CMUG Phase 2 Deliverable

Number:	**D1.2:**
Due date:	**October 2016**
Submission date:	**January 2017**
Version:	**1**

Climate Modelling User Group

Deliverable 1.2

Meeting the Needs of the Climate Community – EO for climate foresight report

Centres providing input: Met Office, ECMWF, DLR

Version nr.	Date	Status
0.1	15 Nov 16	First draft for partner input
0.2	16 Dec 16	Partner contributions
1.0	27 Jan 17	Submission to ESA

CMUG Phase 2 Deliverable

Number:	**D1.2:**
Due date:	**October 2016**
Submission date:	**January 2017**
Version:	**1**

CMUG Phase 2 Deliverable 1.2

Meeting the Needs of the Climate Community – EO for climate foresight report

Table of Contents

CMUG Phase 2 Deliverable
Number: D1.2:
Due date: October 2016
Submission date: January 2017
Version: 1

Meeting the Needs of the Climate Community – Earth Observations for climate foresight report

1. Summary

The exploitation of satellite data for climate research has expanded significantly in recent years with space agencies around the world engaged in reprocessing activities to create satellite climate data records. This report summarises the current status of how it is being provided to the climate community and what might be done to improve it from a European perspective. There are a number of recommendations made on how to improve the access to the satellite records and providing tools which can be used for the evaluation of climate models. Although the focus of the report is on the needs of climate modellers other applications are also considered here.

2. Introduction

Over the past decade the number of satellite climate data records established has expanded significantly through initiatives such as the EUMETSAT reprocessing efforts, the dedicated EUMETSAT Climate Monitoring Satellite Application Facility, and the ESA Climate Change Initiative in Europe. In the U.S. there is the NASA Measures Programme and NOAA also have several climate datasets being produced, and based in the U.S. but with an international remit is the Obs4MIPs programme. Other nations such as China and Japan are also starting activities in their satellite programmes and how climate scientists will access these data also needs to be considered. As a result, a wide range of datasets encompassing different levels of data processing from Level 1b (geo-located radiances) to Level 4 ((re)analyses) specifically for the climate community and climate studies have become available.

One of the motivations for climate data records has been the various global reanalyses which have been run during the past decade (e.g. ERA-Interim, MERRA and JRA-55) and more recently regional reanalysis (e.g. UERRA) which require consistent satellite datasets for assimilation throughout the lifetime of the instrument record. Another motivation has been driven by the need to confront climate model simulations with observations of the atmosphere, ocean and land surface to assess their validity. The CMIP[1] activities have been in need of observations, with associated uncertainties, of some of the GCOS Essential Climate

[1] Climate Model Intercomparison Project, see: http://cmip-pcmdi.llnl.gov/

Variables (ECVs) to assess the model performance and there remains much to be done here as the complexity and thus the number of variables represented in the latest climate models continue to increase. The CMIP infrastructure enforces data standards and conventions for model output and documentation accessible via the ESGF[2], additionally publishing observations (Obs4MIPs, Teixeira et al. (2014), Ferraro et al. (2015)) and reanalyses (ana4MIPs) for Model Intercomparison Projects using the same data structure and organization as the ESM output. This largely facilitates routine evaluation of the climate models.

GCOS have devised the framework of ECVs in the atmosphere, ocean and terrestrial domains which need to be measured to monitor the state and trends of the Earth's climate system. This has resulted in satellite agencies focussing on producing climate quality datasets for those ECVs which can be inferred from satellite data and Table 1 shows all the ECVs which can be inferred from satellite data using existing technology which is at least 33.

Atmosphere	Surface	Air temperature; Precipitation, Pressure, Surface radn budget, Wind
	Upper Air	Clouds, Wind, Earth Radn Budget Upper air temp, water vapour, *lightning*
	Composition	Carbon dioxide, methane & GHGs Ozone, Aerosol properties
Ocean	Surface	SST, Sea-level, Sea-ice, Ocean colour Sea state, Salinity, *CO_2 partial pressure, Currents, Heat flux, Stress*
	Sub-surface	Temperature, Salinity, Current, Nutrients, Carbon, Ocean Tracers, Phytoplankton, *Biogeochemistry variables*
Terrestrial	Glaciers & Ice sheets and *shelves*, Land cover, *LST*, Fire disturbance, FaPAR, LAI, Albedo, Biomass, Lakes, Snow cover, Soil moisture, Water use, Ground water, River discharge, Permafrost, *Seasonally frozen ground, Soil carbon, Human use of natural resources, GHG fluxes*	

Table 1. GCOS ECVs. Those in blue can be measured from EO data and those in italics are the new updated ECVs introduced in the latest GCOS Implementation Plan.

[2] Earth System Grid Federation: http://esgf.llnl.gov/

To produce these satellite climate data records the original algorithms to produce geophysical products from the level 1 satellite data have been upgraded with the latest scientific methodology and made consistent throughout the time span of the data record. The associated metadata and documentation have also been included with the data sets and version control systems put in place.

ESA CMUG contributes to the development of the Earth System Model Evaluation Tool (ESMValTool, Eyring et al., 2016a) to enable the capability for climate model assessments in the CMIP framework. The ESMValTool using CCI (and other) datasets can assess climate model results with a variety of different performance metrics and diagnostics. This works with all models and allows inter-comparison of model outputs taking into account the observational uncertainties. Over time, as this capability matures, we expect to produce an increasingly systematic characterization of models, which, compared with early phases of CMIP, will more quickly and openly identify the strengths and weaknesses of the simulations (Eyring et al., 2016b).

3. Current status

There are only a limited number of producers of satellite climate data records at present based on the space agencies. Table 2 gives an overview of the CDRs types generated by agencies like EUMETSAT and ESA in Europe, and NASA and NOAA in the USA. A number of other space agencies or meteorological agencies are anticipated to enter the field in the near future, such as JMA, KMA, CMA and ISRO. The challenge is to co-ordinate access to all these datasets and try to ensure a common format where possible at various different processing levels.

Level of Processing	Variable	Spatial Sampling	Temporal Sampling	Application
1 FCDR	Directly measured quantity (e.g. radiance)	Orbit by orbit	Continuous	Assimilation, model evaluation
2 TCDR	Retrieved essential climate variable	Orbit by orbit	Continuous	Process studies, assimilation, model evaluation
3 TCDR	Retrieved essential climate variable	Gridded average	Hourly, Daily Monthly means	Model validation, trends, attribution and evaluation

Table 2. The characteristics of the different levels of the satellite data.

ESA is funding the climate change initiative (CCI) programme, which is addressing 13 ECVs and has released climate data records for each ECV. There is proposed a follow-on CCI+ project to add more ECVs to the ESA portfolio. Some of the current CCI ECVs are being migrated into the new European Copernicus Climate Change Service (C3S). In order to provide efficient access to the CCI datasets ESA have set up a data access portal at http://cci.esa.int with a dashboard, viewer and search engine, see Figure 1. This is a good model for providing data from a particular project to the user community.

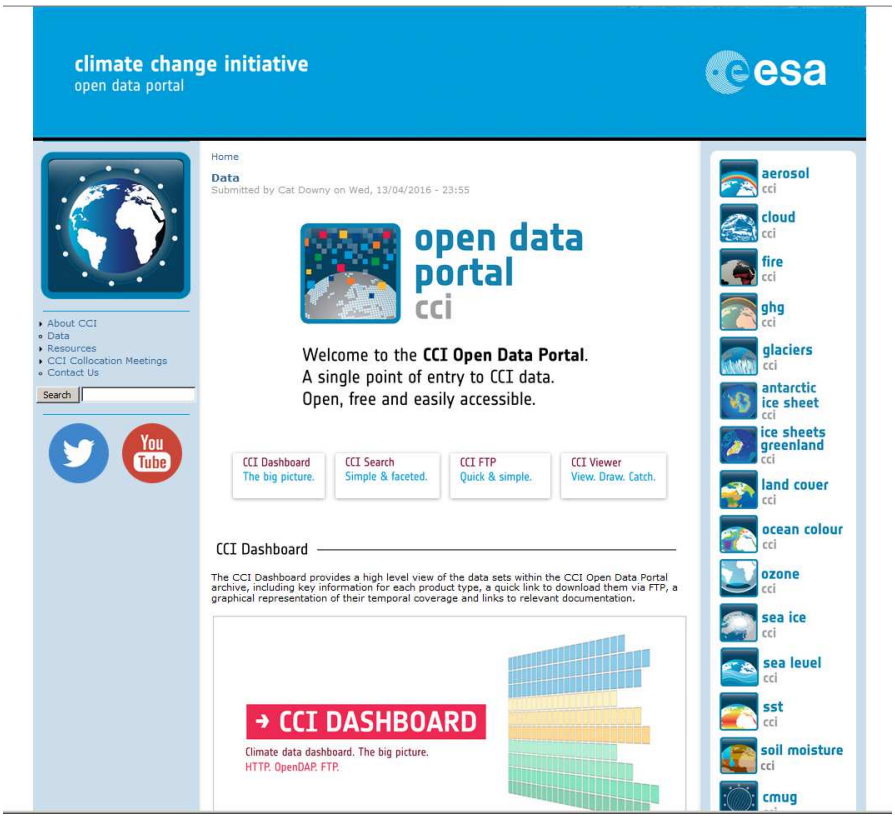

Figure 1: screenshot of the ESA CCI Open Data Portal homepage (January 2017).

ESA also has a data utilisation element (DUE) program, which enables research into developing CDRs and produces datasets under the Globxxx names. These datasets can be accessed from the ESA DUE web page http://due.esrin.esa.int/page_projects.php. Some of the Globxxx datasets are subsequently adopted and updated by the CCI programme. As part of a joint and cooperative approach in Europe aimed at preserving the EO European data from member states' missions, a Long-Term Data Preservation initiative is also funded by ESA since 2008. The main objective is to guarantee the preservation of the data from all Earth

Observation ESA and Third Parties (ESA managed) missions on the long term, also ensuring their accessibility and usability.

EUMETSAT generates climate data records from their satellites both in their central facility (CAF) and in their Climate Monitoring Satellite Application Facility (CMSAF). The CAF provides mainly FCDRs (e.g. SEVIRI/MVIRI radiances, ASCAT backscatter,..) but also some products such as reprocessed AMVs and surface albedo. The CMSAF also produces a mix of FCDRs (e.g. SSM/I) and mainly CDRs (e.g. cloud and radiation products). The datasets are available from the EUMETSAT earth observation portal at www.eumetsat.int and the CMSAF data portal www.cmsaf.eu. Worth mentioning is that additional reprocessing activities are also carried out by other SAFs, for instance atmospheric composition data records are reprocessed by the O3M SAF, and soil moisture and snow cover L2 data is reprocessed by the H-SAF.

The European Union is now setting up the Copernicus Climate Change Service (C3S) co-ordinated by ECMWF which will 'operationalise' some of the satellite CDR production from the ESA and EUMETSAT datasets. This is in the process of being set up.

In the U.S. NOAA is producing CDRs from their geostationary and polar satellites. NOAA's National Centers for Environmental Information (NCEI) is responsible for preserving, monitoring, assessing, and providing public access to the US climate data of all kinds but including satellite data. It can be accessed from their archive https://www.ncdc.noaa.gov/data-access/satellite-data/satellite-data-access-datasets and one notable climate dataset is the ISCCP data record used by modellers for many years. NOAA STAR also produce satellite climate datasets but access to them is provided through the NOAA Comprehensive Large Array data Stewardship System (CLASS) web site http://class.ncdc.noaa.gov. Other NOAA centres such as CIMSS in Madison, Wisconsin provide reprocessed AMVs from the GOES satellites which have been valuable for global reanalyses. NASA have the MEaSUREs (Making Earth System Data Records for Use in Research Environments) program focussing on generating CDRs from their satellites and they have a list of CDRs which are available at https://earthdata.nasa.gov/community/community-data-system-programs/measures-projects. Finally another NASA initiative at the NASA Space Science Data Co-ordinated Archive (NSSDCA), which has been extremely valuable, is to rescue various old NASA satellite datasets from missions flown in the 1970s. The data are being stored on old magnetic tapes and there has been a programme to transfer the data from magnetic tapes to on-line access.

Another international initiative which is relevant is the Obs4MIPs project illustrated in Figure 2. This grew out of the WCRP CMIP where many different climate model projections are compared and there was a need to provide satellite datasets which have a great potential to

provide a representation of the actual state of the variable being predicted. To facilitate this the Obs4MIPs project was devised to provide reformatted satellite datasets in a form that made it easy for climate modellers to compare with their outputs. Datasets have to go through a formal approval process before being made accessible in an agreed NetCDF-CF format which climate modellers use. The data typically consist of monthly means on a regular latitude-longitude grid (e.g. 1x1 degree) that can be directly compared with the model fields. Approved datasets are provided on the Earth System Grid (ESGF) shown in Figure 3 which facilitates easy and fast access to large datasets such as model fields and observations.

There are various national initiatives to archive and reprocess satellite climate datasets to numerous to mention here but these datasets add to the plethora datasets which are potentially useful for climate research.

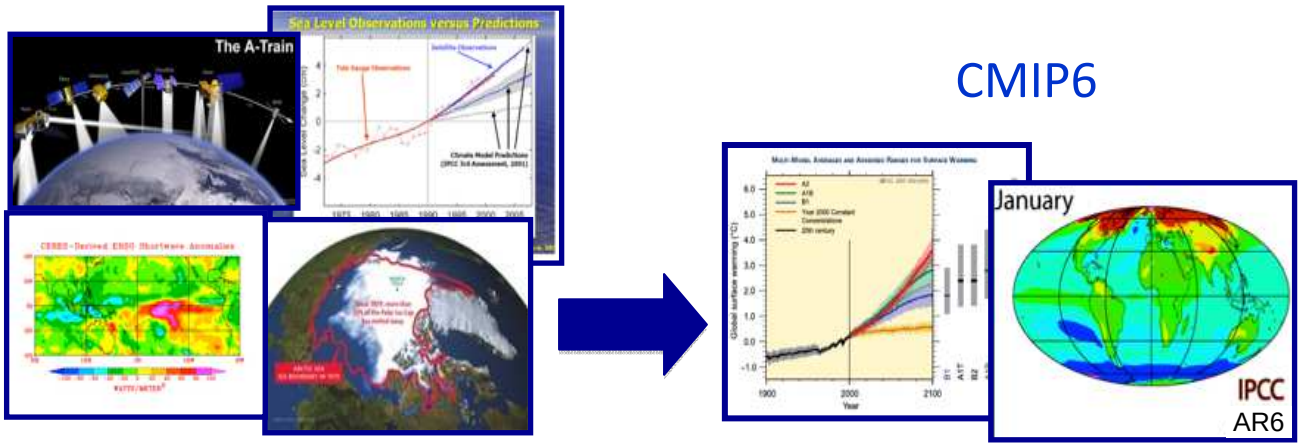

Figure 2. Concept of the Obs4MIPs project to exploit underutilised satellite observations for climate modelling.

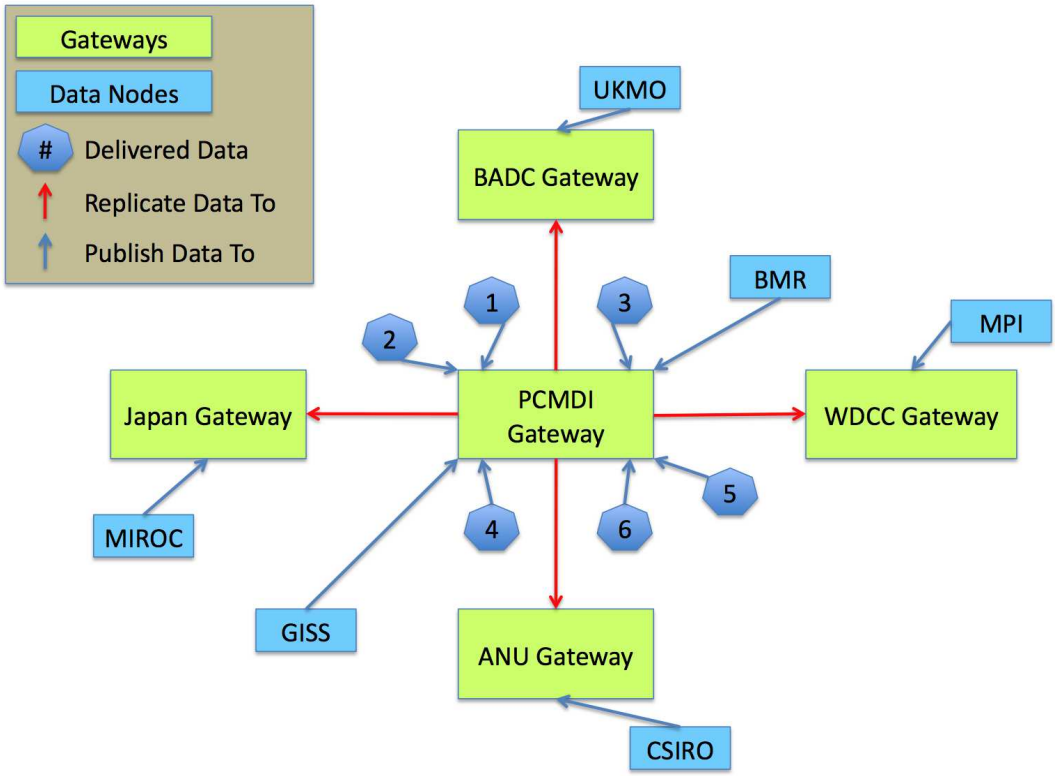

Figure 3. The current structure of the Earth System Grid Federation for model data.

4. Recommendations for Future Data Provision

In November 2016 there was a workshop at ECMWF on "Applications of Satellite Climate Data Records in Numerical Modeling" which provided useful input for future data provision of satellite CDRs and during the discussion at that meeting the requirements of modellers were addressed. One factor that remains uncertain within Europe is exactly how the C3S service will emerge to cover climate data provision. Here it is assumed it will cover some but not all ECVs and be one player in several in the climate dataset production. There are several aspects to meeting the needs of the climate community and each will be addressed in separate sections.

4.1 Central web portals for climate data information

The first requirement of climate research scientists is a regularly updated website with the latest information on climate data records. There are several good examples already in existence but they are not globally representative. For example:

- The *reanalysis.org* web site is a good example for reanalyses
- The UCAR climate data guide *climatedataguide.ucar.edu* is another very good site which is also linked with social media through a twitter feed to get more traction with potential users of climate datasets.
- The Copernicus Climate Change Service has recently launched a web site *https://climate.copernicus.eu/* to cover climate datasets for the public. However it doesn't appear to address the needs of climate modellers as this is more for 'downstream' users of the data.
- The Integrated Climate Data Centre distributes a selection of quality-controlled satellite data, reanalyses and in-situ data: http://icdc.cen.uni-hamburg.de/1.html

All these sites include in-situ as well as satellite datasets which is a requirement of modellers as they are interested in different kinds of observational datasets. The more satellite specific web portals are given above in section 3. There is also of course the CCI data portal, which serves only CCI data, but includes uncertainty information, and tools for data search and viewing.

Recommendation 1: A European funded site similar to the UCAR site should be setup for climate datasets (both satellite and in situ) which is regularly updated and includes a social media feed. Data suitable for obs4MIPs should additionally be contributed to this international archive that facilitates the use of model output and observations.

4.2 Data portals for accessing climate datasets

The overall framework for accessing satellite climate datasets is shown in Figure 4 where a climate gateway services the needs of all climate scientists. The requirements for climate modellers and those doing more detailed studies are somewhat different and they are described separately in the sections below.

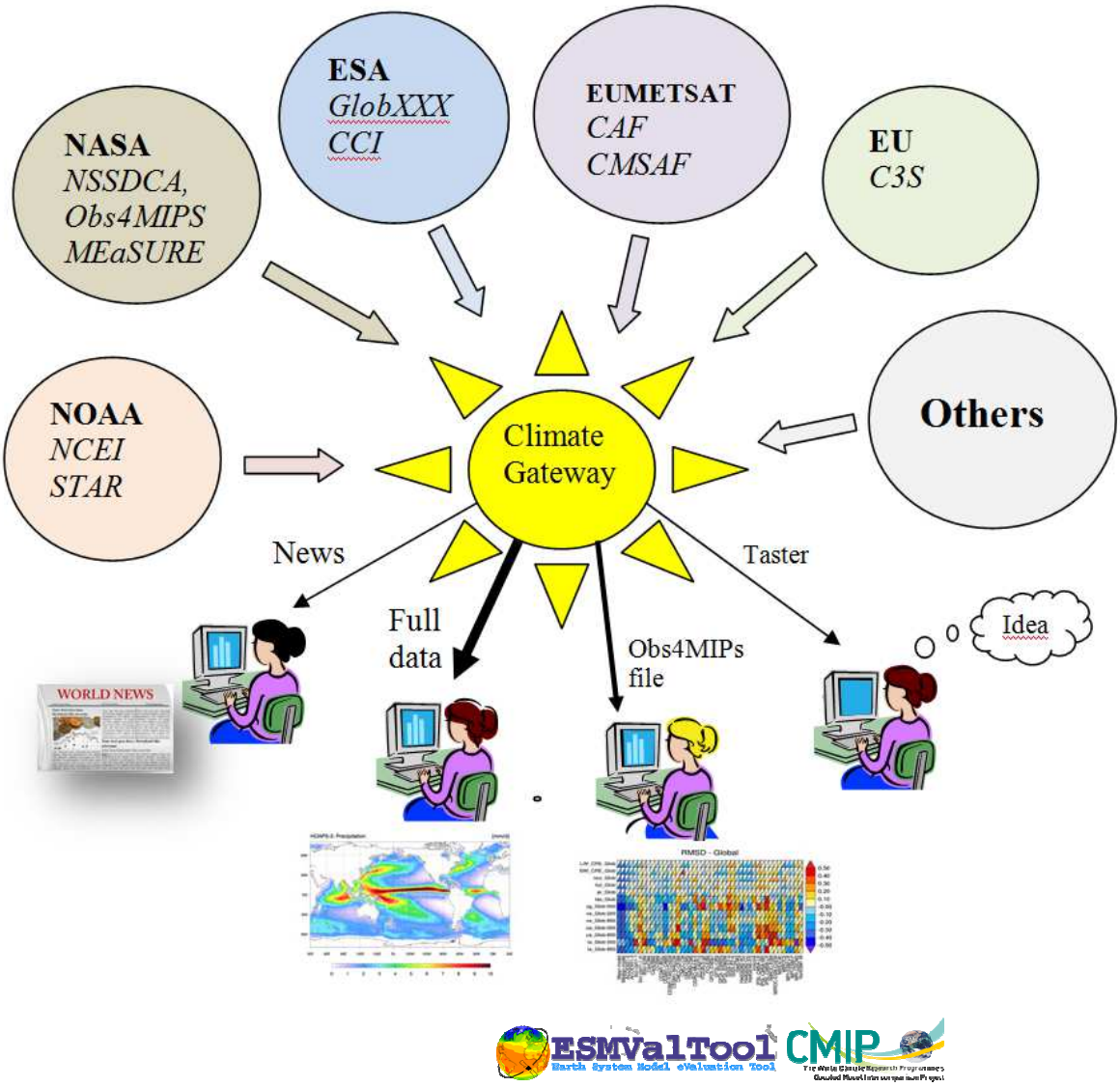

Figure 4. Data distribution for climate datasets.

4.2.1 Datasets for climate modelling

The Obs4MIPs programme requires submitted datasets to be accompanied by a technical note, which includes, for example, discussion of uncertainties and guidance as to aspects of the data product that are particularly relevant to model evaluation. Similar documentation efforts for observations specifically meant for use in model evaluation can be found at the National Center for Atmospheric Research (NCAR) climate data guide[3]. Ideally, standard technical documentation as defined by Obs4MIPs will be adopted broadly by the international

[3] https://climatedataguide.ucar.edu

observational community and will be hosted alongside (or integrated with) the CMIP model and simulation standard documentation (ES-DOC). Additionally, there are proposals being considered to include non-gridded data in Obs4MIPs (e.g., data collected by ground stations or during aircraft campaigns), and the possibility that auxiliary data such as land-sea masks, averaging kernels, and additional uncertainty data might also be provided. Whatever datasets are used for model evaluation, it will be important to determine the size of observational error relative to the errors in the models. One approach being developed is to provide ensembles of observational estimates, all based on a single sensor or product and generated by making many different choices of retrieval algorithms or parameters, all considered to be reasonable. The goal is that Obs4MIPs can be extended to better characterize observational uncertainty.

Recommendation 2: To enhance the Obs4MIPs site as outlined in this report. We encourage ESA and other data providers to contribute observations for model evaluation to the Obs4MIPs archives alongside with a technical note and observational uncertainty estimates.

A key need of climate scientists is to have a 'one stop shop' for accessing all observational climate datasets including satellite, ground based remote sensing and in-situ including documentation of the data. Here, search functions allowing to restrict the search results to given dataset properties (e.g. variable name, data type, temporal resolution, time range, geographical region, etc.) and a possibility for automated (script-based) downloads becomes more important as the available datasets are increasing in number and volume. For the climate modelling community the closest example of good practice would be the Obs4MIPs site where currently 78 satellite datasets from various measurement platforms are available in NetCDF-CF format which allows easy comparison with model data. The data are made available via the ESGF to facilitate easy access on several continents. The Obs4MIPs site is now managed by the WCRP Data Advisory Council (WDAC) so it has an international oversight. The challenge is to bring together all the different datasets from around the globe, review them and add them to the site. From a European perspective there needs to be resources to assist the dataset providers to submit their datasets to the Obs4MIPs site.

There are improvements which could be made to the Obs4MIPs site however and these could be recommended through the WDAC:

- The current layout of the datasets needs to be improved as all are on the one page at present. Suggest separating out into the different domains at least and within each domain have a separate sub-domain for each satellite instrument.
- In addition to monthly mean values and their associated uncertainties the mean diurnal variation or other variability could also be captured for some parameters.

- Consider a more 'Amazon-like' user interface for accessing the datasets. Current users are probably happy with the existing interface but new scientists to the field will gain familiarisation more quickly with commonly used interfaces elsewhere on the web. This could also accommodate reviews and access to metadata (e.g. using the CHARMe button).
- 'Taster' datasets which provide the user with a quick look at the particular data being considered could be beneficial. These could be advertised using social media feeds and should be quick to download (i.e. <20MB).
- The ability to select specific time periods, geographical regions, etc. before downloading the data, but with the option of users being able to get quick look plots in advance of downloading.
- Different levels of quality should be indicated (quality-controlled long-term record, near real-time operational data without quality control, experimental data sets with possible shortcomings etc.). All such data sets would be helpful for different applications of climate researchers and it'd be very helpful if this can be reflected by the data base
- Along the same line: a detailed search engine becomes more and more important, similar to what we have for CMIP5 data. It should be possible to find data records by time period, spatial coverage, temporal resolution, physical parameter, quality level, satellite processing level, etc.

One important factor for some ECVs is the availability of an observation simulator and this should be clearly identified as part of the metadata. Without this modellers may be unable to accurately compare their model data with the satellite products.

Recommendation 3: To ensure European datasets are efficiently submitted to the Obs4MIPs site for climate modelling applications a dedicated resource needs to be provided. ESA, EUMETSAT and potentially C3S datasets all should be considered.

4.2.2 Datasets for monitoring and attribution of climate change

Climate scientists more focussed on detailed monitoring and attribution will often need more detailed datasets than 1 deg monthly means. For these cases the archives of the data providers (i.e. space agencies) will be a more appropriate location to get the full dataset from. As with Obs4MIPs the suggestions given above apply equally to these websites and in an ideal world a similar interface for all agencies would be preferable to reduce the learning curve the user has to endure for each site. There are several different options to provide satellite datasets to users as listed in Table 2 and different applications will require different options. The length

of the record is often a key factor for these applications but observation simulators (see above) can also be important.

Recommendation 4: All agencies to strive to provide a common interface for accessing satellite climate data records.

4.2.3 Datasets for reanalysis applications

Reanalysis productions are normally performed at Numerical Weather Prediction (NWP) Centres. These are well connected to most space agencies, in particular, and data producers, in general. This direct and open dialogue facilitates the data distribution to the reanalysis centres while being often instrumental to drive upgrades and improvements to the satellite retrieval algorithms.

Two aspects are particularly important for reanalyses:

- The data homogeneity and consistency; and
- The characterization of the observation uncertainty.

Regarding the **data homogeneity and consistency**, a number of activities have been launched over the past decade or so that represent a good starting point, although often limited to specific data types and not always with the climate and reanalysis communities in mind, for example:

- The *Global Space-Based Inter-Calibration System* (GSICS, http://gsics.wmo.int/) is an international collaborative effort initiated in 2005 by WMO and the CGMS to monitor, improve and harmonize the quality of observations from operational weather and environmental satellites of the Global Observing System (GOS). Although the focus is primarily on operational weather forecasts, a benefit for climate reanalysis applications can also be envisaged. Agencies involved are EUMETSAT, NOAA/NESDIS, JMA, KMA, and CMA/NSMC.
- The NASA and NOAA agencies have produced a 40-year long record of ozone retrievals from the SBUV/SBUV-2 instruments using a fixed algorithm.
- The CCI community is looking at both aspects and from different perspectives, especially for what concerns data consistency (e.g. consistency between data records from similar instrument types, from different instrument types measuring the same parameter, and across ECVs).

Recommendation 5: All agencies to define best practices towards data homogeneity and consistency, to share findings from current efforts and to promote more systematic and wider international collaborations on data homogeneity than currently exists.

The uncertainty characterization has also received some attention in the last few years. This is a crucial aspect for any study, but it is of paramount importance for applications that rely on data assimilation, as the impact an observation has depends inversely on its uncertainty. A recently launched Horizon 2020 project (*Fidelity and uncertainty in climate data records from Earth Observations:* FIDUCEO[4]) aims to create new FCDRs that include state-of-the-art information about observational uncertainty. The project will define best practice to follow, how to define and propagate through different processing levels the observational uncertainty. This will be applied to four key instrument types:

- Meteosat Visible and Infra-Red Imager (MVIRI), 1982-2016
- Advanced Very High Resolution Radiometer (AVHRR), 1982-2016
- High-resolution Infra-Red Sounder (HIRS), 1982-2016
- Microwave humidity sounder series (SSM/T2, AMSU-B, MHS), 1992-2016

FIDUCEO represents an initial effort that can pave the way to additional activities covering the vast majority of available and used instruments.

Recommendation 6: Agencies and data retrieval experts to promote efforts such as that of FIDUCEO in terms of best practice, and knowledge on providing information on uncertainties to extend that work to other data records.

4.2.4 Datasets for initialising seasonal/decadal forecasts

The recent development of starting to issue seasonal to decadal forecasts at various centres has resulted in a need for observations to initialise them such as sea surface temperature and height, snow and ice cover, soil moisture, ocean circulation, stratospheric state, solar spectral irradiance, etc. Such fields are required for operational production and so are needed in near real time and therefore cannot use the climate data records. Hence in some cases these fields are taken from operational NWP model analyses for the atmosphere but for the ocean good observational datasets on ocean circulation are important. There are also runs in hindcast mode when climate data records can be used to initialise the model runs which may be better than using a near real time product from model analyses or observations. For evaluation of the

[4] http://www.fiduceo.eu

seasonal to decadal forecasts then a whole range of climate data records are valuable to assess how well the forecasts perform.

4.2.5 Datasets for specialised non-expert use

With greater access to, and ever increasing volumes of climate data, there exists outside of the mainstream climate research community a small set of users who are interested in working with climate data in a non-research and non-commercial setting. Such users are typically schools, local environmental groups, volunteer organisations or charities which have environmental interactions (e.g beekeepers, birdwatchers) and outdoor or sporting associations (e.g. skiing groups). There data needs are small scale but specific and their specific knowledge (often with a local focus) can sometimes provide valuable information in a research context. These users can only work with open data, especially if it has been processed at source to take it closer to their requirements. Frequently this group is classed as citizen science, and as such in some countries receives acknowledgement and support.

4.3 Routine evaluation of ESMs with observations with the ESMValTool

CMIP is now moving into its 6th phase (Eyring et al., 2016c). Given the diversity and complexity of Earth system models (ESMs), we argue that the CMIP community has reached a critical juncture at which many baseline aspects of model evaluation need to be performed much more efficiently to enable a systematic and rapid performance assessment of the large number of models participating in CMIP. To support routine evaluation in CMIP and at individual modeling centers, community tools such as the Earth system model evaluation tool (ESMValTool[5], Eyring et al., 2016a) are developed that allow for comparison of single or multiple models, either against predecessor versions or against observations. The ESMValTool has been developed in such a way that additional diagnostics and performance metrics can be easily added. The priority of the effort so far has been to target specific scientific themes focusing on selected Essential Climate Variables and a range of known systematic biases. The tool also integrates other packages, such as the NCAR Climate Variability Diagnostics Package or the cloud regime error metric, and can reproduce most of the analysis of the IPCC AR5 evaluation chapter. The ESMValTool together with other efforts such as the PCMDI metrics package (PMP, Gleckler et al., 2016) can be used to broadly and comprehensively characterize the performance of the wide variety of models and model versions that will contribute to CMIP6. **Error! Hyperlink reference not valid.**Ultimately, we envisage running these tools alongside the Earth System Grid Federation as soon as the CMIP model output is submitted utilizing observations available in standard

[5] http://www.esmvaltool.org/

formats (obs4MIPs) or provided by the user (Eyring et al., 2016b). The ESA CCI is exploiting a large number of satellite observations to create robust long-term global records of selected ECVs from numerous satellites and instruments.

In the second phase of ESA CMUG, a subset of the ESA CCI Phase 2 ECVs has been implemented into the ESMValTool. ESA CCI data sets implemented so far include sea surface temperature, sea ice, cloud, soil moisture, land cover, aerosol, ozone, and greenhouse gases (Lauer et al., 2017). These ESA CCI data can now be fully exploited for the evaluation of new CMIP simulations in a much more effective manner than this was previously possible. It is envisaged to include additional ESA CCI data as the project moves on.

Recommendation 7: The ESMValTool facilitates routine evaluation of the CMIP models with observations. A subset of the ESA CCI data has already been integrated. To enhance this capability for CMIP, we encourage experts to develop new diagnostics that fully exploit additional ESA CCI and other data while considering observational uncertainty.

5. Conclusions

An analysis has been made as to how the climate community can be better served with satellite climate datasets in the future. As a result a number of recommendations were made which are given here as a summary and should be considered by the space agencies for possible implementation.

A European funded site similar to the UCAR site should be setup for climate datasets (both satellite and in situ) which is regularly updated and includes a social media feed. Data suitable for Obs4MIPs should additionally be contributed to this international archive that facilitates the use of model output and observations.

To enhance the Obs4MIPs site as outlined in this report. We encourage ESA and other data providers to contribute observations for model evaluation to the Obs4MIPs archives alongside with a technical note and observational uncertainty estimates.

To ensure European datasets are efficiently submitted to the Obs4MIPs site for climate modelling applications a dedicated resource needs to be provided. ESA, EUMETSAT and potentially C3S datasets all should be considered.

All agencies to strive to provide a common interface for accessing satellite climate data records.

All agencies to define best practices towards data homogeneity and consistency, to share findings from current efforts and to promote more systematic and wider international collaborations on data homogeneity than currently exists.

Agencies and data retrieval experts to promote efforts such as that of FIDUCEO in terms of best practice, and knowledge on providing information on uncertainties to extend that work to other data records.

The ESMValTool facilitates routine evaluation of the CMIP models with observations. A subset of the ESA CCI data has already been integrated. To enhance this capability for CMIP, we encourage experts to develop new diagnostics that fully exploit additional ESA CCI and other data while considering observational uncertainty.

It is believed that if these recommendations were acted upon then climate scientists in Europe would be better served with climate quality satellite data records.

6. References

Eyring, V., Righi, M., Lauer, A., Evaldsson, M., Wenzel, S., Jones, C., Anav, A., Andrews, O., Cionni, I., Davin, E.L., Deser, C., Ehbrecht, C., Friedlingstein, P., Gleckler, P., Gottschaldt, K.D., Hagemann, S., Juckes, M., Kindermann, S., Krasting, J., Kunert, D., Levine, R., Loew, A., Mäkelä, J., Martin, G., Mason, E., Phillips, A.S., Read, S., Rio, C., Roehrig, R., Senftleben, D., Sterl, A., van Ulft, L.H., Walton, J., Wang, S. and Williams, K.D., 2016a. ESMValTool (v1.0) – a community diagnostic and performance metrics tool for routine evaluation of Earth system models in CMIP. Geosci. Model Dev., 9(5): 1747-1802.

Eyring, V., Gleckler, P.J., Heinze, C., Stouffer, R.J., Taylor, K.E., Balaji, V., Guilyardi, E., Joussaume, S., Kindermann, S., Lawrence, B.N., Meehl, G.A., Righi, M. and Williams, D.N., 2016b. Towards improved and more routine Earth system model evaluation in CMIP. Earth Syst. Dynam., 7(4): 813-830.

Eyring, V., Bony, S., Meehl, G.A., Senior, C.A., Stevens, B., Stouffer, R.J. and Taylor, K.E., 2016c. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geosci. Model Dev., 9(5): 1937-1958.

Ferraro, R., Waliser, D.E., Gleckler, P., Taylor, K.E. and Eyring, V., 2015. Evolving Obs4MIPs to Support Phase 6 of the Coupled Model Intercomparison Project (CMIP6). Bulletin of the American Meteorological Society, 96(8): ES131-ES133.

Gleckler, P., Doutriaux, C., Durack, P., Taylor, K., Zhang, Y., Williams, D., Mason, E. and Servonnat, J., 2016. A More Powerful Reality Test for Climate Models. Eos, 97.

Lauer, A., V. Eyring, M. Righi, M. Buchwitz, P. Defourny, M. Evaldsson, P. Friedlingstein, R. de Jeuf, G. de Leeuw, A. Loew, C. J. Merchant, B. Müller, T. Popp, M. Reuter, S. Sandven, D. Senftleben, M. Stengel, M. Van Roozendael, S. Wenzel, and U. Willén: Benchmarking CMIP5 models with a subset of ESA CCI Phase 2 data using the ESMValTool, Remote Sensing of Environment (accepted).

Teixeira, J., Waliser, D., Ferraro, R., Gleckler, P., Lee, T. and Potter, G., 2014. Satellite Observations for CMIP5: The Genesis of Obs4MIPs. Bulletin of the American Meteorological Society, 95(9): 1329-1334.