WORLD METEOROLOGICAL ORGANIZATION

FINAL REPORT OF THE CGMS-WMO OPTIMIZATION WORKSHOP
Geneva, 28-29 August 2006

OPTIMIZATION OF SATELLITE OBSERVATION MISSIONS: ISSUES AND RECOMMENDATIONS

1. GENERAL ASPECTS

1.1 General remarks

In its Action 33.21, CGMS-XXXIII agreed on the need to review plans for GEO and LEO orbits with the aim to optimize these plans.

Optimization is understood as "how to best make use of available resources to achieve the goal". This includes maximizing the benefit from already planned missions, but also adapting future plans if necessary to best address complementary objectives.

As concerns maximizing the benefit of planned missions, areas of optimization are:

- improving data availability (data access, data dissemination, data formats, coordinated operation of ground segment, e.g. data downlink). These issues are being considered in the framework of other CGMS working groups : IGDDS, codes;
- improving data quality, through precise and globally consistent calibration, continuity and reliability standards for processing. The calibration aspect is being addressed in the framework of the Global Space-based Inter-Calibration System (GSICS.)

In its discussion, as in the rest of this report, the workshop focused on the optimization of the space-based observation capability itself, which is not addressed in any other CGMS group.

In this respect, it is assumed that each agency has its own process to define and optimize its own missions with respect to its agreed requirements, taking into account its available resources. This process may be conducted individually or, for example, in bilateral partnerships.

However a single agency doesn't have the capability to address the total set of WMO requirements but rather contributes to address only part of them.

One aspect of the optimization issue is to ensure that the individual contributions of CGMS members are well coordinated with, and complementing each other, that their addition provides a comprehensive response to the needs and that the overall system is sound and cost-effective.

The CGMS Action defining this workshop was initially generated in the context of operational satellite planning; however the workshop agreed that optimization should not be limited to the operational component but should involve both operational and R&D components, and address as well the possible trade-off between LEO and GEO observation. The workshop strongly recommended that R&D agencies should attend future discussions on optimization.

1.2 Approach taken

- To recall the agreed baseline GOS, i.e. the target configuration described in WMO agreed reference documents: Manual on the GOS, Vision for the GOS in 2015, Implementation Plan for the Evolution of the GOS;
- To compare currently available plans with this baseline, and identify existing or anticipated gaps and/or margins;
- To review possibilities for adapting current plans to reduce the gap between the baseline and the plans, and express recommendations in this respect. This is a first level of optimization;
- If relevant, to review the definition of the space-based GOS baseline in cases where this baseline doesn't appear practical or if alternative configurations appear preferable, in order to ensure that the target that is defined is the most appropriate way to meet the requirements, which is the ultimate goal. To put forward recommendations in this respect to CGMS. This is another level of optimization.

2. LOW EARTH ORBIT

2.1 Scope of LEO optimization

The following aspects need to be considered for optimizing the Space-based observing capability in LEO:

a) <u>Number and distribution of orbits</u>

Distributing the satellites on well-separated orbital planes provides independent data sets and improves the quality of sampling of the atmosphere and Earth surface.

The WMO Global Observing System (GOS) baseline configuration includes four operational LEO satellites "optimally spaced in time".

A minimum global coverage with limited temporal gaps can be achieved with 3 equally-distributed orbital planes with Equatorial Crossing Times (ECT) e.g., at 13:30, 17:30 and 21:30 (ascending), such as in the current Joint Polar System baseline.

Satellites in additional orbital planes can further improve the coverage.

b) System robustness

Maintaining a limited level of redundancy increases the probability to achieve operational continuity of comparable data sets:

- o If two satellites were operated on orbits with same or similar ECT, this would improve robustness rather than coverage. Coverage would be slightly improved, depending on the varying phase difference between them. Maintaining the phase difference at a constant value (e.g., 50 minutes) would put a strong constraint on orbit control of both spacecraft;
- o A better compromise between robustness and independence would be achieved in operating satellites on pairs of orbits with approximately 12 hours difference in ECT, which implies that one has an ascending node where the other has a descending node.

c) Instrument performances

The considerations above regarding improving data sampling and system robustness are assuming comparable and adequate instrument performances. Instrument performances have to be assessed precisely against requirements.

Orbit distribution thus needs to be looked at for each of the instrument category described in the baseline GOS, with instruments of comparable performances.

2.2 Microwave and IR sounding

- GOS baseline: 4 MW and IR sounders “optimally spaced in time” plus 2 for back-up including at least 3 with hyperspectral IR sounders;
- Current plans: Up to 5 MW & 6 IR sounders around 2 orbits (mid-am, early pm) for the next two decades. Sounding is no longer planned on any early am mission.

Global sounding coverage with sufficient temporal sampling is a high priority mission for global NWP. It is important to distribute the sounding packages on orbits that allow achieving an efficient sampling of the atmosphere. Distributing the sounding packages on 3 regularly spaced orbital planes (e.g., with approximately 4 hours difference in ECT) would be considerably more useful than the current plans where all soundings are performed within 2 time slots (mid-am and early pm). With 6 sounding package in total there would be sufficient redundancy on each orbital plane.

Recommended evolution:

- ➢ First priority is to implement one mission with sounding package in early am, in addition to the one planned in mid-am and pm;

- Next priority is to implement a second mission with sounding package in early am to secure redundancy on all 3 orbits, to provide the required robustness;
- This result would be achieved e.g. if one of the 3 missions currently planned for mid am could fly on early am and if NPOESS –C2 could include a sounding package;
- Noting that with METOP and NPOESS, the JPS partnership will provide one coordinated coverage of the 3 orbit types (mid-am, pm, early am), that FY-3Ais already being prepared for launch in mid-am (where it will provide redundancy to MetOp) with plans for FY-3B in pm orbit, and that Meteor-M is planned on an am. ascending orbit, it is suggested to look at possibilities for Meteor-M to fly on an earlier am orbit (e.g., 5:30 ascending);
- As soon as possible, all MW and IR sounders should equal or approach the standard of IASI or CrIS and AMSU/MHS or ATMS.

2.3 Visible and Infrared imagery

- GOS baseline: 4 multispectral imagers "optimally spaced in time" plus 2 for back-up;
- Current plans: Up to 6 imagers, around 2 orbits (mid-am, pm) until 2016 then 3 orbits (mid-am, pm, early am).

This will include one coordinated system covering the 3 orbits (NOAA-EUMETSAT JPS) one programme by China covering 2 orbits, and an independent programme by the Russian Federation. The preferred approach is to maintain 6 satellites on three orbits (mid-am, pm, early am) so as to ensure adequate sampling while providing some redundancy for each orbit type.

Recommended evolution:

- Move to early am one of the 3 missions currently envisaged in mid-am;
- Noting that with METOP and NPOESS, the JPS partnership will provide one coordinated coverage of the 3 orbit types (mid-am, pm, early am), that FY-3A is already being prepared for launch in mid-am (where it will provide redundancy to MetOp) with plans for FY-3B in pm orbit, and that Meteor-M is planned on an am ascending orbit, it is suggested to look at possibilities for Meteor-M to fly on an earlier am orbit (e.g., 5:30 ascending);
- This would avoid a gap on early am until 2016. After 2016, it could provide some redundancy with NPOESS-C2allowing to achieve robustness of observation from the 3 types of orbits (mid-am, pm, early am)As soon as possible, all multispectral imagers should equal or approach the VIIRS standard.

2.4 Ocean surface altimetry

- GOS baseline: 2 altimetry missions;
- Current plans: Plans beyond Topex-Poseidon and Jason-1,2 are still being discussed. It is anticipated that there will be one mission ensuring continuity of the JASON-type observations, either as a Jason-3 or as the ESA Sentinel-3. Current uncertainty creates a risk of gap after Jason-2. The risk depends also on the actual operational life of Jason-1 and 2.

There are also plans for R&D altimetry missions for ice shelf monitoring, which address different requirements and cannot optimally fulfill the need for ocean surface topography.

The requirement for special Jason orbit (1336 km altitude) is going to be relaxed once the knowledge of the GEOID will be improved through the GRACE and GOCE missions. Radar altimeters can then be flown on lower orbits, which open more opportunities to implement the two altimetry missions.

Recommendations:

- ➢ Confirm the plans for at least one Jason follow-on series of altimetry satellites;
- ➢ Clarify the status of such a programme that should aim at operational continuity.

2.5 Earth Radiation Budget

- GCOS requirement is for 1 Earth Radiation Budget mission with continuity and overlap, in addition to GEO sensors for diurnal cycle;
- Current plans in LEO: anticipated gap for ERB before NPOESS-C1, and no follow-on after NPOESS-C1. ScaRaB on Megha-Tropiques only covers intertropical regions. Possible ERB instrument aboard FY-3 is still to be confirmed.

The requirement is based on the understanding that the diurnal cycle is covered by GERB-like instruments on all operational geostationary satellites. Currently, this is not planned on GOES-R and MTG. The requirement should thus be reviewed.

Recommendations:

- ➢ Clarify and confirm CMA plans regarding an ERB instrument aboard FY-3;
- ➢ Invite GCOS to re-consider its requirement for LEO ERB in the light of the current GEO plans. In order to capture the diurnal cycle, observations may need to be performed at least every 3 hours;
- ➢ Refine the definition of the baseline GOS in respect of ERB measurements, taking into account the complementary roles of GEO and LEO ERB sensors.

2.6 Radio-occultation sounding

- GOS baseline: Radio occultation sounders on all of the 4 "optimally spaced" operational satellites, plus R&D constellations;
- Current plans: 2 RO sounders in mid-am plus a R&D constellation (COSMIC) only in 2006-2011.

The requirement for flying the mission on the 4 operational satellites does not take into account that occultation is a rare event. Four orbital planes are all right but, in order to meet the requirement of 300 km resolution every 6 hours, the number of satellites in each plane should be around 6 (i.e., a constellation of 24 satellites). The constellation of only 4 satellites would only meet climatological requirements. In addition, the outcome of several accommodation exercises on multi-purpose satellites has demonstrated higher level of difficulty than expected. A sound technical approach should be in terms of constellation of up to 24 micro-satellites (threshold: 12).

Recommendations:

- ➢ WMO: to formulate the requirement in terms of resolution/cycle (e.g., 300 km / 6 h).
- ➢ Given the potential of small satellite constellations for ROS, encourage plans for further dedicated ROS constellations;
- ➢ Encourage in particular plans for continuity of the current dedicated ROS constellation (COSMIC);
- ➢ Recall the action, as stated in the Implementation Plan for the Evolution of the GOS, to initiate within CGMS a cooperation for sharing ground support network for precise time-referencing needed for accurate signal processing.

2.7 Ocean surface wind through radar scatterometry or MW imagery

- GOS baseline: at least 3 of the operational LEO satellites should include MW imagers with polarimetric capability or radar scatterometer.
- Current plans: after end of life of WindSat on Coriolis and SeaWinds on QuikScat (around 2008), there will be one scatterometer (ASCAT) only. A full-polarization MW imager (CMIS) will be available on NPOESS-C2 (planned for 2016) and another one ultimately on NPOESS-C3 in 2020. Dual-polarisation MW imagers such as those of the GPM constellation (SSM/I-like) only provide speed information and may play a supportive role.

The requirement is going to be well approached (3 satellites instead of 4) in the long term (as of 2020, with NPOESS-C3). The period 2008-2016 will be problematic since only one satellite (MetOp) will have sea-surface wind vector observation capability.

Recommendation: Consider a gap-filler for ocean surface wind vector in the 2008-2016 period and possibly up to 2020.

3. GEOSTATIONARY ORBIT

3.1 GOS baseline and current plans

The CBS vision for the GOS in 2015 foresees a constellation of 6 GEO satellites "near-equally spaced", all with VIS/IR multispectral imagers and "some" with hyperspectral sounders.

Critical requirements are recalled in the WMO-CGMS global contingency plan:

- Images taken under a zenith angle ≤ 70 deg are available over all latitudes ≤ 50 deg;
- The contingency plans of satellite operators should ensure coverage of those regions of the world where severe weather conditions develop (e.g., cyclones, tornadoes)

Comparison of current plans with the agreed baseline shows that in the coming decade there will be up to 11 functional GEO satellites, which should allow to provide the nominal configuration plus the necessary redundancy.

In particular, the 3 critical areas identified by the CGMS Contingency working group (South-America, Indian Ocean, Asia-Pacific) are expected to benefit of sufficient coverage taking into account:

- relocation of GOES-10 at 60°W to cover South-America until the availability of advanced imaging capability with GOES-R;
- continuation of IODC mission by EUMETSAT with Meteosat-6 and -7;
- confirmation of Russian Federation's plans regarding GOMS;
- confirmation of CMA plans regarding the parallel availability of 2 FY-2 satellites and their possible follow-on with 2 FY-4 satellite series;
- confirmation of KMA's plans for COMS and a possible follow-on;
- confirmed status of MTSAT-1R,-2, and considerations for their follow-on.

3.2 Discussion

The workshop suggested that WMO reviews the formulation of the baseline GOS as concerns hyperspectral sounding, since a logical implication of accurate soundings from GEO orbit would be to require that all GEO operational satellites have an hyperspectral IR sounder.

In the light of current plans, the baseline configuration of 6 operational GEO satellite appears both justified and achievable. Nominal locations are confirmed.

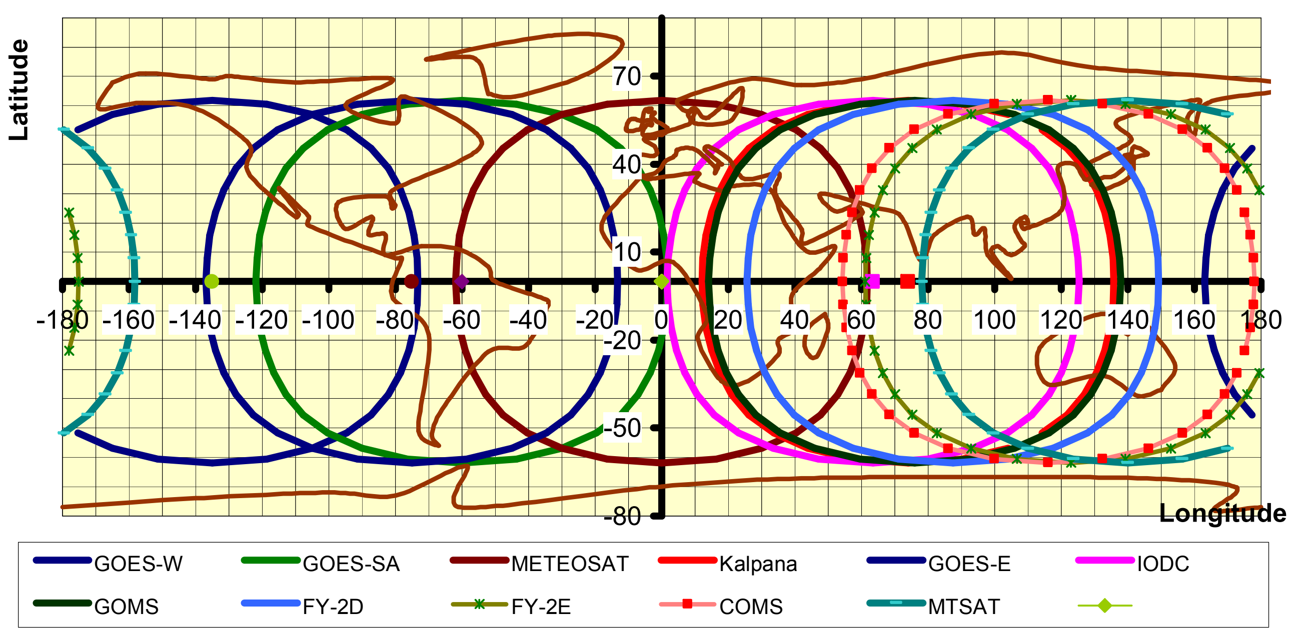
Furthermore, the GEO satellites that are currently planned to be available in addition to the nominal locations would provide a back-up capability, which is necessary to ensure the robustness of this essential operational component.

It is suggested to update the description of CGMS contingency capability (§ 5.3.2 of CGMS Global contingency planning) as indicated below:

Region	Nominal operator(s)	Nominal locations		1st contingency mode	2nd contingency mode	Remarks
		Operat.	spare			
Americas & East Pacific	USA (NOAA)	135 W 75 W	105 W **60 W**	Use of spare at the failing location	One single satellite in 105 W (reduced coverage) or interregional support	Bilateral back-up agreement with EUMETSAT
Europe & Africa	EUMETSAT	0	10 E **3.4 W**	Use of spare	Interregional support	Bilateral back-up agreement with NOAA
Indian Ocean Asia & West Pacific	Russia China Japan	76 E 105 E 140 E	**65 E** (EUMETSAT) **86.5 E** (China) **128.2 E** (Korea) 93 E (India)	Use of spare or interregional support	Use of 2 of the 3 satellites (reduced overlap) or interregional support	NOAA JMA Bilateral

It was confirmed that a prerequisite for taking optimal benefit from the planned systems was to ensure full and open data availability and timely access, as well as data quality (e.g. navigation, calibration and completeness).

The workshop noted the concern expressed by the ET-EGOS about the balance between GEO and LEO space-based capabilities.



4. SUMMARY

The level of resources for space-based observation as currently planned for the next two decades allows each space agency of CGMS membership to provide a valuable contribution to meeting WMO programme requirements.

However, when considering these plans in parallel, there are, on the one hand, some overlap beyond the margins that are necessary to ensure robustness and continuity, and, on the other hand, some gaps and deficiencies.

The workshop is convinced that within the same level of resources, some adjustment of the plans and a closer cooperation towards data quality and availability would allow a much better response to WMO needs and considerably improve the overall benefit. Furthermore it is unlikely that essential WMO requirements will be met if such adjustments are not performed and the cooperation strengthened.

The main recommended directions for adjusting the plans are:

<u>For LEO</u>

- Consider with priority a sounding package on early am;
- Consider moving one mid-am mission to early am for sounding and imagery. (A minimum fall-back would be to spread mid-am orbits between 8:00-11:00, and pm orbits between 13:00-16:00);
- Plan continuity for one ocean altimetry series;
- Clarify/confirm continuity of ERB and review complementary contributions of GEO/LEO satellites for ERB measurements;
- Review formulation of requirements for RO sounding;
- Implement dedicated ROS missions, in particular plan continuity of ROS constellation beyond current experimental mission, and consider cooperation on RO ground support networks;
- Consider with urgency a gap-filler for sea surface wind measurements until 2016-2020.

<u>For GEO</u>

- Review GOS baseline statement about GEO IR hyperspectral sounding;
- Update CGMS Global contingency planning as concerns additional satellites complementing the nominal locations to ensure system robustness.

<u>For GEO and LEO</u>

- Recall prerequisite of full and timely access, data exchange;
- Recall need for harmonized data quality namely through consistent global calibration within GSICS.

ANNEX I:

CGMS-WMO Workshop on Optimization of Geostationary and Low-Earth Orbit Satellite Plans, 28-29 AUGUST 2006

DRAFT AGENDA

Monday 28 August- 09:00 – 17:00): Optimized operations of LEO systems

1. **Introduction** (WMO)
   - 1.1. Welcome and working arrangements;
   - 1.2. Recall of WMO requirements and CGMS baseline.
2. **Update on LEO plans** (satellite operators, e.g., 10 minutes per programme)
   - 2.1. Operational systems, with emphasis on Equatorial Crossing Time (if sun-synchronous) and type of instrumentation;
   - 2.2. R&D systems with relevance to the GOS, with emphasis on Equatorial Crossing Time (if sun-synchronous), type of instrumentation and data access.

3. **Prospective analysis for the next 15 to 20 years**
   - 3.1. For each main type of measurements: orbit complementarity and resulting temporal sampling, comparison with requirements, gap/redundancy analysis;
   - 3.2. Recommendations for optimization and robustness of key observations from LEO.

Tuesday 29 August, morning - (9:00 – 13:00): Regionally optimized operations of GEO systems

4. **Update on geostationary plans** (satellite operators, 10 min per programme) with emphasis on equatorial locations and type of instrumentation

5. **Prospective analysis for the next 15 to 20 years**
   - 5.1. For each region (Asia-Pacific, Indian Ocean, Europe-Africa and Atlantic, Americas and East Pacific) and each main type of measurements: adequacy with respect to coverage and contingency requirements, gap/redundancy analysis
   - 5.2. Regional interoperability of ground segments for contingency cases
   - 5.3. Recommendations for optimization and robustness of key observations from GEO

6. **Concluding remarks for the optimization workshop**

ANNEX II:

LIST OF PARTICIPANTS

Sean BURNS	(EUMETSAT)
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ANNEX III : Timeline for planned altimetry, LEO Earth Radiation Budget and Ocean Surface Wind measuring missions

Table 1. Timeline for planned altimetry missions

Satellite	ECT (A) Or Inclination	Sensor	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Envisat	22:00	RA-2															
Jason-1	66°	Poseidon															
Jason-2	66°	Poseidon															
Sentinel 3	22:00	Altimeter															
ICESat	94°	GLAS															
Cryosat-2	92°	SIRAL															

Precision ocean altimetry   Ocean altimetry   Ice sheet altimetry

Table 2. Timeline for LEO Earth Radiation Budget missions

Satellite	ECT (A) Or Inclination	Sensor	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Terra	22:30	CERES																
Aqua	13:30	CERES																
NPOESS-C1	13:30	CERES																
FY-3A	22:00	ERBU																
Megha-tropiques	20° incl	SCARAB																

Polar orbiting satellite (global coverage)   Inclined orbit satellite (inter-tropical region coverage)

Table 3. Timeline for ocean surface wind measuring missions (scatterometry or microwave imagery)

Satellite / Sensor	ECT (A) or inclination	Characteristics	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ERS-2 (AMI-Wind)	22:30	Single swath scatterometer															
QuickSCAT (SeaWinds)	06:00	Wide swath scatterometer															
METOP (ASCAT)	21:30	Double swath scatterometer															
Oceansat-2	00:00	Wide swath scatterometer															
NPOESS-C2	17:30	(Microwave Imager/Sounder replacing CMIS)															
NPOESS-C3	13:30																
DMSP (SSM/I,IS)	17:30	Conical scanning MW imager 4 freq./ 3 dual polarization															
Meteor-M (MTVZA)	10:20	Conical scanning MW imager 21 freq./ 8 dual polarization															
FY-3A (MWRI)	22:00	Conical scanning MW imager 6 frequencies with dual polarisation (12 channels)															
FY-3B (MWRI)	14:00																
TRMM (TMI)	35°	Conical scanning microwave imager 5 frequencies, 4 of which with dual polarization															
GPM core (GMI)	65°																

Scatterometer (wind speed + direction)   Full polarization MW Imagery (speed + direction)   Dual polarization MW Imagery (speed only)