THE POTENTIAL OF GRAS TO CONTRIBUTE TO CLIMATE MONITORING

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ABSTRACT

We analyzed Radio Occultation (RO) data from the GRAS instrument (GNSS Receiver for Atmospheric Sounding) onboard Metop-A and compared them with RO data from CHAMP (CHAllenging Minisatellite Payload for geoscientific research) and Formosat-3/ COSMIC (Formosa Satellite Mission 3/Constellation Observing System for Meteorology, Ionosphere, and Climate; hereafter COSMIC). Our results confirm the high quality of GRAS data and its potential to significantly contribute to climate monitoring.

1. INTRODUCTION

Global Navigation Satellite System (GNSS) Radio Occultation (RO) data can be used to compute climatologies of the upper troposphere and lower stratosphere (UTLS), which are characterized by high accuracy and long-term stability [1, 2]. Accurate phase (change) measurements of GNSS signals are the basis for the retrieval of near vertical profiles of bending angle, radio refractivity, density, pressure, and temperature [2]. RO data are platform-independent to a high degree, and data from different satellites can be combined to a climate record, if the same retrieval is used [3]. RO data from CHAMP [4], with (almost) continuous measurements from September 2001 until September 2008, enabled the creation of first RO-based climatologies of the UTLS [5]. COSMIC is a constellation of six satellites in six orbit planes, which delivers climate-quality RO data since August 2006 [6]. GRAS is the first operational RO mission, yielding up to 650 RO profiles per day [7]. RO data from the three consecutively launched Metop satellites will be crucial for the setup of a long-term climatology of the UTLS since they will provide measurements with essentially the same instruments over a period of about 15 years.

2. DATA and METHODS

At the Wegener Center we developed a retrieval scheme, which aims at minimizing potential biases of atmospheric parameters for climate applications. Background information, which is needed for high altitude initialization in the step from bending angle to refractivity, is introduced in a transparent way [8, 9, 10]. The profile retrieval, termed "Occultation Processing System" (OPS; current version: 5.4), starts from phase delay data for each occultation event, including precise position and velocity information for the transmitting and receiving satellites. The most important change to the previous processing version [10] is that we use now short-term forecasts (instead of analyses) from the European Centre for Medium-Range Weather Forecasts (ECMWF) for high-altitude initialization.

We assessed the quality of the different RO receivers on three missions (Metop, COSMIC, and CHAMP), based on bending angle data at high altitudes, which have been computed with the same retrieval (OPSv5.4). Thereby we followed the approach by Pirscher et al. [10]. As input we used GRAS PPF (Product Processing Facility) phase delay data in the version PPFv2.12. While PPFv2.12 bending angle data are already operational, the quality of broadcasted PPFv2.12 phase delay and orbit data (which are needed for our retrieval) is still insufficient. Therefore we used a set of GRAS profiles for a test day (Sep 30, 2007), which has been processed in offline-mode (A. v. Engeln, EUMETSAT, pers. comm.). COSMIC and CHAMP data have been downloaded from CDAAC (COSMIC Data Analysis and Archive Center, UCAR, Boulder, CO, USA). Due to the comparatively small number of daily CHAMP profiles, we also used CHAMP profiles from the two adjacent days (Sep 29 and Oct 1) in order to get a representative ensemble with more than 400 profiles.

We computed the observational error based on bending angle statistics in the Mesosphere, at impact heights between 65 km and 80 km (the impact height is the impact parameter minus the local radius of curvature). Here, the contribution from the neutral atmosphere is small and measurement noise and ionospheric residuals dominate. Using data from the same day(s) we can expect that the residual ionospheric noise is very similar for the different satellites and that differences in measurement noise are dominated by the different qualities of the RO receivers under consideration. Systematic differences have been computed with respect to the MSISE-90 climatology [11].

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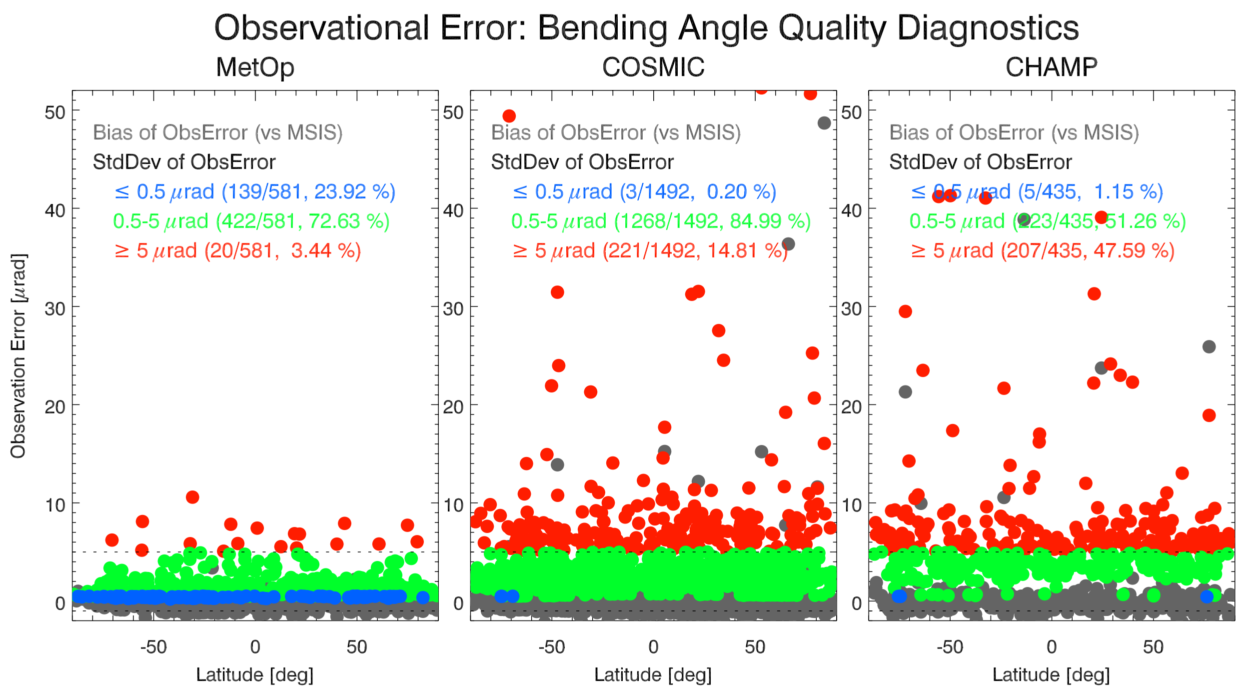

Figure 1. Bending Angle statistics for RO data from Metop-GRAS, COSMIC and CHAMP in the impact height rang 65 km – 80 km: Bias with respect to MSISE-90 climatology (grey) and standard deviation (different colors).

3. RESULTS and DISCUSSION

Figure 1 shows the bending angle statistics as function of geographic latitude. The percentage of profiles with comparatively large standard deviations > 5 µrad (red) is clearly largest for CHAMP and smallest for Metop-GRAS. Profiles with very small noise values ≤ 0.5 µrad (blue) are almost entirely restricted to the GRAS ensemble. Further details are revealed in Fig. 2, when looking into the bending angle range < 5 µrad. For climate applications it is very important that the bias (compared to the MSIS climatology) is close to zero and very similar for all satellites (–0.10 µrad, –0.13 µrad, and –0.16 µrad for GRAS, COSMIC, and CHAMP, respectively).

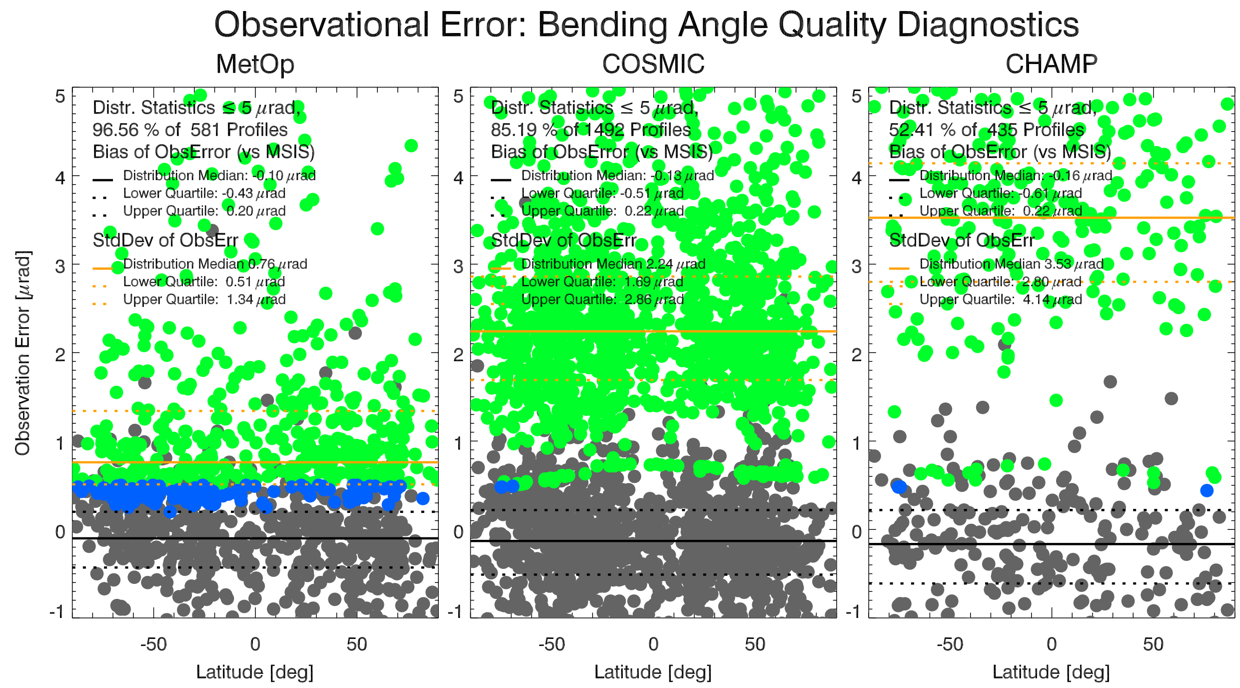

Figure 2. Bending Angle statistics for RO data, same as Fig. 1 but zoom into the ≤5 µrad range.

The median of the standard deviations shows a clear increase from GRAS (0.76 µrad) via COSMIC (2.24 µrad) to CHAMP (3.53 µrad).
Since the test day (Sep 30, 2007) represents low solar activity with a small ionospheric noise level, the standard deviations in Fig. 1 and Fig. 2 primarily reflect the quality of the different receivers. A small contribution, which has yet to be quantified, stems from the fact that the correction for potential clock errors is performed differently for CHAMP, COSMIC, and GRAS [12]. While an ultra-stable oscillator onboard Metop allows for "zero-differencing" of GRAS data (no correction), data from COSMIC and CHAMP are processed with "single-differencing", using signals from a reference GPS satellite. This additional satellite link introduces additional ionospheric noise.
The retrieval step from bending angles to refractivities requires background information. Within the OPSv5.4 retrieval we perform statistical optimization at altitudes above 30 km: The retrieved bending angle profiles and ECMWF forecast data as background information are combined using an inverse covariance weighting approach. As a measure of the relative importance of background and observation (after the statistical optimization), profiles of the square root of the ratio of the diagonal elements of the retrieval error and background error covariance matrices are analyzed, where the retrieval-to-background error ratio (RAER) can be regarded as the fraction of the retrieval error stemming from the background [9]. RAER, given in percent, allows to define background dominated (RAER > 50 %) and observation dominated (RAER <50 %) altitude ranges.
The transition height (zRAER50) between these two regimes (the altitude where RAER equals 50 %) is shown in Fig. 3 as function of latitude. The color of the dots corresponds to the estimated observational error standard deviations in Fig. 1 and Fig. 2. Small observation errors lead to large zRAER50 values, since the observations are inversely weighted with the measurement error, when performing statistical optimization. zRAER50 values for GRAS are therefore considerably higher than for COSMIC and CHAMP. Profiles with very small observation errors ≤ 0.5 µrad (blue) have transition heights of about 70 km, but in case of large observation errors (red) zRAER50 can be as low as 30 km. The majority of the GRAS profiles are essentially background-independent below 40 km, for CHAMP this is only the case below about 30 km.
This illustrates another important point for climate applications. If the background (used for statistical optimization) is biased, this bias will translate into a bias in the retrieved profile, depending on the weighting of observations and background. A smaller observation error leads to a larger value of the transition height and therefore to a larger altitude range, in which RO data can be safely used for climate applications.

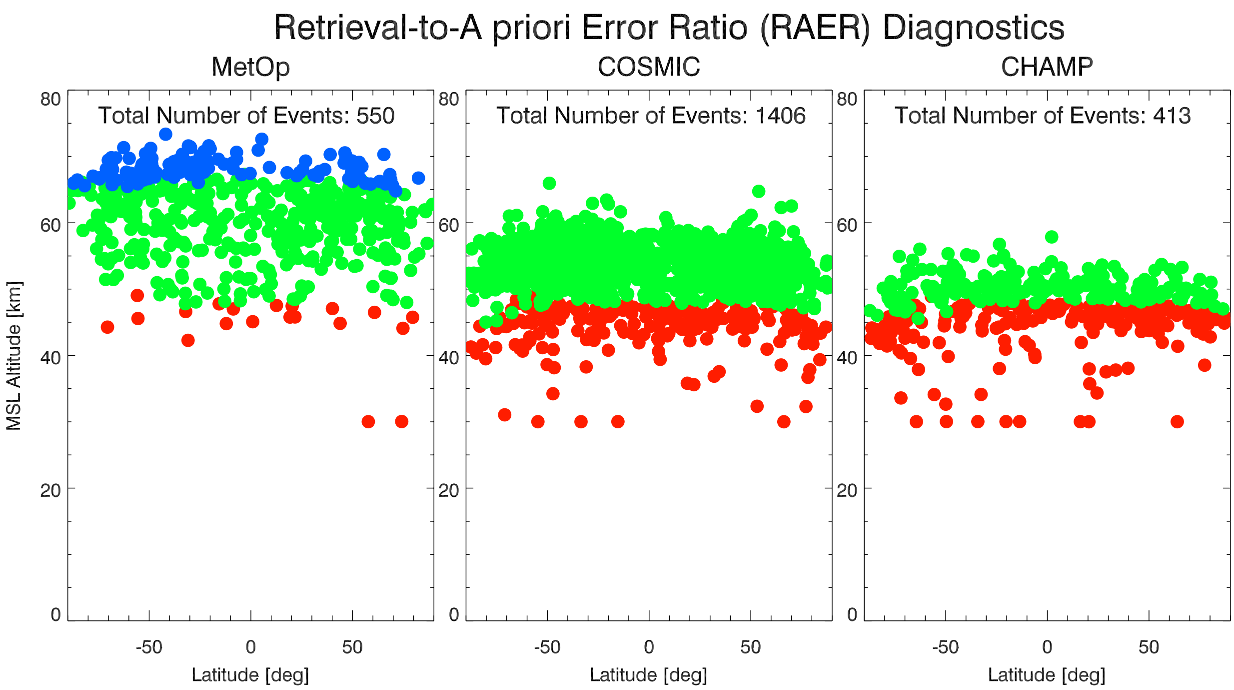

Figure 3. Transition heights between observation dominated and background dominated regimes (zRAER50) for RO profiles from Metop-GRAS, COSMIC, and CHAMP.

4. CONCLUSIONS

Our results show an overall high quality of Metop-GRAS RO data. Based on one day of validation data (Sep 30, 2007) we can estimate the bending angle errors (standard deviations) of GRAS data (computed in the impact height range 65 km to 80 km) to be about a factor 1.7 (2.7) smaller than those of COSMIC (CHAMP) data, which are already of high quality. As a consequence, the height range where GRAS RO profiles are observation-dominated, extends considerably higher than for COSMIC or CHAMP. These results, if confirmed over a longer validation period, underpin the expected potential of Metop GRAS data for climate monitoring [7]. Our experience with RO climatologies [5, 3] shows that the influence of the (potentially biased) background begins to show up at altitudes of about 30 km, when CHAMP data are used. Using GRAS data the range of high quality climatologies can presumably be extend by about 10 km upwards to ~40 km. Given the projected large temperature changes at these altitudes and the expected long-term record of Metop data (~15 years) we can be confident that Metop-GRAS data will contribute substantially to climate monitoring, especially in the stratosphere where the superior data quality of Metop-GRAS compared to other RO missions will become important.

5. ACKNOWLEDGEMENTS

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