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METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Ionosphere monitoring with Metop GRAS mission

Juha-Pekka Luntama

Finnish Meteorological Institute

Erik Palménin aukio, FI-00560 HELSINKI

Juha-Pekka.Luntama@fmi.fi

Abstract

GRAS (GNSS Receiver for Atmospheric Sounding) is a Radio Occultation (RO) receiver developed by ESA and EUMETSAT in the framework of the EPS (EUMETSAT Polar System) mission. GRAS receivers will be in the payload of three Metop satellites, to be flown successively in the years from 2006 to 2020. GRAS measurement system has been designed to provide data products for operational NWP (Numerical Weather Prediction) applications and climate monitoring. The GRAS data processing system will allow data and product dissemination to the users in NRT (Near Real Time).

GRAS receiver will provide the GPS carrier phase, amplitude and code phase data from two occultation antennas pointing to the flight and to the anti-flight directions of the Metop satellite. TEC (Total Electron Content) estimates from the occultation data are included into the nominal NRT products processed and disseminated to the users by EUMETSAT. However, the potential of the GRAS navigation data is currently not used. The NRT dissemination of the GRAS data provides an opportunity for developing new ionosphere monitoring and prediction applications that can provide information to the users in real time. The Metop GRAS mission provides an opportunity to collect continuous measurement data sets over the 15 year lifetime of the EPS mission. This allows e.g. monitoring of the ionosphere over a full solar cycle. Because EUMETSAT will permanently archive all GRAS data, a complete reprocessing of the data with updated algorithms or for new applications will be possible.

GRAS measurement system elements

The elements of the GRAS measurement system are presented in Figure 1. This system has been designed to enable NRT (Near Real Time) processing and dissemination of the GRAS data products to the users with the required accuracy (Table 1).

GRAS Receiver (see Figure 2):

- Occultation measurements with two high gain antennas pointing to the flight and to the anti-flight directions of the Metop spacecraft.
- In occultation measurements the GPS carrier phase and amplitude sampling at 50 Hz and code phase sampling at 1 Hz.
- Approximately 500 occultation measurements (rising and setting) per day.
- Hemispherical navigation antenna pointing to the zenith direction.
- In navigation measurements the GPS carrier phase and amplitude sampling at 3 Hz and code phase sampling at 1 Hz.
- Automatic determination of the positions of the Metop and the GPS satellites and prediction of the times and azimuth and elevation angles of the occultations.
- GRAS can operate also in codeless-mode if GPS AS (Anti-Spoofing) is activated.
- Automatic ``raw sampling'' measurement mode for lower troposphere where the correlator output is sampled at 1 KHz rate.
- A more detailed technical description of the GRAS receiver is in (Loiselet et al., 2000).

EPS Polar Site:

- EPS has only one ground station in Spitsbergen, Svalbard, Norway.
- Satellite data is downlinked once per orbit => 102 min initial delay in NRT processing.
- Raw satellite data is transferred to EUMETSAT HQ in Darmstadt, Germany for level 1 processing.

EPS CGS (Core Ground Segment):

- Level 1 processing for all EPS instruments.
- GRAS level 1b products are disseminated directly to the users and to the GRAS Meteorology SAF for level 2 processing.
- All GRAS raw data and level 1 products are permanently archived.
- GRAS level 1 products include total bending angle profiles and TEC estimates from the occultation data.

GRAS GSN (Ground Support Network) Service

- Developed to ensure that the positions and velocities of the GPS satellites, and the ground-based measurements to support the GPS clock correction are provided in time to allow NRT occultation data processing.
- Collects ground based GPS measurement data from about 25 globally distributed fiducial GPS stations and performs GPS orbit determination.
- The NRT products provided by the GSN service include:

- GPS position and velocity vectors;
- GPS and fiducial ground station clock offset estimates;
- GPS tracking data from the fiducial stations;
- Earth Orientation Parameters (EOP);
- Troposphere Zenith Delay (TZD) estimates for each fiducial station;
- 1 Hz Sounding Support Data (SSD) of the occulting GPS satellite carrier phase, pseudorange, and SNR for L1 and L2 channels.

- A map of the provisional GRAS GSN ground stations is presented in Figure 3.

GRAS Meteorology SAF:

- Hosted by the Danish Meteorological Institute (DMI) in Copenhagen, Denmark.
- Consortium includes also the Met Office, and the Institut d'Estudis Espacials de Catalunya (IEEC).
- Responsible of the production, dissemination, and validation of the geophysical data products (refractivity, temperature and humidity profiles) from the GRAS level 1b products.
- Performs also off-line re-processing of the GRAS measurement data to generate products for climate applications.
- More information can be found from the SAF web page: http://dmiweb.dmi.dk/pub/GRAS_SAF/.

TEC estimates from GRAS occultation data

The nominal GRAS data products disseminated to the users in NRT include TEC estimates from the occultation measurements. These estimates are derived directly from the code phase measurements by calculating the biased TEC from the carrier phase samples as

$$TEC_{\phi}=\frac{1}{d}\frac{f_{L1}^{2}f_{L2}^{2}}{(f_{L1}^{2}-f_{L2}^{2})}(\phi_{L1}-\phi_{L2})+B\ ,$$

where B represents the bias from the phase ambiguity.

The non-biased, but noisy TEC from the GPS P code phase measurement is calculated from

$$TEC_{CP}=\frac{1}{d}\frac{f_{L1}^{2}f_{L2}^{2}}{(f_{L1}^{2}-f_{L2}^{2})}\left[\frac{c}{10230\cdot 10^{3}}(CP_{L1}-CP_{L2})\right]\ .$$

The final TEC is retrieved with a least squares fit of TEC_{ϕ} to TEC_{CP}.

In GRAS measurement data the TEC must be calculated by subtracting L2 measurements from L1 due to the sign convention used in the AGGA ASIC in the receiver electronics.

Unfortunately the GRAS occultation data is only provided when the ray path tangent height is less than 80 km from the Earth surface. This means that the useful height range of the occultation data for TEC estimation is only of the order of 10 – 20 km.

Plasmasphere monitoring with GRAS navigation data

In the framework of the EPS mission the GRAS navigation data is only used for Precise Orbit Determination (POD) of the Metop spacecraft. However, the GRAS navigation measurements can be used to monitor the electron content above the spacecraft. The use of GPS navigation measurements from a LEO spacecraft have been demonstrated with the CHAMP mission (Jakowski et al., 2002; Heise at al., 2002). Because Metop orbit height is 840 km, GRAS is almost perfectly located to monitor the plasmasphere with very little impact from the ionosphere. Combining GRAS data with TEC estimates from ground based GPS measurements allows potentially separation of the contributions of the plasmasphere and ionosphere to the TEC estimates. This would be very useful for plasmasphere and ionosphere model validation.

The characteristics of the GRAS mission supporting the use of the navigation data for space weather monitoring include:

- All data and level 1 data products are disseminated in NRT (2 h 15 min from the measurement) to operational users.
- All raw data and level 1 products are permanently archived and made available to the users via EUMETSAT archive.
- Continuity of the data for 15 years => data time series will cover a complete solar cycle.

- Carefully characterised and fully documented receiver.
- Fully documented ground processing (including the measurement data reassembly and instrument corrections).
- All measurements are supported by ground based GPS measurements for clock correction (if necessary).
- Accurate GPS and Metop orbit vectors are provided as part of the measurement data.

Finally, Metop satellites also contain a Space Environment Monitor (SEM-2) instruments that provide information about the the intensity of the Earth's radiation belts and the flux of charged particles at the Metop altitude.

Due to the measurement geometry the use of either the occultation or the navigation data from GRAS for ionosphere or plasmasphere monitoring will require assimilation of the data into a suitable model and combining the data with other measurement data (Stankov et al., 2003; Kersley et al., 2005).

Conclusions

EPS GRAS is a radio occultation sounding mission designed to provide meteorological data for operational NWP applications. The measurement data provided by GRAS can be used to estimate the TEC along the signal propagation path. The derivation of the TEC estimated from LEO GPS measurements has been demonstrated with data from the CHAMP satellite mission.

The GRAS occultation data is only provided when the ray path tangent height is below 80 km from the Earth surface. This is a serious limitation for the use of this data for space weather applications. However, the GRAS instrument is almost ideally located to measure the plasmasphere with very limited impact from the ionosphere. When GRAS measurements are combined with ground based TEC estimates, this provides a possibility to separate the impact of the plasmasphere and ionosphere. This is potentially a very useful data set in validation of plasmasphere and ionosphere model validation.

The GRAS receiver will provide data over the 15 years of the EPS mission. The GRAS receiver hardware and software are both well characterised. The measurement data will be disseminated in NRT to the operational users and made available to other users via the EUMETSAT permanent data archive.

References

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Table 1. GRAS product accuracy requirements.

		Level 1b products	Level 2 products	
		Total bending angle	Specific humidity	Temperature
Horizontal sampling		The average distance between individual soundings over a period of 12 h is less than 1000 km		
Vertical range		Sfc – 80 km	Sfc – 100 hPa	Sfc – 1 hPa
Vertical sampling[1)]	0 – 5 km	2 - 5 Hz	0.4 – 2 km	0.3 – 3 km
	5 – 15 km		1 – 3 km	1 – 3 km
	15 – 35 km		-	1 – 3 km
	35 – 50 km		-	1 – 3 km
RMS accuracy[2)]	0 – 5 km	1 µrad or 0.4 %[3)]	0.25 - 1 g/kg[4)]	0.5 – 3 K
	5 – 15 km		0.05 - 0.2 g/kg[4)]	0.5 – 3 K
	15 – 35 km		-	0.5 – 3 K
	35 – 50 km		-	0.5 – 5 K
Timeliness		2 h 15 min	3 h	3 h

[1)] After noise filtering.

[2)] With no systematic biases.

[3)] Whichever is greater.

[4)] Equivalent to a requirement of 5% in Relative Humidity.

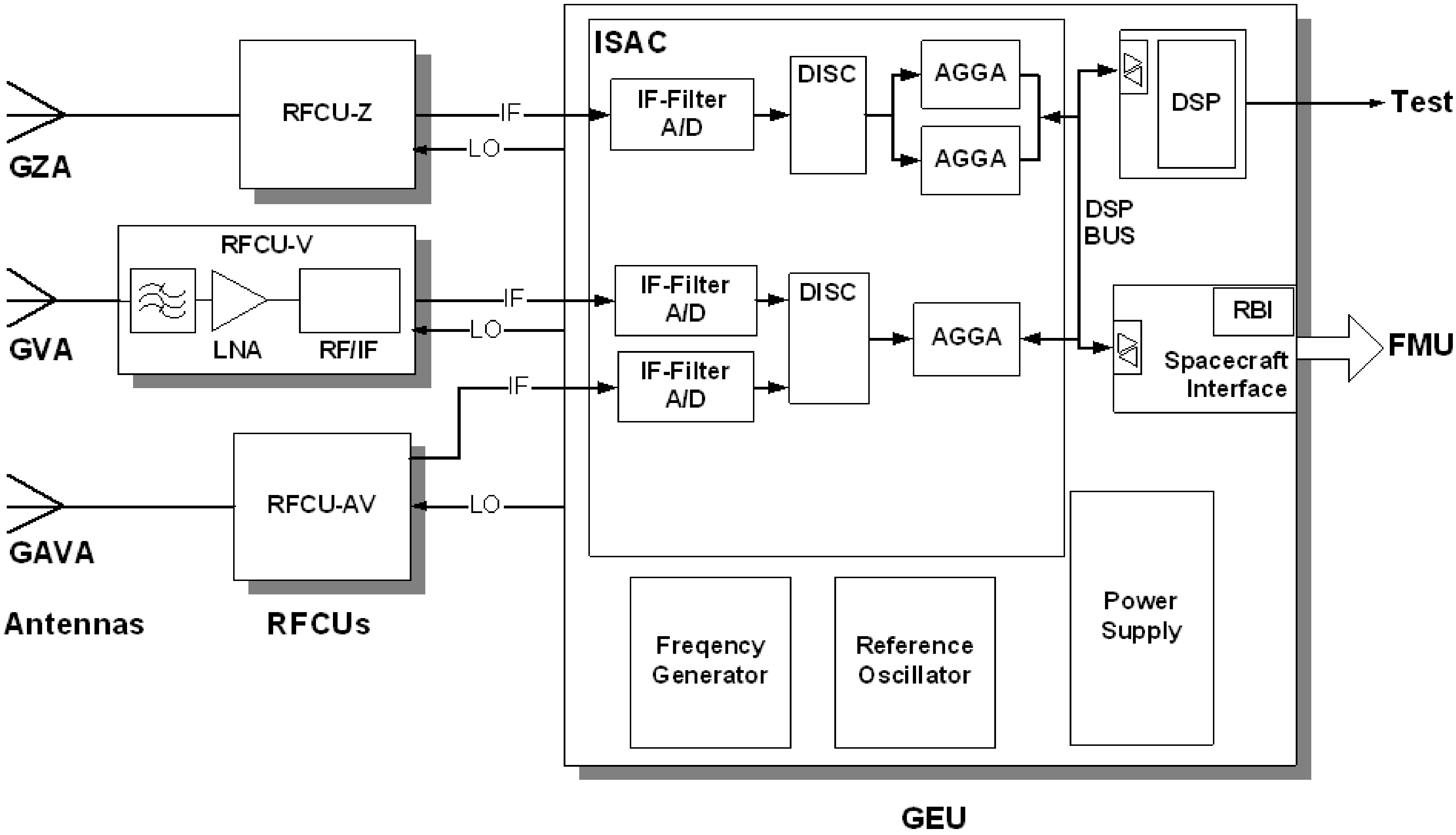

Figure 2. A block diagram of the GRAS receiver.

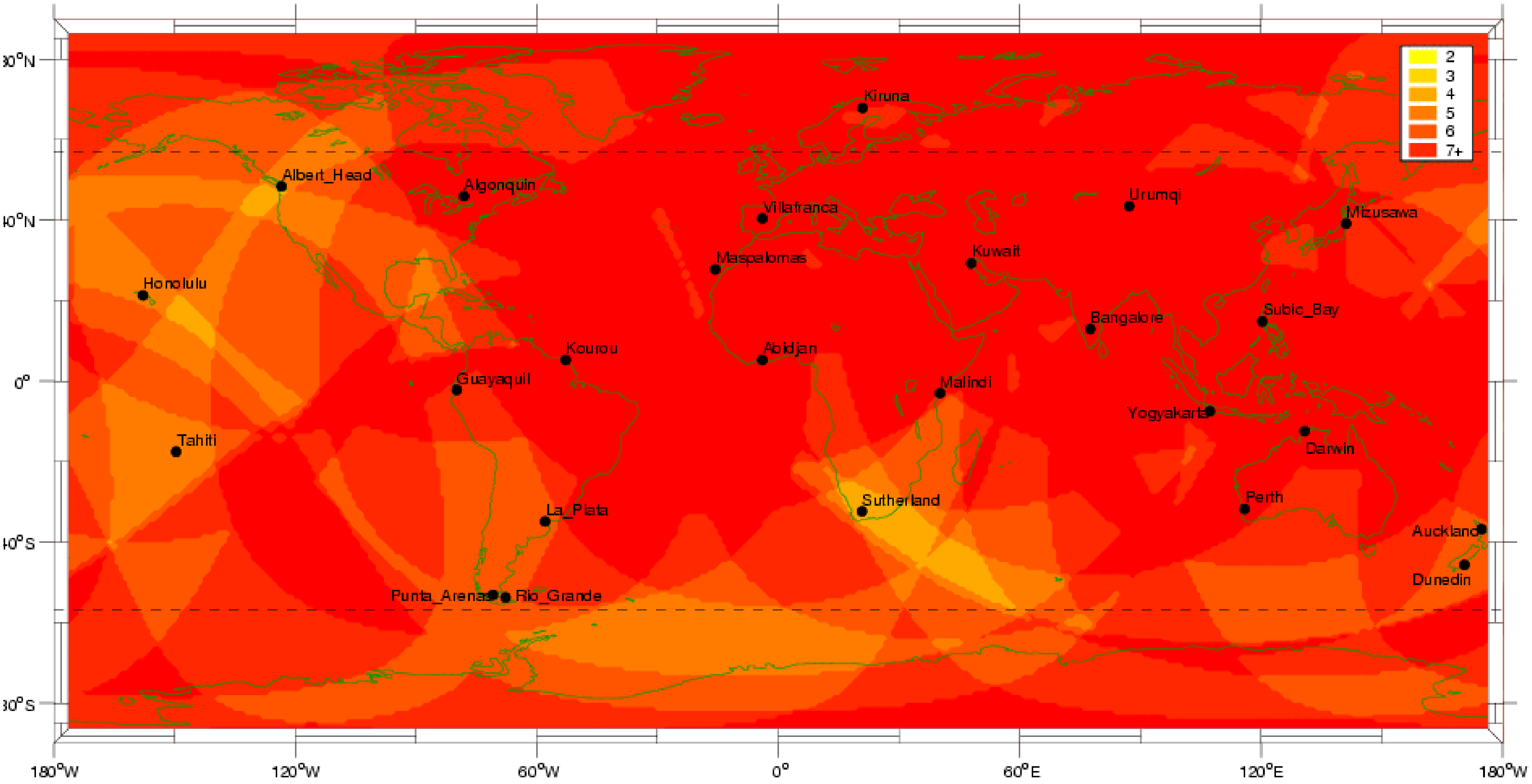

Figure 3. A map of the provisional GRAS GSN network. The colors indicate the number of the ground stations that have visibility to a GPS satellite above those coordinates. 15° elevation cut off limit has been used in the visibility calculation.