ATMOSPHERIC PRODUCTS FROM THE GRAS METEOROLOGY SAF

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ABSTRACT

The GRAS (GNSS Receiver for Atmospheric Sounding) Meteorology SAF (Satellite Application Facility) is a development project under Eumetsat. The GRAS SAF will deliver atmospheric products in near real time using the data stream from the GRAS instrument onboard the EPS/Metop satellite. The planned launch of the EPS/Metop satellite is in late 2003, at which time the software developed by the GRAS SAF will enter the final operational testing phase. Atmospheric products of the GRAS SAF will be available in the second half of 2004. The GRAS instrument is a high precision GPS receiver capable of tracking the phase variations of the signal with millimeter accuracy. This allows a measurement of the signal delay caused by the atmosphere. The measurement is performed as an occultation when the EPS/Metop satellite moves around the Earth. Inverting this measured phase delay results in very accurate vertical profiles of temperature, pressure and water vapor with a vertical resolution of 1km through the stratosphere and troposphere. The quality of the retrieved vertical profiles depends on several geophysical conditions. The influence of the ionosphere on the signal can be subtracted using both GPS frequencies, however this subtraction still leaves a small residual. During solar maximum conditions this residual is the dominating error source. In the troposphere, sharp layers of water vapor will introduce multipath propagation and possible errors on the retrieved profiles.

1. INTRODUCTION

The GRAS Meteorology 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 was initiated April 8, 1999 and will continue for five years. The operational GRAS SAF will take over when the EPS/Metop satellite is launched and providing data in 2004.

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 [1], [2].

The following diagram shows the main GRAS SAF data flow and relationship to other systems:

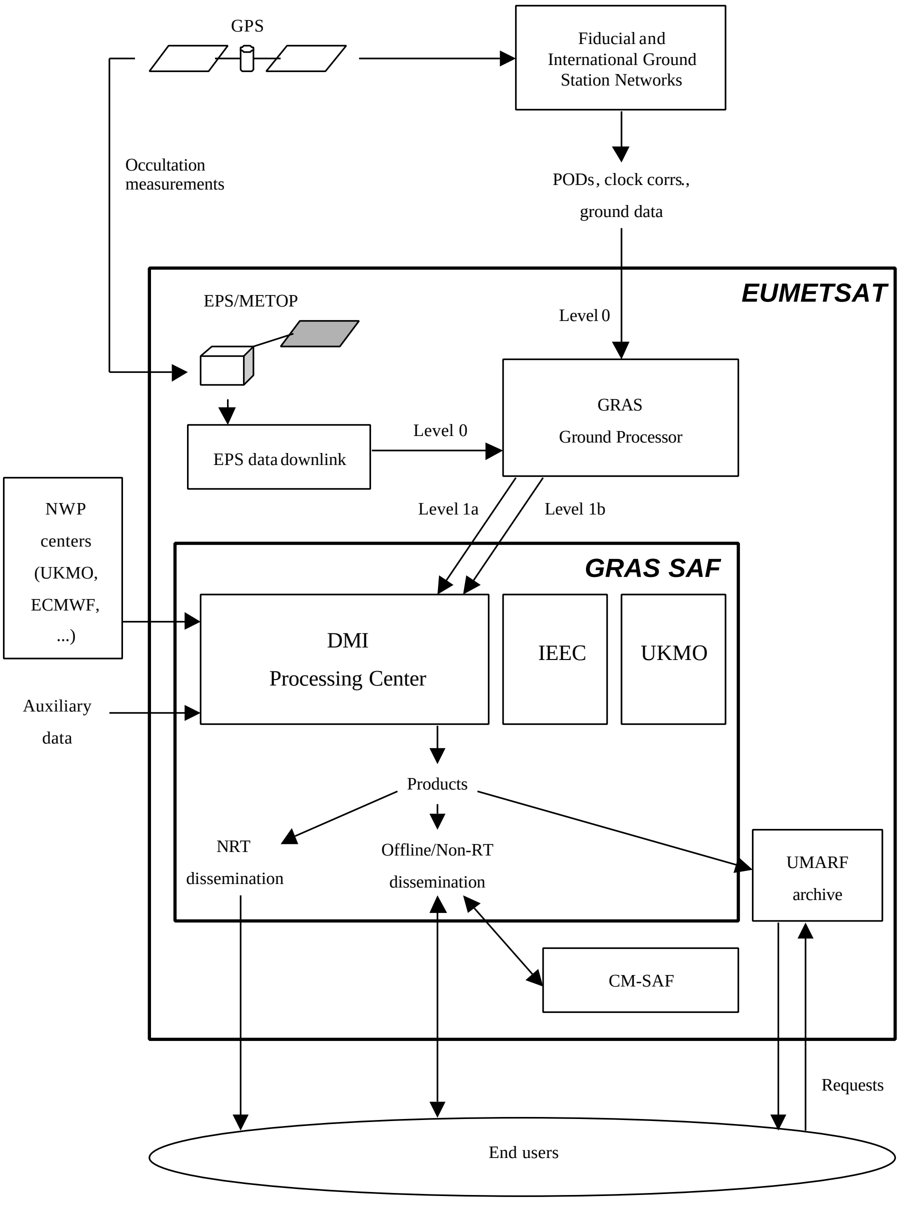

Figure 1 GRAS SAF data flow model

The major satellite instrument data type will be the GRAS instrument from the EPS/Metop series of satellites, potentially complemented with the other low Earth orbiting satellite products providing the same basic atmosphere 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 Meteorology SAF will make possible the delivery of improved data products beneficial to all NMSs and Eumetsat. An activity, which will make the large investments in meteorological/climatological 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 GRAS Meteorology 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. OCCULTATION MEASUREMENTS IN THE GRAS SAF

Here we will introduce the principles of the radio occultation technique, with focus on the applications in the GRAS SAF. The atmospheric profiling technique provides measurements of the Doppler shift of the probing GPS signals that have passed through the limb of the atmosphere. The magnitude of the shift is related to the atmosphere refractivity gradients along the path of the signal. These in turn are related to the neutral atmosphere temperature, pressure and humidity fields. The GRAS receiver on Metop-1 will only track the GPS satellites, resulting in about 550 setting and rising occultations per day.

As a potential, the GLONASS and GALILEO satellite constellations may open for future system improvements. Current plans of a European constellation, GALILEO, if successfully undertaken, will result in even more sources for occultations in future versions of the GRAS receiver.

Occultation measurements are performed as the GPS satellites rise or set, as seen from the Metop satellite and are occulted by the atmosphere/ionosphere. 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, cf. Figure 2. The presence of matter and free charges produces refraction, leading to slight changes in the propagation speed and direction (bending). The refraction produced by the free charges is also dispersive, which produces differences in the bending and arrival time between the two components, L1 and L2, of the GPS radio signal. Irregularities and strong gradients present in the propagating medium can also produce caustic phenomena and other amplitude fluctuation (scintillation) effects in the strength of the received signal. The tangent character of the propagation magnifies the impact of all these phenomena.

Provided that the signal has sufficiently high quality (i.e. signal-to-noise ratio) and that other variables of the experiment (e.g. the positions of the transmitter and receiver, and the effects of the ionosphere) are known to sufficient accuracy, information on the temperature and humidity fields can be retrieved. More specifically, from a series of measurements obtained during the occultation event, the profiles of temperature and humidity close to the tangent point of the signal path can be estimated.

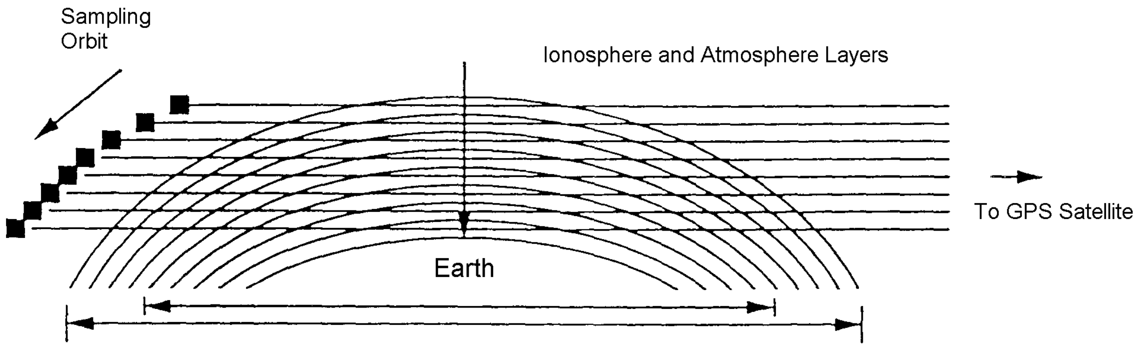

Figure 2 Schematic representation of the data observed on the low orbiting satellite during an occultation. The ray paths for the GPS signals are drawn as straight lines for clarity. Only the lowest part of the observations contains phase and amplitude changes that originate both from the atmosphere and the ionosphere.

3. THE GPS/MET EXPERIMENT

The principle of limb sounding has been used for at least 25 years for determining the properties of the atmosphere of other planets in our solar system. Some 10 years ago it was suggested that global navigation satellite systems provide a sufficient number of signals to give a high-resolution measurement of the Earth's atmosphere using a receiver on a low earth orbiting satellite. In April 1995 GPS/MET a proof-of-concept mission was launched, and continued until 1997 to give good atmosphere profiling results based on the limb sounding method [3], [4].

The GPS/MET experiment used a modified high precision Turbo-Rogue GPS receiver. It was located on the micro-satellite MicroLab-1 in a low Earth near-polar orbit with an inclination of 70 degree. The orbit height was about 740 km, and it was close to a circular orbit. The GPS/MET experiment produced about 200 occultations per day, based on only one antenna for setting occultations.

Data from the GPS/MET experiment has been used extensively by many researchers to derive high quality meteorological measurements. It has been demonstrated that the occultation technique is capable of measuring temperature profiles which agree with radiosonde measurements and NWP fields within 1K in mean deviation [4]. The standard deviations are generally about 2-3 K. In Figure 3, we show an example temperature profile derived using the DMI processing software [5], [6] on a GPS/MET occultation. Due to limitation in the antenna gain, GPS/MET was only in very few cases able to perform measurements at heights lower than 5 km in the troposphere. This will be different with the GRAS receiver, which has two high-gain antennas that will enable it to carry out measurements down to near the surface.

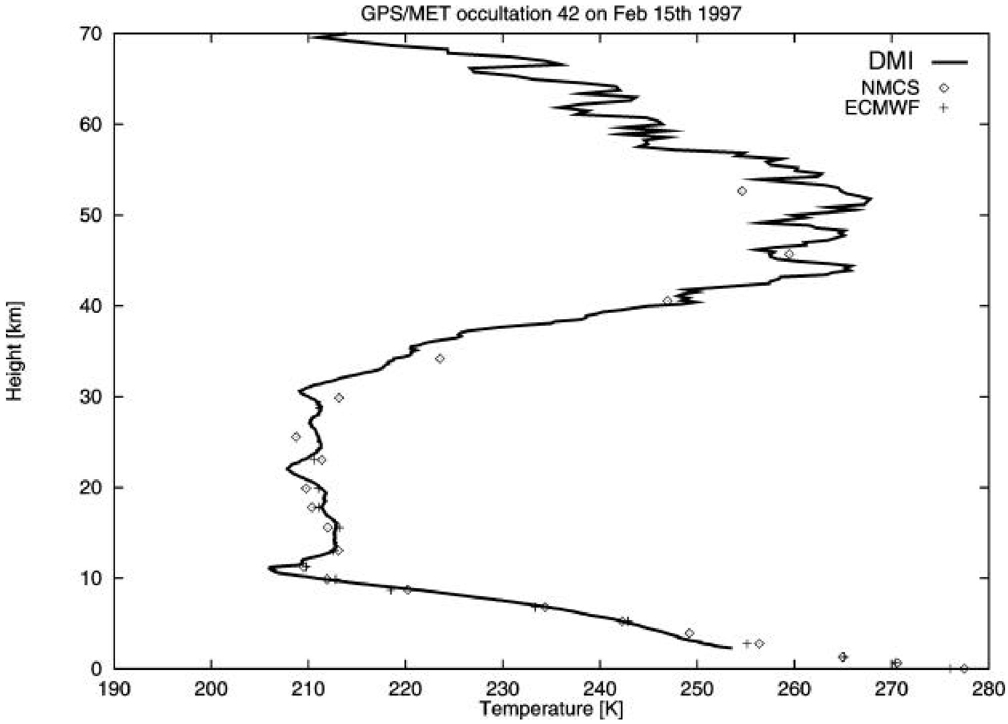

Figure 3. Temperature profile obtained using a GPS/MET occultation measurement. This is occultation #42 from February 15, 1997. The curve show the temperature derived using the DMI processing software. The data points are output from the NMCS and ECMWF numerical weather prediction models.

4. GRAS SAF 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 its navigation mission with performances compatible with the performance requirements of the Level 1b product. 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.

The sampling rate of the carrier phase, code phase, signal amplitude, occultation and navigation measurement will be separately selectable among the following steps: 0.1, 0.5, 1, 10, 25, 50 Hz. The occultation measurement will be nominally sampled at 50 Hz.

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 impact parameter 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/Mesosphere	(HS)	10hPa to 1hPa	(35km to 50km)

The GRAS Science Advisory Group (SAG) has identified several classes of users, as noted in [7]. 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.

		Temp	Specific Humidity	IWV	Surface Pressure	Refractivity	Bending Angle
Horizontal Domain		Global	Global	Global	Global	Global	Global
Horizontal Sampling		100–2000km	100 – 2000km	100–2000km	100–2000km	100–2000km	100–2000km
Vertical Domain		Sfc–1 hPa	Sfc–100 hPa	Column	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	1–12 hrs
RMS Accuracy [4)]	**LT**	0.5–3 K	0.25–1 g/kg [5)]	1–5 kg/m²	0.5–2 hPa	0.1–0.5%	1 μrad or 0.4% [7)]
	HT	0.5–3 K	0.025–0.1g/kg[5)]	–	–	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	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, which is currently under review [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 [2)]	**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)]		3–24 hrs	3–24 hrs
RMS	**LT**	0.5–3 K	0.25–1 g/kg [6)]

Accuracy [4]	**HT**	0.5–3 K	0.025–0.1 g/kg [6]
	LS	0.5–3 K	0.025–0.1 g/kg [6]
	HS	1–3K	0.025–0.1 g/kg [6]
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 Requirements for Climate

5. CONCLUSIONS

The GRAS SAF is currently in the development phase and will in 2004, when the EPS/Metop satellite has been launched, 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.

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

6. REFERENCES

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