CGMS-46 WMO-WP-14
v1A Draft, 9 May 2018

Prepared by WMO
Agenda Item: 3.1
Discussed in WG III

RISK ASSESSMENT AND GAP ANALYSIS

In response to CGMS Action WG-III-A45.02, HLPP reference: 1.1.7

This WP aims at supporting the discussion on gap analysis and risk assessment by the Working Group on Operational Continuity and Contingency Planning (WG III). It is based on the gap analysis maintained by WMO in the Observing Systems Capability Analysis and Review Tool (OSCAR), available at https://www.wmo-sat.info/oscar/gapanalyses.

This working paper is an update of CGMS-45 WMO-WP-11. The Paper were reviewed for updating information and possible recommendations.

The detailed analysis of the eight open issues are reported in Appendix 1. The current asset of the Gap analysis considered in OSCAR/Space is provided in Appendix 2.

Actions proposed:

Working Group III members are invited to review and update the status of the identified critical items, to inform on any new risk that should be monitored, and to advise on mitigation actions.

WMO to draft the new WMO Gap Analysis against the WMO's requirements to be submitted in CGMS-47, as discussed in the CGMS WG-III Workshop in March 2018.

APPENDIX 1 - REVIEW OF THE STATUS OF RISK ASSESSMENT ISSUES
APPENDIX 2 - INFORMATION ON THE OSCAR/SPACE GAP ANALYSIS

RISK ASSESSMENT AND GAP ANALYSIS

This working paper is an update of CGMS-45 WMO-WP-11. The results of the discussion at CGMS-45, were as follows:

-	GEO coverage of Indian Ocean	No longer an issue
-	Transition to GOES-R in South America	No longer an issue
-	Imagery and sounding in early morning	No longer an issue
-	Continuity of afternoon primary missions	No longer an issue
1	Geostationary infrared sounding	JMA, NOAA and KMA to implement hyperspectral sounding on the next generations of Himawari, GOES and GEO-KOMPSAT satellites.
2	Radio-occultation	NOAA is encouraged to successfully implement COSMIC-2B.
3	Altimetry	CNES (for SWIM and KaRIN) and JAXA (for SHIOSAI) to continue and intensify their efforts on large-swath altimetry.
4	Active ocean surface wind	Roscosmos and ISRO are encouraged to manifest their long-term plan for the follow-on of Meteor-M N3 and OceanSat-3.
5	Earth Radiation Budget	CMA to investigate whether it is feasible to install ERM-2 on FY-3F. ERB instruments to be considered for future generations of GEO.
6	Limb sounding	Plans for limb sounding in IR and MW to be considered.
7	Passive microwave imaging	NEW, added following WGIII/5.1.1 A45.02 (… include the potential risk of gaps in the capability for passive microwave imaging …)
8	Spectral gaps on future hyperspectral sounders	GSICS to provide base line specification for the inter-calibration of IR imagers making use of hyperspectral sounders

Updated statements of the problems, analysis of the scenarioes, conclusions and possible recommendations are deployed in Appendix 1. The updated list of conclusions/recommendations is tabled as follows:

1	Geostationary infrared sounding	It is recommended that ISRO, JMA, KMA and NOAA implement hyperspectral sounding on the next generations of INSAT, Himawari, GEO-KOMPSAT and GOES satellites.
2	Radio-occultation	It is recommended that NOAA and allied agencies attempt to recover the plan for the COSMIC-2b constellation.
3	Altimetry	It is recommended that CNES, NASA and JAXA bring to completion their development of large-swath altimeters.
4	Active ocean surface wind	It is recommended that ISRO and RosHydroMet consider the issue of long-term continuity of radar scatterometers in the afternoon orbits.
5	Earth Radiation Budget	It is recommended that the agencies that are about to start defining the mission for their next-generation GEO satellites (ISRO, JMA and NOAA) give consideration to an ERB instrument.
6	Limb sounding	It is recommended that R&D agencies with a strong heritage in atmospheric chemistry missions (e.g., ESA with ENVISAT, NASA with Aura) give consideration to a limb sounding mission in IR and Mm-submm.
7	Passive microwave imaging	It is recommended that • CMA/CNSA and NASA report on progress with development of MW sounders in GEO. • NASA/DoD report on progress with development of MIS to provide large-antenna measurements in the early morning. • CMA confirms the FY-3RM programme and its long-term continuation. • ESA and NASA give consideration to follow-on missions for L-band radiometry for sea-surface salinity and volumetric soil moisture.
8	Spectral gaps on future hyperspectral sounders	It is recommended that: • WMO and GSICS to continue the interaction on the subject of spectral gaps. • GSICS to continue reporting on the instruments used for intercalibration exercises.

Working Group III members are invited to review and update the status of the identified critical items, to inform on any new risk that should be monitored, and to advise on mitigation actions. Details are provided in Appendix 1 (Review of the status of risk assessment issues) and Appendix 2 (Information on the OSCAR/Space gap analyses).

APPENDIX 1 - REVIEW OF THE STATUS OF RISK ASSESSMENT ISSUES

In the following tables, for each of the eight issues addressed in CGMS-45, the follow-on activities are recorded. The report include:

- the formulation of the issue;
- plotting of the scenario from the *OSCAR/Space Gap analysis by Mission* as of 10 May 2018;
- a summary analysis of the scenario;
- possible recommendations.

1. Geostationary infrared sounding	Hyperspectral sounding from GEO is basic for high-vertical-resolution, frequent temperature and humidity profiling, and derived winds.

150°W - 90°W	90°W - 30°W	30°W - 30°E	30°E - 90°E	90°E - 150°E	150°E - 150°W	Hyperspectral

Position	Satellite	Instrument	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
137°W	GOES-15	SOUNDER	X	X	X																				
137°W	GOES-17	no sounder	X	X	X	X	X	X	X	X	X	X	X	X											
137°W	GOES-T	no sounder			X	X	X	X	X	X	X	X	X	X	X	X									
105°W	GOES-14	SOUNDER	X	X	X	X																			
75°W	GOES-16	no sounder	X	X	X	X	X	X	X	X	X	X													
75°W	GOES-U	no sounder									X	X	X	X	X	X	X	X	X	X	X				
14.5°W	Electro-L N3	no sounder	X	X	X	X	X	X	X	X															
14.5°W	Electro-M N1	IRSF-GS								X	X	X	X	X	X	X	X	X	X	X					
14.5°W	Electro-M N1	IRSF-GS								X	X	X	X	X	X	X	X	X	X	X					
3.4°W	Meteosat-11	no sounder	X	X	X	X	X																		
0°	Meteosat-10	no sounder	X	X																					
0°	MTG-S1	IRS						X	X	X	X	X	X	X	X	X									
0°	MTG-S2	IRS														X	X	X	X	X	X	X	X	X	
3.7°E	Meteosat-8	no sounder	X	X																					
9.5°E	Meteosat-9	no sounder	X	X																					
9.5°E	MTG-I1	no sounder				X	X	X	X	X	X	X	X	X											
9.5°E	MTG-I2	no sounder								X	X	X	X	X	X	X	X	X							
9.5°E	MTG-I3	no sounder												X	X	X	X	X	X	X	X	X			
9.5°E	MTG-I4	no sounder																X	X	X	X	X	X	X	X
74°E	Kalpana	no sounder	X																						
74°E	INSAT-3DR	SOUNDER	X	X	X	X	X	X	X																
74°E	INSAT-3DS	SOUNDER					X	X	X	X	X	X	X	X											
76°E	Electro-L N2	no sounder	X	X	X	X	X																		
76°E	Electro-L N5	no sounder					X	X	X	X	X	X	X	X	X	X	X								
76°E	Electro-M N2	IRSF-GS									X	X	X	X	X	X	X	X	X	X	X				
82°E	INSAT-3D	SOUNDER	X	X	X	X																			
86.5°E	FY-2E	no sounder	X																						
86.5°E	FY-2H	no sounder	X	X	X	X	X																		
86.5°E	FY-4C	GIIRS			X	X	X	X	X	X	X	X													
86.5°E	FY-4E	GIIRS										X	X	X	X	X	X	X	X						
86.5°E	FY-4G	GIIRS																X	X	X	X	X	X	X	X
105°E	FY-2G	no sounder	X																						
105°E	FY-4A	GIIRS	X	X	X	X																			
105°E	FY-4B	GIIRS	X	X	X	X	X	X	X	X															
105°E	FY-4D	GIIRS						X	X	X	X	X	X	X	X										
105°E	FY-4F	GIIRS													X	X	X	X	X	X	X	X			

112°E	FY-2F	no sounder	x																						
128.2°E	COMS	no sounder	x	x																					
128.2°E	GEO-KOMPSAT-2A	no sounder	x	x	x	x	x	x	x	x	x	x	x	x											
128.2°E	GEO-KOMPSAT-2B	no sounder		x	x	x	x	x	x	x	x	x	x	x	x										
140.7°E	Himawari-8	no sounder	x	x	x	x	x	x	x	x	x	x	x	x											
140.7°E	Himawari-9	no sounder	x	x	x	x	x	x	x	x	x	x	x	x	x	x									
166°E	Electro-L N4	no sounder			x	x	x	x	x	x	x	x													
166°E	Electro-M N3	IRSF-GS												x	x	x	x	x	x	x	x	x	x	x	

Analysis of the scenario	• Hyperspectral sounding has started with FY-4 (GIIRS) and is planned by Electro-M (IRFS-GS) and MTG (IRS). Foreseen coverage: range of longitudes from ~ 30°W to ~ 130°E at the equator. • Hyperspectral sounding currently is not implemented on GOES, Himawari, INSAT and GEO-KOMPSAT. Uncovered range of longitudes from ~ 100°E to ~ 40°W at the equator, i.e. over ~ 55% of the Earth surface. The gap will last up to at least ~ 2036 (GOES), ~ 2031 (Himawari), ~ 2030 (GEO-KOMPSAT) and ~ 2029 (INSAT).
Recommendation	**It is recommended that ISRO, JMA, KMA and NOAA implement hyperspectral sounding on the next generations of INSAT, Himawari, GEO-KOMPSAT and GOES satellites.**

2. Radio-occultation sounding	Reasonably dense and regularly distributed radio-occultation soundings have been demonstrated of high value for NWP.

Constellation (°)	Drifting (°)	ECT ≥04 to <08 h	ECT ≥08 to <12 h	ECT ≥12 to <16 h

ECT or °	Satellite	Instrument	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
72°	COSMIC-1	IGOR	x																						
72°	COSMIC-2b	TGRS																							
24°	COSMIC-2a	TGRS	x	x	x	x	x	x	x	x															
89°	GRACE-FO	Tri-G	x	x	x	x	x	x																	
66°	JASON-CS-A	SRAL			x	x	x	x	x	x	x	x													
66°	JASON-CS-B	SRAL									x	x	x	x	x	x	x	x							
24°	FY-3RM-1	GNOS			x	x	x	x	x	x															
24°	FY-3RM-2	GNOS						x	x	x	x	x	x												
20°	Megha-Tropiques	ROSA	x																						
06:00	KOMPSAT-5	AOPOD	x																						
06:00	SEOSAR/Paz	ROHPP	x	x	x	x	x	x																	
06:00	TerraSAR-X	IGOR	x																						
06:00	TanDEM-X	IGOR	x																						
06:00	TSX-NG	IGOR	x	x	x	x	x	x	x	x															
06:00	FY-3E	GNOS	x	x	x	x	x	x																	
06:00	FY-3H	GNOS				x	x	x	x	x	x	x	x												
09:30	Metop-A	GRAS	x																						
09:30	Metop-B	GRAS	x																						
09:30	Metop-C	GRAS	x	x	x	x	x	x	x																
09:30	Metop-SG-A1	RO				x	x	x	x	x	x	x	x												
09:30	Metop-SG-A2	RO											x	x	x	x	x	x	x	x					
09:30	Metop-SG-A3	RO																		x	x	x	x	x	x
09:30	Metop-SG-B1	RO					x	x	x	x	x	x	x	x											
09:30	Metop-SG-B2	RO												x	x	x	x	x	x	x	x				
09:30	Metop-SG-B3	RO																			x	x	x	x	x
09:30	Meteor-MP N2	ARMA-MP						x	x	x	x	x	x	x	x										
10:00	FY-3F	GNOS		x	x	x	x	x	x																
10:15	FY-3C	GNOS	x																						
11:50	OceanSat-2	ROSA	x																						
12:00	Meteor-M N3	Radiomet				x	x	x	x	x	x														

			18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
14:00	FY-3D	GNOS	x	x	x	x	x																		
14:00	FY-3G	GNOS				x	x	x	x	x	x														
15:30	Meteor-MP N1	ARMA-MP				x	x	x	x	x	x	x	x												

Analysis of the scenario	• The overall number of payloads flown on operational and R&D satellites is very significant, but only dedicated constellations in drifting orbits can provide regular distribution. • Without the COSMIC-2b constellation, the coverage of medium-high latitude with miss regular distribution.
Recommendation	**It is recommended that NOAA and allied agencies attempt to recover the plan for the COSMIC-2b constellation.**

3. Altimetry	Altimetry is the primary mission for ocean circulation and accurate geoid determination. The viewing capability limited to the nadir requires many satellites for implementing a coverage suitable for daily operations, and prevents use for small-scale applications (e.g., in coastal zones). The coarse resolution limits the accuracy of contours detection, e.g. of sea ice.

Geodetic (°)	Drifting (°)	ECT ≥04 to <08 h	ECT ≥08 to <12 h	Along-track SAR	Large swath

ECT or °	Satellite	Instrument	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
66°	JASON-2	Poseidon-3	x																						
66°	JASON-3	Poseidon-3B	x	x	x	x																			
66°	JASON-CS-A	SRAL			x	x	x	x	x	x	x	x													
66°	JASON-CS-B	SRAL									x	x	x	x	x	x	x	x							
66°	HY-2C	ALT		x	x	x	x	x	x																
66°	HY-2D	ALT			x	x	x	x	x	x															
66°	HY-2F	ALT					x	x	x	x	x	x													
66°	HY-2G	ALT					x	x	x	x	x	x													
92°	CryoSat-2	SIRAL	x																						
78°	SWOT	KaRIN				x	x	x	x																
51°	COMPIRA	SHIOSAI		x	x	x	x	x	x																
06:00	HY-2A	ALT	x																						
06:00	HY-2B	ALT	x	x	x	x	x	x																	
06:00	HY-2E	ALT			x	x	x	x	x	x															
06:00	HY-2H	ALT						x	x	x	x	x	x												
06:00	SARAL	AltiKa	x																						
07:00	CFOSAT	SWIM	x	x	x	x	x																		
07:00	CFOSAT-FO	SWIM					x	x	x	x	x	x													
10:00	Sentinel-3A	SRAL	x	x	x	x	x	x																	
10:00	Sentinel-3B	SRAL	x	x	x	x	x	x	x	x															

Analysis of the scenario	• For the purpose of ocean topography and geodesy the availability of altimeters, currently and in the long term, seems sufficient. • Along-track SAR capability for accurate contours detection is being activily pursued. • Large-swath altimetry for sea-level and sea-state in coastal zones by exploiting multi-beam radar or interferometry is about to be introduced (CFOSAT/SWIM by CNES, SWOT/KaRIN by NASA, COMPIRA/SHIOSAI by JAXA).
Recommendation	**It is recommended that CNES, NASA and JAXA bring to completion their development of large-swath altimeters.**

4. Active ocean surface wind measurement	Wind vectors on the sea surface have become an increasingly important input for NWP. They are also valuable for nowcasting, that require more frequent coverage and NRT data availability implying tight cooperation between the Agencies responsible of the various systems.

Drifting (°)	ECT ≥04 to <08 h	ECT ≥08 to <12 h	ECT ≥12 to <16 h

ECT or °	Satellite	Instrument	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
66°	HY-2C	SCAT		x	x	x	x	x	x																
66°	HY-2D	SCAT			x	x	x	x	x	x															
66°	HY-2F	SCAT					x	x	x	x	x	x													
66°	HY-2G	SCAT					x	x	x	x	x	x													
06:00	HY-2A	SCAT	x																						
06:00	HY-2B	SCAT	x	x	x	x	x	x																	
06:00	HY-2E	SCAT			x	x	x	x	x	x															
06:00	HY-2H	SCAT						x	x	x	x	x	x												
06:00	FY-3E	WindRAD	x	x	x	x	x	x																	
06:00	FY-3H	WindRAD				x	x	x	x	x	x	x	x												
07:00	CFOSAT	SCAT	x	x	x	x	x																		
07:00	CFOSAT-FO	SCAT					x	x	x	x	x	x													
08:45	ScatSat-1	OSCAT	x	x	x	x																			
09:30	Metop-A	ASCAT	x																						
09:30	Metop-B	ASCAT	x																						
09:30	Metop-C	ASCAT	x	x	x	x	x	x	x																
09:30	Metop-SG-B1	SCA					x	x	x	x	x	x	x	x											
09:30	Metop-SG-B2	SCA												x	x	x	x	x	x	x	x	x	x		
09:30	Metop-SG-B3	SCA																			x	x	x	x	x
12:00	OceanSat-3	OSCAT	x	x	x	x	x	x																	
12:00	OceanSat-3A	OSCAT		x	x	x	x	x	x																
12:00	Meteor-M N3	SCAT				x	x	x	x	x	x														

Analysis of the scenario	• The coverage in the early- and mid-morning is provided by several satellites, most belonging to operational series committed to long-term continuity. • In the late-morning the commitment to long-term continuity after Meteor-M N3 and OceanSat 3 and 3A has not yet been expressed. • There is no plan for the afternoon coverage, that usually is provided by some satellites of the Meteor series.
Recommendation	**It is recommended that ISRO and RosHydroMet consider the issue of long-term continuity of radar scatterometers in the afternoon orbits.**

5. Earth Radiation Budget	Although ERB was measured since the earliest stage of space meteorology, it was still considered a scientific issue till recently. With the increasing importance of the climate issue and the interest of NWP (before, for model validation, now for initialisation), ERB measurement from space has become an operational requirement.

30°W-30°E	30°E-90°E	150°E-150°W	Molniya	L1	Drifting (°)	ECT ≥04 to <08 h	ECT ≥08 to <12 h	ECT ≥12 to <16 h	Solar irradiance

ECT or °	Satellite	Instrument	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
51.6°	ISS TSIS-1	TSIS	x	x	x	x	x																		
51.6°	ISS TSIS-2	TSIS			x	x	x	x	x	x															
40.5°	STPSat-3	TIM	x																						

40°	SORCE	SIM	x																					
40°	SORCE	TIM	x																					
40°	SORCE	SOLSTICE	x																					
20°	Megha-Tropique	ScaRaB	x																					
06:00	FY-3E	ERM-2	x	x	x	x	x	x																
06:00	FY-3E	SIM-2	x	x	x	x	x	x																
06:00	FY-3H	ERM-2				x	x	x	x	x	x	x	x											
06:00	FY-3H	SIM-2				x	x	x	x	x	x	x	x											
10:15	FY-3C	ERM-1	x																					
10:15	FY-3C	SIM-1	x																					
10:30	Terra	CERES	x																					
13:25	SNPP	CERES	x																					
13:25	NOAA-20	CERES	x	x	x	x	x	x	x															
13:30	JPSS-2	RBI					x	x	x	x	x	x	x	x										
13:30	JPSS-3	RBI									x	x	x	x	x	x	x	x						
13:30	JPSS-4	RBI														x	x	x	x	x	x	x	x		
13:30	Aqua	CERES	x																					
14:00	EarthCARE	BBR		x	x	x	x																	
14:45	FY-3B	ERM-1	x																					
14.5°W	Electro-L N3	GGAK-E/ISP-2M	x	x	x	x	x	x	x	x														
14.5°W	Electro-M N1	ERBR								x	x	x	x	x	x	x	x	x	x	x				
14.5°W	Electro-M N1	GGAK-E/ISP-2M								x	x	x	x	x	x	x	x	x	x	x				
3.4°W	Meteosat-11	GERB	x	x	x	x	x																	
0°	Meteosat-10	GERB	x	x																				
41.5°E	Meteosat-8	GERB	x	x																				
76°E	Electro-L N2	GGAK-E/ISP-2M	x	x	x	x	x																	
76°E	Electro-L N5	GGAK-E/ISP-2M					x	x	x	x	x	x	x	x	x	x	x							
76°E	Electro-M N2	ERBR									x	x	x	x	x	x	x	x	x	x	x			
76°E	Electro-M N2	GGAK-E/ISP-2M									x	x	x	x	x	x	x	x	x	x	x			
166°E	Electro-L N4	GGAK-E/ISP-2M			x	x	x	x	x	x	x	x												
166°E	Electro-M N3	ERBR												x	x	x	x	x	x	x	x	x	x	x	
166°E	Electro-M N3	GGAK-E/ISP-2M												x	x	x	x	x	x	x	x	x	x	x	
Molniya	Arctica-M N1	GGAK-E/ISP-2M		x	x	x	x	x	x															
Molniya	Arctica-M N2	GGAK-E/ISP-2M				x	x	x	x	x	x													
Molniya	Arctica-M N3	GGAK-E/ISP-2M						x	x	x	x	x	x											
Molniya	Arctica-M N4	GGAK-E/ISP-2M							x	x	x	x	x	x										
Molniya	Arctica-M N5	GGAK-E/ISP-2M								x	x	x	x	x	x									
L1	DSCOVR	NISTAR	x	x	x																			

Analysis of the scenario	• Solar irradiance at TOA, in the long-term, will be measured by Electro L/M in GEO and Arctica in the Molniya orbit. In LEO, the sampling is limited to the dawn-dusk orbit, from FY-3. A long-term commitment for TSIS, currently hosted on the ISS, is missing. • As concerns broad-band ERB in LEO, the long-term plan is based on FY-3 in early morning, and JPSS in early afternoon. This is not sufficient to deal with the diurnal variation affected by rapidly-evolving clouds and water vapour. • GEO observation is supposed to complement LEO for diurnal variation but, in the long-term, is only planned for Electro-M, covering only Europe and Asia. DSCOVR observes all longitudes, but only in daylight, and its long-term future is not known.
Recommendation	**It is recommended that the agencies that are about to start defining the mission for their next-generation GEO satellites (ISRO, JMA and NOAA) give consideration to an ERB instrument.**

6. Limb sounding	Major missions for limb sounding (e.g., Envisat with SCIAMACHY, MIPAS and GOMOS) are no longer

	active, and many others (e.g., Aura with TES and MLS) are being operated beyond their expected EOL. Future plans for limb sounding are focusing on ozone, whereas the requirements from atmospheric chemistry, particularly for climate and global environment, include many more species.

Drifting (°)	ECT ≥04 to <08 h	ECT ≥08 to <12 h	ECT ≥12 to <16 h	Occultation	(UV)/VIS/NIR/(SWIR)	(SWIR)/MWIR/TIR	Mm-submm

ECT or °	Satellite	Instrument	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
74°	TIMED	TIDI	x																						
73.9°	SCISAT-1	MAESTRO	x																						
73.9°	SCISAT-1	ACE-FTS	x																						
51.6°	ISS SAGE-III	SAGE-III	x	x	x	x	x																		
27°	ICON	MIGHTY	x	x	x	x	x	x																	
06:00	Odin	OSIRIS	x																						
06:00	Odin	SMR	x																						
09:30	Meteor-MP N2	ACS-limb						x	x	x	x	x	x	x	x										
10:00	FY-3F	OMS-limb		x	x	x	x	x	x																
13:25	SNPP	OMPS-limb	x																						
13:30	JPSS-2	OMPS-limb					x	x	x	x	x	x	x	x											
13:30	JPSS-3	OMPS-limb									x	x	x	x	x	x	x	x							
13:30	JPSS-4	OMPS-limb														x	x	x	x	x	x	x	x		
13:30	GF-5	AIUS	x	x	x	x	x	x	x	x	x														
13:45	Aura	TES-limb	x																						
13:45	Aura	MLS	x																						
15:30	Meteor-MP N1	ACS-limb				x	x	x	x	x	x	x	x												

Analysis of the scenario	• The long-term scenario indicates that, limited to SW sounding, sufficient coverage will be provided by JPSS, Meteor-MP and FY-3. This is sufficient for ozone and a few aggressive species. • There is no plan for IR, that includes several green-house species, and important ozone-affecting species such as CFC's and HNO_3. • No plan, as well, for Mm-submm sounders, thus, e.g., observation of OH and HCl will be missing.
Recommendation	**It is recommended that R&D agencies with a strong heritage in atmospheric chemitry missions (e.g., ESA with ENVISAT, NASA with Aura) give consideration to a limb sounding mission in IR and Mm-submm.**

7. Passive microwave imaging	MW radiometers address many applications. The degree of compliance with requirements is strongly conditioned by the instrument characteristics, that have a large variability. The risk of gaps changes with the application type v/s the instrument concept.

Drifting (°)	ECT ≥04 to <08 h	ECT ≥08 to <12 h	ECT ≥12 to <16 h	Imager/sounder	Sounder	Imager	Large-antenna	L-band

ECT or °	Satellite	Instrument	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
65	GPM-core	GMI	x																						
24	FY-3RM-1	MWRI			x	x	x	x	x	x															
24	FY-3RM-1	MWHS-2			x	x	x	x	x	x															
24	FY-3RM-2	MWRI						x	x	x	x	x	x												
24	FY-3RM-2	MWHS-2						x	x	x	x	x	x												
05:30	DMSP-F20	SSMIS			x	x	x	x	x	x															
06:00	SMOS	MIRAS	x																						
06:00	SMAP	SMAP	x																						
06:00	FY-3E	MWHS-2	x	x	x	x	x	x																	
06:00	FY-3H	MWHS-2				x	x	x	x	x	x	x	x												
06:00	HY-2B	MWI	x	x	x	x	x	x																	

06:10	Coriolis	WindSat	x																						
06:10	DMSP-F18	SSMIS	x																						
06:30	DMSP-F17	SSMIS	x																						
06:30	NOAA-15	AMSU-A	x																						
07:40	NOAA-18	AMSU-A	x																						
07:40	NOAA-18	MHS	x																						
09:00	Meteor-M N2-2	MTVZA-GY	x	x	x	x	x	x																	
09:00	Meteor-M N2-4	MTVZA-GY				x	x	x	x	x	x														
09:00	Meteor-M N2-6	MTVZA-GY						x	x	x	x	x	x												
09:30	Meteor-MP N2	MTVZA-GY-MP						x	x	x	x	x	x	x	x										
09:30	Metop-A	AMSU-A	x																						
09:30	Metop-A	MHS	x																						
09:30	Metop-B	AMSU-A	x																						
09:30	Metop-B	MHS	x																						
09:30	Metop-C	AMSU-A	x	x	x	x	x	x	x																
09:30	Metop-C	MHS	x	x	x	x	x	x	x																
09:30	Metop-SG-A1	MWS				x	x	x	x	x	x	x	x												
09:30	Metop-SG-A2	MWS											x	x	x	x	x	x	x	x					
09:30	Metop-SG-A3	MWS																		x	x	x	x	x	x
09:30	Metop-SG-B1	MWI					x	x	x	x	x	x	x	x											
09:30	Metop-SG-B2	MWI												x	x	x	x	x	x	x	x				
09:30	Metop-SG-B3	MWI																			x	x	x	x	x
10:00	FY-3F	MWRI		x	x	x	x	x	x																
10:00	FY-3F	MWHS-2		x	x	x	x	x	x																
10:15	FY-3C	MWRI	x																						
10:15	FY-3C	MWHS-2	x																						
13:25	SNPP	ATMS	x																						
13:25	NOAA-20	ATMS	x	x	x	x	x	x	x																
13:30	JPSS-2	ATMS					x	x	x	x	x	x	x	x											
13:30	JPSS-3	ATMS									x	x	x	x	x	x	x	x							
13:30	JPSS-4	ATMS														x	x	x	x	x	x	x	x		
13:30	Aqua	AMSU-A	x																						
13:30	GCOM-W1	AMSR-2	x																						
13:30	GCOM-W2	AMSR-2		x	x	x	x	x	x																
13:30	GCOM-W3	AMSR-2			x	x	x	x	x	x															
14:00	FY-3D	MWRI	x	x	x	x	x																		
14:00	FY-3D	MWHS-2	x	x	x	x	x																		
14:00	FY-3G	MWRI				x	x	x	x	x	x														
14:00	FY-3G	MWHS-2				x	x	x	x	x	x														
14:45	FY-3B	MWRI	x																						
14:50	DMSP-F15	SSM/I	x																						
15:00	Meteor-M N2-5	MTVZA-GY					x	x	x	x	x	x													
15:10	Meteor-M N2-3	MTVZA-GY			x	x	x	x	x	x															
15:30	Meteor-MP N1	MTVZA-GY-MP				x	x	x	x	x	x	x	x												
15:45	NOAA-19	AMSU-A	x																						
15:45	NOAA-19	MHS	x																						
15:50	DMSP-F16	SSMIS	x																						

Analysis of the scenario	• Temperature/humidity sounding - Covered in all the three ECT ranges by dedicated sounders and multi-purpose imager-sounders. Progress on GEO sounding, particularly useful for frequent precipitation rate, is not being reported, although developments are running in CMA/CNSA and NASA. • Sea-surface temperature, snow and ice parameters - Conditioned by the coarse space resolution at low frequencies. Only GCOM-W in the early afternoon is equipped with large antenna. Progress on MIS in the early-morning is not reported by DoD. • Precipitation - Continuity of the Global Precipitation Mission is mostly relying on passive MW

	imagers and imager-sounders. Continuity of the necessary calibration systems relies on the FY-3RM satellites, equipped by precipitation radar associated to MW radiometer. • Sea-surface salinity and volumetric soil moisture - No plan is reported for continuation of L-band systems.
Recommendation	• **It is recommended that CMA/CNSA and NASA report on progress with development of MW sounders in GEO.** • **It is recommended that NASA/DoD report on progress with development of MIS to provide large-antenna measurements in the early morning.** • **It is recommended that CMA confirms the FY-3RM programme and its long-term continuation.** • **It is recommended that ESA and NASA give consideration to follow-on missions for L-band radiometry for sea-surface salinity and volumetric soil moisture.**

8. Spectral gaps on future hyperspectral sounders	Hyperspectral sounders, covering extensive spectral ranges, with line-by-line resolution and accurate calibration mechanism, constitute a powerful reference for the calibration of other instruments. The spectral coverage often presents gaps because of technological reasons (detector sensitivity), in front of the priority given to the signal-to-noise necessary for operational sounding retrieval.

Status of actions	CGMS-45 invited "*GSICS to provide a baseline specification of the future IR hyperspectral sounders for the inter-calibration of IR imagers*". Work is in progress. In order to facilitate GSICS to provide its input, WMO has introduced nine entries in the Gap analysis by Mission, listing all the instruments that operate in nine typical spectral intervals exploited for Earth observation. The spectral characteristics of each instrument can be found in the appropriate instrument descriptive page of OSCAR/Space.

Interval	Definition
200-400 nm	This portion of UV is relevant for solar irradiance, absorbing aerosol, the Hartley and Huggins ozone bands, and several species such as BrO, ClO, HCHO, NO, NO2 and SO2.
400-700 nm	VIS range, for clouds, surface, aerosol, ocean colour, and the ozone Chappuis band.
700-1300 nm	NIR range, to observe clouds, surface, the oxygen A-band around 760 nm, and the water vapour band around 940 nm.
1300-3000 nm	SWIR band, to observe surface, aerosol, cloud microphysics, the water vapour bands around 1380 nm and 2700 nm, and several species such as CH4, CO, CO2 and N2O.
3.0-5.0 μm	This portion of MWIR includes a major atmospheric window to observe surface temperatures and clouds, the CO2 band around 4.3 micrometers, and several species such as C2H6, CH4, CO, CO2, COS and N2O.
5.0-8.5 μm	Major water vapour band, extending across MWIR and TIR. It also observes several species such as C2H2, CH4, ClONO2, HNO3, N2O, N2O5, NO, NO2, PAN and SO2.
8.5-15 μm	This portion of TIR includes a major atmospheric window to observe surface and clouds, the main CO2 band, an ozone band around 9.7 micrometers, and several species such as C2H2, C2H6, CFC-11, CFC-12, ClONO2, COS, HNO3, N2O5, PAN, SF6 and SO2.
15 μm - 1 mm (300-20,000 GHz)	This is the FIR range, that includes the Mm/sub-mm range 300-3000 GHz. It is sensitive to cirrus clouds and it is dominated by several bands of H2O and its continuum, as well as O2, and includes bands of ozone, BrO, ClO, HCl, HDO, N2O and OH.
1-300 GHz	This is the MW range, that includes several window regions for surface observations including wind stress, areas of different sensitivity to liquid water and ice water for precipitation inference, absorption bands of O2 (~54 and ~118 GHz) and H2O (~23 and ~183 GHz) for atmospheric temperature and humidity, and bands of O3 and some other species such as HNO3.

Analysis of the scenario	So far, the following instruments are known being used as reference for intercalibration exercises: • IASI (Metop A & B), AIRS (Aqua) and CrIS (SNPP): intervals 3.0-5.0 μm, 5.0-8.5 μm, 8.5-15 μm • MODIS (Terra & Aqua): intervals 400-700 nm, 700-1300 nm, 1300-3000 nm.
Recommendation	• **WMO and GSICS to continue the interaction on the subject of spectral gaps.** • **GSICS to continue reporting on the instruments used for intercalibration exercises.**

APPENDIX 2 - INFORMATION ON THE OSCAR/SPACE GAP ANALYSIS

1. Structure of the OSCAR/Space Gap analysis

The Gap analysIs is split according to two options:

- by Variable
- by Mission.

2. Gap analysis by Variable

The Gap analysis by Variable is implemented by appropriate listing of the instruments (past, current and planned) capable (in principle) to measure the addressed variable. 11 *Domains* are defined:

01 Basic atmospheric
02 Clouds and precipitation
03 Aerosol and radiation
04 Ocean
05 Sea ice
06 Land surface
07 Solid Earth and magnetic field
08 Atmospheric chemistry
09 Ionospheric disturbances
10 Energetic particles and solar wind
11 Solar monitoring.

Currently, there are 124 Earth observation and 62 Space weather variables addressed, as follows:

Domain: 01 - Basic atmospheric

01.01	Atmospheric temperature	01.06	Height of the tropopause
01.02	Specific humidity	01.07	Temperature of the tropopause
01.03	Integrated Water Vapour (IWV)	01.08	Wind speed over the surface (horizontal)
01.04	Wind (horizontal)	01.09	Wind vector over the surface (horizontal)
01.05	Height of the top of the PBL	01.10	Atmospheric density

Domain: 02 - Clouds and precipitations

02.01	Cloud cover		02.10	Cloud ice	
02.02	1.1	Cloud top temperature	02.11	1.2	Cloud ice (total column)
02.03	1.3	Cloud top height	02.12	1.4	Cloud ice effective radius
02.04	1.5	Cloud type	02.13	1.6	Freezing level height in clouds
02.05	Cloud base height		02.14	1.7	Melting layer depth in clouds
02.06	1.8	Cloud optical depth	02.15	1.9	Precipitation (liquid or solid)
02.07	1.10	Cloud liquid water (CLW)	02.16	1.11	Precipitation intensity at surface (liquid or solid)
02.08	1.12	Cloud liquid water (CLW) total column	02.17	Accumulated precipitation (over 24 h)	
02.09	**1.13**	Cloud drop effective radius	02.18	1.14	Lightning detection

Domain: 03 - Aerosols and radiation

03.01	Aerosol Optical Depth		03.11	1.15	Upward short-wave irradiance at TOA
03.02	Aerosol mass mixing ratio		03.12	1.16	Short-wave cloud reflectance

03.03		Aerosol column burden	03.13		Downward long-wave irradiance at Earth surface
03.04		Aerosol effective radius	03.14	1.17	Downward short-wave irradiance at Earth surface
03.05		Aerosol type	03.15	1.18	Earth surface albedo
03.06		Aerosol volcanic ash	03.16	1.19	Earth surface short-wave bidirectional reflectance
03.07		Aerosol volcanic ash (Total column)	03.17	1.20	Upward long-wave irradiance at Earth surface
03.08	1.21	Downward short-wave irradiance at TOA	03.18	1.22	Long-wave Earth surface emissivity
03.09	1.23	Upward spectral radiance at TOA	03.19	1.24	Photosynthetically Active Radiation (PAR)
03.10	1.25	Upward long-wave irradiance at TOA	03.20	1.26	Fraction of Absorbed PAR (FAPAR)

Domain: 04 - Ocean

04.01	1.27	Ocean chlorophyll concentration	04.08	1.28	Ocean dynamic topography
04.02	1.29	Colour Dissolved Organic Matter (CDOM)	04.09	1.30	Coastal sea level (tide)
04.03	1.31	Ocean suspended sediments concentration	04.10	1.32	Significant wave height
04.04	1.33	Ocean Diffuse Attenuation Coefficient (DAC)	04.11	1.34	Dominant wave direction
04.05	1.35	Oil spill cover	04.12	1.36	Dominant wave period
04.06	1.37	Sea surface temperature	04.13	1.38	Wave directional energy frequency spectrum
04.07	1.39	Sea surface salinity			

Domain: 05 - Sea ice

05.01	Sea-ice cover	05.03	Sea-ice thickness
05.02	Sea-ice elevation	05.04	Sea-ice type

Domain: 06 - Land surface

06.01	Land surface temperature	06.12	Snow status (wet/dry)
06.02	Soil moisture at surface	06.13	Snow cover
06.03	Soil moisture (in the roots region)	06.14	Snow water equivalent
06.04	Biomass	06.15	Soil type
06.05	Fraction of vegetated land	06.16	Land cover
06.06	Vegetation type	06.17	Land surface topography
06.07	Leaf Area Index (LAI)	06.18	Glacier cover
06.08	Normalised Difference Vegetation Index (NDVI)	06.19	Glacier motion
06.09	Fire fractional cover	06.20	Glacier topography
06.10	Fire temperature	06.21	Ice sheet topography
06.11	Fire radiative power		

Domain: 07 - Solid Earth and magnetic field

07.01	Geoid	07.04	Gravity field
07.02	Crustal plates positioning	07.05	Gravity gradients
07.03	Crustal motion (horizontal and vertical)	07.06	Geomagnetic field

Domain: 08 - Atmospheric chemistry

08.01	O3	08.09	ClO	08.17	HCHO	08.25	NO2
08.02	O3 (Total column)	08.10	ClONO2	08.18	HCHO (Total column)	08.26	NO2 (Total column)
08.03	BrO	08.11	CO	08.19	HCl	08.27	OH

08.04	C2H2	08.12	CO_2	08.20	HDO	08.28	PAN
08.05	C2H6	08.13	COS	08.21	HNO3	08.29	PSC occurrence
08.06	CFC-11	08.14	H2O	08.22	N2O	08.30	SF6
08.07	CFC-12	08.15	HC3Br	08.23	N2O5	08.31	SO2
08.08	CH4	08.16	HCFC-22	08.24	NO	08.32	SO2 (Total column)

Domain: 09 - Ionospheric disturbances

09.01	Aurora	09.05		Ionospheric plasma velocity
09.02	Electric field	09.06		Ionospheric radio absorption
09.03	Electron density	09.07		Ionospheric scintillation
09.04	Ionospheric plasma density	09.08	1.40	Ionospheric Vertical Total Electron Content (VTEC)

Domain: 10 - Energetic particles and solar wind

10.01	1.41	Electron integral directional flux	10.09	1.42	Cosmic ray neutron flux spectrum
10.02	1.43	Electron differential directional flux	10.10	1.44	Energetic Neutral Atom (ENA)
10.03	1.45	Proton integral directional flux	10.11	1.46	Solar wind density
10.04	1.47	Proton differential directional flux	10.12	1.48	Solar wind temperature
10.05	1.49	Alpha particles integral directional flux	10.13	1.50	Solar wind velocity
10.06	1.51	Alpha particles differential directional flux	10.14	1.52	Interplanetary magnetic field
10.07	1.53	Heavy ion flux energy and mass spectrum	10.15	1.54	Electrostatic charge
10.08	1.55	Heavy ion angular flux energy and mass spectrum	10.16	1.56	Radiation Dose Rate

Domain: 11 - Solar monitoring

11.01	1.57	Solar gamma-ray flux spectrum	11.14	1.58	Solar VIS flux	11.27	1.59	X-ray flux spectrum
11.02	1.60	Solar X-ray flux	11.15	1.61	Solar VIS flux spectrum	11.28	1.62	X-ray sky image
11.03	1.63	Solar X-ray flux spectrum	11.16	1.64	Solar VIS image	11.29	1.65	EUV flux
11.04	1.66	Solar X-ray image	11.17	1.67	Solar white light image	11.30	1.68	EUV flux spectrum
11.05	1.69	Solar EUV flux	11.18	1.70	Solar H-alpha image	11.31	1.71	EUV sky image
11.06	1.72	Solar EUV flux spectrum	11.19	1.73	Solar radio flux spectrum	11.32	1.74	UV flux
11.07	1.75	Solar EUV image	11.20	1.76	Solar coronagraphic image	11.33	1.77	UV flux spectrum
11.08	1.78	Solar Lyman-alpha flux	11.21	1.79	Solar electric field	11.34	1.80	UV sky image
11.09	1.81	Solar Lyman-alpha image	11.22	1.82	Solar magnetic field	11.35	1.83	VIS flux
11.10	1.84	Solar UV flux	11.23	1.85	Solar velocity fields	11.36	1.86	VIS sky image
11.11	1.87	Solar UV flux spectrum	11.24	1.88	Gamma-ray flux	11.37	1.89	Radio-waves
11.12	1.90	Solar UV image	11.25	1.91	Gamma-ray flux spectrum	11.38	1.92	Heliospheric image
11.13	1.93	Solar Ca II-K image	11.26	1.94	X-ray flux		1.95	

After selecting the Domain and the desired Variable, a timeline is displayed, showing the relevant instruments, sorted by default according to the orbit type (GEO longitude or ECT or inclination). The sorting criterion may be changed. The instruments are rated according to five steps (colours) imported from the originating instrument page.

The bar chart is followed by the full list of instruments potentially capable of measuring the Variable, with indication of the rating and the possible operational limitations.

Currently, the rating is indicated by a colour code. The explanation of the rating is not displayed, and it is not easy to understand, since it is a blend of several elements such as the uncertainty, the vertical resolution, and the frequency and spatial resolution of the retrieved measurement in comparison with the space-time variability of the geophysical parameter.

It is foreseen that, in the near future, the explanation of the rating will be displayed, initially just indicating the criterion currently adopted. Modifications will be possible, following User's comments.

Another User interface, being studied, will introduce filters to split the instruments relevant to one variable according to the instrument type, so as to facilitate comparisons.

3. Gap analysis by Mission

The Gap analysis by Mission is designed as a response to the long-term "Vision" developed by CGMS and WMO to serve as guidance for future development. 40 Missions are currently defined:

01	Multi-purpose VIS/IR imagery from LEO	21	Cross-nadir IR spectrometry (for chemistry) from GEO
02	Multi-purpose VIS/IR imagery from GEO	22	Limb-sounding spectrometry
03	IR temperature/humidity sounding from LEO	23	High-resolution imagery for land observation
04	IR temperature/humidity sounding from GEO	24	Synthetic Aperture Radar
05	MW temperature/humidity sounding from LEO	25	Gravity field measuring systems
06	MW temperature/humidity sounding from GEO	26	Precise positioning
07	MW imagery	27	Data Collection Systems and Search-and-Rescue
08	Radio occultation sounding	28	Space weather: Solar activity monitoring
09	Earth radiation budget from LEO	29	Space weather: Heliospheric radiation monitoring
10	Earth radiation budget from GEO	30	Space weather: Energetic particles monitoring
11	Sea-surface wind by active and passive MW	31	Space weather: Field and wave monitoring
12	Radar altimetry	32	Instruments covering 200-400 nm
13	Ocean colour imagery from LEO	33	Instruments covering 400-700 nm
14	Ocean colour imagery from GEO	34	Instruments covering 700-1300 nm
15	Imagery with special viewing geometry	35	Instruments covering 1300-3000 nm
16	Lightning imagery from GEO or LEO	36	Instruments covering 3.0-5.0 μm
17	Cloud and precipitation profiling by radar	37	Instruments covering 5.0-8.5 μm
18	Cross-nadir SW spectrometry (for chemistry) from LEO	38	Instruments covering 8.5-15 μm
19	Cross-nadir SW spectrometry (for chemistry) from GEO	39	Instruments covering 15 μm - 1 mm (300-20,000 GHz)
20	Cross-nadir IR spectrometry (for chemistry) from LEO	40	Instruments covering 1-300 GHz

The Missions 32 to 40 have been introduced recently, to help the GSICS work of identifying reference instruments for intercalibration exercises. Details are still being negotiated with GSICS.

For each Mission, the main instrument characteristics which are necessary to measure the variables relevant to implement the Mission are listed. Depending on these contributing technical features, the various instruments relevant for the Mission are rated according to the level of compliance with the mission objective. The ratings are split in five steps (colours), and the explanation of the rating principles is provided.

The timeline of instruments contributing to the Mission is displayed sorted by default according to the orbit type (GEO longitude or ECT or inclination). The sorting criterion may be changed. The bar chart is followed by the full list of instruments contributing to the Mission.

Since the number of instrument types and characteristics relevant for one Mission may be rather large, a User interface, filters, to select comparable instruments features has been implemented. However, the current filters are based uniquely on the exploited spectral interval that, for several Missions, is not the most significant feature to single out. A new set of filters optimised for each individual Mission has been defined, but its implementation is rather complex, and not coming soon.