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Characterization of small systematic errors in GPS radio occultation climatologies and potential solutions

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Goal and Outline

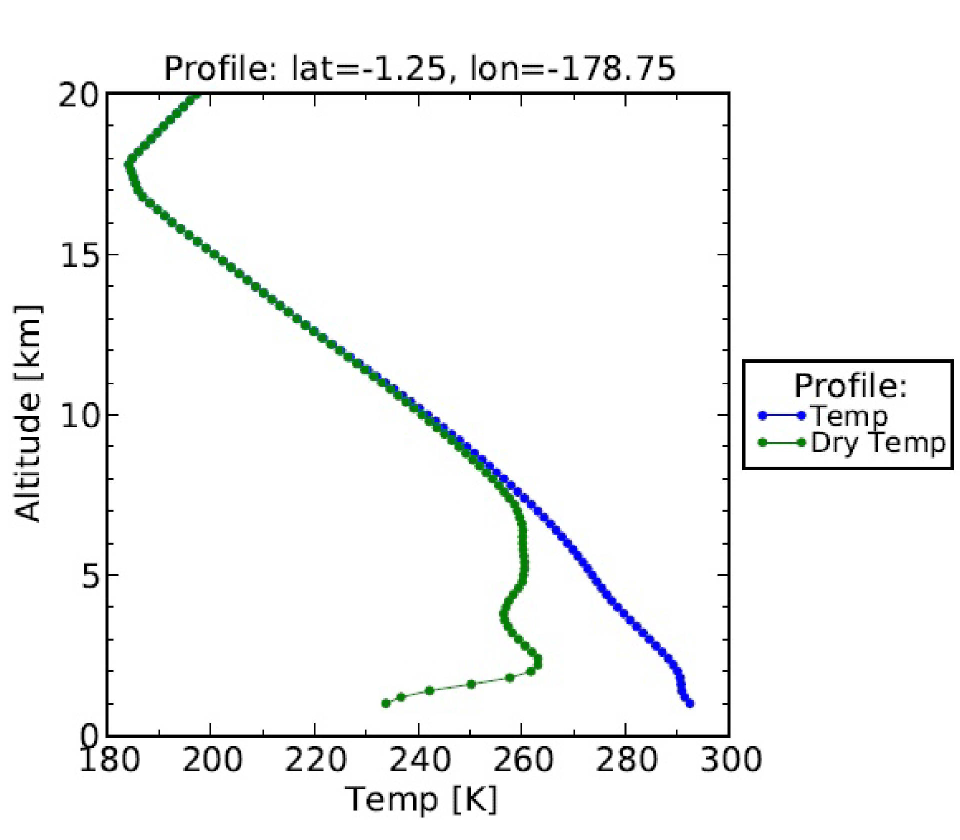
Trying to make the most accurate and stable thermometer in space (© Rick Anthes)
even more accurate.

Possible (small) systematic errors in
(1) Dry Temperature (due to changes in water vapor)
(2) Climatologies – selective sampling due to the
rejection of (apparent) outliers
(3) All parameters due to ionospheric residual errors
(4) Coefficients of the refractivity equation

.. and possible solutions.

(1) Trends in Dry Temperature?

"**Dry temperature**" is a good proxy for physical temperature, where humidity is small. It can be retrieved without (further) background info.



Down to which height is this proxy valid?

In which region of the atmosphere can we be sure, that observed **trends in dry temperature** are caused by **changes in temperature** and not by **humidity changes**?

Further Details in:

Atmos. Meas. Tech., 7, 2883–2896, 2014
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Atmospheric Measurement Techniques
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Influence of changes in humidity on dry temperature in GPS RO climatologies

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Dry Temperature Difference

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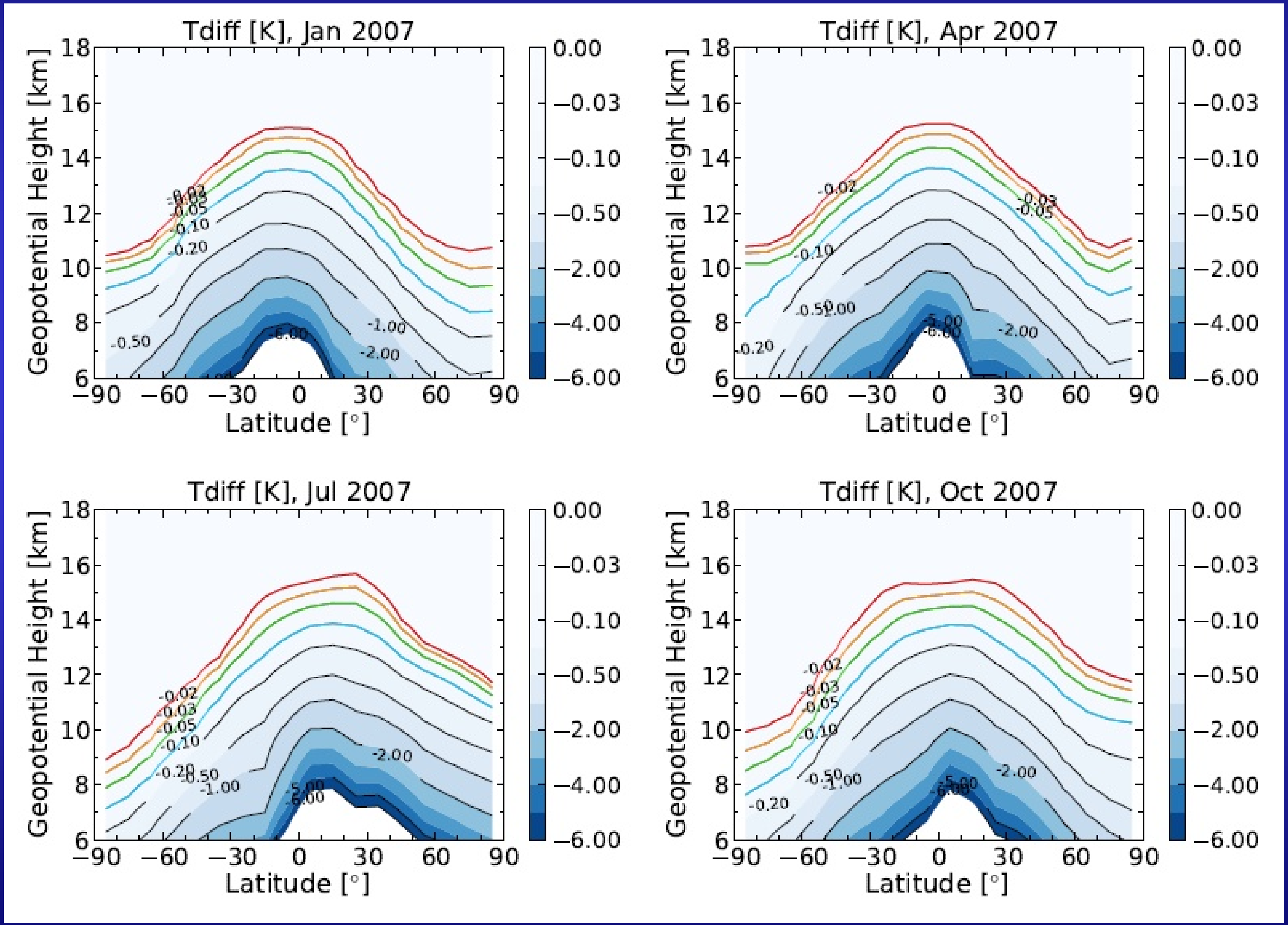
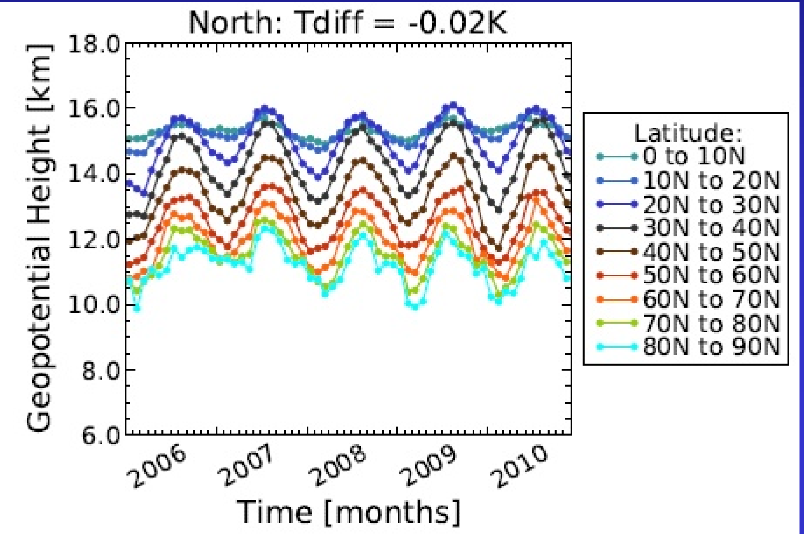
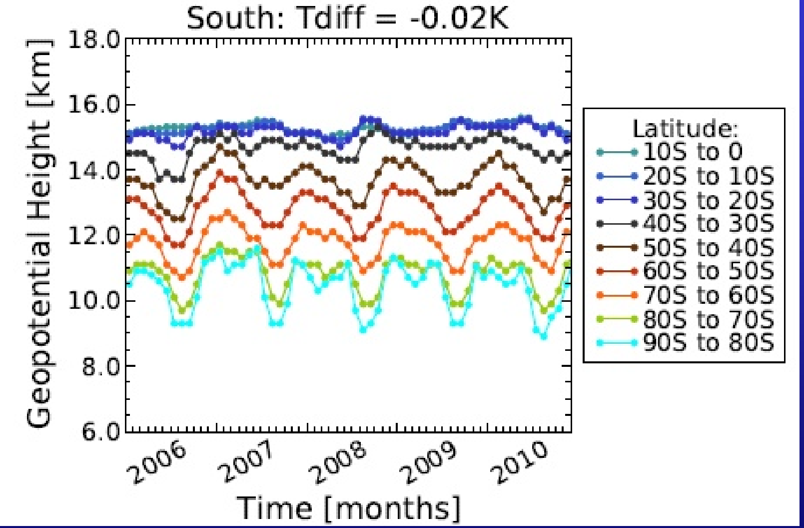
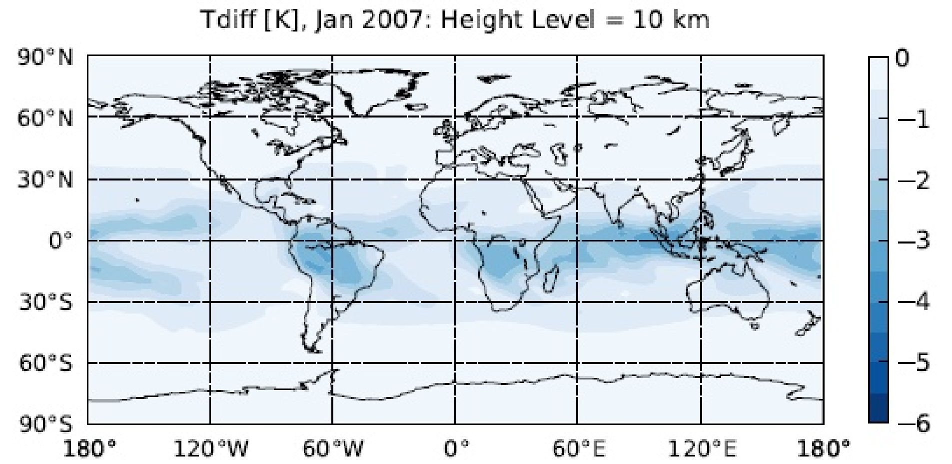


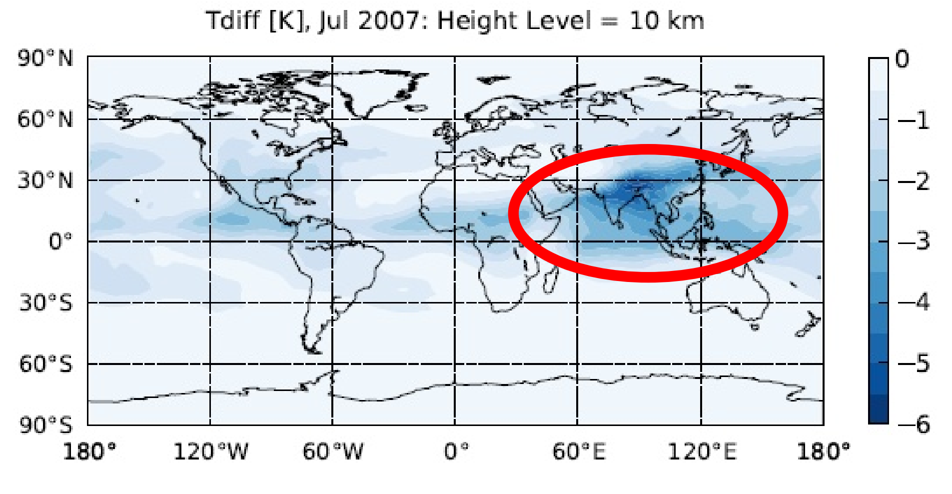
Zonal mean difference between T_{dry} and T, ECMWF analyses.

Dry Temperature Diff. Variations



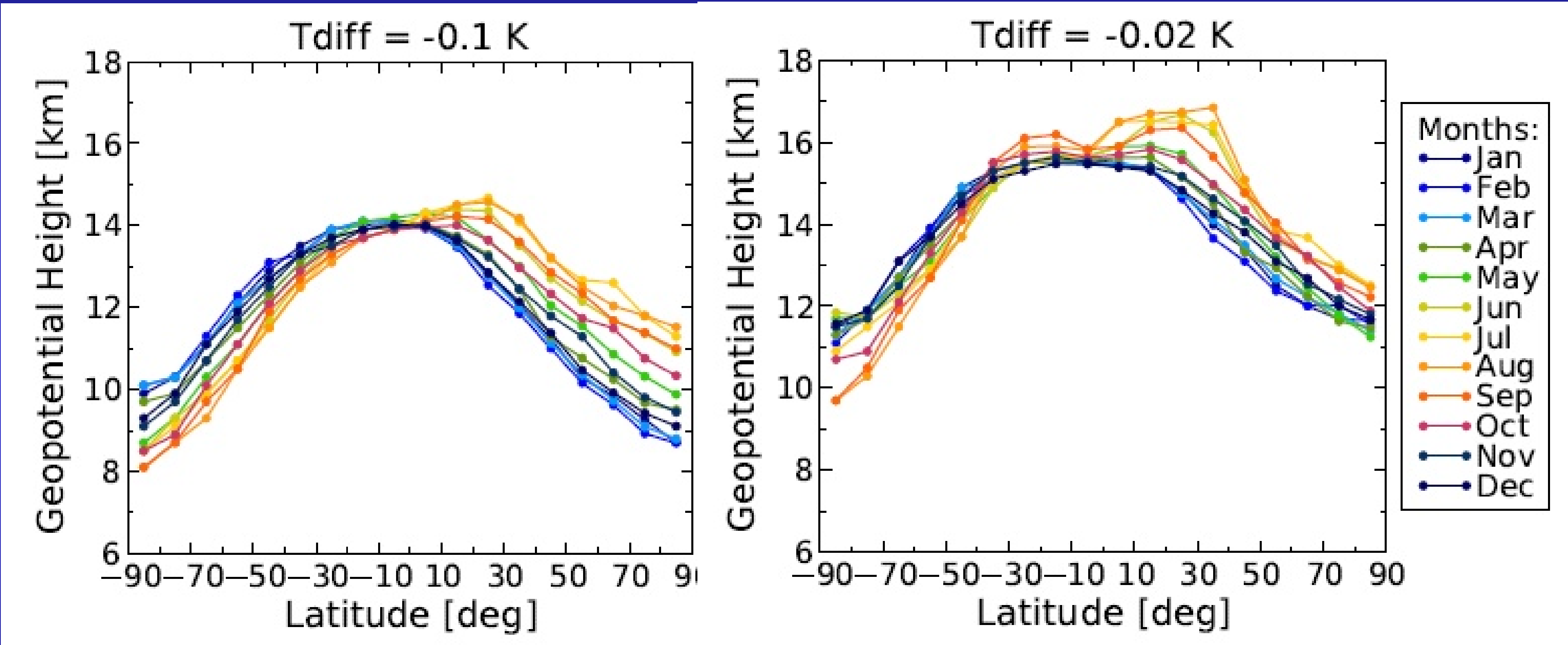






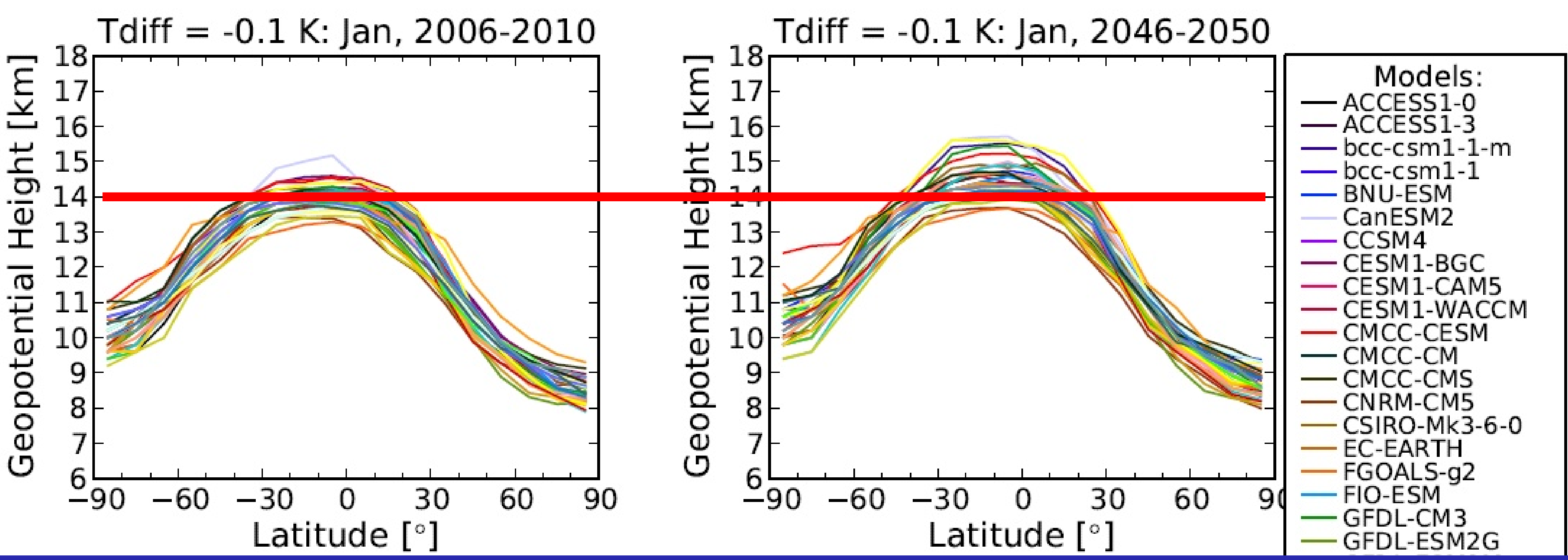
There are seasonal and longitudinal variations.

Dry Temperature



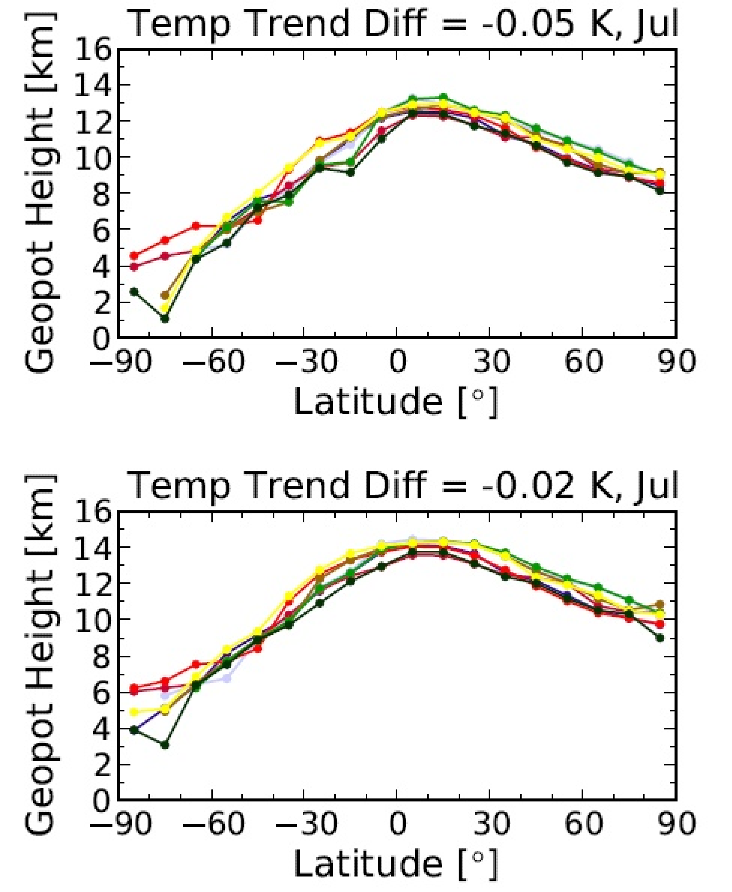
Accounting for seasonal and longitudinal variations, we can identify regions, where T_{dry} is equivalent to T, accepting a specified T_{diff} (T_{dry} – T). For T_{diff} = – 0.02 K this "safe zone" is found above 9 km to 17 km.

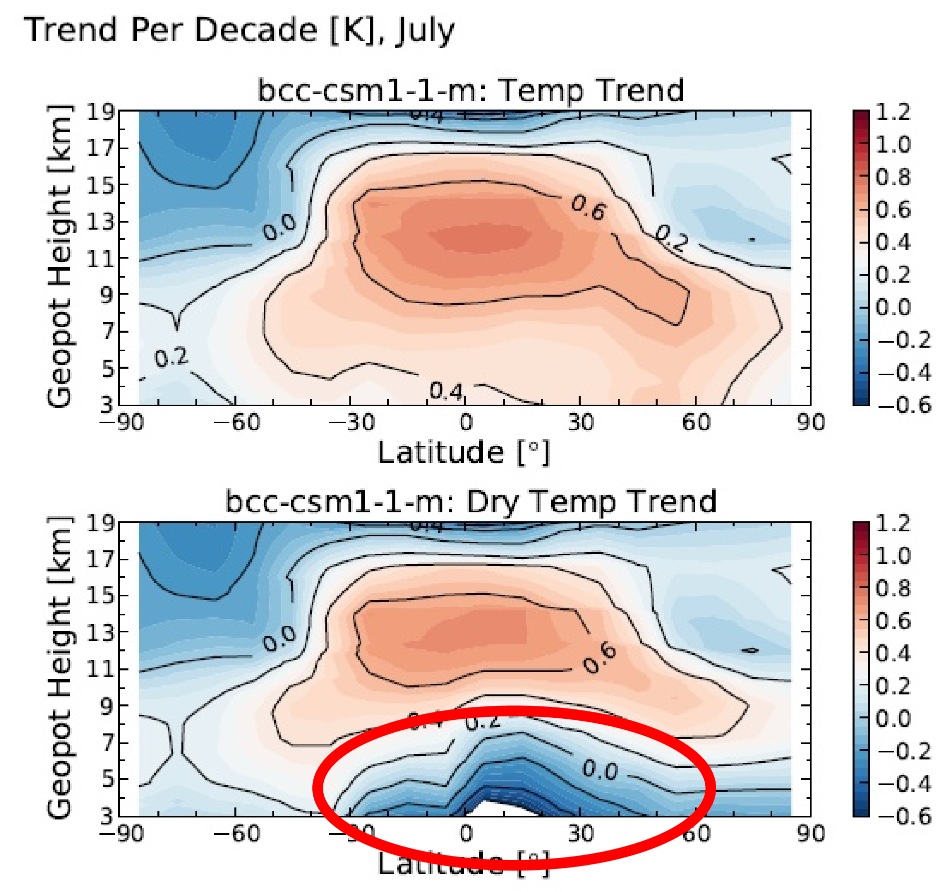
Dry Temperature Diff. Changes



Using all 38 CMIP 5 climate models with the (most extreme) RCP8.5 scenario, we can expect that these transition lines will rise about 250 m per decade (worst case).

Dry Temperature Trends





Differences between T_{dry} and T-trends will likely be less than 0.02 K per decade above 4 km to 14 km. Low latitude T_{dry} trends in the lower troposphere will likely be negative.

(2) Selective Outliers

The elimination of (apparent) **outliers** in the retrieval can lead to a **selective sampling** of the atmosphere.

At one step in the quality control in the operational WEGC retrieval, profiles are **flagged** if **negative bending angles** are found **below a specified altitude**.

This is more likely to happen under **very cold conditions**, and we found that there is indeed a **higher rejection rate** at **high latitudes** in **winter**, leading to a **small warm bias** in climatologies in these regions.

This effect will be **mitigated** in the new version of the WEGC RO profile retrieval (*Schwarz et al.*, in preparation).

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(3) Residual Ionospheric Errors

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Since the ionospheric correction is an approximation, we have to expect residual ionospheric errors – which depend on the ionization level.

Changes in ionization over the solar cycle could introduce false short-term trends in atmospheric parameters at high altitudes.

Rocken et al. (2008) and *Schreiner et al.* (2011) (UCAR) found differences between day- and night-time bending angle data at high altitudes, which increase with solar activity.

Can we reduce this time-dependent bias for climate applications (large ensembles of RO profiles), based on observational data?

Further Details in:

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www.atmos-meas-tech.net/6/2169/2013/
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Note also recent work by *Healy and Culverwell* (AMTD 2014) and *Danzer et al*. (AMTD 2014

Systematic residual ionospheric errors in radio occultation data and a potential way to minimize them

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Observed Residual Errors

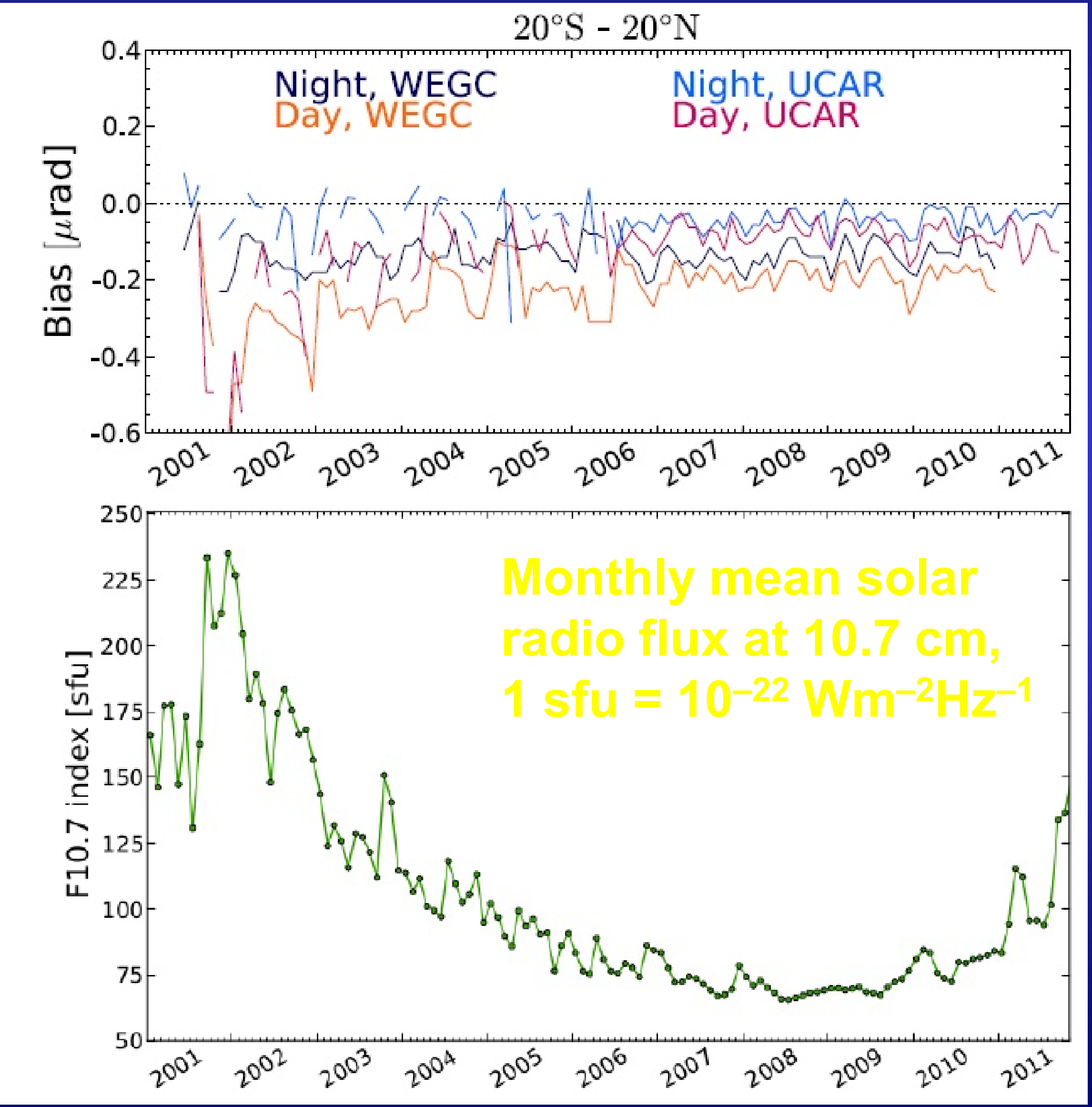
At **WEGC** the bending angle (BA) bias is routinely estimated between **65 km** and 80 km with respect to the (static) **MSIS** climatology.

At **UCAR**-CDAAC: between **60 km** and 80 km with respect to the **NCAR** climatology.

Both climatologies are not the "truth", but serve as **reference**.

First we compared **day-time** (11:00 – 15:00 local time) and **night-time** (2:00 – 6:00 LT) BA bias estimates at UCAR and WEGC over on solar cycle, using RO data from **CHAMP** and **Formosat-3/COSMIC.**

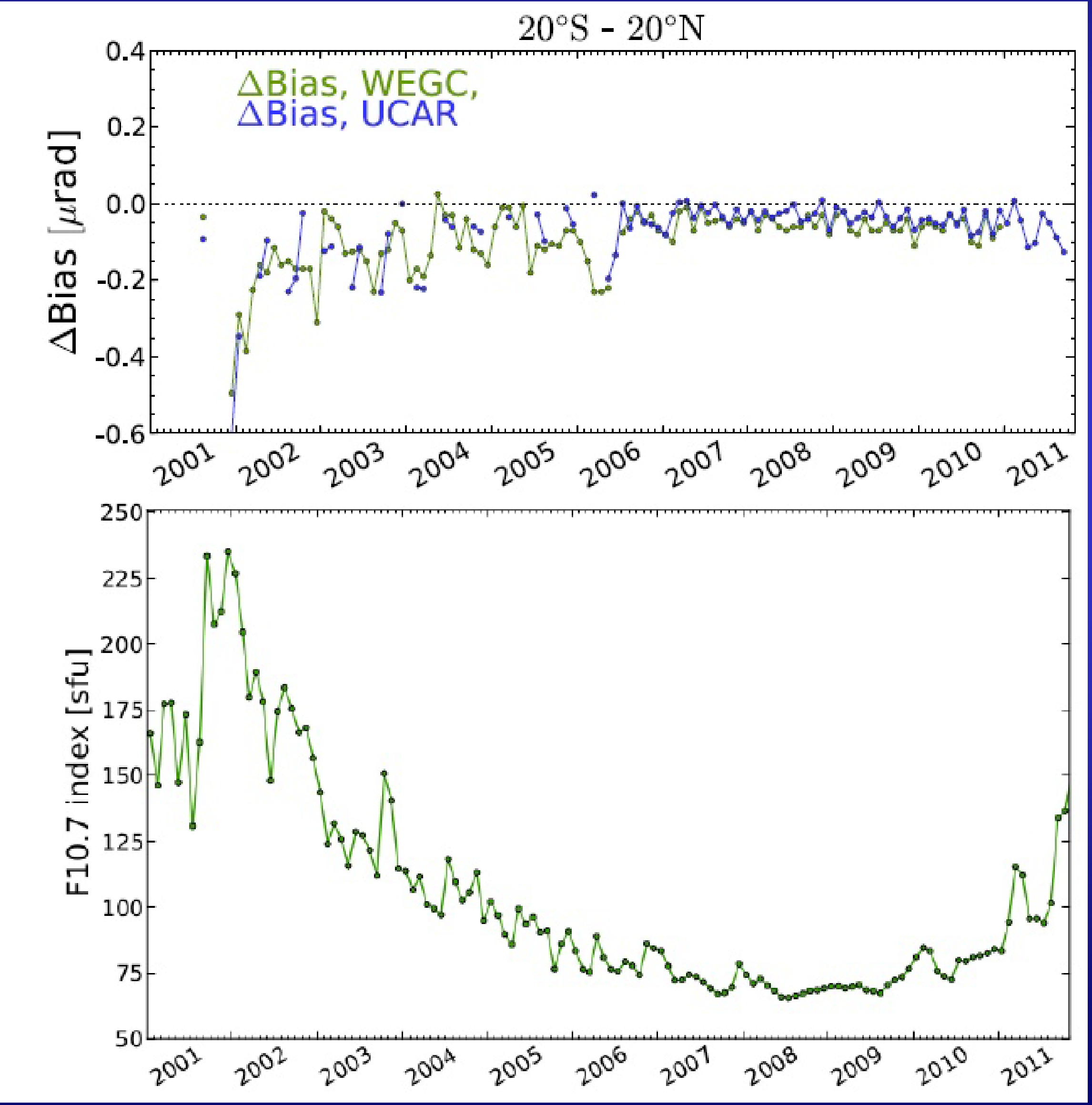
Observed Residual Errors



In both data sets the **night-time bias** is **~constant with time**, while the (negative) **day-time bias increases with solar activity**.

WEGC-UCAR offset is **expected**, due to different reference climatologies and altitude intervals considered.

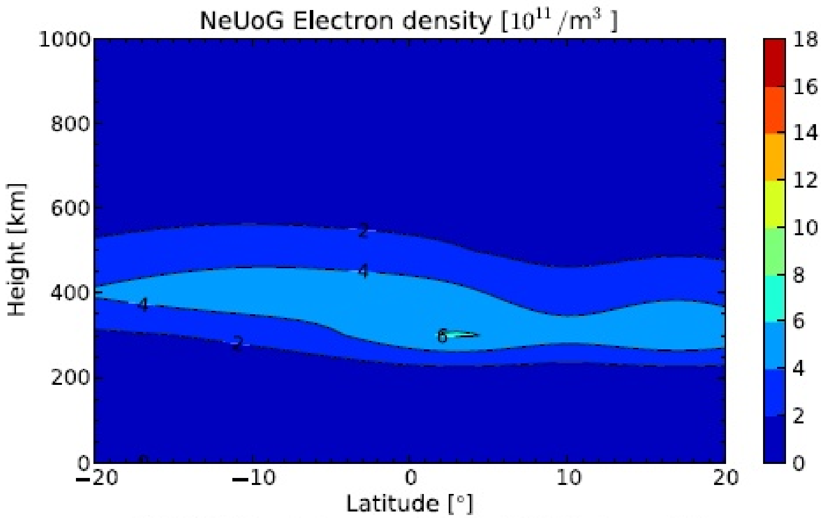
Observed Residual Errors

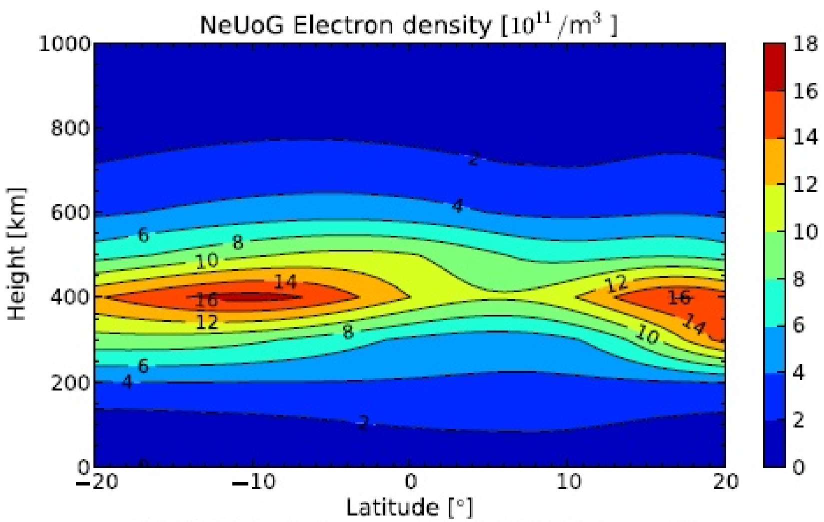


ΔBias – the difference between day-time and might-time bias is very similar at UCAR and WEGC.

Solarmax (2001/02):
ΔBias ~ – 0.6 μrad
Solarmin (2007-09):
ΔBias ~ – 0.05 μrad

Modeled Residual Errors

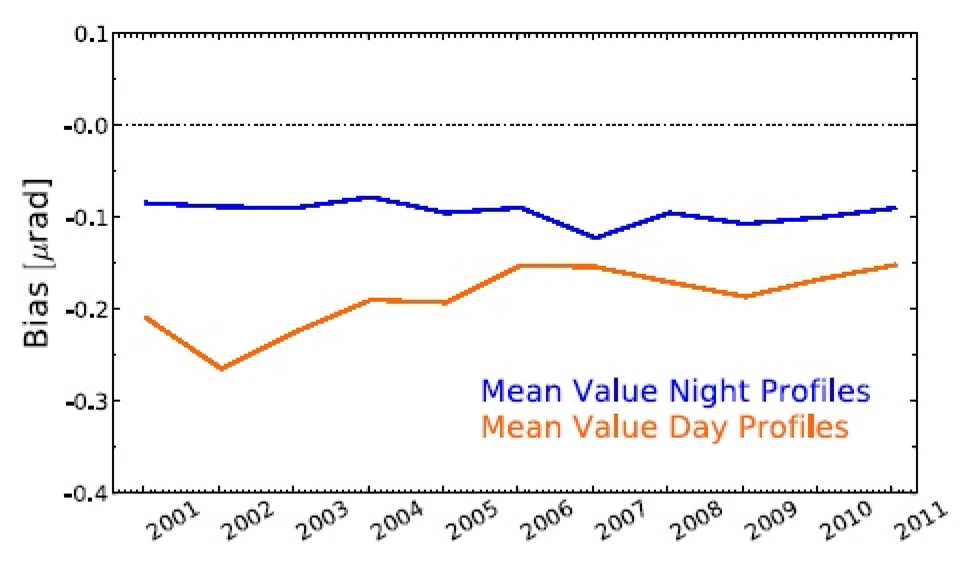




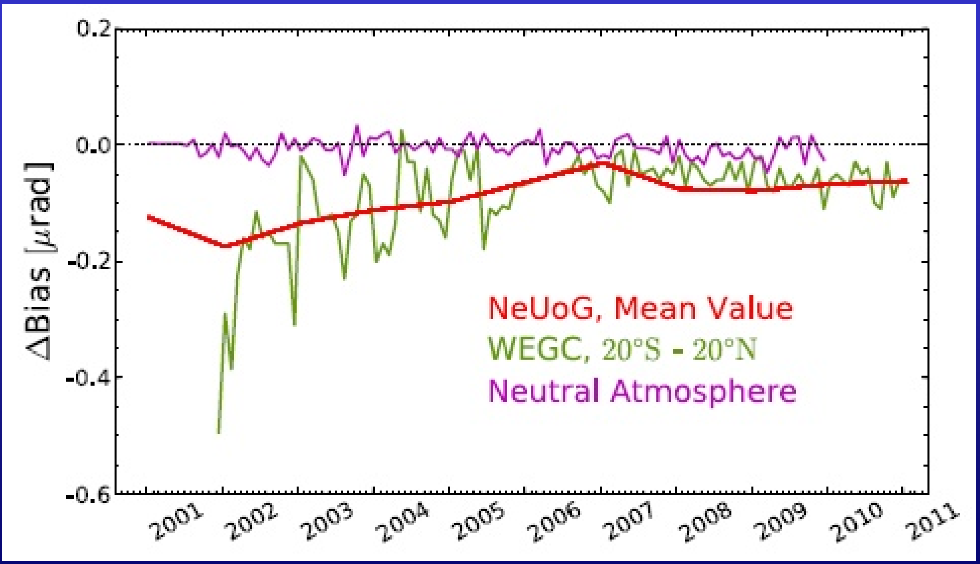
Next we modeled residual ionospheric errors, based on the NeUoG model (*Leitinger et al.*, 1995), which is driven by the F10.7 index.

In addition we estimated the contribution of the neutral atmosphere between 65 km and 80 km (where the iono-spheric residual is deter-mined), based on ECMWF data (we don't want to correct a real atmospheric effect).

Modeled Residual Errors



Also in the modeled world the night-time bias is approximately constant with time, while the day-time bias responds to changing solar activity.



The contribution of the neutral atmosphere is small (with a mean value of – 0.006 μrad) and also almost constant with time.

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A simple correction

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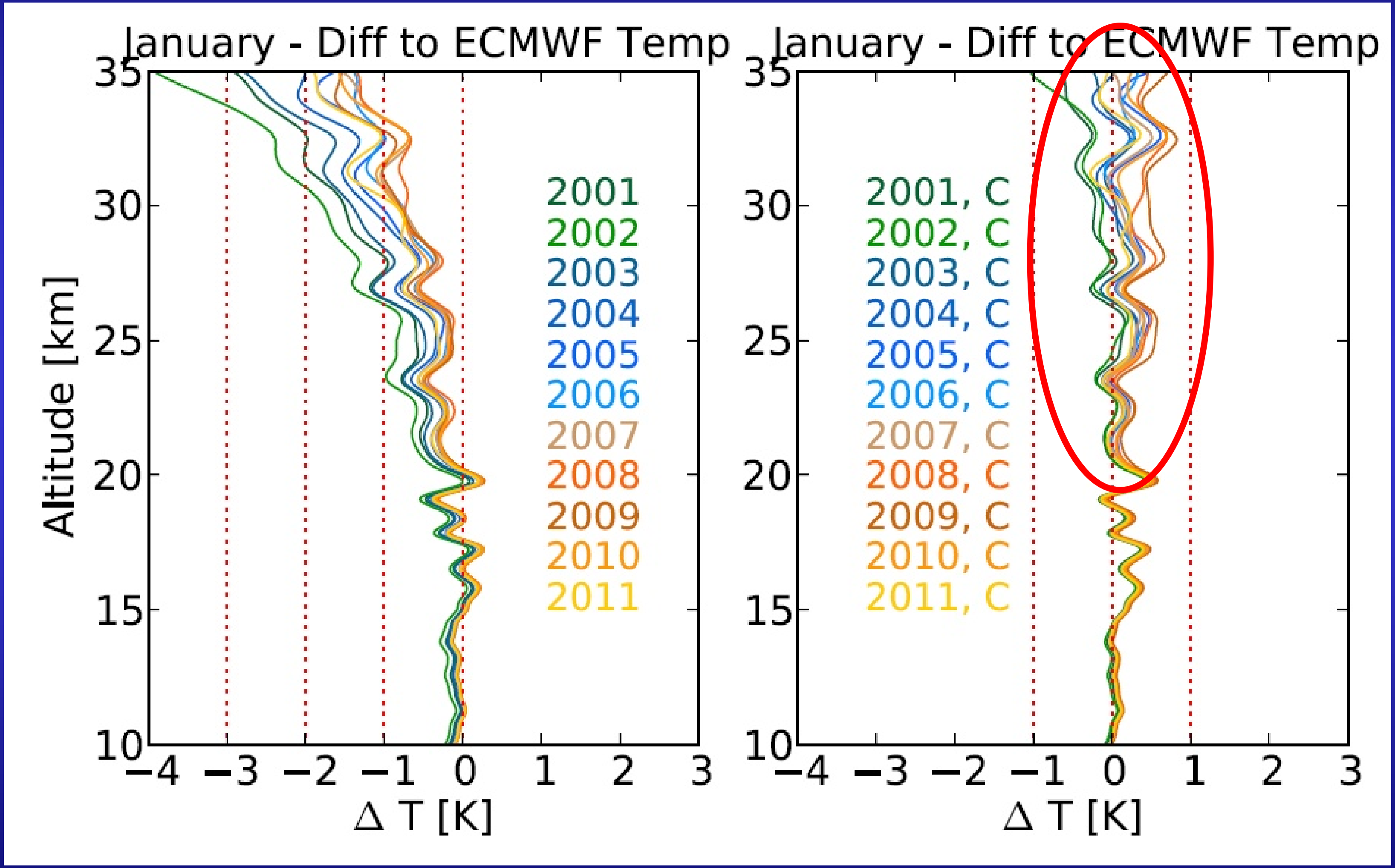
The **difference between day- and night-time bias** is a good indicator for the time-varying ionospheric residual, and can be used as a **correction factor**, which can be applied to **day-time** bending angle profiles.

The entire **bending angle profile is shifted by – ΔBias** (minus the small contribution of the neutral atmosphere), ΔBias is expressed as function of latitude and phase of the solar cycle.

Now we asses how this correction affects **temperature** data, where the effect of the ionospheric residual is **most pronounced** due to the non-local transforms within the retrieval.

Simulation Results



The bias at high altitudes is considerably reduced.

(4) Refractivity Coefficients

The coefficients in the refractivity equation (e.g. k_1 = 77.6 K/hPa, *Smith and Weintraub, 1953*):

$$N = k_1 \frac{p_d}{T} + k_2 \frac{p_w}{T} + k_3 \frac{p_w}{T^2}$$

N – refractivity
T – temperature
p_d – dry air pressure
p_w – water vapor pressure

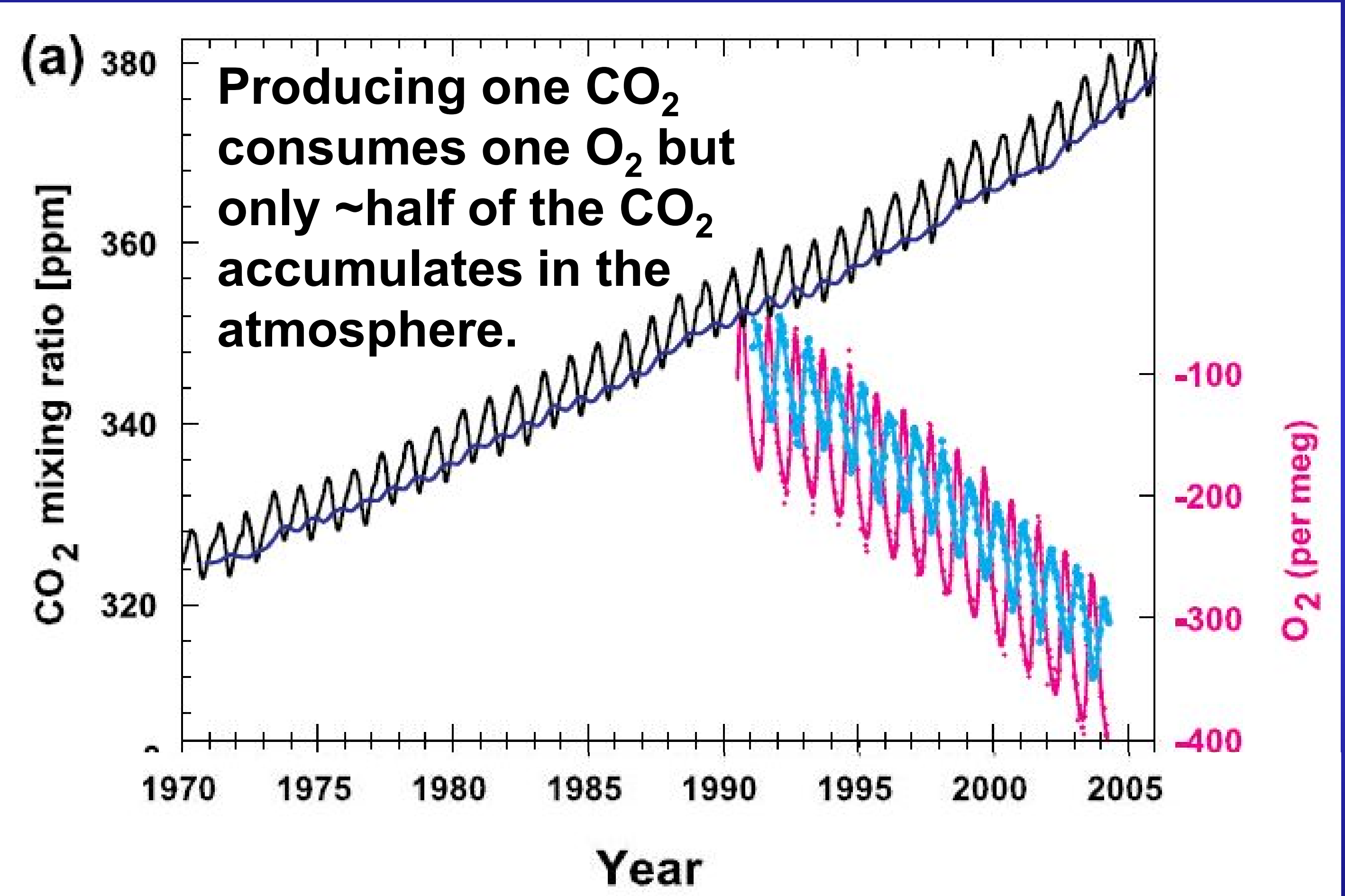
can be related to more fundamental physical constants, like the electric constant ε_0 and the Boltzmann constant k_B, (*Foelsche, 1999*):

$$k_1 \cong \frac{10^6}{2 k_B \varepsilon_0} \overline{\alpha}$$

$\overline{\alpha}$ is the mean weighted polarizability of the constituents of dry air, which changes with its composition. If applied to density (instead of p/T) k_1 would just depend on atmospheric composition.

In a pure CO_2 atmosphere k_1 would be 133 K/hPa
CO_2 doubling (280 to 560 ppm) leads to a (modest) increase of k_1 by ~0.05 % – and an apparent temperature change of ~0.14 K (at p_0).

Refractivity Coefficients



But the current **CO_2 increase** comes with a **decrease in O_2** with about **twice the rate** (IPCC, 2007) – and O_2 has only about **half the polarizability** of CO_2, therefore:

Refractivity Coefficients

A simultaneous **O_2 decrease** at the current rate (about twice that of CO_2), however, basically **cancels the CO_2 increase effect**.

$$k_2 \cong \frac{10^6}{2k_B\varepsilon_0}\alpha_W$$

The expression for k_2 is the same as for k_1, just with the **polarizability of water vapor**.

$$k_3 \cong \frac{10^6}{6k_B^2\varepsilon_0}\mu^2$$

k_3 is related to the **permanent dipole moment** of water vapor, μ.

Foelsche 2??? (in indefinite preparation).

k_2 and k_3 can therefore be expected to be constant in time, but both seem to be rather poorly measured.

See also: *Healy*, JGR 2011*; Aparicio and Laroche*., JGR 2011

Conclusions

We have identified regions, where it is currently save to use **dry temperature as proxy for temperature**, and we have estimated how this regions will **change** due to climate change: Transition lines will rise **~250 m/decade**.

Outlier rejection can lead to **selective sampling** of the atmosphere – this can be mitigated with smarter quality control.

We could confirm that the **day-time residual ionospheric bias increases with solar activity**, while the night-time bias remains essentially constant.

The **observed difference** between day- and night-time bias could be used as a **correction factor**, which can be applied to ensembles of **day-time** bending angle profiles.

Outlook

For a detailed formulation of the climatological ionospheric correction it will be important to include multi-satellite RO data from the current solar maximum.

Fine tuning of the applied correction will comprise a detailed study of the local time dependence and the alternative use of magnetic coordinates.

By determining the ionospheric residual only above 70 km we can avoid the potential problem of correcting an apparent ionospheric bias, which is indeed a real contribution of the neutral upper atmosphere – which also shows changes caused by the solar cycle.

From Australia to Austria

IROWG-5 + OPAC-6 Workshop, Seggau Castle
September 8 – 14, 2016
Information on the latest workshop:
http://www.uni-graz.at/opacirowg2013

Thank you!