Tropical warming in MSU/AMSU vs. GCMs: land and ocean differences

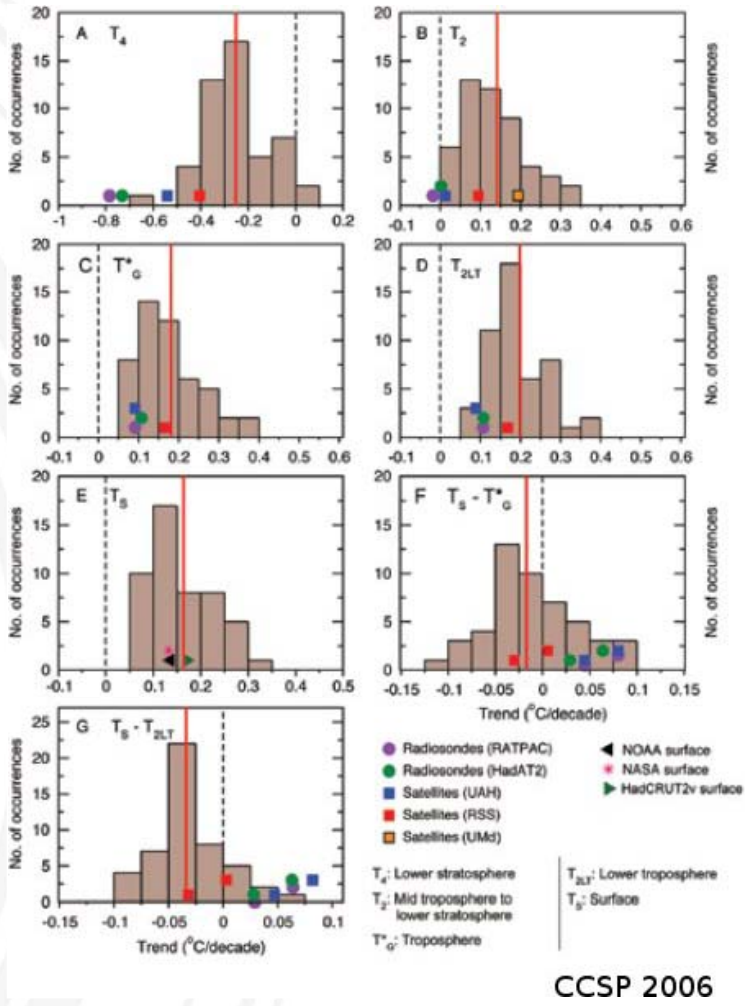
Celeste Johanson and Qiang Fu
University of Washington

2010 Workshop on Climate Data Records from Satellite Microwave Radiometry
March 22 - 24, 2010

Global troposphere and surface temperature trends

- GCM simulations of 20th century climate indicate tropospheric warming at least as much as the surface (CCSP 2006)

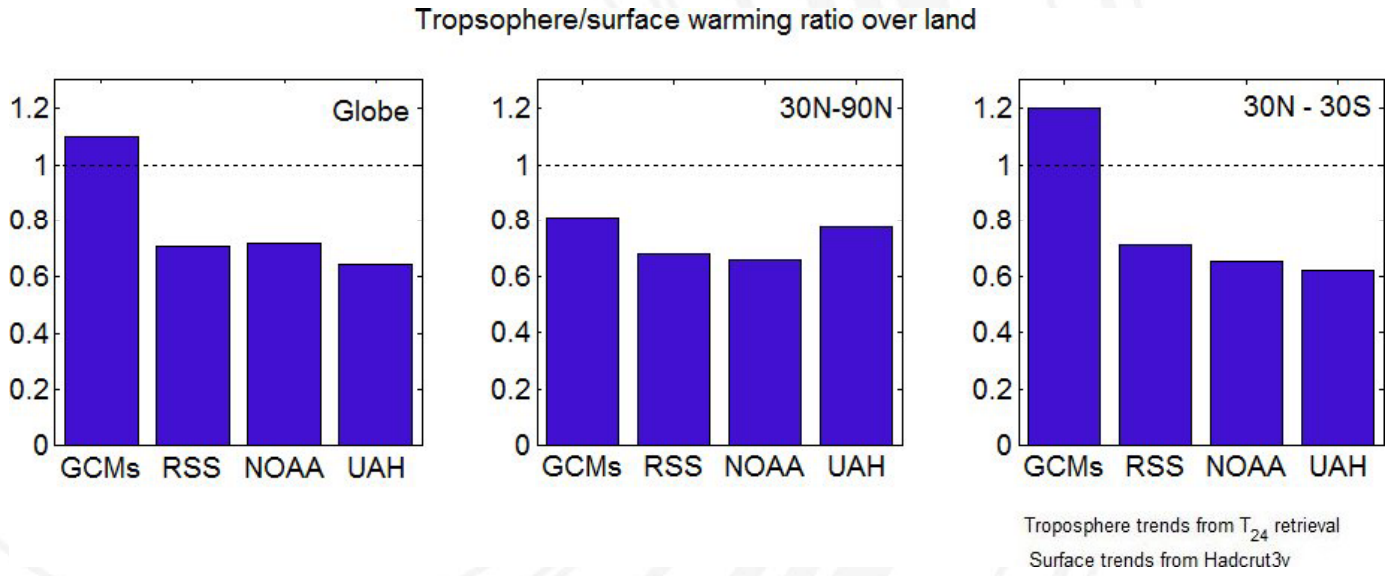
- Observed troposphere surface trends support GCM results
  - Trends 1979-2009
    - Surface: 0.14-0.16 K/dec
    - Lower troposphere (2LT) 0.14-0.16 K/dec
    - Troposphere (24) 0.11-0.20 K/dec



Objective

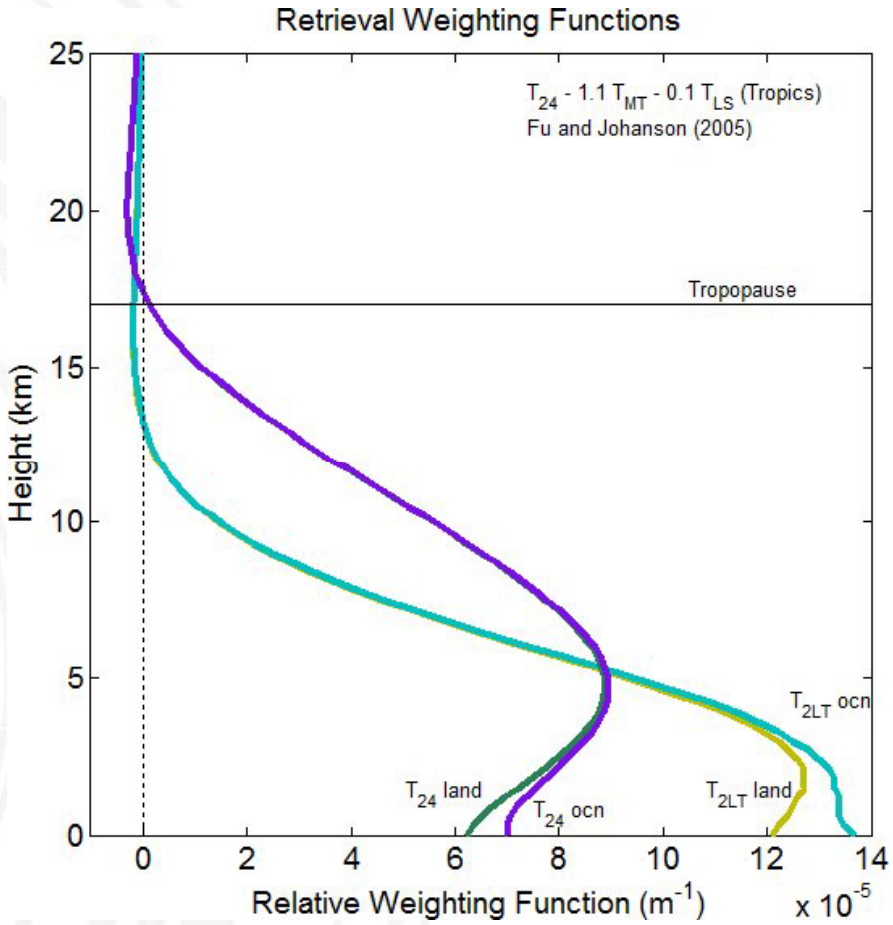
- Consider warming ratio for land and ocean regions separately
  - MSU/AMSU corrections are different over land and ocean (e.g. diurnal correction)
  - Lapse rate changes over land and ocean may be different due to different processes operating at the surface and in the troposphere
- Model/observation discrepancy in troposphere/surface warming ratio largest in Tropics
  - IPCC AR4 GCMs: warming ratio 1.2
  - MSU/AMSU warming ratio: 0.6 – 0.8
    - 0.06-0.1 K/dec less warming in the troposphere over land!

- Objective: Understand the discrepancy between GCM simulations and observations of troposphere/surface warming ratio over land in the Tropics



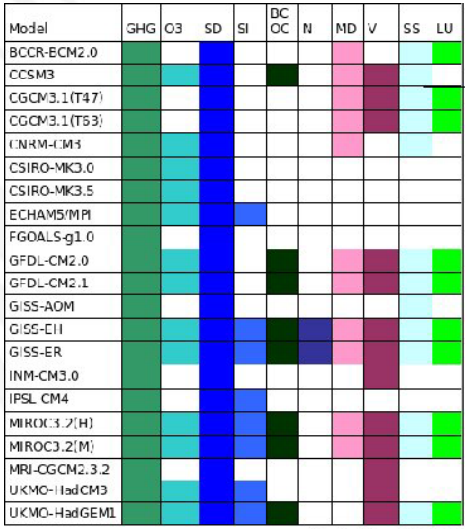
Observational Data

- MSU/AMSU 1979-2009
  - Two retrievals for troposphere temperature trends
    - T2LT lower troposphere, larger surface contribution
    - T24 deep troposphere
  - All data masked to reflect missing data at the surface (based on Hadcrut3v)
  - RSS v3.2
  - UAH v5.1 (T24), v5.2 (T2LT)
  - NOAA v2.0 (T24 only)
- Surface 1979-2009
  - Hadcrut3v
  - NCDC
  - GISTEMP

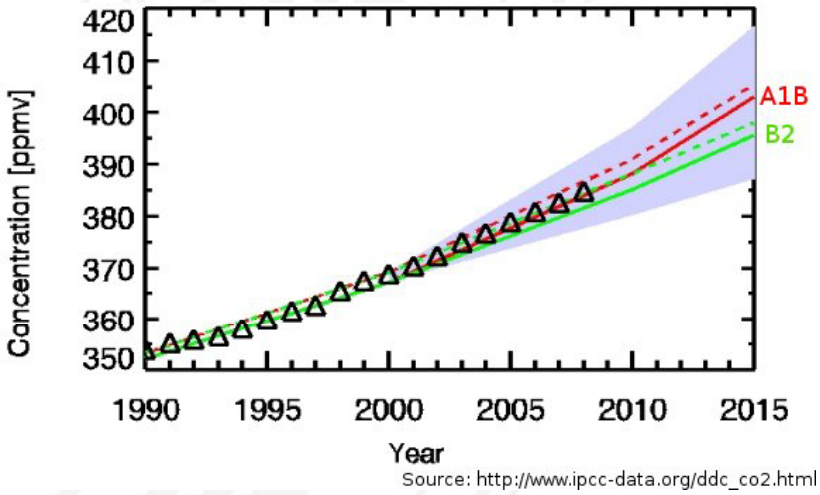


IPCC AR4 GCMs

- 21 coupled models
  - 41 ensemble members
- 1979-2009
  - Historical simulations of 20th century climate 1979-1999
  - Extended to 2009 with simulations of SRES A1B scenario
    - CO_2 concentrations in A1B closely follow observed CO_2 concentrations.
- Data masked to reflect missing data in Hadcrut3v
- Simulated MSU/AMSU layers
  - Static, global mean weighting functions applied to temperature profiles over land and ocean
  - Assume non-varying emissivity
    - Land 0.95
    - Ocean 0.5



Adapted from CCSP 2006

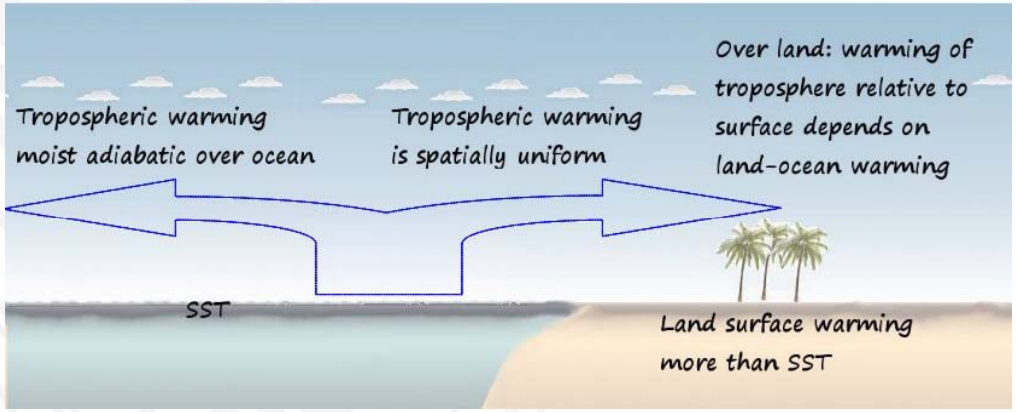


Source: http://www.ipcc-data.org/ddc_co2.html

Conceptual view of warming in the Tropics

Understanding of climate dynamics suggests:

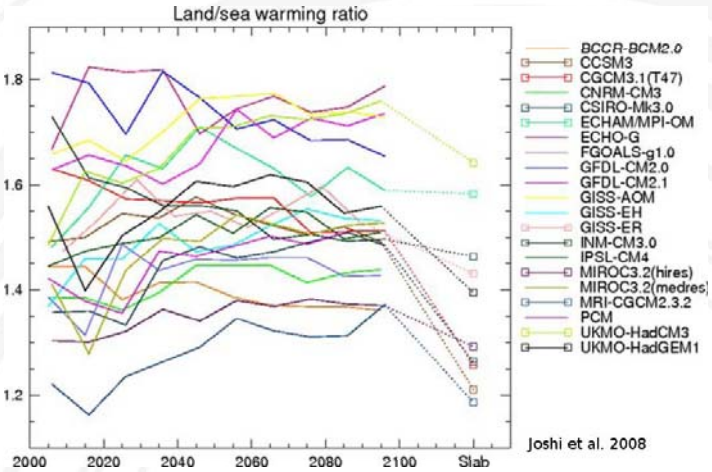
1. Land surface warming should be larger than warming of the SST.
2. SST warming is communicated to the troposphere through moist adiabatic processes
   - surface warming amplified in upper troposphere
3. Warming of the troposphere is spatially homogeneous through wave adjustment (fast)
   - Warming of the entire Tropical troposphere should be larger than SST warming

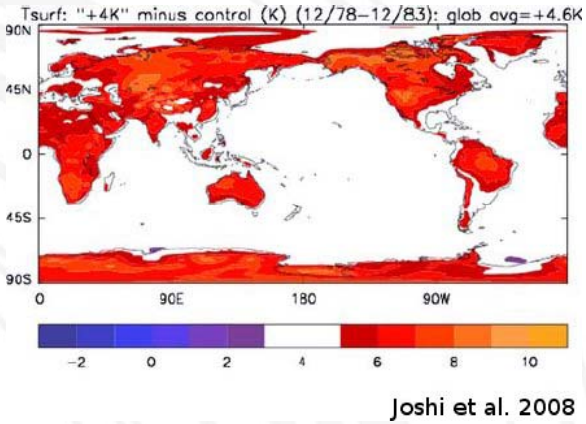


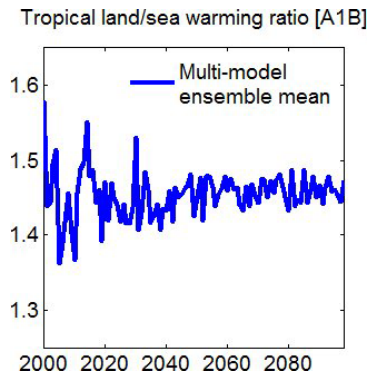
Troposphere/surface warming ratio over land depends on land/ocean warming contrast (LOC)

If LOC is larger than the moist adiabatic amplification ratio, then the troposphere will warm less than the surface over land

Land/ocean warming contrast (LOC) at the surface



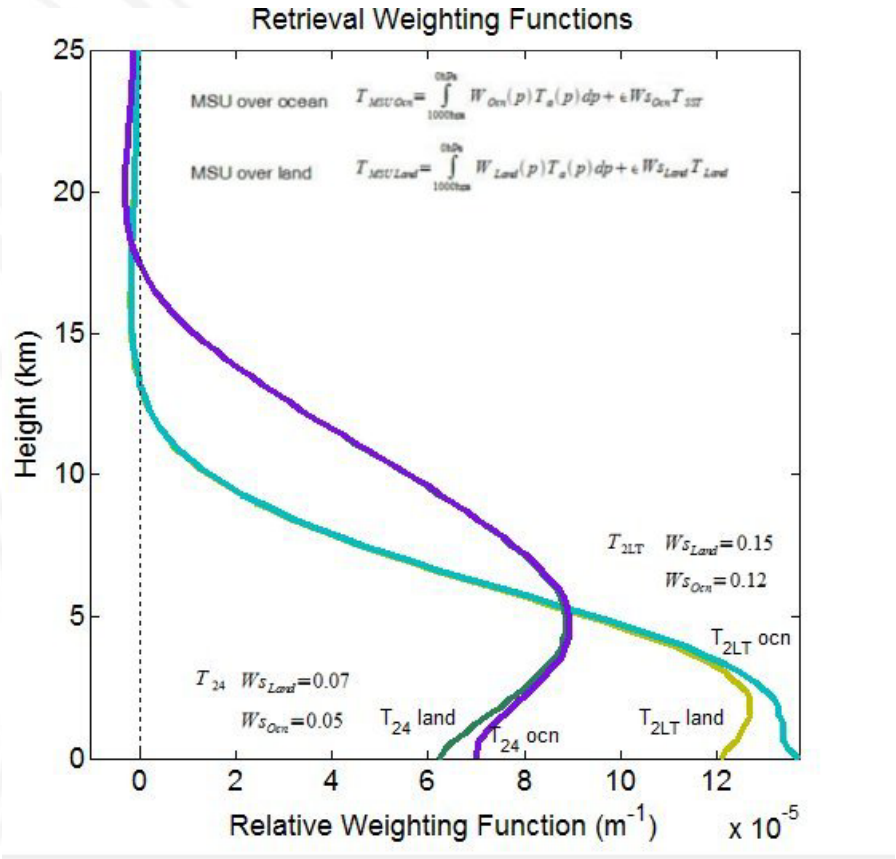




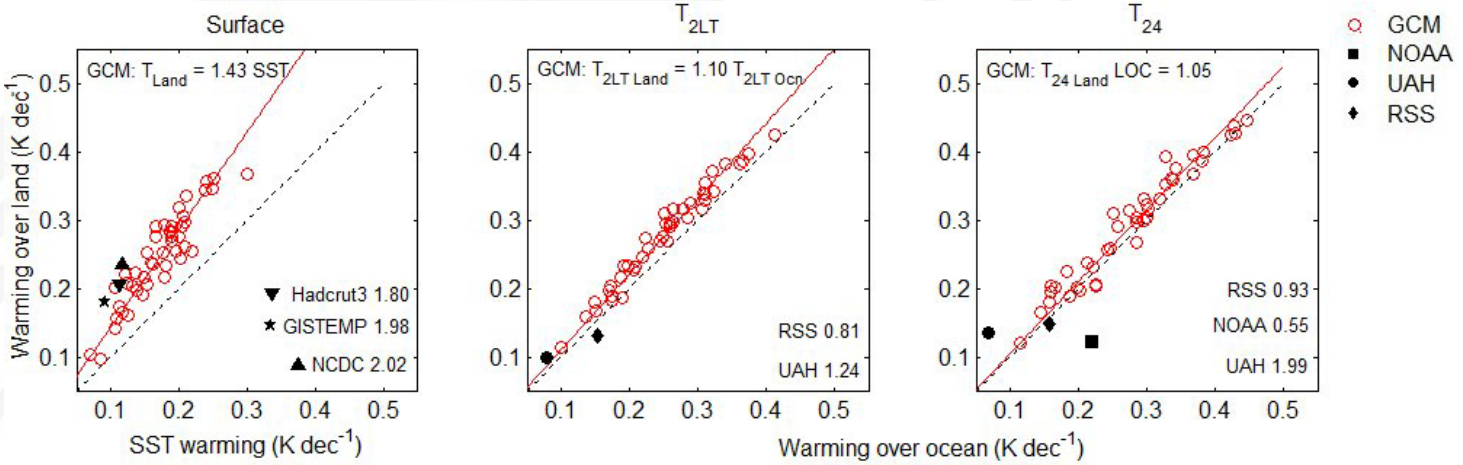
- Enhanced warming of the land surface relative to SST is a robust feature of GCM simulations
  - Transient and equilibrium simulations (Sutton et al. 2007, Joshi et al. 2008)
  - Perturbed SST simulations (Joshi et al. 2008)
- LOC at the surface is relatively constant in most GCMs
- Tropical LOC at the surface ~1.4 from GCMs

Land/ocean warming contrast in the Tropical troposphere from MSU

- Land/ocean warming contrast in MSU/AMSU
  - land/ocean contrast in the troposphere plus a contribution from LOC at the surface.
- Relative contributions from surface emissions are greater over land than ocean, and larger in T2LT than T24.
  - T2LT Land 0.15
  - T2LT Ocean 0.12
  - T24 Land 0.07
  - T24 Ocean 0.05
- Under uniform tropospheric warming MSU/AMSU trends should be larger over land due to the land/ocean warming contrast at the surface.



Land/ocean warming contrast (LOC) at the surface and in the troposphere



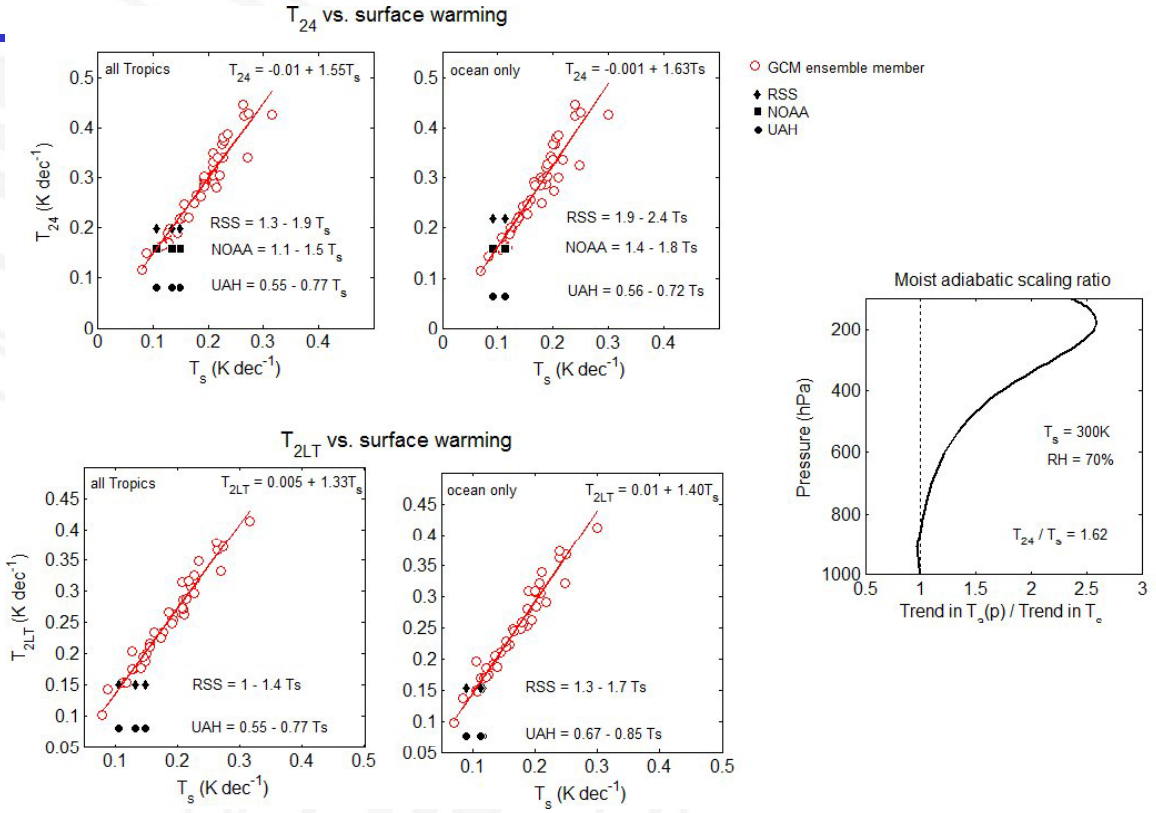
- GCMs
  - Land warming ~1.4 times as fast as SST
  - LOC decreases with height as expected for horizontally homogeneous tropospheric warming
- Observations
  - Land warming 1.8-2 times as fast as SST
  - Ratio of RSS trends over land and ocean regions close to GCM ratio, but trends over land are smaller than warming over ocean.
  - UAH (T24) areas over land warming twice as fast as areas over ocean (0.07K/dec)
  - NOAA: areas over land warming half as much as regions over ocean

Surface LOC	GCMs	Hadcrut3v	GISTEMP	NCDC
Surface	**1.43**	**1.8**	**1.98**	**2.02**

MSU/AMSU LOC	GCMs	RSS	UAH	NOAA
T2LT	**1.10**	**0.81**	**1.24**	-----
T24	**1.05**	**0.93**	**1.99**	**0.55**

Vertical amplification over ocean

- Amplification of surface warming close to moist adiabatic for Tropical average (Santer et al. 2005; Fu et al. 2004)
- GCMs
  - T24 amplification over ocean follows moist adiabat (1.6)
  - T2LT amplification (1.4) slightly larger than moist adiabatic (1.25-1.3)
  - Moist adiabatic amplification is more pronounced in upper troposphere which is better captured by T24 than T2LT



Warming over ocean ~ moist adiabatic?	GCMs	RSS	UAH	NOAA
T2LT	Warming relative to surface is slightly larger than adiabatic ratio	Yes	No (Troposphere warming less than surface)	---------
T24	Yes	Warming relative to surface is larger than adiabatic ratio	No (Troposphere warming less than surface)	Yes

Estimating troposphere/surface warming ratio (TSWR) over land in GCMs

GCMs consistent with picture of warming in the Troposphere
  - Tropospheric warming spatially uniform
  - Troposphere/surface warming ratio over ocean ~ moist adiabatic

- Derive a relationship between troposphere/surface warming over land and LOC
  - Small differences in atmospheric emissions over land and ocean for a given temperature profile

- Troposphere/surface warming ratio over land depends on
  - Land/Ocean warming contrast at the surface
  - Relative surface emission contribution

Estimated amplification over land is correlated (R=0.8) with actual amplification in GCMs

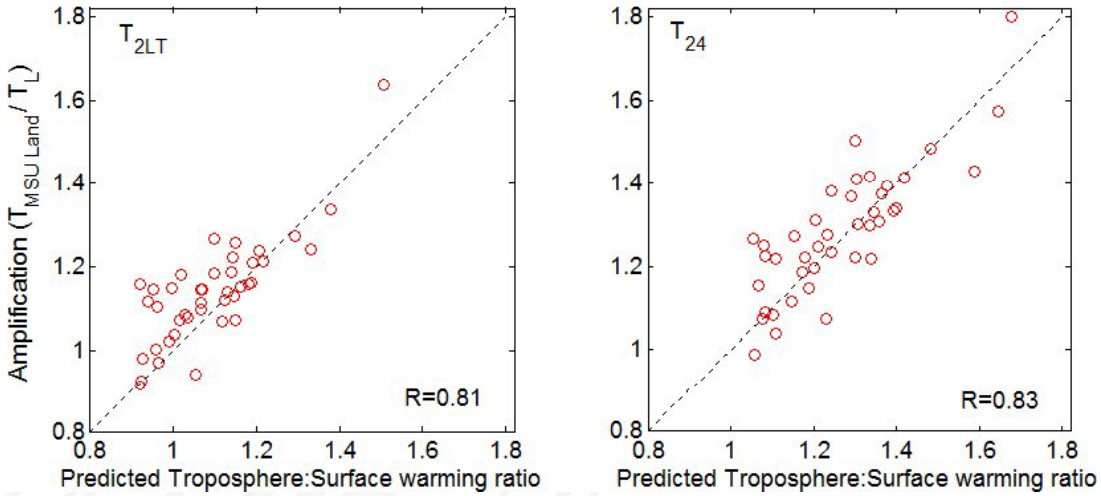
MSU over ocean $T_{MSU\,Ocn} = \int_{1000hpa}^{0hPa} W_{Ocn}(p)\,T_a(p)\,dp + \epsilon Ws_{Ocn} T_{SST}$

MSU over land $T_{MSU\,Land} = \int_{1000hpa}^{0hPa} W_{Land}(p)\,T_a(p)\,dp + \epsilon Ws_{Land} T_{Land}$

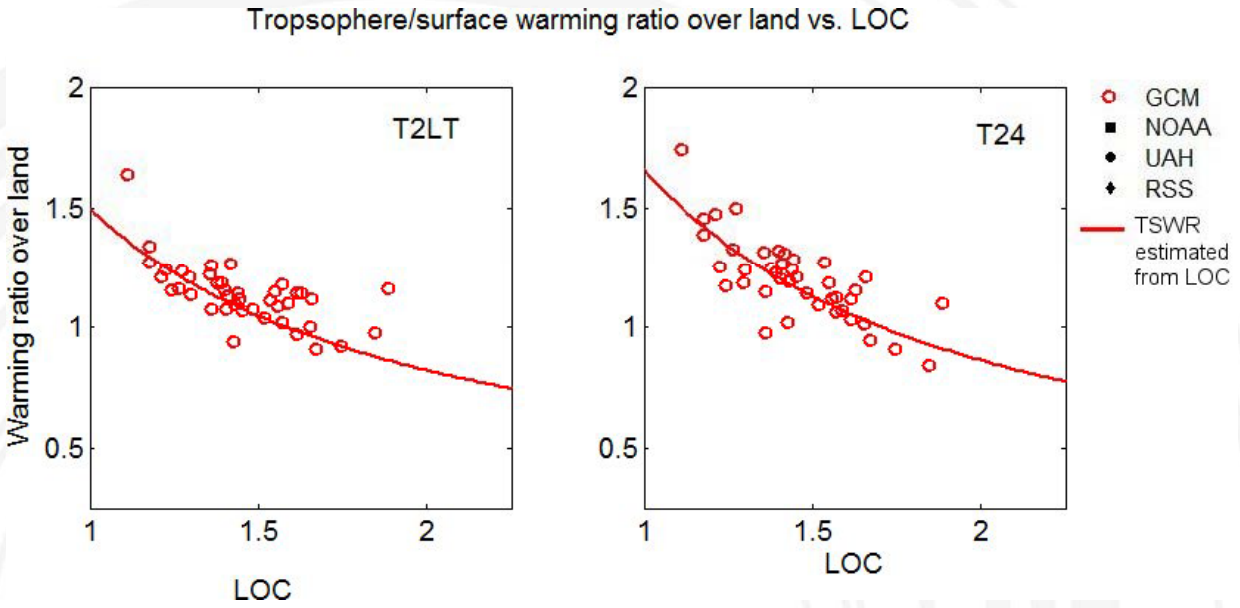
$$\int_{1000hpa} W_{Ocn}(p)\,T_{atm}(p)\,dp \approx \int_{1000hpa} W_{Land}(p)\,T_{atm}(p)\,dp$$

$$\frac{T_{MSU\,Land}}{T_L} = \frac{1}{LOC}\left(\frac{T_{MSU\,Ocn}}{T_{SST}} - \epsilon Ws_O\right) + \epsilon Ws_L$$

Amplification over land in GCMs



Troposphere/surface warming ratio over land vs. surface LOC in GCMs



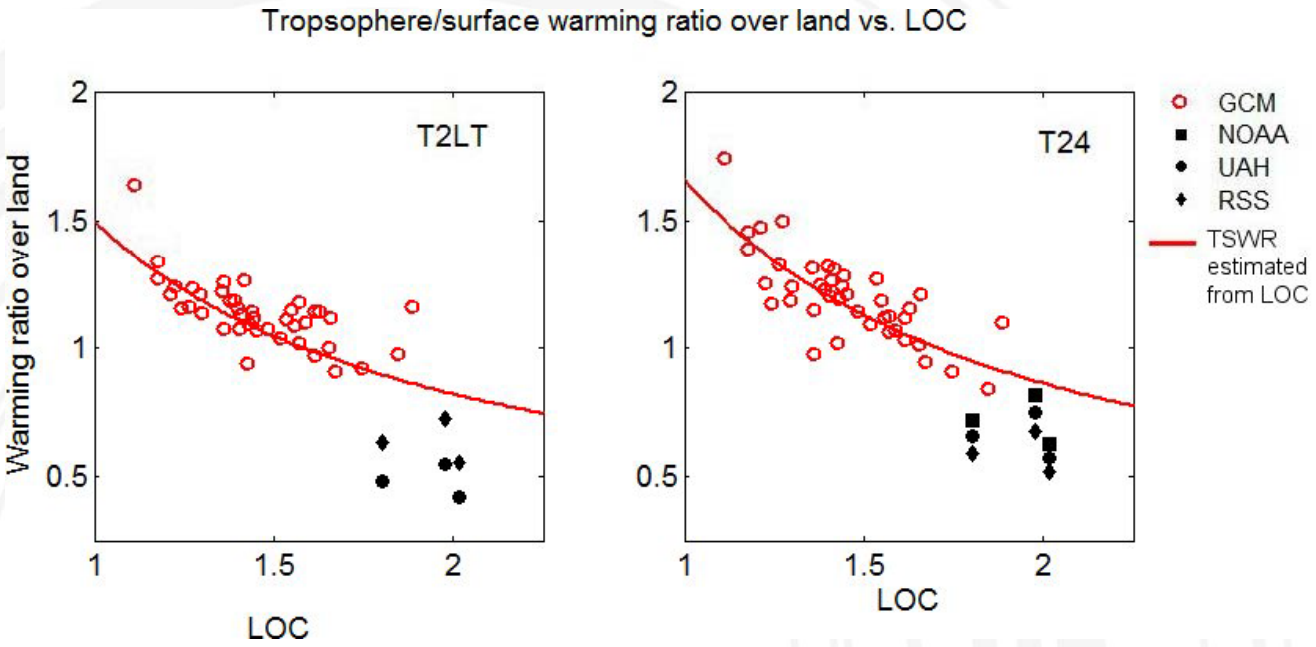
- The ratio of tropospheric warming to surface warming over land in GCMs can be approximated from average surface LOC and amplification over ocean

$$\frac{T_{MSU\,Land}}{T_L} = \frac{1}{LOC}\left(\frac{T_{MSU\,Ocn}}{T_{SST}} - \epsilon\, Ws_O\right) + \epsilon\, Ws_L$$

Expect more warming in troposphere than surface over land when LOC less than ~1.5

- *GCMs LOC = 1.4*
- *Observations LOC = 1.8-2.0*

Troposphere/surface warming ratio over land vs. surface LOC in GCMs and observations



Observations

- The larger observed warming of the land surface relative to the MSU/AMSU observations is consistent with an observed LOC > 1.5
  - In general, the troposphere/surface warming ratio is too small to be explained by observed surface LOC
  - NOAA T24 /GISTEMP warming ratio over land is close to expected value from theoretical considerations

Tropical warming features in GCMs and observations

	GCMs	RSS	UAH	NOAA
Warming over ocean ~ moist adiabatic?	**Yes** for T24 T2LT ratio is larger than moist adiabatic	Warming ratio is larger than moist adiabatic	**No** Amplification over ocean < 1	**Yes**
Land/ocean warming contrast (LOC)	LOC: 1.4 at the surface and decreases with height. It is > 1 for MSU/AMSU retrievals due to differential surface warming contributions over land and ocean	Slightly more warming over ocean than land	T24 over land warming twice as fast as regions over ocean (0.07 K/dec more warming over land than ocean)	T24 over ocean warming 0.09 K/dec more than over land
Troposphere/surface warming ratio	Troposphere/surface warming ratio > 1 as expected for surface LOC ~ 1.4	Troposphere/surface warming ratio < 1, but too small to be explained by observed surface LOC		

Conclusions

- The discrepancy between troposphere/surface warming ratio over land is most pronounced in the Tropics where GCMs indicate amplification of the surface temperature but observations show more warming at the surface
- Differences in GCM simulations and observations of land/ocean warming contrast account for some of the discrepancy.
- Uncertainties in MSU/AMSU observations of Tropical warming
  - Spatial homogeneity
  - Vertical amplification over ocean