CGMS-XXXIV
WMO WP-37
Prepared by WMO
Agenda item: E.2

RESPONSE TO GCOS REQUIREMENTS FOR SPACE-BASED OBSERVATIONS

(Submitted by WMO)

Summary and Purpose of Document

Based on the discussion of GCOS requirements by the Expert Team on Satellite Systems (ET-SAT) during its second session, this document proposes a preliminary response to *GCOS Systematic Observations Requirements for Satellite-based Products for Climate*.

It addresses the possible response to GCOS at different levels:

- GCOS Climate Monitoring Principles and other cross-cutting recommendations
- Identification of relevant instruments to collect the required data
- Comments on the description of products and related instruments
- Suitability of current satellite plans to meet GCOS requirements

This preliminary analysis suggests that current and planned missions provide impressive capabilities to meet most of GCOS requirements, however there are anticipated gaps or risk of such gaps for some specific variables such as Earth Radiation Budget, Sea level, Sea surface winds or Global Precipitation. This points to the need for an optimization of the global space-based observing effort in order to ensure continuity and improve geographical and temporal sampling of the key parameters of the Earth-Ocean-Atmosphere system.

It raises the issue of re-defining the scope of the WMO Global Observing System in order to fully address climate monitoring needs beyond the operational objectives of the World Weather Watch programme, taking due account of the need for long-term sustained measurement of Essential Climate Variables.

This also raises the issue of the necessary transition of some Earth Observation missions from R&D experimental status to a more consolidated and perennial status, which implies close cooperation between R&D and operational agencies, and user involvement.

CGMS is invited to review this document as a basis for a possible CGMS response to GCOS and to consider the proposed actions to consult with CEOS to ensure complementary actions from CEOS and CGMS for refining this preliminary response.

Appendices: I Climate Products and related space-based instruments
II Comments on the "*GCOS Systematic Observations Requirements for Satellite-based Products for Climate*"

DISCUSSION

1. INTRODUCTION

1.1 The present paper refers to the Global Climate Observing System (GCOS) "*Systematic Observation Requirements for Satellite-based Products for Climate* ", which is introduced in CGMS-XXXIV WMO-WP-22, and is thus not summarized here. This GCOS document provides supplemental details to the GCOS Implementation Plan. We will refer to it as "the GCOS supplement".

1.2 The present paper includes a preliminary response to the GCOS supplement as elaborated by the CBS/OPAG IOS Expert-Team on Satellite Systems (ET-SAT) during its second session that was held at WMO Headquarters in Geneva, Switzerland, from 4 to 8 September 2006. It also includes considerations on evolution and optimization of the Global Observing System (GOS) and transition from R&D to operational missions that were addressed by ET-SAT at the same meeting. While these discussions were not exclusively related to GCOS they highlighted a number of points that are directly relevant to the response to GCOS.

1.3 These ET-SAT discussions were chaired by Dr Michael King (NASA) and involved Dr Eva Oriol-Pibernat (ESA), Mr James Gurka (NOAA), Mr Jun Gao (CNSA), Mr Toru Hashimoto and Hitomi Miyamoto (JMA), Mr A.S. Kiran Kumar (ISRO), Mr Lu Naimeng (CMA), Mr Jérôme Lafeuille (WMO Space Programme), as well as Dr Susan Barrell (BoM) who, in her capacity as OPAG IOS co-chair, reported on the outcome of ET-SAT-2 to the 4th session of the Implementation/Coordination Team on Integrated Observing Systems (ICT-IOS).

1.4 The paper recalls the main subjects developed in the GCOS supplement, then focuses on the preliminary response of the Expert Team with related considerations on evolution of the GOS and transition from R&D to operations, it furthermore suggests some steps to be taken by CGMS.

2. BACKGROUND

2.1 At its 33rd session, CGMS discussed the GCOS Implementation Plan and reviewed specific recommendations from the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC). CGMS agreed Actions 33.05 and 33.06 related to archived data and aerosol products as well as Recommendations 33.03 and 33.04 related to cloud products and hyperspectral datasets.

2.2 It is recalled that the 10th Conference of the Parties (COP-10) had formally endorsed the GCOS Implementation Plan through a decision that, *inter alia,* "Invites Parties that support space agencies involved in global observations to request these agencies to provide a coordinated response to the needs expressed in the implementation plan". This was discussed at the 5th Consultative Meeting on High-level Policy on Satellite Matters (CM-5) and it was understood that such a response could present the steps and resources needed to move toward a sustainable satellite constellation that would meet the needs of the Plan.

2.3 The present paper is a contribution to such a coordinated response by CGMS satellite agencies. While previous discussions were focusing on products and data requirements, the paper focuses mainly on the implications of GCOS requirements in terms of instruments and mission planning.

2.4 The main goal addressed by the GCOS supplement is to secure the availability of long-term series of homogeneous geophysical products (generally level 3 or more). Emphasis is put on the quality and continuity of observation data sets from existing and planned sensors to generate such products, through the concept of Fundamental Climate Data Record (FCDR).

2.5 The "*Systematic Observation Requirements for Space-based Products for Climate*" were developed in the January-August 2006 timeframe through a workshop, followed by an open review and continuing interaction with CEOS and the GCOS science panels, as well as the WMO Space Programme. They supplement the GCOS Implementation Plan with additional details with respect to its space-based observation needs. This very comprehensive report identifies:

- 9 cross-cutting recommendations of general nature;
- 35 products based on Fundamental Climate Data Records (FCDR) related to Essential Climate Variables (ECV);
- Needs for reanalysis and reprocessing of historical satellite data records.

2.6 The GCOS supplement further recommends continuous review and update of specifications involving appropriate expert groups and suggests some immediate actions.

2.7 The GCOS supplement was reviewed by the Committee on Earth Observation Satellites (CEOS) who is preparing a CEOS Space Agencies' response to GCOS requirements. This CEOS response will be submitted to the UNFCCC in November 2006.

3. PRELIMINARY ET-SAT RESPONSE TO GCOS REQUIREMENTS

Cross-cutting recommendations

3.1 The first cross-cutting recommendation (C.0) reaffirms the GCOS Climate Monitoring Principles (GCMP). It is recalled that the 10 GCMPs and the 10 additional principles for satellite observations address a number of issues including:

- Continuity and homogeneity of observations,
- Overlap between consecutive satellite series
- Adequate sampling of the diurnal cycle, implying enhanced orbit drift control
- Instrument characterization and calibration (pre-launch, on board, in-situ, intersatellite)
- Quality control, error and bias characterization
- Sustained product derivation
- Smooth transition from research to operations

3.2 CGMS had reviewed these principles at its 30th meeting in 2002. Meanwhile the principles have been finalized, they were agreed by the 14th WMO Congress in 2003 and by CEOS at its 17th session.

3.3 The other 8 cross-cutting recommendations call upon the need for, respectively:

- C1: calibration,
- C2: adequate archiving and dissemination,
- C3: refining detailed specifications of FCDR,
- C4: generating Fundamental Climate Data Records and derived products,
- C5: coordinated reanalysis activities,
- C6: development of new products
- C7: exploitation of historical datasets,
- C8: improved awareness of available and planned missions.

3.4 It can be noted that projects such as GSICS and IGDDS are of direct relevance to recommendations C1 and C2.

3.5 The 9 cross-cutting recommendations, including the GCMPs, are considered sound and CGMS members should be encouraged to implement them, with the understanding that this should involve a wide range of players within the climate community, including - but not limited to - CGMS members (e.g. assimilation centres, GCOS science panels).

3.1 Relevant instruments

3.1.1 In the GCOS supplement, GCOS requirements are primarily expressed in terms of products, with an indication of the necessary Fundamental Climate Data Records (FCDR). ET-SAT has identified, for each climate product, a list of relevant instruments delivering data that could be used for its generation. For past instruments, this list could be refined with more details on the data series actually available.

3.1.2 In a first step, the relevant instruments were identified in a qualitative way. In order to refine this analysis, the CEOS-WMO database was seen as a crucial tool to assess the availability and suitability of these instruments to meet the specified requirements. A prerequisite is that the database is up-to-date with respect to the relevant instrument performances and mission characteristics. This reinforces the need for actions to collect input for updating the database.

3.1.3 ET-SAT members agreed to update the review and identification of past, present and future instruments that have the potential to support the generation of GCOS required FCDRs.

3.1.4 The WMO Space Programme Office agreed to update the database with input provided by ET-SAT members and their organizations.

3.1.5 It is understood that the requirements may evolve. In line with cross-cutting recommendation C3, which considers the current GCOS Supplement as “a starting point”, GCOS should be invited to refine its specifications as appropriate. In particular, with respect to the new format of the CEOS/WMO database on User Requirements and Observing Capabilities within the Rolling Requirements Review (RRR) process, it would be desirable to determine not only threshold and goal but also a breakthrough level for each of the criteria.

3.1.6 Appendix I includes 3 Tables providing, in their right column, the current list of relevant instruments identified for each of the 35 required Essential Climate Variables and corresponding global products for the Atmospheric, Oceanic and Terrestrial domains respectively.

3.2 Comments on the detailed description of products and requirements

In performing its review, ET-SAT 2 had noted some comments related to the detailed description of the products in Sections 3.1, 3.2 and 3.3 of the GCOS Supplement. These comments are contained in Appendix II thereafter.

3.3 Adequacy of currently planned missions

3.3.1 Once the relevant instruments have been identified, it is possible to analyze the suitability of currently known mission plans to fulfil GCOS requirements. A detailed assessment in this respect should rely on detailed comparative analysis of requirements and instrument capabilities.

3.3.2 Pending such detailed analysis, ETSAT-2 has drawn a preliminary overview of the suitability of current plans for the next 15 years, based on the planned period of availability of instruments for each type of measurements, without discussing in detail their actual precise capabilities. This first level evaluation of current satellite plans with respect to GCOS requirements suggested that observations of most of the required variables were expected to be available in the coming one or two decades, however for some of them there was a risk of gap, or lack of long-term planning, or actual performances that may not exactly meet GOS requirements.

3.3.3 ET-SAT 2 highlighted in particular a risk of gap for the following observations:

- Ocean surface altimetry, knowing that only one altimetry mission is currently planned beyond 2013 and that this plan is still subject to funding approval. This illustrated in Table 1 below. (This Table was reviewed after ET-SAT 2 in order to reflect the distinction made by GCOS between Jason-class high precision altimetry and Envisat-class altimetry missions providing complementary coverage).

Table 1. Timeline for planned altimetry missions

Satellite	ECT (A) Or Inclination	Sensor	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Envisat	22:00	RA-2															
Jason-1	66°	Poseidon															
Jason-2	66°	Poseidon															
Sentinel 3	22:00	Altimeter															
ICESat	94°	GLAS															
Cryosat-2	92°	SIRAL															

Precision ocean altimetry Ocean altimetry Ice sheet altimetry

- Global Earth Radiation Budget measurements from LEO orbit. After CERES on Aqua and Terra there are only plans for an experimental ERBU on FY-3A and one CERES on NPOESS-C1. This is illustrated in Table 2 below. The requirements for Earth Radiation Budget measurements should indeed consider simultaneously the capabilities in LEO and GEO orbits.

Table 2. Timeline for LEO Earth Radiation Budget missions

Satellite	ECT (A) Or Inclination	Sensor	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Terra	22:30	CERES																
Aqua	13:30	CERES																
NPOESS-C1	13:30	CERES																
FY-3A	22:00	ERBU																
Megha-tropiques	20° incl	SCARAB																

Polar orbiting satellite (global coverage) Inclined orbit satellite (inter-tropical region coverage)

- The case of Ocean surface wind is more complex since this wind information can be retrieved from either scatterometer measurements or from microwave imagery. Scatterometry was proven as a valuable source of information for wind speed and direction, the main limiting factor being generally the coverage, depending on the instrument swath. Microwave imagers with dual polarisation can support wind speed information, but the wind vector (wind speed and direction) can only be retrieved from full-polarisation conical scanning microwave imagers. Furthermore, while this measurement technique provides valuable data at medium and high wind speed it appears to have very poor performances at low wind speed, i.e. below 5 m/s. This can be a significant limitation for the purpose of ocean circulation and climate

modelling. Table 3 below illustrates the currently available plans for scatterometers and relevant microwave imagers, which suggests an insufficient coverage around 2015, and even afterwards for low winds.

Table 3. Timeline for ocean surface wind measuring missions (scatterometry or microwave imagery)

Satellite / Sensor	ECT (A) or inclination	Characteristics	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ERS-2 (AMI-Wind)	22:30	Single swath scatterometer															
QuickSCAT (SeaWinds)	06:00	Wide swath scatterometer															
METOP (ASCAT)	21:30	Double swath scatterometer															
Oceansat-2	00:00	Wide swath scatterometer															
NPOESS-C2	17:30	(MW imager/sounder replacing CMIS)															
NPOESS-C3	13:30																
DMSP (SSM/I,IS)	17:30	Conical scanning MW imager 4 freq./ 3 dual polarization															
Meteor-M (MTVZA)	10:20	Conical scanning MW imager 21 freq./ 8 dual polarization															
FY-3A (MWRI)	22:00	Conical scanning MW imager 6 frequencies with dual polarisation (12 channels)															
FY-3B (MWRI)	14:00																
TRMM (TMI)	35°	Conical scanning microwave imager 5 frequencies, 4 of which with dual polarization															
GPM core (GMI)	65°																

Scatterometer (wind speed and direction)

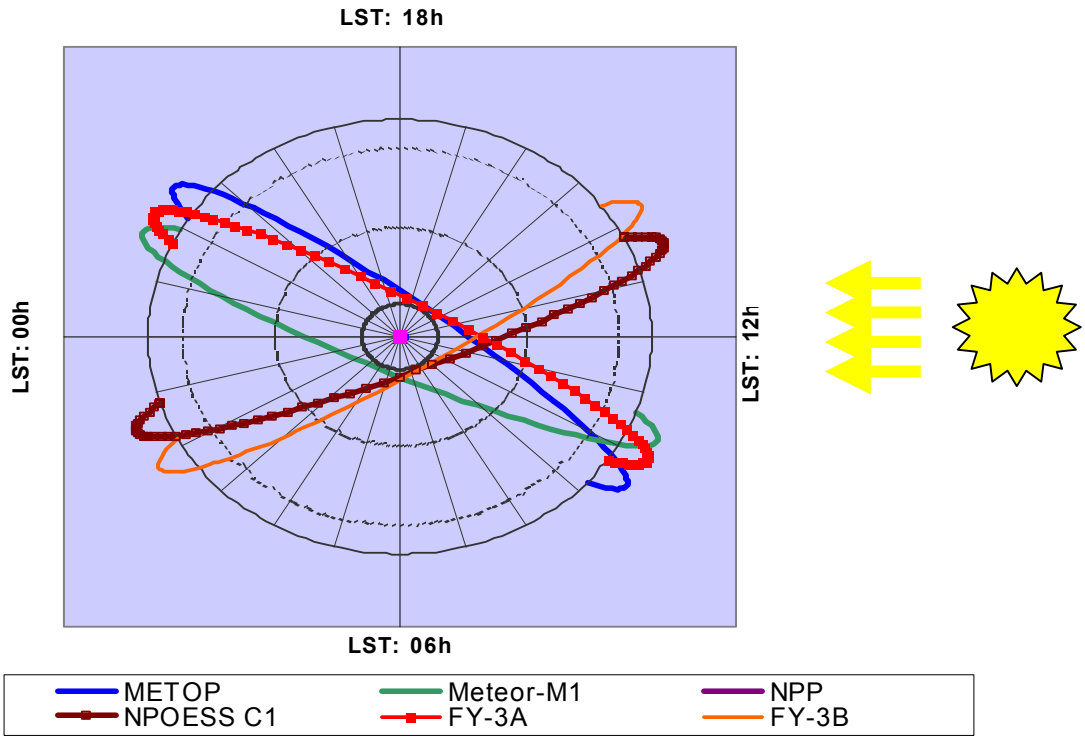
Full polarization MW Imagery (wind speed and direction)

Dual polarization MW Imagery (wind speed only)

- From the review of the evolution of the GOS, it was recommended that long-term continuity should be sought for the Global Precipitation Measurement (GPM) mission, both for operational applications and for the needs of GCOS. GPM combines active precipitation measurements with a constellation of passive microwave imagers, as a follow-on and enhancement of the experimental TRMM mission. The plan for operating TRMM was extended to 2009, but the GPM core satellite is only planned for launch by end 2012. The timely implementation of the GPM mission should be advocated in order to keep to a minimum the gap between TRMM and GPM.

3.3.4 Several concerns emerged from the discussion on evolution and optimization of the GOS, with respect to coverage and adequate sampling of several variables that are relevant for both operational and GCOS requirements:

- According to current plans, Temperature and Humidity sounding instruments in LEO orbits for the next two decades will be concentrated around two sun-synchronous orbital planes in the mid-morning and early afternoon, which can only marginally meet the requirements for temporal sampling. (Figure 1 below)



- Opportunities for a constellation of radio-occultation sounders should be explored and operational implementation planned. It was noted that Oceansat-2/ROSA instrument would enhance the Radio-Occultation constellation and that new Radio-Occultation missions were under consideration by other agencies. Plans for operational follow-on to COSMIC should be discussed by CGMS in 2006.

3.3.5 Furthermore, the "goal" resolution and accuracy may not be fulfilled for many of the observations. This is, however, subject to precise definition by GCOS of its goal/ breakthrough/ threshold requirements. For example, observations of the fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and of the Leaf Area Index (LAI) may not meet the target accuracy requirements

3.4 Evolution of the WMO Global Observing System long-term baseline

3.4.1 The current baseline for the WMO World Weather Watch GOS is defined by the Manual on the GOS, as amended by the 58th WMO Executive Council (EC LVIII), and by the "vision for evolution of the GOS to 2015" adopted by CBS-Ext. in December 2002. It is stated that the operational space-based component is supplemented by a contribution from R&D satellites for which "neither long-term continuity of service nor a reliable replacement policy are assured" but providing valuable additional information. Examples of such additional information are observations related to soil moisture, sea ice, wave height, aerosols, greenhouse gases, forest fires, ocean colour and salinity.

3.4.2 Some of the Essential Climate Variables (ECV) identified by GCOS belong to the core operational observations above and are normally routinely available with plans for continuity (temperature and water vapour profile, cloud cover, atmospheric wind vectors) or are identified at least as data that should be available through the space-based GOS by 2015.

3.4.3 However, GCOS requirements also refer to many ECVs that are not currently acknowledged as "operational" needs. Current or future observations of these variables rely to a large extent on R&D missions, with no plan for long-term availability. These variables include for example:

- atmospheric composition (ozone profile, distribution of GHG and aerosols),
- sea surface salinity,
- ice sheet elevation,
- fAPAR and LAI

(Variables such as sea state or ocean colour are not mentioned in this category considering that planned operational sensors for sea surface altimetry and for visible imagery, respectively, will be able to meet the requirements for those variables as well)

3.4.4 Furthermore, ET-SAT noted that GCOS requirements refer to "operational" data availability. In operational weather forecasting context, the term "operational" also includes an aspect of round-the-clock availability and real-time operation, with guaranteed continuity of service through contingency planning with in-orbit back up and replacement policy. Since the short-term continuity aspects are not thought to be critical for climate monitoring ET-SAT felt that the term "sustained" instead of "operational" could better reflect the GCOS requirement. It is understood that "sustained" availability should imply at least plans for long-term continuity and replacement policy without involving the operational real-time continuity constraints.

3.4.5 In order to fulfil climate monitoring needs in the long-term in a robust way, ET-SAT felt appropriate to review the definition of the space-based GOS and expand its baseline to include namely sustained observations of additional variables required by GCOS such as atmospheric composition, sea surface salinity, ice sheet elevation, fAPAR and LAI.

3.4.6 Reviewing the outcome of ET-SAT, the Implementation/Coordination Team for Integrated Observing Systems (ICT IOS) has acknowledged that expanding the GOS baseline to encompass climate monitoring needs was as a necessary step towards the integration of all WMO Global Observing Systems. ICT-IOS thus agreed that the relevant Expert Teams (ET-EGOS, ET-SAT, ET-SUP) would "initiate an update of the space-based GOS baseline with 2025 as a new horizon, and expand its scope beyond World Weather Watch in order to include sustained observations of additional variables required for climate monitoring, and ultimately address the needs of other programmes as well."

3.5 Issues linked with the transition from R&D to "sustained" or operational status

3.5.1 R&D missions and "sustained" or operational missions have different scopes, and the transition of relevant R&D missions to a more operational status raises delicate issues.

3.5.2 First of all, once an R&D instrument has been successfully demonstrated and when an operational requirement has been confirmed, there may be technical challenges to face in adapting this R&D instrument to an operational use and there will generally be a gap between the demonstration mission and the operational follow-on, unless provisions are made at a very early stage for a "preparatory" mission to bridge such a gap. A preparatory mission aims at initiating potential applications, evaluating the impact of the new technology and preparing the operational framework to exploit it. This requires timely data availability and strong user involvement. A typical case for such a transition is the current ADM-Aeolus Doppler lidar technology demonstration programme, which raises strong interest from the operational community, and for which, if successful, a preparatory programme would be highly desirable before a decision can be made for a fully operational follow-on.

3.5.3 Transferring an R&D mission to operational status is subject to a critical decision process, complicated by the fact that R&D and operational missions are carried out by organizations with

different mandates. There is a continuum of requirements from purely research or demonstration to purely operational requirements, for instance in the case of climate monitoring missions, but there is not always a continuum of “mandate” between R&D and operational organisations. There is thus a risk that neither the R&D nor the operational agency can allocate resources to preparatory missions that would not be among the core priorities of either organization. R&D and operational entities should include into their strategic plans cooperative activities for “transition” of R&D missions into operations, and this should be advocated with decision makers.

3.5.4 Early involvement of future operational users is another key to the success. From a user point of view, it contributes to the learning process, helps to adapt operational tools and environment to the use of new observations, and allows assessing the impact of new data on operational systems. From the agency point of view, NWP centres can provide continuous monitoring and immediate feedback in case of anomalies. Near-real time availability of the data considerably increases their usefulness and is an essential aspect in the transition phase. Operational agencies should prepare timely utilization plans involving users from preparatory activities onwards.

4. CONCLUSION

4.1 CGMS is invited to review and comment the considerations above with a view to forward to GCOS a “CGMS response” on this basis, consolidating the views of CGMS space agencies. It is understood that this would be a preliminary response, pending more detailed assessment.

4.2 In order to further refine this analysis, actions should be taken to update the CEOS/WMO database, as agreed at ET-SAT, with the latest information on instrument capabilities of future missions. Interaction should also take place with GCOS, which is expected to refine some of its requirements. This would allow performing a detailed and objective analysis of the compliance with GCOS requirements.

4.3 In parallel, dialogue should be developed with CEOS, with the aim to ensure that converging views and complementary actions by CEOS and CGMS will result in strengthening the global plans for climate monitoring from space.

CLIMATE PRODUCTS AND RELATED SPACE-BASED INSTRUMENTS

ables A, B, C below are related respectively to Atmosphere, Oceans and Terrestrial domain.

Each table contains the following information:

- Columns 1 to 4 are extracted from the GCOS supplement and describe the global products requiring satellite observations. Each line includes the indication of the corresponding ECV, the product description, proposed types of FCDRs, new product number and the corresponding number in the GCOS Implementation Plan;

- Column 5, gives the reference of the corresponding recommendation in the Implementation Plan for the Evolution of the Global Observing System (GOS), when relevant. “Continuity” means that the related observation is not addressed as an evolution of the GOS since it is already part of GOS baseline;

- Column 6 includes a tentative list of relevant instruments that could provide the observations needed to generate the required products.

Table A : Overview of Products – Atmosphere – and relevant instruments

ECV	Global Products requiring Satellite Observations	Fundamental Climate Data Records (from past, current and future missions)	Product Number (GCOS IP Reference Action)	Related IP-EGOS recommendation	Tentative list of relevant instruments[1]
Surface Wind Speed and Direction	Surface vector winds analyses, particularly from reanalysis	Passive microwave radiances and scatterometry	A.1 (A11)	S7	NSCAT, SEASAT. ERS-1,-2 Scatterometer, ASCAT, SeaWinds, Oceansat-2 scatterometer CMIS-R MWRI, MTVZA, SSM//I, TMI, GMI
Upper-air Temperature	Homogenized upper-air temperature analyses: Extended MSU-equivalent temperature record; New record for upper-troposphere and lower-stratosphere temperature using data from radio occultation; Temperature analyses obtained from reanalyses	Passive microwave radiances; GPS radio occultation; High-spectral resolution IR radiances for use in reanalysis	A.2.1 A.2.2 A.2.3 (A19, A20)	S12	AMSU-A, ATMS, CMIS-R, MWTS GRAS, Radiomet, Cosmic, ROSA HIRS, AIRS, IASI, CrIS, IRFS-2 GEO IR sounders (GOES, MSG, INSAT-3D) HIRDLS, SCIAMACHY, MIPAS, ILAS-1,-2
Water Vapour	Total column water vapour over the ocean and over land; Tropospheric and lower- stratospheric profiles of water vapour	Passive microwave imagery; UV/VIS imagery; IR imagery and soundings in the 6.7um band; Microwave soundings in 183 GHz band	A.3.1 A.3.2 (A7, A21)	continuity	MSU ,AMSU-B, MHS, MWHS, ATMS, CMIS-R, SSM/I, Microwave Radiometers on Altimeters HIRS, AIRS, IASI, CrIS HIRDLS, SCIAMACHY, MIPAS, ILAS-,-2 GOME, GOME-2 VAS, + GEO WV imagery GEO IR sounders MODIS, MERIS,VIIRS, SENTINEL-3*
Cloud properties	Cloud radiative properties (initially key ISCCP products)	VIS/IR imagery; IR and microwave soundings	A.4 (A22, A23)	continuity	AVHRR, MODIS, MERIS, VIIRS, SENTINEL-3* ICESat/GLAS, CALIPSO/Caliop, CPR POLDER HIRS, AIRS, CrIS, IASI, AMSU-A

[1] In this table, relevant instruments are organised by type

ECV	Global Products requiring Satellite Observations	Fundamental Climate Data Records (from past, current and future missions)	Product Number (GCOS IP Reference Action)	Related IP-EGOS recommendation	Tentative list of relevant instruments[1]
					GEO-imagers
Precipitation	Improved estimates of precipitation, both as derived from specific satellite instruments and as provided by composite products	Passive microwave radiances; High-frequency geostationary IR measurements; Active radar (for calibration)	A.5 (A6, A7, A8, A9)	S11	PR, PR2 TMI, AMSR-E, MWR, MWRI, MTVZA GEO IR imagers
Earth Radiation Budget	Top-of-atmosphere Earth radiation budget on a continuous basis	Broadband radiances; Spectrally-resolved solar irradiances; Geostationary multi-spectral imagery	A.6 (A14, A24)	S9	ERBE, SCARAB, CERES, ERBU GERB ACRIM, TIM, SIM
Ozone	Profile and total column of ozone	UV/VIS and IR/microwave radiances	A.7 (A25, A26)	Partly addressed by S19	SBUV, TOMS, GOME, OMI, OMPS AIRS, IASI, CrIS MIPAS, SCIAMACHY, GOMOS, GOME-2, TES MODIS, VIIRS SEVIRI, ABI
Aerosol Properties	Aerosol optical depth and other aerosol properties	VIS/NIR/SWIR radiances	A.8 (A25, A26, A31)	Partly addressed by S19 and S16	AVHRR, ATSR-2, OCT, VIIRS, SeaWiFS, MODIS, MISR, AATSR, MERIS SAGE III TOMS, GOME, OMI, GOME-2 POLDER, APS ADM/Aladin, CALIPSO/Caliop, Earthcare/ATLID SEVIRI, ABI
Carbon dioxide, methane and other GHG	Distribution of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks	NIR/IR radiances	A.9 (A25, A26, A27)	Partly addressed by S19	IMG, AIRS, IASI, CrIS MOPITT MIPAS, MLS, SCIAMACHY, GOME, GOME-2, OMI, TES GOSAT/GGOS, OCO

ECV	Global Products requiring Satellite Observations	Fundamental Climate Data Records (from past, current and future missions)	Product Number (GCOS IP Reference Action)	Related IP-EGOS recommendation	Tentative list of relevant instruments[1]
Upper-air Wind	Upper-air wind analyses, particularly from reanalysis	VIS/NIR imagery; Doppler wind lidar	A.10 (Section 4.2.2)	S10	MODIS ADM-Aeolus (demo) GEO imagery for wind vectors
Most upper-air and some surface ECVs	Atmospheric reanalyses	Key FCDRs and products identified in this report, and other data of value to the analyses	A.11 (C13)		

Table B: Overview of Products – Oceans – and relevant instruments

ECV	Global Products requiring Satellite Observations	Fundamental Climate Data Records (from past, current and future missions)	Product Number (GCOS IP Reference Action)	Related IP-EGOS recommendation	Tentative list of relevant instruments
Sea Ice	Sea-ice concentration	Microwave and visible imagery	O.1 (O23, O24)	Not addressed	SSM/I, MWR, MWRI, MTVZA, AMSR, CMIS-R ASCAT, Cryosat/SIRAL Jason1/Poseidon, Jason2/AKA, Sentinel-3/altimeter* (high priority)
Sea Level	Sea level and variability of its global mean	Altimetry	O.2 (O12)	S8	Jason1/Poseidon, Jason2/AKA, Sentinel-3/altimeter* (high priority)
Sea Surface Temperature	Sea surface temperature	Single and multi-view IR and microwave imagery	O.3 (O9, O10)	Continuity	AVHRR, MODIS, VIIRS, MERSI AATSR , CrIS, AIRS, IASI, TMI, AMSR-E, MWRI, MTVZA, CMIS-R GEO imagers with split-window IR channels
Ocean colour	Ocean colour and oceanic chlorophyll-a concentration derived from ocean colour	Multi-spectral VIS imagery	O.4 (O18)	Not addressed	SeaWiFS, MERIS, VIIRS, FY-1/imager, FY3/VIRR Oceansat/OCM
Sea State	Wave height and other measures of sea state (wave direction, wavelength, time period)	Altimetry	O.5 (O19)	Not addressed	ASAR, Sentinel3/alt*, Jason1/Poseidon, Jason2/AKA
Ocean salinity	Research towards the measurement of changes in sea-surface salinity	Microwave radiances	O.6 (O15)	S14	SMOS (research mode)
Mainly sub-surface and some atmospheric ECVs	Ocean reanalyses utilizing altimeter and ocean surface satellite measurements	Key FCDRs and products identified in this report, and other data of value to the analyses	O.7 (C11, C12, C13)	S 8	

* Sentinel-1, 3 mission is planned but the funding is subject to approval

Table C: Overview of Products – Terrestrial domain – and relevant instruments

ECV	Global Products requiring Satellite Observations	Fundamental Climate Data Records (from past, current and future missions)	Product Number (GCOS IP Reference Action)	**Related IP-EGOS recommendation**	**Tentative list of relevant instruments**
Lakes	Maps of lakes; lake levels; and surface temperatures of lakes in the Global Terrestrial Network for Lakes	VIS/NIR imagery and radar imagery; Altimetry; High resolution IR imagery	T.1.1, T.1.2, T.1.3 (T5, T6, T8)	S 8	MERIS, MODIS, VIIRS, MERSI Poseidon, RA, RA-2, Jason2/AKA, ATSR, AATSR, Sentinel3/alt*, AWIFS, OCM
Glaciers and Ice Caps	Maps of the areas covered by glaciers other than ice sheets; Ice sheet elevation changes for mass balance determination	High-resolution VIS/NIR/SWIR optical imagery; Altimetry	T.2.1, T.2.2 (T13, T14)	Not addressed	Landsat TM/ETM+, ASTER, ICESat/GLAS, ASAR, ERS-1,2/SAR, Sentinel1 * AWIFS
Snow Cover	Snow areal extent	Moderate-resolution VIS/NIR/IR and passive microwave imagery	T.3 (T11, T17)	Not addressed	MODIS, VIIRS, VIRR SSM/I, AMSR-E, AWIFS
Albedo	Directional hemispherical (black sky) albedo	Multi-spectral and broadband imagery	T.4 (T21)	Not addressed	GEO imagery, MISR, MODIS, POLDER, VIIRS, MERIS, AWIFS
Land Cover	Moderate-resolution maps of land cover type; High-resolution maps of land cover type, for the detection of land cover change	Moderate-resolution multi-spectral VIS/NIR imagery; High-resolution multi-spectral VIS/NIR imagery;	T.5.1, T.5.2 (T24, T26, T27)	Not addressed	AVHRR, MODIS, MERIS, AATSR, VIIRS SPOT/VGT, Landsat/ETM+, ALOS/AVNIR-2, Resource/MSU-V, SPOT/HRV AWIFS
fAPAR	Maps of fAPAR	VIS/NIR imagery	T.6 (T28)	Not addressed	Landsat/ETM+, MERIS, MODIS, ASTER, VIIRS
LAI	Maps of LAI	VIS/NIR imagery	T.7 (T28)	Not addressed	Landsat/ETM+, MERIS, MODIS, ASTER, VIIRS, SeaWiFS
Biomass	Research towards global, above-ground forest biomass and forest biomass change	L band / P band SAR; Laser altimetry	T.8 (T31)		ALOS/SAR (research)
Fire disturbance	Burnt area, supplemented by active fire maps and fire radiated power	VIS/NIR/SWIR/TIR moderate-resolution multi-spectral imagery	T.9 (T33)	continuity	AVHRR, MERIS, MODIS, AATSR, VIIRS GEO imagery (GOES, MSG)
Soil moisture[2]	Research towards global near-surface soil moisture (up to 10cm soil depth)	Active and passive microwave	T.10 (T37)	S14	SMOS, ALOS/SAR, AMSR-E

* Sentilnel-1,3 missions are planned but still subject to approval

[2] Soil moisture has been recognized by the GCOS Implementation Plan as an emerging ECV.

APPENDIX II

Comments on the GCOS "Systematic Observation Requirements for Satellite-based Products for Climate "

In reviewing the "Systematic Observation Requirements for Satellite-based Products for Climate", ET-SAT 2 had noted the following comments related to the detailed description of the products in Sections 3.1, 3.2 and 3.3 of the GCOS Supplement.

Section 3.1. ATMOSPHERE

Unless otherwise indicated, the following comments are proposed to be added in the paragraph "*Requirements for satellite instruments and satellite datasets*" of the designed product.

- Product A.1 Surface vector wind analyses, particularly from reanalysis:
    - ASCAT will not have the 10 km resolution, unless further re-processing is done.
    - ERS-1 and ERS-2 archives contain very interesting scatterometer data records
- Product A.2 Homogenized upper-air temperature analyses
    - (Concerning paragraph on partnerships and international coordination) **On Radio Occultation, it is important to build a good ground network of tracking stations. Coordination is needed at international level so as not to duplicate efforts.**
- Product A.3 Water vapour
    - Plans for Sentinel-3 include a MERIS-like instrument.
    - As a follow-on of the MIPAS/GOMOS/SCHIAMACHY suite on Envisat, Sentinel-5 or post EPS may embark an instrument for chemistry.
    - The radiometers used to correct altimetry in ERS-1/ERs-2/Envisat also provided useful records of information.
- Product A.4 Cloud radiative properties
    - There is some interesting data record from Meteosat radiometers starting in 1977.
    - The planned Earth Explorer mission "EarthCare" is aimed at cloud, aerosols and radiation studies using Cloud Profiling Radar (CPR) and Multi-Spectral Imager (MSI).
- Product A.7 Profile and total column of ozone
    - SEVIRI on MSG has an O_3 absorption channel. Continuation is planned on post EPS and Sentinel-5 mission.
- Product A.8 Aerosol optical depth and other aerosol properties
    - The planned Earth Explorer mission "EarthCare" is aimed at cloud, aerosols and radiation studies.

  - ATLID is UV backscatter LIDAR and ADM/Aeolus through its LIDAR will also provide information of relevance to aerosols.

- Product A.9 Distribution of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks
  - The follow-on of GOME-2 on MetOp is considered for Sentinel-5 and/or post EPS

Section 3.2 OCEANS

These comments are proposed to be added in the paragraph "*Requirements for satellite instruments and satellite datasets*" of the designed product.

- Product O.1 Sea-ice concentration
  - Scatterometer can provide useful information about ice coverage. It is doubtful that scatterometer could be useful for drifts due to its low resolution; SAR could certainly be more relevant.
  - There are useful archived data from SAR and scatterometer on ERS-1/ERS-2 .
  - Sentinel -1 will carry a SAR.
- Product O.2 Sea level and variability of its global mean
  - Sentinel-3 plans for an Altimeter, in the following of ERS and Envisat.
- Product O.3 Sea surface temperature
  - There are useful archived data from ATSR and AATSR on ERS and Envisat
  - Plans for Sentinel-3 include an equivalent to AATSR in accuracy and resolution.
- Product O.4 Ocean colour and oceanic chlorophyll-a concentration derived from ocean colour
  - MERIS on Envisat provides some interesting archives.
  - Plans for Sentinel-3 include an equivalent to MERIS in accuracy and resolution
- Product O.5 Wave height and other measures of sea state
  - Altimeter is planned on Sentinel-3
  - Sentinel-1 SAR will provide wave spectra.
  - ERS and Envisat SAR and Altimeter provide archived data
- Product O.6 Research towards the measurements of changes in sea-surface salinity
  - SMOS, in research, does not fulfil the target requirements.

Section 3.3. TERRESTRIAL DOMAIN

- Product T.2.1 Maps of the areas covered by glaciers, other than ice sheets:

in the last paragraph of "Adequacy/Inadequacy of current holdings", replace "*Landsat 7 failed in 2003*" by "*Landsat 7 lost its scan line corrector in 200,3 which reduced the quality of single images at the outer edges of the swath*"

- Product T.4 Directional hemispherical (black sky) albedo:

In the paragraph “Requirements for satellite instruments and satellite datasets”, the text of the first point should read “*Geostationary platforms, which allow wide coverage and good time resolution, but are hard to correct for atmospheric effects or to characterize angular reflectance factors (BRDF) required to convert directional radiance to albedo; they are also inadequate to observe polar regions*”.

- Supporting Product to T.5.1, T.5.2 Land surface temperature, in conjunction with land cover type:

It is understood that the target requirements upon accuracy should be “1°C” instead of “1%”

- **S3.3.10** Soil moisture:

remove the reference to Hydros mission that was cancelled

- Product T.10 Research towards global near-surface soil moisture map (up to 10cm soil depth):
    - in the paragraph ”Requirements for satellite instruments and satellite datasets”, add the following point “*NASA operates the JAXA-provided AMSR-E on Aqua, which uses X-band to derive soil moisture over sparsely vegetated land surfaces. C-band capability is limited due to radio frequency interference in many populated land regions of the world (e.g., Japan, US, Europe) “*
    - in the paragraph “Adequacy/inadequacy of current holdings ”, remove the second point and replace it by *“AMSR-E derived soil moisture results are currently available from NASA for the Aqua time period (2002-present)”*
    - in the paragraph “Immediate action, partnerships and international coordination”, the second point should be “*Robust and reliable algorithms for retrieval of soil moisture are still lacking, especially over densely vegetated surfaces”*