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

EXPERT TEAM ON OBSERVATIONAL DATA REQUIREMENTS
AND REDESIGN OF THE GLOBAL OBSERVING SYSTEM

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PERSPECTIVES OF THE USE OF R&D SATELLITES IN THE GLOBAL OBSERVING SYSTEMS (GOS) OPERATIONS

(Submitted by the WMO Secretariat)

Summary and Purpose of Document

To inform the Expert Team on developments with regard to the space-based Global Observing System (GOS).

ACTION PROPOSED

To review the request from the fifty third session of the Executive Council to the Commission for Basic Systems and make proposals for enhancement to the space-based GOS, utilizing recommendations from the 29th session of the Coordination Group for Meteorological Satellites (CGMS-XXIX)), as appropriate.

Reference: EUM-WP-6 presented at the CGMS-XXIX and reproduced as INF.1 for this meeting.

PERSPECTIVES OF THE USE OF R&D SATELLITES IN THE GLOBAL OBSERVING SYSTEMS (GOS) OPERATIONS

Background

In the period of time since the last Expert Team on Observational Data Requirements and Redesign of the GOS, several activities have occurred that have direct bearing on the work of the Expert Team. The first and most important was the fifty-third session of the WMO Executive Council where the Commission for Basic Systems (CBS) was requested to expand the description of the space-based GOS to include Research and Development (R&D) satellite missions. The second related activity was the twenty-ninth session of the Coordination Group on Meteorological Satellites (CGMS-XXIX)) that discussed a paper prepared by EUMETSAT “towards an updated/upgraded GOS”. The third relevant activity was a meeting of the CBS OPAG IOS Task Team on Regulatory Material held in Geneva 26 – 30 November 2001. The present document reviews the request from the fifty-third session of the WMO Executive Council and recommendations from CGMS.

Fifty-third session of the WMO Executive Council

The Executive Council was informed that the First Consultative Meeting on High Level Policy on Satellite Matters was held in Geneva, Switzerland, 23-24 January 2001 and had reviewed the support provided by the present R&D satellite missions to WMO Programmes. The review highlighted the significant contributions already made by R&D satellite missions in support of WMO Programmes.

The Executive Council endorsed the *Guidelines for requirements for observational data from operational and R&D satellite missions* in order to provide operational users a measure of confidence in the availability of operational and R&D observational data, and data providers with an indication of its utility.

The Executive Council reviewed possible configurations for the space-based component of the GOS that included R&D missions as well as the existing constellations of environmental geostationary and near-polar-orbiting satellites. The configurations were based on the assumption that the *Guidelines for requirements for observational data from operational and R&D satellite missions* would be agreed upon by the space agencies as had been done by the fifty-third Executive Council.

In reviewing the basis for the need to propose new configurations, the Executive Council recalled the requirements setting process within WMO. It noted that WMO followed a process that resulted in a hierarchical set of requirements. At the highest level, WMO was guided by its Long-term Planning Process. The Fifth Long-term Plan was the current plan and spanned the time frame 2000 to 2009. The Executive Council also noted, that in the nearer term, the four year Programme and Budget for WMO contained guidance, objectives, opportunities and challenges that were based on the long-term objectives. The Executive Council recalled that detailed observational requirements for the various application areas found within the WMO and supported programmes were available. Furthermore, CBS in meeting its mandate to provide the basic infrastructure for all WMO Programmes was already considering a redesign of the Global Observing System. The Executive Council was pleased to note the Rolling Review of Requirements (RRR) process that had been formally approved by CBS . The RRR process had four distinct steps: a compilation and review of observational requirements resulting in a consolidated set of observational requirements unique to an application area, development of expected performances for both *in situ* and satellite-based observing systems, an objective comparison of how well the requirements were met by the observing systems, and a Statement of Guidance that was an evaluation of the objective comparison by experts in the various application areas. The Executive Council was informed that three such Statements of Guidance had already been published as WMO Satellite Activities technical documents.

In view of the existing process within WMO to provide a hierarchical set of requirements, the Executive Council felt that the most appropriate manner to satisfy the full suite of present requirements, while recognizing the capabilities of both operational meteorological and Research and Development satellites, would be to expand the present definition of the space-based Global Observing System to include Research and Development satellites, complementing the existing two operational meteorological satellite constellations (geostationary and near-polar-orbiting). Enhancements to the overall space-based component of the Global Observing System would be incremental as new contributions from the R&D satellites were realized. The Executive Council agreed that the expansion of the definition should be through a resolution by WMO constituent bodies, especially CBS, thus formalizing the high-level system requirements that would provide the necessary observational data for WMO and supported programmes.

Therefore, the Executive Council requested CBS to review, as a matter of urgency in order to provide the fourteenth WMO Congress appropriate input, the space-based component of the Global Observing System with a goal of defining an overall system that included appropriately identified R&D satellite missions. The Commission should be guided by the WMO process for its hierarchical set of requirements in order to ensure that the new space-based component would be justified by WMO needs.

The Executive Council also encouraged CBS to be forward looking in proposing enhancements to the space-based component of the Global Observing System. It should account for the differences between operational environmental satellites and R&D satellites. There were different levels of maturity within the various R&D satellites. Flexibility and adaptability must be included into the new design.

The Executive Council suggested that CBS review and make appropriate changes to the definitions as contained in the Guide and Manual for the GOS for the present polar-orbiting and geostationary satellites. The changes should be flexible enough to: (1) accommodate proven and existing operational meteorological and other related environmental observations and services; (2) enhance these capabilities based on the evolution of scientific understanding and technological innovations; and (3) adopt new and mature capabilities and provide the associated services mandated by emerging requirements such as, but not limited to:

- Improved understanding of the structure and dynamics of the atmosphere through, for example, soundings of temperature and humidity, improved wind profiles and better rainfall estimates;

- Improved knowledge of the ocean structure and circulation through, for example, operational surface wind vectors and ocean surface topography;

- Better knowledge of the chemistry of the atmosphere, for example, through measurement of ozone, carbon dioxide, and other trace gases;

- Better understanding of the changes in the terrestrial and marine ecosystems and their role in the carbon cycle;

- Improved knowledge of the cycling of water and energy through the earth system to enable better management of global fresh water resources;

- Increased emphasis on calibrated instruments with a view to a better understanding of climate change;

- Improved global coverage from geostationary orbit using at least six operational spacecraft;

- Improved detection and monitoring of hazardous atmospheric phenomena such as fog and volcanic ash.

Twenty-ninth session of CGMS

EUMETSAT provided a presentation and working paper covering discussions initiated at CGMS-XXVII in October 1999 and continued at CGMS-XXVIII in October 2000. The working paper was also presented to its Scientific and Technology Group (STG). These discussions had been further advanced as a result of a CGMS Workshop on Long-term Future of the Basic Sounding and Imagery Missions held in Geneva from 23-24 April 2001.

The working paper addressed areas where gaps between user requirements and space capabilities could be identified. These gaps were categorised by geophysical parameters and thematic areas (e.g., atmospheric thermodynamics, atmospheric dynamics, atmospheric chemistry, clouds and precipitation, clouds and radiation, ocean surface and sea-ice, land surface and vegetation). As a result of this analysis, 42 recommendations were drawn up on how to fill or reduce the gaps by the 2015 time frame.

The recommendations were subsequently categorised according to approaches taken for their implementation, i.e.:

by advanced geostationary satellites;

by updating the payload of medium-large meteorological operational satellites;

by small satellites, generally in low orbit (but also in GEO, in the case of MW/Sub-mm sounding);

by constellations of mini-satellites;

by a new R&D mission;

by acquiring data from R&D or commercial satellites.

The results of the analysis were collected in two tables (or “manifests”) as discussed further in the document.

The 42 recommendations are contained in the section entitled **“Comments on the CGMS discussion towards an updated/upgraded GOS”** in order to place them directly beside the corresponding **“Comments”.** However, for clarity, the recommendations are also cited in the section below where they have been classified into suggested approaches for implementation.

The 42 recommendations could be implemented by one or more of the following approaches:

- by advanced geostationary satellites;
- by updating the payload of medium-large meteorological operational satellites;
- by small satellites, generally in low orbit (but also in GEO, in the case of MW/Sub-mm sounding);
- by constellations of minisatellites;
- by a new R&D mission;
- by acquiring data from R&D or commercial satellites.

Table 1 shows how the various recommendations could be allocated to one of the implementation approaches.

Table 1 - Strategy to implement recommendations

No.	Recommendation	Advanced GEO	Medium-large LEO	SmallSat GEO/LEO	Constel-lations	New R&D missions	Data from R&D sat's
01	Temperature/humidity IR sounding from GEO.	X					
02	MW/Sub-mm sounding from GEO	X		X			
03	Radio-occultation sounding				X		
04	Water vapour by DIAL					X	
05	Temperature profiles in limb mode						X
06	Improved imagery from GEO for improved winds	X					
07	Winds from overlapping images of LEO		X				
08	Water vapour sounding from GEO for wind profiling	X					
09	Wind profile data by passive Doppler spectroscopy						X
10	Technology development of Doppler lidar for winds			X			
11	Wind data from Doppler lidar demonstration missions						X
12	Winds by 4-D assimilation of soundings from GEO	X					
13	Ozone sounding from GEO	X					
14	Ozone profile and total-column trace gases from LEO		X				
15	Profiles of species other than ozone from LEO						X
16	Special effort on key species from LEO		X				
17	Cloud and water vapour growth from GEO images	X					
18	Accurate cloud top height and observation of cloud base						X
19	Global Precipitation Mission and operational follow-on				X		X
20	MW/Sub-mm radiometry for precipitation from GEO	X		X			
21	Precipitation by 4-D assimilation of soundings from GEO	X					
22	Clouds and radiation monitoring mission			X			
23	ERB observation from GEO and constellations	X			X		
24	Far IR spectroscopy for radiative processes in UT/LS					X	
25	Clouds and radiation data from process study missions						X
26	High-quality sea-surface temperature data from LEO						X
27	Improved sea surface temperatures from GEO	X					
28	Sea surface winds fully operational on LEO		X				
29	Interim sea-surface winds from R&D satellites						X
30	Ocean topography fully operational on LEO			X			
31	Geodetic-class radar or lidar altimeters						X
32	Large-swath radar altimeters for frequent sea-state				X		
33	SAR for wave spectra and other ocean/ice observations						X
34	Ocean colour data for the interim and beyond						X
35	Ocean salinity for meteo-climate applications			X			
36	Ocean salinity for applications in coastal zones						X
37	SAR observation of land snow and ice						X
38	Improved land surface temperatures and fire from GEO	X					
39	Vegetation data for the interim and beyond						X
40	High-resolution optical and SAR imagery of land						X
41	Soil moisture for meteo-climate applications			X			
42	Soil moisture for small-scale applications						X

The first four approaches are based on developments and demonstrations to be carried out with the possible help of R&D space agencies, to be taken over by CGMS partners for long-term follow-on. The second two approaches represent a "data buy" policy of CGMS partners (or WMO) from R&D or commercial programmes. The ultimate purpose of this document is to suggest two "manifests" listing the required developments/demonstrations to be taken over for operational follow-on and the data of operational interest to be procured from R&D or commercial programmes, respectively.

Developments/demonstrations to be taken over for operational follow-on

Advanced geostationary satellite and possible Smallsat in GEO

Geostationary satellites to be operational in the post-2015 should comply with the following recommendations:

- Recommendation 1 - *In the 2015 timeframe, all meteorological geostationary satellites in GOS should be equipped with spectrometers for frequent temperature/humidity sounding in IR*.
- Recommendation 6 - *Imagers of future geostationary satellites should have improved spatial resolution and much improved observing cycle, at least for those channels relevant for wind information retrieval.*
- Recommendation 8 - *Sounders from future geostationary satellites must be designed in such a way as to enable wind profiling by water vapour profiling with conveniently high resolution (horizontal, vertical and time).*
- Recommendation 12 - *Frequent temperature/humidity sounding from geostationary satellites should be implemented also to circumvent (by 4-D assimilation) the difficulty of directly measuring the wind profile.*
- Recommendation 13 - *IR sounding spectrometers from geostationary orbit should contribute to frequent ozone profiling to follow diurnal variations and as an input to 4-D assimilation models intended to improve determination of the wind field.*
- Recommendation 17 - *Depending on the characteristics of the envisaged temperature/humidity sounder, the imagery mission from GEO can be based on different number of channels. The minimum should enable monitoring cloud development and water vapour growth at time intervals in the range of 1-2 min*.
- Recommendation 21 - *Frequent temperature/humidity sounding from geostationary satellites should be implemented also to derive (by 4-D assimilation) precipitation fields to complement actual observations not easy to be performed from space.*
- Recommendation 23 - *In order to make ERB measurements effective for operational radiation climatology, broad-band radiometers should be introduced on each geostationary satellite and on a constellation of LEO.*
- Recommendation 27 - *Future geostationary satellites must have improved capability of observing sea surface temperatures for use in coastal zones. This may be achieved either by IR sounders with good horizontal resolution or IR imagers with a convenient number of channels.*
- Recommendation 38 - *Future geostationary satellites must have improved capability of observing land surface temperatures and fires. This may be achieved either by IR sounders with good horizontal resolution or IR imagers operating at appropriate wavelengths.*

The basic tools to comply with these recommendations could be as follows:

- Introduction on all geostationary satellites of frequent IR sounding by spectroscopic means. This would enable retrieval of temperature, humidity and ozone profiles (Rec. 1 and Rec. 13), improved wind profiling by tracing water vapour 3-D features (Rec. 8), and would provide input to 4-D assimilation models to generate wind profiles (Rec. 12) and precipitation fields (Rec. 21).
- The imagery mission should be improved by providing better resolution and much higher frequency to improve the accuracy of winds (Rec. 6) and monitoring of cloud development and water vapour growth (Rec. 17).
- Improved sea surface temperatures (Rec. 27) and land surface temperatures and fires (Rec. 28) could either be provided by the sounder (if the horizontal resolution is good) or by the imager (which would imply more spectral channels to be included).
- Broad-band radiometers to contribute to global Earth Radiation Budget monitoring should be included (Rec. 23).

The IR sounder also would provide several other measurements, such as: Atmospheric stability index; Height and temperature of the tropopause; Height of the top of the Planetary Boundary Layer; Cloud cover, type, top temperature/height and emissivity. Also it would help to compute: Downwelling long-wave radiation at the Earth surface, and components of Outgoing long-wave radiation at TOA and Outgoing spectral radiance at TOA. The imager could be extended to perform observation of short-wave radiative surface and vegetation parameters, if required because of advantages in monitoring the diurnal cycle under changing illumination conditions.

The subject of MW/Sub-mm sounding from GEO has led to two recommendations:

- Recommendation 2 - *An early demonstration mission on the applicability of MW/Sub-mm radiometry for temperature/humidity* and cloud *sounding from geostationary orbit should be provided, in view of possible operational follow-on in the 2015 timeframe.*
- Recommendation 20 - *An early demonstration mission on the applicability of MW/Sub-mm radiometry for frequent* precipitation *observation from geostationary orbit should be provided, in view of possible operational follow-on in the 2015 timeframe.*

Implementing this recommendation could be made in two steps: first a demonstration mission by a dedicated SmallSat, in the timeframe < 2010; then operational implementation, which could either occur by adding the payload (characterised by a 2-3 m antenna) on the main optical GEO satellite, or by continuing with dedicated SmallSat's launched as piggy-back of the optical GEO.

In addition to the main payload, both the main optical satellite and the dedicated MW/Sub-mm SmallSat could host opportunity payloads to increase cost-effectiveness. Specifically, *lightning mapper* should be considered, to improve cloud nature analysis and precipitation estimates.

Medium-large and SmallSat's in LEO

In this document we have assumed that NPOESS will continue beyond 2015. As for the EPS programme after METOP-3, we could hypothise that there will be a MediumSat substantially smaller than METOP, complemented by SmallSat's. The essential mission of post-METOP, fully concurring with NPOESS, would be:

- temperature, humidity and ozone profiles, and total columns of several trace gases (specifically, "green-house" ones), by IR and UV/VIS/NIR spectrometers and MW sounder;
- multi-purpose VIS/IR imagery for clouds, surface temperatures, ice/snow, vegetation, and for polar winds extraction (which implies improved horizontal resolution and water vapour channels).

This, in association with NPOESS, will enable implementing:

- Recommendation 7 - *Imagers of future polar satellites should be designed as to enable trace motion wind determination in overlapping areas at high latitudes, similarly to what is done from geostationary satellites.*
- Recommendation 14 - *Operational observation of trace gases other than ozone should, in general, be limited to total columns of those species which can be observed by the spectrometers for temperature/humidity/ozone sounding in IR and ozone sounding in UV/VIS/NIR.*

In addition, if some key species is selected for focusing, it could be possible to implement:

- Recommendation 16 - *Special effort on key species of particular value for climate monitoring is possible to be made at operational level by small dedicated instrumentation, provided that the spectroscopic conditions are favourable.*

The post-METOP scenario also is committed, together with NPOESS, to continue implementing:

- Recommendation 28 - *In the 2010 timeframe, sea surface wind must be observed in a fully operational framework (i.e. by NPOESS and METOP/post-METOP). It is urgent to assess whether the multi-polarisation passive MW radiometry is competitive with scatterometry.*

However, if multi-polarisation passive MW radiometry is demonstrated effective for sea-surface wind vector determination, the instrument could better fit with one of the SmallSat's to succeed to METOP-3 in order to allow the main satellite in the post-METOP spread scenario to remain within the limits of a MediumSat. For instance, the MW radiometer could fit within a SmallSat to implement:

- Recommendation 22 - *A mission should be demonstrated, designed to meet operational requirements for atmospheric radiation observations as input to long-term NWP and GCM. Unlike process study missions, which single out a small number of parameters to enhance accuracy and vertical resolution aspects, this mission should provide frequent observation of a wide set of parameters which need to be measured in compliance with strict comprehensiveness and consistency criteria.*

Ocean topography is better measured by altimeters in relatively high orbits. Thus, though NPOESS includes consideration of altimeters, a more appropriate solution is to provide an operational follow-on based on dedicated MiniSat's such as those of the Jason programme. This would implement:

- Recommendation 30 - *Missions for ocean topography, implying a couple of SmallSat's in relatively high orbits, should gradually in the next decade become an integral part of the CGMS-supported operational system.*

As for clear-air wind profiling by Doppler lidar, we have:

- Recommendation 10 - *A long-standing technological programme to follow Aeolus is solicited, to improve coverage characteristics and reduce instrument size to the extent that a sustainable Doppler wind lidar system may become operational in due time.*

The reason to prefer a SmallSat concept for the wind Doppler lidar is that NPOESS is not considering it, and that the main element of the post-METOP scenario, if it would, could not be a MediumSat. Also, the optimal orbit for wind profiling might not be sunsynchronous (lower inclination could be better, and low altitude could favour affordability). Thus, the preference is for a SmallSat, but much technological development is necessary to make this possible.

Finally:

- Recommendation 35 - *A mission to observe ocean salinity for meteo-climate applications, based on a SmallSat to provide limited horizontal resolution and great accuracy should be demonstrated, for possible operational follow-on.*
- Recommendation 41 - *A mission to observe soil moisture for meteo-climate applications, based on a SmallSat to provide limited horizontal resolution should be demonstrated, for possible operational follow-on.*

These two recommendations can be implemented contextually, since the same technology is used (low-frequency MW radiometry). The dedicated SmallSat approach is advisable, since the antenna size needs to be several metres (an embarrassing item to be integrated in a multi-purpose satellite).

Constellations

The following recommendations requiring a constellation:

- Recommendation 3 - *A large constellation of radio-occultation sounders should be implemented, designed to minimise running costs so as to make possible a long-term operational follow-on.*
- Recommendation 19 - *Data from the Global Precipitation Mission must be made available for operational use, and arrangements should be sought to ensure long-term continuity to the system.*
- *Recommendation* 23 - *In order to make ERB measurements effective for operational radiation climatology, broad-band radiometers should be introduced on each geostationary satellite and on a constellation of LEO.*
- Recommendation 32 - *Large-swath radar altimeters for frequent sea-state observation should be demonstrated, with the eventual aim of an operational constellation.*

An effective approach would be to combine all requirements in a single constellation, giving up with the objective of a MicroSat (< 100 kg) and accepting to enter the class of MiniSat (< 500 kg). An example of constellation could be as follows:

- four orbital planes with four satellites in each plane, for a total of 16
- a cluster of four satellites placed in each plane by a single launcher (4 x 500 kg = 2 tons)
- orbit: height 800 km, inclination 70°, period 100 min, dephasing between satellites 25 min
- observing cycle for instruments with 700 km swath: 3 h at the equator, less with increasing latitude
- possible payload:
  - radio-occultation sounder
  - MW (small) radiometer and lightning mapper for precipitation
  - broad-band radiometer for ERB
  - large-swath altimeter for sea-state
  - supporting VIS/IR imager.

The "manifest" of required developments

Table 2 reports the "manifest" listing the missions which should be developed and demonstrated (possibly by R&D space agencies) for successive handing over to CGMS members for operational follow-on. Indications on satellite class and possible time target, geophysical parameters whose determination would be improved, and the type of needed instrumentation are provided.

Table 2 - "Manifest" of developments/demonstrations to be taken over for operational follow-on
(Background: GOES, MSG, MTSAT, GOMS, F-2, INSAT, NOAA/NPOESS, METOP, METEOR, FY-1 in < 2015; NPOESS in > 2015)

System	Improved parameters	Instrumentation
All GEO's upgraded (> 2015) **+**	Temperature, humidity, ozone profiles, winds at specified heights. Atmospheric instability index, tropopause height/temperature, height of PBL top. Cloud pattern, cover, type, top temperature and height. Sea-surface temperature, land surface temperature, permafrost, fires. Short- and long-wave outgoing radiation at TOA. Earth surface short-wave radiation/reflectance, long-wave radiation/emissivity. Products from 4-D assimilation (specifically: wind profile and precipitation field).	Frequent-sounding IR imaging spectrometer exploiting Large Focal Plane Array detectors. Fast VIS/IR imager. ERB radiometer. Short-wave channels.
GEO SmallSat (> 2008).	Precipitation rate and index.	Lightning mapper.
	All-weather temperature and humidity frequent sounding. Cloud water, cloud ice and precipitation frequent sounding.	MW/Sub-mm radiometer.
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. Profiles or total columns of selected key trace gases.	IR/MW sounder. UV/VIS/NIR spectrometer. Improved VIS/IR imager. Narrow-band spectrometer.
+	Sea-surface wind and temperature, sea-ice cover and surface temperature. Icebergs, glacier cover, snow cover and melting conditions. Precipitation rate, precipitation index.	MW radiometer with multi-polarisation and multi-viewing.
SmallSat for Clouds and Radiation (> 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. NDVI, LAI, PAR, FPAR (large scale).	Imagers covering UV, VIS, NIR, SWIR, MWIR, TIR, FIR and Sub-mm, with multi-polarisation and multi-viewing.
MiniSat for ocean topography (> 2008).	Significant wave height, sea level, ocean topography, geoid. Polar ice thickness and sheet topography.	Medium-class altimeter (follow-on of Jason).
SmallSat for wind profile (> 2015).	Wind profile in clear air. Aerosol profile (large scale).	Doppler lidar (follow-on of Aeolus).
SmallSat for salinity & moisture (> 2008).	Ocean salinity (large scale). Soil moisture (large scale).	Low-frequency MW radiometer.
Mini-satellites constellation (> 2008).	Temperature/humidity profile, heights of tropopause and PBL top. Total Electron Content and Electron density profile. Precipitation rate, precipitation index. Short- and long- wave outgoing radiation at TOA. Significant wave height (sea-state).	Radio-occultation sounder. MW radiometer. Lightning mapper ERB radiometer. Large-swath altimeter.

Data of operational interest to be procured from R&D or commercial programmes

The "manifest" listing the information from R&D or commercial programmes, required to be made available for operational use, is shown in Table 3. To be noted that two items, Water-vapour profiling by DIAL (Recommendation 4) and Far IR spectroscopy for water vapour and radiative budget in UT/LS (Recommendation 24) represent a new development. They have not been included in Table 3 because:

- for DIAL, the performances achievable with the present instrument concept are too far from meeting official user requirements, particularly in respect of horizontal resolution and observing cycle; and the mission fails compatibility with the SmallSat condition; thus, technological progress is needed before a fully operational and affordable long-term mission can be defined;
- for FIR spectroscopy the present requirement is dominated by scientific motivations and it is too early to define a mission optimised for operational application.

The structure of Table 3 simply records the relevant recommendations. Some remark is added, specifically to emphasise whether a new development is requested (Rec. 4 and Rec. 24), and whether the requirement is "*ad interim*" (e.g., waiting for NPOESS) or permanent.

Table 3 - "Manifest" of data of operational interest from R&D or commercial programmes

No.	Recommendation	Remark
04	Active sensing of water vapour by DIAL for high-vertical resolution profiling should be pursued, primarily for research purposes, procuring that data are accessible for operational use.	New development requested.
05	Temperature profiles in the higher stratosphere from missions oriented to atmospheric chemistry exploiting limb sounders should be made available for operational use.	Permanent requirement.
09	Any wind profile data available from experimental satellites, e.g., by passive Doppler spectroscopy of the upper atmosphere, should be made available for operational use.	Permanent requirement.
11	Wind profiles from Doppler lidar technology demonstration programmes must be made available for operational use.	Interim requirement waiting for a SmallSat
15	Profiles of species other than ozone, and total columns of species requiring instrumentation exceeding the operational one, as well as high-vertical resolution ozone by DIAL lidar, should be made accessible from scientific programmes for operational use.	Permanent requirement.
18	Accurate measurements of cloud top height and observation of cloud base height performed by research satellites should be made available for operational use.	Permanent requirement.
19	Data from the Global Precipitation Mission must be made available for operational use, and arrangements should be sought to ensure long-term continuity to the system.	Permanent requirement.
24	An exploratory mission should be implemented, to collect spectral information in the Far IR region, with specific emphasis on water vapour profiling significant of the UT/LS region, and on improved knowledge of the water vapour continuum.	New development requested.
25	Data from process study missions on clouds and radiation as well as from R&D multi-purpose satellites addressing Earth's surface characterisation and aerosol should be made available for operational use.	Permanent requirement.
26	Till the advent of NPOESS, high-quality sea-surface temperature data from R&D satellites must be made available for operational use, specifically for climate monitoring.	Interim requirement waiting for NPOESS
29	In the near and mid term future, sea-surface wind data from R&D satellites must be made available for operational use, and relevant satellites programmes should possibly be coordinated so that a two-satellite coverage is achieved.	Interim requirement waiting for NPOESS.
31	Data from geodetic-class radar or lidar altimeters from R&D satellites should be made available for operational use, specifically for the cryosphere.	Permanent requirement.
33	Data from SAR for wave spectra and other observations of ocean and ice should be acquired from R&D and commercial satellite programmes for operational use.	Permanent requirement.

No.	Recommendation	Remark
34	In the near and mid term future, ocean colour data from R&D satellites must be available for operational use. In the NPOESS era, continued access may be useful for specific purposes, particularly in coastal zones.	Interim requirement waiting for NPOESS, continued in coastal zones.
36	Observations of ocean salinity from R&D satellites with horizontal resolution suitable for applications in coastal zones should be made available for operational use.	Permanent requirement.
37	SAR observation data of land snow and ice from R&D and commercial satellites should be made available for operational use.	Permanent requirement.
39	In the near and mid term future, vegetation data from R&D and commercial satellites must be available for operational use. In the NPOESS era, continued access may be useful for small-scale applications.	Interim requirement waiting for NPOESS, continued for small-scale applications.
40	High-resolution optical and SAR imagery data of use for agrometeorology and hydrogeology should be procured from R&D and commercial satellites.	Permanent requirement.
42	Observations of soil moisture from R&D satellites with horizontal resolution suitable for small-scale applications should be made available for operational use.	Permanent requirement.

Summary and conclusion

In this document a detailed analysis has been performed of the gaps of compliance of GOS current and near-future performances with WMO requirements, and recommendations have been put forward on how to fill or reduce the gaps within the 2015 timeframe. The analysis was carried out by geophysical parameters (nearly 100 as defined by CEOS/WMO) and by thematic areas (Atmospheric thermodynamics, Atmospheric dynamics, Atmospheric chemistry, Clouds and precipitation, Clouds and radiation, Ocean surface and sea-ice, Land surface and vegetation).

It has been found that certain gaps should be filled by full integration of appropriate tools into the operational satellite system whose long-term continuity is ensured by CGMS partners. This would require developments and demonstration missions possibly to be carried out with the help of R&D space agencies. A strategic approach has been applied to identify a limited number of missions based on satellites of different classes (MediumSat, SmallSat, MiniSat) to be added to a backbone of very few large satellites already committed for the post-2015 timeframe (e.g., NPOESS and presumably GOES follow-on). <u>A "manifest" of such missions is reported in Table 2</u>. On the other hand, it has been found that, for one or another reason (technological/scientific maturity, affordability, developmental nature, existence of a different driving user community, …), certain data are better procured on the base of a sort of "data-buy policy" from R&D or commercial programmes. <u>A "manifest" of recommendations for data to be procured in this way is reported in Table 3</u>, which also includes a couple of recommended new R&D developments.

This document is the (provisional) result of about three iterations occurred in about two years, starting with CGMS-XXVII in Beijing in October 1999, through CGMS-XXVIII in Woods Hole in October 2000, and culminated with the CGMS Workshop in WMO in April 2001, leading to this issue presented at CGMS-XXIX in Capri in October 2001. The two "manifests", obviously, are evolutionary and will never be perfect, but it is felt that their present version could constitute a useful basis for focusing discussions at the Second "Consultation meetings on high-level policy on satellite matters" between WMO, CGMS and R&D space agencies.

Difficulties in implementing the two "manifests" should not be hidden. For instance:

- as regards the manifest of Table 2, the present mechanisms of R&D space agencies to select new missions to be developed, based on "Call for Ideas" and "Announcements of Opportunity" open to widest scientific communities and controlled by Peer Review Panels, is not favourable to implement comprehensive long-term strategies based on international/interagency understandings;

- as for the manifest of Table 3, the difficulty of getting easy access to data from R&D satellites is well known. R&D space agencies do not have the undertaking of providing user-friendly data circulation schemes (including direct-read-out), standard formats and coding, fast processing and delivery, and product assurance of the level usual for data to be used in operational applications. Therefore, if CGMS partners want to serve their user community by procuring data from R&D satellites, they must set up appropriate arrangements, e.g., true programmes (i.e., budgeted) for the utilisation of third party missions.

Therefore, the two "manifests", in addition to their role for focused technical/scientific and strategic considerations, also offer the opportunity to address the policy and organisational aspects on the base of specific issues.

Comments on the CGMS discussion towards an updated/upgraded GOS

As a result of the presentation at the EUMETSAT STG, the following comments were prepared by Dr John Eyre on 2 November 2001 and are submitted to the Expert Team to further the discussion on changes to the space-based GOS. Each recommendation has been placed just before the appropriate comment and both contained within a box. In some cases, the comments also refer to text from the EUMETSAT Working Paper that was used to justify the recommendation and in that case the text is also placed appropriately. The sub-titles and text in italics signify extracts from the EUMETSAT Working Paper from which the recommendation was proposed.

General

This paper is an excellent contribution to the debate on the Redesign of the Global Observing System (GOS). It moves the debate forward from considerations of user requirements (URs), of observing system capabilities and of general messages resulting from their comparison (as found in the recent report of the WMO/CBS ET-RR, SAT-26) to some specific recommendations on how the space-based component of the GOS might be improved. Whilst I do not agree with all the recommendations (see detailed comments below), I believe the paper sets out the type of recommendations that should now be considered in various fora (e.g., WMO/CBS ET-RR, WMO high-level consultative meetings, CGMS). These recommendations therefore need to be discussed and refined, thus acquiring a wider ownership. If this process is successful then the results might be used to address one of the difficulties described in the conclusions section of the paper, i.e., they might provide a baseline against which space agencies could judge responses for “calls for ideas” or “announcements of opportunities”, to ensure that individual satellite missions contribute to a comprehensive long-term strategy.

Specific comments

Atmospheric thermodynamics

- *the error structure of the measurement is unfavourable for long-term averages intended to achieve the level of accuracy required for climate monitoring;*

Discussion before Rec.1. Shortcomings, bullet 3: "the error structure of the measurement is unfavourable for long-term averages intended to achieve the level of accuracy required for climate monitoring". This is true for many retrieved products, but it is not necessarily true if the data are processed carefully with climate monitoring in mind (e.g., products in radiance space).

Recommendation 1 - In the 2015 timeframe, all meteorological geostationary satellites in GOS should be equipped with spectrometers for frequent temperature/humidity sounding in IR.

Rec.1. Agree.

Recommendation 2 - An early demonstration mission on the applicability of MW/Sub-mm radiometry for temperature/humidity and cloud sounding from geostationary orbit should be provided, in view of possible operational follow-on in the 2015 timeframe.

Rec.2. Agree in general, but would prefer to see emphasis on cloud and precipitation, and even to delete temperature/humidity sounding.

Recommendation 3 - A large constellation of radio-occultation sounders should be implemented, designed to minimise running costs so as to make possible a long-term operational follow-on.

Rec.3. Agree.

Recommendation 4 - Active sensing of water vapour by DIAL for high-vertical resolution profiling should be pursued, primarily for research purposes, procuring that data are accessible for operational use.

Rec.4. Agree, but suggest identify the applications – e.g., climate monitoring and GCM validation – in place of "research purposes".

As mentioned, the accuracy and vertical resolution of temperature profiles observed in cross-nadir mode are not sufficient for the purpose of long-term NWP and climate modelling in the higher stratosphere. However, a problem does not exist, since all atmospheric chemistry instruments operating in limb mode are capable to contextually measure the temperature of the observed layer. This information should therefore made available for operational use, thus we have the recommendation:

Recommendation 5 - Temperature profiles in the higher stratosphere from missions oriented to atmospheric chemistry exploiting limb sounders should be made available for operational use.

Discussion before Rec.5, and Rec.5. It is not clear that limb sounding instruments necessarily have the vertical resolution required to study the phenomena of interest. Radio occultation may be better. Also, Rec.5 should identify the applications for "operational use".

Atmospheric dynamics

These well known problems may be reduced by several improvements to be applied to the imagery mission from geostationary orbit: better resolution to increase the number of tracers; much faster observing cycle (e.g., 1 min) to increase yield and accuracy by tracking short-living targets also more representative of the wind field (being passive). The problem of height assignment is better solved by relying on a co-flying temperature/humidity sounder, rather than by increasing the number of channels of the imager (height assignment requires good spectral information rather than fast observing cycle and high resolution). Thus we have the recommendation:

Recommendation 6 - Imagers of future geostationary satellites should have improved spatial resolution and much improved observing cycle, at least for those channels relevant for wind information retrieval.

Discussion before Rec.6, and Rec.6. I am not convinced that an observing cycle of 1 minute is either necessary or cost-effective. If it is driven by a wind accuracy requirement of 1 m/s, it should be recalled that this is a "maximum requirement"; it is probably in an area of "diminishing returns" and should not be a system driver. Therefore I question "much improved observing cycle" in Rec.6.

Recommendation 7 - Imagers of future polar satellites should be designed as to enable trace motion wind determination in overlapping areas at high latitudes, similarly to what is done from geostationary satellites.

Rec.7. Agree.

Recommendation 8 - Sounders from future geostationary satellites must be designed in such a way as to enable wind profiling by water vapour profiling with conveniently high resolution (horizontal, vertical and time).

Rec.8. Agree.

Recommendation 9 - Any wind profile data available from experimental satellites, e.g., by passive Doppler spectroscopy of the upper atmosphere, should be made available for operational use.

Rec.9. Agree.

The main problem with Aeolus is the observing cycle, requiring about 1 week to get one measurement in each 200-km cell at the equator. As an additional limitation, measurements are only radial, thus full assimilation is required to build the vector information (which, in a sense, biases the use of the data towards the specific model used for assimilation). Notwithstanding the limitations of the presently developing system, this is one way to go, since it is the only one potentially able to provide the required accuracy and vertical resolution. It is reminded that, when certain data have specific high quality characteristics, their impact on the assimilation model is sizeable even with a small number of measurement (Aeolus, will produce about 3000 soundings/day). Two recommendations stem from this discussion:

Discussion before Rec.10: "a small number of measurements (… about 3000 soundings/day)". "Small" needs to be put in context". It should be noted that this is more than the global sonde network and better distributed.

Recommendation 10 - A long-standing technological programme to follow Aeolus is solicited, to improve coverage characteristics and reduce instrument size to the extent that a sustainable Doppler wind lidar system may become operational in due time.

Rec.10. Agree.

Recommendation 11 - Wind profiles from Doppler lidar technology demonstration programmes must be made available for operational use.

Rec.11. Agree.

Finally, the role of 4-D assimilation to retrieve the wind field must be mentioned. Wind is the most active parameter in the motion equations, thus any adjustment of initial conditions to force convergence of predicted and observed values of any parameter sufficiently conservative, automatically leads to adjust the wind field. In this respect, the role of <u>*frequent temperature/humidity sounding*</u> *from geostationary satellite must be re-emphasised. Particularly in areas distant from heat sources, the assimilation of frequent temperature/humidity sounding ("trend") is immediately reflected into dynamical information throughout the* ω*-equation. Thus the recommendation (overlapping with Recommendation 1):*

Discussion before Rec.12. "assimilation of frequent temperature/humidity sounding is immediately reflected into dynamical information through the omega-equation". I agree with the general point, but my colleagues who are dynamics expertise tell me it is not as simple as just the omega-equation.

<u>*Recommendation 12*</u> *- Frequent temperature/humidity sounding from geostationary satellites should be implemented also to circumvent (by 4-D assimilation) the difficulty of directly measuring the wind profile.*

Rec.12. Agree.

Atmospheric chemistry

The situation of user requirements on atmospheric chemistry is rather evolutionary, and it is not easy to distinguish between requirements to be fulfilled in a fully operational fashion (i.e. by instrumentation reasonably conservative to be used for a long time extent) and other ones which could be met within a scattered and evolutionary context. In order to focus discussion, we assume that, within the CGMS membership, priority is given to ozone and to the total columns of the main "greenhouse" gases, whereas it is assumed that other trace gases and the profiles of any gas but ozone are of priority interest for user communities more research oriented.

As regards <u>*ozone*</u>*, operational monitoring is already implemented (e.g., by NOAA SBUV* [1] *and ERS-2 GOME* [2] *in the UV range, and NOAA HIRS* [3] *in IR) and will be further improved in both ranges of UV (by METOP GOME-2 and NPOESS OMPS* [4]*) and IR (by METOP IASI and NPOESS CrIS). To be noted that both UV and IR are necessary, since the IR alone has degraded accuracy in the lower troposphere and higher stratosphere. What could be added is IR observation from geostationary orbit, both to capture possible diurnal variations and for use in 4-D assimilation (target: improved wind field). The associated recommendation is:*

Discussion before Rec.13. Extraction of dynamical information can only be expected to work if the tracer is quasi-passive. This will not be the case if there is a significant diurnal variation. There are probably two separate issues here: use of stratospheric ozone tracers, which are (tbc?) quasi-passive with little diurnal variation, and monitoring any diurnal variation in tropospheric (PBL) ozone.

[1] SBUV = Solar Backscatter Ultra Violet.
[2] GOME = Global Ozone Monitoring Experiment.
[3] HIRS = High-resolution Infrared Radiation Sounder.
[4] OMPS = Ozone Mapper/Profiler Suite.

Recommendation 13 - IR sounding spectrometers from geostationary orbit should contribute to frequent ozone profiling to follow diurnal variations and as an input to 4-D assimilation models intended to improve determination of the wind field.

Rec.13. Therefore needs to be reconsidered.

Recommendation 14 - Operational observation of trace gases other than ozone should, in general, be limited to total columns of those species which can be observed by the spectrometers for temperature/humidity/ozone sounding in IR and ozone sounding in UV/VIS/NIR.

Rec.14. Don't know. Depends on the URs of appropriate applications.

Recommendation 15 - Profiles of species other than ozone, and total columns of species requiring instrumentation exceeding the operational one, as well as high-vertical resolution ozone by DIAL lidar, should be made accessible from scientific programmes for operational use.

Rec.15. Don't know. Would need to see a strong case based on the science and the UR, and to identify the applications for which "operational use" is considered.

Recommendation 16 - Special effort on key species of particular value for climate monitoring is possible to be made at operational level by small dedicated instrumentation, provided that the spectroscopic conditions are favourable.

Rec.16. Don't understand.

Clouds and precipitation

Cloud imagery is the most traditional mission of meteorological satellites since TIROS-I in 1960. It has been upgraded at intervals on both LEO and GEO satellites. The present operational instrument (AVHRR [5]) is rather obsolete, waiting for a step improvement on NPOESS (VIIRS), with precursor NPP. Its main limitation is the lack of water vapour channels. On geostationary satellites, there is a large variability of performances, the highest being those of SEVIRI [6] on MSG. On future GOES, an ABI [7] imager is being thought of, with improved horizontal resolution, number of channels and observing cycle. Due to the dominantly "regional" purpose of cloud imagery from GEO, standardisation of performances is not mandatory, but some "minimum common target" to be accomplished in the 2015 timeframe should be established. The following is recommended:

Discussion before Rec.17. AVHRR is obsolete in its technology, but many capabilities of AVHRR are still not being fully exploited – in many areas in fully meets current URs.

[5] AVHRR = Advanced Very High Resolution Radiometer.
[6] SEVIRI = Spinning Enhanced Visible and Infra Red Imager.
[7] ABI = Advanced Baseline Imager.

Recommendation 17 - Depending on the characteristics of the envisaged temperature/humidity sounder, the imagery mission from GEO can be based on different number of channels. The minimum should enable monitoring cloud development and water vapour growth at time intervals in the range of 1-2 min.

Rec.17. I am not persuaded that this solution would be cost-effective. See also comments on Rec.6 above.

Cloud images are processed to generate parameters such as cover, type, top temperature and derived height. However, for Cloud top height the accuracy achievable by IR measurement (i.e. through the brightness temperature and an estimate of the emissivity) is not sufficient for climatological purposes. More direct observation by backscatter lidar would do the job, but this is a too large facility to be sustainable in an operational framework (and fails to meet operational requirements because of the very long observing cycle due to the nadir-only viewing geometry). Spectroscopy of the oxygen A-band around 760 nm provides results of very variable quality depending on a variety of reasons. Cloud base height can only be estimated by cloud radar, again a too large facility to be sustainable in an operational framework, also failing to meet operational requirements because of lack of scanning capability. However, the observing cycle is sufficient for climatological purposes. Both backscatter lidar and cloud radar are going to be flown in scientific missions (lidar on ESSP-3 [8]; cloud radar on CloudSat) which are expected to have some sort of follow-on, for instance in the ESA framework. We put forward:

Discussion before Rec.18. It is not clear that passive IR data, e.g. from IASI, could not give cloud-top height information of sufficient accuracy for climate purposes. I suspect it will be competitive with other techniques for high and mid level cloud (but probably not for low cloud). Also “climatological” and “operational” should not be considered as opposites (cf. GCOS).

Recommendation 18 - Accurate measurements of cloud top height and observation of cloud base height performed by research satellites should be made available for operational use.

Rec.18. Agree.

Recommendation 19 - Data from the Global Precipitation Mission must be made available for operational use, and arrangements should be sought to ensure long-term continuity to the system.

Rec.19. Agree.

[8] Formerly Picasso-Cena.

Recommendation 20 - An early demonstration mission on the applicability of MW/Sub-mm radiometry for frequent precipitation observation from geostationary orbit should be provided, in view of possible operational follow-on in the 2015 timeframe.

Rec.20. Agree. (Suggest to put this in place of Rec.2.)

Recommendation 21 - Frequent temperature/humidity sounding from geostationary satellites should be implemented also to derive (by 4-D assimilation) precipitation fields to complement actual observations not easy to be performed from space.

Rec.21. Not sure this adds anything. If it is retained, it needs “wind” before “temperature/humidity”.

Clouds and radiation

It is currently considered that the limits of predictability in NWP and the accuracy of General Circulation Models are largely controlled by the poor description of the interaction between clouds and radiation, with the associated fields of aerosol and precipitation. The parameters to be addressed in the context of this theme are:

- *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**;*
- *contextually, the **radiative parameters at the Earth surface**, interacting in both directions with atmospheric radiation.*

The subject implies two aspects: physical processes have to be better understood, to improve modelling and parameterisation; and routine measurements are necessary, to feed initialisation of NWP models as they make progress in explicitly describing radiative processes, and to monitor climate evolution.
Several research missions are being run or have been approved or have been proposed in the area of process study. They generally single out one or very few aspects (e.g., cloud interior by cloud radar; aerosol and cloud top height by backscatter lidar; outgoing radiation at TOA by broad-band radiometry; precipitation by rain radar; Bi-directional Reflectance Distribution Functions by multi-angle and multi-polarisation radiometers; …). In several cases, the mission does not need to be carried out on a long-term basis, beyond what is needed to achieve the scientific objective. Also, often the instrumentation needed for process study is unsuitable for operational use (e.g., because of insufficient observing cycle) or not sustainable (e.g., because of size). One further main reason to make process study missions unsuitable for long-term continuity is that, as a rule, to allow studying so many processes, many satellites are needed, thus necessary "small", so that the addressed observation only constitutes a narrow window in the context of the full set of parameters which should be contextually measured to procure a sizeable impact on operational activities.

In order to prepare for a phase when atmospheric radiation parameters are used for operational application, a new mission should be studied, based on large-swath instruments (thus passive) capable of global coverage in 1-2 days, with moderate resolution as sufficient for this application, but providing a rather comprehensive set of measurements to be co-processed. It is reminded that radiative budgets are very tiny figures to be computed as differences of many large figures, which makes impossible to achieve significant results if the originating observations are taken from different instruments on different platforms under different viewing conditions at different times of the day. In order to acquire the required information without using active techniques, use should be made of the full e.m. spectrum, from UV to MW passing through VIS, NIR, SWIR, MWIR, TIR, FIR and Sub-mm [9], exploiting more polarisations and more viewing angles as needed. The EC-supported "CLOUDS" study has shown that such satellite could stay within the limit of the "SmallSat" class (< 1 ton) [10]. The recommendation is:

Recommendation 22 - A mission should be demonstrated, designed to meet operational requirements for atmospheric radiation observations as input to long-term NWP and GCM. Unlike process study missions, which single out a small number of parameters to enhance accuracy and vertical resolution aspects, this mission should provide frequent observation of a wide set of parameters which need to be measured in compliance with strict comprehensiveness and consistency criteria.

Discussion before Rec.22, and Rec.22. I don't see a need to use broad-band radiation measurements for "operational application" except for GCM validation. I am not persuaded of the case for a separate mission here (at least, not very high priority).

It should be recognised that, even with the addition of a dedicated satellite to what is provided by NPOESS, METOP/EPS and other systems, certain radiative parameters need such frequent observation (because of dependence of solar illumination, on the diurnal cycle of cloud development, etc.) that only the geostationary orbit and/or a constellation of many satellites can help. A specific case is that one of broad-band radiometry for Earth Radiation Budget (typical instruments: CERES [11] and ScaRaB [12] from LEO and GERB [13] from MSG). ERB is not terribly important to initialise NWP, but it is essential to validate CGM's and monitor climate changes. Geostationary satellites can provide observations at changing solar illumination, but only from fixed viewing directions. A constellation of LEO would provide observations from different viewing directions at a number of nearly-fixed local solar hours. The recommendation is:

Discussion before Rec.23. "ERB is not terribly important to initialise NWP". I agree, hence comments above.

[9] Definition: 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.

[10] Definition: NanoSat < 10 kg; MicroSat 10-100 kg; MiniSat 100-500 kg; SmallSat 500-1000 kg; MediumSat 1-2 tons.

[11] CERES = Clouds and Earth's Radiant Energy System.

[12] ScaRaB = Scanner for the Radiation Budget.

[13] GERB = Geostationary Earth Radiation Budget.

Recommendation 23 - In order to make ERB measurements effective for operational radiation climatology, broad-band radiometers should be introduced on each geostationary satellite and on a constellation of LEO.

Rec.23. I am not convinced that, following GERB, we will need this type of continuous monitoring. GERB should teach us how to do it effectively with SEVIRI.

Recommendation 24 - An exploratory mission should be implemented, to collect spectral information in the Far IR region, with specific emphasis on water vapour profiling significant of the UT/LS region, and on improved knowledge of the water vapour continuum.

Rec.24. I am not persuaded that this is required for water vapour profiling – other techniques should have better vertical resolution where needed (near the tropopause). This mission may be may useful for studying cirrus.

To be noted that water vapour profiling significant of the UT/LS layer also can be observed at Sub-mm frequencies such as 380 GHz (with support from the 425 GHz O_2 nearby band for temperature profile). The advantage over FIR is that imagery mode could be obtained (i.e., for frequent coverage), whereas in the FIR only measurements essentially nadir can be obtained. Another method has been proposed, based on LEO-to-LEO occultation of signals generated in the 23 or 183 GHz water vapour bands, but this requires a constellation of satellites to obtain a decent observing cycle.

Notwithstanding the difficulty of making operational use of incoherent data from different instruments on different satellites in different orbits at different time, there are so many interesting data available from R&D programmes that it is worth to collect them, either for model improvement/parameterisation or for initialisation when appropriate. Specifically, it is necessary to collect and evaluate data from clouds and radiation process study missions (e.g., ESSP-3, CloudSat and similar ESA future programmes), and from instruments flown on multi-purpose missions, addressing Earth's surface characterisation and, most important, aerosol (e.g., MERIS [14], MODIS, POLDER [15], MISR [16] and similar future instruments). With the advent of VIIRS on NPOESS several of these observations will become operational, but complementary information from R&D missions will continue to be valuable. We therefore have:

Discussion before Rec.25. I doubt if nadir profiling at 380 GHz (or any frequency!) has sufficient vertical resolution for UT/LS studies. Radio occultation in a water vapour band (e.g. WATS) would seem a better candidate. Also (next para), it is necessary both to collect and **disseminate** in a timely manner data from R&D programmes.

[14] MERIS = Medium Resolution Imaging Spectrometer.
[15] POLDER = Polarisation and Directionality of the Earth's Reflectance.
[16] MISR = Multi-angle Imaging Spectro-Radiometer.

Recommendation 25 - Data from process study missions on clouds and radiation as well as from R&D multi-purpose satellites addressing Earth's surface characterisation and aerosol should be made available for operational use.

Rec.25. Agree.

Ocean surface and sea-ice

Recommendation 26 - Till the advent of NPOESS, high-quality sea-surface temperature data from R&D satellites must be made available for operational use, specifically for climate monitoring.

Rec.26. Agree.

Recommendation 27 - Future geostationary satellites must have improved capability of observing sea surface temperatures for use in coastal zones. This may be achieved either by IR sounders with good horizontal resolution or IR imagers with a convenient number of channels.

Rec.27. Agree, and add for diurnal variation of SST.

Recommendation 28 - In the 2010 timeframe, sea surface wind must be observed in a fully operational framework (i.e. by NPOESS and METOP/post-METOP). It is urgent to assess whether the multi-polarisation passive MW radiometry is competitive with scatterometry.

Rec.28. Agree in principle. However, note that wind speed only (from passive MW) is very useful for global NWP. There is a probably a stronger requirement for wind **vector** for regional NWP, and it is essential for driving ocean models.

Recommendation 29 - In the near and mid term future, sea-surface wind data from R&D satellites must be made available for operational use, and relevant satellites programmes should possibly be coordinated so that a two-satellite coverage is achieved.

Rec.29. Agree.

It should be noted that, at present and till the advent of METOP (2005), Wind over sea surface is only available from R&D satellites. There are, however, several programmes that, with some coordination effort, could provide at least one-satellite coverage (possibly two) to fill the gap. We have:

Global NWP models and General Circulation Models for long-range NWP and climate prediction have increasing need to describe the interaction between atmosphere and ocean circulations. Sea level and Ocean dynamic topography are the most significant active parameters from the ocean to the atmosphere. Their observation requires radar altimeters which therefore, in the long-term future, should be incorporated into the CGMS-supported satellite system. It should be noted that radar altimeters may have rather different complexity (and different optimal orbit characteristics) depending on the requirements they address. For meteo-climate operational applications, relatively simple instruments in relatively high orbits are suitable (e.g., Jason). For "geodetic" applications (Geoid, Sea-ice thickness, Sea-ice elevation, Ice-sheet topography, Icebergs height), more demanding instruments in relatively low orbits are necessary. They might use lidar instead of radar. We have two separate recommendations:

The primitive observation from radar altimeters is the Significant wave height, a very important meteo-climate parameter per-se. However, being the radar altimeter essentially a nadir-only viewing instrument, the observing cycle is totally insufficient for sea-state observation, specifically in coastal zones. Concepts to stretch the swath of altimeters have been proposed (multi-spot for gross sea-state evaluation; interferometry of signals from two side-by-side antennas). The swath would anyway be limited (< 100 km), but could be sufficient if joined to the concept of a constellation. Thus, we have:

Dominant wave period and direction require spectral analysis of SAR images, which also provide Sea surface imagery, Bathimetry and a number of sea-ice parameters (Sea-ice cover and type; and, by interferometry, Sea-ice elevation, Ice-sheet topography, Icebergs fractional cover and height). SAR, however, is a large multi-purpose facility, whose use is driven by other user communities (including commercial ones). The recommendation is:

It should be noted that a number of observations on sea-ice (specifically cover, type and surface temperature) are available from the multi-purpose IR and passive MW radiometers of current and future meteorological satellites, though the horizontal resolution is much worse than with SAR (but the observing cycle much better).

Ocean-colour derived measurements (Water-leaving spectral radiance; Ocean chlorophyll, suspended sediment concentration, yellow substance absorbance) will in future be operationally provided by the VIIRS NPOESS, with sufficient quality and frequency for meteo-climate applications. Till then, and also afterward to improve certain characteristics (accuracy, frequency in coastal waters, …), data from a variety of R&D satellites (and possibly commercial satellites) can be used. We have:

Ocean salinity is one of the few conservative parameters enabling to infer vertical exchanges in the ocean (salinity controls density), in addition to horizontal inflow from rivers and polar ice. It is a difficult measurement, since it requires MW radiometry operating at very-low frequencies (typical, 1.4 GHz), implying very large antenna sizes to get good resolution. Good resolution as required in coastal zones can be achieved by interferometry of thin stick antennas, such as in the ESA SMOS [17] project, to the expenses of accuracy and absolute calibration. For meteo-climate, accuracy must be very good and calibration must be available, whereas the horizontal resolution may be relaxed to some 100 km. Good accuracy also implies that the instrument must include more than the essential channels, in order to enable applying all necessary corrections (for temperature, for roughness/wind, …). Thus we have two recommendations:

Discussion for Recs. 29-36. Needs to be checked with ocean modelling experts.

[17] SMOS = Soil Moisture and Ocean Salinity.

Recommendation 30 - Missions for ocean topography, implying a couple of SmallSat's in relatively high orbits, should gradually in the next decade become an integral part of the CGMS-supported operational system.

Recommendation 31 - Data from geodetic-class radar or lidar altimeters from R&D satellites should be made available for operational use, specifically for the cryosphere.

Rec.30,31. OK?

Recommendation 32 - Large-swath radar altimeters for frequent sea-state observation should be demonstrated, with the eventual aim of an operational constellation.

Rec.32 Not needed? Improved wind field to drive ocean models is the priority?

Recommendation 33 - Data from SAR for wave spectra and other observations of ocean and ice should be acquired from R&D and commercial satellite programmes for operational use.

Rec.33. Agree.

Recommendation 34 - In the near and mid term future, ocean colour data from R&D satellites must be available for operational use. In the NPOESS era, continued access may be useful for specific purposes, particularly in coastal zones.

Rec.34. What does "operational use" mean here?

Recommendation 35 - A mission to observe ocean salinity for meteo-climate applications, based on a SmallSat to provide limited horizontal resolution and great accuracy should be demonstrated, for possible operational follow-on.

Recommendation 36 - Observations of ocean salinity from R&D satellites with horizontal resolution suitable for applications in coastal zones should be made available for operational use.

Rec.35, 36. Don't know.

Land surface and vegetation

Land snow/ice parameters (Snow cover, melting conditions and water equivalent; Glacier cover, motion, topography) are observed to a certain extent by multi-purpose VIS/IR imagers (AVHRR and then VIIRS) and more will be with the advent of MW imagers (CMIS). However, the horizontal resolution will be a limitation for small-scale applications, particularly for hydrology. The optimal observing tool is SAR [18]*, particularly for Snow water equivalent and, by interferometry, Glacier motion and topography. The recommendation is:*

Discussion before Rec.37. Is this statement true for snow water equivalent? I have not seen evidence that CMIS will be adequate.

Recommendation 37 - SAR observation data of land snow and ice from R&D and commercial satellites should be made available for operational use.

Rec.37. OK?

Recommendation 38 - Future geostationary satellites must have improved capability of observing land surface temperatures and fires. This may be achieved either by IR sounders with good horizontal resolution or IR imagers operating at appropriate wavelengths.

Rec.38. Improved capability? Compared to what? Will SEVIRI be OK? Will GOES ABI be OK?

Recommendation 39 - In the near and mid term future, vegetation data from R&D and commercial satellites must be available for operational use. In the NPOESS era, continued access may be useful for small-scale applications.

Rec.39. OK?

Recommendation 40 - High-resolution optical and SAR imagery data of use for agrometeorology and hydrogology should be procured from R&D and commercial satellites.

Rec.40. Don't know.

[18] SAR = Synthetic Aperture Radar.

<u>Recommendation 41</u> - A mission to observe soil moisture for meteo-climate applications, based on a SmallSat to provide limited horizontal resolution should be demonstrated, for possible operational follow-on.

<u>Recommendation 42</u> - Observations of soil moisture from R&D satellites with horizontal resolution suitable for small-scale applications should be made available for operational use.

Recs.41-42. OK?

Developments/demonstrations …

- *The imagery mission should be improved by providing better resolution and much higher frequency to improve the accuracy of winds (Rec. 6) and monitoring of cloud development and water vapour growth (Rec. 17).*

10.1, 2nd set of bullets, bullet 2. Not sure about "much higher frequency" for reasons given re Rec.2.

IR sounder data for downwelling longwave at surface? Downwelling longwave is greatly influenced by cloud-base height, and there is no information on this in the spectrum of the outgoing IR at the TOA.

Summary and conclusions

- *as regards the manifest of Table 2, the present mechanisms of R&D space agencies to select new missions to be developed, based on "Call for Ideas" and "Announcements of Opportunity" open to widest scientific communities and controlled by Peer Review Panels, is not favourable to implement comprehensive long-term strategies based on international/interagency understandings*;

First bullet. I very much agree – see general comments above. This point should be brought out as a high level issue for WMO consultative meetings and CGMS.

CBS OPAG IOS Task Team on Regulatory Material

With regard to the update for the Manual on the GOS - Space-based Observations, the CBS OPAG IOS Task Team on Regulatory Material reviewed a draft revision of Part IV of the Manual on the GOS. The draft revision was largely accepted, but it was agreed that the section on the role of Experimental Satellites should be expanded in the light of recent and foreseen developments in this area. Dr P. Ryder agreed to draft that revision based on the outcome of the meeting of the Expert Team on Observational Data Requirements and Redesign of the GOS, to be held at the end of January 2002.