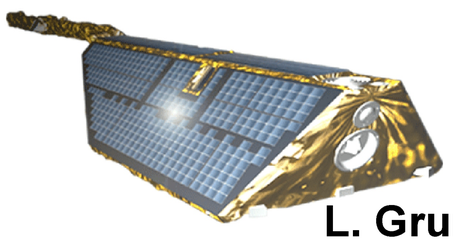
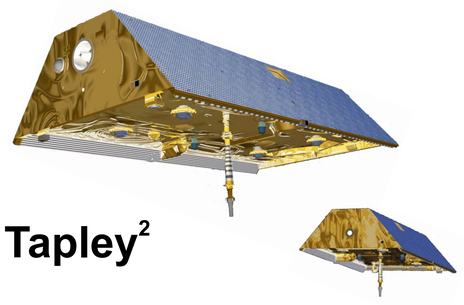


GPS radio occultation with CHAMP and GRACE: Preliminary results



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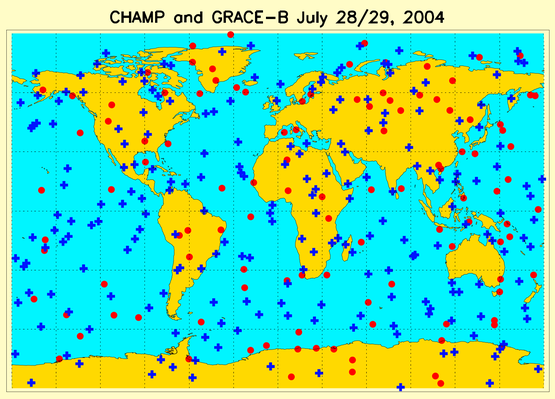
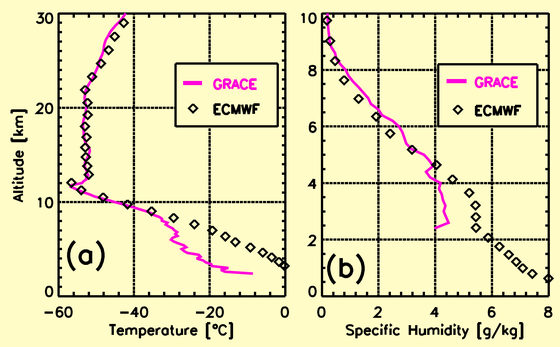
Abstract

First GPS radio occultation (RO) measurements aboard the U.S.-German GRACE-B (Gravity Recovery And Climate Experiment) satellite were recorded on July 28 and 29, 2004, providing globally distributed vertical profiles of refractivity, temperature and specific humidity. The profiles show excellent agreement with meteorological analyses. Almost no refractivity bias is observed between 2 and 30 km, the standard deviation is between 1 and 2% within this altitude interval. The GRACE satellite clock stability is significantly improved in comparison with CHAMP (CHAllenging Minisatellite Payload). This allows for the application of a zero difference technique for precise analysis of the GRACE occultation data. A next campaign was performed between September 23 and 30, 2005 and confirmed the results of the first measurements. A continuous activation of the GRACE occultations would immediately double the number of available precise atmospheric soundings daily and would make a first operational multi-satellite occultation mission reality.

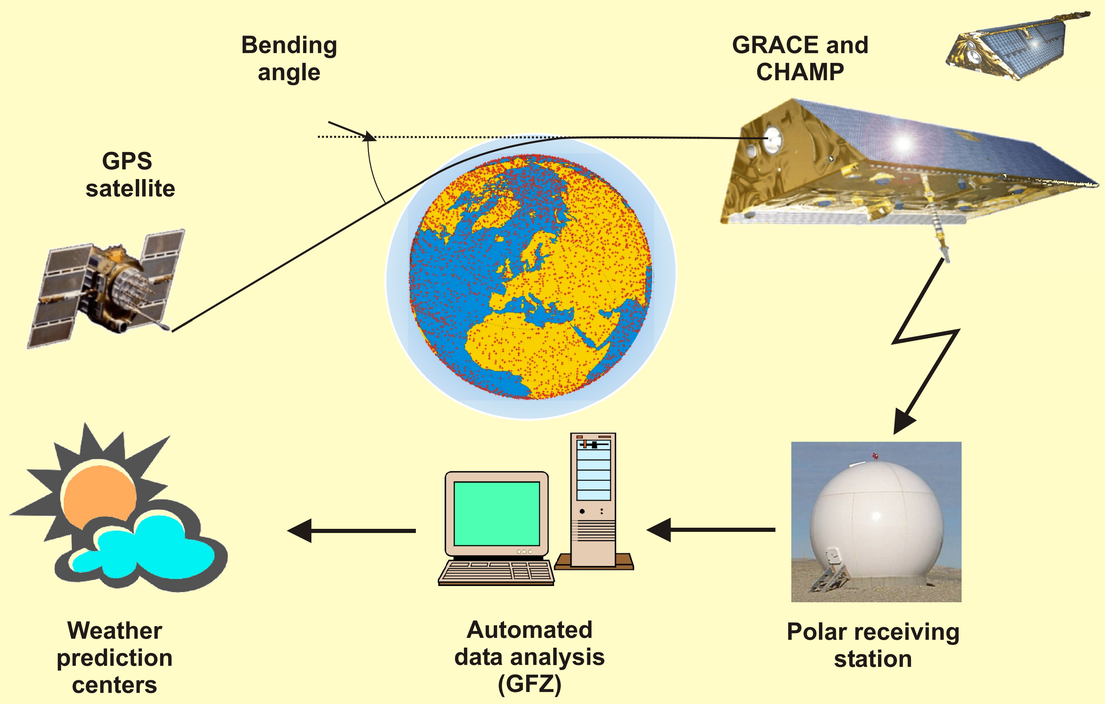


Locations of the first occultations from GRACE (120 events, red circles) and those from CHAMP (218 events, blue crosses) between 28 July (06:00 UTC) and 29 July (07:00), 2004.



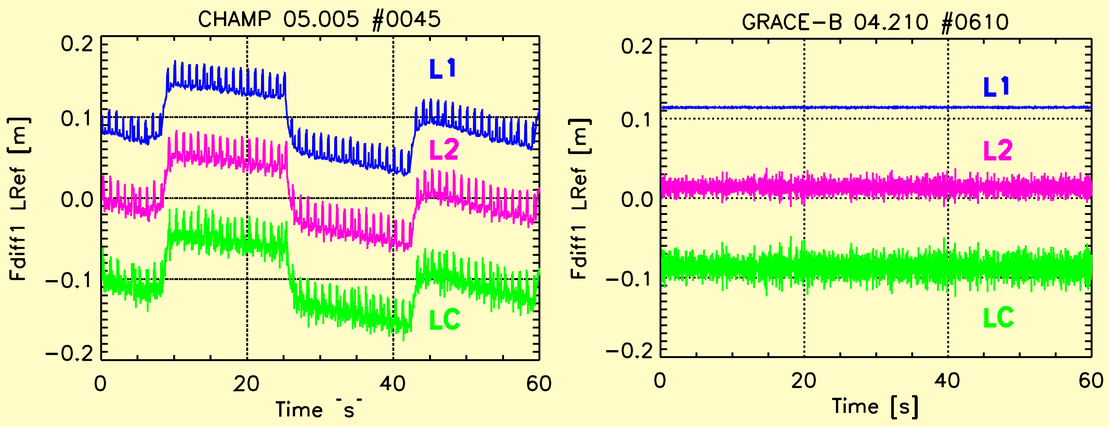
Vertical profiles of (a) dry temperature and (b) specific humidity, derived from the first occultation measurement aboard GRACE, compared with corresponding ECMWF analysis (55.31°N, 22.32°E), 28 July 2004, 06:10 UTC.

Measuring principle and infrastructure



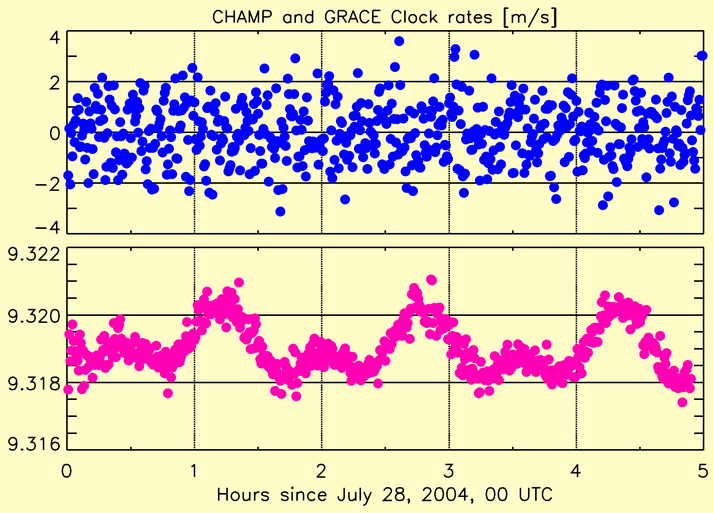
Possible scenario after continuous activation of GRACE occultations. Together with CHAMP the first operational multi-satellite configuration for GPS based atmospheric sounding will be formed. The data of both satellites will be received by the polar antenna Ny-Ålesund, Spitsbergen and transmitted to the operational orbit and occultation analysis centers at GFZ. Globally distributed vertical atmospheric profiles are continuously derived and are transmitted to weather prediction centers, as, e.g., the German Weather Service. A provision to the British MetOffice and the European ECMWF is foreseen for 2005 (at least CHAMP) within a nationally funded research project for the improvement of the global numerical weather prediction (NWP). A near real time data provision with average delay of ~4 h between measurements and data provision is already continuously demonstrated using the CHAMP data since January 2003. A reduction to a delay of ~2 hours is planned as next step of the project. Hereby the GRACE data would double the amount of assimilated data and therefore enable even more impact to the NWP as recently demonstrated by Healy et al. [2005], and Healy and Thepaut [2005].

Satellite clocks



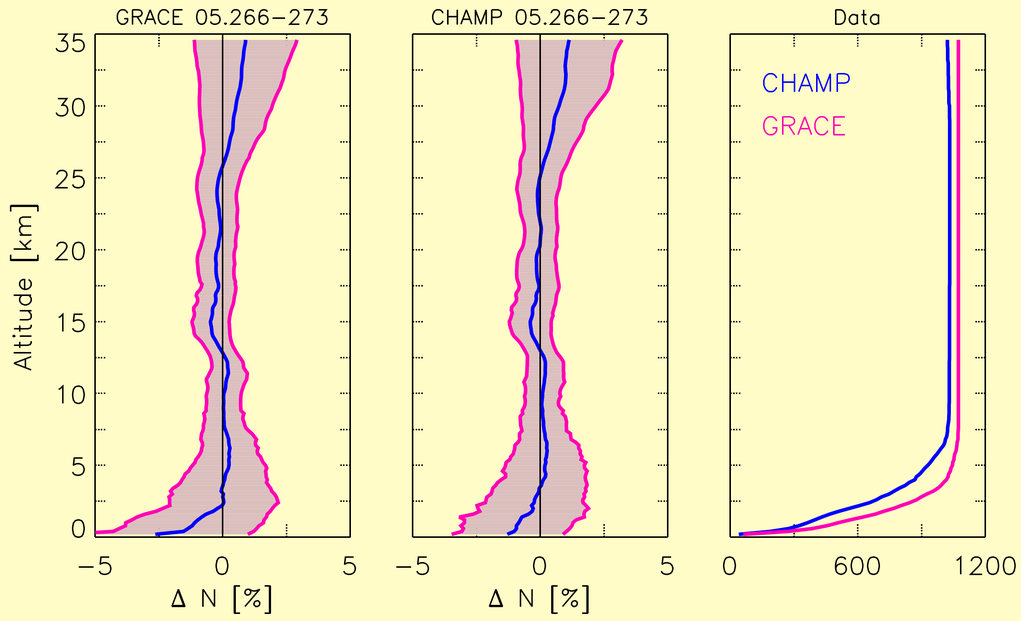
First forward differences (relative motion eliminated) of the phase measurements (reference link) for a CHAMP (left panel) and GRACE (right) occultation. Note the periodic irregularities (left) which can be attributed to the satellite clock behaviour of CHAMP.

In contrast to CHAMP, the GRACE clock is an Ultra Stable Oscillator (USO). Another difference are periodic adjustments which are applied every second by the receiver processing and controlling system to the CHAMP clock, which shows discontinuities (Fig. 4) in contrast to GRACE. The 10s clock solutions of GRACE (Fig. 5) can be used for advantageous modelling of the satellite clock for precise occultation processing (zero differencing).



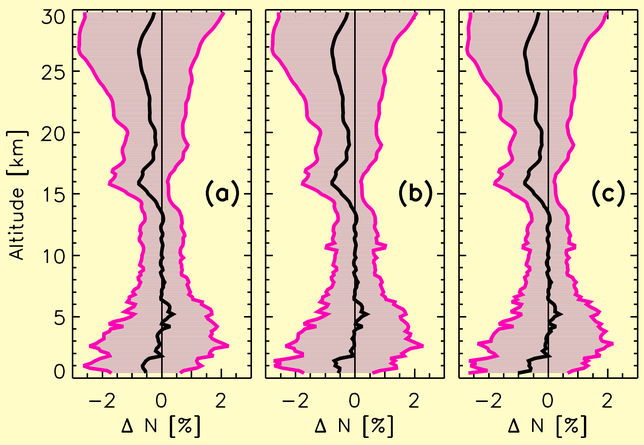
Rate (or drift) of the CHAMP (upper panel) and GRACE (lower panel) 10 s-satellite clock solutions for 28 July 2004. The CHAMP drift is unstable in time, whereas the GRACE clock drift is very stable and can be modelled with sufficient accuracy. The periodic oscillations are not due to relativitic effects and probably caused by the clock calculation process (tbc).

Comparison with meteorological analyses



Preliminary comparison of GRACE and CHAMP refractivity profiles from September 23-30, 2005 with corresponding data from ECMWF (please note: some CHAMP dumps are not yet processed, reducing the total number of CHAMP profiles). An excellent agreement is found. Almost no refractivity bias is observed between 2 and 30 km, the standard variation varies between ~1 and 2%. Deviations can be caused by the measurements but also by the analyses. GRACE data indicate a slightly better performance in the lower troposphere (more data compared to CHAMP).

Zero difference processing



A set of 96 GRACE measurements is used to compare the standard double (a), single (b) and zero (c) differencing refractivity results with meteoroligal analyses from the European Center for Medium range Weather Forecasts (ECMWF). The profiles were obtained using GFZ's operational occultation software (POCS). All data sets show an excellent agreement with ECMWF and no discernable differences.

Summary and Outlook

Our preliminary analysis of the GRACE data from late September 2005 has shown that the occultation data quality is at least comparable with CHAMP and slightly better performance of the GRACE data in the lower troposphere. The data amount from GRACE was reduced by ~50% (zero differencing, no reference measurements necessary), while the number of daily occultations is comparable with CHAMP.

We anticipate that the continuous activation of GPS occultations aboard GRACE will significantly increase the number of globally distributed GPS based atmospheric profiles of high quality. This will allow for more significant studies to improve global weather forecasts and to detect relevant climate change variations of the Earth's atmosphere. In addition: a first small operational multi-satellite GPS radio occultation constellation could be reality before the upcoming (launches planned for spring 2006) operational U.S.-Taiwan FORMOSAT-3/COSMIC (Constellation Observing System for Meteorology Ionosphere and Climate) and the European Metop satellite missions.

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