CGMS-XXXI
WMO WP-18
Prepared by WMO
Agenda item: D.3

POLAR-ORBITING EQUATOR CROSSING TIMES, GEOSTATIONARY SATELLITE POSITIONS, AND SATELLITE INSTRUMENTATION

(Submitted by WMO)

Summary and purpose of document

To inform CGMS Members of WMO activities related to equator crossing times.

ACTION PROPOSED

1. CGMS Members to note WMO activities related to equator crossing times and comment as appropriate;
2. CGMS Members to update Table 1 (Status of polar orbiting satellite equator crossing times)

Appendix: System Aspects of The Space-based Component of GOS

DISCUSSION

Background

1. During previous sessions of CGMS as well as in sessions of the Consultative Meetings on High-level Policy on Satellite Matters, discussions on the issue of equator crossing time coordination have occurred. The Appendix is a discussion paper on equator crossing times, geostationary satellite positions and satellite instrumentation prepared by WMO through a consultancy with Dr B. Bizzarri. The Appendix is submitted as the starting point for a more detailed CGMS discussion on the issues of equator crossing time coordination, geostationary satellite positions and satellite instrumentation. The paper also contains information related to equator crossing times for R&D satellite missions.

2. It should be noted that CGMS has agreed to update a table containing equator crossing time information on a regular basis as a continuing CGMS action item. The latest table as of the beginning of CGMS-XXXI follows (Table 1) and should be updated.

Table 1
Polar orbiting satellite equator crossing times
Status as of

Satellite	Service	Start	EOL	Eq. Cross-time	Freq (MHz)	BW MHz	Data rate (Mb/s)
Metop-1	LRPT	2006	2011	0930	137.9125	.150	.072
Metop-2	LRPT	2010	2015	0930	137.9125	.150	.072
Metop-3	LRPT	2015	2020	0930	137.9125	.150	.072
Metop-1	AHRPT	2006	2011	0930	1701.3	4.5	3.5
Metop-2	AHRPT	2010	2015	0930	1701.3	4.5	3.5
Metop-3	AHRPT	2015	2020	0930	1701.3	4.5	3.5
Metop-1	GDS	2006	2011	0930	7800	63	70
Metop-2	GDS	2010	2015	0930	7800	63	70
Metop-3	GDS	2015	2020	0930	7800	63	70
NPP	HRD	2006	2010	1030D	7812	TBD	15
NPP	SMD	2006	2010	1030D	8212.5	375	300
NPOESS-1	LRD	2009	2015	0930D	1706	8.0	3.88
NPOESS-2	LRD	2011	2018	1330A	1706	8.0	3.88
NPOESS-3	LRD	2013	2019	0530D	1706	8.0	3.88
NPOESS-4	LRD	2015	2021	0930D	1706	8.0	3.88
NPOESS-5	LRD	2018	2024	1330A	1706	8.0	3.88
NPOESS-6	LRD	2019	2025	0530D	1706	8.0	3.88
NPOESS-1	HRD	2009	2015	0930D	7812/7830	30.8	20
NPOESS-2	HRD	2011	2018	1330A	7812/7830	30.8	20
NPOESS-3	HRD	2013	2018	0530D	7812/7830	30.8	20
NPOESS-4	HRD	2015	2021	0930D	7812/7830	30.8	20
NPOESS-5	HRD	2018	2024	1330A	7812/7830	30.8	20
NPOESS-6	HRD	2019	2025	0530D	7812/7830	30.8	20
NPOESS-1	SMD	2009	2015	0930D	25650	300	150
NPOESS-2	SMD	2011	2018	1330A	25650	300	150
NPOESS-3	SMD	2013	2019	0530D	25650	300	150
NPOESS-4	SMD	2015	2021	0930D	25650	300	150
NPOESS-5	SMD	2018	2024	1330A	25650	300	150
NPOESS-6	SMD	2019	2025	0530D	25650	300	150
NOAA-15	APT	1998	2001	0730	137		.017
NOAA-15	HRPT	1998	2001	0730	1702..5		.688
NOAA-15	GAC	1998	2001	0730	2247.5		
NOAA-16	APT	2000	2004	1400	Failed		.072

Satellite	Service	Start	EOL	Eq. Cross-time	Freq (MHz)	BW MHz	Data rate (Mb/s)
NOAA-16	HRPT	2000	2004	1400	1698		.688
NOAA-16	GAC/LAC	2000	2004	1400	1698/1702.5/1707		
NOAA-M	APT	2002	2005	1000	137		.072
NOAA-M	HRPT	2002	2005	1000	1698		.688
NOAA-M	GAC/LAC	2002	2005	1400	1698/1702.5/1707		
NOAA-N	APT	2004	2008	1330	137		.072
NOAA-N	HRPT	2004	2008	1330	1698		.688
NOAA-N	GAC/LAC	2004	2008	1330	1698/1702.5		
NOAA-N’	APT	2008	2012	1330	137		.072
NOAA-N’	HRPT	2008	2012	1330	1698		.688
NOAA-N’	GAC/LAC	2008	2012	1330	1698/1702.5/1707		
FY-1C	CHRPT	1999	2001	0830	1698-1710	5.6	1.3308
FY-1D	CHRPT	2002	2004	0900	1698-1710	5.6	1.3308
FY-3A	AHRPT	2004	2007	1010	1698-1710	5.6	4.2
FY-3B	AHRPT	2006	2009	1010	1698-1710	5.6	4.2
FY-3C	AHRPT	2008	2011	1010	1698-1710	5.6	4.2
FY-3D	AHRPT	2010	2013	1010	1698-1710	5.6	4.2
FY-3E	AHRPT	2012	2015	1010	1698-1710	5.6	4.2
FY-3A	MPT	2004	2007	1010	7750-7850	35	18.2
FY-3B	MPT	2006	2009	1010	7750-7850	35	18.2
FY-3C	MPT	2008	2011	1010	7750-7850	35	18.2
FY-3D	MPT	2010	2013	1010	7750-7850	35	18.2
FY-3E	MPT	2012	2015	1010	7750-7850	35	18.2
FY-3A	DPT	2004	2007	1010	8025-8215 / 8215-8400	120	93
FY-3B	DPT	2006	2009	1010	8025-8215 / 8215-8400	120	93
FY-3C	DPT	2008	2011	1010	8025-8215 / 8215-8400	120	93
FY-3D	DPT	2010	2013	1010	8025-8215 / 8215-8400	120	93
FY-3E	DPT	2012	2015	1010	8025-8215 / 8215-8400	120	93
Meteor 3M	Raw	2001	2004	0915	466.5	3	0.080
Meteor 3M	Raw	2001	2004	0915	1700	2	0.665
Meteor 3M	Raw	2001	2004	0915	8192	32	15.36
Meteor 3M	LRPT	2004	2008	1030	137.89 / 137.1	0.15	0.064
Meteor 3M	HRPT	2004	2008	1030	1700	2	0.665
Meteor 3M	Raw	2004	2008	1030	8192	2	15.36

3. In addition to the discussion on equator crossing time, the Appendix also includes other system-level aspects of the space-based component of GOS, such as the spacing of geostationary satellites along the equator. It is noted that, in addition to updating the table above, referring to sunsynchronous satellites, CGMS should continue to update the corresponding table referring to geostationary satellites.

4. As a second and important system-level aspect, a quick survey of the payload complement has been carried out so as to assess:

- whether all satellites of the GEO and LEO constellations provide a service of comparable quality relative to each other or, anyway, sufficient to meet a common minimum requirement;
- whether there are gaps of compliance with WMO observational requirements.

5. It should be noted that the assessment of the status of instrumentation was somewhat difficult because the information on instruments provided by CGMS members was in a free format. That format is: sometimes very suitable; sometimes potentially contains the needed information but requires some interpretation; and sometimes doesn’t include necessary information. In several cases, missing information has been retrieved from the web, but a few gaps or uncertainties still

remain. At CGMS-XXXI, a suggestion will be proposed on how to structure the information on instruments in a standard format.

SYSTEM ASPECTS OF THE SPACE-BASED COMPONENT OF GOS

Introduction

1. The space-based component of the World Weather Watch's Global Observing System (GOS) for meteorological satellites currently includes approximately 15 satellites in geostationary orbit and approximately 16 in sun-synchronous orbit, including operational and backup satellites. This would, in principle, satisfy the WMO system requirement for at least 6 geostationary satellite and at least 4 sun synchronous satellites. However, in order to meet those requirements as well as satisfying observational data requirement needs for timeliness and observing cycle for various application areas, e.g. NWP, nowcasting, Seasonal-to-Interannual Forecasting, etc.:

- geostationary positions (for GEO) and LST (Local Solar Time) for LEO should be regularly spaced;
- each satellite in the geostationary or polar orbit should have comparable instrument suites or should be able to provide comparable data content;
- contingency plans should be developed for implementation when required (See WMO WP-5 for a further discussion on Global Contingency Planning).

2. This document reviews the current situation for orbits and payloads in the current and near-future planned systems in order to assess how WMO requirements could be met. This document also refers to the WMO approved vision for the space-based component of the GOS approved at CBS Ext. 2002. A more detailed description of the vision can be found in WMO WP-7 (Redesign of the WWW GOS). In this specific discussion paper the role of R&D satellites programmes will not be considered although they are considered very important since they could:

- possibly fill operational gaps (some of them carry instruments with advanced operational capability); and
- complement existing operational missions by providing measurements not provided by those missions.

3. In order to account for the fact that some satellite programmes are in their early stage of implementation, the status of satellite systems at CGMS-XXXI (2003) and the year 2006 will be considered.

Geostationary satellites

4. Missions for geostationary satellites include imagery, data collection, data dissemination and sounding (for some) as described in the CBS approved vision for the space-based component of the GOS (Cairns, 2002). These missions can provide:

- real-time weather monitoring for the purpose of nowcasting
- wind inference from atmospheric tracers for the purpose of global NWP
- possibly, atmospheric stability monitoring for nowcasting and regional NWP
- measurements requiring frequent sampling because of the (fractal) nature of the field (e.g., precipitation) or due to the need to observe the diurnal variation (e.g., radiation budget).

5. Table 1 contains information for satellites that should be operational and in orbit as indicated by the pre-session documentation for CGMS XXXI. Since the WMO requirement could be interpreted to mean 6 regularly-spaced satellites, six sectors of amplitude 60° have been used to classify the satellite missions. Table 2 extrapolates the information to the year 2006, to allow consideration of planned missions, e.g., GOMS-N2 and MTSAT-1R. This table has been supplemented with some subjective evaluation in order to fill gaps of available information.

Additionally, although not yet part of the space-based component of the GOS, IMD satellites have been included in the evaluation because it is anticipated that those satellites will soon be considered as part of the space-based component of the GOS as well as the fact that IMD is part of CGMS.

Table 1
Coverage from GEO as of end 2003 (CGMS XXXI)

Geographic area	Satellite	Position	Status (Oct 2003)	Instruments
30°W - 30°E Europe, Africa, Eastern Atlantic	MSG-1	10.5°W	Being commissioned	SEVIRI, GERB
	Meteosat-7	**0°**	**Operational**	**MVIRI**
	Meteosat-6	10°E	Backup + Rapid scan	MVIRI
30°E - 90°E Western Asia, Indian Ocean	**Meteosat-5**	**63°E**	**Operational**	**MVIRI**
	Kalpana-1	**74°E**	**Operational**	**VHRR**
	INSAT-2E	**83°E**	**Operational** (with limitations)	**VHRR, CCD**
	FY-2A	86.5°E	Partial backup	S-VISSR
90°E - 150°E Eastern Asia, Australia, Western Pacific	**FY-2B**	**105°E**	**Operational**	**S-VISSR**
	INSAT-3A	**93.5°E**	**Operational**	**VHRR, CCD**
	GMS-5	140°E	Telecom functions only	VISSR
150°E - 150°W Oceania, Central Pacific	**GOES-9**	**155°E**	**Operational** (with limitations)	**IMAGER**
150°W - 90°W Eastern Pacific, North-West America	**GOES-10**	**135°W**	**Operational**	**IMAGER, SOUNDER**
	GOES-11	111°W	In-orbit standby	IMAGER, SOUNDER
	GOES-12	**105°W**	**Operational**	**IMAGER, SOUNDER**
90°W - 30°W South America, North-East America, Western Atlantic	**GOES-8**	**75°W**	**Operational** (with limitations)	**IMAGER, SOUNDER**

Table 2
Perspective coverage from GEO as expected in 2006

Geographic area	Satellite	Position	Status (2006)	Instruments
30°W - 30°E Europe, Africa, Eastern Atlantic	Meteosat-8	10°W	In-orbit standby	SEVIRI, GERB
	Meteosat-9	**0°**	**Operational**	**SEVIRI, GERB**
30°E - 90°E Western Asia, Indian Ocean	**Kalpana-2**	**74°E**	**Operational**	**VHRR**
	GOMS-N2	**76°E**	**Operational**	**MSU-G**
	INSAT-3D	**83°E**	**Operational**	**IMAGER, SOUNDER**
90°E - 150°E Eastern Asia, Australia, Western Pacific	**FY-2C**	**105°E**	**Operational**	**S-VISSR +**
	INSAT-3A	93.5°E	Backup	VHRR, CCD
	MTSAT-1R	**140°E**	**Operational**	**JAMI**
	MTSAT-2	~ 140°E	In-orbit standby	JAMI
150°E - 150°W Oceania, Central Pacific				
150°W - 90°W Eastern Pacific, North-West America	**GOES-12**	**135°W**	**Operational**	**IMAGER, SOUNDER**
	GOES-13	105°W	In-orbit standby	IMAGER, SOUNDER
90°W - 30°W South America, North-East America, Western Atlantic	**GOES-11**	**75°W**	**Operational**	**IMAGER, SOUNDER**

6. The distances between operational satellites, to be compared with the goal of 60°, are as follows:

Positions:	Meteosat-9 0°	Kalpana-2 74°E	GOMS-N2 76°	INSAT-3D 83°E	FY-2C 105*E	MTSAT-1R 140°E	GOES-12 135°W	GOES-11 75°W	Meteosat-9 0°
Δ Longitude:	74°	2°	7°	22°	35°	85°	60°	75*	

7. In Figure 1, the fields of view for the eight geostationary satellites are shown, assuming a “useful” field of view as a circle subtending a geocentric angle of 60° (corresponding to a local zenith angle of 68°). It is observed that the coverage, though not optimum in principle, in practice only leaves very few gaps for latitudinal coverage and no gaps for longitudinal coverage. At longitude 177.5°W, the useful field only reaches to approximately 51° latitude, and at 37.5°W and 37°E the useful field only reaches to approximately 54° latitude. These are not considered serious.

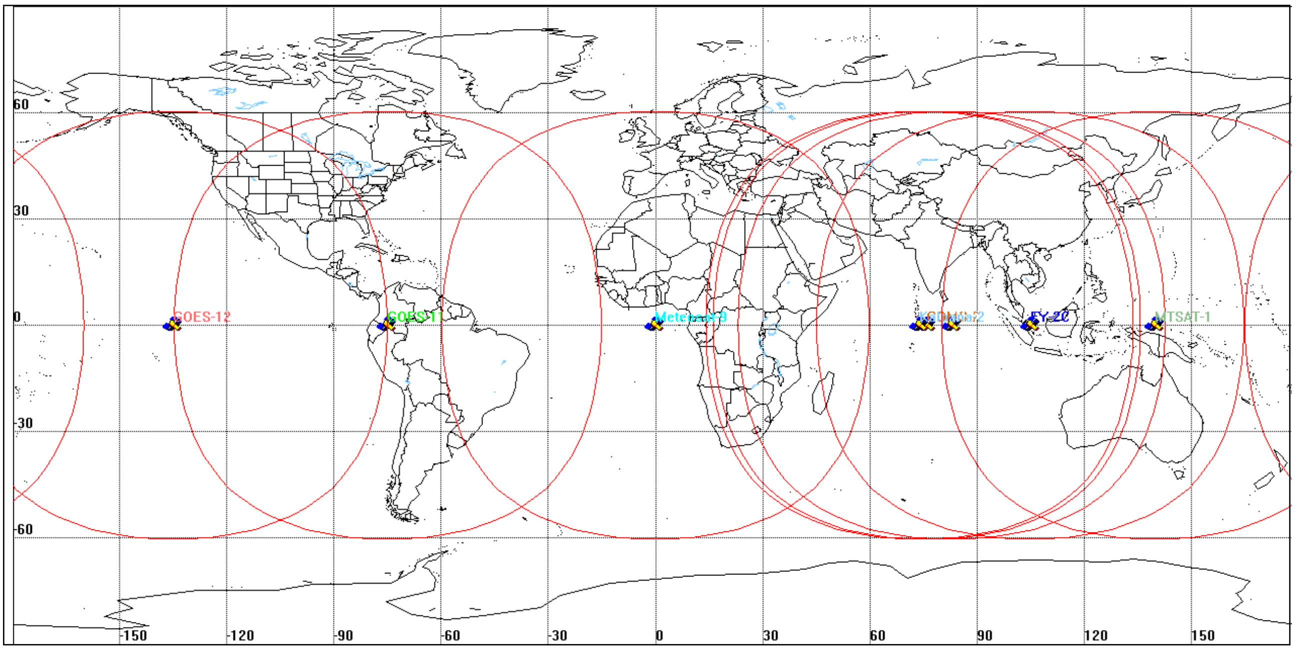

Fig. 1 – Coverage from eight GEO satellites in year 2006 (circle subtending 60° of geocentric angle).

8. However, more serious is the problem of inhomogeneous performance of the instruments that should be striving to provide comparable data content. Table 3 compares the main features of imagers and sounders mentioned in Table 2.

Table 3
Main features of imagers and sounders on-board GEO satellites in 2006

GOES and INSAT-3D SOUNDER (λ & Δν*)		**Meteosat-9 SEVIRI (*)**	**GOES-13 IMAGER**	**MTSAT-1R JAMI**	**GOMS-N2 MSU-G**	**FY-2C S-VISSR +**	**INSAT-3D IMAGER**	**Kalpana-2 VHRR**
14.71 μm	13 cm^{-1}							
14.37 μm	13 cm^{-1}							
14.06 μm	13 cm^{-1}							
13.64 μm	16 cm^{-1}							
13.37 μm	16 cm^{-1}	12.4-14.4 μm	13.0-13.7 μm		~13.4 μm			
12.66 μm	30 cm^{-1}							
12.02 μm	50 cm^{-1}	11.0-13.0 μm		11.5-12.5 μm	11.2-12.5 μm	11.5-12.5 μm	11.5-12.5 μm	
11.03 μm	50 cm^{-1}	9.80-11.8 μm	10.2-11.2 μm	10.3-11.3 μm	10.2-11.2 μm	10.3-11.3 μm	10.2-11.2 μm	10.5-12.5 μm
9.71 μm	25 cm^{-1}	9.38-9.94 μm			9.20-10.2 μm			
7.43 μm	55 cm^{-1}	8.30-9.10 μm			8.20-9.20 μm			
7.02 μm	80 cm^{-1}	6.85-7.85 μm			7.50-8.50 μm			
6.51 μm	60 cm^{-1}	5.35-7.15 μm	5.80-7.30 μm	6.50-7.00 μm	5.70-7.00 μm	6.30-7.60 μm	6.50-7.00 μm	5.70-7.10 μm
4.57 μm	23 cm^{-1}							
4.52 μm	23 cm^{-1}							
4.45 μm	23 cm^{-1}							

GOES and INSAT-3D SOUNDER (λ & Δν*)		**Meteosat-9 SEVIRI (*)**	**GOES-13 IMAGER**	**MTSAT-1R JAMI**	**GOMS-N2 MSU-G**	**FY-2C S-VISSR +**	**INSAT-3D IMAGER**	**Kalpana-2 VHRR**
4.13 μm	40 cm^{-1}							
3.98 μm	40 cm^{-1}							
3.74 μm	100 cm^{-1}	3.40-4.20 μm	3.80-4.00 μm	3.50-4.00 μm	3.50-4.00 μm	3.50-4.00 μm	3.80-4.00 μm	
		1.50-1.78 μm			~ 1.6 μm		1.55-1.70 μm	
		0.74-0.88 μm			0.80-0.90 μm			
0.70 μm	1000 cm^{-1}	0.56-0.71 μm	0.55-0.75 μm	0.55-0.90 μm	0.65-0.80 μm	0.55-0.99 μm	0.52-0.72 μm	0.55-0.75 μm
		0.60-0.90μm			0.50-0.65 μm			
3000 x 3000 km^2 in 42 min. 1000 x 1000 km^2 in 5 min. Full disk in 8 h – IFOV: 8 km.		15 min	30 min	60 min	30 min	30 min	30 min	30 min
		VIS/IR 3.0 km HRVIS 1.0 km	IR 4.0 km VIS 1.0 km	IR 4.0 km VIS 1.0 km	IR 4.0 km VIS/NIR 1.0 km	IR 5.0 km VIS 1.25 km	IR 4km WV 8km VIS/NIR 1.0 km	IR 8.0 km VIS 2.0 km

NOTE
(*) SEVIRI channels are defined as 99 % of encircled energy instead of half-power-width.
(**) The three CCD channels, shadowed in the Table, have IFOV = 1 km.

9. Three categories of instruments can be identified:

- "AVHRR-like" imagers with 3-6 channels: GOES-13/IMAGER, MTSAT-1R/JAMI, FY-2C/S-VISSR+, INSAT-3A/VHRR+CCD and Kalpana-2/VHRR;
- advanced imagers with pseudo-sounding capability: MSG-1/SEVIRI and GOMS-N2/MSU-G;
- sounding radiometers: GOES-13/SOUNDER and INSAT-3D/SOUNDER.

10. SEVIRI is the imager for the Meteosat Second Generation series. In 2006, the GOMS-N2 MSU-G will carry a comparable imager.. These imagers have the distinct advantage over the AVHRR-like" instruments in that they are able to provide more information on water vapour and the microphysical structures of cloud, therefore enabling better monitoring of atmospheric stability and of the linkage between clouds and precipitation. They also should enable improved height assignment to cloud-motion vectors and more wind measurements in clear air though water vapour tracking. Aerosol observation also be improved, as well as surface parameters, such as sea and land surface temperature and vegetation indexes (more window channels).

11. It is planned to update the NOAA/NESDIS GOES-R imager in the 2012 timeframe. Also, EUMETSAT is considering an improved imager for the Meteosat Third Generation (MTG) series, which is due to replace in 2015, the series just initiated (with Meteosat-8 being the first Meteosat Second Generation).

12. One recommendation - in order to provide for comparable data content - to all other CGMS members is that they plan to improve their GEO imagers to at least the SEVIRI level (see main features in Table 3), and possibly to the level foreseen for GOES-R and MTG. Table 4 indicates the current findings concerning the channels considered for these advanced imagers (for MTG there are more configurations; this is only one).

Table 4
Candidate imaging channels of Meteosat Third Generation (2015) and GOES-R (2012)

Candidate channels for the imager of	Meteosat Third Generation	Candidate channels for the imager of	GOES-R
λ [μm]	Δλ [μm]	λ [μm]	Δλ [μm]
0.443	0.02	0.470	0.04
		0.555	0.02
0.645	0.05	0.64	0.10
0.865	0.04	0.86	0.04
1.375	0.03	1.38	0.03
1.61	0.06	1.61	0.06
2.13	0.05	2.26	0.05
3.80	0.60	3.7	0.18
		3.90	0.20
6.70	0.4	6.15	0.9
		7.0	0.4
7.35	0.3	7.4	0.2
8.55	0.3	8.5	0.4
9.70	0.3	9.7	0.2
		10.35	0.5
10.8	1.0	11.2	0.8
12.0	1.0	12.3	1.0
13.4	0.3	13.3	0.6
14.0	0.3		

13. As for the sounding mission, at the present only GOES is equipped with a sounding radiometer, and INSAT-3D will be in about 2005. The GOES instrument was introduced in 1994 with GOES-8. It's use is understood to be generally for limited areas (see Table 3), more for nowcasting (instability monitoring) than for NWP. The prevalent trend within the NWP community is to use frequent sounding from GEO as an input to regional NWP and to mesoscale models. For this purpose, good vertical resolution is needed, which is possible only by using a spectrometer. This has been implemented in LEO (AIRS on EOS-Aqua and will be followed by IASI on EPS/Metop). In GEO, this capability should soon be demonstrated by GIFTS on NMP/EO-3. One important application of frequent sounding from GEO is wind profile retrieval in clear-air by tracking features of the water vapour profile.

14. Both EUMETSAT and NOAA are considering to place an advanced sounder on MTG and GOES-R respectively. General features could be:

- minimum spectral coverage: 4.0-14.3 μm (700-2500 cm^{-1})
- spectral resolution: 0.5 to 0.625 cm^{-1}
- space resolution: 2 to 10 km (most likely: ~ 4 km at 5 μm, ~ 8 km at 14 μm)
- radiometric resolution: 0.2 K @ 280 K
- absolute calibration: 0.5 K @ 280 K
- observing cycle: 15 to 60 min for full disk, proportionally less for limited areas.

15. A second recommendation to other CGMS members is to provide for an IR sounding mission at the time when they move to the next generation of their GEO satellites. This would be consistent with the approved WMO vision that some geostationary satellites have sounding capability.

16. One definite gap in the current and near-future constellation of GEO satellites is the lack of microwave observation for the dual purpose of frequent nearly-all-weather temperature/humidity profiling and associated precipitation products. This subject was discussed at CGMS-XXX (see

CGMS-XXX EUM WP-25). At that time, it was recommended that that the mission main features could be:

- use of absorption bands of O_2 (54, 118 and 425 GHz) and H_2O (183 and 380 GHz) with 6-10 channels in each band as narrow and radiometrically performing as needed for temperature and humidity profiling;
- about 3-m antenna diameter to ensure 10 km resolution at the highest frequency;
- about 1/10 of the disk scanned each 15 min;
- simultaneous retrieval of temperature profile (30 km resolution), humidity profile (20 km), liquid and ice water columnar contents and gross profiles (20 km), and precipitation (10 km).

17. Basic studies of such an instrument have been initiated in the USA (NOAA, NASA and others) and in ESA. Interest has also been expressed by China. The third recommendation to CGMS, in this case, is addressed to the R&D space agencies, since a demonstration mission, possibly by a dedicated small satellite, could be implemented sometimes around 2010, before planning for a full operational capability.

Sun synchronous satellites

18. The WMO approved missions in the vision for the constellation of sunsynchronous satellites states that they should be optimally spaced in time with multispectral imager (MW/IR/VIS/UV), all with sounder (MW), three with hyperspectral sounders (IR), all with radio occultation (RO), two with altimeters and three with conical scanning MW or scatterometer. This suite of instruments would provide:

- global temperature and humidity sounding in clear (by IR) and cloudy (by MW) areas, for NWP
- global imagery of clouds, with finer resolution than from GEO and extending to polar regions
- surface parameters such as temperature, albedo, ice, snow, vegetation
- (by MW) precipitation, polar ice, sea-surface wind
- aerosol, radiation budget, ozone, trace gases and further measurements of increasing importance in the context of climate monitoring and environment survey.

19. Table 5 contains information for satellites in orbit as indicated in the pre-session documentation for CGMS XXXI. Since the WMO requirement is for 4 optimally spaced satellites to provide global coverage at 3-hour intervals, eight time sectors of 3 hours duration in terms of Local Solar Time (LST) has been used to classify the missions. Table 6 is an extrapolation of the information into the year 2006, in order to take into consideration future mission, e.g., EPS/MetOp, Meteor-3M-N2 and FY-3A. This table has been supplemented with some subjective evaluation in order to fill gaps of available information.

Table 5
Coverage from meteorological LEO satellites as of end 2003 (CGMS XXXI)

Time	Satellite	LST	Passes	Instruments
00-03	**NOAA-16**	**01.05**	**00.15-01.55**	**AVHRR/3, HIRS/3, AMSU-A, MHS, SBUV/2,SEM/2, Argos, SARSAT**
03-06				
06-09	**FY-1C**	**06.45**	**08.40-10.20**	**MVISR**
	Block-5D-2 F14	**07.25**	**06.35-08.15**	**SSM/I, SSM/T, SSM/T2 + others not available**
	NOAA-15	**07.30**	**06.40-08.20**	**AVHRR/3, HIRS/3, AMSU-A, AMSU-B,SEM/2, Argos, SARSAT**
	FY-1D	**08.30**	**07.40-09.20**	**MVISR**
	Block-5D-3 F15	**08.40**	**07.50-09.30**	**SSM/I, SSM/T, SSM/T2 + others not available**
09-12	**Meteor-3M-N1**	**09.15**	**08.25-10.05**	**MR-2000M1, Klimat, MIVZA, MTVZA, MSU-E, SAGE-III, SFM-2, KGI-4C, MSGI-5EI**
	NOAA-17	**10.15**	**9.25-11.05**	**AVHRR/3, HIRS/3, AMSU-A, AMSU-B, SBUV/2,SEM/2, Argos, SARSAT**
12-15	**NOAA-16**	**13.55**	**13.05-14.45**	**AVHRR/3, HIRS/3, AMSU-A, MHS, SBUV/2,SEM/2, Argos, SARSAT**
15-18				
18-21	**FY-1C**	**19.35**	**18.45-20.25**	**MVISR**
	Block-5D-2 F14	**20.15**	**19.25-21.05**	**SSM/I, SSM/T, SSM/T2 + others not available**
	NOAA-15	**20.20**	**19.30-21.10**	**AVHRR/3, HIRS/3, AMSU-A, AMSU-B,SEM/2, Argos, SARSAT**
21-24	**FY-1D**	**21.20**	**20.30-22.10**	**MVISR**
	Block-5D-3 F15	**21.30**	**20.40-22-20**	**SSM/I, SSM/T, SSM/T2 + others not available**
	Meteor-3M-N1	**22.05**	**21.15-22.55**	**MR-2000M1, Klimat, MIVZA, MTVZA, MSU-E, SAGE-III, SFM-2, KGI-4C, MSGI-5EI**
	NOAA-17	**23.05**	**22.15-23.55**	**AVHRR/3, HIRS/3, AMSU-A, AMSU-B, SBUV/2,SEM/2, Argos, SARSAT**

Table 6
Perspective coverage from meteorological LEO satellites expected in 2006

Time	Satellite	LST	Passes	Instruments
00-03	**NOAA-18**	**01.10**	**00.20-02.00**	**AVHRR/3, HIRS/3, AMSU-A, MHS, SBUV/2,SEM/2, Argos, SARSAT**
03-06	**Block-5D-3 S17**	**05.30**	**04.40-06.20**	**SSMIS + others not available**
06-09	**Block-5D-3 S16**	**07.10**	**06.20-08.00**	**SSMIS + others not available**
09-12	**Meteor-3M-N2**	**09.15**	**08.20-10.00**	**MSU-MR, IRFS-2, MTVZA, KMSS, Radiomet, Severjanin, GGAK-M**
	MetOp-1	**09.30**	**08.40-10.20**	**AVHRR/3, HIRS/4, AMSU-A, MHS, IASI, GOME-2, GRAS, ASCAT, SEM/2, Argos, SARSAT**
	FY-3A	**09.45**	**8.55-10.35**	**VIRR, MODI, MWRI, IRAS, MWAS, MWHS, TOM/OP**
	NOAA-17	**10.15**	**9.25-11.05**	**AVHRR/3, HIRS/3, AMSU-A, AMSU-B, SBUV/2,SEM/2, Argos, SARSAT**
12-15	**NOAA-18**	**14.00**	**13.10-14.50**	**AVHRR/3, HIRS/3, AMSU-A, MHS, SBUV/2,SEM/2, Argos, SARSAT**
15-18				
18-21	**Block-5D-3 S17**	**18.10**	**17.20-19.00**	**SSMIS + others not available**
	Block-5D-3 S16	**20.00**	**19.10-20.50**	**SSMIS + others not available**
21-24	**Meteor-3M-N2**	**22.05**	**21.10-22.50**	**MSU-MR, IRFS-2, MTVZA, KMSS, Radiomet, Severjanin, GGAK-M**

	MetOp-1	**22.20**	**21.20-23.00**	**AVHRR/3, HIRS/4, AMSU-A, MHS, IASI, GOME-2, GRAS, ASCAT, SEM/2, Argos, SARSAT**
	FY-3A	**22.35**	**21.45-23.25**	**VIRR, MODI, MWRI, IRAS, MWAS, MWHS, TOM/OP**
	NOAA-17	**23.05**	**22.15-23.55**	**AVHRR/3, HIRS/3, AMSU-A, AMSU-B, SBUV/2,SEM/2, Argos, SARSAT**

20. It should be noted that the DMSP satellite series have been included although they are not considered as part of the space-based component of the GOS. The situation depicted in Table 5 is rather misleading, since several satellites have degraded capabilities, some seriously degraded. Thus, it is more appropriate to use Table 6 bearing in mind the inclusion of non GOS satellite missions. It should also be noted that the DMSP Block-5D-3 are not equipped with an IR sounder, nor with an AVHRR-like imager providing real time transmission (they have been included to show what is available for precipitation observation from the MW imager). Regardless of the DMSP satellites, it can be seen that there are two large gaps of coverage, one in the interval 03-09 LST, the other one in the interval 15-21 LST. On the contrary, there an excessive number satellites in the intervals 09-12 LST and 21-24 LST. Figure 2 shows the satellite tracks of NOAA-17, NOAA-18, Meteor-3M-N2, MetOp-1 and FY-3A, i.e., the five satellites carrying the imagery and sounding missions in the year 2006. Figure 2.a refers to the coverage from the five satellites in a 3-hours window. It can be seen that the WMO objective of a global coverage in three hours is not achievable given the present planned equator crossing times. . Figure 2.b shows that nearly-global coverage is achieved only in a 6-hours window.

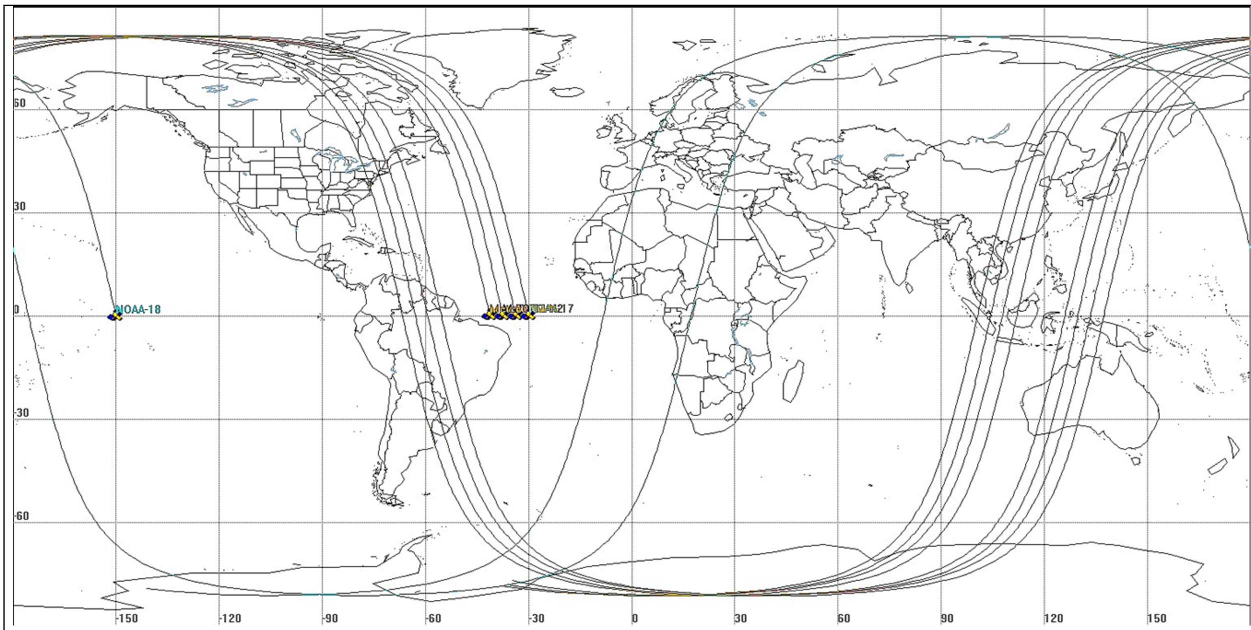

Fig. 2.a – Coverage by NOAA-17, NOAA-18, Meteor-3M-N2, MetOp and FY-3A in 3 hours.

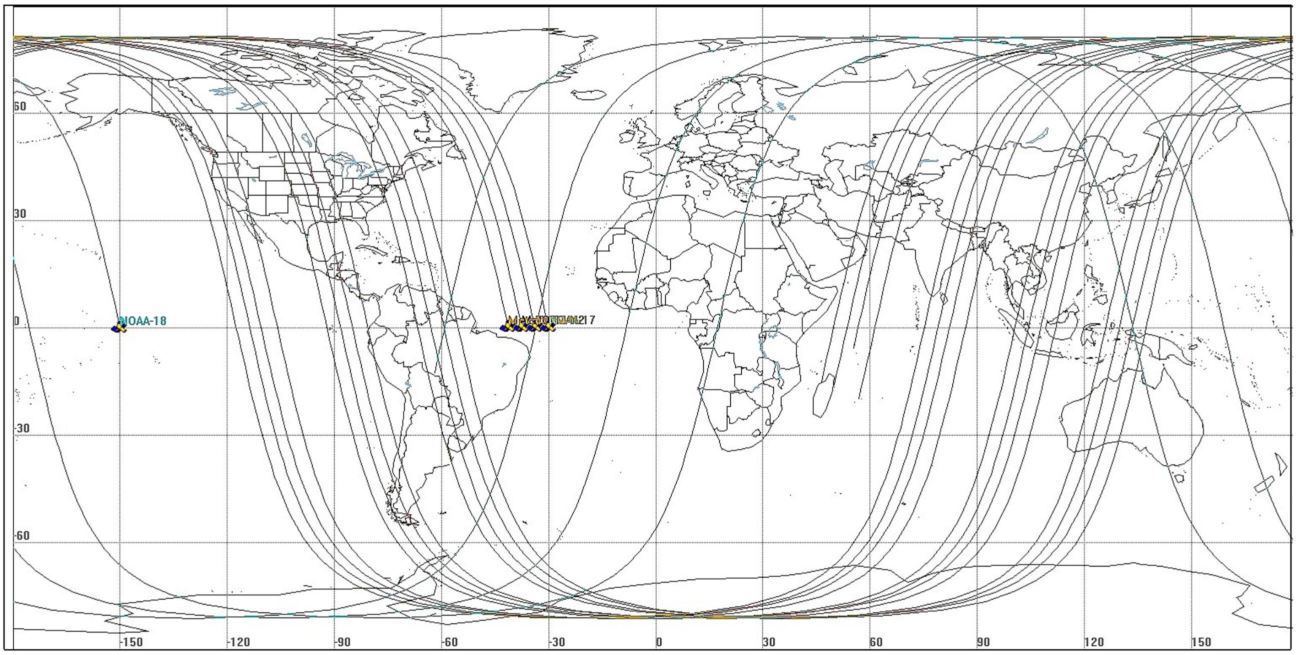

Fig. 2.b – Coverage by NOAA-17, NOAA-18, Meteor-3M-N2, MetOp and FY-3A in 6 hours.

21. For comparison, Figure 3 shows what could be the situation if the LST of four satellites were more regularly spaced. Fig. 3.a shows that near-global coverage could actually be achieved every three hours, and Fig. 3.b confirms that, in a 6-hours window, there could be two near-global coverages.

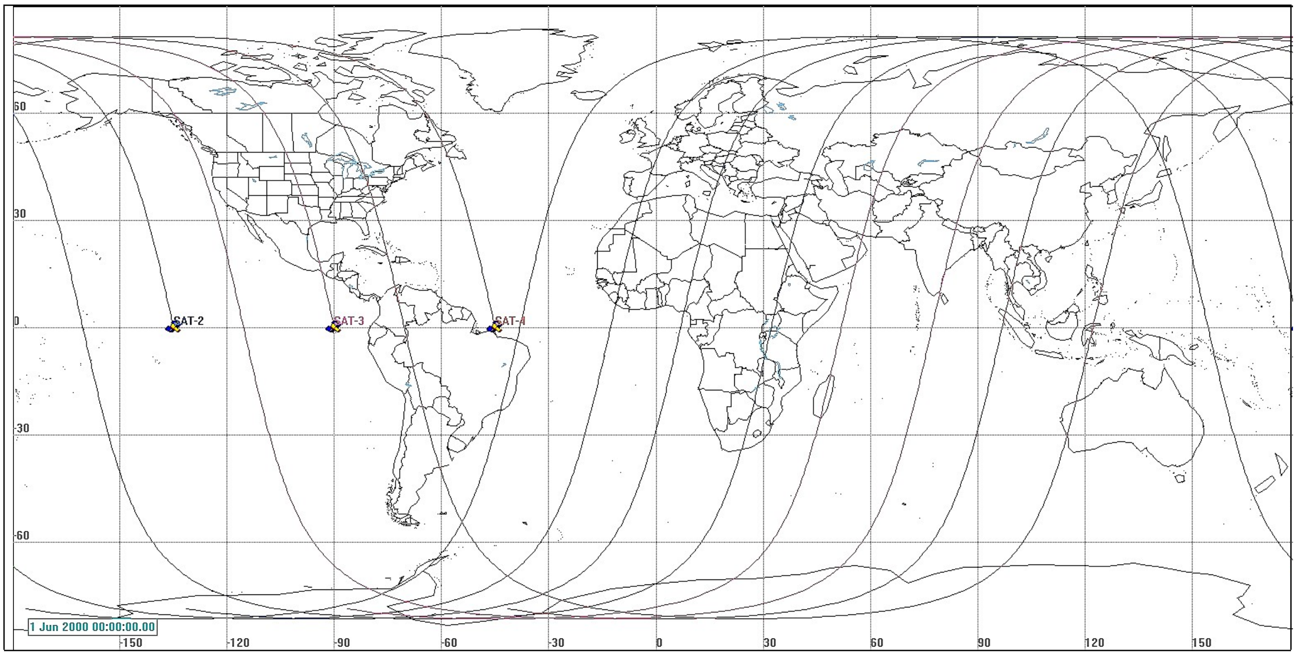

Fig. 3.a – Coverage by four satellites with regularly-spaced LST in 3 hours.

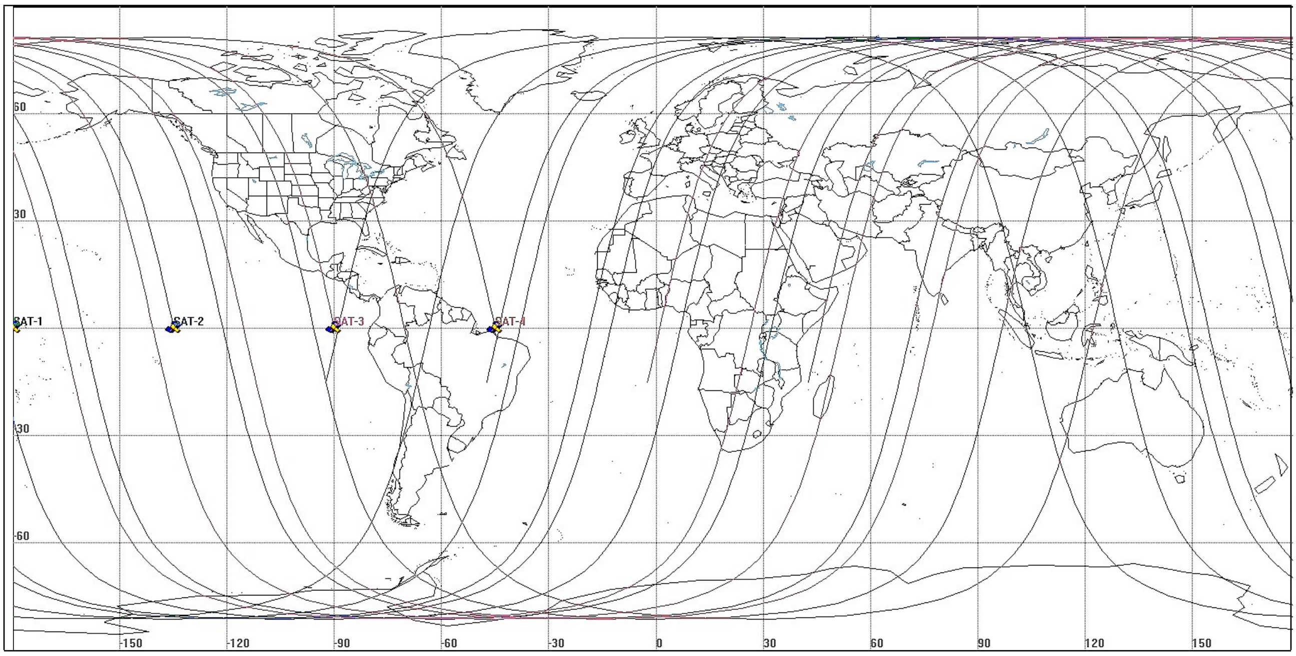

Fig. 3.b – Coverage by four satellites with regularly-spaced LST in 6 hours.

22. The LST differences between operational satellites, to be compared with the goal of 3 h, are as follows:

LST	NOAA-18 01.10	Meteor-3M-N2 09.15	MetOp-1 09.30	FY-3A 09.45	NOAA-17 10.15	NOAA-18 14.00	Meteor-3M-N2 22.05	MetOp-1 22.20	FY-3A 22.35	NOAA-17 23.05	NOAA-18 01.10
∆ LST	8 h 10’	15’	15’	30’	3 h 45’	8 h 5’	15’	15’	30’	2 h 5’	

23. This is a typical situation that actually could become worse. For example, NOAA-18 passes could occur between 00.20 and 02.00 (see Table 6), as early as at 00.20, and Meteor-3M-N2 passes could occur between 08.20 and 10.00, i.e., as late as 10.00, which would means that occasionally there may be gaps of coverage of up to 9 h and 40 min in the early morning, and the same in the late afternoon. The minimum gap is 6 h and 20 min.

24. It could be argued that this unsatisfactory situation is only provisional until the NPOESS series starts. However, the current schedule of NPOESS launches is as follows:

- NPP - 2006 – LST: 10.30 (descending), 23.20 (ascending)
- NPOESS-1 - 2009 – LST: 09.30 (descending), 22.20 (ascending)
- NPOESS-2 - 2011 – LST: 00.40 (descending), 13.30 (ascending)
- NPOESS-3 - 2013 – LST: 05.30 (descending), 18.20 (ascending)

25. This means that the gap in the early morning / late afternoon orbit will not change until year 2013, if current plans are not modified. On the contrary, the mid-morning / late evening timeframes tend to become even more crowded.

26. As for the situation with payloads and comparable data content, *Table 7* shows the situation for VIS/IR imagers, Table 8 for IR sounders and Table 9 for MW sounders. Of the two NOAA satellites, NOAA-18 is referred to since NOAA-17 will be near end-of-life.

Table 7
Channels characteristics of the VIS/IR imagers to be operational in 2006

NOAA-18 and MetOp-1	AVHRR/3	Meteor-3M-N2	MSU-MR	FY-3A	VIRR
λ	Δλ	λ	Δλ	λ	Δλ
12.00 μm	1.00 μm	12.00 μm	1.00 μm	12.00 μm	1.00 μm
10.80 μm	1.00 μm	11.00 μm	1.00 μm	10.80 μm	1.00 μm
3.74 μm	**0.38 μm**	3.80 μm	0.6 μm	3.75 μm	0.4 μm
1610 nm	**60 nm**	**1700 nm**	**200 nm**	1610 nm	60 nm
				1360 nm	70 nm
912 nm	375 nm	950 nm	300 nm	865 nm	50 nm
630 nm	**100 nm**	**600 nm**	**200 nm**	630 nm	100 nm
				555 nm	50 nm
				505 nm	50 nm
				455 nm	50 nm
6	**channels**	**6**	**channels**	10	channels
Swath:	**2900 km**	**Swath:**	**3100 km**	**Swath:**	**2800 km**
IFOV:	**1.1 km**	**IFOV:**	**1.1 km**	**IFOV:**	**1.1 km**

Table 8
Main features of IR sounders to be operational in 2006

Parameter	NOAA-18 & MetOp-1 HIRS/4	MetOp-1 IASI	FY-3A IRAS	Meteor-3M-N2 IRFS-2
Spectral range	**3.7-15.0 μm + 0.7 μm**	**3.62-15.5 μm**	**3.7-15.0 μm + 0.6-1.7 μm**	**5-15 μm**
Spectral resolution	**16 cm^{-1} at 14 μm, 23 cm^{-1} at 4.5 μm**	**0.25 cm^{-1} (unapodised)**	**16 cm^{-1} at 14 μm, 23 cm^{-1} at 4.5 μm**	**0.5 cm^{-1} (apodised)**
Channels	**19 IR + 1 VIS**	**8460**	**20 IR + 6 VIS/NIR**	**~ 4000**
IFOV at s.s.p.	**10 km**	**12 km**	**17 km**	**35 km**

Sampling	**56 IFOV/scan**	**2 x 2 in 48 x 48 km^2 FOV 30 FOV/scan**	**56 IFOV/scan**	**1 in 100 x 100 km^2 FOV 20 FOV/scan**
Swath	**2250 km**	**2230 km**	**2250 km**	**2000 km**

Table 9
Main features of MW sounders to be operational in 2006

Parameter	NOAA-18 and	MetOp-1	FY-3A		Meteor-3M-N2
	AMSU-A	MHS	MWAS	MWHS	MTVZA
Spectral range	**23-90 GHz**	**88-195 GHz**	**50-57 GHz**	**150-183 GHz**	**18-57 GHz and 90-183 GHz**
Channels	**15**	**5**	**4**	**4 (1 with two pol.)**	**20 (6 with two polarisations)**
IFOV at s.s.p.	**48 km**	**16 km**	**70 km**	**15 km**	**68 km at 54 and 183 GHz, 34 km at 37 GHz, 17 km at 91 GHz**
Sampling	**30 IFOV/scan**	**90 FOV/scan**	**~ 20 IFOV/scan**	**~ 100 IFOV/scan**	**Conical scanning**
Swath	**2250 km**	**2250 km**	**2250 km**	**2250 km**	**2200 km**

27. From the viewpoint of payload and comparable data content, it is can be seen that the mid-morning / late evening timeframes exhibit an overlapping of satellite missions and associated capabilities. Both MetOp-1 and Meteor-3M-N2, flying with a 15 minute separation, will be equipped with IR sounding interferometers and comparable MW sounders, as well as very similar VIS/IR imagers. This situation would be further exacerbated with the addition of NPOESS-1 in 2009.

28. A weakness that contributes to a gap in the early morning / late afternoon is the payload of NOAA-18 in the night / early afternoon timeframe. NOAA-18 isn't equipped with an advanced IR sounder and therefore does not seem adequate to meet requirements through the decade. The next improvement would occur with NPOESS-2 (2011).

29. There is one positive aspect that could mitigate the less-than-optimum spacing in the mid-morning and late evening timeframes. Several satellites will provide additional capabilities above that for basic imagery and sounding. They are listed in Table 6. Those of meteorological/climatological interest are as follows.

EPS/MetOp-1:

- GOME-2 (Global Ozone Monitoring Experiment - 2), UV/VIS spectrometer for ozone profile and total columns of NO_2, BrO, ClO, OClO; resolution/swath: 60 km / 960 km or 80 km / 1920 km;
- GRAS (GNSS Receiver for Atmospheric Sounding), for radio-occultation sounding;
- ASCAT (Advanced Scatterometer), for sea-surface wind (speed and direction).

Meteor-3M-N2:

- KMSS, a VIS/NIR radiometer with 4 channels, resolution 100 m, swath 100 km;
- Radiomet for radio-occultation sounding;
- Severjanin, an X-band Synthetic Aperture Radar, resolution 450 or 900 m, swath 450 km.

FY-3A:

- MODI (Moderate-resolution Visible and Infrared Imager), a 20-channel VIS/NIR/TIR imager, resolution 250 m and 1 km, for ocean colour and vegetation;
- MWRI (Micro-Wave Radiation Imager), conical scanner with 6 dual-polarisation channels.
- TOM/OP (Total Ozone Mapper and Ozone Profiler), two nadir-viewing spectrometers for total ozone and ozone profile, respectively; resolution 200 km.

NOAA-18:

- SBUV/2 (Solar Backscatter Ultraviolet - 2): 12-channel UV spectroradiometer for ozone profile, resolution 170 km horizontal, 7 km vertical, nadir-viewing

Conclusions and recommendations

30. This short overview of the space-based component of the GOS at system level shows that there are several issues that require coordination for possible improved efficiency for the overall space-based component of the GOS.

31. For the **geostationary constellation**, the following issues have been identified:

- while the spacing between operational satellites is not regular or even, it doesn't constitute a serious concern; also, there appears to be sufficient satellites in-orbit to provide sufficient contingency margins (See WMO WP-5 for a further discussion on Global Contingency Planning);
- it is suggested that several imagers should be upgraded to at least the level of SEVIRI (timeframe: 2015);
- it is suggested that frequent IR frequent sounding be made by spectrometers (timeframe: 2015)
- it is suggested that MW soundings in GEO be investigated by a demonstration mission (timeframe: 2010).

32. For the **constellation of sunsynchronous satellites**, the following has been found:

- although the number of satellites in orbit is adequate, there could be two coverage gaps of potentially over 8 hour duration in the early morning and late afternoon; with the present plans, this would continue until at least 2013;
- there is a over abundance of satellites in the mid-morning and late evening timeframes; the basic sounding and imaging mission would be heavily redundant; however the satellite missions differ for the remaining payload;
- the payload in the night /early afternoon timeframe would not be state-of-art, specifically for the sounding mission; with present plans, this would continue until 2011.