Wegener Center for Climate and Global Change
University of Graz

GNSS Radio Occultation Trend Patterns for Atmospheric Climate Change Detection With a Fingerprinting Method

Bettina C. Lackner[1], Andrea K. Steiner[1], Gabriele C. Hegerl[2], Gottfried Kirchengast[1]

(1) Wegener Center for Climate and Global Change & Inst. for Geophysics, Astrophysics and Meteorology/Inst. of Physics, University of Graz, Austria
(2) University of Edinburgh, School of GeoSciences, Edinburgh, U.K.
bettina.lackner@uni-graz.at

The Global Navigational Satellite System (GNSS) Radio Occultation (RO) method provides a new high-quality data record of thermodynamic variables for the upper troposphere-lower stratosphere (UTLS). RO climatologies fulfill the requirements for a climate record, such as long-term stability, self-calibration, global coverage, nearly all-weather capability. This study aims to demonstrate the utility of RO data in climate research using an optimal fingerprinting approach. Refractivity (N), geopotential height (Z), and temperature (T) trend patterns of two periods are assessed with respect to the detection of a climate change signal consistent to three CMIP3 models. The robustness of the detection results is explored accounting for the quasi-biennial oscillation (QBO) and the El Niño-Southern Oscillation (ENSO).

1 Data

We investigate N, Z, and T trend patterns between 50°S and 50°N for **2 periods** ("intermittent" based on monthly means of 10/1995, 02/1997, 09/2001–06/2006, 09/2006–07/2010, "continuous" based on 09/2001–06/2006, 09/2006–07/2010) and **for 2 resolutions** (20° zonal mean bands, 50°S to 50°N zonal mean average). In the vertical we focus on 8 UTLS pressure levels between 300 hPa and 30 hPa (≈ 9 to 25 km).

Observational data set

RO climatologies (WEGC OPSv5.4/CLIPSv1.3; Source: www.wegcenter.at/globclim) of multi-satellite measurements (GPS/Met, CHAMP, SAC-C, GRACE-A, Formosat 3/ COSMIC FM1-6), see Fig. 1. The data were used with the estimated sampling error removed.

QBO and ENSO indices to separate and remove the signal of these atmospheric patterns from the data via a multiple linear regression model:

- 50 hPa zonal wind (Source: www.cpc.ncep.noaa.gov)
- N3.4 index (Source: www.esrl.noaa.gov).

3 CMIP3 global climate models (GCM)

CCSM3, ECHAM5, HadCM3

- 20th century simulations are concatenated with A2 and B1 scenario simulations (fGCM; 20 simulations in total).
- Pre-industrial control simulations (PICTRL; 340 years of monthly mean data of each model, i.e., 1020 years in total) are used to estimate natural variability.

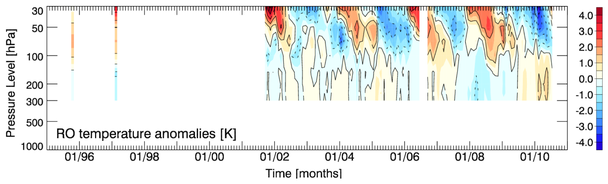

Fig. 1: Tropical (10°S to 10°N) monthly mean time series of RO temperature anomalies.

2 Method

Optimal detection can be considered as general multi-variate regression (e.g., Hegerl et al. 2007):

$$\boldsymbol{y} = \mathbf{X}\,\boldsymbol{a} + \boldsymbol{u}$$

$\boldsymbol{y}$ … observed RO trends
$\mathbf{X}$ … forced ensemble fGCM trends
$\boldsymbol{a}$ … scaling factors
$\boldsymbol{u}$ … internal variability (estimated by PICTRL).

- All calculations are performed in a dimension-reduced EOF space, which is based on PICTRL trend matrices.
- The residual consistency test (Allen and Tett, 1999) is used to check the model simulated variances at scales that are retained (EOFs).
- Climate change is "detected" if its likelihood of occurrence by chance due to internal variability alone is small.
- The uncertainty in the scaling factors $\boldsymbol{a}$ is assessed with an independent estimate of natural variability (PICTRL trends, sampled consistently to observations).

Multiple-linear regression was used to remove the QBO from RO and ENSO from RO and GCM data (see Fig. 2).

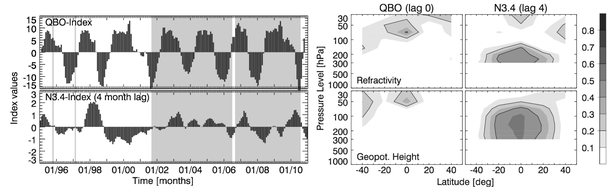

Fig. 2: QBO and ENSO indices (left). Months of RO measurements are highlighted in gray. Explained variance (R^2 in MLR) of QBO/ENSO induced variability in RO record (right). Temperature results are similar to refractivity.

3 Results

The results are presented via two multi-panel figures. Fig. 3 depicts the results for trends of the latitude-resolved patterns and Fig. 4 for the average trend profiles between 50°S and 50°N. The influence of removing QBO and ENSO from the data is discussed for each resolution separately.

A Latitude-height trend pattern results

- The RO trend patterns (Fig. 3a) are stronger than those in GCMs, particularly in the tropics.
- Elimination of ENSO/QBO increases the trend amplitudes (subject to pattern phase), leads to a cleaner climate signal and better consistency between RO and GCMs in the truncated space (Fig. 3b, black lines; values within confidence limits). If ENSO/QBO are not removed, the observations show higher variability than the models. (Fig. 3b, gray lines).
- The scaling factors show good consistency of RO and GCM trend patterns (Fig. 3c; scaling factors around 1), best for the continuous period and for geopotential height in the intermittent period. Removing ENSO/QBO causes slightly lower scaling values, especially for the intermittent period.

B 50°S–50°N mean trend profile results

- RO and GCMs show very similar trends (stronger GCM trends in UT, weaker in tropopause/LS, Fig. 4a).
- Residual consistency is given if ENSO/QBO signals are eliminated for all variables but refractivity in the intermittent period. ENSO/QBO mainly influence residual consistency for temperature (Fig. 4b).
- Detection at 90% confidence level for all variables and periods except for refractivity in the intermittent period. Natural variability of trends including ENSO/QBO is considerably larger, but hardly affects the emerging climate signal detection (Fig. 4c).

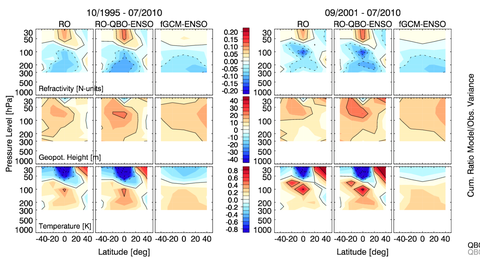

Fig. 3a: N (top), Z (middle), and T (bottom) trend patterns (10-yr trends) based on original RO anomalies (left), RO with QBO/ENSO removed (middle), and fGCM ensemble (right) for the two study periods.

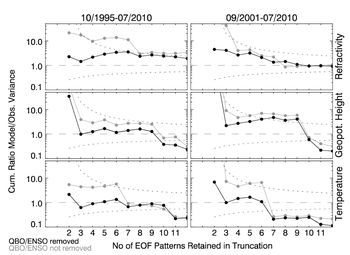

Fig. 3b: Residual consistency results, i.e., cumulative model to observation ratios of residual variability. Dotted lines mark 5% and 95% χ^2 limits.

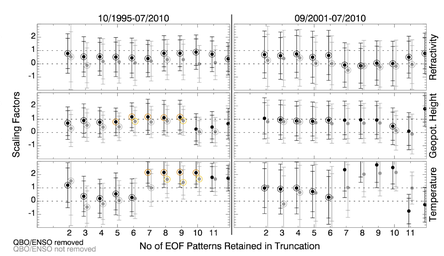

Fig. 3c: Uncertainty in scaling factors. Error bars signify the 10% to 90% and the 5% to 95% uncertainty range. If for a certain k the residual consistency test is passed, it is marked with a circle. The color marks detection at 90% confidence level or better.

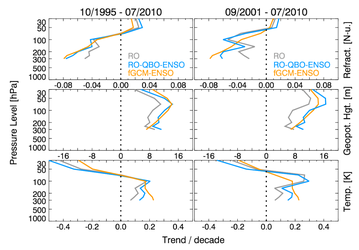

Fig. 4a: As Fig. 3a for zonal mean 50°S–50°N profiles.

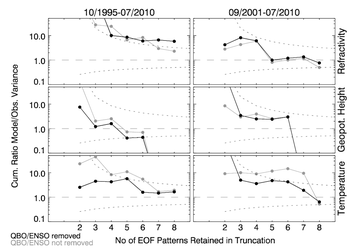

Fig. 4b: As Fig. 3b for zonal mean profiles.

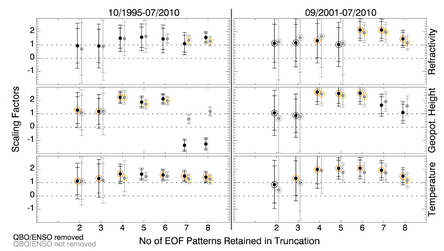

Fig. 4c: As Fig. 3c for zonal mean profiles.

4 Conclusions

The multi-satellite RO record within 1995 to 2010 shows an emerging UTLS climate change signal, which is consistent with the climate change signal in GCM projections. The signal evolves most clearly in geopotential height fields, which reflect the overall tropospheric warming. For this variable, detection at the 90% confidence level is given. RO temperature trends are stronger than GCM trends and allow for detection when the small scale aspects of variability are resolved. When QBO and ENSO are not removed from the data, detection levels are below 90% confidence for latitude-resolved patterns. This is caused on the one hand by larger natural trend variability and on the other hand by slightly lower trend values in the observations. Nevertheless, the patterns are consistent with the GCM projections. More details are given by Lackner et al. (2011).

References

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