Assessment of the benefits of a satellite mission in an early morning orbit

Report from the WMO-CGMS Tiger Team

April 2013

1. INTRODUCTION

1.1 Scope

The scope of this report is to evaluate the benefits of a future satellite mission in a polar sun-synchronous "early morning" orbit, in response to a request from the Coordination Group for Meteorological Satellites (CGMS). This evaluation is addressed first from a generic standpoint and then applied more specifically to the potential deployment by the China Meteorological Administration (CMA) of a FY-3 mission in such an orbit.

The report is based on the work of the Tiger Team established on this matter by the World Meteorological Organization (WMO) and CGMS. It summarizes the outcome of the Tiger Team seminar hosted by CMA in Beijing on 25 and 26 April 2013.

Figure 1: Participants in the Tiger Team seminar.

1.2 Background

The baseline configuration of the core Low Earth Orbit (LEO) operational constellation has evolved from a two-orbit system (mid-morning and afternoon orbits) to a three-orbit system (mid-morning, afternoon, and early morning) in accordance with the "Vision for the Global Observing System (GOS) in 2025" (WMO, 2009), developed by WMO. An illustration of the three orbits is given in Fig.2.

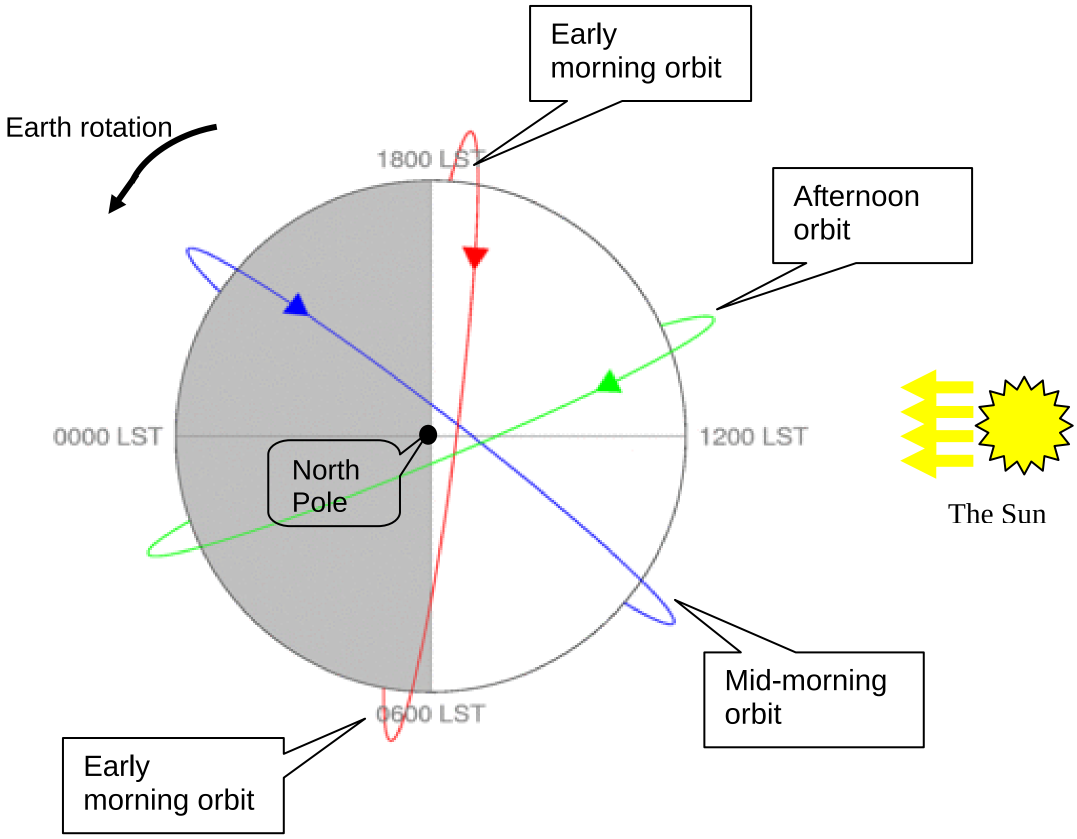

Figure 2: Schematic representation of the three orbital planes over the northern hemisphere. The early morning orbit, in red on this figure, is near the limit between the sun-illuminated face of the Earth (here on the right) and the night side of the Earth (left). LST= Local Solar Time.

The long-term plans of Europe, the United States of America (USA) and China are expected to provide robust components for the a.m. and p.m. orbits but, at present, anticipate a gap in the early morning orbit beyond the current Defense Meteorological Satellite Programme (DMSP) of the USA. This critical situation has been highlighted on several occasions by CGMS and by the WMO Commission for Basic Systems.

The fortieth session of CGMS (Lugano, 5-8 Nov. 2012) dedicated a particular attention to this issue. It reviewed the outcome of past studies to assess the importance of three-orbit coverage. CGMS noted with appreciation that options were being investigated by China for redeploying a FY-3 mission from either a.m. or p.m. orbit to the early morning if both the benefit and the feasibility of such a change were confirmed. Since the optimization of the core LEO constellation is central to the mission of CGMS, it was agreed that every effort should be made to share studies or other relevant information for a critical evaluation of the benefit of such redeployment in order to help CMA to make the best-informed decision.

CGMS therefore recommended the following course of actions:

- WMO Secretary General shall invite CMA to further consider redeploying FY-3 to an early morning orbit and offer international support to reach this objective;

- WMO shall convene a CGMS “Tiger Team” to coordinate the technical evaluation of the global and regional impacts of flying a FY-3 satellite in early morning orbit, in order to support CMA in the assessment process of such an option;

- Numerical Weather Prediction (NWP) centres should perform Observing System Experiments (OSEs) on the regional impact of a potential gap of sounding from the early morning orbit;

- CGMS Members should support CMA in further investigations of the benefit and technical consequences of potential move of a mid-morning mission to an early morning mission.

In response to these recommendations, an exchange of letters occurred between WMO and the Permanent Representative of China who agreed on this approach. WMO has set up a Tiger Team involving seven NWP centres from Asia, Europe and the United States who undertook dedicated impact studies between November 2012 and April 2013, the list of which is provided in Annex 1.

Upon invitation from CMA, a seminar was convened on 25 and 26 April in Beijing to perform a critical analysis of the results of the various impact studies conducted by the Tiger Team. The seminar participants (See Annex 2) were also informed on activities conducted in the meantime by CMA and the Shanghai Academy of Spaceflight Technology (SAST), including further studies for payload selection, modification and accommodation for a potential early morning orbit mission, as well as user workshops to assess user expectations at the national level. The seminar was chaired by the WMO Secretariat representatives. The present report summarizes the outcome of this seminar.

2. BENEFITS OF AN EARLY MORNING MISSION FOR NWP

2.1 Outcome of NWP impact studies based on microwave sounding

The constellation of polar-orbiting satellites in three orbital planes roughly 60 degrees apart, as shown in Fig.2, will provide observational coverage approximately every 4 hours at mid and low latitudes. (At high latitudes, observations will be more frequent because successive orbits give overlapping coverage.) The justification for having at least three operational polar-orbiting satellites, rather than two, has been supported by many numerical weather prediction (NWP) impact studies over the last decade, some of which are summarised by Eyre and English (2008).

Further Observing System Experiment (OSE) studies have been undertaken to establish the benefits of the early morning orbit using the NOAA-15 AMSU-A microwave sounding instrument as a proxy. Benefits were shown by all studies: CMA, JMA, ECMWF, JCSDA and DWD. Additionally Forecast Sensitivity to Observations (FSO) studies at KMA and the Met Office have also supported this conclusion. Evolving from 1 to 3 sounders adds on average about 8 hours forecasting range to a 5-6 day forecast, which is a considerable impact.

There have been fewer studies of the benefits of having three satellites in well-spaced orbits, rather than in any other spacing; prior to the Tiger Team activity one such study (Di Tomaso and Bormann, 2011) showed the positive impact of microwave sounding observations from the combination of Metop-A, NOAA-18 and NOAA-15 satellites compared with those from the less uniformly spaced combination of Metop-A, NOAA-18 and NOAA-19.

Further studies have been undertaken by the Tiger Team on this specific issue. Results from ECMWF and JCSDA, which studied the impact of a limited microwave sounding capability, showed that the benefit of this sounding capability was higher in three well spaced orbits than using data from satellite instruments in one morning and two afternoon orbital planes. Furthermore conceptual studies at the Met Office support the ECMWF and JCSDA OSE/OSSE conclusions.

2.2 Regional impact

There was consensus from the Tiger Team that the regional impact is expected to be consistent with the result of the studies on a global and hemispheric scale. OSEs focusing on a regional scale would need longer periods to obtain statistically robust results and therefore the best guidance available for regional impact in, for example, East Asia is the average northern hemisphere impact. Nonetheless, DWD OSEs attempted to quantify the regional impacts from global OSEs, and the Met Office and KMA similarly quantified FSO results on a regional scale. In all these studies a strong positive impact was found from NOAA-15 in the East Asia region, suggesting an early morning sounder will improve regional forecast accuracy for this region.

2.3 Impact on severe weather situations

A particular finding of the conceptual experiment conducted by the Met Office is that a more uniform temporal spacing of observations had a particularly large impact in situations where the forecast error is rapidly increasing, such as rapidly evolving weather situations. Therefore the practical benefit of regularly spaced observations is thought to be particularly important in severe weather situations, which are having major societal impact.

2.4 Expected impact of full payload

The theoretical studies from the Met Office imply that the conclusions reached for a limited microwave sounder will be generally true for any observing system known to make a positive contribution to global NWP: including high spectral resolution infrared sounders, radio occultation, scatterometer and microwave imagery. Therefore the difference in forecast skill using evenly spaced orbits is likely to be larger with a full payload than that demonstrated in sections 2.1 and 2.2 with a limited microwave sounding capability only.

2.5 Expected further benefit with progress in assimilation

The impacts will increase with improvements in data assimilation, in particular those aimed at using more data over land where currently data is under exploited. This will be particularly important for East Asia for forecasting weather systems developing over the large Asian land mass.

3. BENEFITS FOR OTHER APPLICATIONS

3.1 Diurnal cycle and daily operations schedule

Many national and regional forecast offices make routine weather briefings at the beginning of the working day, typically in the 8 a.m. to 9 a.m. time frame. It is advantageous for the briefing staff to have access to the latest meteorological imagery and products. In addition the diurnal variation of a quantity such as fog makes early morning imaging highly desirable. In the high latitudes where the effective horizontal resolution of the geostationary imagery deteriorates, frequent revisits by polar orbiting imagers are essential for monitoring rapidly developing weather systems. Having a satellite in an early morning orbit would address these concerns.

3.2 Tropical cyclones and other severe events

Satellite data – especially microwave imagery and sounder data - are used for describing and analyzing the structure and intensity of tropical cyclones. Scatterometer surface wind observations are used to help position the circulation and estimate the strength of the surface circulation. Night-time images of tropical cyclones provided by the Day-Night Band Imager may provide additional information about the structure and characteristics of deep convection. This would also be the case of images acquired with low solar illumination around the day-night terminator.

Currently no plans exist for obtaining any of these data from the early morning orbit, thus leaving a long temporal gap between the afternoon and the mid-morning orbit observations. Frequent revisits of the area of interest are essential, especially since the motion of the weather patterns may cause one or more overpasses to miss the cyclone. Similar considerations apply to the monitoring of severe weather events and hydrometeorological disasters in general.

3.3 Climate monitoring

Full sampling of the diurnal cycle of, e.g., surface and atmospheric temperature and humidity and precipitation is important for climate monitoring. Early morning orbit coverage would complement the data from the existing mid-morning and afternoon orbit systems and help provide up to six measurements per day over most of the globe in the infrared and microwave bands.

3.4 Air quality

While the use of UV measurements is problematic in the early morning orbit due to the low solar elevation angle, the temperature contrast between the skin temperature and the atmospheric boundary layer that is characteristic of this orbit offers certain advantages for the monitoring of trace gases such as CO and O_3 in the infrared. The generally smaller amount of cloud and the lower absolute moisture in the early morning can also be an advantage for such air quality monitoring.

3.5 Solar observations

The early morning orbit also offers the potential to observe the Sun in an almost continuous manner[1], which provides significant advantages: for example, solar constant and solar spectrum measurements for climate monitoring, solar activity and active regions for space weather.

4. INTERNATIONAL PERSPECTIVE

The latest plans for the core operational constellation in Low Earth Orbit (LEO) presented by Europe (Metop and Metop-SG), the USA (POES, DMSP, SNPP and JPSS) and China (FY-3)[2], are expected to provide robust components for the a.m. and p.m. orbits but anticipate a gap in the early morning orbit beyond the current DMSP programme. The plan for a successor of DMSP, DWSS, was officially stopped in January 2012 and no replacement is planned so far.

In this context, there is a unique opportunity for China to take primary responsibility for the early morning orbit with one of its future FY-3 satellites. At the Tiger Team workshop,

[1] Apart from Winter eclipse near one Pole, depending on satellite height

[2] Future Russian Federation missions Meteor-M,MP might supplement the constellation in a.m. or p.m. orbit.

participants took note with appreciation of the studies undertaken by CMA and SAST since CGMS-40 on payload and platform adaptations needed to fly a FY-3 satellite in a 6:00 Equatorial Crossing Time orbit, as well as the actions needed to secure a launch by 2016, as currently anticipated.

A decision by China to fly a FY-3 satellite in this orbit would have a particular significance at international level. In becoming the primary satellite provider in the early morning orbit, China would share a global responsibility with Europe in the mid-morning orbit and with the USA in the afternoon orbit. Such a decision would enable the community to meet the baseline configuration agreed by CGMS Members in support to the “WMO Vision for the GOS in 2025”.

For this decision to be a win-win scenario, bearing in mind the advantages which are demonstrated in this report, it is essential to ensure that data from the three orbits continue to be shared between satellite operators. It should be noted that for the mid-morning orbit, CMA and EUMETSAT are currently renewing their Agreement on cooperation in meteorological satellite data application, exchange and redistribution. Anticipating a possible decision of CMA, this Agreement already includes provisions on the free and open access by CMA to current and future EUMETSAT polar-orbiting satellites (in mid-morning orbit) and on cooperation on orbit coordination.

Another type of cooperation that the international community should develop with CMA in support to its decision is to ensure that maximum benefits are generated from the utilization of the proposed new constellation of satellites. This would involve sharing of expertise in the use of the data and their assimilation into NWP models. CGMS Members and WMO will have a key role to play to ensure that such cooperation takes place and the framework for its implementation is developed.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Benefits of an early morning orbit mission

There is a consensus among scientific experts in the international community to acknowledge the benefits that will be brought by a satellite mission in an early morning orbit, i.e., with an Equatorial Crossing Time around 6:00 in Local Solar Time.

Significant benefits will arise from improved accuracy of weather forecast through assimilation of sounding radiances into Numerical Weather Prediction models, thanks to the optimum temporal distribution of observations provided by the early morning, mid-morning and afternoon satellite missions respectively.

Further benefits are expected from the direct use of imagery and derived products in a number of applications. These include in particular:

- Shorter revisit time for tropical cyclone monitoring by infrared and microwave imagery and sounding,
- More efficient fog and fire detection in the early morning and late afternoon,
- More efficient air quality monitoring for particular species (e.g. CO and O_3) in thermal infrared channels,
- Improved sampling of the diurnal cycle for accurate climate data records,
- Quasi-continuous monitoring of the Sun for space weather and climate applications.

It was underlined that satellite observations acquired from early morning / late afternoon overpasses provide valuable information that are well timed for the daily or twice daily briefings held by weather services at the beginning and end of operational shifts (i.e., 8:00 and 20:00 local time in the case of CMA).

5.2 Potential deployment of FY-3 satellites in an early morning orbit

The Tiger Team acknowledged that the FY-3 programme offers a unique opportunity to China to play this important role as one of the three major components of the global constellation besides the European programme in the mid-morning orbit and the USA's programme in the afternoon orbit, while complementary missions would provide the necessary redundancy for operational robustness.

It is therefore strongly recommended to CMA to implement a FY-3 mission in an early morning orbit, with the appropriate platform and payload adaptations, and to sustain such mission in the long term. The forthcoming CGMS-41 meeting in July 2013 would enable CMA to update CGMS Members on its plans and to exchange views and experience on any outstanding platform or payload issues.

5.3 Cooperation and data usage

In addition, the Tiger Team stressed the need to strengthen international cooperation to maximize the benefit from the data and made thus the following recommendations:

- WMO and CGMS to support trade-off studies (including e.g. OSSEs) as necessary in the course of the development phase of the FY-3 early morning mission;
- CMA and international partners to pursue strong international collaboration on data assimilation in order, as soon as possible, to maximize the benefits of future (early morning) and current FY-3 missions;
- CMA with international community to further prepare to exploit the benefit of the early morning orbit polar satellite monitoring payload for space weather, climate monitoring, air quality and disaster monitoring;
- WMO and CGMS to promote the use of FY-3 early morning data, contributing to a robust and efficient Global Observing System, taking advantage of the Asia-Oceania Meteorological Satellite Users Conference.

References

- Di Tomasi E. and N.Bormann, 2011. Assimilation of ATOVS radiances at ECMWF, EUMETSAT/ECMWF Fellowship Progress Report No.22.
- Eyre J.R. and S.J. English, 2008. Impact studies with satellite data at the Met Office. Proceedings of 4th WMO Workshop on "The impact of various observing systems on NWP"; Geneva; 19-21 May 2008. http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-4_Geneva2008_index.html
- WMO, 2009. The Vision for the GOS in 2025. http://www.wmo.int/pages/prog/www/OSY/gos-vision.html

ANNEX 1:

LIST OF NWP IMPACT STUDIES

Centre	Type of study	Scenarios	Evaluation Period
ECMWF	OSE	AMSU-A/B on Metop-A, N15, N18, N19, N16, N17 http://cimss.ssec.wisc.edu/itwg/itsc/itsc18/program/files/links/4.36_DiTomaso_po.pdf	
ECMWF	OSE	NPP/ATMS, Metop-A/AMSU-A, + NOAA-15/AMSU-A (selected channels) + NOAA-18/AMSU-A (selected channels)	2012/09/26 to 2012/12/26
ECMWF	OSE	NPP/ATMS,CrIS, Metop-A/ AMSU-A,IASI + NOAA-15/AMSU-A (selected channels) + NOAA-18/AMSU-A (selected channels)	2012/09/26 to 2012/12/26
Met Office	Conceptual experiment	Impact of temporal spacing of observations on analysis errors http://www.metoffice.gov.uk/learning/library/publications/science/weather-science/forecasting-research-technical-report Report No.573.	-
DWD	OSE	NOAA-15/AMSU-A denial. (N15 assimilated over sea only)	Nov 2012
KMA	FSO	FSO experiments as a function of time Global / Regional(East Asia)	July to Sept 2012
Met Office	FSO	FSO experiments as a function of time Global / Regional(East Asia)	Feb to March 2012
JMA	OSE	Relative impact of AMSU-A radiances of N15, Metop-A, N18 when added to the set of other data (e.g. GNSS-RO, scat). Comparison of 3 satellites /2 satellites	Aug 2012
JCSDA	OSSE	OSSE for DoD with different sounder options in Early Morning orbit	Summer/ Winter
JCSDA	OSE	Comparison of 1-2-3 sats; impact of N15 added to a.m./p.m. constellation.	
CMA / NWPC	OSE	NOAA-15/AMSU-A denial. (N15 assimilated over sea only, verification over East Asia)	July 2011

CMA/NWPC: China Meteorological Administration/Numerical Weather Prediction Centre

DWD: Deutscher Wetterdienst (Germany)

ECMWF: European Centre for Medium-Range Weather Forecasts (Europe)

JCSDA: Joint Center for Satellite Data Assimilation (USA)

JMA: Japan Meteorological Agency (Japan)

KMA: Korea Meteorological Administration (Rep. of Korea)

Met Office: Met Office (United Kingdom)

ANNEX 2:

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