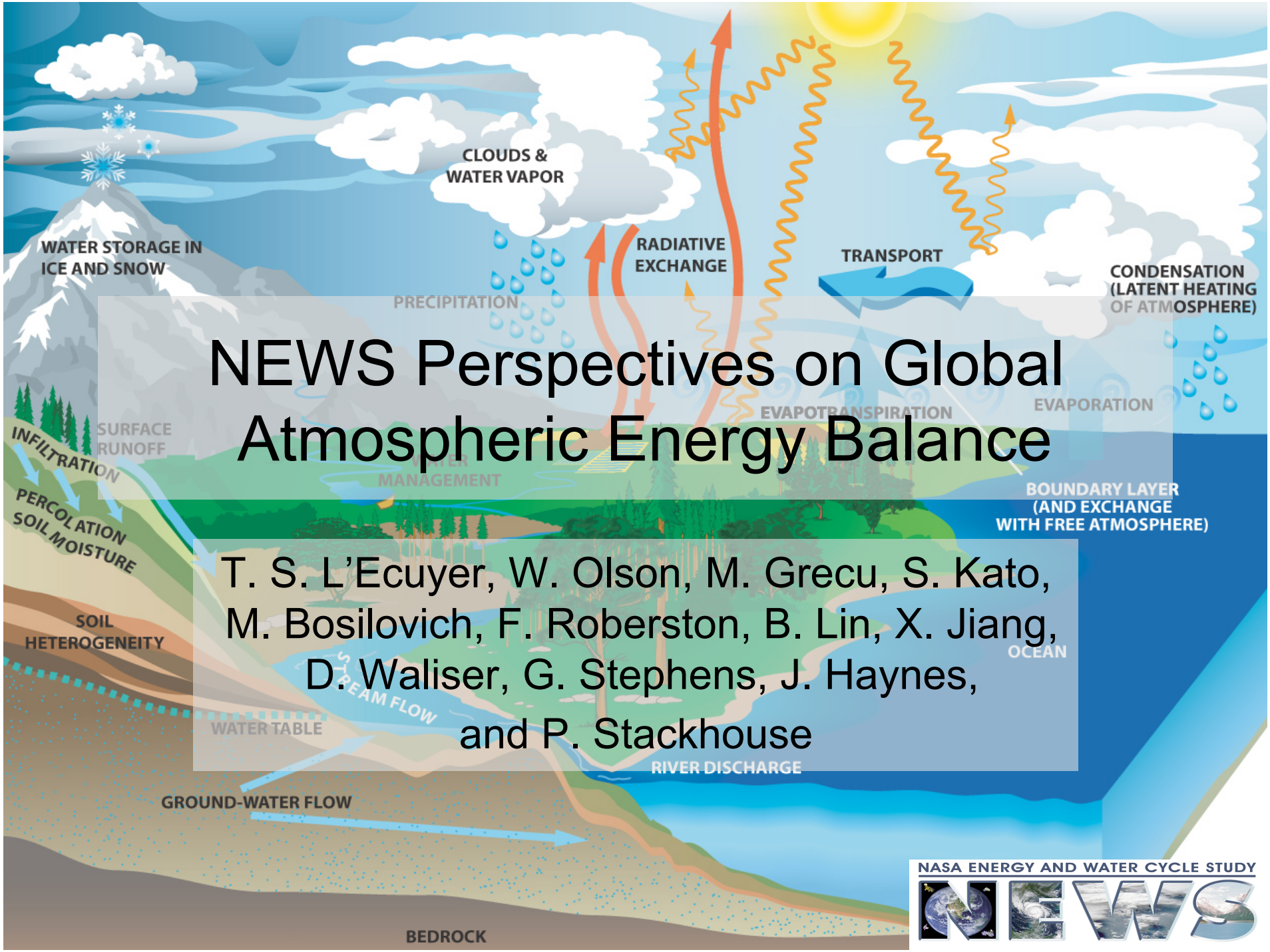
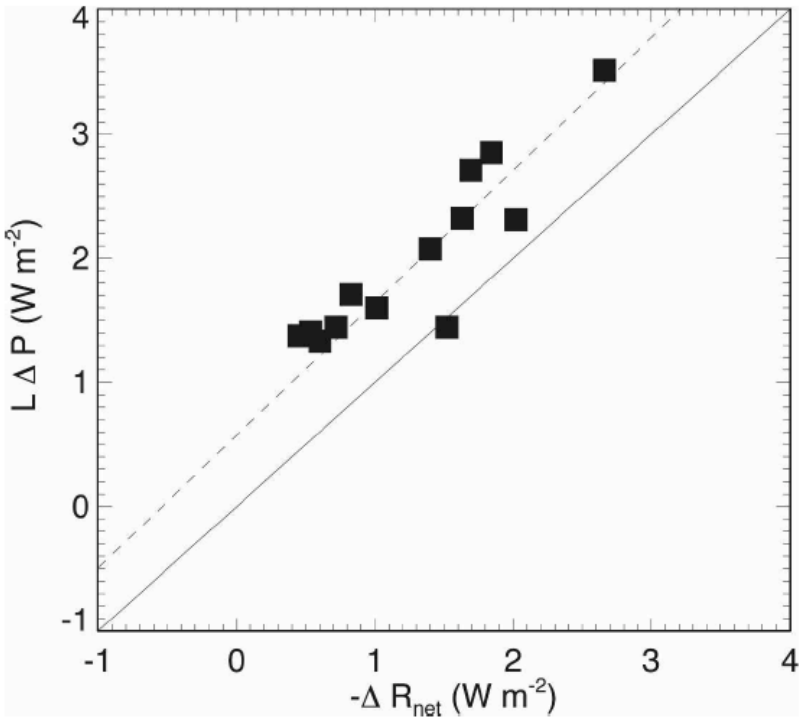
NEWS Perspectives on Global Atmospheric Energy Balance

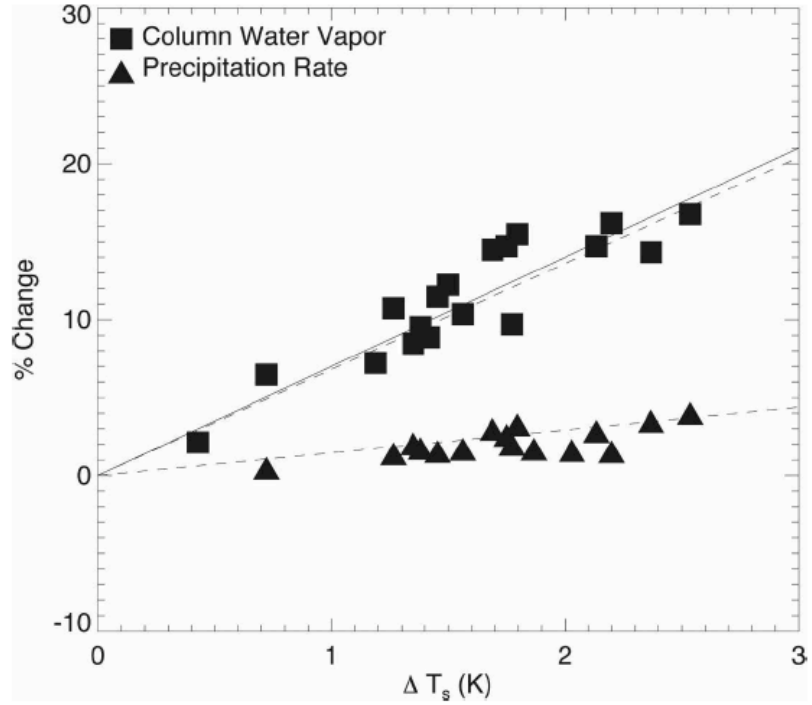
T. S. L'Ecuyer, W. Olson, M. Grecu, S. Kato, M. Bosilovich, F. Roberston, B. Lin, X. Jiang, D. Waliser, G. Stephens, J. Haynes, and P. Stackhouse



NASA ENERGY AND WATER CYCLE STUDY
NEWS

E & WC Coupling in Climate Models

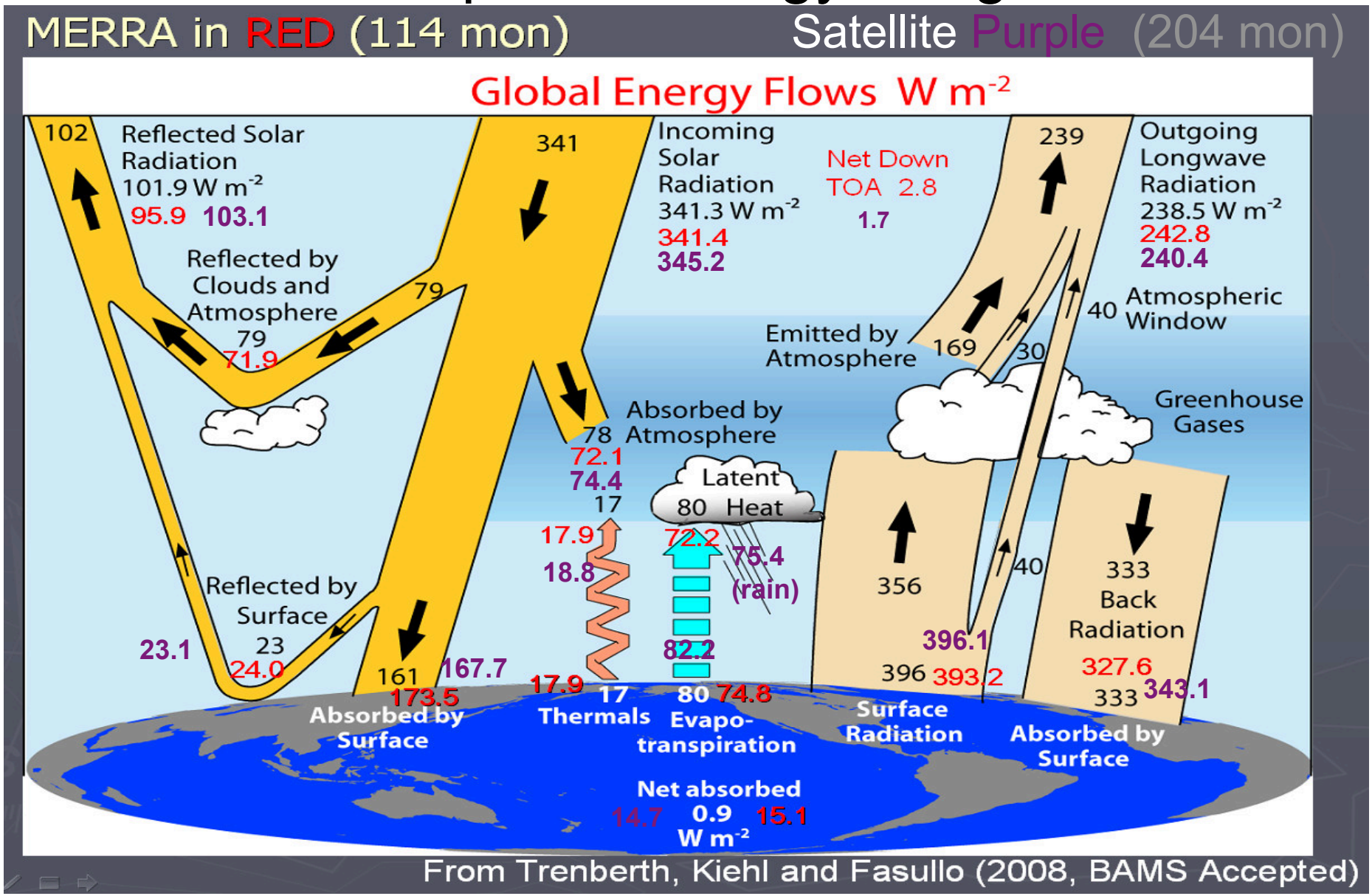




- ✧ To first order, energy balance constrains precipitation changes to balance changes in LW cooling.
- ✧ LW cooling effects of water vapor further impose constraints on the relative increases in precipitation and water vapor.

Stephens and Ellis, J. Climate, 2008

How Well Do we Know the Current Atmospheric Energy Budget?



From Trenberth, Kiehl and Fasullo (2008, BAMS Accepted)

Atmospheric Energy Balance?

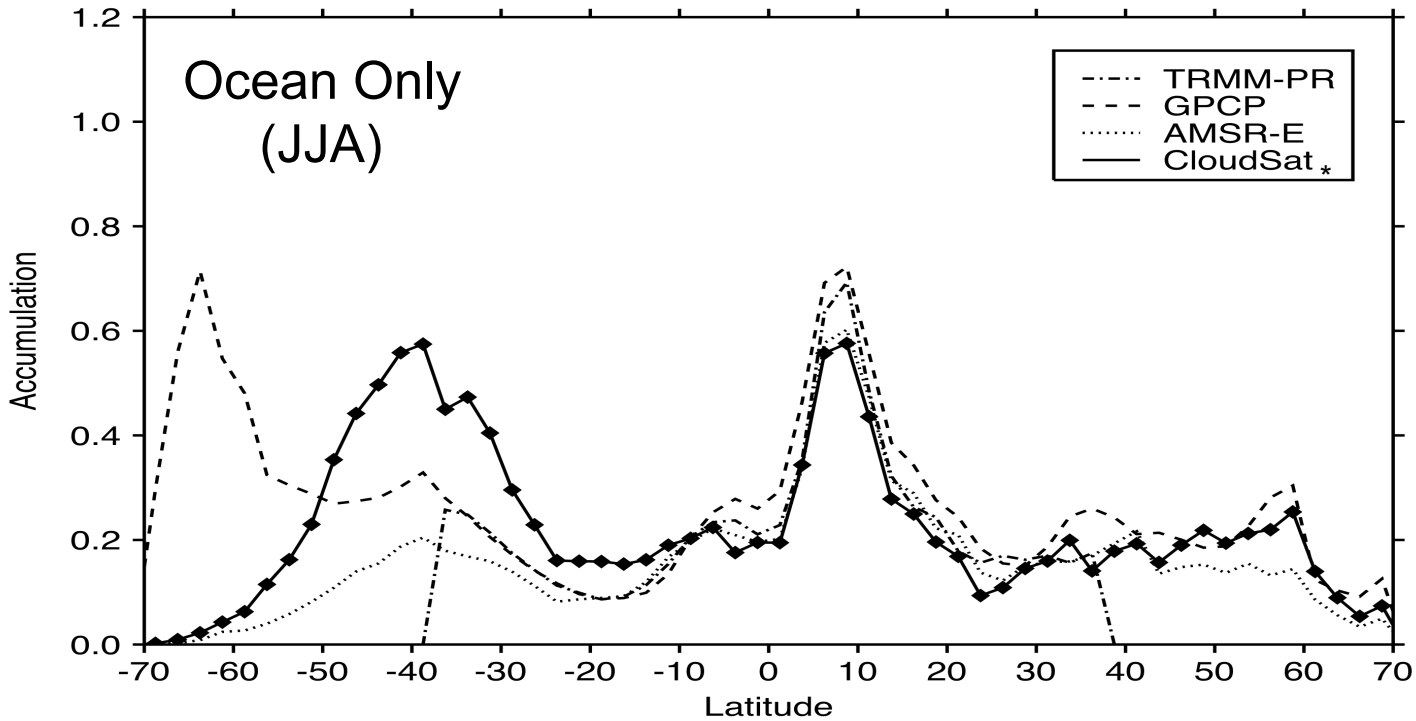
Product	OLR	σT^4	DLR	ΔLW	ΔSW	NET
CERES EBAF (untuned)	239.7	397.9	342.2	-184	74.6	-109.4
ISCCP	240.4	393.7	343.1	-189.8	74.4	-115.4
ERA40	244.8	396.2	341.7	-190.3	80.9	-109.4
MERRA	242.8	393.2	327.6	-177.2	72.1	-105.1
Trenberth	238.5	396	333	-175.5	78	-97.5
CloudSat[1]	242.7	398.8	341.2	-185.1	61.9	-123.2
CloudSat/CALIPSO[1]	228	398	358.8	-188.8	64.8	-124
CCCM scaled (Kato)[2]	236.2	399.1	350.2	-187.3	78.9	-108.4

Product	ET	LH	SH	Total
MERRA	74.8	72.2	17.9	90.1
Trenberth	80	80	17	97
"Satellite"	82.2	75.4	18.8	94.2

[1] Only covers 82 N to 82 S
[2] Mean of 4 months scaled to annual.
EBAF source: Loeb et al. J. Climate 2008.
CERES estimate: 6.0 W m^{-2} extra absorption by the atmosphere due to adjustment made at TOA by EBAF within the uncertainty of instruments and algorithms

Integration Efforts to Address Energy and Water Cycle Closure

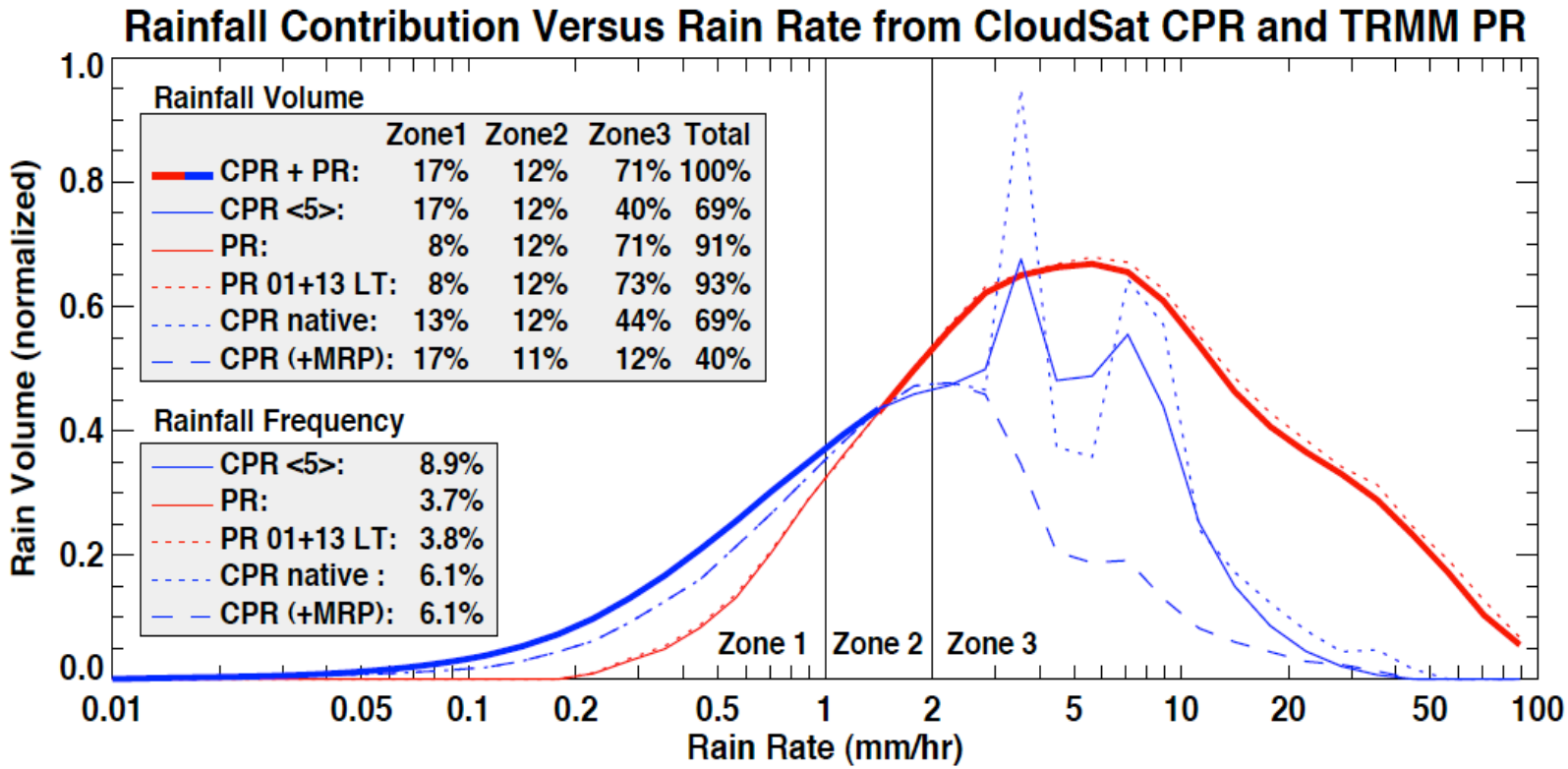
Missing Heating?



* CloudSat = level-3 CloudSat/TRMM PR combined product

- ✧ What is true global rainfall?
- ✧ Rainfall discrepancies particularly large at higher latitudes in winter.
- ✧ Could other regimes pose similar difficulties? (eg. topography)
- ✧ What about snow?

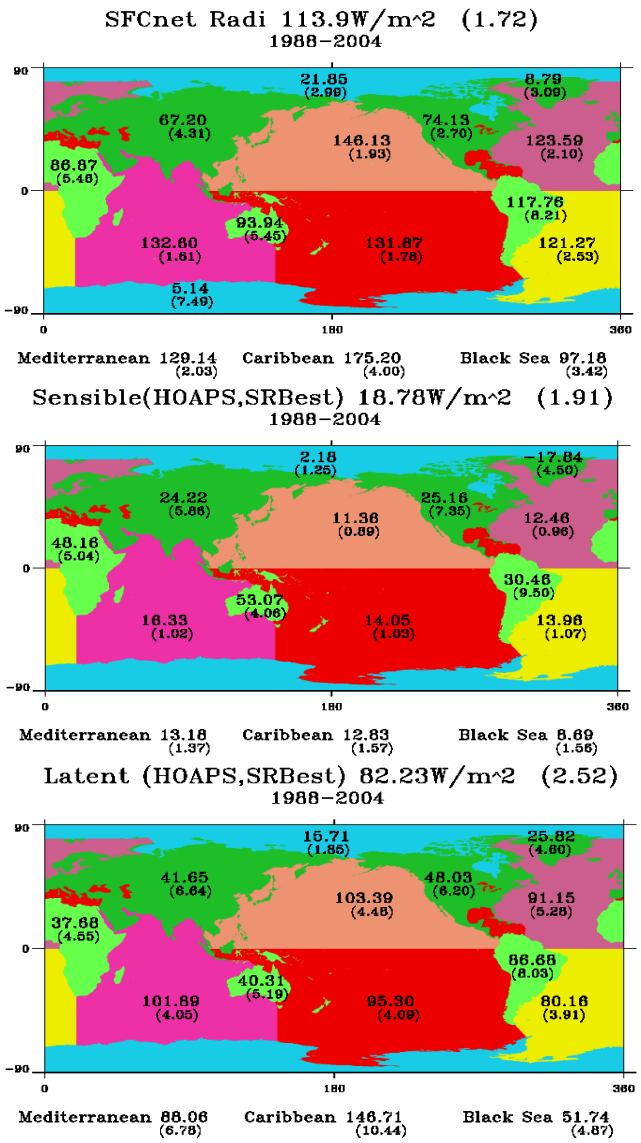
Integrating Satellite Rainfall Products

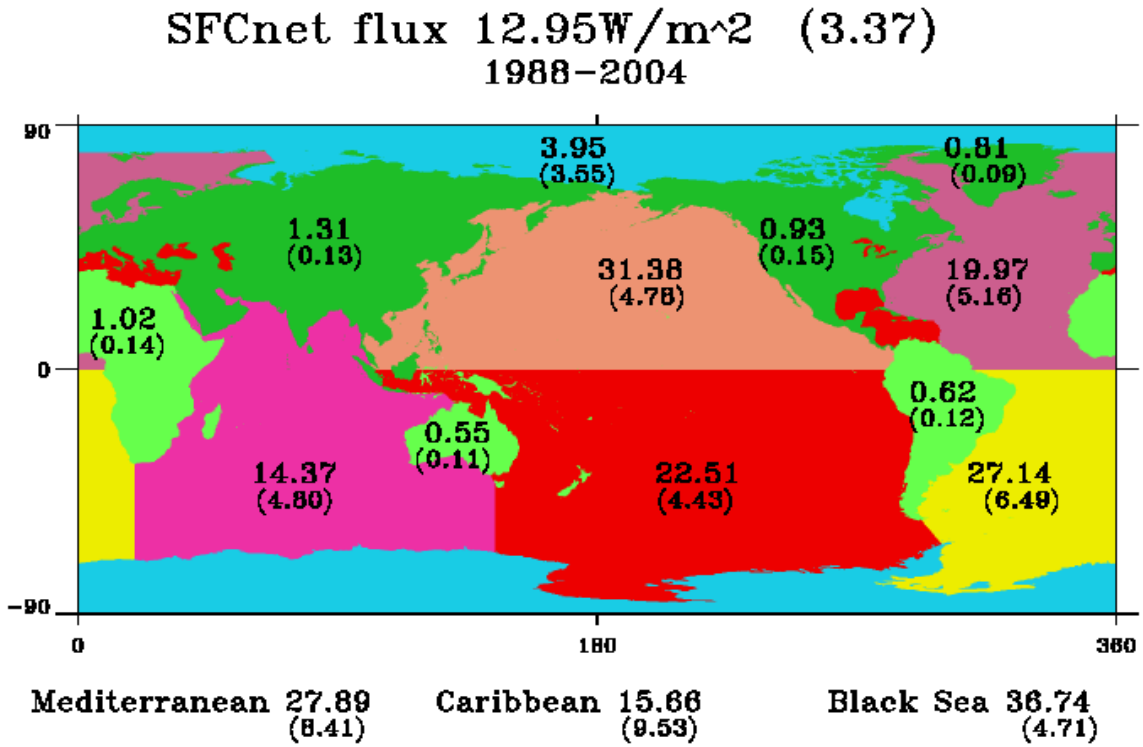


- R < 1 mm h^{-1}: CPR accumulation is 0.47 mm/d, PR's is 0.19
- R > 5 mm h^{-1}: CPR accumulation is 1.35 mm/d, PR's is 1.86

Berg et al., J. Climate, in press.

Continental Scale Energy Budgets





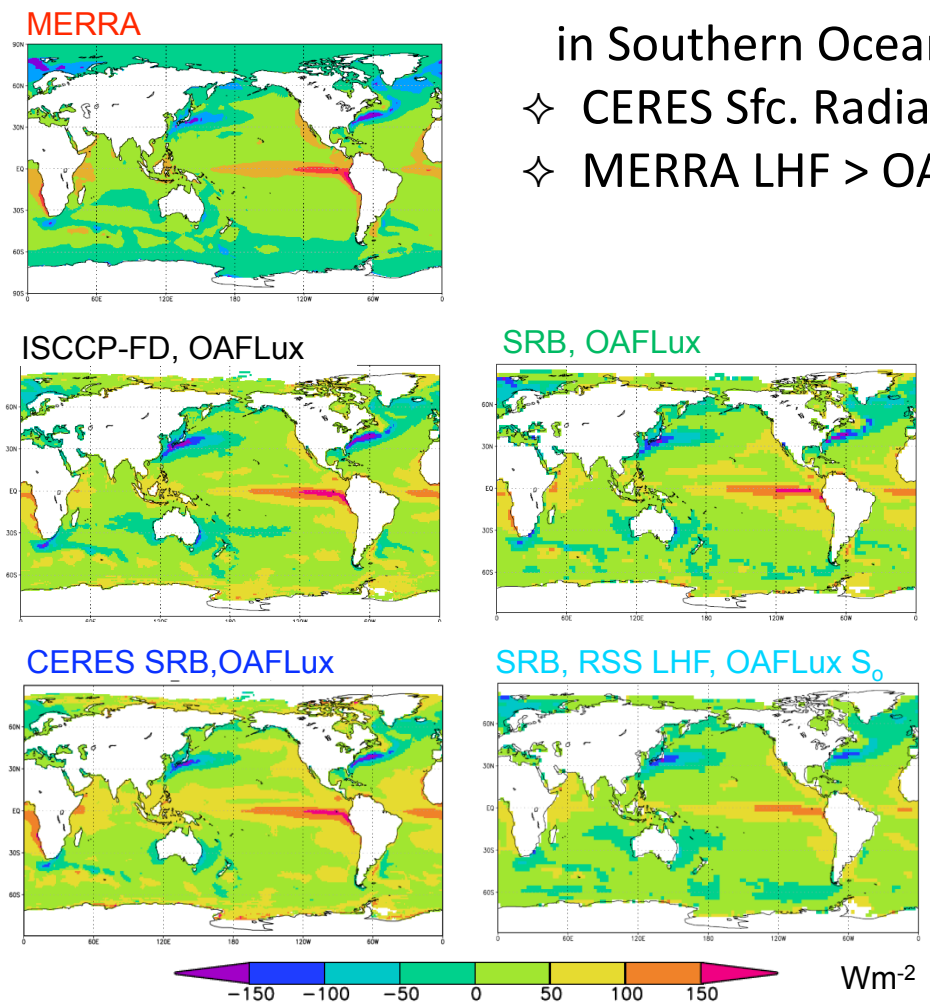
- ✧ Moving to continental scales may offer insights into 'trouble spots' where datasets need to be improved.
- ✧ Also allows analysis of land-ocean heat and moisture transports.

Courtesy: B. Lin and the Climatology WG

Neat Surface Heat Flux and Ocean Transport

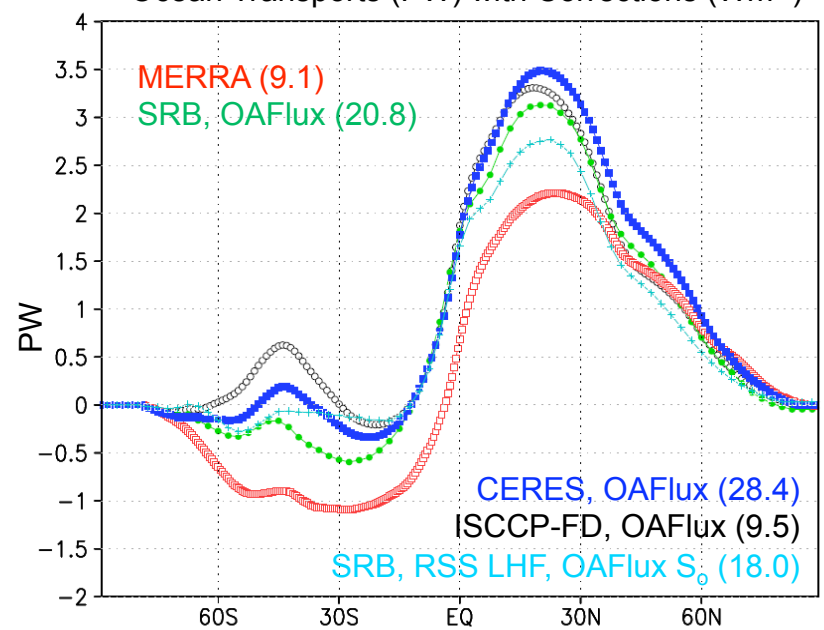
** Flux uncertainties yield transport uncertainties of order 1 PW **

- ✧ Satellite retrievals indicate equatorward heat transport in Southern Ocean (SO); not evident in MERRA
- ✧ CERES Sfc. Radiation > SRB, ISCCP
- ✧ MERRA LHF > OAFlux in SO; RSS LHF > OAFlux in tropics



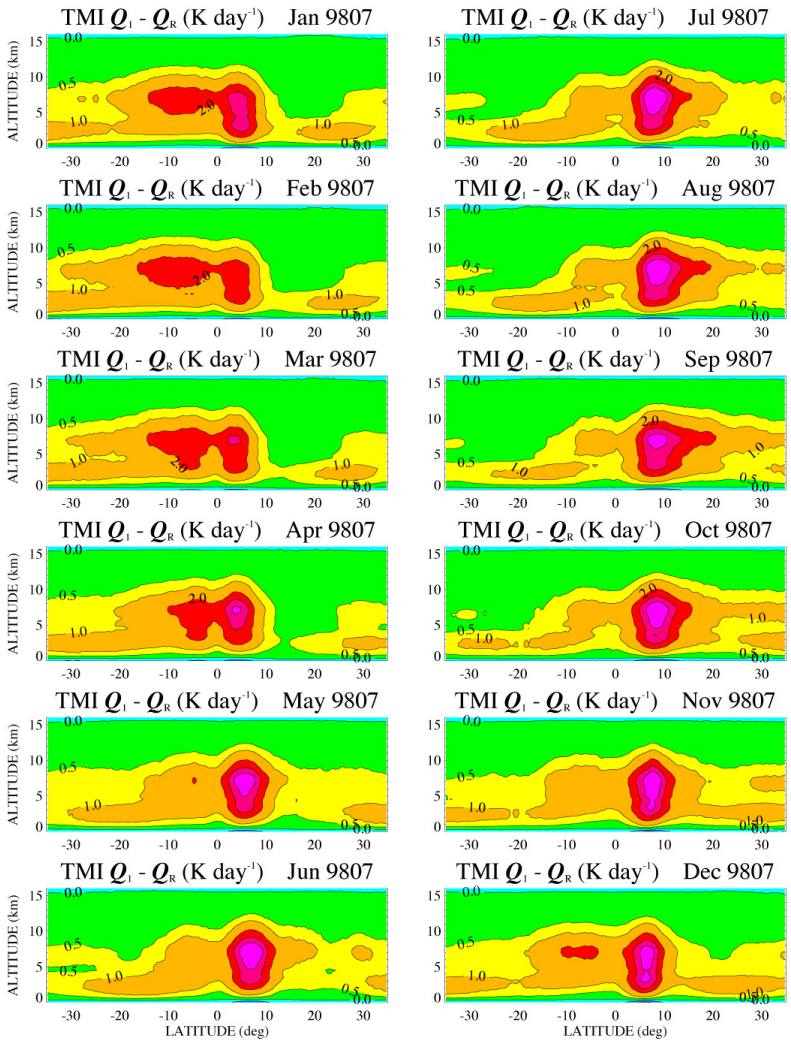
$$T_o(\phi) = 2\pi a \int_{-\pi/2}^{\phi} (\langle N(\phi)\rangle - \alpha)\cos(\phi')d\phi'$$

Ocean Transports (PW) with Corrections (Wm^{-2})

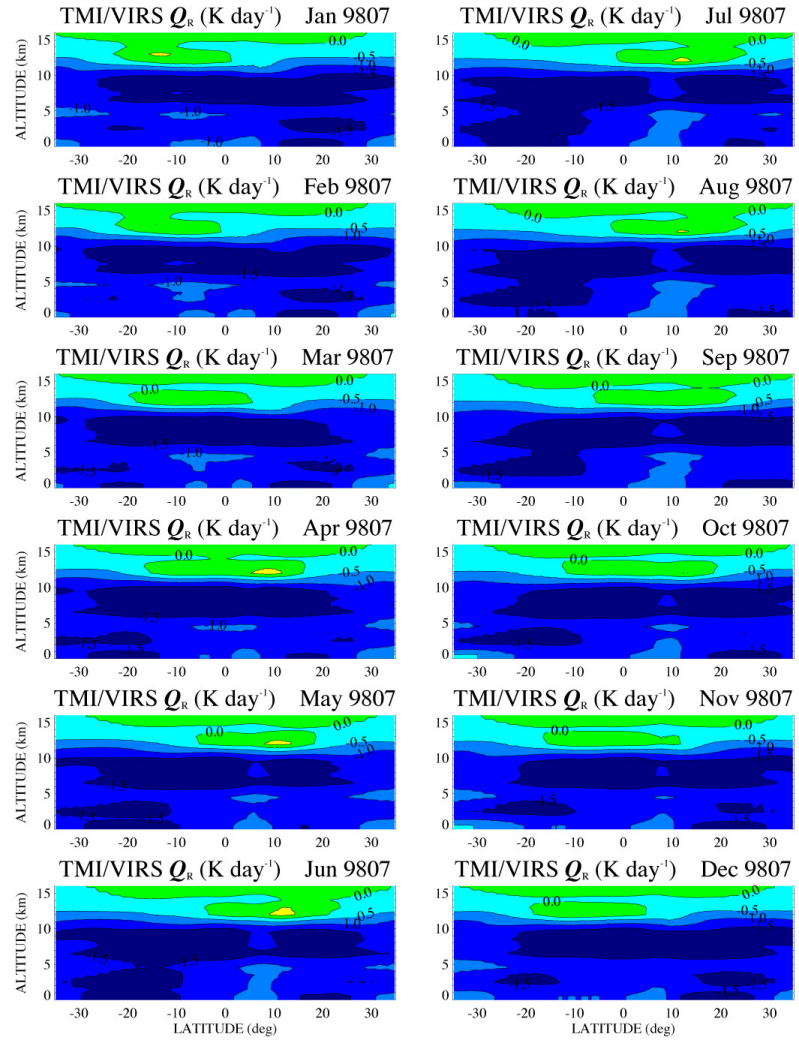


Courtesy: Pete Robertson

Adding the Vertical Dimension

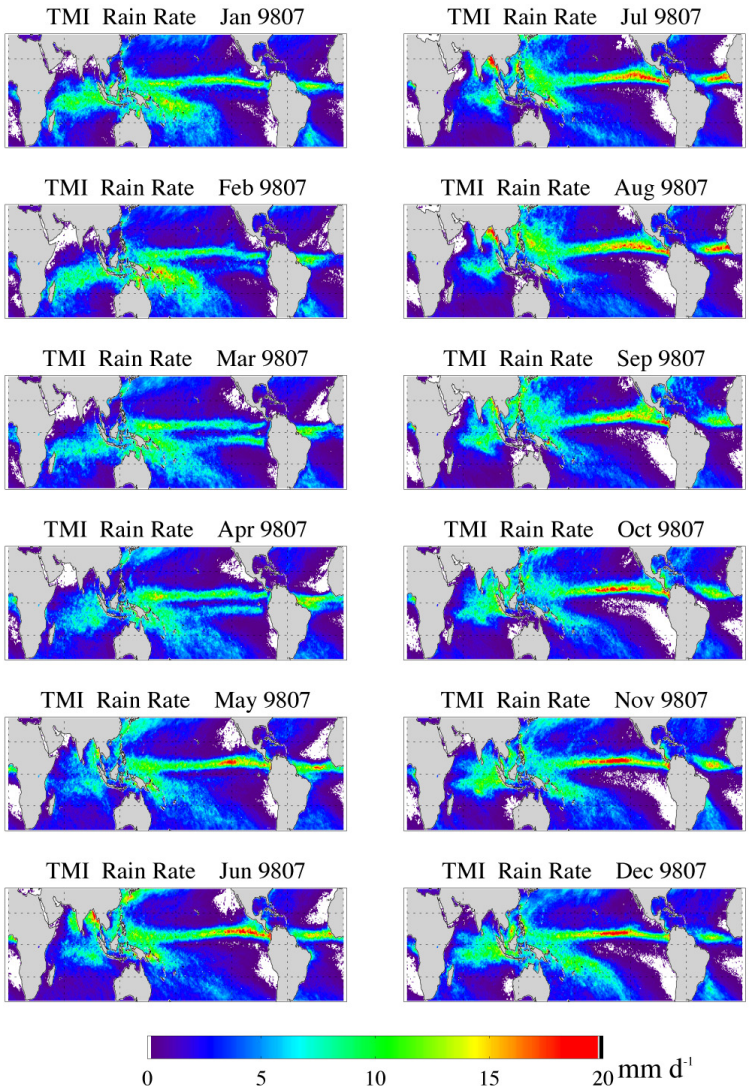


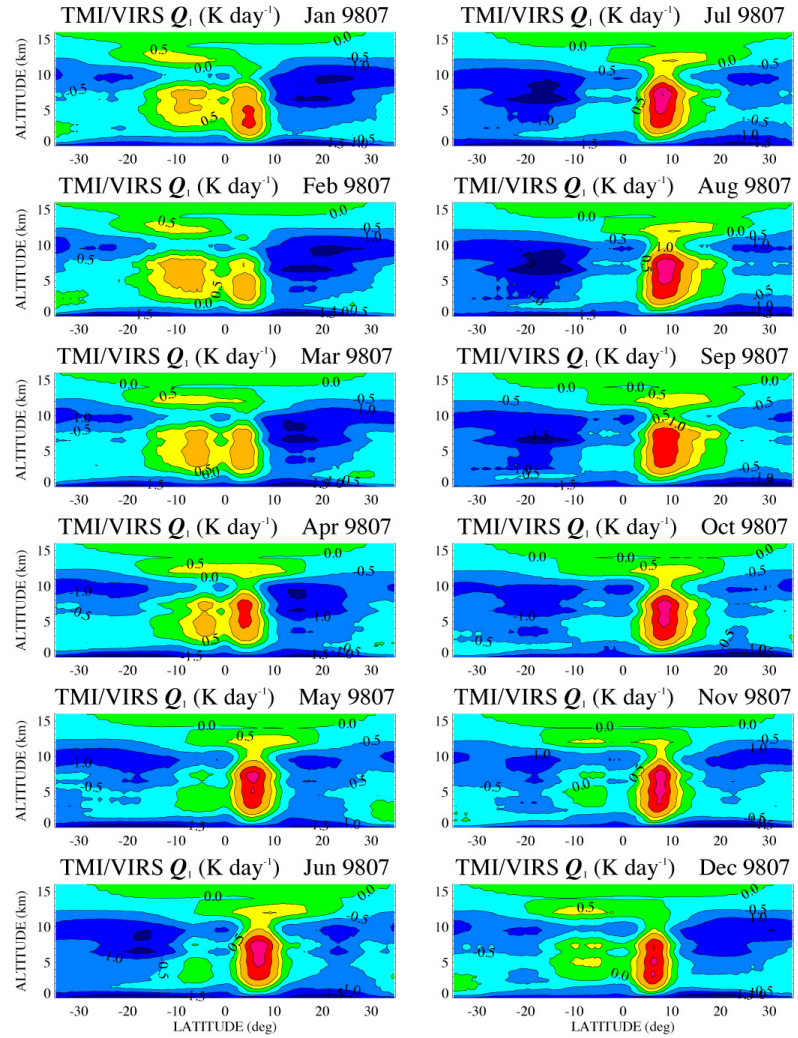
Zonal-mean Latent Heating (Olson et al.)



Zonal-mean Radiative Cooling (L'Ecuyer et al.)

Vertical Distributions of Diabatic Heating

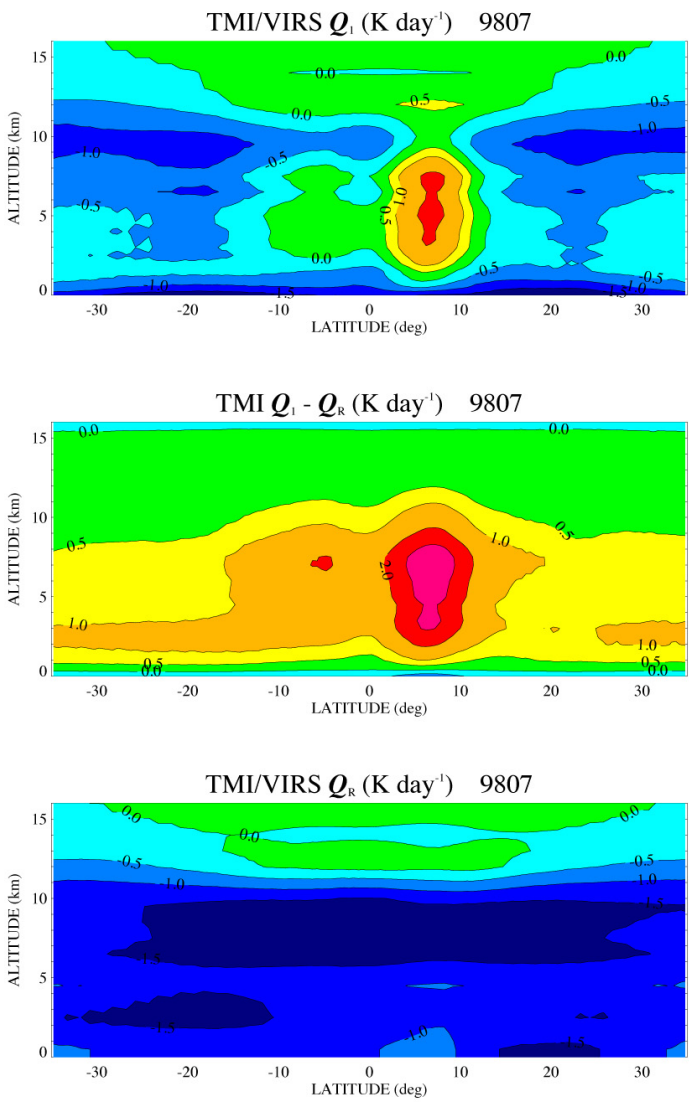


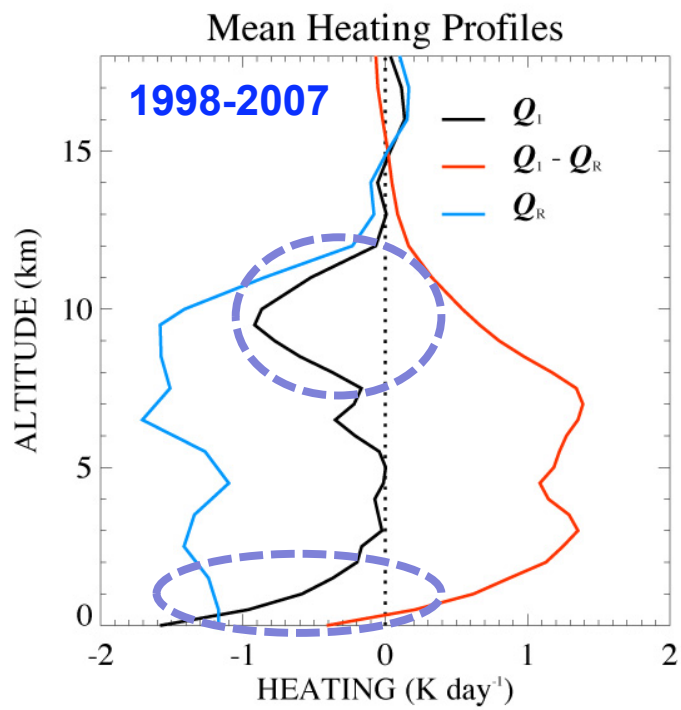


Vertically-resolved Q_1

Courtesy: W. Olson and M. Grecu

Identifying Problem Areas



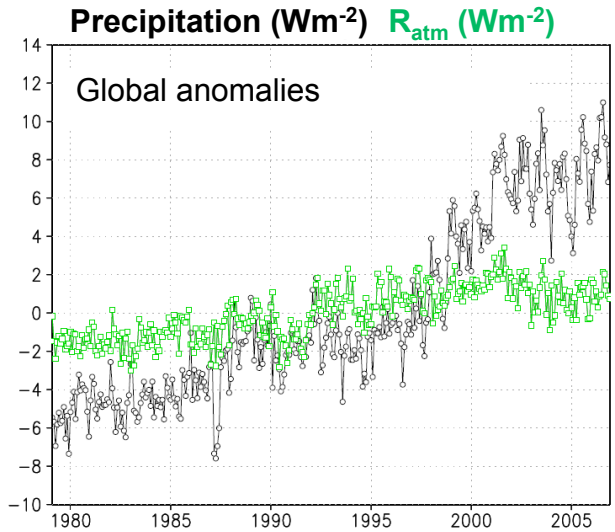


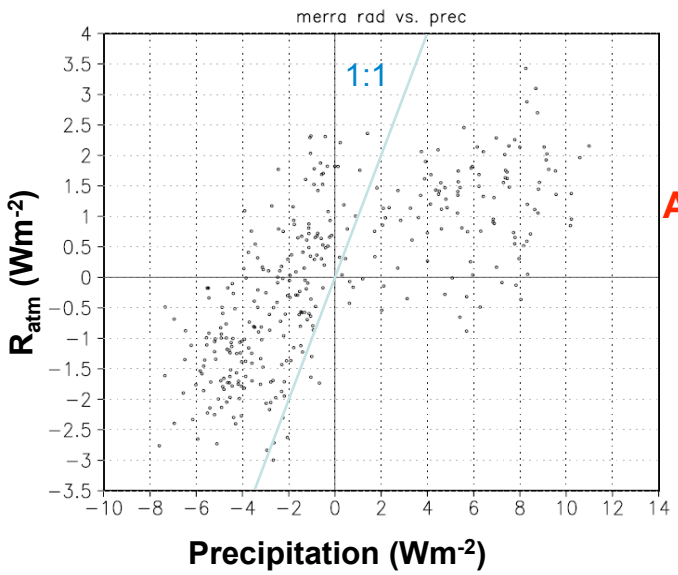
- ✧ Apparent imbalances indicate potential biases in products.
- ✧ Current analysis is limited to ocean regions and 35°N – 35°S.

Courtesy: W. Olson and M. Grecu

Model Evaluation

How Does MERRA Precipitation Scale with Net Atmospheric Radiative Cooling?

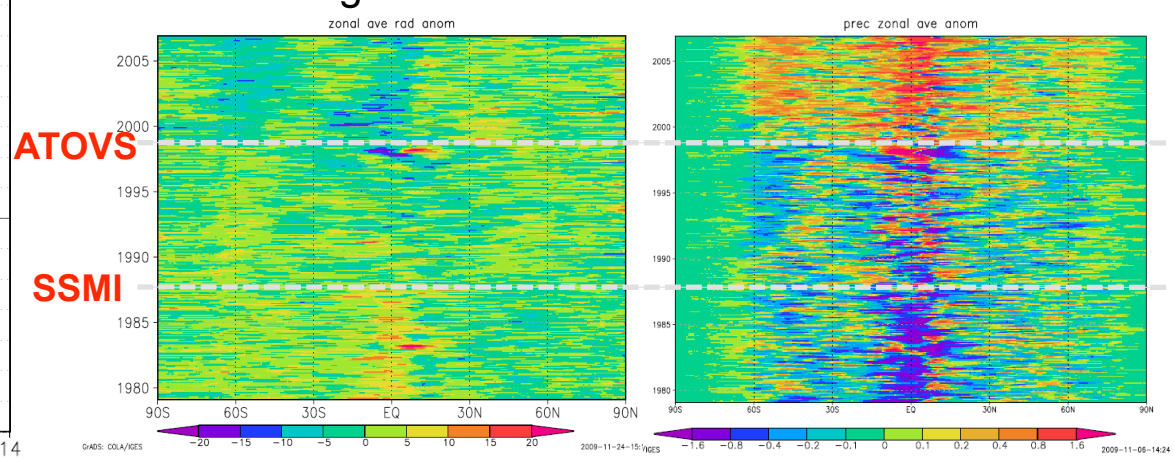




- Based on energy conservation, global changes in LP $+S_o$ should be balanced by changes in atmos radiative cooling, R_{atm}
- At present, the analysis increments of T, q produce artificial trends in each of these quantities that do not preserve this state of radiative-convective equilibrium

Zonal Mean Radiative Cooling Anomalies

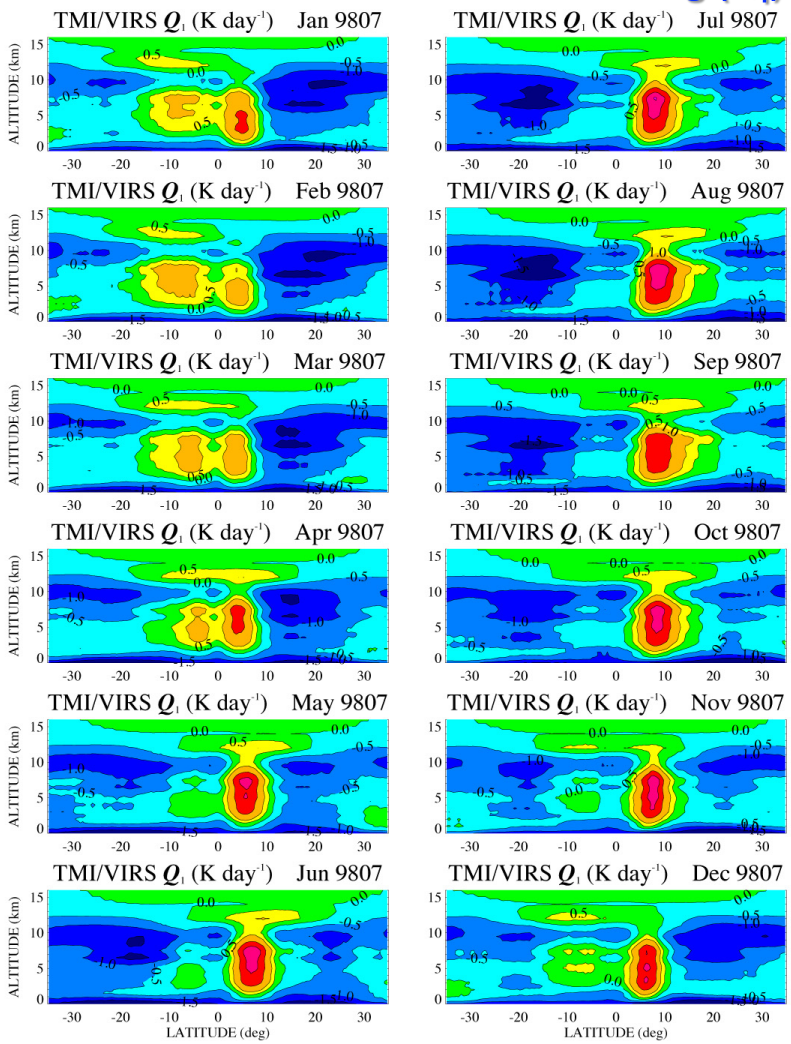
Zonal Mean Precipitation Anomalies



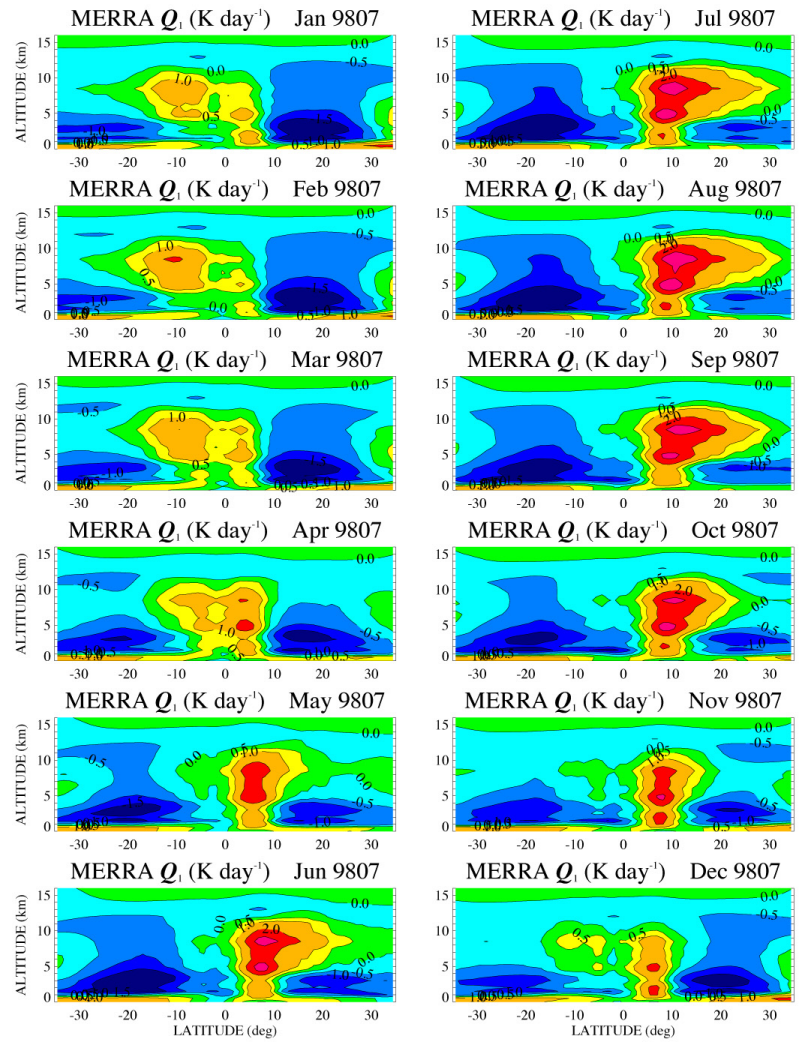
Courtesy: Pete Robertson

Atmospheric Heating

TMI/VIRS Zonal-Mean Diabatic Heating (Q_1)



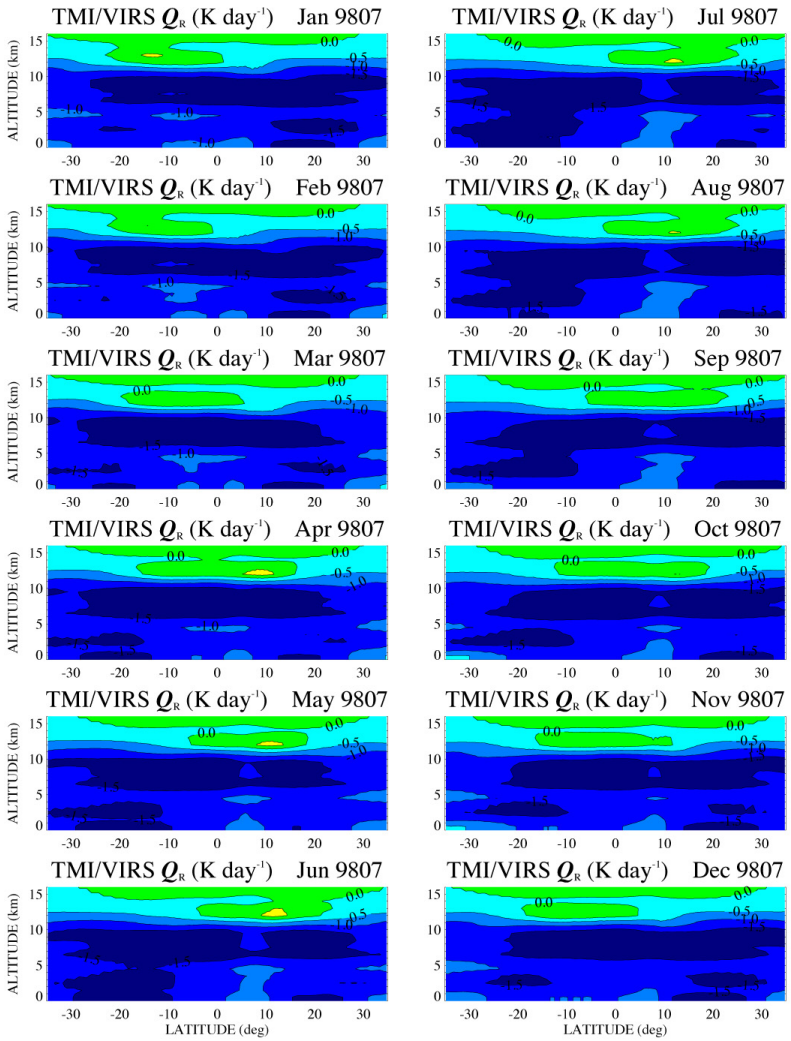
MERRA Zonal-Mean Diabatic Heating (Q_1)



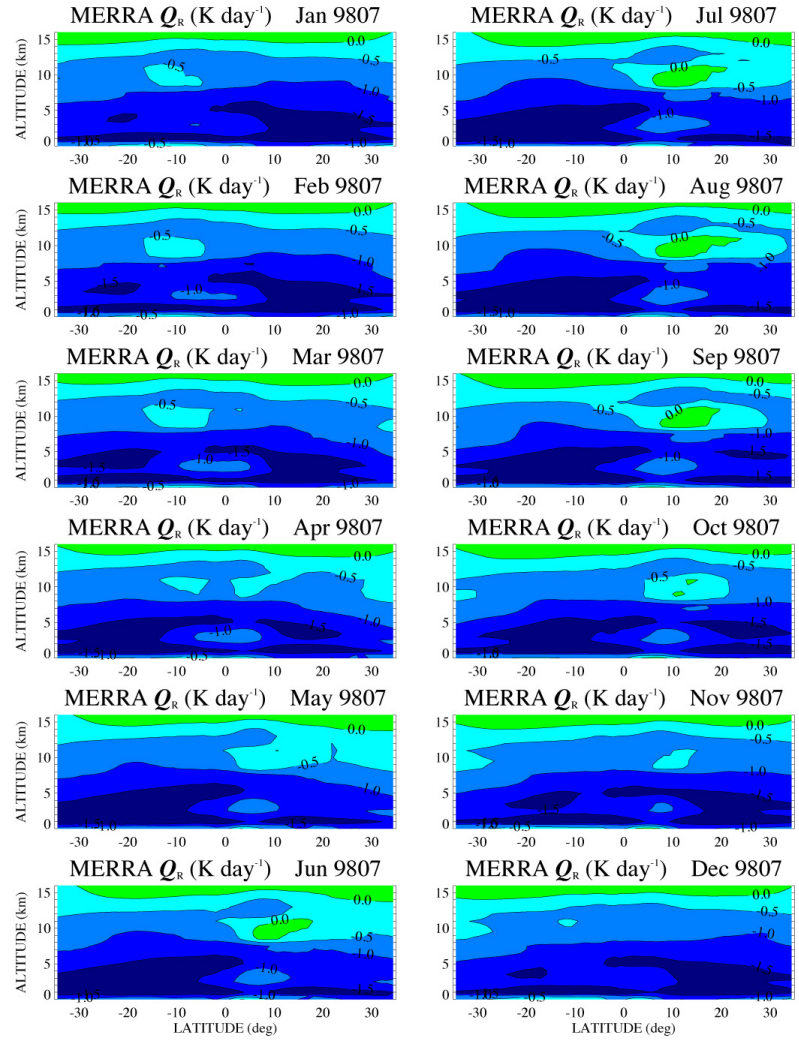
Courtesy: W. Olson, M. Grecu, M. Bosilovich

Radiative Heating (QR)

TMI/VIRS Zonal-Mean Radiative Heating (Q_R)



MERRA Zonal-Mean Radiative Heating (Q_R)

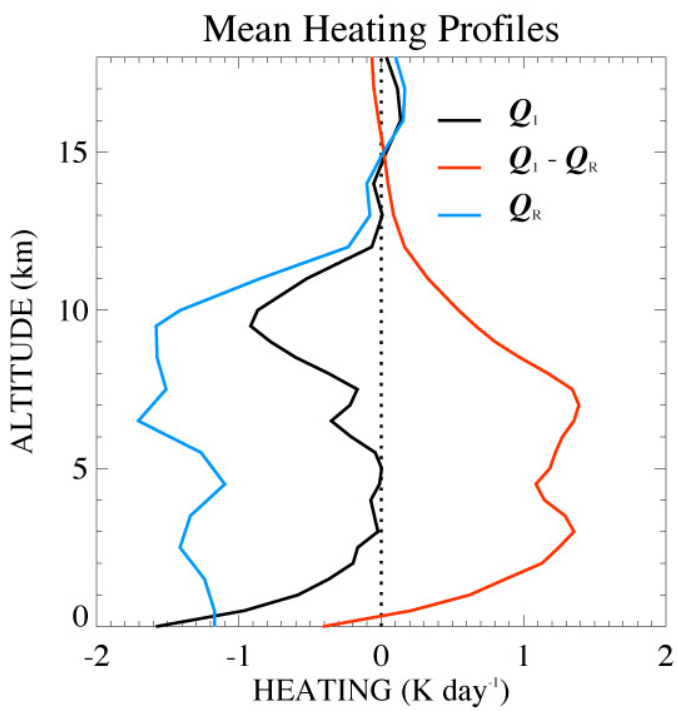


Courtesy: W. Olson, M. Grecu, M. Bosilovich

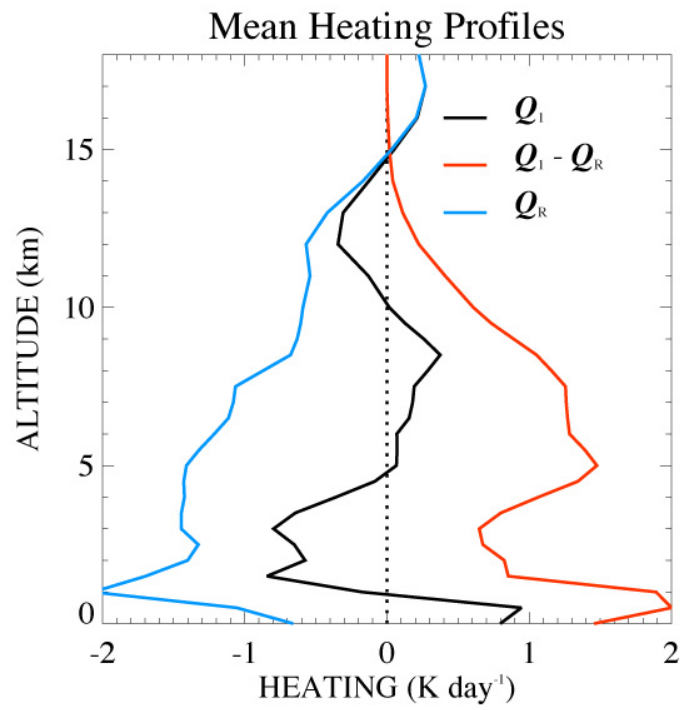
Mean Vertical Q_1 Profiles

Ocean regions between 35°N and 35°S

TMI/VIRS 1998-2007



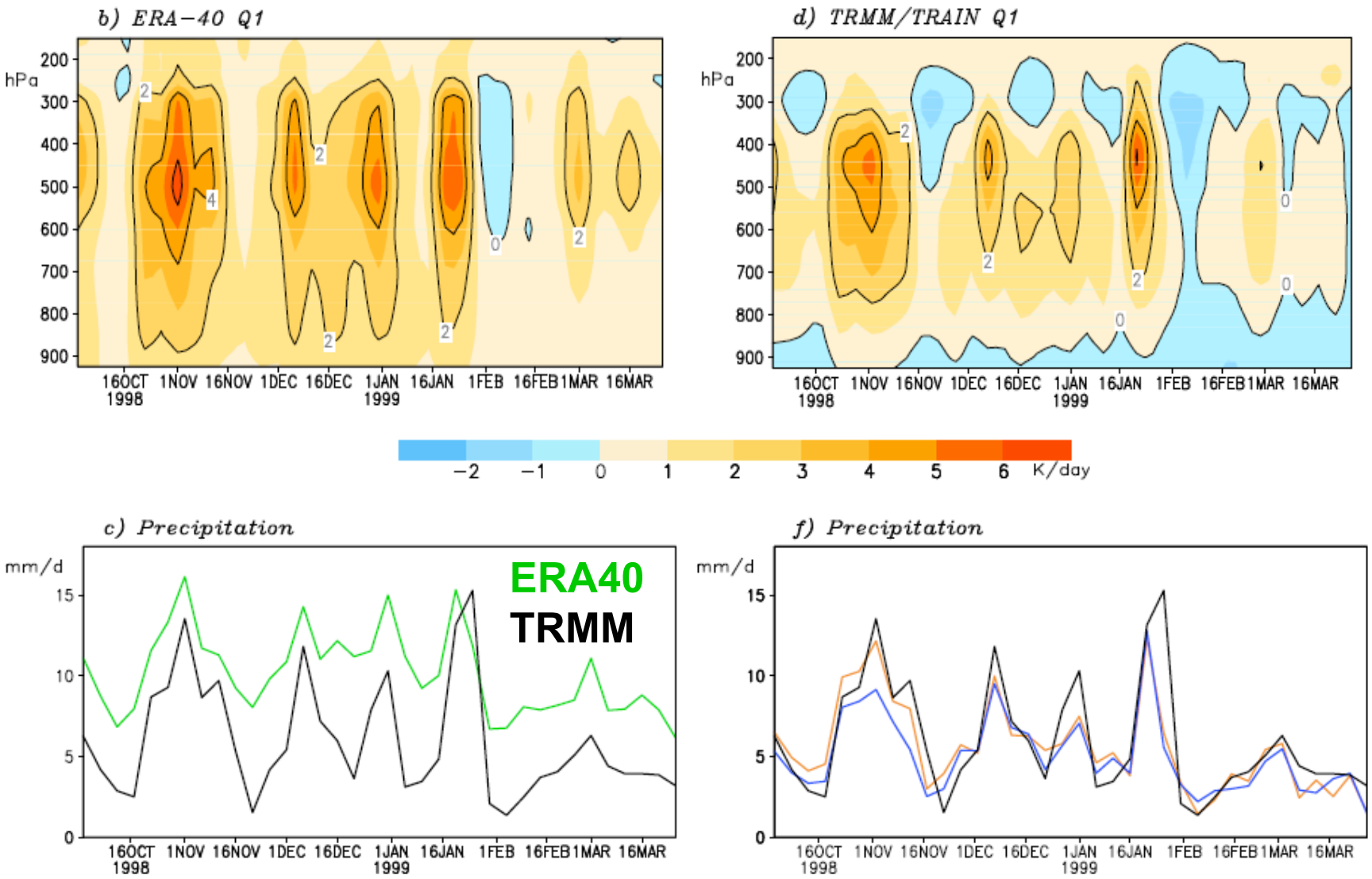
MERRA 1998-2007



- Shallow convective heating and low-level sensible heating missing in TMI/VIRS.
- Congestus heating mode around 2.5 km missing in MERRA?

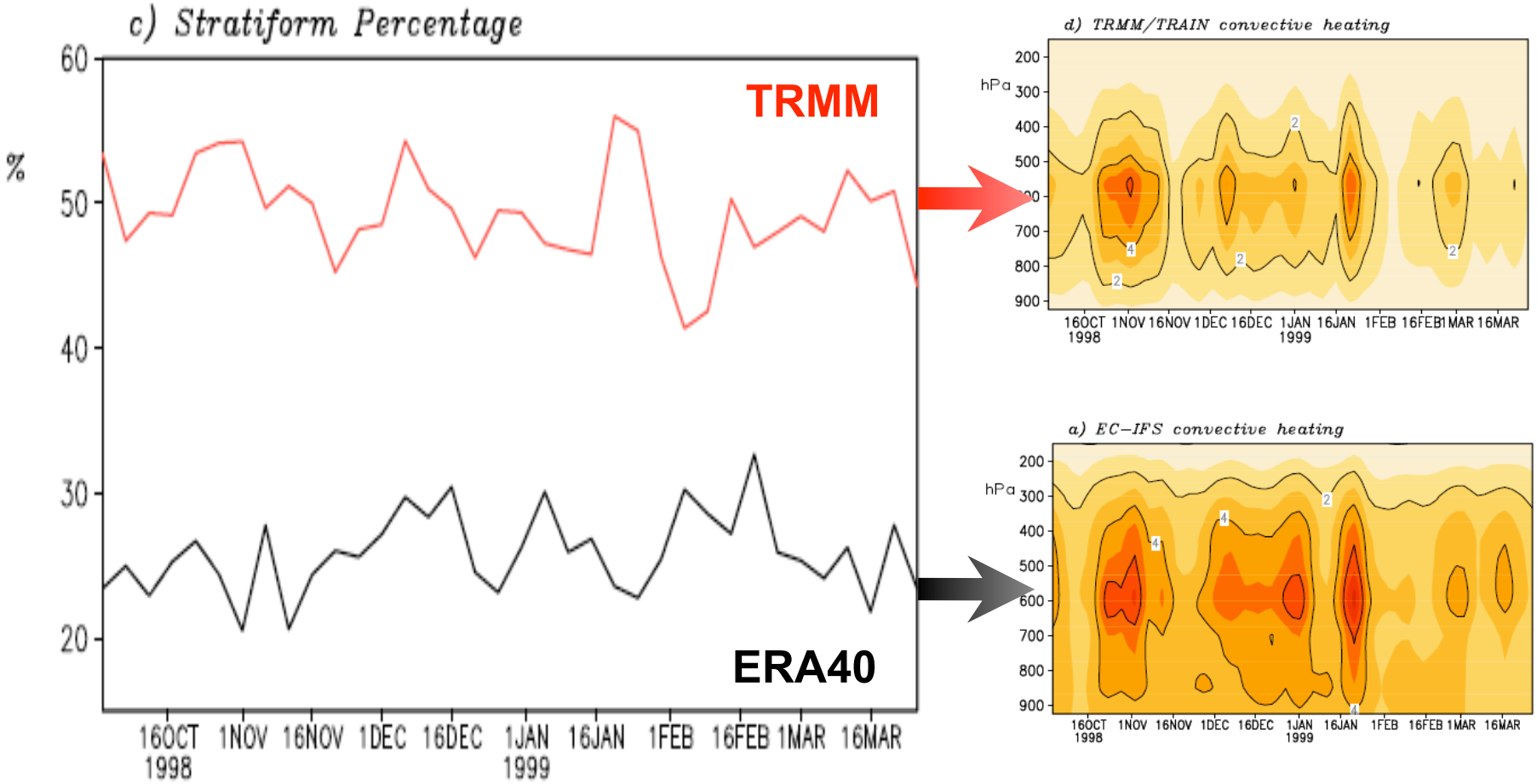
Courtesy: W. Olson, M. Grecu, M. Bosilovich

Model Evaluation in the Context of MJO



Jiang et al, J. Climate, 2009

Too Much Convective Rainfall?



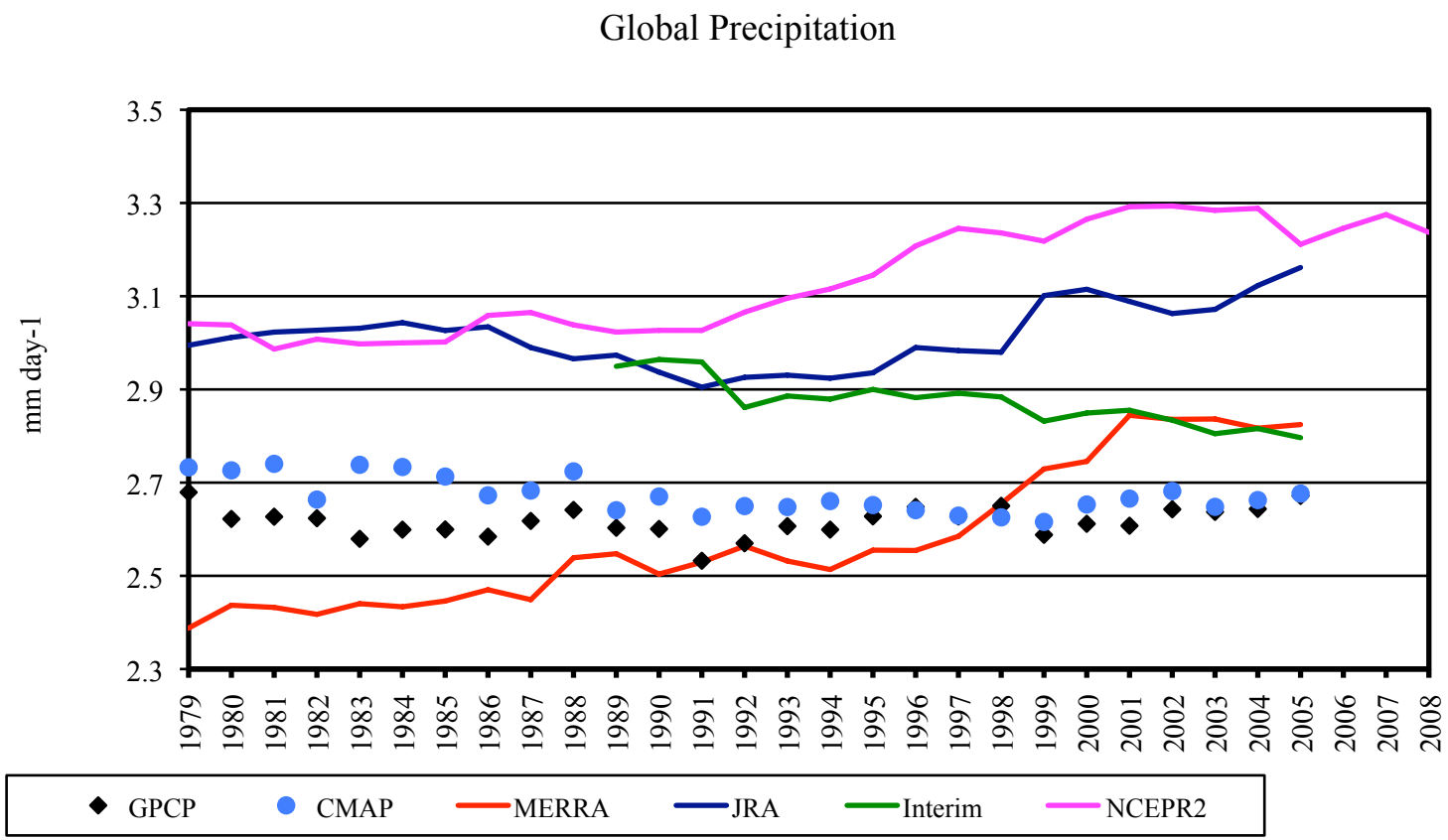
Jiang et al, J. Climate, 2009

Summary

- Significant imbalances remain in the global/annual-mean atmospheric energy budget. Largest discrepancies seem to be associated with high-latitude precipitation and the impacts of low clouds on DLR.
- Identifying error sources and dataset deficiencies requires that we look at progressively finer scales (Global-Meridional-Continental-Regional) and more detail (eg. vertical structure).
- Integration efforts within NEWS are helping to generate error estimates, identify algorithm shortcomings, and ultimately improve datasets.
- Analysis of new datasets are also leading to insights at the process-level that are central to evaluating and improving predictability.

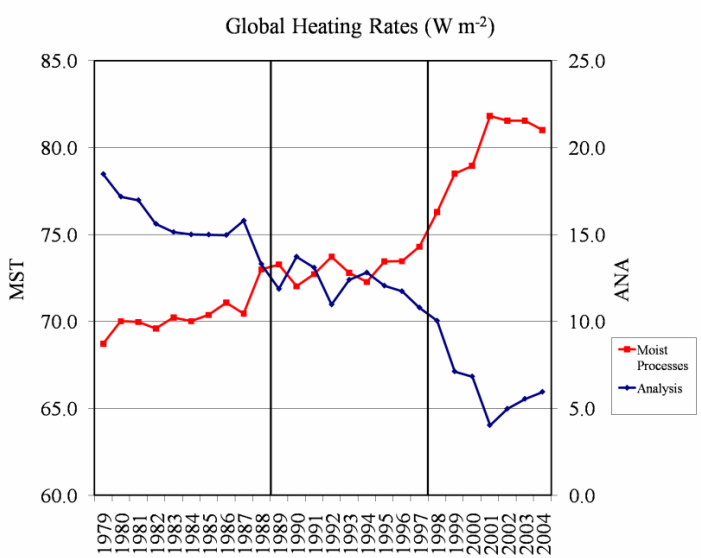
Extra Slides

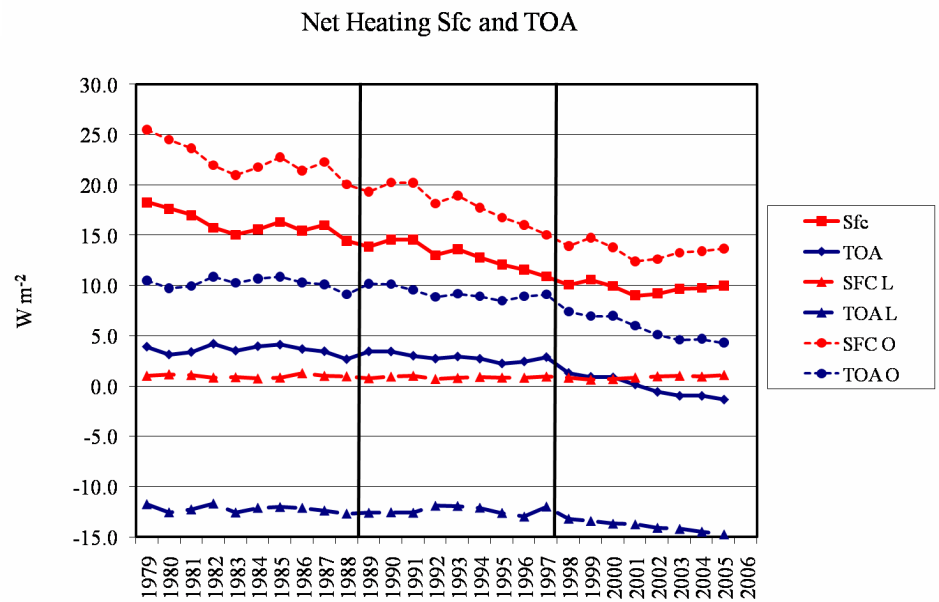
MERRA Precipitation Increases More than 1% per Year



Impact of Satellite Epoch on MERRA

- Time-dependent biases in q_v, T, u, v analysis increments result from varying satellite information content interacting with a constant but imperfect GEOS5 assimilation model
- Model physics respond to this varying "forcing" with artifacts in fluxes
- Is there a connection between DLR and surface rainrate in MERRA?



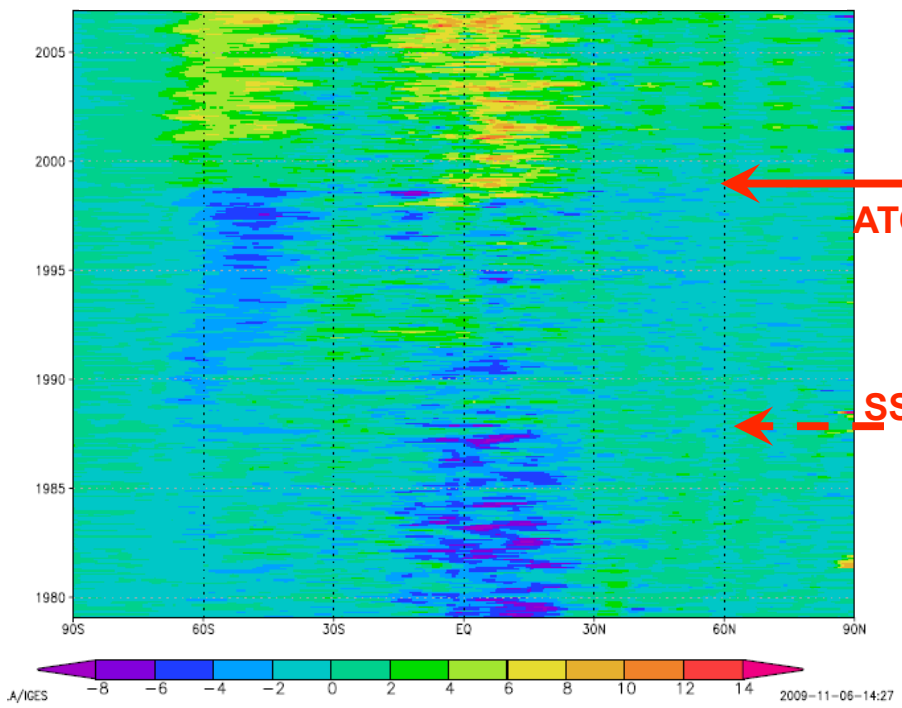


Time Dependent q_v Analysis Increments Affect Rainfall

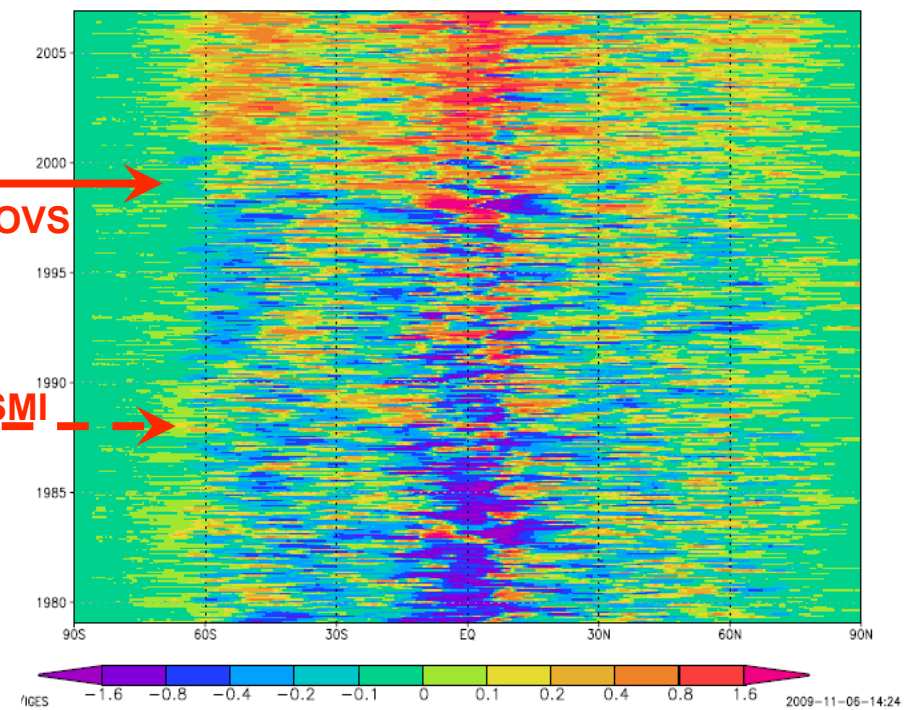
Zonal Mean Time Series (Mean Annual Cycle Removed)

- Onset of ATOVS data in 1998 increases convective moisture source (SSMI in 1988 less so). Temperature tendency (not shown) also impacts precipitation
- Leading mode of precipitation variability is non-physical trend, strongly coupled to the moisture increment

Vert Integ zonal mean $dq_v dt$-ana



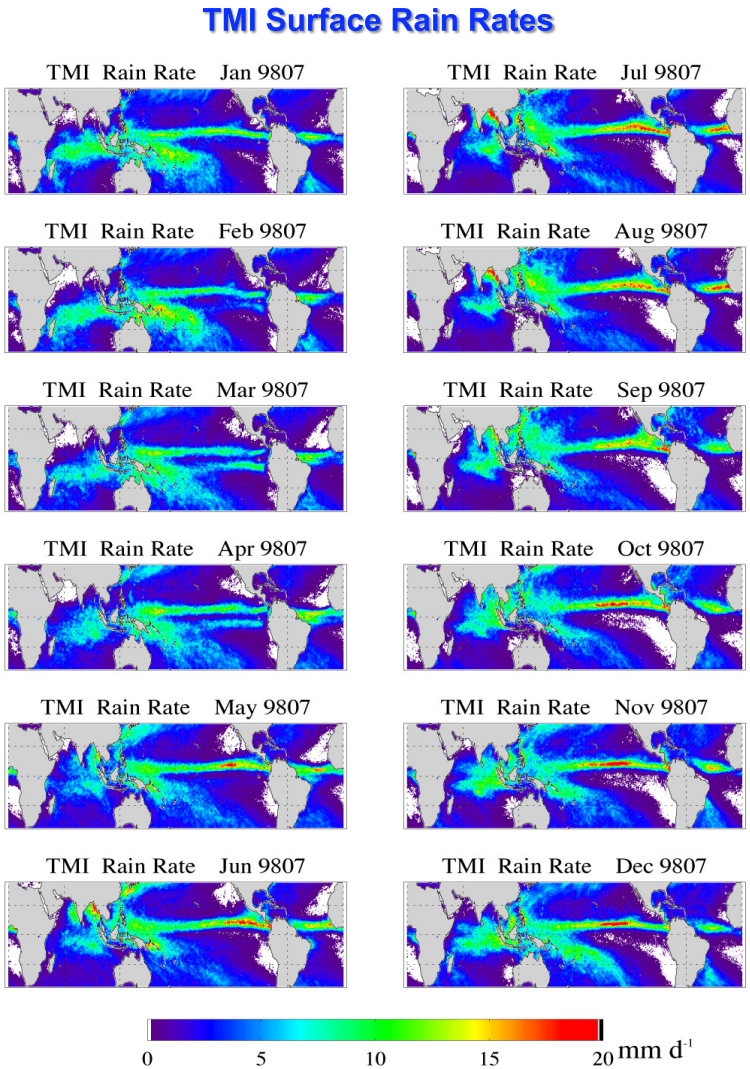
Zonal mean MERRA precip

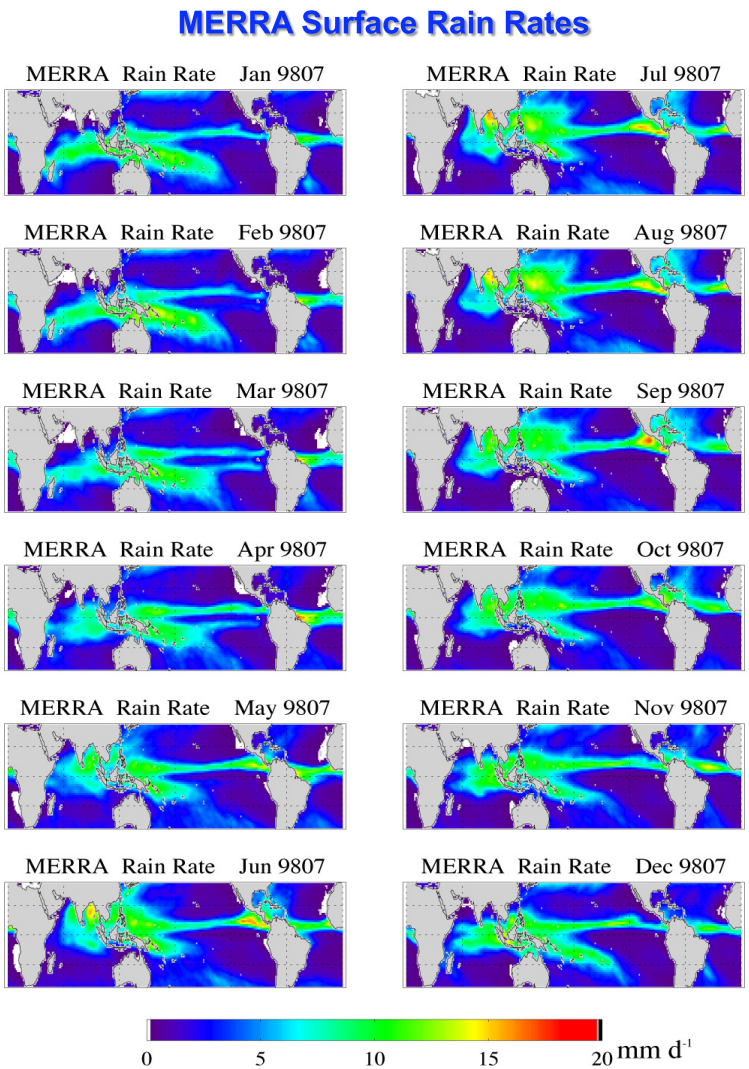


ATOVS

SSMI

Precipitation

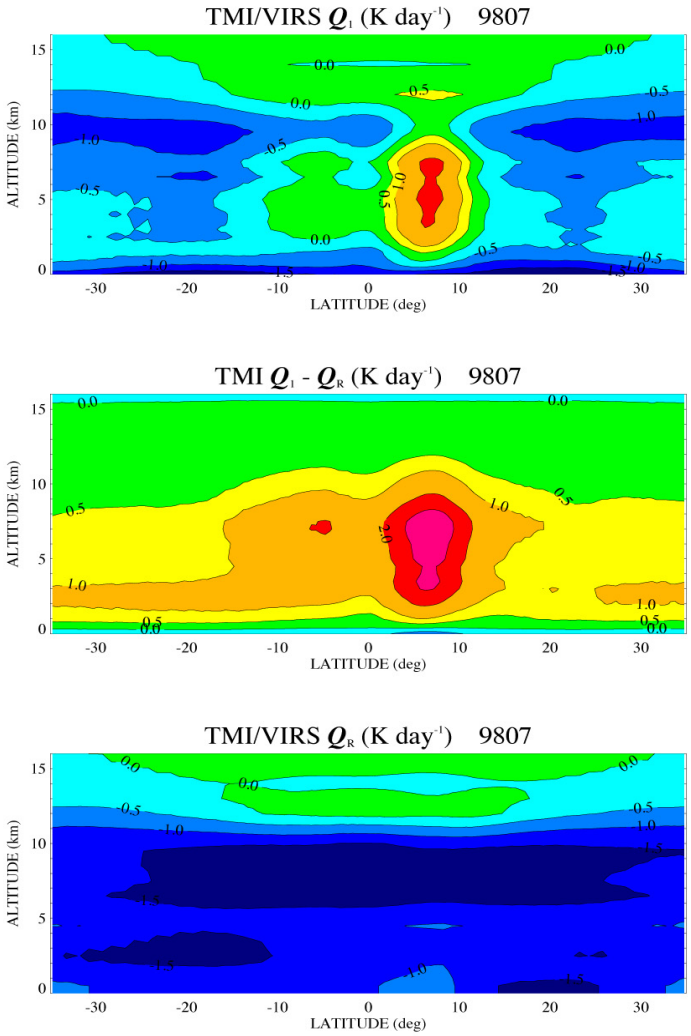




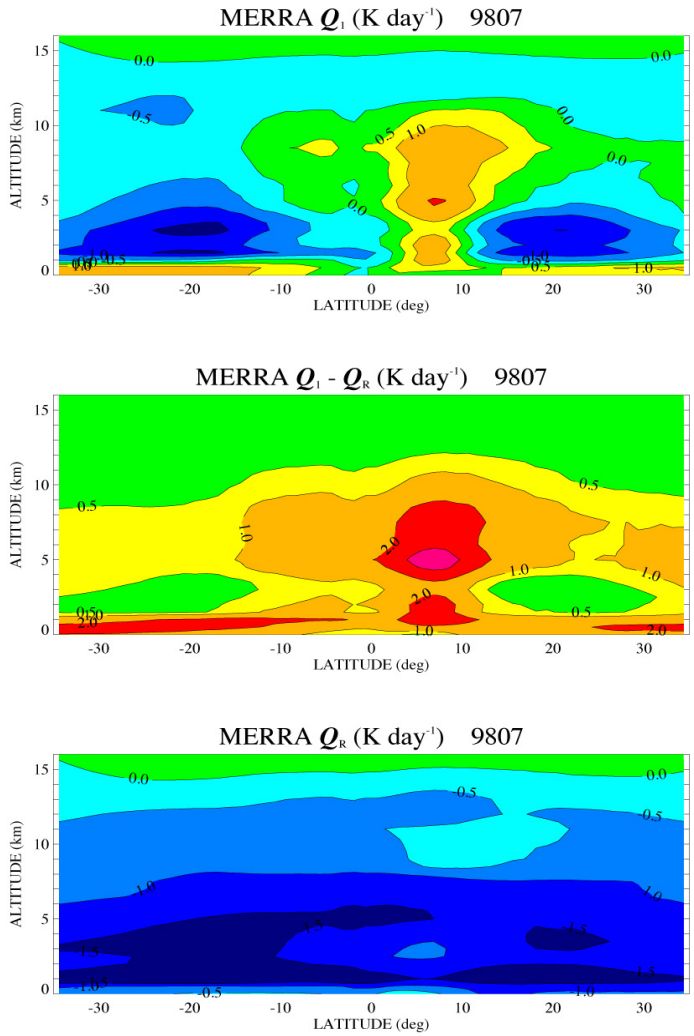
Courtesy: W. Olson, M. Grecu, M. Bosilovich

Zonal-Means (Ocean Only)

TMI/VIRS 98-07 Grand Zonal-Mean Heating



MERRA 98-07 Grand Zonal-Mean Heating



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