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Prepared by IROWG
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STATUS OF THE GLOBAL RADIO OCCULTATION OBSERVING SYSTEM

In response to CGMS Action 39.03: IROWG to review the status of the global RO system and report to CGMS-40.

Prepared by IROWG (http://www.irowg.org)

The current and future Radio Occultation (RO) observing system is presented, focussing on the period up to the year 2027. There are about 2100 occultations per day available for assimilation (July 2012), where more than 650 come from an operational satellite (Metop-A), and the remainder is provided primarily by the COSMIC-1/FORMOSAT-3 constellation (about 950). The occultations provided by COSMIC-1/FORMOSAT-3 are decreasing, with current levels about 60% below peak level, temporarily this has even gone down to about 700 occultations per day over the last months.

An observational data gap is identified between about 2012/13 (COSMIC-1/FORMOSAT-3 assumed ceased) and at least 2016 (earliest date when the approved COSMIC-2/FORMOSAT-7 mission can provide low latitude data). There will likely be 2 Metop satellites providing about 1300 occultations per day in this period - but these will have no full diurnal coverage since they are in a sun-synchronous orbit with a 09:30 Equator crossing time.

There are no other operational mission planned which would cover this gap. For that reason efforts should be made to bridge it with available research or commercial missions. In the longer term however, a fully operational observing system is needed, providing at least 10000 occultations per day.

Several options exist to fill the data gap, one is to provide data from the ROSA (Radio Occultation Sounder for Atmosphere) instrument in NRT (Near Real Time), since three instruments are already flying on different research missions. Two of the three missions have already some NRT support available. The three ROSA receivers could provide up to 1300 occultations per day, however some issues with the tracking of the second GPS frequency need to be addressed urgently. Additionally, there are (a) the Chinese FY-3C satellite with a potential of about 500 occultations per day (RO is included for research purposes), and (b) the planned commercial CICERO constellation, offering data-buy options (assuming it is launched on time and governmental funding is available for purchase).

Recommendation proposed: Establish support of research missions to allow NRT streams, establish long term continuity plan for operational RO data.

Status of the global Radio Occultation observing system

1 INTRODUCTION

The current RO (Radio Occultation) constellation is summarized in Figure 1. Launch and operation schedules are based on WMO (World Meteorological Organisation) information provided in the Dossier on the Space-based component of the GOS **[1]**, as well as information gathered from the IROWG (International Radio Occultation Working Group) researchers involved in the various missions, and from more recent available publications. An attempt has been made to distinguish missions as:

- truly operational
- research but with NRT (Near Real Time) access
- pure research that could provide NRT access with dedicated infrastructure
- other missions that do not fall into the other 3 categories for different reasons.

These 4 categories are discussed further in the sections below.

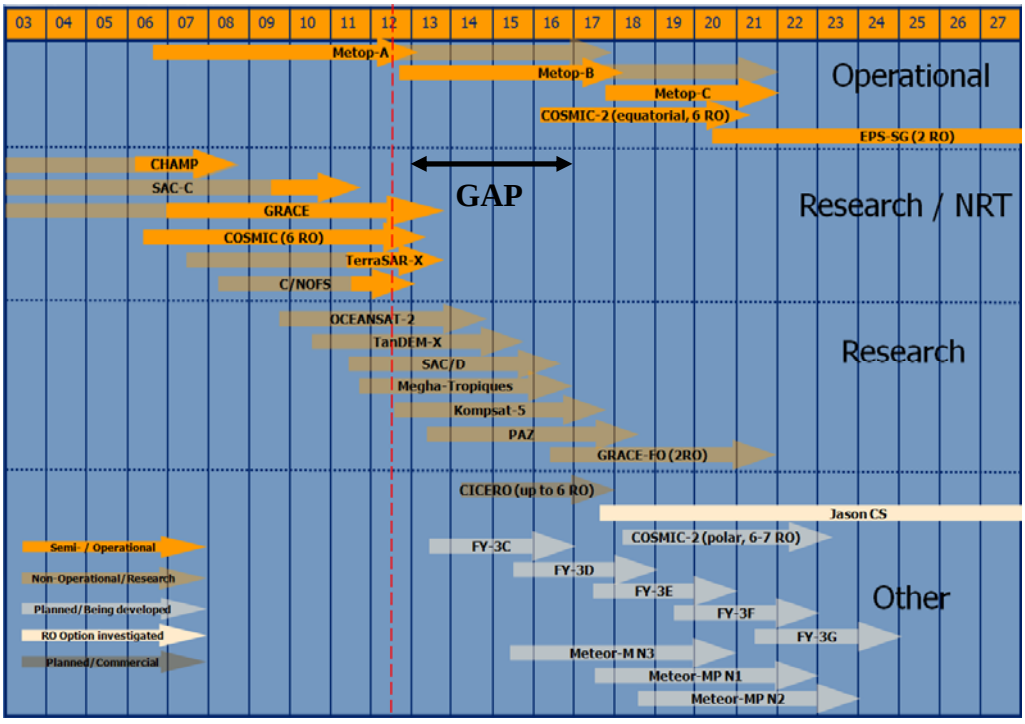

Figure 1 Past, present, and future radio occultation mission overview. Missions are separated into truly operational, research missions that provide NRT (Near Real Time) data, research missions that could provide NRT data but are however currently lacking the infrastructure, and other missions. Constellations are only included as one bar. Potential observation gap is indicated. Red line indicates now. For further details see text.

Currently (July 2012), there are about 2100 occultations per day available on average in NRT **[2]**. Truly operational occultations are about 650 (by the EUMETSAT Metop-A satellite), whereas the remaining are provided primarily from COSMIC-1/FORMOSAT-3 (US-Taiwanese constellation), and to a lesser extent from TerraSAR-X (German), GRACE (US-German), and C/NOFS (US). COSMIC-1/FORMOSAT-3 and C/NOFS data are provided in NRT by UCAR (University Corporation for Atmospheric Research, Boulder, CO, US), and TerraSAR-X and GRACE by GFZ (German Research Centre for Geosciences, Potsdam, Germany).

The COSMIC-1/FORMOSAT-3 data availability is fluctuating strongly (see Figure 2) and shows already strong degradations. Currently, the COSMIC-1/FORMOSAT-3 team is trying to get as many occultations out as possible, e.g. by workarounds where satellites are dormant while in the Earth shadow (since batteries on-board are degraded) and reactivating them once enough energy is collected on the solar arrays.

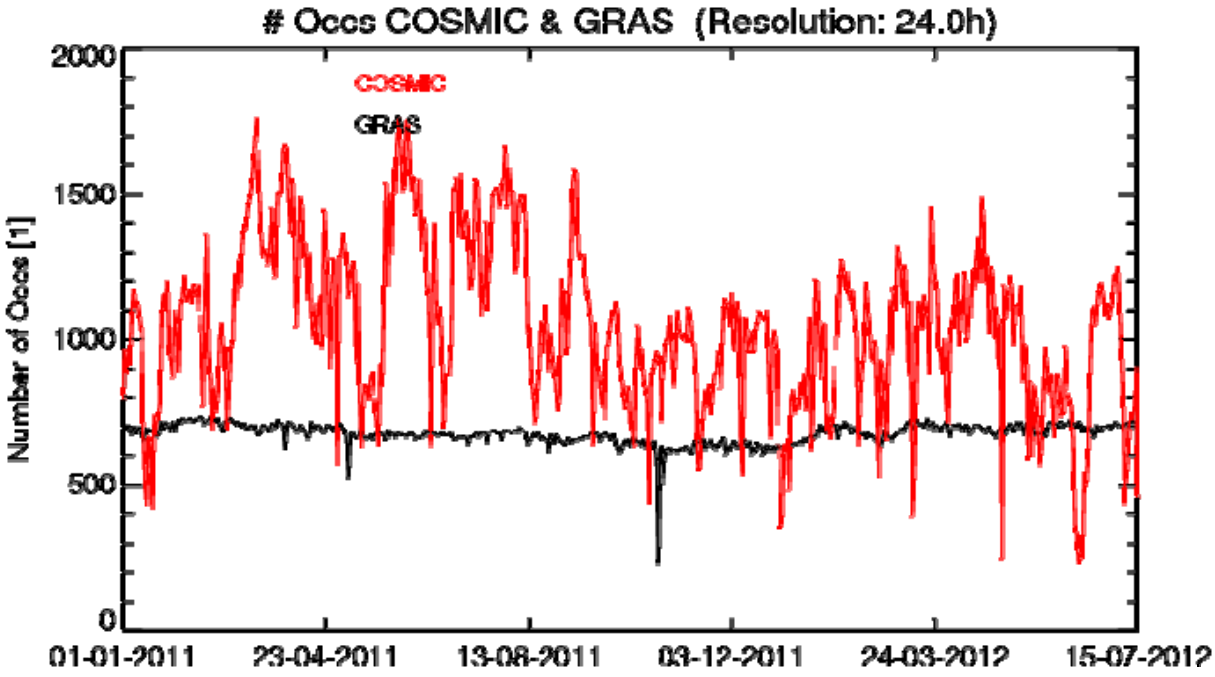

Figure 2 Daily number of occultations from GRAS and COSMIC-1/FORMOSAT-3 for the period 01 January 2011 to mid-July 2012. GRAS shows the impact of a payload switch-off in October 2011.

The analysis of Figure 1 and Figure 2 suggests the risk of an observation gap starting about 2012/13 up to at least 2016, when low latitude observations can be expected from the COSMIC-2/FORMOSAT-7 launch of 6 satellites into a low inclination (24 degrees) orbit. At higher latitudes, the observation gap extends even further.

Once the COSMIC-1/FORMOSAT-3 constellation has ceased to exist, the number of available NRT occultations per day will decrease to about 1300 from the 2 operational Metop satellites (assuming both Metop satellites are healthy), plus potentially about 400 occultations per day from other Research/NRT missions (should they still provide data). This will provide

limited diurnal cycle coverage since both Metop satellites fly in the same mid-morning orbit. Various Research missions exist or are planned which might fill this observation gap, namely the 3 ROSA receivers (flying on Oceansat-2, SAC/D, Megha-Tropique), the FY-3C satellite, and the commercial CICERO mission (planned late 2014).

The latest IROWG workshop in March/April 2012 recommends an operational availability of at least 10000 occultations per day for assimilation into NWP, based on NWP (Numerical Weather Prediction) impact experiments **[3]**. It additionally recognises that research missions do not provide a substitute for operational data. They are however able to bridge the data gap and all efforts should be made to bring this research data into the NRT stream.

2 RADIO OCCULTATION MISSIONS

2.1 Operational

Truly operational missions are defined here as missions that have strict requirements on the number of provided occultations and which have an overall re-launch strategy. Currently, only the EPS (EUMETSAT Polar System) with its Metop satellites can be considered truly operational with respect to RO observations, providing with one satellite about 650 occultations per day. Metop satellites all serve the same mid-morning orbit, thus diurnal coverage is limited. As long as two Metop-satellites are healthy, they can provide about 1300 occultations per day.

An update of the GPS signal structure at the end of 2020, as announced by the GPS authorities **[4]**, would make observations from Metop impossible, as the GRAS instrument is unable to receive the new frequencies. This may in particular limit the use of the GRAS instrument on Metop-C.

The COSMIC-2/FORMOSAT-7 program has recently been approved and is funded for the first set of 6 RO instruments, which are planned to be launched into a low latitude/inclination (24 degrees) orbit. These 6 satellites have an operational requirement of 4000 occultations per day.

The follow on to the EPS program (-SG, Second Generation) is currently assuming 2 RO instruments flying at the same time, with an operational requirement of at least 1000 occultations per day and satellite. It is planned for the mid-morning orbit, as the current Metop satellites.

2.2 Research / NRT

There are four research missions that currently provide NRT data, in total about 1300 to 1400 occultations per day. NRT here does generally mean a “best effort” service, thus data is sometimes not available within 3 hours after observation (this affects primarily the C-NOFS data, while COSMIC-1/FORMOSAT-3, TerraSAR-X, GRACE are mostly available within 3 hours). The majority of the observations is by the COSMIC-1/FORMOSAT-3 mission (~950). TerraSAR-X currently provides about 200 rising events but could provide in addition the same amount in setting events; however, the related antenna / data stream is currently not activated. The number of profiles observed by C/NOFS is expected to be increased in the near future, to potentially about 200 occultation per day (currently about 130 are provided). The GRACE mission in addition provides about 150 occultations per day.

2.3 Research

Four further research missions are currently flying, which could provide data in NRT. Note however that:

- TanDEM-X (German) flies very close to TerraSAR-X, thus all occultations are closely collocated. They could however be very valuable for inter-satellite evaluation of e.g. different on-board software algorithms, and for climate sensitivity studies of RO;
- Three missions carry the ROSA receiver, where no full evaluation of the data quality of this receiver has been performed yet. First test data from Oceansat-2 has however been analyzed, showing promising performance but also problems with tracking the GPS L2 frequency that need to be addressed.

The ROSA data does offer an attractive option for filling the data gap since all 3 instruments are already flying, and 2 (Oceansat-2 (India), Megha-Tropique (India-France)) also already have some NRT support. Support of SAC-D (Argentine-US) is discussed. In total, these 3 missions could provide up to 1300 occultations per day.

Planned research missions include the Spanish PAZ satellite (514km orbit, 06:00 Equator crossing time, includes horizontally/vertically-polarized RO antenna to attempt sensing of intense precipitation events), it is planned to provide NRT data (about 200 occultations per day), and the Korean KOMPSAT-5 (550km orbit, 06:00 Equator crossing time, about 250 occultations per day, NRT options are investigated). Further into the future, and only partly suited for gap filling are the GRACE-FO satellites (485km orbit, 89 Degree inclination) that could also provide options for NRT RO data.

2.4 Other

The "Other" category encompasses missions that do not fall under the categories above for the following reasons: (a) being of commercial nature (CICERO); (b) investigating an RO option as a secondary mission (Jason-CS); (3) unclear funding situation (COSMIC-2/FORMOSAT-7, polar); (4) fully new RO receiver development (FY-3X, Meteor).

CICERO: This would be a commercial provider of RO data. It should be noted that there are currently no mechanisms in place to "buy" data for the global NWP community. CICERO plans to launch CICERO-1 in 2014, with an operational phase from 2014-2017. It includes 2 satellites, sun synchronous polar orbit, providing more than 900 GPS occultations per day, with plans to launch more in the future. Note also that other satellite operators are discussing to build up a data-buy constellation for RO data.

Jason-CS: This is the continuation of the Jason satellites for ocean altimetry. It is an attractive possibility to include RO since it is (a) operational; (b) already includes a POD (Precise Orbit Determination) receiver that is easily upgraded to include RO. First assessments estimate a potential of up to 1000 occultations per day based on several GNSS (Global Navigation Satellite Systems) observed. Investigations to add RO as a secondary mission are ongoing.

COSMIC-2/FORMOSAT-7 (polar): The second batch of COSMIC-2/FORMOSAT-7 receivers for polar orbit is planned with at least 6 RO receivers, all observing several GNSS. It could provide at least 4000 occultations per day. Funding is currently not secured for this 2nd set of 6 COSMIC-2/FORMOSAT-7 satellites.

FY-3X: A new Chinese RO instrument development that is planned to be flown among other instruments on the FY-3X satellites, capable of tracking GPS and the Chinese BeiDou GNSS

signals. It has been introduced from FY-3C (2013 – 2016) onwards. The RO instrument on FY-3C is planned to be a research mission, the later ones are planned for operational use. The FY-3X satellites could provide each at least 500 operational occultations per day.

Meteor: A new Russian RO instrument development that is planned to be flown among other instruments on the Meteor satellites. It is capable of tracking GPS and GLONASS, providing possibly at least 1000 operational occultations per day and satellite.

3 CONCLUSIONS

The current and future Radio Occultation (RO) observing system has been presented, focussing on the period up to the year 2027. There are currently about 2100 occultations per day available for assimilation (July 2012), where more than 650 come from an operational satellite (Metop-A), and the remainder is provided primarily by the COSMIC-1/FORMOSAT-3 constellation (about 950). The occultations provided by COSMIC-1/FORMOSAT-3 are decreasing, with current levels about 60% below peak level, temporarily this has even gone down to about 700 occultations per day over the last months.

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References

[1] WMO Dossier on the Space-based component of the GOS, available at: http://www.wmo.int/pages/prog/sat/gos-dossier_en.php

[2] ROM SAF Monitoring Pages, available at: http://www.romsaf.org/monitoring/

[3] Report from the 2nd International Radio Occultation Workshop, CGMS-40 EUM-WP-01

[4] Federal register Vol. 73, No. 185, pp.54792-54793; available online at http://www.gps.gov/technical/codeless/2008-FRN.pdf