Towards an improved climate data record of the cloud liquid water path from microwave radiometry

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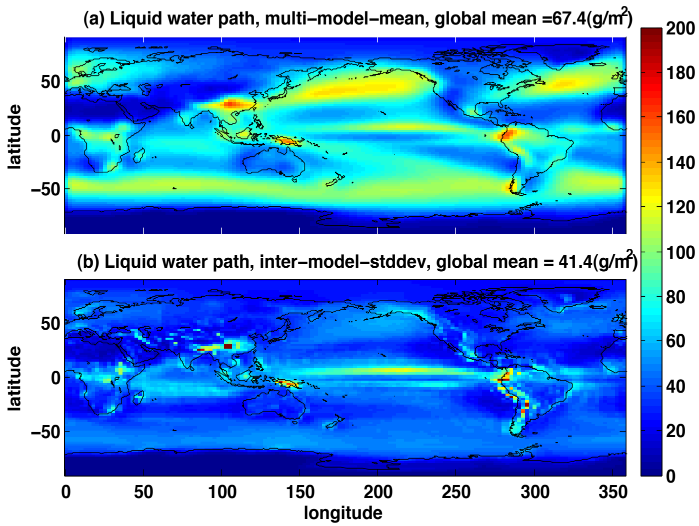
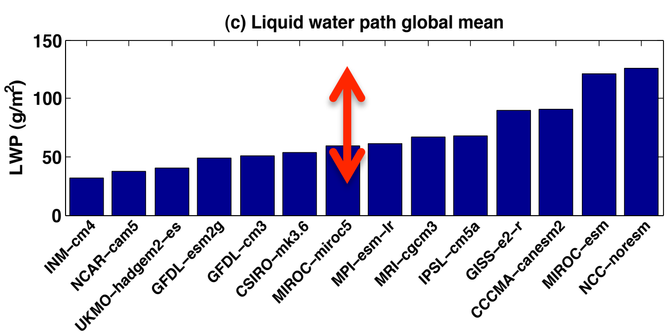
Cloud Liquid Water Path

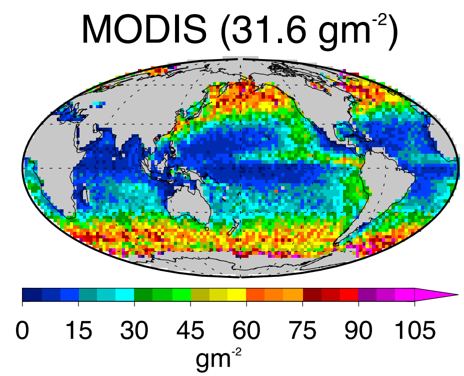
Models have a large spread

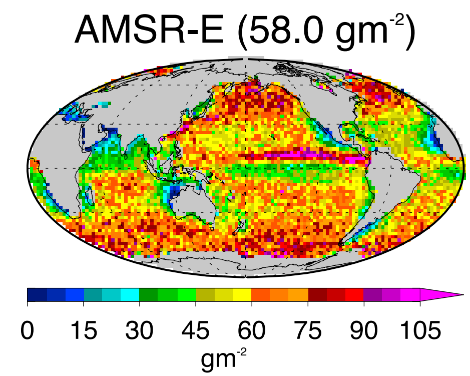


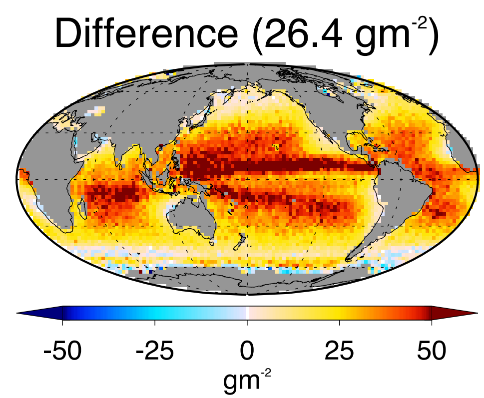


- Output from CMIP-5 historical runs

No consensus in observations







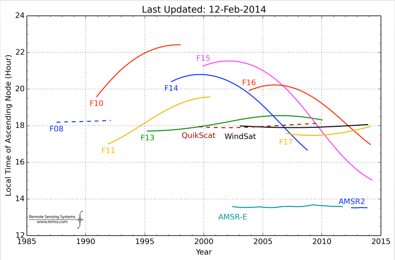
- Common data filter for ice-free daytime pixels
- MODIS collection 5.1
- AMSR-E version 6

Multi-sensor Advance Climatology (MAC)-LWP Climatology)

Inputs and Formulation

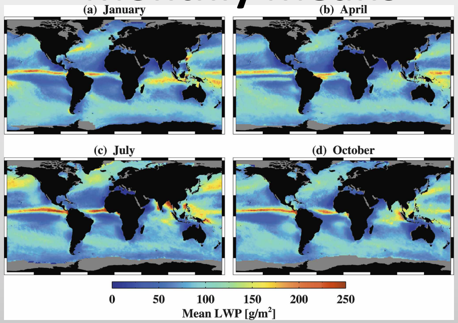
TABLE 1. Properties of microwave sensors used in this work.

Sensor	Platform	Dates employed	ECT range (LT)	Orbit	Footprint (km)
SSM/I	F8	Jan 1988–Dec 1991	0615	Polar	32
SSM/I	F10	Dec 1990–Nov 1997	1942–2226	Polar	32
SSM/I	F11	Dec 1991–May 2000	1700–1938	Polar	32
SSM/I	F13	May 1995–Dec 2005	1739–1833	Polar	32
SSM/I	F14	May 1997–Dec 2005	2049–1908	Polar	32
SSM/I	F15	Dec 1999–Dec 2005	2133–2042	Polar	32
AMSR-E	*Aqua*	Jun 2002–Dec 2005	1330	Polar	12
TMI	TRMM	Dec 1997–Dec 2005	Varies	Equatorial	13

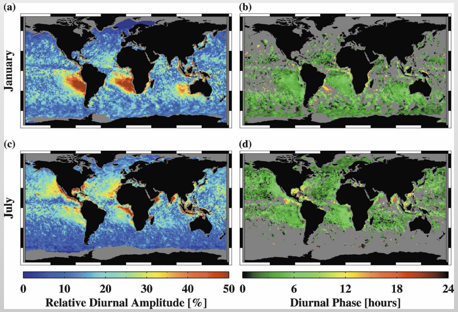


$$\mathrm{LWP}(Y_i, t_i) = \overline{\mathrm{LWP}}(Y_i) + A_1 \cos\omega(t_i - T_1) + A_2 \cos 2\omega(t - T_2) + n(t),$$

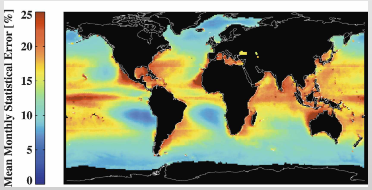
Monthly Means



Diurnal Cycle



Random Uncertainty



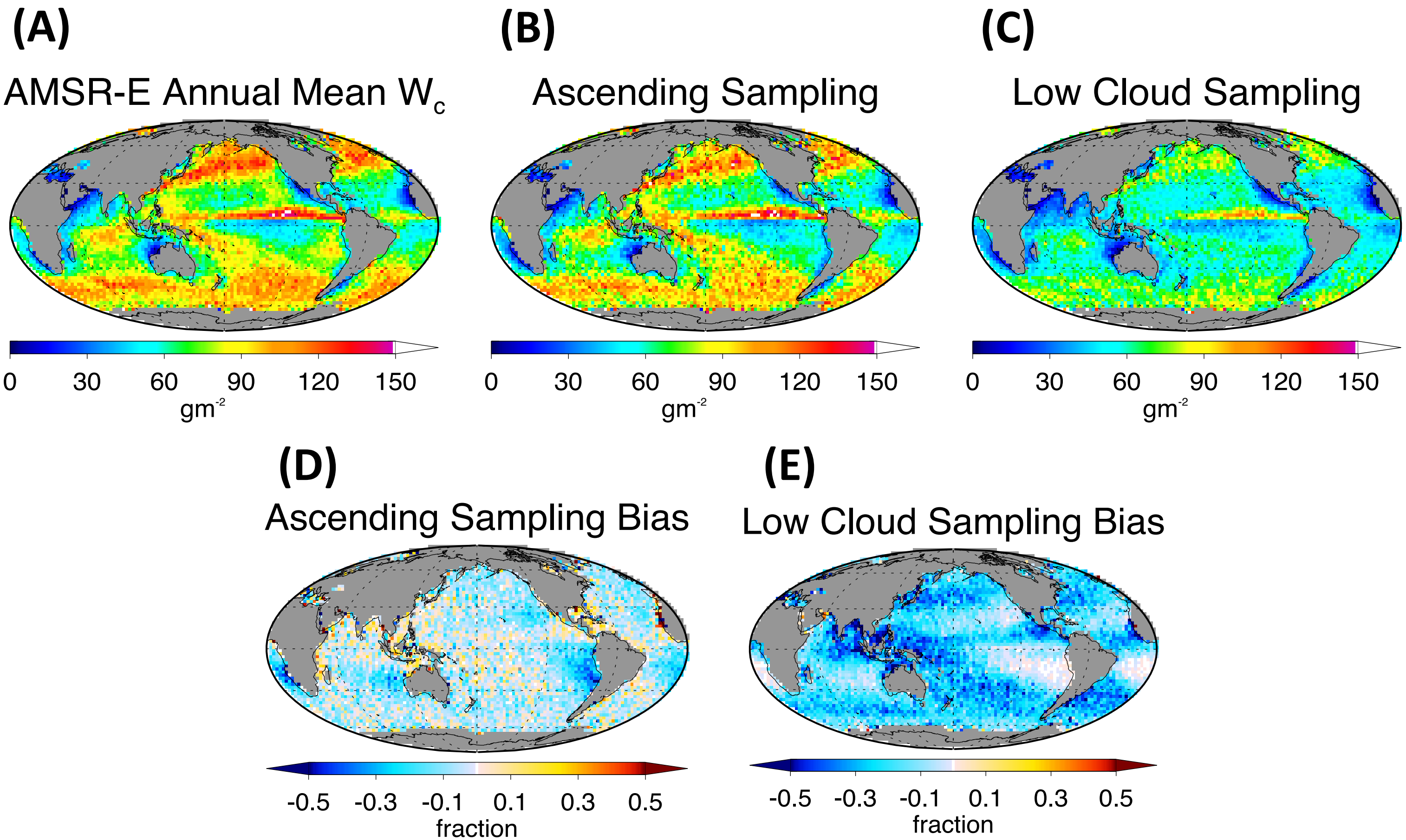
Benefits

1. Consistent inter-calibrated input data set
   – Based on Remote Sensing System SSM/I since 1987, AMSR-E, and TMI
2. No systematic regional *sampling* biases
3. Accounts for diurnal, inter-annual and monthly variability
4. Explicit uncertainty estimation

Limitation

1. Must be bias corrected. Precipitation related biases are particularly difficult.

Why Microwave?



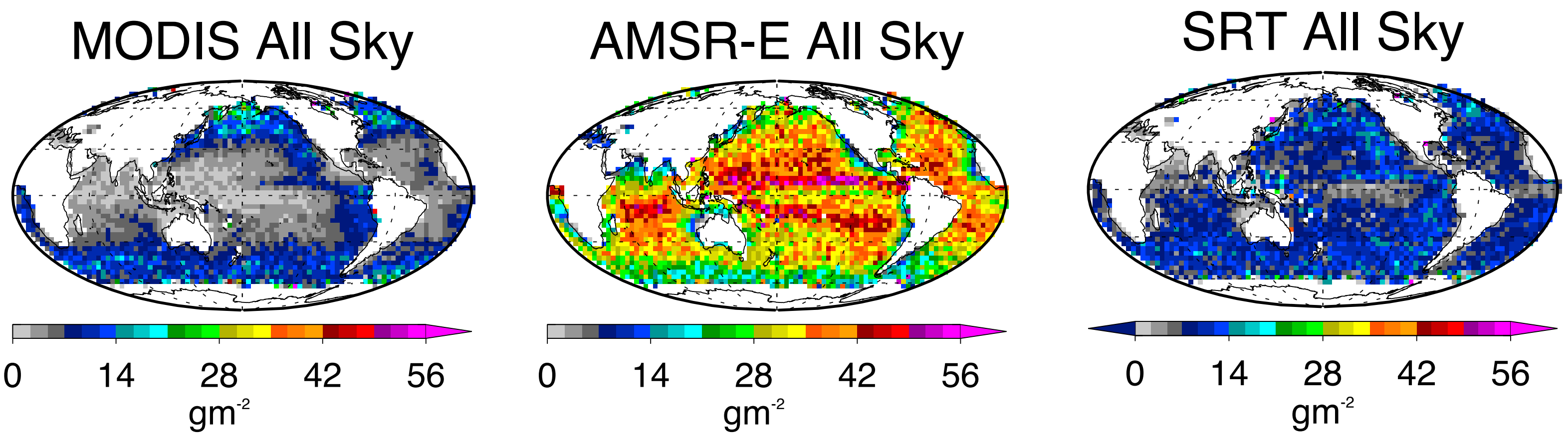
- Unlike reflected solar approaches microwave provides near continuous sampling over oceans.

Bias quantification strategy:

Use independent A-Train data from MODIS, CloudSat, and CALIPSO to evaluate AMSR-E

1. Precise cloud detection (lidar)
2. Precise precipitation detection (radar)
3. Quantitative precipitation retrieval (radar)
4. Quantitative cloud retrieval using a Surface Reference Technique [SRT] (radar+lidar)
5. Independent cloud water path (MODIS)

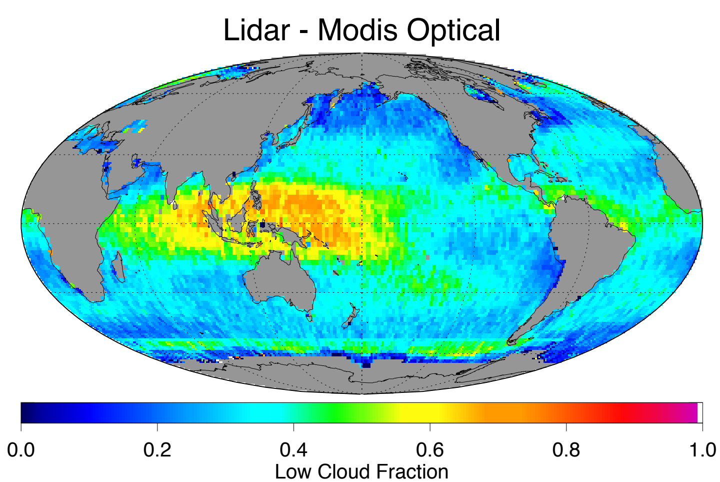
MODIS / AMSR-E / CloudSat



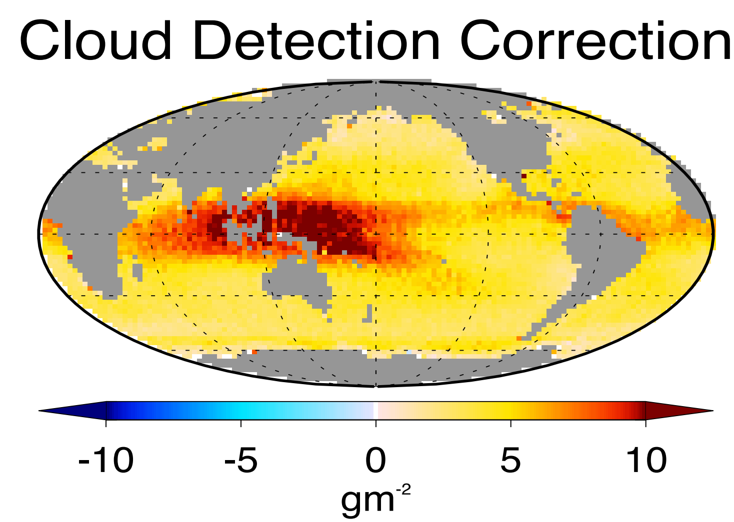
- AMSR-E is clear outlier. Why?
  - MODIS missed clouds
  - MODIS solar zenith angle dependence
  - Precipitation influence on AMSR-E
  - Clear sky bias in AMSR-E

MODIS Cloud Detection

- Can MODIS '*missed*' clouds explain the difference?
  - Algorithm has missed cloud detection
  - Algorithm deliberately excludes cloud edges
- Use the SRT to determine the '*missed*' water path
  - Has the same spatial pattern as the total AMSR-E/MODIS difference
  - Only explains about 20% of the AMSR-E/MODIS difference

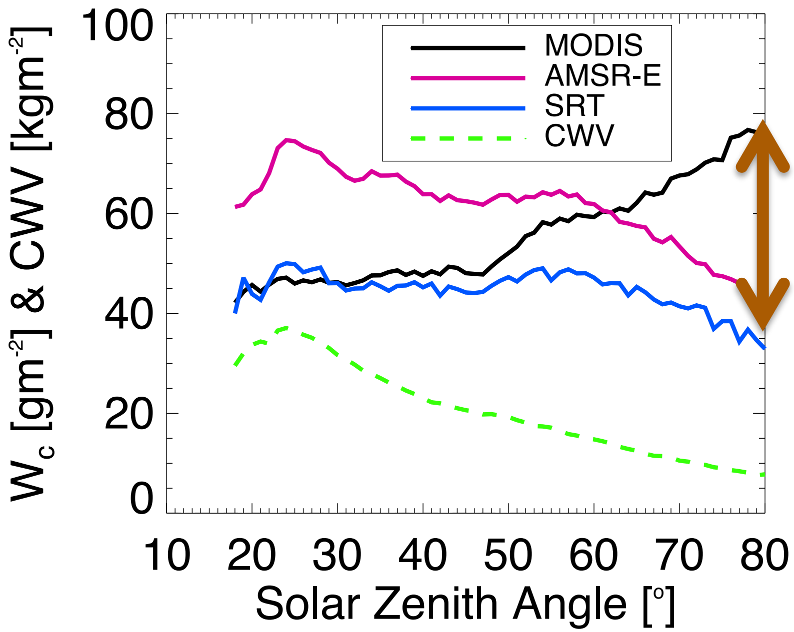


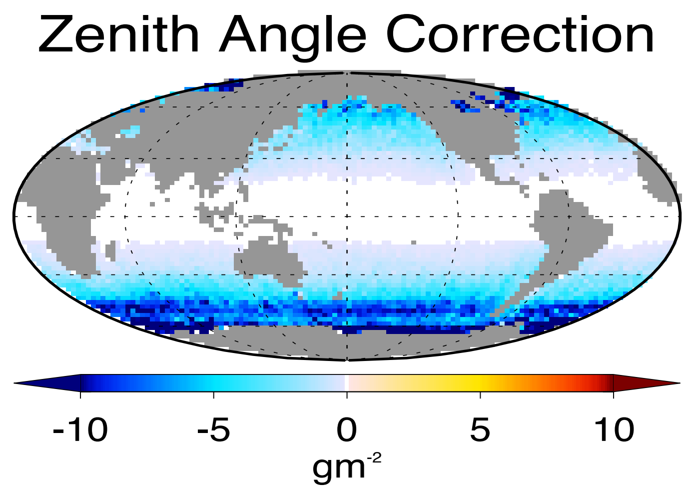
Missed Cloud Fraction



Total '*missed*' water path

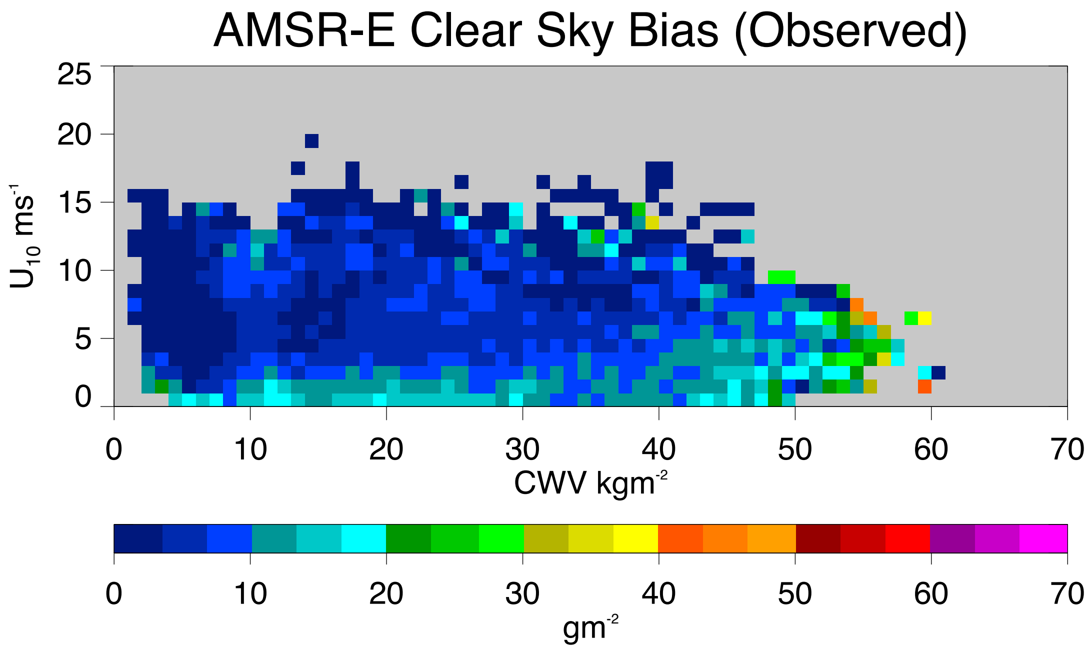
MODIS Solar Zenith Angle Dependence





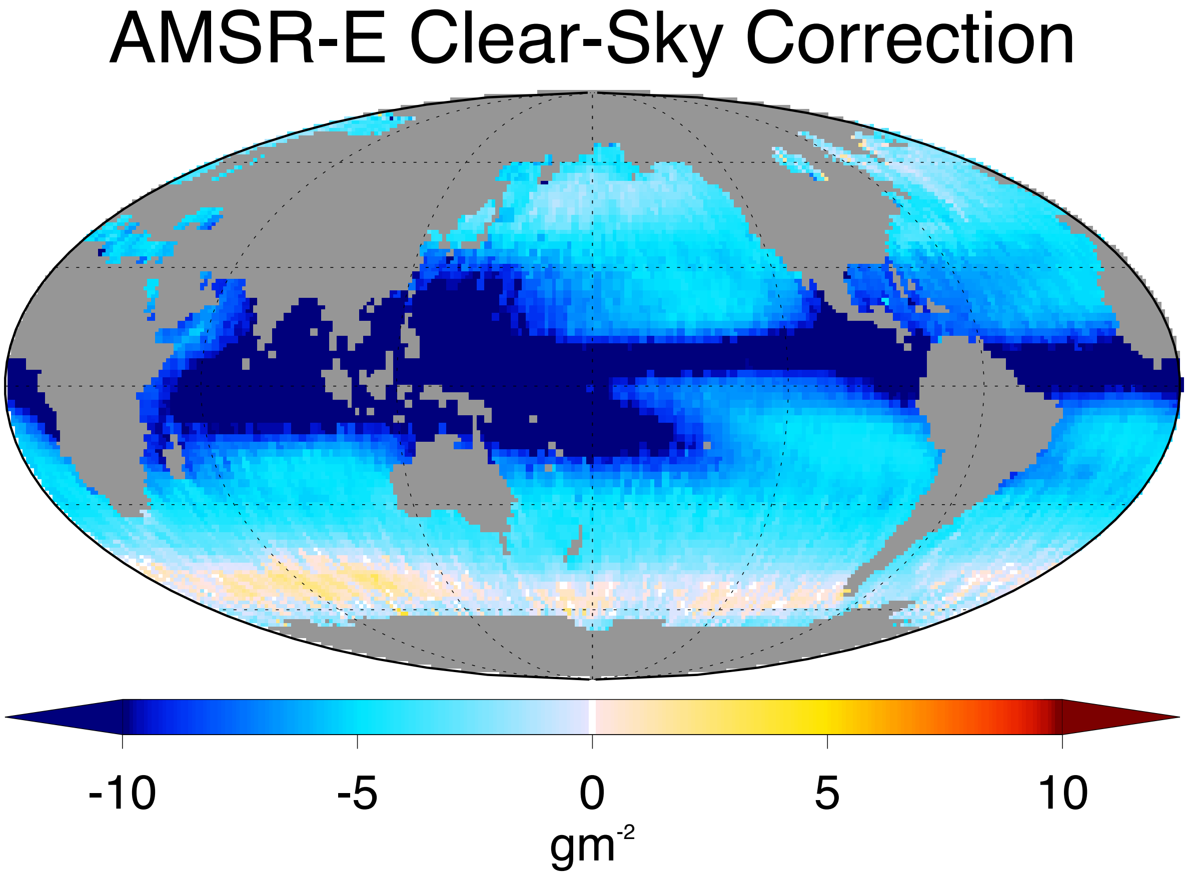
- MODIS optical depths are biased high at high latitudes
  - Solar zenith angle bias is roughly linear for $\vartheta_0 > 45^o$.
  - Modest -2.3 gm^{-2} global mean effect.
  - Evident in high latitudes only. Does not help explain large tropical biases.

AMSR-E Clear Sky Bias

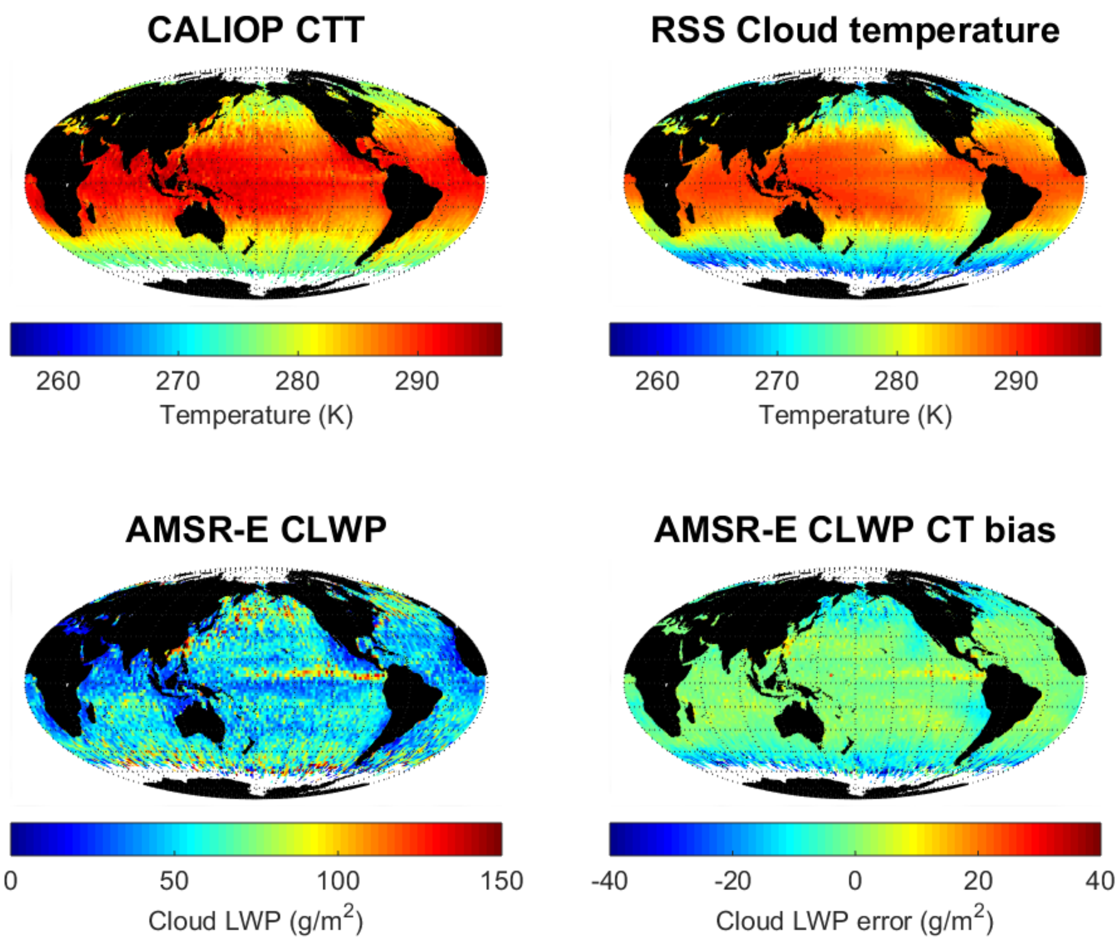


- AMSR-E tends to retrieve positive cloud water path in clear skies
  - ~6 gm^{-2} (20% of total bias)
  - Clear sky determined using MODIS (MYD35) cloud fraction on one degree daily grids

AMSR-E clear sky bias



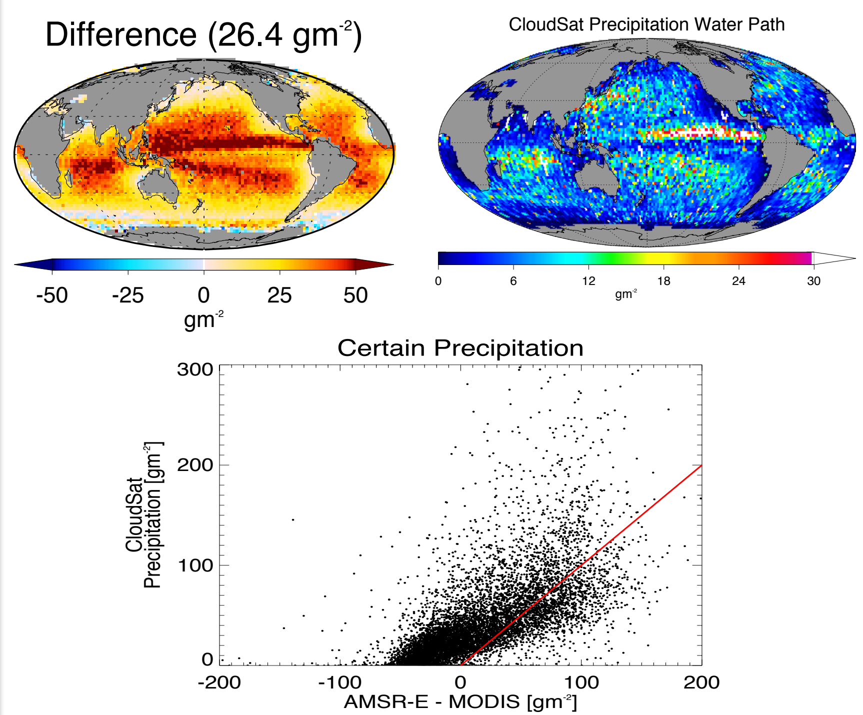
Cloud Temperature Bias

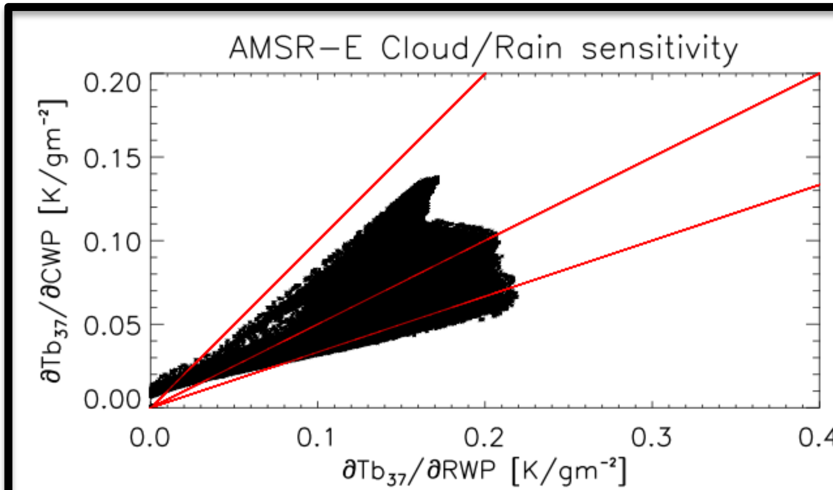


- Largest temperature differences occur at higher latitudes and in ocean upwelling regions
- These same areas have the largest CLWP biases but significant biases also appear along the ITCZ and off coast of China

Precipitation Bias

- Bias pattern at low latitudes is clearly correlated with the precipitation water path
- Cannot fully explain the bias (even if all rain water was treated as cloud water)
- Difficult to understand what aspect of precipitation causes the difference
  - AMSR-E assumed cloud/rain ratio
  - AMSR-E assumed rain drop size distribution





Modeled sensitivity of AMSR-E 37 GHz Tbs to cloud water path and rain water path for 50 Modis and CloudSat orbits. Sensitivity ratio varies between roughly 1 and 3 assuming a Marshall-Palmer DSD.

See Andrew Manaster poster

Evaluation of Interannual Variability of Cloud Liquid Water Path in Climate Models Using A Multidecadal Record of Passive Microwave Observations

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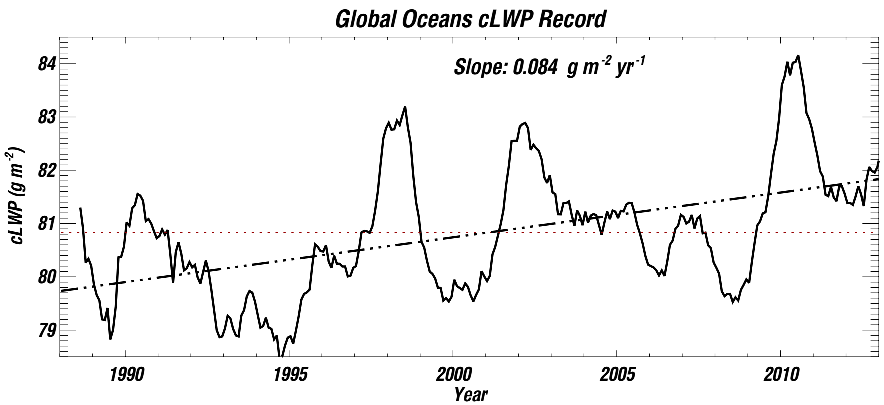
Colorado State University

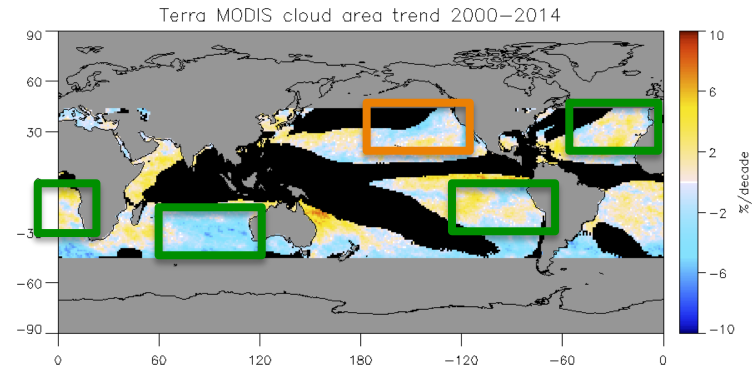
Conclusions

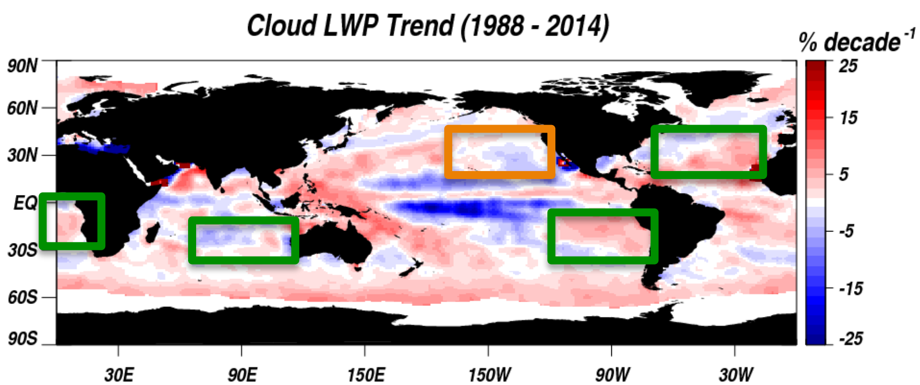
- No well characterized global climatology of cloud water path yet exists
- Bias between MODIS/AMSR-E results from several mechanisms including
    1. Cloud detection
    2. Solar zenith angle
    3. ‘Clear sky’ bias
    4. Cloud Emission Temperature
    5. Precipitation influence on microwave
- A revised MAC-LWP climatology is under-construction
    – Based on RSS version 7 input
    – Will include random uncertainty and bias errors

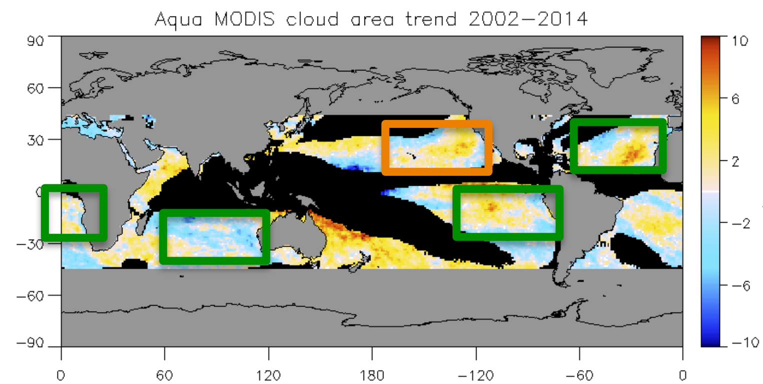
Backup

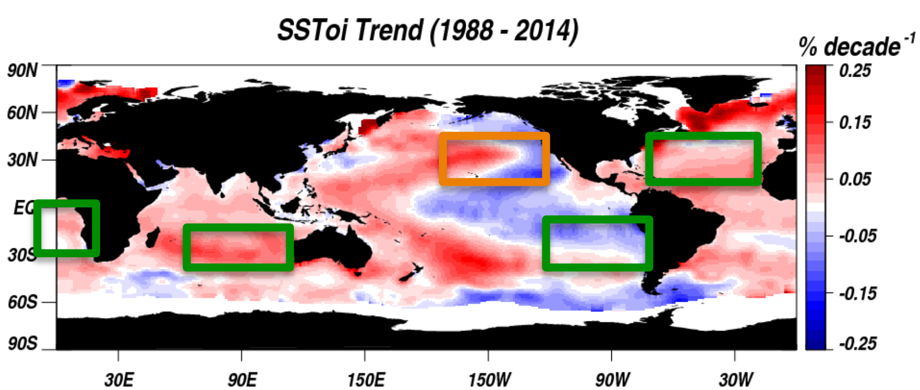
Cloud Trends







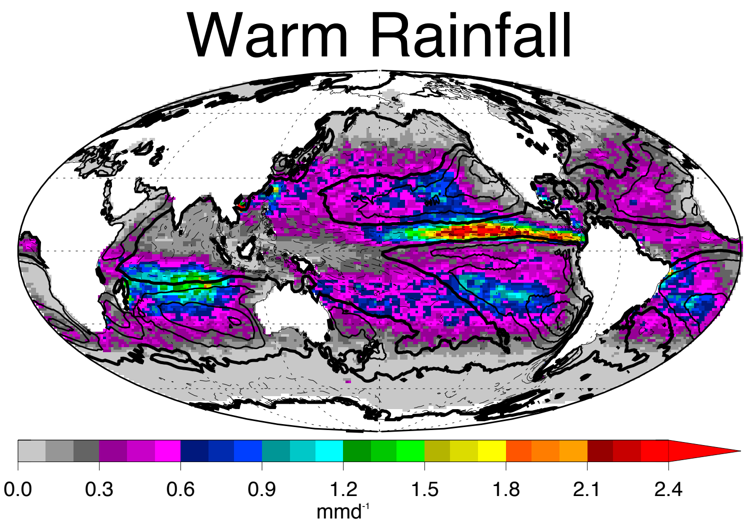




- Global cloud water path has increased
  - Regional variation consistent with large scale circulations
- Some consistency with MODIS cloud cover and SST

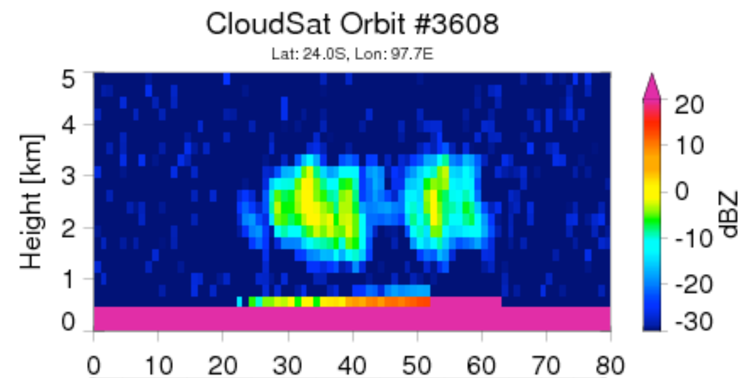
Useful CloudSat and CALIPSO products

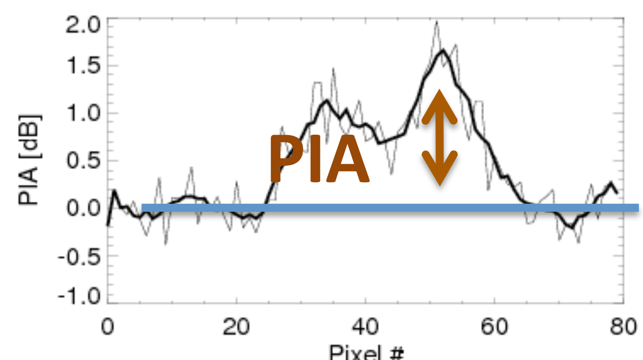
CloudSat Rain Profiling



- Variational approach using both reflectivity and path integrated attenuation constraint
- Provides first global survey of light precipitation in boundary layer clouds

CloudSat/CALIPSO Surface Reference Technique





- Provides an independent accurate measure of cloud water path
- Not accurate in precipitation/ overcast conditions