Processing of CHAMP Radio Occultation Data Using GRAS SAF Software

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Summary. EUMETSATs operational GRAS SAF System will receive Level 0, Level 1a (phases and amplitudes) and Level 1b data (bending angles, impact parameters, and some auxiliary data) from the EPS Core Ground Segment (CGS), process the data into Level 2 products, and distribute these to NWP and climate research users. The products are vertical profiles of refractivity, temperature, pressure, and humidity. They come in two types: Near-Real Time (NRT) products, disseminated less than 3 hours after sounding, and Offline products, disseminated/available less than 30 days after sounding. All products will be archived at the GRAS SAF Archive at DMI. Archived products will be available through EUMETSATs Unified Meteorological Archive and Retrieval Facility (UMARF). We give an overview of the system, processing algorithms, data flows, products, dissemination systems, and archive.
The GRAS SAF software consists of routines to derive excess phase data from the raw data (used in the offline processing), to process the excess phase data to bending angles (used in offline processing), inversion routines to obtain the refractivity (used in both NRT and offline processing), standard routines to derive dry pressure and temperature (NRT and offline), and the 1dvar routine for deriving temperature and humidity (NRT). Offline temperature and humidity are derived using the standard iterative method. The GRAS SAF data products and processing system is discussed together with a preliminary product validation based on statistical analysis of retrieved temperature and humidity using radio occultation data from the German CHAMP (CHAllenging Minisatellite Payload) satellite.

Key words: GPS, radio occultation, CHAMP

1 Introduction

The main objective of the GRAS SAF is to develop and deliver products and software on the usage of radio occultation measurements obtained by the GRAS (GNSS Receiver for Atmospheric Sounding) instrument on the Metop satellites. The products are delivered in both NRT in benefit of improved weather forecasts and as Offline products with enhanced accuracy to National Meteorological Services in all EUMETSAT member states. The software products are developed and delivered to NWP centres to assist the data assimilation of this new type of meteorological products.

The GRAS SAF started in 1999 with participation from the Danish Meteorological Institute (DMI), the IEEC (Spain), and Met Office (UK). The host institute is the DMI and this will also be the physical location of the operational GRAS SAF data facility. The GRAS SAF will receive raw and pre-processed GPS radio occultation data from the GRAS instrument onboard the Metop satellites and process these into meteorological products.

The meteorological products delivered by the GRAS SAF consist of profiles of temperature, pressure, and specific humidity, with a high vertical resolution and with an exceptional global coverage not matched by present systems based on radiosonde observations. In combination with the meteorological products the GRAS SAF will deliver software modules to support data assimilation of GPS occultations using the 4DVAR techniques at NWP centres. The role of the GRAS SAF is to facilitate the input data from the GRAS instrument to NWP centres and climate change communities in order to increase the usage of radio occultation measurements in a more effective manner than possible today.

2 Data products and processing system

The GRAS SAF data products will all be derived from the measurements of the GRAS receiver onboard Metop. The first steps of the radio occultation data processing will take place at the EUMETSAT Core Ground Segment (CGS) at the EUMETSAT headquarters in Darmstadt, Germany. This includes data collection from Metop as well as ground based measurements in real time of the GPS satellites for precise orbit determination and clock differencing. The near real time processing (within 2 hrs and 15 min) up to and including bending angles as function of impact parameter is the responsibility of the CGS. The GRAS SAF is responsible for the near real time processing (3 hrs) and dissemination of atmosphere products, including: refractivity, temperature and humidity as function of height [1], with accuracies as specified by the GRAS SAF user requirements [2]. The details of the processing system are described in the architectural design [3]. The GRAS SAF also includes continuously reprocessing (offline) of all data products and bending angles when improved orbit and reference data is available. In addition the GRAS SAF develops software deliverables for NWP centres to facilitate the direct data assimilation of both bending angles and refractivity. The list of GRAS SAF products is shown in Table 1.

GRAS SAF Products List	Description of product
NRT Data products	
Refractivity profile	The refractive index of the atmosphere in units of $(n-1)10^6$
Temperature profile	Temperature as function of height at tangent point
Pressure profile	Pressure as function of height at tangent point
Specific humidity profile	Specific humidity as function of height at tangent point
Surface pressure	Pressure estimate at surface level
Error covariance matrix	Error covariance matrix as average for all profiles
Offline Data Products	
Bending angle profile	Bending angle as function of impact parameter
Refractivity profile	The refractive index of the atmosphere in units of $(n-1)10^6$
Temperature profile	Temperature as function of height at tangent point
Pressure profile	Pressure as function of height at tangent point
Specific humidity profile	Specific humidity as function of height at tangent point
Error covariance matrix	Error covariance matrix as average for all profiles
Global map of temperature	Global map based on monthly averages of temperature profiles
Global map of specific humidity	Global map based on monthly averages of humidity profiles
Global map of geopotential height	Global map of monthly averages of geopotential height profiles
Software Deliverable Products	
1D-var pre-retrieval software (pre-existing)	Software module used to generate NRT temperature, pressure and humidity products from refractivity and a user's background profile
3/4D-var assimilation software	Forward operators and their adjoints to allow for 3/4DVAR data assimilation of GRAS SAF and level 1b products into existing NWP models
Pre-processing tools	Pre-processing tools to assist the data assimilation of GRAS SAF and level 1b products

Table 1. GRAS SAF data and software products.

3. Validation results using CHAMP data

CHAMP data from the first 8 weeks of 2003 starting 1 January and continuously until 25 February 2003 (56 days) has been selected for this first validation analysis. Note that we do not include data below the height corresponding to the time when the fly-wheeling flag is set for the first time.

The atmosphere parameters such as temperature and humidity are obtained by means of the 1dvar algorithm [4], [5]. We use a background matrix used also for operational processing of ATOVS data, from the Met Office, with 43 pressure levels (up to 0.1 hPa) and 26 humidity levels (up to 100 hPa). The measurement

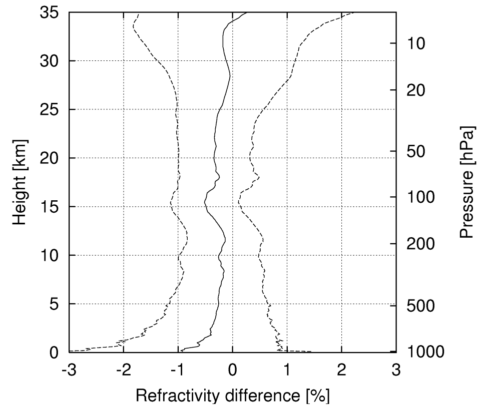

Fig. 1. The relative difference between the observed refractivity and the analysis data from ECMWF. The solid line shows the mean difference and the dashed lines indicate +/- one standard deviation away from the mean.

error-covariance matrix is defined as follows: the standard deviation is 2% at the surface, falling linearly to the constant value 0.2% from 12 km and up. In addition, the minimum (absolute) error is fixed at 0.02 N-units. This corresponds to an increase in the relative error above 25 km, reaching approx 2% at 40 km. The correlations are assumed to fall off exponentially with a correlation length of 3.0 km. These error magnitudes are based on results from simulation experiments [6], [7] combined with analysis of CHAMP data.

We have found that using an acceptance ratio of 4.5 for the 1dvar solution yields acceptable results and we obtain that about 90% of the profiles are accepted by the 1dvar algorithm. The background field is obtained from the ECMWF (European Center for Medium-range Weather Forecasts). The field resolution is 1° with values for temperature and humidity given at 60 pressure levels (determined by the surface pressure). The ECMWF analysis field is interpolated to the actual location of the occultation.

Refractivity is the input to the 1dvar algorithm. The observed refractivity, derived from bending angles using the Abel transform, is compared against the ECMWF values in Fig. 1. The mean difference is approx. 0.5% and standard deviations are less the 1% between 8-25 km, and approximately 2% both close to the surface and at 35 km. These results are in accordance with the CHAMP validation results by other groups [8], [9]. The small negative bias in refractivity seen close to 15 km could by caused by e.g. coarse resolution in the ECMWF model (also observed by [8] for an even lager sample of CHAMP occultations), but it requires more analysis and validation of other periods to investigate possible seasonal effects.

In order to measure the quality of the 1dvar solution we construct the difference of the 1dvar solution and the ECMWF background field at the given location. In

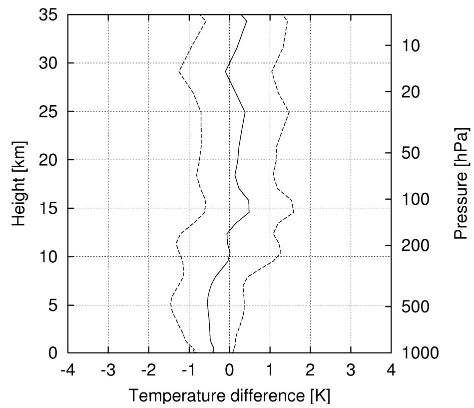

Fig. 2. Temperature difference between the derived 1dvar temperature and the ECMWF. The solid line shows the mean difference and the dashed lines indicate +/- one standard deviation away from the mean.

Fig. 2 we show the difference for the 1dvar temperature profile. The mean difference is less then 0.5 K and the standard deviation is approx. 1 K between the surface and 35 km. As the 1dvar solution and the background are not independent, the interpretation of the statistics in Fig. 2 is not straightforward, and hence the apparent deviations cannot directly be used as error estimates. The deviations become smaller close to the surface, as the measurements decrease in number near the surface, which gives more weight to the model in the solution.

The fact that we obtain temperature profiles which still include deviations in the order of 1K suggest that we have found a suitable balance between the background errors and the measurement errors used in the 1dvar algorithm.

4. Conclusions

We have presented a brief overview of the GRAS SAF data products which will be produced on the basis of the future GRAS radio occultation mission onboard the Metop satellites. Refractivity and temperature profiles derived using CHAMP data are compared against analysis data from ECMWF. The refractivity difference shows high accuracy of 0.5% to 1% in the range between 8-25 km, with deviations of 2% or more close to the surface or at 35 km. This is an upper limit on the accuracy on the retrieval and consistent with the assumed errors in the 1dvar algorithm. The 1dvar temperature compared against ECMWF shows consistent deviations of less than 1K, however this cannot directly be interpreted as an accuracy estimate. A comparison against a completely independent measurement is difficult to achieve, as e.g. the radiosonde measurements that are suited for direct comparison already has been used as one of the inputs to the ECMWF model. Future GRAS SAF validation studies will be carried out using the CHAMP radio occultation measurements, and will study effects such as seasonal variation, residual ionosphere contributions, and skew profiles using high vertical resolution ECMWF data.

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