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GPS RADIO OCCULTATION FOR CLIMATE APPLICATIONS

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Summary: Observation of the atmospheric climate and the detection of changes require high quality data. Radio Occultation (RO), based on signals from Global Positioning System (GPS) satellites, provides a new climate record with high quality and vertical resolution in the upper troposphere and lower stratosphere (UTLS). RO data are considered a climate benchmark data type since they are based on timing with precise atomic clocks, tied to the international definition of the second. Long-term stability and the consistency of RO data stemming from different satellites (without need for inter-calibration) make RO well suited for climate applications. First RO data exist from the GPS/Met proof-of-concept mission intermittently in the years 1995 to 1997. Continuous RO observations are available from the CHAMP satellite from September 2001 to September 2008, complemented and continued by SAC-C, GRACE, Formosat-3/COSMIC, and MetOp/GRAS data.

We discuss the utility of RO-based climatologies for observing the atmosphere and for providing climate change indicators, i.e., parameters and regions reacting most sensitive to climate change. Results reveal that RO accessible parameters cover the whole UTLS as useful climate indicators, being most robust in the tropics. Refractivity is most sensitive in the LS, pressure near the tropopause, and temperature in the UT and LS.

We present results of a climate change detection study based on RO data revealing significant climate trends relative to natural variability in the UTLS region within 9–25 km (300–30 hPa). While an emerging warming trend in the tropical UT is obscured by El Niño variability, a significant cooling trend is revealed in the LS in February 1997 to 2009. A consistent trend signal is also detected in refractivity. The results are in agreement with trends in radiosonde records though those trends are not significant themselves due to less stable error characteristics. Climate model trends basically agree as well but they show less warming/cooling contrast across the tropical tropopause. Beside comparison to conventional upper air satellite data, intercomparison of RO data from different processing centers confirms the consistency of RO data products fulfilling the needs of climate monitoring.

1 INTRODUCTION

Intensive efforts have been undertaken to reconcile differences of atmospheric temperature trends stemming from observations and climate models. Radiosonde and operational satellite data show general agreement in tropospheric warming and in stratospheric cooling, broadly consistent with climate model trends. But disparities in quantitative trends remain due to structural uncertainties, since neither of the instruments was designed for climate monitoring.

The special climate utility of RO data arises from the fact that RO phase measurements are based on time measurements with precise atomic clocks allowing climate benchmark quality[1] and long-term stability. Atmospheric profiles of bending angle, refractivity, pressure, geopotential height, and temperature are retrieved with high accuracy (< 1 K) and vertical resolution (0.5–1 km) in the UTLS, with global coverage and all-weather capability. Data from different RO missions can be combined without need for inter-calibration and overlap provided a consistent processing scheme is used[2]. Structural uncertainties amongst RO data from different processing centers are low: < 0.03 %/5yrs for global-scale refractivity trends, proportional to < 0.06 K/5yrs for temperature trends[3]. A range of climate applications has been demonstrated[4,5] including observing system simulations for climate monitoring and modelling[6,7,8], and the first detection of trends in RO data only recently[9].

We give an overview on the utility of RO based climatologies as climate change indicators (Section 2) and for trend detection (Section 3), with conclusions and outlook in Section 4.

2 RO BASED CLIMATOLOGIES AND CLIMATE CHANGE INDICATORS

We investigated monthly mean zonal mean RO climatologies within 1995–2008/2009 from GPS/Met (10/1995, 02/1997), CHAMP (09/2001–02/2008), GRACE (10/2007–02/2009), and COSMIC (10/2006–02/2009). We focused on the UTLS within 9–25 km (300–30 hPa), and on 50ºN–50ºS for trend detection. Error characteristics are well defined with a total error < 0.3–0.5 K[5,9] in temperature climatologies. We used WegCenter OPSv5.4 data available via www.wegcenter.at/globclim.

A systematic exploration of climate datasets with an innovative visualization technique, the SimVis software, identified regions and parameters reacting most sensitive to climate change[10]. Subsequent statistical analysis revealed most robust indicators in the tropics. Fall and summer are favorable indicator seasons. Regarding height sensitivity, refractivity is a good indicator in the LS at 18–24 km (~70–30 hPa), pressure near the tropopause at 13–16 km (~150–100 hPa), temperature in the UT at 9–12 km (~300–200 hPa). Temperature also emerges as LS indicator above 20 km, refractivity in the UT around 12 km. Together, the set of RO accessible parameters covers the whole UTLS as useful climate indicators[11].

3 CLIMATE CHANGE DETECTION WITH GPS RADIO OCCULTATION

Standard and multiple linear regression was applied to temperature time series for February (1997 and 2002–2009) and for October (1995 and 2001–2008), taking RO errors into account. In the tropics, we investigated the influence of stratospheric quasi-biennial oscillation (QBO) and tropospheric El Niño-Southern Oscillation (ENSO). We inspected whether the observed trend exceeds inter-annual variability in the study period. We also tested whether the trend exceeds long-term natural variability as estimated from pre-industrial control runs of three representative global climate models of the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). Results are shown in Fig. 1. A significant cooling trend is detected relative to inter- annual variability (90 % significance level) and to natural variability (95 % signif. level) in the tropical LS (100–30 hPa) in February for the period 1997–2009 (Fig. 1a). About 50 % of the inter-annual variability in the LS is explained by an ENSO-related signal while the QBO signal vanishes due to the large averaging area (20°S–20°N zonal mean/LS layer). In the tropical UT (300–200 hPa; Fig. 1b) a strong ENSO signal (Fig. 1c) explains most of the variability in the investigated period

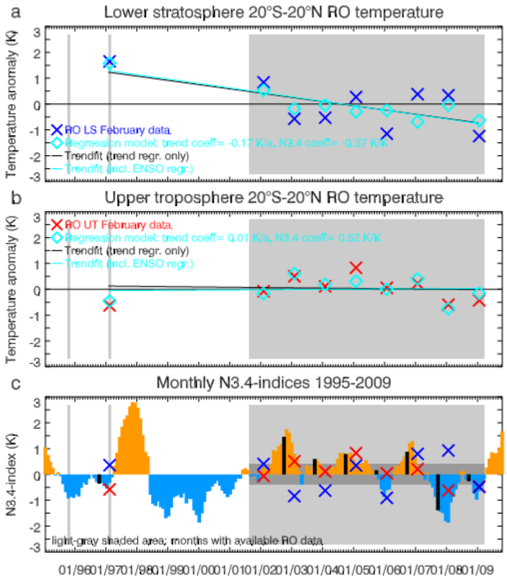

Figure 1: RO temperature anomalies (crosses) and trends (solid) are shown for February 1997–2009 for the tropical LS (a) and UT (b). Periods with RO data availability are gray shaded. Trend regression only in black, regression model values (diamonds). Trends calculated incl. ENSO, represented by monthly Nino3.4 SST with a 4-month lag (c), are in light blue, Nino3.4 exceeds 0.4 K/–0.4 K for El Niño/La Niña (dark gray)

obscuring an emerging warming trend signal. The results are in agreement with trends in radiosonde records, though those trends are not significant due to less stable error characteristics. Climate model simulations basically agree as well but they show less warming/cooling contrast across the tropical tropopause[9].

As a second method an optimal fingerprinting technique was applied to the whole record of RO accessible parameters refractivity, geopotential height, and temperature to detect a forced climate signal.

Pre-industrial control runs of global climate models were employed to estimate natural climate variability. The response pattern to the external forcings was presented by an ensemble mean of the models' A2 and B1 scenario runs.

Optimal fingerprinting shows that a climate change signal can be detected in the RO temperature (90 % significance level) and refractivity record (> 85 % significance level). The results are consistent with detection time estimates[6,7,8].

4 CONCLUSIONS

RO provides an independent climate record of high quality with long-term stability. The set of RO accessible parameters covers the whole UTLS as most useful climate indicators. We found the RO data capable to start detecting significant UTLS climate trends over a period of 10–13 years, consistent with expected detection times. Trend results from the current RO record are basically consistent with model data and with radiosonde records; RO trends are tentatively more pronounced. For future studies closer comparison to climate models and how they represent the thermal structure of the tropical UTLS is of particular interest, e.g., in view of its key role in the water vapor-lapse rate feedback. Overall, the performance of the short RO record to date underpins its capability to serve as a climate benchmark record into the future.

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