WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS
OPEN PROGRAMME AREA GROUP ON INTEGRATED OBSERVING SYSTEMS

EXPERT TEAM ON SATELLITE SYSTEMS

SEVENTH SESSION

GENEVA, SWITZERLAND, 17-19 APRIL 2012

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GAP ANALYSIS OF SPACE-BASED MISSIONS

Gap analysis review and recommendations

(Submitted by the Secretariat)

Summary and Purpose of Document

One of the two approaches of the Gap Analysis consists of comparing the actual capabilities and plans with an agreed reference, which involves :

- Defining the reference configuration required for each observing capability;
- Compiling the satellite mission plans;
- Assessing the gaps between the reference and the plans.

This used to be the scope of Volume 3 of the GOS-Dossier, and will be from now on supported by the SOCRAT database and tool described in Doc 6.2. As concerns this Gap Analysis, the GOS-Dossier and the SOCRAT tool are equivalent in content.

The reference configuration is based on the Vision for the GOS in 2025. In a few cases, as the Vision only provides an outline of the required capabilities, a more specific description was developed in order to support a meaningful analysis.

ET-SAT will be invited to comment on both the methodology and the outcome of the analysis. For quick reference, the “Reference configuration” and the “Gap Analysis” of each capability have been compiled hereafter, as extracted from the GOS-Dossier, Vol. 3. One should however refer to the GOS-Dossier, Vol. 3 itself, or to the SOCRAT demo at the meeting, to find the satellite mission information that supports this whole Gap Analysis.

ACTION PROPOSED

The Expert Team is invited to:

- Note the “Reference configuration” and comment as appropriate;
- Consider the resulting Gap Analysis with reference to the Vision for the GOS in 2025 and express guidance as concerns the major anticipated gaps.

REFERENCE: GOS-Dossier, Volume 3 (http://www.wmo.int/pages/prog/sat/gos-dossier_en.php)

APPENDICES: Extract from the GOS-Dossier, Volume 3

GAP ANALYSIS REVIEW AND RECOMMENDATIONS

1. BACKGROUND

It is among the responsibilities of ET-SAT to advise the Commission for Basic Systems (CBS) on satellite matters and, in particular, to keep under review the status and plans of the space-based GOS in order to identify potential gaps and recommend appropriate actions.

In the context of the migration of the Dossier on the Space-based Global Observing system (GOS-Dossier) to a web-based database and analysis tool, special attention is paid to the validation of the contents that has been transferred.

2. REFERENCE CONFIGURATION

The reference configuration is based on the categories of missions identified in the Vision for the GOS in 2025, which include:

- Operational geostationary satellites,
- Operational polar-orbiting sun-synchronous satellites distributed within 3 orbital planes (~13:30, 17:30, 21:30 ECT),
- Additional operational missions in appropriate orbits (polar-orbiting, geostationary, others)
- Operational pathfinders and technology demonstrators,
- Polar-orbiting and geostationary platforms/instruments for space weather.

In the Vision, the reference configuration is relatively well defined for the core meteorological missions (GEO and LEO) and the ocean surface topography. However, there is a lack of details for other missions such as: atmospheric composition, radio-occultation, ocean colour imagery, and space weather. In such cases, which are highlighted in the appendix, the Vision has been interpreted. ET-SAT may wish to focus its attention on these cases, while noting that additional advice can be sought from the relevant application communities (e.g. in the case of atmospheric composition).

No reference configuration is defined in the Vision as concerns operational pathfinders or technology demonstrators, since the principle is to consider lessons learnt from the demonstration phase before defining whether and how such capabilities should be operationally implemented.

3. SELECTION AND RANKING OF RELEVANT INSTRUMENTS

For each element of the reference configuration, the planned availability and degree of suitability of relevant instruments are indicated in Volume 3 of the GOS-Dossier and in the SOCRAT tool to be demonstrated at the meeting (See Doc. 6.2). ET-SAT may wish to comment on the selection and ranking of instruments.

4. CONCLUSION

ET-SAT is invited:

- To note the “reference configuration”, which underpins the gap analysis and is intended to reflect the Vision for the GOS in 2025; suggestions can be made if necessary to clarify, update or amend either the reference configuration, or the Vision itself.

- To check that the ranking of instruments is sound and adequately supports a Gap Analysis;

- To review the resulting conclusions of the Gap Analysis, and to provide guidance on the main gaps or risks, and possible actions to address them.

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<table>
<tr><th>Category (with ref. to the Vision for the GOS in 2025)</th><th>Capability (with ref. to the Vision for the GOS in 2025)</th><th>Reference Configuration (as stated in the GOS-Dossier, with highlighted comments)</th><th>Gap Analysis (as stated in the GOS-Dossier)</th></tr>
<tr><td>1
Polar-orbiting sun-synchronous on 3 orbits</td><td>Multi-purpose VIS/IR imagery from LEO</td><td>• three orbital planes (early morning: 5:30 ± 2 h; mid-morning: 9:30 ± 2 h; early afternoon: 13:30 ± 2 h);
• one fully compliant instrument in each plane, and one backup, as similar as possible.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the “Multi-purpose VIS/IR imagery from LEO” after 2020</th></tr>
<tr><td>05:30 ± 2 h</td><td>Coverage of the early-morning orbit will rely on the DWSS VIIRS, subject to confirmation of near-real time data availability from this US military programme. No redundancy is planned.</td></tr>
<tr><td>09:30 ± 2 h</td><td>Adequate data are expected to be provided by the MetOp-SG MetImage, the likely follow-on of the FY-3 MERSI-2 and the Meteor-MP MSU-MR-MP.</td></tr>
<tr><td>13:30 ± 2 h</td><td>Adequate data are expected to be provided by the JPSS VIIRS, the likely follow-on of the FY-3 MERSI-2 and the Meteor-MP MSU-MR-MP.</td></tr>
<tr><td>Overall</td><td>Issues in the early morning orbit: DWSS/VIIRS data access and lack of redundancy.</td></tr>
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<tr><td>2
Geostationary</td><td>Multi-purpose VIS/IR imagery from GEO</td><td>• six sectors, 60 degrees wide along the equator (centres: 0°, 60°E, 120°E, 180°E, 120°W, 60°W);
• at least one “SEVIRI-class” instrument in each sector, and one backup, as similar as possible.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the “Multi-purpose VIS/IR imagery from GEO” after 2020</th></tr>
<tr><td>0° ± 30°</td><td>Adequate data are expected to be provided by the MTG-I FCI (with redundancy) and the likely follow-on of the Electro-M MSU-GSM.</td></tr>
<tr><td>60°E ± 30°</td><td>Adequate data are expected to be provided by the FY-4 AGRI and the likely follow-on of the Electro-M MSU-GSM.</td></tr>
<tr><td>120°E ± 30°</td><td>Adequate data are expected to be provided by the FY-4 AGRI, the Himawari AHI and the likely follow-on of the COMS-2 MI-FO.</td></tr>
<tr><td>180° ± 30°</td><td>Only the Electro-L MSU-GS is planned to station in this sector. Possibly to be improved if Electro-M with MSU-GSM follows</td></tr>
<tr><td>120°W ± 30°</td><td>Adequate data are expected to be provided by the GOES-W ABI, backed by a GOES in stand-by position at 105°, also backing GOES-E.</td></tr>
<tr><td>60°W ± 30°</td><td>Adequate data are expected to be provided by the GOES-E ABI, backed by a GOES in stand-by position at 105°, also backing GOES-W.</td></tr>
<tr><td>Overall</td><td>All sectors covered with redundancy, except sector 180°± 30°, that lacks redundancy.</td></tr>
</table>
</td></tr>
<tr><td>3</td><td>IR</td><td>• three orbital planes (early morning:</td><td>Gap analysis for the mission “IR temperature/humidity sounding from LEO” after</td></tr>
</table>

<table>
<tr>
<td>Polar-orbiting sun-synchronous on 3 orbits</td>
<td>temperature/humidity sounding from LEO</td>
<td>5:30 ± 2 h; mid-morning: 9:30 ± 2 h; early afternoon: 13:30 ± 2 h);
• one fully compliant instrument in each plane, and one backup, as similar as possible.</td>
<td>
<table>
<tr><th colspan="2">2020</th></tr>
<tr><td>05:30 ± 2 h</td><td>No IR sounding planned in the early morning orbit.</td></tr>
<tr><td>09:30 ± 2 h</td><td>Adequate data are expected to be provided by the MetOp-SG IAS and the likely follow-on of the FY-3 ASI and the Meteor-MP IKFS-2.</td></tr>
<tr><td>13:30 ± 2 h</td><td>Adequate data are expected to be provided by the JPSS CrIS and the likely follow-on of the FY-3 ASI and the Meteor-MP IKFS-2.</td></tr>
<tr><td>Overall</td><td>Full gap of IR sounding in the early morning orbit. Only MW, with non-optimal scanning (conical).</td></tr>
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<td>4
Geostationary</td>
<td>IR temperature/humidity sounding from GEO</td>
<td>• six sectors, 60 degrees wide along the equator (centres: 0°, 60°E, 120°E, 180°E, 120°W, 60°W)
• at least one hyperspectral instrument in each sector, and one backup, as similar as possible.</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “IR temperature/humidity sounding from GEO” after 2020</th></tr>
<tr><td>0° ± 30°</td><td>Adequate data are expected to be provided by the MTG IRS and the likely follow-on of the Electro-M HIS.</td></tr>
<tr><td>60°E ± 30°</td><td>Adequate data are expected to be provided by the FY-4 GIIRS and the likely follow-on of the Electro-M HIS.</td></tr>
<tr><td>120°E ± 30°</td><td>Adequate data are expected to be provided by the FY-4 GIIRS at 105°E, backed by an FY-4 at 123.5°E.</td></tr>
<tr><td>180° ± 30°</td><td>No satellite planned to station in this sector. However, since Russia is planning to place Electro-L N3 (without sounder) at 166°E, maybe that a Electro-M N3 (with the HIS sounder) follows.</td></tr>
<tr><td>120°W ± 30°</td><td>No sounder planned to station in this sector.</td></tr>
<tr><td>60°W ± 30°</td><td>No sounder planned to station in this sector.</td></tr>
<tr><td>Overall</td><td>Three consecutive sectors, from 150°E to 30°W, i.e. half of the total coverage from GEO, will have no sounder, that implies not only missing temperature and humidity profiles (that in some way are provided by LEO satellites), but also wind profile that is derived from frequent humidity profiling from GEO. A possible follow-on of Electro-L N3 (Electro-M N3) would fix the problem, though lacking redundancy.</td></tr>
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<tr>
<td>5
Polar-orbiting sun-synchronous on 3 orbits</td>
<td>MW temperature/humidity sounding from LEO</td>
<td>• three orbital planes (early morning: 5:30 ± 2 h; mid-morning: 9:30 ± 2 h; early afternoon: 13:30 ± 2 h);
• one fully compliant instrument in each plane, and one backup, as similar as possible.</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “MW temperature/humidity sounding from LEO” after 2020</th></tr>
<tr><td>05:30 ± 2 h</td><td>In the early morning orbit, only conical scanning, not optimal for sounding, is foreseen (DWSS MIS). Both temperature and humidity. No redundancy. Near-real time availability of MW imagery / sounding from these military satellites is subject to confirmation by the USA.</td></tr>
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<tr><td></td><td></td><td></td><td>
<table>
<tr><td>09:30 ± 2 h</td><td>Adequate data are expected to be provided by the MetOp-SG ATMS and the likely follow-on of the FY-3 MWTS-2 + MWHS-2. Contribution also expected from the likely follow-on of the Meteor-MP MTVZA-GY-MP, less performing because of conical scanning.</td></tr>
<tr><td>13:30 ± 2 h</td><td>Adequate data are expected to be provided by the JPSS ATMS and the likely follow-on of the FY-3 MWTS-2 + MWHS-2. Contribution also expected from the likely follow-on of the Meteor-MP MTVZA-GY-MP, less performing because of conical scanning</td></tr>
<tr><td>Overall</td><td>Issues in the early morning orbit: DWSS/MIS lower performance in respect of sounding, no confirmation of near-real time availability, and lack of redundancy.</td></tr>
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<tr><td>6
Operational pathfinders and technology demonstrators</td><td>MW temperature / humidity sounding from GEO</td><td>There is no reference observing strategy for GEO MW at the moment since this mission is not yet part of the operational baseline for the GOS. The Vision for the GOS in 2025 calls for operational pathfinder missions. Ultimately, such mission could be implemented as follows:
six sectors, 60 degrees wide along the equator (centres: 0°, 60°E, 120°E, 180°E, 120°W, 60°W);
at least one instrument in each sector, either viewing the full disk or addressing selected areas.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “MW temperature/humidity sounding from GEO” after 2020</th></tr>
<tr><td>0° ± 30°</td><td>GAS is a technological study being run by ESA. Actual flight not yet planned.</td></tr>
<tr><td>60°E ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>120°E ± 30°</td><td>Nothing is planned. (To be updated, noting the FY-4 M plan of CMA)</td></tr>
<tr><td>180° ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>120°W ± 30°</td><td>GeoSTAR is a technological study being run by NASA. A demonstration flight (PATH, Precipitation and All-weather Temperature-Humidity) has been proposed in the framework of the U.S. Earth Science Decadal Survey.</td></tr>
<tr><td>60°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>Overall</td><td>No operational plan is available for the foreseeable future; only a possible pathfinder in the 120°W ± 30° sector.</td></tr>
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<tr><td>7
Polar-orbiting sun-synchronous on 3 orbits</td><td>Multi-purpose MW imagery</td><td>three orbital planes (early morning: 5:30 ± 2 h; mid-morning: 9:30 ± 2 h; early afternoon: 13:30 ± 2 h);
one fully compliant instrument in each plane, and one backup, as similar as possible;
additional satellites, including some in low-inclination non-sunsynchronous orbits, so as to</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Multi-purpose MW imagery” after 2020</th></tr>
<tr><td>05:30 ± 2 h</td><td>Coverage of the early-morning orbit will rely on the DWSS MIS, with good resolution and wide spectral range. No redundancy. Near-real time availability of MW imagery/sounding data from these military satellites is subject to confirmation by the USA.</td></tr>
<tr><td>09:30 ± 2 h</td><td>Several instruments will be available, all with limitations: missing low frequencies (MetOp-SG MWI), or coarse resolution (likely follow-on of Meteor-MP MTVZA-GY-MP and FY-3 MWRI).</td></tr>
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<td>implement the 3-hourly global observing cycle required by the Global Precipitation Measurement mission. (See Mission 19)</td>
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<table>
<tr><td>13:30 ± 2 h</td><td>The GCOM-W AMSR-2 covers most applications with good resolution and wide spectral range. The likely follow-on of Meteor-MP MTVZA-GY-MP and FY-3 MWRI may contribute, though with coarse resolution.</td></tr>
<tr><td>Drifting orbits</td><td>Flights in non-sunsynchronous orbits are not committed for long-term continuation, neither in low-inclination orbit, nor at the relatively high inclination orbit of the GPM “core”.</td></tr>
<tr><td>Overall</td><td>Few high-resolution instruments (DWSS MIS in early morning and AMSR-2 in afternoon), and lack of plans for long-term continuation of the Global Precipitation Measurement mission.</td></tr>
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<td>8
Operational pathfinders and technology demonstrators</td>
<td>Low-frequency MW imagery</td>
<td>• each main parameter to be observed by at least one satellite, generally of R&D nature.
Note: There is no reference observing strategy for GEO MW at the moment since this mission is not yet part of the baseline for the GOS.</td>
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<table>
<tr><th colspan="2">Gap analysis for the mission “Low-frequency MW imagery” after 2020</th></tr>
<tr><td>Soil moisture in the roots region and ocean salinity</td><td>Currently, there is no plan for continuing systems such as Aquarius on SAC-D and MIRAS on SMOS. SMAP will take over, but is planned as a one-shoot mission.</td></tr>
<tr><td>Sea surface temperature, surface soil moisture</td><td>Adequate data are expected to be provided by DWSS MIS and GCOM-W AMSR-2.</td></tr>
<tr><td>Sea surface wind including direction</td><td>MIS on DWSS addresses this application by exploiting polarimetry.</td></tr>
<tr><td>Precipitable water over the sea</td><td>All MW radiometers, except those limited to the 1.4 GHz band, include a 23 GHz channel.</td></tr>
<tr><td>Overall</td><td>The main gap consists of the lack of long-term plans for exploiting L-band (1.4 GHz) for ocean salinity and volumetric soil moisture.</td></tr>
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<td>9
Additional operational missions in appropriate orbits</td>
<td>Radio occultation sounding</td>
<td>• to have at least 12 satellites, each one capable of at least 1000 soundings/day, in several distinct orbital planes, not necessarily sun-synchronous, and including some with low-inclination for more regular coverage with latitude.
(Note: the Vision called for “at least 8 receivers” without details)</td>
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<table>
<tr><th colspan="2">Gap analysis for the mission “Radio occultation sounding” after 2020</th></tr>
<tr><td>Number of occultations/day</td><td>Although current RO payloads generally provide less than 1500 occultations / day, future systems (MetOp-SG RO, Tri-G on COSMIC-2 and GRACE-2, GNSS-RO on CLARREO) will meet this performance by exploiting GPS, GLONASS and Galileo and tracking GNSS satellites both fore- and aft-.</td></tr>
<tr><td>Number of satellites in sunsynchronous orbit hosting a RO payload</td><td>Long-term commitment seems secured by the MetOp-SG A&B RO, and the likely follow-on of GNOS on FY-3 (a.m. and p.m.) and Radiomet on Meteor-MP (a.m. and p.m.), for a total of six satellites.</td></tr>
<tr><td>The constellation approach</td><td>COSMIC-2, with the 1500 occultations/day Tri-G instrument and 12 satellites split in both high-inclination and low-inclination orbital planes, if provided with long-term continuity, already fulfils the minimum requirement.</td></tr>
<tr><td>Overall</td><td>The achievement of the observing strategy critically depends on the</td></tr>
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<tr><td></td><td>implementation and long-term continuation of the COSMIC-2 plan.</td></tr>
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<tr><td>10
Additional operational missions in appropriate orbits</td><td>Earth radiation budget from LEO (incl. TSI)</td><td>• at least two observations/day of upward radiation, in the morning and in the afternoon (say, ~ 9:30 and 14:30);
• as for solar irradiance, it is sufficient to measure at daily intervals, from any orbit.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Earth radiation budget from LEO” after 2020</th></tr>
<tr><td>Issue of irradiance computation</td><td>In order to convert radiances into irradiances, information on the angular distribution of the radiance is necessary. CERES, providing both cross-track and bi-axial scanning, is suitable, but it is not planned to fly beyond JPSS-1. The likely follow-on of FY-3 ERM-2 might respond to the need. RER on MetOp-SG will be suitable in combination with a co-flying multi-viewing instrument (3MI).</td></tr>
<tr><td>Problem of the diurnal cycle</td><td>Both the MetOp-SG RER+3MI and the follow-on of the FY-3 ERM-2 are planned only in the morning orbit. There is no plan for CERES in the afternoon orbit beyond JPSS-1. Frequent GEO images are assumed to support coverage of the diurnal cycle.</td></tr>
<tr><td>Solar irradiance</td><td>TSIS is not planned to fly beyond JPSS-1. The likely follow-on of SIM-2 on FY-3 is expected to be sufficient.</td></tr>
<tr><td>Overall</td><td>Serious problem of long-term continuation of upward radiation measurements in the afternoon orbit. Need to demonstrate that the combined use with GEO VIS/IR frequent images (missing UV and FIR) is sufficient to interpolate/extrapolate for the diurnal cycle.
For downward solar irradiance, there is no redundancy in the long-term.</td></tr>
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<tr><td>11
Additional operational missions in appropriate orbits</td><td>Earth radiation budget from GEO</td><td>• to include a broad-band radiometer on a number of operational GEO satellites so as to realise about 60° spacing around the equator.

(Not specified in detail in the Vision. Mentioned for “selected positions” in the CGMS baseline)</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Earth radiation budget from GEO” after 2020</th></tr>
<tr><td>0° ± 30°</td><td>Covered by the likely follow-on of Electro-M ERBR.</td></tr>
<tr><td>60°E ± 30°</td><td>Covered by the likely follow-on of Electro-M ERBR.</td></tr>
<tr><td>120°E ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>180° ± 30°</td><td>Nothing is planned. However, since Russia is planning to place Electro-L N3 (without ERBR) at 166°E, maybe that a Electro-M N3 (with ERBR) follows.</td></tr>
<tr><td>120°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>60°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>Overall</td><td>Only sectors 0° ± 30° and 60°E ± 30° covered. Need to demonstrate that the GEO VIS/IR frequent images are sufficient to support the measurements from LEO to account for the diurnal cycle.</td></tr>
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<tr><td>12
Polar-orbiting sun-synchronous on 3 orbits</td><td>Sea-surface wind by active and passive MW</td><td>• three orbital planes (early morning: 5:30 ± 2 h; mid-morning: 9:30 ± 2 h; early afternoon: 13:30 ± 2 h;
• radar scatterometers in at least two of the planes;
• redundant radar scatterometers or MW polarimeters in the three orbital planes for contingency;
• exploitation of other MW radiometers, though missing the information on direction, in order to have an average observing cycle of 3 hours.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Sea-surface wind by active and passive MW” after 2020</th></tr>
<tr><td>05:30 ± 2 h</td><td>The DWSS MIS will provide wind information, subject to confirmation of near-real time data availability by the USA, but is not expected to be accurate for low-intensity wind. The HY-2 SCAT is not known to be planned for long-term continuity, and near-real time data availability is still to be confirmed by China.</td></tr>
<tr><td>09:30 ± 2 h</td><td>Adequate data are expected to be provided by the MetOp-SG SCA, the likely follow-on of the FY-3 WindRAD and the Meteor-MP N3 SCAT.</td></tr>
<tr><td>13:30 ± 2 h</td><td>Adequate data would be provided by the OceanSat SCAT if long-term continuity is confirmed.</td></tr>
<tr><td>Over all</td><td>Due to the limited swath of radar scatterometers and conical-scanning MW radiometers, the 3-hour observing cycle would require 8 regularly spaced satellites. The temporal gap could be mitigated by blending the data from radar scatterometers and MW polarimeters with other (without full polarization) passive MW radiometers providing incomplete information (missing the direction).</td></tr>
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<tr><td>13
Additional operational missions in appropriate orbits</td><td>Radar altimetry</td><td>• at least one satellite in high orbit (less perturbed), drifting (for filtering out tidal effects);
• two satellites in sunsynchronous orbit, possibly with SAR capability, for sea ice and regional purposes.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Radar altimetry” after 2020</th></tr>
<tr><td>High-altitude, drifting orbit</td><td>The orbit appropriate for large-scale oceanography and geodetic observation will continue to be covered by the JASON Poseidon.</td></tr>
<tr><td>Missions in sunsynchronous orbits</td><td>Altimeters in sunsynchronous orbits are more sensitive to local circulations and sea state. The Sentinel-3 SRAL will cover the mid-morning orbit. The HY-2 could cover the early morning orbit, but it is not known to be planned for long-term continuity.</td></tr>
<tr><td>SAR capability</td><td>Detection of borderlines, e.g. of polar ice, as well as land/ice topography, are possible by processing the altimeter signal in a SAR fashion. The Sentinel-3 altimeter (SRAL) will have SAR capability.</td></tr>
<tr><td>Overall</td><td>Within the known limits of nadir-viewing only, the altimetry mission seems in good shape, especially if the HY-2 programme is provided with long-term continuity. The very important perspective of large-swath altimetry will be explored by SWOT (of the US Decadal Survey).</td></tr>
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<td>14
Additional operational missions in appropriate orbits</td>
<td>Ocean colour imagery from LEO</td>
<td>• two satellites, one in late morning (say, ~ 10) and one in early afternoon (say, ~ 14)
• more satellites across the day to increase probability of cloud-free conditions.

(Number not specified in the Vision)</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Ocean colour imagery from LEO” after 2020</th></tr>
<tr><td>Late morning</td><td>Adequate data are expected to be provided by the Sentinel-3 OLCI and the GCOM-C SGLI, and likely follow-on of the FY-3 MERSI-2 and the Meteor-MP N3 OCS.</td></tr>
<tr><td>Early afternoon</td><td>The JPSS VIIRS and the FY-3 MERSI-2 will provide a baseline service. OCM on OceanSat will be supportive, if OceanSat is provided with long-term continuity.</td></tr>
<tr><td>Overall</td><td>The late morning will be covered by more and generally better performing instruments than the early afternoon. If confirmed, the PACE OES (proposed in the US Decadal Survey) should present improved performance and might benefit of multi-spectral, multi-polarisation and multi-viewing capability of the APS-NG companion instrument.</td></tr>
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<td>15
Operational pathfinders and technology demonstrators</td>
<td>Ocean colour imagery from GEO</td>
<td>(Not part of operational baseline, only as pathfinder or demonstrator)
• no need for international coordination, except among countries in the same field of view. It is a mission for sub-regional purposes (on coastal waters).</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Earth radiation budget from GEO” after 2020</th></tr>
<tr><td>0° ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>60°E ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>120°E ± 30°</td><td>The COMS GOCI will continue to provide ocean colour data for national purposes.</td></tr>
<tr><td>180° ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>120°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>60°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>Overall</td><td>Coverage limited to a partial area of sector 120°E ± 30°. The mission is for sub-regional use.</td></tr>
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<td>16
Additional operational missions in appropriate orbits</td>
<td>Imagery with special viewing geometry</td>
<td>• at least one dual-angle IR instrument for accurate sea-surface temperature (backup is the VIS/IR imagery mission on the backbone LEO satellites, i.e. those in the 05:30, 09:30 and 13:30 LST orbits);
• at least one instrument specifically designed for multi-angle/multi-spectral/multi-polarisation observation for aerosol, cirrus clouds and bidirectional reflectances (partial backup is the VIS/IR imagery mission on the backbone LEO</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Imagery with special viewing geometry” after 2020</th></tr>
<tr><td>Sea surface temperature</td><td>The SLSTR of Sentinel-3 will provide continuity to ATSR, ATSR-2 and AATSR of ERS-1, ERS-2 and Envisat, respectively.</td></tr>
<tr><td>Aerosol, cirrus clouds, BRDF</td><td>The MetOp-SG 3MI will provide observation of aerosol, cirrus clouds and BRDF by exploiting multi-spectral, multi-polarisation and multi-viewing capability. The knowledge of the BRDF is also needed to convert radiances into irradiances, for the purpose of Earth radiation budget.</td></tr>
<tr><td>Overall</td><td>If confirmed, the PACE APS-NG (proposed in the US Decadal Survey), that also embarks OES for ocean colour, would extend the multi-spectral, multi-polarisation and multi-viewing capability to the early afternoon orbit.</td></tr>
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<tr><td></td><td></td><td>satellites,, i.e. those in the 05:30, 09:30 and 13:30 LST orbits).
(The second item is not specified in the Vision)</td><td></td></tr>
<tr><td>17</td><td>Lightning imagery from LEO</td><td>(The Vision does not specify Lightning from LEO orbit, only GEO)
• Lightning imagery from LEO should complement GEO lightning imagery. At least one payload in LEO should be operated, both for extending the observation at high latitudes, and for “calibrating” the GEO system.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Lightning imagery from LEO” after 2020</th></tr>
<tr><td>High latitudes</td><td>No lightning mission is planned, although high latitudes are not well served from GEO.</td></tr>
<tr><td>Low latitudes</td><td>No plan is considered to continue a lightning mission in LEO beyond TRMM.</td></tr>
<tr><td>Overall</td><td>There is a gap of lightning observation from space at high latitudes. Continuation of lightning mission in LEO should be considered in the context of possible continuation of the GPM mission.</td></tr>
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<tr><td>18
Geostationary</td><td>Lightning imagery from GEO</td><td>• six sectors, 60 degrees wide along the equator (centres: 0°, 60°E, 120°E, 180°E, 120°W, 60°W);
• at least one instrument in each sector, and one backup, as similar as possible.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Lightning imagery from GEO” after 2020</th></tr>
<tr><td>0° ± 30°</td><td>Adequate data are expected to be provided by the MTG LI (with hot standby) and the Electro-M LM.</td></tr>
<tr><td>60°E ± 30°</td><td>Adequate data are expected to be provided by the FY-4 LMI and the Electro-M LM.</td></tr>
<tr><td>120°E ± 30°</td><td>Adequate data are expected to be provided by the FY-4 LMI at 105°E, that has a backup at 123.5°E.</td></tr>
<tr><td>180° ± 30°</td><td>Nothing is planned. However, since Russia is planning to place Electro-L N3 (without LM) at 166°E, maybe that a Electro-M N3 (with LM) follows.</td></tr>
<tr><td>120°W ± 30°</td><td>Adequate data are expected to be provided by the GOES GLM at 135°W, that has a backup at 105°W.</td></tr>
<tr><td>60°W ± 30°</td><td>Adequate data are expected to be provided by the GOES GLM at 75°W, that has a backup at 105°W.</td></tr>
<tr><td>Overall</td><td>Reduced latitude coverage in the Pacific Ocean and lack of redundancy in the 120-170°W longitude range.</td></tr>
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<tr><td>19
Additional operational missions in appropriate</td><td>Cloud and precipitation profiling by radar</td><td>• to exploit the synergy with passive MW radiometers so as to limit the number of radar-equipped satellites to what is needed to “calibrate” passive MW radiometers.</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Cloud and precipitation profiling by radar” after 2020</th></tr>
<tr><td>Precipitation radar</td><td>The DPR radar of GPM “core” will cover most types of precipitation. The spacecraft on a drifting orbit frequently crosses the sunsynchronous orbital planes, which provides opportunities for inter-calibration of passive MW radiometers. However, follow-on of the GPM mission is not yet planned,</td></tr>
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<tr>
<td>orbits</td>
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<table>
<tr><td>Cloud radar</td><td>No plan after CloudSat and Earth-CARE. Missions considered for process study.</td></tr>
<tr><td>Overall</td><td>Long-term continuity of cloud and precipitation radar is currently not planned.</td></tr>
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<tr>
<td>20
Operational pathfinders and technology demonstrators</td>
<td>Lidar-based missions (for wind, cloud/aerosol, trace gases, altimetry)</td>
<td>(Not part of the operational baselin, the Vision only calls for operational pathfinders and technology demonstrators)
• operational status to be pursued only for Doppler wind lidar, assuming satisfactory demonstration with ADM-Aeolus. At least one satellite to be provided, possibly two to improve coverage and reliability.</td>
<td>
<table>
<tr><td colspan="2">Gap analysis for “Laser-based missions” after 2020</td></tr>
<tr><td>Doppler wind lidar</td><td>No plan is currently envisaged for an ADM-Aeolus follow-on. 3D-Winds is considered in the framework of the U.S. Decadal Survey.</td></tr>
<tr><td>Differential absorption lidar (DIAL)</td><td>In the U.S. Decadal Survey: CO_2 lidar is planned on ASCENDS; O_3 lidar is considered on GACM.</td></tr>
<tr><td>Aerosol profiling lidar</td><td>Follow-on of CALIPSO and Earth-CARE is not planned.</td></tr>
<tr><td>Lidar altimeter</td><td>In the U.S. Decadal Survey: ATLAS is planned on ICESat-2; a Lidar altimeter is planned on DESDynI; a mapping lidar altimeter (for topography) is considered on LIST.</td></tr>
<tr><td>Overall</td><td>Long-term continuity of lidar-based missions is currently not planned.</td></tr>
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<tr>
<td>21
Additional operational missions in appropriate orbits</td>
<td>Cross-nadir short-wave spectrometry (for chemistry) from LEO</td>
<td>• at least two instruments on sunsynchronous satellites with ECT in mid-morning and early afternoon.</td>
<td>
<table>
<tr><td colspan="2">Gap analysis for the mission “Cross-nadir short-wave spectrometry from LEO” after 2020</td></tr>
<tr><td>Mid-morning</td><td>Adequate data are expected to be provided by the MetOp-SG UVNS (also called “Sentinel-5), possibly backed by the likely follow-on of FY-3 OMS that, however, is currently planned for UV only.</td></tr>
<tr><td>Early afternoon</td><td>No plan for an instrument with wide spectral range. OPMS-nadir on JPSS, UV-only, is essentially limited to ozone and very few other species.</td></tr>
<tr><td>Overall</td><td>Satisfactory time coverage and redundancy are only planned for ozone. Wide spectral range is only provided by MetOp-SG UVNS, only in the morning.</td></tr>
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<tr>
<td>22
Additional operational missions in appropriate orbits</td>
<td>Cross-nadir short-wave spectrometry (for chemistry) from GEO</td>
<td>• no need for international coordination, except among countries in the same field of view: in fact, it is a mission for local/regional purposes.</td>
<td>
<table>
<tr><td colspan="2">Gap analysis for the mission “Cross-nadir short-wave spectrometry from GEO” after 2020</td></tr>
<tr><td>0° ± 30°</td><td>Service provided by the MTG-S UVN (also called “Sentinel-4), with limited area coverage and no SWIR.</td></tr>
<tr><td>60°E ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>120°E ± 30°</td><td>Service provided by COMS-2B, with limited area coverage and no SWIR.</td></tr>
<tr><td>180° ± 30°</td><td>Nothing is planned.</td></tr>
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<tr><td></td><td></td><td></td><td>
<table>
<tr><td>120°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>60°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>Overall</td><td>Coverage limited to partial areas of sectors 0° ± 30° and 120°E ± 30°. The mission is for sub-regional use.</td></tr>
</table>
</td></tr>
<tr><td>23
Additional operational missions in appropriate orbits</td><td>Cross-nadir IR spectrometry (for chemistry) from LEO</td><td>• considering that there will be operational IR spectrometer sounders for the core temperature/humidity sounding mission, it will be sufficient to have one additional high-spectral-resolution sounder for atmospheric chemistry.
(Atmospheric composition is not detailed in the Vision)</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Cross-nadir IR spectrometry from LEO” after 2020</th></tr>
<tr><td>Total columns</td><td>Total columns of greenhouse species will be observed by several sounders, primarily designed for operational temperature and humidity profile.</td></tr>
<tr><td>Vertical profiles</td><td>The MetOp-SG IASI-NG and the likely follow-on of the Meteor-MP IKFS-2 will have higher spectral resolution, thus will be capable of profiling a few species. The likely follow-on of the FY-3 GAMI might have sufficiently high spectral resolution for profiling more species.</td></tr>
<tr><td>Overall</td><td>Without a very-high spectral resolution IR sounder, the profiles of species such as HNO_3, SF_6, N_2O_5, PAN, C_2H_6 and C_2H_2 could not be observed. Currently only the EOS-Aura TES (approaching end-of-life) is suitable. It is assumed that the FY-3 GAMI could be comparable,</td></tr>
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<tr><td>24
Additional operational missions in appropriate orbits</td><td>Cross-nadir IR spectrometry (for chemistry) from GEO</td><td>• to maintain one IR spectrometer in each geostationary sector for at least the purpose of total columns (in addition to temperature/humidity profiling.

(Atmospheric composition is not detailed in the Vision)</td><td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Cross-nadir IR spectrometry from GEO” after 2020</th></tr>
<tr><td>0° ± 30°</td><td>Total columns of few greenhouse species will be observed by the MTG-S IRS and the Electro-M HIS.</td></tr>
<tr><td>60°E ± 30°</td><td>Total columns of few greenhouse species will be observed by the Electro-M HIS and the FY-4 GIIRS.</td></tr>
<tr><td>120°E ± 30°</td><td>Total columns of few greenhouse species will be observed by the FY-4 GIIRS at 105°E, that is backed by one FY-4 at 123.5°E.</td></tr>
<tr><td>180° ± 30°</td><td>No satellite planned to station in this sector. However, since Russia is planning to place Electro-L N3 (without sounder) at 166°E, maybe that a Electro-M N3 (with the HIS sounder) follows.</td></tr>
<tr><td>120°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>60°W ± 30°</td><td>Nothing is planned.</td></tr>
<tr><td>Overall</td><td>The mission covers one half of the longitude sectors, though only for total columns.</td></tr>
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<td>25
Additional operational missions in appropriate orbits</td>
<td>Limb-sounding short-wave spectrometry</td>
<td>• at least one instrument on a sunsynchronous satellite should be flown, to provide the necessary high vertical resolution in the stratosphere and above; a second one would be desirable, since the chemistry of the high atmosphere is affected by the diurnal cycle;
(Atmospheric composition is not detailed in the Vision)</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Limb-sounding short-wave spectrometry” after 2020</th></tr>
<tr><td>Overall</td><td>There is no long-term plan for providing chemistry observation in the limb mode. Therefore, it will not be possible to observe profiles with sufficiently high vertical resolution in the stratosphere and mesosphere. In the short-wave range, important species such as ClO, BrO and ozone will be missing. This gap adds to similar gaps for IR and millimetre/sub-millimetre instruments.</td></tr>
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<tr>
<td>26
Additional operational missions in appropriate orbits</td>
<td>Limb-sounding IR spectrometry</td>
<td>• at least one instrument on a sunsynchronous satellite should be flown, to provide the necessary high vertical resolution in the stratosphere and above; a second one would be desirable, since the chemistry of the high atmosphere is affected by the diurnal cycle.
(Atmospheric composition is not detailed in the Vision)</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Limb-sounding IR spectrometry” after 2020</th></tr>
<tr><td>Overall</td><td>There is no long-term plan for providing chemistry observation in the limb mode. Therefore, it will not be possible to observe profiles with sufficiently high vertical resolution in the stratosphere and mesosphere. In the IR range, important species such as HNO_3 (but also ozone !) will be missing. This gap adds to similar gaps for SW and millimetre/sub-millimetre.</td></tr>
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<tr>
<td>27
Additional operational missions in appropriate orbits</td>
<td>Limb-sounding millimetre-submillimetre wave spectrometry</td>
<td>• at least one instrument on a sunsynchronous satellite should be flown, to provide the necessary high vertical resolution in the stratosphere and above.
(Atmospheric composition is not detailed in the Vision)</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Limb-sounding millimetre-submillimetre wave spectrometry” after 2020</th></tr>
<tr><td>Overall</td><td>There is no long-term plan for providing chemistry observation in the limb mode. Therefore, it will not be possible to observe profiles with sufficiently high vertical resolution in the stratosphere and mesosphere. In the millimetre-submillimetre range, important species such as HCl and OH and ozone will be missing. This gap adds to similar gaps for SW and IR. The only millimetre-submillimetre limb-sounding mission currently considered is GACM in the framework of the US Decadal Survey.</td></tr>
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<td>28
Additional operational missions in appropriate orbits</td>
<td>High-resolution imagery for land observation</td>
<td>• to aim at a constellation of sensors to provide sufficient temporal coverage. The ECT, generally mid-morning, is constrained by illumination conditions.</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “High-resolution imagery for land observation”</th></tr>
<tr><td>Overall</td><td>No problem of data availability is foreseen. The issue is to ensure user friendly data access and minimum cost and delivery time.</td></tr>
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<tr>
<td>29
Additional operational missions in appropriate orbits</td>
<td>Synthetic Aperture Radar</td>
<td>• to aim at a constellation of SAR in order to provide sufficient temporal coverage. The ECTs are constrained by technical advantages (06:00) and synergy with optical instruments (10:30).</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission “Synthetic Aperture Radar” after 2020</th></tr>
<tr><td>C-band</td><td>Continuing availability of C-band SAR seems to be secured, as a minimum from Sentinel-1 and RadarSat Constellation. RISAT-1 also is considered, perhaps with long-term perspective.</td></tr>
<tr><td>L-band and S-band</td><td>L-band SAR is the only instrument to measure soil moisture in the roots region with the spatial resolution required for hydrology. The baseline L-band SAR service will be provided by the ALOS PALSAR and the Argentinean SAOCOM. S-band also is being developed, for HJ-1C.</td></tr>
<tr><td>X-band</td><td>X-band SAR is the most useful instrument for all-weather recognition. The baseline X-band SAR service is provided by the COSMO-SkyMed and TerraSAR programmes, likely to be continued in the long-term, also thanks to the dual interest (civilian and military). The Meteor-MP operational satellites also carry X-band SAR, noticeably within a meteorological mission.</td></tr>
<tr><td>Multi-frequency SAR</td><td>Clustering of SAR’s in the dawn-dusk orbit (06/18) is convenient for technical reasons (nearly-all-time availability of sun illumination to supply power to the platform). It is also convenient for the geophysical applications, since the synergy of L-band, C-band and X-band has been demonstrated useful by early experiments with the Space Shuttle (SIR-C/SAR-X).</td></tr>
<tr><td>Overall</td><td>Main issues with SAR utilisation is the timeliness, conditioned by the need for intensive processing, and the cost, limiting the use of SAR for operational meteorology and climatology.</td></tr>
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<td>30
Operational pathfinders and technology demonstrators</td>
<td>Solid Earth (gradiometers /accelerometers)</td>
<td>• to maintain operational programmes for the bulk of information stemming from precision orbitography;
• to periodically implement dedicated missions for the study of the gravity field and the Earth’s interior.

(Note: the terms “gradiometers/ accelerometers” are used in the database and in the draft CIMO Guide instead of “gravimetric sensors” used in the Vision)</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the mission to “Solid Earth” after 2020</th></tr>
<tr><td>Space geodesy</td><td>Numerous operational satellites contribute, either directly (e.g., altimetry missions addressing the geoid) or indirectly (through the information on precise orbitography, including that one stemming from radio occultation sounders used in their capacity for accurate positioning). Dedicated missions (e.g., CHAMP, GRACE, GOCE) need a follow-on at appropriate intervals. Long-living specific satellites for laser ranging (e.g., LAGEOS, STELLA) also need to be refreshed one day.</td></tr>
<tr><td>Earth interior</td><td>Supported by very few missions based on observation of the magnetosphere (CHAMP, Ørsted, SWARM). Follow-on at appropriate intervals is needed.</td></tr>
<tr><td>Overall</td><td>The Solid Earth theme suffers of being on the border line between application and research. Progress is steady but slow, considering the relevance of issues such as earthquakes and tsunami.</td></tr>
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<td>31
Polar-orbiting and geostationary platforms / instruments for space weather

(for solar imagery, particle detection, electron density)</td>
<td>Space Weather from LEO, GEO, and specific high orbits for:</td>
<td>The reference observing strategy is currently being defined by the appropriate expert group. It is expected:
• to rely on operational programmes for basic solar monitoring (GEO)
• to call for dedicated missions in appropriate orbits, in particular for precise solar activity monitoring (includes high orbits)
• to rely on operational meteorological programmes for in situ measurements, which also perform for platform housekeeping purposes (LEO+GEO);
• to exploit the radio occultation constellation for monitoring the ionosphere (LEO);
• to call for dedicated missions for the study of the magnetosphere (specific orbits).

(Note: in the database, the following types of missions are distinguished, which are broader than the three items listed in the Vision : Solar activity monitoring, Space environment monitoring, Electric and magnetic fields)</td>
<td>
<table>
<tr><th colspan="2">Gap analysis for the “Space Weather mission from LEO” after 2020</th></tr>
<tr><td>Charged particled</td><td>Most operational meteorological satellites include charged particle detectors, also because useful for platform and payload safety. Long-term continuity of service seems secured.</td></tr>
<tr><td>Magnetic field</td><td>Among meteorological satellites in LEO, only DMSP provides magnetic field measurements, not confirmed on DWSS. All other measurements in LEO are performed by specific scientific missions that are not committed for long-term follow-on.</td></tr>
<tr><td>Solar activity</td><td>Generally monitored from GEO, solar activity is also observed by several LEO missions. However, commitment for long-term follow-on is only based on Meteor-MP.</td></tr>
<tr><td>Radio occultation</td><td>The coverage and observing cycle of the currently planned radio-occultation systems do not meet the requirements of Space Weather, but radio occultation is still the only system that provides 3-D electron distribution in the region most relevant for Space Weather.</td></tr>
<tr><td>Overall</td><td>With the exception of in situ charged particles monitoring, and radio occultation, very few missions to Space Weather are planned with long-term continuity, especially in the outmost important fields of magnetosphere and of solar activity.</td></tr>
</table>
<table>
<tr><th colspan="2">Gap analysis for the “Space Weather mission from GEO” after 2020</th></tr>
<tr><td>Charged particled</td><td>GOES, FY-2/FY-4 and Electro-L/M are equipped with energetic particle detectors; Meteosat, INSAT / Kalpana, Himawari and GEO-KOMPSAT are not, and plans are not known.</td></tr>
<tr><td>Magnetic field</td><td>Only GOES and Electro-L/M measure the local magnetic field, that also is scarcely observed from operational meteorological satellites in LEO.</td></tr>
<tr><td>Solar activity</td><td>Solar activity is monitored in GEO by GOES, Electro-L/M and FY-4. The time sampling provided by GOES W and E, Electro W and E and FY-4 W and E is probably sufficient.</td></tr>
<tr><td>Overall</td><td>The contribution from GEO satellites to Space Weather monitoring is substantial, also because measurements from GEO are probably more accurate (less impact from the atmosphere and the Van Allen belts). More effort is required in the area of magnetic field observation.</td></tr>
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<table>
<tr><th>Gap analysis for the “Space Weather from specific high orbits” after 2020</th></tr>
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			Solar activity	All current missions are running well beyond their design life time. A proposal for replacement of ACE, SOHO and WIND in the L_1 Lagrange point, DSCOVR (Deep Space Climate Observatory), is being now advocated by NOAA.
			Magnetosphere	Although no explicit commitment for long-term continuity is made, missions to the Magnetosphere are considered with attention by R&D space agencies.
			Overall	Since solar-terrestrial relationship is still at the border-line between science and application, programmes are basically undertaken in a research framework with no explicit long-term commitment. However, it is expected that R&D space agencies will continue to implement and operate suitable missions with sufficient continuity.