Upper-Air Temperature Trends
History of a Controversy

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by PW Thorne, JR Lanzante, TC Peterson, DJ Seidel and KP Shine

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What is the controversy?

- Is atmospheric temperature changing as predicted?
  - Is the troposphere warming?
  - Is the troposphere warming relative to the surface?
  - Is the stratosphere cooling? (not today's topic)
- Can we believe our observations?
- Can we believe our models?
- What are the implications for environmental policy?

Why revisit this topic?

- Historical overview of complex topic
- Big scientific issues often lost amid technical details
- 20th anniversary of Spencer and Christy (Science, 1990)
- Lots of literature to review (>250 peer-reviewed pubs)
- "Climate-gate" – one of several prominent topics
- Public policy implications (> 16 US congressional hearings since 1997)
- Career retrospective

Outline

- Observations and monitoring
- Climate model projections
- Our evolving understanding
  - Chronological treatment
  - Illustrations from key papers
  - IPCC assessments
- Current understanding
- Lessons learned
- My biases:
  - Observations (radiosondes) and metadata
  - NOAA-centric

Global temperature observations

- Surface Observations
- Radiosondes (weather balloons)
- Satellite Observations - Microwave Sounding Unit

Surface observations

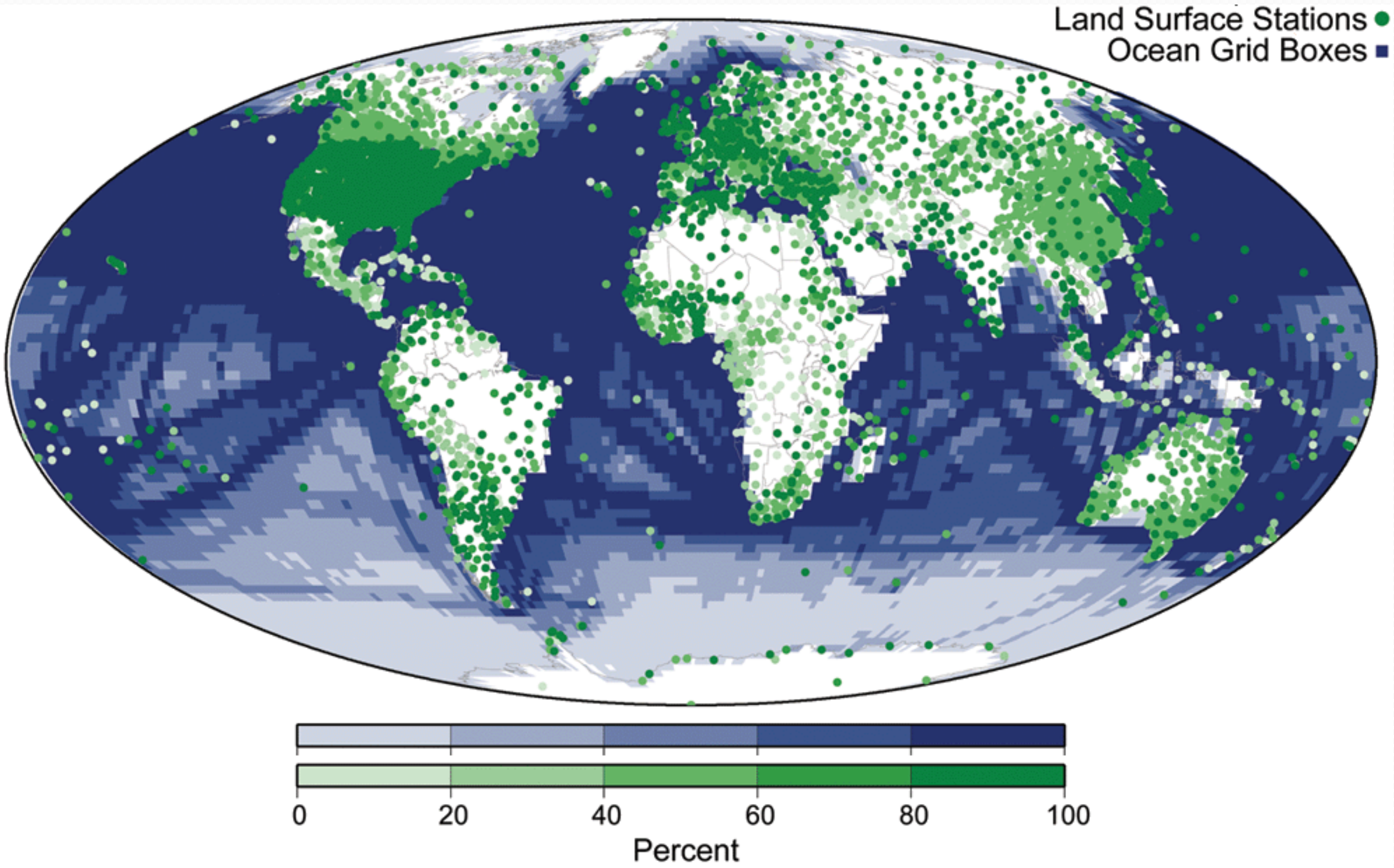
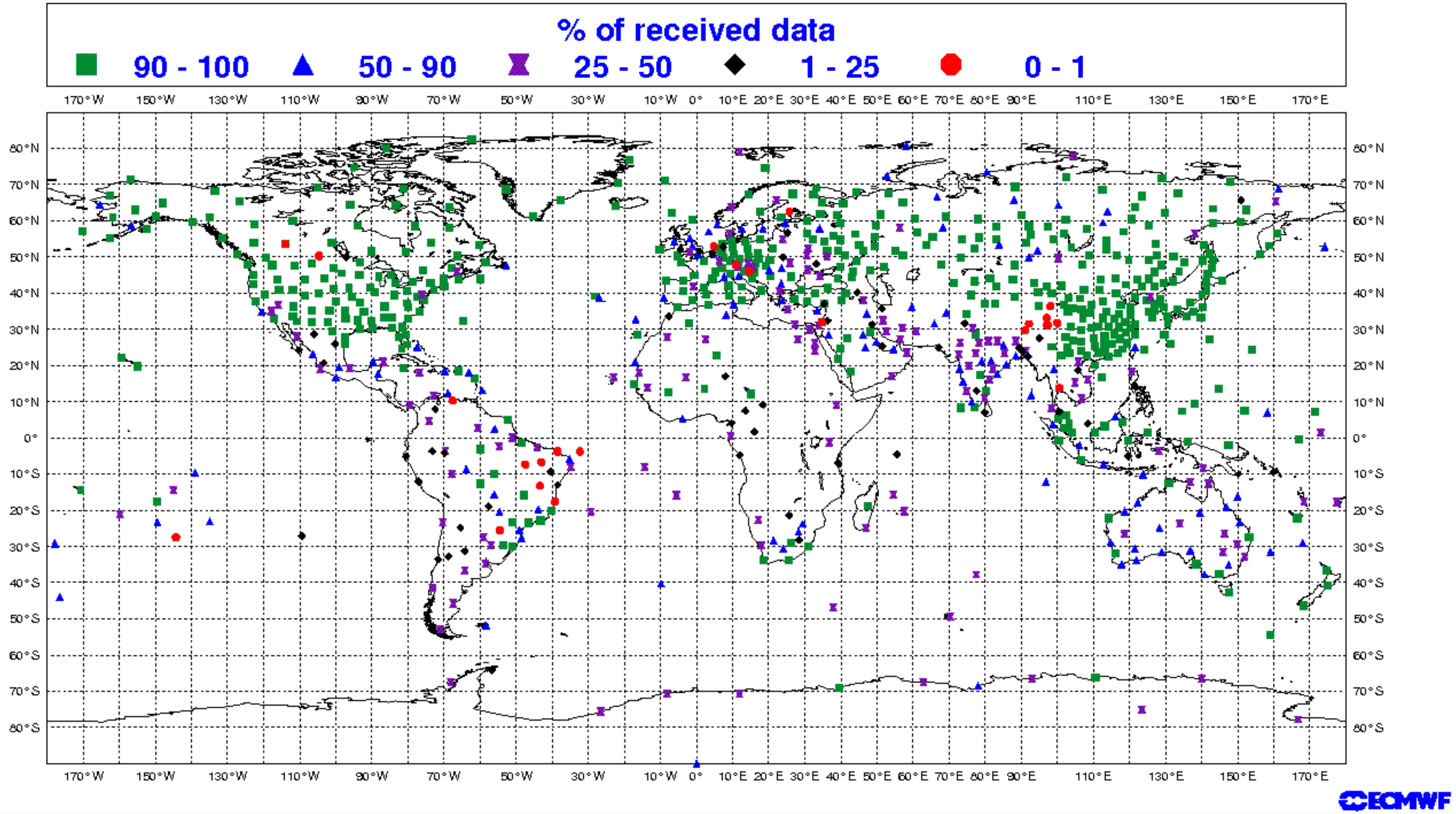


Figure 2.1 CCSP SAP1.1 (2006)

land stations (green) and SST observations (blue) reporting temperatures used in the surface temperature data sets over the period 1979-2004. Darker colors represent locations for which data were reported with greater frequency.

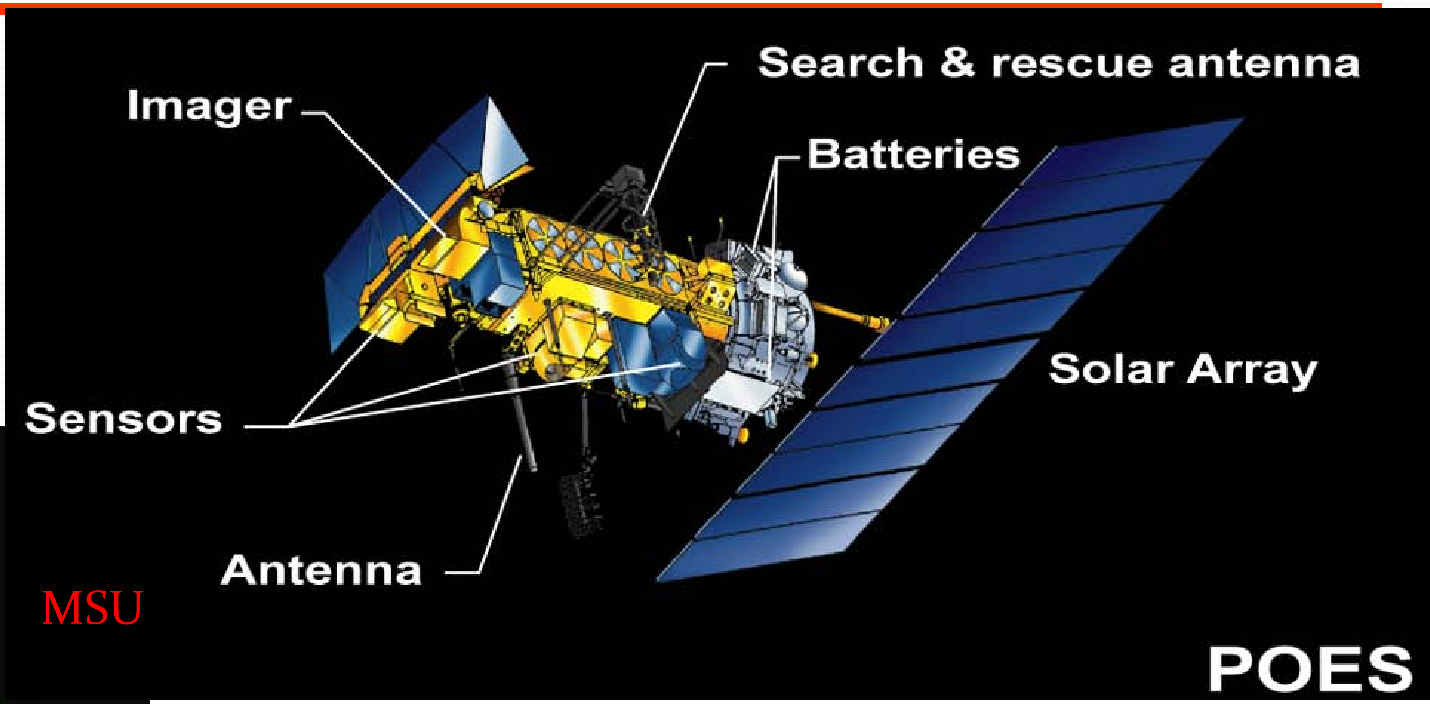
Radiosondes

Radiosondes

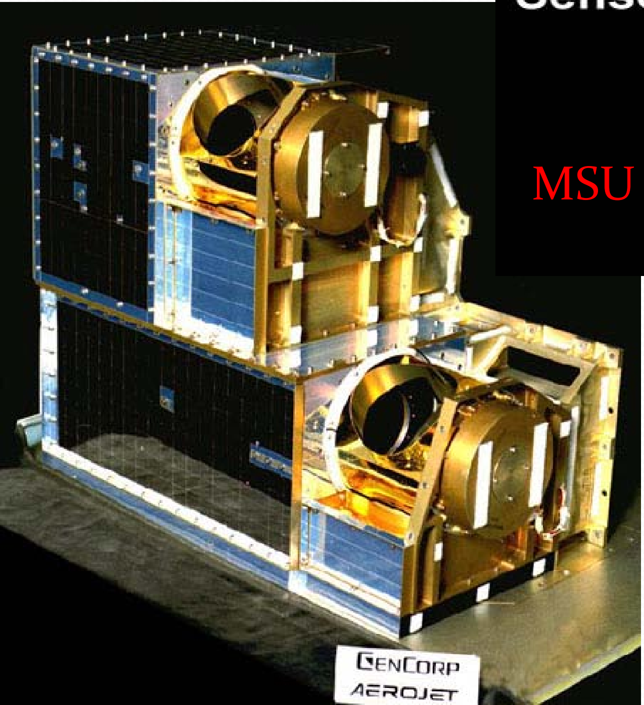


July 2009 700 hPa data reception at ECMWF

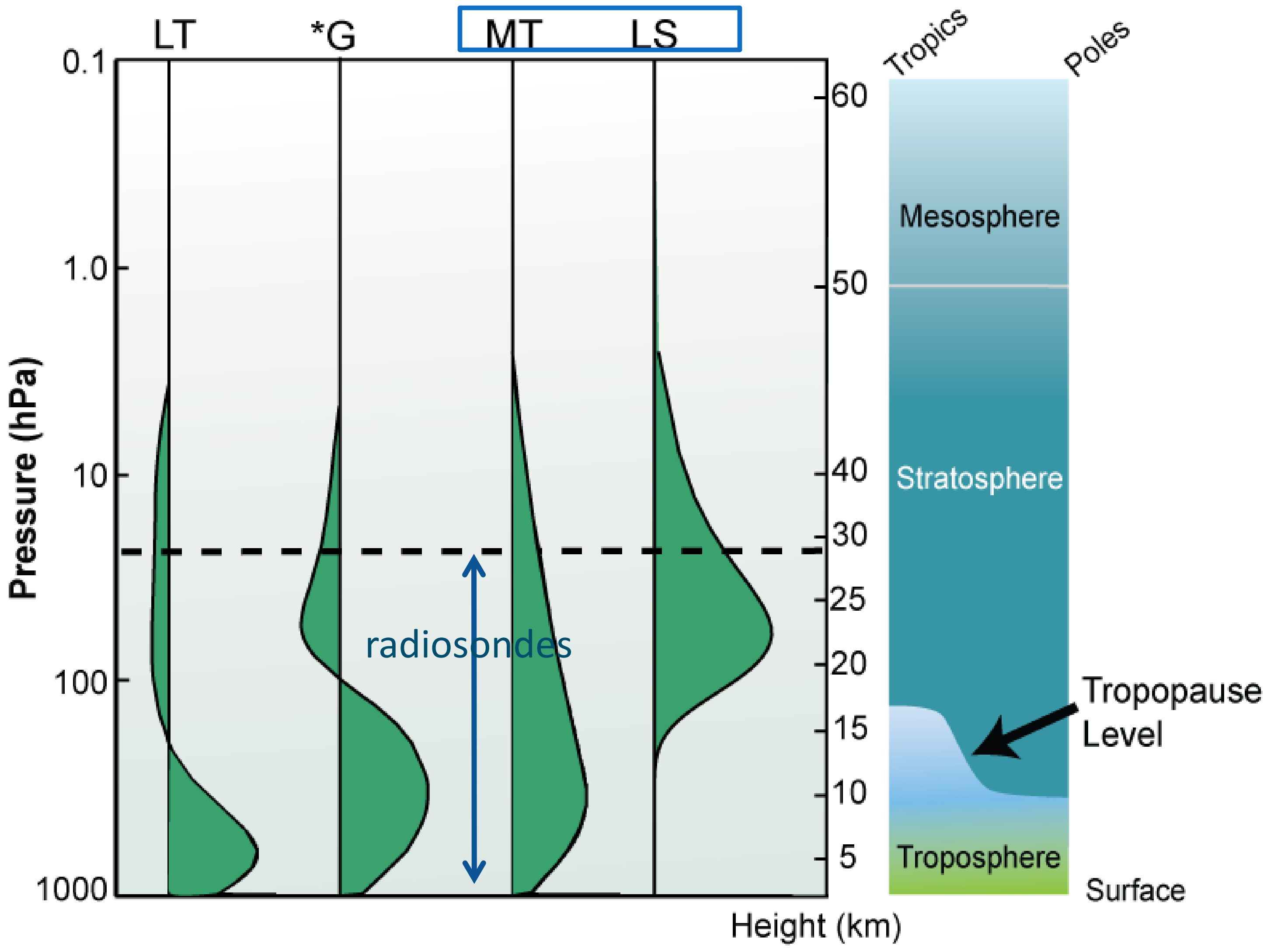
Microwave Sounding Unit



MSU



Vertical sampling

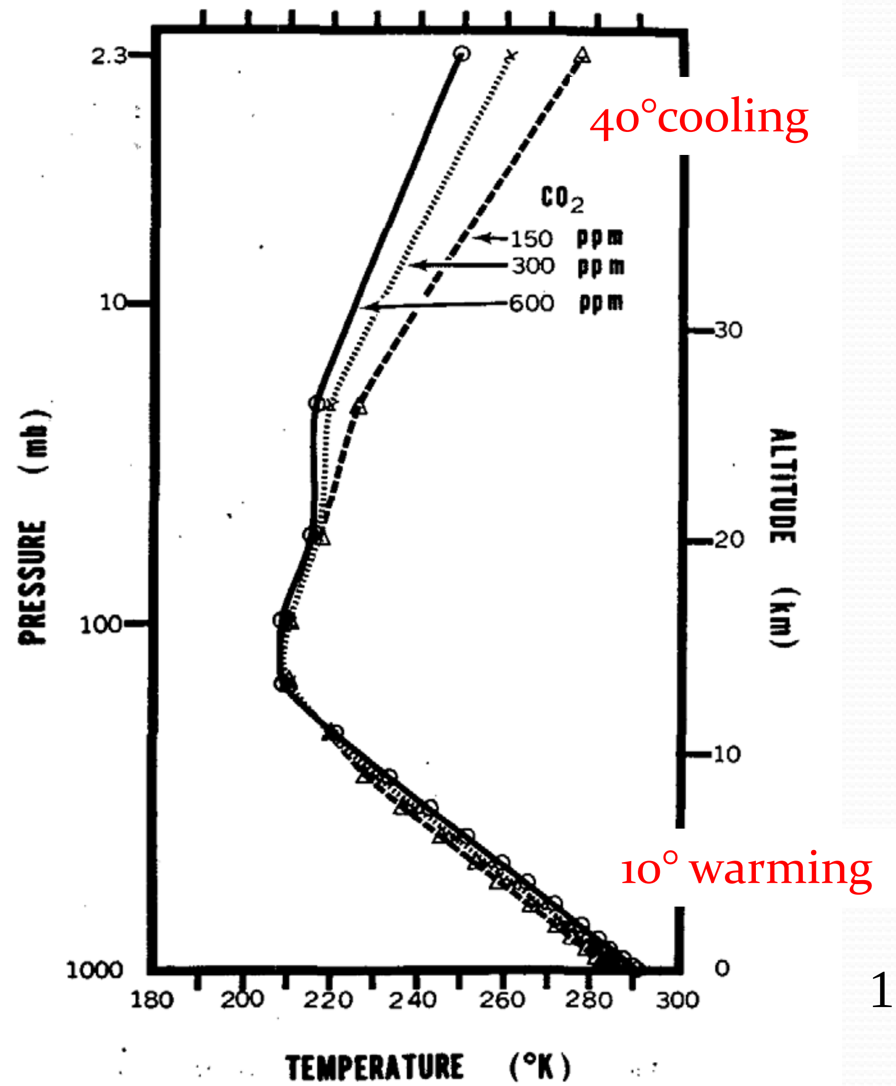


Global climate models

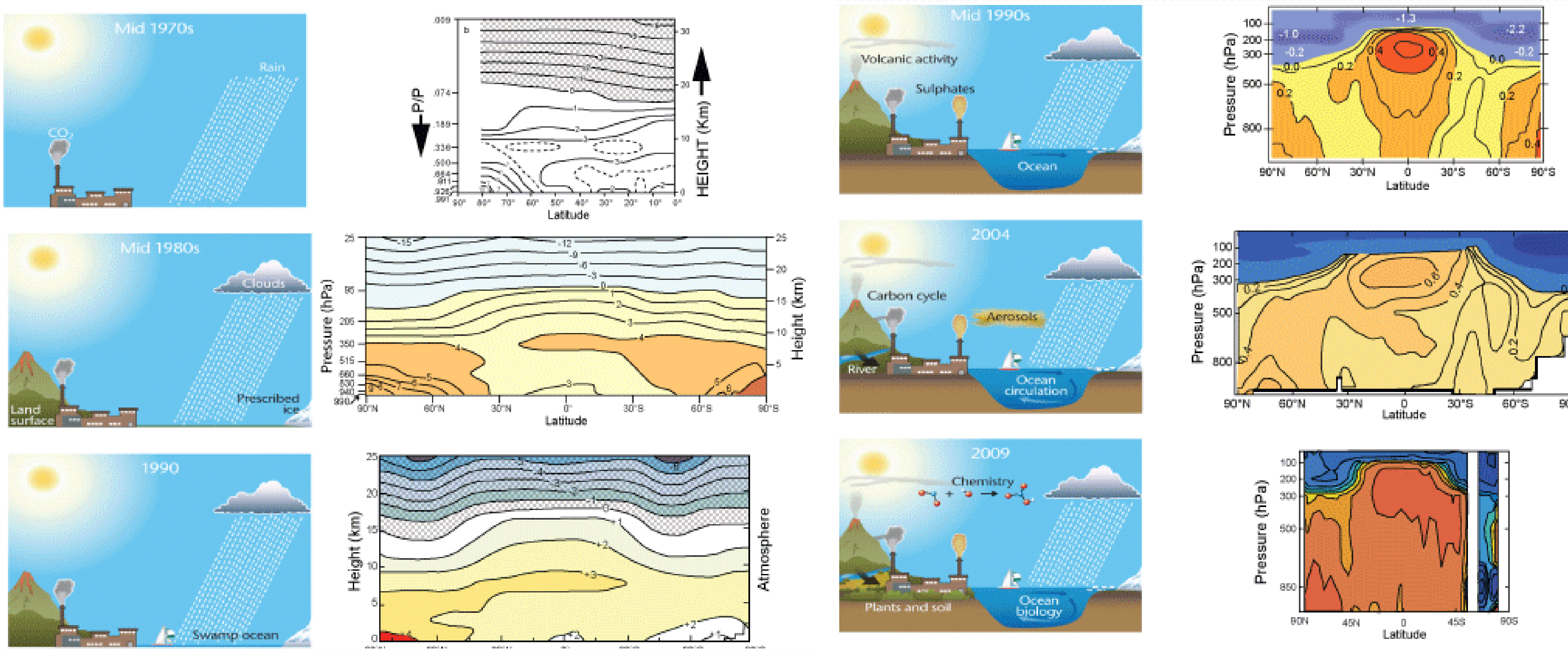
- RCMs -- Radiative-convective models
  - 1-D (vertical)
  - Convection linked to lapse rate
- GCMs -- General Circulation (Global Climate) models
  - 3-D
  - More physical processes than RCMs
  - Computer advances influence
    - Resolution
    - Processes
    - Coupling (air/ocean/land)
    - Ensembles

Pioneering model study

- Manabe and Wetherald (JAS, 1967)
- Effect of quadrupling CO_2 on T(z)
- 1D RCM



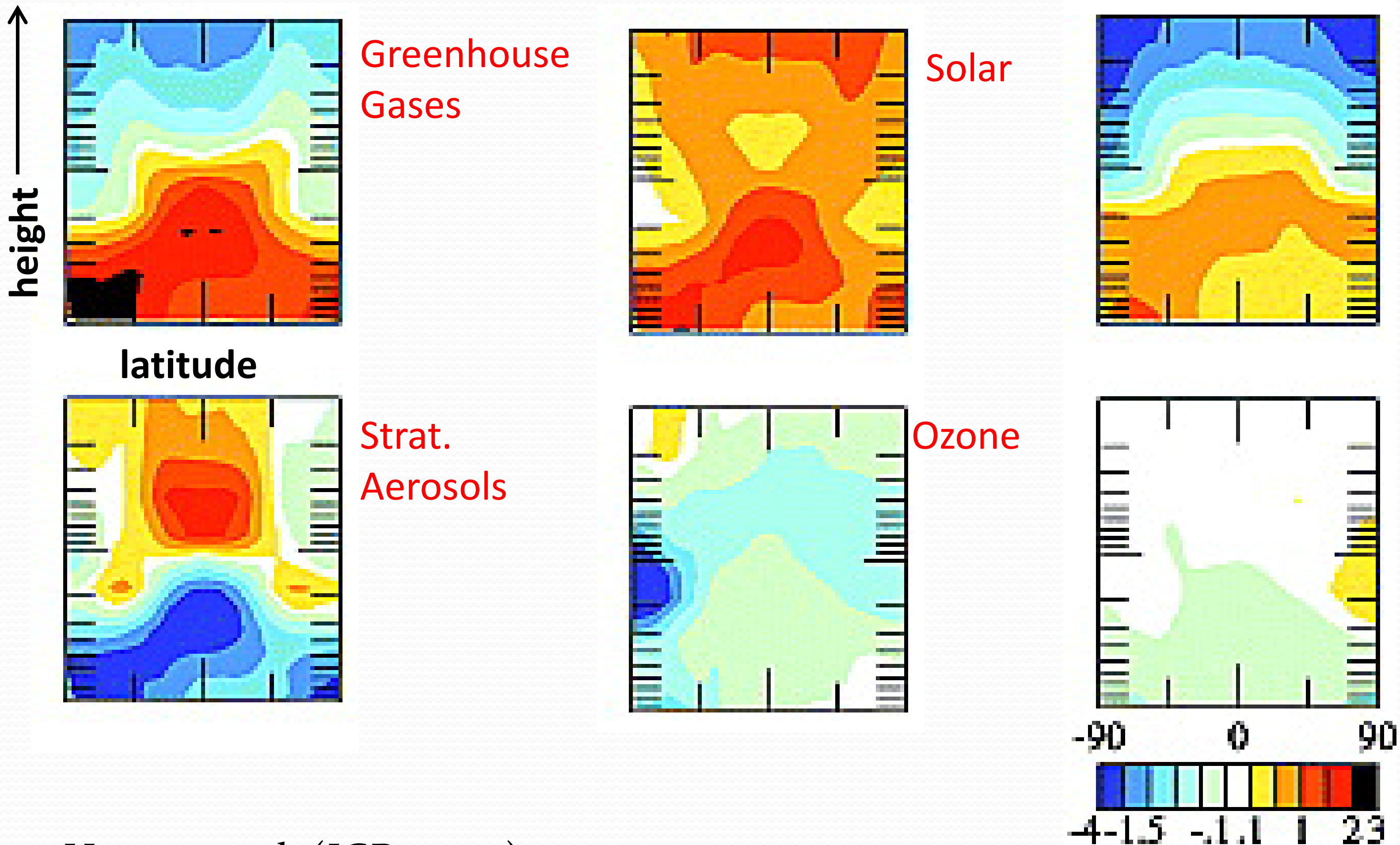
Consistent model response



NOAA GFDL models
Manabe and Wetherald (1975)
Manabe (1983)
Manabe et al. (1994)

UK Met Office/Hadley Centre models
Tett et al. (1996)
Tett et al. (2002)
Stott et al. (2006)

Distinctive “fingerprints”



Hansen et al. (JGR, 2002)

Pioneering observational studies

- Angell and Korshover (MWR, 1975)
- 63-station radiosonde network

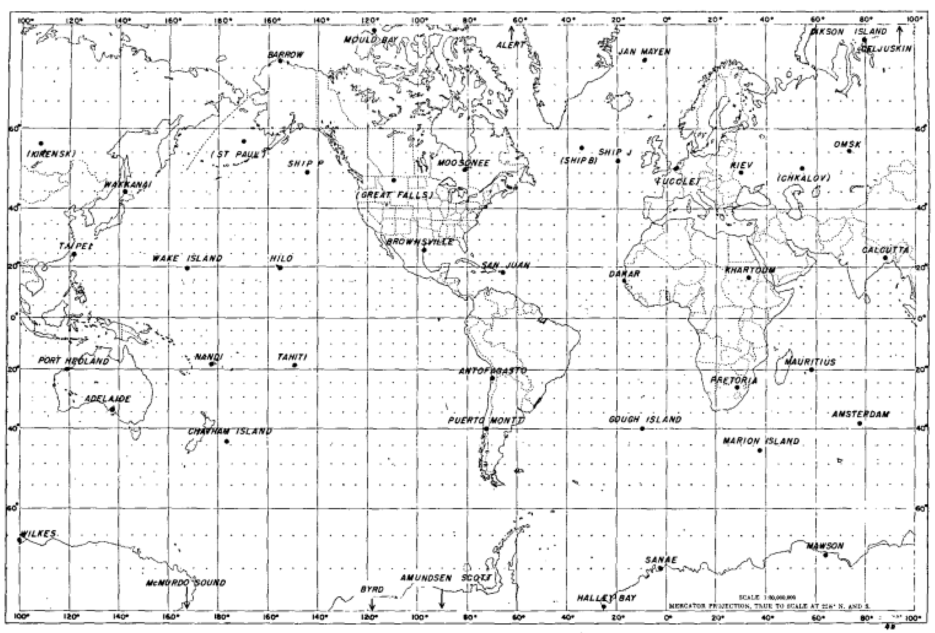
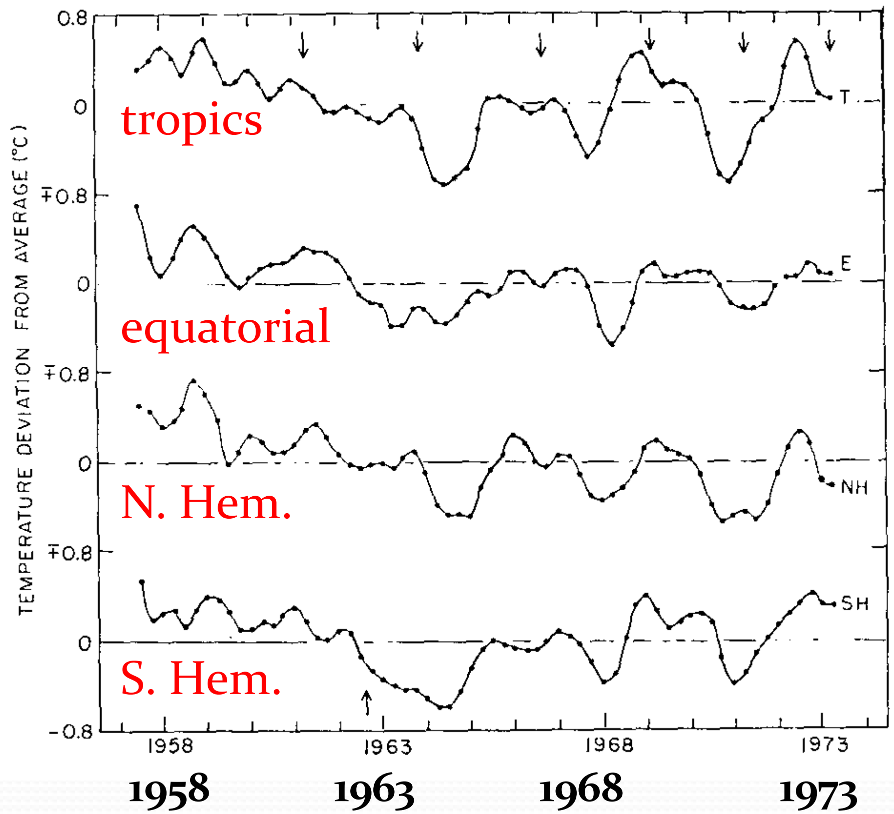
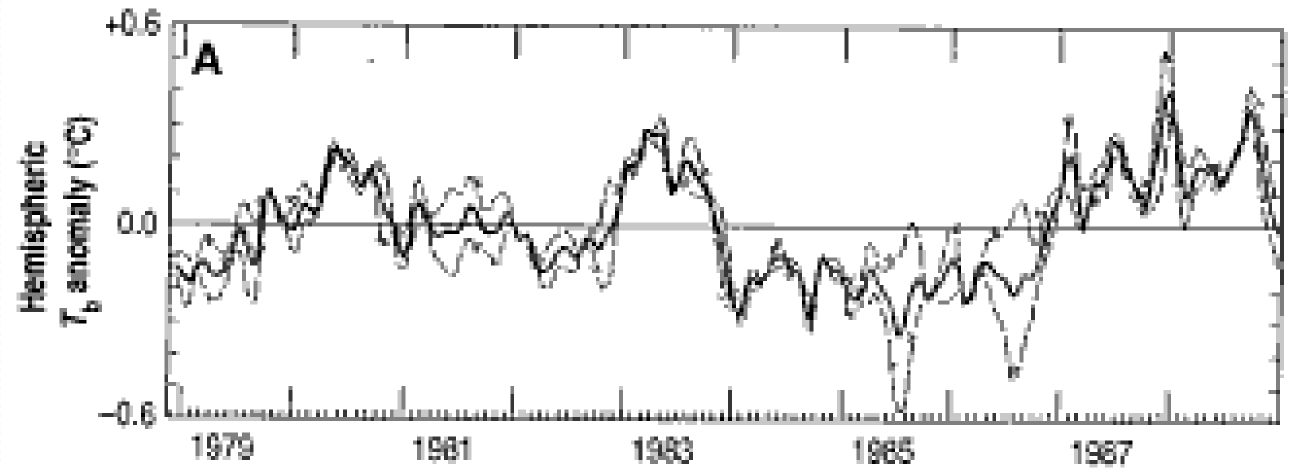


FIG. 1. Radiosonde stations used in the analysis. In north temperate latitudes (about 50°N) the temperature trend at stations within parenthesis was compared to the trend at stations without parenthesis in order to determine the representativeness of a limited data sample.



300-700 hPa T anomalies

Pioneering observational studies



- Spencer and Christy (Science, 1990)
- Global MSU data
- Instigated 20-yr controversy

> important factors in the climate system. Analysis of the first 10 years (1979 to 1988) of satellite measurements of lower atmospheric temperature changes reveals a monthly precision of 0.01°C, large temperature variability on time scales from weeks to several years, but no obvious trend for the 10-year period. The warmest years, in descending

Radiosonde data problems

- Radiosondes monitor weather, not climate
- Trends affected by
  - Instrument changes
  - Data processing and corrections
  - Station moves
- Gaffen (JGR, 1994)
- Parker and Cox (IJC, 1995)

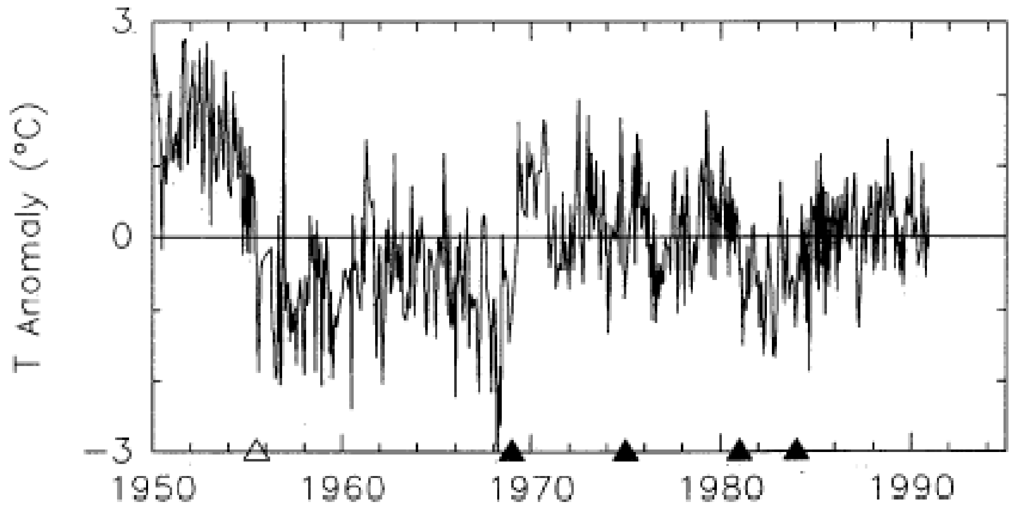
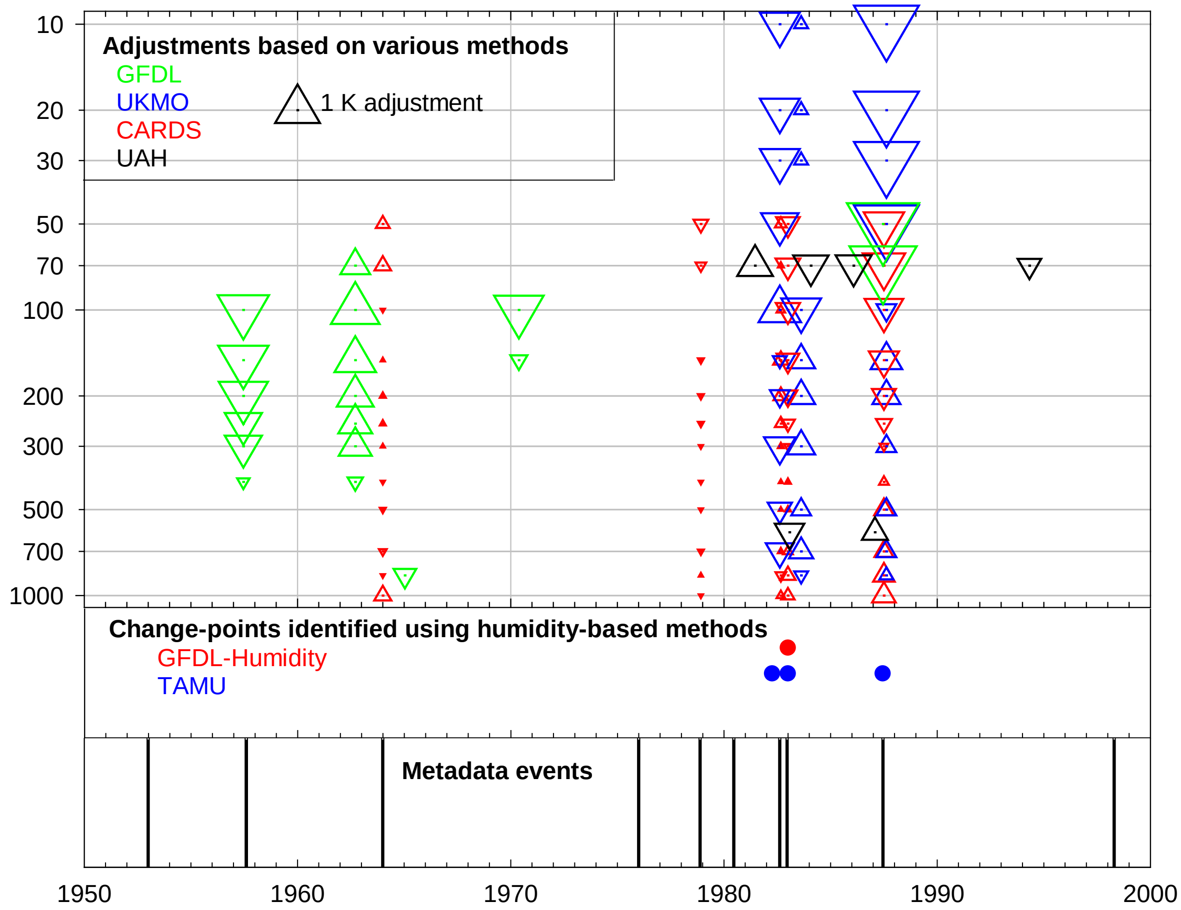


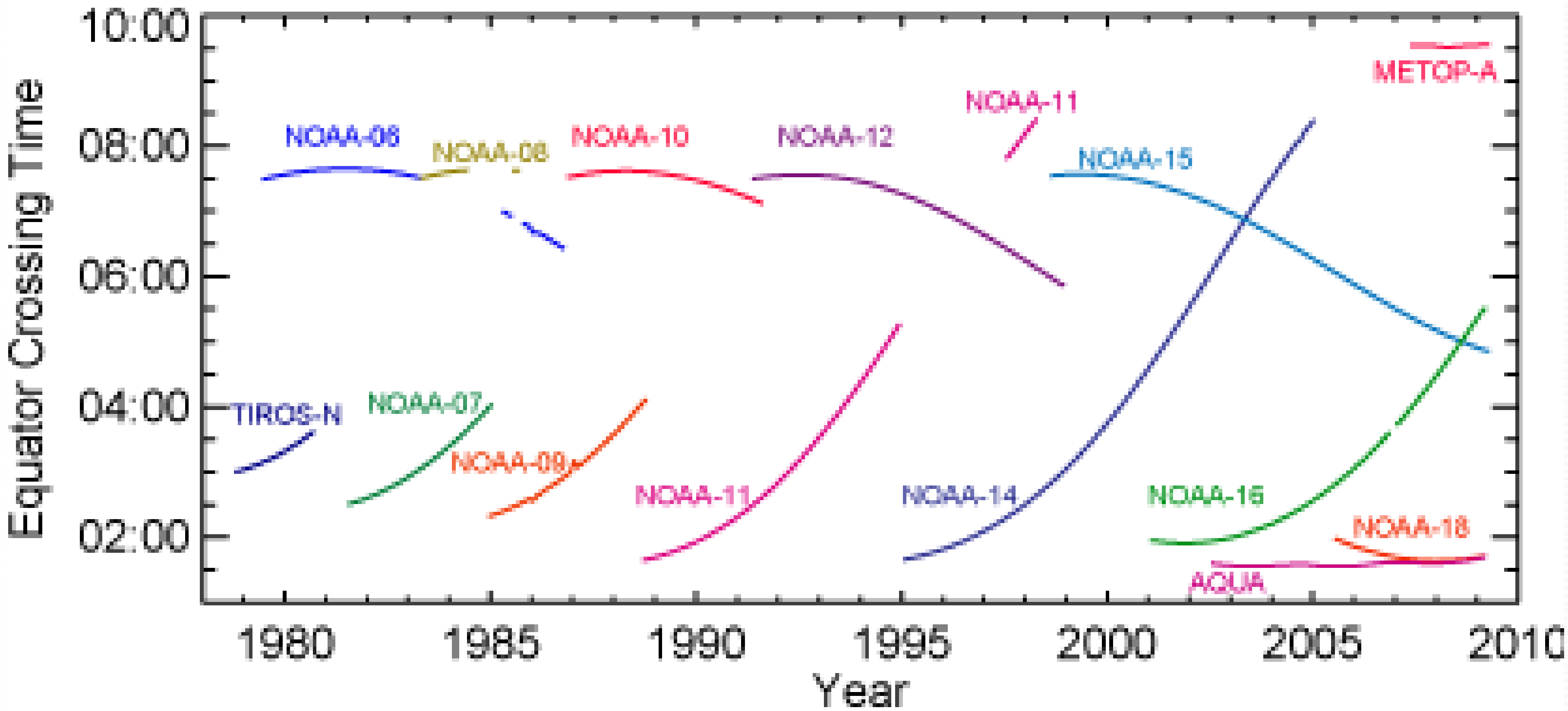
Figure 3. Time series of 200-hPa monthly temperature anomalies at Hong Kong. Open arrow shows date of change in radiation corrections, while solid arrows show dates of known radiosonde type changes, as noted in the text.

The homogenization challenge

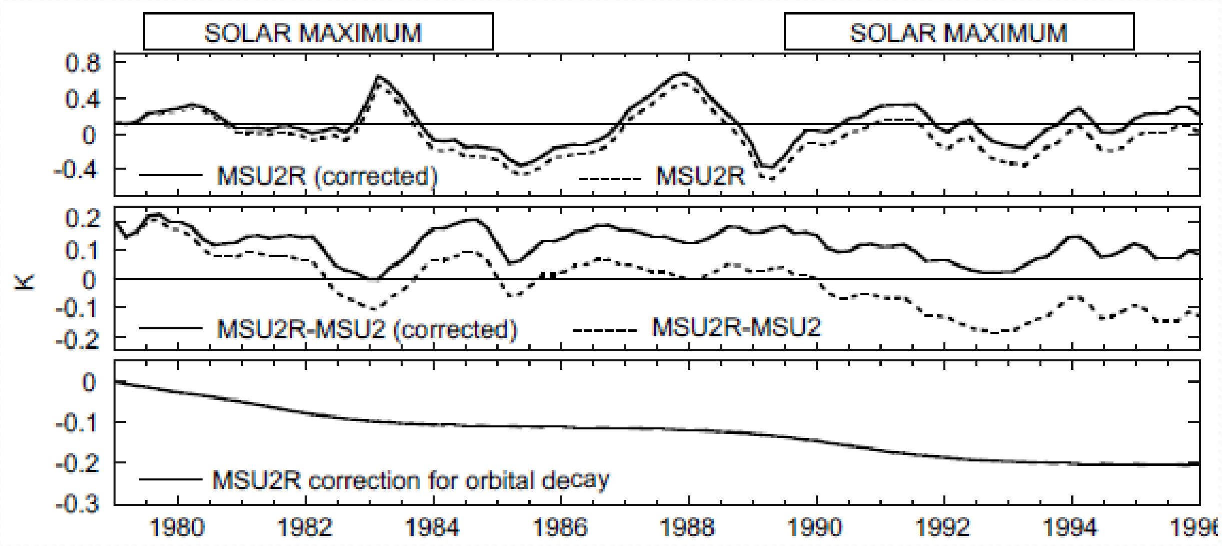
- Free et al. (BAMS, 2002)
- 2000 workshop compared approaches by several groups
- Example from Darwin, Australia
- A tough assignment!



MSU satellite platforms

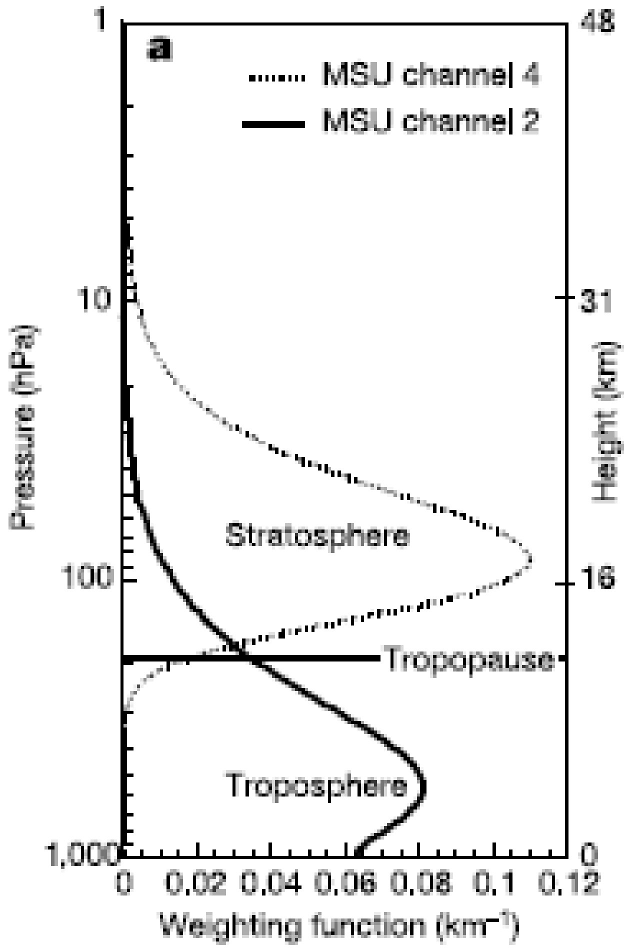


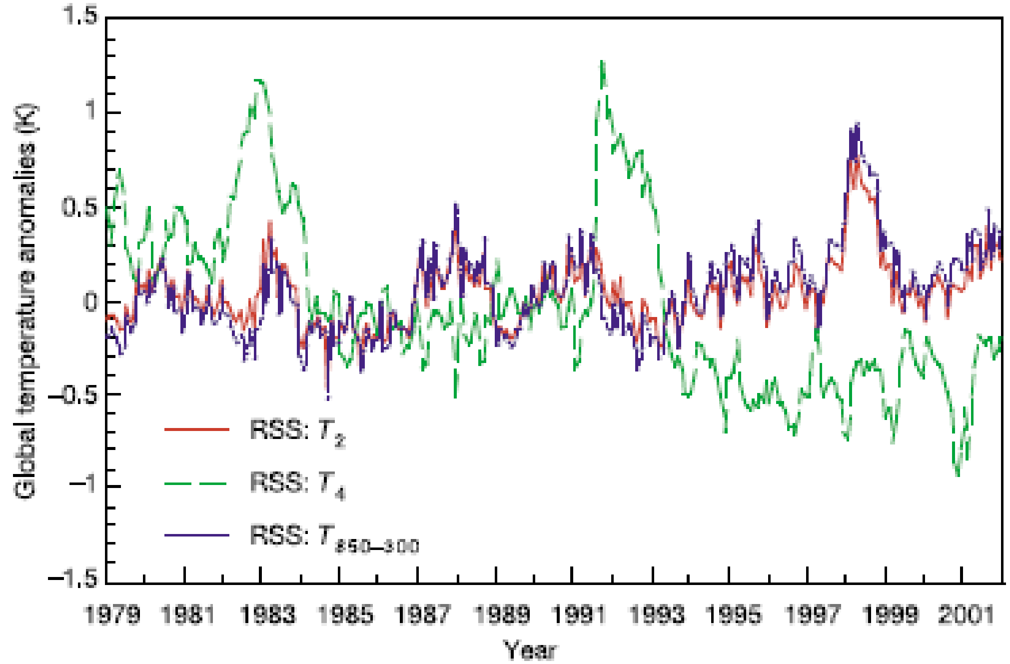
MSU data homogeneity



- Drag on satellites, particularly during solar max, caused orbital decay
- Affects off-nadir views, LT layer
- Spurious cooling trend
- Wentz and Schabel (Nature, 1998)

Stratospheric influence on MSU



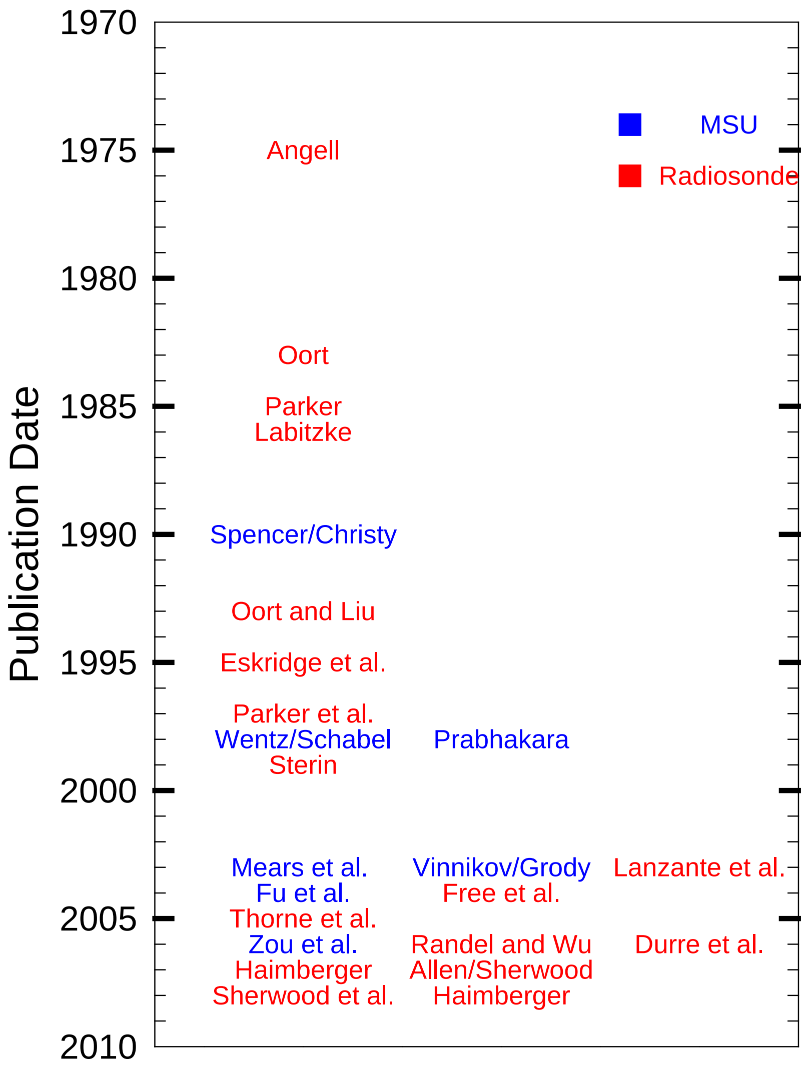


tures. The resulting trend of reconstructed tropospheric temperatures from satellite data is physically consistent with the observed surface temperature trend. For the tropics, the tropospheric warming is ~1.6 times the surface warming, as expected for a moist adiabatic lapse rate.

$T(850\text{-}300\ hPa) = a_o + a_2T(MT) - a_4T(LS)$

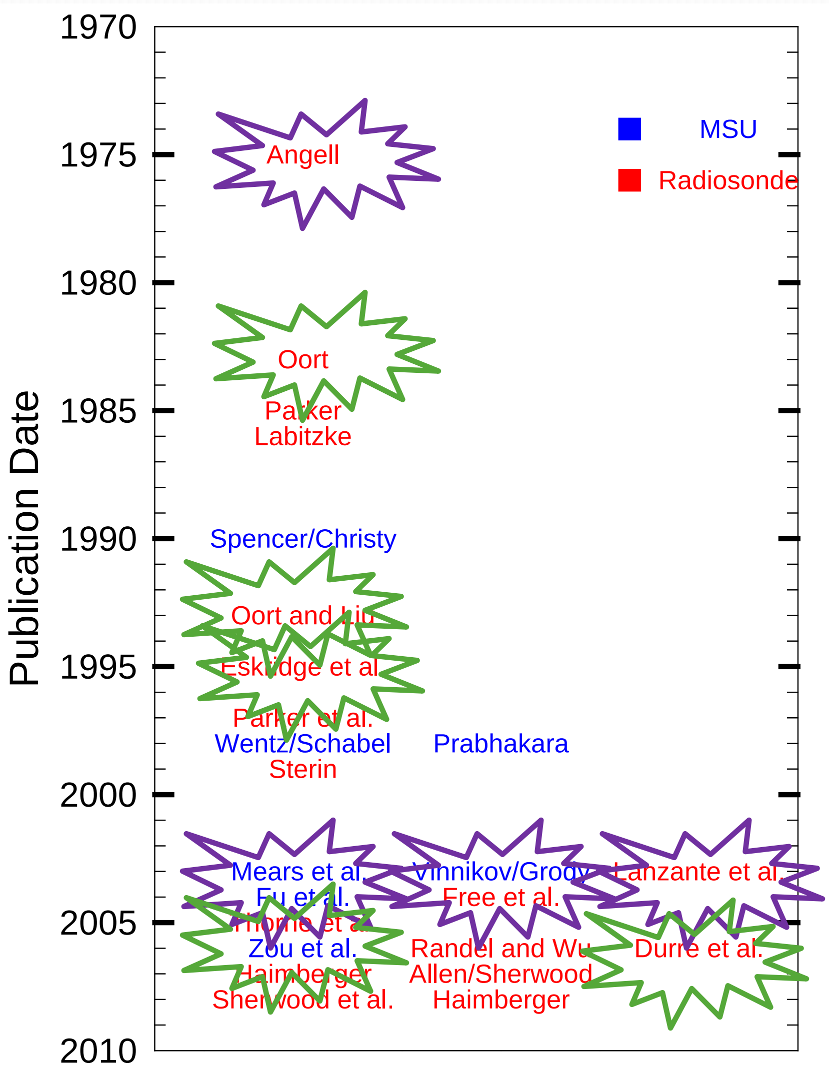
Fu et al. (Nature, 2004)

Proliferation of datasets

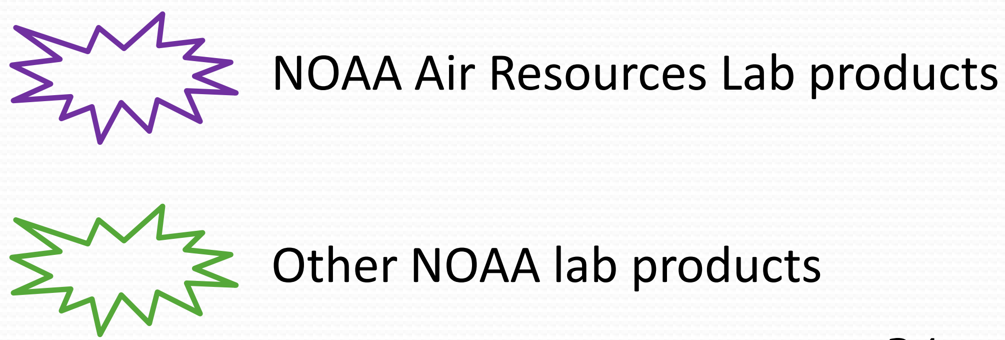


- Multiple, independent attempts to "homogenize"
- More radiosonde products than MSU

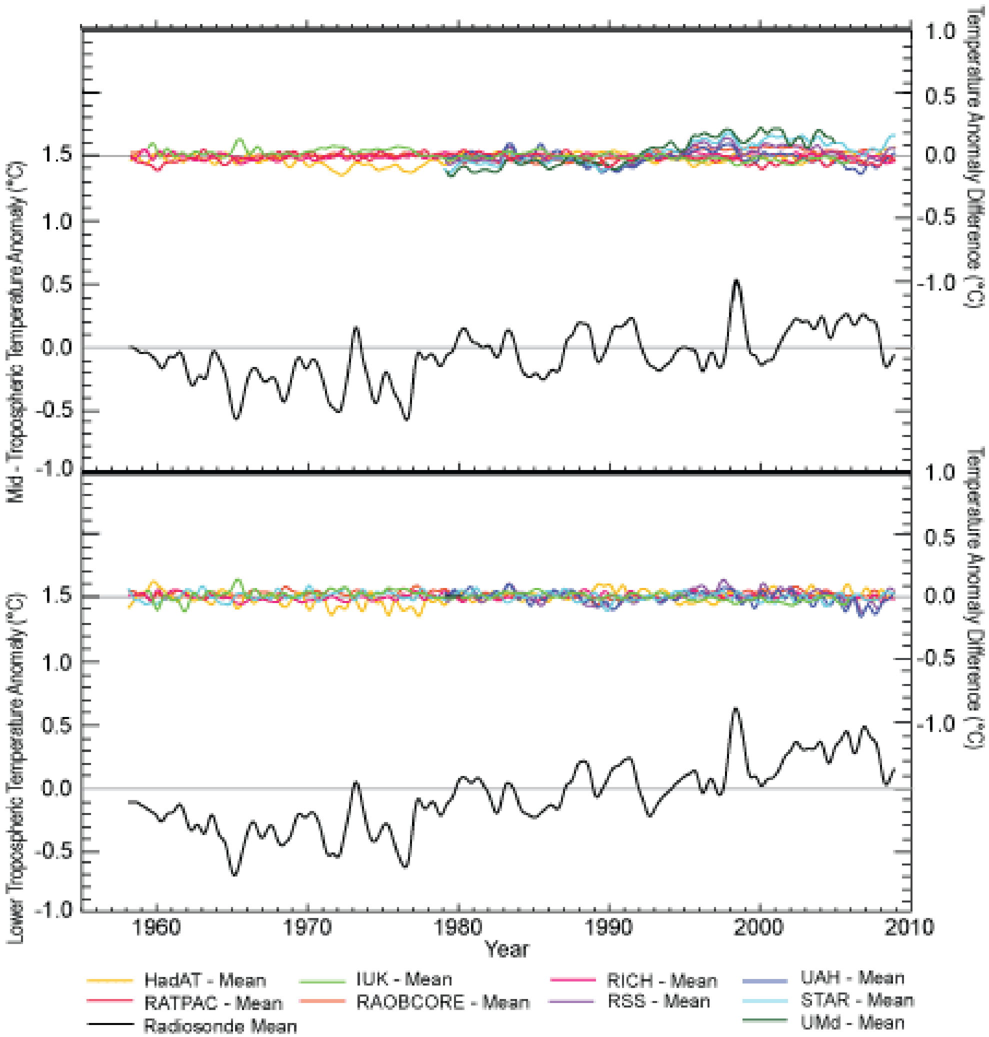
Proliferation of datasets



- Multiple, independent attempts to "homogenize"
- More radiosonde products than MSU
- Major NOAA contributions

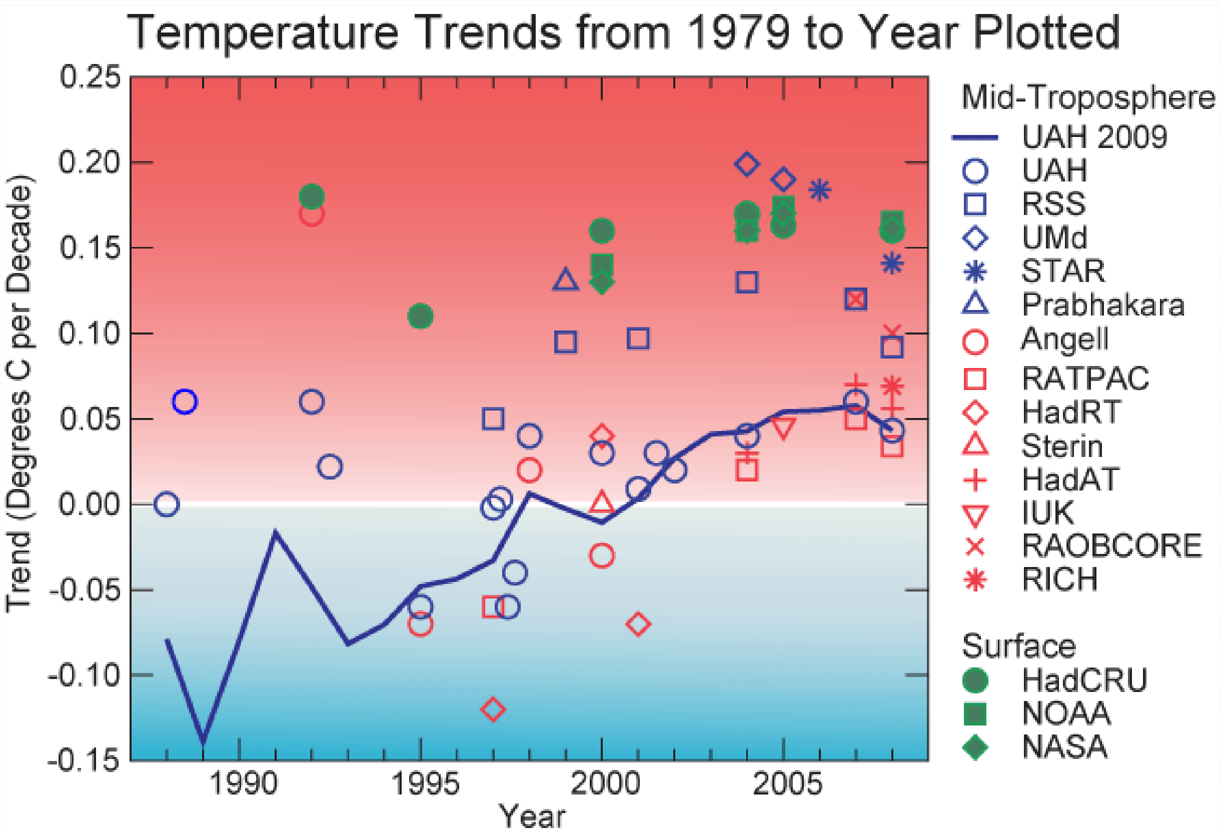


Global tropospheric T variations



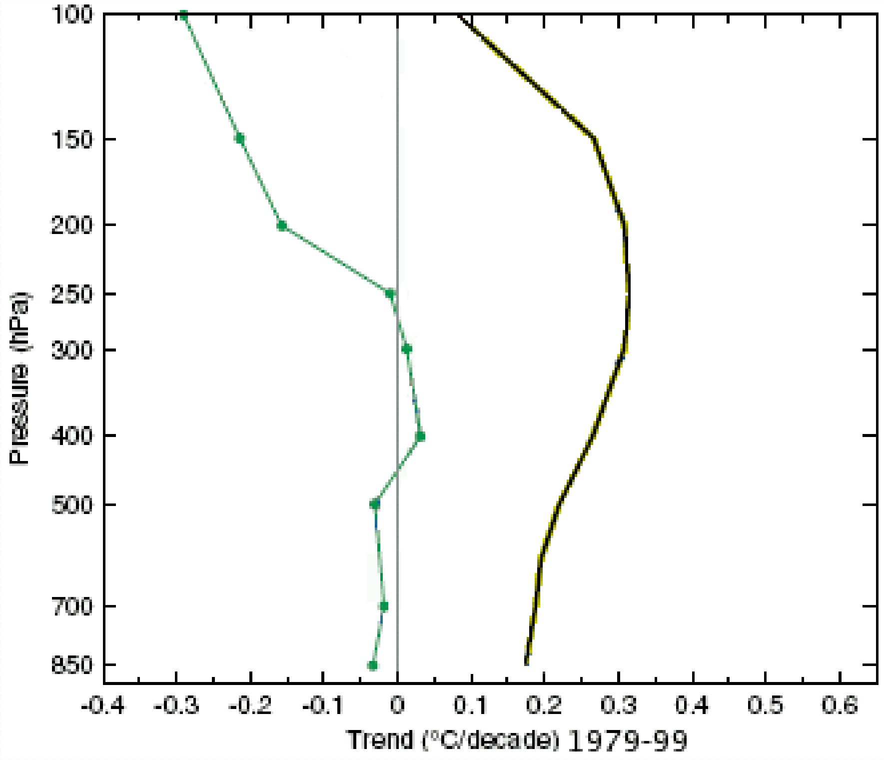
- Middle troposphere
- Lower troposphere
- *State of the Climate in 2008* (BAMS, 2009)

Trends in temperature trends



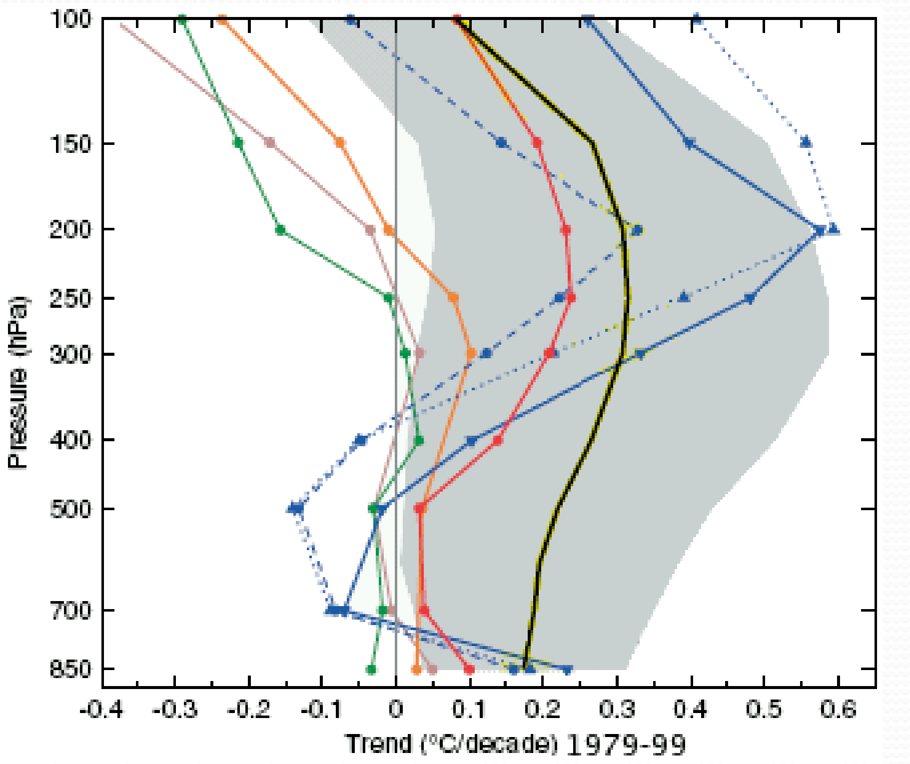
- UAH 2009 shows increasing warming with time
- Compare UAH 2009 with earlier UAH versions
- Compare UAH and other MSU
- More warming in recent (adjusted) radiosonde datasets
- Consistency of surface datasets
- Overall convergence

Advances in characterizing uncertainty

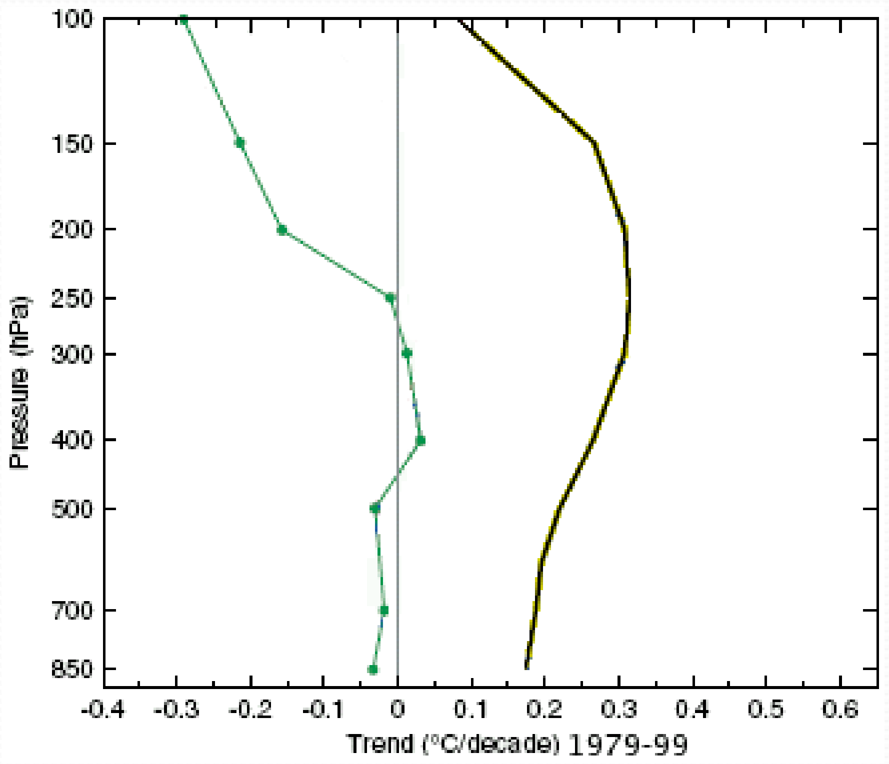


20-year trends based on 1990 level of understanding

Advances in characterizing uncertainty



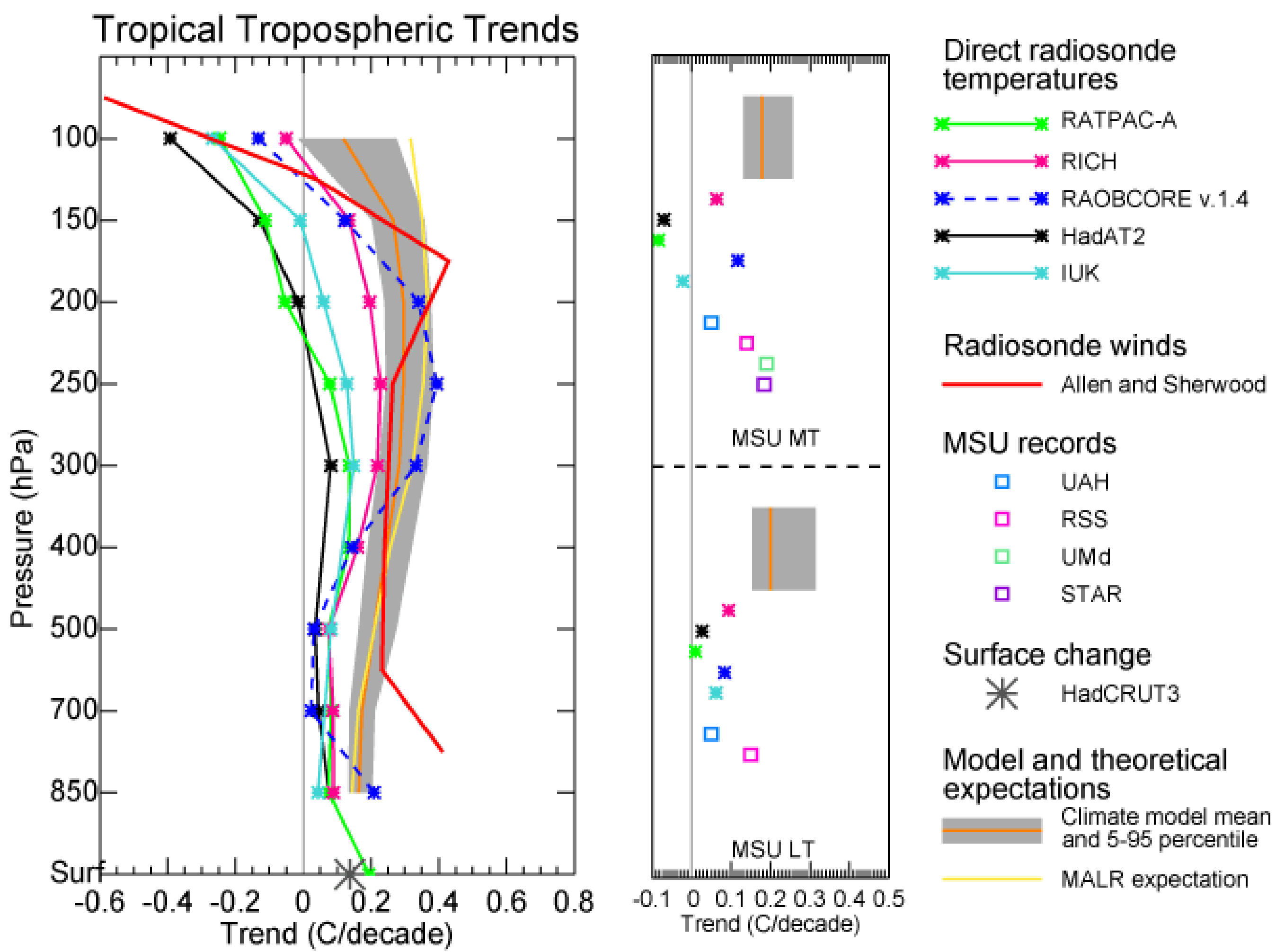
20-year trends based on 2008 level of understanding



20-year trends based on 1990 level of understanding

Current understanding of tropical trends

- 1979-2005 trends
- adjusted datasets
- multi-model ensembles

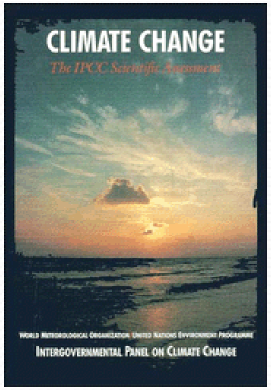


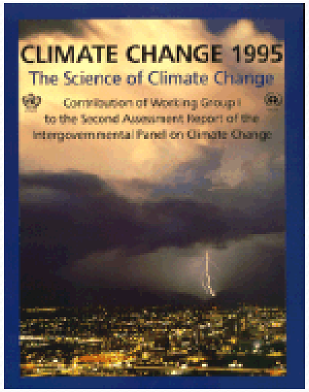
Scientific assessments

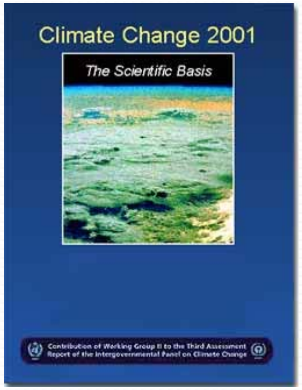
1970s

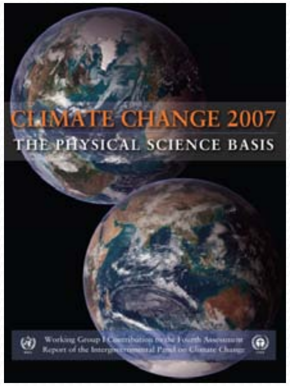
1990s

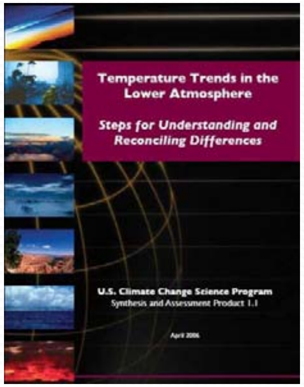
2000s











IPCC Assessment statements

- IPCC AR1 (1990):
  - "...broad agreement between the observations and equilibrium model simulations...."
  - main differences related to height of change from warming to cooling
- IPCC AR2 (1995): "...there is no serious inconsistency between the most recent model predictions and MSU-based trend estimates"

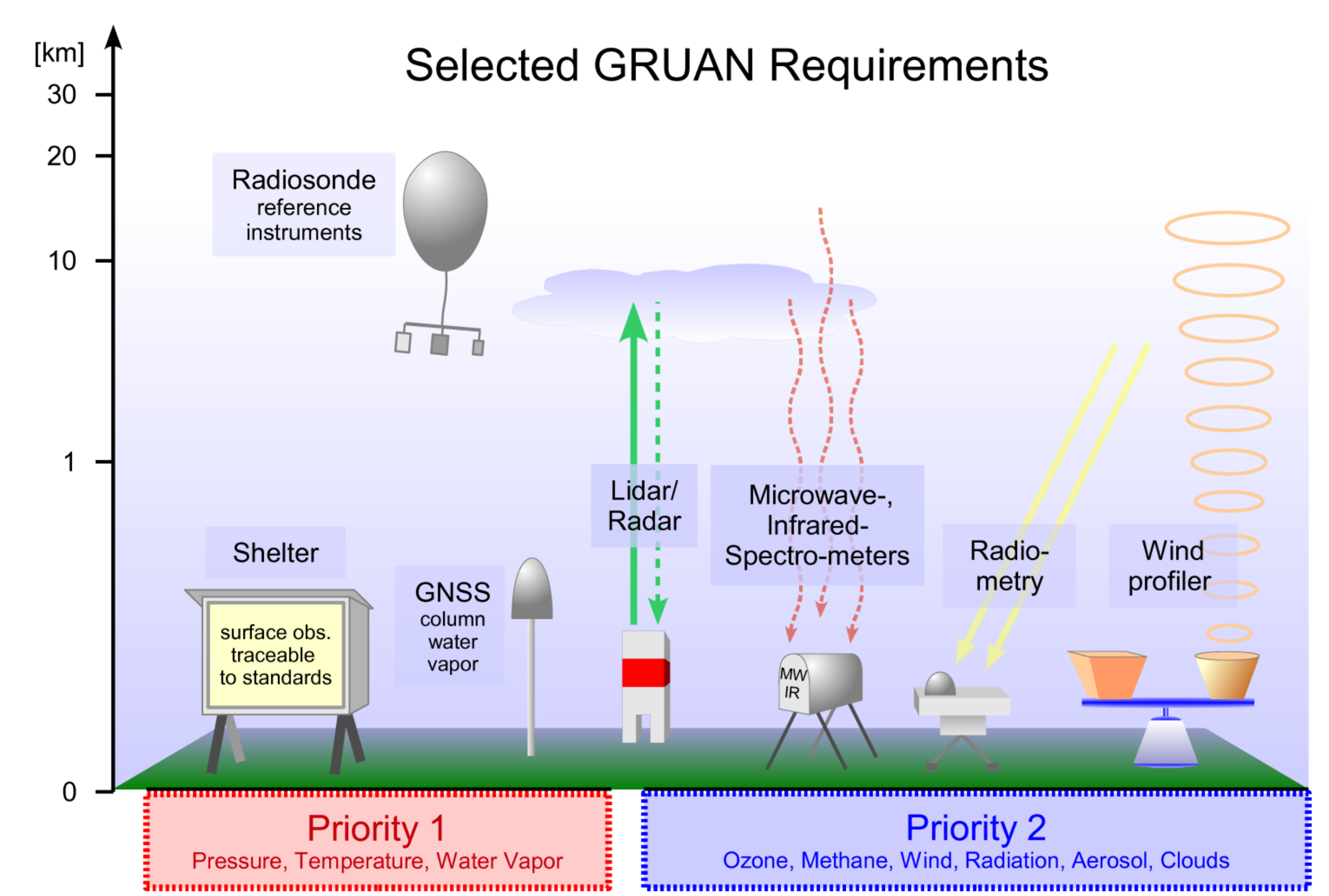
IPCC Assessment Statements

- IPCC AR3 (2001): "… anthropogenic factors account for a significant part of recent observed changes, whereas internal and naturally forced variations alone, at least as simulated by current models, cannot explain the observed changes"
- IPCC AR4 (2007):
  - "… there is agreement that the uncertainties about long-term change are substantial"
  - "… it is difficult to make quantitatively defensible judgements as to which, if any, of the multiple, independently-derived estimates is closer to the true climate evolution"

What have we learned?

- Multiple, independent observing systems and analyses help characterize structural uncertainty
- Observational <u>and</u> model uncertainty must be fully characterized when comparing theory and reality
- Reference observations are needed to anchor data from operational systems
- Scientific assessments can spur scientific advances

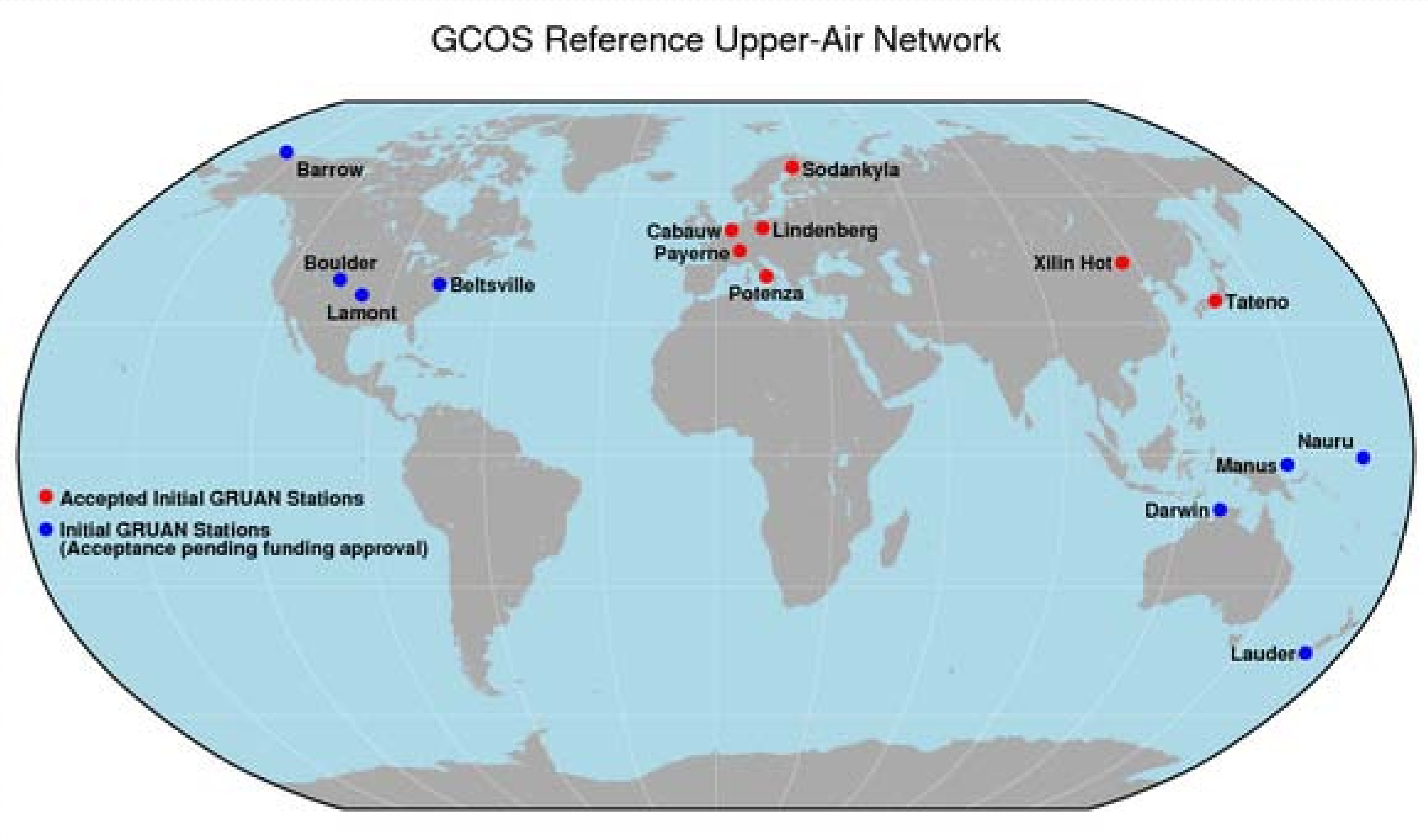
Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN)



Seidel et al. (BAMS, 2009)

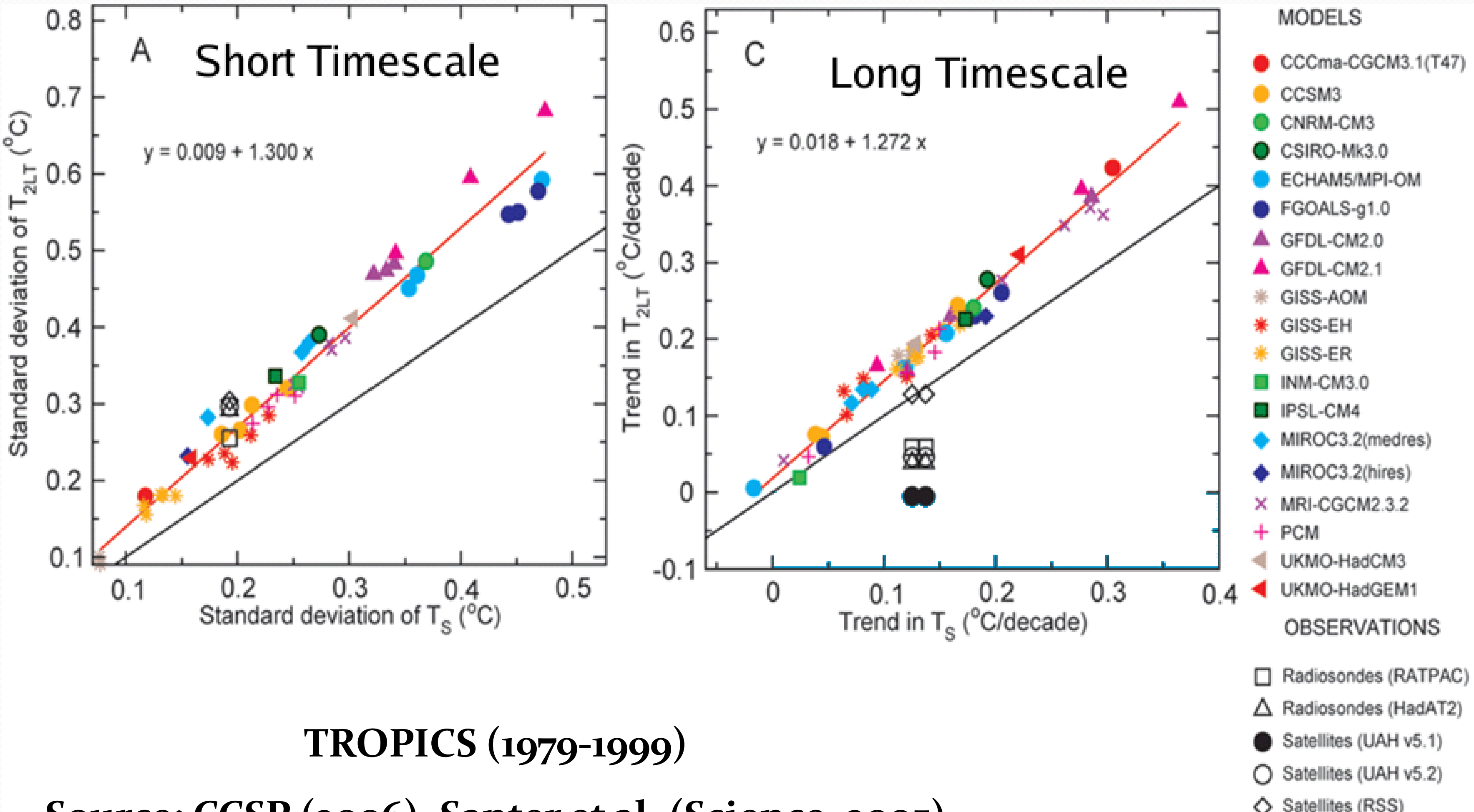
Thank you!

Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN)



Seidel et al. (BAMS, 2009)

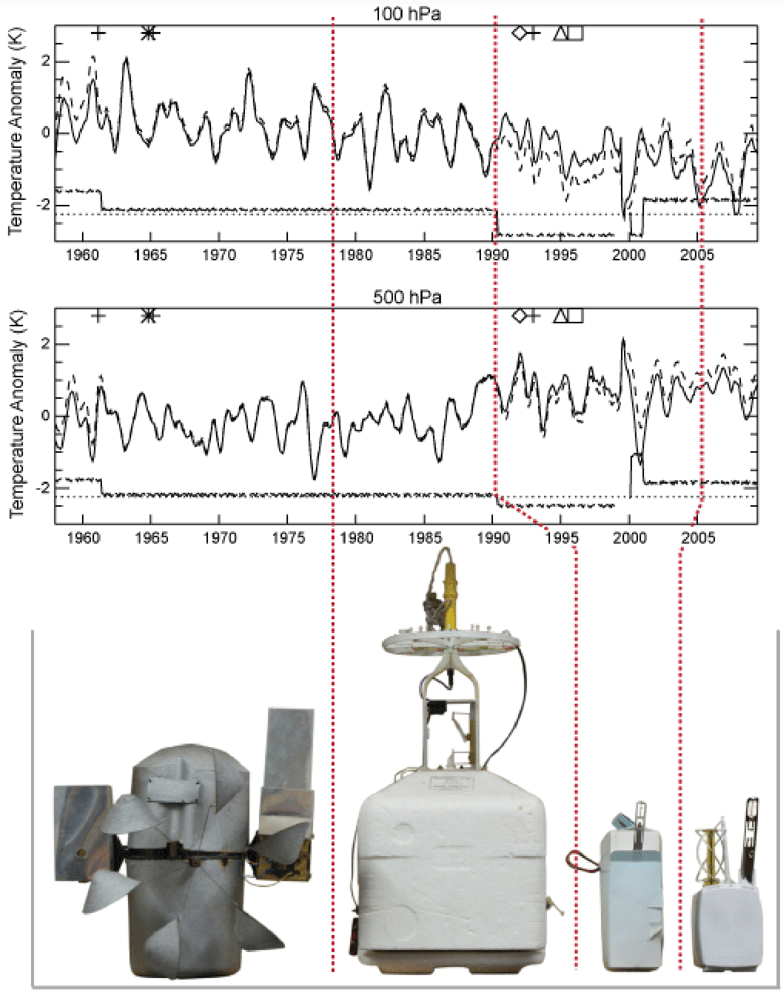
Surface & tropospheric coupling



TROPICS (1979-1999)

Source: CCSP (2006), Santer et al. (Science, 2005)

Radiosonde homogeneity problems



Sondes and 100 hPa T anomalies at Camborne

Surface Observations

Advantages

- Land
  - Fixed, well-maintained stations
  - Infrequent and non-simultaneous instrument changes
- Ocean
  - Multiple independent systems
  - Central data archive
- Long records

Drawbacks

- Land
  - Local effects
  - Local environmental changes
  - Variable spatial coverage
- Ocean
  - Ships and buoys move
  - Changing observational mix
  - Variable spatial coverage
  - Satellites limited by clouds

Radiosondes

Advantages

- Long record
- Reports at many levels from surface to lower stratosphere
- Co-located pressure, wind, and humidity observations
- Daily (or 2x, 4x) at fixed times

Drawbacks

- Irregular spatial sampling
- Inconsistent vertical reach
- Frequent, often undocumented changes in instruments and practices
- Variable data quality across the network

Microwave Sounding Unit

Advantages

- Near-global coverage
- All-weather capability
- Direct measurement equivalence to bulk temperature
- Overlapping observations
- Complete metadata

Drawbacks

- Effects unique to each satellite can only be quantifying statistically
  - Crossing time drift
  - Satellite elevation
- Imperfect match of AMSU and MSU channels
- Stratospheric and surface influences on Channel 2
- Poor vertical resolution
- Short overlaps (once none)