UKEOF
ENVIRONMENTAL OBSERVATION FRAMEWORK

Coordinating climate science observations

Final Report

Prepared for: UKEOF

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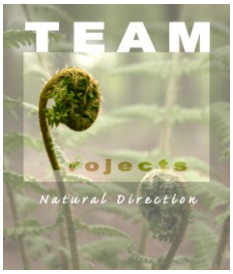

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Living With Environmental Change

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Glossary of Terms

Essential Climate Variable (ECV)	A set of systematically observable variables for climate assessment. The 50 GCOS Essential Climate Variables are required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations.
Climate observing	Systematic observations of the full range of elements that describe the climate system.
GCOS	Global Climate Observing System - a global, co-operative, integrated network of global observing systems for climate.
GCOS network	A hierarchy of climate relevant observing networks of GCOS.
In situ (observations)	Observations made using instruments in direct contact with the subject.
Observational data	Data acquired from routine measurement of a defined variable, using particular protocols as part of an objective, scientific measurement activity (eg environmental monitoring, sensor-derived measurements).
Observation activity	A defined scientific project (in the context of UK environmental data collection) that acquires data describing the environment.
Monitoring activity	A defined scientific project (in the context of UK environmental data collection) that acquires repeat observational data.
Remote sensing (observations)	Observations made by instruments (in this context, typically space-borne satellites) that are not in physical contact with the variables being observed.

Acronyms

AOPC	Atmospheric Observation Panel for Climate
AURN	Automatic Urban and Rural Network
BAS	British Antarctic Survey
CEOS	Committee on Earth Observation Satellites
COP	Conference of the Parties (to the UNFCCC)
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DFID	Department for International Development
EA	Environment Agency
EC	European Commission
ECN	Environmental Change Network
ECV	Essential Climate Variable
ESA	European Space Agency
GAW	Global Atmospheric Watch
GCOS	Global Climate Observing System
GCMP	GCOS Climate Monitoring Principles
GEO	Group on Earth Observations
GHG	Greenhouse Gas
GHRSST	Group for High Resolution Sea Surface Temperature
GIP	GCOS Implementation Plan
GOOS	Global Ocean Observing System
GSN	GCOS Surface Network
GTOS	Global Terrestrial Observing System
GUAN	GCOS Upper Air Network
IDC	International Data Centre
IPCC	Intergovernmental Panel on Climate Change
LWEC	Living With Environmental Change
NCEO	National Centre for Earth Observation
NCIC	(Met Office) National Climate Information Centre
NERC	Natural Environment Research Council
NMP	National Meteorological Programme
NWP	Numerical Weather Prediction
OOPC	Ocean Observations Panel for Climate
ODS	Ozone Depleting Substances
OSCAR	Observing Systems Capability Analysis and Review Tool

POL	Proudman Oceanographic Laboratory
RBCN	Regional Basic Climate Network
RoTAP	Review of Transboundary Air Pollution
SEPA	Scottish Environment Protection Agency
TOPC	Terrestrial Observation Panel for Climate
UKEOF	UK Environmental Observation Framework
UNFCCC	United Nations Framework Convention on Climate Change
VOSClim	Voluntary Observing Ship Climate Project
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation

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Executive Summary

The Global Climate Observing System (GCOS) was established in 1992 and is an international undertaking to meet the need for comprehensive, continuous, reliable, climate-related observational data and information. GCOS encompasses the total climate system. It provides an operational framework for integrating, and enhancing as needed, observational systems of participating countries and organisations into a comprehensive system focused on the requirements for climate issues. It includes both *in situ* and remote sensing components. The GCOS Implementation Plan (GIP) (GCOS, 2010a)[1] provides a programme of recommendations and actions over a five-year period to assist countries in understanding, predicting and managing their response to climate and climate change. It calls for sustained observations of 50 'Essential Climate Variables' (ECVs).

This project sought to improve understanding of the relevance of UK climate-related observation activities to the GCOS ECVs, identifying those UK observations that contribute to GCOS and assessing where there are gaps in knowledge about UK observational data supporting the ECVs. It also sought to improve knowledge of *climate-related* uses of the observation data (beyond their primary purpose) and understand more about observation standards in use.

An email-based consultation of those responsible for environmental monitoring (via a questionnaire) and desk study were used to obtain information to address these needs. There was a good (88%) response rate to the consultation.

Observation activities contributing to GCOS networks and actions set out in the GIP (GIP) were identified through the consultation process. The findings have been used to characterise the responding observation activities into one of three groups, namely:

Group 1: those that contribute observational data to one or more 'well-established' GCOS networks[2]. The UK has formally accepted responsibility to provide a contribution to GCOS ECVs through these networks.

(*25 of 68 responses, representing 37% of the activities that responded to the consultation*);

Group 2: those that are contributing to GCOS ECVs, and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified in key documents[3] as having the potential to do so.

(26 of 68 responses, representing 38% of the activities that responded to the consultation);

Group 3: other activities not thought to be engaged with delivery of the GIP, but which are known to be collecting climate-related observation data of the type used for the GCOS ECVs.

(17 of 68 responses, representing 25% of the activities that responded to the consultation)

Twenty four of the Group 1 *in situ* activities reported that they are contributing data to 26 of the 'well-established' GCOS networks. Many of these activities collect a range of observational data of relevance to the ECVs and 13 contribute data to more than one of the 'well-established' GCOS networks, with observation data delivered mostly into GCOS networks concerned with monitoring changes to the atmosphere.

In addition, a further five activities (from Group 2) reported that they were 'a recognised activity contributing to ECVs through GCOS' (eg being involved with the development of other climate observing networks or part of climate research programmes that support the GCOS ECVs.)

Observation activities delivering data to 'well-established' GCOS networks (Group 1), where the UK has formally accepted responsibility to provide a contribution to GCOS, together with key research activities in Group 2, are collecting observational data relevant to all of the atmospheric ECVs and all oceanic ECVs (with the exception of 'tracers').

[1] www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

[2] See: Chapter 2 paragraph 13: in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

[3] Whitelaw (2008) and UKEOF (2011)

Many terrestrial ECVs are at an early stage of development and there are relatively few 'well-established' GCOS networks in place. UK funded observation activities currently contribute observational data to the GCOS networks for 'river discharge' and 'snow cover' ECVs. However, the UK is funding a wide range of monitoring and other activity of relevance, or potential relevance, to many of the other terrestrial ECVs.

The consultation established that the UK funds a high number and very wide range of *in situ* monitoring activities that systematically and routinely acquire observational data of relevance to the GCOS ECVs. Many of the observation activities consulted (85% of responses) reported that they are collecting data suitable for use for 'climate applications' in addition to their primary purpose. A very high proportion of these activities were found to have taken into account factors that are important for climate observing when setting up their activities and have in place the type and range of protocols, procedures and systems required as a pre-requisite to developing a climate observing capability.

Knowledge, awareness and implementation of guidelines and procedures reflect the nature and degree of involvement activities already have with the GCOS observing systems and delivery of actions in the GIP. Those providing data to the 'well-established' GCOS networks reported having fully or partly implemented key guidance**.**

Stations that contribute to GCOS Baseline networks have to meet certain criteria, make specific commitments (ie 'shall') and follow best practice (ie 'should') (eg GCOS-73 (2002)); these networks stipulate the strictest adherence to requirements for climate observing. Of the 24 activities providing climate observations to GCOS networks, two-thirds (67%, representing 16 activities) are providing observational data to GCOS Baseline networks.

At the time of the previous round of reporting for the 5th National Communication to the UNFCCC (Whitelaw *et al.,* 2008) there were high numbers of observation activities reporting that they operated their stations in accordance with GCOS Climate Monitoring Principles (GCMPs). Whilst some information on compliance with GCMPs was provided in the consultation, it was incomplete and further data will need to be gathered for the 6th National Reporting. There is also a need to:

- consult a few monitoring activities that did not respond to the questionnaire but which have been identified as likely to be contributing to GCOS networks or actions in the GIP, and
- check, validate and supplement some findings in order to report progress with the GIP for the 6th National Communication.

A key focus of GCOS is in how to combine *in situ* and satellite measurements in the observing programmes.

The UK's contribution to the development and deployment of satellite measuring systems is mainly via international programmes, mainly through ESA, EUMETSAT and the EU. As well as contributing financially and engineering know-how to build satellites, the UK is also very active in programmes to use the resulting satellite data streams to derive and make use of ECV datasets. These programmes are funded through ESA, EUMETSAT and the EU but also nationally (eg through programmes in NERC Centres such as National Centre for Earth Observation). Programmes are gathering momentum but continued cycles of improvement and development will be needed.

Long-term funding for some key measurements from satellites is not secure. A key problem is to find mechanisms to support programmes emerging from R&D activities now requiring operational / long-term solutions. This is equally a challenge for international partners and leads to a situation that threatens the continuity of capability that has been developed, demonstrated to be operationally viable and in some cases vital to sustain climate data records.

The UK does more climate-related monitoring than is included in the UKEOF Catalogue, which should be updated to incorporate further relevant monitoring activity identified by this study. The study was tasked with making the UKEOF catalogue more useful for responding to GCOS reporting requirements and recommendations have been made to facilitate this.

There is a need to strengthen national coordination of UK observational activity in support of GCOS, in order to better enable tracking of progress with delivery of the UK's contribution to the GIP (a complex task) and meet the known demand (identified through this study) from the environmental monitoring community for support to deliver the actions in the GIP. There is also a need to raise awareness amongst key stakeholders of both the UK contribution to GCOS and the uses of climate-related data. A fully coordinated approach would also help UKEOF identify opportunities for, and encourage, re-use of the data in other applications and seek and facilitate further contributions as necessary.

1 Introduction

1.1 Target audience and scope of the study

This report is intended to inform both climate data users and providers of the monitoring activities that the UK is undertaking, and raise awareness of the guidance and reference material available to support this task.

The project scope covers climate observations taken by, or on behalf of, the UK that are of relevance to climate science, with a focus on consideration of how Essential Climate Variables (ECVs) are used in the UK for understanding and modelling climate. This report seeks to improve knowledge and inform on progress with actions on the GCOS Implementation Plan (GIP) but is not a definitive statement of the situation. A formal statement of the UK's position is provided by the UK's Sixth National Communication and First Biennial Report under the United Nations Framework Convention on Climate Change (UNFCCC) (DECC, 2013).

The report uses the UKEOF definition of observations:

> *'the taking of any form of observations relative to the status of the environment, regardless of frequency, purpose for which the observations are made, or however they are made (from satellites, ships, etc). Such observations are designed to meet a wide range of societal needs by providing a variety of products and services'*

1.2 Policy context

In 1992, countries joined an international treaty, the UNFCCC, to cooperatively consider what they could do to limit average global temperature increases and the resulting climate change, and to cope with whatever impacts were, by then, inevitable[4].

Worldwide systematic observation of the climate system is a key prerequisite for advancing scientific knowledge on climate change. The Convention calls on Parties to promote and cooperate in systematic observation of the climate system, including through support to existing international programmes and networks, as indicated in Articles 4.1(g) and 5 of the Convention. A key means of implementing those Articles has been the cooperation with the Global Climate Observing System (GCOS) secretariat of the World Meteorological Organization (WMO) and other agencies participating in WMO's Climate Agenda.

COP 3 (Kyoto, December 1997) and COP 4 (Buenos Aires, November 1998), adopted decisions supporting GCOS and its partner agencies, urging Parties to engage fully with their work and provide resources to reverse the decline in the existing observational networks.

At COP 5, the COP urged Parties to address deficiencies in climate observing networks. It adopted reporting guidelines on global climate observing systems and invited Parties to provide detailed reports on systematic observation as part of their national communications (on a voluntary basis, in the case of non-Annex I Parties). This report is intended to help with this process.

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. Climate-related observational data are collected through a range of UK funded environmental monitoring programmes and activities, many of which form part of wider UK, regional or global data collection initiatives. These observational data underpin research and monitoring of the climate system.

[4] http://unfccc.int/essential_background/items/6031.php

Funding for climate-related observations comes from the Department for Business, Innovation and Skills (which funds work on new technologies and provides funding for the Research Councils), as well as the UK Space Agency, the Met Office, Department for Environment, Food and Rural Affairs (Defra), Department of Energy and Climate Change (DECC), the Devolved Administrations and others. Collection of UK funded observations is widely distributed and includes both *in situ* observations throughout the UK and overseas, and contributions to earth observation activities. Many government Departments and agencies, laboratories, universities and commercial companies are involved.

1.3 Research context

The Living With Environmental Change (LWEC) partnership[5] recognises the value of high quality environmental observational data and, through the activities of the UK Environmental Observation Framework[6] (UKEOF), is developing more strategic and coordinated approaches to the collection, management and sharing of observational data, both nationally and internationally. UKEOF was launched in response to the long term issues that surround environmental monitoring, and is a self-contained core activity of LWEC, funded by the major sponsors of environmental observations in the UK. UKEOF has set up a group of experts to oversee coordination of UK GCOS activities, the 'Coordinating Climate Observations Group' (CCOG), which works with the UKEOF Management Group, LWEC, the GCOS Secretariat and other relevant stakeholders to ensure better coordination of GCOS activities within the UK.

The LWEC strategy[7] (LWEC, 2011) guides the design, delivery and uptake of research to understand how and why the environment is changing, to predict changes and to better understand what the impacts might be.

The Climate Challenge Strategic Framework[8] (LWEC, 2013) sets out the policy, business, societal and international context, within which the LWEC partnership has established priorities for research and other activities. It identifies 'development of observational programmes' as one of the eight highest priority areas to be addressed over the next five years.

1.4 Global Climate Observing System

The Global Climate Observing System (GCOS) was established in 1992 and is an international undertaking to meet the need for comprehensive, continuous, reliable climate-related observational data and information. GCOS encompasses the total climate system (physical, chemical and biological properties in atmospheric, oceanic, terrestrial, hydrologic and cryospheric environments) and is built on a set of national contributions which collectively provide a global capability. The UK has access to the full global network which operates on the basis of free and open data exchange. It provides an operational framework for integrating, and enhancing as needed, observational systems of participating countries and organisations into a comprehensive system focused on the requirements for climate issues. It includes both *in-situ* and remote sensing components.

1.4.1 GCOS Essential Climate Variables

The GIP (GIP)(GCOS, 2010a)[9] provides a programme of recommendations and actions over a 5 year period to assist countries in understanding, predicting, and managing their response to climate and climate change. It calls for sustained observations of 50 ECVs to support this work. Current and historical observations of ECVs (Table 1) are needed to sustain progress and to support the work of the UNFCCC and will provide essential observations required by the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC).

[5] www.lwec.org.uk/about
[6] www.ukeof.org.uk
[7] www.lwec.org.uk/sites/default/files/LWEC%20Strategy%202008~2013.pdf
[8] http://www.lwec.org.uk/sites/default/files/LWEC%20Climate%20Challenge%20Strategic%20Framework%20-%2004%20March%202013.pdf
[9] www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

Table 1: GCOS Essential Climate Variables (ECV) Data Access Matrix. (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 Color **	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 Vapor **	**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	Links in this table will take you to a summary description for each ECV that describes: 'main climate application', 'contributing networks and satellite observations', 'issues relevant to observation and analysis', 'current capability' and 'data.' These are produced by the Global Observing Systems Information Centre (GOSIC).
Precursors (supporting Aerosols and Ozone ECVs) **[3]** *	Temperature	
	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 metres

* 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)' (page 19). ** State of the Climate in 2011 data available *** Not an official GCOS ECV

To various degrees, monitoring the ECVs requires *in situ* and / or satellite-based observations (with linkage between the two a common requirement). Science panels[10] define the observations needed in each of the main global domains (atmosphere, oceans, and land), to prepare specific programme elements and to make recommendations for implementation. This work is ongoing. The term '*variable' or 'parameter*' is used in this report to distinguish specific measurements from their respective ECVs (which may involve the measurement of more than one variable). Some ECVs have been subject to nomenclature changes and there are 'emerging' ECVs, such as soil carbon (Table 1).

These evolving requirements for comprehensive climate observations are essential to:

- underpin research and monitoring of the climate system
- support the attribution of causes of climate change
- model and predict the climate system
- assess the impacts of climate change
- inform activity on climate adaptation measures.

[10] Atmospheric Observation Panel for Climate (AOPC); Ocean Observations Panel for Climate (OOPC); Terrestrial Observation Panel for Climate (TOPC)

1.5 National Reporting

The UK contributes to the GCOS climate observing networks. These contributions to GCOS are described in the periodic reports on systematic observations for climate, prepared as part of the regular National Communication to the Conference of the Parties of the UNFCCC (DECC, 2009). A summary of UK Contributions to GCOS was produced in 2008 (Whitelaw *et al.*, 2008).

An update on National Activities with respect to the GIP is due in January 2014 in conjunction with the 6th National Communication.

Reporting guidelines on global climate change observing systems were revised in 2007[11] to reflect the priorities of the GIP and incorporate the reporting on ECVs (UNFCCC, 2008).

Although responsibility for reporting to the UNFCCC lies with DECC, there is not, however, a central coordination point to oversee the UK input to climate observations. Nor is there a structured process to sustain long-term observations (UKEOF, 2011) although the issues surrounding long-term environmental observations have recently come to the fore with the establishment in 2013 of the Government Chief Scientific Advisor chaired Observations Committee. A subset of the roles of a National Coordinator is undertaken by the Met Office, UKEOF and DECC.

1.6 Rationale for this project

The (former) LWEC Climate Challenge Steering Group and the UKEOF Management Group agreed UKEOF should commission a project seeking to improve understanding of UK climate observation activities, with the intention of:

- getting a clear picture of UK observations that contribute to GCOS
- identifying and describing what the climate observations relevant to GCOS are currently being used for in addition to their primary purpose
- identifying which activities are collecting data to GCOS climate science observation standards;
- identifying the gaps in our knowledge of what UK observational data activities are supporting the ECVs, develop a better understanding of the gaps that exist, and recognising the need to address these gaps
- making the UKEOF Environmental Observation Activity Catalogue (the 'UKEOF Catalogue') more useful for responding to GCOS reporting requirements.

The known issues to achieving this were:

- There is no easy way to identify observation activities in the UKEOF Catalogue that contribute to GCOS. It can be difficult to make the connection between information that is available that describes contributions to GCOS and the information held on the UKEOF Catalogue.
- Sourcing information can be challenging as information is widely dispersed. There are many organisations involved in acquiring climate-related observational data. Activities that contribute to GCOS also serve other functions, so may not be readily identifiable as of particular relevance to the GIP or as a contributor to a GCOS network. Climate-related monitoring programmes led by GCOS partners may contain activities that contribute to GCOS networks and others that do not, because the programmes have a broader remit. They may not explicitly state which activities are contributing to GCOS networks. Similarly, data are held in shared data centres that serve a range of application areas.

[11] http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

1.7 Further Background on GCOS and climate observing

GCOS is a network of global observing systems for climate and most environmental practitioners will be more familiar with its contributing observing systems (Table 2), climate observing networks[12] and the associated international data centres.

Table 2. The main contributing 'observing systems' of GCOS

Contributing Observing System	What the observing systems cover
Global Observing System (GOS)	Atmospheric physical and dynamical properties
Global Atmospheric Watch (GAW)	Atmospheric constituent and chemical properties, and other WMO climate-related observing systems
Global Ocean Observing System (GOOS)	Physical, chemical and biological properties of the ocean
Global Terrestrial Observing System (GTOS)	Land surface ecosystem, hydrosphere, and cryosphere measurements

There are a range of other specific research observing networks such as IGBP[13] and WCRP[14]. The Committee on Earth Observation Satellites (CEOS) coordinates civil space-borne observations at the global level. Some observing networks are under development, especially those in the terrestrial domain.

It is important to note that the contributing observing systems have their own remits and objectives, which extend beyond climate observing; they therefore contain programs and activities that are not directly relevant to GCOS. The same is true of the international Data Centres which hold data from GCOS networks.

1.8 Climate observing, data acquisition and GCOS requirements

GCOS is involved in both defining the observational requirements for a robust record of climate and in addressing the needs for improving such a record. The requirements are broadly defined in the GIPGIP (2004 and 2010 update). A particular concern of GCOS is global coverage and an appropriate balance of in-situ and satellite observations.

A wide range of processes are in place to ensure observational systems and the data they produce for GCOS are fit for purpose.

1.8.1 GCOS Climate Monitoring Principles (GCMPs)

The GCMPs provide guidance regarding the planning, operation, and management of observing networks and systems. Only homogeneous climatological datasets are suitable for many climatological purposes, especially for the evaluation of trends in climate. 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 (GCOS, 2010b).

1.8.2 Rolling Review of Requirements (RRR) process

General guidance for the generation of long-term data records and derived ECV products based on surface-based, airborne and satellite-based observing systems is given by the 'GCOS requirements'.

The GCOS requirements are based on a broad consensus by the international climate community and are reviewed on a regular basis. They are the result of a formalised process known as the 'Rolling Review of Requirements'[15] (RRR) where user requirements for observations are compared with the capabilities of present and planned systems.

[12] https://www.wmo.int/pages/prog/gcos/index.php?name=ObservingSystemsandData
[13] International Geosphere-Biosphere Programme
[14] World Climate Research programme
[15] http://www.wmo.int/pages/prog/www/OSY/Documentation/RRR-process.pdf

User requirements are collected for a range of applications addressing WMO Programmes and co-sponsored programmes. This includes GCOS Climate Monitoring. The GIP (and its 2010a update) and the Satellite Supplement[4] are an output of the RRR process.

Monitoring systems, GCOS observing requirements and the role of international standards are still being developed for some ECVs. The Implementation Plan demonstrates that this process of developing operational global networks is lengthy and requires long term commitment.

1.8.3 Observing Systems Capability Analysis and Review Tool (OSCAR)

WMO's OSCAR[16] is a searchable database and holds the most recent version of GCOS requirements (it also holds details for other application areas).

Observing requirements are expressed in terms of five criteria: horizontal resolution, vertical resolution, observing cycle, timeliness and uncertainty.

OSCAR provides information on satellite observing capability (satellites and instruments) and the outputs of a 'gap analysis' of satellite capability. Users can search to see which satellites and instrumentation are considered to provide good capability for observing a particular variable (including those that support the ECVs).

A similar capability is being developed for surface-based observing and is due to be made available in April 2014 (pers. comm.).

1.8.4 Governance

GCOS is directed by a Steering Committee which provides guidance, coordination and oversight to the programme. Three science panels, reporting to the Steering Committee, have been established to define the observations needed in each of the main global domains (atmosphere, oceans, and land), to prepare specific programme elements and to make recommendations for implementation. These are:

- Atmospheric Observation Panel for Climate (AOPC)
- Ocean Observations Panel for Climate (OOPC)
- Terrestrial Observation Panel for Climate (TOPC).

These scientific advisory panels provide expert advice, for example, on the observing strategy, observation requirements, and the status of networks and systems. They work closely with the intergovernmental bodies (especially the WMO technical commissions such as the Commission for Instruments and Methods of Observation (CIMO), Commission for Atmospheric Science (CAS), Commission for Climatology (CCI), the Commission for Hydrology (CHy) and the WMO-IOC Joint Commission for Oceanography and Marine Meteorology (JCOMM)) and other international bodies which are responsible for the coordinated implementation of the component systems of GCOS.

1.9 Climate observations

The following description is taken from the WMO website[17]:

Climate observations are sourced from the numerous meteorological and related observational networks and systems throughout the world. It is these observations that provide the basis for applications such as weather forecasting, air pollution modelling and environmental impact assessments.

However not all climate observations are the same and some are considered of higher quality than others. There are three factors involved in collecting climate observations:

[16] http://www.wmo-sat.info/oscar/

[17] http://www.wmo.int/pages/themes/climate/climate_observation_networks_systems.php

- Climate observations need to account for the full range of elements that describe the climate system – not just those that describe the atmosphere. Extensive observations of the ocean and land-based systems are also required.
- An observation at any point in time won't mean very much unless it can be compared to a reference climate (ie a reference climatological period must be selected - eg the current reference dates are from 1961-1990). For this reason, the observations from a station that only exists for a short period (ie from days to a few years) or which relocates very frequently, will generally be of less value than those observations from a station whose records have been maintained to established standards over many years. Thus, in order to derive a satisfactory climatological average (or normal) for a particular climate element, a sufficient period record of homogeneous, continuous and good quality observations for that element is required.
- A climate observation should be associated – either directly or indirectly - with a set of data (metadata) describing the conditions in which the climate observations were collected and that will provide users with information, often implicitly, on how the observation should be interpreted and used.

1.9.1 *In situ* observing: types of climate observing networks

The more stringent requirements on observation networks and systems for monitoring climate, including the detection of climate change, has led to the development of special networks at national, regional and global scales.

The GIP (2010) describes four categories of networks that provide observations specifically for climate purposes (Table 3). GCOS generally focuses on ensuring the implementation of 'baseline' and 'reference' networks, supplemented where possible by global coverage from satellites.

Table 3. Categorisation of climate observing networks (source: GIP 2010)

Type of observing network	Type of observations they provide
Global Reference observing networks	Highly-detailed and accurate observations at a few locations for the production of stable long time series and for satellite calibration/validation purposes. These consist of formally identified GCOS Reference Networks such as the GCOS Reference Upper Air Network (GRUAN).
Global Baseline observing networks	A limited number of selected locations that are globally distributed and provide long-term high-quality data records of key global climate variables and enable calibration for the comprehensive and designated networks. These are networks that have been formally identified as baseline climate networks by the GCOS Steering Committee and include, for example, the GCOS Surface Network (GSN), the GCOS Upper Air Network (GUAN) and the Baseline Surface Radiation Network (BSRN)
Comprehensive observing networks	Include regional and national networks and, where appropriate/possible, satellite data. Observations are provided at the detailed space and time scales required to fully describe the nature, variability and change of a specific climate variable and include the GCOS-affiliated Global Atmospheric CO2 and CH4 Monitoring Networks. Comprehensive networks comprise national climate reference networks, comprehensive national climate networks and national and regional networks that are operated primarily for non-climate reasons but which provide important observations for climate purposes.
Ecosystem monitoring sites	Where long-term observations of ecosystem properties, including biodiversity and habitat properties, are made in order to study climate impacts. To identify climate impacts, these measurements need to be made together with observations of the local physical climate and changes in the surrounding environment.

There are also 'Research observation networks' (experimental networks as part of time-limited research programmes and 'Complete national networks' (the totality of the national observing networks that contribute to meeting climate needs at a national level.[18]

[18] http://www.wmo.int/pages/prog/gcos/documents/GCOS_brochure_Small.pdf

1.9.2 Observations from satellites

Since the formation of GCOS in 1992, the contribution of satellite data has been a significant consideration. Worldwide coordination has been directed through the CEOS[19] of which GCOS is an Associate Member. A key document with respect to satellite data requirements was produced by GCOS in 2006, *'Systematic Observation Requirements for Satellite-Based Products for Climate: Supplemental details to the satellite-based component of the 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC'*[20] with the main intention to assist Parties that support Earth observation from space to respond to the requirements of the GIP (GCOS, 2010a). Importantly, the document identified those ECVs largely dependent upon satellite observations and looked in detail regarding what is needed for:

> *'Ensuring continuity and overlap of key satellite sensors; recording and archiving of all satellite meta-data; maintaining currently adopted data formats for all archived data; providing data service systems that ensure accessibility; undertaking reprocessing of all data relevant to climate for inclusion in integrated climate analyses and reanalyses.'* (GCOS, 2010a Action C10)

The relationship between satellite missions/instruments, the measurements they make and derived ECVs is complex but, as noted in the GIP, Action C10, (GCOS, 2010a) continuity, overlap between instruments and good record keeping are key. A 2010/11 update on progress with satellite measurements for climate was also published[21].

At the 24th CEOS Plenary in Rio de Janeiro, Brazil, October 2010 CEOS agreed to adopt a new Working Group on Climate (WGClimate), to coordinate and encourage collaborative activities between the world's major space agencies in the area of climate monitoring[22]. It is working explicitly to facilitate the implementation and exploitation of ECV time series through coordination of the existing and planned activities of CEOS member agencies.

Other international groupings, looking at the use of satellite data for climate, include the Group on Earth Observations (GEO) and the Group for High Resolution Sea Surface Temperature[23] (GHRSST). GEO is open to all member States of the United Nations and to the European Commission and is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS) in 9 Societal Benefit Areas, including climate. The short term aims of GEO with respect to climate are to:

> *'Achieve effective and sustained operation of the global climate observing system and reliable delivery of climate information of a quality needed for predicting, mitigating and adapting to climate variability and change, including for better understanding of the global carbon cycle'.*

In practice this leads back to a call for full implementation of the GIP (2010).

GHRSST is an open international science group that promotes the application of satellites for monitoring sea surface temperature (SST) by enabling SST data producers, users and scientists to collaborate within an agreed framework of best practice. For climate-related data, this means using guidelines set by GCOS and the WCRP to ensure that accuracy and stability of the GHRSST time series are well defined.

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[19] Established in 1984, the Committee on Earth Observation Satellites (CEOS) coordinates civil space-borne observations of the Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit. Currently, 52 members and associate members made up of space agencies, national, and international organizations participate in CEOS planning and activities. http://www.ceos.org/index.php?option=com_content&view=featured&Itemid=417

[20] GCOS – 107, (WMO/TD No. 1338), http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf

[21] GCOS – 154, http://www.wmo.int/pages/prog/gcos/Publications/gcos-154.pdf

[22] http://www.ceos.org/index.php?option=com_content&view=category&layout=blog&id=168&Itemid=278

[23] https://www.ghrsst.org/

1.9.3 Raising Awareness of GCOS requirements and standards for observing the ECVs

There is a comprehensive range of guidance available through the websites of GCOS and its partners. GCOS has published guidelines for the generation of satellites-based datasets and products.[24]

Some of this information has been brought together in the form of a Guidance Note (www.ukeof.org.uk/our-work/coordinating-climate-observations), produced as part of this project to help raise awareness of GCOS requirements and standards for observing the ECVs and signpost UK data providers and data users to these. It provides general background on climate observing through reference to key documents, in particular those describing requirements for data acquisition. The Guidance Note also provides links to GCOS observing requirements for each ECV (through links to the OSCAR tool). The Guidance Note is not a substitute for full documentation, nor does it provide a comprehensive list of reference sources for a particular ECV. The sources listed may be superseded at any time. Definitive guidance should be sought and obtained from GCOS and its partner agencies operating the observational networks.

[24] GCOS-128, March 2009 https://www.wmo.int/pages/prog/gcos/Publications/gcos-128.pdf

2 Approach

Separate approaches were adopted for satellite and *in situ* observations with the gap analysis of satellite based observing building on work carried out by the Met Office in 2009.

2.1 *In situ* observations

This section deals with a range of observations taken from instruments on the ground and on aircraft and measurements from the ocean and also includes some ground-based, remotely sensed measurements. These are referred to as '*in situ*' observations, and used within this report to describe observations 'not from satellites'. The approach followed is illustrated in Figure 1 and involved identifying relevant monitoring activities to include in a consultation on a range of matters of relevance to GCOS climate observing. The process involved reviewing a pre-selected list of observation activities from the UKEOF Catalogue to identify climate–related monitoring of relevance to the study. Additional relevant climate-related monitoring was identified from the UKEOF Catalogue and from other sources. Individuals with knowledge of, and involvement in, the resulting group of climate-related monitoring activities were consulted using an email-based questionnaire.

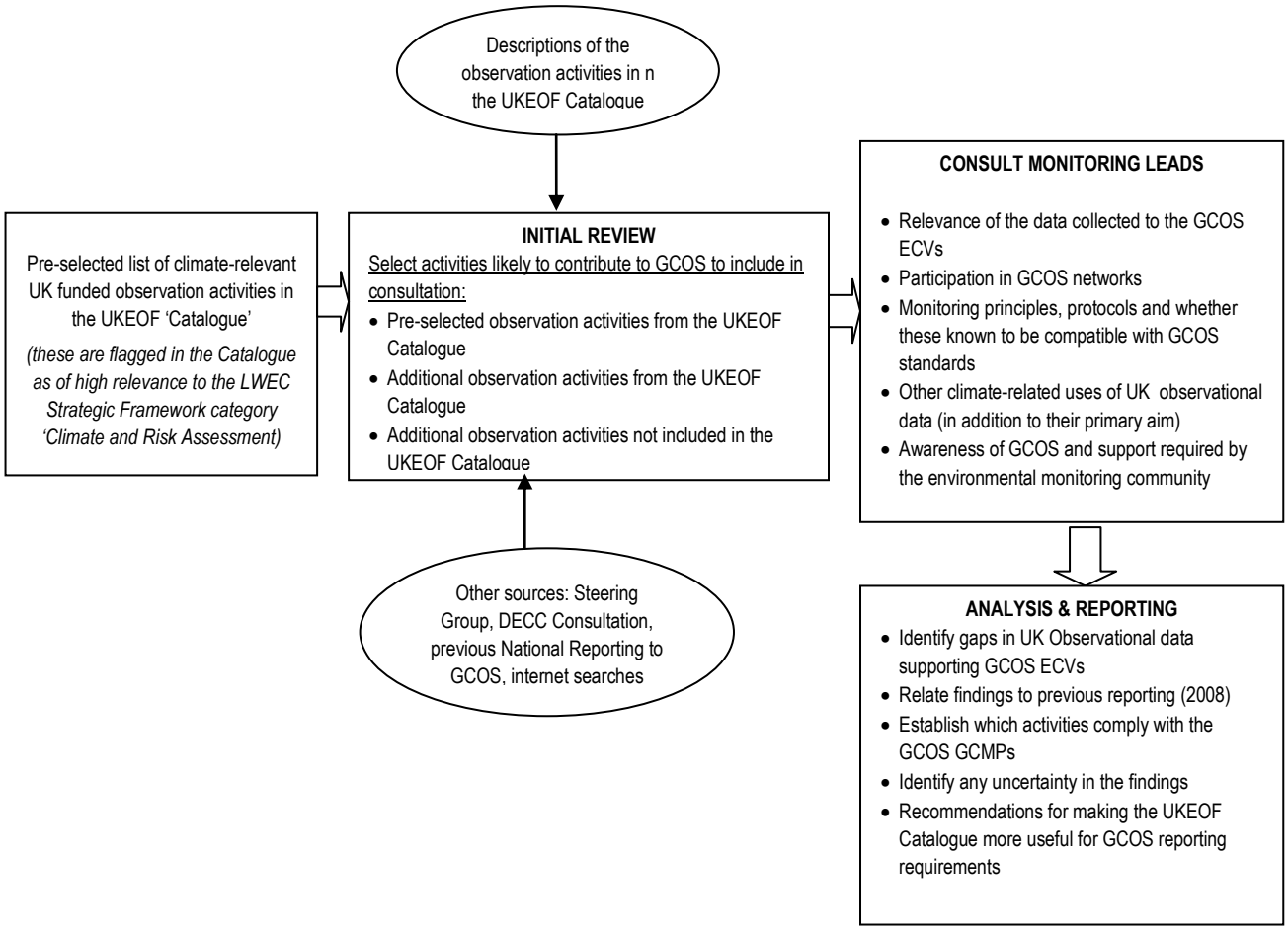


Figure 1: Project methodology

2.1.1 Identify observation activities that are likely to contribute to GCOS

As UKEOF Catalogue entries do not identify measurements of ECVs, the start-point for the study was a pre-selected list of 127 'ongoing' observation activities flagged in the UKEOF Catalogue as producing observations and outputs of high relevance to the LWEC Strategic Framework category 'Climate and Risk Assessment'. These were considered by UKEOF to be most likely to contain climate-related monitoring relevant to the GCOS ECVs. Over 900 (of the 1050)

records in the UKEOF Catalogue are flagged as potentially contributing evidence relevant to climate change and narrowing the search in this way provided a cost-effective start-point for the project.

2.1.2 Review observation activities to establish their likely relevance to GCOS

The pre-selected list of observation activities (Figure 1) was reviewed to check whether the data they collect and the nature of the monitoring was likely to be of relevance to the study objectives. This was done prior to the consultation to ensure it targeted relevant observation activities. The review was achieved by checking the UKEOF Catalogue metadata (eg parameters measured, description of the monitoring) for each of the observation activities. Each activity was assigned to an environmental domain on the basis of the metadata held on the UKEOF Catalogue (and where possible, consistent with the environmental domains in the UKEOF Catalogue). On the basis of the findings, each observation activity was allocated to one of three categories based on a traffic light system: 'include in the consultation'; 'possibly include'; 'suggest exclude' (Table 4).

Table 4: Outcome of the initial review of selected UKEOF Catalogue activities

Environmental Domain	Number of observation activities and their relevance to the consultation		
	Include in consultation	Possibly include	Suggest exclude (includes satellite observing activities)
Atmosphere	21	18	14
Marine	14	3	2
Terrestrial	2	17	36
TOTAL	**37**	**38**	**52**

The observation activities identified for inclusion at this stage were of two main types:

- those where evidence suggested they are contributing to GCOS
- those that involve long-term climate-relevant monitoring which collect data that is relevant to the ECVs but for which there was no evidence that they contribute to GCOS.

The high numbers of exclusions in part reflect some duplication and overlap in the activities that are described as individual records in the UKEOF Catalogue. Equally, some records were too aggregated in their descriptions (dealing only at the programme level and not identifying separate component monitoring activities). This is likely to be a function of operating an 'open-door' approach to encourage the voluntary participation of the monitoring community in providing information about observation activities and in keeping the UKEOF Catalogue up to date. However, it can make the resulting data difficult to work with from a strategic perspective (see recommendations in section 5.5.1).

The 'Climate and Risk Assessment' list contained short-term research that had terminated, observation activities that were not concerned with data collection (but rather data collation), site-specific experimental studies, activities that did not collect relevant parameters, some of marginal relevance, country-level observation activities that formed part of nationally run programmes (which it was thought might be better served by a single collated response in the consultation) and component parts of programmes (covering differing types of monitoring, not all of which were relevant and some individual sites within such programmes).

The initial review found that most of the marine monitoring activities flagged as relevant to the LWEC 'Climate and Risk Assessment' strand of the LWEC strategy are collecting observational data likely to be relevant to the GCOS ECVs (and are therefore relevant to the consultation). At this stage in the project, very few (2) of the activities in the terrestrial domain were readily identifiable as collecting observations that would support the terrestrial ECVs. Quite a few (14) atmospheric monitoring activities appeared not to be relevant to the consultation (mainly those collecting data for human health purposes).

2.1.3 Identification of additional relevant activities

Checks were made to ensure key monitoring activities likely to be contributing to GCOS were not overlooked by the study. There was insufficient resource for a systematic review, so further relevant observations were identified on an *ad hoc* basis. This involved dialogue with members of the project Steering Group and other members of the UKEOF Management Group, calls to monitoring leads (many of whom who were contacted prior to the consultation) and some searches of the UKEOF Catalogue. Two key reports were sourced: The 'UK Report on National Activities with respect to the GIP' (Whitelaw *et al.,* 2008) submitted as part of the 5th National Communication (see section 1.5) and the results of a recent consultation by UKEOF on behalf of DECC on the GIP (UKEOF, 2011).

A further 15 monitoring activities were identified for inclusion in the consultation from these sources.

The previous report on 'National Activities with respect to the GIP' (Whitelaw *et al.* 2008), identifies climate observations that contribute to the GCOS networks but does not always make reference to the titles of the monitoring activities from which these observations are sourced. Where there are references to observing networks or monitoring activities in the report these were not always easily traceable to the observation activities as named or described in the UKEOF Catalogue. Some were not included in the UKEOF Catalogue. This study has where possible made these linkages and identified omissions from the UKEOF Catalogue (see section 5.5.1) to facilitate continuity in reporting to GCOS and highlighted where uncertainty or gaps in the information held by UKEOF remain.

2.1.4 Rationalising the list of monitoring activities

The consultation specifically sought to establish the relevance of observations to the GCOS ECVs, improve knowledge of climate-related uses of the observation data (beyond their primary purpose) and understand more about observation standards in use.

The consultation comprised a self-completion survey questionnaire (Appendix 1). The initial draft was circulated to the Steering Group for comment and amended to take account of the feedback received. It was then tested by an activity lead in the Met Office for an observation activity included in the study and further amended before being issued with a covering email. The first question was pre-populated using available information (mainly from the UKEOF Catalogue) with the parameters known to be monitored which were assigned to the related GCOS ECVs. This provided context to the questions that followed and was designed to reduce the burden on consultees.

Although as systematic an approach as possible was taken to identifying relevant observation activities, there was still a risk of overlooking key monitoring activities relevant to the study. To counter this, respondents who took part in the consultation were requested to advise the project team if they were responsible for other activities that they felt were relevant to the study.

In all, 79 questionnaires were prepared and sent to 45 individuals (copied to key colleagues as appropriate) in 25 organisations. Three organisations had high numbers of observation activities that were considered relevant to the study: The Met Office (16 observation activities), British Antarctic Survey (12 observation activities) and the Centre for Ecology and Hydrology (16 activities). BAS and the Met Office assigned coordinators to facilitate responses. Two new activities were identified as a result of the survey. In two cases, responses for separately listed activities in the UKEOF Catalogue were represented in a single questionnaire. Two of the responses are from satellite based monitoring activities; these have been included in the analysis in section 3. The observations they provide are described in section 4, the satellite based analysis.

Reminders were sent prior to the survey deadline. The initial survey period was extended and an email sent from NERC and follow-up calls made to selected monitoring leads to encourage responses.

2.1.5 Response Rate

There was an 88% response rate which included two observation activities that are now 'closed' or have been subsumed by other programmes (these are described in Appendix 4). Sixty eight responses to the consultation were included in the analysis described in Section 3, and these describe 72 separately identified activities. The non-responses include observation activities in all three environmental domains: atmosphere (2); terrestrial (3) and marine

(5). Non responses from the marine domain are most likely to have an impact on the reporting and analysis because all five activities were considered highly relevant to GCOS with some known to be contributing data to the GCOS networks.

2.1.6 Results and analysis

All activities were assigned to an environmental domain, as identified by GCOS (atmosphere, atmospheric composition, marine and terrestrial) to assist with analysis of the findings.

To assist with reporting requirements for the 6th National Communication, some of the findings of the questionnaire have been compiled in a similar format to the tables required by the UNFCCC guidelines 'Reporting on global observing systems for climate'[25] which are used to provide reports in conjunction with National Communications. The findings have been subject to an initial comparison with previous reporting in 2008 (Whitelaw *et al*., 2008). This has helped to identify where additional information will need to be sought.

2.2 Satellite observations

The gap analysis is based upon a desk-review of existing information, including a gap analysis of satellite-based observing of ECVs, similar to that required by the study, carried out in 2009 by the Met Office (Appendix 3). This information included two new catalogues which detail the current situation with respect to satellite data and ECVs which are under development:

- WMO's OSCAR (section 1.8.3) which provides information about observation requirements (across a range of applications areas, not just climate change) and capabilities of Earth observation satellite missions and instruments. The database provides a good starting point for assessing which variables in the ECV list are being measured by satellite and for assessing continuity of measurements. At present, the database does not explicitly match instruments and their measurements against ECV requirements however the database does provide some general indication of 'quality' of the measurements in 5 categories (primary, high, medium, useful, marginal).

- The ECV Inventory of CEOS which catalogues ECV datasets derived from satellite data[26]. This database enables a quick assessment of ECV datasets currently in existence or being generated, eg through the European Space Agency's Climate Change Initiative[27]. Taken together with the information in the WMO OSCAR database, it is possible to make an assessment of progress to date and likely future continuity regarding the generation of ECVs using satellite data. This is based on a review of literature and information held on databases (sections 4 and 5).

[25] FCCC/CP/2007/6/ADD.2 which is at: http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

[26] http://ecv-inventory.com/ecv-inventory/ceos?_dm_flow=user2&_dm_event=actions

[27] http://www.esa-cci.org/

3 Contribution of UK funded *in situ* observations to ECVs

Key Findings based on responses to the consultation:

KF1. The UK funds a high number (at least 51) and wide range of *in situ* monitoring activities that systematically and routinely acquire observational data of relevance to the GCOS ECVs.

KF2. A very high proportion of the activities included in this study have taken into account factors that are important for climate observing when setting up their activities and have in place the type and range of protocols, procedures and systems required as a pre-requisite to developing a climate observing capability.

KF3. Those contributing to GCOS networks and actions set out in the GIP have been identified. However, further work is required in advance of the 6th National Reporting to remove some uncertainty over the nature of the contribution to GCOS of a few activities.

KF4. GCOS Baseline networks stipulate the strictest adherence to requirements (Targets) for climate observing. Of the 24 activities providing climate observations to GCOS networks, two-thirds (67%, representing 16 activities) are providing observational data to GCOS Baseline networks.

KF5. Knowledge, awareness and implementation of guidelines and procedures reflect the nature and degree of involvement activities have with the GCOS observing systems and delivery of actions in the GIP. Those providing data to the 'well-established' GCOS networks reported having fully or partly implemented key guidance.

KF6. There is a clear need to strengthen national coordination of UK observational activity in line with GCOS recommendations and UKEOF should action this at the earliest opportunity in order to:

- better enable tracking of progress with delivery of the UK's contribution to the GIP (a complex task)
- facilitate meeting reporting requirements of the UNFCCC
- meet the known demand, established as a result of this study, from the environmental monitoring community for support to deliver the actions in the GIP
- raise awareness amongst key science and policy stakeholders, funders, data providers, commercial organisations and academic researchers of the UK contribution to GCOS, and the uses and potential benefits of climate-related data
- help identify opportunities for, and encourage, re-use of the data in other applications
- seek and facilitate further contributions as necessary.

KF7. The UK does more climate-related monitoring than is included in the UKEOF Catalogue, which should be updated to incorporate further relevant monitoring activity identified by this study.

3.1 General observations on the consultation responses

3.1.1 Consistency of the responses

The evidence provided in this section is derived mainly from responses to the consultation (section 2) which comprised an email-based questionnaire sent to monitoring leads of selected UK funded monitoring activities. Most responses were complete, or near complete, and most responses were internally consistent. However, some respondents stated that did not have a high level of confidence that they had fully understood all the questions and in some cases made clear they did not have access to all of the information that the consultation was seeking. In the small number of cases where there was a lack of clarity as to whether the monitoring activity contributed data to

networks contributing to the GCOS ECVs, this was followed up by members of the project Steering Group to improve the certainty of the results. In common with other questionnaire-based surveys, the questionnaire responses may contain errors, and the results should be used and interpreted accordingly. In a few cases the need for further checking and/or validation of the findings was identified. Comments on the completeness and consistency of responses to each section of the questionnaire are provided in Appendix 2.

It was beyond the scope of this project to follow up on all areas of uncertainty, so these are flagged up in the reporting in Section 3 and accompanying tables in the appendices. Further checks and data will be required for information and data that will be used for reporting as part of the 6th National Communication to the UNFCCC in 2013/14.

3.2 Overall results: Climate observations and ECVs

3.2.1 Characterising the UK funded *in situ* data that are relevant to the ECVs

Nearly all respondents to the consultation categorised their monitoring activities (Question 2) as:

- suitable for use for climate applications in addition to their primary purpose (58 /68 responses), and/or
- a recognised climate observing activity contributing to ECVs through GCOS (31/68 responses).

There were eight non-responses to this question and two responses indicating that the data were not considered suitable for climate applications.

This information together with other responses to the questionnaire, responses to the recent consultation by UKEOF on behalf of DECC (UKEOF, 2011 and previous reporting to the UNFCCC (Whitelaw *et al.*, 2008), enabled the monitoring activities to be allocated to one of three groups for the purposes of reporting, namely:

Group 1: contribute observational data on ECVs to GCOS via 'well-established' systems and networks that can be quantified[28].

(*25 of 68 responses, representing 37% of the activities that responded to the consultation*)

Group 2: contribute to ECVs and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified in key documents as having potential to do so.

(26 of 68 responses, representing 38% of the activities that responded to the consultation)

Group 3: other activities not thought to be engaged with delivery of the GIP but known to be collecting climate-related data of the type used for the GCOS ECVs.

(17 of 68 responses, representing 25% of the activities that responded to the consultation)

3.2.2 Nature and scope of the data acquisition

The UK funds a high number and very wide range of *in situ* monitoring activities that systematically and routinely acquire observational data of relevance to the GCOS ECVs (Tables 5, 6 and 7 based on responses to Question 1) [29].

[28] See: C. Chapter 2: Atmospheric ECVs in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

[29] Excludes activities that are now closed or that responded that their observations were not suitable for climate applications.

Short descriptions of these activities are provided in Appendix 4. Where there is uncertainty about the categorisations made, these are shown in red in these tables.

The monitoring activities have been assigned to an environmental domain that reflects the nature of the observational activity.

The consultation targeted activities that it was considered may be collecting data of relevance to the ECVs. Figure 2 illustrates that nearly all of the marine activities that responded to the consultation are contributing to GCOS networks (Group 1), GIP actions (Group 2) or have already been identified as having potential to do so (Group 2). By contrast, there are considerable numbers of activities, particularly in the terrestrial and atmospheric chemistry domains, that collect data that may be of relevance to the GCOS ECVs but which are not thought to be engaged with delivery of the GIP and have not yet been identified as having potential to do so (Group 3).

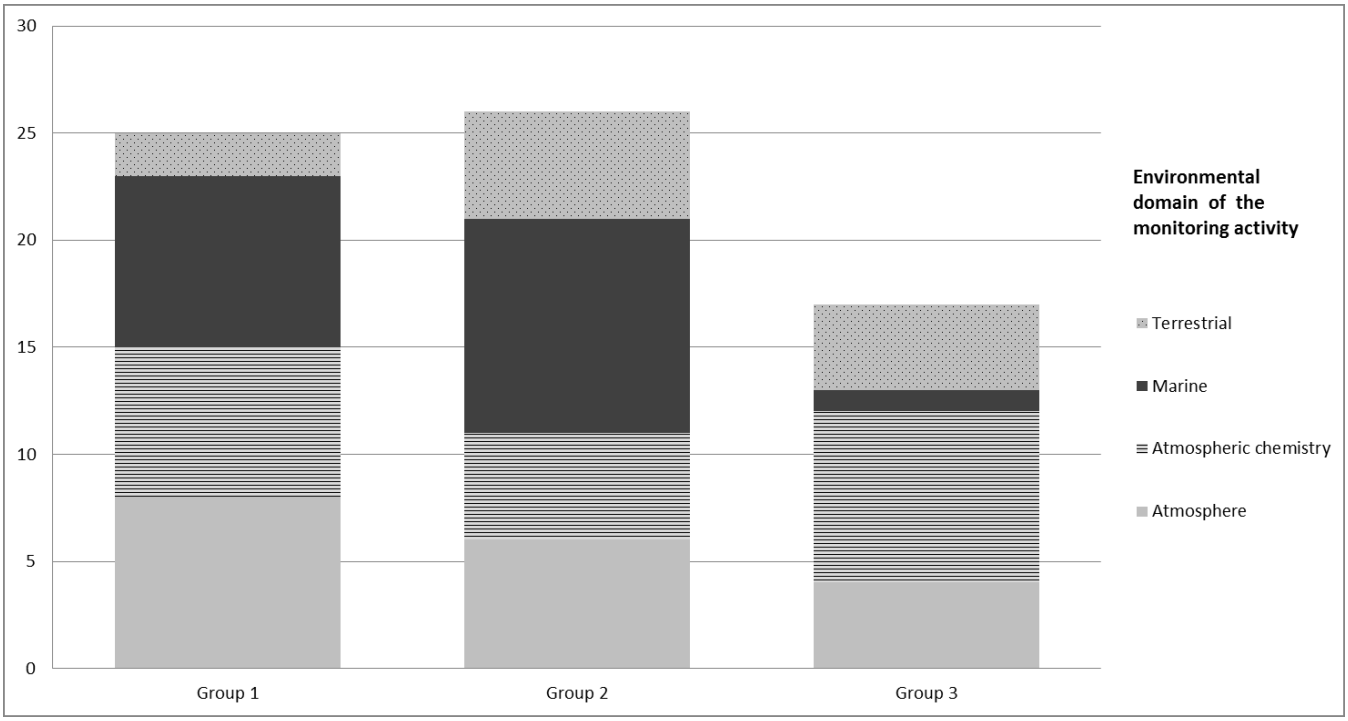


Figure 2: Characteristics of the monitoring activities that responded to the questionnaire, in terms of their environmental domain and the known use of their data for supporting GCOS ECVs (y axis refers to number of activities).

Table 5: Responses from observation activities identifying *in situ* data observing that are of known, or potential, relevance to ECVs (atmospheric ECVs)

OBSERVATION ACTIVITIES	GCOS ESSENTIAL CLIMATE VARIABLES (ECVs) ATMOSPHERIC DOMAIN															
	Atmospheric chemistry					Atmosphere surface						Atmosphere Upper Air				
	aerosol properties	carbon dioxide	methane and other long lived greenhouse gases	ozone	precursors (supporting aerosols and ozone ECVs)	surface air pressure	surface air temperature	surface precipitation	surface radiation budget	water vapour (humidity)	near surface wind speed and direction	cloud properties	air temperature	earth radiation budget (incl. solar irradiance)	water vapour (humidity)	wind speed and direction
Acid Gas and Aerosol (AGANet) and National Ammonia Monitoring Network (NAMN)					x											
Air Quality Database	x			x	x											
AMDAR programme - Met Office weather observations from commercial aircraft													x		x	x
Atmospheric Monitoring - Air and Snow sampling (BAS LTMS)		x	x													
Atmospheric Monitoring - Mesospheric Temperatures (BAS LTMS)													x			
Atmospheric Monitoring - Ozone observations (BAS LTMS)				x												
Atmospheric Monitoring - Surface Meteorology (BAS LTMS)						x	x			x	x	x				
Atmospheric Monitoring - Upper Air Measurements (BAS LTMS)													x		x	x
Atmospheric Monitoring - VLF measurements (BAS LTMS)												x				
Baseline Measurement of Stratospheric Ozone and UV				x										x		
Cape Verde Atmospheric Observatory	x		x	x	x	x	x	x	x	x	x					
Central Management & Coordination Unit for the UK Automatic Urban and Rural Monitoring Network	x			x	x											
Chilbolton Facility for Atmospheric and Radio Research (CFARR)	x						x	x	x	x		x			x	
Environmental Change Biodiversity Network (England) / LTMN – Climate & LTMN air pollution					x		x	x	x	x	x					

Legend – categorisation of monitoring activity

GROUP 1	contributes observational data to 'well-established' GCOS networks
GROUP 2	contribute to ECVs and the GIP through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so
GROUP 3	not thought to be engaged with delivery of the GIP but which produce climate-related data relevant to the ECVs

Legend – categorisation of monitoring activity

GROUP 1	contributes observational data to 'well-established' GCOS networks
GROUP 2	contribute to ECVs and the GIP through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so
GROUP 3	not thought to be engaged with delivery of the GIP but which produce climate-related data relevant to the ECVs

OBSERVATION ACTIVITIES	GCOS ESSENTIAL CLIMATE VARIABLES (ECVs) ATMOSPHERIC DOMAIN															
	Atmospheric chemistry					Atmosphere surface						Atmosphere Upper Air				
	aerosol properties	carbon dioxide	methane and other long lived greenhouse gases	ozone	precursors (supporting aerosols and ozone ECVs)	surface air pressure	surface air temperature	surface precipitation	surface radiation budget	water vapour (humidity)	near surface wind speed and direction	cloud properties	air temperature	earth radiation budget (incl. solar irradiance)	water vapour (humidity)	wind speed and direction
Environmental Change Network: atmospheric chemistry & ECN: meteorology					x	x	x	x	x	x	x	x				
Experimental catchments (Plynlimon etc)							x	x	x		x					
ICP Forests - Chemical Parameters; Plants; Habitats					x	x	x	x	x	x	x					
Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland and the UK DECC Network	x	x	x	x	x	x	x	x		x	x					
Met Office ATDnet system - Long Range Lightning Detection Network												x				
Met Office Baseline Surface Radiation Network						x	x	x	x	x	x	x		x		
Met Office Drifting Buoys Programme						x										
Met Office GPS Water Vapour programme															x	
Met Office Land Automatic Weather Station Network (excludes automated climate)						x	x	x	x	x	x	x				
Met Office Land Climate Station Network (manual and automated)							x	x	x	x		x				
Met Office Marine Automatic Weather Station Network (MAWS) including Met Office Moored Buoys						x	x			x	x					
Met Office Ozone Sonde				x					x							
Met Office Radiosonde Network													x		x	x
Met Office rainfall observing network (in collaboration with EA / SEPA / others)								x								
Met Office Shipborne Radiosonde Stations													x		x	x

OBSERVATION ACTIVITIES

Legend – categorisation of monitoring activity

GROUP 1	contributes observational data to 'well-established' GCOS networks
GROUP 2	contribute to ECVs and the GIP through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so
GROUP 3	not thought to be engaged with delivery of the GIP but which produce climate-related data relevant to the ECVs

	GCOS ESSENTIAL CLIMATE VARIABLES (ECVs) ATMOSPHERIC DOMAIN															
	Atmospheric chemistry					Atmosphere surface						Atmosphere Upper Air				
	aerosol properties	carbon dioxide	methane and other long lived greenhouse gases	ozone	precursors (supporting aerosols and ozone ECVs)	surface air pressure	surface air temperature	surface precipitation	surface radiation budget	water vapour (humidity)	near surface wind speed and direction	cloud properties	air temperature	earth radiation budget (incl. solar irradiance)	water vapour (humidity)	wind speed and direction
Met Office Weather Radar Network								x								x
Met Office Windprofiler network																x
Monitoring of airborne particulate concentrations and numbers in the UK	x															
Ocean Acidification monitoring		x														
Operation of EMEP Supersite at Auchencorth Moss	x	x	x	x	x		x	x		x	x					
Operation of EMEP Supersite at Harwell	x	x		x	x		x	x		x	x					
Porcupine Abyssal Plain (PAP) Observatory							x				x					
PrecipNet and NO2 Net (part of UKEAP)					x			x								
The NERC Mesosphere-Stratosphere-Troposphere Radar Facility at Aberystwyth						x	x	x	x	x	x	x			x	x
UK Black Carbon Network	x															
VOS programme - Marine meteorological observations from Voluntary Observing Ships incl. VOS CLIM						x	x			x		x				
Western Channel Observatory - marine based measurements						x	x				x					
Weybourne Atmospheric Observatory (WAO)	x		x	x	x	x	x		x	x	x			x		
Wytham wood sun photometer	x													x		

Table 6: Responses from observation activities identifying *in situ* data observing that is of known, or potential, relevance to ECVs (oceanic ECVs)

OBSERVATION ACTIVITES	GCOS ESSENTIAL CLIMATE VARIABLES (ECVs) : OCEANIC DOMAIN																	
Legend – categorisation of monitoring activity	Ocean Surface										Ocean Subsurface							
GROUP 1: contributes observational data to 'well-established' GCOS networks GROUP 2: contribute to ECVs and the GIP through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so GROUP 3: not thought to be engaged with delivery of the GIP but which produce climate-related data relevant to the ECVs	CO2 partial pressure	sea current	ocean acidity	ocean colour	Phytoplankton	sea ice	sea level	sea state	sea surface salinity	sea surface temperature	carbon	Current	nutrients	acidity	oxygen	sub surface salinity	sub surface temperature	tracers
Atlantic Meridional Overturning Circulation Monitoring		x					x		x	x		x				x	x	
Atlantic Meridional Transect (AMT)	x		x	x	x				x		x		x	x	x	x	x	
Continuous Plankton Recorder (CPR) Survey					x				x	x								
Cryospheric Monitoring - Sea ice observations (BAS LTMS)						x												
Ellett line and extended Ellet line oceanographic section									x	x		x	x		x	x	x	
Global Sea Level Observing System Tide gauges							x											
Met Office Drifting Buoys Programme		x								x								
Met Office Marine Automatic Weather Station Network including Met Office Moored Buoys								x		x								
North Sea quarter 3 International Bottom Trawl Groundfish Survey									x	x						x	x	
Ocean Acidification monitoring	x		x										x	x				
Oceanographic Monitoring - CTD stations (BAS LTMS)									x	x						x	x	
Oceanographic Monitoring - moorings (BAS LTMS)									x	x						x	x	
Oceanographic/Biological Monitoring - Rothera Oceanographic and Biological Time Series					x	x			x	x			x			x	x	
Porcupine Abyssal Plain (PAP) Observatory	x				x			x		x		x	x		x	x	x	
UK Argo Programme									x	x		x			x	x	x	
Marine meteorological observations from Voluntary Observing Ships incl. VOS CLIM						x		x		x								
Water Framework Directive Monitoring Overview																		
Western Channel Observatory - marine based measurements				x	x				x	x	x		x		x	x	x	
Wyville Thomson Ridge mooring		x								x		x					x	

Table 7: Responses from observation activities identifying *in situ* data observing that is of known, or potential, relevance to ECVs (terrestrial ECVs)

OBSERVATION ACTIVITES	GCOS ESSENTIAL CLIMATE VARIABLES (ECVs): TERRESTRIAL DOMAIN															
Legend – categorisation of monitoring activity GROUP 1: contributes observational data to 'well-established' GCOS networks GROUP 2: contribute to ECVs and the GIP through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so GROUP 3: not thought to be engaged with delivery of the GIP but which produce climate-related data relevant to the ECVs	river discharge	water use	ground water	lakes	snow cover	glacier and ice caps	permafrost	albedo	land cover	FAPAR	LAI	above ground biomass	fire disturbance	soil moisture	soil carbon	ice sheets
Cryospheric Monitoring - Isostatic rebound (BAS LTMS)																x
Environmental Change Biodiversity Network (England) / LTMN - Climate					x			x								
Environmental Change Biodiversity Network (England) /LTMN - soil, vegetation									x					x	x	
Environmental Change Network: - soil, vegetation	x								x					x	x	
Environmental Change Network: meteorology								x								
Experimental catchments (Plynlimon etc)	x															
Harmonised Monitoring Scheme (England and Wales + Scotland)	x															
ICP Forests - Chemical Parameters; Plants; Habitats												x		x	x	
Met Office Baseline Surface Radiation Network					x			x								
Met Office Land Automatic Weather Station Network (excludes automated climate)					x											
Met Office Land Climate Station Network (manual and automated)					x											
National River Flow Archive (UK) - incl. hydrometric networks and hydrological monitoring	x		x													
UK Acid Waters Monitoring Network (to become the UK Upland Waters Monitoring Network)	x			x												
Water Framework Directive Monitoring Overview	x		x	x												

Characteristics of Group 1

> Group 1: contribute observational data on ECVs to GCOS via 'well-established' systems and networks that can be quantified[30]. The UK has accepted responsibility to provide a contribution to GCOS ECVs through these networks.

Just over a third (25/68 responses, representing 37% of the activities that responded to the consultation) provide climate observing data that are in this Group, including one satellite-based earth observation activity.

There are currently 26 'well-established' networks and systems managed by GCOS partners (Table 8) for managing observations from *in situ* monitoring activities (Met Office, pers. comm.). Not all these networks are fully operational, as they contain an element of instrumentation and/or processing that is still in the R&D phase. Areas of uncertainty are flagged in red.

DECC, on behalf of the UK, periodically report to the UNFCCC the number of UK funded stations that contribute observational data to these GCOS networks (see: Whitelaw et. al 2008). Details of the activities and the GCOS networks and type of ECVs they are contributing to have been provided to UKEOF (with any uncertainty in any of the responses highlighted in the tables) to assist with the 6th National Reporting to the UNFCCC.

Twenty-four *in situ*[31] that responded to the consultation operate stations that contribute data to these GCOS networks. Many activities collect a range of observational data of relevance to the ECVs (Tables 5, 6 & 7) and contribute data to more than one of the GCOS networks. There are eleven activities that contribute observational data to a single GCOS network, ten that contribute data to two GCOS networks, one activity that contributes data to three networks and two activities that each contributes observational data to five GCOS networks.

Of the responding monitoring activities, 24 *in situ* activities provide 33 separate sources of observational data, with observation data delivered mostly into GCOS networks concerned with monitoring changes to the atmosphere (Figure 3).

It should be noted that five key marine monitoring activities that are thought to be contributing to GCOS did not submit responses to the questionnaire so the marine contributions are likely to be underestimated.

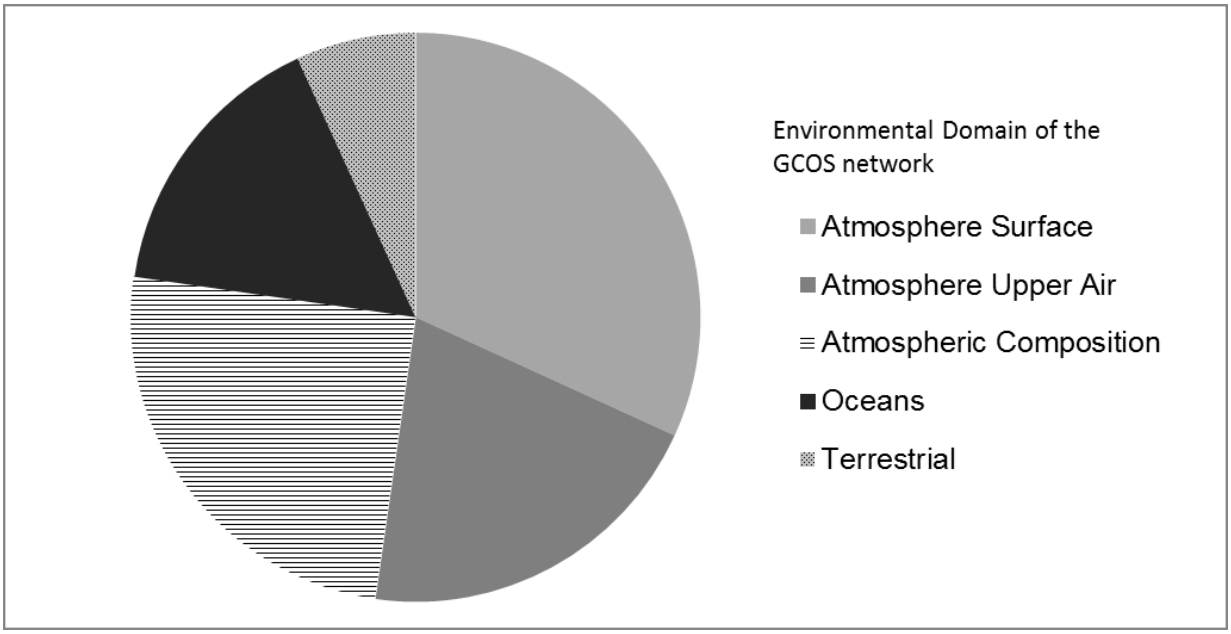


Figure 3: Contributions made to GCOS networks (characterised by the environmental domain with which they are associated) from 24 'Group 1' monitoring activities that responded to the survey

[30] See: Chapter 2: Atmospheric ECVs in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

[31] This excludes one satellite monitoring activity.

Table 8: Sources of scientific guidance that networks contributing to GCOS ECVs adhere to, or aspire to meet, for climate observing (source: Met Office, draft 2013)

Name of network contributing to GCOS ECVs (by domain)	**GCOS Baseline Network**: Member Commitment Managed by GCOS Scientific guidance from GCOS	**GCOS Baseline Network**: Member Commitment Managed by Partner Scientific guidance from GCOS	**Underpinning Network**: Aspire to meet the requirements of the WMO RRR including climate	**Contributing Network**:	**Number of activities contributing to these networks (based on responses to the consultation)**
Domain: Atmosphere Surface					
GCOS Surface Network (GSN) and Regional Baseline Climate Network (RBCN)	YES				3
Regional Baseline Synoptic Network (RBSN) – WMO/GOS			YES		4
Global Tropical Moored Buoy Network		YES			0
Global Reference Mooring Network		YES			2
Baseline Surface Radiation Network		YES			1
Global surface drifting buoy array		YES			1
Voluntary Observing Ships		YES			2
GLOSS Core Sea-level Network (Surface pressure)		YES			1
Domain: Atmosphere Upper-Air					
GCOS Reference Upper-air Network (GRUAN)	YES				0
GCOS Upper-air Network (GUAN)	YES				3
Upper Air Network (UAN) – WMO/GOS			YES		3
Profiler (radar) network			YES		1
Aircraft (ASDAR etc)			YES		1
Ground-based GPS receiver network				YES	1
Domain: Atmosphere Composition					
GCOS-affiliated WMO/GAW Global Atmospheric N2O, CO2 & CH4 Monitoring Networks		YES			3
WMO/GAW GCOS Global Baseline Profile Ozone Network		YES			4
WMO/GAW GCOS Global Baseline Total Ozone Network		YES			3
WMO/GAW Aerosol Network			YES		1
Domain: Oceans					
Global surface drifting buoy array		YES			1
Voluntary Observing Ships (VOS)		YES			2
GLOSS Core Sea-Level Network		YES			1
Global Tropical moored buoy network		YES			0
Global reference mooring network		YES			2
Argo Array		YES			1
Coastal/National moored buoy network				YES	0
Domain: Terrestrial					
GCOS/GTOS Baseline Global Terrestrial Network – Rivers (GTN-R)		YES			1
GCOS/GTOS Baseline Terrestrial Network – Glaciers (GTN-G)		YES			0
GCOS/GTOS Baseline Global Lake Network		YES			0
GCOS/GTOS Baseline Terrestrial Network - Permafrost (GTN-P)		YES			0

WWW/GOS synoptic network (snow)			YES		0[32]
Global Terrestrial Network Hydrology (GTN-H)		YES			2

The 'well-established' networks and systems contributing to GCOS EVCs were assigned to one of four types by the Met Office to reflect the source of scientific guidance they adhere to, or aspire to meet, for climate observing (Table 8). Most of the observational data from activities are contributed to the GCOS Baseline Networks. The questionnaires identified:

- six contributions of observational data (from 6 activities) to networks that are actively managed by GCOS (GCOS documented and monitored)
- a further 27 contributions (from 16 activities) to networks for which partner bodies coordinate climate requirements, in collaboration with GCOS (partner documented and monitored)
- 10 contributions to the 'Underpinning' networks (from 9 activities), which aspire to meet the requirements of the WMO RRR including climate requirements, and
- one contribution to the 'contributing' networks.

GCOS Baseline networks stipulate the strictest adherence to requirements (Targets) for climate observing. Of the 24 activities providing climate observations to GCOS networks, two-thirds (67%, representing 16 activities) are providing observational data to GCOS Baseline networks.

Characteristics of Group 2

> Group 2: contribute to ECVs, and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so.

A further 26 activities (38% of 68 responses) that responded to the consultation are in this group, which includes activities contributing to the development of new networks and other programmes that will contribute observations of the ECVs (such as work on climate observations being undertaken in climate research programmes).

It also includes activities that have been identified by the UK environmental monitoring community as being relevant, or potentially relevant, to the delivery of the GIP (sources used: Whitelaw *et al*. 2008; UKEOF, 2011, responses to Q2 option 6 of the questionnaire). The recent consultation by UKEOF on behalf of DECC on the GIP (UKEOF, 2011) and the report on 'National Activities with respect to the GIP' (Whitelaw *et al.* 2008) provide descriptions of the current or potential contribution that many of these activities make to achieving the actions set out in the GIP.

Some of the activities in this group are leading or involved with establishing climate observing networks in support of the GCOS ECVs (eg Action O6 of the GIP 'to deploy a ship based reference network of instrumentation for biogeochemical and ecosystems variables - to which the Continuous Plankton Recorder activity makes a major contribution'). As these (Group 2) networks achieve a fully operational status, they will become the types of 'well-established networks' listed in Group 1 (ie moving from Group 2 to Group 1) and reported on in future National Reporting.

Five of the activities in Group 2 identified their monitoring as '*a recognised activity contributing to ECVs through GCOS*' and a further five agreed that the '*acquisition of observations of ECVs from their activity are highly relevant to the GIP*'. These ten activities are:

- Atlantic Meridional Overturning Circulation Monitoring
- Atlantic Meridional Transect (AMT)
- Atmospheric Monitoring - VLF measurements (BAS LTMS)
- Continuous Plankton Recorder (CPR) Survey
- Ellett line and extended Ellet line oceanographic section
- Met Office Marine Automatic Weather Station Network (MAWS) including Met Office Moored Buoys

[32]Met Office Land network measures snow at 68 synoptic sites, although this was not reported through the questionnaire.

- Western Channel Observatory - marine based measurements
- Weybourne Atmospheric Observatory (WAO)
- Wytham wood sun photometer
- Wyville Thomson Ridge mooring.

Characteristics of Group 3

> Group 3: other activities not thought to be engaged with delivery of the GIP but known to be collecting climate-related observation data of the type used for the GCOS ECVs

One quarter (25%) of the activities (17 of 68 responses) are observing parameters of the type used for GCOS ECVs. None of the respondents for these activities identified their observational activity as '*highly relevant to achieving the actions for ECVs set out in the GIP the GIP'* (question 2, option 6).

This group includes 10 activities that respondents considered were collecting *'(some) observational data that could be used for climate applications*'. It also includes two activities where the observational data were not considered suitable for climate applications and three where the respondent indicated that they were not sure of the applicability of the observational data for climate applications.

As might be expected, almost all in this group responded that they did not know how well their activities might comply with GCOS protocols and standards (16 of 17 responses).

3.3 Overall results: Data Centres

Respondents had good knowledge of the data centres responsible for the observational data acquired by their monitoring activity and all but two activities provided details of at least one data centre holding the observational data produced (question 4).

It was notable that relatively few (8 of 25 *in situ* activities) in Group 1 (ie those contributing data to the 'well-established' GCOS networks) ticked the option *'the relevant GCOS International Data Centre(s)'*. Instead they tended to name the International Data Centres (IDC) or did not provide any information on this. A recent UKEOF consultation of members of the climate science community (UKEOF, 2011) highlighted that '*data is not generally sent directly to International Data Centres (IDCs) by the responsible organisation*'. This may go some way to explaining this finding.

It is also the case that the contributing observing systems of GCOS have their own remits and objectives, which extend beyond climate observing; they therefore contain programmes and activities that are not directly relevant to GCOS. The same is true of the international Data Centres which hold data from GCOS networks.

This may explain the difficulty a few respondents reported in establishing whether they are contributing data to GCOS networks (eg where they were aware of the network they were contributing to, but not sure whether this was a GCOS network).

3.4 Overall results: Uses of climate-related data

Just over half (56%) of the 68 activities provided information on climate-related uses of their data. Figure 4 provides an overview of the types of climate-related applications that the observational data from the monitoring activities is supporting.

The results are separated by the environmental domain of the monitoring activity (from which the data originates).

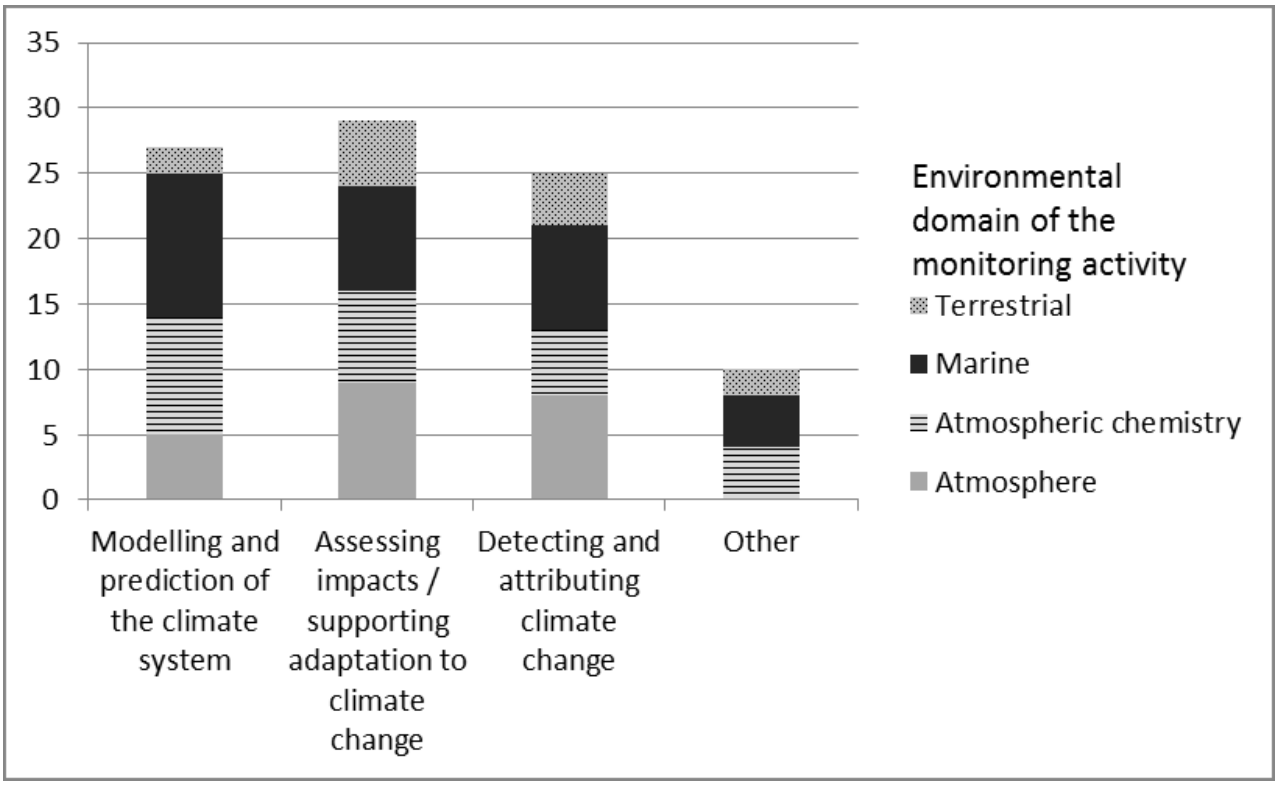


Figure 4: Uses of monitoring data in climate applications (separated by domain of the monitoring activity from which the data originates) (y axis refers to number of activities).

A good range of examples of climate-related uses were provided, although many referred to other initiatives rather than describing them. Some of the responses received are described in Table 9. Details were provided in some, but not all, cases, of how the data feed into the various applications described (eg via particular initiatives). Some respondents to the consultation reported that the end uses were too numerous to describe as their data are very widely used in scientific research.

Table 9: Examples of climate-related uses of monitoring data deriving from activities included in the consultation

Monitoring activity and description of use(s) Group 1: activities that contribute observational data to 'well-established' GCOS networks
Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland: contributes data to climate modelling and climate impact assessment activities via two key initiatives Advanced Global Atmospheric Gases Experiment (AGAGE) and the 'UK DECC network'. The AGAGE has measured the composition of the global atmosphere continuously since the 1980s with a global capability to measure almost all of the important species in the Montreal Protocol (eg CFCs and HCFCs) and almost all of the significant non-CO2 gases in the Kyoto Protocol (eg CF4, SF6, HFCs, methane, and nitrous oxide). The 'UK DECC Network' is a new network of UK measurement sites set up to complement the measurements that take place at Mace Head. Gases measured are CO2, CH4, CO, N2O, SF6 a full suite of ODS and GHG compounds. The data from Mace Head are used as input into the NAME/InTEM inversion model to determine UK emissions at the devolved administration level.
Rainfall collection sites: Data are stored in Met Office MIDAS database. Data are used by NCIC for monitoring of UK climate trends, putting weather events into context and the provision of advice on a wide range of climate-related topics. It is also shared with the Environment Agency and Scottish Environment Protection Agency for their hydrological monitoring. A small subset of the data is used in real-time for calibration of radar measurements.
Baseline Measurement of Stratospheric Ozone and UV: The data support calibration of the OMI – AURA satellite

Table 9 (continued) Examples of climate-related uses of monitoring data deriving from activities included in the consultation

Monitoring activity and description of use(s)
Group 2: activities that are engaged in other activity in support of the GIP or identified as being relevant, or potentially relevant to its delivery
Chilbolton Facility for Atmospheric and Radio Research (CFARR): Continuous monitoring of cloud profiles has allowed evaluation of model biases/errors to be identified. This approach, pioneered at Chilbolton is being implemented at other observatories around the world, notably US ARM. Data are supplied via the European CLOUDNET project Cloud data has been used to evaluate cloud processes in the latest generation of coupled climate models (CMIP5[33]) and by the Met Office to improve prediction of stratocumulus in the GA3.0 climate model. With data feeding into the activity via the Cloud Feedback Model Intercomparison Project (CFMIP).
Ellett line and extended Ellet line oceanographic section and **Wyville Thomson Ridge mooring:** both activities provide data to the EU Framework 7 programme: North Atlantic Climate Variability (NACLIM) which is investigating and quantifying the predictability of the North Atlantic/ European climate.
Operation of EMEP Supersite at Auchencorth Moss: contributes to: ACTRiS. (Aerosols, Clouds, and Trace gases Research InfraStructure Network) an EU project for developing protocols and linkages between air quality and climate. ICOS (CO2, methane fluxes). ICOS provides the long-term observations required to understand the present state and predict the future behaviour of climate, the global carbon cycle and greenhouse gases emissions. ECLAIRE (Effects of Climate Change on Air Pollution and Response Strategies for European Ecosystems) is a four year project funded by the EU's Seventh Framework Programme: Auchencorth provides measurements of ecosystem parameters, N and C chemistry.
Monitoring activity and description of use(s)
Group 3: activities that are not engaged with delivery of the GIP but produce climate-related data relevant to the ECVs
Experimental catchments (Plynlimon etc): Data from Plynlimon are used in the JULES model (Joint UK Land Environment Simulator) and other models of land atmosphere interactions and climate effects.
ICP Forests (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests): Forest Research monitoring affiliated to FLUXNET - a flux tower Eddy covariance system is used to measure CO2 emissions from forests at three ICP sites. In addition, at one site through the Environmental Change Network (ECN) there is collection of data using standardised biological and chemical protocols to aid in the identification of climate change.
PrecipNet and NO2 Net (part of UKEAP): Rain data feeds into RoTAP: Understanding the changing deposition of inorganic N and S to the UIK surface, used in UK and transboundary pollution climate studies (not -ongoing, but data record is from 1985 - current). Pollution climate mapping: NO2 diffusion tubes provide the rural background underpinning the high resolution measurements made in the AURN (Automatic Urban and Rural Network, funded by Defra).

3.5 Overall results: Operating practices

It is of major importance for climate observing that data from different locations and times are comparable or can be made comparable. GCOS and partner organisations provide standards and guidance for generating ECVs to help data producers make their observations useful for global climate assessment. Many monitoring activities that contribute data to GCOS observing systems were not originally set up to do so and have adapted or strengthened their operating practices, standards and metadata to meet the exacting standards necessary, sometimes for a subset of stations.

[33] Cloud Feedback Model Intercomparison Project

3.5.1 Awareness of key guidance supporting climate observing

Respondents to the consultation were asked to indicate their awareness of a range of guidance, including technical guidance that supports GCOS climate observing. They were also asked if they knew whether the guidance had been implemented (question 6, Appendix 1). Respondents with activities contributing observational data to GCOS networks and actively involved with delivering the actions in the GIP (ie Group 1 and some in Group 2) were expected to have greater awareness of the guidance than those managing activities where currently there is no operational involvement with GCOS climate observing activities. The results from respondents reflect this (Figure 5).

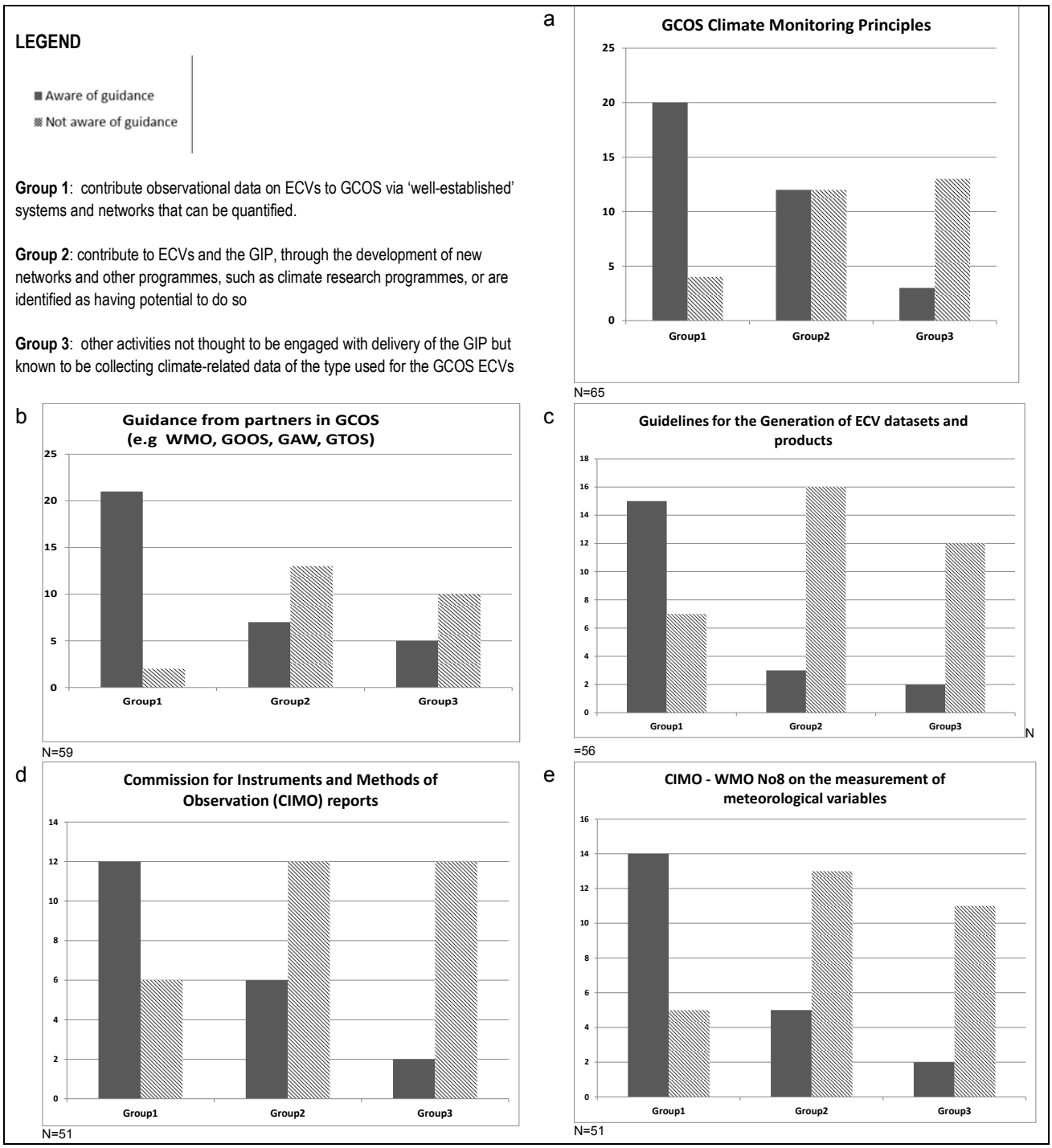


Figure 5: Awareness of key guidance supporting climate observing (y axis refers to number of activities).

Twenty-one activities reported that 'Guidance for GCMPs' and 'Guidance from GCOS or partners' had been partly or fully applied. One activity in Group 1 indicated that these two forms of guidance had not been implemented and it subsequently transpired (through follow-on work for the UK submission to the 6th National Communication) that this terrestrial activity was not a GCOS contributing activity and is a 'Group 3' activity. There were four non responses from Group 1; though three provided information on procedures in place (eg reporting that they followed procedures provided by the relevant authority) with one terrestrial activity subsequently reporting compliance with the GCMPs

(through follow-on work to report for the UK submission to the 6th National Communication).

3.5.2 Setup of the monitoring activities

Respondents were asked to indicate which considerations had been taken account of when setting up their site(s) or networks; the questionnaire listed seven of the main considerations set out in the GCOS CMPs and other key guidance from GCOS (question 7, Appendix 1). Responses showed that a very high proportion of all activities have been set up taking into account of these factors (Figure 6) irrespective of whether they are contributing to GCOS.

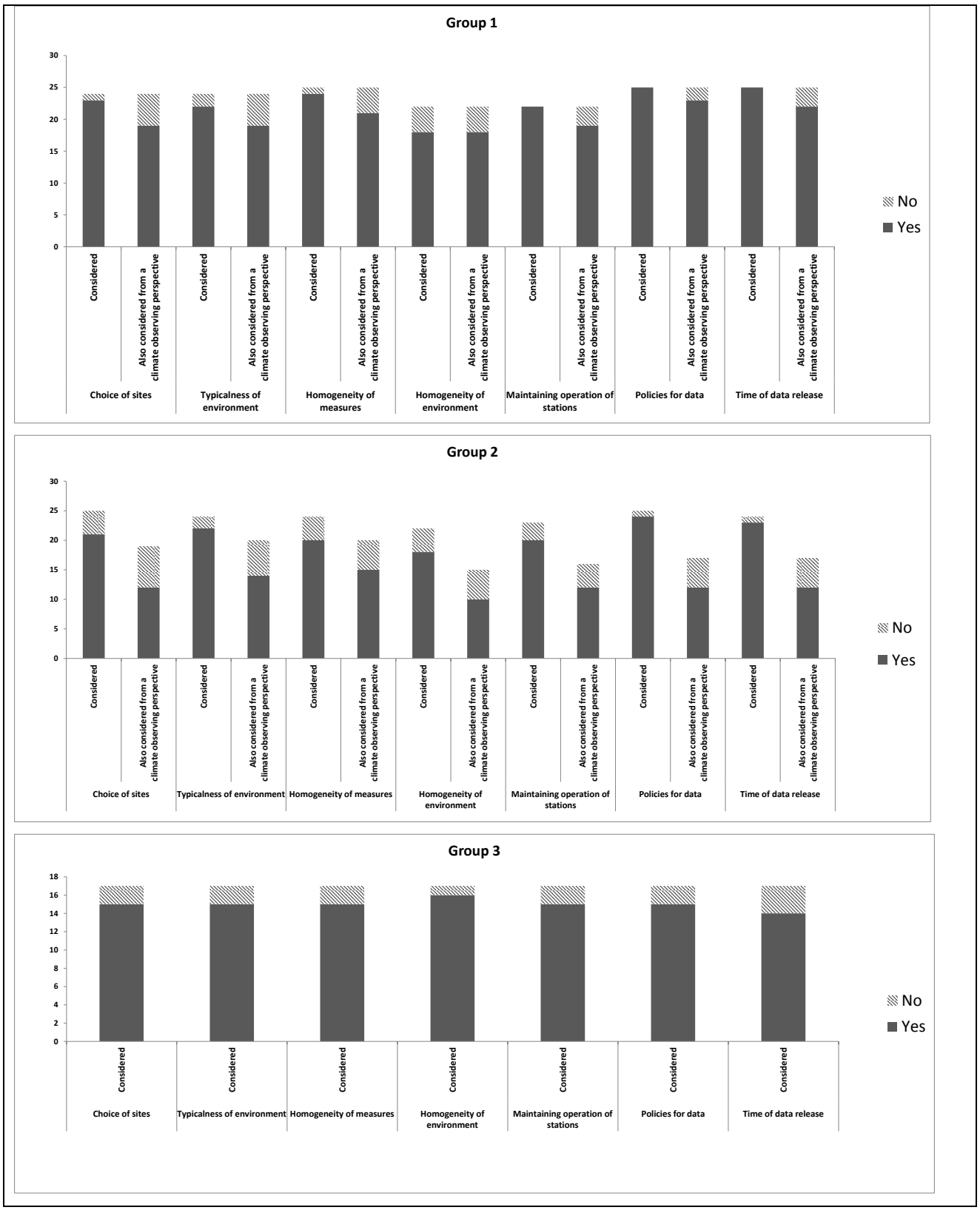


Figure 6: Considerations taken into account of when setting up site(s) or networks (y axis refers to number of activities).

In Group 1 and Group 2 respondents indicated that good numbers of activities have also taken these factors into account from a climate observing perspective. For Group 3, where there would be no expectation that the activities would be set up with climate observing in mind, there were a couple of activities that reported that some of the factors had been taken into account.

3.5.3 Protocols, procedures and systems

Respondents to the consultation were asked to indicate the types of protocols, procedures and systems in place for observing ECV parameters (question 8, Appendix 1). The types of protocols, procedures and systems described (Figure 7) are those considered essential from a climate observing perspective. All but two activities provided responses.

The numbers of activities with some or all of the protocols, procedures and systems in place (Figure 7) ranged from 63 (of 66 responses) for 'setup / calibration of instruments' and 'consistency of data', to 50 (of 66 responses) for 'assessing accuracy' and 'version control'. Analysis of the findings by the three groups of activities (Figure 7a, 7b & 7c) showed that with the exception of 'version control', very high numbers of Group 1 activities have these types of protocols in place and for all ECV related parameters. A similar situation was reported for Groups 2 and 3, with high numbers of the activities having the protocols in place, though it is notable that for these groups the protocols were more often in place for some, rather than all ECV related parameters. This is not to suggest that all the activities in Group 2 and 3 are operating their sites and platforms to the standards required for climate observing for GCOS (although some are contributing to the actions in the GIP). However, when coupled with the findings on site set-up (section 3.5.2) it does suggest that many sites appear to have been set up in a way that suggests they are conducive to monitoring for climate applications and may have the requisite protocols, practices and procedures in place that can be adapted or strengthened to meet the exacting standards necessary for climate observing.

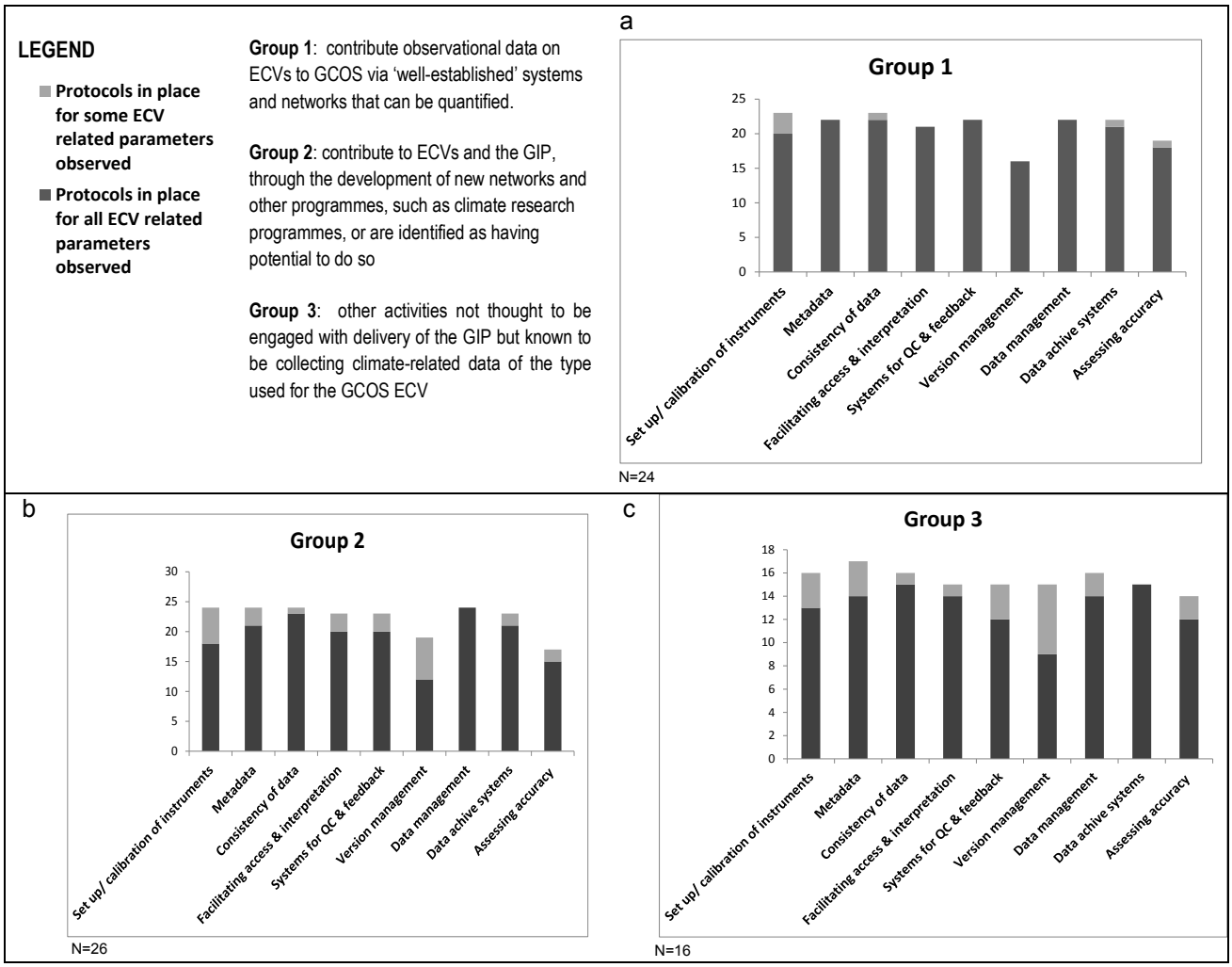
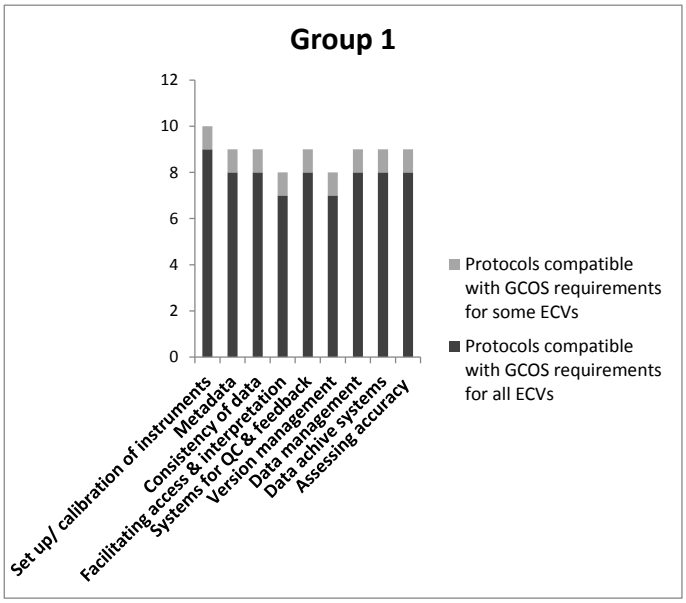


Figure 7: Types of protocols in place for observations of data relevant to ECVs (y axis refers to number of activities).

Thirteen respondents in Group 1 and one respondent in Group 2 (leading an activity that is currently in the process of

applying to join a GAW network) reported that they had assessed the compatibility of protocols with GCOS requirements for some or all ECVs. Ten respondents from Group 1 provided further details, regarding the compatibility of their protocols with GCOS requirements (Figure 8).



N=10

Figure 8: Assessment of protocols for compatibility with GCOS requirements (y axis refers to number of activities).

It should not be assumed that such assessment has not taken place for other activities in Group 1; the respondent may not necessarily be aware of the outcome of such assessment.

3.5.4 GCOS data standards and protocols: raising awareness and providing support

Thirty three respondents (48%), from all the groups, requested further information about GCOS data observing standards with an almost equal number advising that they did not require support. A range of support has been requested; some generic and some very specific (Box 1). The requests were commonly for support tailored to meet the circumstances and specific needs of individuals.

It is recommended that CCOG follow up on the requests for further information, details of which have been provided to the UKEOF secretariat. This will help further raise awareness of GCOS requirements and standards for observing the ECVs and ensure that those delivering to GCOS on behalf of the UK are kept abreast of developments that are of direct relevance to them.

Box 1: GCOS protocols and standards – selected comments on the need for advice and support

'Some background, coordinated information on GCOS data standards would be useful, as would more general information about GCOS. We have never really had much in the way of communication about this, other than through what we have picked up through our links with the international data centre'.

'More interaction is required at the grass roots level'.

'Anything indicating that updated operating standards are needed'

'Guidance on the most appropriate sources of information about the GCOS data standards for measurements'

'The scope is quite broad; guidance on what is most relevant to our activity would be helpful'

A site contributing to GCOS: *'Independent assessment of the site by qualified representatives of GCOS'* and a similar site applying to join a GCOS network: *'Perhaps a visit from someone to discuss GCOS and the reasons for it and the process'*

'support to check how the GCOS protocols compare to current UK protocols and EU level protocols'.

Two organisations (BAS: 6 activities and Met Office: 2 activities) reported having made assessments of the benefits to the GCOS networks that would arise from the inclusion of compliant measurements from their monitoring activities

(Question 9).

A Guidance Note (www.ukeof.org.uk) has been produced to help raise awareness of GCOS requirements and standards for observing the ECVs (see section 1.9.3).

3.6 Overall results: GCOS requirements for data acquisition

The final section of the questionnaire was specifically for those activities in Group 1 (already contributing to a 'well-established' GCOS networks) or those in Group 2 who are involved with the delivery of the GIP. Twenty one responses were provided regarding a question and a selection of these are provided in Box 2.

Box 2: Is there any intention or commitment to make changes to your activity to either assess, or improve, its compliance with GCOS international standards or GCMPs? (selected responses)

No, best practice is already in place

Constantly assessing observations against WMO guidelines and wherever possible following GCOS principles to maintain the quality of observations.

No current intention to do so. Protocols are well established. However, we are always keen to check our standards.

We can if that would be useful, we are keen to do all measurements to the best available protocols within reason

Where practical the GCOS monitoring principles are taken into consideration. However, give the relatively high cost of maintaining offshore observation this is not always possible.

We would consider any changes that did not compromise the 20 year monitoring records we have collated to date, providing resources were available to implement them.

No formal commitment, but would be interested to find out more.

Information from Question 12 of the questionnaire (about awareness and application of guidance) has been provided to UKEOF to assist with the compilation of data for the 6th National Reporting.

3.7 National coordination

This study provides a snapshot of activity. The information it sought to address in the objectives of the study is highly dispersed and the process of obtaining it was time consuming; the system of GCOS observing systems and networks itself can be complex to understand and navigate for information retrieval. The range and number of actions in the GIP that require tracking is very large.

The GIP is taking forward a very wide range of actions and the contributions the UK makes to these and the networks of observing systems are evolving. With the *in situ* observing of some ECVs at an early stage there are many who have a steep learning curve to climb.

Respondents to the consultation have provided a valuable body of evidence that has furthered the understanding of the nature of UK climate-related monitoring and contributions to GCOS. This will be used to improve the capacity of the UKEOF Catalogue to support National Reporting (section 5). Many respondents to the consultation have requested specific information about GCOS in support of their work (see section 3.5.4).

GCOS recognise the value of national coordination and in 2009 the Executive Heads of all four sponsors of GCOS jointly urged countries to appoint GCOS National Coordinators and/or establish GCOS National Committees. 'Key Need 5' and 'Key Need 6' in the GIP (2010) encourage the establishment of National GCOS Coordinators and National GCOS Committees.

A focal point with both an overview and knowledge of the component parts of the system could actively maintain a watching brief on progress with the delivery of GIP. They could also act as a conduit, encouraging involvement and facilitating those less familiar with the system to obtain the information and support they need. This should benefit all those responsible for, and involved with, UK contributions to the GIP and is in line with the Terms of Reference for GCOS coordinators[34].

[34] There are currently 130 designated GCOS National Coordinators (08 July 2013). More details, including their Terms of Reference, are available at http://www.wmo.int/pages/prog/gcos/index.php?name=NationalActivities

In the UK there is currently no single focal point and no national coordination in the UK for the delivery of the GIP. Some, but not all, aspects of the role of a National Coordinator are undertaken by the Met Office, UKEOF and DECC. For example, the Met Office has recently taken on the responsibility of providing the role of the GCOS Implementation Manager, through funding from Met Office and DECC. Nevertheless the UK delivery of the GIP would benefit considerably from having a single focal point responsible for national coordination. Without this, the study team believes the risk of loss of knowledge, and momentum gained by this study, is very high. GCOS state[35] that:

> '*Needs of the UNFCCC and other users for global climate observations and products can be addressed only if plans are developed and implemented in a coordinated manner by national organisations. Such mechanisms are usually best sustained when national coordinators or focal points are designated. Their assigned responsibility should include to coordinate planning and implementation of systematic climate observing systems across the many national departments and agencies involved with their provision*.'

There is a clear need to strengthen national coordination of UK observational activity in support of GCOS, and the formation of CCOG has begun to address this. It is recommended that CCOG should consider whether it, in conjunction with the Met Office and UKEOF, can fulfil this role, and if not, what should be done to strengthen national coordination.

[35] http://www.wmo.int/pages/prog/gcos/documents/NatCoord-TOR.pdf

4 Contribution of UK funded satellite observations to ECVs

Key Findings

KF8. The UK's contribution to the development and deployment of satellite measuring systems is mainly via international programmes, mainly through ESA, EUMETSAT and the EU.

KF9. As well as contributing financially and engineering know-how to build satellites, the UK is also very active in programmes to use the resulting satellite data streams to derive and make use of ECV datasets. These programmes are funded through ESA, EUMETSAT and the EU and but also nationally (eg through programmes in NERC Centres such as NCEO). Programmes are gathering momentum but continued cycles of improvement and development will be needed.

4.1 Satellite observations and ECVs

Two new catalogues which detail the current situation with respect to satellite data and ECVs were used to derive a summary of the overall position (Table 10).

Table 10: GCOS Essential Climate Variables (April 16, 2013). Satellite based ECV datasets already available/being developed (green)[36], planned but not currently available (yellow) and finally where capability to measure from space exists or should exist in the future but there are no plans at present (red). Unshaded ECVs are ones where satellites are not expected to contribute significantly.

ATMOSPHERIC (over Land, Sea & Ice)	OCEANIC	TERRESTRIAL
Surface	**Surface (Ocean)**	
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 Color	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	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	Oxygen	Ice Sheets
Ozone	Salinity	Land surface temperature
Precursors (supporting Aerosols and Ozone ECVs)	Temperature	
	Tracers	
	Global Ocean Heat Content	

As indicated above, not all satellite based ECV datasets are at the same level of maturity and long term continuity of underlying measurement systems is not always assured (section 5.4).

4.2 UK contribution to satellite based ECVs

The UK's main contribution to satellite based ECVs is through participation in international programmes of EUMETSAT, ESA and the EU. The UK's financial contributions to EUMETSAT, European Space Agency (ESA) and the European Union (EU) may result in UK building satellite missions or instruments but the UK does not currently

[36] Using satellite data based on the CEOS ECV inventory

have its own independent programme for building climate relevant instruments or missions. The UK contributes to the following European satellite programmes:

- EUMETSAT's polar orbiting METOP and METOP Second Generation (METOP-SG) series of satellites and the geostationary series (METEOSAT, MSG, MTG)
- the multi-agency JASON series of satellites
- ESA/EU Copernicus Sentinel series of satellites which provide long term continuity of many measurements started under the ESA ERS-1, 2 and ENVISAT missions
- ESA's Earth Observation Envelope Programme (EOEP).

EUMETSAT's polar orbiting and geostationary programmes, the JASON programme and the Copernicus Sentinels are all designed to provide long term continuity of measurements, a key requirement for climate ECVs. ESA's EOEP programme provides one-off scientific missions, which have potential to contribute to ECVs but long term continuity is not assured.

In the past, the UK also provided instruments to international programmes. DECC (from 2008 to the end of the ENVISAT mission in 2012; and its predecessor departments) sponsored the Advanced Along Track Scanning Radiometer (AATSR) satellite instrument, which monitored sea surface temperature. It was launched in 2002 on ESA's ENVISAT satellite platform and continued to operate successfully until the end of the ENVISAT mission in 2012. The AATSR instrument extended the record of highly accurate sea surface temperature measurements obtained from its precursor instruments ATSR and ATSR-2, also funded and built in the UK, and launched in 1991 (ERS-1) and 1996 (ERS-2) respectively. While there has been a break in the series with the failure of ENVISAT, similar future European capabilities are planned with the expected launch of the Sea and Land Surface Temperature Radiometer instrument on the Copernicus Sentinel 3 platform in 2014, extending the series of highly accurate SST to 2022.

The UK also funded, designed and built the first Geostationary Earth Radiation Budget (GERB) instrument which measures solar reflected radiance and total reflected/emitted radiance. In all, a series of four GERB instruments on successive EUMETSAT geostationary satellites are planned providing a 20 year time series from 2002 to 2022.

In addition to European satellite missions and instruments, the UK is involved in European programmes which develop ECVs, from satellite data, notably at present:

- the UK Met Office contributes to EUMETSAT's Climate Monitoring Satellite Application Facility (CM-SAF). The CM SAF generates and archives datasets for specific climate application areas, derived primarily from EUMETSAT satellite data and also from US meteorological missions.

The UK contributes to the ESA Climate Change Initiative. It is the second largest contributor to the programme and leads ECV production activities in sea surface temperature and ocean colour. UK Met Office also leads the user group for the programme. An overview of UK involvement in summarised in Table 11.

Table 11: UK participation in the ESA CCI programme

ECV	UK groups leading/participating
Aerosol	University of Oxford, Swansea University, Rutherford Appleton Laboratory
Cloud	University of Oxford, Rutherford Appleton Laboratory
Fire	University of Leicester
GHG	University of Leicester
Glaciers	Universities of Leeds, University of Bristol
Ice sheets	Universities of Leeds
Land cover	Met Office, Hadley Centre
Ocean colour	Plymouth Marine Laboratory (lead), University of East Anglia, Telespazio-Vega
Ozone	University of Cambridge, Rutherford Appleton Laboratory
Sea ice	UCL, University of Cambridge, CGI (formerly Logica)
Sea level	CGI (formerly Logica)
Soil moisture	-

Sea surface temperature	University of Edinburgh, Reading (lead), University of Leicester Met Office, Space Connexions
User group	Met Office (lead)

ESA sponsors other relevant research, eg through its Data User Element (DUE) programme[37] and the Support to Science Element (STSE) programme[38] which develop global data sets (eg the DUE GLOB series of projects). Although not officially designated 'ECVs' many of the activities are relevant to ECV production. A summary of current and recent projects relevant to ECV production with UK participants is summarised in Table 12[39/40].

Table 12: Other ESA sponsored projects relevant to ECV production with UK participation

ESA project	Description	UK participation
GlobAerosol	Development of a satellite data processing system to generate a standard reference multi-year global aerosol product (GAP) over land and water.	Rutherford Appleton Laboratory, University of Oxford
GlobAlbedo	Developing and delivering a multi-annual global albedo dataset that has the potential to be sustained into the future using data from operational European satellites, such as the Copernicus Sentinels.	University College London, University of Swansea
GlobColour	Demonstrated the production of a merged data set from several different satellite data streams: MERIS, SeaWiFS and Aqua / MODIS. The objective was to combine these data streams in such a way that the output product is as far as possible independent of the input data source	University of Plymouth
GlobIce	To derive information data sets over sea ice, which will improve our understanding of the role of the Arctic in global climate.	University College London, Met Office, Planetary Visions
GlobVapour	To support user requirements for a long, homogenous time series of satellite borne global water vapour measurements.	Met Office
GlobWave	The objective of the GlobWave project is to improve the uptake of satellite-derived wind-wave and swell data by the scientific, operational and commercial user community.	CGI (formerly Logica), National Oceanography Centre, SatOC Ltd
OceanFlux GHG	To improve quantitative air-sea flux estimates of CO2 and other greenhouse gases using EO data in synergy in the Atlantic Ocean.	North Highland College, Plymouth Marine Laboratory, National Oceanography Centre
Alanis-Methane	To investigate the potential of EO data to reduce current uncertainties in methane emissions from boreal lakes and wetlands through the synergistic use of EO-based products in a coupled land surface-atmosphere model.	Centre for Ecology and Hydrology

The UK is also active in the development of the EU's Copernicus climate service[41]. An operational service is still being defined. UK is participating in a range of EU 7th Framework Programme projects aimed at developing climate services incorporating the use of satellite data.

Internationally, the UK participates in CEOS and GEO/GEOSS and leads the coordination of GHRSST (with UK funding from NERC[42].

[37] http://due.esrin.esa.int/

[38] http://due.esrin.esa.int/stse/

[39] http://due.esrin.esa.int/duedirectory2010.pdf provides a complete list of all DUE projects.

[40] http://due.esrin.esa.int/stse/files/document/STSE_report_121016.pdf provides a complete list of all STSE projects

[41] http://copernicus.eu/pages-principales/services/climate-change/

[42] https://www.ghrsst.org/contact/ghrsst-project-office-contacts/

National activities also include:

- development and use of ECVs within NERC's NCEO[43], including activities which span most of the satellite related ECVs (Table 13). There is close collaboration with the ESA CCI programme.
- activities within other NERC Centres, eg CEH produce daily and monthly burnt area of the boreal forests based on MODIS-based circumpolar data (2001 onwards)[44].
- funding for national infrastructure to develop and archive ECVs through NERC's (Climate and Environmental Monitoring from Space (CEMS)[45] facility located at Rutherford Appleton Laboratory and closely associated with the new Satellite Applications Catapult. CEMS is currently undergoing a major development with funding from NERC, via its 'Big Data' initiative[46].

The UK Space Innovation and Growth Strategy highlights opportunities for development of climate and other services using satellite data. Recommendation 6 reads:

> *'Take a leadership role in climate-change monitoring, mitigation and agreement verification'.*[47]

In addition the UK, primarily through the National Physical Laboratory (NPL), has a leading role in standards and techniques for pre- and post-launch calibration and validation to ensure that satellite datasets are consistent and reliable. NPL leads a European Commission funded project to establish a 'European Meteorology Centre for Earth Observation and Climate'[48]. This is one of a number of projects within NPL's Centre for Carbon Measurement, which also includes participating in work led by the World Meteorological Organisation to look at the role of Meteorology in Environmental Monitoring. Topics covered range from global monitoring of gases to satellite monitoring of land and ocean temperature.

[43] http://www.nceo.ac.uk/

[44] http://www.ceh.ac.uk/staffwebpages/drfrancegerard.html

[45] http://www.stfc.ac.uk/e-Science/38663.aspx and http://sa.catapult.org.uk/cems/climate-and-environmental-monitoring-from-space/

[46] http://www.nerc.ac.uk/research/capability/environmental.asp

[47] 'Space Innovation and Growth Strategy – Leadership in Climate Technologies and Services', Executive Summary

[48] http://www.emceoc.org/

Table 13: NCEO funded institutions carrying out work related to satellite ECVs

Satellite related ECV	NCEO funded institution
Atmosphere: surface air	
Surface Precipitation	University of Reading, Centre for Ecology and Hydrology
Surface Radiation Budget	Imperial College London
Near-Surface Wind Speed and Direction	National Oceanography Centre, University of Southampton
Atmosphere: upper air	
Cloud Properties	University of Oxford, Rutherford Appleton Laboratory, University of Reading
Earth Radiation Budget (including Solar Irradiance)	Imperial College London, University of Reading
Temperature	University of Leicester
Water Vapour	University of Leicester
Wind Speed and Direction	
Atmospheric composition	
Aerosols Properties	University of Oxford, Rutherford Appleton Laboratory
Carbon Dioxide	University of Edinburgh, University of Leicester
Methane and other Long-Lived Green House Gases	Rutherford Appleton Laboratory, University of Leicester, University of Edinburgh, University of Leeds, Centre for Ecology and Hydrology
Ozone	Rutherford Appleton Laboratory, University of Leeds
Precursors (supporting Aerosols and Ozone ECVs)	Rutherford Appleton Laboratory, University of Leicester
Oceanic: surface	
Ocean Color	Plymouth Marine Laboratory
Sea Ice	University College London
Sea Level	National Oceanography Centre
Sea State	
Sea Surface Salinity	National Oceanography Centre
Sea Surface Temperature	University of Edinburgh, University of Reading, University of Southampton
Terrestrial	
Lakes	-
Snow Cover	University of Reading
Glacier and Ice Caps	University of Leeds, University of Bristol
Albedo	University of Swansea
Land Cover (including Vegn Type)	-
Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	University of Swansea, University College London
Leaf Area Index (LAI)	University of Swansea, University College London
Above Ground Biomass	University of Sheffield, University College London, University of Edinburgh
Fire Disturbance	Kings College London, University College London
Soil Moisture	
Ice Sheets	University of Leeds
Land surface temperature	University of Leicester, Centre for Ecology and Hydrology

5 GAPs analysis

Key Findings: GAPS analysis of UK funded *in situ* observations

KF10. Activities acquiring relevant data exist for almost all GCOS ECVs, either via the GCOS networks or via activities supporting other actions in the GIP.

KF11. There is quite a large number of marine monitoring activities that the UKEOF need to engage with that are known to be relevant to GCOS activity or may have potential to be.

KF12. Information on the extent to which stations operate in accordance with GCMPs will need to be obtained to provide an update on the situation since the 5th National Reporting.

KF13. There is a need to address omissions in the UKEOF Catalogue and improve the way information is recorded so that the Catalogue can better support National Reporting. Recommendations have been made to achieve this.

Key Findings: UK funded satellite observations

KF14. Long term funding for some key measurements is not secure.

KF15. A key problem is how to find mechanisms to support programmes emerging from R&D activities now requiring operational / long-term solutions. This is equally a challenge for international partners and leads to a situation that threatens the continuity of capability that has been developed, demonstrated to be operationally viable and in some cases vital to sustain climate data records.

KF16. Continuity of the JASON class of altimeters (to measure sea level in particular) is a key concern. Other examples where the transition from R&D to operations will need to be considered include: surface salinity (ESA SMOS follow-on needed), wind profiles (ESA ADM-Aeolus successor), earth radiation budget and carbon dioxide (no agreed plans for a European measurement system, although CarbonSat is a candidate ESA mission).

5.1 Purpose of the GAPs analysis

The GAPs analysis sought to:

- establish what is known about UK funded contributions to GCOS observing networks
- identify gaps in our knowledge about UK climate-related observing relevant to GCOS ECVs
- identify gaps in the information held in the UKEOF catalogue.

It did not seek to identify capability gaps in global observing systems.

5.2 Approach for *in situ* observations

It was agreed with the project Steering Group that a relatively high level assessment of gaps would meet the project needs. The analysis addresses:

- Are UK funded *in situ* observations measuring ECVs?
- If so, are the activities contributing ECV data to 'well-established' GCOS networks (Group 1) or are they known to be contributing to delivery of other actions in the GIP (Group 2)?
- Are there likely to be other activities measuring ECVs that UKEOF should be engaging with and might they address any gaps identified?
- Do activities (that could potentially address identified gaps) meet GCOS observing standards?

5.2.1 Future analysis

In future the GAPs analysis for *in situ* monitoring could be extended to include:

- are measurements of sufficient quality and duration to provide high quality ECVs? (*based on surface based capability assessment due to be published on OSCAR in 2014*)

- are programmes and initiatives in place to support the development of *in situ* monitoring in support of the ECVs?

5.3 Findings of the GAPs analysis for *in situ* observations

Twenty-four *in situ* activities[49] that responded to the consultation operate stations that contribute data to 26 GCOS networks. An initial analysis of the ECVs these activities are contributing to via the GCOS networks is provided in Appendix 5.

5.3.1 Atmospheric ECVs

Are UK funded in situ *observations measuring the atmospheric ECVs?*

Yes, the results of the consultation show that UK funded activities are acquiring observations of relevance to:

- all atmospheric ECVs (Table 5).

Are the activities contributing ECV data to 'well-established' GCOS networks or are they known to be contributing to delivery of other actions in the GIP?

Yes, activities in 'well-established' GCOS networks (Group 1), where the UK has formally accepted responsibility to provide a contribution to GCOS, are collecting observation data relevant to all of the atmospheric ECVs.

In addition, 13 activities in Group 2 are also collecting observation data relevant to the atmospheric ECVs. This group of activities has already been identified as contributing to the actions of the GIP, or as having potential to do so. Of these, five are identified through the consultation as '*a recognised activity contributing to ECVs through GCOS*' or with '*acquisition of observations of ECVs that are highly relevant to the GIP'*.

It should be noted that the Earth Radiation Budget ECV is derived from satellite data. Solar irradiance is an input. *In situ* measurement of solar irradiance is taken by four activities (see Table 5); two in Group 1 and two in Group 2. It is not known whether these observations are contributed to GCOS to be used for this purpose.

Are there likely to be other activities measuring ECVs (GCOS and non-GCOS) that UKEOF should be engaging with and might they address any gaps identified?

The consultation identified a further nine activities making observations of the atmosphere.

Three activities included in the consultation are not represented in the Catalogue and should be contacted for inclusion:

- Wytham Wood Sun Photometer
- Weybourne Atmospheric Observatory
- Cape Verde Atmospheric Observatory.

In addition, there is the need to better represent the full range of contributing stations of the Deriving Emissions linked to Climate Change (DECC) Network'.

5.3.2 Oceanic ECVs

Are UK funded in situ *observations measuring the oceanic ECVs?*

Yes, the results of the consultation show that UK funded activities are acquiring observations of relevance to:

- all oceanic ECVs, with the exception of 'tracers' (Table 5).

[49] This excludes one satellite monitoring activity.

If so, are the activities contributing ECV data to 'well-established' GCOS networks or are they known to be contributing to delivery of other actions in the GIP?

Activities that contribute observational data to 'well-established' GCOS networks (Group 1) are collecting measurements relevant to:

- all oceanic ECVs, with the exception of 'ocean acidity', 'ocean colour', 'carbon' and 'tracers' . (Table 6).

In addition, ten activities in Group 2 (Table 6) also collect observational data relevant to the oceanic ECVs. Many of these acquire biogeochemical observations, which means that they are collecting measurements of relevance to all oceanic ECVs, with the exception of tracers.

Most of these activities are part of GOOS Ocean Watch international collaborative research programmes[50] and six are identified through the consultation as '*a recognised activity contributing to ECVs through GCOS*' or with '*acquisition of observations of ECVs that are highly relevant to the GIP.'*

No monitoring activities consulted during the study reported collecting data on tracers. There is no specific GCOS baseline network for tracers. The primary network contributing to sub-surface tracers is the Global Ocean Ship-based Hydrographic Investigations Program, complemented by research observations. With technology development, some tracers are expected to be observable from the time series reference moorings within the decade.[51]

Are there likely to be other activities measuring ECVs that UKEOF should be engaging with and might they address any gaps identified?

The other four activities in Group 2, which have been identified as having potential for contributing to the actions in the GIP (UKEOF, 2011, Whitelaw *et al.,* 2008) and with which the UKEOF should be engaging are:

- Oceanographic/Biological Monitoring - Rothera Oceanographic and Biological Time Series (BAS LTMS)
- Ocean Acidification monitoring
- Oceanographic Monitoring - CTD stations (BAS LTMS)
- Water Framework Directive Monitoring Overview.

In addition to the activities in Group 2, there is one activity in Group 3 (Table 6) that the UKEOF should be engaging with as it collects a range of ECV data: North Sea quarter 3 International Bottom Trawl Groundfish Survey. There are a range of similar surveys listed in the Catalogue.

A number of marine monitoring activities did not respond to the consultation but are represented on the UKEOF Catalogue. These are known to collect data of relevance to the ECVs, with one collecting measurements of phytoplankton. In addition two activities identified by the consultation are not represented in the UKEOF Catalogue:

- Drake Passage Ocean Flow measurements
- Ellett line and extended Ellet line oceanographic section (responded to consultation but not in Catalogue)
- Irish Sea Observatory (phytoplankton)
- National Tide and Sea Level Facility
- Ocean Acidification Monitoring (responded to consultation but not in Catalogue)
- West Atlantic Variability Experiment Sensor Array
- WaveNET
- WebMET.

Other activities that are not represented in the Catalogue and which it may be relevant for UKEOF to engage with (source: Ocean Watch[52]) are:

- Scottish West Coast Observatory
- Arctic Shelf Time Series

[50] http://noc.ac.uk/ocean-watch/why-we-need-sustained-observations
[51] http://gosic.org/content/gcos-oceanic-sub-surface-ecv-tracers
[52] http://noc.ac.uk/ocean-watch/why-we-need-sustained-observations

- Ships of Opportunity Programmes (Ferrybox, SNOMS, Sea surface flux climatology)
- The Western Core Box (BAS).

5.3.3 Terrestrial ECVs

Are UK funded in situ observations measuring the terrestrial ECVs?

The responses to the consultation identified 14 UK funded activities acquiring observations of relevance to 10 of 16 terrestrial ECVs (Table 5). There were no reported observations for the following ECVs:

- glacier and ice caps, FAPAR, LAI and fire disturbance.

It should be noted that satellite derived observations are the primary source for these four ECVs (Table 10).

The UK does not have locations with year round permafrost.

If so, are the activities contributing ECV data to 'well-established' GCOS networks or are they known to be contributing to delivery of other actions in the GIP?

Terrestrial monitoring activities contribute observational data to 'well-established' GCOS networks for the 'river discharge' and 'snow cover' ECVs.

For the 'water use' ECV, UK information derived from Defra and Cranfield University data/statistics is available in the Aquastat database (UKEOF, 2011).

Are there likely to be other activities measuring ECVs that UKEOF should be engaging with and might they address any gaps identified?

Many terrestrial ECVs are at an early stage of development and there are relatively few 'well-established' GCOS networks in place[53]. There is recognition of the importance of developing capabilities for observing and delivering 'integrated' terrestrial ECV information products that are derived from a combination of *in situ* and satellite data (GTOS, 2010). There is also recognition of the importance of taking co-located *in situ* measures.

UK funded monitoring activities identified as relevant to the actions in the GIP (UKEOF, 2011) are shown in Table 14 and demonstrate that the UK is funding a wide range of monitoring and other activity of relevance, or potential relevance to these ECVs. All of these activities were included in the consultation, though responses were not received from some (Table 14).

Other terrestrial activities that are not represented in the Catalogue and which it may be relevant for UKEOF to engage with are:

- FLUXNET (only Harwood Forest Site is represented in the Catalogue).

[53] http://www.wmo.int/pages/prog/gcos/index.php?name=ObservingSystemsandData#terrestrial

Table 14: UK funded terrestrial *in situ* monitoring activities in the study that acquire data of relevance, or potential relevance to the GAPs identified for terrestrial ECVs

ECV	GCOS network in place	Which activities identified by the study are collecting relevant observational data?	References to these monitoring activities in the UKEOF/DECC consultation 2011 (draft) and associated action in the GIP
Ground water	GTN-H	Water Framework Directive Overview (UK) National Hydrometric Networks	Reference to the National Groundwater Level Archive (GIP - ACTION T11)
Lakes	GTN-L & GTN-H	UK Acid Waters Monitoring Network UK AWMN (to become the UK Upland Waters Monitoring Network) Water Framework Directive Overview (UK) Cumbrian Lakes (no information supplied to study)	All three of these monitoring activities are named and recognised for their potential to contribute to this ECV. 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. (GIP- ACTION T8)
Glacier and ice caps	GTN-G		Reference to BAS monitoring of glaciers in British Antarctic Territory (GIP - ACTION T17)
Ice sheets	GTN-G	Cryospheric Monitoring - Isostatic rebound (BAS LTMS)	Reference to BAS ice sheet measurements Currently these data are collected as part of internal BAS programmes. (GIP - ACTION T18)
Albedo		Environmental Change Network Environmental Change Biodiversity Network / LTMN Flux tower at Harwood Forest (FLUXNET) – (no information supplied to consultation)	Reference made to use of *in situ* sources for satellite validations (Baseline Surface Radiation Network) and FLUXNET sites (to which the UK has 14 contributory sites). (GIP - ACTION T24)
Land cover		Environmental Change Network Environmental Change Biodiversity Network / LTMN	References to the CEH Land Cover Map and the assessment of its accuracy through other means (GIP – ACTIONS: T26, T27 & T28)
FAPAR		None	Reference to a calibration /validation network. Forest Research are mentioned but no specific activity identified. GIP - ACTION T29)
LAI		None	ACTION T29: In reference to a calibration /validation network FLUXNET is referred to.
Above ground biomass		ICP Forests - Chemical Parameters; Plants; Habitats	ACTION T32: In reference to 'demonstration datasets a Forestry Commission / Forest Research forest database is identified.
Fire disturbance		None	
Soil moisture	GTN-SM being developed	ICP Forests - Chemical Parameters; Plants; Habitats Environmental Change Network (ECN) Environmental Change Biodiversity Network / LTMN	ACTION T14: Environmental Change Network (ECN) and Environmental Change Biodiversity Network / LTMN identified as potential *in situ* sources with recognition that there are many other sources but no coordinated assessment of what these are.
Soil carbon		Environmental Change Network Environmental Change Biodiversity Network / LTMN EMEP supersites (Mace Head / Auchencorth / Harwell?) ICP Forests - Chemical Parameters; Plants; Habitats (3 sites contribute to FLUXNET)	ACTION T33: Gridded database of soil carbon measurements - Environmental Change Network identified. ACTION T34: Gridded estimates of terrestrial carbon flux - wide range of *in situ* monitoring identified incl. 'sites run by Forest Research.' Also refers to are 12 Flux sites, Mace Head.

5.3.4 Are measurements of sufficient quality and duration to provide high quality data relevant to ECVs?

It is not possible to address this question fully with the information available from the consultation, to do so would require a fuller set of up to date information on compliance with the GCMPs for activities in Group 1. The last round of reporting for the 5th National Communication to the UNFCCC (Whitelaw *et al.*, 2008) reported high levels of compliance with the GCMPs for UK funded contributions with:

- all stations reported as 'operating in accordance with the GCMPs' for the well-established GCOS networks in the atmospheric composition (four networks), upper-air (two networks) and terrestrial (two networks) domains[54]
- all stations reported as 'operating in accordance with the GCMPs' for three well-established GCOS networks for surface-based atmospheric ECVs and stations in a further three well-established GCOS networks reporting partial compliance
- all stations reported as 'operating in accordance with the GCMPs' for three GCOS well-established networks for oceanic ECVs and 250 (of 300 stations) 'operating in accordance with the GCMPs' for the other well-established GCOS network.

Similar data will be collated for the 6th National Communication to the UNFCCC in 2014, with similarly high levels of compliance expected.

The consultation found that a very high proportion of the monitoring activities consulted (ie including activities in Group 2 and Group 3) have taken into account many or all of the considerations described in the GCMPs and have in place the type of protocols and standards required as a pre-requisite to developing a climate observing capability.

5.4 Findings of the GAPS analysis for climate observations from satellites

As noted in Section 4.2, the UK's main contributions to climate observations from satellites are as a result of international collaborations, particularly in Europe through EUMETSAT, ESA and the EU. The assessment of gaps has therefore been on the basis of:

1. Are European satellites measuring ECVs?
2. If so, are measurements of sufficient quality and duration to provide high quality ECVs?
3. Are programmes in place to turn the raw satellite datasets into climate quality datasets?
4. If there are gaps in European measurements (quality and/or duration) are there activities elsewhere in the world which fill the gaps?

Appendix 6 shows the basis for the analysis of points 1 to 3:

- Those satellite series with a grey background (EUMETSAT systems, the multi-agency JASON series, Copernicus Sentinels) have good long term continuity, although for later missions such as JASON-CS or the instrument suite on METOP-SG there is still some uncertainty, eg regarding funding and/or priorities, which may mean the situation changes.
- Those satellites with a white background are one-off ESA EOEP missions. Some have counterparts in other agencies. The measurements are of good quality but the duration of currently planned measurements is a concern.
- The **quality** of the measurements from each instrument with respect to the variable of interest is based on the assessment in the WMO OSCAR database (Dark green – primary: light green- high, yellow - medium, orange - useful, red –marginal). The table shows a very wide variation in the number of EUMETSAT, ESA and EU instruments contributing to a particular variable and the quality of measurements. The complex relationships

[54] For those networks that the UK contributes to.

between instruments and ECVs means it is difficult to be precise regarding the quality of ECVs which might be derived from a particular instrument combination.

- Appendix 6 also notes which agencies are involved in the production of ECV datasets (information taken from the CEOS ECV Inventory and the ESA CCI programme web site).

With respect to point 4 above, a detailed analysis of the current situation with satellite data has been published by GCOS in the '*Systematic Observation Requirements for Satellite-Based Data Products For Climate 2011 Update Supplemental details to the satellite-based component of the 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)'*[55].

A further factor, given the wide range of satellite measuring systems and programmes developing ECVs, is prioritisation. As noted in the Met Office analysis in Appendix 3, the UK does not have clear Departmental responsibilities identified for the funding of climate observations. Instead responses to date have depended on difficult and time consuming cross-Departmental discussions. This is particularly difficult for satellite observations where decision-making also depends on international partners, and programmes take many years from concept to deployment. There has been no attempt to prioritise ECVs (ie say some are more important than others) as this would require a more complete analysis of UK stakeholders than has been possible during this short study. It can be noted that with respect to ECVs with a major satellite contribution, the DECC EO Strategy[56] particularly singles out precipitation, sea surface temperature and sea level as being important for the future development of the Met Office Hadley Centre Climate programme.

Table 15 looks at each satellite-based ECV with UK involvement in turn and summarises information from the 2010/11 GCOS update (GCOS, 2010a) and Appendices 3 and 6, highlighting European programmes to which the UK makes contributions (for example via funding for building instruments). Where there are specific links to the GIP these are noted. The contributions described in Table 15 comprise the European space missions to which the UK contributes financially and a range of other 'in-kind' contributions such as scientific expertise. A common requirement for nearly all ECVs is a better link between satellite and non-satellite measurements. This is noted here but has not been included in Table 1.

Table 15 shows that long term funding for some key measurements is not secure. A key problem is to find mechanisms to support programmes emerging from R&D activities now requiring operational / long-term solutions. This is equally a challenge for international partners and leads to a situation that threatens the continuity of capability that has been developed, demonstrated to be operationally viable and in some cases vital to sustain climate data records. Continuity of the JASON class of altimeters (to measure sea level in particular) is a key concern. Other examples where the transition from R&D to operations will need to be considered include: surface salinity (ESA SMOS follow-on needed), wind profiles (ESA ADM-Aeolus successor), Earth radiation budget, carbon dioxide (no agreed plans for a European measurement system, although CarbonSat is a candidate ESA mission).

[55] December 2011, GCOS – 154, http://www.wmo.int/pages/prog/gcos/Publications/gcos-154.pdf

[56] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48428/5592-decc-earth-observation-strategy.pdf

Table 15: Summary assessment of the contribution of satellites with UK involvement to ECVs

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
ATMOSPHERIC (over Land, Sea & Ice)			
Surface			
Surface Precipitation	**EUMETSAT**, NASA, JPL, JAXA	Estimates of liquid and solid precipitation are derived from numerous instruments and provided by composite products. Currently mainly rely on passive microwave radiances. Specialist missions such as GPM will develop capabilities Current products are not yet adequate for monitoring climate change, as demonstrated by differences in time series from different products and from discontinuities in single products. A combination of microwave radiances and precipitation radar with geostationary imagers is needed to obtain an hourly product.	European capability will be improved if EUMETSAT METOP Second Generation B, Microwave Imager is chosen (from 2022) ESA EOEP EarthCARE also relevant. High level of UK scientific expertise, with UK science lead on EarthCARE mission but follow-on are not currently planned Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action A8] Ensure continuity of satellite precipitation products			
Surface Radiation Budget	**EUMETSAT,** NOAA	Broadband radiances Spectrally-resolved solar irradiances Geostationary multispectral imager radiances Capability based on geostationary and polar orbiting satellites. An updated and extended archive of Baseline Surface Radiation Network (BSRN) measurements is needed to support and supplement the satellite-based measurements, for example with spectral irradiance measurements at the surface Maintaining of high quality observations of clouds (with diurnal sampling), temperature and water vapour profiles, aerosols, trace gasses, and surface properties, required for surface ERB	Capability via EUMETSAT geostationary (METEOSAT, MSG, MTG) and polar orbiting programmes (METOP, METOP-SG).
Near-Surface Wind Speed and Direction	**EUMETSAT,** NASA, JAXA,	Measurements are made from space over oceans only. Main instruments scatterometers (speed and direction) and microwave imagers (speed)	European capability via EUMETSAT polar orbiting programmes (METOP, METOP-SG). Programmes provide important continuity of scatterometer data
Link to GIP [IP-10 Action A11] Ensure continuous generation of wind-related products from morning (AM) and afternoon (PM) satellite scatterometers or equivalent observations.			

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Upper-Air			
Cloud Properties	**ESA, EUMETSAT,** NOAA, NASA, JAXA	VIS/IR imager radiances IR and microwave radiances Lidar Wide variety of variables of interest including cloud amount, top pressure and temperature, optical depth, water path and effective particle radius Current products are adequate for the evaluation of climate models as well as for monitoring large- scale spatial structure and regional variability such as El Nino Southern Oscillation (ENSO); Current products are not adequate for monitoring climate change because the existing observing system lacks homogeneity (eg orbital drift, change in channel spectral response)	UK contributes via EUMETSAT geostationary (METEOSAT, MSG, MTG) and polar orbiting programmes (METOP, METOP-SG). ESA EOEP EarthCARE mission will enhance capabilities but long term continuity is not assured. High level of UK scientific expertise, with UK science lead on EarthCare mission and contribution to ESA CCI programme
Link to GIP [IP-10 Action A23] Continue the climate data record of visible and infrared radiances, for example from the International Satellite Cloud Climatology Project, and include additional data streams as they become available; pursue reprocessing as a continuous activity taking into account lessons learnt from preceding research; [IP-10 Action A24] Research to improve observations of the three-dimensional spatial and temporal distribution of cloud properties.			
Earth Radiation Budget (including Solar Irradiance)	**EUMETSAT,** NOAA	Broadband radiances Spectrally-resolved solar irradiances Geostationary multispectral imager radiances	Via EUMETSAT geostationary (METEOSAT, MSG, MTG) and polar orbiting programmes (METOP, METOP-SG) No plans for continuing GERB series of instruments (on MSG satellites) into MTG programme Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action A25] Ensure continuation of Earth Radiation Budget observations, with at least one dedicated satellite mission operating at any one time			

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Temperature	**EUMETSAT,** NOAA, NASA	Passive microwave and IR radiances GNSS radio occultation bending angles Very good continuity via meteorological agencies Accuracy and continuity are generally adequate for interannual climate variability; Work has started to put together GNSS-RO data as a climate-data record.	Main European capability via EUMETSAT polar orbiting programmes (METOP, METOP-SG) and geostationary MTG
Link to GIP [IP-10 Action A20] Ensure the continued derivation of MSU-like radiance data and establish FCDRs from the high-resolution IR sounders in accordance with the GCMPs; [IP-10 Action A21] Ensure the continuity of the constellation of GNSS RO satellites.			
Water Vapour	**EUMETSAT,** NASA, NOAA, JAXA, JMA,	Passive microwave radiances UV/VIS imager radiances IR and microwave radiances Limb soundings Total column-water vapour over oceans from US SSM/I is well established, and different datasets have systematic global mean differences of less than 0.5 kg/m2 HIRS, Meteosat and AMSU-B/MHS, products are used for model validation, climate variability analysis and trend identification Stratospheric water-vapour measurements are available only from research instruments.	European capability mainly via EUMETSAT polar orbiting programmes (METOP, METOP-SG) and geostationary (MSG, MTG)
Link to GIP [IP-10 Action A8] Ensure continuity of satellite precipitation products; [IP-10 Action A26] Establish long-term limb-scanning satellite measurements of profiles of water vapour, ozone and other important species from the UT/LS up to 50km			
Wind Speed and Direction	**EUMETSAT,** JMA	VIS/IR imager radiances Doppler wind lidar VIS/IR imager radiances from geostationary satellites, are used to measure Atmospheric Motion Vectors (AMVs) derived from successive images Similar processing for VIS/IR imager radiances from polar orbiters with overlapping successive orbits Demonstration data records will be available from the wind lidar ESA ADM-Aeolus mission	European capability mainly via EUMETSAT geostationary (METEOSAT, MSG, MTG) ESA EOEP ADM/Aeolus will demonstrate wind lidar but at present long term continuity not assured

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Composition			
Aerosols Properties	**ESA, EUMETSAT**, NOAA, NASA, CSA, JAXA	UV/VIS/NIR/SWIR and TIR radiance UV/VIS/IR limb sounding (scatter, emission, occultation) Lidar profiling Complex set of requirements with contributing instruments from many agencies. Space agencies have on-going projects to produce improved consistent datasets from several instruments; there is a lack of integrated products	EUMETSAT missions, Sentinels 3, 4, 5P, 5, and ESA EOEP EarthCARE and ADM/Aeolus missions all contribute Related research sponsored through NERC NCEO and contribution to ESA CCI programme
Link to GIP [IP-10 Action A33] Develop and implement a coordinated strategy to monitor and analyse the distribution of aerosols and aerosol properties; the strategy should address the definition of a GCOS baseline network or networks for *in situ* measurements, assess the needs and capabilities for operational and research satellite missions for the next two decades, and propose arrangements for coordinated mission planning.			
Carbon Dioxide	**ESA**	NIR/IR radiances Production of ECVs still at early stages of development Research needed towards improved future capabilities Long term satellite measurement systems not secure	Quality of measurements would be enhanced if ESA candidate mission CarbonSat was chosen Related research sponsored through NERC NCEO and contribution to ESA CCI programme
Link to GIP [IP-10 Action A29] Assess the value of the data provided by current space-based measurements of CO2 and CH4 and develop and implement proposals for follow-on missions accordingly.			
Methane and other Long-Lived Green House Gases	**ESA,** CSA (CH4)	NIR/IR radiances Satellite products are still under development, and accuracy requirements have not yet been met (except for CH4 total column) Research needed towards improved future capabilities	Some capability on EUMETSAT polar orbiters. Sentinel-5P and Sentinel-5 will improve monitoring Related research sponsored through NERC NCEO and contribution to ESA CCI programme
Link to GIP [IP-10 Action A29] Assess the value of the data provided by current space-based measurements of CO2 and CH4 and develop and implement proposals for follow-on missions accordingly.			
Ozone	**ESA,** NASA, CNES, CSA	UV/VIS and IR/microwave radiances, from nadir and limb sounding	Good continuity of measurements through EUMETSAT METOP, METOP-SG and Sentinels 4, 5P, 5

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Link to GIP [IP-10 Action A26] Establish long-term limb-scanning satellite measurement of profiles of water vapour, ozone and other important species from the UT/LS up to 50km; [IP-10 Action A32] Continue production of satellite ozone data records (column, tropospheric ozone and ozone profiles) suitable for studies of interannual variability and trend analysis; reconcile residual differences between ozone datasets produced by different satellite systems.		Total column measurements provide a largely adequate data record of gross change and fluctuations; Vertical profile information from present instruments is most often of limited vertical resolution and/or low accuracy in the lower stratosphere and troposphere; Planned missions will ensure the continuity of the total ozone, but the continuity of limb viewing and occultation missions is not guaranteed; Space agencies have on-going projects to create homogenous data records of total ozone, low-resolution ozone profiles and high-resolution ozone profiles, by combining several instruments; There is a need for more routine ozone sonde ascents to support calibration and validation.	Related research sponsored through NERC NCEO and contribution to ESA CCI programme
Precursors (supporting Aerosols and Ozone ECVs)	CNES (CO)	UV/VIS/NIR/SWIR and TIR radiances UV/VIS/IR limb sounding (scatter, emission, occultation) Long term datasets at early stages of development.	Good continuity of measurements through EUMETSAT METOP, METOP-SG and Sentinels 4, 5P, 5 Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action A34] Ensure continuity of products based on space-based measurement of the precursors (NO2, SO2, HCHO and CO, in particular) of ozone and aerosols and derive consistent emission databases, seeking to improve temporal and spatial resolution			
OCEANIC			
Surface Ocean			
Ocean Colour	**ESA,** NASA, JAXA	Multispectral VIS imager radiances Good international coordination via International Ocean Colour Coordinating Group and good continuity of measurements. Need to revisit of instrument calibration for historical OC sensors to improve consistency.	Good continuity of measurements through Sentinel 3 High level of UK scientific expertise, with UK lead on ESA ocean colour ECV development Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action O15] Implement continuity of ocean colour radiance datasets through the plan for an Ocean Colour Radiometry Virtual Constellation.			
Sea Ice	**ESA, EUMETSAT**, NOAA, NASA, JAXA	Passive and active microwave and visible imager radiances, supported by Synthetic Aperture Radar (SAR)	EUMETSAT missions, Sentinels 1, 2, 3, and ESA EOEP Cryosat and EarthCARE all contribute

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Link to GIP [IP-10 Action O19] Ensure sustained satellite-based (microwave, SAR, visible and IR) sea-ice products; • [IP-10 Action O20] Document the status of global sea-ice analysis and reanalysis product uncertainty and prepare a plan to improve the products.		Altimetry The existing 30+-year data record of passive microwave instruments is a unique opportunity to derive uniform information on sea-ice concentration, large-scale sea-ice motion, and sea-ice type. Several sea-ice concentration datasets span the whole data record as of today; Extensive satellite data exist from a variety of missions and are available but require further processing, homogenization and integrated analysis	High level of UK scientific expertise, with UK science lead on Cryosat mission Related research sponsored through NERC NCEO and contribution to ESA CCI programme
Sea Level	**ESA**, NASA	Satellite altimetry, supplemented with tide gauges, has proved adequate to revolutionize the view of global and regional sea-level variability and change. Current analysis efforts need to be maintained and strengthened; Reprocessing of data holdings for the coastal regions could greatly enhance the view of coastal sea-level variability	Significant European contribution through multi-agency JASON series of high precision altimeters. Long term continuity being discussed (JASON-CS) but funding not secure. European contribution to medium precision altimetry via Sentienl 3. Related research sponsored through NERC NCEO and contribution to ESA CCI programme
Link to GIP [IP-10 Action O10] Ensure continuous coverage from one higher-precision, medium-inclination altimeter and two medium-precision, higher-inclination altimeters			
Sea State		Altimetry, SAR GCOS identifies immediate action needed reprocessing and promotion of use of existing sea-state data records, such as from ERS, Envisat and Jason; The altimeters on board of past, present and planned missions only provide the significant wave height and wave period, and coverage is limited relative to synoptic scales of variability; Synthetic Aperture Radars (SARs) estimate the spectral properties of the ocean waves and have been flying since 1981; however, SAR has the disadvantage of a strongly distorted image spectrum, caused by the motion of the ocean surface, thereby resulting in a minimum detectable wavelength of about 150-200m; in addition, exchange of SAR data has been limited; Sea-state data records exist from many altimeter and SAR instruments, but homogenization is needed if data records from different instruments are to be used together. Efforts needed to make comprehensive use of planned altimeter- and SAR-bearing satellites in order to ensure the continuity of the existing sea-state information and to build on the existing altimeter and SAR-based decade-long satellite data records; •	Significant European contribution through multi-agency JASON series of high precision altimeters. Long term continuity being discussed (JASON-CS) but funding not secure. European contribution to medium precision altimetry via Sentinel 3. Sentinel 1 (SAR) also contributes
Sea Surface Salinity		Microwave radiances Only two missions, both short term, currently provide measurements: SMOS (ESA) and Aquarius (NASA/CONAE)	European contribution via ESA SMOS but long term measurements not secure Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action O12]			

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Research programmes should investigate the feasibility of utilizing satellite data to help resolve global fields of SSS.			
Sea Surface Temperature	**ESA,** NOAA, NASA, JAXA	Single and multi-view IR and microwave imager radiances SST data holdings are extensive and widely used with coordination through GHRSST. Further reprocessing is required to address known problems such as regional biases, cloud, rain, side-lobe and aerosol contamination, and consistently analysed geostationary and polar-orbiting data to resolve the diurnal cycle.	Very significant UK contribution through the development of the (A)ATSR class of instruments (multi-view IR). Continuity of instrument type assured through Sentinel 3. EUMETSAT polar and geostationary instruments also contribute significantly. High level of UK scientific expertise, with UK lead on ESA sea surface temperature ECV development Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action O4] Ensure coordination of contributions to CEOS Virtual Constellations for each ocean surface ECV in relation to *in situ* ocean observing systems; [IP-10 Action O7] Continue the provision of best possible SST fields based on a continuous coverage- mix of polar-orbiting IR and geostationary IR measurements, combined with passive microwave coverage and appropriate linkage with the comprehensive *in situ* networks.			
TERRESTRIAL			
Lakes	NASA	VIS/NIR imager radiances, and radar imager radiances Altimetry Lake levels and areas of lakes in the Global Terrestrial Network for Lakes (GTN-L) Current data holdings fragmented	In principle many imagers and altimetry contribute. UK lead on one key data set: River & Lake (De Montfort University, UK/ESA) although this is not formally part of ESA CCI programme
Link to GIP [IP-10 Action T8] Submit weekly/monthly lake-level/area data to the International Data Centre; submit weekly/monthly altimeter-derived lake levels by space agencies to Hydrolare.			
Snow Cover	NASA, JAXA	Moderate-resolution VIS/NIR/IR and passive microwave imager radiances Snow areal extent, supplemented by snow water equivalent	EUMETSAT missions, Sentinels 1, 2, 3 all contribute Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action T16] Obtain integrated analyses of snow cover over both hemispheres.			
Glacier and Ice Caps	**ESA**, NASA	High-resolution VIS/NIR/SWIR optical imager radiances, supplemented by microwave InSAR and along-track optical stereo imaging 2D vector outlines of glaciers and ice caps (delineating glacier area), supplemented by digital elevation models	UK contribution via European Sentinel 1, 2, 3 and Cryosat missions Related research sponsored through NERC NCEO and contribution to ESA CCI programme
Albedo	**EUMETSAT,** EC, NASA	Multispectral and multiangular imager radiances	EUMETSAT missions contribute

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Link to GIP [IP-10 Action T24] Obtain, archive and make available *in situ* calibration/validation measurements and co-located albedo products from all space agencies generating such products; promote benchmarking activities to assess the quality and reliability of albedo products; [IP-10 Action T25] Implement globally coordinated and linked data processing to retrieve land-surface albedo from a range of sensors on a daily and global basis, using both archived and current Earth Observation systems;		Reflectance anisotropy (BRDF), black-sky and white-sky albedo Albedo products have been generated by major space agencies for over a decade and are routinely used in a range of applications; validation and satellite-product intercomparison efforts have been initiated.	Related research sponsored through NERC NCEO
Land Cover (including vegn Type)	**ESA,** NASA, JAXA	Moderate-resolution multispectral VIS/NIR imager radiances High-resolution multispectral VIS/NIR imager radiances, supplemented by radar Moderate-resolution maps of land-cover type High-resolution maps of land-cover type, for the detection of land-cover change An exact requirement for land cover is difficult to set, due to the complex relationship between the number and type of land-cover classes, and physical characteristics that might be consistently linked with these classes, such as roughness, albedo and primary production.	Sentinel 2. 3 provide the main European contributions. UK government has also contributed to the DMC constellation of satellites built by SSTL in the UK UK contributes to ESA CCI programme
Link to GIP [IP-10 Action T26] Produce reliable accepted methods for land-cover map accuracy assessment; [IP-10 Action T27] Generate annual products documenting global land-cover characteristics and dynamics at resolutions between 250m and 1km, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy; [IP-10 Action T28]: Generate maps documenting global land cover, based on continuous 10-30m land surface imagery every five years, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy.			
FAPAR	**EC, ESA,** NASA, JAXA	VIS/NIR multispectral imager radiances	Main contributing European satellites include METOP,

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
Link to GIP [IP-10 Action T31] Operationalize the generation of FAPAR and LAI products as gridded global products at spatial resolution of 2km or better over as lengthy time periods as possible;		Space agencies and other institutional providers generate various FAPAR products at different temporal and spatial resolutions over the globe. Over ten years of space-derived FAPAR products are now available from different sources, at spatial resolutions typically in the range of 1 to 2km and temporal resolutions, such as daily, weekly, every ten days or monthly. Comparing these products reveals discrepancies that are mainly due to differences between concepts and definitions, retrieval methodologies or input-data quality. Periodic satellite data re-processing exercises, to take advantage of new findings and especially improvements in instrument calibration, have improved the reliability and consistency of these products. T	METOP-SG, MTG series and Sentinel 3
Leaf Area Index (LAI)	**EC,** NASA, USGS, JAXA	VIS/NIR multispectral imager radiances Space Agencies and other institutional providers generate various LAI products at different temporal and spatial resolutions over the globe. Over ten years of space-derived LAI data are now available from different sources at spatial resolutions typically in the range of 1 to 2km and temporal resolutions such as daily, weekly, every ten days or monthly. Comparing these products reveals discrepancies that are mainly due to differences between concepts and definitions, retrieval methodologies or input data quality. Periodic satellite data re-processing exercises, to take advantage of new findings, especially advances in instrument calibration, have improved the reliability and consistency of these products;	Main contributing European satellites include METOP, METOP-SG, MTG series and Sentinel 2, 3
Link to GIP [IP-10 Action T29] Establish a calibration/validation network of *in situ* reference sites for FAPAR and LAI and conduct systematic, comprehensive evaluation campaigns to understand and resolve differences between the products and increase their accuracy; [IP-10 Action T30] Evaluate the various LAI satellite products and benchmark them against *in situ* measurements to arrive at an agreed operational product; [IP-10 Action T31] Operationalize the generation of FAPAR and LAI products as gridded global products at spatial resolution of 2km or better over as lengthy time periods as possible;			
Above Ground Biomass	NASA	Long-wavelength radar and lidar Regional maps have been generated, but most of them have not yet been subject to peer-review. There are large differences between different products, particularly over tropical regions.	ESA Biomass mission (from 2020) will enhance capabilities. Mission has a UK science lead but currently long term funding not secure Related research sponsored through NERC NCEO
Link to GIP [IP-10 Action T32] Develop demonstration datasets of above ground biomass across all biomes.			
Fire Disturbance	**EC, ESA,** NASA	VIS/NIR/SWIR/TIR moderate-resolution multispectral imager radiances Maps of burnt area, supplemented by active-fire maps and fire-radiative power Calibration, especially of the SWIR channel, is not good enough in most currently available	UK contributes via EUMETSAT geostationary (METEOSAT, MSG, MTG) and polar orbiting programmes (METOP, METOP-SG) and Sentinels 1, 2, 3
Link to GIP [IP-10 Action T35] Reanalyse the historical fire-disturbance satellite			

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
data (1982 to present); [IP-10 Action T36] Continue generation of consistent burnt area, active fire, and FRP products from low-orbit satellites, including version intercomparisons, to allow un-biased, long term record development; [IP-10 Action T37] Develop and apply validation protocol to fire-disturbance data; [IP-10 Action T38] Make gridded burnt area, active fire, and FRP products available through links from a single International data portal; [IP-10 Action T39] Develop set of active fire and FRP products from the global suite of operational geostationary satellites		global processed time series. Long time-series are needed to quantify the link between climate and burnt area. Standardization of product format, meta-data, and reporting of uncertainty is needed so that modellers can easily understand the structure of the product	Related research sponsored through NERC NCEO UK contributes to ESA CCI programme
Soil Moisture	**ESA,** NASA, JAXA	Active and passive microwave International cooperation is needed to improve understanding of the relative performance of different satellite instruments (frequency, active versus passive, sampling and radiometric accuracy) and retrieval approaches (empirical approaches, change detection, semi-empirical models and theoretical models); Even though the first soil moisture time series based on merging active and passive soil moisture datasets exist, research to blend surface soil moisture observations with satellite observations remains a key challenge.	ESA SMOS is main European contribution at present (long term continuity not assured) Continuity more certain with scatterometers on METOP series and Sentinel 1
[IP-10 Action T13] Develop a record of validated globally-gridded near-surface soil moisture from satellites;			
Ice Sheets	**ESA,** NASA	Radar and laser altimetry, supplemented by:SAR, gravity Ice-sheet elevation changes, supplemented by fields of ice velocity and ice-mass change	Main UK contribution via Sentinel 1, 2, 3 and Cryosat (UK science lead) Related research sponsored through NERC NCEO UK contributes to ESA CCI programme
Link to GIP [IP-10 Action T20] Ensure continuity of laser-, altimetry-and gravity-satellite missions, adequate to monitor ice masses over decadal timeframes			
Land surface temperature	**EUMETSAT,** NASA, JAXA	High-resolution IR radiances from geostationary and polar-orbiting satellites; Microwave radiances from polar-orbiting satellites Spatial resolution (1-2km) of most current and planned spaceborne sensors is more than	UK contributes via EUMETSAT geostationary (METEOSAT, MSG, MTG) and polar orbiting programmes (METOP, METOP-SG) and Sentinels 3
[IP-10 Action T 23] Implement operational mapping of seasonal soil			

ECV with significant space component	ECV datasets (responsible organisation)	Summary assessment	Comment on EUMETSAT, ESA and EU missions/ECV programmes to which UK contributes (current and future programmes)
freeze/thaw through an international initiative for monitoring seasonally-frozen ground in non-permafrost regions.		satisfactory for climate applications; Temporal resolution remains an issue, as surface temperature changes significantly over periods ranging from hours to years and beyond; geostationary satellites provide very adequate temporal resolution under clear conditions; obtaining the full diurnal cycle, which changes amplitude in cloudy conditions, requires combined infrared-microwave analysis. Global datasets based on AVHRR and the geostationary weather satellite radiometric data have been available since 1983; Global LST maps with an accuracy of 1ºK and emissivity maps with an accuracy of 0.005ºK will be available from MODIS and ASTER, and AATSR data are available for many surface types.	Historical data from (A)ATSR series very relevant. Related research sponsored through NERC NCEO

5.5 Gaps in information held in the UKEOF Catalogue

There were ten monitoring activities that did not provide responses to the survey questionnaire. This includes at least two that are thought to be contributing to GCOS networks in the oceanic domain. These two activities will need to be contacted for further information in preparation for the 6th National Reporting.

At the early stage of this project, 15 monitoring activities were identified for inclusion in the consultation that were not in the original list supplied (some of these were included in the Catalogue) and the project team was made aware of an additional two monitoring activities that were not included in the Catalogue during the consultation. Further activities of likely relevance to achieving the actions in the GIP have been identified during the study (eg section 5.3.2). Details of these have been provided to UKEOF.

This suggests that whilst this study (with the assistance of many in the environmental monitoring community) has improved UKEOF's knowledge of UK funded contributions to ECVs, there are still further activities with which UKEOF should be engaging and other potentially relevant monitoring which has been 'missed' by the study. A further systematic check of a recent consultation by UKEOF on behalf of DECC on the GIP (UKEOF, 2011) and of the report by Whitelaw *et al.* (2008) might identify further relevant observational activities.

5.5.1 Making the UKEOF catalogue more useful for responding to GCOS reporting

The project was tasked with making the UKEOF catalogue more useful for responding to GCOS reporting requirements (Table 16). The following actions are recommended:

Table 16: Recommendations for making the UKEOF catalogue more useful for responding to GCOS reporting requirements

Recommendations	Comments
1. Address omissions in the UKEOF Catalogue. Include all monitoring activities known to be contributing to the GCOS networks or the delivery of the GIP. Flag these as relevant to 'Climate and Risk Assessment'.	Requests have been made to respondents to the consultation to facilitate this and details of responses (all positive) will be passed to the UKEOF secretariat.
2. Flag all activities listed in Table 5 as either: a. 'contributing to GCOS networks' b. 'supporting the delivery of the implementation plan' c. 'other climate relevant monitoring assessed for relevance to ECVs' (this requires follow-on work to eliminate some uncertainty regarding the reporting status to GCOS of some activities).	a. GCOS networks being those published on the GCOS website. b. a code for the relevant 'action' (as provided in the Implementation Plan) could be added as could the network or initiative that the data contributes to (but this requires additional research / consultation with respondents to the consultation or other key players).
3. The following information could be added to the UKEOF Catalogue to provide evidence and an audit trail to support National Reporting: a. ECV name and code b. Relevant parameters observed for each ECV c. GCOS network that contributed to (and the ECVs) and number of contributing stations and year reported. d. Whether GCMPs are fully or partially met.	Not all these fields need to be visible publically. a. Suggest use GTOS alphanumeric codes for Terrestrial ECVs. The GCOS secretariat is not aware of codes in use for other ECVs but something similar would work. Consideration needs to be given to how these fields would be structured and inter-related. c. In some cases there might be merit in recording whether these are UK stations or overseas.
4. Update the UKEOF Catalogue with details of current contacts for monitoring activities. Ensure activity names are the same.	The project team has been advised changes in leadership. Details will be passed to UKEOF.
5. Consider restructuring how some activities are recorded? (either by grouping or disaggregation) to create new unique activities that reflect feedback from monitoring leads and some restructuring of existing entries on the UKEOF Catalogue (done with the agreement of monitoring leads and prior to the consultation). As	For example, The Met Office have high level programme descriptions in the UKEOF Catalogue in comparison with other organisations

Recommendations	Comments
an alternative perhaps use Catalogue IDs to maintain links between related observation activities (eg country contributions)	
6. Consider whether further guidance, requirements and/or vetting process should be put in place to ensure a more common level of granularity of the observation activities included in the UKEOF Catalogue.	See section 2.1.2. This would benefit strategic studies. At present the UKEOF Catalogue presents an essential resource for such studies but substantial time is spent dealing with overlap and duplication.

5.6 What other gaps are there in our knowledge about UK climate-related observing relevant to ECVs?

Whilst this study identified the range of parameters measured that are of the type required to support the GCOS ECVs, interpretation was required to identify how relevant these were to the particular GCOS networks, especially where a wide range of measurements are observed. There are also cases where more than one activity may be reporting a contribution (for example, if co-located meteorological measurements are reported through the consultation but also reported through an overarching atmospheric monitoring activity). It will be important to check tables compiled for the 6th National Communication with the appropriate specialists to ensure that they correctly represent the role of all observed data in the GCOS networks. Descriptions of the activities (Appendix 4) could also be checked at this time.

Information on the numbers of stations contributing to the GCOS networks and the extent to which these operate according to the GCMPs is incomplete and will require updating in advance of the 6th National Communication.

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Appendix 1: Survey Questionnaire

UK-Environmental Observation Framework (UK-EOF)

Co-ordinating climate science and risk assessment observations

Survey Questionnaire

Background

Climate-related observational data are collected through a wide range of monitoring programmes and activities, many of which form part of wider UK, regional or global data collection initiatives. These observational data underpin research and monitoring of the climate system. The LWEC partnership (www.lwec.org.uk/about) recognises the value of high quality observational data and, through the activities of the UK-EOF (www.ukeof.org.uk) is developing more strategic and co-ordinated approaches to the collection, management and sharing of this data, both nationally and internationally.

The Global Climate Observing System (GCOS) is an international undertaking to meet the need for comprehensive, continuous, reliable climate-related observational data and information. It encompasses the total climate system (physical, chemical and biological properties in atmospheric, oceanic, terrestrial, hydrologic and cryospheric environments). The GCOS implementation plan (www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf) calls for sustained observations of 50 "Essential Climate Variables" (ECVs). Current and historical observations of ECVs are needed to sustain progress in the generation of global climate products and to support the work of the UNFCCC[1] and the IPCC[2].

The UK-EOF has commissioned Team Projects Ltd to undertake a study to improve understanding of:

- which UK funded monitoring activities are collecting observational data relevant to ECVs;
- what UK climate-related observational data are being used for;
- how observational data and information gained from these monitoring activities feeds into other initiatives / programmes;
- observation standards in use, identifying observations of ECVs meeting international standards.

The findings will be used to ensure UK efforts towards meeting GCOS ECV recommendations are better known and valued, and assess where there are gaps in UK observational data supporting the ECVs.

What is its scope?

Long-term monitoring activities collecting climate-related observational data considered relevant to this study have been identified by UK-EOF from their Environmental Observation Activity Catalogue (www.ukeof.org.uk/catalogue/default.aspx). This includes one or more of the activities that you are involved with. This survey questionnaire is designed to collect further information about individual activities, so if you lead more than one monitoring activity you will be provided with a separate survey questionnaire for each activity.

Who should complete the survey questionnaire?

This survey questionnaire should be completed by the activity lead or someone else with good knowledge of the monitoring activity. To make completion as easy as possible, some questions have been partially pre-populated and should be checked. The person completing the survey questionnaire may wish to consult with others to complete all or parts of it (for example on observation standards). It will take up to an hour to complete.

Your participation in this survey is greatly valued and we would like to stress that the study is not intended to be judgemental in any way. We will send you a copy of the report of the study which will be available in autumn 2013.

When should I return it?

Please complete the survey questionnaire and return it by email to jacqueline@teamprojects.co.uk by **Friday May 17th 2013**.

If you have any questions please contact Jacqueline by email.

Data protection

NERC may be required to release information, including personal data and commercial information, on request under the Environmental Information Regulations 2004 or the Freedom of Information Act 2000. However, NERC will not permit any unwarranted breach of confidentiality nor will we act in contravention of our obligations under the Data Protection Act 1998.

1 United Nations Framework Convention on Climate Change

2 Intergovernmental Panel on Climate Change

To fill in, type in the grey open response area - reached by using the "tab" key. For tick boxes, click on tick box with mouse, it will check, click again to uncheck. Information in most pre-populated fields can be changed if it is incorrect.

Observation Activity Title	
UK-EOF ID	
Lead Organisation	
Survey completed by:	

Section 1: Climate Observations and ECVs

Sections 1 and 2 will enable us to understand more about the relevance of your monitoring activity to climate assessment.

Many monitoring activities included in this study are producing, or are capable of producing, a time-series of measurements of sufficient length, consistency, and continuity to measure the effects of climate change. Some are already part of international "climate observing" systems and some support the production of GCOS ECVs. For others, we know less about their potential relevance or use for climate assessment.

Table 1 shows the GCOS ECVs grouped according to six environmental domains (some contain links that provide information about the ECV and its measurement). Your monitoring activity has been identified as producing data of potential relevance to those ECVs highlighted yellow in the table.

Table 1: GCOS Essential Climate Variables (ECV) Data Access Matrix. (January 7, 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 Color **	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 *(incl. Vegetation Type) (ECV T9)*
Temperature	Sea Surface Temperature (SST) **	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) *(ECV T10)* **
Water Vapor **	**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)' (page 19)

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

Section 1: Climate Observations and ECVs

Q1 The tables below have been pre-populated using information from the UK-EOF Environmental Observation Activity Catalogue. The tables show the parameters measured by your monitoring activity for each of the ECVs highlighted in Table 1. Subsequent questions will explore the relevance of this information.

Please check this information and amend if incorrect. Then use the "tick boxes" to indicate you have done this.

Please also add details of any other parameters that are monitored by your activity that you know are relevant to these or other ECVs. Add these into the table for the relevant environmental domain.

A generic table is provided at the end in case there is insufficient space in the tables provided for specific environmental domains.

Domain: ATMOSPHERIC – SURFACE							
ECV:		ECV:		ECV:		ECV:	
Parameter(s) measured		Parameter(s) measured		Parameter(s) measured		Parameter(s) measured	
I confirm the information provided is correct	☐						
I have amended / added to the information provided	☐						
Supporting Comments:							

Domain: ATMOSPHERIC – UPPER AIR							
ECV:		ECV:		ECV:		ECV:	
Parameter(s) measured		Parameter(s) measured		Parameter(s) measured		Parameter(s) measured	
I confirm the information provided is correct	☐						
I have amended / added to the information provided	☐						
Supporting Comments:							

Domain: ATMOSPHERIC COMPOSITION							
ECV:		ECV:		ECV:		ECV:	
Parameter(s) measured		Parameter(s) measured		Parameter(s) measured		Parameter(s) measured	
I confirm the information provided is correct	☐						
I have amended / added to the information provided	☐						
Supporting Comments:							

Domain: MARINE – SURFACE							
ECV:		ECV:		ECV:		ECV:	
Parameter(s) measured		Parameter(s) measured		Parameter(s) measured		Parameter(s) measured	
I confirm the information provided is correct	☐						
I have amended / added to the information provided	☐						
Supporting Comments:							

Section 1: Climate Observations and ECVs

Domain: MARINE – SUB-SURFACE							
ECV:		ECV:		ECV:		ECV:	
Parameter(s) measured		Parameter(s) measured		Parameter(s) measured		Parameter(s) measured	
I confirm the information provided is correct	☐						
I have amended / added to the information provided	☐						
Supporting Comments:							

Domain: TERRESTRIAL							
ECV:		ECV:		ECV:		ECV:	
Parameter(s) measured		Parameter(s) measured		Parameter(s) measured		Parameter(s) measured	
I confirm the information provided is correct	☐						
I have amended / added to the information provided	☐						
Supporting Comments:							

Domain:	Atmosphere: Surface ☐	Atmosphere: Upper-air ☐	Atmosphere: Composition ☐	Oceanic: Sub-surface ☐	Oceanic: surface ☐	Terrestrial ☐
ECV:		ECV:		ECV:		ECV:	
Parameter(s) measured		Parameter(s) measured		Parameter(s) measured		Parameter(s) measured	
Supporting Comments:							

QiEnd

Section 1: Climate Observations and ECVs

Q2 Please indicate whether you agree or disagree with these statements describing the observational data from your monitoring activity identified in Q1?

Choose one response to each statement:	Agree	Disagree	Don't know
1. This is a recognised climate-observing activity contributing to ECVs through GCOS (*this may be from a subset of stations/platforms or for a subset of observational data identified in Q1*)	☐	☐	☐
2. I am confident that (some) observational data from this activity could be used for climate applications (e.g. a time series for monitoring change) in addition to their primary purpose	☐	☐	☐
3. I am not sure whether any observational data from this activity (from any of the sites / stations) could be used for climate applications as they are collected for other purposes	☐	☐	☐
4. I do not think any of the observational data from this activity (from any of the sites / stations) are suitable for climate applications. I don't envisage any observations we make ever being suitable for use for rigorous climate assessment.	☐*	☐	☐
5. The acquisition of observations of ECVs in this activity complies well or fully with the relevant GCOS international protocols and standards" (*this may be from a subset of stations/platforms or for a subset of observational data identified in Q1*).	☐	☐	☐
6. The acquisition of observations of ECVs in this activity is considered highly relevant to achieving actions for ECVs set out in the GCOS implementation plan.	☐	☐	☐

If you agreed with Statement 4 (marked with an asterisk *) please complete Question 2b, if not go to Q3

Q2b If you agreed with statement 4 of Q2, please provide a brief explanation of why observational data from your monitoring activity are unsuitable for climate applications (e.g. sites are in unsuitable environments).

Then, if your observational data has been used in climate applications please complete Q4 and Q5, otherwise go to Q9.

Section 1: Climate Observations and ECVs

Q3 **Please complete the table below if your activity contributes observational data to a GCOS network.**

Indicate which GCOS networks your activity contributes data to. Tick all that apply

Domain: Atmosphere Surface			
GCOS Surface Network (GSN)	☐	Baseline Surface Radiation Network (BSRN)	☐
Full WWW/GOS Surface Network	☐	Global Drifter Array	☐
Global Tropical Moored Buoy Network	☐	Voluntary Observing Ships	☐
Global Reference Mooring Network	☐	GLOSS Core Sea-level Network	☐
Domain: Atmosphere Upper-air			
GCOS Reference Upper-air Network (GRUAN)	☐	GCOS Upper-air Network (GUAN)	☐
Full WWW/GOS Upper Air Network	☐	Aircraft (ASDAR etc)	☐
Profiler (radar) network	☐	Ground-based GPS receiver network	☐
Domain: Atmosphere Composition			
GCOS-affiliated WMO/GAW Global Atmospheric N2O, CO2 and CH4 Monitoring Networks	☐	WMO/GAW GCOS Global Baseline Total Ozone Network	☐
WMO/GAW GCOS Global Baseline Profile Ozone Network	☐	WMO/GAW Aerosol Network	☐
Domain: Oceans			
Global surface drifting buoy array on 5x5 degree resolution	☐	Global Tropical moored buoy network	☐
Voluntary Observing Ships (VOS)	☐	Global reference mooring network	☐
GLOSS Core Sea-Level Network	☐	Argo Array	☐
Domain: Terrestrial			
GCOS/GTOS Baseline Global Terrestrial Network – Rivers (GTN-R)	☐	GCOS/GTOS Baseline Global Lake Network	☐
GCOS/GTOS Baseline Terrestrial Network – Glaciers (GTN-G)	☐	GCOS/GTOS Baseline Terrestrial Network - Permafrost (GTN-P)	☐
WWW/GOS synoptic network (snow)	☐	Global Terrestrial Network Hydrology (GTN-H)	☐
GCOS networks not covered above			
Domain:		Domain:	
CGOS network name:		CGOS network name:	
Relevant ECVs:		Relevant ECVs:	

Section 1: Climate Observations and ECVs

Q4 Which UK Data Centre(s) and recognised international Data Centre(s) hold the observational data identified in Q1?

Data Centres	Tick those that apply	ECV(s)
British Atmospheric Data Centre	☐	
British Oceanographic Data Centre	☐	
Antarctic Environmental Data Centre	☐	
National Water Archive	☐	
Met Office Hadley Centre	☐	
European Centre for Medium Range Weather Forecasts	☐	
Global Collecting Centre for Marine Climatological Data	☐	
The relevant GCOS international Data Centre(s)	☐	
Other (please specify):	☐	
Other (please specify):	☐	
Other (please specify):	☐	
Other (please specify):	☐	

If you would like to add information to support your answers on data centres please do so here:

Section 2: What are UK climate-related observational data are being used for?

The value to science and policy, as well as the cost effectiveness, of climate-related observation increases when data are used for a range of purposes. The primary purpose of your monitoring activity (which may be for purposes other than climate observation) is described in the UK-EOF Catalogue. The UK-EOF would like to identify climate-related uses being made of data and information gained from your monitoring activity (in addition to their primary purpose), particularly if used in climate modelling. It would be useful to understand how data feeds into these other activities.

Q5 Please use the table below to provide information about other climate-related applications that use the observational data identified in Q1 (e.g. climate modelling, studies of climate impacts, providing in situ calibration for satellite measurements). Include GCOS applications.

Please allocate the use to one of the following four categories using the check boxes:

Climate use categories:	**A:** Modelling and prediction of the climate system **B:** Assessing impacts of, and supporting adaptation to, climate variability and change **C:** Detecting and attributing climate change **D:** Other

Note: If the work is described in the UK-EOF Catalogue you can add the title and/or UK-EOF ID and we can access the description.

Climate use category	Name or acronym of the activity/programme, brief description of the data or information supplied and what they are used for	Way the data feed into the activity
A: ☐ B: ☐ C: ☐ D: ☐		via GCOS network ☐ via other programme or initiative (please specify):
A: ☐ B: ☐ C: ☐ D: ☐		via GCOS network ☐ via other programme or initiative (please specify):
A: ☐ B: ☐ C: ☐ D: ☐		via GCOS network ☐ via other programme or initiative (please specify):
A: ☐ B: ☐ C: ☐ D: ☐		via GCOS network ☐ via other programme or initiative (please specify):
A: ☐ B: ☐ C: ☐ D: ☐		via GCOS network ☐ via other programme or initiative (please specify):
A: ☐ B: ☐ C: ☐ D: ☐		via GCOS network ☐ via other programme or initiative (please specify):
A: ☐ B: ☐ C: ☐ D: ☐		via GCOS network ☐ via other programme or initiative (please specify):

Section 3: Standards and practices

It is of major importance for climate observing that data from different locations and times are comparable or can be made comparable. GCOS and partner organisations provide standards and guidance for generating ECVs to help data producers make their observations useful for global climate assessment. Many monitoring activities that contribute data to GCOS observing systems were not originally set up to do so and have adapted or strengthened their operating practices, standards and metadata to meet the exacting standards necessary, sometimes for a subset of stations.

Q6 **Are you aware of the following types of guidance that support climate observing and have you applied such guidance to your activity (this could be for a subset of stations or measurements)?**

	Aware of guidance?		Guidance applied?		
	Yes	No	No	Fully	Partly
GCOS Climate Monitoring Principles (GCMPs) - The GCMPs provide basic guidance regarding the planning, operation, and management of observing networks and systems http://www.wmo.int/pages/prog/gcos/documents/GCOS_Climate_Monitoring_Principles.pdf	☐	☐	☐	☐	☐
Relevant guidelines, recommendations, training material and publications provided by GCOS networks (such as GOOS, GRUAN, GAW, GTOS and GLOSS) and WMO	☐	☐	☐	☐	☐
Guidelines for the Generation of ECV Datasets and Products www.wmo.int/pages/prog/gcos/Publications/gcos-143.pdf	☐	☐	☐	☐	☐
Relevant reports from the Commission for Instruments and Methods of Observing	☐	☐	☐	☐	☐
(specifically and where relevant) CIMO guide WMO No8 on the measurement of meteorological variables www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html	☐	☐	☐	☐	☐

Q7 **Please indicate which of the following considerations have been taken into account in your activity** (either in setting-up the activity or subsequently in the context of contributing to climate observing)

Please tick all that apply	Taken into consideration?		Also considered from a climate observing perspective?	
	Yes	No	Yes	No
Choice of sites – representation geographically /spatial resolution	☐	☐	☐	☐
Representativeness of the environment from which measures are taken	☐	☐	☐	☐
Long-term stability and homogeneity of measures	☐	☐	☐	☐
Homogeneity of the environment (some environments change rapidly e.g. urban)	☐	☐	☐	☐
How to maintain uninterrupted operation of individual stations	☐	☐	☐	☐
Policies to facilitate the exchange and archiving of data	☐	☐	☐	☐
Timeliness of data release to the user community to enable monitoring activities	☐	☐	☐	☐

Section 3: Standards and practices

Q8 **Please complete the following table about protocols, procedures and systems**

Please tick all that apply	In place for observational data identified in Q1?		Has compatibility with GCOS requirements for ECVs been assessed for these data?			If yes, are the standards/ protocols considered compatible with GCOS requirements for ECVs? (*can be for subset of sites*)	
Protocols, procedures and systems:	Yes for all	Yes for some	No	Yes for all ECVs	Yes for some ECVs	Yes for all ECVs	Yes for some ECVs (please specify the ECVs)
Set up, calibration /validation activities of instrumentation	☐	☐	☐	☐	☐	☐	
Metadata describing where and how the observations are taken	☐	☐	☐	☐	☐	☐	
Consistency and quality of data collected	☐	☐	☐	☐	☐	☐	
Facilitating access, use and interpretation of data	☐	☐	☐	☐	☐	☐	
Systems for quality control and feedback	☐	☐	☐	☐	☐	☐	
Version management	☐	☐	☐	☐	☐	☐	
Data management	☐	☐	☐	☐	☐	☐	
Data archival systems	☐	☐	☐	☐	☐	☐	
Assessing the accuracy, stability and resolution (time, space) of data products	☐	☐	☐	☐	☐	☐	

If you would like to add information to support your answers on guidance, standards and practices please do so here:

Q9 **Have you made an assessment of the benefits to the GCOS networks that would arise from the inclusion of compliant measurements from your monitoring activity?**

Yes ☐
No ☐

If you would like to add information to support your answer please do so here:

Q10 **Would you find it helpful to have more support or information about GCOS data standards for measurements of ECVs?**

Yes ☐
No ☐

What kind of information or support would you find useful?

(please specify in your answer if this relates to a particular ECV(s))

If UK-EOF were to provide information to raise awareness about GCOS international standards for climate observing would you be interested in receiving this? If so, please tick box ☐

Section 4: ECVs: GCOS requirements for data acquisition

Please complete this section if:

- **your monitoring activity contributes to a GCOS Network; or**
- **you have made any kind of assessment of how compliant your activity is with GCOS standards and protocols or GCOS Climate Monitoring Principles.**

Working groups led by GCOS partner organisations provide, and continue to develop, international standards for ECVs to ensure data are obtained to the exacting standards necessary for a long-term climate observing system. For some ECVs, in particular the terrestrial ECVs, guidance is available but the way in which measurements are to be collected, the associated standards for data collection and the international networks of contributing sites are still being developed.

The observing of ECV climate variables carried-out as part of your activity may already meet some or all of the standards for data acquisition, or you may be actively working towards achieving them. This section seeks further information about GCOS standards applied and the contributions to ECVs made by your activity.

Q11 Is there any intention or commitment to make changes to your activity to either assess, or improve, its compliance with GCOS international standards or GCOS Climate Monitoring Principles?

If so, please can you describe these here:

Q12 If your activity contributes data to one or more GCOS Networks (see Q3) please complete the table(s) below.

Contributing Network specified in the GCOS implementation plan:		Contributing Network specified in the GCOS implementation plan:	
ECV(s):		ECV(s):	
Number of stations or platforms currently operating (in the GCOS Network):		Number of stations or platforms currently operating (in the GCOS Network):	
Number of stations or platforms operating in accordance with the GCMPs:		Number of stations or platforms operating in accordance with the GCMPs:	

Contributing Network specified in the GCOS implementation plan:		Contributing Network specified in the GCOS implementation plan:	
ECV(s):		ECV(s):	
Number of stations or platforms currently operating (in the GCOS Network):		Number of stations or platforms currently operating (in the GCOS Network):	
Number of stations or platforms operating in accordance with the GCMPs:		Number of stations or platforms operating in accordance with the GCMPs:	

Section 4: ECVs: GCOS requirements for data acquisition

Contributing Network specified in the GCOS implementation plan:		Contributing Network specified in the GCOS implementation plan:	
ECV(s):		ECV(s):	
Number of stations or platforms currently operating (in the GCOS Network):		Number of stations or platforms currently operating (in the GCOS Network):	
Number of stations or platforms operating in accordance with the GCMPs:		Number of stations or platforms operating in accordance with the GCMPs:	

Q13 Are there any issues about completing this survey that you would like to draw to our attention?

Follow Up

Can we contact you if we need clarification or further information about answers you have provided in this questionnaire?

Yes ☐
No ☐

If so, please provide contact details

Name	
Telephone	
Email	

Thank you for your help. Please save the questionnaire to a file on your computer then return by email to jacqueline.parker@teamprojects.co.uk by **Friday May 17th 2013**.

Appendix 2: Comments on the completeness and consistency of questionnaire responses

Section	Comments
1. Climate observations and ECVs	Q1: the pre-populated data from the UKEOF Catalogue appeared to have been carefully checked and amended as necessary. Good linkage made between parameters and ECVs resulting in complete and internally consistent data. Q2: responses generally as expected with the climate observing option only selected by those contributing to GCOS activities. A few activities which it thought are contributing data to GCOS networks did not indicate this. Q3 Occasional inconsistency between responses for: • Question 3 (tick list of GCOS networks that the activity contributes to) and • Question 14 supply details of (GCOS network) + (number stations) More often Q3 completed but not Q14 so supporting evidence not provided. Q3 A couple of obvious errors were made and corrected by follow-up calls or emails. Some respondents are contributing to networks managed by GCOS partners (eg the wider 'observing systems' of GOOS, GAW) and which are relevant to the delivery GIP. These were occasionally added to the 'additional GCOS networks' option with comments indicating uncertainty as to whether the network identified was in fact a GCOS network. Q4: Responses were provided from all monitoring activities. No checks made of the accuracy of this information.
2. Uses of climate-related data	Q5: A few responses restated primary uses of the data rather than additional uses. The way data fed into the uses was not always provided. Some responded to say end uses too numerous to describe as data widely used.
3. Standards and practices	Q6, Q7, Q9, Q10 – nearly all completed these questions fully, providing a good level of supporting comment. Q8 First column generally completed fully, latter columns (on compatibility with GCOS) not always completed.
4. GCOS requirements for data acquisition	Q11. Optional. Relatively few responses Q12: Some activities did not complete this section or only partially completed it. Some internal inconsistency between responses to this question and information about extent to which GCMPs applied provided in Q6 or named GCOS networks in Q3.
Feedback on any issues about completing the survey	Q13: Feedback was supplied. It suggested some respondents to the consultation found parts of the questionnaire quite difficult to complete. The questionnaire appeared to be more challenging to complete for those in Group 1 who were required to complete more questions than other respondents. Some respondents reported that it was difficult to fully understand how their observation activity related to GCOS and had insufficient time available to establish this.

Appendix 3: Met Office analysis of Operational Environmental Observing Funding Shortfall

Met Office analysis of Operational Environmental Observing Funding Shortfall (2009[57]). The key problem from our perspective is that we have a major funding gap that is preventing / hindering the UK's ability to support programmes emerging from R&D activities now requiring an operational / long-term solution. This is equally a challenge for many of our international partners and leads us with a situation that threatens the continuity of capability that has been developed, demonstrated to be operationally viable and in some cases vital to sustain climate data records.

We identify a problem, most acute in the case of the space component, where we have:

- An established, and stretched, funding mechanism for leading-edge observation system R&D activities (primarily through UKSA funding of ESA EO Missions).
- An equally stretched funding stream for the sustained provision of operational Satellites through EUMETSAT (primarily BIS / Met Office funded).
- In both cases we have done our best to improve efficiencies to create funding for new capability but this is becoming increasingly difficult (particularly in the case of EPS-SG where we identify a significant challenge to simply achieve continuity given the situation in the USA regarding the provision of their next generation polar orbiting meteorological satellites).

This results in no capacity within existing funding streams for the UK to support the transition of new capabilities into sustained operations. This problem exists for two application areas:

- Sustained provision of climate quality datasets that have been initially based on R&D programmes but now need a more permanent 'operational' solution.
- Sustained provision of operational capabilities now emerging from R&D missions that might significantly benefit operational services and those resulting from initiatives such as GMES.

Our most immediate concerns relate to:

1. Jason-3 (high precision sea level) for which the relatively small financial contribution (25€M) from the European Commission (EC) remains in doubt.
2. Jason-CS; the follow-on mission for Jason-3 that requires funding commitments to ESA and EUMETSAT
3. Argo float programme (temperature and salinity profiles) for which a significant proportion of the funding for the UK contribution has been lost following MOD's decision to withdraw from the funding consortium.

A number of other examples of this problem exist including those relating to:

4. Surface salinity (SMOS follow-on ~2015)
5. Wind profiles (ADM-Aeolus successor ~ 2014)
6. Earth radiation budget (~ 2019)
7. Uncertainty over the continuity of some EPS missions including Ozone

The main problem is that we don't have clear Departmental responsibilities identified for the funding of climate observations. Instead our response depends on difficult and time consuming cross Departmental discussions.

[57]This Met Office analysis was updated in 2012, but was not available to UKEOF until after this report was completed, so could not be taken into account.

Capability of measuring the GCOS Essential Climate Variables, which can be measured from space, from present to 2023 (Met Office analysis):

GCOS ECV	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Sensors	Post EPS
Atmospheric																				
Surface precip																			**SSM/I, AMSR, TMI, SSMIS, AMSU, GEO Vis/IR**	CPR, MWI
Surface wind																			**2 Scatt only over ocean, Windsat, SSMI, SSMI(S)**	Scatt, MWI
TOA radn budget																			**CERES, EarthCARE**	RER
Solar irradiance																			**ACRIM, SORCE, Picard, GLORY**	TSIM
Temp profile																			**Sounder radiances, GPS-RO**	IRS, MWS
Water vapour profile																			**Sounder radiances**	IRS, MWS
Wind profile																			**AMVs, DWL**	DWL
Cloud properties																			**Cloudsat, VIS/IR images (GEO/LEO)**	CPR, MWI
Carbon dioxide																			**AIRS,IASI,OCO,CRIS, GOSAT**	IRS
Methane																			**AIRS,IASI, GOSAT**	IRS
Ozone																			**GOME-2,IASI,AIRS,CRIS, IR, UV limb, OMPS**	UVNS
Other GHG																			**IASI, GOME-2, UV/IR limb, GOSAT**	IRS, UVNS
Aerosols																			**AVHRR, VIRSS, GOME-2, MERIS, MODIS, GLORY?**	3MI
Oceanic																				
SST																			**AATSR, SLSTR, AVHRR, AMSR, MODIS**	MWI,DVR
Surface salinity																			**SMOS, Aquarius**	MWI-Ocean
Sea level																			**Jason-1,2,3?, Sentinel-3 ALT**	ALT
Sea state																			**Jason-1,2 Sentinel 3 ALT**	ALT
Sea-ice																			**SSM/I, AMSR, SSMI(S), Cryosat-2, ICESAT-2**	MWI
Currents																			**Jason-1,2,3?, Sentinel-3 ALT**	ALT
Ocean colour																			**MERIS, MODIS, VIRSS**	OCI, VII
Terrestrial																				
LST																			**AATSR, SLSTR, AVHRR, AMSR, MODIS**	DVR, VII
Lake levels																			**Jason-1,2,3?, Sentinel 3 ALT**	ALT
Snow cover																			**SSM/I,AVHRR,MODIS, AMSU, Geo Imagers**	MWI
Glaciers and ice caps																			**GRACE, Cryosat, ICESat, ASTER, Landsat**	
Permafrost																			**MODIS, VIRSS,SAR**	VII
Albedo																			**AVHRR, MODIS, VIRSS**	VII
Land cover (inc veg)																			**MODIS, VIRSS, Landsat, TerraSAR**	VII
fAPAR																			**MODIS, VIRSS, MERS**	VII
LAI																			**MODIS, VIRSS, MERIS**	VII
Biomass																			**Sentinel-1 SAR, L-Band?**	VII
Fire																			**Geo imagers, ATSR, AVHRR, VIRSS**	VII
Soil moisture																			**ASCAT, SMOS**	Scatt

Key

Good capability
Some capability but needs improvement
Poor capability
Capability lost
Capability reduced
No capability
Assumes US fly microwave imager

Appendix 4: Description of monitoring activities that responded to the consultation

Atmospheric chemistry

Description of the monitoring activities contributing to the GCOS Networks

Group 1: contribute observational data on ECVs to GCOS via 'well-established' systems and networks that can be quantified[58].

Cape Verde Atmospheric Observatory

The Cape Verde Atmospheric Observatory[59] was established in 2006 and is part of a bilateral German-UK initiative to undertake long-term ground and ocean-based observations. The Observatory measures greenhouse gases, stratospheric ozone depleting gases, short lived air pollutants, biogenic emissions, aerosols and particulates, atmospheric radiation, and precipitation and is located in the tropical Eastern North Atlantic Ocean. It is one of four long term observatories that are part of NERC's NCAS Facility for Ground based Atmospheric Monitoring programme.

The University of York is responsible for trace gas measurements at this site and operates as part of WMO/GAW GCOS Global Baseline Profile Ozone Network. Measurements of gaseous mercury are provided to GMOS a five year project (2010-2015), funded by the European Commission 7th Framework.[60] Although this was identified in the survey questionnaire as a GCOS network this is not thought to be the case though monitoring may be of relevance to delivery of the GIP.

The Observatory has been audited by WMO GAW for ozone, carbon monoxide, greenhouse gases and VOCs. Co-located meteorological measurements are also taken at 10m and 30m but they were not identified as contributing to the GCOS Surface Network.

Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland

Atmospheric composition monitoring began at Mace Head in 1987 (with measurements of ozone) and now cover a wide range of parameters relevant to all of the atmospheric ECVs including measurements of ozone, CO, CO_2 methane and other GHGs (including N_2O, SF_6, halocarbons and a range of ozone depleting substances) and aerosol optical depth. Mace Head is an EMEP supersite, part of AGAGE and the 'UK DECC Network'. The site operates as part of the GCOS-affiliated WMO/GAW Global Atmospheric N2O, CO2 and CH4 Monitoring Networks (GHGs and their precursors), the WMO/GAW GCOS Global Baseline Profile Ozone Network (ozone) and WMO/GAW Aerosol Network (AOD). *Co-located* surface meteorological measurements are taken as part of the GCOS Surface Network and Full WWW/GOS Surface Network.

Met Office Ozone Sonde

The Met Office Ozone Sonde provides vertical measurements of ozone concentration accompanied by supporting measures of solar radiation in support of the ozone ECV. The observation activity is part of WMO/GAW GCOS Global Baseline Profile Ozone Network and the WMO/GAW GCOS Global Baseline Total Ozone Network. The site operates a Dobson system.

Baseline Measurement of Stratospheric Ozone and UV

Baseline Measurement of Stratospheric Ozone and UV is a Defra funded initiative that measures column ozone and takes place at two sites - Reading and Lerwick. The Lerwick site makes column ozone measurements with a Dobson Spectrophotometer. At both sites, spectrally resolved UV measurements are also made and can be used both independently and in conjunction with the ozone measurements during both long term trend and event analysis. The sites are part of the WMO/GAW GCOS Global Baseline Total Ozone Network and WMO/GAW GCOS Global Baseline Profile Ozone Network. Ozone measurements are also made at Manchester and Reading using Brewer spectrophotometers but the data records are much shorter.

[58] See: C. Chapter 2: Atmospheric ECVs in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

[59] http://www.ncas.ac.uk/index.php/en/cvao-home

[60] http://www.gmos.eu/index.php/background

Observations in cryospheric environments

The British Antarctic Survey (BAS) began taking measurements of ozone at the Halley (since 1957) and Rothera stations through the **Atmospheric Monitoring - Ozone observations (BAS LTMS)** activity**.** One station (Halley) operates as part of the WMO/GAW GCOS Global Baseline Total Ozone Network.

Since 1983, Halley station has contributed to the carbon cycle measurement program of the NOAA collaborative sampling network through the **Atmospheric Monitoring - Air and snow sampling (BAS LTMS)** activity. Whole air samples are collected approximately weekly in glass flasks and returned to NOAA's Global Monitoring Division in the US for analysis of various gases including CO_2, CH_4, CO, H_2, SF_6, N_2O. The monitoring forms part of the GCOS-affiliated WMO/GAW Global Atmospheric N2O, CO2 and CH4 Monitoring Networks.

Other UK funded monitoring collecting data of relevance to the atmospheric chemistry ECVs.

> Group 2: contribute to ECVs and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so

Weybourne Atmospheric Observatory measures surface ozone, CO2, CO, oxides of nitrogen, VOCs and GHGs. *Co-located* surface meteorological measurements (AWS) including surface radiation data (relevant to the surface radiation budget ECV) are taken.

UK DECC network

The 'UK DECC Network' is a new network of UK measurement sites set up to compliment the measurements that take place at Mace Head, Ireland. Gases measured are CO2, CH4, CO, N2O, SF6 and a full suite of ODS and GHG compounds. In 2011, the University of Bristol and the Met Office were awarded a contract to establish an expanded programme of atmospheric observations to deliver increased spatial and temporal resolution in emissions estimates. The methodology chosen to achieve this was to establish two new tall tower observation sites based in Ridge Hill (Herefordshire) and Tacolneston (Norfolk) and to adopt an existing station Angus (Scotland).

Sun Photometers

Sun photometer measurements of the direct (collimated) solar radiation provide information to calculate the columnar aerosol optical depth (AOD). There are three activities that collect data using sun photometers for the assessment of aerosol optical depth[61], two of which submit data to AERONET: **CFARR** (at Chilbolton) and the **Wytham Wood sun photometer**, located at one of CEH's ECN sites. The **sun photometer at the PML** site uses instrumentation that precludes its inclusion in AERONET (data are held locally).

Defra funded networks monitoring air pollution: UKEAP

A further two **UK EMEP 'supersites'** in the UKEAP network monitor a comprehensive range of atmospheric composition parameters that are highly relevant to all of the GCOS atmospheric ECVs.

The **Auchencorth EMEP supersite** facility in Scotland is run by CEH and has begun the processes required for inclusion in the GAW programme, so is listed by GAWSIS as 'contributing (prospective)'. In addition, one monitoring lead (from an EMEP site) reported they wish to become a GAW site and have begun the process of application to achieve this. Measurements of particulate mercury at Auchencorth are provided to the GAW **GMOS project.** A wide range of measurements relevant to all of the atmospheric composition ECVs are monitored: ozone, aerosols properties (including particulates, trace gas fluxes, emerging chemicals of concern (ECOCs)), precursors (supporting the ozone and aerosols ECVs), CO_2 and CH_4 and other long-lived GHGs. In addition there are *co-located* meteorological measurements using AWS (includes radiation measurements, surface wetness, soil surface and below surface temperature, water vapour fluxes). There are significant amounts of *co-located* data from the past decade for Auchencorth Moss relevant to terrestrial ECVs. This includes soil, vegetation, PAR and land use (from UK and EU projects). There are also water measurements made at the stream that flows out of the site including flow, composition and GHG gas exchange information (held internally at CEH).

[61] See: p22 of www.ukeof.org.uk/documents/UK%20Report%20on%20National%20Activities%20with%20respect%20to%20the%20GCOS%20implementation%20Plan_2008.pdf

Group 3: other activities not thought to be engaged with delivery of the GIP but known to be collecting climate-related data of the type used for the GCOS ECVs

The **Harwell EMEP supersite** in Oxfordshire is run by Ricardo-AEAT and also monitors parameters relevant to the atmospheric ECS (ozone, aerosols properties, CO_2 and precursors supporting aerosols and ozone ECVs (including ECOCs, particulates, trace gases). In addition there are *co-located* meteorological measurements using AWS (includes water vapour fluxes). Harwell contributes some data to the same data centres used by GCOS but via EMEP.

The **UK Eutrophying and Acidifying atmospheric Pollutants (UKEAP)** network is funded by Defra and measures air pollutants at rural sites across the UK and comprises five components. An over-arching objective is to provide on-going high and low frequency chemical monitoring and campaign mode measurements of the rural and semi-rural background atmosphere to inform the scientific understanding of the non-urban contributions to PM levels, at urban, UK and international scales (source Defra website). The UKEAP project data are reported to the European Monitoring and Evaluation Programme (EMEP) annually.

The other networks of the UKEAP monitor parameters relevant to the 'precursors supporting aerosols and ozone ECV'. The **UK Acid Gases and Aerosols Monitoring Network** monitors acid gases and aerosols and the **National Ammonia Monitoring Network** provides monthly gas phase ammonia concentrations in air and particulate phase ammonia at a subset of sites; they have been in operation since 1999 and 1996 respectively. There are 39 sites in **PrecipNet** which monitor the chemical composition of rainwater (fortnightly inorganic anion & cation concentrations). The nitrogen dioxide measurements of **NO2-Net** are made at a subset of the PrecipNet sites using diffusion tubes.

Other Defra funded networks monitoring air pollution

The **Black Carbon network** and the observation activity **Monitoring of airborne particulate concentrations and numbers in the UK** collect data relevant to the 'aerosols properties ECV and provide information on the composition of particulate matter in the UK. **The UK Automatic Urban and Rural Monitoring Network** takes measurements relevant to three of the atmospheric composition ECVs: aerosols properties (particulates), ozone (surface ozone) and precursors (NO_2, SO_2 and CO). Ozone data from their Eskdalemuir site is submitted to the World Data Centre for GHGs[62] (last update 2006). The UK Rural Monitoring network for ozone appears to have been subsumed into other networks (most likely AURN). Stations in the 'Air Quality Database' are thought to be contributing to GCOS via other activities already described in this appendix.

Atmospheric chemistry measurements made at ECN and ECBN/LTMN sites

The **Environmental Change Network** (see section 4.3.2 for description) measures NO_2 (precursors supporting aerosols and ozone ECVs). In addition, ozone monitoring was initiated at the Cairngorm ECN site in 2011, while a rolling campaign of short term ozone monitoring at all ECN sites to test downscaled national model predictions is planned. The **Long-term Monitoring Network (LTMN)** is building on the work of the ECN and is England's contribution to the UK-wide network. LTMN measures ammonia (in air) and a range of chemical measures in rainfall.

Atmospheric composition measurements that have recently discontinued

The **Aberystwyth atmospheric composition monitoring** led by the University of Manchester used a SOAZ to measure surface ozone and NO_2. The SAOZ instrument continues to operate at Aberystwyth but the data from it have not been analysed for the past two years due to staff shortages and the activity is considered 'closed' as a result.

Surface and upper air measurements

Observation activities contributing to the GCOS networks: upper air

Group 1: contribute observational data on ECVs to GCOS via 'well-established' systems and networks that can be quantified[63].

[62] http://ds.data.jma.go.jp/gmd/wdcgg/cgi-bin/wdcgg/accessdata.cgi?lang=&contributor_index=200612120073

[63] See: C. Chapter 2: Atmospheric ECVs in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

Met Office activities: upper air

The **GPS Water Vapour Programme** provides vertical integrated water vapour data as part of the Ground-based GPS receiver network. Data from roughly 250 stations are processed by the UK (though this varies). Most sites are run by external bodies, so data and most site choice is third party. However, the placement of sites with respect to GPS water vapour measurements from ground stations is not as critical as chosing a land observing enclosure. All the sites need is a good unobstructed view of the sky, and a very stable location. Most sites are chosen to be of a roughly equal spatial distribution, and some are chosen to be specifically near to radiosonde stations.

The **Radiosonde Network** is part of the Full WWW/GOS Upper Air Network and GCOS Upper-air Network (GUAN – Camborne, Lerwick) and provides measurements of air temperature, water vapour and wind speed and direction. The data are widely used for climate measurement and model verification. There are more UK platforms /stations operating to the GCMPs than included in the GCOS networks. The **Shipborne radiosonde network** is part of the Full WWW/GOS Upper Air Network and also monitors upper air wind speed and direction, air temperature and water vapour. The UK Met Office no longer operates any upper air ASAP ships itself. These have now been integrated mangerially and financially into the EUMETNET E-ASAP programme. The Met Office is a member nation of E-ASAP, to which it contributes financially based upon GNI.

The **Windprofiler network** provides observations of the vertical and horizontal velocity upper air wind speed and direction (doppler winds) and is part of the Profiler (radar) network.

The Met Office **weather observations from commercial aircraft programme** (**AMDAR)** obtains upper air temperature and wind speed and direction measures. Some aircraft in Europe have a water vapour sensor installed as part of the E-AMDAR Extended Humidity Trial. During 2013/14 the number of aircraft equipped will rise to nine. The E-AMDAR Programme also hopes to expand further (in the US, the reporting of water vapour from commercial aircraft has advanced further with a network of 60+ aircraft equipped). AMDAR is part of the Aircraft (ASDARetc) network and Full WWW/GOS Upper Air Network.

British Antarctic survey: upper air

BAS Upper-air measurements acquires measures of air temperature, air pressure, wind speed and direction and water vapour. The upper air programme at the Halley station is fully GCOS compliant and forms part of GUAN network. Rothera upper air programme is GCOS compliant in all respects except that it has flights on only 4 out of 7 days a week, it is not a GUAN station but still submits its data via GTS.

Other UK funded observation activities collecting data of relevance to the ECVs: upper air

Group 2: contribute to ECVs and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so

Met Office: Upper Air

The **Met Office Weather Radar Network** monitors upper wind speed and direction. Part of the Met Office Remote Sensing Systems Programme, the weather radar network is a vital meteorological capability, principally measuring precipitation, but also Doppler winds. This information is crucial in underpinning real-time monitoring and forecasts.

The British Antarctic Survey monitor lightening activity in the magnetosphere, which is noted as not being directly connected with cloud monitoring activity; however given that lightening frequency and spatial variation may be indicative of climatic change it is being noted that this is a monitoring activity. The lightning data are held by University of Washington (WWLLN - World Wide Lightning Location Network).

NCAS Facility for Ground based Atmospheric Monitoring: Long-term observatories

The **Chilbolton Facility for Atmospheric and Radio Research** (CFARR) in southern England is funded by NERC and operated by the Rutherford Appleton Laboratory. A description of the instrumentation at the site was provided in previous national reporting (ref). The activity collects water vapour density measurements. *Co-located* surface meteorological measurements including solar irradiance (relevant to the surface radiation budget) are taken. Continuous monitoring of cloud profiles has allowed evaluation of model biases/errors to be identified. Monitoring began in 1998 and is important for understanding the mechanisms by which aerosol in the atmosphere leads to the formation of different cloud types, which is important for predicting climate change. This approach, pioneered at Chilbolton, is being implemented at other observatories around the world, notably US ARM sites.

The **Mesosphere-Stratosphere-Troposphere Radar Facility at Aberystwyth** is operated by the Rutherford Appleton Laboratory. The facility measures cloud properties (cloud base height), upper air wind speed and direction and water vapour (at various heights). *Co-located* surface meteorological measurements of solar irradiance are taken.

Group 3: other activities not thought to be engaged with delivery of the GIP but known to be collecting climate-related data of the type used for the GCOS ECVs

British Antarctic Survey: Upper Air

Upper air temperatures recorded by the BAS activity **Mesospheric temperatures** do not comply with the GCOS Upper-Air ECV - Temperature specification (which requires tropospheric and stratospheric temperatures).

Met Office: Upper Air

The **Met Office ATDnet system - Long Range Lightning Detection Netw**ork provides information on lightening stroke location. Using long range lightning location data as sensed by a network of ground based sensors such as ATDNet (sensing at VLF) would most probably not be very appropriate to support the cloud properties ECV, unless the network was very stable (in terms of the number of operational sensors) and global (which it it not). Sensitivity to lightning from such a network is variable. It is possible satellite based lightning sensing instruments might be more suitable for such a task in the future.

Observation activities contributing to the GCOS networks: surface

Met Office activities: surface meteorology

Group 1: contribute observational data on ECVs to GCOS via 'well-established' systems and networks that can be quantified[64].

[64] See: C. Chapter 2: Atmospheric ECVs in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

The **Met Office Baseline Surface Radiation Network** has two stations in the BSRN Network (Lerwick, Camborne) that provide surface radiation measurements. Data have not been submitted to BSRN since July 2007 as they have not yet been processed. The **Land AWS network** has six stations in the GCOS Surface Network (GSN) and Full WWW/GOS Surface Network submitting all measures other than snow depth. The UK's contribution to the GSN comes from the national network (for the UK itself) of 20 stations within the UK's Regional Basic Climate Network (RBCN) and the 31 stations within the UK's Reference Climate Network.

British Antarctic Survey: surface meteorology

BAS contributes meteorological measurements (pressure, temperature, humidity, wind speed and direction) through three networks, Full WWW/ GOS Surface Network, GUAN through the activity **Surface meteorology (BAS LTM)**.

Ocean-based observations: surface meteorology

The **Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM)** can be sub-divided into 2 categories: ships that provide manual observations and ships that have automated weather stations (AWS) installed. Note that some AWS systems permit manual observations to be added when these are made. VOS manual meteorological observations are made by 280 ships and those from AWS by 40 ships.

The Met Office **Drifting Buoys Programme** provides surface air pressure measurements to the global surface drifting buoy array. BAS also contribute to the VOS Network through their **Surface meteorology (BAS LTM)** activity.

A Met Office buoy is located at **The Porcupine Abyssal Plain (PAP) Observatory** and contributes measurements of surface air temperature and near surface wind speed and direction to the GCOS Surface Network (GSN), Full WWW/GOS Surface Network and Global Mooring Network.

Other UK funded observation activities collecting data of relevance to the ECVs: air surface

Group 2: contribute to ECVs and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so

Met Office

The Met Office Land Climate Station Network comprises 250 stations, many of which have very long records and are used extensively in climate studies. However, a sub-set of stations from the Land AWS Network contribute to GCOS. The Met Office, EA and SEPA have collaborated for a long time to measure **rainfall** and share the data. GCOS presently omits the contribution of data from coastal buoy networks that are operated by many countries. These networks deliver data relevant to many ECVs. This includes the **Met Office Marine Automatic Weather Station Network (MAWS) including Met Office Moored Buoys which** provides meteorological data and measurements of sea state and sea surface temperature**.** A subset of the moored buoys also makes directional spectral wave measurements. One Met Office moored buoy is operated (in collaboration with the NOC) at the PAP site which is part of the global reference mooring network (see UKEOF469674). There are time-series in excess of 20 years and the observing meets the GCMPs.

Meteorological measurements made at ECN and ECBN/LTMN sites

All ECN terrestrial sites collect meteorological (weather) data using automatic weather stations (AWSs). As well as standard meteorological measurements, solar net radiation, cloud cover and albedo are also observed. ECBN / LTMN sites do not measure air pressure but do measure total solar radiation and snow depth.

NCAS Facility for Ground based Atmospheric Monitoring: Long-term observatories

The **Chilbolton Facility for Atmospheric and Radio Research (CFARR)** in southern England is funded by NERC and operated by the Rutherford Appleton Laboratory. *Co-located* surface meteorological measurements including solar irradiance (relevant to the surface radiation budget) are taken.

Oceanic Observations

Observation activities contributing to the GCOS networks: surface and subsurface oceanic measurements

Group 1: contribute observational data on ECVs to GCOS via 'well-established' systems and networks that can be quantified[65].

Voluntary Observing Ships

The Met Office **Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM)** provide measurements of sea surface temperature, sea ice and sea state (the latter two measurements being from manually observing VOS). Sub-surface observations are not made from any UK VOS. BAS contributions to the VOS are described in the UKEOF activities **Cryospheric Monitoring - Sea ice observations (BAS LTMS) and Atmospheric Monitoring - Surface Meteorology (BAS LTMS).**

Met Office activities:

The **Drifting Buoys Programme** provides sea surface temperature measurements to the global surface drifting buoy array. Sea surface currents are derived from buoy positions. The Met Office do not operate any drifters with thermistor strings for sub-surface measurements. Once drifting buoys are deployed the measurements are monitored against NWP data. When the measurements are suspect those data are suppressed (ie not exchanged on GTS or archived). There are few (if any) other observational data against which to verify drifter measurements.

The **Met Office Argo Programme** that contributes to the Argo Array Network takes measures of temperature and salinity in the water column. Normally the uppermost temperature and salinity measurement from Argo floats is at around 4-5m depth, however a sub-set of the Argo array continue to sample temperatures closer to the surface. Typically temperature and salinity are measured to 2,000m depth although new float designs that can go deeper are currently being tested. As at May 2013 over 200 floats are also measuring dissolved oxygen. Deep ocean currents are derived from positions. The definitive (ie best quality) global Argo data sets are those available from the 2 Argo Global Data Assembly Centres (Coriolis and USGODAE). Climate users should use the delayed-mode data that have been subjected to scientific QC.

National Oceanographic Centres (Southampton and Proudman, Liverpool)

The **Global Sea Level Observing System Tide Gauges** run by NOC, Liverpool, provides sea level and supporting measures of air pressure to the GLOSS Core Sea-Level Network. The UK contributes 3 from the UK itself (Lerwick, Newlyn and Stornoway) plus Gibraltar and 8 sites in the S Atlantic which are in different states of working or needing maintenance visits. Assistance is also provided for some stations situated in Africa.

The **Porcupine Abyssal Plain (PAP) Observatory** contributes to The Global Reference Mooring Network for a range of measurements relevant to sea surface temperature, currents, nutrients in the water column, phytoplankton and oxygen (at 30m depth) and subsurface salinity (at 30m depth). The Observatory contributes measurements of partial pressure (pCO2) and fugacity (fCO2) of carbon dioxide in the water column at 2m (and 30m).

British Antarctic Survey

An interim response was provided for the **Oceanographic Monitoring - moorings (BAS LTMS)** as the science lead was not available. It is thought to provide measures of temperature of the water column, salinity of the water column (but there may be other measures and these may be incorrect) to the Global Reference Mooring Network.

Other UK funded observation activities collecting data of relevance to the oceanic ECVs

Group 2: contribute to ECVs and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so

[65] See: C. Chapter 2: Atmospheric ECVs in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

British Antarctic Survey

Oceanographic/Biological Monitoring - Rothera Oceanographic and Biological Time Series (BAS LTMS) known as **RaTS** is a manned time series sampling site (over 15 years) providing a comprehensive range of measurements of relevance to many of the oceanic surface and subsurface ECVs. This includes measurements relevant to the phytoplankton, salinity of the column, temperature of the column, sea ice and nutrients ECVs monitored in compliance with the GCMPs. **Oceanographic Monitoring - CTD stations (BAS LTMS)** observes temperature of the water column and salinity of the water column. The UKEOF Catalogue entry is for the CTD datasets for the Marguerite Trough. BAS holds other CTD datasets collected in consistent sampling areas over time, eg Drake Passage and Western Core Box, in addition to those collected in the Marguerite Trough.

National Oceanographic Centres (Southampton and Proudman, Liverpool)

The **Atlantic Meridional Overturning Circulation Monitoring** is funded by NERC's RAPID-WATCH programme and run by NOC Southampton and became operational in late March 2004. It comprises a monitoring array of 25 moorings and contributes measurements of sub-surface temperature, salinity and currents. It also measures pressure (relevant to deriving sea level).

Plymouth Marine Laboratory

The **Atlantic Meridional Transect (AMT)** provides a wide array of measurements of relevance to ocean acidity, phytoplankton, ocean colour partial pressure CO2,carbon, nutrients, oxygen, temperature of the column and salinity of the column ECVs. The **Western Channel Observatory** is a NERC funded oceanographic time-series and marine biodiversity reference site in the Western English Channel. *In situ* measurements are undertaken weekly at the coastal station and fortnightly at the open shelf station, and comprise parameters relevant to the temperature and salinity ECVs (water column), ocean colour, phytoplankton, carbon, nutrient and oxygen ECVs. The WCO has some of the longest time-series in the world for zooplankton and phytoplankton, and the hydrographic series dates from 1903. These long data series are complemented by hourly measurements made at moorings situated at both stations. PML also takes standard meteorological measurements at their site as part of the WCO.

The Scottish Association for Marine Science (SAMS)

The Ellett line and extended Ellet line oceanographic section also provides a comprehensive range of measurements of relevance to many of the oceanic surface and subsurface ECVs. This includes measurements relevant to the nutrients, oxygen, salinity of the column, temperature of the column and subsurface current. Measurement standards are maintained through long-established 'best practice' amongst UK marine scientists. These are reported and logged with the data as meta data through the BODC. The **Wyville Thomson Ridge Mooring** monitors the horizontal and vertical velocity of the sea current, and temperature of the water column. This activity finished after 10 years in May 2013. The observational programme will be relocated and integrated into a sustained observing array (OSNAP) that is planned to begin in 2014. The data from both of these activites have been used for the EU Framework 7 programme: North Atlantic Climate Variability (NACLIM) for investigating and quantifying the predictability of North Atlantic/ European Climate.

Continuous Plankton Recorder

The **Continuous Plankton Recorder** survey is the world's most geographically extensive and longest-running large-scale plankton biodiversity monitoring activity (it started 1931). The survey determines the abundance and distribution of microscopic plants (phytoplankton) and animals (zooplankton) in our oceans and shelf seas. Using ships from about 20 shipping companies, it obtains samples at monthly intervals on about 30 routes across the oceans.

Water Framework Directive Monitoring

The **Water Framework Directive Surveillance monitoring network** includes measurements in coastal areas, covers Transitional and Coastal Waters. In England and Wales monitoring takes place up to 1 nautical mile from the shore and in Scotland this is extended to 3 nautical miles. Measurements relevant to a wide range of ECVs are monitored (nutrients, dissolved oxygen, salinity, temperature, phytoplankton, benthic invertebrates, macroalgae, seagrass and saltmarsh).

Group 3: other activities not thought to be engaged with delivery of the GIP but known to be collecting climate-related data of the type used for the GCOS ECVs

Plymouth Marine Laboratory

The **North Sea quarter 3 International Bottom Trawl Groundfish Survey** monitors the temperature of the column and salinity of the column ECVs. There are a range of other similar surveys listed on the uKEOF website.

Terrestrial Observations

Observation activities contributing to the GCOS networks: terrestrial

> Group 1: contribute observational data on ECVs to GCOS via 'well-established' systems and networks that can be quantified[66].

The **National River Flow Archive** collates river flow information from the UK measuring authorities, applies quality control (QC), archives and disseminates data and analyses data from over 1200 river flow gauging stations in the UK. Parallel datasets (related to catchment climate, morphology, hydrogeology, land cover and metadata related to the flow gauge and river regime) are maintained. The NRFA also provides the continuous daily flow data required to complement the water quality data archived as part of the Harmonised Monitoring Scheme. The NRFA contributes flow data relevant to the River Discharge ECV to the GCOS/GTOS Baseline Global Terrestrial Network – Rivers as well as to the Global Terrestrial Network Hydrology (GTN-H). Data from stations contributing to the GCOS networks are provided to the Global Runoff Data Centre. There are sub-networks of NRFA catchments which have been identified as being suitable for climate appplications (eg the Benchmark network of near-natural catchments). These sites have excellent data quality, and undisturbed flow records, and are therefore likely to be suitable for climate observation initiatives.

Other UK funded observation activities collecting data of relevance to the terrestrial ECVs

> Group 2: contribute to ECVs and the GIP, through the development of new networks and other programmes, such as climate research programmes, or are identified as having potential to do so

Ice Sheets ECV

BAS has been taking GPS measurements of ice sheets at selected sites within the British Antarctic Territory since 2005 as part of their long monitoring and survey programme (LTMS). This *in situ* monitoring '**Isostatic rebound (BAS LTMS)'** is relevant to the ice sheets ECV**.**

Groundwater ECV

Measurements of Groundwater data are held by the **National Groundwater Level Archive** run by British Geological Survey. A Global Terrestrial Network – Ground water (GTN-GW) and a Global Ground water Monitoring Information System (GGMIS) as a web-portal for all GTN-GW datasets needs to be established (ref: GOSIC).

Lakes ECV

The **CEH Cumbrian Lakes monitoring programme** has been monitoring long term changes in the environmental condition of lakes since 1945. Algal populations, nutrient chemistry, water temperature and fish populations are monitored in seven lake basins in Cumbria. Data from three basins contribute to ECN. Lake depth profiles of temperature and oxygen concentration, surface (0-5 or 0-7m) chemical composition, pH, alkalinity, chlorophyll a, phytoplankton and zooplankton populations, light penetration and lake level are observed. *Co-located* meteorological measurements are taken including of cloud cover. Not all parameters are observed at each basin or for the same length of time.

Co-located ecological monitoring

Information on the **Water Framework Directive Monitoring Overview** (compiled for UK, with input from SEPA) covers the Water Framework Directive Surveillance monitoring network. This is a fixed monitoring network designed to measure long term environmental changes in rivers, lakes, transitional waters (estuaries) and coastal waters.

[66] See: C. Chapter 2: Atmospheric ECVs in http://unfccc.int/resource/docs/2007/cop13/eng/06a02.pdf

Parameters relevant to the terrestrial ECVs include river discharge, lakes and groundwater. The requirements for WFD surveillance monitoring of groundwater is built into a wider strategic network. The broad range of parameters measured are considered to have potential for contributing to the development of a subset of current LTER and FLUXNET sites into a global terrestrial reference network for monitoring sites with sustained funding perspective, and *co-located* measurements of meteorological ECVs (action T3 and T4 from the Implementation Plan for the Global Observing System for Climate in support of the UNFCCC). The Water Framework Directive Surveillance water bodies also cover Transitional and Coastal Waters.

The **Environmental Change Network** (ECN) was launched in 1992 and is a long-term ecosystem research network that gathers information about the pressures on and responses to environmental change in physical, chemical and biological systems. As part of a broad suite of *co-located* measurements at 12 terrestrial and 45 freshwater sites, the ECN measures soil moisture, soil carbon and landcover which are relevant to the terrestrial ECVs. There are *co-located* measurements of meteorological ECVs. ECN is a member network of ILTER (International Long-term Ecological Research Network), a global network of research sites located in a wide array of ecosystems with a focus is on long-term, site-based research and monitoring. ECN is working towards achievement of a global network of ecosystem observatories where co-located measurements of biological, hydrological, geochemical and climate measurements are undertaken and data made available through linked systems to contribute to global scale assessments of the effects of climate change impacts on ecosystems and ecosystem services.

The **Long-term Monitoring Network (LTMN)** is building on the work of the ECN and is England's contribution to the UK-wide Environmental Change Biodiversity Network (ECBN). In common with ECN, the LTMN collects a range of collocated environmental data across a range of sites. In England there are 27 sites but this is planned to increase to 40 by 2015. LTMN measures ammonia (in air) and a range of chemical measures in rainfall, local climate, land cover (vegetation), a number of soil parameters, breeding birds, butterflies and records land management. The LTMN is delivered by Natural England on its own sites, and in partnership with a number of bodies on third-party sites.

The ECN and ECBN are relevant to Action T4 in the GIP (Initiate an ecosystem monitoring network acquiring 'Essential Ecosystem Records').

Group 3: other activities not thought to be engaged with delivery of the GIP but known to be collecting climate-related data of the type used for the GCOS ECVs

The **UK Acid Waters Monitoring Network** (which will become the **UK Upland Waters Monitoring Network)** has water level monitoring data for two years for two lake sites and flow gauging at one station run by SEPA co-located with a UKUWMN site. Data is provided to the National River Flow Archive. (*Note: this activity was initially identified as being in Group 1*).

The **Groundwater Ecology** (macrofauna) monitoring by BGS monitors groundwater levels and stygobyte (a groundwater-adapted species) populations in aquifers, however the data are not considered suitable for climate applications as there is still very limited understanding on the controls on distribution of groundwater fauna. A wide range of factors may influence their distribution and in this context the relative importance of climate change on species distributions, let alone ecosystem composition and functioning is entirely unknown.

Fire Disturbance ECV

CEH produce burnt area maps in the activity **Daily and monthly burnt area of the boreal forests (circumpolar).** This is a satellite-remote sensing activity recorded in the UKEOF Catalogue as **Forest Cover of Central Siberia.**

Co-located ecological monitoring

The **Harmonised Monitoring Scheme** provides routine monitoring at 230 sites (monthly measures) in the UK providing monitoring water quality and flow since the mid 1970's. Flow, chemical and ecological measurements are made. The scheme is administered by the Environment Agency in England and Wales, SEPA in Scotland and Rivers Agency in Northern Ireland and involves routine monitoring at 230 sites, including 56 river systems in Scotland.

ICP Forests was launched in 1985 under the Convention on Long-range Transboundary Air Pollution of the UNECE and monitors the forest condition in Europe, in cooperation with the European Union using two different monitoring intensity levels. Within the programme NO2 and NH3 measurements are made at one site.

In the **Experimental Catchments (Plynlimon etc)** catchment and sub catchment streamflow are measured. Within the catchments there are automatic weather stations in the **Met Office Land AWS network**. The combined datasets include river flow; rainfall, cloud and stream hydro-chemistry; meteorology; and a variety of detailed spatial datasets representing the topography, soils and rivers of the catchments.

Appendix 5: UK funded *in situ* observation activities that submit data to the 'well-established' GCOS Networks

Twenty-four *in situ* activities that responded to the consultation operate stations that contribute data to 31 GCOS networks. Details of ECVs that the measurements from the various activities support (via the GCOS networks) are provided in the tables below. All activities highlighted red require follow-up to check that the information in the table is correct.

Environmental Domain:	**ATMOSPHERIC COMPOSITION (over land sea and ice)**			
GCOS ECVs	Other terrestrial	Cryosphere	Marine	Role of satellite derived measures
Aerosols Properties	Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland			*satellite based ECV datasets already available/being developed*
Carbon Dioxide	Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland	Atmospheric Monitoring - Air and snow sampling (BAS LTMS)		*planned but not currently available*
Methane and other Long-lived Green House Gases	Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland	Atmospheric Monitoring - Air and snow sampling (BAS LTMS)		*planned but not currently available*
Ozone	Baseline Measurement of Stratospheric Ozone and UV Cape Verde Observatory Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland Met Office Ozone Sonde	Atmospheric Monitoring - Ozone observations (BAS LTMS)		*satellite based ECV datasets already available/being developed*
Precursors (supporting the aerosols and ozone ECVs)	Cape Verde Atmospheric Observatory? Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland			*satellite based ECV datasets already available/being developed*

Environmental Domain:		**ATMOSPHERE SURFACE AND UPPER AIR (over land sea and ice)**				
GCOS ECVs		Other terrestrial	Cryosphere	Marine	UK funded airborne activities	Role of satellite derived measures
Air temperature	Surface	Met Office Land AWS network Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland	Surface meteorology (BAS LTMS)	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) Surface meteorology (BAS LTMS) Porcupine Abyssal Plain (PAP) Observatory		*No plans at present*
	Upper Air	Met Office Radiosonde Network	Upper air measurements (BAS LTMS)	Met Office Shipborne radiosonde network	AMDAR	*satellite based ECV datasets available/ being developed*
Wind speed & direction	Surface	Met Office Land AWS network Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland	Surface meteorology (BAS LTMS)	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) Surface meteorology (BAS LTMS) Porcupine Abyssal Plain (PAP) Observatory		*satellite based ECV datasets available/ being developed*
	Upper Air	Met Office Windprofiler network Met Office Radiosonde Network	Upper air measurements (BAS LTMS)	Met Office Shipborne radiosonde network	AMDAR	*satellite based ECV datasets available/ being developed*
Water vapour	Surface	Met Office Land AWS network Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland	Surface meteorology (BAS LTMS)	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) Surface meteorology (BAS LTMS)		*No plans at present*

Environmental Domain:		ATMOSPHERE SURFACE AND UPPER AIR (over land sea and ice)				
GCOS ECVs		Other terrestrial	Cryosphere	Marine	UK funded airborne activities	Role of satellite derived measures
	Upper Air	Met Office GPS Water Vapour Programme Met Office Radiosonde Network	Upper air measurements (BAS LTMS)	Met Office Shipborne radiosonde network	AMDAR	satellite based ECV datasets available/ being developed
Pressure (surface)		Met Office Land AWS network Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland	Surface meteorology (BAS LTMS)	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) Met Office Drifting Buoys Programme Surface meteorology (BAS LTMS)		*No plans at present*
Precipitation (surface)		Met Office Land AWS network Long Term Atmospheric Trace Gas monitoring at Mace Head, Ireland		Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM)		*satellite based ECV datasets available/ being developed*
Surface radiation budget		Met Office Baseline Surface Radiation Network				
Earth radiation budget						
Cloud properties		? Met Office Land AWS network		?Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM)		

Environmental Domain:		MARINE SURFACE AND SUBSURFACE		
GCOS ECVs		Other ocean and coastal environments	Cryosphere environments	Role of satellite derived measures
Current	Surface	Met Office Drifting Buoys Programme (derived from positions)		*No plans at present*
	Sub-surface	Met Office Argo Programme (derived from positions) Porcupine Abyssal Plain (PAP) Observatory		
Temperature	Surface	Met Office Drifting Buoys Programme Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) Met Office Argo Programme	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) Oceanographic Monitoring - moorings (BAS LTMS) – TBC – based on an interim response	*satellite based ECV datasets available/ being developed*
	Sub-surface	Met Office Argo Programme Porcupine Abyssal Plain (PAP) Observatory	Oceanographic Monitoring - moorings (BAS LTMS) - TBC – based on an interim response	*No plans at present*
Salinity	Surface	Met Office Argo Programme	Oceanographic Monitoring - moorings (BAS LTMS) - TBC – based on an interim response	*Satellites not expected to contribute significantly*
	Sub-surface	Met Office Argo Programme Porcupine Abyssal Plain (PAP) Observatory	Oceanographic Monitoring - moorings (BAS LTMS) - TBC – based on an interim response	
Carbon dioxide partial pressure	Surface	Porcupine Abyssal Plain (PAP) Observatory		*No plans at present*
Ocean acidity	Surface			
	Sub-surface			
Sea level		Global Sea Level Observing System Tide Gauges		*satellite based ECV datasets available/ being developed*
Sea state		Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) ? Porcupine Abyssal Plain (PAP) Observatory	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM)	*Satellites not expected to contribute significantly*

Environmental Domain:	MARINE SURFACE AND SUBSURFACE		
GCOS ECVs	Other ocean and coastal environments	Cryosphere environments	Role of satellite derived measures
Sea ice	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM)	Marine meteorological observations from Voluntary Observing Ships (incl. VOS CLIM) Cryospheric Monitoring - Sea ice observations (BAS LTMS)	*satellite based ECV datasets available/ being developed*
Ocean colour			
Phytoplankton	?Porcupine Abyssal Plain (PAP) Observatory		No plans at present
Nutrients	Porcupine Abyssal Plain (PAP) Observatory		
Oxygen	Met Office Argo Programme Porcupine Abyssal Plain (PAP) Observatory		
Tracers			

Environmental Domain:	TERRESTRIAL			
GCOS ECVs	Terrestrial – Soil / Rock and Vegetation	Cryosphere environments	Freshwater and coastal	Role of satellite derived measures
River discharge			National River Flow Archive	*No plans at present*
Water use				
Groundwater				
Lakes				*planned but not currently available*
Snow cover	Met Office Land AWS network Met Office Baseline Surface Radiation Network?			*satellite based ECV datasets available/ being developed*
Glaciers and ice caps				
Ice sheets				
Permafrost				*No plans at present*
Albedo				*satellite based ECV datasets available/ being developed*
Land cover				
Fraction of absorbed photosynthetically active radiation (FAPAR)				
Leaf area index (LAI)				
Above ground biomass				*planned but not currently available*
Soil carbon				*No plans at present*
Fire disturbance				*satellite based ECV datasets available/ being developed*
Soil moisture				*planned but not currently available*

Appendix 6: Basis of the gaps analysis for satellite-derived observations

			ATMOSPHERIC (over Land, Sea & Ice)													
			Surface			Upper-Air					Composition					
		Instrument type	Surface Precipitation	Surface Radiation Budget	Near-Surface Wind Speed and Direction (over ocean only)	Cloud Properties	Earth Radiation Budget (including Solar Irradiance)	Temperature	Water Vapour	Wind Speed and Direction	Aerosols Properties	Carbon Dioxide	Methane and other Long-Lived Green House Gases	Ozone	Precursors (supporting Aerosols and Ozone ECVs)
EUMETSAT/METOP	2006-2023															
	AMSU-A	microwave sounding radiometer														
	ASCATT	scatterometer														
	AVHRR/3	moderate resolution optical imager														
	GOME-2	scanning short wave sounder														
	IASI	scanning infrared sounder														
	MHS	scanning microwave radiometer														
	GRAS	GNSS radio-occultation sounder														
	HIRS/4 only to 2018	scanning infrared sounder														
EMETSAT/METOP SG	2021-2043															
(Instrument suite tbc)	IAS	scanning infrared sounder														
	VII	moderate resolution optical imager														
	MWS	microwave sounding radiometer														
	SCA	scatterometer														
	RO	GNSS radio-occultation sounder														
	MWI	microwave imaging radiometer														
	UVNS (sentinel 5)	scanning short wave sounder														
	3MI	moderate resolution optical imager														
	RER	broad band radiometer														
EMETSAT/MSG	2002-2022															
	GERB	broad band radiometer														
	SEVIRI	moderate resolution optical imager														
EUMETSAT/MTG I	2018-2038															
	FCI	moderate resolution optical imager														
EUMETSAT/MTG S	2020-2035															
	IRS	scanning infrared sounder														
	Sentinel-4	scanning short wave sounder														
EUMETSAT/multi-agncy	2008-2019															
	JASON2,3	radar altimeter														
Sentinel 1	2013-2022															
	SAR	imaging radar														
Sentinel 2	2014-2022															
	MSI	high resolution optical imager														
Sentinel 3	2014-2023															
	MWR	microwave radiometer														
	OLCI	moderate resolution optical imager														
	SLSTR	moderate resolution optical imager														
	SRAL	radar altimeter														
Sentinel5P	2015-2021															
	TROPOMI	scanning short wave sounder														
JASON CS	2019-	radar altimeter														

			ATMOSPHERIC (over Land, Sea & Ice)												
			Surface			Upper-Air					Composition				
		Instrument type	Surface Precipitation	Surface Radiation Budget	Near-Surface Wind Speed and Direction (over ocean only)	Cloud Properties	Earth Radiation Budget (including Solar Irradiance)	Temperature	Water Vapour	Wind Speed and Direction	Aerosols Properties	Carbon Dioxide	Methane and other Long-Lived Green House Gases	Ozone	Precursors (supporting Aerosols and Ozone ECVs)
ESA?EOEP missions															
ESA/SMOS	2009-2013	microwave radiometer													
ESA/Cryosat2	2010-2014	radar altimeter													
ESA/Earthcare	2015-2018														
	ATLID	space lidar													
	BBR	broad band radiometer													
	CPR	cloud and precipitation radar													
	MSI	moderate resolution optical imager													
ESA/ADM Aeolus	2015-2018	space lidar													
ESA/Biomass	2020-2025	imaging radar													
Development of ECV datasets current or planned			EUMETSAT, NASA, JPL, JAXA	EUMETSAT, NOAA	EUMETSAT, NASA, JAXA,	ESA, EUMETSAT, NOAA, NASA, JAXA	EUMETSAT, NOAA	EUMETSAT, NOAA, NASA	EUMETSAT, NASA, NOAA, JAXA, JMA,	EUMETSAT, JMA	ESA, EUMETSAT, NOAA, NASA, CSA, JAXA	ESA	ESA, CSA (CH4)	ESA, NASA, CNES, CSA	CNES (CO)

Note: Colour coding relates to the quality of the data from a particular instrument for a particular measurement. Data are taken from the WMO OSCAR database. (Dark green – primary: light green- high, yellow - medium, orange - useful, red –marginal)

			OCEANIC					
			Surface Ocean					
		Instrument type	Ocean Colour	Sea Ice	Sea Level	Sea State	Sea Surface Salinity	Sea Surface Temperature
EUMETSAT/METOP	2006-2023							
	AMSU-A	microwave sounding radiometer						
	ASCATT	scatterometer						
	AVHRR/3	moderate resolution optical imager						
	GOME-2	scanning short wave sounder						
	IASI	scanning infrared sounder						
	MHS	scanning microwave radiometer						
	GRAS	GNSS radio-occultation sounder						
	HIRS/4 only to 2018	scanning infrared sounder						
EMETSAT/METOP SG	2021-2043							
(Instrument suite tbc)	IAS	scanning infrared sounder						
	VII	moderate resolution optical imager						
	MWS	microwave sounding radiometer						
	SCA	scatterometer						
	RO	GNSS radio-occultation sounder						
	MWI	microwave imaging radiometer						
	UVNS (sentinel 5)	scanning short wave sounder						
	3MI	moderate resolution optical imager						
	RER	broad band radiometer						
EMETSAT/MSG	2002-2022							
	GERB	broad band radiometer						
	SEVIRI	moderate resolution optical imager						
EUMETSAT/MTG I	2018-2038							
	FCI	moderate resolution optical imager						
EUMETSAT/MTG S	2020-2035							
	IRS	scanning infrared sounder						
	Sentinel-4	scanning short wave sounder						
EUMETSAT/multi-agncy	2008-2019							
	JASON2,3	radar altimeter						
Sentinel 1	2013-2022							
	SAR	imaging radar						
Sentinel 2	2014-2022							
	MSI	high resolution optical imager						
Sentinel 3	2014-2023							
	MWR	microwave radiometer						
	OLCI	moderate resolution optical imager						
	SLSTR	moderate resolution optical imager						
	SRAL	radar altimeter						
Sentinel5P	2015-2021							
	TROPOMI	scanning short wave sounder						
JASON CS	2019-	radar altimeter						

			OCEANIC					
			Surface Ocean					
		Instrument type	Ocean Colour	Sea Ice	Sea Level	Sea State	Sea Surface Salinity	Sea Surface Temperature
ESA?EOEP missions								
ESA/SMOS	2009-2013	microwave radiometer						
ESA/Cryosat2	2010-2014	radar altimeter						
ESA/Earthcare	2015-2018							
	ATLID	space lidar						
	BBR	broad band radiometer						
	CPR	cloud and precipitation radar						
	MSI	moderate resolution optical imager						
ESA/ADM Aeolus	2015-2018	space lidar						
ESA/Biomass	2020-2025	imaging radar						
Development of ECV datasets current or planned			ESA, NASA, JAXA	ESA, EUMETSAT, NOAA, NASA, JAXA	ESA, NASA			ESA, NOAA, NASA, JAXA

Note: Colour coding relates to the quality of the data from a particular instrument for a particular measurement. Data are taken from the WMO OSCAR database. (Dark green – primary: light green- high, yellow - medium, orange - useful, red –marginal).

			TERRESTRIAL											
			Lakes (not identifed as a variable in WMO OSCAR)	Snow Cover	Glacier and Ice Caps	Albedo	Land Cover (including vegn Type)	FAPAR	Leaf Area Index (LAI)	Above Ground Biomass	Fire Disturbance	Soil Moisture	Ice Sheets	Land surface temperature
		Instrument type												
EUMETSAT/METOP	2006-2023													
	AMSU-A	microwave sounding radiometer												
	ASCATT	scatterometer												
	AVHRR/3	moderate resolution optical imager												
	GOME-2	scanning short wave sounder												
	IASI	scanning infrared sounder												
	MHS	scanning microwave radiometer												
	GRAS	GNSS radio-occultation sounder												
	HIRS/4 only to 2018	scanning infrared sounder												
EMETSAT/METOP SG	2021-2043													
(Instrument suite tbc)	IAS	scanning infrared sounder												
	VII	moderate resolution optical imager												
	MWS	microwave sounding radiometer												
	SCA	scatterometer												
	RO	GNSS radio-occultation sounder												
	MWI	microwave imaging radiometer												
	UVNS (sentinel 5)	scanning short wave sounder												
	3MI	moderate resolution optical imager												
	RER	broad band radiometer												
EMETSAT/MSG	2002-2022													
	GERB	broad band radiometer												
	SEVIRI	moderate resolution optical imager												
EUMETSAT/MTG I	2018-2038													
	FCI	moderate resolution optical imager												
EUMETSAT/MTG S	2020-2035													
	IRS	scanning infrared sounder												
	Sentinel-4	scanning short wave sounder												
EUMETSAT/multi-agncy	2008-2019													
	JASON2,3	radar altimeter												
Sentinel 1	2013-2022													
	SAR	imaging radar												
Sentinel 2	2014-2022													
	MSI	high resolution optical imager												
Sentinel 3	2014-2023													
	MWR	microwave radiometer												
	OLCI	moderate resolution optical imager												
	SLSTR	moderate resolution optical imager												
	SRAL	radar altimeter												
Sentinel5P	2015-2021													
	TROPOMI	scanning short wave sounder												
JASON CS	2019-	radar altimeter												

			TERRESTRIAL											
		Instrument type	Lakes (not identifed as a variable in WMO OSCAR)	Snow Cover	Glacier and Ice Caps	Albedo	Land Cover (including vegn Type)	FAPAR	Leaf Area Index (LAI)	Above Ground Biomass	Fire Disturbance	Soil Moisture	Ice Sheets	Land surface temperature
ESA?EOEP missions														
ESA/SMOS	2009-2013	microwave radiometer												
ESA/Cryosat2	2010-2014	radar altimeter												
ESA/Earthcare	2015-2018													
	ATLID	space lidar												
	BBR	broad band radiometer												
	CPR	cloud and precipitation radar												
	MSI	moderate resolution optical imager												
ESA/ADM Aeolus	2015-2018	space lidar												
ESA/Biomass	2020-2025	imaging radar												
Development of ECV datasets current or planned			NASA	NASA, JAXA	ESA, NASA	EUMETSAT, EC, NASA	ESA, NASA, JAXA	EC, ESA, NASA, JAXA	EC, NASA, USGS, JAXA	NASA	EC, ESA, NASA	ESA, JAXA, NASA	ESA, NASA	EUMETSAT, NASA, JAXA

Note: Colour coding relates to the quality of the data from a particular instrument for a particular measurement. Data are taken from the WMO OSCAR database. (Dark green – primary: light green- high, yellow - medium, orange - useful, red –marginal.