CMUG Deliverable

Number:	**Deliverable 4.1**
Due date:	**March 2013**
Submission date:	**October 2013**
Version:	**Version 3.1 Final**

Climate Modelling User Group

Deliverable 4.1 Version 3.1

Scientific Exploitation Plan (SEP)

Centres providing input: MOHC, MPI-M, ECMWF, MétéoFrance

Note: This is version 3.1 of the Scientific Exploitation Plan.

Table of Contents

CMUG Scientific Exploitation Plan – Version 3

1. Introduction

The first phase of the ESA climate change initiative (CCI) project is to generate satellite climate data records (CDRs) from global satellite data products (GSDPs) for 13 of the essential climate variables (ECVs) defined by GCOS. This scientific exploitation plan documents how the CDRs for each ECV generated by the ESA CCI projects will be exploited by the climate modelling and reanalysis communities at large and how they will assess the CCI datasets within their centres. This document outlines a variety of different approaches for the use of these data for climate modelling and reanalyses.

Section 2 gives an overview of the generic use of the CCI datasets for climate applications and section 3 lists for each ECV specific plans where the data will be exploited. The plans of the Climate Modelling User Group, CMUG, for outreach are also given in section 4. This document has been updated twice during the CMUG phase 1 contract.

2. Climate modelling applications of CCI datasets

There are a variety of different ways the satellite CDRs can be exploited in climate models and reanalysis systems. This section gives a brief outline of the kinds of applications the CDRs will be used for and how they will be assessed by the users at large. An illustrative example is given for each ECV in section 3. Table 1 summarises the anticipated uses of the 13 ESA ECVs. It should be recalled that all the CDR datasets generated will also have associated error characteristics as defined in annex A which are essential for all of these applications.

	Application			
ECV	**Model Initialisation**	**Model Evaluation / Development**	**Climate Record**	**Q/C in situ data**
Sea surface temp	🟩	🟩	🟩	🟩
Ocean colour	🟩	🟨	🟩	🟨
Sea level	🟩	🟩	🟩	
Sea ice	🟩	🟩	🟩	
GHG gas concentration	🟩	🟩	🟩	
Clouds		🟩	🟩	
Aerosols	🟩	🟩	🟩	🟨
Ozone	🟩	🟩	🟩	🟨
Glaciers & Ice caps	🟩		🟩	
Land cover	🟩		🟩	
Fire Disturbance	🟩		🟩	
Soil moisture	🟩	🟩	🟩	🟨
Ice sheets	🟩		🟩	

Table 1. Anticipated use of 13 ECVs of first phase of ESA CCI in climate model and reanalysis centres yellow is possible future requirement, green is definite current requirement.

2.1 Climate monitoring, model initialisation and use in reanalyses

For climate monitoring the datasets need to span at least several decades in order to be able to monitor climate change. Some satellite datasets already approach 30 years in length, but many are shorter than 20 years although continually expanding.

The land surface parameters (Glaciers, ice sheets, soil moisture, land cover and fire disturbance), ocean parameters (sea surface temperature and sea ice cover) and atmospheric gas concentrations (Ozone and greenhouse gases, GHG) are all used to initialise models to better define the surface and atmospheric state. Model-based atmospheric reanalyses make use of existing datasets to prescribe boundary conditions (SST, sea ice, land cover, fire disturbance) and atmospheric forcing (GHG, aerosols). Both accuracy and consistency are essential requirements for these input parameters to be useful for the production of climate-quality reanalyses. Accordingly, the suitability for reanalysis purposes of some of the ECV products can be tested by means of sensitivity experiments, in which these products are used as input to the reanalysis system. This would involve an assessment of their impact on the reanalysed atmospheric fields, as well as on the quality of re-forecasts generated from the reanalyses.

Global atmospheric reanalyses generate estimates of ozone and cloud based on a broad variety of assimilated meteorological observations, originating from both in-situ and remote sensing instruments using an NWP model assimilation to impose the consistency between the different thermodynamical fields of the reanalysis. ECV products for ozone and cloud therefore can be directly compared with those produced by the reanalyses. If the ozone products are of sufficiently high quality, then they may also be assimilated in an atmospheric reanalysis system. Similarly, GHG and aerosol ECV products can be compared with output from the MACC reanalysis, and it may be possible to perform experiments with the MACC system to evaluate the impact of assimilating some of these new atmospheric ECV products.

In general, ECV products from the ESA CCI are being incorporated in a comprehensive climate monitoring system which is being developed at ECMWF. This web-based system displays multi-decadal time series of a broad variety of atmospheric climate parameters in an integrated view. It provides facilities for comparing different variables and products and, where applicable, generating departures between the ECV products and their reanalysis-equivalents. The underlying reanalysis data will be made available to the CCI projects to allow further in-depth evaluation. The ultimate aim is to assimilate CDRs for these ECVs and demonstrate improvements in the model initial state over the existing datasets.

2.2. Confronting climate models and reanalyses with observations

Confidence in climate model predictions can only be obtained by confronting the model predictions for current and past periods with observations from a variety of sources. Satellite data provides a means to assess the validity of the global model fields: in many cases, e.g. clouds, they provide the only source of complete global coverage. High-level satellite products can be compared directly with their model-simulated equivalents and this remains a valuable source of information, particularly for identifying first-order errors and inconsistencies in the simulations. Increasingly, however, climate modellers are forward modelling the quantities actually measured by the satellite instruments, e.g. radiances at specific wavelengths. The reason for doing this is to try and avoid the ambiguities introduced in the retrieval process and which make direct comparisons between satellite-derived products and model fields problematic. In order to do this satellite data “simulators” or “observation operators” have to be provided with the observations. These are used to compute given the model state $\boldsymbol{X}$ a simulated set of observation $\boldsymbol{y(X)}$ from the model which is equivalent to the real observations $\boldsymbol{y^o}$. The observations $\boldsymbol{y(X)}$ can be computed from temporally averaged fields (e.g. six hourly or monthly mean) or be for instantaneous conditions. If the former the observations also have to be averaged in time and space to match the mean model fields. An example of the comparison of the observations $\boldsymbol{y}^{o}$ with the simulated observations $\boldsymbol{y(X)}$ is shown in Figure 5 where satellite clouds for low levels (<680hPa) are compared with model simulations of the same cloud definition for thick and medium clouds. Two versions of the Met Office Hadley Centre model are shown with the newer model fitting the satellite data better. The newer model has a better representation of the cloud physical processes included.

2.3 Validating model process studies

In order that NWP and climate models can represent all the significant physical processes in the atmosphere and surface and at the same time be computationally affordable these processes have to be parameterised in some way. This leads to inevitable compromises between accuracy and speed of computation. Satellite data can help to validate the parameterisations in the model for some physical processes through studying diurnal and seasonal variations and comparing statistical relationships between variables in both the model and observational domains. An example using Cloudsat data is given in section 3.8 below.

2.4 Feedback of CCI projects into numerical weather prediction

The reprocessing of the satellite datasets will not only benefit climate models but also these improvements should feedback to the operational NWP satellite processing. The preparation of satellite data for the reanalysis datasets for example has led to improved processing of satellite data. One example is the discovery of the incorrect representation of the Zeeman Effect in the radiative transfer calculations of high peaking microwave sounding channels at ECMWF discovered by comparing the SSU temperature record with the AMSU-A temperature record of the upper stratosphere. When this was corrected a better fit of the microwave radiances to other observations in the upper stratosphere was seen. The operational real time assimilation of these radiances now include this beneficial change in the radiative transfer model which leads to better analyses of the upper stratosphere in NWP models. Another example is the assimilation of the satellite ocean colour product where the CCI datasets have helped to demonstrate this in reanalysis mode *before* it is implemented in real time operational systems. Normally the opposite is the case. This implies it will be important to feedback improvements in the processing of satellite data products developed in the CCI projects to the operational satellite agencies and NWP centres.

2.5 Monitoring of in-situ observations

Satellite measurements provide a globally complete coverage with the same sensor whereas in situ measurements provide point measurements sometimes with a diversity of different sensors. The satellite data can be used to compare with the in situ measurements to identify there are any biases or sudden changes in the characteristics of a particular sensor for example a drifting buoy or radiosonde. An example of the former is shown in Figure 1 where drifting buoys are compared with AATSR SSTs. Many buoys exhibit the behaviour shown in the top panel but some buoys show a changing bias with time as shown in the bottom panel. The distribution of the differences between in situ and satellite measurements can also inform users about the error characteristics (i.e. precision, stability and representativity) of the in situ data, for example this shows the proportion of real outliers and where quality control thresholds could be set.

A similar application is to compare the satellite CDRs with other satellite datasets through building up matchup files. Again more can be inferred about the error characteristics of the datasets. It will be important that the CCI projects provide matchup datasets with the CDR datasets they produce to aid validation studies.

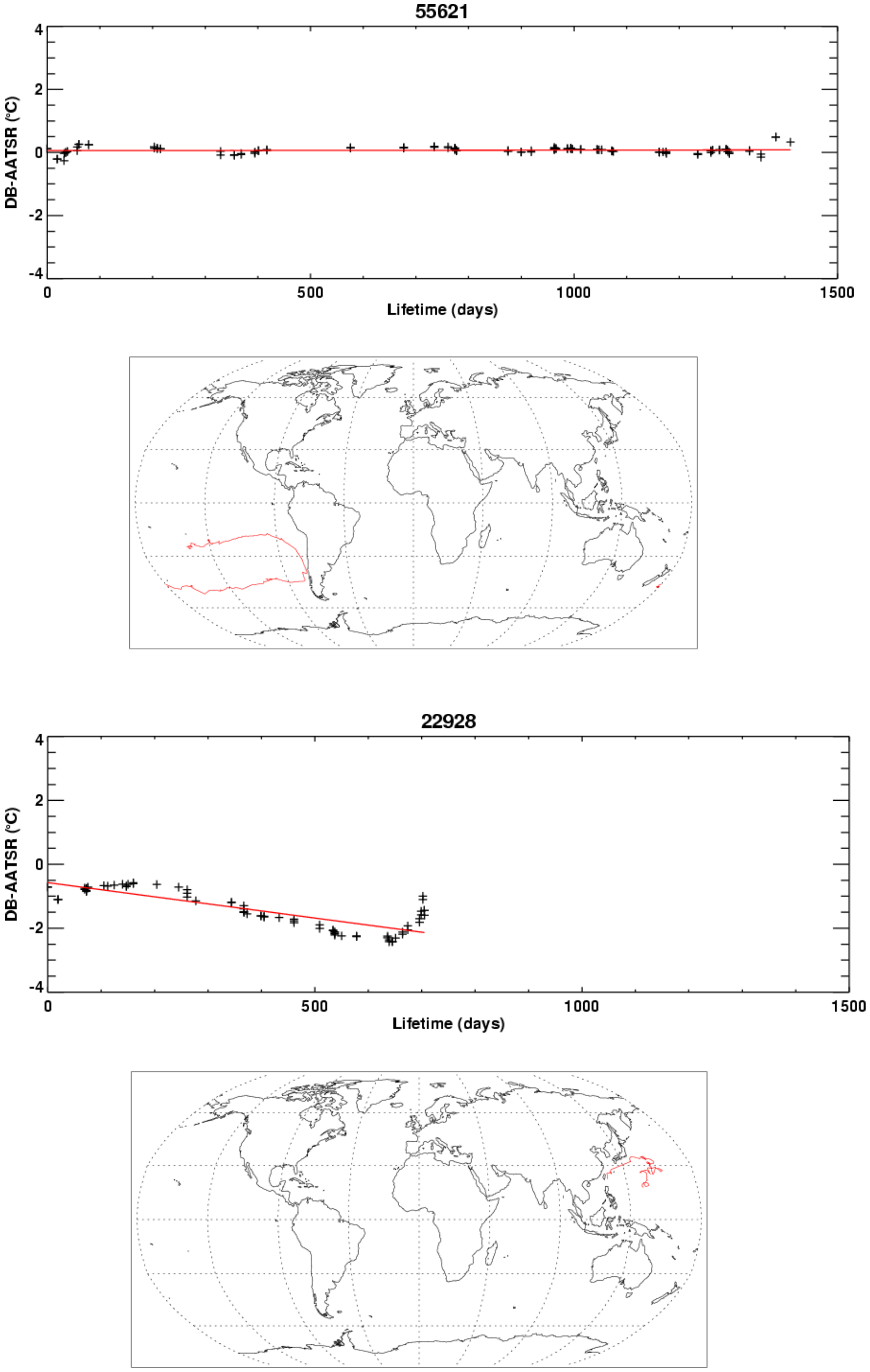

Figure 1. Comparison of one drifting buoy SST measurements with those from AATSR over several years. The top panel shows a ‘good’ buoy and the lower panel shows a ‘bad’ buoy as identified by the satellite data.

3. Exploitation of CCI ECVs

3.1 Sea-Level

The impact of climate change on sea level is an important issue that is discussed at length in the last IPCC report (WG1 AR5 2013). One key result is the rising global sea level at an average rate of 1.7+/-0.2mm yr^{-1} over the period 1901-2010. This trend is accompanied by an important interannual and decadal variability that could explain at least part of the observed accelerated rate over the 1993-2010 period (3.2+/-0.4mm yr^{-1}). In addition, sea-level change is non-uniform spatially with regions where sea level is falling and others regions where the sea level rising rate is several times the global mean. Satellite altimetry gives the opportunity to record this high temporal and spatial variability either directly or by combination with in-situ hydrographic data through their assimilation in ocean models. One possible first application of the CCI sea level product will be to document this variability that could serve as an input to studies aiming at determining the magnitude of the different contributions to sea level change in different regions (thermal expansion, glaciers and ice-cap melting, continental hydrology).

The CMIP5 (Coupled Model Intercomparison Project) coordinated climate model experiments provide an incomparable data base of climate simulations covering the 20th century and 21st century. Global average sea level change, global average steric sea level change, and global thermosteric sea level change are required outputs of the modelling exercise. In addition, some groups will diagnose 2D fields of these different variables. This gives the opportunity to compare the outputs from the models with the CCI sea level product covering the satellite altimetry period i.e. from the very beginning of the 1990s. A complete validation of the models will not be of course possible due to the random character of the internal climate variability simulated by the models that are not constrained with observations. However, trend analyses over the observation period, at the global and possibly at the basin or sub-basin scale could be done to evaluate the consistency between the simulated sea-level rates of change with the observed one. Particular attention could be given to those simulations of the CMIP5 exercise aiming at evaluating the ability of models to predict at the decadal scale (10-year and 30-year hindcast predictions). In this case, models will indeed be initialized with more realistic atmospheric and ocean conditions.

Ocean reanalyses are now being created or planned and the sea-level observations will be an important part of this activity. A list of reanalysis activities can be found here: http://reanalyses.org/ocean/overview-current-reanalyses

Pre-cursor CDR datasets for the sea level are from Jason (1/2) and Topex-Poseidon (1992-2010) with the latter providing a good time series. The assessment of the sea-level CCI datasets within the CMUG will be performed by comparing products from the Mercator assimilation system (in particular reanalyses) with the SSH produced by the CCI product. Special attention should be given to events such as ENSO, for checking the ability of models to forecast occurrence and intensity of related variables like sea surface height, SSTs etc.

3.2 Sea-Ice

The decline in arctic sea-ice in recent years is a clear indicator of climate change in the arctic region as shown in Figure 2. Models however have not accurately predicted this reduction and so an accurate sea-ice dataset (extent and thickness) is required as the basis for developing improved model predictions. The interaction between the sea-ice, SST and sea-level ECVs needs to be studied in order to better model the decline in sea-ice extent.

Accurate ocean surface fields of SST and sea-ice are important to provide boundary conditions for NWP, ocean and climate model runs and reanalyses. The presence of sea-ice is critical for the ocean to atmosphere energy exchanges in these models. With coupled models increasingly being developed the sea-ice can more directly affect the overlying atmospheric conditions and these can feed back on the sea-ice fields. Before being presented to the NWP models the SST fields and sea-ice fields are merged in to a complete ocean surface field (e.g. HadSST) which is then presented to the models. Interest is now being shown in ice surface temperature as a new sea-ice variable of interest for defining the energy budget although this is not part of the CCI sea-ice dataset.

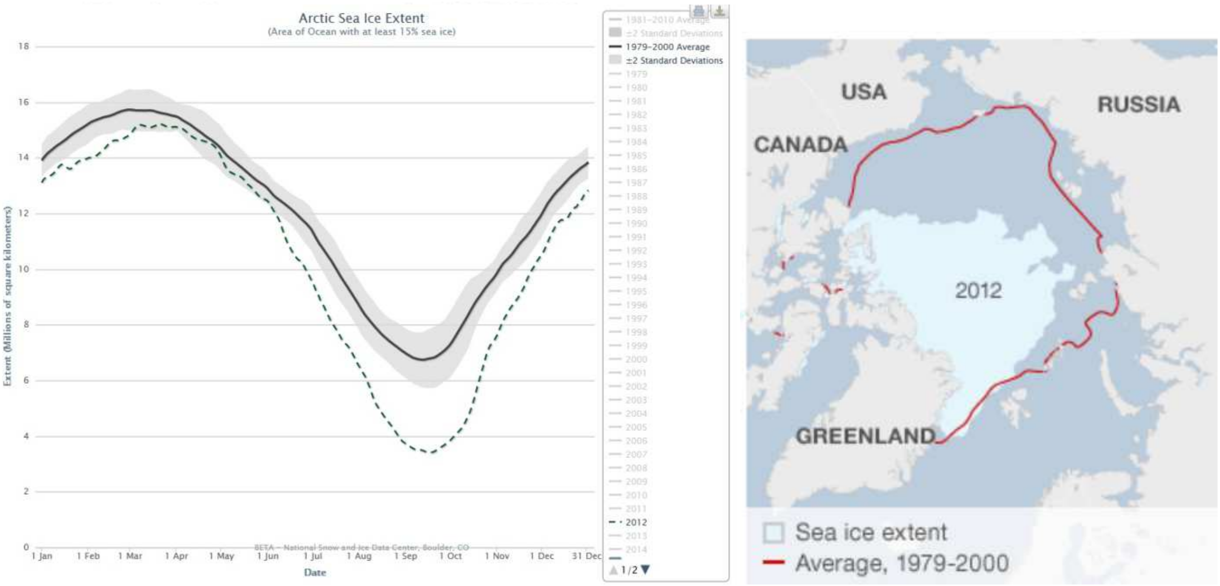

Figure 2. The decline in sea-ice extent from 1979 to 2012.

3.3 Sea surface temperature

The sea surface temperature record is an important indicator of climate change and the surface skin temperature is something which can be easily measured from space. The SST CDRs produced during the CCI will be used both as independent records of global SST and also for assimilation into climate quality analyses such as HadISST. These analyses in turn are used for climate model runs (e.g. for IPCC studies) and as input to reanalyses. The SST CDRs can also be used for seasonal and decadal model predictions by direct assimilation into a coupled ocean atmosphere system.

One of the challenges of the SST measurements from satellites is to convert the measurement from a radiative skin temperature to a bulk SST which is representative of a daily mean value. The CCI dataset will provide bulk SSTs but original skin SSTs may also be useful in future climate model analysis which would be adapted to provide skin SSTs providing a better basis to compare with the satellite observation. This will then require an observation operator for skin SST to be included in the model SST analysis.

Before the full exploitation of the SST CDRs they will be assessed in the following ways:

- Comparison with equivalent precursor datasets (e.g. ATSR Reprocessing for Climate - ARC dataset from the (A)ATSR series of instruments)

- Comparison with independent in situ and satellite datasets (e.g. buoys, ship temperatures and ship-borne radiometers and satellite microwave SSTs)
- Compare with ECMWF and OSTIA reanalysis ocean surface temperatures
- Assimilate in ocean models and compare impacts with precursor datasets

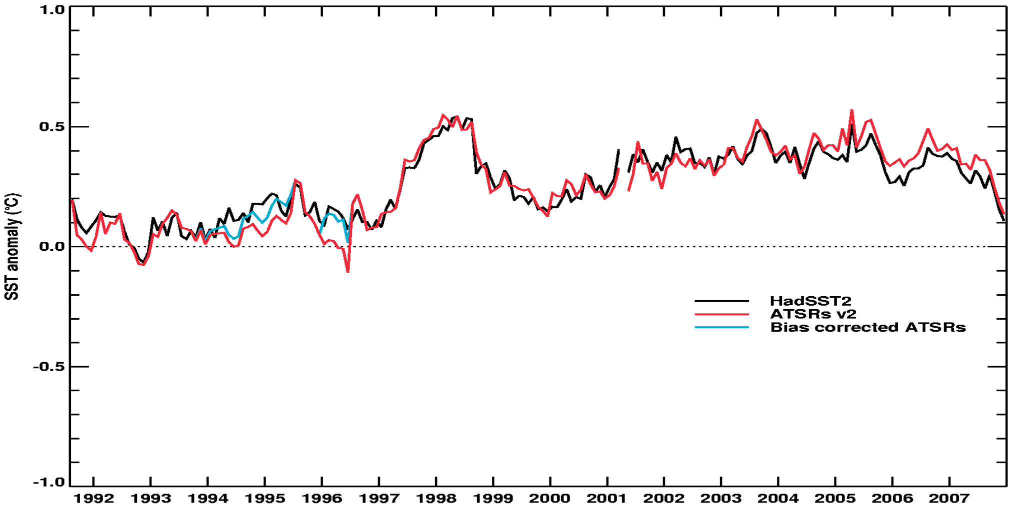

Figure 3. ATSR SST anomaly (red line) and Hadley Centre SST climate analysis anomaly (black line). An improved ATSR-1 processing is shown in blue.

An example of a satellite time series compared with model analysis is the sea surface temperature record from (A)ATSR. Figure 3 shows a comparison of the satellite SST anomaly compared with the model SST anomaly from 1991 to 2008 for the near real time operational ESA retrieved SST.

For the CCI dataset evaluation by the CMUG the ARC SST product derived from the (A)ATSR instruments will be an ideal pre-cursor. The sea surface temperature data records will be compared with the MOHC climate quality SST analysis, HadISST and the MeteoFrance ARPEGE analysis. In addition comparisons will be made between the CCI product and Mercator reanalyses. The new CCI SST data products, will also be incorporated in ECMWF’s reanalysis monitoring systems. This will facilitate a general assessment of data quality in a comprehensive geophysical framework, e.g. by studying the response to known climate signals and variability. It will also help detect spurious signals in the data caused by observing system changes and/or algorithmic issues. In addition, the new satellite product, if available in time, might also be evaluated in the context of the HyMeX observing periods (planned in 2011 and 2012) in comparison with in-situ observations and other SST products covering the Mediterranean (e.g. MERCATOR analyses). If the HyMeX data are not available in time a comparison over the Tropical Atlantic will be made using the PIRATA and AMMA-EGEE datasets. It will also be important to assess the consistency of the SST fields with other related ocean and atmospheric datasets such as sea-ice, sea level, ocean colour and clouds. This can be done in the framework of the ERA and MOHC FOAM models.

Not part of phase 1 of CMUG but eventually the impact on the climate model predictions and reanalyses will be ascertained through an OSE using ERA-Interim only with the new SST fields (and new sea-ice if available) and compare the overall quality of the analyses with respect to the old ERA-Interim fields. Near surface fields should benefit from an improved SST/sea ice field. Specific events such as response to ENSO or anomalies due to volcanic eruptions would be studied.

3.4 Ocean Colour

The impact of climate change on marine ecosystems and the ocean carbon cycle, from global to regional scales, can only be quantified by using long-term data sets, including satellite ocean colour. Synoptic fields of ocean colour (derived chlorophyll pigment), are used as an index for phytoplankton biomass, which is the single most important property of the marine ecosystem. Ocean colour is also the basis to infer primary production (CO_2 uptake by algae) and is currently the only source of observational data offering complete global coverage. This offers a wide scope of ocean colour CDRs applications, which include:

- initialisation and verification of coupled ocean-biogeochemical models and potentially ocean-atmosphere-biogeochemical models.
- data assimilation for state, as well as parameter estimation.

Novel data assimilation schemes for ocean colour data have been successfully adapted and integrated in coupled ocean-biogeochemical circulation models (Edwards *et al.*, 2009)[1] at basin and regional scales, and shown their ability to improve the representation and estimation of ocean carbon cycle diagnostics, e.g. primary production, the exchange of CO_2 between the ocean and the atmosphere. An area that has not been explored so widely is that of data assimilation for parameter estimation, which consists of using data to constrain poorly known model parameters for the purposes of improving representation of, in this case, the carbon cycle.

The patterns of ocean phytoplankton concentration provided by the ocean colour data, combined with models, are an important source of information to physical-biogeochemical process studies, such as primary production, respiration and interactions at the air-sea interface. For example, in most parts of the ocean, phytoplankton controls the optical turbidity and hence impact on the ocean heat budget, the stability of the water column (mixed layer depth) and the ocean circulation. Hence, ocean colour data provide the observational link between the ocean ecosystems, the physics of the mixed layer and the heat fluxes between the ocean and the atmosphere.

The GlobCOLOUR datasets will be a good precursor for the ocean colour CCI dataset. Limited validation can be performed with a few in situ data points from ship cruises, and island monitoring sites. When available the ocean colour ECV would be assimilated into the MOHC FOAM model to produce a derived chlorophyll field in the model.

3.5 Land Cover

3.5.1 Relevance of land cover data in climate modelling

An adequate representation of the land surface characteristics and dynamics is necessary for climate modelling. The land surface acts as a lower boundary condition for the atmosphere, exchanging energy and matter fluxes with the atmosphere at multiple time scales. Memory effects of the land surface can alter the exchange processes with the atmosphere at time scales from minutes to years.

To appropriately simulate the interactions of the land surface with the atmosphere, climate models need a detailed characterization of the land surface . Typical model surface parameters are listed in Table 2.

Thus, even though land cover products provide the spatial pattern of different land cover types, the land cover classes need to be translated into model relevant surface parameters that can be used

---

[1] Edwards, K., Ford, D., Lea, D., Barciela, R. M. and Martin M. (2009). Assimilation of GlobColour products into operational models. ESA Project report.

in the model equations. Typically this is realized by assigning the necessary surface parameters as attributes to the land cover classes using typical values from the literature or auxiliary data sets.

Background albedo	
Vegetation albedo	α
Leaf area index	LAI
Forest ratio	fR
Fractional vegetation cover	fc
Surface roughness length	z0
Plant available soil water holding capacity	W_{fc}
Volumetric wilting point	W_{wilt}

Table 2: List of common land surface parameters used in climate models (actual parameters might vary dependent on the model)

As climate models are used at spatial resolutions in the order of tens to hundreds of kilometres, they cannot sufficiently resolve the heterogeneity pattern of the land surface. The model parameterization is therefore either based on aggregated land surface parameters (Hagemann, 2002)[2] or a model grid box is divided into different fractions (tiles) of different land cover types. The model simulations are then conducted individually on these tiles and the simulated fluxes are aggregated using area fraction weighting. These tiles might comprise different overarching land cover classes or might be separated into different plant functional types (PFT's).

3.5.2 Assessment of ECV land cover

The assessment of the ECV and cover product has the objective to investigate how the new land cover data product can be used to best simulate current climate. As the land cover is closely related with the surface parameters as albedo and vegetation parameters, required by the model, an integrated assessment of the land cover product together with auxiliary remote sensing based data sets will be made.

The ECV land cover product will be combined with remote sensing information of relevant surface parameters to generate a consistent land surface parameter data set that can be used as a boundary condition in climate models. The land surface parameter data set will be generated with the highest possible spatial resolution to allow for its use in regional and global climate models. The data set will include characterizations of the uncertainties of the surface parameters. The assessment of the developed land cover and associated parameter data set will be made using the MPI-M Earth System Model (ESM). The development and first assessment will be based on pre-cursor data products, like those listed in Table 3. The methodology will be adapted to the ECV land cover data set subsequently.

---

[2] Hagemann, S., 2002 An improved land surface parameter dataset for global and regional climate models. MPI Report No. 336, Max Planck Institute for Meteorology, Hamburg.

Parameter	Data set	Period	Spatial coverage	Resolution	Data provider
Land Cover	GlobCover	2005	global	300 m	ESA
	Cyclopes				
faPAR	GlobCarbon	1998-2007	global	10 km … 0.5°	ESA
	JRC-TIP	2005	Global	1km	JRC, Bernard Pinty
	Cyclopes	1999 – 2007	global	1 km	Postel
LAI	GlobCarbon	1998-2007	global	10 km … 0.5°	ESA
	JRC-TIP	2005	Global	1km	JRC, Bernard Pinty
	Cyclopes	1999 – 2007	global	1 km	Postel
fCover	Cyclopes	1999 – 2007	global	1 km	Postel
	JRC-TIP	2005	Global	1km	JRC, Bernard Pinty
albedo	GlobAlbedo	TBD	global	TBD	ESA project ongoing

Table 3: List of potential pre-cursor data sets for the generation of land surface parameter dataset. JRC-TIP like product might be derived from GlobAlbedo, once the dataset is available to extend temporal coverage

3.6 Fire disturbance

Fire is an integral Earth System process, which is controlled by climate and at the same time impacts climate in multiple ways. As such fires form a feedback mechanism in the Earth System, which might amplify or dampen climate change. Fires control vegetation dynamics and link the land carbon cycle and the hydrological cycle. In addition, fires affect climate by the means of many other climate relevant processes, such as changes in land surface characteristics and atmospheric concentrations of greenhouse gases, chemically active gases and aerosols. Because of these inherently complex fire climate interactions, Earth System Models form the critical tool to explore the fire-climate feedback. State-of-the-art ESMs, however, neglect the integral role fires have in the Earth System mainly because of the lack of prognostic fire models that are able to simulate fire occurrence on a global scale. Satellite CDRs on fire disturbance can be used to improve prognostic fire models.

The land surface scheme JSBACH (Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg) within the MPI-M/ESM simulates fluxes of energy, water, momentum, and CO_2 between land and atmosphere. The vegetation dynamics considers competition between different plant functional types (PFTs), as well as natural and disturbance driven mortality. Satellite CDRs on fire disturbance will be employed to evaluate the simulated fire disturbance. The evaluation will be primarily performed with burned area as derived from satellite but when suitable also products such as active fire counts and fire radiative power will be used as supplementary information. Metrics will be defined to best benchmark the model performance with respect to spatial distribution as well as seasonal and interannual variability of fire occurrence. Thereby, it is essential to include an understanding of the uncertainties related to the satellite based CDRs into these metrics. In addition, such benchmarking activities will benefit from long-term fire CDRs. Therefore, the CCI fire disturbance ECV will best suit the fire process model evaluation when it covers a long time period and is supplemented by consistently derived uncertainty values.

Process based prognostic fire models are essential to assess the fire-climate feedback. In addition vegetation models can be utilized to diagnostically simulate fire emissions by combining information on burned area, available fuel load and burning conditions. Satellite observed burned areas can be used as direct input to the vegetation model. The fire model within JSBACH will allow a direct forcing by externally prescribed burned area datasets as an alternative to the prognostic burned area simulation. As such JSBACH will be used to simulate fire emissions in accordance with the CCI fire disturbance ECV. This approach is similar to offline diagnostic fire emission models, but the use of a vegetation model overcomes the need to prescribe besides the burned area the available fuel load. This approach is still limited by an uncertain quantification of parameters that depend on the burning conditions (e.g. combustion completeness, mortality rates, emission factors). The development and first assessment will be based on the burned area reported in the GFEDv3 product and will be extended to the fire ECV subsequently.

When burned area products extended by uncertainty estimates are introduced into the model these can be translated into subsequent uncertainties in the derived emissions. Such information will be very valuable for the use of these emissions in atmospheric chemistry models. When applied in the MPI-M ESM framework the emissions could be directly utilized in the atmospheric model to simulate the atmospheric composition and the subsequent climate impact. Consistency with the GHG and aerosols CDRs produced in the CCI can then form an important check on the fire disturbance product.

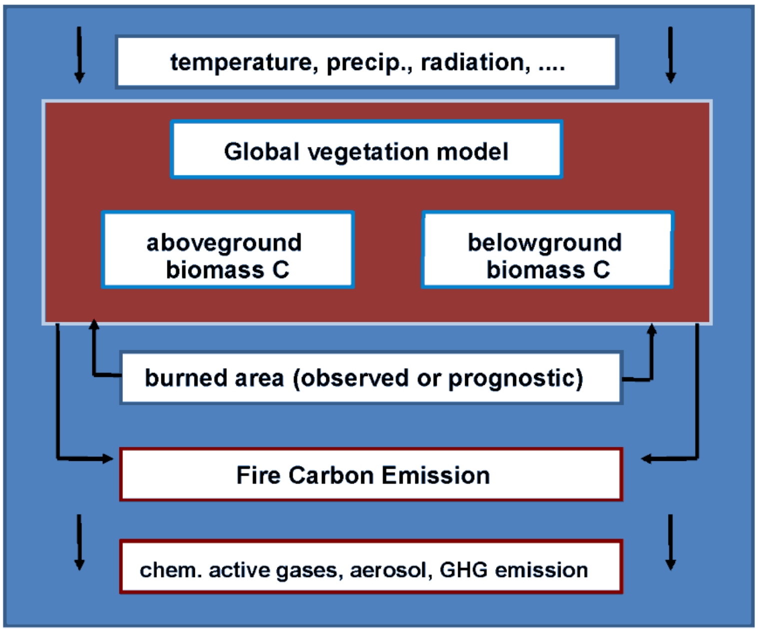

Figure 4: Application of the CCI fire disturbance ECV in a vegetation model.

3.7 Ice sheets, Glaciers and ice caps

New models of glaciers are being included in land surface models (e.g. JULES, EC-EARTH, HIGHNOON). The satellite products will validate these land ice models and eventually the data will be used to initialise the land ice fields in the models. This will be the first time that satellite climate datasets are used by these models to improve their representation of land-ice.

Regional climate models (e.g. ECHAM5-MPI-OM) are also interested to use the extent and mass balance of glaciers on a sub-grid scale using a tiled approach. Glacier inventory data are important for both **model development** of representation of glaciers in their surface schemes and also for **model applications** (initialization and evaluation).

Over the last decade, the Greenland Ice Sheet has decreased in volume significantly which is an important change in the cryosphere and as such it is important to monitor this change. In common with glaciers the accurate representation of these ice sheets in climate models both in the Arctic and Antarctic are crucial to correctly model other variables such as sea-level rise.

3.8 Clouds

Cloud feedbacks remain one of major sources of uncertainty associated with model predictions of future climate, both globally and regionally. The most recent IPCC report (WG1 AR5 2013), for example, highlighted cloud feedbacks (in particular those related to changes in boundary layer clouds) as the largest contributor to uncertainties in global climate sensitivity, i.e. the global mean equilibrium temperature increase in response to CO_2 doubling. Consequently, a great deal of attention is currently focused on improving the representation of clouds and cloud processes in climate models, with the Cloud Feedback Intercomparison Project (CFMIP) leading this effort (see http://cfmip.metoffice.com). CFMIP is a co-ordinated international activity which aims to bring together the global climate modelling, process modelling and observational communities to work on these issues. The importance of cloud processes and feedbacks is such that specific experiments in CMIP5/AR5 are included to address the requirements of CFMIP. A key aspect of

CFMIP is how to best exploit satellite observations for model evaluation and development and, if possible, to assess the credibility of model-simulated cloud feedbacks. The use of CCI cloud data sets by the CMUG will thus be within the context of CFMIP and its goals.

The cloud modelling community has taken the lead in the forward modelling approach described in Section 2.2 above. The ISCCP simulator, which allows climate models to simulate the cloud optical depth (TAU) versus cloud top pressure (CTP) histograms produced by ISCCP has been extremely successful in identifying model systematic errors and is now employed by all of the major climate modelling centres. An example is shown in Fig 5: this shows the improvements in the simulation of boundary layer cloud in the most recent version of the Met Office Hadley Centre climate model HadGEM1, compared to the previous model HadCM3.

The utility of the ISCCP data stems from the fact that statistical summaries (the TAU-CTP histograms), when employing the ISCCP simulator, can be compared to climate model output in a very straightforward manner. This has been recognised by the observational community and ISCCP-like histograms are now produced using both MODIS and MISR data (see example in Fig 6). Work is also being done to produce these histograms from CERES data. The ISCCP simulator has now evolved into a much more sophisticated tool (COSP – http://cfmip.metoffice.com/COSP.html) which allows models to simulate a range of satellite instruments, including those shown in Fig. 6 together with CloudSat and CALIPSO (see below). COSP includes modules to reproduce model versions of the ISCCP, MODIS and MISR TAU-CTP histograms, taking into account the individual characteristics of the different measurements.

The CMUG initial suggestion to the CCI clouds project will thus be to produce similar ISCCP-like histograms; and then the CMUG will develop a new module for COSP to simulate these in climate models. This approach has several advantages:

- It puts the CCI data into a format that is already familiar to modellers.
- It allows the CCI data to be easily compared to other cloud data sets.
- It allows the CCI data to be easily integrated into pre-existing and tested methods for exploiting satellite cloud data for model evaluation.

COSP is already being used by all of the major worldwide modelling centres, so the development of a CCI clouds module will allow the data to be widely used by the modelling community.

The experience and feedback to the CCI project gained using the data in this way should also provide the basis for development of new, specifically CCI clouds products for climate modelling applications. In the first instance, however, it is important to demonstrate that the CCI clouds data is relevant to the goals of CFMIP/IPCC and the requirements of the cloud modelling community. As noted above, a wide range of useful techniques already exist for comparing climate models with satellite cloud data: these include, for example, clustering techniques, which allow cloud structures to be examined in detail, and combining the cloud data with reanalysis information and other observations. Examples of the latter include combining the cloud data with:

- Earth radiation budget data (e.g. CERES) enabling consistency between clouds and cloud radiative effects to be examined in models;
- Information on the large-scale circulation from reanalyses, enabling clouds to be examined in relation to dynamical regimes, e.g. areas of large-scale ascent/descent or areas of high/low boundary layer stability.

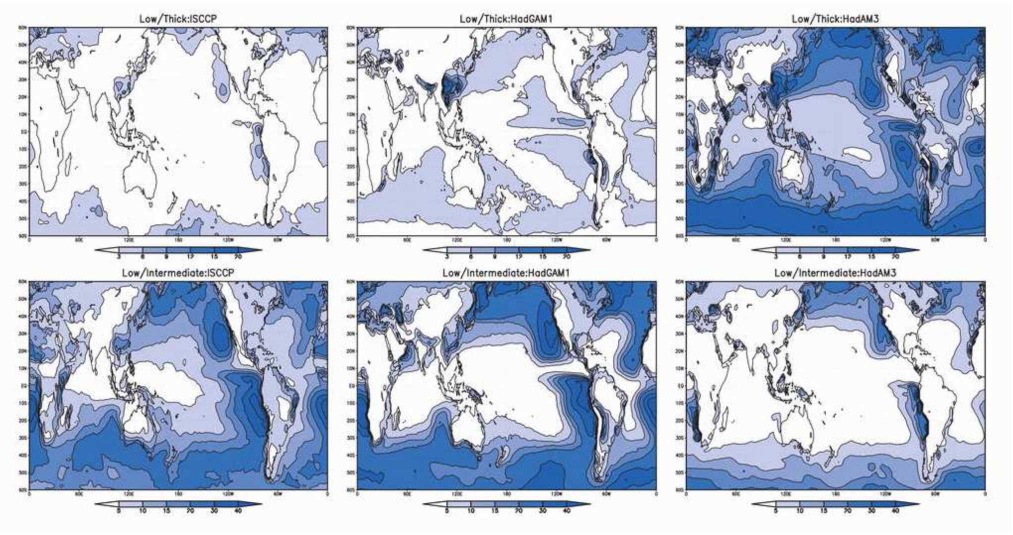

Figure 5. Comparison of optically thick low cloud coverage (in percent, upper panels) and medium thickness low-level cloud coverage (lower panels) from satellite data (left panels) and with the two most recent Hadley Centre models (centre and right panels) for a 20 year average 1984-2002.

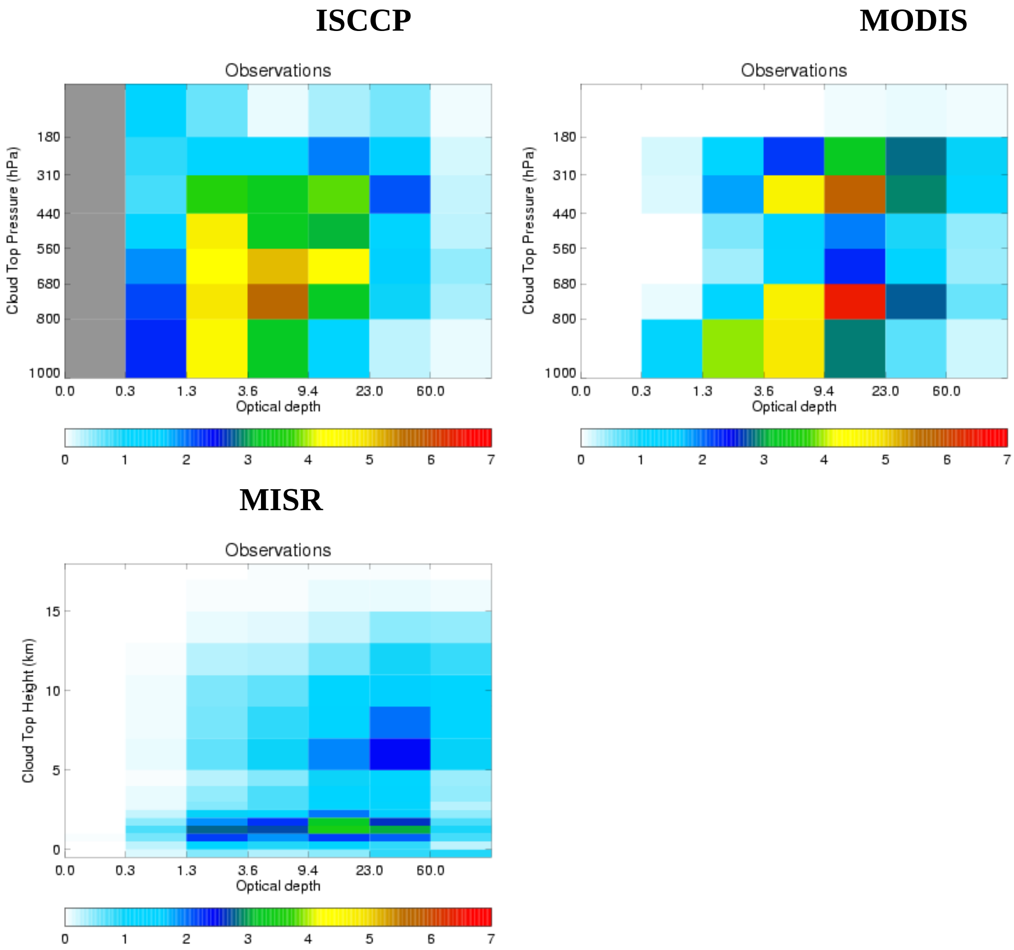

Figure 6. Comparison of TAU-CTP histograms from ISCCP, MODIS and MISR for the North Pacific Ocean for September-October-November 2006.

These methods will be applied to the CCI clouds products alongside similar work with the ISCCP and other cloud data sets: in this way the CCI data will also provide information on the range of observational uncertainty.

A multi-year record will allow interannual cloud variations to be determined and compared with model simulations. The most prominent of these are the cloud anomalies which develop over the Pacific Ocean during ENSO events: comparison of the cloud response to the anomalous SST and circulation patterns provides a powerful test of models used for seasonal to long-term prediction. Also consistencies between the cloud record and aerosols (e.g. Saharan dust outbreaks, stratospheric aerosol) should be verified in the context of climate model runs and reanalyses.

Subsequent work will examine the novel characteristics of the CCI clouds data – what information does it provide in addition to pre-cursor datasets such as ISCCP, MODIS, etc? Examples might be improved information on the vertical distribution of cloud or better detection of high thin cirrus. The former is a particular asset of CloudSat and has led to its rapid exploitation by the modelling community (see Fig. 6). The role of the CCI clouds data from a modelling perspective will need to be examined in relation to CloudSat, CALIPSO and, eventually, EarthCARE.

Finally, if a goal of the CCI cloud project is to produce a data set suitable for examining long-term trends then, if these prove to be reliable, they will compared to model simulations of present-day variability, e.g. at decadal time scales. This can be done both globally and regionally according to the robustness of the observed trends at different spatial scales.

For the CMUG assessment of the “CCI clouds” they will be evaluated using the MOHC HadGEM2 and HadGEM3 climate models in relation to other studies with ISCCP data and other satellite based cloud products such as those from the GEWEX cloud climatology assessment. The COSP simulator will be enhanced to include the CCI cloud products to enable model equivalent clouds to be generated for comparison purposes. Properties to be compared include the annual and seasonal cycles of cloud cover, cloud altitude, cloud optical depth / water content and cloud microphysics. The evaluation of these cloud properties will take place in the context of other studies to assess the simulation of the impact of clouds on the solar and infrared radiative energy balance at the top of the atmosphere, within the atmosphere and at the surface. A key goal is to ensure consistency in the simulations of cloud properties and their radiative impacts and to minimise compensating errors. Other comparisons will also be done with the CNRM-CM model using the ISCCP cloud simulator.

New CCI cloud data products will be incorporated in ECMWF’s reanalysis monitoring systems, to allow a detailed comparison with reanalysed cloud distribution and cloud properties. The reanalysed cloud parameters are model-generated but constrained by all observations used, and therefore provide an independent check on the quality of the cloud data products. The outcome of such a comparison will be qualitative but very useful nevertheless, since the consistency of the cloud estimates with other parameters represented in the reanalysis (e.g. humidity, temperature, and precipitation) can be ascertained in this way.

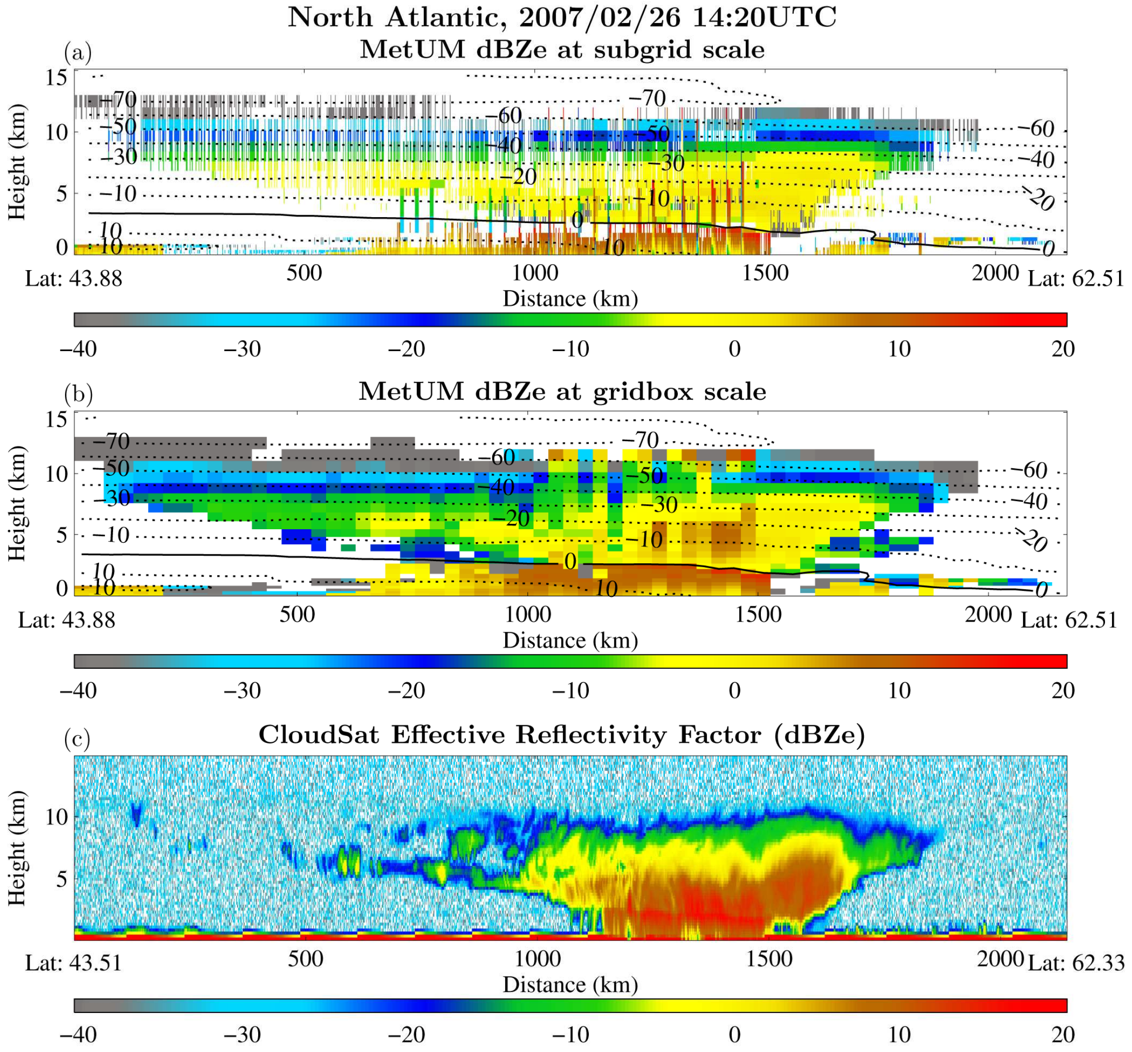

Figure 6. Vertical profiles of radar reflectivities as simulated by the Met Office global forecast model at two different scales along a transect through a mid-latitude cloud system. The observed profile of reflectivity from CloudSat along the same transect are shown in the lower panel.

3.9 Aerosols

Atmospheric aerosols (both tropospheric and stratospheric) are of great importance because of their impacts on human health, visibility, continental and maritime ecosystems, the stratospheric ozone layer, or the Earth's climate. A better knowledge of the climate sensitivity is critical to climate and air quality policy-making. As a result dedicated monitoring of their concentrations and properties on global scales is required. There is a need to understand regional to intercontinental transport of aerosols in order to design efficient policies for monitoring of aerosols and their precursors and emission abatement strategies. The impact of aerosols on climate is often cited as one of the most uncertain factors governing climate change. Aerosols have offset part of the warming expected from anthropogenic emissions of greenhouse gases. It is very important to decrease the uncertainties on the aerosol forcing because this will contribute to better constrain the climate sensitivity from current observational climate records.

The dominant radiative forcing mechanisms for aerosol are scattering and absorption of incoming solar radiation (direct effect) and the increase in cloud condensation nuclei on which cloud droplets form, leading to an increased cloud albedo (first indirect effect). Complementing estimates from global modelling, the MOHC and the MPI-M have been developing methods based on remote sensing data from ground and space to identify aerosols of anthropogenic origin and estimate their direct and first indirect effects. Mineral dust, sea-salt, sulphate, nitrate, carbonaceous, and biomass burning all exert a significant perturbation to the Earth's radiation budget via the direct and indirect effects. While these effects have been comprehensively investigated in climate models over the last decade and their importance in climate and climate change noted, there has been relatively little study of the effects of aerosols in numerical weather prediction (NWP) models. Recently, it has been shown that the error in the top of the atmosphere outgoing longwave earth radiation budget in the Met Office NWP model over dusty areas of the Sahara desert was of a greater magnitude than the error associated with both convective and stratiform clouds indicating that the time is right for aerosols to be explicitly included in NWP models to reduce systematic biases. The current aerosol climatologies within NWP global models are extremely basic and essentially consist of time-invariant two-dimensional fields.

Precursor datasets for aerosols include the GlobAerosol products (1995-2007) and the MODIS deep blue aerosol optical depth (2003-2010). The CCI aerosol datasets will be compared with MACC analyses in the first instance and later assimilation in the MACC model will be contemplated. Assimilation of pre-cursor aerosol amount (aerosol optical depth) and aerosol size (Angstrom parameter) of MODIS Terra (am) and Aqua (pm) satellite sensors into the ECWMF modelling environment is being undertaken with MACC.

At MPI-M basic evaluations of the CCI aerosol ECV products will be performed against reference products such as the AERONET sun-/sky-photometer network and to nudged hindcast simulations of the AeroCom exercises. AeroCom is an international global modelling initiative to understand and improve the capabilities of aerosol modules in global atmospheric models. The comparisons will be co-ordinated with the GEWEX aerosol assessment.

In addition at a later stage, impact studies for the new data products may be conducted based on data assimilation experiments with the MACC system once the aerosol CCI datasets are of sufficient quality. It should be noted that the fire datasets will be relevant for the aerosol assimilation. Statistics on spatial and temporal distribution would also be valuable for exploitation of satellite observations, where aerosols can introduce large regional biases (e.g. for measurements of GHGs). The consistency with the cloud datasets must also be considered as there is close interaction between these ECVs.

3.10 Ozone

The CCMVal (Chemistry-Climate Models Validation) activity was initiated by the Stratospheric Processes And their Role in Climate (SPARC) core project of the WCRP. It is aimed at assessing the ability of Chemistry-Climate Models (CCMs) to reproduce past observations in the stratosphere and the future of stratospheric ozone and climate under one particular scenario. Among the analyses, some attention is given to the ability of the models to reproduce observed natural stratospheric ozone variability and their ability to reproduce the key natural processes that determine this variability. Several ozone profile data sets based on satellite observations were employed for the analyses. The production of a new satellite-derived ozone product from the CCI gives the opportunity to include it in a following phase of this international exercise. In addition, the compilation and assessment of observational databases suitable for model evaluation is the focus of a future SPARC activity. It should be noted that for tropospheric ozone more stringent verification of the products is required for which special activities would need to be setup.

The investigation of ozone variability can also be done through the assimilation of satellite observations in a chemical-transport model. Such an analysis has been performed for the cold northern hemisphere winter of 2004-2005. The assimilation of ozone and NO_2 from Aura/MLS in the MOCAGE-PALM assimilation system, enabled evaluation of the role of dynamical processes on the ozone loss profile (El Amraoui et al, 2008)[3]. This is only an example of the potential scientific exploitation of CCI ozone through an assimilation system. It is however worth noting that the case study referred to demonstrates a particular advantage of combining the assimilation of different chemical variables in order to better constrain the chemical-dynamics system.

In addition, global atmospheric reanalyses generate estimates of ozone based on a broad variety of assimilated meteorological observations, originating from both in-situ and remote instruments. ECV products for ozone therefore can be directly compared with those produced by the reanalyses. If the ozone products are of sufficiently high quality, then they may also be experimentally assimilated in an atmospheric reanalysis system.

For ozone the pre-cursor datasets are TOMS, GOME-1/2, Sciamachy and SBUV with TOMS and SBUV providing long time series. The total ozone column simulated by the MOCAGE-Climate model driven with ECMWF analyses will be compared to the CCI corresponding products and with alternative products from satellite observations (e.g. the assimilated NIWA database that combines satellite-based ozone measurements).

Assimilation of IASI radiances have also been demonstrated[4] to usefully complement UV measurements. Long time series will be available and the optimal way to combine with CCI ozone should to be defined. In addition, the diurnal ozone cycle has to be investigated to quantify the impact on radiative budget and chemistry processes.

Finally, intrusions of stratospheric ozone are easily detectable and would provide climate indicators which should be valuable to investigate.

3.11 Greenhouse gases

In the same way as for ozone GHG ECV products can be compared with output from the MACC reanalysis, at least for the period 2003-2010, and it may be possible to perform experiments with the MACC system to evaluate the impact of assimilating some of the new ECV products. Pre-cursor datasets for GHGs are very limited but the datasets for methane and carbon dioxide from Sciamachy may be suitable. As with ozone the consistency of the GHG datasets will be compared with the ozone datasets in MACC. Also the consistency of the GHG datasets with the land cover, fire and aerosol ECVs should be verified.

3.12 Soil moisture

An accurate representation of the land surface moisture field is important for all model forecast ranges. For short range NWP the soil moisture can influence the forecast precipitation and low level humidity field as shown in various studies. As a result soil moisture from ASCAT is now being

---

[3] L. El Amraoui, V.-H. Peuch, P. Ricaud, S. Massart, N. Semane, H. Teyssèdre, D. Cariolle, and F. Karcher 2008 Ozone loss in the 2002-2003 Arctic vortex deduced from the assimilation of Odin/SMR O_3 and N_2O measurements: N_2O as a dynamical tracer Quart J. Roy. Meteorol. Soc., **134**, 630, pp. 217-228.

[4] A. McNally and Wang 2008

assimilated into operational NWP models e.g. Dharssi et. al.[5]. For seasonal forecasts an accurate soil moisture is also important in governing the precipitation e.g. Koster et. al. 2004[6]. Soil moisture is a key variable in forecasting droughts, dust storms, fires, floods, river run-off and crop yields. It is also related to sea-level as the more water that is resident on land the lower the sea-level is and so when considering sea level rise this should be taken into account.

4. Future plans for exploitation of GCOS ECVs

This section should look beyond the 13 ESA CCI datasets and propose what else might be done post phase 1 of the CCI projects in the exploitation of satellite CDRs. There are clearly important ECVs not covered by the ESA CCI which do need to be addressed. Some key points are:

- Need to co-ordinate with EUMETSAT (and others) so that efforts are complementary.
- It is important that the current 13 data sets are used to evaluate CMIP6/AR6[7] simulations and become part of any co-ordinated effort to create a model evaluation data base.
- Consider when new ECVs should be considered for implementation.

From the online questionnaire of the CMUG climate modellers have stated that the following ECVs are the most important to be considered for the next phase of the CCI.

Atmospheric ECVs:
- Precipitation
- Earth radiation budget
- Surface winds
- Water vapour

Marine ECVs:
- Salinity

Terrestrial ECVs:
- Snow cover
- Albedo

It is recommended that ESA consider this priority list for the next phase of the CCI project if these are not being covered by other agencies.

5. Future developments in the application of climate data

An area currently under development in Europe and elsewhere is using climate information in applied research for managing natural systems and for the benefit of society. This is commonly referred to as ‘Climate Services’. Climate information in this context includes both climate observation and model projection data, and as such the CCI ECVs have a significant role to play in contributing observation data to the former. The European Commission is funding Climate Services for Europe through Copernicus, a programme which comprises several component projects covering different domains and sectors (Land, Marine, Atmosphere, Emergency, Security, and Climate). The CMUG should have links with these component projects of Copernicus to ensure

---

[5] Dharssi, I., Bovis, K. J., Macpherson, B., and Jones, C. P. (2011). Hydrol. Earth Syst. Sci., 15, 2729-2746, doi:10.5194/hess-15-2729-2011.

[6] Koster, R.D. et. al. (2004) Science, 305, 1138-1140.

[7] A decision on the nature of the next IPCC assessment report is expected in 2015.

that the value which modelling can bring to climate observation datasets is appreciated. There are also a number of FP7 funded projects which support the development of climate research and climate data development within Copernicus, and again, CMUG should develop links with these projects. These projects include: ERA-CLIM2, UERRA, QA4ECV, CLIPC, and EUCLEIA, and in many cases CMUG partners are also partners in these projects.

6. Plans for outreach

There are many channels of communication to the climate modelling and reanalysis communities, hereafter referred to as users, which will be used to make the users aware of the new CCI CDRs to be generated for the 13 ECVs which this project is initially focussing on. The following channels are being exploited as appropriate:

- Presentations on the planned and sample ESA CCI datasets at meetings during phase 1 of the CCI.
- Continued development of the CMUG web site to make the community aware of the CCI datasets planned and available. This is easily found by Google search, as it is the first entry displayed when “CMUG” is entered. We will aim to Link CMUG/CCI websites off CLIVAR, WCRP, WGCM pages.
- Set up a CMUG newsgroup where important announcements about the CCI datasets are sent out to registered users when CCI datasets become available.
- Consider Webinars on topics of interest to the CCI teams.
- High level awareness of the CMUG activities at the CMUG partner institutes.
- Working level interactions with key scientists in climate modelling and reanalysis centres through the scientists in the CMUG institutes and invitations to CCI/CMUG meetings.
- Lobby to include CCI datasets in appropriate IPCC reviews, CMUG partners contribute to the IPCC reviews and are in a good position to promote this.
- Ensure some of the CCI datasets are available from the Obs4MIPS site.
- Link with GCOS activities through GCOS project office and AOPC.
- Link with relevant EU projects which require CCI data as input. The CMUG has a wide involvement with such projects (e.g. IS-ENES, CHARMe, Core-CLIMAX, SPECS, …)
- Attendance at key climate modelling, reanalysis and satellite data meetings by CMUG staff to promote the CCI datasets (e.g. CMIP5, WCRP Science conference, EUMETSAT Meteorological Satellite Conference, etc)
- Give inputs to the WCRP GEWEX scientific steering group and sub-groups (e.g. WDAP, WGCM) as appropriate.
- Publication of article in Bulletin of American Meteorological Society or similar.
- Co-ordinate outreach with individual CCI projects to ensure consistent message is given
- Advertise early use of CCI datasets in CMUG partner institutes.
- Organise a workshop to promote and inform users about the available CCI datasets. Invite key scientists to attend and offer them travel and subsistence if necessary.
- By working with the CCI projects ensure that the CDRs (and associated observation operators) are easy to access and ingest in commonly used formats. In addition their error characteristics must be provided along with the datasets. Providing the datasets on the Earth System Grid will be a key objective.
- Links to EUMETSAT’s proposed activities on climate monitoring – need to ensure complementarity and avoid any duplication of effort, etc.

Given the activities listed above it is hoped that the awareness of the ESA CCI datasets will be sufficient to allow their exploitation to be as wide as possible by interested users.

Annex A: A Consistent Definition of Error Characteristics

For climate data records it is important to have a consistent definition of error characteristics of these datasets. Depending on the application there are several aspects of the measurements where the uncertainty needs to be defined. A recent meeting[8] between meteorologists and metrologists attempted to define these different aspects of the errors which are given below. It is recommended the CCI projects adopt a consistent definition for error characteristics and a first iteration is given below. Figure A1 is a graphical example of the different types of error.

Bias is the measure of the non-random, systematic error, that defines the offset between the measured value and the true value that constitutes the SI absolute standard

Precision is the measure of reproducibility or repeatability of the measurement without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation. Note that in satellite measurements precision can also refer to the number of bits a raw measurement is stored in.

Uncertainty is a combination of the precision and bias for an individual measurement.

Stability is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error - the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true value.

Representativity is important when comparing with or assimilating in models. Measurements are typically averaged over different horizontal and vertical scales compared to model fields. If the measurements are smaller scale than the model it is important. The sampling strategy can also affect this term.

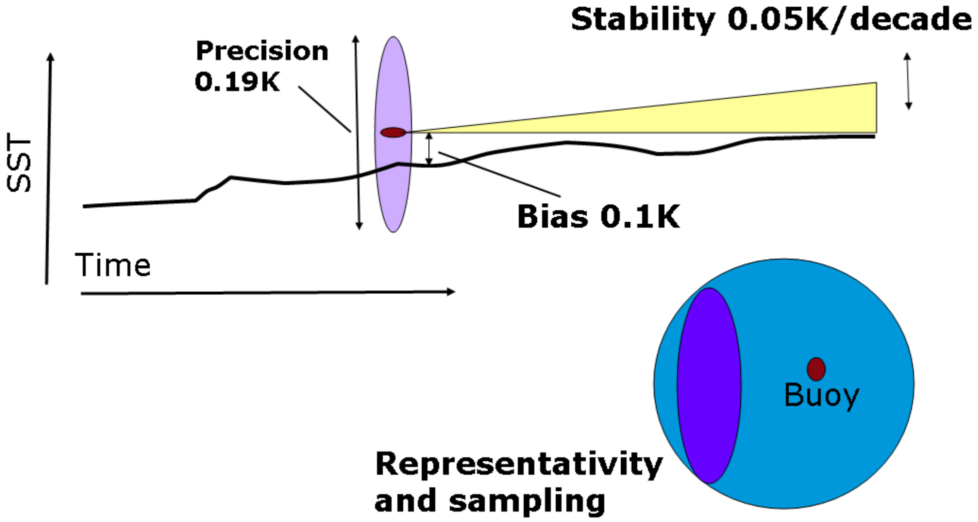

Figure A1. Graphical plot showing different kinds of errors which may need to be defined for satellite CDRs.

---

[8] http://www.bipm.org/en/events/wmo-bipm_workshop/