Guidance Note 1: ECVs - sources of information on GCOS requirements and international standards relevant to climate observing

Prepared for: UKEOF

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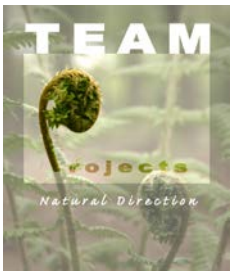

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ECVs: sources of information on GCOS requirements and international standards relevant to climate observing

General Background on ECVs

The GCOS Implementation Plan provides a programme of recommendations actions over a 5 year period to assist countries in understanding, predicting, and managing their response to climate and climate change. In the GCOS implementation plan (2010 update), a set of 50 'Essential Climate Variables' (ECVs) are defined. These are systematically observable variables for climate assessment, all of which are considered both technically feasible and cost-effective for systematic observation. These ECVs are needed to make significant progress in the generation of global climate products and derived information.

GOSIC, the Global Observing Systems Information Centre provide overviews for each ECV that describe: 'main climate application', 'contributing networks and satellite observations', 'issues relevant to observation and analysis', 'current capability' and 'data.' The links in Table 1 will take you to these.

Table 1: GCOS Essential Climate Variables (ECV) Data Access Matrix. (Latest Update April 16, 2013)

ATMOSPHERIC (over Land, Sea & Ice)	**OCEANIC**	**TERRESTRIAL [2]**
Surface [4]	Surface (Ocean) [6]	
Surface Air Pressure	Carbon Dioxide Partial Pressure	River Discharge *(ECV T1)* **
Surface Air Temperature	Current **	Water Use *(ECV T2)*
Surface Precipitation	Ocean Acidity *	Ground Water *(ECV T3)*
Surface Radiation Budget	Ocean Colour **	Lakes *(ECV T4)* * **
Water Vapour (Surface humidity)	Phytoplankton *	Snow Cover *(ECV T5)* **
Near-Surface Wind Speed and Direction	Sea Ice	Glacier and Ice Caps *(ECV T6)* *
Upper-Air [5]	Sea Level **	Permafrost *(ECV T7)*
Cloud Properties **	Sea State	Albedo *(ECV T8)* * **
Earth Radiation Budget (including Solar Irradiance) *	Sea Surface Salinity (SSS) **	Land Cover *(including vegn Type) (ECV T9)*
Temperature	Sea Surface Temperature (SST) **	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) *(ECV T10)* **
Water Vapour **	Sub-Surface (Ocean)	Leaf Area Index (LAI) *(ECV T11)*
Wind Speed and Direction	Carbon	Above Ground Biomass *(ECV T12)* *
Composition	Current	Fire Disturbance *(ECV T13)* **
Aerosols Properties **	Nutrients	Soil Moisture * **
Carbon Dioxide	Ocean Acidity *	Soil Carbon *
Methane and other Long-Lived Green House Gases [1]	Oxygen *	Ice Sheets *
Ozone **	Salinity	
Precursors (supporting Aerosols and Ozone ECVs) [3] *	Temperature	Assessment reports on available methodological standards and guides for terrestrial ECVs can be found at: http://www.fao.org/gtos/Pubs.html
	Tracers	
	Global Ocean Heat Content ***	

[1] The 'Other long-lived greenhouse gases' ECV includes Nitrous Oxide (N_2O), CFCs, HCFCs, HFCs, SF_6, and PFCs.

[2] Includes Runoff ($m^3\ s^{-1}$), Ground Water Extraction Rates ($m^3\ yr^{-1}$) & Location, Snow Cover Extent (km^2) & Duration, Snow Depth (cm), Glacier/Ice Cap Inventory & Mass Balance ($kg\ m^{-2}\ yr^{-1}$), Glacier Length (m), Ice Sheet Mass Balance ($kg\ m^{-2}\ yr^{-1}$) & Extent (km^2), Permafrost Extent (km^2), Temperature Profiles & Active Layer Thickness, above ground Biomass (t/ha), Burnt Area (ha), Date & Location of Active Fire, Burn Efficiency (% Vegetation Burned/Unit Area)

[3] NO_2, SO_2, HCHO, CO

[4] including measurements at standardised but globally varying height in close proximity to the surface

[5] Up to the stratopause

[6] Including measurements with the surface mixed layer, usually with the upper 15 meters

* Added or modified per 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC - August 2010, GCOS-138 (GOOS-184, GTOS-76, WMO-TD/No. 1523)'

** State of the Climate in 2011 data available *** Not an official GCOS ECV

A climatic element is defined (WMO, 1996) as one of the properties or conditions of the atmosphere, from ground level to the upper troposphere which, when combined with other elements, describes the weather or climate at a given place for a given period of time. It has to be emphasised that only homogeneous climatological records are suitable for many climatological purposes, especially for the evaluation of trends in climate (eg in climate change detection). In this respect the Manual on the Global Observing System (WMO 1981a) states that '*each climatological station should be located at a place and under an arrangement that will provide for the continued operation of the station for at least ten years, and for the exposure to remain unchanged over a long period, unless it serves a special purpose that justifies its functioning for a shorter period*'.

Experience with historical climate data records has shown that continuous, cyclical improvement of the quality of datasets and products is generally needed, since historical records usually have challenges in terms of homogeneity. An audit trail associated with climate data records is needed to document how such challenges have been met.

Some organisations have created 'Fundamental Climate Data Records' (FCDR). This is a term used to denote a quality-controlled time-series of long-term data, generally involving a series of instruments (all platforms), with potentially changing measurement approaches, but with overlaps, calibration and quality control sufficient to allow the generation of homogeneous products providing a measure of the intended variable that is accurate and stable enough for climate monitoring. FCDRs include the ancillary data used to calibrate them.

General guidance for the generation of FCDRs and derived ECV products based on surface-based, airborne and satellite-based observing systems, and subsequent quality assessment by providers as well as users, is given by the GCOS requirements. (eg, for accuracy, stability, temporal/spatial resolution) as recommended in the GCOS Implementation Plan (and its 2010 update) and the Satellite Supplement[4]; these requirements are based on a broad consensus by the international climate community; and are reviewed on a regular basis.

General guidance

Box 1: Guidelines for the Generation of Datasets and Products Meeting GCOS Requirements (2010)

These guidelines help producers of climate-relevant ECV datasets assess the quality of their data, produce documentation and publicise their work related to the generation, processing and analysis of climate datasets and derived products so that there is transparency and evidence of the quality and fitness for purpose of climate datasets and products. They apply to observations from surface-based, airborne and satellite based instruments.

Following this Guideline would help to:

- facilitate the self-assessment of quality by data producers
- ensure transparency in the generation of climate datasets and products, and thereby
- enable users to judge the quality and fitness for purpose of climate datasets and products.

These guidelines set out the GCOS Climate Monitoring Principles (see Box 2)

GCOS (2010): Guideline for the Generation of Datasets and Products Meeting GCOS Requirements, GCOS-143 (WMO/TD-No.1530), May 2010. http://www.wmo.int/pages/prog/gcos/Publications/gcos-143.pdf

Box 2: GCOS Implementation Plan (and its 2010 update) and the Satellite Supplement

The **GCOS Implementation Plan** has led to the formulation of detailed observational requirements for all ECVs within the WMO Rolling Review of Requirements process.

GCOS (2010) Update of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, GCOS-138,

August 2010. http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

The **Satellite Supplement** stated requirements for datasets and products addressing 26 ECVs for which there is a major satellite observing component, as well as nine cross-cutting needs related to systematic observation of climate from space. The document indicated expected target accuracy, stability and resolution of ECV satellite products.

GCOS (2006): Systematic Observation Requirements for Satellite-based Products for Climate – Supplemental details to the satellite-based component of the GCOS Implementation Plan, GCOS-107, September 2006, http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf

Box 3: GCOS Climate Monitoring Principles (GCMPs)

http://www.wmo.int/pages/prog/gcos/documents/GCOS_Climate_Monitoring_Principles.pdf

These provide guidance regarding the planning, operation, and management of observing networks and systems. There are 20 principles (those specific to operators of satellite systems can be found using the link above). Those common to all observing methods are:

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (ie, metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

Box 4: GCOS requirements - Observing Systems Capabilities Analysis and Review tool (OSCAR)

http://www.wmo-sat.info/oscar/ (for the OSCAR tool)

http://www.wmo.int/pages/prog/www/OSY/Documentation/RRR-process.pdf summary of the rolling requirements review process

OSCAR is a component of the Rolling Requirements Review process (RRR process) for recording observational requirements and observing capabilities and conducting critical reviews of how well the capabilities address the requirements. OSCAR holds the most recent version of GCOS requirements.

This searchable database is the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes. The RRR database consists of two main components that contain information on:

(i) technology free user requirements broken down by application areas, and
(ii) surface and space-based observing system capabilities (only space based capabilities currently provided).

User requirements

User requirements are collected for various application areas addressing WMO Programmes and co-sponsored

programmes. For each application area[1], and for each required variable[2], the user requirements part of the RRR database includes observing requirements expressed for geophysical variables in terms of 5 criteria: **horizontal resolution, vertical resolution, observing cycle, timeliness** and **uncertainty**. eg http://www.wmo-sat.info/oscar/requirements/view/676.

For each of these criteria three values determined by experts are provided:

(a) the 'threshold' which is the minimum requirement to be met to ensure that data are useful
(b) the 'goal' which is an ideal requirement above which further improvements are not necessary, and
(c) the 'breakthrough' which is an intermediate level between 'threshold' and 'goal' which, if achieved, would result in a significant improvement for the targeted application.

The space-based component of OSCAR (OSCAR/Space) was released in 2012. It will be gradually enhanced with further instrument details and additional information fields. It contains reference information on Earth Observation satellites and instruments, as well as an expert assessment of the variables that can be derived from each instrument category.

Information on surface-based observing capabilities are planned to be made available through the surface-based component of OSCAR (OSCAR/Surface). This component is currently under development (planned release April 2014) and surface-based observing capabilities are therefore not available in OSCAR for the time being.

A **summary table of all the GCOS requirements for climate observation** held in the OSCAR database (last updated July 2007) including those for ECVs is available at: www.wmo.int/pages/prog/gcos/documents/GCOS_WCRP_ObservationRqmts_July2007_ECV.pdf

Box 5. Guide to Climatological Practices

Describes basic principles and modern practices important in the development and implementation of all climate services, and provides specific methods and examples of best practices in climatology. It has a chapter on Climate Observations, Stations and Networks.

For stations used or established to determine long period climate change, such as reference climatological stations and other baseline stations in the GCOS network, constancy of exposure and operation is required over many decades.

WMO No. 100 'Guide to Climatological Practices' (third edition, draft)
www.wmo.int/pages///prog/gcos/documents/gruanmanuals/WCP_CCl/guide_third_edition_draft_may2007.pdf

[1] : The following application areas are currently considered in the Rolling Review of Requirements: (1) Global Numerical Weather Prediction (NWP), (2) High Resolution NWP, (3) Synoptic Meteorology, (4) Nowcasting and Very Short Range Forecasting, (5) Seasonal to Inter-annual Forecasts, (6) Aeronautical Meteorology, (7) Atmospheric Chemistry, (8) Ocean Applications, (9) Agricultural Meteorology, (10) Hydrology, (11) Climate Monitoring (GCOS) in the atmospheric, oceanic and terrestrial domains, (12) Climate Applications (Other aspects addressed by the CCl), (13) Climate Research (WCRP). In addition WMO is now considering adding the following application areas: (1) Global terrestrial requirements that are not already addressed by GCOS (non-GCOS requirements of GTOS), and (ii) Space Weather.

[2] : The database currently addresses 112 variables. Work is underway – initially through the ET-SAT in consultation with CEOS for the satellite part – for standardizing the names and definitions of the variables.

GCOS requirements and international observing standards: Terrestrial Domain

The following tables for terrestrial ECVs draw on information available in OSCAR (Box 4), individual ECV assessment reports containing information on standards and aiming at establishing best practices (www.fao.org/gtos/topcECV.html) and the Proposed Workplan for Terrestrial ECVs (Box 6). However, it should be noted that some of these reports refer to ISO standards and other documentation that may have been superseded. Soil Carbon and Terrestrial biodiversity and habitat properties were proposed as candidate ECVs in 2009 (SBSTA, 2009c).

The GOCS Implementation Plan (see Box 2) notes that biodiversity and habitat properties are important to climate impact studies but that they are currently impossible to define as an ECV as only aspects of these complex properties can be measured, and only at a relatively small number of sites. Therefore, the Plan seeks the establishment of 'Essential Ecosystem Records' at sites where such observations will be conducted in adherence to high standards (with collocated measurement of meteorological variables) and will be sustained over the long term to allow future impact assessments.

The development and use of international standards for terrestrial ECVs was discussed by the GCOS Steering Committee, at its 19th session in September 2011; that expressed its concern '*at the amount of work and expense required to establish standards for the terrestrial ECVs through a formal International Organization for Standardisation (ISO) process and at the risk that emphasis on standardisation would divert effort from other tasks*.' It states: '*After extensive further consultations by GCOS and its partners, it is suggested to maintain the focus on keeping the highest level of data quality and error estimates, as well as to guaranteeing data quality. Therefore, GCOS and GTOS through their shared terrestrial expert panel TOPC and in cooperation with partner organisations responsible for global observing systems for land will continue to work on updating and upgrading the existing ECV reports on standards aiming at establishing best practices* (http://www.fao.org/gtos/topcECV.html)'.

Box 6: A Framework for Terrestrial Climate-Related Observations and The Development of Standards for the Terrestrial Essential Climate Variables: Proposed Workplan (2010)

Table 2 pages 12 to 14 of this document provide details of the types of in situ observations required and outline the role of satellite data. The importance of co-located *in situ* measurements for many of the ECVs is apparent.

The workplan uses previously collected information on the status of standardisation for individual ECVs to identify critical issues that need to be addressed during the standardization process. For each ECV this includes a brief summary of:

- importance and urgency
- readiness and feasibility
- available documentation (to use in drafting the standards)
- existing expertise (specialized scientific/ technical groups, committees).

Annex 6.3 of this report (pages 36 to 47) provide a brief description of the status and standardisation needs for in situ observing of the terrestrial Essential Climate Variables (ECVs).

GTOS (2010) A Framework for Terrestrial Climate-Related Observations and The Development of Standards for the Terrestrial Essential Climate Variables: Proposed Workplan, Report to the 33rd session of the SBSTA. September 2010, GTOS - 77 http://www.fao.org/gtos/doc/pub77.pdf

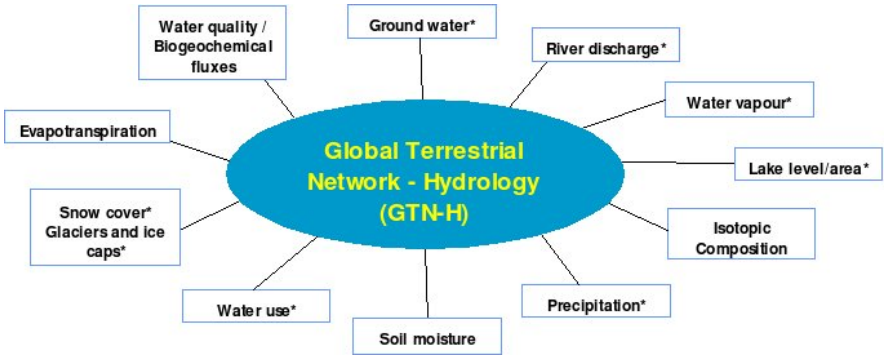
Box 7: Assessment of the status of the development of the standards for the Terrestrial ECVs – GTOS TV1 – (individual reports for the terrestrial ECVs - GTOS -56 to GTOS- 68)

Assessment reports on available methodological standards and guides are available for many of the terrestrial ECVs and can be found at: http://www.fao.org/gtos/Pubs.html They contain details of technical guidance and relevant international standards (though some that are referred to have been superseded).

Box 8: GCOS relevant network components and systems in the terrestrial domain

In situ networks for the terrestrial domains are listed at: http://www.wmo.int/pages/prog/gcos/index.php?name=ObservingSystemsandData#terrestrial Those relevant to the UK (ie excluding permafrost are):

Network or System (in situ)	Essential Climate Variables (ECVs)	International Data Centres and Archives
GCOS/GTOS Baseline Global Terrestrial Network - Rivers (GTN-R)	River Discharge	Global Runoff Data Centre
GCOS/GTOS Baseline Global Lake Network (List of Lakes)	Lake Level/ Area/ Temperature	International Data Centre on the Hydrology of Lakes and Reservoirs (HYDROLARE)
WWW/GOS synoptic network	Snow Cover	National Snow and Ice Data Center (NSIDC)
GCOS/GTOS Baseline Global Terrestrial Network - Glaciers (GTN-G)	Glaciers mass balance and length, also Ice sheet mass balance	World Glacier Monitoring Service (WGMS) National Snow and Ice Data Center (NSIDC)
Global Terrestrial Network Hydology (GTN-H)	All hydrological ECVs. An overarching system with a focus on bringing together data from existing global hydrological observation networks (including from GCOS networks for ECVs) to enhance their value through integration. (see diagram)	Distributed



Terrestrial ECV (with link to GOSIC description)	Main variables (and observing unit) (sources: ECV data matrix, OSCAR, GTOS -77 report)	Use of satellite and *in situ* measurements (source GTOS -77 report, Table 2)	*In situ* observations: Sources of information about the current status of the observing networks, methods, protocols and observation standards
River Discharge (ECV T1)	Runoff (m3 s-1)	*In situ* measurement requires co-located point measures of: • Velocity of water. • Riverbed profile Satellite not used (some research on laser /radar altimetry).	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T1-River** http://www.fao.org/gtos/doc/ECVs/T01/T01.pdf Version 9, 2009 • For *in situ* measurement, existing standards set by ISO and guides from the WMO should be adhered to and are described in the GTOS assessment report (link above). These cover a range of instruments. Relevant ISO standards (as at 2009), weblinks and references are listed on pages 11-12 of the GTOS assessment report. The revision process of these standards and guides is well established and adequate. • The WMO Commission for Hydrology is carrying out an assessment of flow measurements and techniques (www.wmo.int/pages/prog/hwrp/Flow/flow_tech/index.php), which includes a collection of international standards and guidelines to be available on the web.
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/676		
Water Use (ECV T2)	Location and area irrigated Amount of water used	A priority is production of gridded global datasets of irrigated area using satellite data at 250m resolution on a regular basis using satellite data.	The GTOS report on the status of the development of the standards for the Water Use ECV is still under development. The FAO defines requirements for information on irrigation water use by international, regional, national and local communities and archives and disseminates information related to irrigated water use through its on-line AQUASTAT database on water resources and irrigation, available on the web. http://www.fao.org/nr/water/aquastat/dbase/index.stm
	GCOS Observation Requirements defined in OSCAR: none		
Ground Water (ECV T3)	Ground water level (cm) & location. Ground water extraction Rates (m3 yr-1)	*In situ* measurement are the primary source and require co-located point measures of: • Ground water level (m) • Recharge and discharge (m/s) • Well groundwater level (m) • Water quality (chemical, physical, biological, radiological). Water level is supported by a range of satellite derived gravity measurements.	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T3-Groundwater** http://www.fao.org/gtos/ECV-T03.html Version 5, 2008 There are various sources of information describing ground water data collection methodologies. They include WMO reports (WMO, 2008a), ISO standards, a guideline on groundwater monitoring (Jousma, 2006), and various other publications by national or international agencies (refer to SBSTA, 2009a). WMO (2008a): www.wmo.int/pages/prog/hwrp/publications/Technical_report_series/1095_en_4_Web.pdf Jousma, G. (Ed.) 2006. Guideline on: Groundwater monitoring for general reference purposes. Report GP 2006-1, International Groundwater Resources Centre Assessment Centre, Utrecht, The Netherlands. [Annex C contains a description of different measurement tools and methods and collections of guidelines on sampling methods, sample conservation and physical, chemical and biological testing methods'
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/667		

Terrestrial ECV (with link to GOSIC description)	**Main variables (and observing unit)** (sources: ECV data matrix, OSCAR, GTOS -77 report)	**Use of satellite and *in situ* measurements** (source GTOS -77 report, Table 2)	***In situ* observations: Sources of information about the current status of the observing networks, methods, protocols and observation standards**
Lakes (ECV T4)	Lake area (m^2) Lake level (cm) Lake surface temp. (K) If possible: freeze and break-up dates	*In situ* measurement requires co-located point measures of: • Lake- specific area-volume curve • Water level (cm) Satellite data contributes to lake area and is being developed in a supporting role for water level (satellite radar altimetry).	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T4-Water Level** http://www.fao.org/gtos/doc/ECVs/T04/T04.pdf Version 8, 2009 An initial priority list of 156 lakes has been drawn up by TOPC (at present this does not include a UK lake). The intention is to increase this number to the order of 500 lakes. Information on changes in lake level and area is required on a monthly basis for climate assessment purposes. The measurement methods are similar to those for river discharge and are thus described in WMO technical regulations (WMO, No. 49, 2006) and guides (WMO, 2008a). Numerous ISO standards have also been published (refer to SBSTA (2009a) for a list). There is an identified need to prepare a single standard document, possibly taking as a base ISO /TR 11330:1997 (purely informative now).
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/669 (area) www.wmo-sat.info/oscar/requirements/view/670 (level) www.wmo-sat.info/oscar/requirements/view/671 (surface temp)		
Snow Cover (ECV T5)	Snow Cover Extent (km2) Duration (days) Snow Depth (cm)	Satellites are the primary observing source for measures of: • extent (km) • duration (daily) and supports the measurements made by *in situ* observing, which is the primary method for: • Snow depth (cm) • Snow water equivalent (mm) (these need to be co-located)	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T5-Snow** http://www.fao.org/gtos/doc/ECVs/T05/T05.pdf Version 8, 2009 *In situ:* Identified GCOS requirements are for point measurements of daily snow depth at GSN (ground station network) stations but these requirements are expanded by wide ranging domestic needs for such data. Guidelines for snow measurements have in the past been prepared by the WMO and by commissions and associations of International Union of Geodesy and Geophysics (see SBSTA 2009a for references); the responsible groups continue to monitor new developments and undertake revisions. There may be a need to formulate a new international standard for

Terrestrial ECV (with link to GOSIC description)	Main variables (and observing unit) (sources: ECV data matrix, OSCAR, GTOS -77 report)	Use of satellite and *in situ* measurements (source GTOS -77 report, Table 2)	*In situ* observations: Sources of information about the current status of the observing networks, methods, protocols and observation standards
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/677 (extent) http://www.wmo-sat.info/oscar/requirements/view/109 (SWE)		snow measurements that would encompass both *in situ* and satellite-based measurement methodologies. WMO Commission on Hydrology has been the leading group in preparing documents on standardised *in situ* snow measurements. The thematically closest ISO group is probably TC207 or TC211, depending on whether the measurement itself or data handling and presentation aspects of the standard are the primary concern.
Glacier and Ice Caps (ECV T6)	Glacier/ice cap inventory mass balance (kg m-2 yr-1), Glacier Length (m)	Satellite is the primary source for: • glacier area • glacier front variation (m) and supports measurement of specific mass balance (m) *In situ* measurement for validation requires co-located measures of these same variables.	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T6- Glaciers and ice caps** www.fao.org/gtos/doc/ECVs/T06/T06.pdf version 10 2009 Substantial literature exists to support this task. SBSTA (2009a) lists 14 different publications that collectively provide strong foundation for an international standard. Within ISO, TC207 (Environmental Management) is most closely related to measurement aspects in this thematic area. TC211 (Geographic Information/ Geomatics) has developed standards handling geospatial data that apply to glaciers as well as other environmental information. Other variables measured to understand the glacier distribution, behaviour and related processes include: location, exposition, lowest and highest glacier point length, winter/summer balance, altitude of the equilibrium line altitude and ratio of accumulation area to total glacier area and further parameters (references regarding measurement of these are provided in the GTOS assessment report).
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/666 (topography) www.wmo-sat.info/oscar/requirements/view/665 (cover/inventory)		
Permafrost (ECV T7)	Permafrost Extent (km2), Temperature Profiles & Active Layer Thickness		Not relevant to the UK (source: 5th national communication)
Albedo (ECV T8)	Earth [Land?] surface albedo (%) (hemispherically integrated reflectance of the Earth surface in the range 0.4-0.7)	Both satellite and *in situ* observation are used to measures: • Direct, diffuse and incoming solar radiation • Reflected radiation *In situ* measurement requires co-located point measures of these variables.	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T8- Albedo** http://www.fao.org/gtos/doc/ECVs/T08/T08.pdf version 12 2009 The WMO CIMO provide guidance on the measurement of meteorological variables, including incoming solar (downward) radiation. Several applicable ISO standards have also been developed (SBSTA, 2009a). Long-term, high-quality, calibrated field measures of direct and diffuse land surface incident and reflected radiation are being collected from tower-mounted pyranometers at a limited

Terrestrial ECV (with link to GOSIC description)	Main variables (and observing unit) (sources: ECV data matrix, OSCAR, GTOS -77 report)	Use of satellite and *in situ* measurements (source GTOS -77 report, Table 2)	*In situ* observations: Sources of information about the current status of the observing networks, methods, protocols and observation standards
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/662 (earth surface albedo)		number of sites by the BSRN. ILTER sites and regional flux tower networks also collect reflected radiation measurements. Guidelines for data collection protocols and standardisation across the flux networks are being developed under the auspices of the Terrestrial Carbon observation effort. WMO. 2008b. Guide to Meteorological Instruments and Methods of Observation. WMO-No. 8, Seventh edition, World Meteorological Organization, Geneva, Switzerland. http://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/CIMO/CIMO_Guide-7th_Edition-2008.pdf
Land Cover (ECV T9)	Land cover type	Satellite: primary source of measurement of: • Land cover type • Land cover attribute • Change in land cover With *in situ* measurements used for validation purposes	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T9- Land cover http://www.fao.org/gtos/doc/ECVs/T09/T09.pdf** version 16 2009 Numerous national inventory and mapping systems have been developed but so far there is no agreed- upon international standard. A UN Land Cover Classification System (LCCS) concept for a globally applicable land cover classification and mapping has been adopted as the basis for an ISO standard which is currently under development through the ISO Technical Committee 211. At this stage it is uncertain whether fractional land cover products and land cover change information are sufficiently mature to permit standardisation. New land-cover maps should document the spatial distribution of land-cover characteristics with attributes suitable for climate, carbon, and ecosystem models and using a common language for class definitions. Global land-cover databases must be accompanied by a description of class-by-class thematic/spatial accuracy. The CEOS WGCV, working with GOFC-GOLD and GLCN has published agreed validation protocols. The current protocols base accuracy assessment on a sample of high-resolution (1-30 m) satellite imagery, itself validated by in situ observations wherever possible.
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/672 (land cover) http://www.wmo-sat.info/oscar/requirements/view/679 (wetland extent)		
(FAPAR) (ECV T10)	Fraction of PAR absorbed by vegetation for photosynthesis processes (%)	Satellite is the primary method. • PAR measurements above and below canopy FAPAR can be determined at three levels - canopy, green leaves and chlorophyll. *In situ* measures used for validation	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T9- FAPAR** http://www.fao.org/gtos/doc/ECVs/T10/T10.pdf version 8 2009 No standard has been defined yet for the procedure to compute FAPAR and in particular to agree on the selection of environmental conditions and inputs datasets to use. However, use of physically-based approach is now the main methodology to retrieve the FAPAR products from ground-based measurements and space data. Observation programs in North America developed a consensus regarding FAPAR *in situ*

Terrestrial ECV (with link to GOSIC description)	Main variables (and observing unit) (sources: ECV data matrix, OSCAR, GTOS -77 report)	Use of satellite and *in situ* measurements (source GTOS -77 report, Table 2)	*In situ* observations: Sources of information about the current status of the observing networks, methods, protocols and observation standards
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/664		measurements for forest and shrub canopies (Law et al., 2008). Proper use of specialised radiation instruments (pyranometers) is described in a WMO guide (WMO, 2008b). Several ISO standards for solar radiation measurements have been published (SBSTA, 2009a). The WMO CIMO is the main technical body concerned with methods of standardising radiation measurements themselves. Within ISO, two groups are relevant TC172 (Standardization of terminology, requirements, interfaces and test methods in the field of optics and photonics) ISO TC207 (Environmental Management).
Leaf Area Index (*ECV T11*)	Total one-sided area of photosynthetic tissue per unit ground surface area (%)	Satellite is the primary method for: • Total leaf area per unit ground area supported by *in situ* measures for validation. In situ measures are the primary method for: • Canopy clumping index (a measure heterogeneity of leaf distribution in the canopy) supported by satellite measures.	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T9- LAI http://www.fao.org/gtos/doc/ECVs/T11/T11.pdf** version 10 2009 There are no ISO standards directly applicable to LAI measurements. Within the ISO, TC207 is the most closely related group. The CEOS WGCV (Land Products Validation Subgroup) presently has most expertise regarding LAI measurements for ECV related purposes. The interest in information on LAI distribution and changes has grown substantially due to its intrinsic importance and the emerging capability for LAI estimation using satellite measures. A guide for forest canopies has recently been published for indirect measurements based on remote observations (Law et al., 2008 www.fao.org/gtos/doc/pub55.pdf and Chen and Law, 2007 http://public.ornl.gov/ameriflux/AmeriFlux_LAI_Data_Submission_Guidelines.doc Sampling strategies for larger areas have been elaborated (Morisette et al., 2006). The performance of various measurement methods has been documented in published literature.
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/674		
Above Ground Biomass (*ECV T12*)	above ground Biomass (t/ha)	*In situ*: measurement requires co-located point measures of: • above ground biomass • below ground biomass • dead mass • litter Satellite provides a supporting role via land cover.	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T9- Biomass http://www.fao.org/gtos/doc/ECVs/T12/T12.pdf** version 10 2009 Satellite data are playing increasingly important roles. However, their use requires *in situ* biomass data for calibration and validation of satellite- based products, and consequently a methodology which is internationally consistent to permit inter-comparisons and cross-validation. A candidate methodology, developed through international scientific collaboration, has been

Terrestrial ECV (with link to GOSIC description)	Main variables (and observing unit) (sources: ECV data matrix, OSCAR, GTOS -77 report)	Use of satellite and *in situ* measurements (source GTOS -77 report, Table 2)	*In situ* observations: Sources of information about the current status of the observing networks, methods, protocols and observation standards
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/661		produced (Law et al., 2008 www.fao.org/gtos/doc/pub55.pdf). It is consistent with procedures previously employed in projects undertaken in various countries, mostly in forest or grassland ecosystems, to determine biomass content of trees/overstory woody biomass, overstory foliage, understory and ground cover, litter, soil and roots. Within ISO, TC207 is the most closely related group. The Forestry and Natural Resources Departments of FAO has probably the most experience with standardising forestry reports based on national inventories and inputs to UN-REDD. Three existing international groups possess the needed technical expertise: the FLUXNET team, the IPCC team that compiled Good Practice Guidelines (IPCC, 2003 www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html); and the GOFC-GOLD Biomass Working Group (http://www.gofc-gold.uni-jena.de/).
Fire Disturbance (*ECV T13*)	Burnt Area (ha), Date & Location of Active Fire, Burn Efficiency (% Vegetation Burned/Unit Area)	Satellite measurement is the primary source for: • Active fires • Radiated power (kW*m^{-2} • Total burned area /Fire fractional cover % (fire area and location) In situ methods provide some validation.	**GTOS: Assessment of the status of the development of the standards for the Terrestrial ECVs T9- Biomass http://www.fao.org/gtos/doc/ECVs/T13/T13.pdf** version 27 2009 If made, in situ measurements are limited to small areas and serve to calibrate, validate and inter-compare satellite- derived products and thereby ensure their accuracy over time. No international standards have been established for satellite, aircraft or in situ measurement strategies. Among the many ISO standards dealing with fires, only few appear relevant (SBSTA, 2009a). Although progress has been made toward standardization of the individual variables, preparation of a comprehensive standard is considered not urgent, and for radiated power arguably not feasible at this time (GTOS, 2020 – see Box 4). Standardization of *in situ* measurements in support of satellite-based fire disturbance monitoring is at an early stage of development. A burned area validation protocol was developed by the CEOS Working Group on Calibration and Validation (WGCV) Land Products Validation LPV) Subgroup (http://lpvs.gsfc.nasa.gov/PDF/BurnedAreaValidationProtocol.pdf).
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/663		
Soil Moisture	Fractional content of water in a volume of wet soil. Surface layer m^3/m^3	Satellite measurement is the primary source for: • Landscape profile distribution With *in situ* measurements for validation I*n situ* measurement are the primary	There is no ECV documentation on standards and guidelines and the topic is not ready for definitive standardisation. In practice, only space- based measurements are potentially capable of providing the spatial and temporal resolution required for soil moisture information. However, available sensing technologies can only respond to surface moisture (not soil profile), and they need to be

Terrestrial ECV (with link to GOSIC description)	Main variables (and observing unit) (sources: ECV data matrix, OSCAR, GTOS -77 report)	Use of satellite and *in situ* measurements (source GTOS -77 report, Table 2)	*In situ* observations: Sources of information about the current status of the observing networks, methods, protocols and observation standards
		source for: • Profile moisture distribution	calibrated with surface measurements. Thus both site and landscape level soil moisture information is required, and *in situ* soil moisture determination is an essential element of the overall measurement strategy. While point soil moisture measurements are well established, the main challenge for this ECV is standardization in describing and reporting the distribution of near-surface soil moisture in support of satellite- based sensing strategies. Although methodology development in this respect has not progressed far enough to attempt standardization, a guide documenting possible approaches and their relative merits would be valuable for current and upcoming satellite missions.
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/678		
Soil Carbon	CO2 flux measurements	CO2 flux measurements based on the eddy covariance technique covering various biomes around the world. Satellite measures are not directly applicable; estimates of Leaf Area Index (LAI) and Above-ground Biomass can provide proxy information	Standards for data acquisition processing and archiving have been set in the framework of large international scale projects (GTOS Terrestrial and Atmospheric Carbon Observation Initiative (TCO), the Global Carbon Project (GCP)) and continental scale carbon projects (CarboEurope, CarboAfrica, US, Carbon Cycle Plan, etc). The GOSIC also makes reference to the Integrated Carbon Observation System (ICOS) a European infrastructure dedicated to the high precision monitoring of greenhouse gas fluxes. The UK ICOS contribution is described at: http://www.icos-infrastructure.co.uk/map_of_uk_sites.html
	GCOS Observation Requirements defined in OSCAR: none		
Ice Sheets	Ice sheet mass balance (kg m-2 yr-1) Extent (km2), Ice sheet topography (cm)	Satellite measurement is the primary source, supported by targeted observations by aircraft of surface elevation, ice thickness, and basal characteristics and *in situ* measurements of firn temperature profile and surface climate.	The GOSIC description provides information on the observing of this ECV (Ice Sheets)
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/668 (topography)		

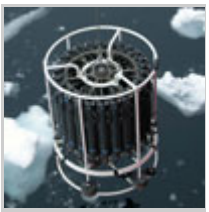
SBSTA. 2009a. Assessment of the status of the development of standards for essential climate variables in the terrestrial domain and development of a framework for climate-related terrestrial observations: Update on progress. Report CCC/SBSTA/2009/MISC.8, Subsidiary Body for Scientific and Technological Advice, Thirtieth session, Item 6 of the provisional agenda, Research and systematic observation, Revised submission from the secretariat of the Global Terrestrial Observing System, Bonn 1–10 June. 2009. 86p. http://unfccc.int/resource/docs/2009/sbsta/eng/misc08.pdf

GCOS requirements and international observing standards: Oceanic Domain

The following tables for the oceanic domains cover *in situ* measurements of the surface, subsurface and water column of the sea. Information on GCOS climate observing requirements is taken from OSCAR (see Box 3). The Ocean Observations Panel for Climate (OOPC) is a scientific expert advisory group charged with making recommendations for a sustained global ocean observing system for climate in support of the goals of its sponsors GCOS, GOOS and the WCRP.

Details of instrumentation and supporting documentation for the measurement of ECVs can be sourced through the websites and contacts provided for the contributing networks. These are provided on the OOPC website (see extracts below copyright: © 2005-6 IOC/UNESCO).

Subsurface composite network: http://ioc-goos-oopc.org/obs/subsurface.php

	Component network	ECVs	International coordination provided by:
	Reference mooring network (29 moorings)	all autonomously observable ECVs	OceanSITES
	Sustained and repeated ship-based hydrography network	All feasible ECVs, including those that depend on obtaining water samples	GO-SHIP (from a programme initiated in IOCCP and CLIVAR)
	Argo network	Temperature, Salinity, Current	Argo
	Repeat XBT line network (41 lines)	Temperature	JCOMM Ship Observations Team (SOT)
	Critical current and transport monitoring	Temperature, heat, freshwater, carbon transports, mass	CLIVAR, IOCCP , OceanSITES

Dated: 25/10/2013

Surface composite network: http://ioc-goos-oopc.org/obs/surface_insitu.php

	Component network	ECVs	International coordination provided by:
	Global surface drifting buoy array with 5° resolution (1250 total)	SST, SLP, Current (based on position change)	JCOMM Data Buoy Cooperation Panel (DBCP)
	Global tropical moored buoy network (~120 moorings)	*typically:* SST and surface vector wind *can include:* SLP, Current, Air-sea flux variables	JCOMM DBCP Tropical Moored Buoy Implementation Panel (TIP)
	Volunteeer Observing Ship (VOS) fleet	all feasible surface ECVs	JCOMM Ship Observations Team (SOT)
	VOSClim	all feasible surface ECVs plus extensive ship metadata	JCOMM Ship Observations Team (SOT)
	Global reference mooring network (29 moorings)	all feasible surface ECVs	OceanSITES
	GLOSS core sea-level network, plus regional/national networks	sea level	JCOMM GLOSS: www.gloss-sealevel.org/
	Carbon VOS	pCO_2, SST, SSS	IOCCP
	Sea ice buoys	sea ice	JCOMM DBCP IABP and IPAB

Dated: 25/10/2013

Many of the elements of the *in situ* networks transmit their data in real time to agreed data centres, where the data are then sent in real time over the WMO Global Telecommunications System and made available on internet servers. The Observations Programme Area of JCOMM has undertaken monitoring activities for both real-time transmitted data and other delayed-mode observing platforms.

Marine ECV (with link to GOSIC description)	Variables (observing unit) (sources: ECV data matrix, OSCAR –OOPC /AOPC)	Use of satellite and *in situ* measurements	Background and relevant links
Surface: Carbon Dioxide Partial Pressure	Partial pressure of carbon at the surface of the sea (microatm)	*In situ* is the primary source of measurement	CO2 flux is determined from measurements of atmospheric and surface sea water partial pressure of CO2 (pCO2) and wind speed. In order to fully characterize this chemical state of the inorganic carbon system in the surface ocean, a second property, in addition to pCO2, needs to be measured, ie, either dissolved inorganic carbon (DIC), alkalinity (Alk – a measure of the content of carbonate or bicarbonate), or pH. DIC is the cumulated concentration of inorganic carbon species (dissolved carbon dioxide, carbonic acid, bicarbonate and carbonate) in solution. **International Ocean Carbon Coordination Project (IOCCP)** promotes the implementation of a global network of ocean carbon observations through development of international agreements on standards, methods, and databases. IOCCP helps develop manuals on ocean carbon measurement methods and systems, for example, the *Guide to Best Practices for Oceanic CO_2 Measurements*. Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. *Guide to best practices for ocean CO2 measurements*. PICES Special Publication 3, 191 pp.
	GCOS Observation Requirements defined in OSCAR: http://www.wmo-sat.info/oscar/requirements/view/558 (pCO2)		
Sub Surface: Carbon	Dissolved inorganic carbon (Mol. Kg^{-1})	*In situ* is the primary source of measurement	
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/551 (DIC)		
Surface: Ocean Acidity **Sub surface:**	Ocean acidity or alkalinity (pH)	*In situ* is the primary source of measurement	
	GCOS Observation Requirements defined in OSCAR: none (pH)		
Surface: Current **Sub Surface:** Current	Ocean surface currents (vector) – cm/s	*In situ* is the primary source of measurement	OOPC website contains links to the in situ surface and subsurface composite networks making these measures: http://ioc-goos-oopc.org/obs/subsurface.php http://ioc-goos-oopc.org/obs/surface_insitu.php
	GCOS Observation Requirements defined in OSCAR: none		
Sub Surface: Global Ocean Heat Content	Ocean temperature (K)		New ECV - 3D field of temperature in upper and deep ocean
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/556 (OOPC)		
Sub Surface: Nutrients	Nutrients (phosphate, nitrate, silicates, silicic acid)	*In situ* is the primary source of measurement	These networks are research and/or pilot programmes and require technology development to attain reliable and accurate autonomous sensors and to deploy observing systems to sample better sub-surface nutrient variability. *Source: GOSIC*
	GCOS Observation Requirements defined in OSCAR: none		

Marine ECV (with link to GOSIC description)	Variables (observing unit) (sources: ECV data matrix, OSCAR –OOPC /AOPC)	Use of satellite and *in situ* measurements	Background and relevant links
Surface: Ocean Colour	Ocean colour radiance Chlorophyll-a concentration (a proxy for phytoplankton biomass) Coloured organic matter (COM) Particulate organic carbon (POC) Suspended sediments	*In situ* measures are made of chlorophyll, COM, POC, suspended sediments. Measurements also used for calibrating and validating satellite products. Satellite is source for ocean colour radiance	International coordination via International Ocean Colour Coordinating Group http://www.ioccg.org/ promotes the application of remotely sensed data.
	GCOS Observation Requirements defined in OSCAR: none		
Surface: Phytoplankton	Microflora and microfauna (species abundance and composition) Phytoplankton colour index (4 values) Ocean chlorophyll concentration (mg/m^3)	*In situ* measurement of near surface plankton Satellite measure of ocean chlorophyll concentration	OOPC website contains links to the in situ surface and subsurface composite networks making these measures: http://ioc-goos-oopc.org/obs/subsurface.php http://ioc-goos-oopc.org/obs/surface_insitu.php
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/552 (OOPC) -ocean chlorophyll concentration		
Surface: Sea Surface Salinity (SSS) **Sub surface:** Salinity	Ocean salinity (psu)	*In situ* is the primary source of measurement	
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/555 upper ocean (OOPC) www.wmo-sat.info/oscar/requirements/view/554 deep ocean (OOPC)		
Surface: Sea Surface Temperature (SST) **Sub Surface:** Temperature	Ocean temperature (K)	*In-situ* data from surface drifting buoys, marine vessel and platform reports and surface moorings. Near-global coverage of SST is provided by operational satellite sensors. *In-situ* observations are essential for accuracy and vertical resolution	OOPC website contains links to the in situ surface and subsurface composite networks making these measures: http://ioc-goos-oopc.org/obs/subsurface.php http://ioc-goos-oopc.org/obs/surface_insitu.php For air and sea surface temperature measurement, the Guide to Meteorological Instruments and Methods of Observation (WMO, 1996) sets the required accuracy of the measurement system
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/557 upper ocean (OOPC) www.wmo-sat.info/oscar/requirements/view/556 deep ocean (OOPC) www.wmo-sat.info/oscar/requirements/view/106 sea surface (AOPC)		

Marine ECV (with link to GOSIC description)	Variables (observing unit) (sources: ECV data matrix, OSCAR –OOPC /AOPC)	Use of satellite and *in situ* measurements	Background and relevant links
Surface: Sea Ice	Sea ice cover (%) Sea ice thickness (cm)	Satellite is the primary source supported by *in situ* observations	Relevant documents can be found on the sea ice website of GCOS (OOPC/ AOPC) working group on SST and Sea Ice. http://ocean.dmi.dk/GCOS/documents.html Sea ice thickness is related to sea-ice elevation and ice density.
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/561 (sea ice cover OOPC) www.wmo-sat.info/oscar/requirements/view/562 (sea ice thickness - OOPC)		
Surface: Sea Level	Sea level (cm)	Global network of sea level gauging stations provide *in situ* measurement. Satellite (low precision altimetry and high precision altimetry) also used and supported by *in situ* measurements	IOC. 2006. Manual on sea-level measurement and interpretation. Volume 4 - An update to 2006. Intergovernmental Oceanographic Commission Manuals and Guides No. 14. IOC, Paris, 80pp. (eds. Aarup, T., Merrifield, M., Perez, B., Vassie, I and Woodworth, P.). (See IOC 1985 for Volume 1, 1994 for Volume 2 and 2002 for Volume 3). Available as a PDF file.
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/553 ocean dynamic topography (OOPC) www.wmo-sat.info/oscar/requirements/view/550 coastal sea level (OOPC)		
Surface: Sea State	Significant wave height (m) Dominant wave direction (degrees) Dominant wave period (seconds) Wave energy	*In situ* is the primary source for all parameters Satellite is used for measurement and 10m windspeed of significant wave height but not operationally (*source: GOSIC*)	Wave height and upcrossing or peak period are measured at moored buoys. A small number of moored buoys also measure the wave energy spectrum giving full detail of the directional and frequency distribution of wave energy. Visual observations are made by ships of the Voluntary Observing Fleet. OOPC website contains links to the in situ surface composite networks making these measures: http://ioc-goos-oopc.org/obs/surface_insitu.php
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/107 significant wave height at (AOPC)		
Sub Surface: Oxygen	Subsurface dissolved oxygen concentration (Mol. Kg^{-1})	*In situ* is primary method but there is no specific GCOS baseline network yet.	Networks are research and/or pilot programmes and require substantial up-scaling in order to adequately sample sub-surface oxygen variability. The possibility of linking the recently developed sensors with autonomous platforms (eg, Argo floats) to create a large-scale observing network is being examined.
	GCOS Observation Requirements defined in OSCAR: none		
Sub Surface: Tracers	Concentration of trace molecules such as tritium and CFCs (Mol. Kg^{-1})	*In situ* is primary method but there is no specific GCOS baseline network yet.	See GO-SHIP in OOPC website links to the in situ subsurface composite networks: http://ioc-goos-oopc.org/obs/subsurface.php
	GCOS Observation Requirements defined in OSCAR: none		

GCOS requirements and international observing standards: Atmosphere Domain

The following tables for atmosphere domains (surface, upper air, atmospheric composition) cover *in situ* measurements of the atmospheric surface and upper air and of atmospheric chemistry over land, sea and ice. The information on GCOS climate observing requirements is taken from OSCAR (see Box 3).

The organisations that promote and facilitate co-operation for constituent components of GCOS climate observing systems of the atmosphere are:

Organisation	**Sources of further information**
WMO Global Observing System (GOS)	Atmospheric physical and dynamical properties. GOS is the WMO coordinated system of methods and facilities for making meteorological and other environmental observations on a global scale in support of all WMO Programmes. There are a range of observation components that provide climate observations to GCOS and summary descriptions of these are provided by the WMO at: http://www.wmo.int/pages/prog/www/OSY/Gos-components.html GOS encompasses a sub-system of two GCOS networks of observing stations with a configuration specifically to meet the needs of global climate applications: • GCOS Surface Network **(GSN)** for **s**urface observations. GCOS Upper-air Network (**GUAN**) for upper-air observations (which incorporates a GCOS Reference Upper-Air Network (GRUAN) to serve as a reference network for other radiosonde sites, for calibration and validation of satellite records, and for other applications
WMO Global Atmosphere Watch (GAW)	Atmospheric constituent and chemical properties GAW is considered the atmospheric chemistry component of GCOS.
World Climate Research Project (WCRP) Global Energy and Water Exchanges Project (GEWEX)	The Baseline Surface Radiation Network is an activity of the Global Energy and Water Cycle Experiment (GEWEX) and is designated by GCOS for surface radiation monitoring. http://www.bsrn.awi.de/en/project/background/
International Geosphere-Biosphere Project (IGBP) and WCRP research networks	Monitoring of terrestrial ecosystems, clouds and the hydrological cycle, the earth's radiation budget, ice sheets and precipitation over the oceans.

Box 9: Vision for the GOS in 2025

Provides high-level goals to guide the evolution of the GOS in the coming decades and envisages major changes and new approaches in science.

Space-based components (page 2) and surface based components (page 4) are summarised in tables that provide details of platforms and the geophysical variables they will measure (which are pertinent to the ECVs).

From the perspective of climate observing it envisages:

- increased standardization of instruments and observing methods
- improvements in calibration of observations and the provision of metadata, to ensure data consistency and traceability to absolute standards
- improved methods of quality control and characterization of errors of all observations
- increased interoperability, between existing observing systems and with newly implemented systems.

Surface-based observations of atmospheric composition (complemented by balloon- and aircraft-borne measurements) will contribute to an integrated three-dimensional global atmospheric chemistry measurement network, together with a space-based component. New measurement strategies will be combined to provide near real-time data delivery.

Surface and space-based observing systems will be planned in a coordinated manner to cost-effectively serve a variety of user needs with appropriate spatial and temporal resolutions.

http://www.wmo.int/pages/prog/www/OSY/WorkingStructure/documents/CBS-2009_Vision-GOS-2025.pdf

Atmosphere Domain: Surface and Upper Air measurements

Box 6. Guide to the GCOS Surface and Upper-Air Networks: GSN and GUAN

http://www.wmo.int/pages/prog/gcos/Publications/GCOS-144_en.pdf

The GSN and GUAN networks are based mainly on stations which are included in the networks of the WMO World Weather Watch Global Observing System (GOS). This guide explains the scope and purpose of these two Networks and the importance of:

- homogeneity of the data time-series relating to observing practices
- representativeness of the environment, and
- homogeneity of the environment in climate observing.

It also sets out the observation requirements for stations operating in the networks.

GCOS-144: WMO/TD No. 1558, 'Guide to the GCOS Surface and Upper-Air Networks: GSN and GUAN' (2010)

WMO 'CIMO' Guide to Meteorological Instruments and Methods of Observing

http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html

This comprehensive technical guide provides advice on good practices for making meteorological measurements and observations, recognising that they serve a wide variety of purposes, from weather forecasting to climate research. It covers measurement in surface and upper air environments using a range of observing equipment (including aircraft, radar and satellite observing techniques) relevant to the acquisition of data in support of the ECVs. As well as dealing with measurement from the technical perspective it also considers the operational characteristics that must be considered.

WMO Guide to Meteorological Instruments and Methods of Observation ('CIMO Guide'), WMO-No. 8 (2008 edition, updated in 2010).

Box 6. Guide to Climatological Practices

Describes basic principles and modern practices important in the development and implementation of all climate services, and provides specific methods and examples of best practices in climatology. It has a chapter on Climate Observations, Stations and Networks.

For stations used or established to determine long period climate change, such as reference climatological stations and other baseline stations in the GCOS network, constancy of exposure and operation is required over many decades.

WMO No. 100 'Guide to Climatological Practices' (third edition, draft) https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/WCP_CCl/guide_third_edition_draft_may2007.pdf

<table>
<tr><th>Atmosphere ECV</th><th>Variables (observing unit)
(sources: ECV data matrix, OSCAR)</th><th>Use of satellite and in situ measurements</th><th>Key sources relating to observation standards of ECVs</th></tr>
<tr><td rowspan="2">Surface:
Surface Air Pressure</td><td>Air Pressure (hPa)</td><td>In situ is the primary method. On land from Automatic Weather Stations in the GCOS Surface Network and Full www/GOS Surface Network. In marine environments from ships, moored and drifting buoys and stationary platforms.</td><td rowspan="2">WMO ‘CIMO’ Guide to Meteorological Instruments and Methods of Observing http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html
• Part I :Measurement of Meteorological Variables. Chapter 3 (atmospheric pressure)
• Part II: Observing Systems. Chapter 1 (measurements at AWS) and Chapter 4 (marine observations)
Guide to the GSN and GUAN (2010 update of GCOS 73)
https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf</td></tr>
<tr><td colspan="2">GCOS Observation Requirements defined in OSCAR:
www.wmo-sat.info/oscar/requirements/view/67 (over land)
www.wmo-sat.info/oscar/requirements/view/68 (over sea)</td></tr>
<tr><td rowspan="2">Surface:
Surface Air Temperature</td><td>Air Surface temperature (K)</td><td>In situ is the primary method. On land from Automatic Weather Stations in the GCOS Surface Network and Full www/GOS Surface Network. In marine environments from ships, moored and drifting buoys and stationary platforms. Satellite data has a supporting role, where sea-surface temperature measurement (IR, microwave) is used in the analysis of air temperature over the ocean.</td><td rowspan="2">WMO ‘CIMO’ Guide to Meteorological Instruments and Methods of Observing http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html
• Part I :Measurement of Meteorological Variables. Chapter 2 (temperature)
• Part II: Observing Systems. Chapter 1 (measurements at AWS) and Chapter 4 (marine observations)
Guide to the GSN and GUAN (2010 update of GCOS 73)
https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf</td></tr>
<tr><td colspan="2">GCOS Observation Requirements defined in OSCAR:
http://www.wmo-sat.info/oscar/requirements/view/70</td></tr>
<tr><td rowspan="2">Surface:
Surface Precipitation</td><td>Accumulated precipitation (mm over 24hrs)
Precipitation intensity at the surface (mm/h)
Precipitation intensity at the surface (solid) mm/h</td><td>In situ is the primary method.
Land based are from Automatic Weather Stations in the GCOS Surface Network and Full www/GOS Surface Network.
In situ in marine environments come from ships, moored and drifting buoys and stationary platforms.</td><td rowspan="2">WMO ‘CIMO’ Guide to Meteorological Instruments and Methods of Observing http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html
• Part I : Measurement of Meteorological Variables. Chapter 6 (precipitation)
• Part II: Observing Systems. Chapter 1 (measurements at AWS) and Chapter 4 (marine observations)
Guide to the GSN and GUAN (2010 update of GCOS 73)
https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf</td></tr>
<tr><td colspan="2">GCOS Observation Requirements defined in OSCAR:
www.wmo-sat.info/oscar/requirements/view/54 (accum. Precipitation)
www.wmo-sat.info/oscar/requirements/view/104 (precipitation intensity)
www.wmo-sat.info/oscar/requirements/view/105 (precipitation intensity - solid)</td></tr>
</table>

<table>
<tr><th>Atmosphere ECV</th><th>Variables (observing unit)
(sources: ECV data matrix, OSCAR)</th><th colspan="2">Use of satellite and in situ measurements</th><th>Key sources relating to observation standards of ECVs</th></tr>
<tr><td rowspan="2">Surface:
Surface Radiation Budget</td><td>Downward long-wave irradiance at Earth surface (W/m2)
Downward short-wave irradiance at earth surface (W/m2)
Earth surface short-wave bidirectional reflectance %
Upward long-wave irradiance at earth surface (W/m2)</td><td colspan="2">Satellite is the primary source for deriving:
Downward SW and LW irradiance at the Earth surface
Earth surface bidirectional reflectance
In situ solar and atmospheric radiation is measured with instruments of the highest available accuracy and with high time resolution (1 to 3 minutes) and support validation of satellite estimates.</td><td rowspan="2">WMO ‘CIMO’ Guide to Meteorological Instruments and Methods of Observing http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html
Part I: Measurement of Meteorological Variables. Chapter 7 (Radiation) and 8 (sunshine duration).
Part II: Observing Systems.

The Baseline Surface Radiation Network is an activity of the Global Energy and Water Cycle Experiment (GEWEX) and is designated by GCOS for surface radiation monitoring. http://www.bsrn.awi.de/en/project/background/

The Surface Radiation Budget project is aimed at detecting important changes in the Earth's radiation field at the Earth's surface which may be related to climate changes.</td></tr>
<tr><td colspan="2">GCOS Observation Requirements defined in OSCAR:
www.wmo-sat.info/oscar/requirements/view/95 downward LW irradiance
www.wmo-sat.info/oscar/requirements/view/93 downward SW irradiance
www.wmo-sat.info/oscar/requirements/view/96 SW bi-directional reflectance.
www.wmo-sat.info/oscar/requirements/view/118 over sea - upward LW irradiance.</td></tr>
<tr><td rowspan="2">Surface:
Water Vapour (Surface humidity)</td><td>Air surface humidity g/kg</td><td colspan="2">In situ is the primary method.
Land based measurements are from Automatic Weather Stations in the GCOS Surface Network and Full www/GOS Surface Network. In situ in marine environments come from ships and moored buoys.</td><td rowspan="2">WMO ‘CIMO’ Guide to Meteorological Instruments and Methods of Observing http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html
Part I: Measurement of Meteorological Variables. Chapter 4 (humidity).
Part II: Observing Systems. Chapter 1 (measurements at AWS) and Chapter 4 (marine observations)

Guide to the GSN and GUAN (2010 update of GCOS 73)
https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf</td></tr>
<tr><td colspan="2">GCOS Observation Requirements defined in OSCAR:
http://www.wmo-sat.info/oscar/requirements/view/69</td></tr>
</table>

Atmosphere ECV	Variables (observing unit) (sources: ECV data matrix, OSCAR)	Use of satellite and *in situ* measurements	Key sources relating to observation standards of ECVs
Surface: Near-Surface Wind Speed and Direction	Wind speed over the surface m/s Wind vector over the surface m/s	***In situ*** is the primary method. Land based measurements are from Automatic Weather Stations in the GCOS Surface Network and Full www/GOS Surface Network. In situ in marine environments come from ships and buoys. Satellite scatterometers provide generalized wind information over the ocean surface except the sea-ice covered areas.	**WMO 'CIMO' Guide to Meteorological Instruments and Methods of Observing** http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html Part I: Measurement of Meteorological Variables. Chapter 5 (surface wind) Part II: Observing Systems. Chapter 1 (measurements at AWS) and Chapter 4 (marine observations) Guide to the GSN and GUAN (2010 update of GCOS 73) https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/564 vector over sea (OOPC) www.wmo-sat.info/oscar/requirements/view/123 vector over sea (AOPC) www.wmo-sat.info/oscar/requirements/view/327 speed over sea (GOOS) www.wmo-sat.info/oscar/requirements/view/563 speed over sea (OOPC)		

Atmospheric ECV (with link to GOSIC description)	Variables (observing unit) (sources: ECV data matrix, OSCAR – all are source: AOPC)	Use of satellite and *in situ* measurements	Key sources relating to observation standards of ECVs
Upper Air: Cloud Properties	Cloud cover % Cloud ice (total column)- g/m^2 Cloud top height (km) Cloud top temperature (K) Cloud liquid water (total column) kg/m^2	Satellites (cloud radar and LiDAR) provide measures of: • *In situ* observations of: • Cloud cover	**WMO 'CIMO' Guide to Meteorological Instruments and Methods of Observing** http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html Part I: Measurement of Meteorological Variables. Chapter 15 (Observation of clouds). Part II: Observing Systems. Chapter 1 (measurements at AWS) and Chapter 4 (marine observations) Guide to the GSN and GUAN (2010 update of GCOS 73) https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/86 temperature www.wmo-sat.info/oscar/requirements/view/85 top height www.wmo-sat.info/oscar/requirements/view/84 liquid water column www.wmo-sat.info/oscar/requirements/view/82 ice total column www.wmo-sat.info/oscar/requirements/view/81 cover		
Upper Air: Earth Radiation Budget (including Solar Irradiance)	Downward short-wave irradiance at top of atmosphere (TOA) W/m^2 Upward short-wave irradiance at TOA W/m^2 Upward long-wave irradiance at TOA		Downward short-wave irradiance at TOA – flux density of the solar radiation at the top of the atmosphere Upward short-wave irradiance at TOA - Flux density of solar radiation, reflected by the Earth surface and atmosphere, emitted to space at the top of the atmosphere Temperature of the apparent surface of land (bare soil or vegetation) Land surface temperature: www.wmo-sat.info/oscar/requirements/view/97 over land (AOPC)
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/116 up SW rad at TOA www.wmo-sat.info/oscar/requirements/view/94 down SW irr TOA www.wmo-sat.info/oscar/requirements/view/117 up LW irr at TOA		
Upper Air: Temperature	Temperature profile (K)		**WMO 'CIMO' Guide to Meteorological Instruments and Methods of Observing** http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html Part I: Measurement of Meteorological Variables. Chapter 12 (upper air pressure, temperature, humidity). Part II: Observing Systems. Chapter 3 (aircraft observations)
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/71 HS&M		

	www.wmo-sat.info/oscar/requirements/view/72 high troposphere www.wmo-sat.info/oscar/requirements/view/73 LS www.wmo-sat.info/oscar/requirements/view/74 LT	Guide to the GSN and GUAN (2010 update of GCOS 73) https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf
Upper Air: Water Vapour	Specific humidity g/kg Specific humidity total column – kg/m^2 GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/110 HS&M www.wmo-sat.info/oscar/requirements/view/111 high troposphere http://www.wmo-sat.info/oscar/requirements/view/112 LS http://www.wmo-sat.info/oscar/requirements/view/113 LT www.wmo-sat.info/oscar/requirements/view/114 total column www.wmo-sat.info/oscar/requirements/view/115 troposphere column	**WMO 'CIMO' Guide to Meteorological Instruments and Methods of Observing** http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html Part I: Measurement of Meteorological Variables. Chapter 12 (upper air pressure, temperature, humidity). Part II: Observing Systems. Guide to the GSN and GUAN (2010 update of GCOS 73) https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf
Upper Air: Wind Speed and Direction	Wind speed (horizontal) m/s GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/119 HS&M www.wmo-sat.info/oscar/requirements/view/120 high troposphere www.wmo-sat.info/oscar/requirements/view/121 LS www.wmo-sat.info/oscar/requirements/view/122 LT	**WMO 'CIMO' Guide to Meteorological Instruments and Methods of Observing** http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html Part I: Measurement of Meteorological Variables. Chapter 13 (upper wind). Part II: Observing Systems. Chapter 3 (aircraft observations) Guide to the GSN and GUAN (2010 update of GCOS 73) https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/GCOS/GCOS-144_en.pdf

Atmosphere Domain: Atmospheric Chemistry measurements

Box 7. Status of the GAW networks (April 2013)

The document reports on progress and on planned activities regarding the development of the atmospheric composition ECVs for ozone profiles, greenhouse gases and aerosols.

GCOS has recognized several of the WMO/GAW networks as follows:

- Global Atmospheric CO2 & CH4 networks as baseline and comprehensive observing networks of GCOS
- Global Atmospheric N2O network as a baseline and a comprehensive observing network of GCOS
- Global Atmospheric Total Ozone network as a baseline observing network of GCOS, and
- Global Atmospheric Ozone profile network as a baseline observing network of GCOS.

GAW with its contributing networks are the basis for the observation of other Essential Climate Variables (ozone precursors, other greenhouse gases, aerosol, surface radiation).

WMO/GAW aerosol observations are not yet recognized as GCOS networks but provide high quality internationally coordinated observations within the framework of the GAW Programme. The GAW Scientific Advisory Group (SAG) plans to develop a GAW aerosol optical depth network for GCOS within next 5 years. The plan includes formulation of a vision for such a network that complies with GCOS requirements, including the steps towards implementation, similar to the CO2 and greenhouse gases approach. The SAG will develop a proposal during 2014 for a surface network for aerosol optical properties (in situ light absorption, scattering and extinction measurements, and particle number concentration) for consideration by GCOS. The SAG will develop a GCOS proposal for vertical profile network through GALION.

Further developments are expected in the quality assurance system for GHGs, in particular, the publication of the updated measurement guidelines

http://www.wmo.int/pages/prog/gcos/aopcXVIII/7.1_GAW.pdf

Box 8. Procedure for inclusion in the GAW programme

The GAW website describes the formal procedure to be followed for inclusion of observing stations in their programmes. The requirements that need to be met differ for three types of stations identified in the GAW Strategic Plan 2008-2015 (section 3 'Observing systems'): GAW Global, GAW Regional and Contributing stations. All the stations should satisfy the 'essential characteristics' based on the criteria listed in the GAW Strategic Plan 2008-2015. There are additional essential characteristics needed for a GAW Global Station.

http://www.wmo.int/pages/prog/arep/gaw/join_GAW.html

Box 6. Guide to Climatological Practices

Describes basic principles and modern practices important in the development and implementation of all climate services, and provides specific methods and examples of best practices in climatology. It has a chapter on Climate Observations, Stations and Networks.

For stations used or established to determine long period climate change, such as reference climatological stations and other baseline stations in the GCOS network, constancy of exposure and operation is required over many decades.

Additional constraints on siting apply to GAW stations established to provide data on atmospheric chemical composition (see chapter B2 of WMO No. 49). These include the need for no significant changes in land use practices within 50 kilometres of the site, and freedom from the effects of local and area pollution from, for example, major population centres, industrial and extensive farming activities, highways, volcanic activity, and forest fires. Both global and regional GAW stations should be within 70 kilometres of an upper air synoptic station.

WMO No. 100 'Guide to Climatological Practices' (third edition, draft) https://www.wmo.int/pages///prog/gcos/documents/gruanmanuals/WCP_CCl/guide_third_edition_draft_may2007.pdf

GAW Research and Monitoring Reports

http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html

Several GAW Scientific Advisory Groups monitor operations at sites and recommend the development of networks, observation methodologies and techniques for the focal areas of GAW (which include ozone, greenhouse gases, reactive gases, aerosols, UV radiation, precipitation chemistry). They also develop measurement procedures and guidelines, data quality objectives and, when applicable, standard operating procedures. Details of relevant documents describing these are listed on the GAW website.

Atmospheric ECV (with link to GOSIC description)	Variables (observing unit) (sources: ECV data matrix, OSCAR)	Use of satellite and *in situ* measurements	Key sources relating to observation standards of ECVs
Atmospheric composition: Aerosols Properties	Aerosol optical depth Aerosol extinction co-efficient (m^{-1}) Aerosol absorption optical depth		**WMO/GAW Standard Operating Procedures for In-situ Measurements of Aerosol Mass Concentration, Light Scattering and Light Absorption (GAW Report 200)** http://www.wmo-gaw-sag-aerosol.org/reports.html **WMO/GAW Aerosol Measurement Procedures Guidelines and Recommendations No. 153** http://www.wmo-gaw-sag-aerosol.org/reports.html **WMO 'CIMO' Guide to Meteorological Instruments and Methods of Observing** http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html Part I: Measurement of Meteorological Variables. Chapter 7 (Radiation)
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/63 AOD - HS&M www.wmo-sat.info/oscar/requirements/view/64 AOD - HT www.wmo-sat.info/oscar/requirements/view/65 AOD - LS www.wmo-sat.info/oscar/requirements/view/66 AOD - LT www.wmo-sat.info/oscar/requirements/view/55 AEC HS&M www.wmo-sat.info/oscar/requirements/view/56 AEC HT www.wmo-sat.info/oscar/requirements/view/57 AEC LS www.wmo-sat.info/oscar/requirements/view/58 AEC LT www.wmo-sat.info/oscar/requirements/view/684 AAOD HS&M www.wmo-sat.info/oscar/requirements/view/685 AAOD LT http://www.wmo-sat.info/oscar/requirements/view/686 AAOD HT http://www.wmo-sat.info/oscar/requirements/view/687 AAOD LT		
Atmospheric composition: Carbon Dioxide	CO2 mol/mol		See: **GAW Research and Monitoring Reports** http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html
	GCOS Observation Requirements defined in OSCAR: www.wmo-sat.info/oscar/requirements/view/87 HT www.wmo-sat.info/oscar/requirements/view/88 HS&M www.wmo-sat.info/oscar/requirements/view/89 LS www.wmo-sat.info/oscar/requirements/view/90 LT www.wmo-sat.info/oscar/requirements/view/91 total column www.wmo-sat.info/oscar/requirements/view/92 troposphere column		
Atmospheric composition: Methane and other	CH4 (mol/mol) Nitrous Oxide (N2O), CFCs, HCFCs, HFCs, SF6, and PFCs		See: **GAW Research and Monitoring Reports**

<table>
<tr><td>Long-Lived Green House Gases</td><td colspan="2">GCOS Observation Requirements defined in OSCAR:
www.wmo-sat.info/oscar/requirements/view/75 HS&M
www.wmo-sat.info/oscar/requirements/view/76 high mesosphere
www.wmo-sat.info/oscar/requirements/view/77 LS
www.wmo-sat.info/oscar/requirements/view/78 LT
www.wmo-sat.info/oscar/requirements/view/79 total column
www.wmo-sat.info/oscar/requirements/view/80 troposphere column</td><td>http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html</td></tr>
<tr><td rowspan="2">Atmospheric composition:
Ozone</td><td>O3 mol/mol
O3 (Total column) DU – Dobson unit</td><td>A wide range of in situ monitoring is the primary basis for:
• Surface ozone
• Column ozone (UV spectrometers, ozone sondes)
• vertical profile of ozone (lidar and microwaves)
And supports calibration of satellite measurements of:
• Total ozone;</td><td rowspan="2">GAW Research and Monitoring Reports
http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html
The Standard Operating Procedures for Ozonesondes has been published (GAW report No. 201) and are available on the GAW web site.
WMO ‘CIMO’ Guide to Meteorological Instruments and Methods of Observing http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html
Part I: Measurement of Meteorological Variables. Chapter 16 (Ozone) and 17 (atmospheric composition)
Part II: Observing Systems. Chapter 10. (Balloon techniques). Chapter 9 (Radar techniques)</td></tr>
<tr><td colspan="2">GCOS Observation Requirements defined in OSCAR:
www.wmo-sat.info/oscar/requirements/view/100 LS
www.wmo-sat.info/oscar/requirements/view/101 LT
www.wmo-sat.info/oscar/requirements/view/98 HS&M
www.wmo-sat.info/oscar/requirements/view/99 HT
www.wmo-sat.info/oscar/requirements/view/102 total column
www.wmo-sat.info/oscar/requirements/view/103 troposphere column</td></tr>
<tr><td rowspan="2">Atmospheric composition:
Precursors (supporting Aerosols and Ozone ECVs)</td><td>NO2, SO2, HCHO, CO</td><td>In situ monitoring is the primary method.</td><td rowspan="2">GAW Research and Monitoring Reports
http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html</td></tr>
<tr><td colspan="2">GCOS Observation Requirements defined in OSCAR:</td></tr>
</table>