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Climate Modelling User Group

Deliverable 2.1

Scientific Impact Report

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Deliverable 2.1

Scientific Impact Report

Contents

Scientific Impact of the CCI on the Climate Research Community and beyond

1. Summary

Every CCI project can demonstrate through both quantitative (e.g. journal papers) and qualitative (e.g. conference presentations) metrics an impact on climate research. The key driver of the impact is the increase which the CCI dataset has over existing ‘state of the art’ data sets. Each CCI project has produced a dataset which has its own unique, identifiable improvement over existing data sets, and although the improvements are often technical and incremental they are easily demonstrated. Such improvements are currently best appreciated by the key users of each project’s dataset, although these improvements are finding their way into the wider research community through existing channels of science dissemination. Assessment of CCI project impacts shows mostly that those which generated the longest datasets, and delivered them sooner, have had the greatest impact. Projects which delivered datasets with the shortest temporal extent generally achieved a lower level of impact. The CCI project that directly addressed a GCOS/CEOS observation requirement achieved a very high level of impact on the climate research community. Some of the impact of the CCI is perceived to come from its integrated and consistent approach. It is acknowledged that there is great potential for the growth in future impacts of CCI data as the data spreads beyond the immediate area of climate research, reanalyses and modelling (into climate change impacts, adaptation, or mitigation studies), as more users take up the data (such as climate services), as requirements become more detailed and refined (to include validation and QA) and new ECVs are considered.

2. Purpose, scope and content of this report

This document aims to demonstrate to climate researchers, policymakers and non-experts alike the value of the new CCI climate quality satellite data records by demonstrating the impact it has to date on climate research. It should be borne in mind this is a snapshot of the exploitation of the data within a year after their initial release and it is expected the take up by users will expand with time. Climate researchers often take some time to be convinced that a new dataset is worth using and one of the roles of CMUG is to promote the CCI datasets to accelerate their usage. However, when the CCI climate data sets achieve mainstream acceptance and use by the climate modelling, research and reanalyses communities it will only be a short time before they will be taken up more widely by climate service providers, businesses, climate consultancies and other users and purveyors of climate information.

These impacts are described: i) within the international framework for climate research (e.g. IPCC, GCOS etc); ii) at a programme level (e.g. Randolph Glacier Inventory, obs4MIPs); iii) by feedback from individual researchers, and; iv) for their potential in the newly emerging areas of climate services.

Metrics such as number of papers published for each ECV are used to demonstrate the take-up of the datasets for each ECV. It is expected this report will help guide ESA on defining the CCI-2 activities proposed to start in 2017.

3. Introduction

The Climate Change Initiative of the European Space Agency is a logical step in the evolution of satellite Earth observations being integrated with the climate research community to support and enhance research for climate modelling, reanalyses and other areas of climate research. The strengths of the programme are that: i) it is driven by user requirements; ii) there is engagement with user communities; iii) there is integration between projects; and iv) that data products are independently assessed in a range of research applications by the CMUG project.

At the time of writing the CCI has successfully completed Phase 1 (of four years duration) where the user requirements were gathered, the processing algorithms selected, scientific and technical issues resolved and the first CCI datasets produced for 13 ECVs. The CCI has now started Phase 2. The initial user uptake of the Phase 1 datasets, and the CMUG evaluation are all evidence that Phase 1 CCI data is of more value to researchers than other comparable available climate datasets.

The impact of individual ECV datasets within their own user communities needs to be examined in detail as well as uptake and impact in the wider climate research community. This is done in sections 5.1 to 5.14 of this report. Reports of the CMUG assessment of Phase

1 data (where it was available) are available and these document the potential use and nascent uptake by the research community at the time they were published. It is worth mentioning that the CMUG is committed to outreach and engagement with the climate research community and beyond, to users of climate information (such as climate services), and is working to demonstrate the benefits and potential in the application of CCI data.

4. What is a ‘scientific impact’?

4.1 *Defining scientific impact*

To assess the ‘scientific impact’ of a new climate data record a number of different ways need to be used to measure the impact. The methods used in this report are itemised below.

- Number of peer reviewed papers authored by the CCI teams (Section 5)
- Number of peer reviewed papers citing CCI datasets (Appendix 1)
- Number of CCI papers cited in the IPCC AR5 whose work is based on CCI datasets (Section 5)
- Number of CCI researchers who concurrently worked on the IPCC AR5 (Section 5)
- Analysis of Climate Assessment Reports from CCI teams and of papers using the CCI datasets (Section 6)
- Evidence from recent scientific conferences (e.g. Climate Symposium in Darmstadt, Oct 14) (Section 6)
- Talking to climate researchers in major modelling centres to assess their plans (Section 6)
- Number of user requests for CCI datasets (Section 6)
- Assessing the plans for future climate research initiatives (e.g. CMIP6) (Section 7)
- Assessing future directions (e.g. for climate services) (Section 8)

4.2 *Measuring scientific impact*

Citations of CCI related papers (as opposed to just numbers of CCI papers published) is another metric, and apart from citations within the AR5 (impact described in Section 6) it was felt too early to examine this for all CCI ECV project papers. However, the Glacier ECV project provided statistics on citations of their papers and these are described in Section 5 and in Table 1. Data on citations of papers whose work is based on CCI data should be widely available at the end of phase 2 of the CCI programme and by then sufficient statistical information should allow more robust conclusions.

Other metrics about CCI data can be collected online automatically and be analysed to understand the impact that the data has for the user. Such information would be collected at the points where CCI data is served and may involve user registration, data updates for users, usage of ancillary information, web statistics, user feedback, onward licensing of data, use by European funded research projects and online user tutorials or workshops. An online system known as CHARMe was developed to provide feedback and information on the experiences of data users for other data users (similar to TripAdvisor for travellers) and this system (currently in beta test at ECMWF, DLR and KNMI) also allows data providers to learn about how users apply data and the impact it has. If the CHARMe system becomes operational then it could be used to help measure the scientific impact of CCI data.

Clearly as time goes on the methods for measuring scientific impact of CCI data will become more accurate and representative as a greater number of users engage with the CCI data. Some ECVs are more mature than others in terms of user engagement which is a function of whether there was previous use of similar datasets (e.g. SSH) and also the perceived quality of the new CCI datasets. CMUG (2014) have documented their independent assessments of the dataset quality for each of the ECVs[1].

It is also important to identify new application areas where satellite CDRs are being used as a result of the ESA CCI project in areas which they were not previously being exploited. This is covered in Sections 6, 7 and 8.

5. CCI results in papers and international assessments

5.1 Papers

The number of papers published in peer reviewed journals authored by CCI projects including CMUG for CCI Phase 1 is shown in Figure 1. The totals do not include papers that are in draft or submitted, and it should be recognised that results from Phase 1 will continue to be published until Phase 2 results become widely available, hence these numbers are expected to rise over the next few years. The total number of papers is 188, with over 60% of these published by four CCI ECV projects (Greenhouse Gases, Ozone, Glaciers and Soil Moisture). These climate variables have well established research communities so it is likely that the CCI CDRs represent useful new datasets for those communities that have opened up new areas of interest and research upon which these papers were published. These projects are also

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[1] Available on the CMUG website at: http://ensembles-eu.metoffice.com/cmug/D3.1_Rep_v2.1.pdf

consortia comprised of many partners who are all able to publish results in journals. Eight CCI projects have published between five and nineteen papers (Ocean Colour, SSH, Clouds, Fire, Land Cover, Ice Sheets, Aerosol and CMUG) and this represents a smaller but still significant contribution to understanding the new insights which the CCI ECVs brought to these areas of climate research. There are two CCI ECV projects that have published fewer than five papers and this can be explained either that they operate in an area of climate research in which there are existing mature data sets (SST) or that the project started late (Sea Ice). One paper published in the Bulletin of the American Met. Soc. (Hollmann 2013) describes the entire CCI Phase 1 and its aims. As the only paper about the whole programme it is cited when a generic CCI reference is needed, and to date is has been cited fifty times[2].

The CMUG project has published five papers all on the evaluation and validation of CCI data sets. One paper published covers the whole of the CCI programme. The full list of these papers is provided in Appendix 1.

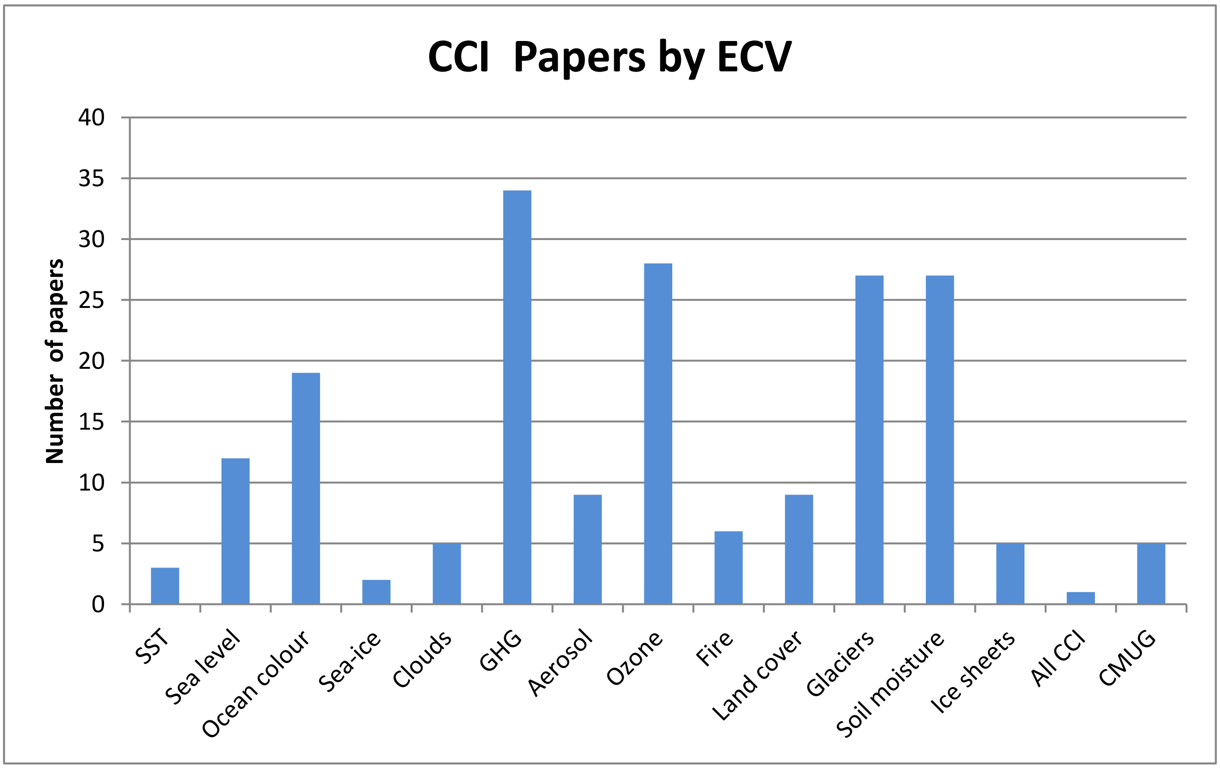

Figure 1: Scientific papers published in peer reviewed journals authored by CCI projects (including CMUG) for CCI Phase 1, as listed in Appendix 1. (Excludes papers in draft or submitted.)

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[2] Citation information from Google scholar.

The IPCC published the Working Group I contribution (Climate Change 2013: The Physical Science Basis) to its Fifth Assessment Report in 2013, and a number of papers with CCI results are cited in the report, even at this early stage in the CCI. Table 1 lists the CCI project, the papers and the number of citations within the report.

Project	**No. of papers**	**No. of ISI citations**	**Times cited in IPCC AR5**
GHG	1		
	Sussmann et al. 2012	12	1
Glaciers	7		
	Kääb et al. 2012	91	1
	Gardner et al. 2013	90	19
	Rastner et al. 2012	23	2
	Bolch et al. 2012	154	3
	Bolch et al. 2013	10	1
	Leclercq et al. 2012	5	2
	Heid and Kääb 2012b	15	1
Ice Sheets	1		
	Shepherd et al. 2012	227	20
Ozone	1		
	Loyola and Coldewey-Egbers, 2012	6	2
Sea Level	1		
	Ollivier et al. 2012	4	1
Soil Moisture	1		
	Dorigo et al., 2012	31	1
SST	1		
	Merchant et al., 2012	12	1
TOTAL	**13**	**680**	**55**

Table 1: Journal publications containing CCI results cited in the IPCC Working Group 1 report of the AR5.

For Glaciers_cci, several papers have been cited in IPCC AR5 that have used the key dataset (Randolph Glacier Inventory) compiled from results provided by Glaciers_cci and other teams. These include: Giesen and Oerlemans (2013), Grinstedt (2013), Huss and Farinotti (2012), Jacob et al. (2012), Marzeion et al. (2012), and Radic et al. (2014). These studies have already been cited 12, 20, 46, 197, 38, and 14 times (total 327), respectively.

In addition to work by the IPCC there are other international assessments of climate and climate change which draw upon key results in published scientific literature, and the CCI datasets should be expected to appear in them. The last WMO/UNEP Scientific Assessment of Ozone Depletion was published in 2014 and this has contributions from scientists working on the CCI project and cites CCI papers

Another measure to examine the extent of the CCI in climate research, and thus the reach of any impact, is the number of CCI experts (CCI science leads, climate research group scientists, etc) who also work in other international projects or initiatives. The IPCC Special Report on Extreme Events and also the IPCC Working Group 1 Fifth Assessment Report are used here for this evaluation. IPCC reports are independent of national considerations, cover relevant areas of climate research, and carry high status in the climate research community. Table 2 shows that 28 scientists from twelve CCI projects worked on the report as Coordinating Lead Authors, Lead Authors, Contributing Authors, Review Editors, or Editors.

IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
Chapter 3: Changes in Climate Extremes and their Impacts on the Natural Physical Environ. Sonia Seneviratne (**Soil_Moisture_cci** climate research group member), Coordinating Lead Author
IPCC WG1 AR5
Chapter 1: Introduction Peter Wadhams (**Sea_Ice_cci** climate research group member), review editor
Chapterr 2: Observations: atmosphere and surface Chris Merchant (**SST_cci** science leader) contributing author. Stefan Kinne (**CMUG/Aerosol_cci** climate research group member), contributing author John Kennedy (**SST_cci** climate research group) contributing author
Chapter 4: Observations: cryosphere David Vaughan (**Ice_Sheets_cci**, climate research group) coordinating lead author. Frank Paul (**Glaciers_cci** science leader), lead author. Anthony Payne (**Glaciers_cci** climate research group), contributing author Peter Wadhams (**Sea_Ice_cci** climate research group), contributing author Matthias Huss (**Glaciers_cci,** climate research group), contributing author Michiel van den Broeke (**Ice_Sheets_cci** climate research group), contributing author Jan Ove Hagen (**Ice_Sheets_cci** climate research group), contributing author
Chapter 6: Carbon and other biogeochemical cycles Philippe Ciais (**Fire cci**, climate research group), coordinating lead author Corinne Le Quéré (**Ocean_colour_cci,** climate research group), contributing author Frederic Chevallier (**GHG_cci** climate research group), contributing author Sander Houweling (**GHG_cci** climate research group), contributing author Philippe Peylin (**Land_Cover_cci** climate research group), contributing author Ben Poulter (**Land_Cover_cci,** climate research group), contributing author

Silvia Kloster (**CMUG**), contributing author
Chapter 7: Clouds and aerosol Michael Schulz (**Aerosol_cci** climate research group), contributing author Claudia Stubenrauch (**Cloud_cci** climate research group), review editor
Chapter 9: Evaluation of climate models Veronika Eyring (**CMUG** Phase 2), lead author Serge Planton (**CMUG**), review editor
Chapter 13: Sea level change Anny Cazenave, (**SeaLevel_cci** science leader), lead author Antony Payne (**Glacier_cci** climate research group), lead author Detlef Stammer (**Sea_Ice_cci** climate research group, **Sea_Level_cci** climate research group), lead author Michiel van den Broeke (**Ice_Sheets_cci** climate research group), contributing author Anne Le Brocq (**Ice_Sheets_cci** climate research group), contributing author
Annex III: Glossary Serge Planton, (**CMUG**) Editor
Technical Summary Philippe Ciais (**Fire cci,** climate research group), contributing author
Summary for Policymakers: David Vaughan (**Ice_Sheets_cci,** climate research group), drafting author John Kennedy (**SST_cci** climate research group), draft contributing author Philippe Ciais (**Fire cci,** climate research group), draft contributing author

Table 2: List of CCI experts who contributed to the IPCC Working Group 1 report of the AR5.

The Glaciers CCI project records that the seven papers it has cited in the IPCC Working Group 1 report of the AR5 have themselves been cited 715 times from the AR5. Other CCI projects have not recorded (or reported) this level of information. Although it is difficult to further quantify the tangible impact of (the number of) CCI papers, CCI paper citations in AR5, and participation of CCI experts in an international assessment, it is possible to make some qualitative statements. It is clear from the interactions and engagement described in this section that the CCI datasets are of sufficient size and quality to have generated a significant number of papers in peer reviewed journals, and that these papers are of sufficient quality and relevance to key research issues to have been cited in international climate assessments. It is also evident that the scientists working to generate the CCI datasets have a high level of professional status in the international arena.

5.2 International climate research programmes

There are many international initiatives in climate change research that the CCI datasets have the potential to make a valuable contribution to, such as Obs4MIPs and Core-CLIMAX. Interaction with both of these initiatives is ongoing and if maintained will lead to the two-way benefit of demonstrating the benefits of using CCI data to the climate research community and enhancing the value of these initiatives when using ‘best of kind’ CCI data. Section 7 discusses further the special role which the CCI can play in MIP initiatives.

6. Impact of the CCI by ECV

This section describes the initial uses of the first release of the CCI CDRs at the end of phase 1 for each CCI ECV individually. The developments made to produce the CCI data products and the improvements they give over the pre-existing state of the art is described in detail for each ECV dataset. Where this has had an impact upon an area of climate research, on the research community or on the level of scientific understanding this is described.

6.1 Clouds

According to the latest IPCC AR5 report clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the Earth's changing energy budget. To better constrain cloud processes and feedbacks long term consistent records are needed as stated by the WCRP Grand Challenge on Clouds, Circulation and Climate Sensitivity (http://www.wcrp-climate.org/grand-challenges/gc-clouds). The Cloud-CCI data-set which plans to cover 30 years (1982-2013) aims to contribute to this challenge by adding a new data set with consistent cloud variables and uncertainty information.

The Cloud CCI phase 1 data record, 2007-2009, was too short to have a discernible impact on the climate modelling community outside the CCI. However, a "community cloud retrieval" was developed, applied to measurements of three different multi-spectral imagers (AVHRR, MODIS and AATSR) and written up in climate research journals. In addition, a synergetic retrieval for the EnviSat instruments AATSR and MERIS has been developed, leading to the FAME-C dataset, which is being used by the climate research community.

Verification of the Cloud CCI data for 2007-2009 has been through comparison with existing global satellite datasets, reanalysis data and regional and global climate model simulations. The GEWEX Cloud Assessment of L3 cloud products of 12 global "state of the art" datasets (Stubenrauch et al. 2013) and ERA-Interim data (Dee et al 2011) have been used to assess the Cloud CCI data. The results for phase 1 show that the Cloud CCI data regional and seasonal variations correlate well with GEWEX Cloud Assessment data base and with ERA-Interim reanalysis data. However, there are problems detecting high cirrus and some issues over regions with challenging surface properties (mountain and sea-ice), similar problem regions as for many other satellite datasets (Stubenrauch et al 2013). Knowledge of these results in the climate research community in addition to the short time series will have slowed the uptake of the data products.

The Cloud CCI data sets were also used for evaluating regional and global climate model simulations. The regional climate model, COSMO, had optically thicker clouds compared to Cloud CCI data. Sensitivity experiments changing the ice sedimentation in COSMO reduced this bias and demonstrated the utility of the data. However, due to the phase 1 problem detecting high clouds, these experiments should be repeated for the re-processed data and should use several satellite datasets. For the global climate model EC-Earth, sensitivity experiments were made with reference to mixed-phase clouds. The results were compared to Cloud CCI data and the uncertainties were useful in showing larger values over problem surfaces, a positive outcome for users.

A number of scientific papers have been published by the Cloud-CCI team on the new retrieval and issues how to produce long term satellite datasets, which have impact on the scientific community. Summaries of the results are as follows:

- Karlsson and Johansson (2014) investigated the Cloud-CCI aim of compiling the longest possible time series of cloud products from one single multispectral sensor, the five-channel AVHRR instrument and how to include corresponding products based on other instruments, MODIS, AATSR, MERIS, VIRS as well as future sensors. They found that the radiances agreed within 3% for visible, the differences were mainly due to temporal and spatial matching as well as spectrally varying surface and atmospheric conditions. For the infrared channels there was very good agreement less than 0.2% deviations.

- An accurate calibration of satellite imagers is a prerequisite for using their measurements in climate applications. A method for the inter-calibration of geostationary and polar-orbiting imager solar channels based on regressions of collocated near-nadir reflectances to be used by Cloud CCI has been developed by Meirink et al 2014.

- The accuracy of the AVHRR product has been compared with data from CloudSat, CALIPSO and AMSR-E data by Stengel et al 2013. They found good agreement for correct cloud detection and evaluation of the cloud phase. For cloud-top height, negative biases were found for cirrus clouds, which has been addressed in the reprocessed Cloud CCI data.

- For MERIS and AATSR, and the merged product, and Bayesian cloud detection has been developed (Hollstein et al 2014). Carbajal Henken et al 2014 found that the FAME-C cloud property retrieval has reasonable accuracies for derived cloud micro-physical properties compared to MODIS-TERRA data. Cloud top heights are underestimated compared to ground-based instruments mainly due to difficulties in detecting high thin clouds and multilayer clouds.

6.2 Aerosols

In Phase 1 of ESA CCI, the Aerosol CCI project focused on algorithm improvement and comparisons of different algorithms. Eight algorithms for aerosol optical depth (AOD) went through a three-step process: algorithm experiments (Holzer-Popp, et al., 2013), round robin exercise (de Leeuw, et al., 2013), and ECV production and validation (paper in preparation). The extensive efforts on algorithm development, testing, and comparison have been a major step forward in Phase 1, which led to a significant improvement of several algorithms and inclusion of pathfinder pixel-level uncertainty estimates into the products. However, since the algorithms were only applied to one year data sets towards the end of Phase 1, the scientific impact of these datasets cannot yet be assessed.

In addition, the potential scientific impact of a more recently released 17-year (1996-2012) ATSR aerosol climate data record (produced within a Phase 1 option) is estimated to be significant. This new data record for mid-visible AOD (550nm) and Angstrom parameter is competitive to commonly used data records of NASA sensors (e.g. MODIS, MISR, SeaWIFs) but goes further back in time until 1996 (note that Angstrom parameters from all ESA and NASA datasets show major weaknesses). All data are released in netCDF format and are freely available through the Aerosol CCI website via ftp (http://www.esa-aerosol-cci.org/). Work is underway to make the dataset fully compliant with the requirements of the observation for Model Intercomparison Projects (obs4MIPs, Teixeira et al., 2014) project. The Aerosol CCI team then plans to contribute this dataset to obs4MIPs which will allow to fully exploit the dataset for climate model evaluation and analysis. Given that large uncertainties exist in the representation of AODs in current climate models (see, for example, IPCC AR5 Figure 9.29 in Flato et al., 2013), additional observations and particularly longer observational records as the one from the Aerosol CCI are urgently required.

The Aerosol CCI has also initiated the International Satellite Aerosol Science Network (AEROSAT) with the following goals: (1) make satellite aerosol data as useful as possible to customers, especially climate modelers (e.g., AeroCom), (2) achieve open and active exchange of information, and (3) establish a forum for satellite aerosol retrieval experts to learn from each other, to initiate new developments, and to discuss harmonization, (4) promote the use of satellite data, and (5) establish a forum for satellite data users (in particular climate modelers). The AEROSAT network provides a promising collaboration between modelers and satellite experts required to ensure that retrieval uncertainties are properly considered in climate model studies, and to ensure that the correct data are derived.

Other data improvements include Phase 1 CAR showing that AATSR long term regional trends in aerosol optical depth are highly consistent with in-situ measurements and show lower bias than MODIS collection 5. That assimilation of the CCI/AATSR and MODIS aerosol together in the ECMWF IFS model showed improved results compared to assimilation of MODIS aerosol products alone. Lastly that GOMOS stratospheric aerosol products were found to be useful for evaluation of the EMAC chemistry-climate model.

6.3 Ozone

Aiming at generating harmonized ozone Climate Data Records (CDRs) to assess the variability of ozone changes at different scales in space and time, the Ozone CCI has established three lines of production, one for total ozone columns from multiple backscatter UV satellites, and two for ozone profiles from nadir backscatter instruments and high-resolution ozone profiles from limb sensors, respectively. Preliminary assessment of the quality offered by these datasets already show important improvements compared with currently available equivalents which is starting to have a significant impact on this research community

The Ozone CCI datasets

A total column retrieval algorithm (Van Roozendael et al., 2012) has been implemented and applied to all existing ESA and ESA Third Party backscatter UV sensors to produce a 16 year long data record [Lerot et al, 2013]. This algorithm includes a number of improvements compared to other existing retrieval schemes, for instance improved corrections for the Ring effect and polarisation dependencies, as well as a new L1 soft-calibration scheme that accounts for both broadband and spectral features errors in the measured reflectance spectra and reduces the inter-instrumental biases on the level-2 data sets, thus reducing the need for additional adjustments [e.g. Spurr et al, 2013].

As part of a Round-Robin inter-comparison (Keppens et al, 2014) involving key European experts in ozone profile algorithm development, a new retrieval baseline was defined and tested. This algorithm, which makes optimal use of backscatter UV channels in the spectral range from 270 up to 340 nm, was shown to have improved information content in the troposphere.

Homogenized ozone profile datasets based on limb and occultation measurements from sensors on board of ENVISAT and from ESA Third Party Missions (OSIRIS, SMR and ACE-FTS) have also been created within the Ozone CCI project [Sofieva et al, 2013]. The so-called harmonized single instrument data set includes individual profiles reported on a common pressure grid and concentration unit. Auxiliary information for unit conversion and for obtaining the data over a geometric altitude vertical grid, as well as drift and bias tables for each pair of instruments is also provided.

Climate Model Evaluation

The Ozone CCI datasets will play a key role in the validation of atmospheric Chemical Transport Models (CTMs) and Chemistry-Climate Models (CCMs) with respect to their ability to well represent the depletion and describe the recovery of the ozone layer. Some results of this analysis are documented in the Ozone CCI Climate Assessment Report. These assessments are also part of initiatives such as the Chemistry-Climate Model Evaluation (CCMVal) and its successor the Chemistry-Climate Model Initiative (CCM-I).

International initiatives and assessments

The Ozone CCI data sets also provide an important input for international programmes like IOC and IGACO-O3, as well as the joint SPARC-IOC-IGACO-NDACC (SI2N) initiative. The latter, in particular, aims at assessing the current knowledge of the vertical distribution of ozone [Dameris and Loyola, 2012]. Outcome and results are also discussed in the 2014 WMO Scientific Assessment of Ozone Depletion to be published in 2015 [e.g. Dameris and Baldwin, 2012; Dameris and Loyola, 2012].

Furthermore, the Ozone CCI data sets are used in the international StratoClim research project (Stratospheric and upper tropospheric processes for better climate predictions, Dec 2013 - Mar 2018). This is an EC FP7 project that aims at producing more reliable projections of climate change and stratospheric ozone by a better understanding and improved representation of key processes in the Upper Troposphere and Stratosphere (UTS). This will be achieved by an integrated approach bridging observations from dedicated field activities, process modelling on all scales, and global modelling with a suite of chemistry climate models (CCMs) and Earth system models (ESMs).

Moreover, the O3-CCI project is also playing an important role in improving the understanding of the connection between ozone and climate (change). In particular, results obtained within the O3-CCI project have provided important contributions to recent international assessment reports, for instance the UNEP/WMO Scientific Assessment of Ozone Depletion and the Climate Assessment Report of IPCC, and are expected to influence future studies and future WMO reports. In this respect, as mentioned in section 5.1, many of the O3-CCI members have directly or indirectly contributed to the last WMO ozone assessment, confirming the high level of professional status of many scientists within the CCI community.

Data assimilation

Assimilation trials have been performed by CMUG to assess the impact of several level-2 datasets produced by the Ozone CCI. These trials made use of the ECMWF reanalysis system. Preliminary results show a positive impact of these products resulting in generally improved quality of the ozone analyses and in some cases also in a better usage of other observations as well as improved forecasts of the main meteorological fields. These are strong indications that not only can the assimilation of the Ozone CCI datasets improve the ozone analyses but also potentially improve the internal consistency of the system. Based on these results, it is anticipated that a number of the Ozone CCI level 2 products will be used in the forthcoming ERA5 reanalysis due to start in 2015.

6.4 GHG

The GHG CCI aims at delivering high quality satellite retrievals of anthropogenic GHGs. The combination of these high quality satellite observations and models should permit an accurate estimation of the regional GHGs' sources and sinks. Such an accurate estimation of the GHGs' sources and sinks, particularly at regional scales, is paramount to obtain better and more reliable prediction of the Earth's future climate, as also recognized by GCOS (2006, 2011).

The GHG CCI datasets

The GHG CCI products consist of satellite-derived column-averaged mole fraction of carbon dioxide (XCO_2) and methane (XCH_4) from ENVISAT SCIAMACHY and TANSO-FTS GOSAT measurements. The datasets benefit from fully characterized uncertainties, and are derived to meet demanding quality requirements after data filtering and bias correction.

Detailed assessments of the agreement between the GHG CCI GOSAT retrievals and co-located measurements from the Total Carbon Column Observing Network (TCCON) have been performed and documented, among others, in the GHG-CCI Product Validation and Intercomparison Report (PVIR) and Climate Assessment Report (CAR). The results show that in general, the satellite retrievals well capture the temporal and spatial pattern observed in the TCCON data. The high quality of the XCO_2 and XCH_4 retrievals also permits to identify unambiguously source/sink signals such as the seasonal cycle and its amplitude for XCO_2 and the XCH_4 inter-hemispheric gradient [e.g. Butz et al, 2011, Schneising et al., 2011, Reuter et al., 2013]. This is a significant development for climate research in this field.

Algorithm improvements

One of the GHG CCI foci in Phase 1 was to improve existing retrieval algorithms in order to generate data products which met the challenging user requirements. Several algorithms per data product have been further developed and iteratively improved in competition in a so-called Round-Robin (RR) exercise [Buchwitz et al., 2013]. It is worth mentioning that, although the aim of the RR exercise was to identify the best algorithm to use to generate the GHG datasets, it was not always possible to select a single retrieval scheme per variable. For these products several algorithms (typically two) have been selected for further development and analysis of the resulting data products.

Significant improvements have been achieved with the RR exercise and many of the user requirements met. For instance, Reuter et al. (2011) presented first results from the application of the advanced BESD algorithm [Reuter et al., 2010] to SCIAMACHY X CO_2 retrieval. BESD was designed to generate an improved CO_2 product from SCIAMACHY nadir observations by reducing the systematic errors caused by thin clouds (e.g. sub-visual cirrus clouds) and aerosols compared to the simpler but much faster WFMD algorithm. Buchwitz et al. (2013) and Dils et al. (2014) showed that this goal has been achieved.

Estimation of regional sources and sinks

Schneising et al. (2014a) compared the WFMD SCIAMACHY longitudinal XCO2 gradients with outputs from NOAA's CO_2 assimilation system CarbonTracker during the vegetation growing season over Canadian and Siberian boreal forests finding a generally good agreement for the total boreal region and for inter-annual variations, but also systematic differences for the individual regions. These differences suggest a stronger Canadian boreal forest growing season CO_2 uptake and a weaker Siberian forest uptake compared to CarbonTracker.

Reuter et al. (2013) computed CO_2 seasonal cycle amplitudes using various satellite X CO_2 data products from GHG-CCI, from NIES in Japan [Oshchepkov et al, 2011; Yoshida et al, 2013] and the NASA ACOS [O'Dell et al, 2012]. The amplitude of the seasonal variation in these products compared well with that from the TCCON data while being significantly higher than that obtained from the CarbonTracker. This would suggest that CarbonTracker underestimates the CO_2 seasonal cycle amplitude by approximately 1.5±0.5 ppm.

Using global GOSAT XCO_2 data, Basu et al. (2013) presents CO_2 surface flux inverse modelling results for various regions. Their analysis suggests a reduced global land sink and a shift of the carbon uptake from the tropics to the extra-tropics, as well as that Europe is a stronger carbon sink than expected. Chevallier et al. (2014) also obtained a stronger European carbon sink but argued that this could be due issues related to long-range transport modelling and satellite biases. Reuter et al. (2014b) studied this issue in detail using an ensemble of satellite XCO_2 data products (SCIAMACHY and GOSAT GHG-CCI Phase 1 and 2 products and also Japanese [Oshchepkov et al, 2011; Yoshida et al, 2013] and NASA [O'Dell et al, 2012] GOSAT products) and using an inversion method not, or significantly less, affected by the potential issues mentioned in Chevallier et al. (2014) and concluded: "We show that the satellite-derived European terrestrial carbon sink is indeed much larger (1.02 +/- 0.30 GtC/year in 2010) than previously expected".

Reuter et al (2014a) used data from the SCIAMACHY to derive nitrogen dioxide and carbon dioxide trends from 2003 to 2011. Using a spatial high-pass filtering method to isolate the anthropogenic carbon dioxide signal from overlaying signals due to uptake and release of carbon dioxide by vegetation, they were able to better see where and when carbon dioxide was emitted. They quantified emission ratios and emission trends. Their results showed that, for instance, less CO_2 from local anthropogenic sources is emitted during weekends in Europe and North America compared to week days.

Schneising et al. (2014a) used the SCIAMACHY XCO_2 to study aspects related to the terrestrial carbon sink by looking at co-variations of XCO_2 growth rates and seasonal cycle amplitudes with near-surface temperature. They found very good agreement with CarbonTracker.

Trend analysis

Schneising et al. (2013) compared the regional CO_2 enhancements and trends from multi-year SCIAMACHY XCO_2 data set with the emission inventory EDGAR. They found no significant trend in the central Europe and the US East Coast but a significant increasing trend for the Yangtze River Delta in China of about 13±8%/year, in agreement with EDGAR (10±1%/year).

Emission estimation

Ross et al. (2013) used CO_2 and CH_4 GOSAT data to obtain information on wildfire emissions. Wildfires are one of the most important factors affecting atmospheric constituency, and accurate estimates of their emissions are critical to modelling many atmospheric chemistry and climate-related processes. An ability to derive emission ratios from space-borne spectroscopy would offer many benefits, including measurement at remote locations and of intense burns and strongly-lofted plumes. They showed that, because of the proximity of the CO_2 and CH_4 retrieval wavelengths, these retrievals can be used to calculate wildfire emissions accurately in most situations.

Guerlet et al., 2013, analyzed GOSAT XCO_2 retrievals focusing on the Northern Hemisphere. They identified a reduced carbon uptake in the summer of 2010 and found that this is most likely due to the heat wave in Eurasia driving biospheric fluxes and fire emissions. Using a joint inversion of GOSAT and surface data, they estimated an integrated biospheric and fire emission anomaly in April–September of 0.89±0.20 PgC over Eurasia. They found that inversions of surface measurements alone fail to replicate the observed XCO_2 inter-annual variability (IAV) and underestimate emission IAV over Eurasia. They highlighted the value of GOSAT XCO_2 in constraining the response of land-atmosphere exchange of CO_2 to climate events.

Schneising et al. (2014b) analysed GHG-CCI Phase 2 SCIAMACHY XCH_4 retrievals over major US "fracking" regions and quantified methane emissions and leakage rates. For two of the fastest growing production regions in the US, the Bakken and Eagle Ford formations, they estimated that emissions increased by 990±650 ktCH$_4$/year and 530±330 ktCH$_4$/year between the periods 2006–2008 and 2009–2011. Relative to the respective increases in oil and gas production, these emission estimates correspond to leakages of 10.1%±7.3% and 9.1%±6.2% in terms of energy content, calling immediate climate benefit into question and indicating that current inventories likely underestimate the fugitive emissions from Bakken and Eagle Ford.

6.5 Sea Ice

Changes in the Earth's sea-ice cover are one of the most direct indicator of climatic changes. Satellite records of sea-ice observables are hence widely used by the climate-research community. The ESA CCI sea-ice record goes beyond existing products by providing spatially and temporally resolved data on both concentration and thickness and their respective uncertainties. In addition, these records provide more information on the underlying processing than previous other records. A very detailed summary of the impact of this new data record on climate-related research during the past few years is given in the project's "Climate Assessment Report" (Kern et al., 2014) and is summarised here.

Uncertainties of satellite products

The ESA CCI sea ice project put substantial emphasis on deriving uncertainty estimates for all its products. As part of this work, Ivanova et al. (2014) provide the first extensive overview of the quality of different sea-ice algorithms, which allows researchers to choose the best algorithm for their needs. Kern et al. (2015) provide an overview of the impact of snow and ice properties on retrieved estimates of sea-ice thickness.

Initialising seasonal and decadal forecast systems

Data from ESA CCI are currently used in a number of centres for the initialisation of seasonal and decadal forecast systems. At MPI-M in Hamburg, Felix Bunzel has shown that the initialisation of the MPI Earth System Model with both sea-ice thickness and sea-ice concentration outperforms a setup where only sea-ice concentration is assimilated. The use of sea-ice thickness data for model initialisation has only become possible through the ESA CCI project (compare Kern et al. 2014).

Also as part of the SPECS EU FP-7 project CCI Sea Ice data are used for model initialisation. This project aims to develop a new generation of European Forecast Systems. Application of CCI Sea Ice data by this project is a high profile 'impact' in that it demonstrates that both the European climate research community, and research funders at the EC, recognise the utility and scientific value of the data.

Model evaluation

Data from ESA CCI sea ice have been used to evaluate model performance. In particular, researchers at the University of Reading have used SICCI sea-ice thickness data to evaluate the performance of two ocean-ice models, namely the PIOMAS model and the ORAP5 model. Also model simulations of the Norwegian Earth System Model NorESM have been extensively evaluated against SI CCI data. However, for both these projects, a major hindrance lies in the currently apparently large bias of the CCI sea-ice thickness data compared to independent observations, while sea-ice concentration data is similar to those from other algorithms.

Scientific meeting
The work on Sea Ice CCI has also sparked international scientific discussion regarding the uncertainty of satellite estimates of sea-ice observables. Major progress in this respect was made during a Sea Ice CCI workshop that brought together many leading sea-ice modellers and observers in Hamburg in Autumn 2014. This meeting provided modellers with a state-of-the-art overview of current possibilities of satellite retrievals of sea-ice properties. Such valuable direct exchange between modelers and observers was fostered through the Sea Ice CCI project and involved many researchers that do not work within the Sea Ice CCI project.

6.6 SSH

The scientific exploitation of the Sea Level CCI (SL CCI) by the project science team and by the CMUG is a representative illustration of the use of the sea level data by the scientific community. It covers in particular the evaluation of the quality of the dataset compared to existing comparable products and its use for trend analysis including the interpretation of these observed trends. It also covers the emerging use of the data to evaluate the ability of climate models to simulate the observed sea level trends over the last decades, in particular at the regional scale. This last application is of particular interest to make this data more widely used by the climate modelling community. We present below several studies, some of them mentioned in the SL CCI climate assessment report (CAR), others published in the peer-reviewed literature, according to different application domains.

Comparison to other datasets
The comparison between the SL-CCI dataset and the SL AVISO reported in the CAR shows that the largest differences in interannual variability are located along the sea-ice edge, in the ITCZ region and in regions of large eddy activity like in the western boundary currents, but with very good agreement elsewhere. At the hemispheric scale an improvement of the trends over the last decades is attributed to improvements in the processing of the orbit corrections. At the regional scale some differences are not necessarily associated to an improvement in particular in the Tropical Pacific. But this is at least the case in the Arctic ocean when comparing the two satellite products to hydrographic data showing the added value of the new dataset (NERSC). In the same domain, the results of Valladeau et al. (2012) demonstrate that the improved altimeter sea level time series can be used as input for controlling the quality of tide gauge observations.

Trend analysis
As part of the SL CCI scientific team activity, the global mean sea level (GMSL) time series were computed from the SL CCI and compared to other similar products. A comparison with steric and ocean mass components derived from Argo and GRACE datasets was also performed. It is concluded that the CCI product fits better the sum of the different climatic contributions to sea level rise. The paper of Hollmann et al (2012) confirms that the uncertainty on GMSL trend has decreased from 0.5-0.6 mmyr^{-1} to about 0.3 mmyr^{-1}. The CCI product has also been used in a paper of Cazenave et al (2014) showing that when correcting

for interannual variability, the past decade's slowdown of the global mean sea level disappears, leading to a similar rate of sea-level rise (of 3.3+/-0.4 mmyr^{-1}) during the first and second decade of the altimetry era.

Regional climate

As part of the CMUG activity, the SL CCI was used to assess the ability of a coupled regional climate system model over the Mediterranean domain (Sevault et al., 2014) to reproduce the interannual, seasonal and spatial variability of inferred sea level. This study demonstrates that this product is suitable for regional climate studies over the Mediterranean basin, even at a scale of a few tens of kilometres (CMUG D3.1). The specific interest of the SL CCI for regional climate studies is confirmed with a paper from Johannessen et al. (2014) focussed on the Nordic seas and Arctic ocean. Combined with an estimate of the mean dynamic topography from GOCE satellite, and with hydrographic data, the SL CCI indeed allows to infer ocean circulation and volume transport in this region and a direct comparison with corresponding diagnostics from three coupled sea ice–ocean models.

IPCC AR5

The SL CCI was not available to replace the SL AVISO in the Obs4MIPs database before the beginning of the CMIP5 model evaluation and thus to indirectly contribute to the AR5 preparation. However, Ollivier et al. (2012), in a paper referred in the AR5 dealing with improvements of the Global and Regional Mean Sea Level trend using Envisat data, acknowledge the CCI project for downstream assessment of their results as well as for the development of dedicated climate-oriented comparison methods.

6.7 SST

The use of the SST CCI data has been highlighted in several areas listed below but it should be borne in mind that most use of the data will be indirect where the SST CCI data is assimilated into an analysis along with other satellite data and in-situ observations and it will be the analysis that is widely used by researchers for climate model applications. The main climate quality SST analysis is HadISST, Rayner *et. al.* (2003), is due to incorporate AVHRR SSTs from the CCI SST dataset in the next version for release in 2015. This will result in the data being widely used by a large number of climate modellers though HadISST.

There have already been several studies including CMUG's (CMUG-D3.1_1A, 2012), assessing the CCI SST data compared to other datasets but these are not summarised here as they are not exploiting the data for a particular application. In summary these studies show the CCI dataset is if climate quality with potential improvements over existing datasets.

SST datasets

The Danish Meteorological Institute (DMI) has used the CCI SST data to produce a historical dataset of the SST analysis over the Arctic, initially for 2006-2008, and compared it to existing SST climatologies in that region. The CCI data were found to be better than AVHRR Pathfinder 5.1 but showed a cold summer bias relative to reference data. The seasonal variation of the DMI analysis showed improvements for the period using CCI data.

Data Assimilation and Ocean Forecasting

Improvements in the European northwest shelf ocean reanalysis were obtained through assimilation of the CCI SST data into the Met Office FOAM model from 1991 onwards. The CCI data were bias corrected before assimilation in to the model using AATSR and in-situ data. The uncertainties provided with the data were used in the assimilation to estimate the observation error assumed in the assimilation process. This work is part of the MyOcean project.

Evaluating Climate Models

The SPECS EU FP-7 project aims to develop a new generation of European Forecast Systems and uses the CCI SST data to prescribe the SST for European waters.

The daily mean SST CCI analysis is used for evaluating coupled climate model simulations of heat transport by tropical instability waves. At the Met Office both the model mean state and its variability for the HadGEM3 model are examined. The variance is lower when the CCI SST data is compared with the model analysis than with previous SST datasets. Some results of this analysis are documented in the CCI_SST Climate Assessment Report (section 4.1.3). In particular it highlighted the problems of desert dust in the nadir view only AVHRR retrievals.

The SST CCI analysis is also being used as part of a process-based model comparison study studying heat transport by tropical instability waves in the ORCA025 and ORCA1 ocean models at the Met Office. These waves form in the tropical Pacific and Atlantic Oceans where there is shear between the westward currents on the equator and the eastward currents to the north and south. Daily mean SST data (as provided by the SST CCI analysis) is much more useful than foundation SST data (as provided by OSTIA v1) for this purpose because foundation SST is expected (and seen) to be cooler than the daily SSTs simulated by the models. Large differences were found and this highlights the importance of eddy permitting model resolution for simulation of the heat budget of tropical instability waves (Graham, 2014).

The CCI SST data input to an OI analysis data has also been compared with the AMIP dataset. The analyses show the largest variability in the tropical pacific and mid-latitudes and show similar spatial patterns in their anomaly fields. The mean climatologies of the SST analyses are biased with respect to each other. The OI is coolest whilst the AMIP is warmest overall. The correlations between precipitation and SST are mostly positive, where significant, whereas between cloud amount and SST it is both positive and negative. Areas of positive correlation, mainly across ENSO regions, are linked to the relationship between precipitation and SST whereas areas of negative correlation are not and indicate regions of marine stratocumulus cloud.

IPCC AR5

The CCI SST data was provided too late for inclusion in the IPCC AR5 WG-1 report but the precursor dataset, ARC, produced from (A)ATSR data was used. A plot was included in Figure 2.17 of chapter 2 of the AR5 report showing the ARC data compared with the in-situ observations from the HadSST3 analyses. It was observed that the ARC SST products were more accurate than many in situ observations (Embury *et al.*, 2013). When (A)ATSR and in situ data are compared in analyses, Kennedy *et al*. (2012) used the satellite SST data to characterise the biases and random errors of in situ SST observations. It is expected the ARC data will be replaced by the CCI SST dataset for AR6 as the extension of the time period will only be under the CCI project.

6.8 Ocean Colour

The exploitation of satellite ocean colour datasets is still in its infancy but the GlobColour and OC-CCI datasets are making a start to expand the use of these data for various applications mentioned below. For the future it will be important to engage and consult international expert groups, notably the International Ocean-Colour Coordinating Group (IOCCG) to promote the use of these datasets.

Data Assimilation and Ocean Forecasting

The CCI Ocean Colour data (CCI-OC), released in December 2013, has been assimilated into the Met Office's FOAM-HadOCC system, a global coupled ocean-biogeochemical model which is part of a framework used for multiple applications, from climate to seasonal/decadal and short-range predictions and studies. This assimilative model run generated a global reanalysis, from September 1997 to July 2012, which is the period covered by the CCI-OC data. In parallel, a second global reanalysis was produced, which instead assimilated ocean colour from the ESA's GlobColour core dataset, the CCI-OC precursor. Both reanalyses were preliminarily assessed, through comparisons with each other, a control run, and independent *in situ* observational datasets, in order to investigate the different impacts the assimilation of CCI-OC and GlobColour data had on the model carbon and biogeochemical cycles, including patterns of seasonal and inter-annual variability.

In summary, our assessments at this stage show the assimilation of CCI-OC or GlobColour data has a very similar, and positive, impact on the modelled biogeochemical and carbon cycles. Assimilating ocean colour consistently reduces the bias seen in the model and so model results better match independent *in situ* observations. In terms of carbon, the assimilation of CCI-OC data has a small impact, mainly on the magnitude of the air-sea flux of CO_2 rather than its temporal variability.

Both ocean colour datasets are suitable for data assimilation, although neither of them has shown to be significantly superior to the other. However, one added advantage of the CCI dataset is its improved spatial data coverage, particularly in areas of highly important biological and fisheries production, such as the Mauritanian upwelling region. It is in these regions of CCI-OC added coverage, where most of the differences between the two reanalyses appear to be and where the CCI-OC could potentially have most impact.

Ocean colour variability

The Indian Ocean Dipole is recognised as a major atmosphere-ocean phenomenon in the Indian Ocean that can arise in the presence or absence of the El Nino (La Nina) Southern Oscillation. CCI-OC data has been used to study the Gulf of Aden. OC-CCI data was used for an investigation into the full seasonal succession of phytoplankton biomass (Gittings *et. al*.

2015). Analysis of indices of phytoplankton phenology (bloom timing) reveals that the Gulf of Aden exhibits distinct phytoplankton growth periods in different parts of the gulf: a large peak during August (summer monsoon) in the western part of the gulf, and a smaller peak during November (winter monsoon) in the lower central gulf and along the southern coastline. The monsoon wind reversal is shown to play a key role in controlling phytoplankton growth in different regions of the Gulf of Aden.

Ocean colour trends

The combination of the three ocean-colour missions SeaWiFS, MERIS and MODIS-Aqua in the OC_CCI dataset has led to the creation of a >15-year time series which can start to be used for trend analyses. In addition correlations between SST and chlorophyll-a trends can be estimated. Some preliminary results on this are presented in the OC-CCI climate assessment report. More work on this will be done during phase 2 of the CCI.

6.9 Land Cover

LSCE-IPSL was one of three “Climate Users” for the ESA CCI Land Cover (LC-CCI) Project, with the aim of assessing the impact of the new Land Cover (LC) maps on offline and coupled simulations using the ORCHIDEE LSM within the IPSL ESM.

Firstly, a new procedure was developed within the project team for mapping between land cover classes and PFTs (Poulter et al., submitted). The fractional coverage of the resultant 13 PFTs within ORCHIDEE was compared to the default Olson land cover map and LC – PFT conversion used in ORCHIDEE.

The new LC-CCI product showed increases in bare soil and decreases in C3 grasses at high northern latitudes, together with a shift from C3 grasses to Boreal forest in the mid-to-high latitudes. In the tropics, there was a change from C4 grasses to C4 crops, especially in the Sahel, as well as reductions in tropical tree cover in the arc of deforestation in the Amazon, however; a conversion from grass to forest was seen in the African Congo Basin. See Figure 2.

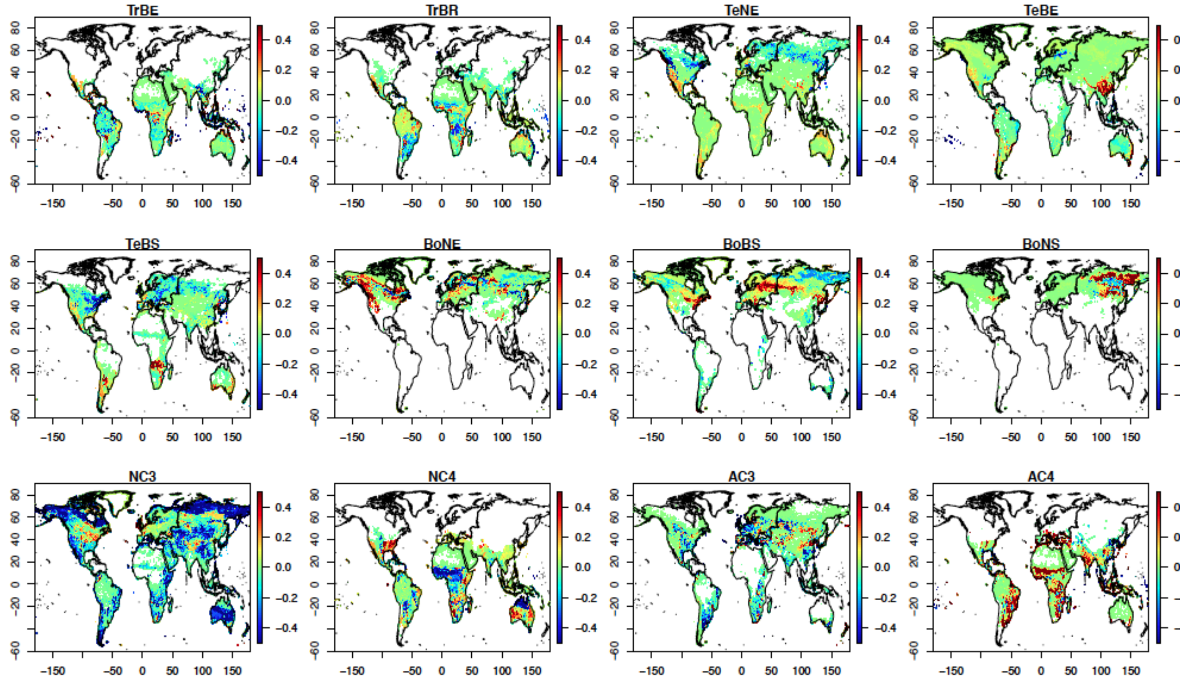

Figure 2: Fractional differences between PFT coverage used from the Olson PFT dataset and the LC_CCI dataset used in the ORCHIDEE DGVM. Negative values reflect decreases in PFT cover introduced by using the LC_CCI dataset and positive values indicate increases in PFT cover. (Courtesy of Natasha McBean)

The impact of the change in PFTs on model state variables related to water, carbon and energy budgets were also examined, and several benchmarking datasets were used for evaluation. The change in vegetation from grass to bare soil in high latitude areas results in a reduction in NPP and GPP, and therefore also a reduction in the positive bias when compared to satellite and FLUXNET-derived benchmarking datasets. This also resulted in decreases in soil carbon, decreased LAI and an increase in albedo. A reduction in the amplitude of atmospheric CO_2 simulations was also observed.

In the tropics, an increase in NPP was observed due to a higher C4 crop fraction, resulting in a weaker global NEE sink. Global biomass decreases were noted, which resulted in a reduction in the positive bias compared to satellite-derived benchmark datasets, however most of this change was explained by a lower forest, and higher crop, fraction in the tropics.

Finally, the differences observed in the ORCHIDEE simulations were compared to two other LSMs: JS-BACH (MPI-Hamburg) and JULES (Hadley Centre). The LC-CCI map resulted in significant changes in the vegetation fractional cover for all models, mostly in the tropics and high northern latitude regions. These differences induced significant differences in terms of surface albedo, the partition between latent and sensible heat fluxes and the gross and net carbon fluxes and stocks. However, when comparing model results the picture is more complicated. This is because there are differences in the PFT descriptions for each model (for example, ORCHIDEE has a representation for crops, but JULES does not), in the reference maps used by each modelling group, and in the cross-walking procedure (e.g. the climate dataset and rules used to partition between “tropical”, “temperate” and “boreal” biomes). Thus, it is more useful to compare relative improvement when compared to benchmark datasets between modelling groups.

Although no overall metric has been established, it is clear that on average LC-CCI dataset brings an improvement to model simulations when compared to benchmark datasets. The picture is often more complicated when looking in greater detail however; for example modelling groups report different relative improvements for each variable, or may find an improvement for one region but not another, or may find the opposite pattern in the offline and coupled simulations

In order to make a more general statement of the benefit of having a more accurate satellite-derived LC dataset, it will be more useful to assess the impact of uncertainty in the LC-CCI dataset on the model simulations, so that all models have the same reference. This will be addressed in Phase 2 of the LC-CCI, as will the impact of uncertainty in the cross-walking procedure, and the relative contribution of both sources of uncertainty. It is expected that by performing factorial experiments with a tighter constraint on each source of uncertainty, we will better be able to answer the question of how important it is to have an accurate LC dataset to drive climate models.

Further to the direct exploitation of the LC maps within the ESA CCI LC project, these maps were used in other projects such as DOFOCO and LUC4C. All the uses of the new LC maps were driven by the fact that these maps brought additional value compared to existing ones. Other projects have also used the LC maps (at regional scale, over the arctic regions) include CLASSIQUE (ANR), PAGE21 (EU-FP7) and WSIBISO (MEGAGRANT).

6.10 Fire

The Fire CCI project released the first Phase 1 Burned Area (BA) products at the end of October 2014. The products include BA pixels at full MERIS resolution with date of detection, confidence level and land cover burned in GeoTIFF format. The BA as a gridded product is computed for 0.5 degree resolution every 15 days, and include total BA, standard error, fraction of observed area, number of burned patches and sum of BA for each land cover type. The products cover the period from 2006 to 2008 inclusive. See Figure 3.

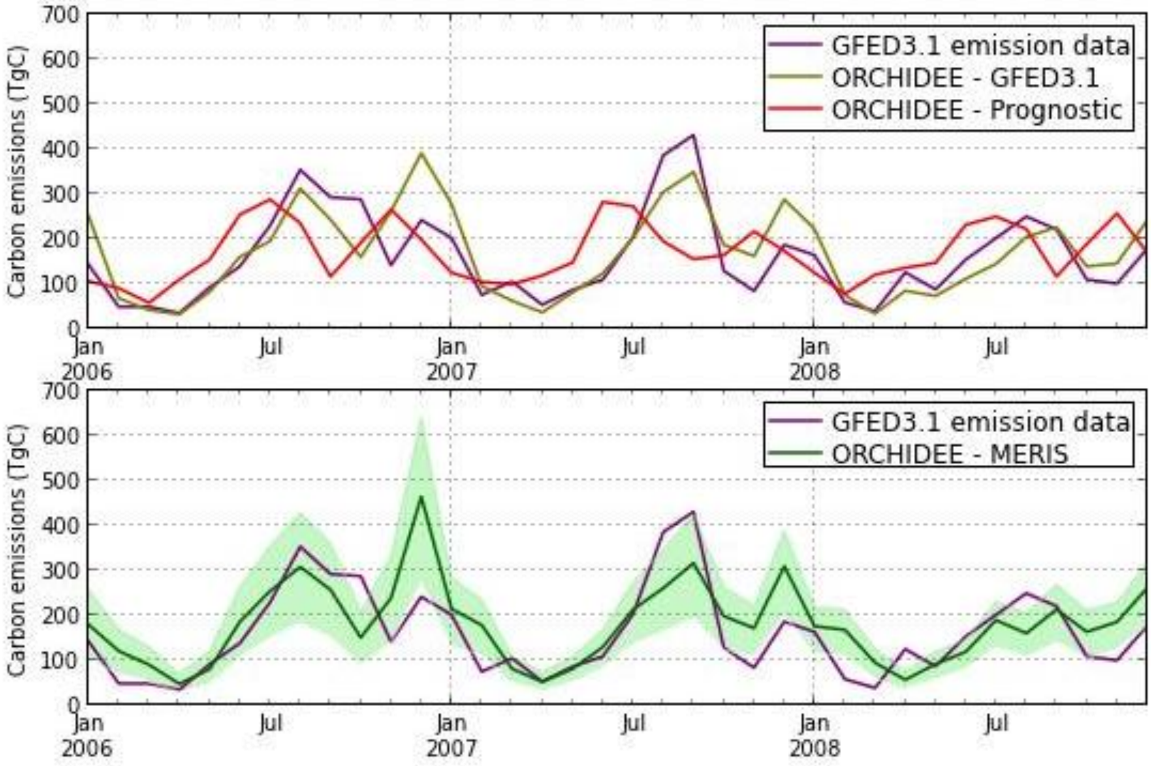

Figure 3. Monthly carbon emissions (TgC month^{-1}) for 2006-2008 from open biomass burning by different estimations. Data are presented for GFED3.1 emission data set (purple line), ORCHIDEE forced by GFED3.1 burned area data (yellow line), ORCHIDEE prognostic simulation (red line), and ORCHIDEE forced by ESA CCI Fire MERIS data (green line). The green shaded area in the lower panel indicates emission uncertainties as influenced by the one-sigma uncertainty in the burned area given by the CCI Fire MERIS data. (Courtesy of Chao Yue)

Due to the late release of the product within CCI phase I there has been limited use of the data outside the CCI team itself up to the end of 2014. The Fire CCI team, however, released a detailed climate assessment report (Fire_cci_Ph3_LSCE_D4_2_CAR_v2_1) drafted by their climate research group. This included a comparison of the Fire CCI burned area with regional and national statistics, an application of the burned area product in a global vegetation model as boundary condition and an analysis of the pixel-based product. In summary all of these studies showed that the Fire CCI product performs comparably to the widely used GFEDv4 burned area product and outperforms previous released burned area data based on ESA products (GLOBCARBON, L3JRC). The products are comparable in terms of annual burned area, interannual variability and spatial distribution. They also share the same limitations, as they both do not capture small fires. This deficiency reveals in a comparison of the burned area product with national statistics at the country/state level. The Fire CCI product was used to benchmark the land vegetation model ORCHIDEE. For this exercise the additional parameter of the landcover class burned reported in the Fire CCI product was used, which revealed that the overestimation in model burned area can be related to temperate forest and grasslands. In addition, the Fire CCI burned area product was prescribed in the ORCHIDEE model as boundary condition and translated into fire emission of CO and CO2 by prescribing spatial explicit combustion completeness parameters. The resulting emissions are comparable to the ones reported in the GFEDv3 product. For this analysis, also the burned area uncertainty reported in the Fire CCI product was used and translated into an uncertainty in simulated CO and CO2 emissions from fires.

As part of the exploitation of the CCI Fire burned area product the users expressed the following feedbacks, valuable for future improvements and studies, and also for judging the impact:

- The current length (3 years) is not sufficient, data covering 10 years would be more relevant.
- The spatial resolution (0.5°) is satisfactory.
- The Fire ECV provides differentiating features such as fire size, pixel based information, which allow, for example, for fire shape analysis.
- Since the use of the Fire ECV enables for obtaining better carbon budgets, this ECV should be used in projects such as GCP.
- The use of the ESA CCI Land Cover data as the land cover input, combined with the CCI Fire data would allow for better localization of peat fires and deforestation fires. This is facilitated by the consistency between Fire and LC ECVs. Yet, consistency between Fire ECV and other ECVs is highly desired.
- The merged product combining burned area derived from MERIS and SPOT VEGETATION is also discussed in the CAR, although not part of the Fire CCI release data. The merged product significantly overestimates burned area, which can be attributed to an overestimation in the SPOT VEGETATION product.

The currently available Fire CCI product, although not yet assessed by CMUG or applied in other research does have a technical specification and supporting information (e.g. uncertainty description) which should make it useful for climate change research especially in Carbon cycle research, the Carbon Cycle-MIP and land surface process studies.

6.11 Soil Moisture

Soil moisture climate datasets have large potential for applications in numerous fields in climate research. The CCI soil moisture dataset (CCI SM) provides a unique long term record of soil moisture over several decades and has been already used in manifold applications like summarized below. An excellent summary of the achievements and work conducted as part of the ESA CCI soil moisture project is given in the project's "Climate Assessment Report" (Mittelbach et al., 2014).

International visibility

The ESA CCI soil moisture project has contributed to international activities like the annual "State of the climate" reports, published in BAMS (DeJeu et al., 2011,2012; Parinussa et al., 2013; Dorigo et al., 2014, 2015) and the WMO statement on the status of the global climate (Wagner et al., 2012) A preliminary version of the CCI soil moisture dataset has been studied in Dorigo et al. 2012, and was referenced in the IPCC 5th assessment report. Even though the CCI soil moisture project started only in 2012, already 2 major product versions and several minor updates were released. These products have found their way to over 1500 registered users, of which 29% are from the climate research community, 20% from the water community and 15% from the weather community

Land-atmosphere interactions and fluxes

The relationship between the CCI soil moisture dataset and land-atmosphere interactions has been studied in several publications. Hirschi et al. (2014) assessed the suitability of the CCI SM dataset for diagnosing soil-moisture temperature coupling on the global scale. Loew et al. (2013) investigated the relationship between CCI SM anomalies and precipitation anomalies at the regional to global scale and found that the CC SM dataset can be used as a good proxy for precipitation dynamics. Brocca et al. (2013, 2014) used the skill of CCI SM to represent the surface precipitation dynamics to infer actual precipitation rates from the CCI SM dataset.

Climate trends and teleconnections

Significant covariance between CCI SM and other climate signals were found across the globe. Dorigo et al. (2012) found significant correlations between CCI SM decadal trends and corresponding vegetation trends. Miralles et al. (2014) and Bauer-Marschallinger et al. (2014) could identify teleconnections between the monthly soil moisture signal to El-Nino, La-Nina cycles as well as oceanic oscillations. Albergel et al (2013) compared the CCI SM product with reanalysis data and found reasonable trends between the reanalysis results and the CCI SM product. Similar results were obtained from Loew et al. (2013).

Evaluating Climate Models

The potential and limitations of using the CCI SM dataset has been evaluated by Loew et al. (2013). The general potential of CCI SM to provide a reference dataset for the evaluation of soil moisture anomalies at climatic timescales is outlined and the requirements for further developments of the CCI soil moisture dataset to provide a useful reference dataset for improved climate model parameterizations is summarized. In this role, the CCI SM dataset has made an important contribution in evaluating the soil moisture fields of ERA-Interim/Land reanalysis (Albergel et al., 2013) and several land surface models (Szczypta et al., 2014; Spenneman et al, 2015), and the widely used scPDSI drought data set (van der Schrier et al., 2013).

Vegetation dynamics and the carbon cycle

Soil moisture availability is the primary climatic driver of vegetation growth across many biomes worldwide. Thus, it impacts the efficiency of vegetation as a terrestrial carbon sink. Several studies use the CCI SM dataset to study the connectivity between soil moisture patterns and vegetation dynamics in different parts of the world (Chen et al., 2014; Munoz et al., 2014, Barichivich et al., 2014). Traore et al. (2014) used CCI SM to benchmark soil moisture states of the ORCHIDEE ecosystem model.

6.12 Ice Sheets

The Ice Sheets CCI project started later in Phase 1 than the majority of the other CCI projects and therefore in comparison to the other CCI projects examined here has a later timeline for delivering reports and data. The ECV data produced by the Ice Sheet CCI project are essential for both initializing and constraining models that project the future of the ice sheets, however, these data are still under production.

Elevation changes (SEC) and surface velocity (IV) have already been applied to ice sheet modelling, the SEC as constraints (Aschwanden et al., 2013) and for data assimilation (Larour et al., 2014; Brinkerhoff and Johnson, 2013) and the IV to inferring basal conditions for model initialization (Gillet-Chaulet et al., 2012; Seddik et al., 2012). The modelling work that takes advantage of and incorporates the observed variables is essential for identifying the missing physics in transient ice-flow models in order to better characterize the intra- and inter annual variability in surface elevation changes and mass loss of the ice sheets. A dialog with the modelers to further advance the work and use of the ECVs in large scale ice sheet modelling is planned during the Ilulissat Climate Days in June 2015.

The citation of an Ice Sheet CCI paper in the IPCC AR5, and the inclusion of one of the Ice Sheet CCI project team in the authorship of that report show a level of impact for this project in climate research, as does the publication of five peer-reviewed journal papers from the project.

In 2010, the IPCC highlighted the disagreement in ice sheet mass balance estimates as a primary emerging topic and they expressed concern that progress would not be made in the run up to the fifth assessment report and noted the potential value of inter-comparison projects for addressing the problem (Stocker et al 2010). The Ice sheet Mass Balance Inter-comparison Exercise (IMBIE) was established with the aim of providing reconciled estimates of ice sheet mass balance. The 2012 team consisted of 47 scientists from 26 separate institutions and 7 different countries. The team consisted of expertise in radar and laser altimetry, gravimetry, the input-output method, glacial isostatic adjustment and surface mass balance modelling, glaciology, and ice sheet modelling. The project was co-led by Professor Andrew Shepherd and Dr Erik Ivins. In 2012, IMBIE achieved this aim and reconciled measurements of ice sheet mass balance using satellite altimetry, gravimetry and the input-output method (Shepherd et al 2012). Through a series of experiments that used common spatial definitions and time periods, and that investigated the impacts of various ancillary datasets used, it was shown that there is good agreement between estimates of Antarctic and Greenland mass balance determined from the three techniques. The project highlighted the complementary nature of the three approaches, showing that by combining techniques, the coverage and confidence of the results is improved.

The goal of the Ice_Sheets_cci project, which has been running since 2011, is to produce long term and reliable Ice Sheet Essential Climate Variable (ECV) datasets from available and future satellite observations. Essential Climate Variable’s (ECV’s) describing changes in ice sheet mass balance are societally relevant, because their losses contribute to global sea level rise (0.59 +/- 0.20 mm/yr over the period 1992 to 2011 in Shepherd et al, 2012). Both the Greenland and the Antarctic Ice Sheets are losing ice mass at accelerating rates (McMillan et al., 2014; Rignot et al., 2011) in response to atmospheric (van den Broeke et al., 2009) and oceanic forcing (Joughin, 2012). Phase 1 of the Ice_Sheets_cci project was restricted in geographical scope to the Greenland Ice Sheet because it was not feasible to cover a larger spatial region within the financial and temporal constraints of the CCI Phase 1 schedule. However, in April 2015 during Phase 2 of the CCI program, a new Antarctic_cci (AIS_cci) project was started to produce scientifically valuable long term satellite datasets over the Antarctic Ice Sheet.

An AIS_cci user survey was conducted with the aim of canvassing the opinion of the scientific community about what type and specification of Antarctic satellite data products are required from the AIS_cci project. The survey was designed to poll information on the types of data product required by the users, such as surface elevation change, ice velocity, etc., and the spatial and temporal sampling of the products, for example full ice sheet coverage verses specific regions of interest. The user survey was extremely successful with over 100 independent scientists completing the survey and over 98 users registering their interest in the AIS_cci project by providing personal contact details in order to stay informed about future progress. The respondents were primarily from an EO background and 55% of people had over 10 years of experience in their field of interest suggesting that we received high quality, knowledgeable replies. Overall the respondents indicated that mass balance, ice velocity and surface elevation change were the most important data products by a significant margin however a large number of respondents also prioritised Grounding Line Locations highly therefore all 4 ECV products will be produced over the next 3 years of the AIS_cci project. The AIS_cci project is currently adapting the algorithms and software used in Phase 1 of the Greenland_cci project and we will produce a first set of Antarctic_cci data products by the end of the first year in April 2016.

The Ice Sheet CCI Climate Assessment Report was not available at the time of writing.

6.13 Glaciers

From the outset it was planned for the main aim of the Glaciers cci project to make a direct contribution to an existing study of a component of the Earth system: the Randolph Glacier Inventory. This meant the project had a coherent user group with well defined needs, and from this the project aims and desired outcomes were equally well defined. At the start of the project there was a clear view of what the main impacts of Phase 1 should be, and how they could be measured. Other work conducted the Glaciers cci team had impacts for modellers (glacier and hydrology) and on the IPCC Fifth Assessment Report (IPCC 2013).

The Glaciers cci dataset has had a major impact on Earth system research through its contribution to the Randolph Glacier Inventory (RGI). Significant gaps in the RGI have been filled so that physical descriptions of all glaciers (outline, elevation and velocity) now exist. This means that now, for the first time, there is an accurate estimate of the global number, area and volume of all glaciers worldwide. This marks an important stage in fulfilling GCOS goals.

This result has lead to further impacts in science research, such as that on journal citations described in Section 5, as glacier and hydrology modellers have used Glaciers cci data (embedded in the RGI) to better estimate and understand past and future glacier contributions to sea level rise. Such research was a key contribution to the IPCC AR5 as this information was not available to previous IPCC assessments.

7. MIPs and uptake of ECVs in combination

A key feature of CCI datasets are the connections between ECV data, as CCI data may be produced from common sensors and processing, and where applicable made available with common grids and masks. Further, the datasets are made to be consistent - meaning that there should be consistency between variables, for example between sea-ice and SST, or, Fire and Aerosols, aerosols and clouds (here the consistency of underlying cloud masks has been evaluated within a targeted analysis). This approach provides an added benefit to climate researchers over other available datasets.

Model Intercomparison Projects (MIPs) are now an established way of comparing and validating (climate) models, including validation against observations. The best known of these is the CMIP which provides the framework for model projections and validation studies for the climate models used in IPCC Assessment Reports. Other MIPs are used for specific areas of climate research, for example AMIP for the atmosphere, and CCMIP for the carbon cycle. The observations employed in CMIP5 came from the Obs4MIPs project, and were provided on common grid and format compatible with model data. Obs4MIPs used the precursors of CCI data products as the CCI products were not then available and information about this is provided in the ECV sections of this report (Section 6.2 Aerosols; 6.6 SSH; 6.7 SST; and 6.10 Fire). The scope and content for CMIP6 is currently under discussion but it can reasonably be assumed that it will be similar to its predecessors and that relevant CCI datasets will be provided to Obs4MIPs by the CCI project teams with all the benefits of CCI consistency and uncertainty characterisation. This will have a measurable impact on the value of CMIP6. It should also be noted that CMUG phase 2 research includes a component to demonstrate the value of using CCI datasets with the ESMVal tool.

There are ongoing projects or initiatives which will benefit directly from the consistency of CCI data due to the nature of their investigations. For example the Southern Ocean Observing System (SOOS - http://www.soos.aq) has discussed with CMUG the CCI datasets which can help its study of the Essential Ocean Variables for the Southern Ocean and acknowledges the potential impact that the CCI data can bring to its work (CMUG Phase 2 Deliverable 1.1: User Requirements Document).

8. International data requirements and assessments

Of the many international initiatives supporting climate research through improving access, quality and other aspects of data there are two which are key to the CCI fully achieving its scientific potential and impact.

The first of these is for CCI ECV datasets to meet, or even exceed, the GCOS requirements[3] on "Systematic observation requirements for satellite-based data products for climate". The GCOS requirements are a well defined set of thresholds for a wide range of satellite observational data, which were gathered from a diverse set of climate research needs. The CMUG has assessed the CCI ECV datasets against the GCOS and its own (CMUG) requirements in CMUG Phases 1 and 2, with the most recent result being that the majority of CCI ECV datasets meet many aspects of the GCOS requirements.

The second expectation of CCI ECV datasets for achieving significant scientific impact in the international arena is to produce a maturity assessment of its data products, using a system such as has been developed by the project CORE-CLIMAX[4]. This work is already underway in the CCI and it is anticipated that it at the end of Phase 2 many of the datasets will have sufficient quality to achieve a high performance level in the CORE-CLIMAX maturity assessment. The CORE-CLIMAX maturity assessment examines seven key quality aspects of climate data (record length, spatial coverage, temporal sampling, spatial sampling, bias, precision, and temporal stability), and consistency of the matrix between datasets allows users to understand the fitness for purpose of a dataset, and to compare datasets.

One other aspect of the CORE-CLIMAX work is that it is a precursor project of the Copernicus Climate Change Services (C3S) programme, and as such an early adoption by the CCI ECV projects of the system will help smooth the uptake of CCI data in to C3S. There are also other C3S precursor projects (e.g. QA4ECV, UERRA, CLIPC) that the CCI ECV projects are engaging with to increase the uptake and impact of the CCI. The future possible scientific impacts from CCI input to the C3S is covered in the next section.

9. Future impacts

Although this report is concerned with the impact that the CCI Phase 1 datasets have had to date it should be noted that not only will the impact of the CCI on climate research continue, in the next decade it is expected to grow considerably, for two reasons. Firstly, this will be as more CCI data becomes available, and is taken up more widely by the scientific research community who recognise the value of high quality CDRs. Secondly, evolutionary changes to

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[3] 2011 update available online at: http://www.wmo.int/pages/prog/gcos/Publications/gcos-154.pdf
[4] http://www.coreclimax.eu/

CCI data are also anticipated, driven by changing user requirements, and if these requirements can be met then the impact which the CCI could have on both the climate research community and society will be maximised.

A major initiative in Europe is the Copernicus program which has relevant components to the CCI of the Copernicus Climate Change Service (C3S) and the Copernicus Atmosphere Monitoring Service (CAMS). While C3S is currently defining the type and extent of the services it will offer, CAMS has already defined its scope and started testing the use of CCI data for assimilation. As a major user of climate datasets it is likely to drive further development of CCI datasets through its user requirements. Such requirements would include: ensuring data quality (including uncertainty and maturity indices); integrated data validation (through modelling and other observational studies); and data production and accessibility, to name a few. Other drivers will be from the climate modelling community where in the near future global climate models will be running at very high resolution – much higher than current CCI data resolution, or from the reanalyses community who are looking to improve assimilation techniques and resolution. There is also the question of what new ECVs could be added to the CCI portfolio and how much of an impact they could potentially make.

The future impact of the CCI will be measured against how far it can meet the user requirements of its key users: climate modellers, C3S and CAMS, and other climate researchers.

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12. Appendix 2: List of acronyms

AOD	Aerosol Optical Depth
ARn	IPCC Assessment Review n
AVHRR	Advanced Very High Resolution Radiometer
BA	(Fire) Burned Area
BAMS	Bulletin of the American Meteorological Society
C3S	Copernicus Climate Change Services
CAMS	Copernicus Atmosphere Monitoring Service
CAR	Climate Assessment Report
CCI	Climate Change Initiative
CDR	Climate Data Record
CEOS	Climate and Earth Observation System
CLIPC	Climate Information Platform for Copernicus
CMIP	Coupled Model Intercomparison Project
CMUG	Climate Modelling User Group
CORE-CLIMAX	Coordinating Earth observation data validation for re-analysis for climate services
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)
ECMWF	European Centre for Medium-Range Weather Forecasts
EC FP7	European Commission Framework Programme (2007-2013)
ECV	Essential Climate Variable
ENSO	El Niño Southern Oscillation
ERA	ECMWF ReAnalysis
ESA	European Space Agency
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GHG	Greenhouse Gas
GPP	Gross Primary Production
IPCC	Intergovernmental Panel on Climate Change
KNMI	Royal Netherlands Meteorological Institute
LC	Land Cover
MACC	Modelling Atmospheric Composition and Climate
MIP	Model Intercomparison Project
NASA	National Aeronautics and Space Administration (US)
NPP	Net Primary Production
PFT	Plant Functional Types
QA4ECV	Quality Assurance for ECVs
RGI	Randolph Glacier Inventory
SI	Sea Ice
SM	Soil Moisture
SSH	Sea Surface Height
SST	Sea Surface Temperature

UERRA	Uncertainties in ensembles of regional reanalyses
UNEP	United Nations Environment Programme
WCRP	World Climate Research Program
WMO	World Meteorology Organisation