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Requirements and possible approach to update/upgrade the satellite-based component of GOS

This document is a follow-on of paper *"Compliance of the post-2000 satellite-based component of GOS with requirements and possible approach to up-date/up-grade future systems"* presented and discussed at length at CGMS XXVII in Beijing. The purpose of the paper is to feed discussions on the future asset of the Global Observing System. It follows the following logic :

- analysis of the status of compliance of GOS with WMO requirements
- projected evolution of GOS and identification of what could be "affordable" and "appropriate" to CGMS members (so-called *GOS-proper*)
- identification of what is likely never to be affordable or appropriate within GOS-proper, thus could be acquired by cooperation with other satellite programmes of scientific/technological/commercial nature
- necessary developments to extend GOS-proper to full strength
- examples of missions towards full-strength GOS-proper
- the case for an "Atmospheric Dynamics Theme" within IGOS.

Note: this document has been prepared by Dr. B. Bizzarri on request of NOAA as an input for discussion at CGMS XXVIII. This does not imply NOAA endorsement of the content, which remains responsibility of the Author.

1. Introduction

At CGMS XXVII in Beijing, document EUM-WP-06 was presented:

- *"Compliance of the post-2000 satellite-based component of GOS with requirements and possible approach to up-date/up-grade future systems".*

The document addressed two interleaved issues:

- whether important gaps exist in the post-2000 satellite-based component of GOS, and how they could be filled at best by minimal additional efforts;
- how to prepare for the replacement of the elements currently in use or being developed, in view of next generation satellite systems to be used in the post-2010 era.

The elaboration :

- identified the most serious gaps in the post-2000 GOS, and proposed missions to fill them, all based on small-medium size satellites;
- showed the strategy leading to the eventual replacement of current/developing large satellites by smaller elements within a spread context.

The follow-on discussion in CGMS recognised the need to revise the (rather obsolete) concept of Global Observing System. In addition, the opportunities offered by a large number of missions of scientific, or technological, or commercial nature, to complement GOS in fulfilling a number of requirements impractical to be addressed by CGMS members (because of affordability within the context of zero-growth resources and growing responsibilities), were recognised.

Re-structuring the satellite-component of GOS is an activity which should derive from the *"Rolling Requirements Review"* (RRR) process in WMO (see Section 2, next). The subject of complementing GOS by data from scientific/technological/commercial satellite programmes was dealt with in a meeting called by WMO in Geneva on 24-25 January 2000, attended by CGMS members and their corresponding national authorities in charge of R & D space programmes.

In the light of progress stemming from the RRR process, and of some follow-on thought developed after the Geneva meeting, it seems appropriate to re-structure and update doc. CGMS XXVII EUM-WP-06. This document is structured according to the following logic:

- the status of compliance of GOS with WMO requirements is re-assessed, also in the light of the latest report following the RRR process[1];
- the near future evolution of GOS as known from CGMS status reports is extrapolated in the mid-term future and long-term future by adding a number of elements which seem to be "affordable" to CGMS members and "appropriate" to be an integral part of what we will call ***GOS-proper*;**
- a cross-check of the possible evolution of GOS-proper against the level of compliance with requirements, function of time, will be carried out, showing that, anyway, a number of requirements will continue either not to be cover, or defectively covered, thus could be addressed by cooperation with other satellite programmes of scientific/technological/commercial nature;
- focus will then be placed on those developments which are necessary to extend the GOS-proper capability to full strength; examples of missions will be described, showing that these developments could be based on small-medium class satellites;
- in the conclusion, the case for an *"Atmospheric Dynamics Theme"* within IGOS[2] will be made.

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[1] .RRR = Rolling Requirements Review - see Section 2, next.

[2] IGOS = Integrated Global Observing Strategy.

2. Status of requirements

User requirements for meteorology and climate are not a crystallised issue. There is a *Rolling Requirements Review* process (RRR), shown in ***Fig. 1,*** which enables to update requirements periodically, following four steps:

- step 1 - review of user requirements for observations needed to support WMO programmes;
- step 2 - review of the observing capabilities of existing and planned satellite systems;
- step 3 - "critical review" of the extent to which the capabilities meet the requirements;
- step 4 - "statement of guidance" based on step 3.

Requirements initially stem from the *Open Programme Area Group on Integrated Observing Systems* (OPAG-IOS) of the WMO Commission for Basic Systems (CBS). Space capabilities are initially stated by the *Space Agencies*. Step 3, which is the engine to make progress, is carried out by the Expert Team on Observational Data Requirements and Redesign of the Global Observing System (ET-ODRRGOS). Their most recent "Statement of Guidance" is dated 2000[3]

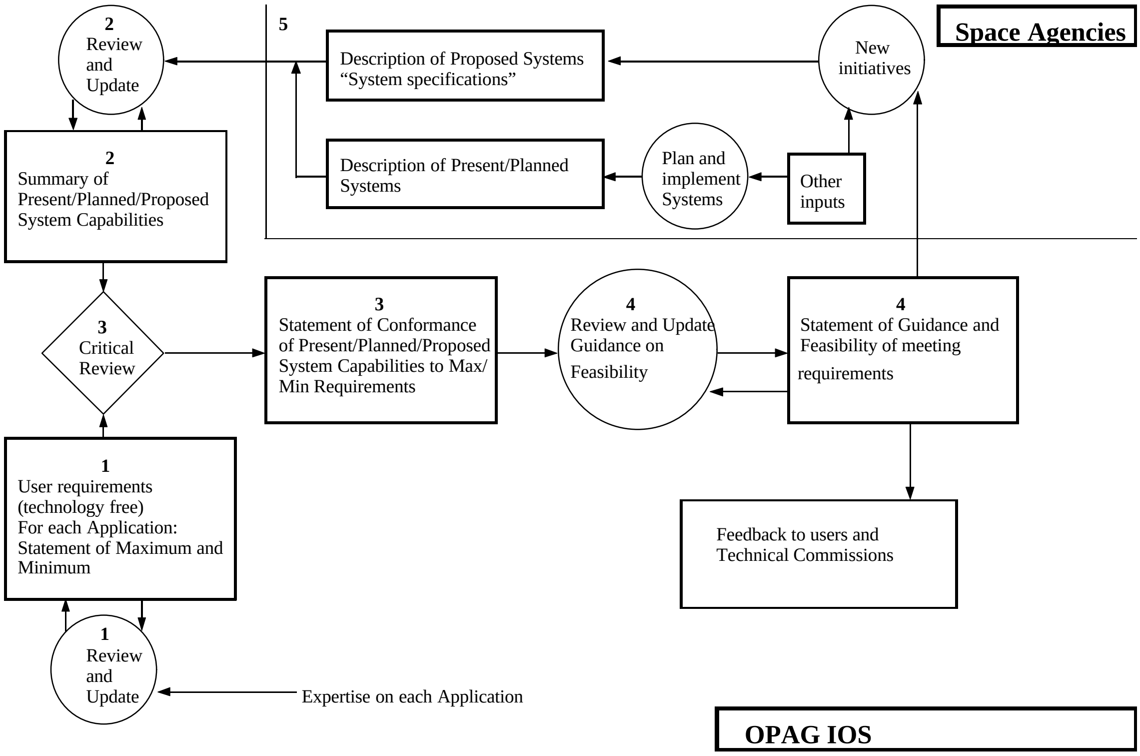

Fig. 1 - ***Scheme of the Rolling Requirements Review process.***

So far, the ET-ODRRGOS has only dealt with the following applications, so-called "WMO-proper":

- Global Numerical Weather Prediction
- Regional Numerical Weather Prediction
- Synoptic Meteorology
- Nowcasting
- Agricultural Meteorology
- Hydrology
- Atmospheric Chemistry.

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[3] WMO/TD No. 992 - Statement of Guidance regarding how well satellite capabilities meet user requirements in several application areas - SAT-22 dated 2000.

For CGMS comfort, the detailed requirements from these seven applications, from the CEOS/WMO Database as appearing on Internet[4] on July 2000, are reported in ***Appendix, Table A1*** (split in 6 sheets, the last being devoted to Atmospheric Chemistry). It could be noted that the data set is rather well structured, though a few inconsistencies and gaps are still present. For climate, the situation at this time is somewhat less consolidated. ***Appendix, Table A2*** (split in 9 sheets) is extracted from the same CEOS/WMO Database by selecting the requirements from GCOS, GOOS, GTOS and WCRP. Requirements are spread according to the following eleven sources:

- GCOS AOPC (Atmosphere Observation Panel for Climate)
- GOOS Climate large-scale
- GOOS Climate meso-scale
- GOOS Marine biology (open ocean)
- GOOS Marine biology (coastal water)
- GTOS Terrestrial climate
- WCRP Global modelling
- WCRP SPARC (Stratospheric Processes and their Role in Climate)
- WCRP GEWEX (Global Energy and Water Cycle Experiment)
- WCRP ACSYS (Arctic Climate System Study)
- WCRP CLIVAR (Climate Variability and Predictability).

The detailed considerations in the "Statement of Guidance", issue 2000, will probably be reported to CGMS under a different document. They only refer to the seven WMO-proper applications, at present. Account of the Statement of Guidance will be taken under Section 4 (*Evolution of compliance level with GOS-proper development*). For climate, an authoritative source of guidance such as ET-ODRRGOS has not yet operated, thus, for the purpose of Section 4, the assessment of compliance level stays with the Author. Looking at Appendix, Table A2, it is clear that, for practical purposes, it would be extremely useful to extract a sub-set of requirements to be incorporated in the WMO-proper set (consistently with the existence of the WMO World Climate Programme led by the Commission of Atmospheric Science).

3. Perspective evolution of GOS-proper

In order to evaluate the evolving level of compliance of evolving GOS-proper with requirements (assumed to remain reasonably stable), it is necessary to refer to different timeframes, as follows.

Near future (< 2009) - The satellite-based component of GOS in this period is fully defined, since it is unlikely that any new development not yet announced and already undertaken can come to operations before, say, 2009. Thus, GOS-proper is implemented by:

- in geostationary orbit: GOES, MSG, MTSAT, FY-2, GOMS, INSAT, for essentially an imagery mission, with some pseudo-sounding capability on MSG and coarse-resolution sounding on GOES; and GERB on MSG;
- in polar orbit: NOAA, Meteor, FY-1 and, after a while, METOP, essentially for imagery and sounding, with extension to ozone and some other species (GOME, SBUV, IASI) and to sea-surface wind (ASCAT).

Mid-term future (2009-2015) - The main event which should produce a step improvement of the GOS-proper service is the replacement of NOAA with NPOESS and, on a regional basis, the upgrading of GOES. The addition of further (small) satellites could be envisaged. In detail:

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[4] Site http://www.wmo.ch, then "Satellite activities", then "Online database information", then "Satellite systems and data requirements information (CEOS/WMO database)", then "Observational requirements", then "WMO".

- if the presently announced NPOESS instruments are confirmed, the sounding mission will improve the IR component to a IASI-like level (CrIS[5]), and redesign the MW component to increase performances (ATMS[6]). The new imager (VIIRS[7]) will be extended to 20 channels, to improve the quality of all ocean/land/atmosphere observations from medium-resolution VIS/IR imagery. A MW imager, CMIS[8], will introduce MW imagery in the operational GOS environment: it will provide sea-surface wind (both speed and direction, by multi-polarisation, to replace radar scatterometer) as well as the traditional MW measurements on ice, precipitation, liquid water, etc.. There will be an instrument for ozone and a number of other species (OMPS[9]), an ERB instrument (CERES[10]) coupled to a solar irradiance monitor (TSIS[11]) and a radio-occultation sounder (GPSOS[12]). Data collection & location, space environment monitoring, search & rescue, will continue to be provided;
- the main GOES envisaged upgrade will be a high-vertical-resolution IR sounder. The imager also is proposed to be upgraded to 10 channels, with improved resolution. Additional up-gradings have been proposed, first of all MW/Sub-mm wave sounding, either as additional payload, or as a dedicated small satellite attached to GOES. Greatly improved sounding by an imaging interferometer (GIFTS[13]) also is being studied within the New Millennium Programme;
- a number of additional missions based on small-size satellites, or micro/mini-satellites[14] in constellation, could be considered, to fill specific gaps in critical areas of operational interest. A small list could be (including those identified in doc. CGMS-XXVII/EUM-WP-06):
    - a SmallSat in polar orbit for clouds, aerosol, radiation and precipitation
    - a SmallSat in polar orbit for large-scale ocean salinity and soil moisture
    - a constellation of micro/mini-satellites to perform those observations which, for one or another reason (poor coverage due to lack of scanning capability; strong dependence of the parameter to be observed from the diurnal cycle; …) benefit from a constellation concept.

  It is desirable that developmental space agencies help CGMS by prototyping these possible elements of GOS-proper.

Long-term future (> 2015) - The characterising events are the replacement of the MSG series in the Meteosat Programme, and of the METOP series in the EPS programme. Consistently with the vision expressed in doc. CGMS-XXVII/EUM-WP-06, it is assumed that the mission of the (large) METOP satellite is extended and implemented by spreading the total load over smaller units. The possible scenario would be:

- in geostationary orbit, all satellites upgraded to GOES-next level, i.e. with frequent high-vertical-resolution sounding and faster imagery;
- in polar orbit, NPOESS continuation, and replacement of METOP in the EPS programme by a medium-size satellite mostly dedicated to temperature/humidity/ozone sounding, basic imagery and total columns of a few key trace gases;
- a number of SmallSat's: the same already demonstrated in the mid-term period (for clouds-aerosol-radiation-precipitation, for ocean salinity and soil moisture, for measurements requiring a constellation) plus (if it could be demonstrated) one for clear-air wind profile by Doppler lidar or another technique.

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[5] CrIS = Cross-track IR Sounder.
[6] ATMS = Advanced Technology MW Sounder.
[7] VIIRS = Visible/Infrared Imager Radiometer Suite.
[8] CMIS = Conical MW Imager/Sounder.
[9] OMPS = Ozone Mapper/Profiler Suite.
[10] CERES = Clouds and Earth's Radiant Energy System.
[11] TSIS = Solar Irradiance Sensor.
[12] GPSOS = GPS Occultation Sensor.
[13] GIFT = Geostationary Imaging Fourier Transform Spectrometer.
[14] Definitions: nanosat < 10 kg; microsat 10-100 kg; minisat 100-500 kg; smallsat 500-1000 kg; mediumsat 1-2 tons.

4. Evolution of compliance level with GOS-proper development

The assessment of the compliance level of GOS-proper services with requirements has been carried out with great detail. However, only a brutal synthesis of results is reported here, specifically summarised in ***Table 1.*** The approach is by geophysical parameters, all those appearing in the Appendix, i.e. relative to the seven WMO-proper list (Table A1) and to the eleven GCOS/GOOS/GTOS/WCRP entries (Table A2). Some parameters with identical requirement figures have been associated in the same box. When reading Table 1, a basic finding of this document, the following *caveats* should be kept in mind:

- the "statement of guidance" following the RRR exercise (WMO document SAT-22) covers a large number of parameters, but not all (climatology has not yet been considered); the missing fields have been filled by the Author, by in-depth analysis but not so authoritative;
- in general, the compliance levels quoted in Table 1 seem less optimistic than those quoted in SAT-22, particularly as the near future (< 2009) is concerned. The reasons are:
    - in Table 1, the compliance level is quoted integrating over all seven applications (actually 7 distinct tables should have been more appropriate); obviously, the systematic lack of compliance for small-scale applications has weighted unfavourably;
    - in SAT-22 a strict limitation to what, in this document, has been defined as "GOS-proper" has not been applied; i.e., the sources of information considered as available are more numerous than in this document. In this document, the need to use data from systems outside GOS-proper (e.g., DMSP, EOS …) will be derived as a result of the existence of gaps in GOS-proper;
    - in the near-future period, certain capabilities of 4-D assimilation models which have been assumed in SAT-22 might not yet be fully available. Also, the launch dates of certain satellites have been shifted, thus the average service performance in the period has decreased;
- the level of compliance is not the most important message from Table 1. The real purpose of Table 1 is to emphasise:
    - the trends of increasing compliance with time, identifying the event that causes the improvement (which also implies indication of what is necessary to happen to actually increase compliance);
    - the fact that a number of parameters will never be observed within GOS-proper; and others will be defective until GOS-proper is fully developed: therefore, acquisition of data from non-GOS-proper programmes is necessary on either interim or permanent basis.

  These two aspects will be better focused in the next two Sections.

Table 1 - Evolving coverage of requirements by GOS-proper and reasons of improvements

Compliance code	Insignificant	Poor	Fair	Good	Excellent
	⬜	🟨	🟩	🟦	🟥

Required geophysical parameter	**< 2009**	**2009-2015**	**> 2015**
Temperature profile (stratosphere)	🟨	🟩 CrIS on NPOESS; radio-occultation constellation.	🟩
Temperature profile (troposphere)	🟩	🟦	🟥 Sounding on GEO's.
Humidity profile (troposphere)	🟨	🟩	🟦
Wind profile (troposphere)	🟨	🟨	🟦 Frequent sounding on GEO's; Doppler lidar.
Wind profile (stratosphere)	⬜	⬜	🟨
Cloud water profile (troposphere)	🟨	🟦 CMIS on NPOESS; CLOUDS sat.	🟦
Cloud ice profile (troposphere)	⬜	🟦 CLOUDS sat.	🟦
Cloud ice profile (stratosphere)	⬜	⬜	⬜
Aerosol profile (troposphere)	🟨	🟦 VIIRS on POESS; CLOUDS sat.	🟦
Aerosol profile (stratosphere)	⬜	⬜	⬜
Ozone profile	🟩	🟦 CrIS and OMPS on NPOESS.	🟥 Sounding on GEO's.
Trace gases other than ozone (total columns)	🟨	🟩 OMPS on NPOESS.	🟩
Trace gases other than ozone (profiles)	⬜	⬜	⬜
Cloud pattern, cover, type, top temperature	🟩	🟦 VIIRS on NPOESS; CLOUDS sat.	🟥 Upgraded GEO's.
Cloud top height	🟨	🟩	🟥
Cloud base height	⬜	⬜	⬜
Atmospheric instability indexes	🟨	🟩 CrIS on NPOESS; radio-occultation constellation.	🟥 Sounding on GEO's.
Tropopause height and temperature	🟨	🟦	🟥
Height of planetary boundary layer	⬜	🟨	🟩
Cloud optical thickness	🟨	🟦	🟦
Cloud drop size (at cloud top)	🟨	🟩 VIIRS on NPOESS; CLOUDS sat.	🟩
Aerosol size (average on total column)	⬜	🟩	🟩
Solar irradiance at TOA	⬜	🟥 TSIS on NPOESS.	🟥
Short-wave outgoing radiation at TOA	🟨	🟩 CERES on NPOESS; CLOUDS sat; ERB on constellation.	🟦 ERB on all GEO's.
Long-wave outgoing radiation at TOA	🟩	🟦	🟥
Short-wave Earth surface radiation	🟨	🟩	🟦
Long-wave Earth surface radiation	🟩	🟦 VIIRS on NPOESS; CLOUDS sat.	🟥 Upgraded GEO's.
Short-wave Earth surface reflectance	🟨	🟩	🟦
Long-wave Earth surface emissivity	🟩	🟦	🟥
Precipitation rate at the ground	⬜	🟩 CMIS on NPOESS; CLOUDS sat; lightning mapper in constellation.	🟦 Frequent sounding on GEO's.
Precipitation index (daily cumulative)	🟨	🟦	🟥
Surface wind (over sea)	🟩	🟦 CMIS on NPOESS; CLOUDS sat.	🟦
Sea surface temperature	🟩	🟦 VIIRS/CMIS on NPOESS. CLOUDS	🟥 Sounding on GEO's.
Significant wave height	⬜	🟩 Mini-altimeter on constellation.	🟩
Dominant wave period and direction	⬜	⬜	⬜
Ocean chlorophyll, suspended sediments, yellow matter	⬜	🟥 VIIRS on NPOESS.	🟥
Ocean salinity	⬜	🟦 Low-frequency MW sat.	🟦
Geoid	⬜	⬜	⬜
Sea level / ocean topography	⬜	⬜	⬜
Sea-ice cover and surface temperature	🟩	🟦 CMIS on NPOESS; CLOUDS sat.	🟦
Ice thickness and sheet topography	⬜	⬜	⬜
Icebergs (extension and height)	🟨	🟩 VIIRS and CMIS on NPOESS; CLOUDS sat.	🟩
Glacier cover	🟨	🟩	🟩
Snow cover and melting conditions	🟩	🟦	🟦
Snow depth and water equivalent	⬜	⬜	⬜
Land surface temperature, permafrost	🟨	🟩 VIIRS on NPOESS.	🟦 Upgraded GEO's.
Soil moisture	⬜	🟦 Low-frequency MW sat.	🟦
Normalized Difference Vegetation Index (NDVI)	🟦	🟥	🟥
Leaf Area Index (LAI) and hydric stress indexes	🟨	🟦 VIIRS on NPOESS; CLOUDS sat.	🟦
Photosynthetically Active Radiation (PAR), Fractional PAR	🟨	🟦	🟦
Fires (extension and temperature)	🟨	🟩 VIIRS on NPOESS.	🟦 Upgraded GEO's.
Land cover and use; soil type, vegetation type	⬜	⬜	⬜
Land surface topography	⬜	⬜	⬜

5. Required developments to extend GOS-proper to full strength

In Table 1, it was postulated that the level of compliance of GOS-proper with requirements will improve in future. However, the only improved elements of GOS-proper so far planned are NPOESS and GOES-next, both to be launched around 2009. One main purpose of this document is to make progress with identifying other developments to be pursued in order to have GOS-proper deployed to full strength, say, in the > 2015 timeframe. These are better focused in ***Table 2*** and will be the subject of further Sections. The Table reports, for each system to upgrade or to add, the parameters which would have improved quality. Also, the type of suitable instrumentation is mentioned. The additional systems are recommended to be an integral part of GOS-proper for one or another reason, such as:

- they address parameters of such an operational nature (specifically in the areas of weather prediction and climate monitoring) as to be unlikely to attract the interest of science-oriented space agencies;
- anyway, long-term continuity within a conservative technological context is required, which again in inappropriate to developmental space agencies (except for the initial demonstration phase);
- requirements for meteo-climatic usage are too different (either more severe or more relaxed) from what is needed by other user communities or for science (e.g., process studies);
- data have so high priority in operational meteo-climatology that programme management cannot be delegated to non-CGMS entities.

A very welcome contribution from developmental space agencies in implementing the programmes listed in Table 2 would be in the areas of developing the prototypes of the SmallSat's to be followed by operational series.

Table 2 - Required developments to extend GOS-proper to full strength

(Background ≤ 2015: GOES, MSG, MTSAT, GOMS, F-2, INSAT, NOAA/NPOESS, METOP, METEOR, FY-1. >2015: NPOESS)

System	Improved parameters	Instrumentation
All GEO's upgraded (> 2015)	Temperature, humidity, wind, ozone profiles. Cloud pattern, cover, type, top temperature and height. Atmospheric instability index, tropopause height and temperature, height of PBL. Short- and long-wave outgoing radiation at TOA. Earth surface short-wave radiation/reflectance, long-wave radiation/emissivity. Precipitation rate, precipitation index. Sea-surface temperature, land surface temperature, permafrost, fires.	Frequent-sounding spectrometer, fast imager, ERB radiometer.
SmallSat (CLOUDS) (> 2008)	Cloud pattern, cover, type, top temperature, height, optical thickness, drop size. Cloud water, cloud ice and aerosol profiles; aerosol size. Short- and long-wave outgoing radiation at TOA. Earth surface short-wave radiation/reflectance, long-wave radiation/emissivity. Precipitation rate, precipitation index. Sea-surface wind and temperature, sea-ice cover and surface temperature. Icebergs, glacier cover, snow cover and melting conditions. NDVI, LAI, PAR, FPAR, hydric stress indexes.	Imagers covering UV, VIS, NIR, SWIR, TIR, FIR, Sub-mm, MW, with multi-polarisation and multi-viewing.
SmallSat (> 2008)	Ocean salinity.(large scale) Soil moisture.(large scale)	Low-frequency MW radiometer.
Mini-satellites constellation (> 2008)	Temperature/humidity profile, instability index, heights of tropopause and PBL. Short- and long- wave outgoing radiation at TOA. Precipitation rate, precipitation index. Significant wave height.	Radio-occultation. ERB radiometer. Lightning mapper. Mini-altimeter.
SmallSat (> 2015)	Wind profile.	Follow-on of Doppler lidar exp.
MediumSat (post-METOP) (> 2015)	Temperature, humidity and ozone profiles; total columns of key trace gases. Cloud pattern, cover, type, top temperature and height.. Sea/land/ice surface temperatures, sea-ice cover, icebergs, NDVI, fires.	IR/MW sounder. SW spectrometer. VIS/IR imager.

6. Role of non-GOS-proper programmes to fulfil meteo-climatic requirements

One indication from Table 1 is that certain parameters are not likely to be ever observed by GOS-proper satellites, for one or another reason, such as:

- the required instrumentation is so large (e.g., high-resolution imagers, geodetic-class altimeters, SAR, …) that it cannot be reasonably added to the (already too large) multi-purpose satellites (NPOESS or METOP-like), nor flown as an additional SmallSat;
- there are other user communities (e.g., oceanographers, land observation users, …) which are more entitled to set requirements and more motivated to establish systems (this reason is particularly strong in case these other communities have actually established systems of relatively reliable continuity; e.g., Landsat, SPOT, Radarsat, a possible Topex-Poseidon follow-on, …);
- either the instrumentation or the user requirements, or both, are of evolutionary nature (e.g., in the area of atmospheric chemistry) so as not to comply with the long-term continuity characteristics appropriate to GOS-proper. This class includes short-duration missions for process studies.

Table 2 lists the parameters which, rather than being measured within GOS-proper, could better be acquired through cooperation with programmes of scientific or technological or commercial nature, or addressing applications driven by other user communities. The Table also indicates the need to complement GOS-proper in the short-term (say, < 2009) waiting for GOS-proper being fully developed. Cooperation is also sought to improve the quality of GOS-proper data when not fully satisfactory.

Table 3 - Requirements possible to be fulfilled by cooperation with non-GOS-proper programmes

Parameters	Timeframe	Required information
Temperature and humidity profiles	< 2009	High vertical resolution profiles in the lower atmosphere (cross-nadir spectrometers)
	Permanent	Good quality profiles in the higher atmosphere (by limb sounding)
Wind profile	< 2009	Data from early Doppler lidar experiments for evalution
	Permanent	Data from further missions (Doppler lidar or other technique) if SmallSat unfeasible
Cloud ice, liquid water, aerosol profiles	< 2009	Data from cloud radar and backscatter lidar to improve modelling/parameterisation
	Permanent	Ice and aerosol profiles in the higher atmosphere (by limb sounding)
Ozone and other trace gases	< 2009	Profiles of ozone and other few species, and total columns of all other required ones
	Permanent	High vertical resolution ozone and profiles of all other required species
Clouds and discontinuities	< 2009	Cloud top height (direct determination), optical thickness, drop size
	Permanent	Data from radar and backscatter lidar for heights of cloud top and PBL, cloud base
TOA and Earth surface radiation	< 2009	Broad and narrow-band radiometers with multi-viewing capability
	Permanent	Radiometers from any platform in different orbits to deal with sampling problem
Precipitation	< 2009	Large-antenna MW images. Rain radar to improve modelling and parameterisation
	Permanent	Data from missions carrying rain radar (for calibration purposes)
Sea-surface wind, temperature, waves	< 2009	Wind from scatterometers and MW imagers. Accurate sea-surface temperatures
	Permanent	Wave height from radar altimeters and spectra from SAR
Ocean colour, sea-level, geoid	< 2009	Ocean colour data to derive chlorophyll, suspended sediments, yellow matter
	Permanent	Sea-level/topography from radar altimeter. Geoid from gravity missions
Ocean salinity, soil moisture	< 2009	Data from low-frequency MW radiometers for evaluation
	Permanent	Data from further missions (including SAR) if SmallSat unfeasible
Sea-ice cover, iceberg extension, snow cover	< 2009	Large-antenna MW imagery
	Permanent	SAR imagery
Ice thickness, glaciers, iceberg height, snow depth/water equivalent	Permanent	Geodetic-class radar/lidar altimetry and SAR imagery/interferometry
Land temperature, permafrost, NDVI, LAI, PAR, FPAR	< 2009	Medium-resolution optical imagery
Land cover, use, type, surface topography; vegetation type	Permanent	High-resolution optical imagery and SAR imagery/interferometry

7. Concepts to upgrade geostationary satellites

Table 1 shows very clearly that, before GOS-proper reaches full strength, the series of geostationary satellites around the equator must be upgraded. The driving requirements for this are:

- WMO requirements (see Appendix/Table A1) call for 1 h observing cycle for temperature/humidity sounding as “target” for Global NWP and “threshold” for Nowcasting;
- frequent temperature/humidity sounding is not only for describing the mass field: 4-D assimilation of frequent sounding also allows to infer wind profile, which is difficult to be measured directly in all conditions and at all required levels; and precipitation, which also is problematic as a direct observation (and probably of little prognostic value as compared with what could be retrieved as a balance with the other fields of high prognostic value);
- images frequency must be dramatically increased (say, to 1-min level) to improve the accuracy of trace-motion derived winds to what is required (say, 1 m/s), and also to better monitor cloud development and growth rate of water vapour;
- Earth Radiation Budget from geostationary is extremely effective to account for the diurnal cycle;
- a few surface parameters (e.g., temperature of land and sea in coastal waters, land radiative parameters conditioned to the diurnal cycle) also need frequent observation.

One concept of advanced geostationary satellite was introduced in doc. CGMS-XXVII/EUM-WP-06. It was based on two instruments:

- an IR sounding interferometer for high-vertical resolution temperature/humidity sounding at 1-hour intervals over the whole Earth disk (resolution: 12 km, image-mode scanning); attached broad-band channels for ERB and narrow-band short-wave channels for surface radiative parameters;
- a VIS/IR imager for rapid scanning (1 min, resolution 1 km in VIS and 3 km in IR), with a small number of channels (VIS, WV and IR).

Table 4 lists the products achievable by this sort of Advanced Geostationary Satellite (AGS).

Table 4 - Expected products from an Advanced Geostationary Satellite

Geophysical parameter	Hor. resolution	Ver. resolution	Accuracy	Cycle
Temperature profile	50 km	1 km	1 K	1 h
Humidity profile	50 km	1 km	10 %	1 h
Cloud detection and monitoring	3 km	n/a	n/a	1 min
Mid-troposphere water vapour growth	3 km	n/a	n/a	1 min
Wind profile (by 1-min imagery)	100 km	3 km	1 m/s	1 h
Ozone profile	50 km	2 km	10 %	1 h
Tropopause evolution (from total ozone)	12 km	n/a	n/a	1 h
Atmospheric instability index	50 km	n/a	16 classes	1 h
Cloud cover	100 km	n/a	1 %	1 h
Cloud type	12 km	n/a	8 classes	1 h
Cloud top temperature	12 km	n/a	1 K	1 h
Cloud top height	12 km	n/a	0.5 km	1 h
Cloud optical thickness	12 km	n/a	10 %	1 h
Precipitation at ground (index)	12 km	n/a	8 classes	1 h
Short-wave radiation at TOA	50 km	n/a	0.5 W/m^2	1 h
Long-wave radiation at TOA	50 km	n/a	0.5 W/m^2	1 h
Sea surface temperature	12 km	n/a	0.5 K	1 h
Land surface temperature	12 km	n/a	2 K	1 h
Vegetation index	12 km	n/a	2 %	1 h
Thermal inertia (to infer soil moisture)	12 km	n/a	1 K^{-1}	1 h
Wind profile and precipitation rate	from 4-D assimilation - data quality unspecified			

At CGMS-XXVII instrument and system concepts were shown, as well as a satellite sketch (***Fig. 2***).

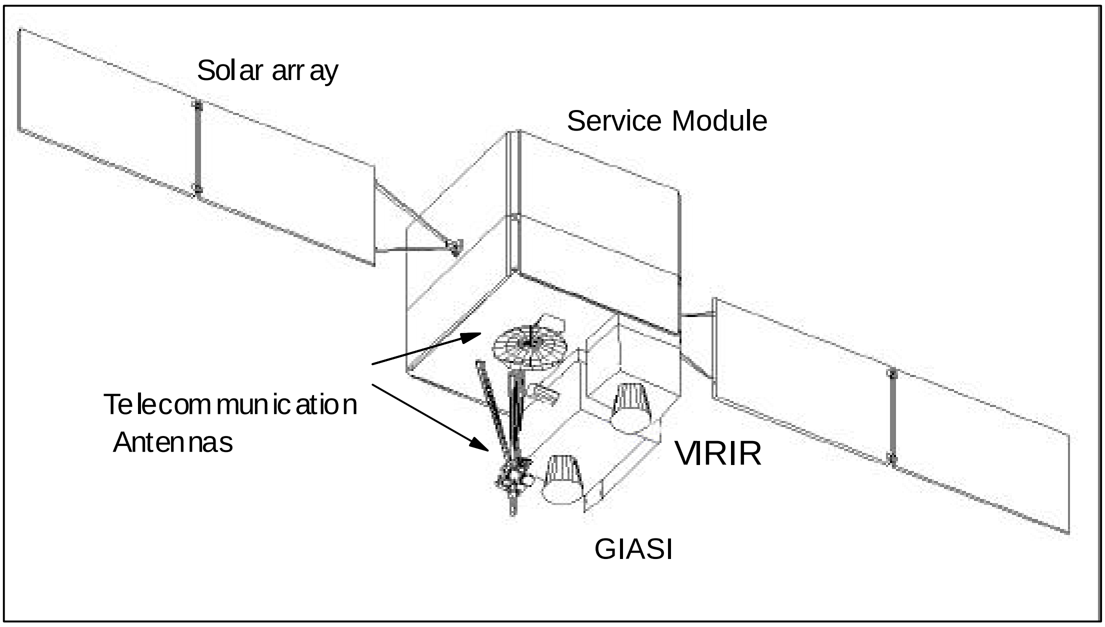

Fig. 2 - ***Sketch view of an Advanced Geostationary Satellite.***

Size comparison with MSG and GOES is as follows:

- AGS - payload mass: 180 kg, dry mass: 530 kg, mass at launch: 950 kg, power: 650 W
- MSG - payload mass: 281 kg, dry mass: 1074 kg, mass at launch: 2042 kg, power: 800 W
- GOES - payload mass: 298 kg, dry mass: 977 kg, mass at launch: 2105 kg, power: 1100 W.

The driving concept of the AGS sounder, GIASI[15] is that, if there is a high-vertical resolution frequent sounder with attached a number of opportunity channels, most quantitative products presently derived from multi-channel imagers (see, for instance, MSG/SEVIRI with 12 channels) could better be derived from the sounder, thus enabling great simplification of the imager (VIRIR[16]) so that the requirement for very-frequent image cycle and improved resolution as necessary for improved winds can be implemented without dramatically growing instrument size and data rates.

In the present concept for GOES-next (2008) the sounder, ABS[17], is very similar to GIASI (except for the opportunity channels), but also the imager, ABI[18] is improved in respect of spectral information (10 channels against 5 of the present GOES Imager), and the improvement in frequency is limited to 5 min. The horizontal resolution would be 0.5 km in VIS and 2 km in IR. To be noted that these upgrades could be accommodated without having to change the basic GOES platform, which offers comfortable margins for mission growth.

Another approach, combining the sounding and imaging capabilities, is going to be experienced in 2004 with GIFTS (Geostationary Imaging Fourier Transform Spectrometer), a mission of the US New Millennium Programme. Spectrally speaking, GIFTS is a sounding interferometer similar to GIASI and ABS (except for a gap between 6.0 and 8.8 μm), but the horizontal resolution is 4 km (1 km in VIS), as in the current GOES Imager. This would, i.a., enable tracking water-vapour features at several levels for clear-air wind profiling. The instrument is operated in several modes, to enhance one or another application. When focusing on cloud imagery, the spectral resolution is reduced to 50 cm^{-1} and images

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[15] GIASI = Geostationary IASI - IASI = Infrared Atmospheric Sounding Interferometer.

[16] VIRIR = Visible-Infrared Rapid-Imaging Radiometer.

[17] ABS = Advanced Baseline Sounder.

[18] ABI = Advanced Baseline Imager.

are taken at 5 min intervals. For sounding, the spectral resolution is either 15 cm^{-1} each 10 min (gross vertical resolution and disk coverage) or 0.625 cm^{-1} each 30 min (high vertical resolution and regional coverage). There is also a "chemistry" mode with horizontal resolution 16 km, spectral resolution 0.25 cm^{-1}, each 60 min (sub-regional coverage). Clearly, GIFTS requires a rather large platform. It is unlikely to become a true operational instrument, but it should provide invaluable contribution to the definition of an operational instrument for the long-term future.

One obvious thought when thinking to sounding from geostationary is the use of MW, to enable sounding in cloudy conditions, and also to appreciate precipitation. Unfortunately, from geostationary height, the law of diffraction implies that large antennas are necessary to achieve reasonable resolution. For instance, sounding at 57 GHz with 30 km resolution would require about 8-m antenna diameter. To reduce antenna size, use of higher frequencies, in the Sub-mm wave range[19], is possible. For instance, suitable frequencies would be 119 and 425 GHz for temperature, and 183 and 380 GHz for water vapour. Unfortunately, Sub-mm frequencies such as 380 and 425 GHz are nearly blind to the lower troposphere, which is a priority target for nowcasting. In addition, with increasing frequency, the sensitivity to clouds sharply increases. This is shown in ***Fig. 3***, reporting experimental results from aircraft. On the other hand, Fig. 3 suggests that, accepting that Sub-mm waves are unsuitable for true sounding, one possible (and very important) use would be for ***cloud interior sensing.***

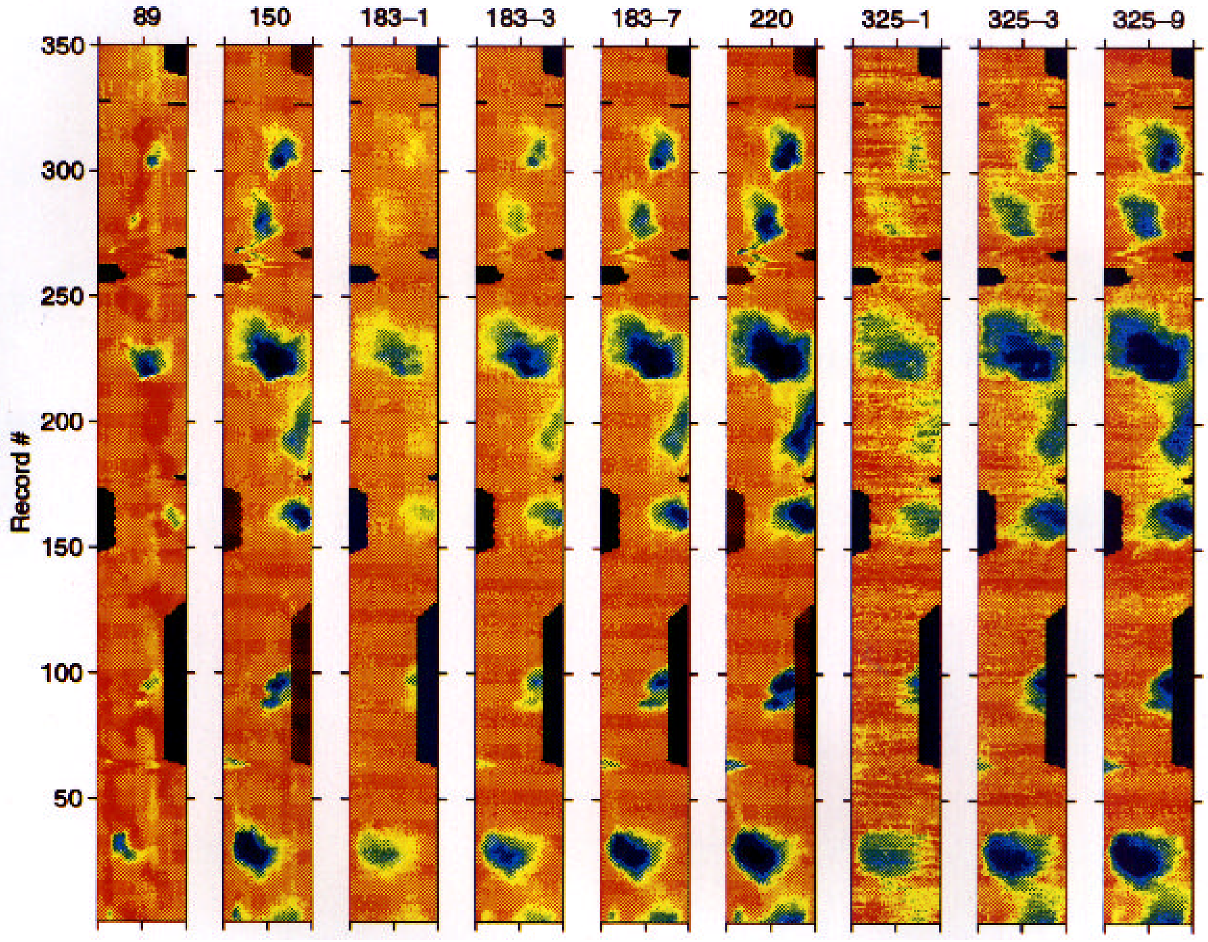

Fig. 3 - ***Strip map imagery of convective precipitation cells over ocean obtained by an airborne multi-channel radiometer. Scene size: 40 km wide x 200 km long (from Gasiewski et al, 1994, Proceedings of International Geoscience and Remote Sensing Symposium, Pasadena, Ca. August 8-12 1994, p.663-665).***

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[19] E.m. ranges used for remote sensing: UV 0.01-0.38 µm; VIS 0.38-0.78 µm; NIR 0.78-1.3 µm; SWIR 1.3-3 µm; MWIR 3-6 µm; TIR 6-15 µm; FIR 15-1000 µm (= 300 GHz); Sub-mm (part of FIR) 3000-300 GHz; MW 300-0.3 GHz.

Summing-up with MW/Sub-mm sounding from geostationary, ***Table 5*** reports the possible applications, function of the affordable antenna size. Three typical sizes are considered:

- 1 m: possible to be added to existing geostationary satellites (3-axes stabilised), e.g. GOES
- 2 m: possible to be integrated on a newly-designed (large) satellite with IR sounder and imager
- 3 m: only conceivable as a stand-alone mission (which could be not very large).

Table 5 – Possible MW/Sub-mm sounding performances, function of antenna size

Ø	**Channels/bands concerned and geometric resolution (IFOV)**	**Applications and approximate product resolution**
1 m	Windows: 340 and 400 GHz (40 km); H_2O: 380 GHz (40 km); O_2: 425 GHz (30 km).	Higher troposphere temperature/humidity sounding (40 km) Large-scale, deep convection (40 km) Cloud water phase (40 km)
2 m	Windows: 89 GHz (75 km), 150 GHz (45 km), 220 GHz (30 km), 340 and 400 GHz (20 km); H_2O: 183 GHz (40 km) and 380 GHz (20 km); O_2: 119 GHz (60 km) and 425 GHz (15 km).	Higher troposphere temperature/humidity sounding (20 km) Lower troposphere temperature/humidity sounding (50 km) Large-scale convection (30 km) Cloud water phase (20 km) and drop size (50 km)
3 m	Windows: 89 GHz (50 km), 150 GHz (30 km), 220 GHz (20 km), 340 and 400 GHz (15 km): H_2O: 183 GHz (25 km) and 380 GHz (15 km); O_2: 57 GHz (80 km), 119 GHz (40 km) and 425 GHz (10 km)	Higher troposphere temperature/humidity sounding (15 km) Lower troposphere temperature/humidity sounding (30 km) Medium-scale convection (20 km) Cloud water phase (15 km) and drop size (30 km)

The subject of MW sounding from geostationary satellite has been studied in-depth in the US by the Geosynchronous Microwave Sounder Working Group (GMSWG[20]). From the study, a proposal has been derived for a *Geostationary Microwave (GEM) Observatory* to be demonstrated within the New Millennium Programme. It is based on a 2-m antenna with frequency bands at 57, 119, 183, 380 and 425 GHz (the 57 GHz band has been included though the resolution would be 120 km). It could be a stand-alone SmallSat, associated to GOES as piggy-back.

8. SmallSat for clouds, aerosol, radiation and precipitation

It is currently considered that the limits of predictability in Numerical Weather Prediction and General Circulation Models is largely controlled by the poor description of the interaction between clouds and radiation, with the associated fields of aerosol and precipitation. At CGMS XXVII a model mission was described, *CLOUDS (a Clouds and Radiation Monitoring Mission)* aiming at providing the necessary information on routine basis by exclusively passive radiometry, complemented by multi-polarisation and more viewing geometries. The mission objectives of CLOUDS, an EC-funded study terminated in May 2000 and now submitted to ESA for consideration, imply observing:

- the ***cloud "classical" parameters*** mostly referring to the top surface, with emphasis on ice/liquid discrimination and drop size;
- the ***cloud interior***, specifically water phase (ice or liquid) and whether drop size is likely to produce precipitation;
- the ***outgoing radiation*** from the Top of Atmosphere to space;
- the main parameter impacting with both clouds and radiation in the 3-D atmosphere, i.e. ***aerosol***;
- the primary source of clouds, i.e. ***water vapour***, also primary factor of radiative processes in the 3-D atmosphere;
- the indicator of final removal of water from the atmosphere, i.e. ***precipitation***.

Table 6 lists the mission requirements for CLOUDS radiometric channels.

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[20] GMSWG members: Staelin, Kerekes, Solmann III and, in a second phase, Gasiewski and Shields.

Table 6 - Mission requirements for the CLOUDS radiometric channels

Channel	**Bandwidth (half-power)**	**Radiometric accuracy (*)**	**Absolute accuracy**	**Polarisations**	**Dual view**	**IFOV**
340 nm	6 nm	300 @ 10 % albedo	5 %	not required	required	5 km
388 nm	6 nm	300 @ 10 % albedo	5 %	not required	required	5 km
443 nm	20 nm	200 @ 10 % albedo	5 %	not required	required	5 km
555 nm	20 nm	200 @ 10 % albedo	5 %	three	required	5 km
670 nm	20 nm	200 @ 10 % albedo	5 %	three	required	5 km
865 nm	20 nm	200 @ 10 % albedo	5 %	not required	required	5 km
940 nm	50 nm	200 @ 10 % albedo	5 %	not required	required	5 km
1,240 nm	50 nm	200 @ 10 % albedo	5 %	three	required	5 km
1,375 nm	30 nm	200 @ 10 % albedo	5 %	not required	required	5 km
1,610 nm	30 nm	200 @ 10 % albedo	5 %	not required	required	5 km
3.74 µm	0.4 µm	0.10 K @ 300 K	1 K	not required	required	10 km
6.25 µm	1.0 µm	0.30 K @ 250 K	1 K	not required	required	10 km
7.35 µm	0.5 µm	0.30 K @ 250 K	1 K	not required	required	10 km
8.70 µm	0.5 µm	0.10 K @ 280 K	1 K	not required	required	10 km
9.66 µm	0.5 µm	0.30 K @ 220 K	1 K	not required	required	10 km
10.8 µm	1.0 µm	0.10 K @ 300 K	1 K	not required	required	10 km
12.0 µm	1.0 µm	0.10 K @ 300 K	1 K	not required	required	10 km
13.4 µm	0.5 µm	0.30 K @ 280 K	1 K	not required	required	10 km
18.2 µm	2.0 µm	0.50 K @ 220 K	1 K	not required	required	10 km
24.4 µm	2.0 µm	0.50 K @ 220 K	1 K	not required	required	10 km
Total short-wave	0.3-4.0 µm	0.3 W m^{-2} sr^{-1}	1.0 W m^{-2} sr^{-1}	not required	required	40 km
Total energy	0.3-100 µm	0.3 W m^{-2} sr^{-1}	0.5 W m^{-2} sr^{-1}	not required	required	40 km
$\alpha = 21^\circ$, $\zeta = 23.9^\circ$ $\alpha = 33^\circ$, $\zeta = 38.1^\circ$ $\alpha = 45^\circ$, $\zeta = 53.2^\circ$ $\alpha = 57^\circ$, $\zeta = 71.7^\circ$	0.4-1.0 µm	200 @ 10 % albedo	5 %	not required	required	5 km
874.38 ± 6.0 GHz	3.0 GHz	1.0 K @ 240 K	1.5 K	two	required	10 km
682.95 ± 6.0 GHz	3.0 GHz	1.0 K @ 240 K	1.5 K	two	required	10 km
462.94 ± 3.0 GHz	2.0 GHz	1.0 K @ 240 K	1.5 K	two	required	10 km
220.50 ± 3.0 GHz	2.0 GHz	1.0 K @ 240 K	1.5 K	two	required	10 km
183.31 ± 1.0 GHz	1.0 GHz	1.0 K @ 240 K	1.5 K	one	required	10 km
183.31 ± 3.0 GHz	2.0 GHz	1.0 K @ 260 K	1.5 K	one	required	10 km
183.31 ± 7.0 GHz	4.0 GHz	1.0 K @ 280 K	1.5 K	one	required	10 km
150 GHz	4.0 GHz	1.0 K @ 300 K	1.5 K	two	required	10 km
118.75 ± 1.0 GHz	1.0 GHz	0.5 K @ 230 K	1.5 K	one	required	10 km
118.75 ± 1.5 GHz	1.0 GHz	0.5 K @ 250 K	1.5 K	one	required	10 km
118.75 ± 2.0 GHz	1.0 GHz	0.5 K @ 270 K	1.5 K	one	required	10 km
118.75 ± 4.0 GHz	1.0 GHz	0.5 K @ 290 K	1.5 K	one	required	10 km
89.0 GHz	3.0 GHz	1.0 K @ 300 K	1.5 K	four	required	5 km
55 GHz	0.5 GHz	0.5 K @ 230 K	1.5 K	one	required	10 km
54 GHz	0.5 GHz	0.5 K @ 250 K	1.5 K	one	required	10 km
53 GHz	0.5 GHz	0.5 K @ 270 K	1.5 K	one	required	10 km
50 GHz	0.5 GHz	0.5 K @ 290 K	1.5 K	one	required	10 km
36.5 GHz	1.0 GHz	0.7 K @ 300 K	1.5 K	four	required	10 km
23.8 GHz	0.4 GHz	0.6 K @ 250 K	1.5 K	two	required	20 km
18.7 GHz	0.2 GHz	0.5 K @ 300 K	1.5 K	four	required	20 km
10.6 GHz	0.1 GHz	0.4 K @ 300 K	1.5 K	four	required	40 km
6.9 GHz	0.3 GHz	0.3 K @ 300 K	1.5 K	two	required	40 km

(*) *Radiometric accuracy* is intended as the random component of the error budget. The quoted quantities represent:

- for broad-band channels: NEΔR [W m^{-2} sr^{-1}]
- for short-wave narrow-band channels: SNR [specified at a certain scene albedo]
- for long-wave narrow-band channels: NEΔT [K specified at a certain scene temperature]

It can be seen from Table 6 that the principle of CLOUDS is to exploit a widest range of the e.m. spectrum, from 340 nm to 4.3 cm, i.e. spanning over five orders-of-magnitude ! This is shown in ***Fig. 4***.

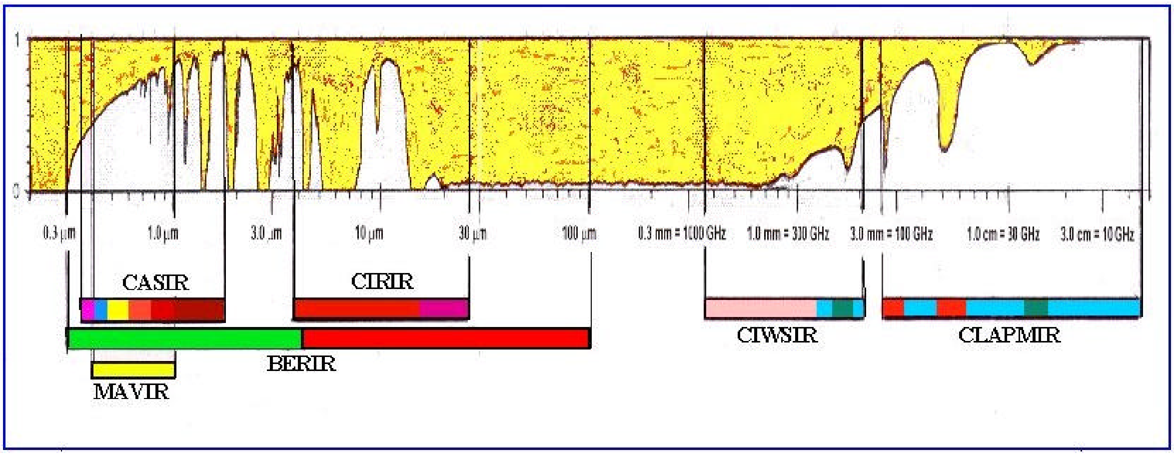

Fig. 4 - ***Spectral coverage of the six instruments defined for the CLOUDS mission***

The satellite would follow METOP in orbit, 30 min dephased. ***Fig. 5*** shows a CLOUDS sketch view. It is noted that the four optical instruments are integrated in a single package (*CIOP, CLOUDS Integrated Optical Payload*; the other instruments are: *CLAPMIR, Cloud Liquid-water And Precipitation MW Imaging Radiometer* and *CIWSIR, Cloud Ice and Water-vapour Sub-mm Imaging Radiometer*). According to the study carried out for the EC, the main sizing parameters of CLOUDS are estimated as:

- mass: ~ 900 kg; power: ~ 1600 W; direct data (S-band): 1.1 Mbps; global data (X-band): 30 Mbps.

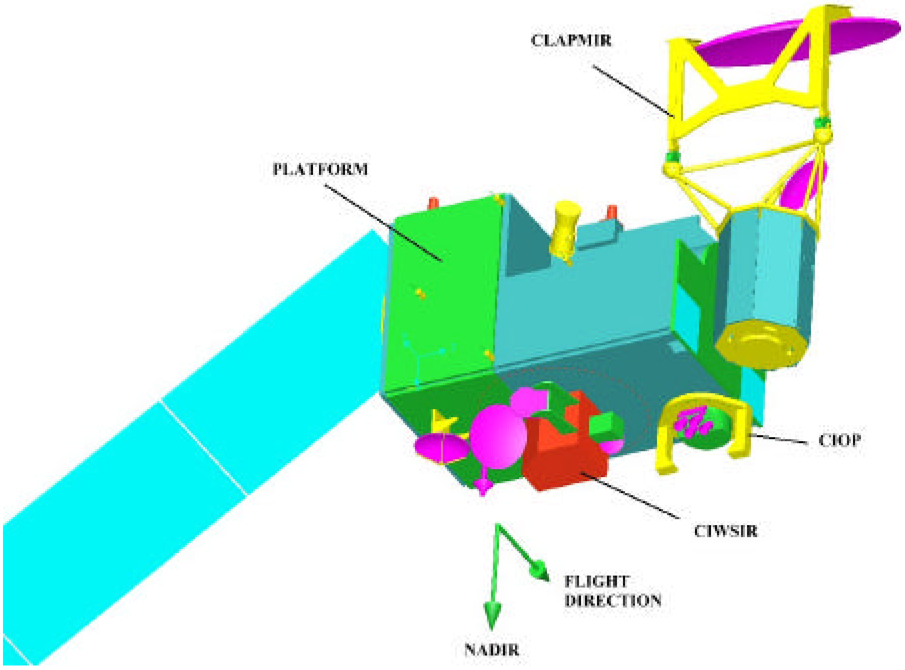

Fig. 5 - ***Sketch view of the CLOUDS satellite***

The list of products from CLOUDS is reported in ***Table 7.*** Very detailed information on the mission objectives and requirements, and on the industrial feasibility study are available from the Web[21].

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[21] ftp://romatm9.phys.uniroma1.it/pub/clouds/report.

Table 7 - Expected products from the CLOUDS mission

Geophysical parameter	Horizontal resolution	Vertical resolution	Accuracy (r.m.s.)	Observing cycle	Delay of availability	Confidence level
B A S I C (mostly from CLOUDS)						
Cloud water (< 100 μm) total column	40 km	N/A	1 g/m^2	24 h	3 h	expected
Cloud water (< 100 μm) profile	40 km	3 km	20 %	24 h	3 h	potential
Cloud water (> 100 μm) total column	40 km	N/A	1 g/m^2	24 h	3 h	expected
Cloud water (> 100 μm) profile	40 km	3 km	20 %	24 h	3 h	potential
Cloud ice total column	40 km	N/A	0.1 g/m^2	24 h	3 h	expected
Cloud ice profile	40 km	3 km	30 %	24 h	3 h	speculative
Cloud drop size (at cloud top)	40 km	N/A	2 μm	48 h	3 d	speculative
Cloud ice content (at cloud top)	40 km	N/A	10 %	24 h	3 h	expected
Cloud optical thickness	40 km	N/A	10 %	48 h	3 d	expected
Water vapour total column	20 km	N/A	100 g/m^2	24 h	3 h	demonstrated
Precipitation rate at the ground	10 km	N/A	1 mm/h	24 h	3 h	demonstrated
Precipitation index (daily cumulative)	60 km	N/A	1 mm/d	24 h	3 h	expected
Short-wave outgoing radiation at TOA	20 km	N/A	3 W/m^2	48 h	3 d	demonstrated
Long-wave outgoing radiation at TOA	20 km	N/A	2 W/m^2	24 h	3 d	demonstrated
Aerosol total column	40 km	N/A	10 %	48 h	3 h	expected
Aerosol profile	40 km	3 km	10 %	48 h	3 h	expected
Short-wave cloud reflectance	40 km	N/A	5 %	48 h	3 d	demonstrated
Long-wave cloud emissivity	40 km	N/A	1 %	24 h	3 d	demonstrated
B A S I C (also available from METOP)						
Cloud imagery	5 km	N/A	N/A	24 h	3 h	demonstrated
Cloud type	40 km	N/A	0.1 classes^{-1}	24 h	3 h	demonstrated
Cloud cover	40 km	N/A	5 %	24 h	3 h	demonstrated
Cloud top height	40 km	N/A	0.5 km	24 h	3 h	demonstrated
Cloud top temperature	40 km	N/A	1 K	24 h	3 h	demonstrated
SUPPORT TO BASIC						
Temperature profile	20 km	3 km	3 K	24 h	3 h	demonstrated
Relative humidity profile	20 km	3 km	10 %	24 h	3 h	demonstrated
Ozone total column	40 km	N/A	30 DU	24 h	3 h	demonstrated
ADDITIONAL						
Wind over sea surface	20 km	N/A	3 m/s	24 h	3 h	expected
Sea surface temperature	80 km	N/A	1 K	24 h	3 h	expected
Ice/snow imagery	5 km	N/A	N/A	24 h	3 h	demonstrated
Sea-ice cover	40 km	N/A	5 %	24 h	3 h	demonstrated
Sea-ice type	40 km	N/A	0.5 classes^{-1}	24 h	3 h	demonstrated
Icebergs	5 km	N/A	100 %	24 h	3 h	expected
Snow cover	40 km	N/A	10 %	24 h	3 h	demonstrated
Snow melting conditions	40 km	N/A	0.3 classes^{-1}	24 h	3 h	demonstrated
Short-wave Earth surface radiation	40 km	N/A	10 W/m^2	48 h	3 h	expected
Long-wave Earth surface radiation	80 km	N/A	10 W/m^2	24 h	3 h	expected
Land surface temperature	80 km	N/A	3 K	24 h	3 h	expected
Soil moisture	60 km	N/A	20 g/kg	24 h	3 h	potential
Apparent Thermal Inertia (ATI)	80 km	N/A	1 K^{-1}	48 h	3 h	demonstrated
Normalised Difference Vegetation Index (NDVI)	40 km	N/A	5 %	48 h	3 h	expected
Photosynthetically Active Radiation (PAR)	40 km	N/A	10 W/m^2	48 h	3 h	demonstrated
Fractional PAR (FPAR)	40 km	N/A	5 %	48 h	3 h	expected
Leaf Area Index (LAI)	40 km	N/A	10 %	48 h	3 h	potential

It is noted that the "additional" products, i.e. those not part of the primary objective of the (atmospheric) CLOUDS mission, cover very important ocean, ice and land parameters.

9. SmallSat for ocean salinity and soil moisture

One next major limiting factor for long-term NWP and GCM, is the lack of information necessary to describe fluxes through the PBL. Many surface measurements are or will be provided by GOS-proper satellites in the near or mid-term future, other ones could be acquired from non-GOS-proper programmes. In the case of ocean salinity and soil moisture, however, the requirements from users not addressed by CGMS could be substantially different from what is necessary for operational meteorology and climatology (e.g., focus could be on river outflow in coastal waters, or on hydro-agriculture, requiring very high horizontal resolution and relatively relaxed accuracy). Therefore, it would be appropriate to develop an optimal ocean salinity / soil moisture mission in the context of GOS-proper.

At CGMS XXVII it was suggested that, for the purpose of CGMS, the following applications should be focused, both requiring relatively coarse horizontal resolution and rather high accuracy:

- **ocean dynamics** as determined by, and traced through, the distribution of ***salinity.*** The main addressed phenomena are the evolution of the polar ice cap, and the input of water of different density from large basins into the ocean (example: flow of denser Mediterranean water into the Atlantic ocean, which determines a bi-static circulation in North-East Atlantic). Apart from the interest of evaluating polar ice cap reduction, which is so important in the context of Global Change, distribution and changes of salinity (which affects density) are one of the very few indicators which allow to infer the three-dimensional ocean dynamics;
- **large-scale air mass transformation** when crossing continents affected by variable ***soil moisture.*** Present parameterization of large-scale soil moisture for the purpose of representing humidification processes in Global NWP is extremely brutal, and constitutes one of the present limiting factors in weather predictability. The lack of knowledge of soil moisture (which is very difficult to be measured even in-situ) is such that climate characterisation is very defective in this aspect, thus climate modelling and model performance evaluation also are affected.

Ocean salinity and soil moisture from space require low-frequency MW (typically, 1.4 GHz), which are associated to large antennas, because of the law of diffraction. An additional difficulty is that the signatures from the target geophysical parameters are convoluted with the signatures from other effects (temperature, roughness, …). ***Table 8*** shows the convoluted effects of various parameters at various MW frequencies.

Table 8 - Sensitivity of MW channels to various geophysical parameters of convoluted effects

	1.4 GHz	2.7 GHz	6.8 GHz	10.6 GHz	18.7 GHz	23.8 GHz
Ocean salinity	****	*				
Soil moisture	****	***	**	*		
Surface temperature (ocean and land)	**	***	****	***	**	*
Wind (ocean) and roughness (land)	*	*	**	***	****	**
Precipitation (ocean)			*	***	****	**
Sea ice boundaries and type				*	****	**
Total column water vapour				*	**	****

In doc. CGMS-XXVII/EUM-WP-06 an example of mission was suggested, based on the following instrument and system characteristics:

- orbit: sunsynchronous, LST 06/18, 500 km height
- conical scanning 45° off-nadir, fore- and aft- viewing
- antenna size: 2.5 m
- dual polarisation in all channels, quadruple in one
- swath 700 km, observing cycle 2 days
- radiometric channels: as specified in ***Table 9.***

Table 9 - Suggested channel for a global ocean salinity and soil moisture radiometer

ν	$\Delta\nu$	NEΔT	abs.cal.	polariz.	viewing	IFOV	sampling
1.4 GHz	27 MHz	0.1 K	1 K	V & H	fore & aft	120 km x 80 km	14 km x 40 km
2.7 GHz	10 MHz	0.1 K	1 K	V & H	fore & aft	60 km x 40 km	14 km x 20 km
6.8 GHz	0.2 GHz	0.2 K	1 K	V & H	fore & aft	25 km x 16 km	14 km x 10 km
10.6 GHz	0.1 GHz	0.2 K	1 K	V & H	fore & aft	16 km x 10 km	14 km x 10 km
18.7 GHz	0.2 GHz	0.2 K	1 K	V, H, + 45°, - 45°	fore & aft	9 km x 6 km	14 km x 5 km
23.8 GHz	0.4 GHz	0.3 K	1 K	V & H	fore & aft	7 km x 5 km	14 km x 5 km

The results of a sizing exercise were:

- mass: ~ 500 kg, electric power: ~ 300 W, data rate: ~ 30 kbps.

The expected products from such a mission are listed in ***Table 10.***

Table 10 - Expected products from an ocean salinity / soil moisture mission

Geophysical parameter	Horizontal resolution	Accuracy	Observing cycle	Delay of availability
Ocean salinity	100 km	0.3 $^0/_{00}$	2 d	1 d
Soil moisture	50 km	30 g/kg	2 d	1 d
Sea surface temperature	20 km	1 K	2 d	1 d
Land surface temperature	20 km	1 K	2 d	1 d
Sea surface wind	10 km	3 m/s	2 d	1 d
Precipitation rate (on ocean)	10 km	1 mm/h	2 d	1 d
Sea ice boundary	10 km	1 km (*)	1 d	1 d
Sea ice type	10 km	0.3 classes^{-1}	1 d	1 d
Total column water vapour	10 km	500 g/m^2	2 d	1 d

(*) accuracy of boundary positioning on monthly maps.

Experimental missions for large-scale ocean salinity and soil moisture are being prepared (see, e.g., SMOS[22] in the ESA Earth Explorer opportunity missions), exploiting synthetic aperture antennas (correlating interferometer) to have reasonable horizontal resolution with reasonable size antenna (the SMOS antenna simulates a size of 4.5 m), but these techniques are only applicable to one or two frequencies (1.4 GHz for SMOS) and can provide radiometric accuracy probably sufficient for soil moisture but certainly not for open ocean salinity (the reflector collecting energy is mostly empty !). Data processing also is problematic, because all convoluted effects which are not measured need to be accounted for by inputting external information. Absolute calibration problems also exist, which make the measurement unsuitable for long-term change monitoring.

Since a comprehensive and compliant low-frequency MW mission for ocean salinity and soil moisture can be implemented as a SmallSat, it is appropriate to incorporate it into GOS-proper.

10. SmallSat for clear-air wind profiling

Wind profiling is a first priority requirement for NWP and GCM, thus any effort should be done to incorporate appropriate instrumentation or missions in GOS-proper. Present and developing practise based on tracking clouds and water-vapour features provides limited yield in both horizontal and vertical domains, and unfavourable error structure (correlated errors, frequent gross errors, …). Indirect inference by 4-D assimilation, particularly if frequent temperature/humidity sounding from geostationary is implemented, is a powerful tool to generate wind fields but, of course, the result cannot be considered as an "observation", since its usage is biased to the application addressed by the

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[22] SMOS = Soil Moisture and Ocean Salinity.

assimilation model utilised. A direct measurement, particularly in clear-air, would be extremely valuable. This can be made by exploiting Doppler shift of line radiation from molecules (passive method, only applicable in the upper atmosphere), or of atmospheric eddies "signed" by aerosol and/or molecular scattering (active method requiring Doppler lidar). Only Doppler lidar is applicable to troposphere and low stratosphere.

Unfortunately, Doppler lidar are rather voluminous, heavy, power-consuming and short-lived instruments, particularly if they use a coherent source and relative long wavelength (which would be better for the low troposphere). Present demonstrative missions such as the ESA "core" Earth Explorer Aeolus[23] make use of incoherent laser. The Aeolus instrument, ALADIN[24], will operate in the UV field (355 nm) and provide a coverage equivalent to one measurement each 250 km in 5 days. It is a 300 kg / 300 W payload which, even in the optimal orbital conditions selected for the demonstration (400 km height, sunsynchronous at dawn-dusk), leads to a 800 kg / 600 W satellite. As an additional difficulty, the basic observation is only radial in the viewing direction, thus the retrieval of the full vector relies on 4-D assimilation (which biases the use of the wind information). The expected accuracy is 2-3 m/s.

Since it would very problematic to embark this type of instrument on a multi-purpose satellite, a dedicated mission is more appropriate. This is conceivable only if technological effort is pursued, to reduce the mission to a SmallSat class. Improvement of the product performance, particularly in the lower troposphere, also is desirable. Therefore, a possible SmallSat is conceivable only in the long-term future (> 2015) provided that technological effort continues on Doppler lidar or some new system.

11. Constellation of mini-satellites

At CGMS XXVII strong emphasis was given to the need to improve the vertical resolution of temperature/humidity sounding in such a way as to allow accurate determination of the atmospheric discontinuities, specifically the heights of the tropopause and of the top of the Planetary Boundary Layer. We also see from Table 1 that there is a gap of quality (vertical resolution and accuracy) in the higher atmosphere. The system proposed to solve this problem was radio-occultation of signals from the Global Navigation Satellite System (GNSS = GPS + GLONASS). Since the occultation event is rather infrequent, a ***constellation*** of satellites was recommended. Follow-on studies performed by ESA have estimated that a suitable satellite embarking the radio-occultation package would weight a bit less than 100 kg. The constellation could be based on clusters of 8 satellites placed in orbit by a single launch, and about four orbital planes (thus, four launches), would be suitable. It was found that the launch aspect had a very large impact on the cost of establishing and maintaining the constellation.

Question arises whether there are other missions that would benefit of a constellation concept, for one or another reason, such as:

- the measurement principle does not allow frequent sampling (e.g., radio-occultation because of infrequent occultation occurrence; radar altimetry because of the essentially nadir viewing, …);
- the parameter to be measured is critically sensitive to the diurnal cycle (e.g., precipitation, Earth Radiation Budget, …), thus requires frequent sampling at more Local Solar Times.

To fix ideas, a cost-effective constellation could consist of four orbital planes with four satellites in each plane, for a total of 16. The cheapest launcher of the envisaged class, at present (Eurockot), can place up to 1 ton in a 800 km high orbit. Reserving 200 kg for the dispenser[25], we have a limit of 200 kg for each satellite, which therefore would be a mini-, not a micro- satellite.

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[23] *Aeolus* was previously called ADM, Atmospheric Dynamics Mission.

[24] ALADIN = Atmospheric Laser Doppler Instrument.

[25] The *dispenser* is the device to sequentially release a cluster of satellites in orbit.

The observation objectives selected for this constellation give regard to the results of the compliance analysis summarised in Table 1. The following have been identified:

- temperature/humidity high-vertical-resolution sounding capable of resolving discontinuities and meet quality requirements in the higher atmosphere; the need for a constellation stems from the fact that the only suitable technique, radio-occultation, is based on infrequent events;
- sea-state, specifically in coastal waters; the need for a constellation stems from the fact that the only suitable technique, radar altimetry, is only practical around the nadir or somewhat off;
- Earth Radiation Budget; the need for a constellation stems from the sensitivity of the measurement to the diurnal cycle;
- precipitation rate; the need for a constellation stems from both the sensitivity to the diurnal cycle and the generally limited instrument swath.

For the ***radio-occultation sounding***, the following requirements are proposed:

- horizontal resolution: 300 km (ultimate limit for this *limb sounding* technique)
- space/time coverage: global each 6 hours
- vertical resolution: < 0.5 km in the troposphere, 1.0 km in the stratosphere
- domain: from surface to 800 km (the layer 100-800 km is required for "space weather"[26])
- accuracy: < 1 K for temperature, < 10 % or 0.2 g/kg (whatever is larger) for humidity.

The payload for this mission has been studied at length (e.g., by ESA). Main specifications would be:

- antennas: one for positioning (zenith ± 75°), two for occultation (azimuth: ± 45° back- and fore-)
- receiver: 16 channels, dual-frequency, for both US GPS and Russian GLONASS
- no. of occultations per day for one payload: about 1000 (average spacing: 700 km)
- sounding generally reaching the ground, except for strong turbulence in the PBL (worst case: 1 km)
- mass ~ 10 kg, volume ~ 20 litres (+ antennas ~100x60x4 cm^3), power ~ 25 W, data rate ~ 20 kbps.

For ***sea-state*** we intend here a rough evaluation in, say, 10 steps (corresponding to WMO code 3700 for reporting on sea-state). Proposed requirements are:

- horizontal resolution: 30 km
- space/time coverage: global each 12 hours
- accuracy: < 0.5 m for significant wave height up to 2 m; < 30 % above.

The instrument for this purpose could be a mini-altimeter, i.e. not of geodetic class. For such rough instrument it is possible to extend the swath by multiple spot, e.g., 5. Main specifications could be:

- IFOV: 30 km; five cross-track IFOV's to cover a 150 km swath
- frequency: 13.78 GHz
- antenna: 70 cm diameter, five beams
- mass ~ 20 kg, volume (electronics) ~ 20 litres, power ~ 25 W, data rate insignificant.

For ***precipitation*** one must be very careful to set requirements, because appropriate instrumentation such as rain-radar or multi-channels MW radiometers are outside the capability of a micro-satellite. Considering that global precipitation is observed by the large multi-channel MW radiometers of NPOESS (at 5.30 and 13.30 LST) and, hopefully, CLOUDS (at 10 LST), it could be sufficient to add a simple precipitation indicator focusing on the type of clouds which really are affected by the diurnal cycle, i.e. <u>convective clouds</u>. Proposed requirements are:

- horizontal resolution: 5 km
- space/time coverage: global each 3 hours
- accuracy: two levels (yes or no) limited to convective precipitation.

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[26] The observed parameters, in the ionosphere, are: Total Electron Content (TEC) and electron density profile.

These requirements could be met by observing one indicator strongly correlated with convective precipitation: ***lightning.*** This has been demonstrated by a dedicated NASA mission flown in 1995 (*OTD, Optical Transient Detector*), and exploited on TRMM (*LIS, Lightning Imaging Sensor*). The proposed specifications are:

- IFOV: 4 km s.s.p. (0.3° from h = 800 km); FOV: 700 km (80° from h = 800 km)
- each IFOV is scanned through a 100 s period; the number of lightnings in the interval is measured
- detectors: 256 x 256 CCD array in VIS or NIR (room temperature)
- mass ~ 20 kg, volume ~ 20 litres, power ~ 20 W, data rate ~ 20 kbps.

For ***Earth Radiation Budget*** the only purpose is to support the comprehensive systems of NPOESS and hopefully CLOUDS, by providing linkage with the diurnal cycle. Very coarse resolution is sufficient. Proposed requirements could be:

- horizontal resolution: 700 km (the reason for this "magic figure" will come later)
- space/time coverage: global each 3 hours
- channels: 0.3-100 µm (total energy) and 0.3-4.0 µm (reflected solar energy)
- accuracy: 0.3 $Wm^{-2}sr^{-1}$ (s.d.); bias: 0.5 $Wm^{-2}sr^{-1}$ (total energy), 1.0 $Wm^{-2}sr^{-1}$ (short wave).

The instrument could be a Flat Plate Radiometer derived from what was used on early Nimbus satellites. Main specifications could be:

- IFOV: 700 km (80° from h = 800 km); sampling at 350 km intervals; no cross-track scanning
- detectors: bolometers (room temperature)
- absolute calibration by internal black body, deep space view and sun diffuser
- mass ~ 10 kg, volume ~ 10 litres, power ~ 10 W, data rate insignificant.

The total amount of resources required from the four instruments is:

- mass ~ 60 kg, volume ~ 60 litres + antennas, power ~ 80 W, data rate ~ 40 kbps.

The main satellite sizing elements could be:

- mass: ~ 200 kg; electric power: ~ 250 W
- data rate: ~ 30 kbps after compression (factor 2) and RS coding (20 % overhead)
- mass memory: ~ 23 MBy/orbit; global data recovery (S-band): ~ 1 Mbps for 3 min.

The ***constellation concept*** is based on four satellites in each of four orbital planes, inclination 70° (i.e. non sunsynchronous, in order to cover all Local Solar Times). With a 800 km height, the period is 100 min and the four satellites are 25 min dephased. This corresponds to 700 km at the equator, so that the four satellites chasing each other cover 2800 km, i.e. what is needed to provide global coverage in 12 hours. The complex of four planes dephased by 45° provides a global coverage each 3 hours. ***Table 11*** summarises the performances of the proposed constellation.

Table 11 - Mission performances of a constellation of 16 satellites in 4 orbital planes

Geophysical parameter	Reference instrument	Horizontal resolution	Observing cycle
Temperature profile Humidity profile Total Electron Content (TEC) (ionosphere) Electron density profile (ionosphere)	GPS/GLONASS receiver	300 km	9 hours
Total outgoing radiation at TOA Short-wave outgoing radiation at TOA	Broad-band radiometer	700 km	3 hours
Convective precipitation	Lightning counter	5 km	3 hours
Sea state	Mini- radar altimeter	30 km	12 hours

12. Post-METOP: a MediumSat ?

The short-term purpose of the SmallSat's so far studied is to fill gaps of compliance of GOS-proper with requirements. However, if SmallSat's such as those suggested in this document are implemented, at the time to replace METOP-3 in the EPS series the following favourable situation will be found:

- requirements in the meantime become of highest priority (e.g., cloud/aerosol/radiation/precipitation, ocean salinity / soil moisture, high-vertical resolution sounding at tropopause level and in the higher atmosphere, possibly clear-air wind profile) will have been solved by dedicated system, thus will not create pressure to further grow the objectives of the post-METOP satellite mission;
- certain observations presently carried out by METOP could be descoped, if they overlap with what is measured by one or another SmallSat.

To check this, it is appropriate to analyse the situation by instruments and objectives.

As regards the ***temperature/humidity*** sounding mission, if all geostationary satellites are equipped with high-vertical resolution frequent sounding, and if there is the radio-occultation constellation to provide accurate tropopause height and high vertical resolution in the higher atmosphere, the post-METOP sounding mission will not need to be strengthened. HIRS/4 and GRAS could be suppressed. AMSU-A and MHS could be slightly updated to re-align the technology to what is foreseen for the NPOESS ATMS. Thus, the sounding mission would be carried out by IASI and an ATMS-like MW sounder.

As regards the ***multi-purpose imagery mission***, if a CLOUDS-type satellite is implemented, it would provide the most comprehensive description of cloud fields, including cloud interior, and of the associated aerosol and precipitation fields, though at a resolution of 5-10 km. The improved imagery mission of the geostationary satellites would ensure continuous observations of all rapid-evolving parameters. The NPOESS VIIRS, flown at 5.30 and 13.30 LST, would ensure high-resolution imagery for surface parameters determination (including sea-surface temperature, ocean colour and vegetation indexes, which do not require frequent sampling). For precipitation, the NPOESS CMIS flown at 5.30 and 13.30 LST, plus the CLOUDS MW radiometer, supported by the lightning counters proposed for the constellation, should be sufficient. Therefore, there is no need to enhance the post-METOP imagery mission beyond the capability, say, of a AVHRR-like radiometer, since its primary purpose would now be to support the sounding mission.

The ***sea-surface wind mission*** would be abundantly covered by NPOESS CMIS flown at 5.30 and 13.30 LST, and the CLOUDS MW radiometer at 10 LST. It is reminded that these radiometers observe wind direction in addition to speed, thanks to multi-polarisation (3 or 4 Stokes components) in a number of channels. The same MW radiometers will ensure optimal ***ice observation.*** In conclusion, ASCAT could be spared from post-METOP.

As regards ***ozone and other trace gases,*** the situation is not so clear. Accepted that high-vertical-resolution ozone profile and profiles of other species are better achieved by acquiring data from scientific satellites, the need to observe at least total columns of green-house gases and of some other ozone-aggressive species, and a reasonable-vertical-resolution ozone profile within GOS-proper, will persist. The species tracked by IASI are: CO, CH_4, N_2O and, of course, O_3 (with profile). However, in the IR, the vertical resolution of ozone is only acceptable in the high troposphere and low stratosphere. To extend ozone observation to lower and higher levels, the use of UV is indispensable. Something similar holds for the H_2O profile in the higher atmosphere, which requires VIS/NIR. Thus, GOME-2 or something similar has to be retained. This will allow to extend the observation to total columns of SO_2, HCHO, BrO, ClO, $ClONO_2$ and OClO (some of these species only observable under special conditions). To go beyond this, i.e. beyond the joint capabilities of IASI + GOME-2, would require a serious effort. IASI would need improved spectral resolution (to at least 0.1 cm^{-1}), thus becoming a monster; GOME would require extension of the spectral range well within the SWIR, thus sharply growing in size and complexity. Anyway, profiles would only be possible for the most abundant species. In addition, the utmost important species for atmospheric chemistry, OH and HCl (which are required as profiles) are only observable in the Far IR or Sub-mm waves. Therefore, to try to improve the atmospheric chemistry mission on post-METOP would be an open-ended issue, thus it is advisable to stay with what is possible by IASI + GOME-2, or something like that.

One exception could be made if a species is considered so important for monitoring purpose that deserves special effort. If that species has a well defined band in a spectral region not contaminated by nearby bands (i.e. in a "window" region), it is possible to use a narrow-band very-high spectral resolution spectrometer (e.g. Fabry-Perot), which could be a rather small instrument. This is the case, for instance, of CH_4 around 3.4 µm or 8 µm, and of CO_2 around 1.6 µm. Several problems should be solved (for instance, in IR there is a strong dependence on temperature; in SWIR a source is needed, which could be sunglint, and aerosol might impact); however, the possibility of focusing on few key species by small, dedicated, instruments exists in principle.

Summing-up, ***Table 12*** shows a possible evolution of the EPS programme from a large METOP (4.5 tons) to perhaps a medium-size satellite (say, < 2 tons, obviously assuming a re-designed platform).

Table 12 - Possible evolution of large-METOP towards medium-METOP after 2015

Instrument	Evolution	Remarks
IASI	Essentially unchanged	Possible re-design at equivalent performance
HIRS/4	Disembarked	Role exhausted after IASI
GRAS	Disembarked	Replaced by constellation
AMSU-A + MHS	Redesigned along NPOESS ATMS	Probable mass/volume saving; better performance
GOME-2	Essentially unchanged	Possible re-design at equivalent performance
AVHRR/3	Re-designed	Main role: support to sounding
ASCAT	Disembarked	Replaced by NPOESS + CLOUDS MW imagers
Fabry-Perot spectrometers	New (small) instruments	For selected key species (e.g., CO_2 and CH_4

13. Conclusion and recommendations - An "Atmospheric Dynamics Theme" in IGOS ?

In this discussion paper we have seen that, with evolving GOS asset, the compliance of the CGMS-provided satellite system could improve considerably (see Table 1). However:

- the GOS-proper system needs to be re-enforced, possibly by adding SmallSat's to fill gaps and prepare for a long-term scenario based on more numerous but possibly smaller satellites (see Table 2 for a view of necessary developments);
- for many parameters, there is little hope (and probably it is not appropriate) to try to fill the gap within GOS-proper: Table 3 lists the requirements that could be fulfilled by cooperating with scientific/technological/commercial programmes, or application programmes led by other user communities. For certain observations the need is provisional, till GOS-proper is sufficiently developed; for other ones the requirement is permanent;
- for the development/demonstration phase of the additional elements to be integrated in GOS-proper, it is appropriate to rely on forces external to CGMS, such as developmental space agencies.

The study shows that, because of de-phased development processes among the various CGMS members, GOS-proper cannot reach full strength before, say, 2015. ***This also, however, will not happen on its own !*** The only plans so far (nearly) consolidated are the upgrade of GOES and the replacement of NOAA by NPOESS, both events to happen around 2009. In addition, it is clear that CGMS needs to cooperate with external forces, both to help with prototypes development/demonstration and to provide data to fill temporary gaps until GOS-proper is fully developed and also after, on a permanent basis, for those observations unlikely to be affordable within GOS-proper. ***It is therefore recommended that CGMS places a strong new impetus on co-planning.***

In the area of ***geostationary satellites*** it is absolutely necessary that the minimum level of performances of at least five, preferably six, equi-spaced satellites is agreed, otherwise their contribution to Global NWP will not be optimal. The minimum level should include high-vertical-resolution IR frequent sounding, rapid imagery and ERB. Through 4-D assimilation, wind profile and large-scale precipitation also would be inferred. The review carried out in Section 7 shows that a newly designed satellite for this purpose might be smaller than expected. Also shown is that options for surpassing the minimum level for the benefit of regional scale and nowcasting have been identified (combined IR imager-sounder and MW/Sub-mm imager-sounder). It is suggested that this task is implemented within CGMS itself.

Assuming that an upgraded geostationary satellite system is implemented, the role of the other elements of GOS-proper could be re-defined. Assuming that NPOESS is finally defined as presently envisaged, what remains can be done by a post-METOP MediumSat for maximum-quality IR/MW sounding, basic imagery and "affordable" atmospheric chemistry (see Section 12); plus a number of "small" missions. The responsibility for post-METOP definition stays with EUMETSAT. Identification of the appropriate "small" missions should start from CGMS, but space agencies responsible of development should have early involvement. It is essential that CGMS takes the leadership in identifying those missions which really have an operational long-term perspective. Developmental space agencies certainly have very clear ideas of what is useful for operational meteorology and climatology, but the procedure they adopt to select "small missions" (Call for proposals or ideas often responded to by scientific groups) tends to favour process study or technological missions, certainly very useful but often unsuitable to have an operational follow-on. A ***CGMS "manifest" of small missions*** required to bring GOS-proper to full strength would be very appropriate. In Sections 8 to 11, four small missions have been recommended (cloud-aerosol-radiation-precipitation, ocean salinity / soil moisture, wind profiling, and the constellation for radio-occultation, sea-state, ERB and precipitation by lightning detection).

The subject of access to data from non-GOS-proper systems is very critical. This study has adopted a number of optimistic assumptions on what could be affordable to integrate in GOS-proper; yet a wide range of non-compliance will persist, particularly in the near future (see Table 1). This fact, i.e. the interest of the meteo-climatological community to have access to, or "acquire", data from non-GOS-proper programmes, should be formally acknowledged, and CGMS should explicitly admit that certain data will not be provided, or will be provided with insufficient quality, by GOS-proper, either in the near-medium-term future or permanently. A ***CGMS "manifest" of data required to complement or support GOS-proper*** would be very appropriate. Table 3 could be an example of such a manifest. This would enable space agencies outside CGMS to evaluate the slice of "market" of their scientific or technological or application or commercial programmes they could expect to be covered by the meteo-climatic user community. It would also help them not to overemphasise the value of certain missions for operational meteorology and climatology, if they are satisfactorily covered by GOS-proper.

Though the recommended initiatives should appropriately start from CGMS, two of them (indication of interest for SmallSat's development/demonstration, and requirements for data to complement/support GOS-proper) should better be framed in a larger context. Perhaps an appropriate context is represented by IGOS, which exploits it mandate by focusing on specific "Themes"[27]. Perhaps an ***"Atmospheric Dynamics Theme"*** could be proposed, to focus on the fact that, whilst great effort must be placed in growing new user communities of Earth observation, the need to keep updated the backbone system for weather forecasting and general circulation modelling must not be forgotten !

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[27] Two have been embarked upon, so far: the "Ocean Theme" and the "Carbon Cycle Theme".

APPENDIX

COLLECTION OF USER REQUIREMENTS FOR METEOROLOGICAL AND CLIMATOLOGICAL APPLICATIONS

Source: ***CEOS/WMO Database on user requirements and space system capabilities.***

Web site: ***http://www.wmo.ch*** , then “Satellite activities”, then “Online database information”, then “Satellite systems and data requirements information (CEOS/WMO database)”, then “Observational requirements”; then entries by several organisations are found.

Contents:

- Table A1 - WMO requirements for data from satellites (split in 6 sheets)
- Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (split in 9 sheets).

Utilised entries:

- for Table A1: WMO, split in the following seven applications:
  - Global Numerical Weather Prediction
  - Regional Numerical Weather Prediction
  - Synoptic Meteorology
  - Nowcasting
  - Agricultural Meteorology
  - Hydrology
  - Atmospheric Chemistry;
- for Table A2: GCOS, GOOS, GTOS and WCRP, split in the following eleven applications:
  - GCOS AOPC (Atmosphere Observation Panel for Climate)
  - GOOS Climate large-scale
  - GOOS Climate meso-scale
  - GOOS Marine biology (open ocean)
  - GOOS Marine biology (coastal water)
  - GTOS Terrestrial climate
  - WCRP Global modelling
  - WCRP SPARC (Stratospheric Processes and their Role in Climate)
  - WCRP GEWEX (Global Energy and Water Cycle Experiment)
  - WCRP ACSYS (Arctic Climate System Study)
  - WCRP CLIVAR (Climate Variability and Predictability).

Tables are structured so as to easier appreciating, for each parameter, how much the requirements change with changing application. For each requirement figure, a range is quoted, reporting:

- the “target” requirement, i.e. what is desirable and could be fully utilised (higher quality would have little added value);
- the “threshold” requirement, i.e. the value beyond which there is no interest for the measurement (it would add nothing to the first guess).

The database version is what appears on Internet on July 2000, except for some updating agreed at the RRR process in early 2000 (SAT-22) and not yet retro-fitted. Actual dates of last update varies with the source.

Table A1 - WMO requirements for data from satellites (sheet 1 of 6)

Geophysical parameter	Atmospheric volume	Req.mt	Unit	Global NWP	Regional NWP	Synoptic Meteorology	Nowcasting	Agricultural Meteorology	Hydrology
Temperature profile	1 Lower troposphere	Δx	km	50 ÷ 500	10 ÷ 500	20 ÷ 200	5 ÷ 200		
		Δz	km	0.3 ÷ 3	0.3 ÷ 3	0.1 ÷ 2	0.5 ÷ 1		
		r.m.s.	K	0.5 ÷ 3	0.5 ÷ 3	0.5 ÷ 3	0.5 ÷ 3		
		Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 12	0.25 ÷ 1		
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.08 ÷ 0.5		
	2 Higher troposphere	Δx	km	50 ÷ 500	10 ÷ 500	20 ÷ 200	5 ÷ 200		
		Δz	km	1 ÷ 3	1 ÷ 3	0.1 ÷ 2	1 ÷ 3		
		r.m.s.	K	0.5 ÷ 3	0.5 ÷ 3	0.5 ÷ 3	1 ÷ 2		
		Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 12	0.25 ÷ 1		
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.08 ÷ 0.5		
	3 Lower stratosphere	Δx	km	50 ÷ 500	10 ÷ 500	20 ÷ 200			
		Δz	km	1 ÷ 3	1 ÷ 3	0.1 ÷ 2			
		r.m.s.	K	0.5 ÷ 3	0.5 ÷ 3	0.5 ÷ 3			
		Δt	h	1 ÷ 12	0.5 ÷ 12	0.3 ÷ 12			
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3			
	4 Higher stratosphere, mesosphere	Δx	km	50 ÷ 500					
		Δz	km	1 ÷ 3					
		r.m.s.	K	0.5 ÷ 5					
		Δt	h	1 ÷ 12					
		delay	h	1 ÷ 4					
Wind profile (horizontal component)	1 Lower troposphere	Δx	km	50 ÷ 500	10 ÷ 500	20 ÷ 200	5 ÷ 200		
		Δz	km	0.4 ÷ 5	0.4 ÷ 5	0.1 ÷ 2	0.5 ÷ 1		
		r.m.s.	m/s	1 ÷ 5	1 ÷ 5	2 ÷ 5	1 ÷ 5		
		Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 12	0.25 ÷ 6		
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.25 ÷ 2		
	2 Higher troposphere	Δx	km	50 ÷ 500	10 ÷ 500	20 ÷ 200	5 ÷ 200		
		Δz	km	1 ÷ 10	1 ÷ 10	0.1 ÷ 2	0.5 ÷ 1		
		r.m.s.	m/s	1 ÷ 8	1 ÷ 8	2 ÷ 8	1 ÷ 8		
		Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 12	0.25 ÷ 4		
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.08 ÷ 0.5		
	3 Lower stratosphere	Δx	km	50 ÷ 500	10 ÷ 500	20 ÷ 200	5 ÷ 200		
		Δz	km	1 ÷ 10	1 ÷ 10	0.1 ÷ 2	0.5 ÷ 1		
		r.m.s.	m/s	1 ÷ 5	1 ÷ 5	2 ÷ 5	1 ÷ 5		
		Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 12	0.25 ÷ 6		
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.25 ÷ 2		
Wind profile (vertical) component)	1 Lower troposphere	Δx	km	50 ÷ 500	10 ÷ 500		5 ÷ 200		
		Δz	km	0.5 ÷ 5	0.5 ÷ 5		0.5 ÷ 2		
		r.m.s.	cm/s	1 ÷ 5	1 ÷ 5		1 ÷ 5		
		Δt	h	1 ÷ 12	0.5 ÷ 12		0.25 ÷ 1		
		delay	h	1 ÷ 4	0.5 ÷ 2		0.08 ÷ 0.5		
	2 Higher troposphere	Δx	km	50 ÷ 500	10 ÷ 500				
		Δz	km	0.5 ÷ 10	0.5 ÷ 10				
		r.m.s.	cm/s	1 ÷ 5	1 ÷ 5				
		Δt	h	1 ÷ 12	0.5 ÷ 12				
		delay	h	1 ÷ 4	0.5 ÷ 2				
	3 Lower stratosphere	Δx	km	50 ÷ 500	10 ÷ 500				
		Δz	km	0.5 ÷ 10	0.5 ÷ 10				
		r.m.s.	cm/s	1 ÷ 5	1 ÷ 5				
		Δt	h	1 ÷ 12	0.5 ÷ 12				
		delay	h	1 ÷ 4	0.5 ÷ 2				
Relative humidity profile	1 Lower troposphere	Δx	km	50 ÷ 250	10 ÷ 100	20 ÷ 200	5 ÷ 200		
		Δz	km	0.4 ÷ 2	0.4 ÷ 2	0.1 ÷ 2	0.5 ÷ 1		
		r.m.s.	%	5 ÷ 20	5 ÷ 20	5 ÷ 20	5 ÷ 20		
		Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 12	0.25 ÷ 1		
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.08 ÷ 0.5		
	2 Higher troposphere	Δx	km	50 ÷ 250	10 ÷ 100	20 ÷ 200	5÷ 200		
		Δz	km	1 ÷ 3	1 ÷ 3	0.1 ÷ 2	1 ÷ 3		
		r.m.s.	%	5 ÷ 20	5 ÷ 20	5 ÷ 20	5 ÷ 20		
		Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 12	0.25 ÷ 1		
		delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.08 ÷ 0.5		
	5 **Total column** (precipitable water)	Δx	km	50 ÷ 500	10 ÷ 250		5 ÷ 50		
		r.m.s.	%	1000 ÷ 5000	1000 ÷ 5000		1000 ÷ 5000		
		Δt	h	1 ÷ 12	0.5 ÷ 12		0.25 ÷ 1		
		delay	h	1 ÷ 4	0.5 ÷ 2		0.08 ÷ 0.5		

Table A1 - WMO requirements for data from satellites (sheet 2 of 6)

Geophysical parameter	Atmospheric volume	Req.mt	Unit	Global NWP	Regional NWP	Synoptic Meteorology	Nowcasting	Agricultural Meteorology	Hydrology
Cloud water profiles: **liquid (< 100 µm)** **liquid (> 100 µm)** **ice**	1 Lower troposphere	Δx	km	50 ÷ 250	10 ÷ 250				
		Δz	km	0.3 ÷ 5	0.3 ÷ 5				
		r.m.s.	%	5 ÷ 20	5 ÷ 20				
		Δt	h	1 ÷ 12	0.5 ÷ 12				
		delay	h	1 ÷ 4	0.5 ÷ 2				
	2 Higher troposphere	Δx	km	50 ÷ 250	10 ÷ 250				
		Δz	km	1 ÷ 10	1 ÷ 10				
		r.m.s.	%	5 ÷ 20	5 ÷ 20				
		Δt	h	1 ÷ 12	0.5 ÷ 12				
		delay	h	1 ÷ 4	0.5 ÷ 2				
	5 **Total column**	Δx	km	50 ÷ 250	10 ÷ 250				
		r.m.s.	g/m^2	10 ÷ 50	10 ÷ 50				
		Δt	h	1 ÷ 12	0.5 ÷ 12				
		delay	h	1 ÷ 4	0.5 ÷ 2				
Aerosol profile	1 Lower troposphere	Δx	km	50 ÷ 500					
		Δz	km	0.1 ÷ 1					
		r.m.s.	%	10 ÷ 20					
		Δt	h	1 ÷ 168					
		delay	h	1 ÷ 168					
	2 Higher troposphere	Δx	km	50 ÷ 500					
		Δz	km	1 ÷ 5					
		r.m.s.	%	10 ÷ 20					
		Δt	h	6 ÷ 168					
		delay	h	12 ÷ 168					
	3 Lower stratosphere	Δx	km	50 ÷ 500					
		Δz	km	1 ÷ 10					
		r.m.s.	%	10 ÷ 20					
		Δt	h	6 ÷ 168					
		delay	h	12 ÷ 168					
	5 **Total column**	Δx	km	50 ÷ 500			5 ÷ 50		
		r.m.s.	%	10 ÷ 20			10 ÷ 20		
		Δt	h	1 ÷ 168			0.25 ÷ 12		
		delay	h	1 ÷ 168			0.25 ÷ 2		
Ozone profile	1 Lower troposphere	Δx	km	50 ÷ 500	10 ÷ 200				
		Δz	km	1 ÷ 5	1 ÷ 5				
		r.m.s.	%	5 ÷ 20	5 ÷ 20				
		Δt	h	1 ÷ 12	0.5 ÷ 3				
		delay	h	1 ÷ 4	0.5 ÷ 2				
	2 Higher troposphere	Δx	km	50 ÷ 500	10 ÷ 200				
		Δz	km	1 ÷ 10	1 ÷ 10				
		r.m.s.	%	5 ÷ 20	5 ÷ 20				
		Δt	h	1 ÷ 12	0.5 ÷ 3				
		delay	h	1 ÷ 4	0.5 ÷ 2				
	3 Lower stratosphere	Δx	km	50 ÷ 500	10 ÷ 200				
		Δz	km	1 ÷ 10	1 ÷ 10				
		r.m.s.	%	5 ÷ 20	5 ÷ 20				
		Δt	h	1 ÷ 12	0.5 ÷ 3				
		delay	h	1 ÷ 4	0.5 ÷ 2				
	5 **Total column**	Δx	km	50 ÷ 100	10 ÷ 100	20 ÷ 50			
		r.m.s.	DU	5 ÷ 20	5 ÷ 20	5 ÷ 20			
		Δt	h	1 ÷ 6	0.5 ÷ 6	0.25 ÷ 12			
		delay	h	1 ÷ 4	0.5 ÷ 2	0.25 ÷ 6			

Table A1 - WMO requirements for data from satellites (sheet 3 of 6)

Geophysical parameter	Req.mt	Unit	Global NWP	Regional NWP	Synoptic Meteorology	Nowcasting	Agricultural Meteorology	Hydrology
Cloud imagery	Δx	km	1 ÷ 50	1 ÷ 50	1 ÷ 10	1 ÷ 5		
	r.m.s.	N/A	N/A	N/A	N/A	N/A		
	Δt	h	0.5 ÷ 6	0.25 ÷ 6	0.25 ÷ 6	0.05 ÷ 0.5		
	delay	h	1 ÷ 4	0.5 ÷ 2	0.25 ÷ 6	0.25 ÷ 1		
Cloud type	Δx	km			20 ÷ 200	1 ÷ 10		
	r.m.s.	classes^{-1}			0.1 ÷ 0.2	0.1 ÷ 0.2		
	Δt	h			0.25 ÷ 6	0.01 ÷ 0.5		
	delay	h			0.25 ÷ 6	0.02 ÷ 0.5		
Cloud cover	Δx	km	50 ÷ 250	10 ÷ 250		1 ÷ 20		
	r.m.s.	%	5 ÷ 20	5 ÷ 20		5 ÷ 20		
	Δt	h	1 ÷ 12	0.5 ÷ 12		0.0083 ÷ 1		
	delay	h	1 ÷ 4	0.5 ÷ 2		0.016 ÷ 0.5		
Cloud top height	Δx	km	50 ÷ 250	10 ÷ 250	1 ÷ 10	1 ÷ 10		
	r.m.s.	km	0.5 ÷ 1	0.5 ÷ 1	0.5 ÷ 2	0.1 ÷ 1		
	Δt	h	1 ÷ 12	0.5 ÷ 12	0.25 ÷ 6	0.01 ÷ 0.5		
	delay	h	1 ÷ 4	0.5 ÷ 2	0.25 ÷ 6	0.02 ÷ 0.5		
Cloud top temperature	Δx	km				1 ÷ 10		
	r.m.s.	K				0.5 ÷ 2		
	Δt	h				0.01 ÷ 0.5		
	delay	h				0.02 ÷ 0.5		
Cloud base height	Δx	km	50 ÷ 250	10 ÷ 250				
	r.m.s.	km	0.5 ÷ 1	0.5 ÷ 1				
	Δt	h	1 ÷ 12	0.5 ÷ 12				
	delay	h	1 ÷ 4	0.5 ÷ 3				
Precipitation rate at the ground (liquid)	Δx	km	50 ÷ 100	10 ÷ 50	20 ÷ 100	5 ÷ 50		
	r.m.s.	mm/h	0.1 ÷ 1	0.1 ÷ 1	0.1 ÷ 1	0.1 ÷ 1		
	Δt	h	1 ÷ 12	0.5 ÷ 6	1 ÷ 6	0.08 ÷ 1		
	delay	h	1 ÷ 4	0.5 ÷ 2	0.25 ÷ 6	0.08 ÷ 0.5		
Precipitation rate at the ground (solid)	Δx	km	50 ÷ 100	10 ÷ 100	20 ÷ 100	5 ÷ 50		
	r.m.s.	mm/h	0.1 ÷ 1	0.1 ÷ 1	0.1 ÷ 1	0.1 ÷ 1		
	Δt	h	1 ÷ 12	0.5 ÷ 12	3 ÷ 6	0.25 ÷ 1		
	delay	h	1 ÷ 4	0.5 ÷ 2	0.25 ÷ 6	0.5 ÷ 0.5		
Precipitation index (daily cumulative)	Δx	km	50 ÷ 250	10 ÷ 250			10 ÷ 50	
	r.m.s.	mm/d	0.5 ÷ 5	0.5 ÷ 5			2 ÷ 10	
	Δt	h	1 ÷ 12	0.5 ÷ 12			24 ÷ 72	
	delay	h	24 ÷ 72	24 ÷ 720			24 ÷ 48	
Atmospheric instability index	Δx	km			20 ÷ 200	5 ÷ 50		
	r.m.s.	classes^{-1}			0.17 ÷ 0.33	0.17 ÷ 0.33		
	Δt	h			1 ÷ 6	0.08 ÷ 0.5		
	delay	h			1 ÷ 3	0.25 ÷ 1		
Tropopause height and temperature	Δx	km				10 ÷ 200		
	rms (height)	km				0.1 ÷ 1		
	rms (temp.)	K				0.5 ÷ 2		
	Δt	h				0.5 ÷ 6		
	delay	h				0.5 ÷ 2		
Height of planetary boundary layer	Δx	km				5 ÷ 50		
	r.m.s.	m				50 ÷ 500		
	Δt	h				0.25 ÷ 1		
	delay	h				0.08 ÷ 0.5		
Short-wave outgoing radiation at TOA	Δx	km	50 ÷ 250	10 ÷ 250				0.1 ÷ 200
	s.d.	W/m^2	5 ÷ 10	5 ÷ 10				5 ÷ 20
	bias	W/m^2	3 ÷ 5	3 ÷ 5				3 ÷ 5
	Δt	h	1 ÷ 6	0.5 ÷ 1				1 ÷ 6
	delay	d	10 ÷ 15	10 ÷ 15				1 ÷ 7
Long-wave outgoing radiation at TOA	Δx	km	50 ÷ 250	10 ÷ 250				10 ÷ 100
	s.d.	W/m^2	5 ÷ 10	5 ÷ 10				5 ÷ 20
	bias	W/m^2	3 ÷ 5	3 ÷ 5				3 ÷ 5
	Δt	h	1 ÷ 1	0.5 ÷ 1				1 ÷ 12
	delay	d	10 ÷ 30	10 ÷ 30				1 ÷7
Cloud drop size (at cloud top)	Δx	km	50 ÷ 250	10 ÷ 250				
	r.m.s.	μm	0.5 ÷ 2	0.5 ÷ 2				
	Δt	h	1 ÷ 12	0.5 ÷ 12				
	delay	h	1 ÷ 4	0.5 ÷ 2				

Table A1 - WMO requirements for data from satellites (sheet 4 of 6)

Geophysical parameter	Req.mt	Unit	Global NWP	Regional NWP	Synoptic Meteorology	Nowcasting	Agricultural Meteorology	Hydrology
Long-wave Earth surface emissivity	Δx	km	15 ÷ 250	5 ÷ 250				0.01 ÷ 250
	r.m.s.	%	1 ÷ 5	1 ÷ 5				5 ÷ 20
	Δt	d	1 ÷ 30	1 ÷30				1 ÷ 12
	delay	d	1 ÷ 30	1 ÷30				1 ÷ 12
Air pressure (at surface)	Δx	km	50 ÷ 250	10 ÷ 250				
	r.m.s.	hPa	0.5 ÷ 2	0.5 ÷ 1				
	Δt	h	1 ÷ 12	0.5 ÷ 12				
	delay	h	1 ÷ 4	0.5 ÷ 2				
Air relative humidity (at surface)	Δx	km	50 ÷ 250	10 ÷ 250				
	r.m.s.	%	5 ÷ 15	5 ÷ 15				
	Δt	h	1 ÷ 12	0.5 ÷ 12				
	delay	h	1 ÷ 4	0.5 ÷ 2				
Air temperature (at surface)	Δx	km	50 ÷ 250	10 ÷ 250	10 ÷ 100	5 ÷ 20		
	r.m.s.	K	0.5 ÷ 2	0.5 ÷ 2	0.5 ÷ 2	0.5 ÷ 1		
	Δt	h	1 ÷ 12	0.5 ÷ 12	1 ÷ 12	0.25 ÷ 1		
	delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 4	0.25 ÷ 0.5		
Wind over surface (vector and speed)	Δx	km	50 ÷ 250	10 ÷ 250	20 ÷ 200	5 ÷ 50		
	rms (vector)	m/s	0.5 ÷ 5	0.5 ÷ 5	2 ÷ 5	1 ÷ 5		
	rms (speed)	m/s	0.5 ÷ 3	0.5 ÷ 3	2 ÷ 5	1 ÷ 5		
	Δt	h	1 ÷ 12	0.5 ÷ 12	1 ÷ 12	0.25 ÷ 3		
	delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3	0.25 ÷ 1		
Sea surface temperature	Δx	km	50 ÷ 250	25 ÷ 250	5 ÷ 50	5 ÷ 50		
	s.d.	K	0.5 ÷ 1	0.5 ÷ 1	0.5 ÷ 2	0.5 ÷ 2		
	bias	K	0.1 ÷ 0.3	0.1 ÷ 0.3	0.1 ÷ 0.3	0.1 ÷ 0.3		
	Δt	h	1 ÷ 12	1 ÷ 12	3 ÷ 24	1 ÷ 6		
	delay	h	1 ÷ 24	1 ÷ 24	1 ÷ 24	1 ÷ 2		
Significant wave height	Δx	km	100 ÷ 250	10 ÷ 50				
	r.m.s.	m	0.5 ÷ 1	0.1 ÷ 0.2				
	Δt	h	1 ÷ 12	1 ÷ 12				
	delay	h	1 ÷ 4	1 ÷ 2				
Dominant wave period and direction	Δx	km	50 ÷ 250	10 ÷ 50	50 ÷ 200			
	rms (period)	s	0.5 ÷ 1	0.5 ÷ 1	0.5 ÷ 1			
	rms (direct.)	degrees	10 ÷ 20	10 ÷ 20	20 ÷ 30			
	Δt	h	1 ÷ 12	1 ÷ 12	3 ÷ 12			
	delay	h	1 ÷ 4	0.5 ÷ 2	1 ÷ 3			
Ocean currents (vector)	Δx	km				10 ÷ 50		
	r.m.s.	cm/s				0.5 ÷ 1		
	Δt	d				0.25 ÷ 6		
	delay	d				0.25 ÷ 4		
Sea level	Δx	km						0.1 ÷ 10
	r.m.s.	cm						2 ÷ 10
	Δt	d						1 ÷ 7
	delay	d						1 ÷ 7
Sea-ice cover	Δx	km	15 ÷ 250	25 ÷ 50		5 ÷ 50		
	r.m.s.	%	5 ÷ 50	5 ÷ 50		10 ÷ 20		
	Δt	d	1 ÷ 15	0.5 ÷ 7		1 ÷ 24		
	delay	d	1 ÷ 7	0.3 ÷ 3		1 ÷ 6		
Sea-ice surface temperature	Δx	km	15 ÷ 200	5 ÷ 100				
	r.m.s.	K	0.5 ÷ 4	0.5 ÷ 4				
	Δt	h	1 ÷ 7	0.5 ÷ 12				
	delay	h	1 ÷ 4	0.5 ÷ 2				
Ice thickness	Δx	km	15 ÷ 250	5 ÷ 250				
	r.m.s.	m	0.5 ÷ 1	0.5 ÷ 1				
	Δt	d	1 ÷ 7	1 ÷ 7				
	delay	d	1 ÷ 7	1 ÷ 7				
Icebergs (extension and height)	Δx	km						1 ÷ 50
	rms (extent)	%						10 ÷ 20
	rms (height)	m						1 ÷ 2
	Δt	d						1 ÷ 12
	delay	d						1 ÷ 4
Snow cover	Δx	km	15 ÷ 250	5 ÷ 250		5 ÷ 50	1 ÷ 10	0.1 ÷ 100
	r.m.s.	%	10 ÷ 50	10 ÷ 50		10 ÷ 20	2 ÷ 10	5 ÷ 20
	Δt	d	0.5 ÷ 7	0.5 ÷ 7		0.04 ÷ 0.25	5 ÷ 7	1 ÷ 7
	delay	d	0.5 ÷ 1	0.25 ÷ 1		0.04 ÷ 0.25	1 ÷ 5	1 ÷ 6

Table A1 - WMO requirements for data from satellites (sheet 5 of 6)

Geophysical parameter	**Req.mt**	**Unit**	**Global NWP**	**Regional NWP**	**Synoptic Meteorology**	**Nowcasting**	**Agricultural Meteorology**	**Hydrology**
Snow melting condition	Δx	km						0.1 ÷ 10
	r.m.s.	classes^{-1}						0.2 ÷ 0.5
	Δt	h						0.5 ÷ 12
	delay	h						1 ÷ 144
Snow depth	Δx	km					1 ÷ 10	0.1 ÷ 10
	r.m.s.	m					0.1 ÷1	0.1 ÷10
	Δt	d					5 ÷ 15	1 ÷ 7
	delay	d					1 ÷ 5	1 ÷ 6
Snow water equivalent	Δx	km	15 ÷ 250	5 ÷ 250			1 ÷ 10	0.1 ÷ 10
	r.m.s.	mm	5 ÷ 20	5 ÷ 20			5 ÷ 500	5 ÷ 20
	Δt	d	0.5 ÷ 7	0.25 ÷ 7			7 ÷ 30	1 ÷ 7
	delay	d	0.25 ÷ 1	0.25 ÷ 1			1 ÷ 7	1 ÷ 6
Permafrost	Δx	km						0.1 ÷ 100
	r.m.s.	%						5 ÷ 25
	Δt	d						0.25 ÷ 3
	delay	d						0.25 ÷ 6
Land surface temperature	Δx	km	50 ÷ 250	10 ÷ 250		1 ÷ 50	0.1 ÷ 10	0.01 ÷ 250
	r.m.s.	K	0.5 ÷ 4	0.5 ÷ 4		0.5 ÷ 3	0.3 ÷ 2	0.3 ÷ 3
	Δt	h	1 ÷ 12	0.5 ÷ 12		0.25 ÷ 1	1 ÷ 72	1 ÷ 168
	delay	h	1 ÷ 4	0.5 ÷ 2		0.08 ÷ 0.5	3 ÷ 24	24 ÷ 168
Soil moisture	Δx	km	15 ÷ 250	5 ÷ 250		5 ÷ 50	0.1 ÷ 1	0.01 ÷ 250
	r.m.s.	g/kg	10 ÷ 50	10 ÷ 50		10 ÷ 50	10 ÷ 50	10 ÷ 50
	Δt	d	1 ÷ 7	1 ÷ 7		0.5 ÷ 2	1 ÷ 7	1 ÷ 3
	delay	d	0.25 ÷ 1	7 ÷ 7		0.25 ÷ 1	1 ÷ 5	1 ÷ 144
Apparent Thermal Inertia (ATI)	Δx	km						10 ÷ 250
	r.m.s.	K^{-1}						0.5 ÷ 3
	Δt	h						1 ÷ 24
	delay	h						24 ÷ 72
Normalized Difference Vegetation Index (NDVI)	Δx	km	50 ÷ 100	10 ÷ 50		5 ÷ 10	1 ÷ 10	0.01 ÷ 250
	r.m.s.	%	1 ÷ 5	1 ÷ 5		5 ÷ 10	5 ÷ 10	1 ÷ 20
	Δt	d	7 ÷ 30	7 ÷ 30		1 ÷ 12	1 ÷ 7	1 ÷ 30
	delay	d	1 ÷ 7	1 ÷ 7		1 ÷ 5	1 ÷ 5	1 ÷ 7
Leaf Area Index (LAI)	Δx	km	50 ÷ 100	10 ÷ 50			0.01 ÷ 10	0.01 ÷ 10
	r.m.s.	%	5 ÷ 20	5 ÷ 20			5 ÷ 10	5 ÷ 20
	Δt	d	7 ÷ 30	7 ÷ 30			5 ÷ 7	7 ÷ 24
	delay	d	1 ÷ 7	1 ÷ 7			1 ÷ 5	1 ÷ 5
Photosynthetically Active Radiation (PAR)	Δx	km					5 ÷ 100	
	r.m.s.	W/m^2					10 ÷ 50	
	Δt	d					0.0416 ÷ 7	
	delay	d					1 ÷ 5	
Vegetation type	Δx	m					50 ÷ 500	10 ÷ 1000
	r.m.s.	classes^{-1}					0.033 ÷ 0.2	0.02 ÷ 0.2
	Δt	d					30 ÷ 60	7 ÷ 365
	delay	d					1 ÷ 7	1 ÷ 30
Fires (extension and temperature)	Δx	km				5 ÷ 250	0.01 ÷ 10	
	rms (extent)	%				10 ÷ 20	10 ÷ 20	
	rms (temp.)	K				500 ÷ 1000	50 ÷ 200	
	Δt	d				0.25 ÷ 12	0.25 ÷ 1	
	delay	d				1 ÷ 4	0.042 ÷ 0.25	
Land cover	Δx	m					100 ÷ 10	10 ÷ 25000
	r.m.s.	classes^{-1}					0.1 ÷ 0.25	0.02 ÷ 0.2
	Δt	y					1 ÷ 2	0.02 ÷ 1
	delay	d					10 ÷ 30	1 ÷ 7
Soil type	Δx	km					0.1 ÷ 10	
	r.m.s.	classes^{-1}					0.067 ÷ 0.2	
	Δt	y					1 ÷ 2	
	delay	d					10 ÷ 30	
Land surface imagery	Δx	m						10 ÷ 25000
	r.m.s.	N/A						N/A
	Δt	d						1 ÷ 365
	delay	d						1 ÷ 7
Land surface topography	Δx	m						100 ÷ 1000
	rms (hor.)	m						1 ÷ 5
	rms (vert.)	m						1 ÷ 5
	Δt	y						10 ÷ 50
	delay	d						30 ÷ 600

Table A1 - WMO requirements for data from satellites (sheet 6 of 6)

(sheet dedicated to Atmospheric Chemistry)

Atmospheric volume	**Req.mt**	**Unit**	**Aerosol**	**O_3**	**H_2O**	**CH_4**	**CO**	**N_2O**	**CO_2**	**CFC-11 , CFC-12**	**OH**	**NO**	**NO_2**	**HNO_3**	**HCl**	**BrO, ClO , $ClONO_2$**	**Cloud imagery**
1 Lower troposphere	Δx	km	50 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500		50 ÷ 500		100 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500			
	Δz	km	1 ÷ 5	1 ÷ 5	1 ÷ 5	1 ÷ 4	1 ÷ 4		1 ÷ 4		1 ÷ 1.5	1 ÷ 4	1 ÷ 4	1 ÷ 4			
	r.m.s.	%	5 ÷ 20	3 ÷ 20	5 ÷ 20	2 ÷ 10	5 ÷ 10		2 ÷ 5		5 ÷ 30	5 ÷ 10	5 ÷ 10	5 ÷ 10			
	Δt	h	6 ÷ 24	3 ÷ 168	6 ÷ 72	6 ÷ 24	6 ÷ 24		6 ÷ 24		6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24			
	delay	h	12 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168		72 ÷ 168		72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168			
2 Higher troposphere	Δx	km	50 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	100 ÷ 500		100 ÷ 500	100 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	100 ÷ 500	100 ÷ 500	
	Δz	km	1 ÷ 5	1 ÷ 5	1 ÷ 5	1 ÷ 4	1 ÷ 4	1 ÷ 3		1 ÷ 3	1 ÷ 1.5	1 ÷ 4	1 ÷ 4	1 ÷ 4	1 ÷ 1.5	1 ÷ 3	
	r.m.s.	%	10 ÷ 20	3 ÷ 20	5 ÷ 20	2 ÷ 10	5 ÷ 10	2 ÷ 20		5 ÷ 10	5 ÷ 30	5 ÷ 10	5 ÷ 10	5 ÷ 10	2 ÷ 5	5 ÷ 10	
	Δt	h	6 ÷ 24	3 ÷ 168	12 ÷ 72	6 ÷ 24	6 ÷ 24	6 ÷ 24		6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	
	delay	h	12 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168		72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	
3 Lower stratosphere	Δx	km	50 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	100 ÷ 500		100 ÷ 500	100 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	100 ÷ 500	100 ÷ 500	
	Δz	km	1 ÷ 5	1 ÷ 5	1 ÷ 5	1 ÷ 4	1 ÷ 4	1 ÷ 3		1 ÷ 3	1 ÷ 3	1 ÷ 4	1 ÷ 4	1 ÷ 4	1 ÷ 3	1 ÷ 3	
	r.m.s.	%	10 ÷ 20	3 ÷ 20	5 ÷ 20	2 ÷ 10	5 ÷ 10	2 ÷ 20		5 ÷ 10	5 ÷ 30	5 ÷ 10	5 ÷ 10	5 ÷ 10	2 ÷ 5	5 ÷ 10	
	Δt	h	6 ÷ 24	3 ÷ 168	12 ÷ 72	6 ÷ 24	6 ÷ 24	6 ÷ 24		6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	
	delay	h	12 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168		72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	
4 Higher stratosphere, mesosphere	Δx	km	50 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500		100 ÷ 500		100 ÷ 500	100 ÷ 500	50 ÷ 500	50 ÷ 500	50 ÷ 500	100 ÷ 500	100 ÷ 500	
	Δz	km	1 ÷ 10	1 ÷ 5	1 ÷ 5	1 ÷ 4		1 ÷ 3		1 ÷ 3	1 ÷ 3	1 ÷ 4	1 ÷ 4	1 ÷ 4	1 ÷ 3	1 ÷ 3	
	r.m.s.	%	10 ÷ 20	5 ÷ 25	5 ÷ 20	2 ÷ 10		2 ÷ 20		5 ÷ 10	5 ÷ 30	5 ÷ 10	5 ÷ 10	5 ÷ 10	2 ÷ 5	5 ÷ 10	
	Δt	h	6 ÷ 24	3 ÷ 48	12 ÷ 72	6 ÷ 24		6 ÷ 24		6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	6 ÷ 24	
	delay	h	12 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168		72 ÷ 168		72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	72 ÷ 168	
5 **Total column**	Δx	km		25 ÷ 100									50 ÷ 500				100 ÷ 200
	r.m.s.	%		6 ÷ 20									5 ÷ 15				N/A
	Δt	h		6 ÷ 48									24 ÷ 48				3 ÷ 12
	delay	h		3 ÷ 168									72 ÷ 168				72 ÷ 72

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 1 of 9)

Geophysical parameter	Atmospheric volume	Req.mt	Unit	GCOS AOPC	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global model	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Temperature profile	1 Lower troposphere	Δx	km	100 ÷ 500						50 ÷ 500	50 ÷ 500			
		Δz	km	0.1 ÷ 2						0.3 ÷ 3	0.5 ÷ 2			
		r.m.s.	K	0.5 ÷ 2						0.5 ÷ 3	0.5 ÷ 1			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	2 Higher troposphere	Δx	km	100 ÷ 500						50 ÷ 500	50 ÷ 500			
		Δz	km	0.5 ÷ 1						1 ÷ 3	0.5 ÷ 2			
		r.m.s.	K	0.5 ÷ 2						0.5 ÷ 3	0.5 ÷ 1			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	3 Lower stratosphere	Δx	km	100 ÷ 500						50 ÷ 500	50 ÷ 500			
		Δz	km	0.5 ÷ 1						1 ÷ 3	1 ÷ 3			
		r.m.s.	K	0.5 ÷ 2						0.5 ÷ 3	0.5 ÷ 2			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	4 Higher stratosphere, mesosphere	Δx	km	100 ÷ 500						50 ÷ 500	50 ÷ 500			
		Δz	km	2 ÷ 3						5 ÷ 10	0.5 ÷ 2			
		r.m.s.	K	1 ÷ 3						1 ÷ 3	0.5 ÷ 1			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
Wind profile (horizontal component)	1 Lower troposphere	Δx	km	100 ÷ 500						50 ÷ 500	200 ÷ 500			
		Δz	km	0.1 ÷ 2						0.3 ÷ 5	0.5 ÷ 2			
		r.m.s.	m/s	2 ÷ 5						2 ÷ 5	3 ÷ 5			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	2 Higher troposphere	Δx	km	100 ÷ 500						50 ÷ 500	200 ÷ 500			
		Δz	km	0.5 ÷ 1						1 ÷ 5	0.5 ÷ 2			
		r.m.s.	m/s	2 ÷ 5						2 ÷ 5	3 ÷ 5			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	3 Lower stratosphere	Δx	km	100 ÷ 500						50 ÷ 500	200 ÷ 500			
		Δz	km	0.5 ÷ 1						1 ÷ 5	0.5 ÷ 2			
		r.m.s.	m/s	2 ÷ 5						2 ÷ 5	3 ÷ 5			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	4 Higher stratosphere, mesosphere	Δx	km	100 ÷ 500						50 ÷ 500	200 ÷ 500			
		Δz	km	2 ÷ 3						2 ÷ 5	0.5 ÷ 2			
		r.m.s.	m/s	3 ÷ 7						3 ÷ 5	3 ÷ 5			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 2 of 9)

Geophysical parameter	**Atmospheric volume**	**Req.mt**	**Unit**	**GCOS AOPC**	**GOOS Clim large**	**GOOS Clim meso**	**GOOS Marine open**	**GOOS Marine coast**	**GTOS**	**WCRP Global model**	**WCRP SPARC**	**WCRP GEWEX**	**WCRP ACSYS**	**WCRP CLIVAR**
Specific humidity profile	1 Lower troposphere	Δx	km	100 ÷ 500						50 ÷ 100	50 ÷ 500			
		Δz	km	0.1 ÷ 2						0.5 ÷ 2	0.5 ÷ 2			
		r.m.s.	g/kg	0.25 ÷ 1						0.25 ÷ 1	0.1 ÷ 0.25			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	2 Higher troposphere	Δx	km	100 ÷ 500						50 ÷ 100	50 ÷ 500			
		Δz	km	0.5 ÷ 1						0.5 ÷ 2	0.5 ÷ 2			
		r.m.s.	g/kg	0.025 ÷ 0.1						0.025 ÷ 0.1	0.01 ÷ 0.025			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	3 Lower stratosphere	Δx	km	100 ÷ 500						50 ÷ 250	50 ÷ 500			
		Δz	km	0.5 ÷ 1						0.5 ÷ 2	0.5 ÷ 2			
		r.m.s.	g/kg	0.025 ÷ 0.1						0.025 ÷ 0.1	0.01 ÷ 0.025			
		Δt	h	3 ÷ 6						3 ÷ 12	6 ÷ 72			
		delay	h	3 ÷ 12						720 ÷ 1440	24 ÷ 168			
	4 Higher stratosphere, mesosphere	Δx	km							50 ÷ 250	50 ÷ 500			
		Δz	km							1 ÷ 3	0.5 ÷ 2			
		r.m.s.	g/kg							0.025 ÷ 0.1	0.01 ÷ 0.025			
		Δt	h							3 ÷ 12	6 ÷ 72			
		delay	h							720 ÷ 1440	24 ÷ 168			
	5 **Total column** (precipitable water)	Δx	km	100 ÷ 500										
		r.m.s.	g/m^2	1000 ÷ 1000										
		Δt	h	3 ÷ 6										
		delay	h	3 ÷ 12										
Cloud water profile **liquid (< 100 µm)** **liquid (> 100 µm)**	1 Lower troposphere	Δx	km									50 ÷ 250		
		Δz	km									1 ÷ 5		
		r.m.s.	%									5 ÷ 20		
		Δt	h									3 ÷ 12		
		delay	h									720 ÷ 1440		
	2 Higher troposphere	Δx	km									50 ÷ 250		
		Δz	km									1 ÷ 10		
		r.m.s.	%									5 ÷ 20		
		Δt	h									3 ÷ 12		
		delay	h									720 ÷ 1440		
	5 **Total column**	Δx	km	100 ÷ 500								50 ÷ 250		
		r.m.s.	g/m^2	missing								10 ÷ 50		
		Δt	h	3 ÷ 6								3 ÷ 12		
		delay	h	3 ÷ 12								720 ÷ 1440		

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 3 of 9)

Geophysical parameter	Atmospheric volume	Req.mt	Unit	GCOS AOPC	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global model	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Cloud ice profile	1 Lower troposphere	Δx	km									50 ÷ 250		
		Δz	km									1 ÷ 2		
		r.m.s.	%									5 ÷ 20		
		Δt	h									3 ÷ 12		
		delay	h									720 ÷ 1440		
	2 Higher troposphere	Δx	km									50 ÷ 250		
		Δz	km									1 ÷ 5		
		r.m.s.	%									5 ÷ 20		
		Δt	h									3 ÷ 12		
		delay	h									720 ÷ 1440		
	3 Lower stratosphere	Δx	km									50 ÷ 250		
		Δz	km									1 ÷ 5		
		r.m.s.	%									5 ÷ 20		
		Δt	h									3 ÷ 12		
		delay	h									720 ÷ 1440		
	4 Higher stratosphere, mesosphere	Δx	km									50 ÷ 250		
		Δz	km									1 ÷ 5		
		r.m.s.	%									5 ÷ 20		
		Δt	h									3 ÷ 12		
		delay	h									720 ÷ 1440		
	5 **Total column**	Δx	km	100 ÷ 500								50 ÷ 250		
		r.m.s.	g/m^2	missing								10 ÷ 20		
		Δt	h	3 ÷ 6								3 ÷ 12		
		delay	h	3 ÷ 12								720 ÷ 1440		
Aerosol profile	1 Lower troposphere	Δx	km							50 ÷ 500	100 ÷ 500			
		Δz	km							0.1 ÷ 1	0.5 ÷ 2			
		r.m.s.	%							10 ÷ 20	10 ÷ 20			
		Δt	h							6 ÷ 168	6 ÷ 72			
		delay	h							720 ÷ 1440	24 ÷ 168			
	2 Higher troposphere	Δx	km							50 ÷ 500	100 ÷ 500			
		Δz	km							1 ÷ 5	0.5 ÷ 2			
		r.m.s.	%							10 ÷ 20	10 ÷ 20			
		Δt	h							6 ÷ 168	6 ÷ 72			
		delay	h							720 ÷ 1440	24 ÷ 168			
	3 Lower stratosphere	Δx	km							50 ÷ 500	100 ÷ 500			
		Δz	km							1 ÷ 10	0.5 ÷ 2			
		r.m.s.	%							10 ÷ 20	10 ÷ 20			
		Δt	h							6 ÷ 168	6 ÷ 72			
		delay	h							720 ÷ 1440	24 ÷ 168			
	4 Higher stratosphere, mesosphere	Δx	km								100 ÷ 500			
		Δz	km								0.5 ÷ 2			
		r.m.s.	%								10 ÷ 20			
		Δt	h								6 ÷ 72			
		delay	h								24 ÷ 168			
	5 **Total column**	Δx	km						1 ÷ 4					
		r.m.s.	%						missing					
		Δt	h						24 ÷ 48					
		delay	h						24 ÷ 120					

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 4 of 9)

Geophysical parameter	Atmospheric volume	Req.mt	Unit	GCOS AOPC	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global model	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Ozone profile	1 Lower troposphere	Δx	km								50 ÷ 500			
		Δz	km								0.5 ÷ 2			
		r.m.s.	%								5 ÷ 10			
		Δt	h								6 ÷ 72			
		delay	h								24 ÷ 168			
	2 Higher troposphere	Δx	km								50 ÷ 500			
		Δz	km								0.5 ÷ 2			
		r.m.s.	%								5 ÷ 10			
		Δt	h								6 ÷ 72			
		delay	h								24 ÷ 168			
	3 Lower stratosphere	Δx	km								50 ÷ 500			
		Δz	km								0.5 ÷ 2			
		r.m.s.	%								5 ÷ 10			
		Δt	h								6 ÷ 72			
		delay	h								24 ÷ 168			
	4 Higher stratosphere, mesosphere	Δx	km								50 ÷ 500			
		Δz	km								0.5 ÷ 2			
		r.m.s.	%								5 ÷ 10			
		Δt	h								6 ÷ 72			
		delay	h								24 ÷ 168			
	5 **Total column**	Δx	km	50 ÷ 200					1 ÷ 8					
		r.m.s.	DU	10 ÷ 20					missing					
		Δt	h	24 ÷ 48					24 ÷ 48					
		delay	h	3 ÷ 7					240 ÷ 720					

Geophysical parameter	Req.mt	Unit	GCOS	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global mod	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Cloud imagery	Δx	km						1 ÷ 10					
	r.m.s.	N/A						N/A					
	Δt	h						3 ÷ 12					
	delay	h						12 ÷ 24					
Cloud cover	Δx	km	100 ÷ 500								50 ÷ 250		
	r.m.s.	%	10 ÷ 20								5 ÷ 20		
	Δt	h	3 ÷ 6								3 ÷ 12		
	delay	h	3 ÷ 12								720 ÷ 1440		
Cloud top height	Δx	km	100 ÷ 500									100 ÷ 500	
	r.m.s.	km	0.5 ÷ 2									0.5 ÷ 1	
	Δt	h	3 ÷ 6									12 ÷ 24	
	delay	h	3 ÷ 12									24 ÷ 48	
Cloud top temperature	Δx	km									50 ÷ 250		
	r.m.s.	K									0.5 ÷ 2		
	Δt	h									3 ÷ 12		
	delay	h									720 ÷ 1440		
Cloud base height	Δx	km									50 ÷ 250		
	r.m.s.	km									0.5 ÷ 2		
	Δt	h									3 ÷ 12		
	delay	h									720 ÷ 1440		

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 5 of 9)

Geophysical parameter	Req.mt	Unit	GCOS	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global mod	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Precipitation rate at the ground (liquid)	Δx	km	100 ÷ 500					1 ÷ 10					
	r.m.s.	mm/h	0.6 ÷ 2					0.05 ÷ 0.1					
	Δt	h	3 ÷ 6					3 ÷ 6					
	delay	h	3 ÷ 12					24 ÷ 120					
Precipitation rate at the ground (solid)	Δx	km	100 ÷ 500					1 ÷ 10					
	r.m.s.	mm/h	0.6 ÷ 2					0.05 ÷ 0.1					
	Δt	h	3 ÷ 6					3 ÷ 6					
	delay	h	3 ÷ 12					24 ÷ 120					
Precipitation index (daily cumulative)	Δx	km									50 ÷ 250		
	r.m.s.	mm/d									0.5 ÷ 5		
	Δt	h									1 ÷ 12		
	delay	h									720 ÷ 1440		
Solar irradiance at TOA	Δx	N/A	N/A						N/A				
	s.d.	W/m^2	5 ÷ 10						0.1 ÷ 1				
	bias	W/m^2	missing						missing				
	Δt	d	0.125 ÷ 7						1 ÷ 6				
	delay	d	0.125 ÷ 1						30 ÷ 90				
Short-wave outgoing radiation at TOA	Δx	km	200 ÷ 500							50 ÷ 250			
	s.d.	W/m^2	5 ÷ 10							5 ÷ 10			
	bias	W/m^2	missing							missing			
	Δt	h	3 ÷ 6							3 ÷ 6			
	delay	h	3 ÷ 24							720 ÷ 2160			
Long-wave outgoing radiation at TOA	Δx	km	200 ÷ 500					50 ÷ 100		50 ÷ 250			
	s.d.	W/m^2	5 ÷ 10					5 ÷ 10		5 ÷ 10			
	bias	W/m^2	missing					missing		missing			
	Δt	h	3 ÷ 6					480 ÷ 1440		3 ÷ 6			
	delay	h	3 ÷ 24					720 ÷ 2160		720 ÷ 2160			
Aerosol (total column) size	Δx	km				4 ÷ 50	1 ÷ 10						
	r.m.s.	μm				0.1 ÷ 1	0.1 ÷ 1						
	Δt	h				24 ÷ 48	24 ÷ 48						
	delay	h				3 ÷ 7	3 ÷ 7						
Cloud optical thickness	Δx	km										100 ÷ 500	
	r.m.s.	%										15 ÷ 30	
	Δt	h										12 ÷ 24	
	delay	h										24 ÷ 48	
Short-wave Earth surface radiation	Δx	km						25 ÷ 100					
	r.m.s.	W/m^2						5 ÷ 10					
	Δt	h						24 ÷ 120					
	delay	h						24 ÷ 720					
Long-wave Earth surface radiation	Δx	km						25 ÷ 100					
	r.m.s.	W/m^2						5 ÷ 10					
	Δt	h						3 ÷ 6					
	delay	h						24 ÷ 120					

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 6 of 9)

Geophysical parameter	Req.mt	Unit	GCOS	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global mod	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Air pressure over sea surface	Δx	km				50 ÷ 100							
	r.m.s.	hPa				10 ÷ 15							
	Δt	h				24 ÷ 48							
	delay	h				3 ÷ 7							
Air relative humidity (at surface)	Δx	km						25 ÷ 100				100 ÷ 500	
	r.m.s.	%						1 ÷ 2				10 ÷ 20	
	Δt	h						3 ÷ 6				12 ÷ 24	
	delay	h						24 ÷ 72				24 ÷ 48	
Air temperature (at surface)	Δx	km						25 ÷ 100				100 ÷ 500	
	r.m.s.	K						0.2 ÷ 0.5				0.2 ÷ 0.5	
	Δt	h						3 ÷ 12				12 ÷ 24	
	delay	h						24 ÷ 48				24 ÷ 48	
Wind over land surface (vector and speed)	Δx	km						25 ÷ 100					
	rms vector	m/s						2 ÷ 5					
	rms speed	m/s						missing					
	Δt	h						24 ÷ 120					
	delay	h						24 ÷ 240					
Wind over sea surface (vector and speed)	Δx	km	100 ÷ 500	25 ÷ 100		4 ÷ 50			50 ÷ 250			25 ÷ 100	50 ÷ 250
	rms vector	m/s	2 ÷ 5	1 ÷ 2		2 ÷ 5			1 ÷ 5			1 ÷ 5	1 ÷ 5
	rms speed	m/s	missing	1 ÷ 2		missing			missing			missing	missing
	Δt	h	3 ÷ 6	24 ÷ 168		24 ÷ 48			12 ÷ 24			12 ÷ 24	12 ÷ 24
	delay	h	3 ÷ 12	24 ÷ 168		3 ÷ 7			720 ÷ 1440			720 ÷ 1440	72 ÷ 168
Sea surface temperature	Δx	km	100 ÷ 500	10 ÷ 300	1 ÷ 10	10 ÷ 50	1 ÷ 5		50 ÷ 250			25 ÷ 100	10 ÷ 50
	s.d.	K	0.3 ÷ 1	0.1 ÷ 1	0.1 ÷ 2	0.1 ÷ 0.5	0.1 ÷ 0.5		0.5 ÷ 2			0.5 ÷ 2	0.1 ÷ 0.3
	bias	K	missing	missing	missing	missing	missing		missing			missing	missing
	Δt	h	24 ÷ 72	6 ÷ 720	6 ÷ 12	24 ÷ 48	24 ÷ 48		1÷ 12			24÷ 48	3 ÷ 6
	delay	h	3 ÷ 12	6 ÷ 720	2 ÷ 4	3 ÷ 7	3 ÷ 7		720 ÷ 1440			720 ÷ 1440	24 ÷ 72
Significant wave height	Δx	km	100 ÷ 250						100 ÷ 250				
	r.m.s.	m	0.5 ÷ 2						0.5 ÷ 1				
	Δt	h	3 ÷ 6						12 ÷ 24				
	delay	h	3 ÷ 12						720÷ 1440				
Dominant wave period and direction	Δx	km			10 ÷ 30								
	rms period	s			0.5 ÷ 1								
	rms direct.	degrees			missing								
	Δt	h			1 ÷ 6								
	delay	h			2 ÷ 4								
Ocean topography	Δx	km		100 ÷ 300	25 ÷ 100								100 ÷ 200
	r.m.s.	cm		2 ÷ 5	2 ÷ 10								2 ÷ 5
	Δt	d		10 ÷ 30	7 ÷ 30								5 ÷ 10
	delay	d		10 ÷ 30	2 ÷ 15								10 ÷ 30

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 7 of 9)

Geophysical parameter	Req.mt	Unit	GCOS	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global mod	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Ocean chlorophyll	Δx	km		25 ÷ 100		10 ÷ 50	1 ÷ 5						100 ÷ 500
	r.m.s.	mg/m^3		0.1 ÷ 0.5		0.1 ÷ 0.5	0.1 ÷ 0.5						missing
	Δt	d		1 ÷ 3		1 ÷ 3	1 ÷ 3						1 ÷ 6
	delay	d		1 ÷ 3		3 ÷ 7	3 ÷ 7						30 ÷ 90
Ocean suspended sediments	Δx	km											100 ÷ 500
	r.m.s.	mg/m^3											missing
	Δt	d											1 ÷ 6
	delay	d											30 ÷ 90
Ocean yellow substance	Δx	km				1 ÷ 5							100 ÷ 500
	r.m.s.	mg/m^3				0.3 ÷ 1							missing
	Δt	d				1 ÷ 2							1 ÷ 6
	delay	d				3 ÷ 7							30 ÷ 90
Ocean salinity	Δx	km		200 ÷ 500									100 ÷ 250
	r.m.s.	‰		0.1 ÷ 1									0.1 ÷ 0.3
	Δt	d		10 ÷ 30									30 ÷ 60
	delay	d		10 ÷ 30									9 ÷ 120
Sea-ice cover	Δx	km	100 ÷ 500	10 ÷ 100					15 ÷ 250			25 ÷ 100	15 ÷ 50
	r.m.s.	%	10 ÷ 20	2 ÷ 10					5 ÷ 50			5 ÷ 10	2 ÷ 5
	Δt	d	1 ÷ 7	1 ÷ 6					1 ÷ 15			1 ÷ 7	1 ÷ 3
	delay	d	0.125 ÷ 1	0.125 ÷ 1					30 ÷ 90			7 ÷ 30	3 ÷ 7
Sea-ice surface temperature	Δx	km										100 ÷ 500	
	r.m.s.	K										1 ÷ 2	
	Δt	h										12 ÷ 24	
	delay	h										24 ÷ 48	
Ice-sheet topography	Δx	km						0.01 ÷ 0.05				0.1 ÷ 0.5	
	rms (hor.)	m						0.5 ÷ 1				5 ÷ 10	
	rms (vert.)	m						missing				missing	
	Δt	y						5 ÷ 10				10 ÷ 15	
	delay	d						365 ÷ 720				30 ÷ 90	
Ice thickness	Δx	km			25 ÷ 100							200 ÷ 500	
	r.m.s.	m			0.5 ÷ 1							1 ÷ 2	
	Δt	d			1 ÷ 6							7 ÷ 30	
	delay	d			1 ÷ 6							30 ÷ 90	
Icebergs (extension and height)	Δx	km										1 ÷ 10	
	rms ext.	%										10 ÷ 20	
	rms height	m										missing	
	Δt	d										365 ÷ 1500	
	delay	d										30 ÷ 90	

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 8 of 9)

Geophysical parameter	Req.mt	Unit	GCOS	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global mod	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Snow cover	Δx	km	100 ÷ 500					1 ÷ 5			15 ÷ 250	1 ÷ 25	
	r.m.s.	%	10 ÷ 20					5 ÷ 10			10 ÷ 50	10 ÷ 20	
	Δt	d	1 ÷ 7					1 ÷ 3			1 ÷ 7	1 ÷ 5	
	delay	d	0.125 ÷ 1					2 ÷ 3			30 ÷ 90	7 ÷ 30	
Snow melting condition	Δx	km						10 ÷ 25					
	r.m.s.	classes^{-1}						0.167 ÷ 0.5					
	Δt	h						24 ÷ 72					
	delay	h						48 ÷ 72					
Snow depth	Δx	km						25 ÷ 100				10 ÷ 25	
	r.m.s.	m						0.02 ÷ 0.2				0.05 ÷ 0.2	
	Δt	d						1 ÷ 10				1 ÷ 5	
	delay	d						1 ÷ 5				7 ÷ 30	
Snow water equivalent	Δx	km	100 ÷ 500					10 ÷ 25			15 ÷ 250	10 ÷ 25	
	r.m.s.	mm	5 ÷ 10					5 ÷ 10			5 ÷ 20	5 ÷ 20	
	Δt	d	1 ÷ 7					1 ÷ 3			0.5 ÷ 7	1 ÷ 5	
	delay	d	0.125 ÷ 1					2 ÷ 3			30 ÷ 90	7 ÷ 30	
Glacier cover	Δx	m						10 ÷ 100					
	r.m.s.	%						10 ÷ 20					
	Δt	y						30 ÷ 50					
	delay	d						720 ÷ 1500					
Permafrost	Δx	km						0.01 ÷ 1					
	r.m.s.	%						missing					
	Δt	d						10 ÷ 365					
	delay	d						90 ÷ 365					
Land surface temperature	Δx	km	100 ÷ 500								50 ÷ 250		
	r.m.s.	K	1 ÷ 3								1 ÷ 4		
	Δt	h	3 ÷ 6								3 ÷ 12		
	delay	h	3 ÷ 6								720 ÷ 1440		
Soil moisture	Δx	km						25 ÷ 100			15 ÷ 250		
	r.m.s.	g/kg						missing			10 ÷ 50		
	Δt	d						1 ÷ 5			1 ÷ 10		
	delay	d						3 ÷ 5			10 ÷ 30		

Table A2 - GCOS/GOOS/GTOS/WCRP requirements for data from satellites (sheet 9 of 9)

Geophysical parameter	Req.mt	Unit	GCOS	GOOS Clim large	GOOS Clim meso	GOOS Marine open	GOOS Marine coast	GTOS	WCRP Global mod	WCRP SPARC	WCRP GEWEX	WCRP ACSYS	WCRP CLIVAR
Normalized Difference Vegetation Index (NDVI)	Δx	km	50 ÷ 100										
	r.m.s.	%	10 ÷ 20										
	Δt	d	7 ÷ 30										
	delay	d	10 ÷ 30										
Leaf Area Index (LAI)	Δx	km						0.1 ÷ 1					
	r.m.s.	%						20 ÷ 100					
	Δt	d						10 ÷ 30					
	delay	d						10 ÷ 30					
Photosynthetically Active Radiation (PAR)	Δx	km				10 ÷ 50	1 ÷ 5						
	r.m.s.	W/m^2				10 ÷ 50	10 ÷ 50						
	Δt	d				0.04 ÷ 1	0.04 ÷ 1						
	delay	d				3 ÷ 7	3 ÷ 7						
Fractional Photosynthetically Active Radiation (FPAR)	Δx	km						0.1 ÷ 2					
	r.m.s.	%						5 ÷ 10					
	Δt	d						10 ÷ 30					
	delay	d						10 ÷ 30					
Vegetation hydric stress index	Δx	km						0.1 ÷ 4					
	r.m.s.	%						10 ÷ 20					
	Δt	d						0.04 ÷ 1					
	delay	d						1 ÷ 2					
Fires (extension and temperature)	Δx	km						0.1 ÷ 1					
	rms (ext.)	%						10 ÷ 20					
	rms (tem)	K						missing					
	Δt	d						10 ÷ 365					
	delay	d						30 ÷ 90					
Land cover	Δx	m						100 ÷ 1000					
	r.m.s.	classes^{-1}						0.02 ÷ 0.05					
	Δt	y						1 ÷ 10					
	delay	d						90 ÷ 365					
Land use	Δx	m						100 ÷ 1000					
	r.m.s.	classes^{-1}						0.01 ÷ 0.2					
	Δt	y						1 ÷ 10					
	delay	d						180 ÷ 365					
Land surface imagery	Δx	m						1 ÷ 10					
	r.m.s.	N/A						N/A					
	Δt	d						1500 ÷ 3000					
	delay	d						1500 ÷ 3000					
Land surface topography	Δx	m						10 ÷ 1000					
	rms (hor.)	m						30 ÷ 100					
	rms (vert.)	m						missing					
	Δt	y						10 ÷ 30					
	delay	d						720 ÷ 1500					
Geoid	Δx	km		250 ÷ 500									
	r.m.s.	cm		2 ÷ 5									
	Δt	y		20 ÷ 30									
	delay	y		12 ÷ 24									