 | 0.990 |
| F11 | 0.994 | 0.983 |
| F13 | 0.991 | 0.964 |
| F14 | 1.012 | 1.015 |
| F15 | 1.024 | 1.031 |
| F10 | 1.023 | 0.908 |

**In general, early morning satellites (F08, F11, and F13) have adjustments that decrease the average, whereas, late morning satellites (F10, F14, and F15) have adjustments that increase the average. F10 is an outlier with known instrument problems.**

**These scaling factors are not applied to the publicly available UMORA products.**

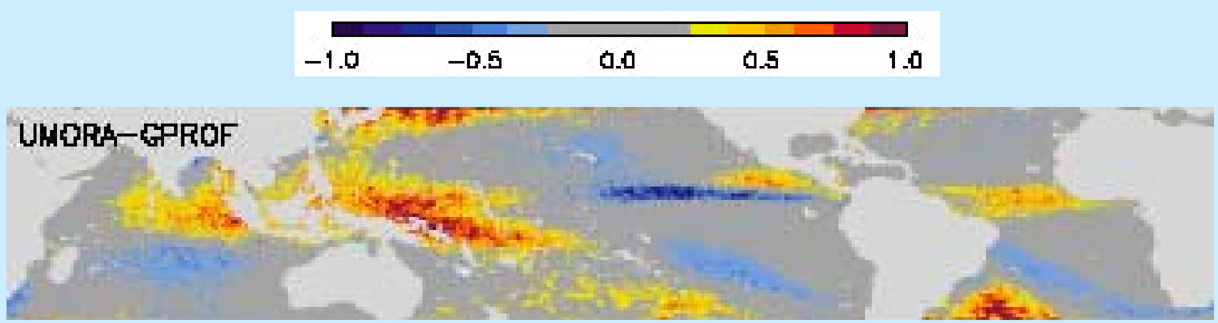
# UMORA and GPROF Agree Well on Average

**TMI for 1998-2005**




**UMORA**
**2.66 mm/day**

**GPROF**
**2.63 mm/day**




**UMORA-GPROF**
**1.2%**

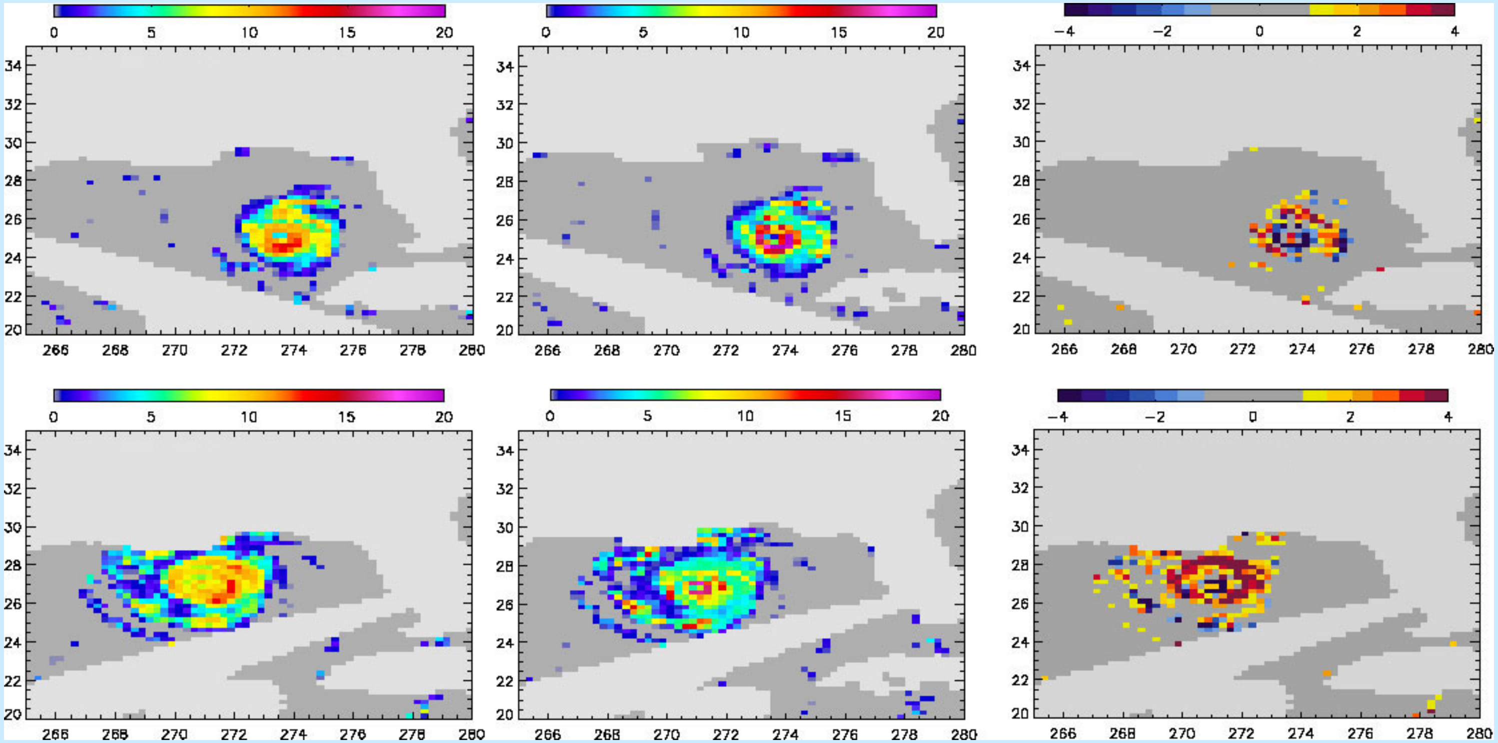
# Hurricane Katrina

**shows the storm-scale structural differences**

**UMORA** | **GPROF** | **UMORA-GPROF**

**28 Aug 2005 03:24 Z TMI**

**28 Aug 2005 21:33 Z TMI**



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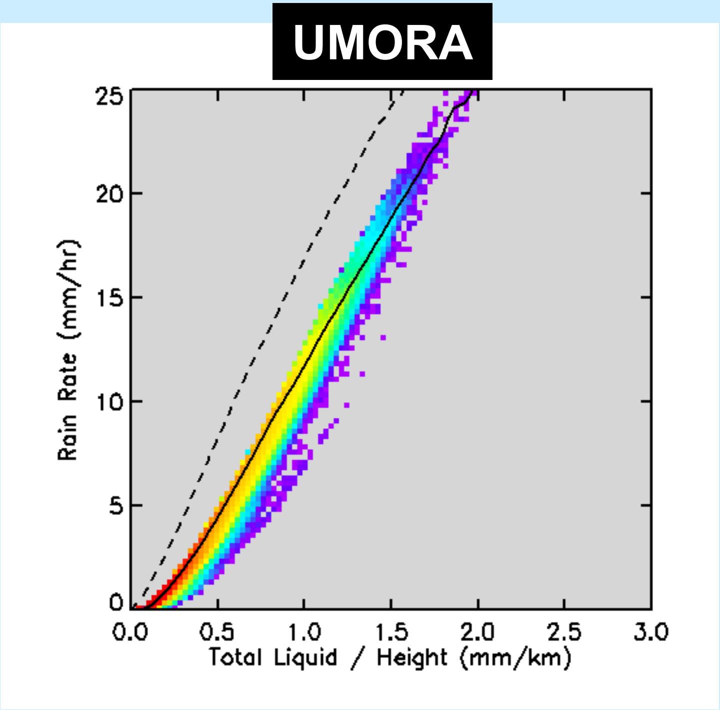
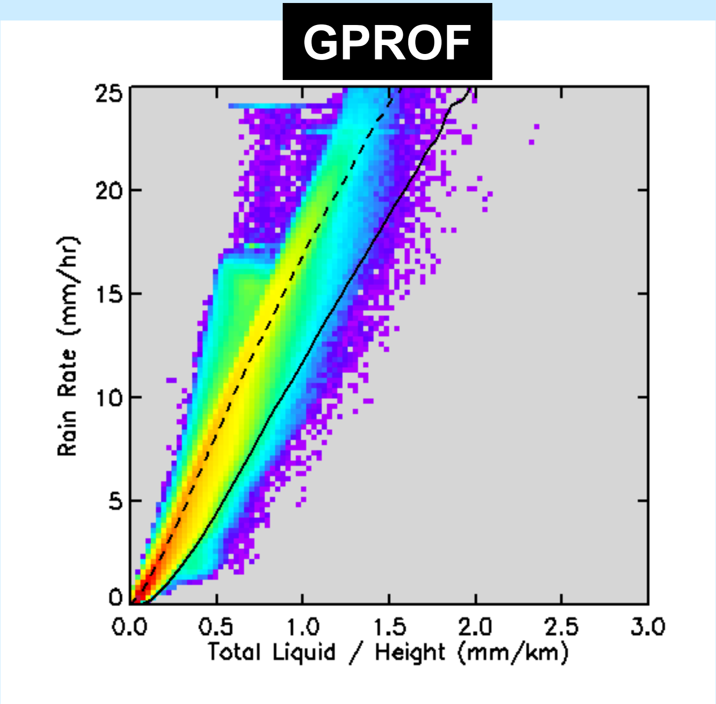
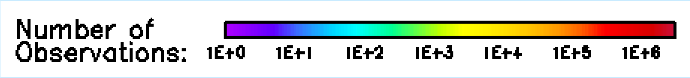
# A Very Different Relationship Between Surface Rain Rate and Total Liquid Water




We have found that UMORA retrieves more liquid water than GPROF . . .



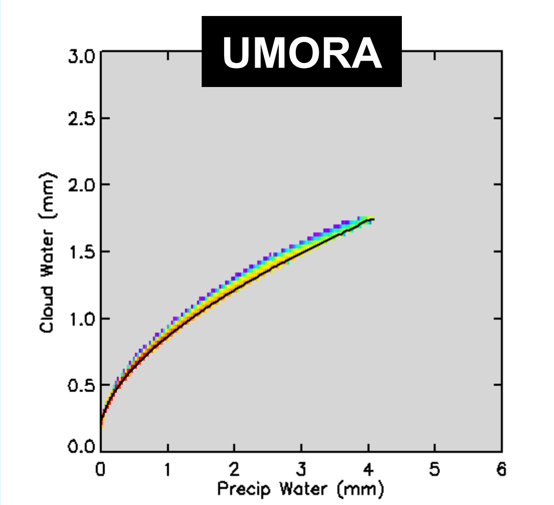

. . . But GPROF retrieves a higher surface rain rate for a given amount of liquid water

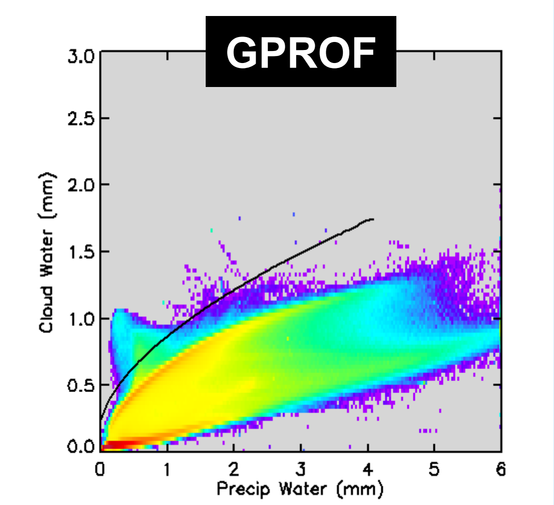


# Microphysical Differences

**explain the total liquid water / surface rain rate differences**

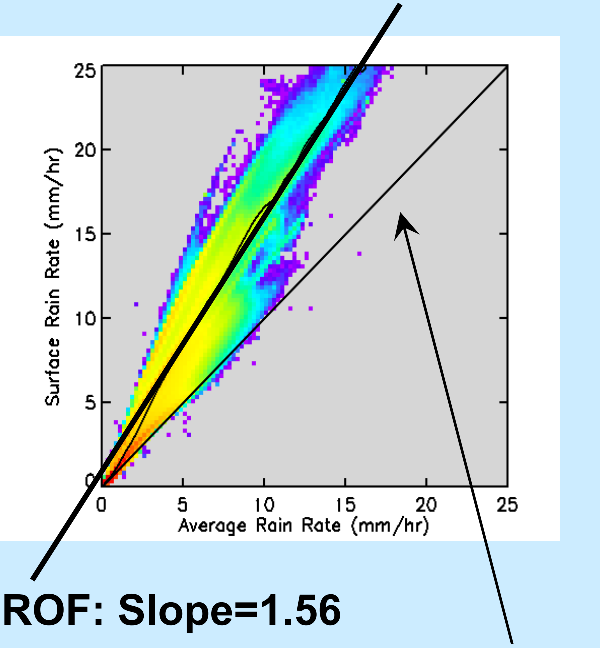
## Cloud / Rain Partitioning

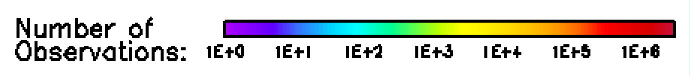



**GPROF cloud < UMORA cloud**
**Typically: 0.5-1.0 mm lower**

## Sfc/Avg Rain



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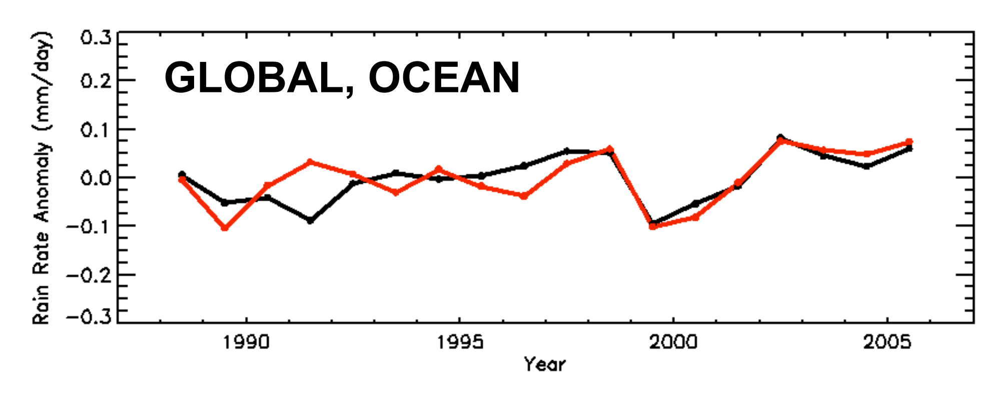
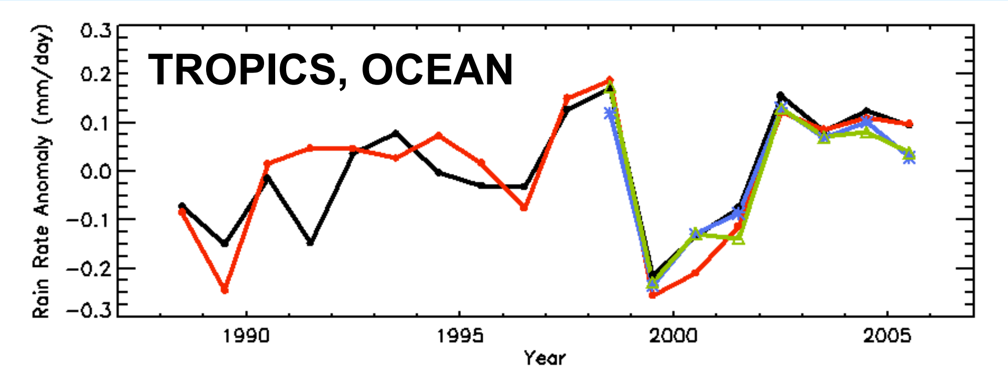
# Rain Rate Trends From Different Rain Products Are Similar



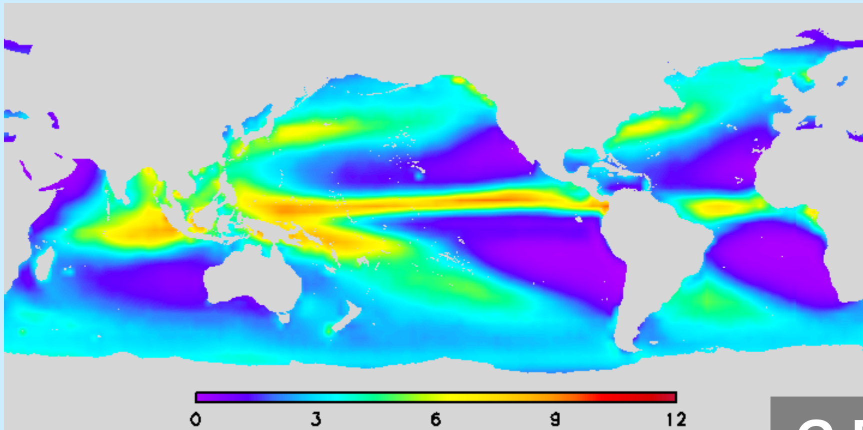

Several leading rain rate datasets show similar trends and variability

GPCP (black)
UMORA SSM/I (red)
UMORA TMI (blue, asterisk)
GPROF TMI (green, triangle)

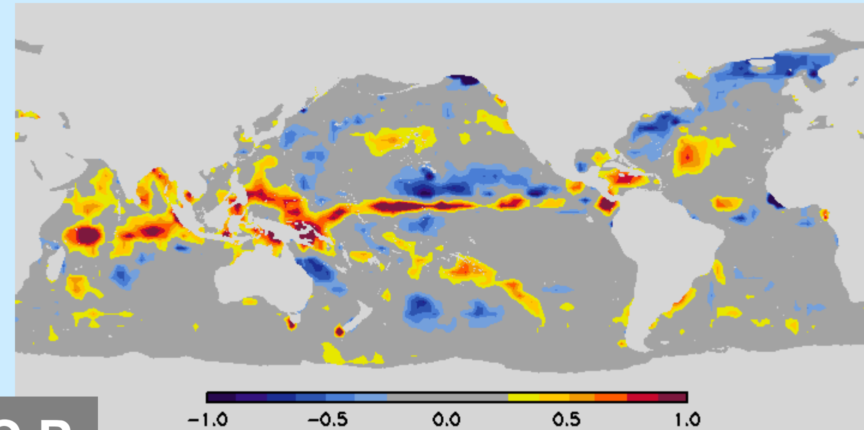


# GPCP and UMORA Rain Trends Are Similar

**Rain Rates (mm/day) for 1988-2005**

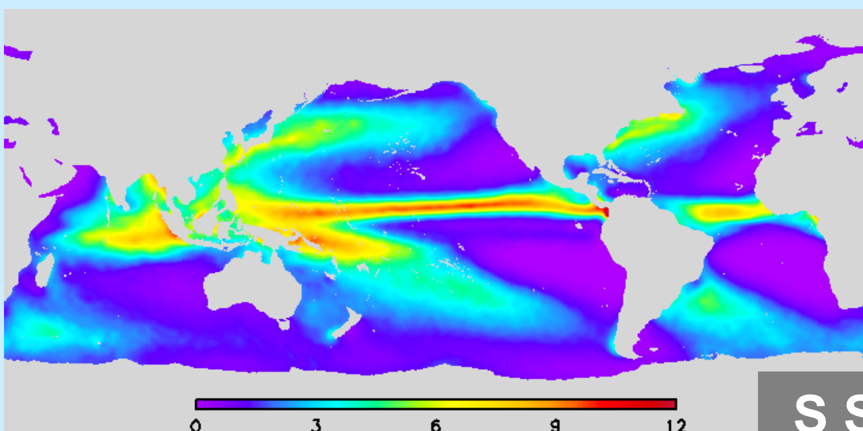


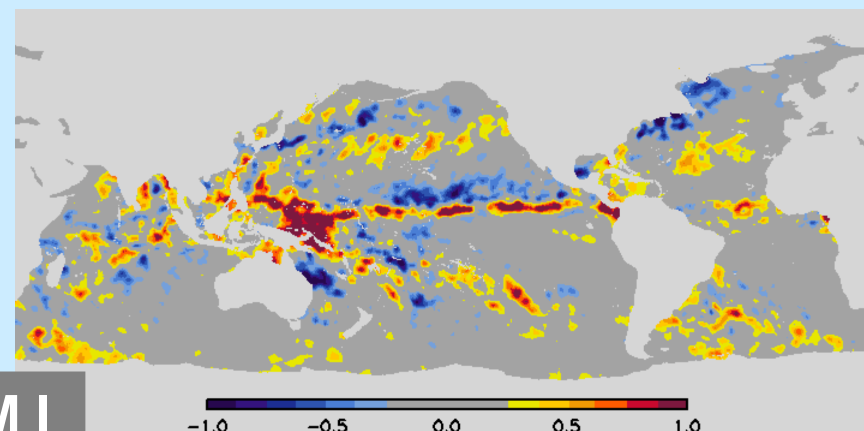

**G P C P**
**(+1.5%/dec)**




**17-Year Average**

**17-Year Trends**




**S S M I**
**(+1.4%/dec)**
**(UMORA)**

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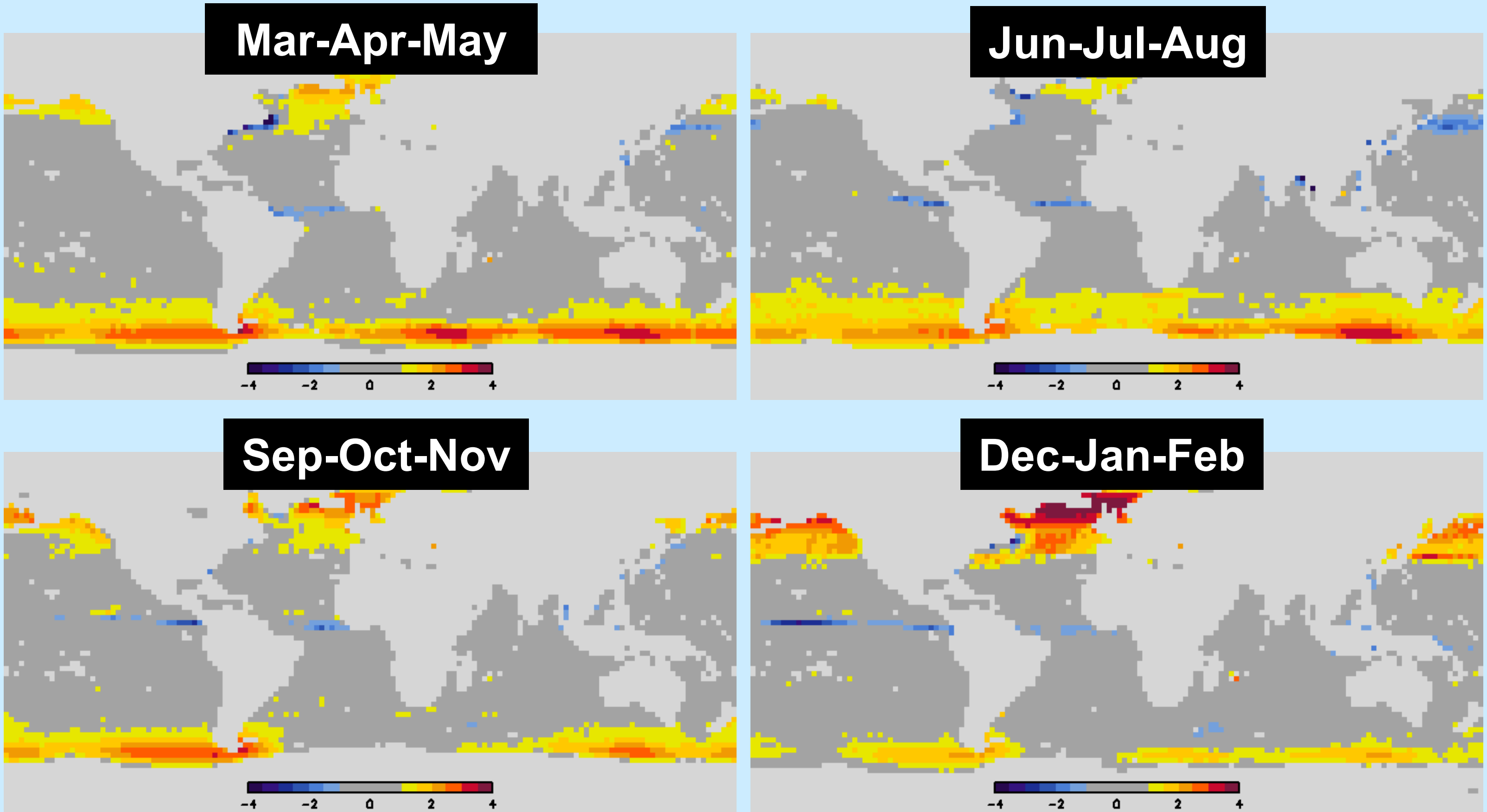
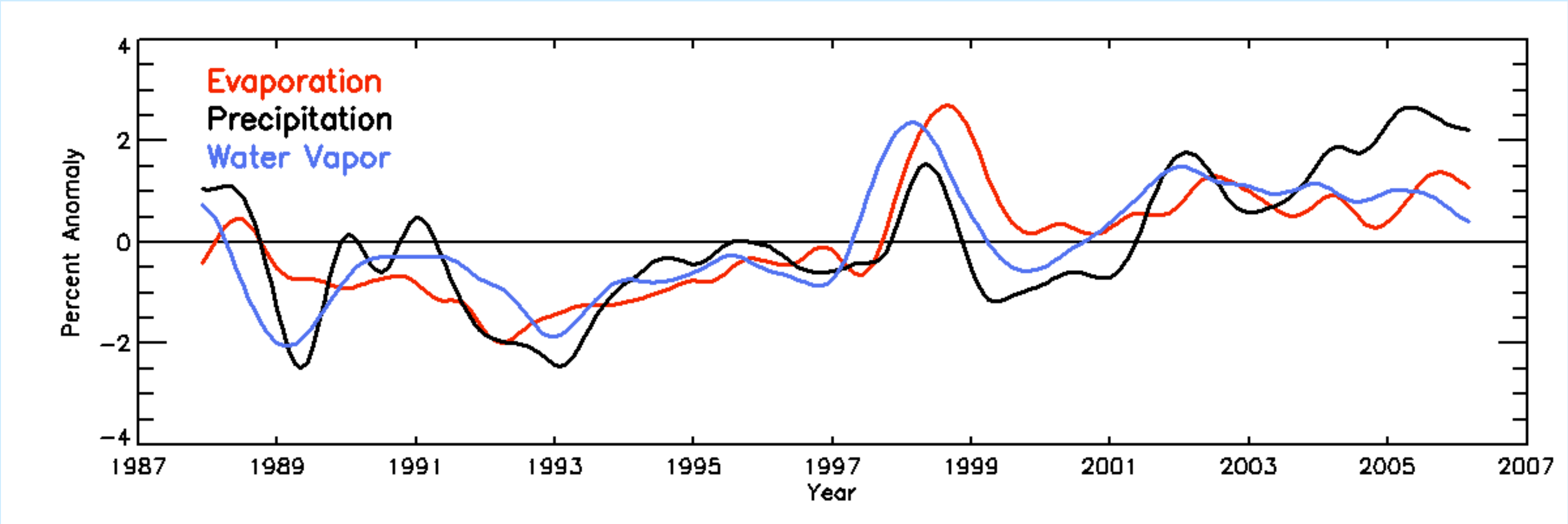
# High Latitude GPCP-UMORA Differences Are Seasonal

**GPCP – UMORA rain rate differences (mm/day) for 1988-2005**




**Note that UMORA is much lower than GPCP in the winter hemisphere.**
**These patterns are similar to Petty (1995) snow observations.**

# 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*.**

# Your Input is Valued

- Data are freely available to anyone: **www.remss.com**.
- We encourage data user questions and comments: hilburn@remss.com.
- Rain algorithm paper in review:
  - Journal Applied Meteorology and Climatology
  - I will be happy to furnish pre-print
- Hydrological balance paper:
  - Wentz et al., “How much more rain will global warming bring?”, Science, 13 July 2007.

# Conclusions

- **UMORA rain rates from different sensors and satellites agree to within 3%**
  - Most of the remaining discrepancy is due to time-of-day effects
- **UMORA and GPROF agree well on average, but have storm-scale differences**
  - Microphysical parameterizations are different
- **Hydrological balance considerations suggest that rain rates in the current version of UMORA are too low in the extratropics**
  - Possibly because UMORA does not retrieve frozen precipitation
  - GPCP averages are more realistic (in terms of the hydrological balance)
- **UMORA, GPROF, and GPCP all have similar positive trends in rain rate**
  - Similar spatial patterns and the magnitudes agree to within 50%
  - Despite remaining uncertainties, satellite rain rates can be carefully used with reasonable confidence for climate studies on time scales of years to decades