The CHAMP Atmospheric Processing System for Radio Occultation Measurements

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Summary. In this paper a description of the CHAMP atmospheric processing system for radio occultation data at GFZ Potsdam is given. The generation of radio occultation products, as e.g. atmospheric excess phases, vertical profiles of refractivity, temperature or water vapour is a complex process. Besides the scientific challenge the design and installation of an automatic data processing system is also of great importance. This system must be able to process the different input data from external data sources, coordinates the different data streams and scientific software modules, and feeds the results into the data centre automatically. Caused by different user demands the CHAMP Atmospheric Processor is divided into two parts: A rapid processing mode makes radio occultation analysis results available on average five hours after measurements. In the standard processing mode quality checked profiles of atmospheric parameters are available with a latency of about two days.

Key words: CHAMP, GPS, radio occultation, CHAMP Atmospheric Processor, near-real time, GFZ Potsdam

1 Introduction

The GPS radio occultation (RO) technique is an excellent method for global and continuous monitoring of the Earth's atmosphere [1, 2, 3]. Data assimilation studies using radio occultation data have already shown that this new type of remote sensing data improves the accuracy of global and regional weather analyses and predictions [4].

The use of analysis results obtained from radio occultation data, as e.g. atmospheric excess phases, by weather prediction centres requires an operational data processing system generating and delivering data products automatically within a certain time limit. Such a continuous Near-Real Time (NRT) data processing system, the CHAMP Atmospheric Processor (CAP), is operating at GFZ Potsdam with radio occultation data from the German CHAMP satellite [5].

Because of different user demands with respect to the availability of CHAMP RO products two data processing modes were introduced: a rapid mode and a standard mode. Currently in the rapid processing mode the daily averaged time delay between occultation measurements and availability of analysis results at the Information System and Data Centre (ISDC) [6] is about 5 hours. In the standard processing mode quality checked profiles of atmospheric parameters are available with a latency of about 2 days.

The realization of CAP follows the principle of separating the processing system into a scientific and controlling part leading to an independent and more flexible software development [7]. Basic considerations and requirements for an automatic processing system with respect to software and hardware can also be found in [7]. This paper is focussed on the controlling components of the CAP that generate a continuous data flow between the scientific software modules and the data centre. The CAP is designed to be easily extendable by additional scientific modules or input data. Thus, it also allows for an extension to other single- or multi-satellite radio occultation missions, as e.g. SAC-C, GRACE, TerraSAR-X.

2 Infrastructure and input data

The generation of radio occultation products requires a complex infrastructure that was developed and installed for CHAMP within the GPS Atmosphere Sounding Project (GASP) beginning in 2000 [8, 9].

The main components are (Fig. 1):

– the Black-Jack GPS receiver (provided by NASA/JPL) onboard CHAMP,
– two downlink stations receiving CHAMP data (Neustrelitz, Germany and Ny-Aalesund, Spitsbergen) in cooperation with DLR,
– the fiducial low latency and high rate GPS ground network operated in cooperation between GFZ and JPL [10],
– an orbit processing facility for determination of precise orbits for the GPS satellites and CHAMP [11],
– the CHAMP Atmospheric Processor generating CHAMP radio occultation data products (atmospheric excess phases, profiles of bending angle, refractivity, temperature, and humidity), and
– the CHAMP Information System and Data Centre (ISDC) archiving and distributing CHAMP data and analysis results [6].

3 The CHAMP Atmospheric Processor

The goal of the CAP is to coordinate the different data streams and to start the various scientific applications automatically when all input data for an application are available. The CAP is a modular structured and dynamically configurable software package consisting of a scientific and controlling part

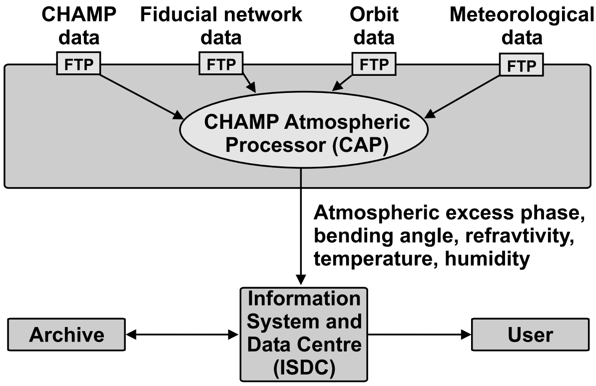

Fig. 1. Infrastructure and input data for GPS radio occultation data processing from CHAMP.

(Fig. 2). The scientific software modules (e.g. DDIFF, ATMO, WVP) calculate the atmospheric excess phases and vertical atmospheric profiles [12]. The controlling components ensure the continuous data flow of all input data through the scientific analysis modules and provide the interface for feeding the radio occultation products into the data centre (ISDC).

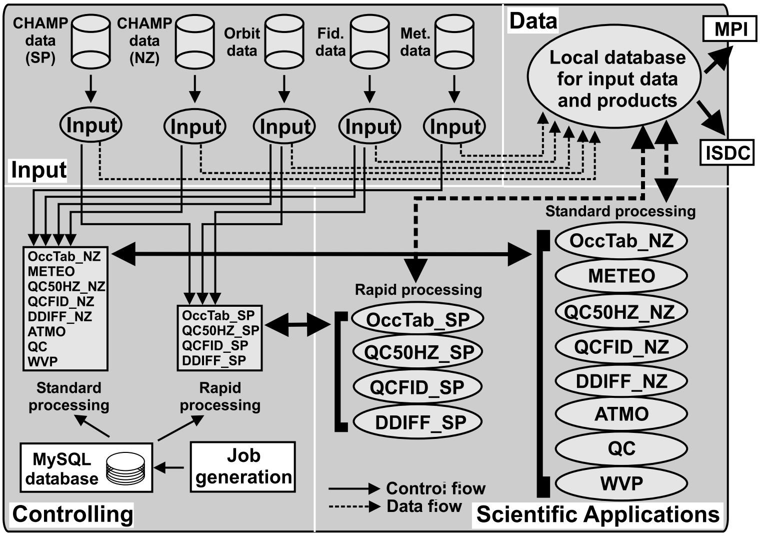

Fig. 2. Schematic view of the CHAMP Atmospheric Processor at GFZ Potsdam.

CAP runs on multiple UltraSparc II/III processor machines and is a combination of different subroutines and scripts written in C++, Fortran, IDL, Perl, and C-Shell.

4 Standard and rapid processing

The processing of radio occultation data at GFZ Potsdam is divided into two parts (Fig. 2):

– the standard processing using CHAMP data via the dump station Neustrelitz, Germany and Rapid Science GPS and CHAMP Orbits (RSO) [13],
– the rapid processing using CHAMP data via the polar dump station at Ny-Aalesund, Spitsbergen and Ultra rapid Science Orbits (USO) [13].

These two modes are necessary due to demands on product availability. The availability of radio occultation data products, i.e. the time delay between measurement and delivery of products to the data centre, depends on two factors: (1) the moment at which all input data for the respective applications (Fig. 2) are available and (2) the duration that CAP needs to process the input data and generate products. Tab. 1 gives an overview of input and output data for the different applications including the availability of the data with respect to the time of the occultation measurements for the standard processing mode.

The delivery of calibrated atmospheric excess phases to weather service centres in a certain time window depends on the availability of CHAMP occultation data, on the precise orbits of GPS satellites and CHAMP, and on the time needed for data processing within this time window. The first

Input	Delay [h]	Scientific Applications	Output	Delay [h]
- CHAMP 50 Hz data (dump files from NZ)	0.5-12	OccTab_NZ	- hourly CHAMP 50 Hz data (RINEX) - occultation table	0.5-12
- daily ECMWF analysis - occultation table	24-48 0.5-12	METEO	- meteorol. data at each occultation point	28-52
- hourly CHAMP 50 Hz data	0.5-12	QC50HZ_NZ	- quality checked hourly CHAMP 50 Hz data	0.5-12
- hourly fiducial network data (1 Hz)	0.5-1.5	QCFID_NZ	- quality checked hourly fiducial network data	0.5-1.5
- occultation table - hourly CHAMP data - hourly fiducial data (1 Hz) - orbit data	0.5-12 0.5-12 0.5-1.5 12-36	DDIFF_NZ	- calibrated atmospheric excess phases	16-40
- met. data at occultation points - atmospheric excess phases	28-52 16-40	ATMO	- vertical atmospheric profiles (refractivity, dry temperature)	29-53
- atmospheric excess phases - vertical atmospheric profiles	29-53	QC	quality checked - atmospheric excess phases - vertical temperature profiles	29-53
- quality checked temperature profiles - met. data at occultation points	30-54	WVP	- vertical water vapour profiles	31-55

Table 1. Input and output data including data availability with respect to the occultation measurement for the standard processing mode.

requirement is fulfilled due to the installation of a polar dump station. This enables a contact to CHAMP about every 90 minutes. Since April 2002 the GPS and CHAMP satellite orbits are available every 3 hours.

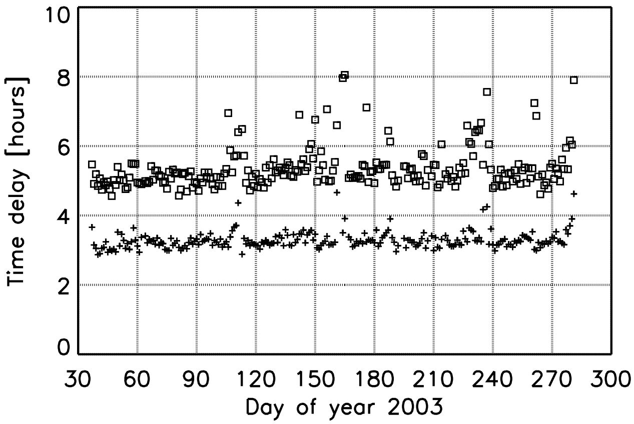

Fig. 3. Daily averaged time delay between CHAMP occultation measurement and product delivery to MPI (squares: average, crosses: minimum).

These USOs cover a 14 hour (CHAMP) and a 24 hour (GPS satellites) time window. The accuracy is comparable to the standard RSOs [12].

A pilot project in cooperation with the Max Planck Institute for Meteorology (MPI) demonstrates for the first time the delivery of CHAMP radio occultation products (atmospheric excess phases) in the rapid processing mode since the beginning of 2003. The averaged time delay between CHAMP measurements and data product delivery is about 5 hours. For single products a time delay less than 3 hours is reached (Fig. 3). The operational use of CHAMP radio occultation products by weather service centres (DWD, Met Office, ECMWF) is in preparation.

5 Summary and outlook

The CAP enables an operational data processing and the delivery of analysis results to the data centre. Since February 2001 more than 116.000 CHAMP radio occultation products, as calibrated atmospheric excess phases, refractivity, temperature and water vapour profiles, have been generated (about 170 daily, as of September 2003).

Due to the modular structure CAP is suitable for easy extension to other single- or multi-satellite radio occultation experiments.

In the standard processing mode quality checked products (refractivity, temperature and water vapour profiles) are available with a latency of about 2 days. A near-polar receiving station at Spitsbergen and a 3-hourly CHAMP and GPS orbit production cycle made it possible to implement for the first time a NRT processing at GFZ Potsdam. Since the beginning of 2003 atmospheric excess phases with a average time delay of about 5 hours between measurement and availability of the analysis results are generated continuously. Weather service centres (Met Office, ECMWF, DWD) will soon follow the current cooperation with the MPI and use the rapid processing products.

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