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GPS radio occultation with CHAMP: Comparison of atmospheric profiles from GFZ Potsdam and IGAM Graz

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Summary. A major application of the CHAMP occultation data is the preparation of processing systems for future occultation missions. The University of Graz (IGAM) uses data and analysis results to prepare for the ACE+ multi-satellite occultation mission, which is currently foreseen to be launched in 2008. We compare vertical profiles of refractivity, derived by GFZ and IGAM, with ECMWF data (European Centre for Medium-Range Weather Forecasts) and discuss the deviations. Good agreement is observed in the upper troposphere and stratosphere. The magnitude of the observed refractivity bias in the lower troposphere depends significantly on the quality control criterion. The bias can be nearly eliminated by the application of the Full Spectrum Inversion analysis method down to ∼1 km above the Earth's surface.

Key words: CHAMP, GPS, radio occultation, remote sensing, GFZ Potsdam, IGAM Graz

1 Introduction

Significant progress for the innovative GPS (Global Positioning System) occultation technique was achieved within the atmospheric profiling experiment onboard the German CHAMP (CHAllenging Minisatellite Payload) satellite [1, 2]. Results of the operational data analysis at GFZ are provided via the CHAMP data center (*http://isdc.gfz-potsdam.de/champ*) and are used by scientist all over the world to improve global weather analyzes, to demonstrate the ability to detect climatic trends and also to develop and improve their occultation analysis systems, e.g., to prepare for the upcoming GPS occultation missions [3]. Comparison studies help to improve the data analysis and to optimize the exploitation of the CHAMP data. One example for such activity is ROSE (Radio Occultation Sensor Evaluation), jointly initiated by GFZ, JPL and UCAR [4, 5].

IGAM Graz uses CHAMP data within the CHAMPCLIM project [6] and to prepare for the ACE+ multi-satellite occultation mission. ACE+ was selected by ESA (European Space Agency) in May 2002 as top priority future

EEOM (Earth Explorer Opportunity Mission) and is currently in phase A until mid 2004. After confirmation the operational phase is foreseen to start in 2008 [7, 8]. ACE+ will provide more than 5,000 occultations daily.

We present first results of a comparison study for GFZ and IGAM inversion results. Both centers use the operationally derived atmospheric excess phase data from GFZ.

2 Data analysis and quality control

The CHAMP data are continuously processed by the operational occultation analysis system at GFZ, detailed descriptions can be found in [1, 9]. The standard products (current ATM version 004) are analyzed using the geometrical optics (GO) approach. Profiles are excluded, if at least one data point above 8 km shows deviations of >10 % in relation to ECMWF. The profiles are cut off in the lower troposphere, if the difference to the analyzes begins to exceed 10 % below 8 km.

The inversion software (geometrical optics) of IGAM is described by [10, 11, 12]. IGAM uses analyzes for quality control as well, refractivity profiles deviating from ECMWF more than 10 % between 5 and 35 km are sorted out entirely. Additionally, the profiles are cut off in the lower troposphere when severe impact parameter/bending angle ambiguities occur, one indication for the occurrence of multipath effects, which make the geometrical optics assumption invalid.

A 7-day period (January 1-7, 2003) was selected for the comparison. The standard analysis results from GFZ form the data set GFZ GO (1,253 profiles). The IGAM set is named as IGAM GO (1,200 profiles). In addition, results of advanced (wave optics based) data analysis were provided by GFZ. The Full Spectrum Inversion technique (FSI, [13]) was used for the processing (GFZ FSI, 1,234 profiles). An internal cut-off criterion without using external data was applied. The profiles were cut-off, when the smoothed FSI amplitude falls below half of its maximum value. A resulting set of 1,147 coincidencing profiles (IN ALL) was used for the comparisons.

3 Results

Whereas the CHAMP results in the upper troposphere and stratosphere exhibit excellent accuracy (e.g. [1]), the lower troposphere data suffer from a negative refractivity bias in relation to independent meteorological data [14]. Therefore we consider these altitude intervals separately. We focus on comparisons of refractivity profiles with interpolated data from 6-hourly operational meteorological analyzes from ECMWF.

3.1 Upper troposphere and stratosphere

The comparison of the GFZ and IGAM refractivity data with ECMWF is shown in Fig. 1. In general both data sets show good agreement. The GFZ profiles exhibit slightly negative bias of <0.5 K, similar bias is observed in the IGAM retrieval. The standard deviation is ∼0.7 % at 10 km for both, GFZ and IGAM, beginning at 15 km to be slightly larger for the IGAM retrievals and becoming ∼1.2 % for GFZ and ∼1.5 % for IGAM at 30 km. The inversion results are comparable in this height interval, despite of the fact, that different methods for the optimization of the bending angles using the MSISE-90 [15] climatology are applied. GFZ uses the approach by [16], assuming 20 % error of MSIS and no vertical error correlations. IGAM applies statistical optimization [17] with 15 % MSIS error and vertical error correlation length of 1 km for the observations and 6 km for the background.

The comparison of temperatures (not shown here) shows significantly different results for both analysis centers. Whereas the GFZ temperatures agree well with the analyzes (bias <0.5 K, STD ∼1 K at 10 km, ∼2 K at 35 km), the IGAM retrievals begin to exhibit significant warm bias above 15 km, reaching ∼5 K at 35 km with standard deviation of ∼10 K. We relate these differences to the initialization of the temperature for the integration of the hydrostatic equation. GFZ uses ECMWF data at 43 km. IGAM integrates up to 120 km, where the air pressure is assumed to be zero.

Our results indicate that the CHAMP refractivity seems to be more appropriate than temperature to build up climatologies for stratospheric altitudes, because it depends less on additional assumptions or external data, as also was concluded by [18].

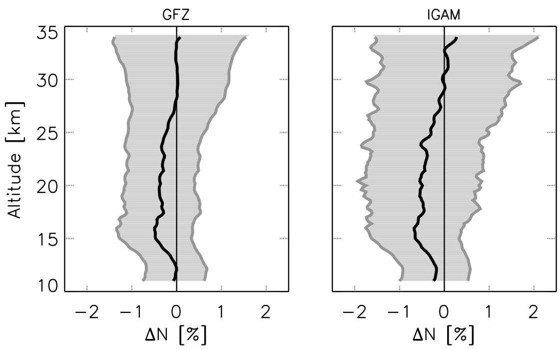

Fig. 1. Statistical comparison of 1,147 vertical CHAMP refractivity profiles (GO) from GFZ (left) and IGAM (right) with corresponding ECMWF data (between January 1 and 7, 2003).

3.2 Lower troposphere

The lower troposphere comparison of the refractivity is shown in Fig. 2. The various cut-off criteria (see Sec. 2) result in different distributions of data points per height for each data set, e.g. the total number reduces to 50 % at different altitudes: 5.0 km (IGAM GO), 4.3 km (GFZ FSI) and 3.2 km (GFZ GO), respectively. The GFZ GO set shows a negative bias of 1 % at 2 km and $\sim$1.5 % at 1 km, the standard deviation is $\sim$2 and $\sim$2.5 % respectively. IGAM GO shows reduced bias and standard deviation characteristics, which we relate to the more rigorous cut-off criterion (see Sec. 2). This obviously removes more data, which are suspect to be influenced by multi-path effects, but also nearly halve the data points in the lower troposphere. The lowest bias exhibits the GFZ FSI data set. Almost bias-free behavior can be observed down to $\sim$1 km, with a standard deviation up to $\sim$1 %. Below, a negative bias up to $\sim$1 % appears. The slightly negative bias of $\sim$0.3 % disappears, which is observed already at 10 km in the GFZ GO and nearly constant down from 10 km almost to the Earth's surface. This is achieved even with having more data available as the IGAM GO set.

In a next step we perform the comparison only at altitudes, where data points from all 3 sets exist. The result (Fig. 3) is completely different from that shown in Fig. 2 and underlines the importance of the cut-off criterion for the lower troposphere data quality and validation. The deviations to ECMWF are nearly identical for all 3 data sets. Almost no bias occurs from 10 km down to 1 km, the standard deviation is nearly constant at $\sim$1 %. Most noticeable is the slightly negative bias ($\sim$0.3) in the IGAM GO and GFZ GO retrievals, which is eliminated in the GFZ FSI profiles.

4 Conclusions

First results of a study comparing CHAMP occultation analysis results from GFZ and IGAM are presented. The refractivity comparison shows good agree-

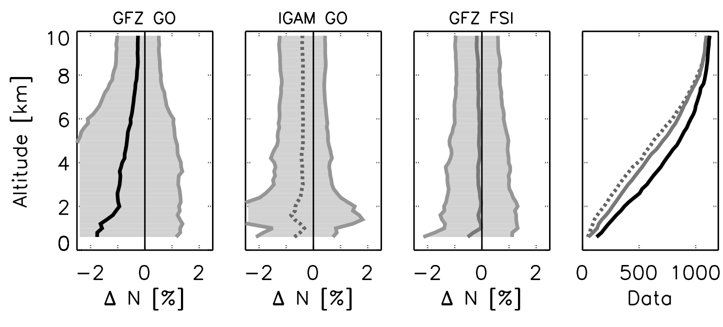

Fig. 2. Statistical comparison of 1,147 vertical CHAMP refractivity profiles (data sets: GFZ GO, IGAM GO and GFZ FSI) with corresponding ECMWF data.

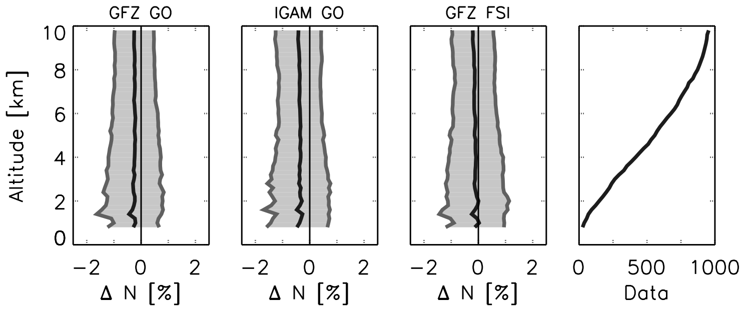

Fig. 3. Statistical comparison of the data sets: GFZ GO, IGAM GO and GFZ FSI with ECMWF (only altitudes were compared, where data from all 3 sets were available).

ment with ECMWF and almost identical results for the upper troposphere and stratosphere, even though different methods for the bending angle optimization were used. The temperature is sensitive to the initialization of the hydrostatic equation, differences in the derived temperatures are already observed at altitudes above 15 km. To carefully compare the data in the lower troposphere, the cut off and quality check criteria and the resulting data points vs. height have to be included to the comparison. The simple IGAM cut off criteria successfully removes problematic data in the lower troposphere, but reduces the data significantly compared to the GFZ GO retrievals. The application of the FSI method is very promising a) for the implementation to operational data analysis systems b) to significantly reduce the negative refractivity bias and c) to provide a cut-off criterion, which can be derived from the data analysis (magnitude of the FSI amplitude) and not from comparison with external meteorological data.

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