CGMS-40 WMO-WP-20
V1, 15 October 2012

Prepared by WMO
Agenda Item: III/3.2 & IV.1
Discussed in: WG III & Plenary

OPTIMIZATION OF SUN-SYNCHRONOUS ORBITAL PLANES
Report on Studies Conducted in the United States

Submitted by Dr. Lars Peter Riishojgaard, USA

In response to Recommendation 39.01

The WMO *Vision for the Global Observing System in 2025* calls for microwave and hyperspectral infrared sounding missions in three roughly equally spaced sun-synchronous polar Low-Earth Orbits (LEO). The evidence supporting this requirement comes from a variety of sources, including both general data denial experiments and specific case studies. Experiments done by the United States are reviewed in this paper. Data denial studies for AMSU-A using NOAA-15, 16 and 17 demonstrate that three orbit-coverage leads to superior Numerical Weather Prediction (NWP) skill in a statistical sense. A series of case studies for selected high-impact weather situations showed that losing coverage from one orbit can lead to severe degradation of the forecast products on an episodic basis. A new series of data impact studies aimed at assessing the potential contribution to skill of a three-orbit configuration in the context of the current Global Observing System is currently underway in the US.

Optimization of Sun-Synchronous Orbital Planes: Report on Studies Conducted in the United States

1 INTRODUCTION

The *WMO Vision for the Global Observing System in 2025* is intended as a guidance document outlining a likely future Global Observing System (GOS) scenario that is (i) technically and financially feasible and (ii) addresses the highest priorities of the WMO members within the available technical and financial means. Concerning the polar sun-synchronous LEO satellite component of the GOS, the Vision calls for

> *"Operational polar-orbiting sun-synchronous satellites distributed within 3 orbital planes (~13:30,17:30, 21:30 ECT)"*

each of which is to carry (among other sensors):

> *"IR hyper-spectral sounders, MW sounders",*

with the primary aim of providing frequent global coverage of temperature and humidity measurements for Numerical Weather Prediction (NWP).

This vision for the LEO satellite component of the GOS was based on:

(i) Studies presented during the Third WMO NWP Impact Workshop in Alpbach showing that the impacts of having two AMSU-A sensors were additive and that the impact did not saturate even when data from three sensors were assimilated simultaneously;

(ii) The original plans for the Initial Joint Polar Systems, in which two orbits would be covered by the US NPOESS platforms and one orbit would be covered by EUMETSAT's EPS, all three carrying both microwave and hyperspectral infrared sounders.

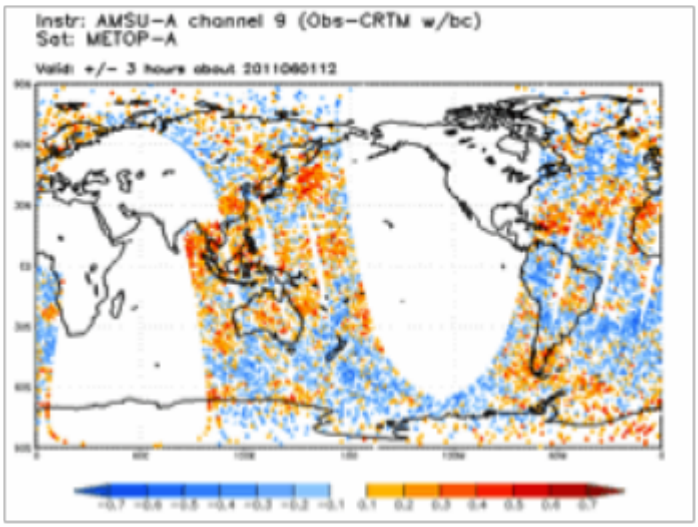

Figure 1. Six-hourly coverage provided by a single AMSU-A sensor (NOAA-19)

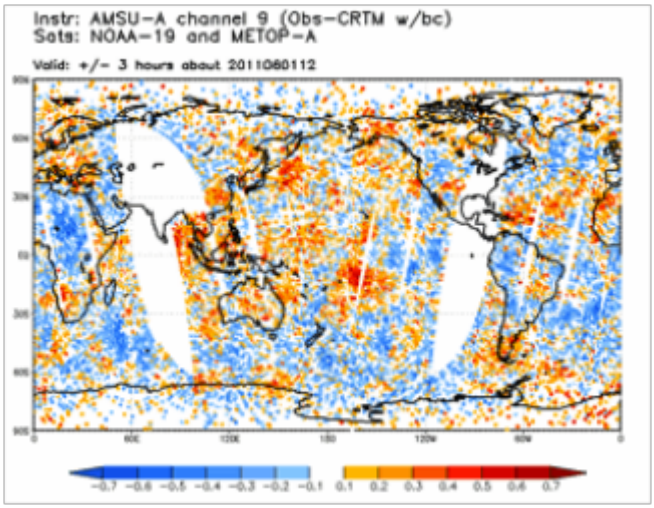

Figure 2. As Fig. 1, but two orbits (NOAA-19 and MetOp-A).

After the cancellation of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program in February 2010, the current (September 2012) situation is that no firm plans for an early morning sounding mission exist. The afternoon sounding mission will be fulfilled via the US NOAA/NASA Joint Polar Satellite Systems. However, the current fly-out schedule does not provide operational redundancy for this mission, and it may therefore be more vulnerable than anticipated earlier to schedule slips and/or on-orbit upsets of various types.

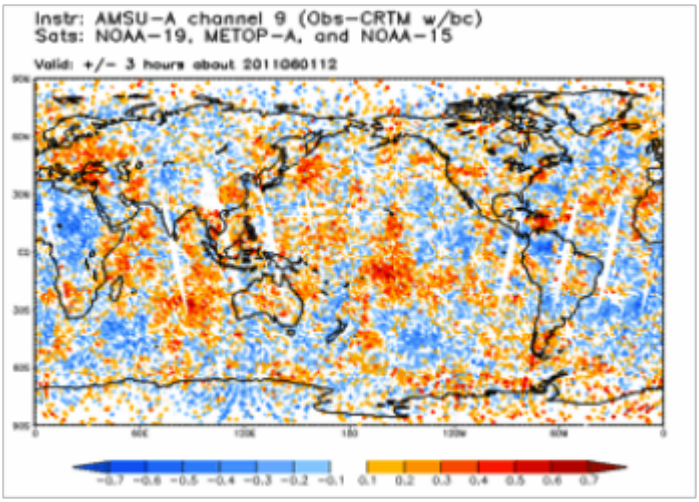

Figure 3. As Fig. 1, but for three orbits (NOAA-15, NOAA-19, MetOp-A).

The purpose of this document is to review existing and ongoing studies undertaken by the United States to examine the impact of having sounders on multiple LEO satellites. It should be emphasized that since there is no current sounding mission in the early morning orbit, the evidence supporting the requirements for such a mission will remain indirect until impact studies for a simulated mission (such as those described in Section 4 below) are completed.

For illustration, the coverage obtained by polar orbiting microwave sensors (AMSU-A) over a typical 6-hour data acquisition period for numerical weather prediction is shown in Fig. 1, 2 and 3 above. It is seen that one orbit (NOAA-19) provides limited coverage, two

orbits (NOAA-19 and MetOp-A) provide coverage over more than 80% of the domain, while three orbits (NOAA-15, NOAA-19 and MetOp-A) provide coverage for nearly the whole global domain, even in a case where the spacing is slightly uneven. It is thus evident that in order to obtain global coverage over six-hour period, observations from three relatively well-separated orbits are in fact needed.

2 CASE STUDIES

A number of case studies have been undertaken by NOAA's National Centers for Environmental Prediction, aimed specifically at highlighting the impact of losing coverage from the early afternoon orbit. At the time of the data denial experiments, data from two PM orbiting satellites (NOAA-19 and NASA's Aqua research platform) were assimilated operationally. In the control experiments, all available data (both conventional and satellite observations) was assimilated. In the perturbation experiments, data from the two PM-orbiters were denied, thereby bringing the sounder coverage down to a level resembling Fig. 1. Five different cases were studied, and the results are summarized in Table 1. As can be seen, two cases showed significant improvement of the forecast when data from the afternoon orbiting sounders were included, while three cases showed negligible impacts.

"Snowmageddon" EC snow storm Feb 2010	Significantly improved forecast
NYC and NE blizzard Dec 2010	Significantly improved forecast
NW Coastal Storm April 2011	Largely unchanged forecast
Tornado Outbreak 1 (April 2011)	Largely unchanged forecast
Tornado Outbreak 2 (April 2011)	Largely unchanged forecast

Table 1. Summary of NCEP case studies and forecast impacts

The discrepancy between the various cases included in Table 1 is not surprising. All NWP systems exhibit a considerable amount of day to day variability both overall and in terms of the attribution of skill to various elements of the observing system. Whether or not an impact is seen in an individual case depends on a complex interplay between a number of factors: the region of genesis of the weather phenomenon under study, the actual data coverage at the time of initialization of the forecast that is being verified, the performance of the model for the particular phenomenon studied, etc.

Two positive outcomes and three neutral out of a total of five cases should therefore be seen as anecdotal evidence for the hypothesis that withdrawing data from one of the orbital planes can have a significant negative impact on skill on an episodic basis. Additional studies would have to be undertaken before any more firm conclusions can be drawn, in particular regarding whether or not anything may be inferred from these results regarding the impact of a possible third orbit.

3 OBSERVING SYSTEM EXPERIMENTS (DATA IMPACT STUDIES)

The Joint Center for Satellite Data Assimilation and the National Centers for Environmental Prediction undertook a series of data denial studies for two experimental periods in 2003 with the NCEP Global Forecast System version used in operations at that time. Many types of experiments were carried out, and we will focus

here on those that showed the respective impacts of having data from one (NOAA-17), two (NOAA-16,17) or three (NOAA-15,16,17) polar LEO satellites included in the assimilation along with the rest of observations routinely assimilated.

Sample results illustrated in Figure 4 show the progression of forecast skill from one to two and three satellites in polar orbit (NOAA-17, NOAA-16 and 17, and NOAA-15, 16 and 17, respectively). In the mid-latitudes the progression is uniform in both hemispheres and at both the 500 and 1000 hPa levels, with three orbits providing the most skill and one orbit providing the least. The picture for the polar regions is more complex, but due to the verification that tends to be based on the model itself rather than on observations in the high-latitude regions, it is difficult to draw any firm conclusion from this. Overall, these experiments along with similar studies done by other NWP centers provide support for the requirement expressed in the WMO *Vision for the GOS in 2025* for sounding missions in three well separated orbital planes.

It should be noted that the impact experiments discussed in this section involved launching just one medium-range forecast for each 24-hour period, at 00Z, and the verification was done only over large regions in particular involving all longitudes. Due to the zonal asymmetry in the data gaps shown in Figures 1 and 2, it is likely that much larger impacts would be seen occasionally on in a setting where either two or four forecasts per day would be issued and where the verification would be done on a regional scale.

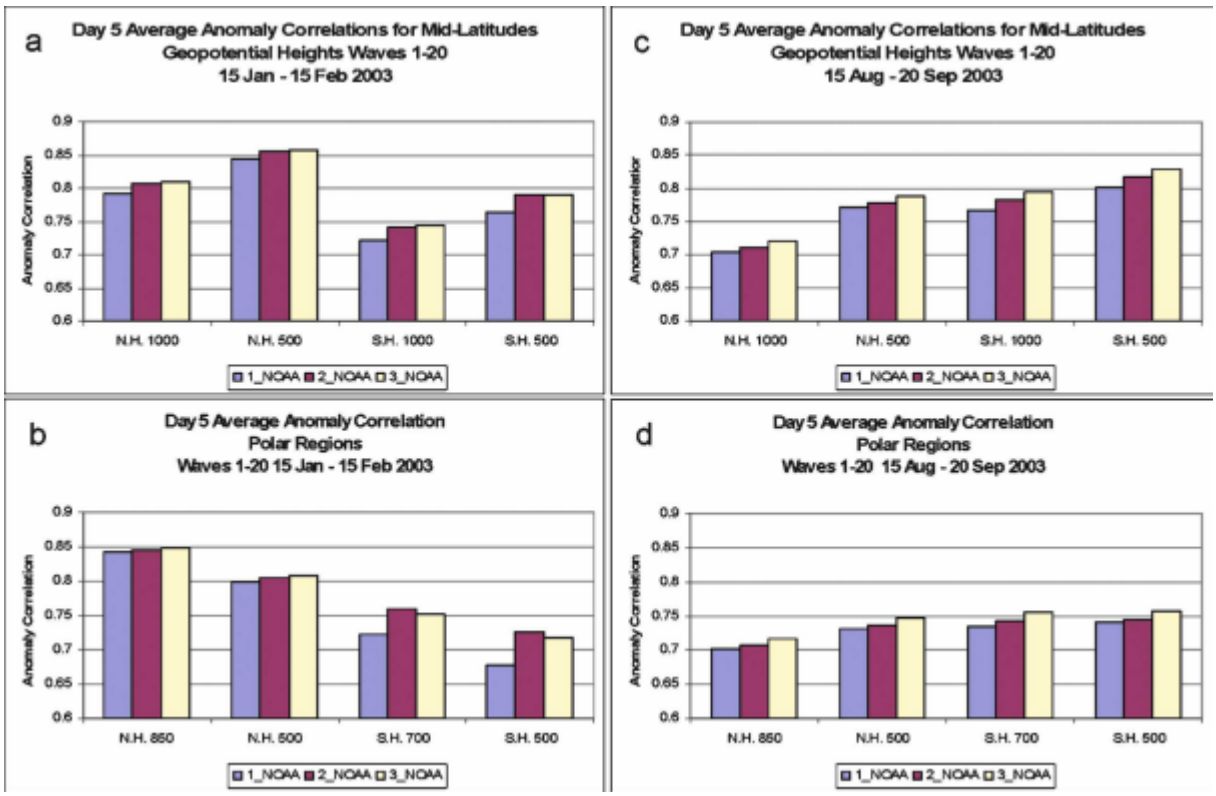

Figure 4. Average day-5 skill (anomaly correlation coefficients) for JCSDA/NCEP data denial experiments described in text.

4 ONGOING OBSERVING SYSTEM SIMULATION EXPERIMENTS

Due to the limited direct potential for doing data denial studies with actual existing sounders, a series of OSSEs designed to assess the impact of various payload configurations for a future early morning orbit satellite is currently underway in the US, led by the Joint Center for Satellite Data Assimilation. The experiments are being carried out using the previous (May 2011) operational version of the NCEP Global Forecast System, and the reference set of observations includes everything assimilated operationally in 2011, with the addition of data from Special Sensor Microwave Imager/Sounder (SSMI/S) flown on several platforms operated under the Defense Meteorological Satellite Program. The perturbation observations will consist of adding data from SSMI/S and/or CrIS and ATMS, all in morning orbits. The experiments are expected to be completed during the first half of 2013.

5 SUMMARY AND CONCLUSIONS

The lack of a current sounder mission in the early morning orbit makes it impossible to make a direct assessment of the impact via data denial studies. General impact studies indicate a very important role for sounders in NWP, and indirect support for the requirement for three well separated orbits can be found both in older studies such as those mentioned in this paper, and from anecdotal evidence provided by newer impact studies. More definitive conclusions should be available when the current US OSSEs for the early morning orbit will be completed.