Upper tropospheric and lower stratospheric variability observed with GPS radio occultation data since 2001: Results from CHAMP, GRACE, TerraSAR-X, and FORMOSAT-3/COSMIC

T. Schmidt, A. Faber, S. Heise, G. Beyerle, G. Michalak, J. Wickert, F. Zus
(GFZ German Research Centre for Geosciences)

A. de la Torre
(Austral University)

P. Alexander
(University of Buenos Aires)

GFZ
Helmholtz Centre
POTSDAM

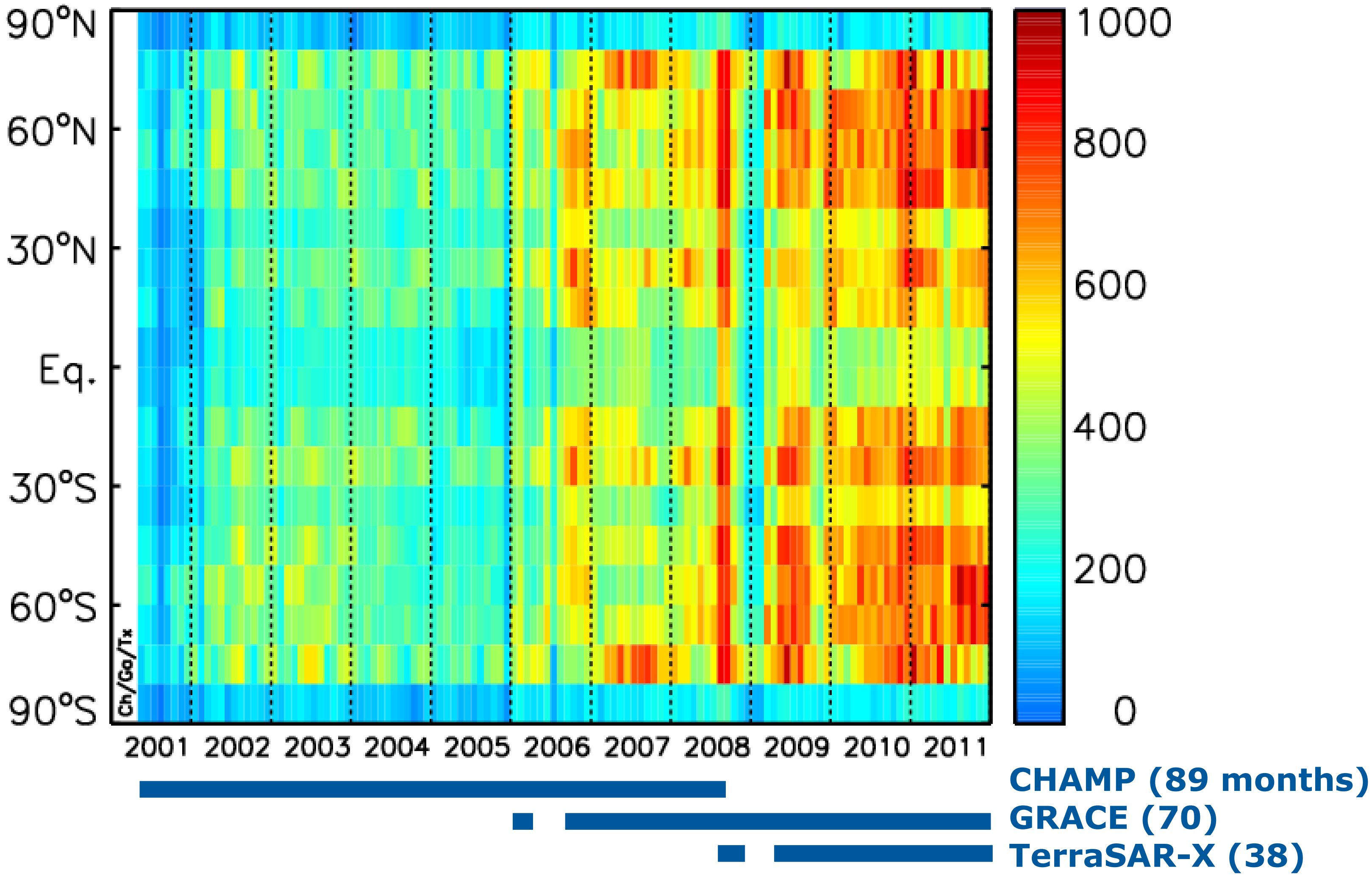
HELMHOLTZ
ASSOCIATION

Overview

- **Data base**
- **Data processing ('from profiles to trends')**
- **Tropopause height and UTLS temperatures**
    - T vs. QBO, ENSO and solar flux
- **UTLS temperature 'short-term trends'**
    - Regression model
    - RO vs. ERA interim
    - Trend significance
    - Trends in different regions
    - Seasonal trends
- **Summary**

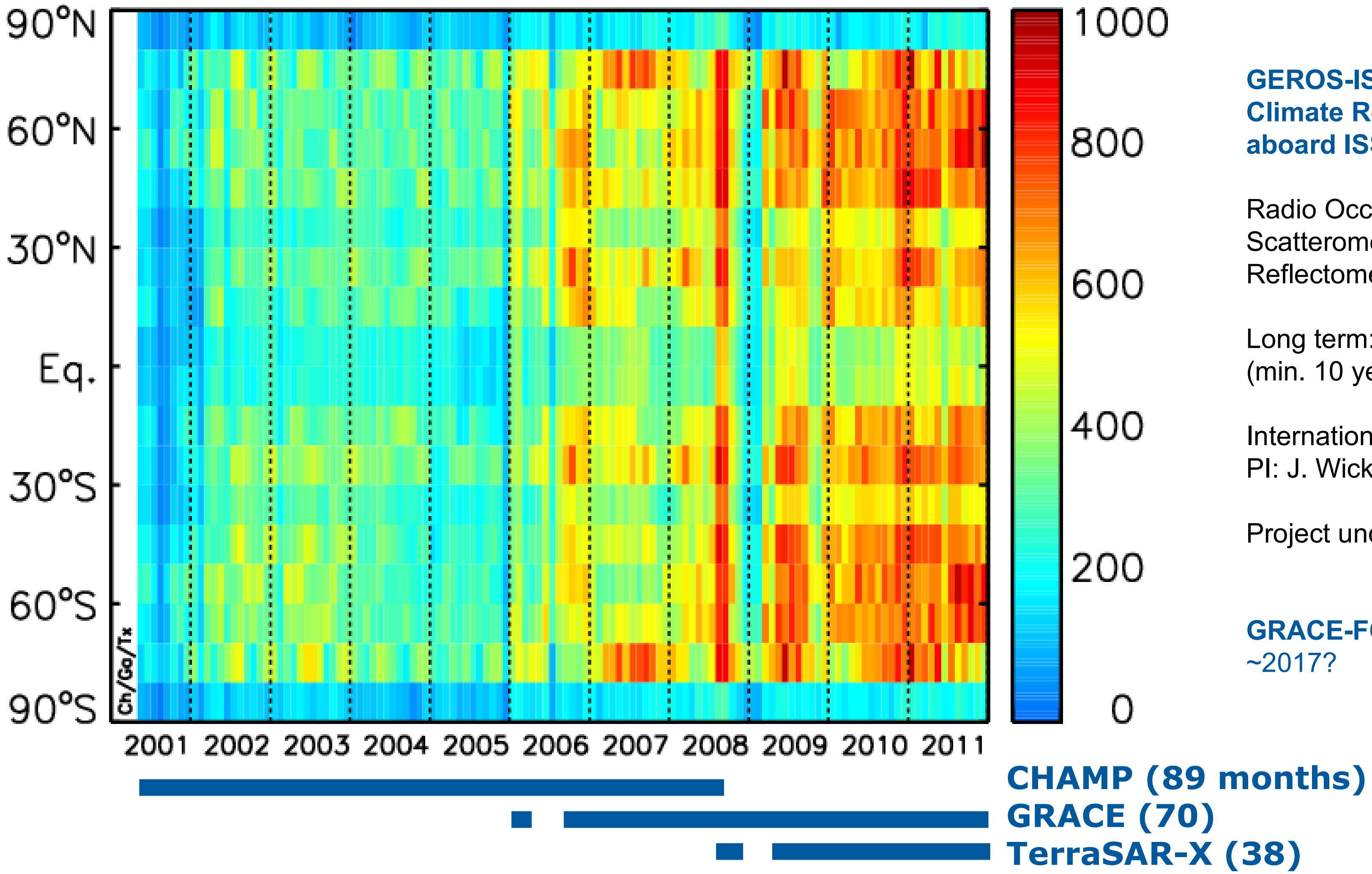
Data base: >1 decade

128 months, processed at GFZ from level 0, including orbits



Data base: >1 decade

128 months, processed at GFZ from level 0, including orbits



GEROS-ISS
Climate Research
aboard ISS

Radio Occultation
Scatterometry
Reflectometry

Long term: ~2016
(min. 10 years)

International team
PI: J. Wickert (GFZ)

Project under evaluation

GRACE-FO
~2017?

Data processing

From single profiles to zonal mean 'trends'

Binning and averaging:

$$\overline{T_s(\phi, z)} = \frac{\sum_{i=1}^{N(z)} T_i(\phi_i, z) \cdot \cos(\phi_i)}{\sum_{i=1}^{N(z)} \cos(\phi_i)}$$

Zonal monthly means
10° latitude bands centered at 85°N … 85°S
5-25 km, 100 m steps
May 2001 – December 2011 (128 months)

Sampling error estimation:

$$\overline{T_{ERA}(\phi, z)} = \ldots$$ Foelsche et al. (2007)

ERA interim (6-hourly daily analyses, 1°X1° resolution)

Sampling error corrected zonal monthly means:

$$\overline{T(\phi, z)} = \overline{T_s(\phi, z)} - \overline{T_{ERA}(\phi, z)}$$

De-seasonalized zonal monthly means:

$$Y(\phi, z, t)$$

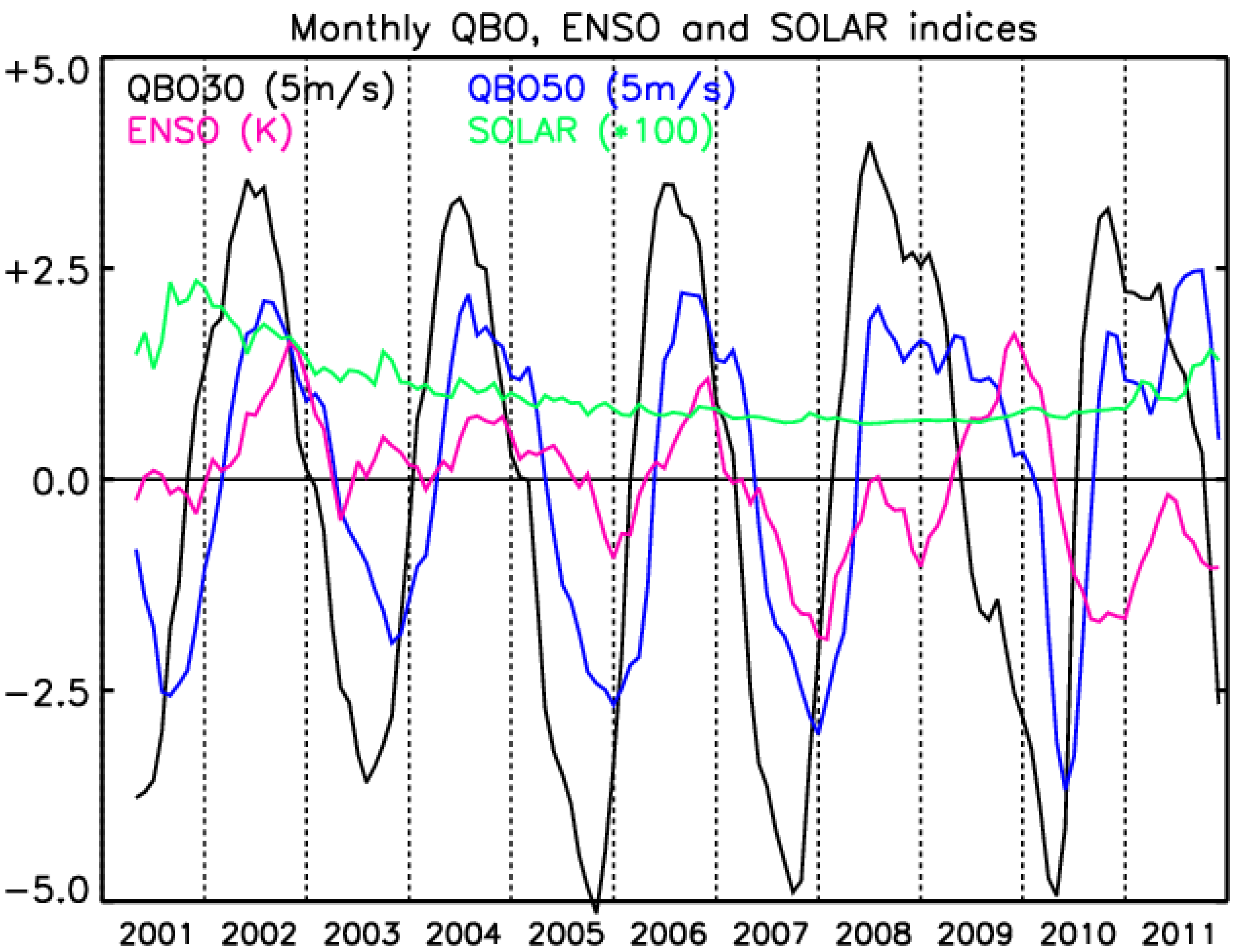
Multiple regression fit to the data:

$$Y_{est}(\phi, z, t) = a + b \cdot t + c_1 \cdot QBO30 + c_2 \cdot QBO50 + d \cdot ENSO\,(+ e \cdot SOLAR)$$

for complete time series and single months

indices from ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices (ENSO=NINO3.4)

QBO, ENSO, and solar flux



GFZ
Helmholtz Centre
POTSDAM

HELMHOLTZ
ASSOCIATION

Data processing

Trend uncertanties (Karl et al., 2006)

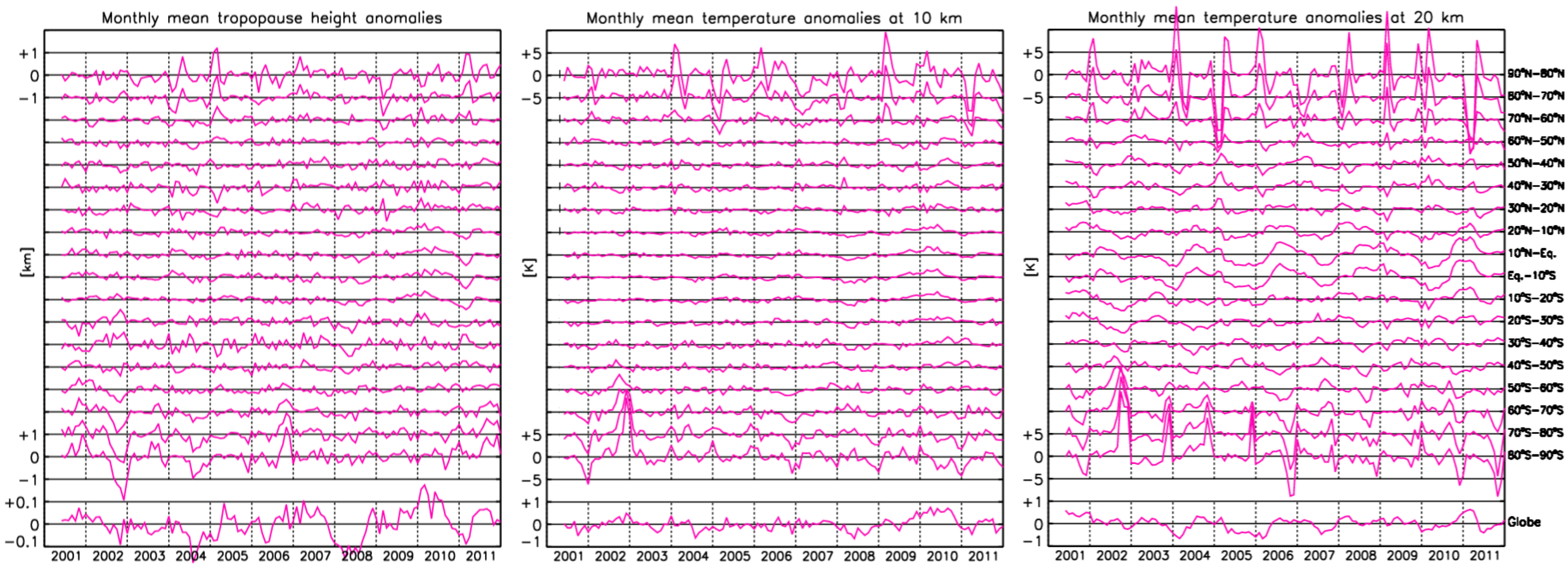
Mean Square Error: $MSE = \frac{\sum e^2}{n-2}$ $e = Y - Y_{est}$

Standard Error: $SE^2 = \frac{MSE}{n(n^2-1)/12}$

Significance: $Y_{sig} = \frac{b}{SE}$

Trend is significant if Y_{sig} > 2 (~2-sigma)

De-seasonolized monthly means

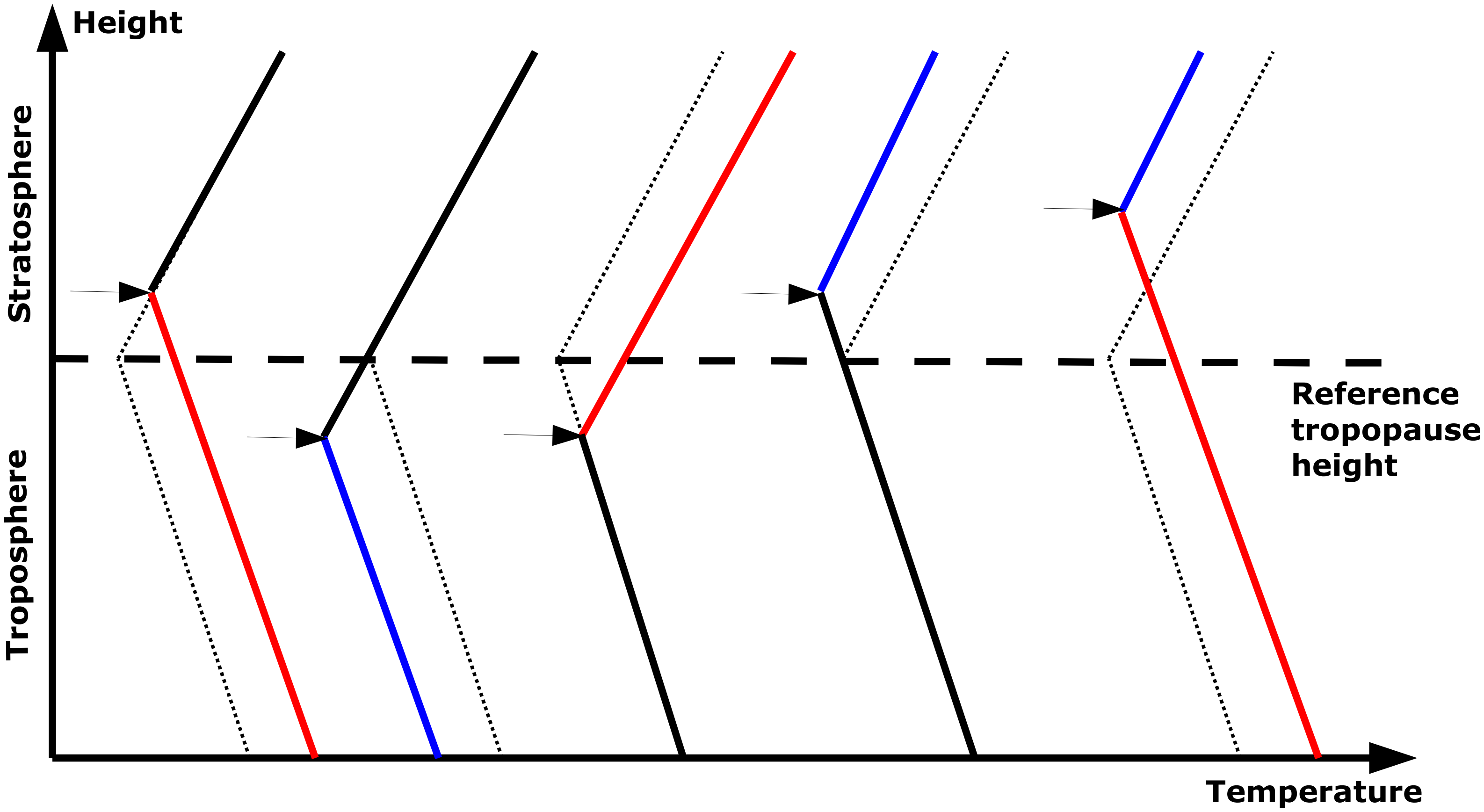


$$Y_{est}(\phi, z, t) = a + b\cdot t + c_1\cdot QBO30(t) + c_2\cdot QBO50(t) + d\cdot ENSO(t)(+e\cdot SOLAR(t))$$

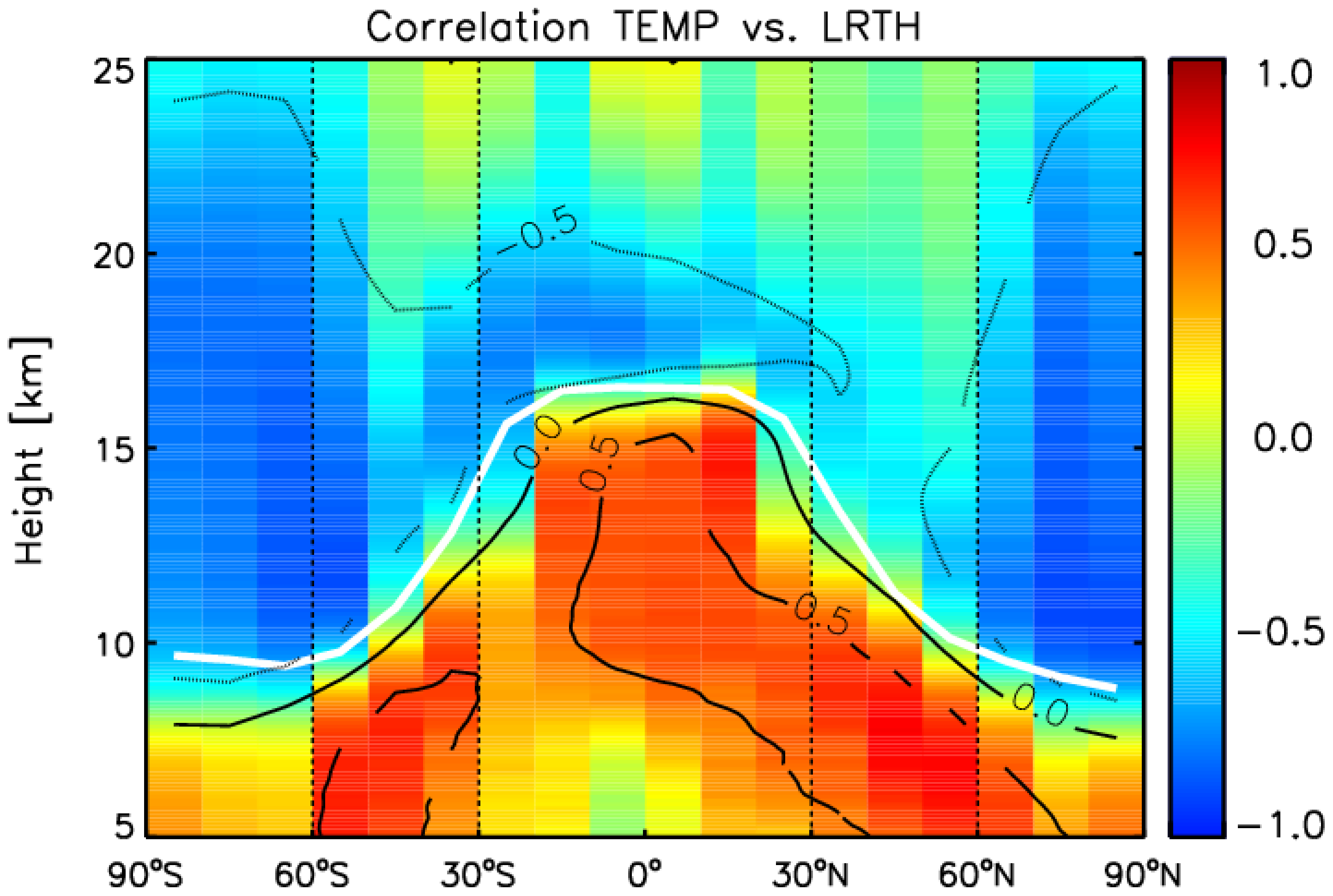
Tropopause and UTLS temperatures

Tropopause forcing mechanisms

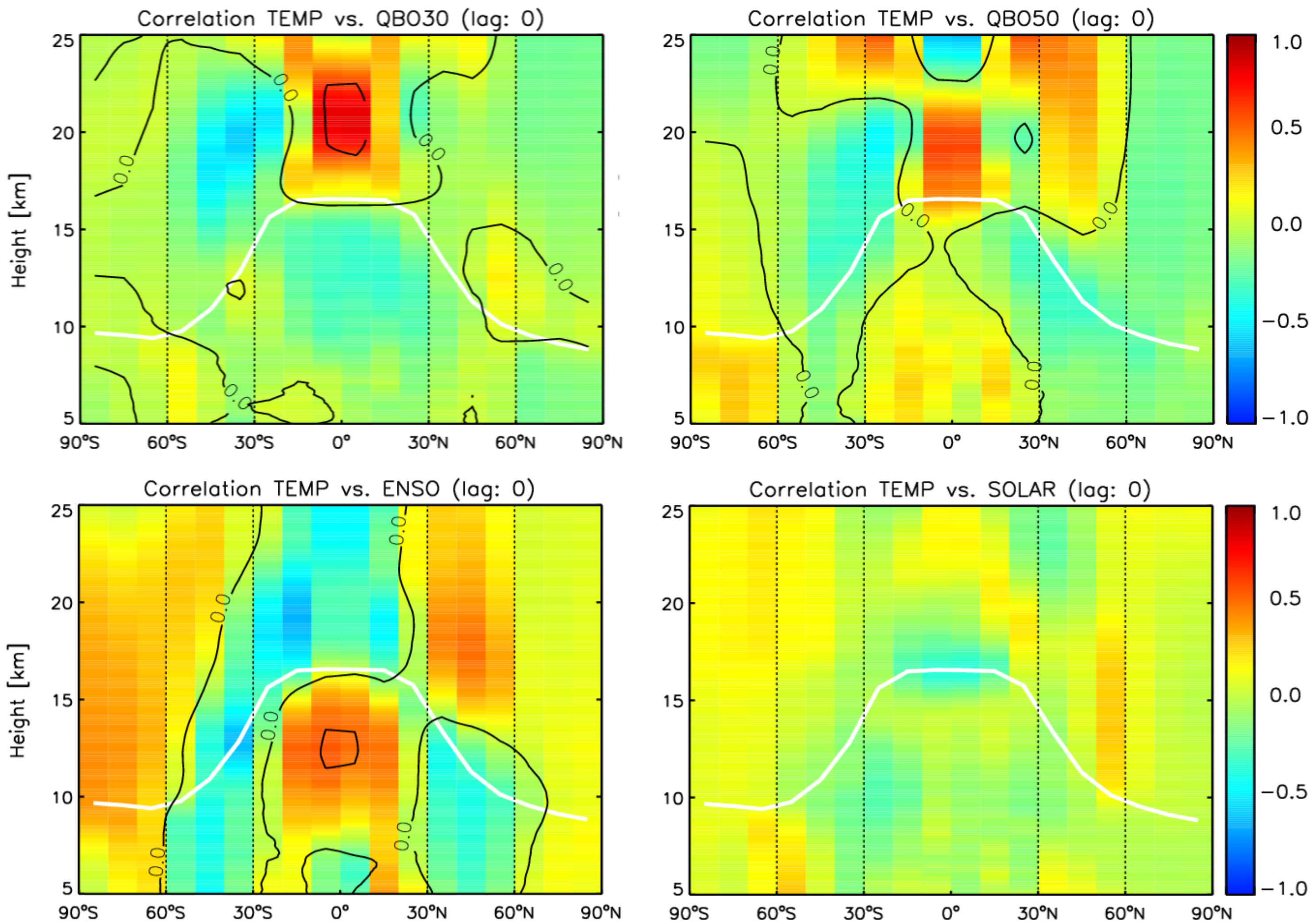
Tropospheric/stratospheric warming and cooling



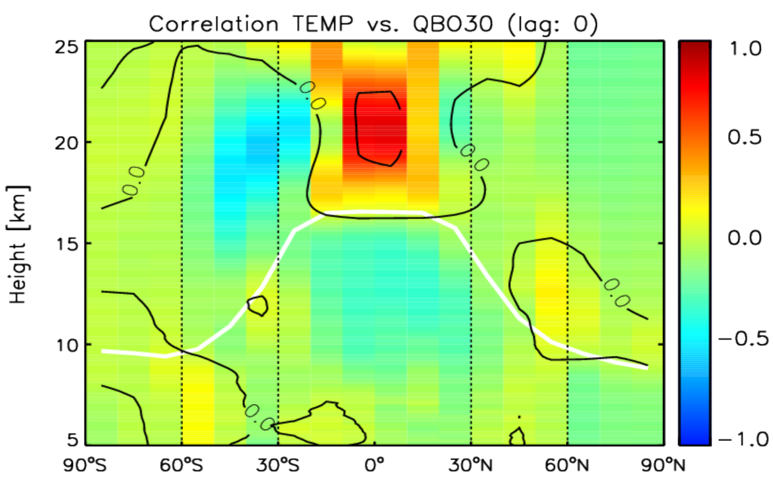
Correlation: Temperature vs. LRTH

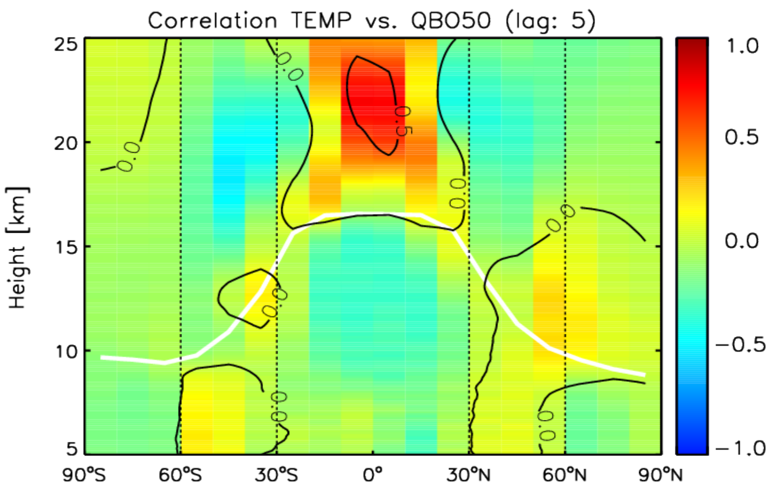


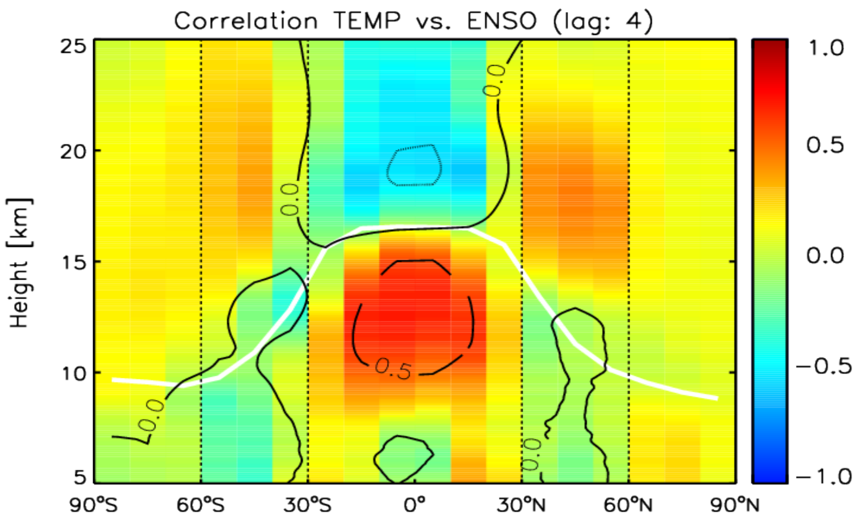
Correlation: T vs. QBO, ENSO, SF



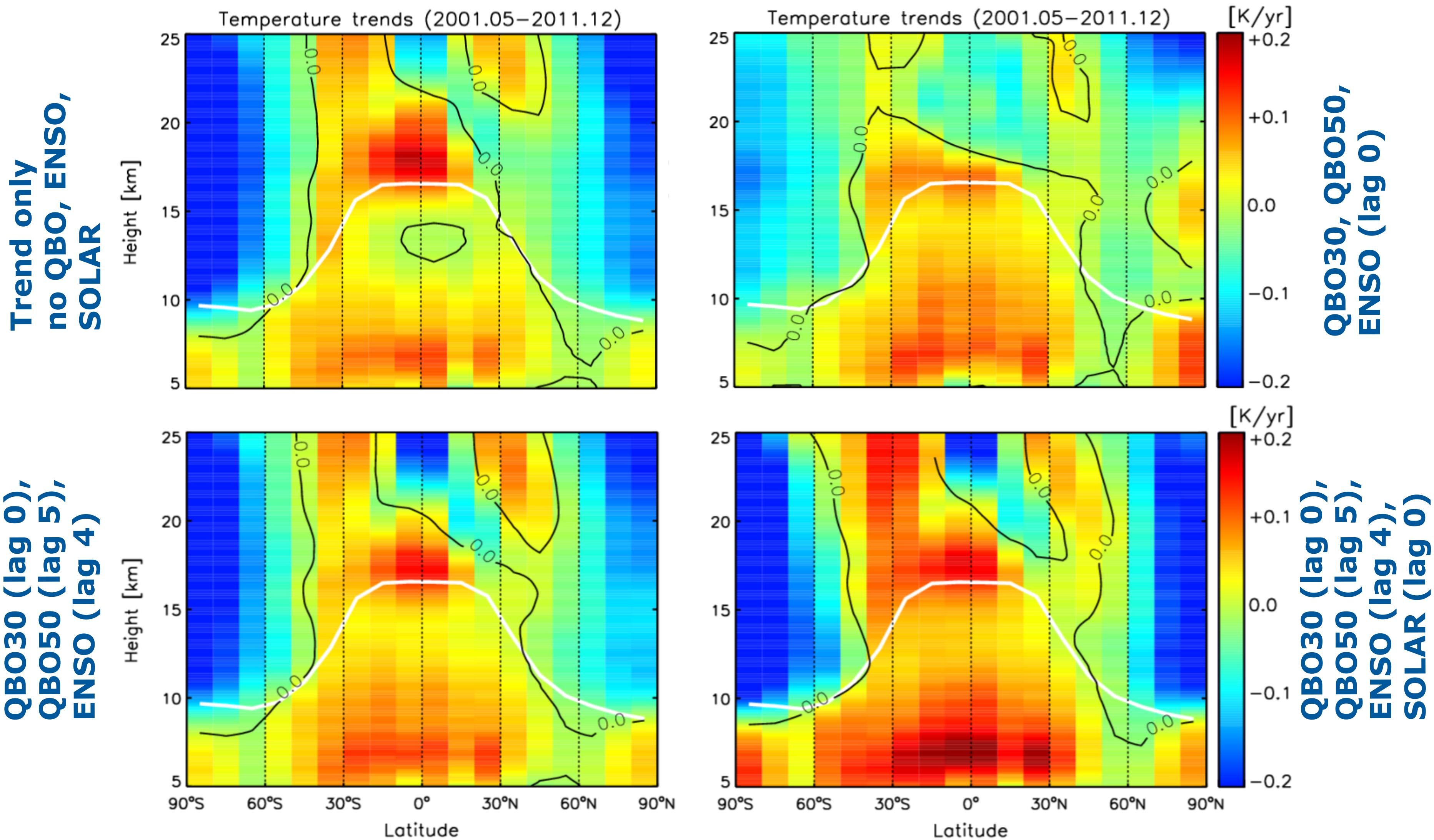
Correlation: Temp vs. QBO and ENSO







Temperature trends

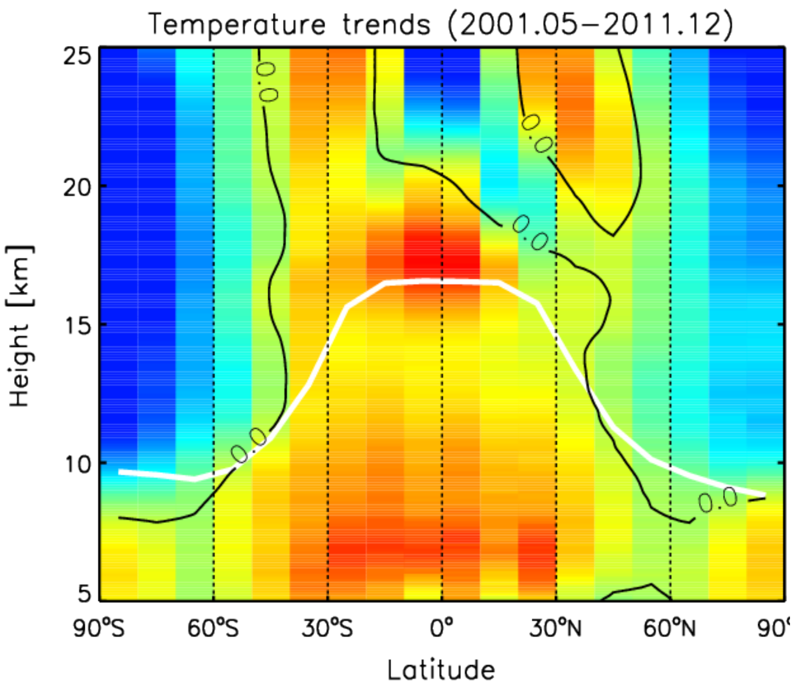


GFZ
Helmholtz Centre
POTSDAM

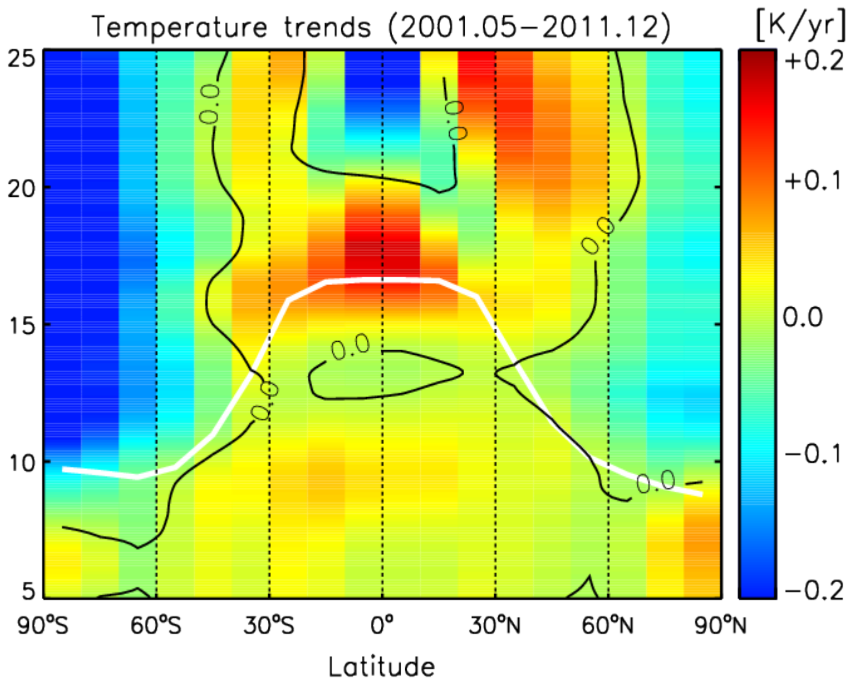
HELMHOLTZ
ASSOCIATION

Temperature trends

RO



ERA interim

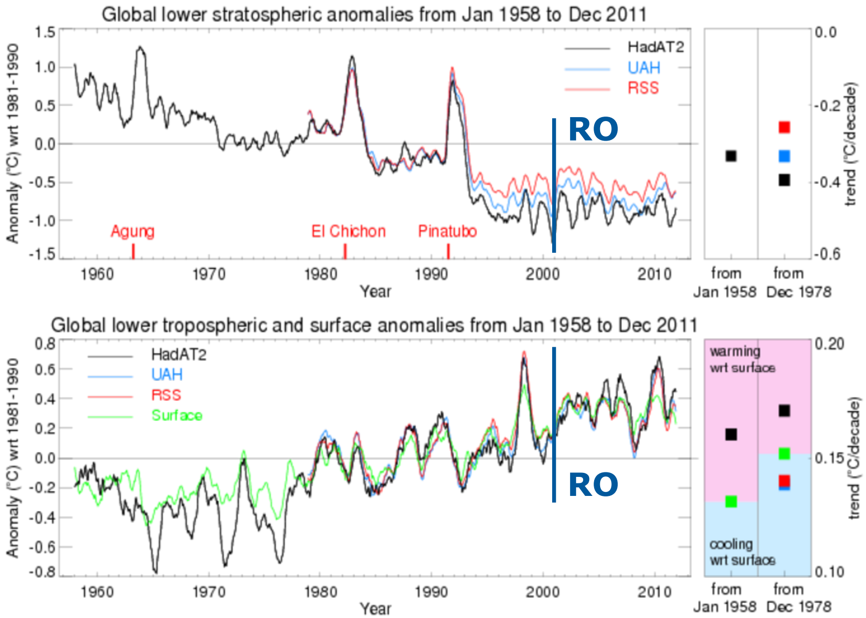


from monthly means based
on 1°X1° and 6-hourly analyses

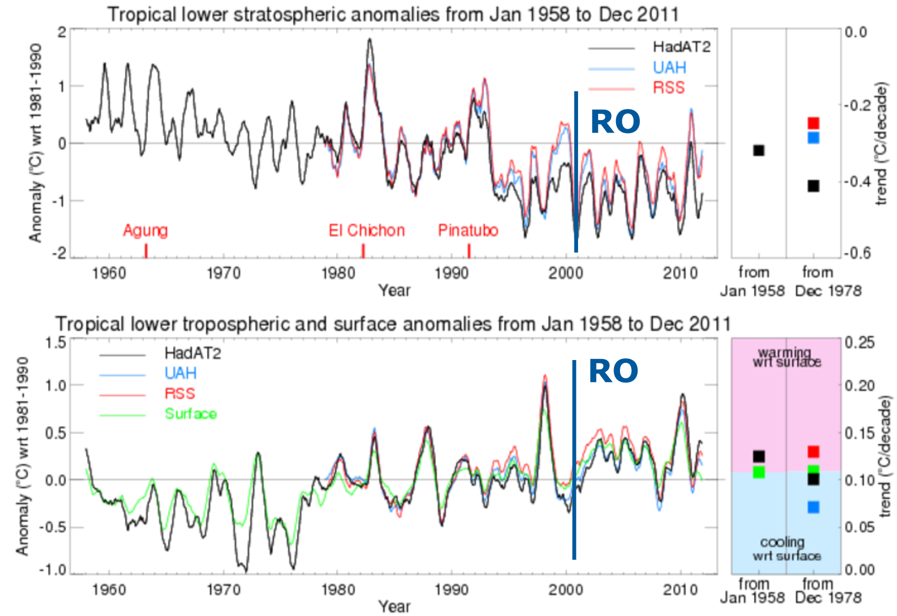
Temperature trends

Long-term data from radiosondes and MSU data

http://www.metoffice.gov.uk/hadobs/hadat/images.html

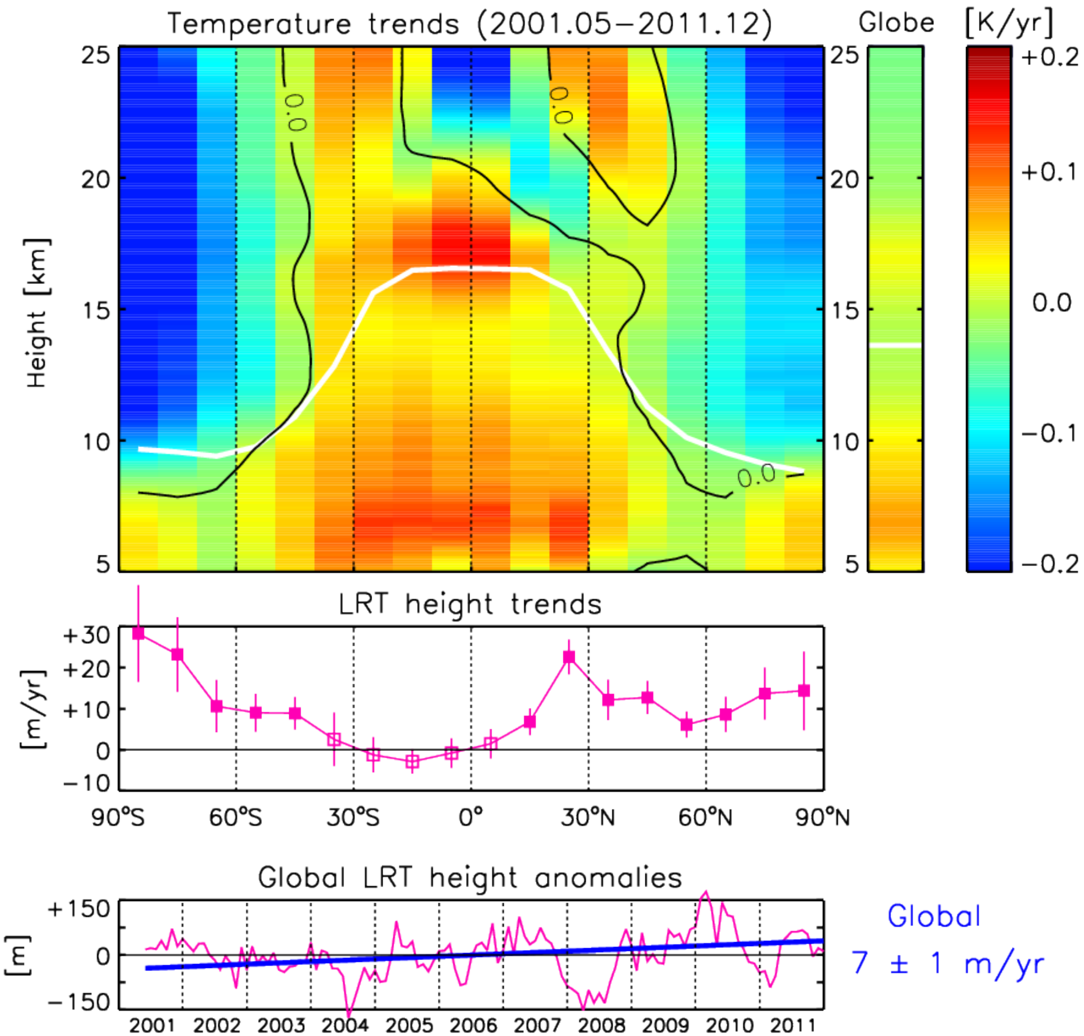


HadAT2 radiosonde data and HadCRUT3 surface data are produced by the Hadley Centre and are available at www.hadobs.org
UAH MSU satellite data are produced by the University of Alabama in Huntsville and are available at www.nsstc.uah.edu/public/msu courtesy of John Christy and Roy Spencer
RSS MSU satellite data are produced by Remote Sensing Systems and are available at www.remss.com courtesy of Carl Mears

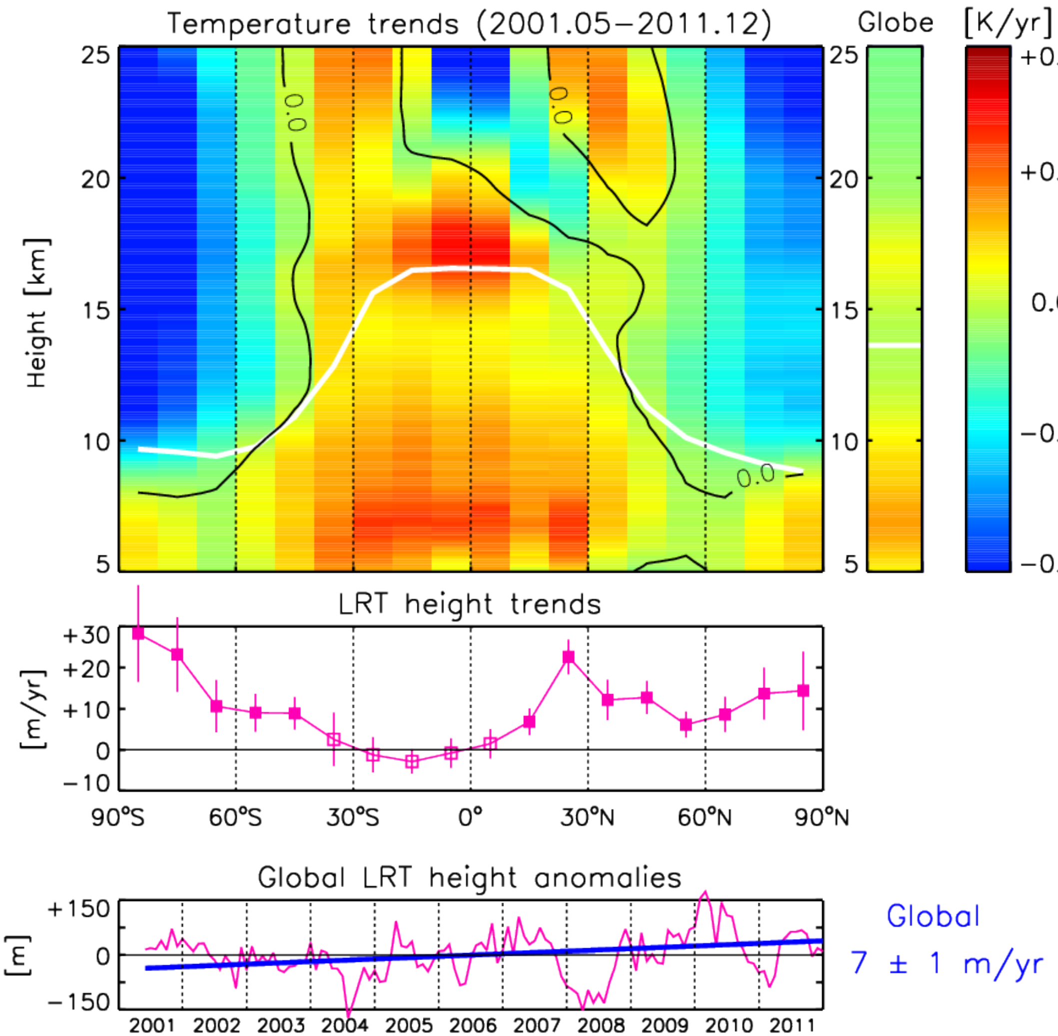


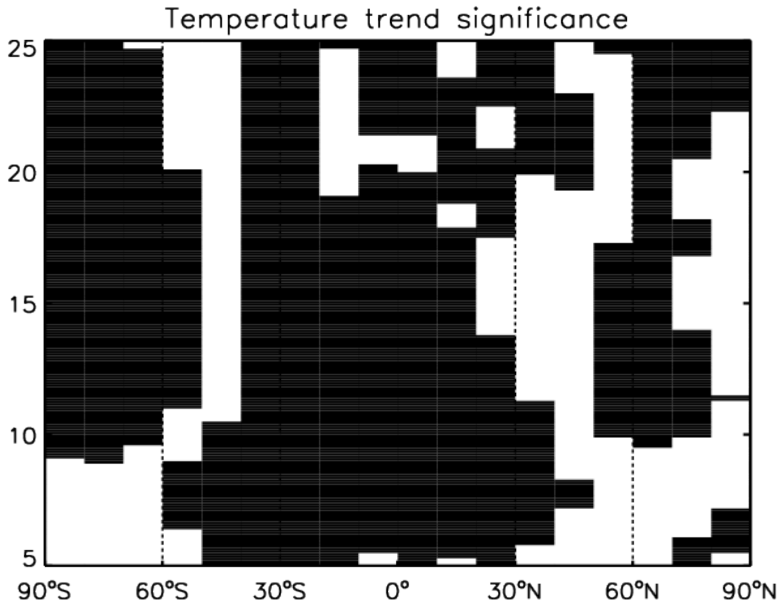
HadAT2 radiosonde data and HadCRUT3 surface data are produced by the Hadley Centre and are available at www.hadobs.org
UAH MSU satellite data are produced by the University of Alabama in Huntsville and are available at www.nsstc.uah.edu/public/msu courtesy of John Christy and Roy Spencer
RSS MSU satellite data are produced by Remote Sensing Systems and are available at www.remss.com courtesy of Carl Mears

Temperature and LRTH trends



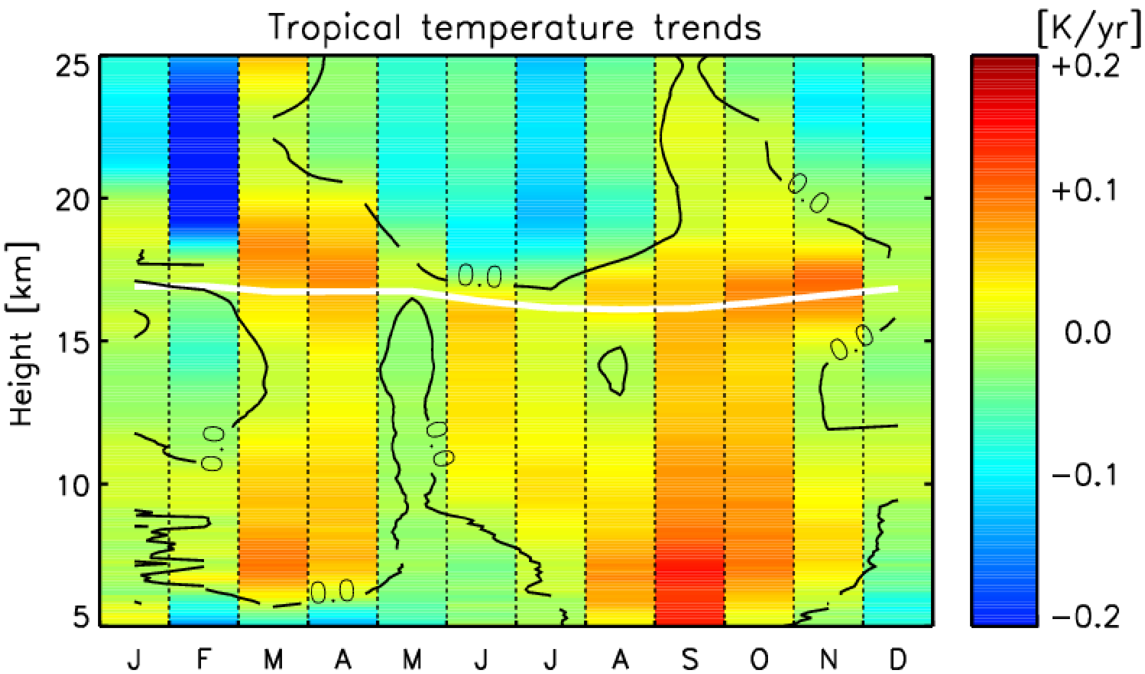
Temperature and LRTH trends

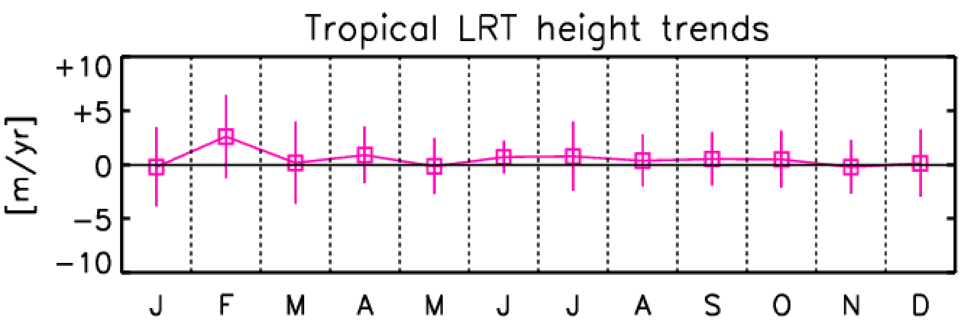


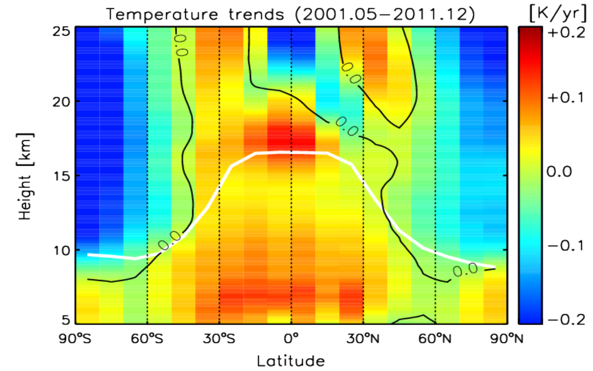


$$Y_{sig} = \frac{b}{SE} > 2$$

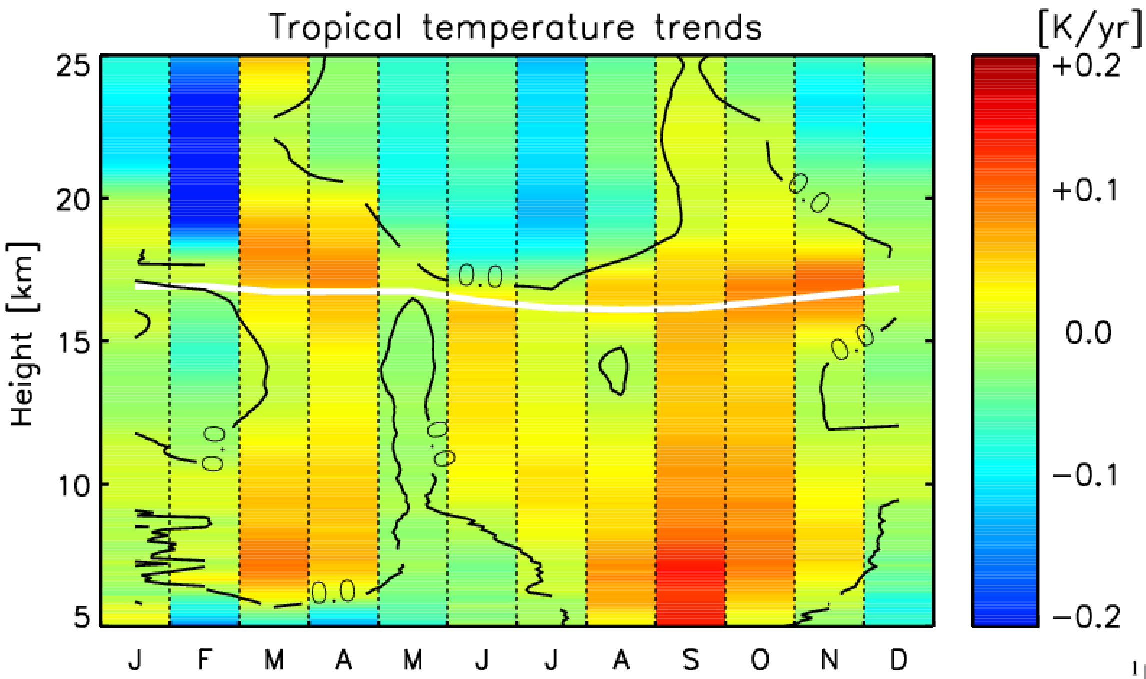
Tropical trends (20°N-20°S)

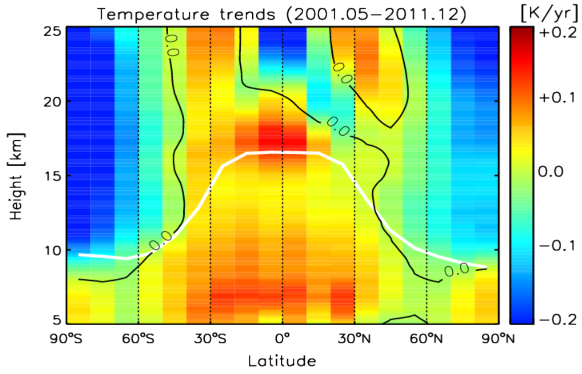


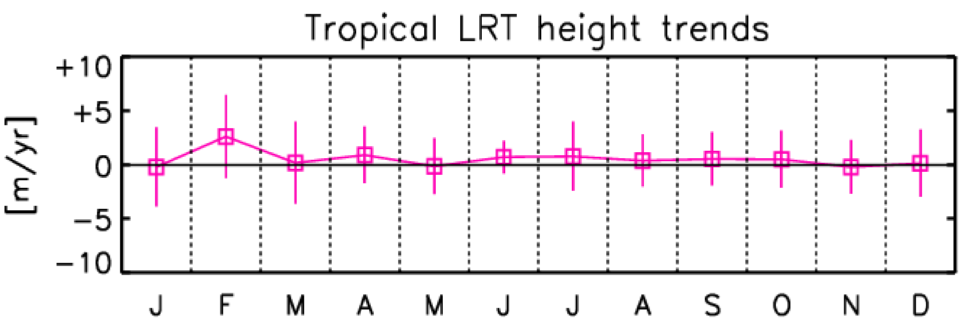


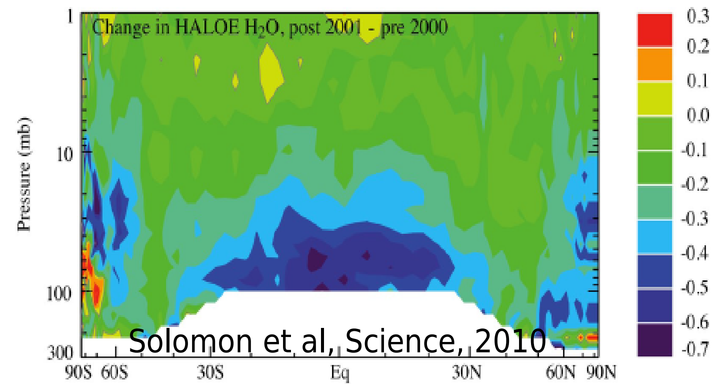


Tropical trends (20°N-20°S)









Solomon et al, Science, 2010

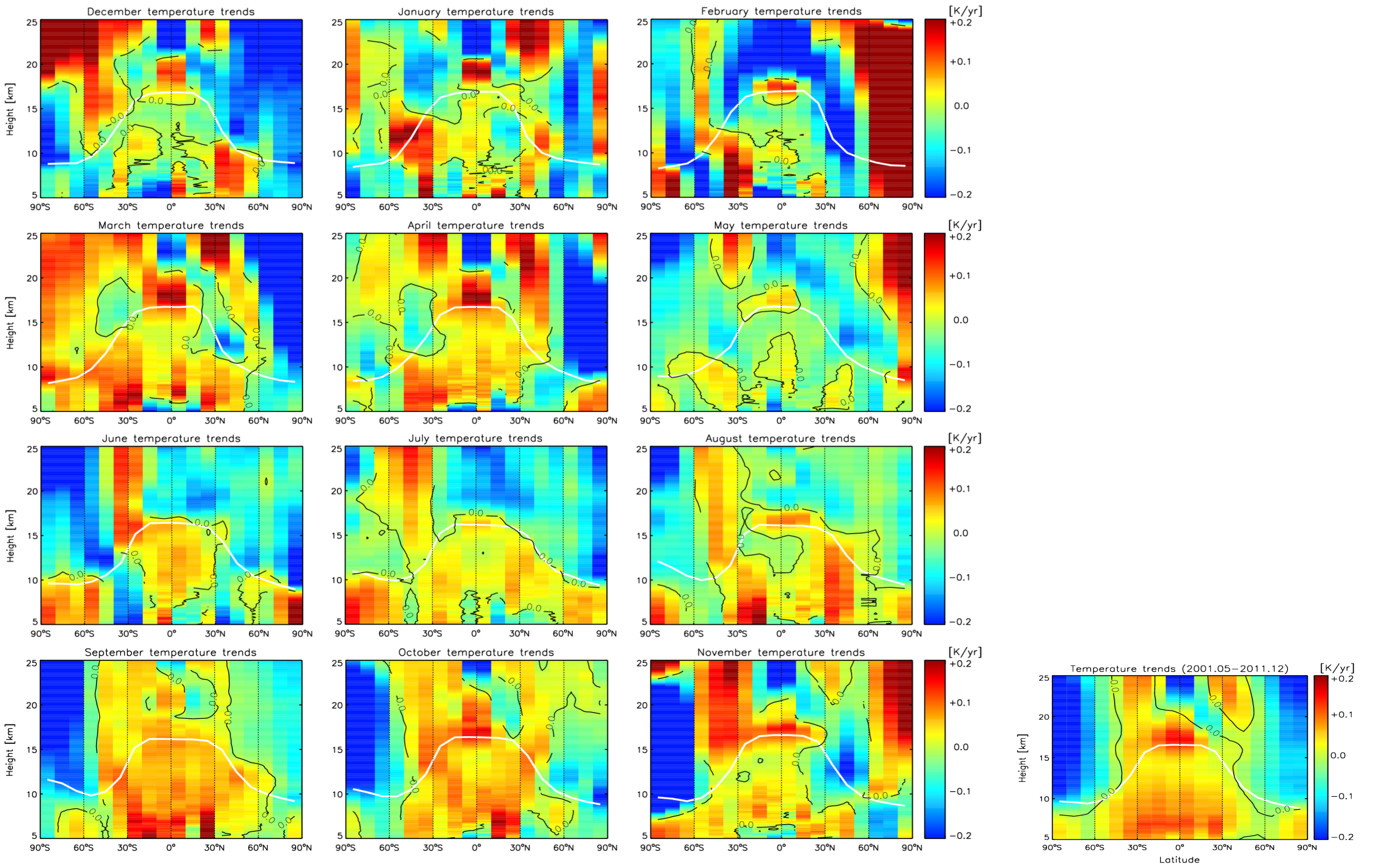
Seasonal trends

DJF

MAM

JJA

SON



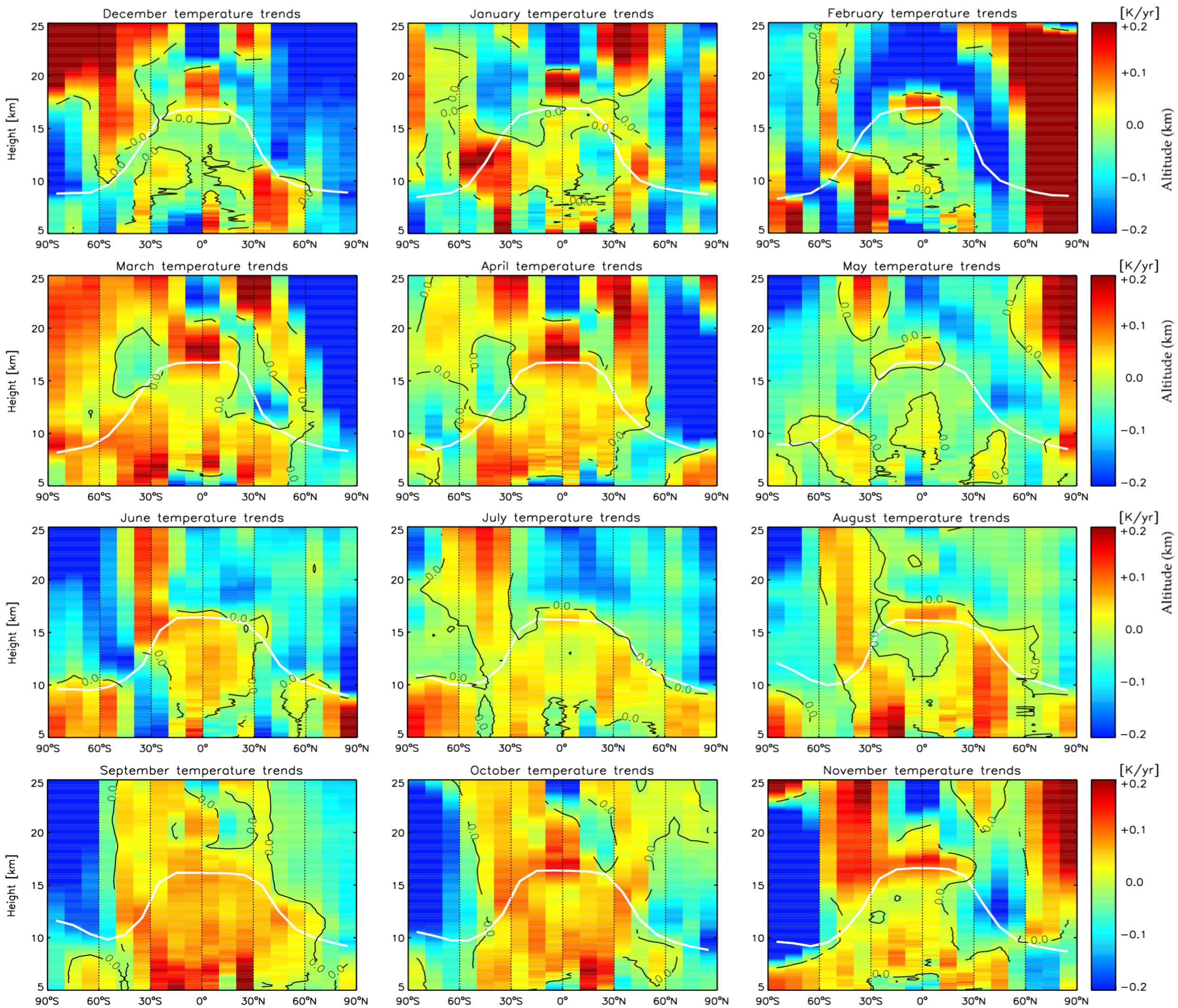
Seasonal trends

DJF

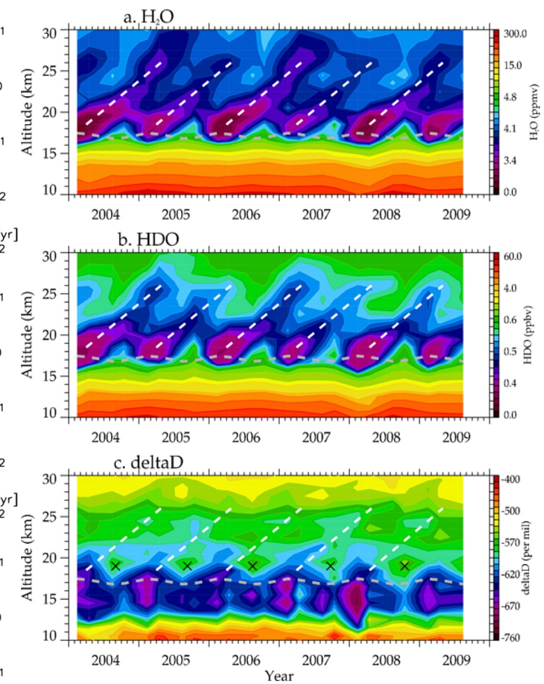
MAM

JJA

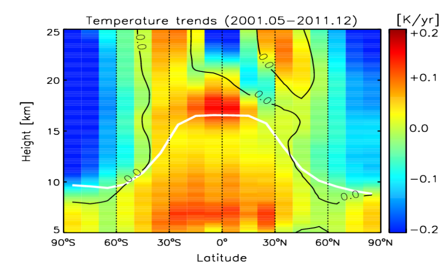
SON



Tropical H_2O (ACE-FTS)



Randel et al. (JGR, 2012)



GFZ
Helmholtz Centre
Potsdam

HELMHOLTZ
ASSOCIATION

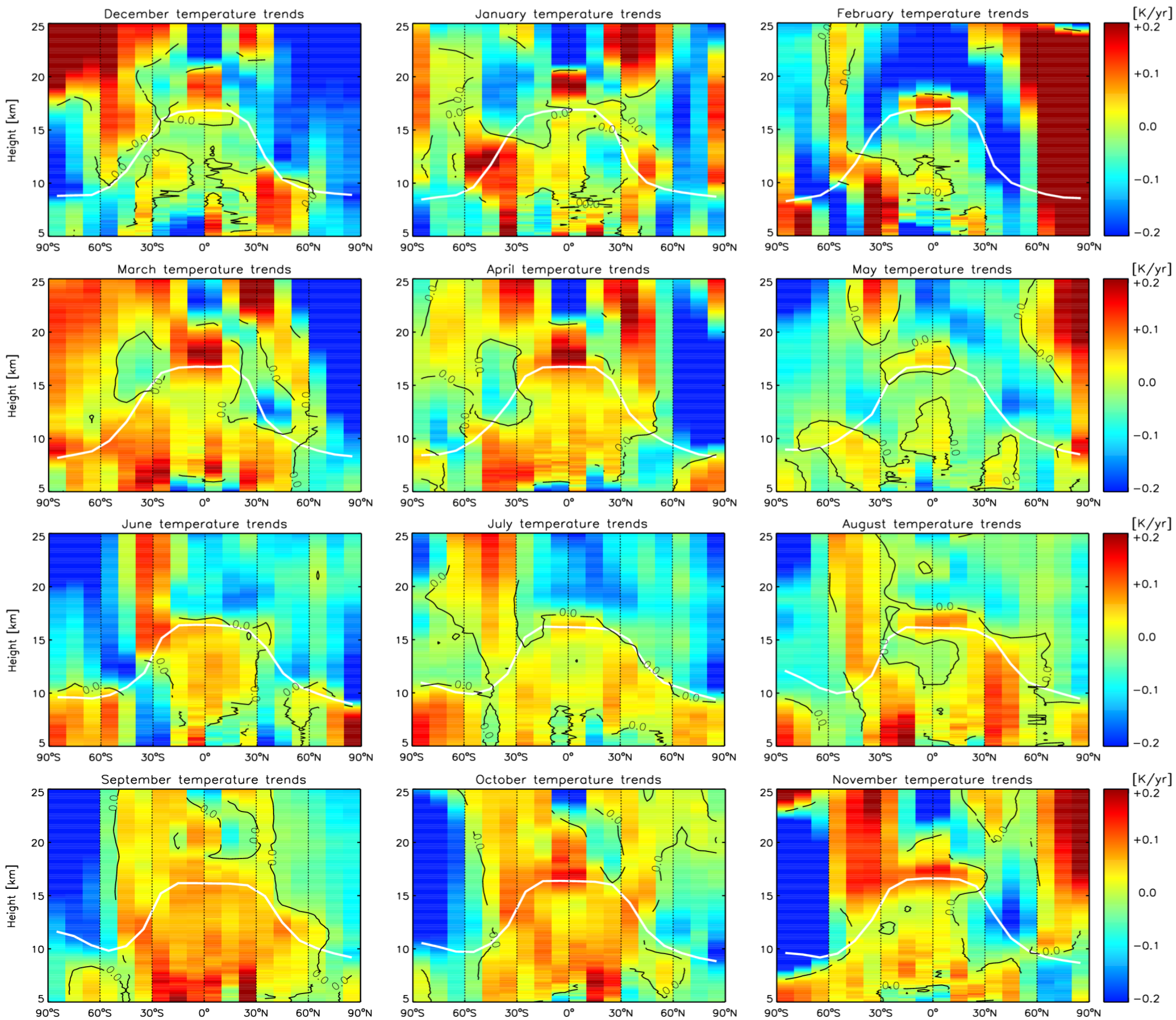
Seasonal trends

DJF

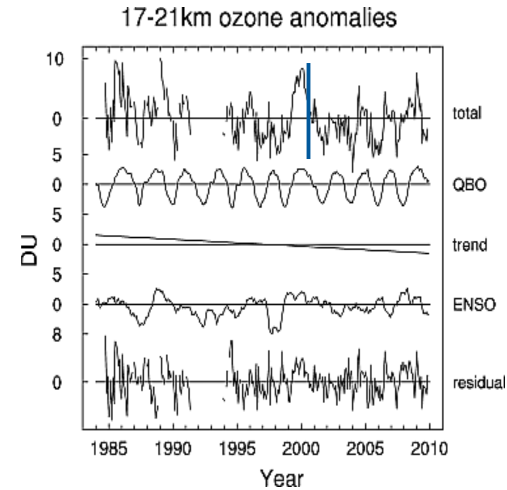
MAM

JJA

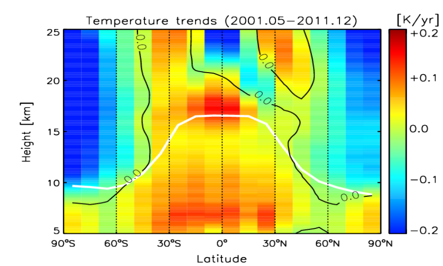
SON



SAGE II and SHADOZ



Randel and Thompson (JGR, 2011)



Summary

- More than 1 decade of RO data
  in a climatological sense not very long, but ...

- UTLS temperature trends are relative robust against the trend model
  – but with larger dependence in the stratosphere

- Trends are mostly significant in the UTLS

- Tropspheric temperature trends: positive

- Stratospheric temperature trends:
  - negative in the extratropics
  - tropics and subtropics?

- Good correlation between LRT height and UTLS temperature trends

- Future work: Explanation of the temporal and spatial trend patterns
  Combining RO data/results with other satellite data
  Tropical tropopause region (CPT trends)
  Temperature trends above 25 km