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DRAFT IMPLEMENTATION PLAN FOR THE EVOLUTION OF GLOBAL OBSERVING SYSTEMS

(Submitted by the WMO Secretariat)

Summary and Purpose of Document

The document addresses the development of the new Implementation Plan for Evolution of Global Observing Systems (EGOS-IP). Version 11 of the draft EGOS-IP is available on: ftp://ftp.wmo.int/Documents/PublicWeb/www/gos/egos-ip/. It incorporates the input provided on satellite matters by the sixth meeting of ET-SAT.

Since ET-SAT-6, further comments or changes to the satellite-related sections have been proposed from the following sources:

- the ET-EGOS Chair commented on Actions C1, S20, and S23
- the ET-SUP-6 proposed minor additions to sections 2.1 and 3.1, and a new text on “product generation, data stewardship, education and training” for inclusion under 6.2
- the Inter-Programme Coordination Team on Space Weather (ICTSW) has developed a new draft of section 6.3.5.
- the Secretariat has raised a few questions and suggested editorial updates.

The document consolidates the proposed changes and other comments mentioned above, for consideration by ET-SAT-7.

ACTIONS PROPOSED

The Expert Team is invited:

- to note how the input from ET-SAT-6 has been incorporated in the current draft EGOS-IP,
- to consider the further comments above, which have been marked in the Appendix,
- and to recommend the appropriate updates.

APPENDIX: Annotated extract from EGOS-IP (Draft version V11.02)

DRAFT IMPLEMENTATION PLAN FOR THE EVOLUTION OF GLOBAL OBSERVING SYSTEMS

1. BACKGROUND

A new Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP) is being developed. Its purpose is to document a set of implementation actions which are required for incremental improvement of global observing systems towards full realization of the Vision for the GOS in 2025.

A first version of the new EGOS-IP was extensively reviewed by ET-SAT at its sixth meeting, as concerns its satellite related contents. The outcome of this review (See Appendix IV of the ET-SAT-6 Final Report) has been fully incorporated in a revised draft which is available on the WMO FTP server: ftp://ftp.wmo.int/Documents/PublicWeb/www/gos/egos-ip/.

Some updates were proposed by the Secretariat, and two substantial inputs were provided by the sixth session of the Expert Team on Satellite Utilization and Products (ET-SUP-6) and the Inter-Programme Coordination Team on Space Weather (ICTSW) respectively.

It is planned to have the document finalized by ET-EGOS at its seventh meeting (7-11 May 2012) in view of submission to the Commission for Basic Systems (CBS) in advance of its next session to be held from 10 to 15 September 2012.

2. SUGGESTIONS FROM THE WMO SECRETARIAT

2.1. Section 5.2 Generic issues on surface-based observing systems

We may consider a new paragraph on the usefulness of surface-based automatic weather station networks for the validation of space-based derived products, with an action to facilitate the awareness, availability and use of such data for validation purpose. (End of Section 5.2)

2.2. Section 5.3.1.5 Ground-based GNSS receivers

The potential use of ground-based GNSS receiver data to inform on the vertical Total Electronic Content (See Section 6.3.5) should be mentioned in the text. Action G24 could be widened in mentioning the processing of data for meteorological *or ionospheric* information.

2.3. Section 5.3.2.4 Lightning detection systems

ET-SAT will note the new action G35 addressing integration of surface-based and ground-based detection systems.

2.4. Section 6.3.2.4 Microwave imagers

The section concludes with no action since the requirements are expected to be met. While microwave imagers are expected to fly in sufficient number, this does not prove however that these instruments will include all the bands required for the applications mentioned. For instance there might be a need for an action for the availability of 6-7 GHz frequency bands for all-weather SST.

2.5. Section 6.3.3.1 Scatterometers

The section concludes with no action since the requirements are expected to be met. While scatterometers are expected to fly in sufficient number, one should check that they are associated with processing chains providing data in near-real time.

2.6. Section 6.3.3.2 Radio-occultation

Action S15 mentions the number of satellites as a performance indicator. One could argue that the performance of one satellite greatly depends on the ability to observe both rising and setting occultation (which requires 2 antennas) instead of only one of them, and the compatibility to one, two or three of the GNSS systems (GPS, Galileo and GLONASS). Hence the expected number of occultations per day might be a better criterion.

2.7. Section 6.3.3.7 Precipitation radars with passive microwave imagers

Since the GPM mission is not yet implemented, and there is no plan for continuity, an action could be considered for instance “to implement at least a Precipitation Radar mission on a low-inclination orbit and to plan for long-term continuity of such a mission.”

In this context ET-SUP suggested to evaluate the benefit of a sounding mission on a low-inclination orbit. ET-SAT may wish to comment on this suggestion, noting in particular that such mission is not currently part of the Vision of the GOS in 2025.

2.8. Section 6.3.4.1 Doppler Wind lidars

Action S23 regarding an operational follow-on to the ADM-Aeolus demonstration mission has been reworded since ET-SAT-6.

2.9. Editorial updates

Minor changes can be made in order to reflect the following:

- LEO satellites are not only polar-orbiting (Section 6.1, line 2629)
- GEO observing cycle is 30 or 15 minutes or less (Section 6.1, line 2631)
- The “Dossier on the Space-based GOS” is at “www.wmo.int/pages/prog/sat/gos-dossier_en.php” and associated with a database (lines 2660); See footnote 49,
- Sentinel-4 and -5 are not platforms but instrument missions (6.3.3.9, Line 3448)
- EarthCARE planned for 2015 (Line 3555)

2.10. Input from ET-SUP-6 and ICTSW

The input from ET-SUP-6 is marked in yellow in the Appendix.

The input from ICTSW is a totally new text for Section 6.3.5 (Instruments for Space weather on polar and geostationary platforms); it is still an early draft. It is anticipated that this section will be updated and restructured, with identified actions.

It is noted that this section does not address only space-based but also surface-based observations (e.g. ground-based GNSS receivers, ionosondes) for space weather. Its space-based component is not be limited to polar and geostationary orbits and includes satellites at Lagrange point L1. The header of this section and its location in the whole document may thus be reconsidered.

3. CONCLUSION

ET-SAT is invited:

- to note how the input from ET-SAT-6 has been incorporated in the draft EGOS-IP,
- to consider the further comments above, which have been marked in the Appendix,
- and to recommend the appropriate updates.

EXTRACT FROM EGOS-IP V11.02 WITH PROPOSED CHANGES

Note: Since ET-SAT has already reviewed a previous version of this document, only the items in bold in the Table of contents below have been included in the extract.
The ET-SUP input is highlighted in yellow, other comments and proposed changes are in blue.

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Annexes

Section 2.1 Overall approach and relationship to WIGOS

[…]

Quality Management Framework (QMF).

WIGOS is expected to provide timely, quality-assured, quality-controlled and well-documented long-term observations. Implementing Quality Management procedures is required to enable better utilization of existing and emerging observing capabilities.

WIGOS will address high-level observing requirements by establishing the effective and sustained organizational, programmatic, governance and procedural structures. These structures will enable a common standardization approach, uniform implementation of WMO regulations, data compatibility and interoperability across all WIGOS observing components. It will also provide a single focus for integrated and coordinated operational management of all WMO observing systems and a mechanism for coordination with WMO co-sponsored and contributing observing systems.

WIGOS will embrace QMF procedures to ensure that observations, records and reports on weather, water, climate and other environmental resources, operational forecasts, warnings, related information and services are of identified quality, and in compliance with relevant joint standards agreed upon with other international organizations.

This should be based on agreed-upon quality assurance and quality control standards, with the goals of developing and implementing an integrated Quality Management System (QMS); in doing this, and only after effective national implementation, it will deliver reliable and timely data streams with adequate quality control and relevant metadata.

Action: Members should incorporate QMF procedures in the operation of the observing systems to the WIGOS.
Who: Members
Time-frame: 2015
Performance indicator: Level of compliance with QMF procedure.

[Note from the Secretariat: QMF procedures should indeed be applied for the operation of observing systems as highlighted by ET-SUP. However, since “WIGOS will embrace QMF procedures” it is anticipated that a set of Quality Management procedures will be developed for WIGOS. As the proposed action would be redundant with such procedures, it is suggested not to include it in the EGOS-IP.].

3. Over-arching and cross-cutting Actions

This section of the Implementation Plan follows closely the description of the general trends and issues, as they are documented in the “Vision for the GOS in 2025”, and develops the general Actions which are necessarily associated with these trends and issues.

Section 3.1 Response to user needs

Global observing systems will provide comprehensive observations in response to the needs of all WMO Members and Programmes for improved data, products and services, for weather, water and climate. Through WIGOS, WMO will continue to provide effective global collaboration in the making and dissemination of observations, through a composite and increasingly complementary system of observing systems.

The sustainability of these observing systems may require partnerships between research and operational agencies. Observations of several variables are made in the context of research programmes or by space agencies whose primary mission is research and development. Once methods are sufficiently mature to guarantee a sustained set of observations to an acceptable level of accuracy, they need to be sustained into the future as an operational observing system if they fulfil the requirements of some user groups.

The operational system includes the acquisition (measurement), the transmission to a pre-processing centre, and archiving and dissemination to all the users with a procedure which is compatible with the WIS. These activities may or may not imply a transfer of responsibility from one organization to another. Whenever new or upgraded observing technologies or data processing systems are developed it is essential that there be interaction between the developers, the intermediate and end users to assess requirements and the impact of the new or evolving system before implementation. This will help ensure that all essential requirements are captured, including requirements for homogeneity of observations in time. Provisions should be made to enable users to prepare for new observing systems well in advance of system deployment in terms of data reception, processing, and analysis infrastructure, and associated education and training.

Action C1

Action: Set up a development scheme for sustained operation of relevant research-based observing systems, once their validation has shown they are sufficiently mature enough and their cost-effectiveness has been assessed.
Who: CBS and CAS to initiate and lead the evolution, with all organizations operating component observing systems.
Time-frame: Continuous. Timetable to be decided on a case by case basis.
Performance indicator: Number of sustained systems.

Action C2

Action: Ensure all operators producing observations are encouraged to adhere to the WIS standards[1]*;*
Who: Organizations and agencies operating observing programmes
Time-frame: Continuous
Performance: Extent to which WIS standards are applied

Action C3

Action : Assess the impact of new observing systems (or changes to existing systems) through prior and ongoing consultation with data users and the wider user community.
Who: CBS and CAS to lead the action, together with other TCs representing the users and all organizations operating component observing systems.
Time-Frame: Continuous
Performance Indicator: Extent to which user community concerns are captured.

Action C4

Action: Prepare data users for new generations of observing systems through the provision and upgrade, as appropriate, of data reception, processing and analysis infrastructure, and the provision of education and training programmes.
Who: All organizations operating component observing systems
Time-Frame: Continuous
Performance Indicator: Extent to which users can satisfy their needs

Users require global observing systems to provide observations when and where they are needed in a reliable, stable, sustained and cost-effective manner. They require observations of specified

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[1] See http://www.wmo.int/pages/prog/wis/

spatial and temporal resolution, accuracy and timeliness. The user requirements will evolve in response to a rapidly changing user and technological environment, based on improved scientific understanding and advances in observational and data-processing technologies. Our ability to measure some key environmental variables is often limited by the lack of suitable techniques. These limitations can vary from the fundamental underlying observing technique to those associated with instrumentation, data processing, suitable calibration/validation techniques, spatial and/or temporal resolution, ease of operation, and cost. As new remotely-sensed observations of environmental variables are made, it is critically important that the validation of both the measurements themselves and the retrieval methods used are carried out under a sufficient broad range of geophysical conditions. It is also important to derive observational products in a physically consistent way across ocean, land and atmosphere domains. The development of integrated products requires blending of different datasets or data sources, which needs to be consistent over time and space.

Some level of targeted observations will be achieved, whereby some observations are made or not made, in response to the local meteorological situation and the particular user needs. Their operation should be guided by and in collaboration with NMHSs to ensure interoperability and potential exchange of the data (see also section 5.3.1.1.5).

Action C5

Action: For each relevant observing system, investigate the feasibility, cost-effectiveness and side effects on the continuity of climate data records of operating it in an adaptive mode, i.e. a process which would vary the observation set according to the meteorological situation.

Who: Organizations operating observing networks on a routine basis. Process to be initiated and coordinated by CAS in cooperation with other TCs, mainly CBS and CIMO.

Time-frame: Continuous reviewing process of the feasibility and cost-effectiveness assessments.

Performance indicator: Number of networks operated with some level of targeting.

3.2. Integration

The GOS will become a core observing component of the WIGOS, which will integrate current GOS functionalities (which have been developed primarily to support operational weather forecasting) with those of other applications, including climate monitoring and operational climate services. Integration will be developed through the analysis of requirements and, where appropriate, through sharing observational infrastructure, platforms and sensors, across systems and with WMO Members and other partners. Surface and space-based observing systems will be planned in a coordinated manner to serve a variety of user needs with appropriate spatial and temporal resolutions in a cost-effective manner.

Data assimilation techniques have an important role to play with respect to a cost-effective integration of the different observing systems serving different applications across different disciplines. Data assimilation techniques are indeed able to add considerable value to observing systems by combining heterogeneous sets of information to provide complete and self-consistent sets of geophysical fields. Taken on its own, each observing system provides only a small sample of information with respect to the ensemble of global requirements as they are documented by the RRR process. However, combined in a global assimilation, the integration of their measurements is able to provide reliable global analyses for many variables, which are essential for many global applications.

For the achievement of this Implementation Plan, an important challenge is to find means for maintaining the long-term operation and the continuity of these observing systems. This does not mean that the continuity of each system should be guaranteed indefinitely; the strategy consists in making sure that the quality of the important variables is not degraded when an instrument or an observing system is replaced by another instrument or another observing system. Several applications use observations which are labelled “research” or “demonstration” for operational purposes. The border between “research” and “operations” is not well-defined and is moving all the time, mainly because it follows the scientific progress in applications and in data utilization methods. In this context, ensuring that observations of important variables are not degraded may mean ensuring the transition of research/demonstration systems into operational systems (which is recognized to be very challenging).

The integrating role of WIGOS is also supported by the strong complementarity between surface-based and space-based observations. Some examples:

- For observing the atmosphere, surface-based systems are more efficient in the boundary layer whereas satellite instruments are more efficient in the stratosphere and above the clouds.
- High horizontal resolution can be obtained with space-based imagers and sounders with global data coverage; this is impossible to achieve with in-situ observing networks which remain the best systems for high vertical resolution, especially in the lower atmosphere.
- The most accurate SST fields are obtained from a combination of satellite retrievals mixed with in-situ reference measurements.

Observations should be made available to the different users with a timeliness respecting their requirements. They should also be made available using standard practices for data processing, coding formats and dissemination, in order to facilitate the utilization.

Action C6

Action: Ensure time continuity and overlap of key components of the observing system and their data records, in accordance with user requirements, through appropriate change-management procedures.
Who: WMO TCs, JCOMM, regional associations, satellite agencies, NMSs and NMHSs, all organizations operating observing systems.
Time-frame: Continuous. Timetable to be decided on a case by case basis.
Performance indicator: Continuity and consistency of data records.

3.3 Data policy

The operating paradigm for the GOS is built on WMO data sharing principles under which all essential data are shared openly among the WMO members. This has been facilitated by the fact that, in the past, observational data have been provided primarily by national governments and international agencies. However, the potential for an increased role in the future for commercial entities - e.g. hosting of instrument payloads or “data buys” and similar mechanisms - raises important issues regarding the continued availability to all WMO members of data obtained under such arrangements.

Action C7

Action: For new observing systems, including satellite systems, ensure continued adherence to WMO data sharing principles irrespective of origin of data, including data provided by commercial entities.
Who: NMSs and NMHSs, and space agencies. Process monitored by CBS.
Time-frame: Continuous.
Performance indicator: Continued availability of all essential observational data to all WMO members.

3.4. Expansion

There will be an expansion in both the user applications served and the variables observed. This will include observations to support the production of datasets related to the GCOS essential climate variables (ECVs), adhering to the GCOS climate monitoring principles, and any additional observations required to implement operational climate services at global, regional and national scales under the GFCS. Atmospheric chemistry and hydrology are also two application types requiring an increasing number of variables to be observed.

The range and volume of observations exchanged globally (rather than locally) will be increased. Several existing local observing systems are currently used only for local or regional applications; they will be used also in global applications as soon as they have proved they are able to bring additional value. The total volume of global data exchange will expand considerably because of new observed variables, because of existing local observations becoming exchanged globally, and because of increased resolutions (time and space) of global observing systems. The role of satellite and radar data sets will expand into applications requiring higher and higher horizontal resolution. This implies that the specialized data centres will have to serve a wider range of applications at all horizontal scales, from global scales to hectometre scale. This data volume expansion puts heavy constraints on the data processing and dissemination processes which will be operated according to the WIS standards (especially important for real-time applications).

Action C8

Action: To evaluate the future evolution of data volumes to be exchanged and handled, based on the projected data volumes generated by the future satellite and terrestrial sources.
Who: WMO TCs (led by WMO/WIS), JCOMM, regional associations, satellite agencies, NMSs and NMHSs, all organizations operating observing systems.
Time-frame: Continuous.
Performance indicator: evolution of the data volumes handled and exchanged.

3.5. Automation

The trend to develop fully automatic observing systems, using new observing and information technologies will continue, where it can be shown to be cost-effective and does not lead to degradation in respect of important requirements of some applications, e.g. climate monitoring. The access to real-time and raw data will be improved. More and more observing systems will have to produce different levels of data, from large volumes of raw data to highly processed data sets. A variety of users will be interested in one or more post-processing levels. It is important to have the different processing packages respecting a general set of WIS standards. Observational data will be collected and transmitted in digital forms, highly compressed where necessary. Data processing will be highly computerized.

A high degree of automation (with minimal checking to ensure observation quality) is especially required for observational networks covering areas highly exposed to severe weather phenomena. For nowcasting and risk mitigation in these areas, it is important to have a telecommunication infrastructure that is robust enough against these phenomena.

3.6. Interoperability, data compatibility, consistency and homogeneity

There will be an increased standardization of instruments and observing methods. There will be improvements in calibration of observations and the provision of metadata, to ensure data consistency and traceability to absolute standards. There will be an improved homogeneity of data formats and dissemination via the WIS, and also increased interoperability, between existing observing systems and with newly implemented systems. Metadata is essential for ensuring the quality, traceability and homogeneity of observations, therefore it is essential that an archive of rigorous metadata is maintained to support standardization, enable homogeneity assessments, and ensure data provenance and fitness for purpose.

To ensure consistency and homogeneity of the data sets, the monitoring principles for satellite data which are documented in the GCOS-IP for climatological purposes are all valid to some extent for other WMO applications, including the real-time applications. This is true for the recommendations which concern the time continuity, homogeneity and overlap of the observation, the orbit stability and sensor calibration, the data interpretation, processing and archiving. Global analyses for weather forecasting and other applications are dependent on several key observing systems. The long-term time continuity of these sensors is obviously very important for climate purposes, but it is almost as important for the other applications, including the real-time ones. All these sensors are used in a “synergetic” way, e.g. where one sensor helps in the evaluation of biases and drifts in other sensors. In this process the role of accurate in-situ observations is also important, supporting the GCOS requirements for the GCOS Reference Upper Air Network (GRUAN).

By 2025 there will be improved methods of quality control and characterization of errors of all observations. Operational systems are needed that can track, identify and notify network managers and operators of observation irregularities, including time-dependent biases, as close to real-time as possible. Such feedback systems are already routine practices for several NWP centres, for the data which are assimilated in operational NWP models, and also for climate monitoring centres to ensure overall data quality. However there is a need to extend these monitoring activities to other applications and also to set up feed-back procedures for observed quantities which cannot be compared to any operational model. Also, even in the existing routine monitoring activities, there is a need to make more rapid and more efficient both the feedbacks to the operators and the correcting actions.

Action C9

Action: Monitor the flow of all essential data to processing centres and to users and ensure timely flow of feedback information to observing network management from monitoring centres.
Who: Data processing centres coordinated by appropriate TCs and international programmes (CBS to lead the process and initiate it when required).
Time-frame: Continuous
Performance indicator: usual monitoring criteria[2]

3.7. Radio-frequency requirements

WIGOS components make use of a number of different radio applications.

Space-based passive sensing is performed in bands allocated to the Earth exploration satellite (passive) and meteorological satellite service. Passive sensing requires the measurement of naturally occurring radiation, usually of very low power levels and containing essential information on the physical process under investigation.

The relevant frequency bands are determined by fixed physical properties (molecular resonances) that cannot be changed or ignored. These frequency bands are, therefore, an important natural resource. Even low levels of interference received by a passive sensor may degrade its data. In addition, in most cases these sensors are not able to discriminate between natural and man-made radiation. In this respect, the International Telecommunication Union (ITU) Radio Regulations enable the passive services to deploy and operate their systems in the most critical frequency bands.

Several geophysical variables contribute, at varying levels, to natural emissions, which can be observed at a given frequency with unique properties. Therefore, measurements at several frequencies in the microwave spectrum must be made simultaneously in order to extract estimates of the variables of interest from the given set of measurements. Passive frequency bands should hence be considered as a complete system. Current scientific and meteorological satellite payloads are not dedicated to one given band but include many different instruments performing measurements in the entire set of passive bands. Also, full global data coverage is of particular

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[2] Http://www.wmo.int/pages/prog/www/ois/monitor/introduction.html

importance for most weather, water and climate applications and services.

Also of great importance is the availability of sufficient and well-protected Earth exploration and meteorological satellite frequency spectrum for telemetry / telecommand, as well as for satellite downlink of the collected data.

The meteorological aids (MetAids) radiocommunication service is used for meteorological and hydrological observations and exploration, and provides the link between an in-situ sensing system (e.g. a radiosonde) for meteorological variables and a remote base station. The base station may be in a fixed location, or mounted on a mobile platform. Additionally, meteorological radars and wind profiling radars provide important observations. There are currently about 100 wind profiler radars and several hundred meteorological radars world-wide, which provide precipitation and wind information and play a crucial role in meteorological and hydrological alert processes.

The issues related to the above radio spectrum requirements and operation are addressed within WMO by the Steering Group on Radio Frequency Coordination (WMO SG-RFC). Within Europe, more than 20 National Meteorological Services and other relevant organizations have established the EUMETFREQ programme in order to coordinate their frequency protection activities. Frequency management and protection are particularly important for the WMO Space Programme and Space Agencies have established the Space Frequency Coordination Group (SFCG[3]) to coordinate their activities in this respect.

Action C10

Action: Ensure a continuous monitoring of the radio frequencies which are needed for the different components of WIGOS, in order to make sure they are protected against other utilizations.
Who: WMO / SG-RFC in coordination with NMSs, NMHSs and national organizations in charge of radio frequency management.
Time-frame: Continuous
Performance indicator: observation frequency bands protected / not protected.

4. Considerations for the evolution of observing systems in developing countries

Many developing countries and countries with economies in transition do not have the capabilities or the resources to provide the essential in-situ observations. This is a challenge for the consistency and the homogeneity of observations, especially at the global scale. The support needed by these countries and the mechanisms able to provide this support are the same as those described in the GCOS-IP (see its section on developing countries) for climate purposes, plus some support often needed to disseminate in real-time observations which are already made, in the proper format to the WIS.

More effort is needed to support these countries, especially Least Developing Countries (LDCs) and Small Islands Developing States (SIDSs), by providing guidelines and organizing training and capacity-building events in the respective Regions. In many areas, including large parts of Africa, Asia and Latin America (Regions I, II, and III and some tropical areas between 25N and 25S), the current GOS provides very few observations. The evolution of observing systems in developing countries must address issues that fall in three categories: (a) lack of public infrastructure such as electricity, telecommunication, transport facilities, etc.; (b) lack of expertise from people to do the job, training, etc.; and (c) lack of funding for equipment, consumables, spare parts, manpower, etc. The lack of infrastructure and expertise may be the result of a lack of funding.

Evolution of observing systems must take into account upgrading, restoring, substitution and capacity building (especially in the use of new technologies). Two aspects need to be considered: the data production and the data use. It is possible that some countries do not and will not be able

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[3] See http://www.sfcgonline.org/home.aspx

to produce data and will therefore only be users of data. To help developing countries produce data for international exchange, due consideration must be given to the three issues previously identified i.e. public infrastructure, expertise and funding.

Possible approaches to observing system evolution in these conditions are the following. A first step should be to identify observing systems that are less dependent on local infrastructure. Where local infrastructures are sufficient or can be externally supported, it may be possible to augment in-situ observations with other technologies such as satellite data, AMDAR, dropsondes, and Automatic Weather Stations (AWS).

A minimum set of reliable radiosondes is required as a backbone to the GCOS Upper Air Network (GUAN). NWP impact studies[4] have shown the prominent importance of isolated radiosonde observations for both global and high resolution NWP.

Obtaining vertical profiles (of wind, temperature and, in the near future, humidity) by AMDAR in many data sparse areas appears as a natural way to obtain observations of some basic atmospheric variables in some countries with important airports and very few conventional atmospheric observations.

Capacity building in some countries continues to need attention. International responsibilities for data exchange may be supported by the migration toward the table-driven codes (BUFR[5] or CREX[6]) as a reliable representation of the data. More importantly, it will be necessary to develop and deploy systems for automatically generating messages (such as CLIMAT reports) and to ensure timely, efficient and quality-controlled flow of essential data, in keeping with the WIS implementation strategy.

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Some countries have satellite receiving stations or receive satellite data through the Global Telecommunication System (GTS), but lack the expertise to utilize the information to their benefit. Some countries are acquiring Doppler radar but need training on how to process and interpret the information. For example, Region I has benefited with expanded access to conventional data and satellite imagery through the Préparation à l'Utilisation de MSG en Afrique (PUMA) project. This type of project should be expanded to include other data types for routine application (synoptic meteorology, aviation, nowcasting).

The following guidelines are proposed for the allocation of priorities for technical cooperation activities for the integrated observing systems:

(a) Highest priority should be given to the projects aiming at improving and restoring the existing, and building the new upper-air observational capabilities, of the RBSN[7]/RBCN with emphasis to the activation of silent upper-air stations and the improvement of coverage over data-sparse areas (in particular as regards the purchase of equipment and consumables, telecommunications and the training of staff);

(b) Highest priority should be given to extend AMDAR coverage to developing countries, LDCs and SIDS to supplement scarce upper-air observations or to provide a cost-effective alternative to countries that cannot afford costly upper-air sounding systems;

(c) High priority should be given to the projects related to the improvement of data quality, regularity and coverage of surface observations of the RBSN/RBCN with emphasis to the activation of silent stations and the improvement of coverage over data-sparse areas;

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[4] See http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-4_Geneva2008_index.html

[5] FM 94 BUFR Global Telecommunication System (GTS) format - Binary universal form for the representation of meteorological data

[6] FM 95 CREX GTS format - Character form for the representation and exchange of data

[7] GCOS Surface Network (GSN) and GUAN stations are part of the RBSN (Regional Basic Synoptic Network)

(d) High priority should be given to projects related to the introduction and/or use of new observing equipment and systems including, where cost-effective, surface-based AWSs, AMDAR, ASAP and drifting buoys;

Finally, the following recommendations should be taken into account when addressing the evolution of observing systems in developing countries:

- Define geographical areas to which priority for additional observations should be given, if additional funding were available.
- Prioritize where the needs are most pressing for WMO Voluntary Cooperation Programme (VCP) or other funding.
- Give high priority, in the Regions and the Secretariat, to maintaining a minimum radiosonde network with acceptable performance within data-challenged regions.
- Employ data rescue activities to preserve the historical observation record in developing countries, and make long-term datasets available for activities including reanalysis, research, adaptation, monitoring and other climate services.
- Encourage Regional Associations in concert with CBS to define field experiments over data sparse areas, for a limited time, to evaluate how additional data would contribute to improve performance at the regional and global scale, following the example of the African Multidisciplinary Monsoon Analysis (AMMA[8]) field experiment.
- Examine the extent to which automated stations could become a viable, cost-effective alternative to manned stations for the surface network in the future, and investigate improved configurations of automated and manual stations.
- Examine how, in data-sparse areas of the world, it may be more cost-effective to make full use of AMDAR ascent/descent data at major airports, whilst noting that the radiosonde network still plays an important role in manual forecasting.
- When changes are made to the climate observing systems, follow the GCOS Climate Monitoring Principles (GCMP) and proper change-management practices, with close collaboration between observations managers and climate scientists.[9] Refer telecommunication problems to CBS, as a priority. Note that for nowcasting and risk mitigation in vulnerable areas, the availability of a robust telecommunication infrastructure is an issue (robust against extreme weather conditions).

Action C11

Action: Establish capacity building strategies in developing countries. This may include establishing training programmes through engagement within the targeted country, e.g., data management, observing practices and seasonal prediction. Use the regional climate centre concept to provide access to specialists who could conduct training and maintenance of more complex systems including AWS.

Who: NMSs / NMHSs with RAs, CBS, Commission on Climatology (CCl) in collaboration with international programmes. Initiation and supervision to be led by RAs.

Time-frame: Continuous. Timetable to be decided by each RA.

Performance indicator: capacity building development in developing countries.

5. Surface-based observing system

[…]

5.2. Generic issues: traceability, instrument calibration, data exchange

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[8] See http://amma-international.org/

[9] See WMO-TD No 1378 on: http://www.wmo.int/pages/prog/wcp/wcdmp/documents/WCDMPNo62.pdf

To guarantee data quality, especially for climate applications, instrument measurements should be traceable to the International System of Units (SI) that should be done through an unbroken chain of comparisons, quality assessments and calibrations of instruments and respective working international standards.

Action G1

Action: Ensure traceability of meteorological measurements to SI, at least within the Regional Basic Synoptic and Climatological Networks (RBSN/RBCN).
Who: NMSs / NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead and supervise.
Time-frame: Continuous
Performance indicator: Number of stations that make measurements traceable to SI.

The increase of data volumes for some specific observing systems, such as radars and wind profilers, has to be accompanied by actions ensuring capability of WIS to cope with the corresponding increase of data exchange. This increase will be partly due to more frequent observations, e.g., through the automation, or to exchange of existing observations that were not exchanged internationally.

OSEs performed with NWP models have shown that global forecasts can be improved significantly by assimilating hourly data, even if the data are available only on a small portion of the globe, such as hourly atmospheric pressure observations from synoptic stations, radar data, data from Global Navigation Satellite Systems (GNSS) receiving stations. Similarly, other applications, including climate and aviation, rely increasingly on sub-hourly data. Open and unrestricted access to all available data and their exchange would be needed to improve scope and quality of services provided by NMSs / NMHSs to their users.

Action G2

Action: Ensure, as far as possible, a global exchange of hourly data which are used in global applications, thinned if necessary to balance user requirements against technical limitations.
Who: NMSs/NMHSs, Regional Associations, in coordination with CBS and international programmes and agencies. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicator: the standard monitoring indicators used in global NWP (see footnote 18 in section 3.6).

Action G3

Action: Promote a global exchange of sub-hourly data in support of relevant application areas.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, Technical Commissions, RAs, and other relevant organizations. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicator: A number of sub-hourly data types exchanged through WIS.

Climate modelling and seasonal forecasts require also an exchange of data between the different centres monitoring the atmosphere, the ocean and the terrestrial sub-system. Although the real-time constraints are less severe than for NWP, it is important to integrate these different observation systems, with common pre-processing and exchange rules, following the WIS and WIGOS standards. Such an action would improve considerably the benefits to the users without creating new observing systems. As the different users have different operational constraints and different requirements in data resolutions, this may imply, for some observing systems producing high data volumes, to organize the processing with different data levels (as done already for many satellite missions).

Action G4

Action: Ensure exchange of observations from atmosphere, ocean, terrestrial observing system, according to the WIGOS standards. If needed, organize different levels of pre-processed observations in order to satisfy different user requirements.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, Technical Commissions, RAs, and other relevant organizations. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicator: Statistics on the data made available to each application.

Mainly for the climate monitoring, but also for other applications, it is important:

– to maintain stations with long historically-uninterrupted observation records;
– to perform a regular calibration of instruments;
– to test and intercompare different observing instrument/systems (e.g., radiosonde systems and remote-sensing systems providing different types of vertical profiles with a view of establishing the interoperability of their data);
– to collect and archive sufficient metadata to enable homogeneity assessments to be made and data provenance and fitness for purpose to be assessed;
– for all countries to maintain their GCOS (GSN, GUAN, and RBCN) stations and for these to provide observations on a continuing basis as long as possible.

For more details, see the Quality Management Framework (footnote 15), section dedicated to instruments and observation methods.

[Suggestion to mention the usefulness of surface-based automatic weather station networks for the validation of space-based derived products, with possible action to facilitate information on, and availability and use of such data for validation purpose.]

[…]

5.3.1.5. GNSS receiver stations

In a similar way to the atmospheric profilers, networks of GNSS ground-based receiver stations have been operational in few regions round the world. The main application of these networks is generally not meteorological. Although they are very heterogeneous in quality and observing practices, the meteorological information has been extracted and collected in real-time from some stations. Starting in 2006, the meteorological information has been assimilated in operational NWP (both global and regional) either in the form of an Integrated Water Vapour (IWV = total water vapour integrated on the vertical), or in the form of a Zenith Total Delay (ZTD). The ZTD contains both the “wet delay” (due to the water vapour) and the “dry delay” directly related to the air density (air density directly related to surface pressure). The positive impact of GNSS ground-based meteorological observations on numerical forecasts has been shown (on the water vapour, precipitation and atmospheric pressure fields). See footnote 20 in section 4 to access to a synthesis of OSEs.

The ground receiver stations in most countries are owned and operated by agencies other than the NMHS. Hence the access to data, the processing to produce meteorological data, and permission to use and redistribute the data are all dependent on collaboration by the NMHS (individually or in multilateral groupings) with the owners/operators. In many cases it is not permitted for the NMHS (individually or in multilateral groupings) to exchange the data with other Members of WMO.

Concerning this observing system which is relatively new in meteorology, one important action is to exploit more the meteorological content of the existing GNSS receiver stations (in the form of IWV or ZTD). This action does not require deployment of new infrastructure. In addition, it would be very beneficial to improve the observation of upper-air humidity with denser receiver networks, taking into account all the other instruments that observe the upper-air humidity, and looking especially at areas for which the climatology is subject to rapid variations (in space and time) of the atmospheric water vapour content.

Action G24

Action: Exploit more the existing GNSS receiver stations by establishing collaborative arrangements with station owners / operators for access to data, processing of data to derive meteorological [or ionospheric] information (ZTD, IWV) and, where possible, permission to exchange the data with other Members of WMO.

Who: NMSs / NMHSs (individually or in multilateral groupings) will lead the Action and will need to collaborate with station owners/operators, with RAs (to determine exchange requirements), and with WMO TCs (for relevant guidance).

Time-scale: Continuous.

Performance indicators: Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring (see footnote 18 in section 3.6).

Action G25

Action: Organize the global exchange of data from a subset of GNSS receiver stations, aiming at satisfying a frequency requirement of about one hour (for meeting requirements in global applications).

Who: Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs / NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g., EUMETNET). CBS to lead the action with RAs.

Time-scale: Continuous.

Performance indicators: A number of GNSS receiver stations whose data are exchanged globally in real-time.

Action G26

Action: Optimize the upper-air water vapour observation over land, considering the collaborative establishment of additional GNSS receiver stations, and also the other humidity observing systems.

Who: Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs / NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g., EUMETNET). NMSs / NMHs to lead the action with RAs.

Time-scale: Continuous.

Performance indicators: Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring (see footnote 18 in section 3.6).

[…]

5.3.2.4. Lightning detection systems

Ground-based (total or only “cloud to ground”) real-time lightning detection and tracking systems have demonstrated their value as an early indicator of the location and intensity of developing convection, and also of the motion of thunderstorms. Especially for nowcasting, severe weather warning and aviation applications, these observing systems may increase the warning lead time associated with severe thunderstorms. For aviation the data coverage requirement is almost global. Advanced lightning systems also provide the 3D structure of the electricity activity for aviation.

In 2025 one can foresee long-range lightning detection systems providing cost-effective, homogenised global data, with a high location accuracy, significantly improving the data coverage in data-sparse areas. High resolution lightning detection systems should be also deployed in some specific areas, for special applications, with higher location accuracy, and with cloud-to-cloud and cloud-to-ground discrimination.

Action G34

Action: Improve global lightning detection efficiency by extending the deployment of long-range lightning detection systems and introducing more of these systems. Priorities should be given to filling gaps in populated areas and along commercial airline routes.

Who: NMSs / NMHSs and agencies operating long-range lightning detection systems RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.
Time-scale: Continuous.
Performance indicators: Data coverage for this type of observations.

Action G35

Action: Develop and implement techniques for the integration of lightning detection data from different systems, including from surface and space-based systems, to enable composite products to be made available.
Who: NMSs / NMHSs and agencies operating lightning detection systems, RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.
Time-scale: Continuous.
Performance indicators: Level of integration of the lightning systems.

Action G36

Action: Improve the exchange of lightning detection data in real-time by establishing and implementing agreed data licensing protocols for the exchange of data.
Who: NMSs / NMHSs and agencies operating lightning detection systems, NMSs, NMHS, RAs and TCs, coordinated by CBS and CIMO, both .
Time-scale: Continuous.
Performance indicators: A percentage of observations exchanged regionally and globally.

[…]

6. Space-based observing system

6.1. Introduction

For several decades two types of satellites have been used in meteorology: geostationary satellites (GEO) and polar orbiting satellites in Low Earth Orbits (LEO). The geostationary satellites are deployed along the equator, with their longitudes chosen to optimize the data coverage. The main advantage of a GEO satellite is the high observation frequency of 30 or 15 minutes or less. The main drawback is that it cannot observe the polar caps (polarward of about 60° of latitude). LEO satellites are generally deployed on a polar sun-synchronous orbit. Their main advantage is the global coverage which can be achieved in 12h with many scanning instruments. The data coverage is quite good near the poles where new observations can be produced at each orbit (i.e. about every 100 minutes). The main drawback is the observation frequency in low latitude regions, where observations are produced generally every 12h for a single platform. A rapid and continuous data collection by the ground segments is also more difficult to organize than for geostationary satellites.

Some satellite series have been operational for several decades, like the American Geostationary Operational Environmental Satellite (GOES) or the European METEOSAT (geostationary satellites), or the American NOAA[10] series of polar orbiting satellites. The main instruments operated on these operational satellites are imagers (visible and infra-red) and atmospheric sounders (infra-red or microwave). Research satellites have played a major role in complementing operational satellites, and they will continue to play a major role in the future, although they cannot guarantee the continuity of observation. Some platforms have different instruments serving different applications, and the tendency to develop multi-user platforms is likely to continue. Some user requirements will be met through constellations of satellites (e.g. the COSMIC[11] constellation for radio-occultation measurements). The data volumes and the variety of instruments which are used routinely for many applications have been increased considerably over the last 20 years. Nowadays, many satellite observing systems (including research satellites) bring a very significant contribution to operational weather and climate monitoring. Data continuity, which is essential for

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[10] National Oceanic and Atmospheric Administration (USA)

[11] Constellation Observing System for Meteorology, Ionosphere and Climate

climate monitoring as well as for operational applications, is being threatened by the potential end of satellite missions before follow-on platforms are launched. Space agencies are encouraged to prolong the lifetime of currently flying instruments on relevant satellite missions.

A detailed description of the current satellites and instruments contributing to global observing systems (or are likely to contribute in the period 2012-2025) can be found in the WMO satellite “Dossier”[12] [See updated link] and the related Satellite Observing Capabilities Review and Analysis Tool (SOCRAT) database. This document set contains a “gap analysis”, i.e. the more critical gaps which lead to recommendations on the development/improvement of satellite observing systems. (-). For the coming 15 years, one can expect an expanded space-based observing capability, an expanded community of space agencies contributing to WMO programmes and an increased collaboration between them. One can expect also a tendency to have more and more satellites serving several applications.

Requirements for instruments on new satellite missions should be more and more developed as a result of the gap analysis of the integrated global observing system in order to make the global observing system as cost-effective as possible. This requires a fundamental re-analysis of capabilities of satellite-based systems against surface-based systems. [This is a new paragraph, however proposed to be deleted]

In the following section (6.2), the generic issues concerning the space-based component of global observing systems are described, with the corresponding recommendations appropriate for implementation in the period 2012-2025. Section 6.3 describes the recommended Actions for the different observing systems classified in the following components (as foreseen in the Vision 2025):

- operational geostationary satellites (sub-section 6.3.1);
- operational polar-orbiting satellites on sun-synchronous orbits (6.3.2);
- other miscellaneous operational satellite missions, with various instruments on various orbits (6.3.3), which complement the two previous components, the ensemble being the backbone of the space-based observing systems;
- R&D satellite missions, operational pathfinders and technology demonstrations (6.3.4) whose role within composite observing systems in 2025 is uncertain, but which are likely to have an operational contribution by then;
- observations for space weather (which are discussed separately in section 6.3.5).

6.2. Generic issues: data calibration, data exchange, product generation, data stewardship, education and training

There will be a tendency towards higher spatial, temporal and spectral resolution for all satellite observing systems. It will enhance the information available, particularly to monitor and predict rapidly-evolving small-scale phenomena. It will increase the demand on data exchange and on processing capabilities. The spatial, temporal and spectral resolutions of the satellite data used in operational forecasting are generally coarser than the resolutions of the instruments, because of limitations in computer resources and in data assimilation methodologies. The resolution of the satellite data which are actually assimilated in meteorological and oceanic models is expected to increase faster than the instrument resolutions, by 2025, because of improvements in data assimilation techniques.

The progress on instrument capabilities and on the use of satellite information will be fully successful only if it is accompanied by actions aiming at improving the availability and the timeliness of the data for the different users and the different applications, from global assimilation in meteorological or oceanic models to the local use in nowcasting. This is more critical for LEO satellites than for GEO. For LEO satellites, direct readout capabilities should be provided wherever

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[12] http://www.wmo.int/pages/prog/sat/gos-dossier_en.php : this WMO web page contains a comprehensive dossier on past, present and future satellites with their instruments.

possible. In combination with direct readout, the development of the RARS (Regional ATOVS[13] Re-transmission Systems) has improved the timely delivery of data. This type of “quick re-transmission” action on satellite radiances for polar orbiting sounders has considerably helped NWP in the recent years, and it will help more and more regional and local forecast systems in the future. Applying such concepts to other data, e.g. imagery, would be beneficial to many other application areas.

For GEO satellites, the data delivery is easier within the geographical area corresponding to the Earth disk which is observed directly by each satellite. The main challenge is the rapid processing and the rapid and global exchange of processed data (such as atmospheric motion vectors, AMVs) which are needed for global NWP with a hourly frequency at least. Other applications have identified different requirements for data latency.

User-friendly data dissemination techniques (internet, Digital Video Broadcast) should be provided as appropriate. These various techniques all contribute to the WIS and should also be used to disseminate products and training material.

Provisions should be made to enable users to effectively use the capabilities provided by the space-based GOS, and to prepare for new satellite capabilities well in advance of system deployment. This includes data reception, processing and analysis infrastructure, including software.

Users relying on satellite-based datasets and products require sufficient information on their quality (e.g., accuracy), the algorithms used, and fitness for purpose. Satellite operators should provide full description of all steps taken in the generation of satellite products, including algorithms used, specific satellite datasets used, and characteristics and outcomes of validation activities. This should be in adherence with the QMF procedure (see section 2.1). Metadata should follow the WMO core metadata profile and be compliant with internationally-agreed formats recognized by WMO (see WMO Guidelines on the use of metadata for WIS, 2010).

For climate monitoring and studies of other long-term phenomena, extended satellite time-series (e.g., Fundamental Climate Data Records) are needed. Long-term data stewardship under scientific guidance is necessary to achieve homogeneous long-term records, which should include regular reprocessing (roughly every five years). User-friendly arrangements for access to data archives should be put in place.

As part of continuous improvement in Members’ capacity, such preparation should include the necessary provision of education and training to users, for example through the WMO-CGMS Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) and its Centres of Excellence. The user requirements related to satellite data, products, infrastructure and training should be regularly assessed on global and regional level, as appropriate, in order to monitor the effectiveness of the Actions proposed.

Action: Enable Members, as appropriate, to fully benefit from evolving satellite capabilities through adequate data reception and dissemination systems, including the necessary infrastructure upgrades.
Who: IGDDS Implementation Group, GEONETCast Implementation Group
Performance Indicator: Level of satisfaction of Members’ user needs
Time-frame: Continuing

Action: Satellite operators to provide full description of all steps taken in the generation of satellite products, including algorithms used, specific satellite datasets used, and characteristics and outcomes of validation activities.
Who: Satellite operators in CGMS and CEOS

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[13] Advanced TIROS Operational Vertical Sounder

Performance Indicator: Number of products fully documented, adhering to the Quality Management Framework procedure
Time-frame: Continuing

Action: Satellite operators to ensure long-term data preservation and scientific stewardship of data, including regular reprocessing (roughly every five years).
Who: Satellite operators, in coordination with SCOPE-CM, WCRP, GCOS
Performance Indicator: Existence of long-term satellite data archives, with regular reprocessing
Time-frame: Continuous.

Action: Members should be enabled to benefit from evolving satellite capabilities through adequate, application-oriented education and training activities (including distance learning).
Who: WMO-CGMS VLab, including Centres of Excellence, and partners
Performance Indicator: Level of satisfaction of Members' training needs
Time-frame: Continuing

Action: Regions should determine and maintain requirements for satellite datasets and products.
Who: Regional task teams and VLab Centres of Excellence, in coordination with Regional Associations and satellite operators
Performance Indicator: Completeness and currency of set of regional requirements
Time-frame: Continuous

Because almost all satellite instruments need other instruments or other measurements to improve their calibration, the role of the Global Space-based Inter-calibration System (GSICS) becomes increasingly important with the increase in the number of observing systems and in its variety. It is also essential to combine in-situ observations into the process of calibration, tuning and validation. These activities will be carried out by satellite agencies, national laboratories and major NWP centres, helped by WMO, CGMS and GEOSS. These activities cover:

- Earth-based reference sites (such as especially-equipped ground sites, ad hoc field campaigns...) used to monitor the satellite instrument performance.
- Extra-terrestrial calibration sources (sun, moon, stars) which are stable calibration targets for monitoring the instrument calibration.
- Model simulations which allow the standard monitoring comparison "observed values vs model values".
- Benchmark measurements of the highest accuracy by special satellite and ground-based instruments.

There should be common spectral bands on GEO and LEO sensors to facilitate inter-comparisons and calibration adjustments. Globally distributed GEO sensors should be routinely inter-calibrated using a given LEO, and a succession of LEO sensors in a given orbit should be routinely inter-calibrated with a given GEO sensor.

Action S1

> **Action:** Maintain and develop the GSICS inter-comparisons and inter-calibrations between GEO and LEO sensors on an operational basis.
> **Who**: GSICS.
> **Time-scale**: continuous.
> **Performance indicators**: quality of the calibrated satellite data as judged by the standard monitoring indicators.

Instruments should be inter-calibrated on a routine basis against reference instruments or calibration targets, using common methodologies. At least two Infra-red and two high-quality Visible and, ultimately, ultra-violet and microwave instruments should be maintained in LEO orbits to provide reference measurements for intercalibration of operational instruments in geostationary or LEO orbit.

For most applications, and especially for climate monitoring, the time continuity of the key satellite sensors has to be planned and organized at the international level. In order to ensure continuity and consistency of data records, there is a need for (i) continuity of observations; (ii) overlap of key reference sensors that are needed to provide traceability, as articulated in the GCOS Climate Monitoring Principles (GCMPs) [14].

Action S2

Action: Ensure continuity and overlap of key satellite sensors, keeping in mind both real-time processing and processing in delayed mode for consistency of climate records, re-analyses, research, recalibration or case studies.
Who: CGMS leading the action, with WMO commissions, satellite agencies and satellite data processing centres.
Time-frame: Continuous.
Performance indicator: Continuity and consistency of data records.

6.3. Issues specific to each observing system component

6.3.1. Operational geostationary satellites

For geostationary meteorological satellites, one key feature is to have them distributed approximately uniformly along the equator, in order to have no gap between their respective observation disks in the tropics and mid-latitudes, so that they can provide a global, frequent (15-30 minutes) continuous data coverage, except for the polar caps (approximately poleward of 60° latitude). To meet the (current and future) different requirements, at least 6 operational geostationary satellites are needed, with no more than 70° longitude gap for their positions along the equator. During recent decades the continuity of coverage over the Indian Ocean has been the main concern. Currently, there is also a 80 to 85° gap along the equator between GOES-W and MTSAT.

Action S3

Action: Ensure and maintain a distribution of at least 6 operational geostationary satellites along the equator, separated by no more than 70° of longitude. Improve the spatial and temporal coverage with GEO satellites over the Pacific.
Who: CGMS leading the action, with WMO commissions, satellite agencies and satellite data processing centres.
Time-frame: Continuous.
Performance indicator: quality of the global coverage by the different instruments of operational geostationary satellites.

6.3.1.1. High-resolution multi-spectral visible/infra-red imagers.

Visible / infra-red imagers are currently available on all the geostationary satellites. The number of channels and the imagery resolution are variable from one satellite to the other. The GEO imagers are used in several applications, primarily for nowcasting and VSRF. They are very useful for detecting dangerous weather phenomena and for monitoring their rapid development and motion. They observe the clouds (amount, type, temperature of the top). From tracking clouds and water vapour features on image time series, wind observations are derived: atmospheric motion vectors (AMVs). Surface temperature is derived over sea and over land, as well as atmospheric stability indices. The GEO imagery is also used to detect precipitation, aerosols, snow cover, vegetation cover, fires and volcanic ash.

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[14] See: http://www.wmo.int/pages/prog/gcos/aopcXVI/8.9_RecognitionDatasets.pdf

By 2025, an increased space/time resolution is expected for most of the GEO satellite imagers, and it is important to improve the data collection and the data exchange accordingly.

Action S4

Action: On each operational geostationary satellite, implement and maintain at least one visible / infra-red imager with at least 16 channels providing full disk coverage, with a temporal resolution of at least 15 minutes and a horizontal resolution of at least 2km (at sub-satellite point).
Who: CGMS leading the action, with WMO commissions and satellite agencies.
Time-frame: Continuous.
Performance indicator: number of geostationary satellites equipped with high resolution imagers.

Action S5

Action: For each geostationary satellite, organize the scanning strategy and the processing of the imagery (together with other instruments or other sources of information) in order to produce AMV with at least a 1h frequency.
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres..
Time-frame: Continuous.
Performance indicator: number of geostationary satellites producing AMVs operationally.

6.3.1.2. Hyper-spectral infra-red sounders

Infra-red sounders have been used for a long time on LEO satellites. Hyper-spectral infra-red sounders are now operational on some LEO satellites (e.g.: IASI on the Metop satellite) but not on GEO. Some years ago, CGMS endorsed the concept of the International Geostationary Laboratory (IGeoLab) which is a joint undertaking to provide a platform for demonstrations from geostationary orbits of new sensors and new capabilities. The evaluation of the potential of hyper-spectral sounders on GEO has been one of the IGeoLab projects; it was also performed with the GIFTS mission which was considered by the USA.

Several operators of geostationary satellites have firm plans to include hyper-spectral infra-red sounders for the next series of satellites. Detailed plans for the different series of GEO satellites are given in the Dossier (section on “Programmes” - see footnote 49 in section 6.1 of this report).

These planned sounders put the emphasis on high horizontal resolution (better than 10km), and on high vertical resolution (about 1km). Their main objective is to provide frequent information on the 3D structure of atmospheric temperature and humidity, for the whole Earth disk seen by the satellite (except in and below clouds). They will be used, together with the imagers, to produce high resolution winds (AMVs from clouds or water vapour features), to track rapidly evolving phenomena, and to determine surface temperature (sea and land). They are also designed to have an important role in the frequent observation of atmospheric chemical composition.

Action S6

Action: All meteorological geostationary satellites should be equipped with hyper-spectral infra-red sensors for frequent temperature and humidity soundings, as well as tracer wind profiling with adequately high resolution (horizontal, vertical, time).
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres..
Time-frame: Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.
Performance indicator: number of geostationary satellites equipped with hyper-spectral sounders.

6.3.1.3. Lightning imagers

A lightning imaging satellite mission has no heritage from any current or past geostationary mission. It is intended to provide a real-time lightning detection and location (with an accuracy of 5 to 10km) capability, primarily in support to nowcasting and VSRF. It is designed to detect cloud-to-cloud and cloud-to-ground strokes with no discrimination between the two types.

As lightning is strongly correlated with storms and heavy precipitation, another objective of a lightning mission is to serve as proxy for intense convection and convective rainfalls. It could serve as proxy for diabatic and latent heating to be assimilated in NWP models. It will also help the generation of a complete lightning climatology, together with the surface-based lightning observing systems (see 5.3.2.4). Finally, lightning plays a significant role in generating nitrous oxides, and lightning observations could be an important source of information for atmospheric chemistry models.

A lightning imaging mission is planned before 2025 for most of the geostationary satellite programmes: the European MTG (LI: Lightning Imager), The American GOES, from GOES-R onwards (GLM: Geostationary Lightning Mapper), the Russian GOMS[15] and the Chinese FY-4[16].

Action S7

Action: All meteorological geostationary satellites should be equipped with a lightning imager able to detect cloud-to-cloud and cloud-to-ground strokes.
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres..
Time-frame: Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.
Performance indicator: number of geostationary satellites equipped with a lightning imager.

6.3.2. Operational polar-orbiting sun-synchronous satellites

For achieving good global data coverage, the Vision-2025 envisages at least 3 operational polar orbiting satellites (with a minimum set of instruments) plus other satellites on various orbits. The Equatorial Crossing Time (ECT) of the 3 satellites is envisaged at 13:30, 17:30 and 21:30 (local time). The orbit ECT choice for the 3 operational satellites (and for all the other polar orbiting satellites) must be permanently monitored through an international cooperation.

Action S8

Action: Ensure the orbit coordination for all core meteorological missions in LEO orbit, in order to optimize temporal and spatial coverage, while maintaining some orbit redundancy. The LEO missions should include at least 3 operational sun-synchronous polar orbiting satellites with ECT equal to 13:30, 17:30 and 21:30 (local time).
Who: CGMS leading the action, with WMO technical commissions and space agencies.
Time-scale: Continuous.
Performance indicators: number and orbit distribution of contributing LEO satellite missions.

These orbiting platforms (with ECT equal to 13:30, 17:30 and 21:30) should be equipped with at least an hyper-spectral infra-red sounder, a microwave sounder and a high resolution multi-spectral visible / infra-red imager.

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[15] Geostationary Operational Meteorological Satellite

[16] FengYun 4 Meteorological Satellite

Compared with geostationary satellites, it is more difficult with polar platforms to implement a rapid data collection (from the platform to the ground segment), and then for the data delivery to meet the timeliness requirements of the several user applications.

Action S9

Action: Improve timeliness of LEO satellite data, especially of the core meteorological missions on the three orbital planes, by developing communication and processing systems which achieve delivery in less than 30 minutes (as done with the RARS network for some data sets).
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: timeliness of LEO satellite data, as judged by the usual monitoring scores.

Action S10

Action: Improve local access in real-time to LEO satellite data, especially to the core meteorological missions on the three orbital planes, by maintaining and developing direct read-out communication and processing systems.
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: volumes of LEO satellite data accessible by direct read-out.

6.3.2.1. Hyper-spectral infra-red sounders.

The current (2012) experience on hyper-spectral sounders is based on the use of IASI on the Metop[17] satellite, and of AIRS on AQUA[18]. Compared to the previous infra-red sounders, they provide much more details in the vertical on the temperature and humidity structure. Their main drawback is that they are limited to sample the clear-sky atmosphere and the portion which is above the clouds. But they are also a significant source of information for sea/land surface temperature, atmospheric composition and cloud variables. Impact studies have shown that they have a strong positive impact on global NWP. They are also expected to have an important role for complementing microwave instruments in the preparation of climate data records (see next section 6.3.2.2 on microwave sounders).

One difficulty for the users of hyper-spectral infra-red sounders is the huge volume of redundant data to process. Each user is interested in the information from a specific subset of this huge volume, and this subset varies from one application to another. For example, global NWP is interested in a representation of the data that gives most information on the temperature and humidity profiles, whilst the atmospheric composition community is interested in information on specific atmospheric constituents. It is a challenge for the centres pre-processing these observations to provide a satisfactory data delivery to all users in an operational context."

Action S11

Action: Design the ground segments for hyper-spectral infra-red sounders in order to define and implement a data reduction strategy which optimizes the information content accessible within the timeliness and cost constraints, whilst addressing the needs of different user communities.
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
Time-frame: Continuous.

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[17] EUMETSAT Polar Orbiting Operational Meteorological Satellite

[18] http://aqua.nasa.gov/

Performance indicator: volume and timeliness of the different data sets distributed to the users of hyper-spectral sounders.

6.3.2.2. Microwave sounders

Microwave sounders have been used in meteorology since the decade 1970-1980, mainly from the American NOAA series of satellites, equipped first with the Microwave Sounding Unit (MSU), then with the Advanced Microwave Sounding Unit (AMSU). They provide information on the atmospheric vertical profiles of temperature and humidity, but with a coarser vertical resolution compared to hyper-spectral infra-red sensors. Their main advantage on infra-red sounders is their capacity to observe in and below the clouds. Currently (2012), they are available for meteorological operations on several satellites (5), and they provide a backbone for large-scale global assimilation systems. NWP impact studies have shown that these observations provide a very strong positive contribution.

In addition to their key role for the observation of atmospheric temperature and humidity, microwave sounders provide information on cloud water content and precipitation.

Specific microwave radiance data from satellites, especially from the MSU and AMSU instruments, have become key elements of the historical climate record, and they need to be continued in the future to sustain a long-term record. A GCOS-IP action aims at ensuring the continued derivation of microwave radiance data for climate data records. This climate recommendation is reinforced by the key role taken by the microwave sounders in global re-analyses.

Action S12

Action: Fill the gap in planned coverage of microwave sounders in the early morning orbit.
Who: CGMS leading the action, with WMO commissions and satellite agencies.
Time-frame: Continuous.
Performance indicator: number of microwave sounders planned for satellites in early morning orbit.

6.3.2.3. High resolution multi-spectral visible/infra-red imagers

Visible / infra-red imagers have been used since the beginning of satellite meteorology in the decade 1960-1970. At this time they provided very useful qualitative information for meteorologists, especially on the type and position of clouds and weather systems. Since then, a lot of technological progress has been performed on imagers, particularly on their horizontal resolutions and on the number of channels. Imagers on LEO satellites complement very well those on GEOs, by observing the middle and high latitudes, although their observation frequency is limited by their orbit configurations.

The observational capabilities of imagers onboard LEO satellites are very similar to those on geostationary satellites (clouds, surface temperature, snow and ice cover, etc. - see 6.3.1.1). They are most useful for nowcasting and VSRF in the polar areas. They can also be exploited for producing AMVs (cloud-tracked winds or water-vapour-tracked winds). MODIS[19] winds have been used in operational NWP for several years, and a very significant positive impact has been demonstrated, probably due to the lack of other types of upper-air wind observations over the polar caps.

Action S13

Action: Use the imagers of all operational polar orbiting platforms to produce AMVs from the tracking of clouds (or water vapour features)

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[19] MODIS: MODerate-resolution Imaging Spectrometer (onboard AQUA and TERRA satellites).

Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Volume and timeliness of the different data sets produced operationally on the polar caps.

Action S14

Action: Implement a water vapour channel (e.g. 6.7 µm) on the imager of all core meteorological polar-orbiting satellites to facilitate the derivation of polar winds from water vapour motion.
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Number of core meteorological polar-orbiting satellites with a water vapour channel in its imager.

6.3.2.4. Microwave imagers

The microwave imagers are similar to the passive microwave sounders discussed in 6.3.2.2, except they have different characteristics in wavelengths and spatial resolution which make them more appropriate for the observation of the land or sea surface. Over the oceans they provide information on sea-ice, surface wind speed and sea surface temperature. Over land they observe surface temperature, soil moisture and snow water equivalent. They also provide information on the precipitation and total column atmospheric water vapour. Polarimetric imagers also provide information on sea surface wind direction.

Since the decade 1990-2000, the total column water vapour and the surface wind speed information provided by the Special Sensor Microwave Imager (SSM-I) instrument onboard the American satellites DMSP[20] have been used widely for weather and climate applications. Initially the use of the data was limited to the ocean, but more recently a lot of progress has been achieved on the use of microwave satellite information over land. The role of these microwave sensors is also important for monitoring the sea ice limits around the polar caps. Thanks to the continuity of the DMSP/SSM-I observations during the last 20 years, these sensors make important contributions both to climate monitoring and to global re-analyses.

To meet the different user requirements, at least 3 satellites with microwave imagers are needed on well separated orbits. According to current plans the requirements are expected to be met.

[Consider an action on availability of MW imagers with all suitable channels, e.g. 6-7 GHz for all-weather SST]

6.3.3. Additional operational missions in appropriate orbits

In addition to the imagers and sounders listed above and operated on GEO and LEO orbits, several other satellite instruments are used for weather, ocean, climate and other applications. Many of them (but not all) are operated on polar orbiting sun-synchronous satellites. Several instruments serve the needs of more than one application.

6.3.3.1. Scatterometers

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[20] DMSP: Defence Ministery Satellite Programme (from the USA): among the different instruments onboard DMSP satellites, the SSM-I is the Special Sensor Microwave Instrument (used in operational meteorology).

Unlike microwave imagers which are passive instruments, scatterometers onboard satellites are an active observing system. Scatterometers provide information mainly on the oceanic surfaces (sea surface wind speed, ice cover) and also for the land surface (soil moisture).

The first scatterometer data to be assimilated in operational global NWP models were the oceanic wind observations of the European ERS-1[21] satellite in the decade 1990-2000. Since then, scatterometers have been provided to NWP and other applications, from satellites like ERS-2, QuikScat[22], Metop (and its ASCAT[23] instrument) - see the Dossier for a list of instruments and missions. They generally provide a very good global data coverage (with some limitations on the maximum wind speed, or over sea ice) which helps considerably to meet the meteorological and oceanic requirements in terms of surface wind. Over land the use of scatterometer data is not as mature, but a lot of progress has recently been achieved on the use of soil moisture information.

At least two satellites flying on well-separated orbits with a scatterometer onboard are needed and should be maintained in the future. According to the present plans the requirements are expected to be met.

[Check that satellite sensors are associated with processing chains providing NRT data]

6.3.3.2. Radio-occultation constellation

The use of radio-occultation in meteorology is a good example of observing systems based on an opportunity: (i) the continuous availability of GNSS radio signals emitted by about 30 GNSS satellites (probably around 60 in 2015-2025), orbiting at an altitude of about 22000 km; (ii) the perturbing role of the atmosphere which slows down the signal propagation, and generates atmospheric refraction. Then, by installing GNSS receivers on other satellites (ad hoc constellation or operational meteorological satellites, generally in LEO), it becomes possible to measure the delays of the signals due to their propagation through the atmosphere. These delays are mainly dependent on the air density, and they provide useful information on temperature, especially in the stratosphere and upper troposphere, and on humidity in the lower troposphere.

Radio-occultation measurements have been assimilated in operational NWP models since about 2005 from several satellites: CHAMP[24], GRACE-A[25], Metop (with its GRAS[26] instrument), the COSMIC constellation[27] (see Poli et al., 2009). Their impact on the analyses and forecasts has been evaluated by several NWP centres, and the main results have been discussed in the 4th WMO workshop on impact studies (see footnote 20, section 4). Taking into account the very indirect character of the observing system through instruments which were not primarily designed for meteorology, this positive impact has been found surprisingly large. In addition, the data coverage obtained from a constellation of receiving satellites is global and quite uniform. The system offers absolute measurements (self-calibrated), not contaminated by clouds, which is a big advantage with respect to (i) the general inter-calibration of satellite data; (ii) the creation of climate data records.

Most of the existing satellites currently providing radio-occultation measurements to operational applications are not operational satellites and do not belong to any satellite programme whose future continuity is guaranteed. For the period 2012-2025, it is important to plan the continuity of a sufficient number of receiving satellites, to avoid losing the benefits of the important investments made on the production of radio-occultation measurements and on their use in operational meteorology.

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[21] ERS = Earth ressource Satellite; ESA mission (ERS-1 started in 1991 and was followed by ERS-2)

[22] Quick Scatterometer (NASA)

[23] Metop's Advanced SCATterometer

[24] CHAllenging Minisatellite Payload

[25] GRACE: Gravity Recovery And Climate Experiment

[26] GNSS Receiver for Atmospheric Sounding

[27] http://www.cosmic.ucar.edu/

Action S15

Action: Ensure and maintain a radio-occultation constellation of at least 8 GNSS receivers onboard 8 platforms on different orbits, and organize the real-time delivery to processing centres.
Who: CGMS to lead the action, with WMO commissions, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Number of satellites providing GNSS signals in real-time.
[The performance may also vary by a factor of 6 depending on number of on-board antennas and number of compatible GNSS systems]

Action S16

Action: Perform an Observing System Simulation Experiment (OSSE) to evaluate the impact of different numbers of platforms in a GNSS constellation, and to estimate the optimal number of platforms required.
Who: NWP centres, in coordination with CBS/ET-EGOS (to lead the action) and CAS/THORPEX.
Time-scale: Before 2013 (end of THORPEX).
Performance indicators: A number of OSSEs carried out.

Another application of the GNSS signals and radio-occultation is the measurement of electron density in the ionosphere. Therefore the future radio-occultation constellations will contribute also to the space weather applications (see section 6.3.5).

6.3.3.3. Altimeter constellation

SSH is one of the key variables to observe for ocean analysis and forecasting and for coupled ocean-atmosphere modelling. SSH has been observed through a series of satellite altimeters since the beginning of the decade 1990-2000: ERS-1 and 2, JASON-1[28] and 2, ENVISAT[29], GEOSAT[30], etc. - see the WMO “Dossier”, footnote 49 in 6.1, for documentation on these satellites and their instrument characteristics. Satellite altimeters provide measurements of the ocean topography and of the significant wave height with a global coverage and a good accuracy. The surface wind can also be estimated from the wave observation. However the horizontal and temporal resolutions are limited by the instrument producing observations only at the nadir of the satellite (for most instruments). The horizontal resolution can be good along the satellite track, and the main limitation is “across-track” in mid-latitudes: there is generally a 300km gap between measurements from two consecutive orbits.

Several altimeters are also able to provide measurements on ice topography (over sea and land) and on the lake levels (applications to glacier monitoring and hydrology). Unfortunately, there is a gap in laser altimetry between NASA’s first and second ICESat satellites. While the radar altimeter on Cryosat-2 is also for sea and land ice measurements, the ideal altimeter constellation would have both laser and radar altimeters. The combination would provide greater accuracy in sea ice thickness estimates, and might provide information on the depth of snow on the ice.

In the future, several altimeter instruments (planned or already flying) will continue to support these applications: ALT on HY-2A[31], AltiKa[32] on SARAL[33] - see WMO Dossier, footnote 49 in section 6.1 for details. In the period 1990-2010, the number of operational altimeters has varied from 1 to 4. It

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[28] Ocean Surface Topography mission (USA/France)

[29] ESA Environmental Satellite mission

[30] GEOdetic SATellite

[31] HaiYang ocean satellite mission (China)

[32] High accurate oceanography altimeter

[33] Environment monitoring mission (India/France)

is generally agreed that a minimum of two satellites on sun-synchronous orbits, plus one reference mission, will be necessary to meet the requirements of operational oceanography.

Action S17

Action: Implement an altimeter constellation comprising a reference mission on high-precision, not sun-synchronous, inclined orbit, and two instruments on well separated sun-synchronous orbits.
Who: CGMS leading the action, with WMO commissions, JCOMM, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Number and orbit geometry of satellites providing altimetry in real-time.

6.3.3.4. Infra-red dual-angle view imager

For climate monitoring purposes it is important to have continuous records of very accurate measurements of SST. In the GCOS-IP an action states: "Continue the provision of best possible SST fields based on a continuous coverage-mix of polar orbiting and geostationary infra-red measurements, combined with passive microwave coverage and appropriate in-situ networks". To achieve the required quality of SST fields it is important to have at least one infra-red instrument with a dual view for accurate atmospheric corrections. Such instruments have already been used: ATSR[34] on ERS, AATSR[35] on ENVISAT - see WMO Dossier, referenced by footnote 49 in 6.1, chapter "Instruments". Another one is planned for the Sentinel 3 mission: the SLSTR (Sea and Land Surface Temperature Radiometer).

Action S18

Action: Ensure and maintain in operations at least one infra-red dual-angle view imager onboard a polar orbiting satellite in order to provide SST measurements of climate monitoring quality.
Who: CGMS leading the action, with WMO commissions, JCOMM, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Operational availability of dual-angle view imagers.

The high-quality SST fields obtained through these infra-red imagers will also be useful for applications other than climate monitoring, in operational meteorology and oceanography. Also these imagers will contribute to the observation of aerosols and clouds.

6.3.3.5. Narrow-band high-spectral and hyper-spectral visible /near infra-red imagers

Remote-sensed observations of the ocean colour are useful for detecting several types of marine pollution, they can provide images of biological variables of the marine life with a high horizontal resolution (a few hundred metres). Observations of ocean colour are required for several marine applications and for the validation of ocean models.

The observations of ocean colour require passive imagers with narrow bands in the visible and near-infra-red spectrum. Several instruments of this type have already been operated, like the COCTS[36] on the Chinese HY-satellite series, the GOCI[37] on the Korean COMS[38] satellite, the

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[34] Along Track Scanning Radiometer

[35] Advanced Along-Track Scanning Radiometer

[36] Chinese Ocean Colour and Temperature Scanner

[37] Geostationary Ocean Colour Imager

[38] Communication, Ocean and Meteorological Satellite

MERIS[39] on the European ENVISAT satellite, or the OCM on the ISRO Oceansat-1 and Oceansat-2 satellites. For the future, other instruments are planned, like the OCS[40], or the OLCI[41] on the Sentinel-3[42].

The narrow-band imagers operated in the visible and near-infra-red are also useful for observing the vegetation (including the monitoring of burnt areas), the surface albedo, the aerosols and the clouds.

This narrow-band mission is currently well covered by LEO satellites.

6.3.3.6. High-resolution multi-spectral visible / infra-red imagers

For vegetation classification, land use monitoring and flood monitoring, visible / infra-red imagers are needed with characteristics emphasizing high horizontal resolution. These high-resolution instruments are normally applicable only on LEO satellites. The Leaf Area Index (LAI) is one of the main variables sought for agrometeorology from satellite data for use in crop simulation models. Although the LAI can be retrieved from several imagers, the highest resolution is achieved through the instruments of the LANDSAT[43] and SPOT[44] series. The land surface is observed with a horizontal resolution of dam order of magnitude. With instruments like the CHRIS onboard PROBA-2[45], the resolution can reach 2.5m on some specific targeted areas.

It is essential to continue this type of satellite mission in the future on order to guarantee the continuity of the existing series. This is important for agrometeorology, hydrology, land use, careful monitoring of disasters (floods, fires) and the very high-resolution imagers will have several other specific utilizations.

6.3.3.7. Precipitation radars with passive microwave imagers

Estimating the global field of precipitation amount (with precipitation type) at different time-scales is one of the more challenging tasks in weather and climate applications. One reason is related to the high variability in space and time of precipitation: in convective situations, flooding rains may affect one area with no precipitation at all a few kilometres away; the accumulated rainfalls (on 1h, 1 day, 1 month or 1 year) varies by one or two orders of magnitude between the equator and the poles, and precipitation are almost non-existent in tropical and sub-tropical deserts. A second reason is that there is no hope to obtain a global coverage of precipitation observation through surface-based raingauges and radars: in spite of the efforts made for expanding and improving the surface-based radar networks (see section 5.3.4.), the coverage will always be limited. However a proper estimation of precipitation fields is essential at all time-scales, from those required by the climate monitoring (several years, globally) to the local estimate of rainfall accumulated on 1h or less (flood monitoring). An ad hoc space-based precipitation observing system is very important to achieve this goal.

The concept of Global Precipitation Measurement (GPM) missions combines active precipitation measurements (made from space-based radars) with a constellation of passive microwave imagers (discussed in 6.3.2.4). The GPM constellation is planned to include a core mission with a 65° inclination orbit (with respect to the equator), plus several satellites developed by several national or international agencies. Its objective is to provide a global coverage of precipitation data at 3h

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[39] MEd Resolution Imaging Spectrometer

[40] Ocean Colour Scanner on the Russian Meteor Satellite

[41] Ocean Land Colour Imager

[42] A multi-instrument ESA satellite mission contributing to the Global Monitoring for Environment and Security (GMES)

[43] Earth-observing satellite mission (NASA/USGS)

[44] Satellite Pour l'Observation de la Terre

[45] CHRIS = Compact High Resolution Imaging Spectrometer, onboard the PROBA-2 (PRoject for OnBoard Autonomy) satellite. PROBA-2 (after PROBA) is a demonstration mission of ESA, which has more and more routine users.

intervals, and 8 satellites are needed to achieve this objective. The satellites will be equipped with active precipitation radars, or passive microwave instruments, or generally both. The characteristics of the existing and planned radars can be found on the WMO Dossier (footnote 49, section 6.1): search for example the CPR (Cloud and Precipitation Radar) or the DPR (Dual-frequency Precipitation Radar) in the instrument chapter of the Dossier.

This type of measurement has already proven its value, first on the TRMM[46] mission (satellite launched in 1997), and on the CLOUDSAT[47] mission, launched in 2006 by the USA, as part of the "A -Train"[48], to monitor the water cycle of the Earth, and also clouds and aerosols. The MEGHA-Tropiques Mission (MTM[49]), prepared through a collaboration between France and India, launched in 2011, also contributes to this project whose emphasis is put on precipitation and water cycle. Several satellites (planned or already flying) will have a low orbital inclination from the equator. For example, the MTM satellite flies between 20S and 20N. In this way, they will provide more frequent data near the equator, compared to the usual polar orbiting satellites whose inclination is close to 90°. This is important for a better understanding and modelling of the diurnal cycle in the tropics. The data availability in real-time is also important for nowcasting and operational hydrology.

Action:

> **Action:** To implement at least one Precipitation Radar mission on an inclined orbit, and maintain continuity
> **Who**:
> **Time-frame:**
> **Performance indicator:**

Action S19

> **Action**: In support of GPM, implement at least one passive MW mission on a low-inclination orbit
> **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
> **Time-frame**: Continuous.
> **Performance indicator**: Availability of one passive MW satellite mission on a low-inclination orbit.

Action S20

> **Action**: Organize the delivery of GPM data in real time to support nowcasting and operational hydrology requirements.
> **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
> **Time-frame**: Continuous.
> **Performance indicator**: Extent to which availability requirements for nowcasting and operational hydrology are met by the GPM mission.

[Note: ET-SUP suggested to evaluate the benefit of a sounding mission on a low-inclination orbit. ET-SAT may wish to comment on this suggestion, noting in particular that such mission is not currently part of the Vision of the GOS in 2025.]

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[46] Tropical Rainfall Measuring Mission

[47] NASA EOS mission to observe clouds

[48] The A-Train includes several satellites flying in formation: AQUA, AURA, CLOUDSAT, CALIPSO, PARASOL (The OCO launch failed in February 2009)

[49] CNES/ISRO Megha-Tropiques Mission to observe the water cycle and energy budget in the tropics

6.3.3.8. Broad-band visible/infra-red radiometers for Earth radiation budget

The Earth Radiation Budget (ERB) measures the overall balance between the incoming energy from the sun and the outgoing thermal (long-wave) and reflected (short-wave) energy from the Earth. It can only be measured from space, thus the continuity of observations is an essential issue for climate applications (see GCOS-IP, section about ERB).

In addition to imagers and sounders on LEO and GEO satellites, and to aerosols and cloud properties measurements (see sections above from 6.3.2), the ERB requires at least one polar orbiting satellite equipped with a broad-band visible / infra-red radiometer and a sensor for measuring the total solar irradiance.

Broad-band radiometers were available in the past on the ERB Satellite (ERBS) and are available on the TERRA and AQUA satellites. The SCARAB[50] instrument flying on MTM also contributes to the ERB.

Action S21

Action: Ensure the continuity of ERB type global measurements by maintaining operational broad-band radiometers and solar irradiance sensors on at least one LEO polar orbiting satellite.
Who: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Number of polar orbiting satellites contributing to the ERB.

6.3.3.9. Atmospheric composition instrument constellation

As mentioned above (5.3.1.4), a number of atmospheric constituents have an important role in climate forcings and feedbacks. This is the case for ozone, methane, CO_2 and others. Details can be found in the GCOS-IP. Several of these constituents will become important variables of NWP-ACM models (or already are, like ozone). The observations of these variables should become fully integrated in the WIGOS and then exchanged in real-time to meet the requirements of atmospheric chemistry applications, including air quality monitoring, and NWP.

Since the decade 1980-90 several above-mentioned sounders (like infra-red sounders) have contributed to the measurements of atmospheric ozone, aerosols and some other gases. In addition, several demonstration satellite missions or instruments have been devoted to atmospheric chemistry, like the Japanese GOSAT[51], specifically addressing the observation of key Green-House Gas (GHG) for climate change, with thermal and near-infra-red instruments onboard . Other examples of instruments devoted to atmospheric chemistry are:

- TOMS and SBUV onboard NOAA and other satellites, POAM[52] onboard SPOT satellites (limb solar occultation sounder for ozone, aerosols and other constituents).
- GOME[53] onboard ERS-2, GOMOS[54] and SCIAMACHY[55] onboard ENVISAT.
- GOME-2 on Metop.

For the future, the OMPS[56] is planned for some American operational satellites. It will add to the nadir measurements the limb sounding for high vertical resolution in the stratosphere. It will

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[50] Scanning radiative budget instrument

[51] GOSAT: Green-house gaz Observing Satellite, launched in January 2009.

[52] POAM: Polar Ozone and Aerosol Measurement

[53] GOME: Global Ozone Monitoring Experiment

[54] GOMOS: Global Ozone Monitoring by Occultation of Stars

[55] SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmosphere Chartography

measure ozone, but also NO_2, SO_2 and a few other constituents. In the European programme GMES[57], the missions called Sentinel-4 (GEO, MTG) and Sentinel-5 (LEO, EPS-SG) should carry ultra-violet, visible and near-infra-red sounders for supporting atmospheric chemistry. See the WMO Dossier (footnote 49) for more details.

Action S22

> **Action**: For atmospheric chemistry, monitoring of green-house gas and of air pollution, ensure the operational continuity of some ultra-violet / visible / near-infra-red sounders, including high spectral resolution ultra-violet sounders on GEO, and at least one ultra-violet sounder on 3 well-separated polar orbits. Ensure also the continuity of limb-sounding capability.
> **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
> **Time-frame**: Continuous.
> **Performance indicator**: Number of GEO and LEO ultra-violet / visible / infra-red sounders contributing to atmospheric chemistry.

For more details about the operational continuity of some atmospheric composition sounders , see GCOS-IP, section dealing with atmospheric chemistry.

6.3.3.10. Synthetic Aperture Radar (SAR)

Compared with a normal radar, the SAR processes the series of images in a special way, in order to increase considerably the spatial resolution locally, which implies some trade-offs on other geometrical variables of the radar measuring technique: scanning angle, swath size, etc. With SAR observing systems onboard LEO satellites, one can obtain locally very high resolution observations of land surface, wave heights (and directions plus spectrum), sea level (especially near the coasts), water level in flooded areas, sea ice caps, ice sheets and icebergs.

The SAR technology has been used on several satellites: ERS-1, ERS-2, ENVISAT (with its Advanced Synthetic Aperture Radar (ASAR) instrument), ALOS[58] (JAXA[59] satellite with its PALSAR[60] instrument). The ESA satellite CRYOSAT-2[61] has been launched in 2010 with its SAR instrument called SIRAL[62]. These SAR instruments have been used for both research and operational applications. For the future, several SAR missions are planned as well; for example the planning and development of the SAR-C instrument (radar in C band) on the GMES Sentinel-1 mission is a very good step towards integration of the SAR observing system into the operational observing systems. The future Radarsat Constellation Mission (RCM) planned for 2015-2023 will include 3 satellites phased on the same orbit, enabling a 4-day revisit time.

It is not feasible to obtain in real-time a global coverage of SAR data. In addition the SAR processing delays are important, which often prevents a rapid delivery. However it is important to have at least one operational SAR satellite mission whose continuity is guaranteed, and integrated in the WIGOS, with proper mechanisms to ensure a rapid delivery of data at the regional and local scales, in order to cope efficiently with high-risk phenomena and disaster management. Because of the local character of the SAR-targeted areas and of the high volume of data to process, it is actually desirable to have more than one satellite mission complying with these operational characteristics.

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[56] OMPS: Ozone Mapping and Profiler Suite

[57] GMES: Global Monitoring for Environment and Security

[58] Advanced land observing Satellite "Daichi"

[59] Japan Aerospace Exploration Agency

[60] Phased Array L-band Synthetic Aperture Radar

[61] ESA ice mission

[62] Synthetic Aperture Interferometric Radar Altimeter

6.3.4. Operational pathfinders and technology demonstrators

It is important to pursue investigations on some new satellite instruments and some new space technologies even if the final operational success is not guaranteed, provided these new systems are expected to help significantly for meeting the user requirements. In the past, several research or demonstration missions produced a beneficial operational outcome much more quickly than expected originally by the potential users. Several pathfinders and technology demonstrators are discussed below. They are all challenging but achievable by 2025, with a good chance to be an operational part of global observing systems by 2025 for some of them, and a reduced chance for some other systems.

6.3.4.1. Lidars on LEO satellites

Lidar instruments flying on satellites have been used in meteorology or are planned to be used as demonstration satellite missions. The lidar can be designed to observe some of the following atmospheric components: profiles of wind components (from Doppler shifts), aerosols, cloud-top and cloud-base height, water vapour profile. Space-borne lidars are also used in altimetry (see 6.3.3.3).

a) Doppler wind lidars

Space-borne Doppler wind lidars are the best hope for filling a big gap in the global data coverage: the lack of wind profile measurements which are currently too dependent on a single observing system, the radiosonde network.

An ESA demonstration mission, ADM-AEOLUS, is planned from 2013 to 2015 to test wind profile measurements made from the ultra-violet lidar, ALADIN[63]. ADM-AEOLUS[64] will be operated from a polar orbiting satellite and will provide global observations of wind profiles. It is very important to have these data delivered in real-time to the main NWP centres to check rapidly (the estimated life-time of ADM-AEOLUS is only 3 years) to what extent they can improve weather forecasts.

Following a successful demonstration mission, it will become a priority to plan and design an operational system based on wind lidars, using the experience accumulated in the demonstration mission, to decide on the appropriate number of satellites and the instrument characteristics.

Action S23

Action: Use the experience of demonstration missions (like the ADM-AEOLUS one) to plan and design an operational observing system based on Doppler wind measurements (providing a global coverage of wind profiles).
Who: CGMS leading the action, with WMO commissions, ESA and other satellite agencies, data processing and NWP centres.
Time-frame: As soon as possible after data have been provided by demonstration missions.
Performance indicator: Number and quality of Doppler wind lidar profiles (made from space) available to the users.

b) Cloud and aerosol lidars

Cloud and aerosol lidar systems can provide accurate measurements of cloud top height and can also observe cloud base height in some cases (e.g.: stratocumulus). They are also able to provide an accurate observation of aerosol layers in the atmosphere.

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[63] See http://www.esa.int/esaLP/LPadmaeolus.html; see also Stoffelen et al. (2005)

[64] Earth Explorer Atmospheric Dynamics Mission

The CALIOP[65] instrument has been available on CALIPSO since 2006, and the ATLID[66] instrument should fly on the EARTH-CARE[67] mission prepared by ESA and Japan, and planned for 2015[68]. Given the potential of these lidars, the data should be delivered for evaluation in operational centres (mainly forecasting and atmospheric chemistry applications). For the design of a possible operational system based on cloud/aerosol lidar, it is important to note that a Doppler wind lidar like the ADM-AEOLUS has also the capacity to observe clouds and aerosols, which raises the possibility of designing an operational system which would integrate wind, cloud and aerosol measurements.

For an efficient evaluation of the lidar data (as soon as the instrument is operated), it is important to have these data distributed in real-time, so that they can be be used (or at least evaluated) in operational numerical models dealing with atmospheric chemistry and weather forecasting.

Action S24

Action: Deliver cloud/aerosol lidar data produced from satellite missions to operational data processing centres and users. Use this experience to decide about a possible cloud/aerosol operational mission (integrated or not with an operational Doppler wind lidar mission).
Who: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, forecasting and atmospheric chemistry users).
Time-frame: Continuous with a special effort phased with the EARTH-CARE mission.
Performance indicator: Data volume produced by space-based cloud/aerosol lidars and used by operational applications.

c) Water vapour lidars

Feasibility studies have been carried out on the measurement of atmospheric water vapour profiles from lidars onboard LEO satellites. The objective has been found highly challenging, and no demonstration mission is currently planned for a water vapour lidar. It is still worth keeping a research activity on such an observing system, and worth planning a demonstration mission when appropriate.

6.3.4.2. Low-frequency microwave radiometer on LEO satellites

Microwave radiometers on LEO satellites have a capacity to observe ocean salinity and soil moisture, but with a limited horizontal resolution. At large scales, the salinity information will be useful in ocean applications, in seasonal and inter-annual forecasting and in climate monitoring. The soil moisture produced from these microwave instruments should also be useful in NWP, seasonal and inter-annual forecasting, hydrology and climate monitoring. The horizontal resolution provided by these instruments may be marginal for meeting the user requirements in the coastal areas and for high-resolution marine applications.

The SMOS[69] satellite was launched in January 2009 and is expected to provide data until 2014. The Argentinean / NASA mission[70] SAC-D is expected to provide similar data between 2012 and 2016. Such research data sets should be delivered to operational meteorological, hydrological and oceanographic centres for quasi real-time evaluation. If the benefits are judged sufficiently significant, an operational mission should be planned.

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[65] Cloud-Aerosol Lidar with Orthogonal Polarisation

[66] ATmospheric LIDar

[67] Earth Clouds, Aerosols and Radiation Explorer - see http://www.esa.int/esaLP/LPearthcare.html

[68] For more details on CALIPSO, CALIOP, EARTH-CARE and ATLID, see the WMO Dossier (http://www.wmo.int/pages/prog/sat/Refdocuments.html#spacebasedgos)

[69] SMOS: Soil Moisture and Ocean Salinity; satellite demonstration mission led by ESA, see: http://www.esa.int/esaLP/ESAMBA2VMOC_LPsmos_0.html

[70] See http://aquarius.nasa.gov/

Action S25

Action: Study the benefits brought by satellite demonstration missions like SMOS (missions based on low-frequency microwave radiometers) on atmospheric, hydrological and oceanic models, in a quasi operational context, and decide if a similar operational mission can be designed.
Who: CGMS leading the action, with WMO commissions, JCOMM, satellite agencies, data processing centres, meteorological, hydrological and oceanic modelling centres.
Time-frame: As soon as possible for impact studies, from 2013 onwards to decide on new missions.
Performance indicator: improvement brought by using these microwave data on different models.

Ocean salinity and soil moisture are variables whose variations are important to consider at the climate scale. The archiving of data series is important; see recommendations in the ocean part of the GCOS-IP.

6.3.4.3. Microwave imagers / sounders on GEO satellites

Using microwave imagers and sounders from geostationary satellites could provide very frequent precipitation observations, together with cloud properties (liquid water and ice content), and atmospheric temperature / humidity profiles. However such instruments are highly challenging for several technical reasons. One reason is the need for very large antennas to be operated on GEO orbits.

The potential benefit of such satellite instruments would be very high in terms of global estimation of precipitation fields (at all time scales). They would be very good complements to the same type of instruments on LEO satellites (see sections 6.3.2.4 and 6.3.3.7 about microwave imagers, GPM and precipitation fields). Therefore there is a good case to plan a demonstration mission with microwave instruments onboard a geostationary satellite, as was considered by IgeoLab (see section 6.3.1.2) for infra-red sounders.

Action S26

Action: Plan and design a demonstration mission with microwave instruments onboard a geostationary satellite, aiming at a significant improvement in terms of real-time observation of clouds and precipitation.
Who: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, meteorological and hydrological modelling centres.
Time-frame: As soon as possible, taking into account the maturity of technology.
Performance indicator: Success of a microwave instrument onboard a GEO satellite, then improvement brought by the data to meteorological and hydrological forecasting.

6.3.4.4. High-resolution, multi-spectral, narrow-band, visible / near-infra-red on GEO satellites

Such instruments on GEO satellites would be the natural complement of the visible / near-infra-red instruments onboard LEO satellites (presented in section 6.3.3.5). They would contribute to the observation of ocean colour, vegetation, clouds and aerosols, and they would help disaster monitoring, with the usual advantage of GEO versus LEO: the frequency of images which makes the observation almost continuous on the Earth disk seen by the satellite. However their implementation is much more challenging than on LEO because of the high altitude of the geostationary orbit.

Action S27

Action: Plan and design a demonstration mission with high-resolution visible / near-infra-red instruments onboard a geostationary satellite, aiming at improving significantly the

observation of ocean colour, vegetation, clouds and aerosols with multi-spectral narrow-band sensors.
Who: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, meteorological, oceanic and environmental centres.
Time-frame: As soon as possible, taking into account the maturity of technology.
Performance indicator: Success of this type of instrument onboard a GEO satellite, then improvement brought by the data to meteorology, oceanography and environmental science.

6.3.4.5. Visible / infra-red imagers on satellites in high inclination and Highly Elliptical Orbit (HEO)

The HEO has never been used in meteorology and oceanography. Its main advantage is that the satellite can stay close to the vertical of one particular region of the Earth (at high altitude) for several hours, and only a reduced time on the opposite side of the Earth. When the orbit inclination on the equator is high, it almost offers the observation continuity similar to that of a geostationary satellite but in a polar region. With visible / infra-red sensors onboard, a HEO satellite would offer an almost continuous observation of the large number of meteorological and oceanic variables normally observed by this type of sensors: clouds (and AMVs) at high latitudes, surface temperature, sea-ice, ash plumes, vegetation, fires and snow cover.

Action S28

Action: Plan and design a demonstration mission with visible / infra-red instruments onboard a HEO satellite with a highly elliptical orbit and a high inclination over the equator, in order to target a polar area). The aim is to obtain the same environmental observations with a quality similar to those obtained from GEO satellites.
Who: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, meteorological and environmental centres.
Time-frame: As soon as possible, taking into account the maturity of technology.
Performance indicator: success of a visible / infra-red instrument onboard a HEO satellite, then improvement brought by the data to meteorology and environmental science.

6.3.4.6. Gravimetric sensors

Satellites have been used for gravimetric measurements for several decades. Several gravimetric sensors are currently flying, like the USA GRACE[71] mission or the ESA GOCE[72] satellite.

Their instruments can measure the Earth gravity field and follow its variations in space and time. From these variations, one can detect information on the ground water mass, or on the mass of water in some lakes and rivers. Thus they contribute to the monitoring of the ground water, together with a set of in-situ observing systems described in 5.3.3.3.

Note that gravimetric instruments are often flying on multi-user platforms: for example GNSS receivers embarked on any gravimetry platform, if properly set up, can be used for radio-occultation of the atmosphere, contributing to forecasting and climate applications, as described in 6.3.3.2.

6.3.5 Instruments for space weather on polar and geostationary platforms

[Note: this section is still an early draft]

Space Weather Observation

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[71] Gravity Recovery and Climate Experiment - http://www.csr.utexas.edu/grace/

[72] Gravity field and steady-state Ocean Circulation Explorer - http://www.esa.int/esaLP/LPgoce.html

Space Weather refers to physical processes, originating at the Sun and ultimately affecting human activities on Earth and in space. In addition to the continuous UV, Visible and Infrared radiation which provides radiative forcing to our weather and climate at the top of the atmosphere, the Sun emits energy in an eruptive mode, as flares of electromagnetic radiation (radio waves, infra-red, visible light, ultraviolet, X-rays), and energetic electrically charged particles through coronal mass ejections and plasma streams. The particles travel outwards as the solar wind, carrying parts of the Sun's magnetic field with them. The electromagnetic radiation travels at the speed of light and takes about 8 minutes to move from Sun to Earth, whereas the charged particles travel more slowly, taking from a few hours to several days to move from Sun to Earth. The radiation and particles interact with the Earth's magnetic field and outer atmosphere in complex ways, causing concentrations of energetic particles and electric currents in the magnetosphere and ionosphere. These can result in geomagnetic variations, aurora, and can affect a number of services and infrastructure on Earth, either at the surface, or airborne or space-borne.

Space weather observations are required: to estimate the occurrence probability of space weather disturbances; to drive hazard alerts when disturbance thresholds are crossed; maintain awareness of current environmental conditions; and to determine climatological conditions for the design of both space based systems (i.e., satellites and astronaut safety procedures) and ground based systems (i.e., electric power grid protection and airline traffic management).

The vastness of space and the wide range of physical scales that control the dynamics of space weather demand that numerical models be employed to characterize the conditions in space and to predict the occurrence and consequence of disturbances. Data assimilation techniques must be utilized to obtain the maximum benefit from our sparse measurements. Space Weather observations are therefore used to drive empirical, physics-based, and data-assimilation models.

Forecasting the space environment conditions is enabled by monitoring the background magnetic configuration and precursor phenomenon that take place on the Sun and propagate in the interplanetary medium before reaching the Earth. This should be based, first of all, on the measurement of the solar electromagnetic output in order to detect eruptive or pre-eruptive structures on the solar disc, which requires measurements at visible, UV and X-ray. In addition, it involves the measurement of the plasma density, speed and magnetic field in the solar wind. The solar wind flows out from the solar surface and impacts the Earth geomagnetic field affecting the radiation environment, the ionosphere and the upper atmosphere.

A comprehensive space weather observation network shall include ground based and space-borne observatories. Both the ground based and the space based segments shall contain a combination of remote sensing and in-situ measurements.

Space Weather observation from the surface

Ground based sensors, play a key role to monitor the ionospheric and the geomagnetic environments.

Ionospheric monitoring is achieved by ground-based GNSS receivers, ionospheric scintillation receivers, ionosondes, riometers and scattering radars. Observations of the neutral wind are performed by ground based Fabry-Perot interferometers (FPIs).

Magnetospheric magnetic field observations are required globally with ground based magnetometers. Ground based geomagnetic monitoring also includes Auroral imaging by all-sky cameras.

The basic ground based observations for solar activity include solar imaging, including H-alpha images and the solar surface magnetic field with vector magnetographs. The solar radio emissions are observed with broad frequency radio spectrographs and radio imaging of the sun. The main limitation for ground based observations, however, is the filtering of the atmosphere for the solar electro-magnetic and particle radiation.

Space Weather observation from space

The solar wind measurements and most of the solar observations in X-ray and UV range can exclusively be performed from space. In particular, space-borne sensors will have to be used for observations of the solar radio wave spectra below ionospheric cut-off frequency. An essential instrument to determine the initial properties of Coronal Mass Ejections that erupt from the Sun and can strike Earth is the coronagraph. These faint, white-light images of the Sun must be obtained from space based sensors, and it is highly advantageous to have multiple coronagraph sensors located both in and away from the Earth-Sun line.

The first Lagrange point L1 is a unique vantage point for solar activity monitoring and interplanetary monitoring, the spacecraft remaining at a stable, intermediate distance between the Sun and the Earth. Provision should however be made for near real-time data acquisition on the ground through the use of at least 3 ground stations or data relay via geostationary or geo-transfer spacecraft. A spacecraft located at L1 can permanently monitor the sun and its corona, or acquire heliospheric imaging with sensors having wide angle visibility of the whole Sun-Earth line. Geostationary observatories also greatly contribute to solar imaging instruments,

Space based measurements of the ionosphere and of the geomagnetic field will enhance the ground-based measurement coverage to a planetary scale. Furthermore, detailed information on local spacecraft environment can best be obtained from observations aboard the spacecraft itself, especially of ionizing radiation and charged particles; the exception for this is the atmospheric drag, which can be deduced from ground based satellite tracking systems or from the data from onboard orbit determination instruments.

Radiative environment sensors have to cross the radiation belts to measure the trapped radiation. Spacecraft on a geotransfer orbit (GTO) can provide a comprehensive sampling of the environment. Scenarios combining sensors on GTO, polar orbiting spacecraft, geosynchronous orbits (GEO) and elliptical orbits should be considered for optimal spatial and temporal coverage taking into account the flight opportunities aboard Earth Observation satellites. All in-situ observations of the space radiation environment have to include spacecraft orbit information at the times of the data sampling.

Spaceborne sensors are also required for in-situ observations of the local magnetic field in space, at altitude ranges from LEO to GEO, and for the observations of the low frequency magnetospheric radio wave spectra. Spaceborne Auroral observations include sensors for auroral visible and UV imaging and auroral kilometric radiation.

Polar orbiting satellites can support ionospheric monitoring, and thermosphere neutral wind and density observations, which are used in combination with ground-based Fabry-Perot Interferometer (FPI) observations for global coverage. Sensor data about the microparticle flux as a function of size, velocity and angular distribution is also required from spaceborne sensors.

Current and future observing systems

The WIND, ACE and SOHO satellites are located near the Lagrangian L1 point, about 1.5 millions kilometres away on the Sun side of the Earth. They make direct in-situ measurements of the velocity, composition, magnetic field, density, oscillations and flux of the solar wind. These measurements could be relayed to Earth perhaps an hour before this wind hits the Earth's magnetopause (about 70000km above surface). This is therefore the maximum advanced warning of potentially damaging impacts on the Earth's environment.

Ground-based observations are, at present, mainly of the Sun itself. Plenty of other instruments make direct observations of the Sun's surface, from X-ray and UV imaging to measurements of its temperature, density, magnetic field and so on. Such observations of perturbations to the solar wind would have a lead time of about 3 days, but it is difficult to use directly for space weather predictions.

Geostationary and polar orbiting satellites also provide some information on the Sun's surface and on charged particles entering Earth's atmosphere, respectively.

The STEREO (Solar TErrestrial RElations Observatory, two satellites launched in 2006) pictures will provide full solar images, but in-situ measurements of fluxes (currently) directed away from Earth.

Some of this information is currently used to make space weather predictions, and to inform space modelling efforts.