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The CHAMPCLIM project: An overview

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Summary. The CHAMP radio occultation (RO) data provide the first opportunity to create real RO based climatologies on a longer term. CHAMPCLIM is a joint project of the Institute for Geophysics, Astrophysics, and Meteorology (IGAM) in Graz and the GeoForschungsZentrum (GFZ) in Potsdam. The overall aim of CHAMPCLIM is to ensure that the CHAMP RO data are exploited in the best possible manner, in particular for climate monitoring. The main objectives of the CHAMPCLIM project can be summarized in form of three areas of study as follows: RO data processing advancements for optimizing climate utility, RO data and algorithms validation based on CHAMP/GPS data, and global RO based climatologies for monitoring climate change. Here we show a summary of the current activities and exemplary results.

Key words: CHAMP, radio occultation, climate monitoring, CHAMPCLIM

1 Introduction

Increasing evidence suggests that the Earth's climate is significantly influenced by human activities (e.g., IPCC 2001). While there is little doubt that the Earth’s surface temperature has risen by about 0.6°C during the 20th century, the amount and even the existence of temperature trends in the troposphere are still under debate (e.g., Christy and Spencer 2003; Vinnikov and Grody 2003). Additional high quality observations of the atmosphere are therefore particularly required in this context. The Global Navigation Satellite System (GNSS) radio occultation (RO) technique has the potential to substantially contribute to this scientific challenge. For a detailed description of the RO technique see, e.g., the reviews of Kursinski et al. 1997 and Steiner et al. 2001.

With respect to climate studies, one of the most important properties of the RO technique is the expected long-term stability of RO data. It is achieved since precise atomic clocks are the basis for accurate measurements during each single occultation event, independent of whether two events are separated by an hour or by decades. Unlike many traditional satellite data like those from passive microwave sounders, radio occultation data are essentially self-calibrated as the measurement principle is basically counting of wave cycles (including fractional ones).

Sensing of the Earth's atmosphere with the RO method was first successfully demonstrated with the GPS Meteorology (GPS/MET) experiment performing measurement campaigns from April 1995 to March 1997. Analysis and validation of GPS/MET data sets confirmed most of the expected strengths of the technique, like high vertical resolution, high accuracy of retrieved parameters, and insensitivity to clouds (Kursinski et al. 1997; Rocken et al. 1997; Steiner et al. 1999).

The climate monitoring capability of a GNSS occultation observing system has not yet been tested due to the lack of long-term measurements. The CHAMP (Challenging Minisatellite Payload) RO data provide the very first opportunity to create real RO based climatologies. Continuous data are available since 2001 and the mission is expected to last until 2007. Wickert et al. (2004a) give an overview of the CHAMP RO experiment, information on the current status can be found in Wickert et al. (2004b).

CHAMPCLIM is a joint project of the IGAM in Graz and the GFZ in Potsdam. The project started in July 2003, its overall aim is to ensure that the CHAMP RO data are exploited as good as possible, with particular focus on climate monitoring. The three main objectives of CHAMPCLIM and some initial results are described in sections 2-4.

2 Radio occultation data processing advancements for optimizing climate utility

The upper stratosphere, where the signal-to-noise ratio of RO data is low and ionospheric effects increasingly influence the signal, is a critical domain for RO based climatologies. The processing advancements part of the study therefore aims at enhancing the RO retrieval algorithms with focus on upper stratospheric retrieval performance (ionospheric correction, statistical optimization). It also deals with better characterization of observation errors, and with the advancement of lower tropospheric retrieval quality.

The inversion of RO data requires some kind of high altitude initialization. So far, an advanced statistical optimization scheme has been developed, which combines observed bending angle profiles with background information derived from the MSISE-90 climatology (Hedin 1991) in a statistically optimal manner (Sokolovskiy and Hunt 1996). The key feature of this scheme is the ability to correct for systematic errors in background information (Gobiet and Kirchengast 2003). Results from a simulation study aiming at validation of the basic IGAM retrieval scheme (without background bias correction) and the advanced IGAM scheme are shown in Figure 1.

The characterization of observation error covariances has been analyzed in simulation studies (Steiner and Kirchengast 2003) and is currently object of studies using measured CHAMP data. The results of these studies aim at advancing the above mentioned statistical optimization and the utility of RO data for use in data assimilation systems.

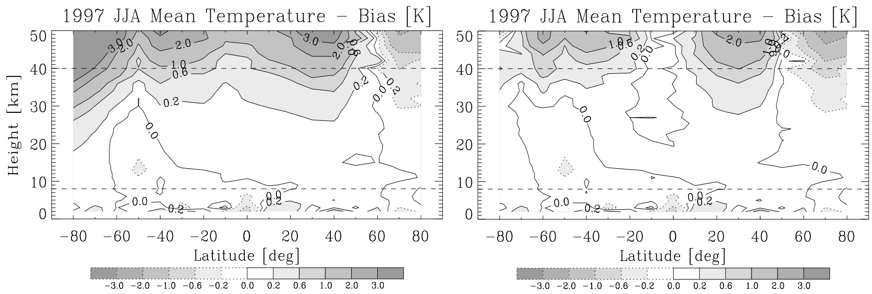


Fig. 1. Bias in seasonal mean dry temperature for a typical (northern) summer season based on an ensemble of ~1,000 simulated RO data. Results from the basic IGAM scheme (left panel) and from the enhanced scheme (right panel).

3 Radio occultation data and algorithms validation based on CHAMP/GPS data

In this part of the study, atmospheric profiles derived from CHAMP RO data are validated against co-located ECMWF analyses. Figure 2 shows results for an ensemble of 1,753 refractivity profiles as an example. Up to 35 km the relative bias (thick line) is smaller than 1 %, the most prominent feature of the bias profile at low latitudes is due to the fact that the sharp tropical tropopause near 17 km altitude is better resolved by radio-occultations than by the ECMF analyses.

Moreover, CHAMP RO data are validated against data derived from the GOMOS and MIPAS instruments onboard ENVISAT. A detailed discussion of first results of these comparisons can be found in Gobiet et al. (2004) in this issue.

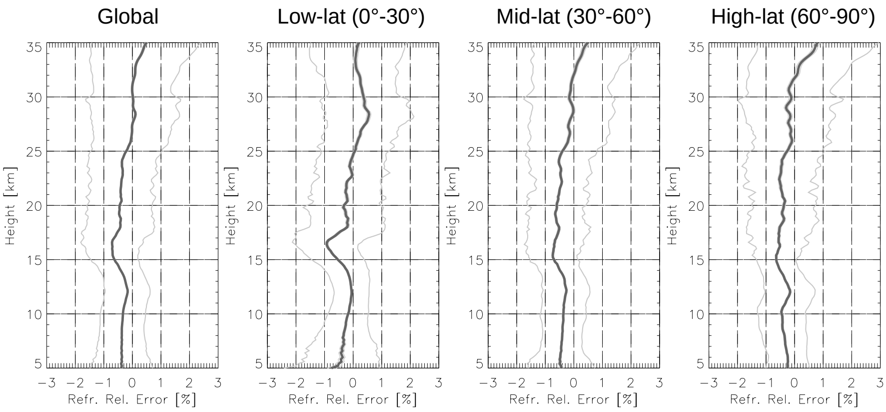


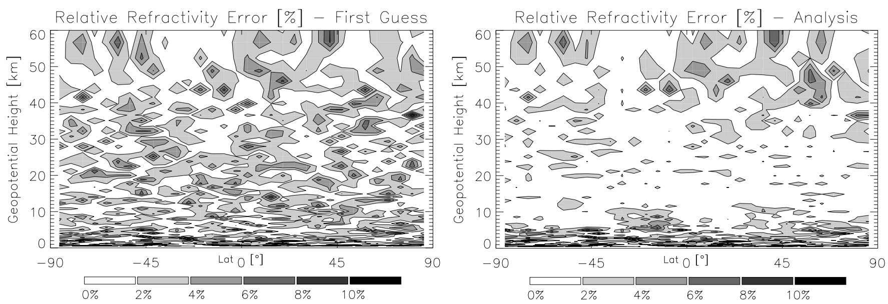
Fig. 2. Statistical comparison for a sample of 1,735 CHAMP refractivity profiles (11 days in 2003). Enhanced IGAM retrieval with MSIS initialization compared to ECMWF analysis profiles. Bias (thick black) and standard deviation (grey). Low-lat: 537 events, mid-lat: 672 events, high-lat: 526 events.

Furthermore, the performance of GFZ Potsdam retrieval algorithms is compared with the performance of the enhanced IGAM algorithm. We examine the retrieval of bending angle, refractivity, pressure, geopotential height, temperature, and humidity profiles, respectively, with particular focus on upper stratosphere and lower- to mid troposphere performance. First results of these comparisons are described in Wickert et al. (2004c) in this issue.

4 Global RO based climatologies

The potential of RO data for climate monitoring has been shown with simulation studies (e.g., Steiner et al. 2001; Foelsche et al. 2003). CHAMP RO data have already been used to derive the height of the tropical tropopause, a potential indicator for climate change, with high accuracy (Schmidt et al. 2004, this issue). Results for the global tropopause can be found in Ratnam et al. (2004) in this issue.

In a first approach, this part of the CHAMPCLIM study aims at direct (model independent) monitoring of the evolution of climatological refractivity, temperature, geopotential height, and humidity fields. Given the somewhat unfavorable



single LEO satellite situation the sampling error has to be considered carefully in this context, as the sampling through occultation events is not dense enough to capture the entire spatio-temporal evolution. Due to the high inclination of the satellite (87.3°), the event density in low latitude regions is particularly small. Comparatively small temperature variations in these bins, however, prevent the sampling error from increasing dramatically. Sampling error studies by Foelsche et al. (2003) suggest that useful temperature climatologies resolving scales > 1000 km can be obtained even with RO data received from a single satellite. In the near future, multi-satellite missions like COSMIC (Lee et al. 2001) and ACE+ (Hoeg and Kirchengast 2002) with ~3,000 and ~4,000 RO profiles per day, respectively, will improve the spatial and temporal sampling significantly. In a second approach we start to perform 3D-variational assimilation of CHAMP RO-derived refractivity data and ECMWF analysis fields into global climate analyses.

Fig. 3. Trial run of the refractivity assimilation system showing the impact of assimilating ~2,000 globally distributed RO profiles into a monthly mean field. Left panel: relative errors of the first guess, right panel: relative errors of the climate analysis.

Figure 3 shows first results of a simulation study to test the assimilation scheme for monthly mean fields (T21L60, ~600 km horizontal resolution at equator). There is an overall improvement of the background field, which is most clearly visible between ~5 km and ~35 km.

The assimilation scheme is tuned for high vertical and moderate horizontal resolution, reflecting the spatial characteristics of RO measurements. The background field (first-guess) was obtained by disturbing the “true” atmospheric mean field with reasonable errors using the error pattern superposition method. Simulated RO measurements have been derived from the “true” atmospheric fields. Realistic errors have been superimposed based on empirical error covariance matrices (Steiner and Kirchengast 2003). About 2,000 globally distributed RO profiles have been assimilated assuming Gaussian error characteristics for the background.

5 Summary, conclusions, and outlook

The continuous and ongoing flow of CHAMP radio RO data is the basis for the first RO based climatologies of atmospheric parameters like refractivity and temperature. CHAMPCLIM is a joint project of the Institute for Geophysics, Astrophysics, and Meteorology (IGAM) in Graz and the GeoForschungsZentrum (GFZ) in Potsdam. The overall aim of CHAMPCLIM is to ensure that the CHAMP RO data are exploited in the best possible manner, in particular for climate monitoring. We described the three main objectives of CHAMPCLIM, namely: RO data processing advancements for optimizing climate utility, RO data and algorithms validation based on CHAMP/GPS data, and global RO based climatologies for monitoring climate change. The project started in July 2003, the first results are already encouraging. We are confident to build reliable RO based climatologies, even with RO data from a single receiving satellite. Results of this study will certainly be valuable for multi-satellite RO missions in the near future.

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