Prepared by EUMETSAT
Agenda Item: WGIII/2.2
Discussed in Plenary/F1.5.2,
WGII/Info, WGIII/2.2

STATUS OF EUMETSAT STUDY ON RADIO OCCULTATION SATURATION WITH REALISTIC ORBITS

In response to CGMS actions *CGMS-41 WGIII A41.36* and *CGMS-42 WGIII/2.2 A42.06*. The provided information is also relevant with respect to Action *Plen IV.4, 40.06* (WMO to coordinate impact studies) and Recommendation *WGIII/2.1 (CGMS-41) WGIII/2.2 (CGMS-42) R41.14* (address the anticipated or potential gaps).

First results of a study currently running at ECMWF are presented. The study looks at saturation effects when assimilating RO observations, where RO observation positions are simulated using realistic LEO and GNSS orbits. This study is thus a refinement of an earlier study that assumed RO occultations to be randomly distributed in space and time.

An Ensemble of Data Assimilation (EDA) approach, using 10 (+1) members in a 4D-Var modern NWP system, was used. Within this study, the following 3 main issues are addressed:

1. Refine the earlier, random occultation position, study with realistic future satellite orbits;
2. Assess which observation constellation is best suited to achieve the best distribution in space and time;
3. Provide guidance on RO instrument deployments on future LEO satellites.

Regarding Point 1, it has been found that although realistic orbits affect occultation positions significantly, a modern NWP system can still effectively use any observations, thus the impact of realistic orbits is small. Regarding Point 2, the more observations are available, the lower forecasting spreads are found; constellations that provide most observations at low latitudes are particularly useful, since here, per area the least occultations are available from polar orbiting RO instruments and the model errors are the largest. Regarding Point 3, it again can be concluded that the more observations, the lower the forecast spread, even if additional instruments are provided in orbits that are already populated with RO instruments.

The study itself is formally finishing by August 2015, with a final presentation at EUMETSAT about 1 month earlier. Underlying EDA runs are already completed, they have been run over the last year. Shown results and discussions, conclusions are thus also entering the final report. The study results have also been presented and discussed at IROWG-4 in April 2015.

Action/Recommendation proposed: CGMS to take note.

Status of EUMETSAT Study on Radio Occultation Saturation with realistic Orbits

1 INTRODUCTION

This Working Paper reports the status of the EUMETSAT funded study: *Impact of different Radio Occultation Constellations on NWP and Climate Monitoring.* The study is a refinement of an earlier, ESA funded, study: *Estimating the optimal number of GNSS radio occultation measurements for Numerical Weather Prediction and climate reanalysis applications.* Both studies were/are carried out by the European Centre for Medium-Range Weather Forecasts (ECMWF), looking into the impact of future RO observations from multiple Global Navigation Satellite Systems (GNSS).

The first preliminary results from the EUMETSAT study were already reported at CGMS-42 (WGIII/2.2, EUM-WP-34). The study itself will formally finish in August 2015; all simulation experiments are however completed and have already been at least partially analysed. Recently, the applied diagnostics have been thoroughly revised, therefore the presentation of the results might be slightly different here, however the main conclusions of the work will be unchanged. The preliminary study results have also been reported at the IROWG-4 meeting (http://irowg.org/workshops/irowg-4/) in April 2015.

Both radio occultation (RO) “Saturation Studies” were launched in order to evaluate whether the impact of such observations in modern Numerical Weather Prediction Systems (NWP) saturate as the RO observation number increases. Initially it was speculated that a few hundred occultations per day would provide all the information required in an NWP system, however the availability of several thousand occultations has shown that no "saturation" effect is visible in an NWP model[1,2], hence more occultations will provide added information to an NWP model. Whether there is a saturation point can be assessed by various NWP tools. For instance Observing System Simulation Experiments (OSSEs)[3] are optimal tools to estimate the impact of a future observing system. OSSEs are analysing the impact of simulated measurements (i.e. all the observations are simulated based on an independent nature run of an NWP model) including the future observations in question. The drawback of OSSEs is that they are computationally extremely expensive and requires time consuming efforts to simulate all observations currently assimilated in NWP. Observing System Experiments (OSEs) are popular techniques to assess the impact of existing real observations. In an OSE the entire present observing system is used and a control experiment without and an experiment with the studied observations are carried out. The performance of the control and the experiment is compared and the quality differences between the two runs are attributed to the impact of the additional observations used in the experimental run. OSEs are expensive since reasonably long data assimilation experiments should be run in

[1] Poli, P., S. Healy, F. Rabier, and J. Pailleux, 2008: Preliminary assessment of the scalability of GPS radio occultations impact in numerical weather prediction. Geophys. Res. Lett., 35 (23), L23 811, doi:10.1029/2008GL035 873

[2] P. Bauer, G. Radnóti, S. Healy, C. Cardinali, 2014: GNSS radio occultation constellation observing system experiments, Mon. Wea. Rev., 142, 555–572. doi: http://dx.doi.org/10.1175/MWR-D-13-00130.1

[3] Masutani, M., et al., 2010: Observing System Simulation Experiments. Data Assimilation: Making sense of observations, B. K. W. Lahoz and R. Ménard, Eds., Springer, 647-679

order to obtain statistically robust impact conclusions. In an OSE real and simulated observations cannot be mixed, making the impact estimation of a future observing system difficult. More recently D. Tan[4] suggested using the Ensemble of Data Assimilations (EDA) approach for impact assessment. Here, only the new observations are simulated and added to the other operationally assimilated observations (the real and simulated observations can be used together). Consequently, the pre-processing of the assimilated data is much more straightforward and simple than that for the OSSEs. The computation costs are high and are related to the fact that EDA is executing more data assimilation cycles (i.e. ensemble of data assimilations) simultaneously. The spread of the ensemble members around the mean is related to the theoretical estimate of the analysis and short-range forecast error statistics, provided the observation and background error statistics of the assimilation system are correct.

Both RO "Saturation Studies" are thus based on an EDA analyses approach. As mentioned above technically these are not OSSEs because they only use simulated RO data, while all other data are real. Simulated observations for deriving the EDA are generated from high resolution NWP fields, using a 2D bending angle operator. Random perturbations are added onto these error free simulations that are in line with the assumed observation error characteristics. The ESA funded study also showed that a 10 member ensemble is sufficient to estimate the spread and consequently the error statistics, and that the assimilation system stabilizes after a few days - thus it is sufficient to run the 10 member (plus the control) EDA for a period of 2 to 3 weeks.

The first, ESA funded, study evaluated whether saturation is observed by randomly distributing RO observations in time and space, locations are thus evenly distributed in space and time. It found that even with 128,000 occultations per day, no saturation was evident[5]. The relative improvement per added occultation is however decreasing, thus 16,000 occultations per day give about 50% of the improvement found for 128,000 observations/day. The study results led to recommendations from IROWG[6] and by WMO[7] to provide at least 10,000 GNSS-RO observations operationally per day.

Addressing the random distribution limitation of the ESA funded study, EUMETSAT initiated a study where RO observations were bound to actual orbits. The main purpose of the study reported here is:

1. Refine the earlier ESA study with realistic future satellite orbits;
2. Assess which observation constellation is best suited to achieve the best distribution in space and time;
3. Provide guidance on RO instrument deployments on future LEO satellites.

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[4] Tan, D. G. H., E. Andersson, M. Fisher, and I. Isaksen, 2007: Observing-system impact assessment using a data assimilation ensemble technique: application to the ADM-Aeolus wind profiling mission. Quart. J. Roy. Meteorol. Soc., 133, 381-390.

[5] F. Harnisch, S. B. Healy, P. Bauer and S. J. English, 2013: Scaling of GNSS radio occultation impact with observation number using an ensemble of data assimilations, Mon. Wea. Rev., 141, 4395–4413. doi: http://dx.doi.org/10.1175/MWR-D-13-00098.1

[6] Report from the 3rd International Radio Occultation Workshop, CGMS-42 IROWG-WP-01

[7] Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP), WMO Integrated Global Observing System, Technical Report No. 2013 - 4

2 OBSERVATION SCENARIOS INVESTIGATED

Table 1 defines the investigated observation scenarios. It is based on an assessment of the possible future RO observing system, taking into account material provided by IROWG[8]. It has been updated and refined throughout the study, thus the Scenario numbering is not continuous any longer. The info column gives some further information on what is investigated within a certain scenario.

The following orbits based on the current, operational observation system were assumed (LST: Local Solar Time):

1. descending node at 9:30 LST, 800km orbit (mid-morning, EPS, EPS-SG - like)
2. descending node at 2:00 LST, 800km orbit (night, NOAA, FY-3 series - like)
3. descending node at 6:00 LST, 800km orbit (early morning, FY-3, research satellites - like)

In addition, the following LEO constellations are considered:

- constellation of 6 RO at 520km, inclination 24 Degrees (COSMIC-2 Equator - like)
- constellation of 6 RO at 800km, inclination 72 Degrees (COSMIC-2 Polar - like)

Scenario 15 in addition assumes that some LEO satellites at 800km are carrying RO instruments as well. The Equator Crossing Times are based on the 3 main peaks of planned, operational, concept satellites as derived from the WM OSCAR[9] data base. A histogram of this Equator Crossing Time distribution is shown in Figure 1.

Scenario	LEO Satellites	GNSS Satellites	Info
1	None	None	Consistency check with earlier study, 8,000 random profiles
4	EPS-SG A1 EPS-SG B1	GPS Galileo	2 EPS-SG satellites, about 2,800 occultations/day
6	EPS-SG A1 RO-Night	GPS Galileo	2 RO satellites, about 2,800 occultations/day; check 2 RO in one orbit plane to 2 RO in different ones
7	EPS-SG A1 EPS-SG B1	GPS Galileo GLONASS BeiDou	2 EPS-SG satellites, about 5,100 occultations/day; maximum number of occultations in one orbit, is a saturation visible in one orbit?
8	EPS-SG A1 EPS-SG B1 COSMIC-2 Eq	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, about 10,500 occultations/day; check impact of few occultations at high/mid latitudes
9	EPS-SG A1 EPS-SG B1	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, 6 COSMIC-2 Polar

[8] Status of the Global Observing System for Radio Occultation (Update 2013), IROWG/DOC/2013/02, available at: http://irowg.org/wpcms/wp-content/uploads/2013/12/Status_Global_Observing_System_for_RO.pdf
[9] WMO Observing Systems Capability Analysis and Review Tool (OSCAR), available at: http://www.wmo-sat.info/oscar/spacecapabilities

	COSMIC-2 Eq COSMIC-2 Po		satellites, about 18,000 occultations/day
10	EPS-SG A1 EPS-SG B1 RO-Night RO-Early Morn.	GPS Galileo	4 RO satellites, about 5,400 occultations/day; check 4 RO coverage compared to COSMIC-2 Polar, Equator
11	EPS-SG A1 EPS-SG B1 COSMIC-2 Eq RO-Night RO-Early Morn.	GPS Galileo	10 RO satellites, about 13,300 occultations/day; check how 4 sun-synchronous RO satellites compensate for no COSMIC-2 Polar
12	None	None	Consistency check with earlier study, 16,000 random profiles
13	EPS-SG A1 EPS-SG B1 Sentinel-6	GPS Galileo	2 EPS-SG satellites, one Sentinel-6 (Jason-CS) satellite, about 3,800 occultations/day
14	EPS-SG A1 EPS-SG B1 COSMIC-2 Eq COSMIC-2 Po Sentinel-6	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, 6 COSMIC-2 Polar satellites, one Sentinel-6 (Jason-CS) satellite, about 19,000 occultations/day
15	EPS-SG A1 EPS-SG B1 COSMIC-2 Eq COSMIC-2 Po LEO-1 (06:00) LEO-2 (10:30) LEO-3 (13:30) Sentinel-6	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, 6 COSMIC-2 Polar satellites, Sentinel-6 satellite, one early morning LEO, one in close by EPS-SG orbits, one in early afternoon orbit, about 22,800 occultations/day

Table 1 Investigated Scenarios

Note that for this study it was assumed that all GNSS provide occultation data with a quality similar to the GPS based one.

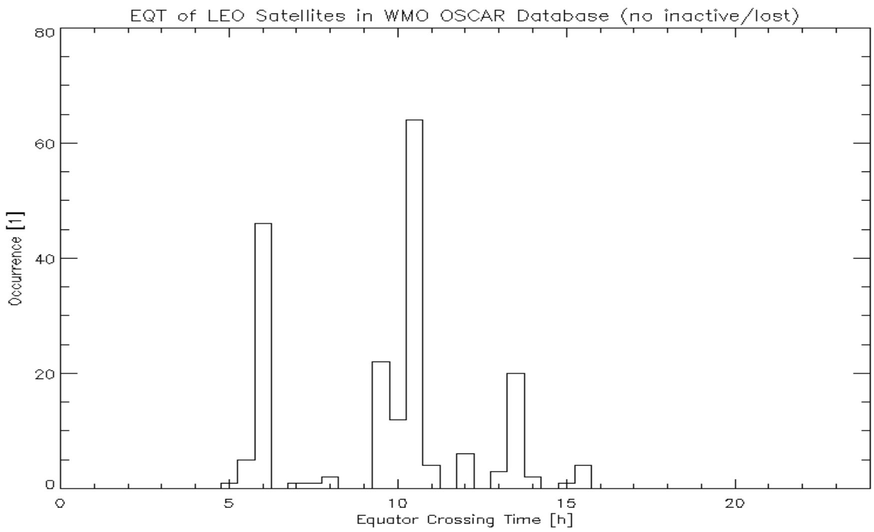

Figure 1 Histogram of LEO satellites over Equator Crossing Time (EQT), taken from WMO OSCAR data base.

The impact of sun-synchronous orbits on the LST of observation for Metop-A is shown in Figure 2. Figure 3 shows the number of occultations per latitude band, also normalized to the area per latitude band.

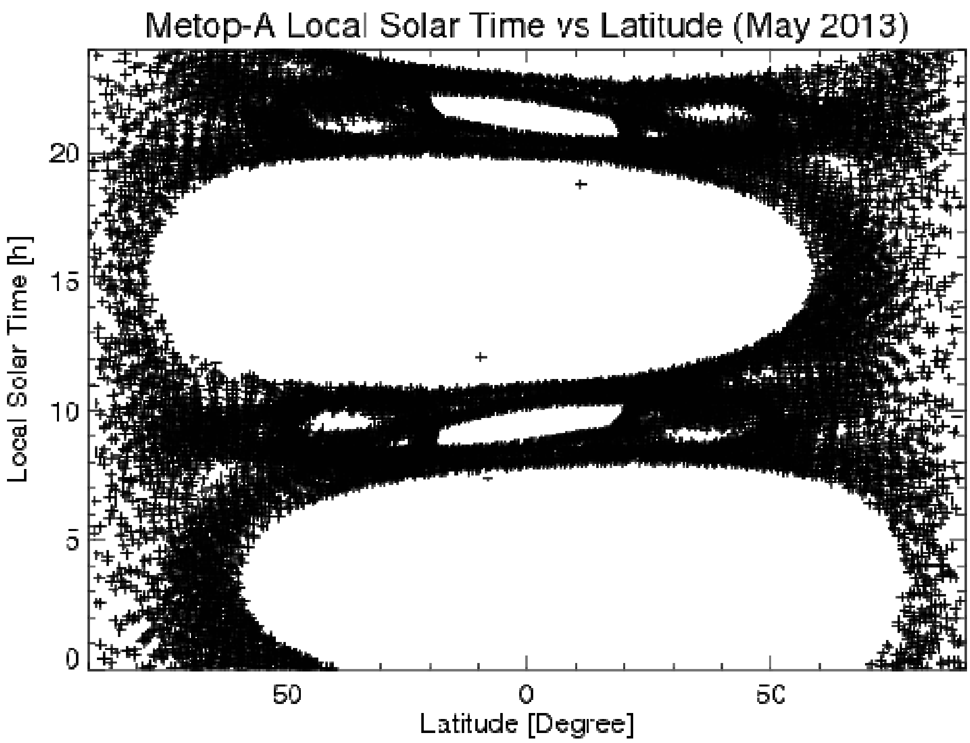

Figure 2 Metop-A local solar time versus latitude (May 2013 data).

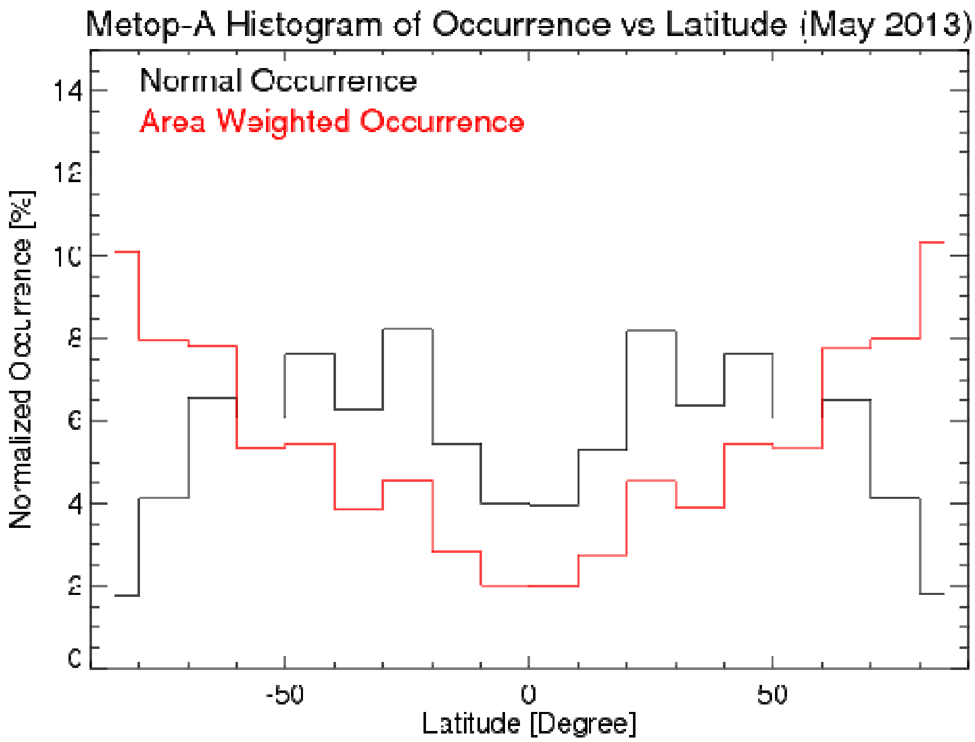

Figure 3 Metop-A histogram of occurrence versus latitude, in red the area weighted occurrence (May 2013 data).

The current RO observation system provides about 2,500 daily radio occultations in Near Real Time (NRT) for assimilation into NWP models. The data is mostly provided by GRAS on Metop-A and Metop-B, the COSMIC constellation, and several research satellites like TerraSAR-X, TanDEM-X, and GRACE. RO actually offers two pieces of information to the assimilation system: (1) temperature and humidity profile information; (2) an absolute anchor point for drifting radiance instruments.

3 THE OPERATIONAL IMPACT OF RO AT ECMWF

A short overview of the impact of RO assimilation at ECMWF is shown below. Figure 4 shows the reduction in temperature and height bias at 100hPa against radiosondes, when RO data was started to be operationally assimilated at ECMWF. Figure 5 shows the impact of various observing systems in terms of Forecast Error Contribution (FEC), which measures the contribution of observations to the reduction of the 24h forecast error. It is remarkable that RO has around 10% impact contribution in spite of the fact that their quantity is around 2-3%.

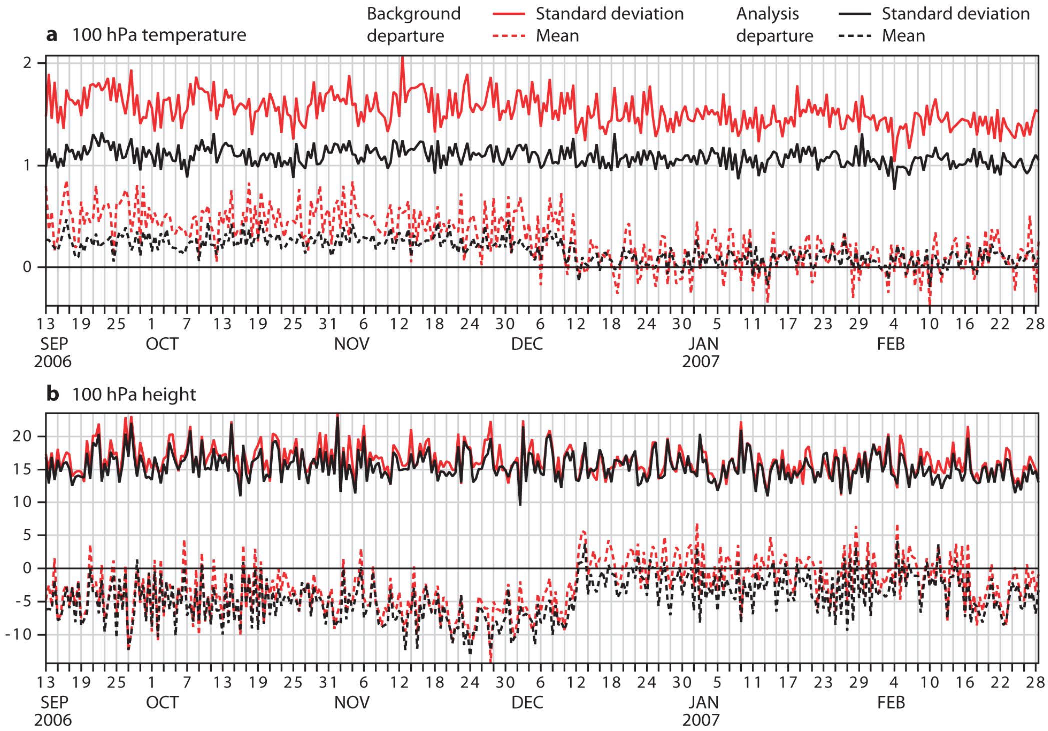

Figure 4 Time series of the mean and standard deviation of the ECMWF operational background and analysis departures for (a) temperature and (b) geopotential height radiosonde measurements at 100 hPa in the Southern Hemisphere. GNSS-RO was introduced on December 12, 2006.

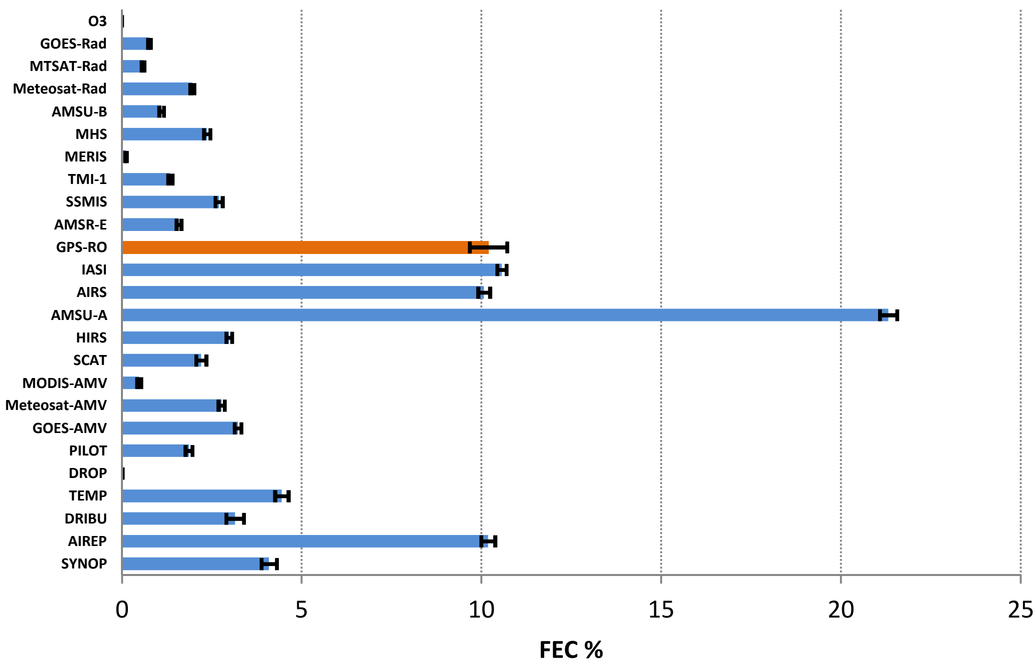

Figure 5 Impact (in %) of various observing systems operationally used (June 2011) at ECMWF for the global reduction of the short range forecast error.

4 EDA METHOD AND SETUP

The EDA is a well established method used for data assimilation; see for instance Žagar et al. 2005[10]; Isaksen et al. 2010[11], Bonavita et al[12,13]. A full description of the EDA method would clearly go beyond this working paper, so just the main qualitative aspects are summarised hereafter. The EDA aims to provide information on the analysis and short-range forecast error statistics (uncertainties) of the NWP model system, accounting properly for the main data assimilation error sources in the NWP system that come from the: (1) observations, (2) model background and (3) the model itself.

This is achieved by running an ensemble of independent 4D-Var data assimilation cycles (10 +1 within this study having the unperturbed and 10 perturbed assimilation cycles) and the ensemble of analyses and forecasts provides information on the analysis and forecast error statistics, which is quantified by the ensemble spread. It is important to emphasise that EDA estimates the analysis (forecast) uncertainty, which is related to the error statistics and not the error itself. It does depend on the assumed input error statistics and not on the actual ones, therefore it provides a realistic estimate of uncertainty if, and only if, the assumed input error statistics are realistic. The spread of the ensemble around the mean actually estimates the error variance of the analysis and short-range forecast. In practise, the EDA spread is computed from the 00 and 12 UTC analyses. Mostly temperature spread is computed since the largest impact is expected in temperature, but e.g. humidity and wind spreads are also provided. Generally the vertical spread profile is plotted. The regions used for averaging are global, Northern Hemisphere (NH) extra-tropics (N20-N90), Southern Hemisphere (SH) extra-tropics (S90-S20), tropics (S20-N20), NH polar (N60-N90), SH polar (S90-S60).

The investigated period spans the 1st to 25th of July 2008; the provided spread values are calculated after 10 days in order to have enough time for the stabilization of the spread values (in practise few days are sufficient for that). The EDA experiments run within this study generally use all operationally assimilated observations except the GNSS RO profiles (they are replaced by the simulated RO observations). Comparisons to the operational assimilation setup are however also made. The data assimilation setup of EDA uses 12-hourly (at 00 UTC and 12 UTC with assimilation window of 21-09 UTC and 09-21 UTC) 4D-Var analyses at T399 L91 resolution having two low resolution minimisations at T95 and T159, respectively.

Simulated bending angle measurements are generated for realistically distributed observation times and locations (latitude, longitude, limb-azimuthal angle) provided by EUMETSAT, using a 2D bending angle operator[14] and adding realistic noise.

[10] Žagar, N., Andersson, E. and M. Fisher, 2005: Balanced tropical data assimilation based on a study of equatorial waves in ECMWF short-range forecast errors. Q. J. R. Meteorol. Soc., 131, 987-1011

[11] Isaksen L, Bonavita M, Buizza R, Fisher M, Haseler J, Leutbecher M, Raynaud L., 2010: Ensemble of data assimilations at ECMWF, Technical Memorandum 636. ECMWF, Reading, UK.

[12] Bonavita M, Raynaud L, Isaksen L., 2011: Estimating background-error variances with the ECMWF Ensemble of Data Assimilations system: Some effects of ensemble size and day-to-day variability. Q. J. R. Meteorol. Soc. 37, 423–434.

[13] Bonavita M, Isaksen L, Holm E., 2012: On the use of EDA background error variances in the ECMWF 4D-Var. Q. J. R. Meteorol. Soc. 138, 1540–1559.

[14] Healy, S., J. Eyre, M. Hamrud, and J.-N. Thépaut, 2007: Assimilating GPS radio occultation measurements with two-dimensional bending angle observation operators. Quart. J. Roy. Meteorol. Soc., 133, 1213–1227.

5 EDA SPREAD RESULTS

5.1 Consistency check against earlier random distribution study

Two random scenarios were included in this refined study (scenarios 1 and 12 having 8,000 and 16,000 randomly distributed RO observations, respectively) in order to allow a cross validation against the earlier obtained random results. The EDA system used in the present study is not exactly the same than that of the ESA project since the EDA and the model itself had been improved. This means that the former and the present results are not directly comparable, but this consistency check provides a good idea about spread differences expected between the old and new systems. Otherwise, it should be kept in mind that the spread is the relative measure of information content; therefore it is not advisable to compare spread values produced with different EDA systems.

Figure 6 shows the temperature spread profiles for the 2 random scenarios, within the old and the updated ECMWF system. First of all it can be seen that the spread of the new system is smaller than that of the old indicating that there were improvements between the two studies. The most important aspect is the fact that the relative spread behaviour between the 8,000 and 16,000 experiments are unchanged, the assimilation of more observations provide significantly smaller spread (larger impact) although the spread differences are slightly smaller. Note that for instance at NH extra-tropics near to the top of the atmosphere (above 30 hPa) the old system behaves better, i.e. their spread is smaller than that of the new ones. Probably, this feature can be linked to changes in the tuning of the physical parameterisation schemes, which is less adequate in the new version for the 91 model levels used in the experiments (since the operational model switched to 137 levels in June 2013).

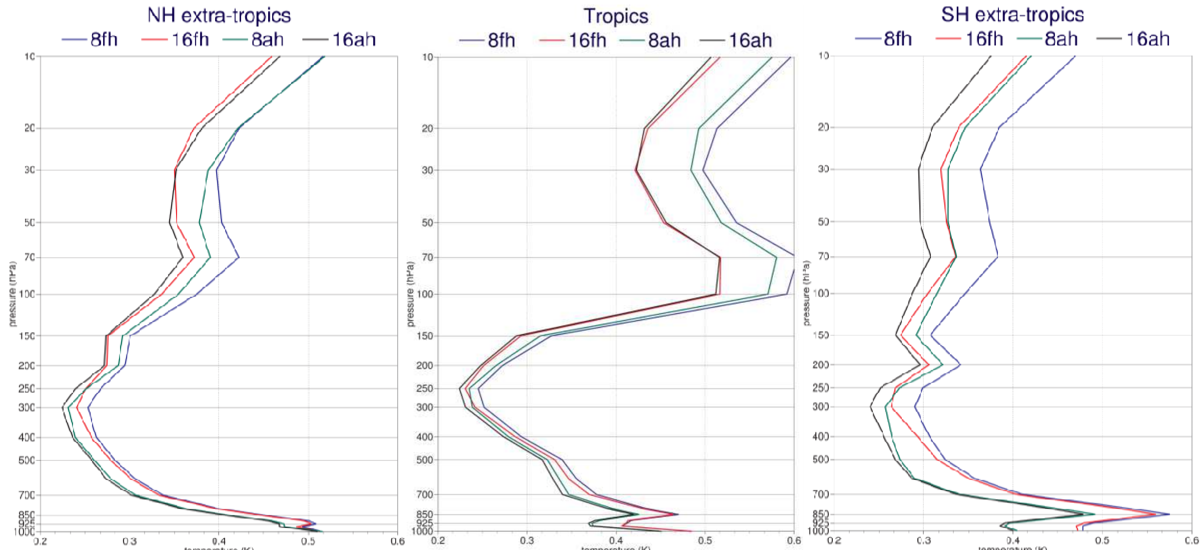

Figure 6 Comparison of temperature spread profiles for "old" (blue and red) and "new" (green and black) EDA results for 8,000 and 16,000 random RO distributions (Scenario 1, 12). Left: Northern Hemisphere extra-tropics; middle: tropics; right: Southern Hemisphere extra-tropics.

5.2 Global RO Impact

Figure 7 shows temperature spreads for different scenarios (except scenarios 1 and 12, discussed in the previous section) averaged for different regions. In particular scenarios that include the COSMIC-2 Equator constellation have a much reduced temperature spread at tropical latitudes, most notable above 100 hPa. Generally, the largest improvements are found above 100 hPa and, in the tropics (particularly, if COSMIC-2 Equator is included).

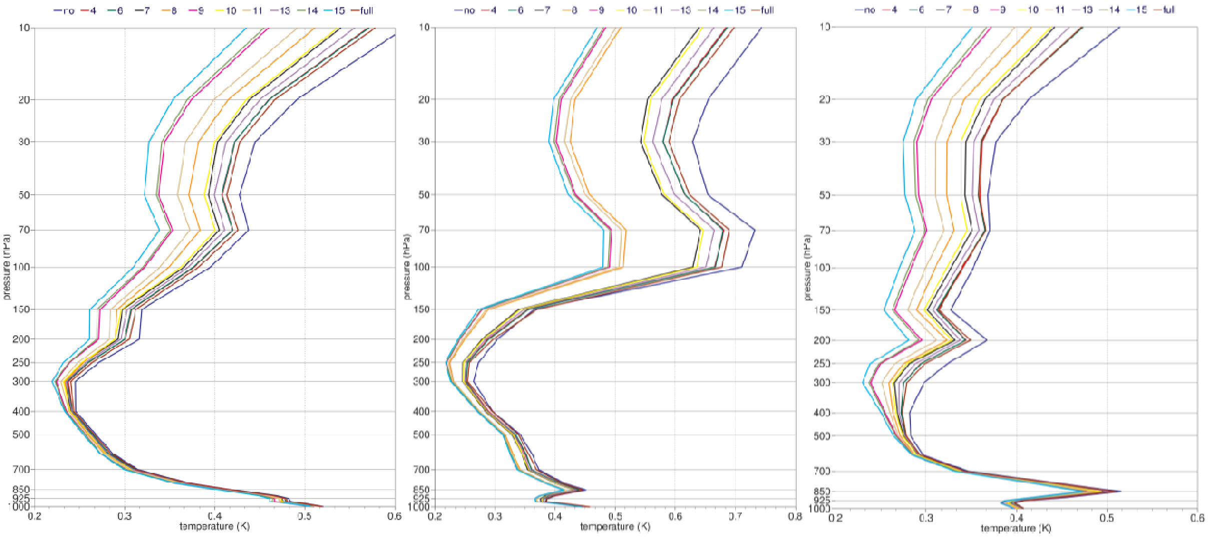

Figure 7 Temperature spread profiles for Northern Hemisphere extra-tropics (left), Tropics (middle), and Southern Hemisphere extra-tropics (right).

The impact on relative humidity is shown in Figure 8. The largest improvements are in the tropics at the 300-850hPa layer (tropical convection) when COSMIC-2 Equator is included; these improvements are smaller than the ones found for temperature since RO observations are affected by temperature and water vapour at lower altitudes and these 2 pieces of information cannot be fully retrieved independently. At the same time the smaller impact at lower altitudes might be linked to assumed larger RO observation errors there.

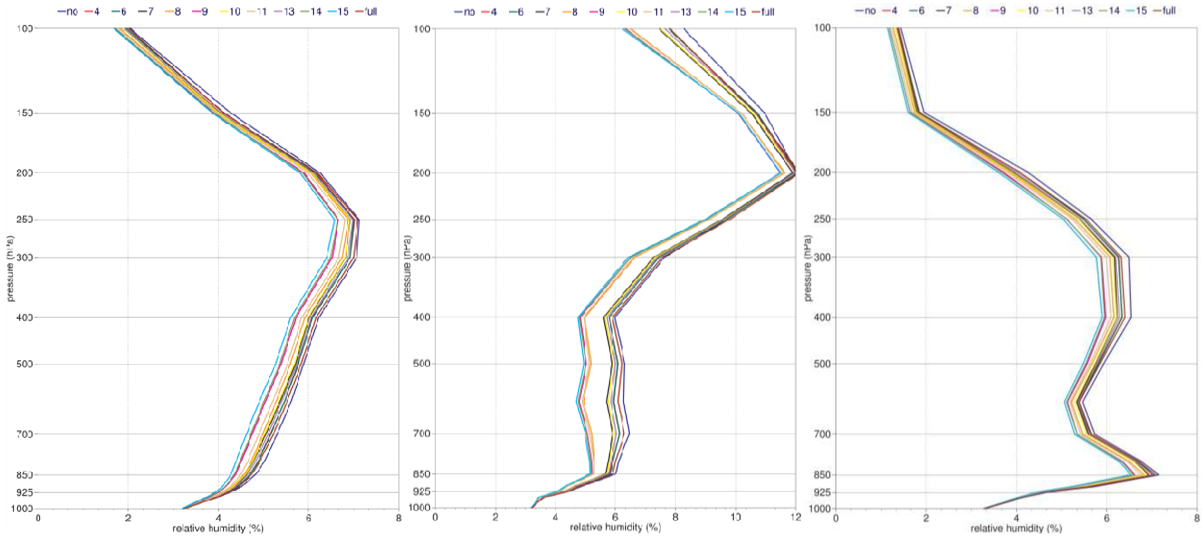

Figure 8 Relative humidity spread profiles for Northern Hemisphere extra-ropics (left), tropics (middle), and Southern Hemisphere extra-tropics (right). Note the highest displayed level is 100 hPa for these figures.

Figure 9 shows the spread profiles for zonal wind. Zonal wind is affected since RO provides information on the temperature. The largest improvements are at the Southern Hemisphere extra-tropics at the 200-500hPa layer, but there are also strong improvements above 100hPa for all latitude bands. The lack of geostrophic relation in the tropics prevents the RO mass (temperature and humidity) observations to influence the wind error statistics.

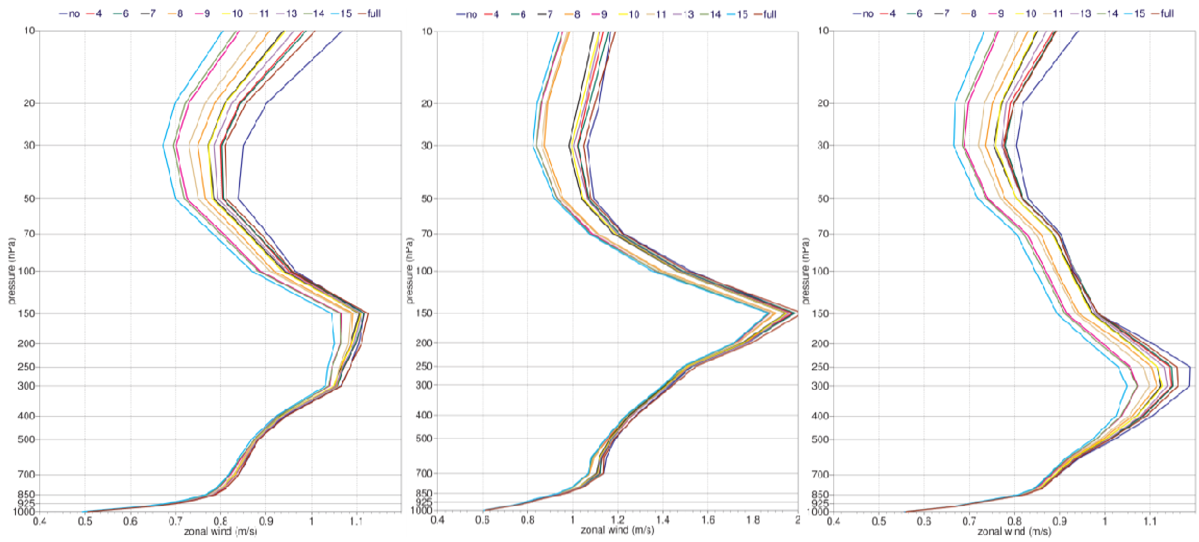

Figure 9 Zonal wind spread profiles for Northern Hemisphere extra-tropics (left), tropics (middle), and Southern Hemisphere extra-tropics (right).

5.3 Impact of Orbit Selection

Scenarios 4, 6 and 7 allow assessing the orbit impact on the spread results. In particular, scenario 4 and 6 compare if 2 RO instruments in the same sun-synchronous orbit (thus observations are always at the same local solar times, see also Figure 2 - note though that the two satellites themselves are 180^{o} or about 50 minutes apart in this orbit) are providing worse results than 2 satellites in different sun-synchronous orbit. Comparing scenario 4 and 7 allows assessing whether 2 RO instruments in the same sun-synchronous orbit, observing 4 GNSS, show any degradation since observations are closer together and thus might provide less information.

Figure 10 shows the global temperature spread for these scenarios. In addition, the two reference runs are also included: the one using no RO data and the one based on the operational RO observations. It can be concluded that 2 RO instrument in the same orbit are very similar to 2 RO instruments in different sun-synchronous orbits (scenario 4 vs. 6, essentially on top of each other). In addition, adding 2 more observed GNSS to scenario 4 does still give substantial improvements (scenario 4 vs. 7), compared to the no RO case, the impact is almost doubled between these 2 scenarios.

The figure also confirms that results are in line with the operational assimilation of real RO observations, which includes slightly less occultations per day and is also slightly worse than scenario 4 and 6.

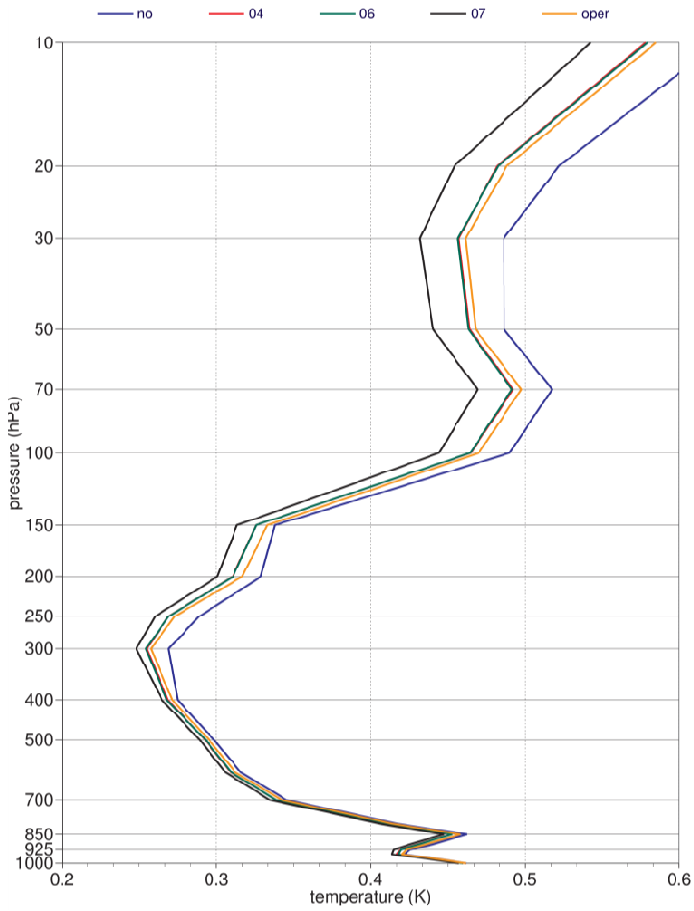

Figure 10 Global temperature spread profiles for scenarios investigating orbit sensitivity.

5.4 Impact of COSMIC-2 Polar

COSMIC-2 consists of 2 constellations, each having a total of 6 satellites. The first batch will be launched into a low latitude orbit (also called COSMIC-2 Equator), the second one into a higher one (also called COSMIC-2 Polar). Current launch times are 2016 and 2018/2019, however there have been several considerations whether the high latitude constellation will really be providing additional information given that the 2 EPS-SG satellites are already providing high latitude coverage, with several others also planned there.

Scenarios 8, 9 and 11 assess the impact of COSMIC-2 Polar, scenario 8 is the baseline, with COSMIC-2 Equator plus 2 EPS-SG satellites with RO instruments; scenario 9 adds the COSMIC-2 Polar to scenario 8; scenario 11 tries to compensate COSMIC-2 Polar by adding to scenario 8 RO instruments in other, operationally used orbits.

Figure 11 and Figure 12 show the temperature spreads for different latitude bands. A RO observation system including COSMIC-2 Polar will always bring better results than one without it, thus the 3 additional COSMIC-2 Polar instruments, when compared to scenario 11, are providing additional, valuable information for an NWP system. In terms of number of satellites, improvements in spread are almost linear, with scenario 11 about half way between scenarios 8 and 9.

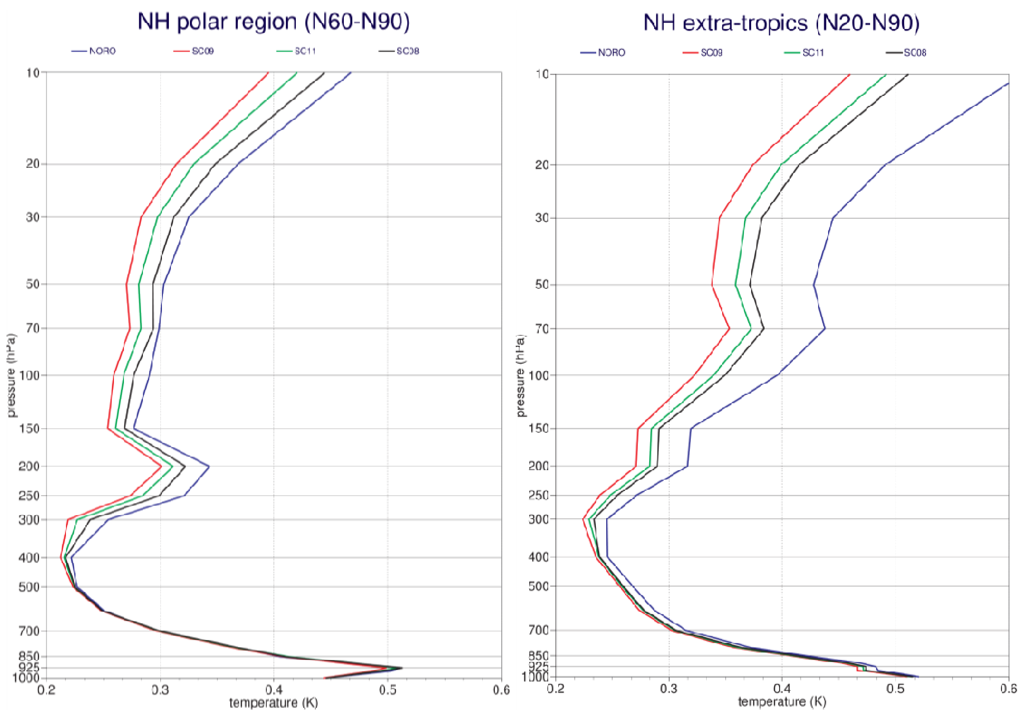

Figure 11 Temperature spread profiles for Northern Hemisphere Polar (left) and extra-tropics (right) that include/exclude COSMIC-2 Polar. Black: Scenario 8, Red: Scenario 09, Green: Scenario 11, blue: No RO.

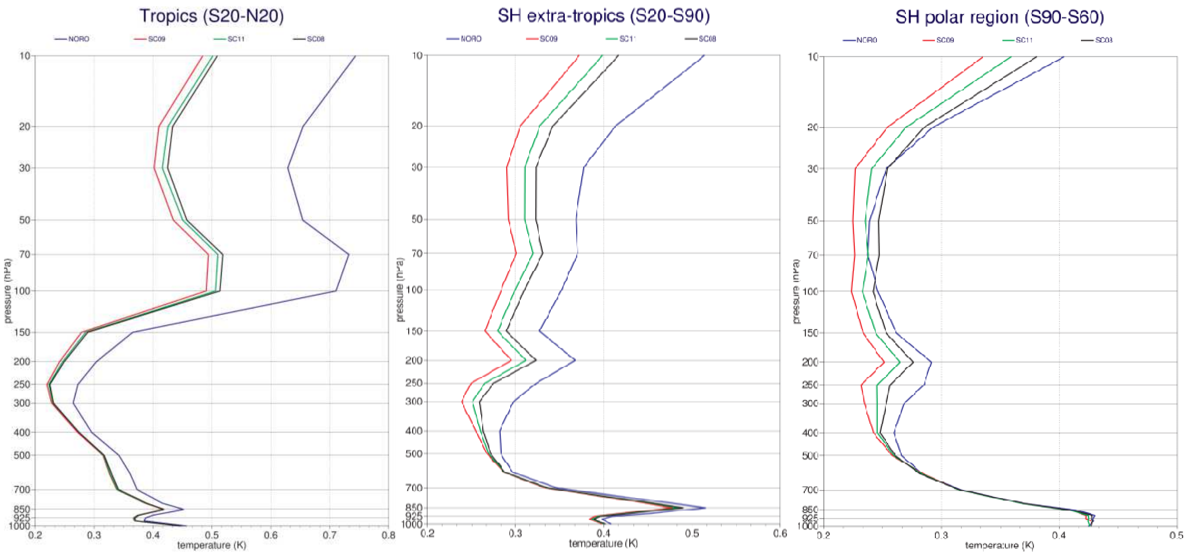

Figure 12 Temperature spread profiles for tropics (left), Southern Hemisphere Extra-Tropics (middle) and Polar (right) that include/exclude COSMIC-2 Polar. Black: Scenario 8, Red: Scenario 09, Green: Scenario 11, blue: No RO.

5.5 Impact of Hosting RO on available Satellites

Comparing scenarios 4, 9, 13, 14, 15 allows assessing to what extent additional RO payloads could contribute to NWP, as shown in Figure 13. Such additional payloads could e.g. be provided by research satellite. Jason-CS and EPS-SG together provide a larger impact than the present operational data coverage (scenario 13 vs. operational). But even with a full COSMIC-2 constellation (scenario 14), or one where several other satellites are carrying RO instruments (scenario 15), the additional RO instruments improve the temperature spread. Similarly, an additional Jason-CS RO instrument would also always add information (scenario 9 vs. 14).

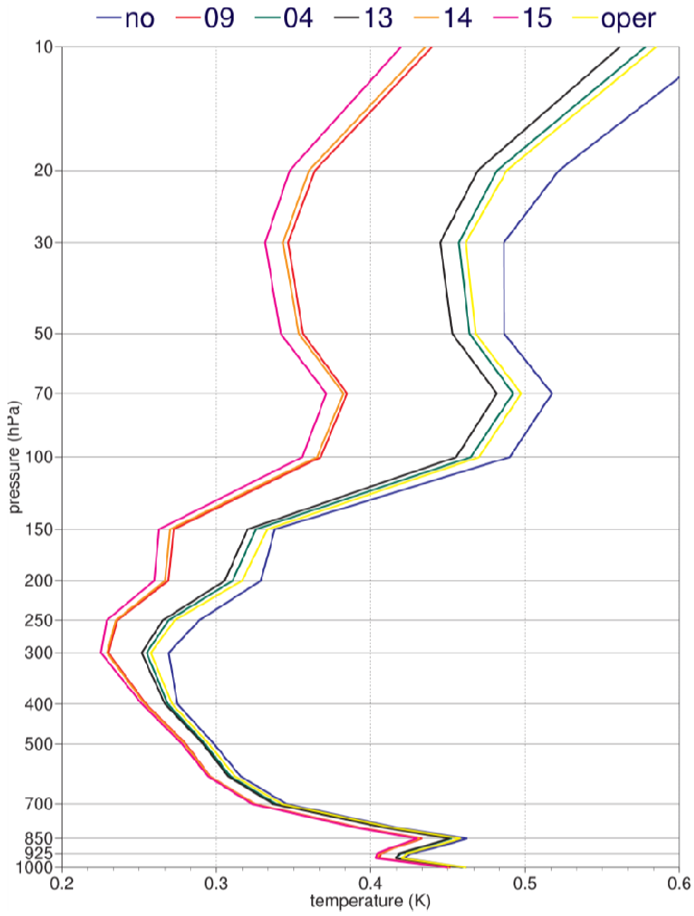

Figure 13 Global temperature spread profiles for scenarios with additonal hosted RO payloads.

6 CONCLUSIONS

First results of a study currently running at ECMWF are presented. The study looks at saturation effects when assimilating RO observations, where RO observation positions are simulated using realistic LEO and GNSS orbits. This study is thus a refinement of an earlier study that assumed RO occultations to be randomly distributed in space and time.

An Ensemble of Data Assimilation (EDA) approach, using 10 (+1) members in a 4D-Var modern NWP system, was used. Within this study, the following 3 main issues are addressed:

1. Refine the earlier, random occultation position, study with realistic future satellite orbits;
2. Assess which observation constellation is best suited to achieve the best distribution in space and time;
3. Provide guidance on RO instrument deployments on future LEO satellites.

Regarding Point 1, it has been found that although realistic orbits affect occultation positions significantly, a modern NWP system can still effectively use any observations, thus the impact of realistic orbits is small. Regarding Point 2, the more observations are available, the lower forecasting spreads are found; constellations that provide most observations at low latitudes are particularly useful, since here, per area the least occultations are available from polar orbiting RO instruments and the model errors are the largest. Regarding Point 3, it again can be concluded that the more observations, the lower the forecast spread, even if additional instruments are provided in orbits that are already populated with RO instruments.

The study itself is formally finishing by August 2015, with a final presentation at EUMETSAT about 1 month earlier. Underlying EDA runs are already completed, they have been run over the last year. Shown results and discussion, conclusions are thus also entering the final report. The study results have also been presented and discussed at IROWG-4 in April 2015.

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