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Climate Modelling User Group

Deliverable 2.4

Technical note
Analysis of how the CCI datasets will meet climate modellers needs

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

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Deliverable 2.1

Technical note

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Table of Contents

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1. Purpose and scope of the Technical note

The purpose of this document is to comment on how the proposed ESA climate change initiative (CCI) programme will meet the current and future needs of climate modelling and reanalysis applications. The aim of the document is to provide ESA with an overview and review of the expected use and value of the CCI portfolio of products by the Climate Modelling Community (CMC).

The basis for the CCI climate datasets is the Product Specification Documents (PSDs) recently issued by each of the CCI project teams defining the datasets they plan to produce. The versions of the PSDs available to the Climate Modellers User Group (CMUG) at the end of May 2011 were taken as the input to this analysis. CMUG is tasked with providing the ECV teams with feedback on their specifications and this is being done in a separate document by CMUG (CMUG, 2011). The expected science value anticipated here is in part conditional upon the extent to which the ECV teams address the issues raised in that feedback. Subsequent evolutions of the datasets may change the assessments given in this report.

The utility of the datasets for each of the 10 essential climate variables (ECVs) listed in Table 1 is first considered separately, followed by an analysis of their combined benefits. Only the 10 currently 'active' ECVs are included in this document and only the requirements for climate modelling, reanalyses and trend analyses for detection and attribution are addressed here. It should be recognised there will be wider applications for some ECVs than climate modelling (e.g. NWP assimilation) but these are not specifically addressed here.

This document attempts to answer for each ECV the following questions:

- Summarise applications for each ECV
- Consider what datasets are available now and being used by the modellers
- Comment on how the new CCI datasets for each variable will build on the existing datasets for the various applications identified
- Document what is missing for climate modelling purposes

The aim is to provide the reader with an overview of what added value the CCI datasets might bring to the climate modelling and reanalysis communities in the 2012-2018 timeframe (commensurate with CCI Phases 1 and 2 which are planned to run from 2010 to 2013 and 2013 to 2016 respectively).

2. Introduction

The climate modelling and reanalysis communities are increasingly making use of satellite data to initialise, assimilate and validate their models. One impetus for this is the increasing complexity of the physical processes now represented in the models and also the increasing resolution (horizontally and vertically). In a recent survey carried out by the CMUG on the most important ECVs for climate model validation are: precipitation, radiation budget, water vapour and cloud but many others are now of interest to the CMC.

ESA has funded 10 consortia to develop thematic climate data records (TCDR) for 10 specific ECVs, as defined by GCOS, which are listed in Table 1 as part of the CCI programme. The ECVs chosen are those which ESA sensors can make a real contribution to. The 10 consortia were formed during the summer of 2010. One of the first tasks of each consortium was to develop a user requirements (URDs) and product specification (PSDs) for their proposed products. The URDs were derived in a number of diverse ways from face to face interviews to on-line web questionnaires, and an analysis of the results was carried out. The GCOS requirements (GCOS-107) were used as the baseline and then further developed taking into account the separate CMUG requirement analysis (CMUG, 2010) where several different application areas were considered in addition to the GCOS long term monitoring requirement. A more recent evaluation of the requirements by GCOS and other initiatives such as the CMIP5 model comparison exercise which will feed into the next IPCC AR-5 report were also considered.

From the URDs products have been proposed to best meet the user requirements where possible. In some cases the user requirements cannot be met and a judgement has to be made whether the TCDR will be useful for climate modelling or reanalysis applications and this is addressed in this report. The URDs contain information not only on the parameters required and their accuracy but also on the data formats, accessibility, metadata and documentation. These aspects are not reviewed in detail here but it is anticipated that all the CCI datasets will meet the requirements of the modellers in this respect.

ECV	Science Leader
Cloud	Deutsche Wetterdienst
Ozone	Belgium Institute for Space Aeronomy
Aerosol	DLR/Finnish Met Institute
GHGs	Univ. Bremen
SST	Univ. Edinburgh
Global Land Cover	Université Catholique de Louvain
Sea level	CLS (Collecte, Localisation, Satellites)
Ocean Colour	Plymouth Marine Labs
Glaciers	Univ. of Zurich
Fire Burnt Area	Univ.of Alcala

Table 1. The 10 CCI ECVs and the lead institutes.

3. Overview of climate modelling community

The principal European climate models which will potentially benefit from the new satellite datasets being produced by the CCI are listed in Table 2. Typically the global models are now run at a horizontal resolution of 100km with 50 levels but continuing to increase in spatial sampling below 100km and number of levels up to 100. The standard climate models are expected to increase in resolution for the next IPCC AR6 report to around 50km resolution. Some climate groups are already using 0.5 degree and higher atmospheric models already in research mode.

Lead Institute	Model name(s)	Model components			Model resolution	
		CC	AT	LU	Atmos.	Ocean
MOHC	HadGEM2-ES HadCM3C	● ●	● ●	●	N96L38 N48L38	1°L40 1.25°L20
IPSL	IPSL-M4_v2 IPSL-CM4-LOOP	 ●		●	N48L19 N48L19	2°L31 2°L31
MPI	MPI-ESM	●	●	●	T63L47/ T159L95	TP10L40/ TP04L80
FUB	EGMAM+		●	●	T30L39	T42 L20
INGV	ECHAM5-OPA-C	●			T31L19	2° L31
CNRM	CNRM-CM5			●	T127L31	1° L42
NERSC	BCM2 BCM2-C	 ●		● ●	T63L31 T63L31	2.4°L35 2.4°L35
EC-Earth	IFS+NEMO+		●	●	T159L62	1°L31
	Reanalyses					
ECMWF	ERA-Interim/ ERA-40	ECMWF IFS model			T159L60/ T255L60	
KNMI/ MOHC	EURO4M	HIRLAM/UM			25km/L70	
MyOCEAN	GLORYS	NEMO/ORCA025				0.25°/50L
ECMWF	HOPE					1.0°/29L

Table 2. European Institutes and their current ocean-atmosphere coupled GCMs and Reanalyses with additional features listed. (CC=carbon cycle component; AT=aerosol transport/chemistry component; LU=transient land use change component; ● = model component included.)

The various physical processes represented in each model are also indicated which governs the type of satellite data needed to validate the different processes. The number of processes represented by the models is expanding all the time and this increases the need for observational datasets to verify them. Many of the models listed in Table 2 are taking part in the CMIP5 comparison which is currently underway and has a range of variables which will need to be validated by satellite data.

The CCI datasets will not be available in time for input to the IPCC AR-5 report but on a longer timescale they will be useful to help assess the CMIP5 model intercomparison results.

Apart from the global perspective there are also many other regional climate models run in Europe covering individual nation states and they benefit both from the global model runs through providing boundary conditions and a denser sampling of the satellite datasets. These regional models typically have resolutions in the range 10-50km and a list of them are documented in the D1.1 report from CMUG (CMUG, 2010).

There are several different applications of satellite data for climate modelling which are listed here:

- Climate Monitoring and Attribution
- Model Initialisation and Definition of Boundary Conditions
- Model Development and Validation
- Input to reanalyses
- Data assimilation for seasonal to decadal forecasts
- Quality control of in-situ data

Some applications are more important than others for each ECV. An overview of the applications applicable for each ECV is given in Table 3 with an assessment of the most important applications and more details of the requirements for each application are in Annex B of the CMUG URD (CMUG, 2010b).

GCOS ECV	Climate Model Initialisation	Prescribe Boundary Conditions	Re-analyses	Data Assimilation	Model Development and Validation	Climate Monitoring/ Attribution	Q/C in situ data
Atmospheric							
Cloud properties			x		X	x	
Ozone	x	x	X	X	X	X	x
Greenhouse gases	x	x	x	X	X	X	x
Aerosols	x	x	X	X	X	X	x
Oceanic							
SST	X	X	X	X	x	X	x
Sea level	X	X	x	X	x	X	x
Sea-ice	X	X	X		x	X	x
Ocean colour				X	x	x	
Terrestrial							
Glaciers and ice caps	X	X			x	X	
Land cover (inc veg)	X	X	X		x	X	
Fire	X	X			X	X	

Table 3. Requirements of CCI ECVs for climate research. The primary applications have the bigger crosses.

The following sections give a review by the CMUG of the proposed datasets for each of the ECVs that were documented in the PSDs at the end of May 2011 and their potential contribution to the climate modelling and reanalysis communities. There is a table for each ECV giving the proposed primary products as defined in the PSDs (highlighted in yellow) and the corresponding user requirements from GCOS-107 and the 2011 update and the more detailed CMUG (2010b) requirements analysis. This allows an easy comparison of how well the ECV products will meet the user requirements. The versions of the PSDs used are given in Annex-A. Several comments on the proposed products relate to the time span covered by them which in some cases is rather limited in phase 1 of the CCI. It is expected that the gaps in the time periods for some ECVs will be filled, where there is valid satellite data, as part of phase 2 of the CCI project. For those ECVs with limited time spans at the end of phase 1 it is unlikely they will be of much interest to the climate modelling and reanalysis communities and it will also make any assessments of products for these ECVs difficult.

4. Comments on the potential contributions of datasets from each ECV team

4.1 Sea surface temperature

The sea surface temperature record is an important indicator of climate change and the sea surface skin temperature is something which can be easily inferred from satellite measurements. The long term global SST record is used as one of the key indicators of climate change. Secondly climate quality analyses such as HadISST (Rayner et. al. 2003), which extend back in time for more than 150 years, are used to initialise climate model runs both free running and forced by observed SSTs. SST analyses are also used for decadal and seasonal forecasting through assimilation in coupled ocean-atmosphere models. Finally they are also important to define the ocean surface temperature for reanalyses (e.g. ERA-Interim).

At present the main input to SST analyses are ships, buoys (drifting and moored) and satellite datasets. The latter that are currently used as input to SST analyses are summarised here. Firstly the NOAA/NASA Pathfinder and GHRSST AVHRR bulk SST datasets are available from several NOAA polar orbiters at 8km resolution through the NASA PODAAC and from the METOP satellite at 1km resolution from the EUMETSAT Ocean Sea-Ice SAF. They provide good coverage in cloud free areas and go back to 1982 but are only accurate to 0.5degK. The (A)ATSR SST ARC skin and bulk SST dataset (Merchant et. al., 2008) provides less coverage in cloud free areas than AVHRR but is far more accurate (better than 0.15degK) and will be used as the reference SST for all other datasets from 1991 onwards once released to the community in 2011. A reanalysis of the OSTIA SST system used in real time has been carried out which includes all available satellite data back to 1985 and this complements the HadISST climate quality analysis which is more conservative in its data use (e.g. no microwave SST data are used). For input to the IPCC AR5 report it is planned to use the new HadISST2 climate analysis which for the first time includes both the (A)ATSR and AVHRR satellite SST datasets. HadISST2 is also being provided to ECMWF for the next generation of reanalyses. To provide more complete coverage SSTs from the geostationary satellite imagers can also be used but a consistent reanalysis of SSTs from geostationary satellites has not been carried out to date. Finally microwave sensors with low frequency channels at 10GHz or lower can be used to provide SST measurements through cloud albeit only at an accuracy of 0.5degK but providing good coverage especially in persistently cloudy regions where there is a paucity of in-situ data. The AMSR-E and TMI datasets have SST datasets going back to 2002 and 1998 respectively which have been reprocessed by Remote Sensing Systems. The current baseline is that most climate models and reanalyses use the HadISST SST analysis which is based on in-situ data (ships, buoys) and AVHRR SSTs back to 1982.

The CCI SST team are planning to provide reprocessed datasets from the (A)ATSR series and the AVHRR series from 1991 to present. The methodology is well proven as the ARC precursor project has already managed one reprocessing of the entire (A)ATSR data. The CCI (A)ATSR dataset should be an incremental improvement over the existing ARC SST dataset in terms of better cloud detection and treatment of the early ATSR-1 period with stated accuracies of 0.1K over 1000km scales and a stability of 0.05degK. The resolution of the level 2 data is stored as 0.05deg or <10km which matches the GCOS requirements and most of the CMUG applications as given in Table 4. The reduction in accuracy for smaller regional areas is important to quantify for trend monitoring. For modelling applications the uncertainty for individual measurements, which will be higher, is the important parameter. The AVHRR pathfinder SST dataset (version 5) has significant biases especially during periods of high aerosol loading (e.g. Saharan dust outbreaks, Pinatubo eruption) and so there is more scope here to reduce the errors by applying the same methodology as used already for the (A)ATSR reprocessing. It is anticipated the CCI (A)ATSR and AVHRR datasets will replace the ARC and AVHRR pathfinder datasets as input to the climate quality SST analyses and for reanalyses when they become available with consequent improvements in the climate model and seasonal/decadal predictions produced. The SST climate data record should also be improved for detection and attribution of trends. It is also anticipated the GHRSST community will adopt these new CCI datasets when they become available as they will be available in the L2P format.

Application		Horizontal resolution	Temporal sampling	Accuracy	Stability	Source
All		0.05°(~5.6 km)	1 day	0.1 K	0.1 K/decade	SST CCI PSD
All	Target	1 km	1 hour	0.1 K	0.1 K/decade	GCOS
	Breakthrough	8 km	3 hour	0.126 K		
	Threshold	500 km	1 day	0.2 K		
Trend monitoring		10 km	1 month	0.1 K	0.05 K/decade	CMUG
Seasonal forecasting		100 km	1 day	0.1 K	0.1 K/decade	CMUG
Decadal forecasting		50 km	1 month	0.1 K	0.1 K/decade	CMUG
Climate quality analysis		50 km	1 month	0.1 K	0.1 K/decade	CMUG
Reanalysis		1 km	3 hour	0.2 K	0.1 K/decade	CMUG

Table 4. Products and Requirements for the SST ECV as stated by GCOS, CMUG-1.2 and the proposed SST CCI project PSD.

There are some additional climate datasets that would be useful for SST but are not included in the CCI. For climate trend monitoring and reanalyses it would be better to start the SST dataset in the late 70's or early 80's when AVHRR data was available even though the measurement uncertainty is higher. This period has not been reprocessed carefully yet. Also the resolution required both temporally and spatially for regional reanalyses is higher than provided by the CCI SST datasets. Another element could be to improve the spatial coverage through use of an improved microwave SST product from AMSR-E, TMI and possibly the SMMR instrument to go back to 1978. These activities would further improve the SST analyses for climate applications especially for the early satellite years.

4.2 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 (e.g. derived chlorophyll concentration), 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 applications, which include:

- initialisation and verification of coupled ocean-biogeochemical models and potentially ocean-atmosphere-biogeochemical models at basin and regional scales 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.
- data assimilation in ocean models for parameter estimation, using data to constrain poorly known model parameters for the purposes of improving representation of the carbon cycle.

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 merged ocean colour dataset that is primarily used by the community at present is GlobColour which started in 2002 and continues to the present. This dataset has associated error characteristics required by the modelling community. Single sensor datasets also exist from the CZCS, SeaWiFS, MODIS and MERIS instruments with the first one extending the record back in time to 1978 although the quality of the CZCS data may not be adequate for climate applications. Recently new ocean colour sensors have been launched by China on FY-3 and by Korea on a geostationary satellite, COMS, but it is too early to assess their suitability for climate purposes. Assimilation of ocean colour data in ocean biochemical models is still in its infancy but work has started using SeaWiFS data (e.g. Natvik and Evensen, 2003; Hemmings *et al*., 2008). Ocean colour data has not been used for climate model runs to date and so its exploitation for climate modelling is still to be developed.

The proposed CCI dataset from the ocean colour team will build on the GlobColour dataset by using a better quality input dataset of level 2 MERIS water leaving radiances (3^{rd} reprocessing) which has improved atmospheric correction and other benefits. A consistent dataset will then be derived at least back to the launch of SeaWiFS in 1997 using MERIS, MODIS and SeaWiFS data. It is not clear yet whether CZCS data will be able to provide data from 1978 to 1986 as the data quality is marginal.

Table 5 compares the overall requirements for chlorophyll alpha concentration from GCOS, the CMUG synthesis and what will be provided by the ocean colour CCI team and in general the proposed dataset meets the requirement for assimilation in to models which is the most critical requirement. The issue of applicability for Case 1 and Case 2 waters will need attention as ideally users will want to use the dataset for both cases. Quantification of derived chlorophyll in the optically more complex Case 2 waters is a difficult task due to the presence of non-algal particles and dissolved coloured material that can significantly contribute to the colour of the water. We believe it will be challenging for the CCI team to achieve the accuracies stated in Table 5 as to date accuracies no greater than 35% have been achieved for both Case 1 and Case 2 waters combined so the utility of the actual datasets may be compromised if the level of accuracy is not achieved.

In addition to chlorophyll alpha concentration the normalised water leaving radiance is the main geophysical measurement from which the chlorophyll alpha concentration is inferred and it can be anticipated that an observation operator will in the future make it possible to compute water leaving radiance from the model's ocean surface. The modelling community will then be able to use the water leaving radiance as the primary measurement variable.

Parameter	Application	Horizontal Resolution	Observing Cycle	Precision	Accuracy	Stability	Source
Derived chlorophyll *a*	All	1 km	1 day	10-25 %	25-30 %	~1 %	OC CCI PSD
Derived chlorophyll *a*	GCOS monitoring	1 km	1 day	5-25 %	Not specified	3 %	GCOS
	Trend monitoring	4 km	1month	30 %	30 %	2 %/decade	CMUG
	Decadal forecasting	50 km	1 month	30 %	30 %	2 %/decade	CMUG
	Assimilation	4 km	1 day	30 %	30 %	Not applicable	CMUG

Table 5. Products (in yellow) and Requirements for the ocean colour ECV as stated by GCOS, CMUG-1.2 and the proposed ocean colour CCI project PSD.

There are other more tentative parameters also proposed by the Ocean Colour CCI team which are not part of the GCOS requirements list but are listed here. The climate community do not have clear requirements for these yet and the extent to which these are best computed within the model itself having used the standard ocean colour products needs to be assessed. They are:

- Diffuse spectral attenuation coefficient (Kd) linked to water turbidity
- Inherent optical properties IOP (i.e. absorption, scattering and back scattering)
- Absorption by coloured dissolved organic matter, CDOM, which are degraded planktons and contribute to the carbon cycle.

- Suspended particulate matter, SPM
- Phytoplankton functional types, PFTs
- Particle size distribution PSD.
- Photosynthetically Available Radiation, PAR

For ocean colour the main limitation at present is the lack of sufficiently accurate satellite products which is linked to the sparse in situ observing network as there are only a few buoys capable of measuring ocean colour and hence able to validate the global satellite datasets. If the ocean colour CCI team achieves its accuracy/precision objectives this will be a real step forward. The other limitation is the short time series (only from late 90's) assuming CZCS is not used.

4.3 Sea Surface Height

The diagnostic of sea level change from coupled Atmosphere-Ocean General Circulation Models (AOGCMs) has only recently been considered in the Coupled Model Intercomparison Project (CMIP). The results of projected sea level over this century from multi-model ensembles were published in the scientific literature about 10 years ago and the analysis of a sub-ensemble of AOGCMs was included in recent IPCC reports. Before that, IPCC scenarios of sea level change concerned only global mean sea level and were calculated by means of single column models. Even if single climate models remain very useful to evaluate sea level change under a very wide range of emission scenarios, the geographical changes in sea level change provided by the AOGCMs is an added value allowing regional estimates. Regional estimates remain challenging due to the limited consistency of the projections between different AOGCMs. Progress is also limited by the fact that AOGCMs for which the oceanic component is a rigid-lid model, cannot provide this part of the sea level that is due to mass changes linked to precipitation and evaporation at the ocean surface, and mass redistribution associated to sea level pressure and ocean dynamics. This implies that with these kinds of models, we have only access to the steric components of sea level change either associated to temperature change (thermosteric) or to salinity change (halosteric) but under a constant mass hypothesis.

New developments are expected from the analyses of the CMIP5 results that will be included in the next IPCC AR5. Global averages and geographical fields of sea level change, steric sea level change, and thermosteric sea level change are part of the recommended outputs from the models giving access to a wider range of diagnostics from the AOGCMs. In addition, more models including a free-surface oceanic component will provide regional estimates of the mass change component due to the water flux at the ocean surface and to dynamical effects. However, the contribution of ice-sheets and glaciers melting to sea level change are not directly provided by the AOGCMs and will have to be estimated independently.

The increasing interest of the CMC for these diagnostics is because sea level change is a key issue for climate change impacts and also because the comparison with sea level inferred from observations could become a new common way of model evaluation. In spite of the above limitations concerning the meaning of the diagnostics from models, the comparison of simulated sea level change with observations from the last two decades could indeed provide some constraint on the simulation of internal climate variability or even on the predictability at the decadal scale that will be studied in the context of CMIP5. The analysis could be performed at the global scale through the analysis of mean sea level, but also at the regional scale since it has been shown that the steric component is the dominant part of geographical variability of sea level at the interannual and decadal scales.

Long time series of homogenized observations are also needed to perform the long term monitoring of sea level, to test for the detection of a signal of change that cannot be explained by internal variability of the climate system and to attribute those possible detected changes to natural or anthropogenic forcing. Datasets from tide gauges allow a reconstruction of sea level over more than a century. However these datasets have several limitations due to their poor coverage since they are mainly located in coastal areas of the Northern Hemisphere, only a fraction of the tide-gauge stations have been working over several decades and the measurements need to have filtered out effects from tide variability and land movement. Satellite-derived sea level are unaffected by these limitations providing valuable observations over the last two decades. These observations can also be used to reconstruct retrospectively sea level changes from tide-gauges for the pre-satellite periods using the information on spatio-temporal variability inferred from the satellite period.

Precursor satellite datasets already exist over the period 1992-2011 and can be accessed though the AVISO portal (http://www.aviso.oceanobs.com/en/home/index.html). Recently, multiple ensemble climate simulations have been produced for the Fourth Assessment Report of the IPCC (Leuliette et. al. 2006). Nearly two dozen coupled ocean-atmosphere models produced model output that can be compared to the long record of sea level provided by altimetry. Generally, the output from these runs is used to initialize simulations of future climate scenarios.

Parameter	Application		Horizontal resolution	Observing cycle	Accuracy	Stability	Source
Global mean sea level	Climate applications		Not Applicable	10 days	0.2 - 0.4 cm	< 3 mm/decade	SL CCI PSD
Ocean dynamic topography	All	Target	25 km	1 day	1 cm	Not specified	GCOS
		Breakthrough	50 km	3 days	1.5 cm		
		Threshold	250 km	30 days	5 cm		
	Model development and Evaluation		50 km	1 month	1cm	2 mm/decade	CMUG
	Long term monitoring and attribution		25 km	2 days	1cm	2 mm/decade	CMUG
Regional sea level	Climate applications		25 - 50 km	1 week	1cm	<1 cm/decade	SL CCI
Coastal sea level change	All	Target	25 km	1 day	1 cm	Not specified	GCOS
		Breakthrough	100 km	2 days	2 cm		
		Threshold	1000 km	10 days	10 cm		
	Model development and Evaluation		25 km	10 days	1 cm	2 mm/decade	CMUG
	Long term monitoring and attribution		2 5km	2 days	1 cm	2 mm/decade	CMUG

Table 6. Products (in yellow) and Requirements for the Sea Level ECV as stated by GCOS, CMUG-1.2 and the proposed SL CCI project PSD.

The added value of the CCI Sea level ECV is to provide a higher quality dataset in particular in terms of temporal homogeneity and reduction of errors. This will not have a big impact on the issue of coupled climate model evaluation due to the poor performance of these models and due to the need to estimate independently the contribution of mass change due to continental ice melting. However, this could have an impact on ocean climate model evaluation in particular at the regional scale when those models are constrained with observations (e.g. a Mediterranean Sea model forced by downscaled atmospheric reanalyses).

Another anticipated positive impact concerns the monitoring and detection/attribution studies for which temporal homogeneity of observed data is a stringent requirement. In addition a better accuracy and stability is important for ocean data assimilation. The impact of the new CCI product on ocean assimilation is part of the activity of the CCI project science team and will be tested within this context. Potential improvements could also come from improved ocean initial conditions for climate prediction at least at the seasonal scale.

The description of the precise requirements for the Sea Level ECV is given in the URD produced by the CCI project team. They are compared in Table 6 with those that have been proposed by GCOS and by CMUG (2010b).

Even if it is incomplete for some applications (ocean reanalysis, ocean model initialization), this table gives a general view of the agreement between the proposed specifications and the requirements identified by CMUG. The requirements are in particular similar in term of resolution and accuracy. The CMUG requirements on temporal sampling are more consistent with a merged product combining satellite observation and tide gauge data and thus can be accommodated with the CCI team proposal for the satellite-derived product. The same remark also applies for the CMUG requirement on stability with also the fact that the more stringent value of CMUG also applies for multidecadal trends rather than the CCI team proposal that applied to decadal ones. Some disagreements with the GCOS target requirements are discussed in the URD document. However it appears that if breakthrough requirement are also considered the gap is not so wide with the CCI team proposal. The GCOS requirements are also in a revision phase to meet the constraints of satellite observation.

4.4 Aerosol

Atmospheric aerosols (both tropospheric and stratospheric) are of great importance because of their impacts on human health, atmospheric visibility, continental and maritime ecosystems, the stratospheric ozone layer and the Earth's climate. 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 important to decrease the uncertainties on the aerosol radiative forcing terms (direct and indirect) because this will contribute to better constrain the climate sensitivity from current observational climate records. For example, it has been shown that the error in the top of the atmosphere outgoing longwave earth radiation budget in the Met Office climate model over dusty areas of the Sahara desert was of a greater magnitude than the error associated with both convective and stratiform clouds. The current aerosol climatologies within global models are extremely basic and often consist of time-invariant two-dimensional fields

Aerosol data from satellite remote sensing has found limited use in climate modelling until now. This is in part related to large uncertainties for retrievals for aerosol amount (i.e. aerosol optical depth AOD). These uncertainties are introduced by an insufficiently defined background signal (especially over land) and a-priori assumptions for aerosol composition, which often do not apply. Currently, there are about 10 different AOD data-sets available, with different strength and weaknesses by regions and season. These datasets include also more recent pre-cursor AOD data of GlobAerosol (1995-2007), MODIS deep blue (2003-present), MISR (2000-present) and MODIS (2000-present). The standard MODIS retrieval, in its current version (collection 5) is probably the most mature aerosol satellite product with potential information for the morning (am) and afternoon (pm) at each location. Assimilation of these MODIS pre-cursor aerosol data for amount (aerosol optical depth) and size (Angstrom parameter) is being undertaken with the MACC system at ECMWF. With limitations to the accuracy and the coverage over land the use of satellite aerosol datasets in modelling is still in its infancy. The AATSR aerosol optical depth product has also been investigated within the MACC assimilation system and found to be less useful due to poorer temporal coverage and a less mature algorithm. In addition, AATSR AOD data are not available in real time. An important constraint for climate models is the direct link between aerosol and clouds, as interactions between aerosol and clouds are highly uncertain and as a consequence poorly parameterized in modelling. Relating individual aerosol retrievals to properties of near-by clouds spatially (e.g. AATSR or MERIS) or both spatially and temporally (e.g. MSG-SEVIRI) would provide useful observational constraints to modelling.

The aerosol CCI team has documented the satellite aerosol products required for climate applications in its URD. For climate model process studies potentially all the parameters might be of interest. For trend analysis aerosol amount (via aerosol optical depth), aerosol composition (via aerosol absorption optical depth) and aerosol size (via the spectral dependence of the aerosol optical depth preferably yielding in a stratification of size contributions by aerosol larger and smaller than 1μm in diameter) are required. Table 7 compares the aerosol requirements GCOS, CMUG and the proposed CCI dataset taken from the PSD.

It should be noted that given the key role of aerosol in the climate system and the growing maturity of aerosol applications, user requirements are likely to develop rapidly over the coming years. This presents significant opportunities for the CCI Aerosol products to make a big impact on climate science but also a challenge to keep up with the user needs. The aerosol products proposed by the CCI team will be the first time such a large number of diverse sensors are used to derive a range of aerosol products. The proposed two years of data should be enough for comprehensive algorithm evaluations. To assist in detailed model process studies involving aerosol and other atmospheric properties (e.g. clouds or ozone) related retrieval of complementary data from the same sensor or at least the same platform for these proposed two years are needed. These associations could be stronger with geo-stationary data (e.g. MSG-SEVIRI) as spatial associations id complemented by temporal association. At this stage the use of geostationary data is covered neither in the aerosol-CCI nor in the cloud-CCI.

Parameter	Application	Horizontal Resolution	Observing cycle	Precision	Accuracy	Stability	Source
Aerosol optical depth at 550nm and other wavelengths	Not specified	10 km	1 day	Not specified	Not specified	Not specified	Aerosol CCI PSD
Aerosol optical depth at 550nm	Trend monitoring	5 - 10 km	4 hours	Not specified	0.03	0.01 /decade	GCOS
Total extinction optical depth (at 4 VIS + IR wavelengths)	Model development	1 km	1 hour	0.02	0.02	Not applicable	CMUG
	Assimilation (e.g. MACC)	5 - 20 km	1 hour (for 500 – 1000 points)	0.02	0.02	Not applicable	CMUG
	Decadal forecasting	50 km	1 month	0.02	0.02	0.01 /decade	CMUG
	Trend monitoring	25 km	6 hours	0.02	0.02	0.01 /decade	CMUG

Table 7. Products (in yellow) and requirements for the aerosol ECV as stated by GCOS, CMUG-1.2 and the aerosol CCI project PSD for aerosol optical depth.

The take-up of CCI aerosol products in applications based on data assimilation (e.g. reanalysis of atmospheric composition in the frame of activities such as MACC), will depend on a number of product characteristics, some of which are not yet available. If suitably developed, the single-sensor AOD Level-2 products (orbit-/swath-based, instantaneous retrievals) could be candidates to become input to the MACC assimilation system, but acceptance as input would depend, *inter alia*, on expert judgement regarding the quality of the new products in terms of their random and systematic errors and their stability etc. The CCI product specifications do not currently indicate provisional quantitative expectations for such characteristics. These judgements typically take into account validation activities and other science applications that provide insight into the quality of the new products, both in absolute terms and in comparison to other products (e.g. from MODIS), emphasizing the key role of product assessment by the aerosol-related climate research community. It should be noted that during the User Requirements exercise, MACC participants expressed a threshold temporal extent of 1-3 years from the "MODIS era" (target 1982-present), and a threshold temporal sampling of 500 observed locations per hour. (target 1000 locations per hour). Instantaneous temporal resolution was requested for the Level-2 products, and data covering both day and night are of interest. In the timeframe of CCI Phases 1 and 2, new aerosol datasets from the CALIPSO mission are expected to provide valuable information and together with MODIS aerosol products arguably provide a benchmark for CCI aerosol products.

Although hourly aerosol products from geostationary imagers are available, useful data-quality products over land have been only demonstrated for MSG-SEVIRI (by Y.Govaerts), which will not provide global coverage. The coverage of extreme aerosol events by the CCI products is limited to the years to be processed of 2008-2009 (which do not include any major volcanic eruptions, which are often used to test the models under anomalous conditions. Finally, the proposed aerosol dataset will not provide long term records for trend analysis.

4.5 Cloud

In recent years there has been a recognition by the climate modelling community that if real progress is to made in reducing uncertainty due to cloud feedbacks – which have consistently been identified as a major contributor to uncertainties in climate predictions by successive IPCC reports, including AR4 – then major efforts need to be focused on improving the representation of the physical processes associated with clouds in climate models. A key aspect of this activity is wider and improved use of satellite observations to (a) evaluate model performance and (b) inform and contribute to the development of better models. In practice, the latter involves providing information that can be usefully employed in the development and testing of improved physical parameterizations.

Parameter	Application	Horizontal Resolution	Observing Cycle	Accuracy	Stability	Source
Cloud amount	Not specified	10 km	1 day	8 - 15 %	Not specified	CCI Clouds PSD
	Trend monitoring	50 km	3 hours	5 - 10 %	0.3 - 3 %/decade	GCOS
	Model development	10 km	1 hour	10 %	1 %/year	CMUG
Cloud top pressure/ height	Not specified	10 km	1 day	Not specified	Not specified	CCI Clouds PSD
	Trend monitoring	50 km	3 hours	15 - 50 hPa	3 - 15 hPa/decade	GCOS
	Model development	10 km	1 hour	10 hPa	10 hPa/year	CMUG
Cloud top temp	Not specified	10 km	1 day	2 - 5 K	Not specified	CCI Clouds PSD
	Trend monitoring	50 km	3 hours	1 - 5 K	0.2 - 1.0 K/decade	GCOS
	Model development	10 km	1 hour	0.25 K	Not specified	CMUG
Cloud water path	Not specified	10 km	1 day	15 - 30 %	Not specified	CCI Clouds PSD
	Trend monitoring	50 km	3 hours	25 %	5 %/decade	GCOS
	Model development	10 km	1 hour	Not specified	Not specified	CMUG
Cloud effective radius	Not specified	10 km	1 day	Not specified	Not specified	CCI Clouds PSD
	Trend monitoring	50 km	3 hours	5 - 10 %	1 - 2 %/decade	GCOS

	Model development	10 km	1 hour	1 µm	1 µm	CMUG
Cloud optical depth	Not specified	10 km	1 day	Not specified	Not specified	CCI Clouds PSD
	Trend monitoring	50 km	3 hours	10 %	2 %/decade	GCOS
	Model development	10 km	1 hour	Not specified	Not specified	CMUG

Table 8. Products (in yellow) and requirements for the cloud ECV parameters as stated by GCOS, CMUG-1.2 and the cloud CCI project PSD.

Following on from IPCC AR4 the modelling community has given a considerable amount of thought to how this might be achieved, leading to the development of CFMIP (Cloud Feedback Model Intercomparison Project, http://cfmip.metoffice.com/) and, in Europe, the EU-funded EUCLIPSE project (http://www.euclipse.eu/). There is great emphasis in CFMIP on bringing together the global modelling and process modelling communities (through the GEWEX cloud systems study – GCSS) in order to make progress on understanding cloud feedbacks, and it is clearly recognized that these cannot be separate activities if this aim is to be realized. CFMIP is thus the essential starting point for understanding the current and future requirements of the climate modelling community regarding the provision of satellite cloud observations to achieve aims (a) and (b) described above.

Indeed, CFMIP has already given a great deal of consideration to the observational requirements of the modelling community (see http://climserv.ipsl.polytechnique.fr/cfmip-obs.html), including developing data sets specifically designed for this purpose (http://climserv.ipsl.polytechnique.fr/fr/cfmip-observations-3.html). These respond to the increasing requirement for observations which are consistent with model outputs. Furthermore, this has been the main driver for the development of model simulators, and in particular the COSP (CFMIP observational simulator package http://cfmip.metoffice.com/COSP.html), the primary aim of which is to facilitate more reliable comparisons between models and observations.

This 'process-oriented' approach to using satellite observations began around a decade ago when modellers began to make increased use of data from the International Satellite Cloud Climatology Project (ISCCP). This included, and was in fact largely driven by, the development of the ISCCP simulator (http://cfmip.metoffice.com/ISCCP.html), the precursor to COSP. This effort has increased substantially and now includes using data from CloudSat, CALIPSO, MODIS and MISR, simulators for all of which are now included in COSP which is the current baseline for use of cloud products by climate modellers. The CMUG requirements for model development in Table 8 reflect this although the CCI products offered are not exactly what the modelling community have asked for.

Turning now to the CCI clouds project, we can make the following observations: (i) the proposed data sets have not been formulated with the requirements of the modelling community as a priority; (ii) as such, they largely do not meet the current and near-future requirements, of climate modellers as outlined above; (iii) in which case, it will be difficult to generate interest in these data sets within the community (CFMIP, EUCLIPSE, etc), meaning that take-up and use of the data by climate modellers is likely to be low. Interest would increase if retrieved aerosol products from clouds could be related to (space and time) associated aerosol properties from the same sensors (through a collaboration with the aerosol-CCI).

The specific issue from the modelling perspective concerns the nature of the defined CCI products. The quantities proposed (total cloud amount, mean cloud top height, etc) are now considered of only limited use for model evaluation and development. These products can be compared to similar model quantities but the comparisons are very much first, or even zeroth, order and are not very informative for either identifying model errors or indicating possible ways to improve parameterizations.

For example, these high-level products do not uniquely define the radiative impact of cloud, which is the key to understanding cloud feedback processes. This was one of the main reasons for using ISCCP data, as it does provide a direct link between clouds and their radiative impacts. Similarly, the widespread use of new data from CloudSat and CALIPSO results from the requirement for more-detailed observations of the vertical distribution of clouds: again, the CCI products will provide only very limited information on this. It follows from this that the CCI clouds products cannot be said to fill a gap compared to what is currently available nor will they build on existing data sets currently used by the modelling community. The PSD very briefly refers to the possibility of performing process studies with the data, although no specific examples are given. In any case, it is difficult to imagine how these data could improve on what is currently being used and planned for the near future in this respect (from a modelling perspective). Finally, a further concern is with the generation of merged products from quite different sensors. Such products are difficult to both interpret and use: indeed, the rationale behind the simulator approach is precisely to avoid such difficulties by generating model equivalents of single-sensor products. It is thus unlikely that such products will be attractive to modellers. In another document (ESA, 2011), it is claimed that Level-2 products from the CCI Cloud project "should in principle address many of the model developers' needs", but the PSD does not give details of such products and their anticipated quality so it is not possible at present to form a view on the probable outcomes.

The CCI clouds project is essentially defined by the GCOS requirements and is to a large extent formulated within the framework of the GEWEX cloud assessment, the primary objectives of which are not oriented towards climate modelling (in the sense of corresponding to the goals of CFMIP and EUCLIPSE). In this context, if the project is able to demonstrate that the final products provide reliable descriptions of long-term variability and trends then this may be of interest to modellers for evaluation studies. However, it should also be noted that the PSD suggests that trend detection will not be attainable, based on current estimates of the requirements for stability and accuracy. CCI clouds will provide input to other CCI projects (e.g. SST, aerosol, etc) and may thus benefit the modelling community indirectly through these interactions.

4.6 Land cover

Global Dynamic Vegetation Models (DGVM) simulate the water, energy and matter fluxes as function of the land surface state. Information on land cover and its dynamics is an important variable for global and regional climate modelling over many timescales. It is used for the initialization as well as a boundary condition in DGVMs. The land cover information is hereby translated into surface parameters (e.g. albedo, LAI, fractional vegetation cover) which provide the lower boundary condition for GCMs. On the other hand, detailed regional land cover information provides very valuable information for process studies like e.g. the assessment of the impact of fires.

Thus, even though land cover data provides essential spatial patterns of different land cover types, the land cover classes need to be translated into model relevant surface parameters or plant functional types (PFT) to be used in the models. The mapping of land cover information into model parameters is performed using literature data (Hagemann, 2002; Poulter et. al. 2011) or remote sensing based climatologies like e.g. ECOCLIMAP (Champeaux et al., 2005).

Currently existing land cover products as derived from the GlobCover project or MODIS data provide land cover information with high spatial detail (< 1 km) compared to typical model resolution of current global (> 100 km) and regional (> 10 km) models. The sub-scale spatial heterogeneity of the land surface is represented by the fractions for each of the land cover types within each model grid cell (tiling). Next generation global climate models will resolve the spatial heterogeneity of the land surface with much more detail (~ 10 km).

Remote sensing based land cover data is widely used in DGVMs. In most cases, a single realization of a land cover map is used which is translated into model relevant parameters by either prescribing the surface conditions by a climatology of surface variables or by specifying the spatial distribution of PFT's through a land cover map. Major obstacles are hereby the different definitions of PFT's and land cover types. Currently existing land cover data sets are limited to specific years. No long-term consistent global land cover data set exists yet which could be used as a boundary condition in models at decadal timescales.

Due to the large discrepancies in scale, current DGVMs can not make full use of the high spatial resolutions of land cover information provided from remote sensing data. However, a higher resolved dataset is definitively required to estimate the sub grid fractions of each PFT. The combining of high resolution land cover data with ancillary remote sensing information of the land surface state (albedo, vegetation characteristics, and fire) allows for a detailed description of PFT parameters and allows for more detailed studies of the impact of fire. Combining land cover data with ancillary state variables (LAI etc) is only useful if they are consistent with one another and with the land cover product used for their application.

The CCI landcover project will provide a new high resolution land cover data set with well characterized uncertainties. The product specifications are in agreement with the overall needs of the climate modelling community as shown in Table 9. The landcover product will comprise a land cover classification which is more compliant with currently used PFTs and should thus reduce the uncertainties in the translation from landcover classes to PFTs. Further, the data product will include ancillary information about the land surface state as derived in other projects. This additional information is expected to be of high value for prescribing land surface states in GCMs if the different surface variables are consistent with each other as well as with the landcover classification. Additional benefit for decadal climate analysis is expected if the CCI landcover project would deliver a long term harmonized multi-decadal landcover data record beyond the SPOT/MERIS era. There is a strong requirement to go back to 1995 if possible with AVHRR 1km data to extend the timescale and test models over a longer time period.

Parameter	Application	Horizontal resolution	Temporal sampling	Accuracy	Stability	Source
Land cover	Not specified	300 m	Best stable map and annual updates	90 – 95 %	> 85 %	CCI Land cover PSD
Land cover change	Not specified	Not specified	Not specified	Not specified	Not specified	CCI Land cover PSD
Land cover	Model development	300 - 1000 m	2 - 5 years	5 – 10 %	< 10 %	CMUG
Land cover change	Trend monitoring	300 - 1000 m	2 - 5 years	5 – 10 %	< 10 %	CMUG

Table 9. Characteristics of proposed CCI land cover products (in yellow) from the CCI land cover PSD and CMUG user requirements.

4.7 Fire Burned Area

Fire is an integral Earth System process, which is controlled by climate and at the same time impacts climate in multiple ways. Burned area (BA) combined with information on fuel load and combustion efficiency allows an estimate of fire emitted trace gases and aerosols. These emission estimates can be applied in climate – chemistry models to asses their climate impact. In addition, fire is an important disturbance factor for vegetation dynamics. Global vegetation models that simulate the vegetation dynamically parameterise fire occurrence. Alternatively, observed BAs can be prescribed as boundary conditions.

The Fire CCI User Requirements Document (URD, version 1.1 issued 09/02/2011) described user requirements for burned area products derived from a questionnaire completed by actual or potential burned area product users. Analysis of the questionnaire revealed that the most useful product types are burned pixels, followed by burned patches and gridded products. For the gridded product higher resolution (0.1 x 0.1 degree, weekly) was preferred over coarser resolution (0.5 x 0.5 degree, monthly). In all cases the preferred projection was regular lat/long grid. Requirements for accuracy and stability are listed in Table 10. These requirements are in line with the CMUG UR, but less stringent than the GCOS requirements. The URD noted that the GCOS requirements cannot be met by present observing systems.

The requirements were translated by the Fire CCI team into product specifications (PSD, version 1.5 24/02/2011). The BA product will consist of a pixel based and a gridded (0.1 x 0.1 degree) product. The gridded product will be mainly of interest for climate modelling. However, the products should be consistent to be useful for the science community as a whole. Both products should be available for the single sensors applied and as a single merged product. To estimate biomass burning emissions from BA products additional information on the vegetation type that burned is needed. This will have to be included in the metadata section of the BA gridded product as fraction of vegetation type per burned area and not as fraction of dominant vegetation cover per grid area as proposed in the PSD. If possible the vegetation type information should be consistent with the land cover CCI product.

Both the Fire URD and the PSD did not specifically address the time series length required for useful applications of burned area products in the different fields. However, the URD noted that users preferred products that cover long time spans (e.g. GFEDv3 1997 -2009). The time series length will be key for the application of the BA product in climate models. BA can be only used as boundary condition in a DGVM as a global product that covers a multiyear time span as fires have a high interannual variability and the individual fire seasons in fuel limited regions are not independent but correlated. The proposed years 1999, 2000, 2002, 2003 and 2005 (DARD) will not allow the usage of the BA product as boundary condition within a DGVM nor will it allow an evaluation of global fire parameterisation included in DGVMs.

The interest in the fire CCI product from a climate modelling perspective will depend on the quality of the product compared to already existing and widely applied products such as the MODIS based GFEDv3 product which is currently the baseline for fire emission inventories and global vegetation model applications.

Additional metadata information on burn intensity from fire radiative power (FRP) could improve biomass burning emission estimates as it allows a better representation of combustion completeness. Although, FRP will be not the target product of the fire CCI it should be considered as possible metadata information.

Parameter	Horizontal Resolution *		Temporal sampling		Accuracy	Stability	Source
Burned Area	Gridded 0.1x0.1 degrees		Target	2.3 days	5 %	5 %	FIRE CCI PSD
			Breakthrough	6.1 days	15 %	15 %	
			Threshold	8.8 days	25 %	25 %	
Burned Area	Target	0.25 km	1 day		10 %	5 %	CMUG
	Breakthrough	1 km	1.5 days		20 %		
	Threshold	5 km	3 days		30 %		

*Table 10. Products (in yellow) and requirements for the Fire ECV from the Fire CCI PSD. * The Fire PSD does not specifically comment on the horizontal resolution, but rather analysed the usefulness of different product types. Burned pixels were rated as most useful, followed by burned patches and gridded products in 0.1 x 0.1 degree resolution.*

4.8 Greenhouse Gases (GHG)

To comment on the relevance of proposed CCI GHG products, it was necessary to supplement the PSD (Version 1 Draft 3, 14th February 2011) with the current GHG URD (Version 1, 3rd February 2011) which specifies the quantitative targets for key quality characteristics (random and systematic errors etc).

The primary application for the proposed GHG products would appear to be determining the distribution of greenhouse gases, such as CO_2 and CH_4, to sufficient quality in order to estimate regional sources and sinks. The need for products targeted at such applications is recognized by the description of GCOS Product A.9 (Distribution of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks) and the CCI GHG project is explicit about their focus on this application. While there are certainly climate-related applications that would need different GHG products, further discussion of those applications is beyond the scope of this document. It is of course conceivable that other climate-research applications will develop ways to benefit from the proposed GHG products but it would be disproportionate to explore those possibilities in this document. The current baseline for use of GHG datasets in models is the assimilation of satellite measurements of CO_2 and CH_4 inferred from AIRS, GOSAT, IASI and SCIAMACHY within the MACC reanalysis. In some cases these are from radiances and in other cases from level 2 products.

For the application under consideration, i.e. estimation of regional sources and sinks, the URD is comprehensive in specifying targets for random error, systematic error and stability. It also specifies important ancillary requirements, e.g. the need for information to construct observation operators. Cross-cutting requirements as described by CMUG, e.g. the need for routines and documentation to easily ingest ECV products, are also acknowledged.

The requirements set by the CCI GHG team given in Table 11, if achieved, would represent a major step towards fulfilling GCOS requirements. They are broadly in line with the requirements gathered by CMUG. As such, there is the prospect that the proposed products will find a use in assimilation-based applications in the frame of activities such as MACC, but a number of challenges remain. In particular, as noted in the GHG URD, the ability to achieve systematic error (“accuracy”) targets is challenging, and so acceptance by the user community will depend on a successful research effort to establish effective strategies and algorithms. Such acceptance is typically based on expert judgements that take into account validation activities and other science applications that provide insight into the quality of the new products, both in absolute terms and in comparison to other sources of GHG information In this context, it is relevant to consider a number of existing datasets as benchmarks: first and foremost the ground-based networks of surface observations, which could be expected to find use in validation, and secondly existing satellite-based GHG products from Envisat/SCIAMACHY and GOSAT/TANSO and from AIRS/IASI. The GHG team are familiar with the existing products, making them well-placed to address the features, especially those concerning systematic errors that detract from climate-quality in the datasets. The amount of progress made on these issues, as evidenced by thorough validation and error characterization, will determine the level of uptake by applications such as MACC. It should be noted that users such as MACC typically give weight not only to the evidence supplied by the data providers but also to the assessments and expert judgement of other users with related applications emphasizing the key role of product assessment by the GHG-related climate research community.

Parameter	Application	Horizontal Resolution		Observing Cycle	Precision		Accuracy	Stability	Source
Total column CH_4	Regional source/sink determination	Satellite $(1000\ km)^2$ "single instrument pixel"		Monthly	Ta	9	3	1 ppb/yr	GHG CCI PSD
					B	17	5	5 ppb/yr	
					Th	34	11	10 ppb/yr	
Total column CH_4	Regional source/sink determination	Ta	10 km	3 hours	20 ppb		0.5 % - 5 ppb	5 ppb/yr	CMUG
		B	50 km	4 hours	40 ppb		0.7 % - 7 ppb	7 ppb/yr	
		Th	250 km	6 hours	100 ppb		1 % - 10 ppb	10 ppb/yr	
CO_2 total Column	Regional source/sink determination	Satellite $(1000\ km)^2$ "single instrument pixel"		Monthly	Ta	0.3	0.2	0.2 ppm/yr	GHG CCI PSD
					B	1	0.3	0.3 ppm/yr	
					Th	1.3	0.5	0.5 ppm/yr	
Total column CO_2	Regional source/sink determination	Ta	50 km	3 hours	3 ppm		0.5 ppm	0.5 ppm/yr	CMUG
		B	100 km	4 hours	4 ppm		0.7 ppm	0.7 ppm/yr	
		Th	500 km	6 hours	6 ppm		1 ppm	1 ppm/yr	

Table 11. Products (in yellow) and user requirements from CMUG and proposed CCI product specifications for GHG. Target, breakthrough and threshold and values, marked as Ta, B and Th respectively, are given for the requirements.

The current proposal is only for one year of GHG products in 2010 which does not allow a good comparison with other ECVs such as fire, land cover and aerosols. The CCI team should be encouraged to provide datasets for a "golden" year along with these other ECVs.

One aspect that arguably warrants more attention concerns the reporting in the GHG products of numerical quantities related to correction of systematic errors. These aspects of product generation are, as noted by the GHG team, some of the most challenging from the scientific perspective, and thus deserving of scientific scrutiny and validation in their own right. Thus, the reporting at pixel level of parameters derived during the computation of systematic error corrections is considered advisable by CMUG. This is a cross-cutting issue relevant to several ECVs and CMUG advises all ECV teams to consider a revision of their product formats to facilitate comprehensive validation of their error characterization.

In conclusion, even if GHG products are already computed for other projects like MACC (the current products are the precursors on which assessment can already be performed) , the ambition of the CCI project to get higher precision and accuracy is justified to be able to provide more accurate evaluation of the sinks/sources distribution needed to improve the models and for climate monitoring.

4.9 Ozone

Ozone, total or partial columns and profiles are an important variable to monitor for climate include in climate models. Ozone is the third largest greenhouse gas as stratospheric ozone absorbs the ultraviolet sunlight that heats the stratosphere. Ultraviolet radiation, when not absorbed by ozone contributes to a reduction of methane. As a result stratospheric ozone exerts a negative forcing globally. Tropospheric ozone, which absorbs infrared radiation, has a positive forcing on surface and tropospheric temperature. Ozone distribution is affected by dynamical and chemical processes. Its presence in the stratosphere results from O_2 dissociation by photons (photolysis) but is strongly perturbed by up-lifted reactive components (e.g. NO_2, bromine, chlorine, etc.) and anthropogenic emissions. Processes determining ozone 4D-distributions are important to understand to be able to predict ozone hole evolution not only for long range forecasts but also at regional scales and for shorter ranges.

Ozone total column has been measured from the surface since 1930 (Dobson technique). The distribution of ozone is easy to quantify from satellite observations. The most well known technique is UV spectrometry (TOMS on Nimbus 7 since 1978). Thermal infrared absorption has also been used with HIRS on NOAA since 1978 but in the thermal IR the measured radiance is more sensitive to high troposphere or low stratosphere, and is also affected by temperature. However, advanced infrared sounders like IASI on Metop give more accurate measurements of temperature profiles and a more precise estimate of the ozone at the UTLS (upper troposphere, lower stratosphere) where its radiative effect can be important to understand dynamical processes and radiative forcing. Limb sounders working in the UV (solar occultation), IR (Thermal emission) or in the Microwave domain (MLS) deliver accurate profiles with a very good vertical resolution but coarse spatial resolution. They also contribute to an improved process description for the models. The ground based information (lidars), or in situ (SAOZ, ozone sondes) are sparse but are very useful for long term trends and also validation of models.

Chemical transport models (CTM) have been developed which include a full description of the chemistry and make use of NWP fields to describe the dynamics. They are well suited to analyse specific events in detail. There are coupled NWP + CTM models used for short range to seasonal forecasts where satellite observations are used to initialize or are assimilated. They are used for confrontation with the model evaluation as well. Reanalyses are performed with these models where satellite data have been used at some point. The CCM (Chemistry-Climate models),which include a fully interactive representation of stratospheric ozone (and very rarely tropospheric ozone) are key tools for attribution and projection of stratospheric ozone changes arising from the combined effects of increase of the GHGs and reduction of ozone depleting substances (ODS). They are evaluated by satellite data in the framework of the CCMVal2 exercise.

Long series of total ozone columns have widely been used to monitor the trends. NIWA has already built up a climatology based on TOMS SBUV and SBUV/2 data from 1979 to 2000 which has been widely used to validate the CCMs (or CTMs). A multi sensor reanalysis of data from 1978 to 2008 is also now available (Van der A et al., 2010). Ozone data are also being assimilated in reanalyses (e.g. MACC) using data from SBUV, OMI, GOME and Sciamachy. Finally there is also an interest to validate if processes are represented in the models through analysis of regional events at the poles (ozone hole depletion) or stratospheric ozone descent in the troposphere. The satellite total columns, limb measurement or nadir profiles are then used, with their errors. Short time series of satellite products (level 3 or assimilated fields) can then be used to be compared with the CCM outputs (after initialization with current conditions). Finally, models with very good observations can also be used for attribution to climate change.

The ozone CCI team has documented the satellite products required for all climate applications in its URD. The proposed products remain mostly focused on the stratospheric ozone. The CCI team does not mention the ACCMIP project which, with some ozone hindcast experiments, addresses the quantification of the impact of tropospheric ozone for:
- changes in emissions of ozone precursors (NOx, CO, hydrocarbons)
- changes in methane
- changes in ozone in the lower stratosphere
- dynamical variability including STE, ENSO, NAO/AO

Parameter	Application	Horizontal Resolution (km)	Vertical Resolution (km)	Observing Cycle (h)	Accuracy (%)	Stability (%)	
Ozone profile							
Higher stratosphere & mesosphere (HS & M)	Model Development and Evaluation	500	3	48	15	3 %/decade	CMUG
	Reanalysis and Data Assimilation	100	1	6	5	1 %/decade	CMUG
Middle atmosphere	Nadir viewing	Not specified	5 - 8	1 - 6 days	Not specified	Not specified	Ozone CCI PSD
	Limb Viewing	240 - 500 km	3 - 5	1 - 6 days	Not specified	Not specified	
Lower stratosphere	Limb viewing	240 - 500	1 - 3	1 - 6 days	8 - 15	1 – 3 %/decade	Ozone CCI PSD
Lower stratosphere (LS)	Model Development and Evaluation	100	2	72	15	3 %/decade	CMUG
	Reanalysis and Data Assimilation	75	1	6	5	1 %/decade	CMUG
UTLS		100 - 200	5 - 8	1 - 6days	Not specified	Not specified	Ozone CCI PSD
Higher troposphere (HT)	Model Development and Evaluation	100	2	72	20	3 %/decade	CMUG
	Reanalysis and Data Assimilation	20	1	6	5	1 %/decade	CMUG
Troposphere		(1°X 1°)	5 - 8	1 - 6 days	Not specified	Not specified	Ozone CCI PSD
Lower troposphere (LT)	Model Development and Evaluation	50	2	72	20	3 %/decade	CMUG
	Reanalysis and Data Assimilation	10	1	3	10	1 %/decade	CMUG
Tropospheric column		Not Specified		Not specified	Not specified	Not specified	Ozone CCI PSD
Troposphere column	Model Development and Evaluation	50		72	15	5 %/decade	CMUG

	Reanalysis and Data Assimilation	10		3	5	3 %/decade	CMUG
Total column		20 - 100 km (1°X 1°)		1 - 6 days	Not specified	Not specified	Ozone CCI PSD
Total column	Model Development and Evaluation	50		72	15	5 %/decade	CMUG
	Reanalysis and Data Assimilation	10		6	5	3 %/decade	CMUG

Table 12. Proposed products (in yellow) from the Ozone CCI PSD and requirements for satellite observations of ozone.

The product specifications differ slightly from the requirements given by the CMUG (Table 12). The discrepancies are mostly the horizontal and vertical resolution in the troposphere (coarser for product). There is no difference between accuracy and precision so only the latter is included in the table. The expected accuracy is more stringent and the stability as well.
The main products that the Ozone CCI project will deliver are described in the latest version of the PSD. These products do not meet the requirements set out in the URDs. For the total ozone, the CCI project will provide data from 1995-2003 and 2007-2008 measured with GOME, GOME-2 and Schiamachy. It is expected that the series will be homogenized and that the total accuracy is improved compared to the existing dataset. However a longer continuous time series back to 1978 with the first TOMS data are certainly more useful for trend analysis. So, despite the greater uncertainty most of the groups would still continue to use datasets such as the one provided by NIWA or from KNMI. Regarding the profiles, for nadir viewing data, the dataset will be based on the same set of sensors plus OMI. The time range is from 1995 to 2011 which makes it attractive for trend analysis. Unfortunately, it is important to note that it has not been planned to include IASI data which started in 2007 but will certainly remain available for several decades. IASI data have demonstrated accurate tropospheric profiles of ozone with a higher accuracy than the UV/VIS profiles. Concerning limb profiles, the processing of MIPAS and GOMOS is certainly valuable. However the absence of MLS is regretted as MLS is the cornerstone for the assimilation of satellite ozone observations.

4.10 Glaciers and Ice Caps

Glaciers and ice caps are affected by changes in climate through changes in mean surface temperature and precipitation, and their temporal and spatial dynamics in a changing climate will affect other components of the climate system (sea level, albedo, and hydrology). Changes in glaciers and ice caps over time will also provide climate researchers with information about trends and attribution.

The simulation of glaciers and ice caps in climate models is currently through land surface models (JULES, EC-EARTH, HIGHNOON) and a single regional climate model (REMO). This will likely change in future as climate models increase in spatial resolution and the number of components they incorporate.

Parameter	Application	Horizontal Resolution	Observing Cycle	Precision	Accuracy	Stability	Source
Glacier Area	Not specified	15 – 30 m	-	-	-	-	Glaciers CCI PSD
	Initialisation	30 m	1 year	0.01 km^2	< 5 %	-	CMUG
	trend monitoring	30 m	5 years	0.01 km^2	< 5%	0.01 km^2/ decade	CMUG
Glacier Topography	Not specified	50 - 100 m 100 - 10,000 m	Years - decades 3 - 35 days	– –	5 - 10m 0.2 - 0.5m	– –	Glaciers CCI PSD
	Initialisation	<100 m	1 year	1 m	5 m	–	CMUG
	trend monitoring	<100 m	5 - 10 years	1 m	5 m	1 m /decade	CMUG
Velocity	Not specified	25 - 100 m	Daily – weekly – yearly	–	5 - 10 m/yr	–	Glaciers CCI PSD
	Initialisation	30 m	1 - 12 months	1 m/yr	10 m/yr	-	CMUG
	trend monitoring	30 m	1 year	1 m/yr	10 m/yr	1 m /decade	CMUG
Snowline	Not specified	-	-	-	-	-	Glaciers CCI PSD
	Initialisation	30 m	1 year	30 m	100 m	–	CMUG
	trend monitoring	30 m	1 week - 1 year	30 m	100 m	30 m /decade	CMUG

Table 13. Characteristics of proposed CCI Glacier products (in yellow) from the project PSD, and CMUG user requirements.

There will also be a demand for information about the environmental and resource impacts of climate change on glaciers and ice caps (e.g. flooding and water resources). Table 13 shows the difference between the CCI products, as described in the Glaciers PSD, and those described by the CMUG. Metrics for observation measurements in the Glaciers PSD is frequently given as conforming to existing glacier measurement data standards (e.g. GLIMS), and not expressed in the terms used by climate modellers.

The main datasets for glaciers and icecaps are currently in global glacier inventories (GLIMS, WGMS) which describe areal extent, with other sets covering elevation and velocity. A spatially averaged version of the glacier area product should be incorporated into the CCI land cover datasets for initialising climate models. The priority expressed by the Glacier CCI project in its PSD is to fill the spatial and temporal gaps in these existing inventories. Thus the processing and data formats will be compliant with these existing data sets and not specified for direct application in climate models.

5. Overall perspective of CCI contributions to climate modelling

The ESA CCI programme is the first attempt in Europe to provide significant resources for the reprocessing of satellite datasets to make them fit for purpose for monitoring climate trends and improving the accuracy of climate predictions. This section considers the potential overall benefits to the climate modelling and reanalysis communities. It is important to bear in mind that as models improve and simulate more variables the range of applications for which satellite datasets are required will increase and the requirements on their accuracy will increase. This document is an evaluation of *current and short term future* modelling needs.

At the lowest level the ECV projects are providing an impetus to improve the homogenization of level-1 data (e.g. ATSR and MERIS reprocessing) and this will feed into some applications like reanalysis that may use the level products directly. There will also be more attention to consistent use of any ancillary datasets for the level 0 to 1 processing. ESA will define the definitive level 1 datasets that are to be used for the CCI projects and this endorsement will be useful for the community.

For many of the ECVs an input to the data processing will be model fields and in most cases the ERA-Interim fields will be used to ensure consistency between ECV datasets. This is an attractive feature of the CCI datasets that they will use a common model input set of variables which as they are derived from a reanalysis will be internally consistent.

For the higher level datasets if there is consistency between some of the climate datasets (e.g. aerosol and cloud, SST and sea-ice, GHG and ozone) this will increase the interest of the modelling community. The zeroth order requirement here is for the different ECV datasets to overlap in time and currently this overlap is suboptimal as Fire and Aerosol do not overlap and GHG do not overlap with Clouds and Aerosol. The CMUG strongly recommend that a 'Golden Year' at least is identified where all the ECV teams provide climate data records to allow cross consistency to be checked.

The characterisation of the specified errors for each of the CCI datasets will be an important activity for the ECV teams to undertake. These errors are crucial to modellers for several applications including assimilation in reanalyses, assessing model processes and interpreting long term trends in parameters. An ensemble of possible solutions for a retrieved ECV dataset is one way to assess the uncertainty.

For some of the 10 ECVs, the time spans of the products proposed in the current PSDs are too short to be of interest to climate modellers. Ozone, Aerosols and Fire are all in this category. Understandably, the climate modelling community generally expects dataset reprocessing activities to cover the full period of instrumental data available. Interest from the user community would be enhanced if the PSDs indicate when users can expect to receive long-time span products. Delays in generating such products will delay their uptake in climate modelling (and by implication IPCC) and reanalysis studies.

The Cloud Feedback Model Intercomparison Project (CFMIP) project is a good example of an initiative from the climate modelling community being set up to confront climate models with observations which in this case is primarily clouds and water vapour datasets. A meeting of the group was recently held (see http://cfmip.metoffice.com/meetings.html for more details) and reaffirmed the need to compare with satellite cloud datasets (i.e. ISCCP and CloudSAT). To facilitate comparisons between the satellite and surface cloud observations and climate models a list of points has been defined (currently 119) with the aim of better understanding the processes in the models. The model parameters are output for every time step of the model and on model levels at these locations in order to allow detailed comparisons with the measurements. Not all points correspond to surface sites but are chosen in areas where important atmospheric and/or surface phenomena occur (e.g. El Nino). The points are defined on the CFMIP web site and updated periodically (see http://cfmip.metoffice.com/CMIP5.html).

In the second phase of processing some CCI datasets can be reprocessed using the CCI datasets created in the first phase (e.g. ocean colour uses SST, aerosols use fire and SST uses sea ice). A complete table of cross linkages is given in Table 14 below which were compiled by the CMUG. Some examples of using datasets from different ECVs to investigate consistency, correlations, feedbacks etc are:

- Aerosols and Ocean Colour and SST to see if ocean colour is affected by deposited desert dust and water temperature
- Aerosols and Fire to check smoke is detected from fires in the aerosol dataset
- Aerosols and Cloud to investigate how cloud properties are modified by high aerosol concentrations
- Ozone and GHG to investigate the relationship between ozone and other gases
- Glaciers and Land cover to check consistency

Many more inter-ECV relationships will emerge from the CCI project activities.

Access to a subset of the CCI datasets, which can be easily compared with climate models, will be through a common portal on the Earth System Grid http://www.earthsystemgrid.org/ which is the commonly used portal for climate modellers. This ensures the climate modellers will have visibility of and easy access to the CCI datasets when they are released in the common NetCDF format and was a strong requirement from the CMC. This is a significant step forward compared to previous satellite CDRs which were made available to the community on a more adhoc basis.

It is a fact that to date the use of satellite data for climate model applications has been rather limited with mainly Earth Radiation Budget and ISCCP data being the main datasets in use. However with increasing complexity of climate models now is the time to start to consider other satellite datasets to be used for model validation (e.g. aerosols is an obvious example). For some of the CCI datasets they will provide new products not previously available to the climate modelling and reanalysis communities for others they will be improvements (e.g. addition of error estimates) and extensions of existing datasets. The provision of observation simulator tools for most of these datasets will be a vital component as was shown with ISSCP data and this development has to be undertaken with close interactions between the modellers and data providers. It took 15 years to convince the modelling community to use ISCCP data for their model validation and the challenge is to reduce this time span to months rather than years for the new CCI satellite datasets.

	SST	Sea level	Clouds	Sea ice	Ocean colour	Aerosol	GHG	Landcover	Fire	Ozone	Glaciers
SST		x	x	X	X	x				x	
Sea level	x			x							
Clouds	x			x	X	x	x	X	x	X	
Sea ice	x	x	x		X					x	x
Ocean colour	X		x	x		x					
Aerosol			x		X			X	x	x	
GHG			x			x			x	X	
Landcover			x			x			x		x
Fire			x			x	x	X		x	
Ozone			x			x	X				
Glaciers				x				X			

Table 14. An analysis of cross linkages between ECVs indicating where comparisons need to be made to ensure consistency. The left hand column is the project with the identified need; the top horizontal row is the provider. The larger crosses indicate where the CDRs generated by that ECV project would potentially be of use in the retrieval of the ECV listed on the left side.

6. References

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CMUG 2010b CMUG User Requirements Document D1.2 http://www.cci-cmug.org/ click on ECV Project Resources

CMUG 2011 Technical note on CCI project User Requirements and Specifications D2.1 http://www.cci-cmug.org/ click on ECV Project Resources

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7. Acronyms/Glossary

ACCMIP	Atmospheric Chemistry and Climate Model Intercomparison Project
AOD	Aerosol optical depth
ARC	(A)ATSR Reprocessing for Climate
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic data
BA	Burnt Area
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (NASA mission)
CMIP5	Cloud Feedback Model Intercomparison Project
CZCS	Coastal Zone Colour Scanner
DGVM	Global Dynamic Vegetation Models
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GHG	Greenhouse Gases
GOME	Global Ozone Monitoring Experiment
HadISST	Hadley Centre Sea Ice and Sea Surface Temperature data set
IASI	Infrared Atmospheric Sounding Interferometer (instrument on EUMETSAT MetOp programme)
KNMI	Koninklijk Nederlands Meteorologisch Instituut
MACC	Monitoring Atmopsheric Composition and Climate (EU project)
MetOp	Series of polar orbiting meteorological satellites operated by EUMETSAT
NASA	National Aeronautics and Space Administration
NIWA	National Institute of Water and Atmospheric Research Ltd
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis
PFT	Plant Functional Types

Annex A: Versions of Product Specification Documents used

The versions of the documents on which this report (v0.5) is based is given in the table below. These documents are continually evolving.

ECV	Version of URD	Version of DARD	Version of PSD
SST	v2	vD	vE
Ocean Colour	v1.9	v1.4	v1.4
Sea Level	issue 1.1	v1.0	v1.0
Clouds	v1	v1.0	v1.0
Ozone	v2.0	v1.1	v2.0
Greenhouse Gases	v1	v1	v1
Aerosol	v1.4	v3.4	v1.1
Glaciers and ice caps	v0.8	Not available	v0.5
Land cover	v2.2	v1.4	v1.2
Fire	v2.0	v1.5	v1.5