On possible reasons for systematic errors in GPS radio occultation climatologies, their characterization and potential ways to remove some of them

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

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?
Influence of changes in humidity on dry temperature in GPS RO climatologies

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Dry Temperature Difference

Zonal mean difference between $T_{dry}$ and $T$, ECMWF analyses.
Dry Temperature Diff. Variations

There are seasonal and longitudinal variations.
Accounting for *seasonal* and *longitudinal* variations, we can identify regions, where $T_{\text{dry}}$ is equivalent to $T$, accepting a specified $T_{\text{diff}}$ ($T_{\text{dry}} - T$). For $T_{\text{diff}} = -0.02$ K this “safe zone” is found above 9 km to 17 km.
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).
Differences between $T_{\text{dry}}$ and T-trends will likely be less than 0.02 K per decade above 4 km to 14 km. Low latitude $T_{\text{dry}}$ trends in the lower troposphere will likely be negative.
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.
Residual Ionospheric Errors

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

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In both data sets the night-time bias is \(\sim\)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 ionospheric residual is determined), 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.
A simple correction

The difference between day- and night-time bias as 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 $-\Delta \text{Bias}$ (minus the small contribution of the neutral atmosphere), $\Delta \text{Bias}$ is expressed as function of latitude and phase of the solar cycle.

Now we assess 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.
Outlook

For a detailed formulation of the climatological ionospheric correction it will be important to include multi-satellite RO data from the currently evolving 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.
Conclusions

We have identified regions, where it is currently safe to use dry temperature as proxy for temperature, and we have estimated how these 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 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.
Thank you!
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**.