NWP model specific humidities compared with CHAMP/GPS and TERRA/MODIS data

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Summary. Limb sounding observations of the Earth's atmosphere by the GPS receiver onboard CHAMP allow to determine vertically resolved profiles of the specific humidity. The specific humidity shows a high variability and is a critical parameter for short term numerical weather prediction (NWP). Specific humidity profiles calculated with the hydrostatic NWP model HRM (High resolution Regional Model) of the Deutscher Wetterdienst over the BALTEX (Baltic Sea Experiment) modelling area are compared with profiles from CHAMP/GPS radio occultation data (14th of May to 10th of June 2001) and from the MODIS detector onboard the TERRA spacecraft (dataset from 1st of December 2001, 1100 UTC). Radiosonde data from the station Lindenberg/Germany (1st of May to 10th of June 2001) and ECMWF data (14th of May to 10th of June 2001) are used to evaluate the results. The HRM model used as boundary conditions 6-hourly analyses of the European Centre for Medium-Range Weather Forecast (ECMWF). Consecutive 30 h forecast starting each day at 0 UTC were performed. The mean difference between the HRM and the radiosonde data or the ECMWF data is below 0.4 g/kg while the biases between HRM and CHAMP/GPS are up to 1.7 g/kg and the biases between HRM and TERRA/MODIS are around 0.5 g/kg. The standard deviations of the specific humidity differences between HRM and CHAMP/GPS, TERRA/MODIS, ECMWF or the radiosonde data from the station Lindenberg/Germany are about 1 to 2 g/kg in the lower troposphere (below about 4 km) and decrease with increasing height.

Key words: HRM model, BALTEX, CHAMP/GPS, TERRA/MODIS, radiosonde data, ECWMF data

1 Introduction

With different networks of groundbased receivers it was shown that the US Global Positioning System (GPS) is an accurate technique to determine the vertically integrated water vapor (IWV) within the atmosphere [1],[2],[3],[4]. Comparisons with the hydrostatic **H**igh resolution **R**egional weather forecast **M**odel **HRM** of the Deutscher Wetterdienst have *e.g.* shown a mean bias of 0.08 kg/m^2 and standard deviations of IWV differences of HRM and GPS of about 2.5 kg/m^2 over Germany. Similar results were found for mean IWV differences between the HRM model and data of the Advanced Microwave Sounding Unit A (AMSU-A), [4].
Between 1995 and 1998 GPS/MET onboard the MicroLab 1 successfully demonstrated the radio occultation technique to probe the Earth's atmosphere through its refraction effects on the signals transmitted by the GPS satellites [5]. Thus also specific humidity profiles could be obtained.

Here specific humidities derived from HRM and compared with CHAMP/GPS and TERRA/MODIS data are presented. Radiosonde and ECMWF data are used to evaluate the results. The objective is to investigate whether specific humidity profiles from CHAMP/GPS and/or from TERRA/MODIS data can be assimilated into NWP models.

2 Comparison of HRM with ECMWF and radiosonde data

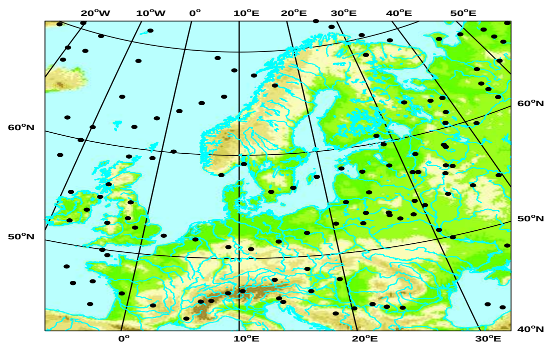

Fig. 1. BALTEX modelling area with 123 CHAMP radio occultations between 14th of May and 10th of June 2001.

The hydrostatic weather forecast model HRM used as boundary conditions 6-hourly analyses of the ECMWF (European Centre for Medium range Weather Forecast) and was initialised by interpolation of the 0 h analysis data. It calculates the water vapor with a horizontal resolution of 0.125° (about 14 km) in 30 vertical layers on a rotated latitude/longitude grid. The time step was chosen to 90 s. Consecutive 30 h forecasts starting each day at 0 UTC including a 6 h spin-up time of the model were performed. The BALTEX (Baltic Sea Experiment, [6]) modelling area shown in Figure 1 is used. Figure 2 (left) shows mean specific humidity differences and their standard deviations of HRM and the ECMWF data between 14th of May and 10th of June 2001. 123 profiles of HRM and ECMWF colocated with the CHAMP/GPS data and interpolated to the GPS levels and times were used. The standard deviations are below 1 g/kg. The HRM model shows slightly (around 0.1 g/kg) smaller specific humidities for most of the heights below about 3 km and slightly larger specific humidities above 3 km. Similar results were obtained by comparing the HRM model results with 145 radiosonde ascents from Lindenberg/Germany between the 1st of May and the 6th of June 2000 (Figure 2, right). The standard deviations are below 1.5 g/kg. The mean absolute differences are below 0.4 g/kg.

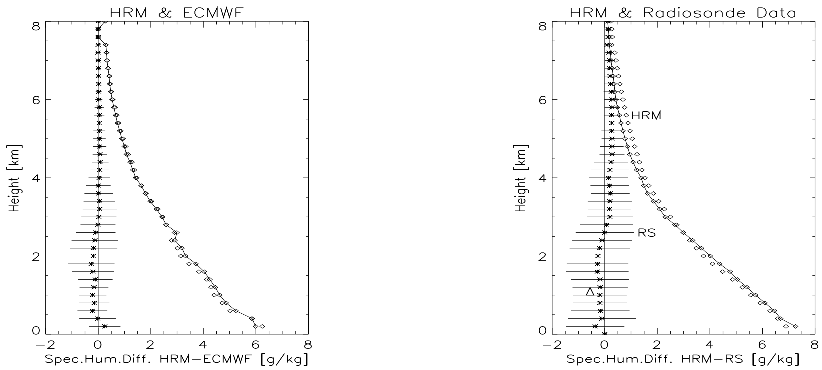

Fig. 2. Left: Mean specific humidity differences between HRM (diamonds) and ECMWF data (diamonds with line) and their standard deviations. **Right:** Mean differences and standard deviations of the specific humidities derived from the HRM model (diamonds) and from 145 radiosonde profiles in Lindenberg/Germany (diamonds with line) between the 1st of May 2000 and the 6th of June 2000.

3 Comparison of HRM with CHAMP/GPS

To derive the specific humidity from CHAMP refractivity (N) data tropospheric temperature information from ECMWF data on 11 standard pressure levels between the surface and 100 hPa is used. To account for the limited vertical resolution of the temperature data the refractivity profiles have been smoothed in the vertical by applying a 1 km boxcar filter of log(N) prior to the derivation of humidity.
Figure 3 (left) shows the mean specific humidities as derived from CHAMP/ GPS and calculated with the HRM model at the points shown in Figure 1. The specific humidity differences from the HRM and CHAMP/ GPS are also represented together with their standard deviations. CHAMP/GPS shows lower specific humidities up to about 1.7 g/kg. The difference increases with decreasing height, maybe due to multipath effects within the lower troposphere [7]. However, recent studies show [8] that the bias problem of the CHAMP refractivities does not seem to be caused solely by multipath effects but corrections e.g. by the canonical transform method show an improvement of the data quality. Effects influencing the GPS phase tracking process causing cycle slips could maybe also explain the bias. For further details see e.g. [11]. Slightly lower standard deviations and smaller biases were obtained for the specific humidity differences of HRM and temporally interpolated ECMWF data (Figure 2, left) or radiosonde ascents from Lindenberg (Figure 2, right).

4 Comparison of HRM with TERRA/MODIS

MODIS is a scanning spectroradiometer onboard the TERRA spacecraft with 36 spectral bands between 0.645 and 14.235 μm [9]. Following the approach of Smith et al. [10] clear sky temperature and moisture profiles (MOD-07 product) together

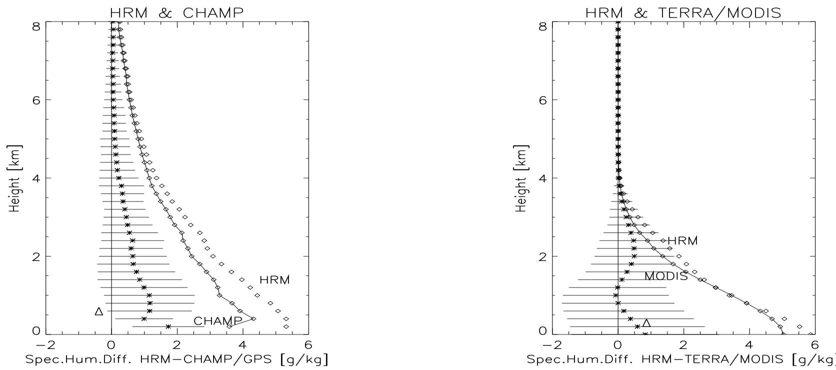

Fig. 3. Left: Mean specific humidities derived from HRM (diamonds) and from CHAMP/GPS (diamonds with line) and their differences Δ calculated with CHAMP radio occultations within the BALTEX modelling area (Figure 1) between 14th of May and 10th of June 2001. **Right:** Mean specific humidities from HRM (diamonds) and TERRA/MODIS (diamonds with line) and its differences and standard deviations for 18142 pixels of the TERRA/MODIS dataset of 1st of December 2001, 1100 UTC.

with the surface temperatures were calculated simultaneously with the help of a radiative transfer equation. Cloud filtering is achieved with the aid of the cloud mask product (MOD-06). The horizontal spatial resolution of one vertical profile is 5×5 km^2.
18142 vertically interpolated specific humidity profiles of TERRA/MODIS were compared with colocated profiles derived with the HRM model. The comparison for this dataset of the 1st of December 2001, 1100 UTC is shown in Figure 3, right: Similar like the CHAMP/GPS dataset this dataset contains a large range of specific humidities (e.g. between 0.5 and 7.5 g/kg in a height of 1 km). It covers nearly the half of the BALTEX modelling area (MODIS data between 36.7° and 58.4° N and between −14.7° and 22.7° E). The HRM model shows slightly (around 0.5 g/kg) larger mean specific humidities for most of the heights between the surface and about 4 km. The standard deviation at the surface between both datasets ($\approx$ 2 g/kg) is a little bit larger compared with CHAMP/GPS. It decreases to less than 0.01 g/kg at 4 km height.

5 Conclusions

In this study a comparison between the specific humidity calculated with the hydrostatic NWP model HRM of the Deutscher Wetterdienst and CHAMP/ GPS radio occultation data is presented. Between the 14th of May and the 10th of June 2001 123 profiles were obtained from the GPS receiver onboard CHAMP over the BALTEX modelling area. The comparison has shown that CHAMP/GPS measures significantly lower mean specific humidities below about 4 km. This is supported by comparisons between the HRM model and the ECMWF analysis data as well as be-

tween the HRM model and radiosonde ascents at Lindenberg/Germany which have shown lower mean absolute differences of about 0.2 g/kg. The standard deviations of the difference between HRM and CHAMP/GPS are similar to the standard deviations between HRM and the radiosonde ascents. The TERRA/MODIS dataset of the 1st of December 2001 1100 UTC shows slightly larger standard deviations of up to 2 g/kg but smaller mean specific humidity differences to the HRM model by comparing 18142 profiles with similar large ranges of specific humidities like from CHAMP/GPS.
If the bias due to the multipath problem or due to noise contributions influencing the GPS phase tracking process can significantly be reduced, the CHAMP/GPS data are a valuable source of specific humidity data and should consequently be assimilated into NWP models for Europe. The slightly larger standard deviations of TERRA/MODIS compared with the HRM could be a problem by using the TERRA/MODIS data for assimilation into NWP models which maybe solved by taking mean values before assimilation. For further details about the assimilation techniques see e.g. [12]. However, due to the good coverage, the high horizontal resolution of the TERRA/MODIS data of about 5×5 km^2 and the acceptable low mean specific humidity difference between TERRA/MODIS and HRM the MOD-07 product could also supplement the radiosonde data quite well, especially in data sparse regions, and should be assimilated into NWP models.

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