GRAS SAF Radio Occultation Data from EPS/Metop

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Abstract

The EUMETSAT network of Satellite Application Facilities (SAFs) will, together with the EUMETSAT central facilities, constitute the future ground segments for the MSG and EPS/Metop satellites. SAFs are located in national meteorological offices or other approved institutes of EUMETSAT member states. The scope of the SAF activities will be to deliver products and/or software to derive these products, at the level of meteorological parameters, based primarily on the satellite data.

The GRAS (Global Navigation Satellite System Receiver for Atmospheric Sounding) SAF will receive raw and pre-processed GPS radio occultation data from the GRAS instrument onboard the EPS/Metop satellite, process these into vertical profiles of refractivity, temperature, pressure, and humidity, and distribute these products continuously to numerical weather prediction and climate monitoring users. The GRAS SAF products promise globally distributed high-vertical resolution data on a 24 hour-basis, forming a considerable improvement on todays measurement methods regarding coverage, vertical resolution, frequency, and cost. The accuracy requirements of the products vary with height. The expected temperature RMS will be between 0.5 and 5 K, pressure RMS between 0.5 and 2 hPa, specific humidity RMS between 0.025 and 1 g/kg, and refractivity RMS between 0.1 and 2 %. Vertical resolution will be between 0.3 and 3 km.

A second objective of the GRAS SAF is to supply software for 4D-VAR assimilation of radio occultation data into Numerical Weather Prediction (NWP) models.

The GRAS SAF is expected to distribute and archive atmospheric products from around 500 occultations per day at least through the expected project lifetime of 15 years. The main users of the GRAS SAF products will be meteorologists doing NWP data assimilation, and users from the climate research and atmospheric science communities, needing comprehensive, globally distributed temperature, pressure, and humidity information. The products will come in two types: Near-Real Time Products (for NWP), disseminated less than three hours after acquisition, Offline Products (improved, for climate research), available less than 30 days after acquisition.

The focus of this paper is on the design of the operational GRAS SAF facility. The GRAS SAF processing system and data products will be described and the user requirements for both Numerical Weather Prediction (NWP) and climate monitoring will be presented.

1 Introduction

The GRAS SAF is a Satellite Application Facility being developed under the EUMETSAT programme for SAFs. The GRAS SAF is host by DMI with the two partner institutes, the Met. Office, UK, and the IEEC, Spain. The GRAS SAF developments were initiated April 8, 1999 and will continue until August 2006. Following the launch of EPS/Metop (scheduled in late 2005) and subsequent commissioning the GRAS SAF will enter into operations and start providing data in the beginning of 2007.

The scope of the GRAS SAF activities is to deliver products in Near Real Time (NRT) as well as offline, at the level of geophysical parameters, based primarily on the satellite data. It is well established that observations of the basic parameters of temperature, pressure, humidity and wind velocity are crucial for the quality of meteorological forecasts and climate change monitoring. The GRAS Meteorology SAF will deliver exactly these products (apart from the air mass velocity vector, but potentially the geostrophic wind velocity) with a resolution comparable to existing soundings and with an exceptional spatial coverage not matched by present systems. The design basis is the user requirements [1] the scientific developments are specified and described in the Science Plan [2]. Here we focus on the design of the operational processing system.

The major satellite instrument type will be the GRAS instrument from the EPS/Metop series of satellites, potentially complemented with other low Earth orbiting satellite products providing the same basic atmospheric parameters. The combination of these new databases with classical ground observations will lead to a large data source for improved knowledge of the Earth's troposphere and stratosphere state and its future evolution. Furthermore, the GRAS observations will complement other observations performed on the EPS/Metop platform that will be used for products by other SAFs.

Thus, the GRAS SAF will make possible the delivery of improved data products beneficial to all National Meteorological Services and EUMETSAT. An activity, which will make the large investments in meteorological satellites more transparent and logical for the national populations and organisations accepting to support the EUMETSAT observational satellite systems. One of the prime factors for improving present operational NWP analysis and products is the effective implementation and exploitation of satellite observations in the evolving NWP models for weather forecasts and climate change monitoring. Especially satellite observations will directly influence present classical observables. The role of the SAF will be to facilitate the input from the EPS/Metop missions to NWP and climate change models in order to increase the usage of satellite data in a more effective manner than possible today [1], [2]. The following diagram in **Fig. 1** shows the main GRAS SAF data flow and relationship to other systems.

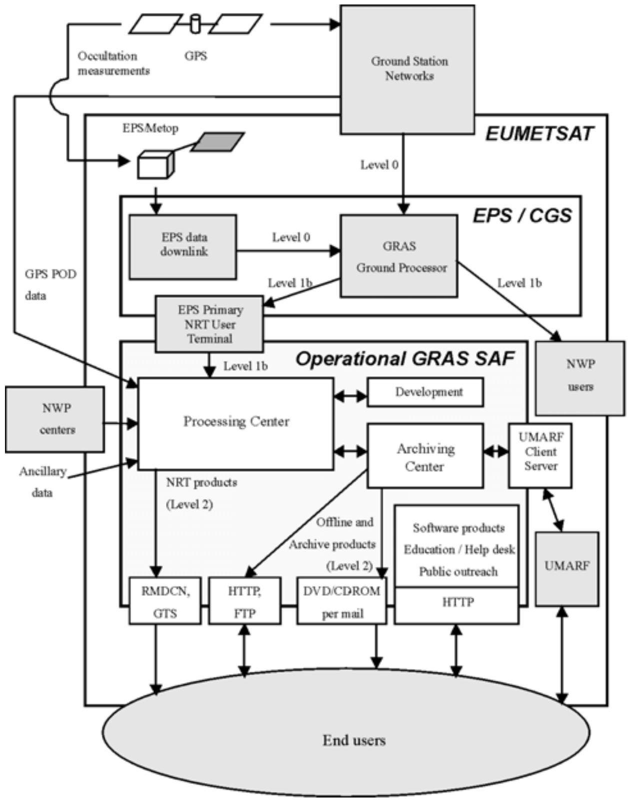

Fig. 1. GRAS SAF data flow diagram.

The GRAS SAF products are important for monitoring the climate system and the problems related to climate change processes and their identification. The products will further strengthen the studies assessing the impact of the climate changes on the environment. Since the data needs no calibration, they will prove very valuable for climate monitoring purposes by combining several data sets and model forecasts.

2 Data products and processing system

Since the successful demonstration of accurate retrieval of atmospheric profiles obtained by the measurements of the GPS/MET experiment [3], [4], there has been a number of research satellite missions capable of GPS radio occultation measurements. The GRAS mission on EPS/Metop is the first mission designed for operational use, in particular for use in NWP.

Occultation measurements are performed as the GPS satellites rise or set, and are occulted by the atmosphere/ionosphere as seen from the EPS/Metop satellite. During an occultation event, the ray path joining the transmitter (GPS satellite) and the receiver (EPS/Metop) traverses the ionosphere, passes through the atmosphere at the limb of the Earth and traverses again the ionosphere. The refraction produced by the free charges is dispersive, which produces differences in the bending and arrival time between the two frequency components, L1 and L2, of the GPS radio signal. This allows a removal of the ionosphere contribution and hence a determination of the bending caused by the neutral atmosphere [5], [6].

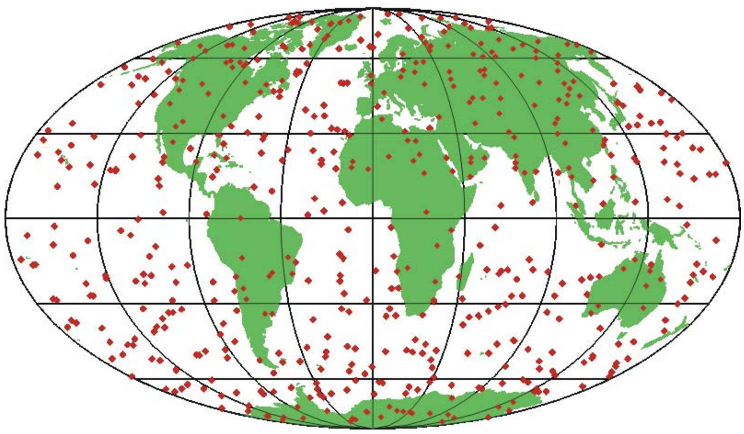

Fig. 2. Distribution of occultations from EPS/Metop in 24 hrs. Based on a simulation using one Metop satellite and 24 GPS satellites.

The basis of the measurement is geometric and relies on very accurate measurements of position of both transmitting and receiving satellites and the signal delay caused by the refraction of the neutral atmosphere. The signal path is bended and the bending angle as function of impact parameter is derived first as part of the level 1b data stream by the EPS core ground segment at EUMETSAT with a time requirement of 2 hours and 15 minutes after measurement. The GRAS SAF will then receive the bending angle profiles in a NRT data stream from EUMETSAT and invert these into vertical profile of refractivity, pressure, temperature and humidity as a function of height at the location of the tangent point [2]. The data products are specified in a product description document [7].

The GRAS receiver on Metop-1 will track signals from the GPS satellites with two occultation antennas (setting and rising) resulting in about 550 globally distributed occultations per day, as illustrated in **Fig. 2**. As a potential, the GALILEO satellite constellation may open for future system improvements. The current plans of the European GALILEO constellation if successfully undertaken, will result in even more sources for occultations in future versions of the GRAS receiver.

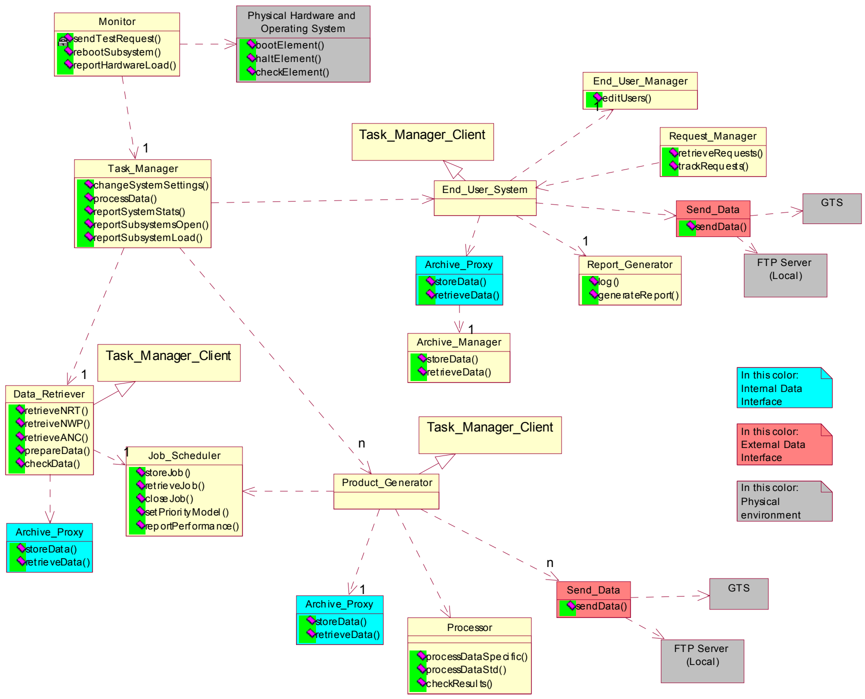

Fig. 3. Processing system components.

The design of the GRAS SAF data processing system is shown in **Fig. 3** as an overview of the involved system components [8]. The GRAS SAF will process the atmospheric profiles in near real time with a timeliness requirement of 3 hrs after measurement. Furthermore the GRAS SAF will also deliver offline products [7]. The offline products are based on reprocessed occultations using higher precision orbit data for both EPS/Metop and GPS satellites. The offline data products available within 30 days of observation will also include bending angles and will further allow for use of improved inversion schemes.

3 User requirements

The raw measurements from the GRAS instrument (Level 0) will be processed into bending angle products as part of the EPS Core Ground Segment (Level 1b). These level 1b data will be the basic input to the GRAS SAF. The GRAS SAF will then process and disseminate the atmospheric products, such as temperature and humidity profiles (Level 2).

The GRAS instrument will provide carrier phase measurements for the occultation and navigation mission with performances compatible with the performance requirements of the Level 1b product specified on the bending angle. The ground processing algorithms will enable the conversion of the instrument Level 0 data to the defined Level 1b data product within its performance requirements.

Bending angles will be provided for altitudes ranging from 80 km down to 5 km (for both setting and rising occultations) with the expectation that many events will extend to near the surface. The bending angle accuracy requirement is to be better than 1 µrad or 0.4% (whatever is larger). The tangent point localisation in Earth coordinates is required to be better than 0.01° in longitude and latitude, and better than 6 metres in altitude.

We break down the requirements by atmospheric layers; these are defined as:

Lower Troposphere	(LT)	1000hPa to 500hPa	(Surface to 5km)
Higher Troposphere	(HT)	500 hPa to 100 hPa	(5km to 15km)
Lower Stratosphere	(LS)	100 hPa to 10hPa	(15km to 35km)
Higher Stratosphere/ Meso sphere	(HS)	10hPa to 1hPa	(35km to 50km)

The GRAS Science Advisory Group (SAG) has identified several classes of users, as noted in [9]. For the purposes of the GRAS SAF, we present user requirements for just two major classes of users – operational meteorology (NWP) and climate.

The requirements for operational meteorology, which reflect the limitation of a single GRAS instrument, are summarised in Table 1.

		Tem-perature	Specific Humidity	Surface Pressure	Refrac-tivity	Bending Angle
Horizontal Domain		Global	Global	Global	Global	Global
Horizontal Sampling		100–2000km	100 – 2000km	100–2000km	100–2000km	100–2000km
Vertical Domain		Sfc–1 hPa	Sfc–100 hPa	Sfc (msl)	Sfc–1 hPa	Sfc–80 km
Vertical Sampling	LT	0.3–3km	0.4–2 km	–	0.3–3 km	2–5 Hz
	HT	1–3 km	1–3 km	–	1–3 km	
	LS	1–3 km	–	–	1–3 km	
	HS	1–3 km	–	–	1–3 km	
Time Window		1–12 hrs	1–12 hrs	1–12 hrs	1–12 hrs	1–12 hrs
RMS Accuracy	LT	0.5–3 K	0.25–1 g/kg	0.5–2 hPa	0.1–0.5%	1 µrad or 0.4%
	HT	0.5–3 K	0.05–0.2g/kg	–	0.1–0.2%	
	LS	0.5–3 K	–	–	0.1–0.2%	
	HS	0.5–5 K	–	–	0.2–2%	
Timeliness		1-3 hrs	1–3 hrs	1–3 hrs	1–3 hrs	1–3 hrs

Table 1. GRAS/Metop user requirements for operational meteorology

Both table 1 and 2 are taken from the GRAS SAF User Requirement document [1].

The requirements for climate applications, which reflect the limitation of a single GRAS instrument, are summarised in Table 2.

		Temperature	Specific Humidity
Horizontal Domain		Global	Global
Horizontal Sampling		100–1000 km	100–1000 km
Vertical Domain		Surface to 1 hPa	Surface to 1 hPa
Vertical Resolution	**LT**	0.3–3 km	0.5–2 km
	HT	1–3 km	0.5–2 km
	LS	1–3 km	0.5–2 km
	HS	5–10 km	1–3 km
Time Resolution)		3–24 hrs	3–24 hrs
RMS Accuracy	**LT**	0.5–3 K	0.25–1 g/kg
	HT	0.5–3 K	0.05–0.2 g/kg
	LS	0.5–3 K	–
	HS	1–3K	–
Timeliness		30–60 days	30–60 days
Time Domain		> 10 years	> 10 years
Long-term Stability		< 0.1 K/decade	< 2% RH/decade
No. of profiles/ grid box/month		> 10	> 10

Table 2. GRAS/Metop user requirements for climate monitoring

4 Conclusions

The GRAS SAF is currently in the development phase and will in 2007, when the EPS/Metop satellite has been launched and commissioned, enter into the operational phase. The basic products from the GRAS SAF will include profiles of refractivity, pressure, temperature and humidity. These products are to be disseminated in NRT with a constraint of 3 hours from actual measurement to the end user and also be available as offline products with improved accuracy within 30 days of measurement.

More information can be found at the GRAS SAF homepage: http://www.dmi.dk/pub/GRAS_SAF/

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