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GCOS

GLOBAL CLIMATE OBSERVING SYSTEM

Meeting Report

WCRP Observation and Assimilation Panel (WOAP)

Report of WOAP Workshop on Evaluation of Satellite-Related Global Climate Datasets
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Foreword

The need for a workshop on "Evaluation of Satellite-Related Global Climate Datasets" was first identified at a meeting of the World Climate Research Programme (WCRP), Group on Coupled Models (WGCM) in the Fall of 2008 in Paris, France. There was a recognition by the participants that the number and diversity of long-term climate observations records are improving rapidly, especially in the area of space-based observations. These data sets offer great value and opportunity for verification and validation of Earth/climate system models in addition to their invaluable use in process understanding and trend studies. The participants at the WGCM meeting agreed to pursue an active partnership with the space agencies to explore greater use of existing climate records in the context of the Fifth Coupled Models Intercomparison Project (CMIP5) in preparation for the next period of the Intergovernmental Panel on Climate Change (IPCC) Assessment. Towards this objective, the US National Aeronautics and Space Administration (NASA) agreed to re-process a sub-set of its long-term observations records such that they will be compatible in format, map projection and error characteristics with the simulated climate results for the past and future decades. The issues of incompatibility of format, projection and error characteristics were identified as major impediments to sub-optimal use of observations in conjunction with Earth/climate system models in the past.

WCRP and the Global Climate Observing System (GCOS) Programmes identified this as an opportunity for bringing the observations and modelling communities together and issued a joint letter to the major developers and users of observations and models and invited their views and support for such an initiative. The broad aim was to promote intercomparison and the evaluation of datasets of Essential Climate Variables (ECV) following the use of Guidelines for the Generation of products meeting the GCOS Requirements. The great responses that we received were all very positive and supportive of such initiative, especially from the major space agencies, modelling centres and operational meteorological organization. We subsequently discussed and deliberated on the scope and format of such an activity at the GCOS-WCRP jointly sponsored Panel on Observations and Assimilation (WOAP) in 2010 in Hamburg, Germany. At this meeting the plans for the workshop in Frascati were further refined and the European Space Agency (ESA) offered kindly to host the workshop. It was also decided that the first workshop should focus on lessons learned and best practices for a manageable sub-set of space-based observations rather than being all encompassing. It was envisioned that subject to the outcome of the first workshop future ones could be designed to focus on in situ and/or additional space-based observational records.

We were extremely pleased with the strong support that we received from the community at large in designing the agenda for the workshop, preparing the background position papers that served the basis of much of very fruitful discussions in Frascati that have resulted in this report. We thank the chair, organizing committee and our host ESA for making this workshop a terrific success. The real and exciting work is ahead of us for implementing the valuable recommendations of the workshop. One major aim will be to establish an international framework for a consistent approach to the production, evaluation and accessibility of global climate datasets, which will eventually lead to an inventory of essential climate data sets. GCOS and WCRP are committed to following up on these recommendations and building on the momentum created as a result of this first workshop in promoting much greater and efficient use of Earth observations with Earth/climate system models in the ensuing decades.

Ghassem R Asrar
Director, WCRP

Carolin Richter
Director, GCOS

Report of WOAP Workshop on Evaluation of Satellite-Related Global Climate Datasets

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Executive Summary

Under the auspices of the WCRP Observations and Assimilation Panel (WOAP), a workshop was hosted by the European Space Agency (ESA) in Frascati, Italy on 18-20 April 2011 to prepare a technical report on the evaluation of global climate datasets; eight satellite-related essential climate variables (ECVs) were considered. The datasets covered the atmospheric, ocean and terrestrial domains of GCOS and they were at different stages of maturity.

As a basis for detailed consideration of global climate datasets, the utility of these datasets was first summarised and it was concluded that global climate datasets are vital components of climate science, supporting activities such as:

- monitoring of climate variability and change on a range of time scales
- monitoring of forcing of the climate system
- prediction of climate variability and change
- attribution of causes of climate change
- characterisation of extreme climate events.

Global climate datasets relating to the eight selected ECVs were evaluated against the GCOS Guidelines of Dataset Generation, which promote a rigorous process for the development and evaluation of global datasets. That process should ensure that the quality, utility and accessibility of datasets is adequate for the identified applications. It is recognised that different datasets may be fit for different purposes.

The eight ECVs selected for evaluation were:

- Atmospheric domain:
    - Cloud properties
    - Surface radiation
- Ocean domain:
    - Sea ice
    - Sea-surface temperature (SST)
    - Surface winds
- Terrestrial domain:
    - Soil moisture
    - Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
    - Snow cover.

For cloud properties, the EUMETSAT Cloud Retrieval Evaluation Workshop (CREW) and the GEWEX Cloud Assessment were considered. These assessments are interesting to compare as the CREW activity was focused mainly on Level 2 data, while the GEWEX activity assessed various physical properties of long-term global cloud (Level 3) datasets. For surface radiation, the GEWEX Radiative Flux Assessment was discussed. Key messages from all these assessments are that formal evaluation is a major task and that dedicated resources need to be allocated to that task.

For SST, datasets developed through the Group for High Resolution SST (GHRSST) were evaluated. Questions remain about how best to exploit the mix of *in situ* platforms available for quality control and evaluation of GHRSST SST products. For surface winds, there was a focus on scatterometer estimates of the surface wind field. It was found that a concerted effort is needed to support appropriate calibration, evaluation and reprocessing activities on surface winds. For sea ice, several different datasets have been assembled, and there have been some inter-comparisons. However, the nature and sources of the differences have not been fully documented.

For soil moisture, Level 2 datasets based on active and passive satellite instruments were evaluated. It is seen that reprocessing of a number of fundamental climate data records (FCDRs) and comparison of existing climate datasets and their associated algorithms would help ensure the consistency and quality of global climate datasets. For FAPAR, the earlier assessment carried out by GTOS was seen to provide adequate documentation for that ECV, but resources are needed to support work on reference sites for *in situ* evaluation. It was noted that land cover classification is an important aspect of modelling used to derive FAPAR, and a consistent approach to the detection of land cover change would help ensure consistency across a range of terrestrial ECVs. For snow cover, satellite-based estimates of snow covered area, snow water equivalent, snow depth and snow wetness are routinely prepared. The impacts of vegetation cover, wet snow and complex terrain can limit the accuracy of global climate datasets of snow cover.

To provide a consistent framework for the workshop evaluations, the status of each dataset was entered in an inventory that itemises the evaluation elements of the GCOS Guidelines. The establishment and maintenance of such an inventory at a site, such as the NOAA Global Observing Systems Information Centre (GOSIC), will provide a consistent and accessible source of information on global climate datasets. The admission of new datasets into the inventory is expected to be managed by the GCOS Panels.

The inventory of global ECV datasets will be a resource for users of climate observations to identify and locate data for their particular applications. It will also be of value to producers of datasets in providing a consist evaluation of strengths and weaknesses, and hence a means for determining priorities for further development. Inspection of inventory components can also highlight the vulnerability of specific ECVs to potential gaps in satellite instruments; for example, the risk to continuity of microwave radiometers with low-frequency channels may impact on the global SST record.

From consideration of the evaluation of the ECV datasets, it is concluded that special attention needs to be given to some issues; in particular

- observing strategies for ECVs
- reprocessing of FCDRs
- atmospheric adjustment for satellite retrievals
- independent expert-group assessment of datasets
- indices of maturity and uncertainty
- interdependence of variables
- long-term homogeneity of datasets.

Conclusions on each of these issues are summarised below.

The global observing system for climate is an integrated system with two major components: complementary data are provided by the satellite constellation and the global *in situ* networks in the atmosphere and ocean and on land and ice. While satellites can generally provide global coverage, they cannot measure all the variables of interest and they often are not designed to provide data with long-term stability and homogeneity. The *in situ* networks can be used for calibration and evaluation of satellite data, and they are vital for the measurement of variables, such as surface air temperature and sub-surface ocean properties, that cannot be measured from satellites. These global systems are supplemented by reference sites ('super-sites'), which provide detailed point measurements of several variables in specific climatic zones. Observations from these sites can provide anchor points for global climate datasets, as well as yielding information on the processes controlling the budgets of water, energy and chemical species. All three components of the global observing system are needed to ensure the quality and comprehensiveness of global climate datasets.

Space agencies are encouraged to give sustained attention to activities that ensure the accuracy and consistency of observational datasets from satellites used to derive ECV products. As calibration methods improve there will be a periodic need to reprocess FCDRs and the ECV products that depend on them. It is vital for these activities to be continued and expanded to meet the full range of user requirements. The international activities of GSICS and SCOPE-CM and the climate reprocessing activities of ESA and NASA are important initiatives supporting these needs.

Many surface variables require the removal of atmospheric effects on radiances measured by satellite instruments, and so atmospheric adjustment is a common procedure for climate datasets. These adjustments use a range of ancillary data in somewhat different ways for different ECV datasets. While the adjustments are statistically based, there is little scope to develop an agreed consistent approach. However, research aimed at the development of an agreed forward model for the calculation of retrievals should lead to greater consistency among ECV datasets.

All producers of climate datasets carry out self-assessment of the utility and uncertainties of the products. However, independent expert-group assessments of the datasets associated with ECVs markedly enhance the utility and encourage improvements of individual datasets. This process is time-consuming and needs to be properly resourced in the future, in order to confirm the commitment of agencies to transparency and quality in the generation of global climate datasets. International independent assessments are seen as an important mechanism to enhance and promote the utility and application of these datasets. For example, it would be timely to commence a coordinated international assessment process for global Level 2 soil moisture datasets, with a view to expanding the scope and depth as scientific progress is made.

In order to promote an effective dialogue between users and producers of global climate datasets, an agreed lexicon based on the maturity index will be used in the ECV inventory to articulate the relative strengths and weaknesses datasets for specific applications. More work is required to develop agreed metrics of uncertainty in global datasets that transparently account for the many sources of error in generating a global climate dataset from satellite-based measurements.

Many ECVs represent a number of physical variables and so it is appropriate to account for their interdependence when generating datasets for each variable. Moreover a group of variables is often constrained by physical processes, such as the conservation of energy or water. Such constraints should be used in the generation of the individual datasets, and they can also be used in the evaluation of datasets. To maximise the benefits of accounting for the interdependence of variables, it is often desirable for agencies to coordinate the reprocessing of their datasets.

The specific variables associated with an ECV can evolve with advances in scientific knowledge and instrumentation, and such changes need to be accounted for to assure the long-term record of ECVs. For example, the products being generated by the Group for High Resolution SST (GHRSST) have enhanced the quality and reproducibility of global SST datasets, but work is required to ensure that the climate record can be extended consistently back in time as well as forward; that is, the long-term homogeneity of global climate datasets must be maintained.

The workshop brought together experts from across the geographical domains and found that, while there are specific issues associated with ECVs for each domain, there are many commonalities in the development and evaluation of global climate datasets across domains. Further international cooperation will lead to enhancements in the quality, utility and accessibility of global climate datasets.

1. Introduction

Especially since the preparation of the Second Adequacy Report (GCOS, 2003), GCOS has worked closely with space agencies on the identification of requirements for space-based observations for climate. The WCRP has a long history of working with these agencies on the research needs for space-based observations as well as on the preparation, assessment and application of climate datasets. In May 2010, WCRP and GCOS wrote to agencies to promote support for the international expert groups that provide the basis for world-class climate research and applications through scientific analysis and assessment of climate datasets. Agencies were encouraged to carry out such activities within the framework of the Guidelines for Dataset Generation (GCOS, 2010). The twelve key points of the GCOS Guidelines are listed in Appendix 1.

Following consideration of priorities for the evaluation of datasets for Essential Climate Variables (ECVs) at the meeting of the WCRP Observations and Assimilation Panel (WOAP) in Hamburg in March 2010 (WCRP, 2010), the European Space Agency (ESA) kindly offered to host a workshop in Frascati, Italy on the evaluation of satellite-related global climate datasets. The workshop was held on 18-20 April 2011 with about fifty experts from thirteen countries (Appendix 2). The primary aim of the workshop was to prepare this technical report on the evaluation of eight ECVs against the GCOS guidelines. The ECVs were selected to cover the three GCOS domains (atmospheric, oceanic, and terrestrial) and to be at different stages of maturity. The chosen ECVs were:

- Atmospheric domain:
  - Cloud properties
  - Surface radiation
- Ocean domain:
  - Sea ice
  - Sea-surface temperature (SST)
  - Surface winds
- Terrestrial domain:
  - Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
  - Snow cover
  - Soil moisture.

It was seen that consideration of available datasets for these ECVs provided the opportunity to identify key issues associated with their quality, utility and accessibility.

The workshop was opened by Dr Maurice Borgeaud, Head of Earth Observation Science, Applications and Future Technologies Department, ESA, and he spoke on the relevant missions of ESA to the workshop especially the ESA Climate Change Initiative. The first part of the workshop was focused on presentations from users of global climate datasets for reanalysis, modelling and diagnostic studies. These discussions (summarised in Section 2 below) identified a number of limitations on the utility of current datasets, as well as highlighting the underpinning role of high-quality observations for climate research and applications. In preparing the systematic evaluation of ECVs across the GCOS domains, the participants refined the basic format for entries in an inventory that gives consistent information of the character and utility of each dataset. The purpose and structure of the inventory is described in Section 3.

The workshop followed the programme in Appendix 3, with break-out groups considering datasets from each of the three GCOS domains. Section 4 of this report summarises the status of datasets for each of the ECVs considered. More detail on the status of these datasets is given in Appendix 4 to 6, including draft entries in the inventory for some datasets. The evaluation of datasets included consideration of priority actions that should be taken to enhance the quality and utility of each dataset.

In preparing the evaluations, the workshop participants identified a number of general issues that affect the quality and utility of global climate datasets. Section 5 of the report summarises consideration of such issues, including the importance of independent assessment of datasets for each ECV. Key conclusions and future actions from the workshop are discussed in Section 6.

2. Utility of global datasets

2.1 Introduction

To provide a background for the evaluation of specific ECVs, the workshop participants first considered the range of applications that utilise global climate datasets. As the climate system is continuously evolving, climate researchers need to measure its changes globally and regionally in order to understand the system, model it, and attribute the causes of the changes. Accordingly, observations play a key role and observational datasets have widespread use for many purposes. These include documenting the state of the climate and how it is varying and changing over time; deriving the "forcing" datasets; analysing the observations into globally gridded products and derived quantities; understanding the variations and changes over time, as well as the product's capability to represent change; and, if possible, why they are happening. Hence the observations are used to produce global analyses and reanalyses and to initialise models which are in turn used to make predictions on various time scales. The observations are then also used to evaluate and improve models.

While diagnostic and empirical studies make extensive use of datasets, actual uses vary considerably. For instance, datasets are required to determine:

- Means, annual cycles, geographic patterns
- Variability on all time scales, from diurnal to multi-decadal
- Understanding of phenomena and their changing frequency over time
- Forcings and boundary conditions of quantities that are not prognostic variables for models of different kinds
- Estimates of uncertainties in model simulations and predictions
- Specification of initial fields for model predictions on seasonal-to-decadal time scales.

Global datasets usually depend upon the integration of measurements from complementary satellite and *in situ* components of the global observing system. Satellite observations provide an important means for obtaining global coverage for ECV datasets. These observations need to be based on satellites and associated sensors that provide long-term accuracy, stability and homogeneity. *In situ* observations remain essential for calibration and validation of satellite data and for measuring variables that are not readily observed from satellites, such as surface air temperature and sub-surface oceanic variables. (Reference networks such as the Global Reference Upper Air Network (GRUAN) are essential in assuring the calibration and validation of both satellite and *in situ* observations.) Some of the applications of satellite-based datasets for climate are to:

- Evaluate the physical processes most relevant to reducing uncertainty in climate predictions
- Inform and prioritise key areas for developing and improving climate models
- Monitor climate, and thereby constrain climate change predictions if possible
- Detect and attribute observed variations to natural and anthropogenic forcing.

To be useful, the climate signals must be well above the noise of spurious variability arising from inhomogeneities and sampling issues. The signal to noise is often adequate for inter-annual variability - but not for decadal variations or trends. Uncertainties must be thoroughly assessed and quantified for each measurement. Error estimates are challenging especially because structural errors are difficult to quantify. Some known issues are the following:

- There are huge variations in the observing system over time. Variations in the quantity, quality and mix of instruments and platforms in the overall observing system often result in spurious variability associated with the changing observing system.
- Nearly all satellite datasets contain large spurious variability associated with changing instruments/satellites, orbital decay and drift, deficiencies in calibration, and different methods of analysis.
- Originally the issue was constructing a single time series. Now there is a proliferation and multiple datasets purporting to be the "one", although many are created for different specific purposes. All differ, often substantially, but the strengths and weaknesses or assumptions may not be well stated.
- Assessments are required to evaluate these aspects and to help improve the datasets.
- Continuous reprocessing is essential and should be the hallmark of any climate observing system.

There are often good reasons for multiple datasets because they are derived for specific purposes. Examples of the many different versions of datasets are given, for instance, by Reynolds and Chelton (2010) who show substantial differences among six products of daily SST. For global sea level after 1992 using altimetry, there are at least four datasets which have similar trends but very different inter-annual variability. For upper ocean heat content there are many estimates which have general trends that are similar but the details vary enormously (e.g., Lyman et al. 2010). Another example is sea ice for which there are eight or more datasets with different characteristics, strengths and weaknesses (Katsoff et al. 2011). Some clouds, such as thin cirrus, may not be well defined because they are a function of the sensitivity of instrument, and clouds can sometimes be confounded with aerosols, which are included in the definition of clear sky. The partitioning into clear and cloudy sky is problematic in cases where aerosols alter clouds. The radiative properties of clouds are very important but there are multiple metrics to describe cloud properties, including cloud amount, optical thickness, microphysical properties, cloud top and base temperature and pressure, and water vapour distribution. For surface fluxes, there are many products featuring different geographic patterns of means, annual cycles, and time series (e.g., Liu et al. 2011). Many seem to have discontinuities associated with changes in satellites. Closure is a major issue for the entire surface heat budget.

2.2 Climate modelling

Given their global spatial coverage, satellite data, which now span more than 30 years, can potentially be used for climate monitoring, model evaluation and initialisation. As climate models are increasing in their complexity to represent the number of physical processes, there are more opportunities for validation by satellite datasets: for example global aerosol distributions. The resolution of the models also continues to increase so that there is increasing consistency between a model grid square and the measurement footprint (or retrieval grid) of many satellite instruments. A recent survey of climate researchers showed that the most popular application of satellite datasets was to evaluate the physical processes in their models.

For comparisons between model and satellite datasets there is a move towards forward modelling of quantities closer to what is actually measured by the satellite (e.g. radiances, radar reflectivities, skin SST) rather than high-level products (profile retrievals of temperature, cloud properties, bulk SST). This implies that an observation simulator is required for each satellite dataset which needs to be developed by the modellers in collaboration with the satellite data producers. An example of this is the COSP simulator http://cfmip.metoffice.com/COSP.html (Bodas-Salcedo et al. 2008) developed as part of the CFMIP project that can simulate Level 1 products (e.g., radiances, radar reflectivity) and Level 2 products (e.g., ISCCP cloud parameters). The use of HIRS channel 12 radiances simulated from the HadAM3 model compared with measured HIRS radiances can provide insights into the model upper tropospheric water vapour and upper level cloud fields.

Another important requirement is the development of a set of metrics to assess climate model performance and how satellite datasets can contribute to this. Metrics based on the model fit to annual mean cloud datasets, their mean diurnal variation and their fit to radiation budget measurements is one possibility. Once these metrics are established and the observational datasets are in place this will provide an incentive for climate modellers to improve their models against the competition. However, there is a risk of tuning to those datasets and independent data must be used for evaluations.

For climate monitoring datasets, different groups can produce defensible but statistically inconsistent estimates of trends. This demonstrates the need for better error characterisation. Another emerging requirement for satellite and *in situ* datasets is to provide initial conditions for seasonal and decadal forecasts, including SST and soil moisture fields. Satellite data that fulfil the GCOS requirements on stability and accuracy can also help provide verification for climate model predictions.

2.3 Reanalysis

Reanalysis uses past observations in a fixed, state-of-the-art data assimilation system. Much of the reanalysis activity has been for the atmosphere, but similar activities are carried for the ocean, sea ice and land variables. It is based on data assimilation, but is distinct from operational numerical weather prediction (NWP) in a number of respects: in particular, it can utilise data that were not available at the NWP cut-off time, including reprocessed data that are more appropriate for climate applications. By fixing the assimilation system for the entire reprocessing period, it removes some of the spurious variations that otherwise appear in the NWP analyses, and it can potentially result in climate-quality globally gridded products. However, further research is required to address other spurious variations, e.g. those arising from observing system changes (introduction of new sensors, expiration of old ones) or from deficiencies in the assimilation system (forecast model and/or analysis components).

Better climate-quality observational datasets are needed to assist in identifying and reducing forecast model biases. Recent progress has led to improved estimates of global trends in atmospheric reanalyses (e.g., Willett et al. 2010), although trends in parameters that are only indirectly constrained by observations (such as precipitation) are still not satisfactory. Conversely, the model forecasts themselves act as a powerful check on inconsistencies and errors in observation datasets and/or the assimilation system. Atmospheric reanalysis is an increasingly mature activity and has developed variational techniques for inferring the relative bias between observations. Reanalysis outputs are recognised by GCOS as an alternative source of ECV products with an advantage that they are globally complete and provide mutual consistency between multiple ECVs and associated variables within the framework of the underlying assimilation system. A large user base is ensured by an open data policy and this enables scrutiny and evaluation of the results.

Experience shows benefits of the integrated and iterative approach inherent in reanalysis. ECV datasets, derived directly from observations, and reanalyses benefit each other through multi-way interactions between people who produce instruments and data, and those who develop models and assimilate data (operational NWP, reanalysis). Reanalysis results in quality flags on all data used, and results in guidance for improving ECV datasets along with suggestions for reprocessing of datasets; for example, reprocessing of GOES Atmospheric Motion Vectors would be a timely contribution to improve the upper atmosphere wind products feeding into reanalyse currently under development. ESA's Climate Change Initiative is one example of a relatively new program with the potential to interact usefully with the climate-science and reanalysis communities. In addition, it is important for users of reanalyses and the developers to exchange knowledge of the systems. A pilot effort using a "wiki" model has been initiated where developers and users can contribute information (see http://reanalysis.org).

The development of assessments for satellite-based ECV datasets is a very useful activity as it provides guidance to the reanalyses developers as to what metrics and diagnostics to test during the systems development stage, as well as during routine production-level monitoring of a reanalysis. Reanalyses use ECV datasets for both system development and product derivation, as well as providing products of

ECVs and related ancillary data. While uncertainties in reanalyses are influenced by many factors, including model bias and error, there are some substantial strengths such as their global scope. For example, biases in one parameter will be reflected in the analyses of other ECVs because the whole climate system is modelled. This permits examination of internal consistency within and among reanalyses and ECV datasets, and can in turn contribute to climate-process evaluations.

In several instances, observational ECV products use reanalyses for gap filling. Examples include global precipitation and surface fluxes. Generally, bias correction is applied by using some trusted validation data (e.g., ship observations for ocean fluxes). This could affect the interpretation of comparisons of reanalyses to that data product. In documenting an ECV dataset, the product developer and assessment team should quantify and/or discuss the impact of including a reanalysis product as part of the development. The product developer should also document the reasoning behind choosing one reanalysis over another, as well as the method of evaluation of the reanalysis data used. This is important, as users need to know if a data product incorporates reanalyses as it may affect the interpretation of the scientific results. In this case, a companion observation-only version of the data product would also be helpful in the assessment.
Users of reanalysis data should take into account the sources of reanalysis uncertainty and the implications for their specific applications. However, uncertainty is difficult to quantify. One approach is to evaluate a multi-reanalysis collection of climate-relevant variables. That approach is increased in value if results can be compared with reanalyses with independently derived observational estimates as in Simmons et al. (2010). In addition, the imbalance of budgets (such as of mass of dry air or water, or energy) in reanalyses is representative of the forecast error (instantaneously), the model climate bias (long term), or long-term changes in the observing system. Lastly, reanalyses can provide data to complement the assimilated observations such as forecast error and sometimes analysis error for each observation. These data should be provided to users in an efficient way (e.g., gridded for simplifying observation-space).

In summary,

- Reanalysis activities require input datasets to be climate-quality; i.e. they need fundamental climate data records (FCDRs) and ECV products that adhere to the GCOS guidelines.
- Reanalysis can contribute to periodic assessment and improvement of observational datasets, with particular emphasis on evaluation of different ECVs from an integrated perspective, and consistency over a wide range of spatio-temporal scales.
- Generation of observational datasets typically involves ancillary inputs and these are sometimes taken from reanalysis products. Two continuing needs are (i) investigations of the sensitivity of observational datasets to ancillary inputs, and (ii) better descriptions of the uncertainties in reanalysis products.

3. Dataset inventory

3.1 Need

There is currently no uniform, robust, centralised set of information that describes datasets available for climate research. Instead, users must query data centres, international programs, and research scientists to find the data that best suit their application. The type of descriptive information for each dataset varies widely, so it is difficult to quickly compare multiple products for the same geophysical variable. An ECV dataset inventory would provide a listing and uniform description of datasets that contain quantitative information on the various GCOS ECVs. Ideally, the datasets will have reached a basic level of maturity, be based on peer-reviewed methods, cover or have the potential to cover a sufficiently long period of time for climate studies, have uncertainty estimates, and be available to the scientific community. The workshop participants agreed that a well-maintained and accurate inventory of ECV datasets would be worthwhile and useful.

3.2 Structure

The inventory description for each ECV dataset will contain:

1. Date of this inventory entry
2. Dataset name
3. Lead agency and investigator
4. Geophysical parameter and related ECV
5. Intended uses and users (existing or potential)
6. History and outlook; sustainability
7. Availability (web/ftp, restrictions, is it registered with DOI system)
8. Maturity (e.g. Bates & Barkstrom (2006) maturity index)
9. Description of how the effort adheres to the twelve GCOS guidelines
10. Strengths and weaknesses or limitations
11. Uncertainty estimates, possibly as a function of time
12. Long-term homogeneity and stability
13. Have there been self and independent assessments? Identify other datasets used in the assessment
14. References to the publication of the algorithm theory, FCDR characteristics, self assessment and independent assessments
15. Dataset details:
    - Product version number
    - Time period covered
    - Spatial coverage (global, Arctic, etc.)
    - Spatial and temporal sampling intervals
    - Based on what fundamental climate data records (FCDR)
    - Ancillary inputs used to derive product
    - Other datasets used in the development of this product:
    - Output data product contents
    - Output product format(s)

While these descriptors capture what the workshop participants agree is the most useful information about a dataset, the list may evolve over the short term. Many of the descriptive elements above are self-explanatory, though a few warrant further explanation:

History and outlook; sustainability: Some datasets are new, others have a more complex history. For example, the NASA Pathfinder program gave rise to many products that have evolved over the last two decades with funding from other sources and, in some cases, with other goals. A brief description of the dataset's history may provide some insight into its maturity. The outlook and sustainability of a data product is also of interest. Will the product be maintained, sustained at an operational agency, reprocessed and extended in time?

Maturity (e.g. Bates & Barkstrom maturity index): Give the maturity index for each element (Software Readiness, Metadata, Documentation, Product Validation, Public Access, and Societal Impacts) as well as an arithmetic average that constitutes the overall maturity.

Description of how the effort adheres to the twelve GCOS guidelines: At a minimum, list which of the guidelines the dataset meets or, conversely, which it does not meet. Additional clarification may be appropriate. A few of the GCOS guidelines also appear in the inventory list of descriptors. This is intentional, meant to emphasise the importance of characteristics such as homogeneity, uncertainty estimates, and maturity.

Strengths and weaknesses or limitations: Describe under what conditions the product excels, and when and where it fails. For example, sea ice concentration products based on passive microwave data have much larger uncertainties under melt conditions. Identifying the strengths and weaknesses helps potential users quickly determine if the product meets their needs.

Uncertainty estimates, possibly as a function of time: Provide a quantitative estimate of uncertainty and explain how uncertainty is presented in the product. If the uncertainty varies as a function of time, region, or other conditions, a brief explanation would be useful. The assessment of uncertainty can be very complex, in which case a link to other documentation would be helpful.

Long-term homogeneity and stability: Changes in instruments, satellite or *in situ*, are the most common cause of instability in climate data records. Inter-calibration methods can alleviate, though not necessarily eliminate, such instability. Briefly describe your approach to this problem and, if possible, provide an estimate of the confidence interval for the stability of the dataset.

Have there been self and independent assessments? An organised, multi-product, multi-investigator, independent assessment of climate datasets is the best way to evaluate uncertainties, strengths, and weaknesses. The GEWEX cloud climatology assessment workshops are a good example of an independent assessment. More commonly, a dataset creator has performed a "self assessment", a comparison to other datasets that is generally more limited in scope than an independent assessment. Briefly describe any assessments that have been performed. Identify other datasets used in the assessment and provide links to additional information and publications.

3.3 Implementation

The inventory should contain descriptions of datasets that have reached a minimum level of overall maturity (e.g., a Bates & Barkstrom maturity index of 3 or higher), be based on methods that have been published, be available to the public (possibly with restrictions), have quantitative estimates of uncertainty, and cover a sufficient period of time for studies of inter-annual variability (minimum 10 years). Any individual, agency, or institution can submit a dataset description to the inventory, though it will generally be completed by the dataset owner(s). It is expected that submission of inventory entries will be through the GCOS Panels for consideration.

The inventory should be available to the public in electronic form, in a manner that it can be easily updated and maintained. The web site of an established data centre would be appropriate. The Global Observing Systems Information Center (GOSIC), maintained by the NOAA National Climatic Data Center (NCDC), would be an appropriate web site for the inventory, as GOSIC currently provides access to ECV datasets.

The inventory entries should be updated as needed. Dataset owners should be encouraged to update the entries when datasets are updated. Reminders should be sent to the owners on a regular basis, perhaps annually. Inquiries should also be made into the validity of datasets whose entries have not been updated for some time, e.g., five years. The maintenance of earlier versions of datasets is encouraged to allow improvements to be assessed.

4. Summary status of assessed ECVs

Each of the ECVs was considered in detail by the workshop participants, and example entries for some datasets are given in Appendices 4, 5 and 6. The following summaries aim to provide an overview of the status of the assessed ECVs in each domain. As well as summarising the current status of relevant datasets, this section also notes future actions that should be taken to enhance the quality and utility of those datasets.

4.1 Atmosphere ECVs

Cloud properties

For cloud properties, two independent assessments were considered: the EUMETSAT Cloud Retrieval Evaluation Workshop (CREW) activity and GEWEX Cloud Assessment. While the GEWEX Cloud Assessment compares various physical properties (averages, meridional variation, seasonal cycle, inter-annual variability) of global long-term cloud datasets, the CREW assessment is focused mainly on detailed comparisons of Level 2 data over a short time period, with consideration of retrievals rather than differences between output variables. However, CREW does have some dedicated full-time scientific support.

The assessment of cloud properties is especially difficult because clouds interact with so many climate variables. Differences were identified between the cloud cover fields by each group, but those differences are now understood. Where possible, fields are evaluated against reference data, such as *in situ* measurements for microphysics. The effects of aerosols can be separated by consideration of radiative fluxes for both cloudy and clear sky observations; that is, cloud and aerosol properties should be analysed together. Comparison of the International Satellite Cloud Climatology Project (ISCCP) products with measurements from the Baseline Surface Radiation Network (BSRN) reveals that ISCCP tends to have too much aerosol over USA but too little over the tropics. Such comparisons should be performed for other cloud datasets.

Because products associated with cloud properties are evolving quite rapidly and more groups are becoming involved in their production and application, there may be a need for a continuous process of independent assessment of the relevant datasets. The GEWEX Cloud Assessment has produced a database of all compared satellite products. The database will be publicly available by the end of 2011 (http://climserv.ipsl.polytechnique.fr/gewexca), together with a WCRP report documenting the strengths, limitations and suitable applications for each of the participating datasets. Such databases should be an integral part of all future assessments, because they not only will underpin future independent assessments but also readily allow product developers to perform self-assessments against a range of existing products.

Surface radiation

The variables related to the surface radiation budget are quite complex. Although the basic set of variables can be given as short-wave and long-wave upward and downward fluxes, in practice the variables need to be further split; for example, for short-wave radiation is composed of direct and diffuse components that are strongly dependent upon the gaseous, aerosol and cloud properties of the atmosphere. These are components of high importance for understanding solar interaction with the biosphere and even for solar energy planning. Specifying clear-sky downward and upward components is important for inferring the effect of clouds and aerosols on the surface radiative fluxes. The downwelling and fraction of absorbed photosynthetically active radiation (FAPAR) should also be identified for ecological applications. The ultra-violet component is important for both chemistry and ecology.

The Surface Radiation Budget (SRB) project began in the 1980s, but it formally became a GEWEX project in the mid-1990s. There have been several releases of SRB products, which are now based on data from ISCCP and reanalysis products from the US Global Modeling and Assimilation Office.

Many different datasets are used to prepare SRB products, and it is difficult to trace the specific sources of uncertainty in these products although researchers provide estimates from sensitivity studies. Other researchers have produced surface radiation products from ISCCP data and geosynchronous data. Recently the CERES (Clouds and Earth Radiant Energy System) mission algorithms have produced estimates of surface radiation quantities as well as associated uncertainties from the instrument and the various atmospheric input properties.

The GEWEX Radiative Flux Assessment (RFA) commenced in 2006, and its relatively slow progress has been due to the absence of a funded project to ensure that experts can dedicate an appropriate amount of time on the various activities, although some funding was provided to support web site and archive. The project is expected to produce a draft report in late 2011 that will be finalised after reviews including one by the GEWEX Radiation Panel, and the report will cover the following topics:

- Incoming solar irradiance
- Long-term TOA flux products
- Long-term satellite-based surface flux product comparison
- Long-term *in situ* surface flux data product comparisons
- Satellite-estimated surface vs *in situ* measurement comparisons
- Column flux divergence
- Global budget diagrams
- Global model comparisons
- Data sets and uncertainties.

Similar to the cloud assessment, the radiation flux assessment activity has an archive that will be made available publicly after the report is finalised (http://gewex-rfa.larc.nasa.gov).

In looking to the future, it is apparent that it will be difficult to sustain an independent assessment process without recognition by agencies that such activities require continuing support. Issues that need to be considered by groups preparing these datasets include sampling errors in the generation of Level 3 gridded values, the balance of precision and stability in instrumentation, support for reference networks, and support for access to datasets and their associated databases.

There needs to be particular emphasis on the scientific processes related to the generation of FCDRs. Important issues include proper calibration and navigation, global coverage, version management, documentation (meta-data) and timely access to data and meta-data.

4.2 Ocean ECVs

Sea-surface temperature (SST)

Sea-surface temperature datasets have many applications including ocean and atmosphere prediction, management of shipping and fisheries, as well as a range of research activities such as ocean reanalysis.

The workshop focused on some of the datasets coordinated within the Group for High Resolution SST (GHRSST). These datasets comprise skin and sub-skin temperatures estimated from satellite measurements. Most data providers within GHRSST are focussed on operational priorities, although long-term stewardship for climate applications is secure. The SST fields are derived from individual radiometers (or combinations), which operate in the infra-red or microwave parts of the electromagnetic spectrum. A key issue for users of SST global climate datasets is the transition from the historical datasets, based mainly on ship and buoy measurements of sub-surface temperatures, commonly referred to as 'bulk temperatures', to the GHRSST datasets. There is considerable activity aimed at ensuring that a homogeneous SST dataset can be extended both forward and backward in time. This issue has a significant impact on models that have been developed using sub-surface temperatures. While the GHRSST sub-skin temperature is related to the sub-surface temperature, further work is needed to ensure that this dataset can be used effectively in all models, especially in conditions of diurnal heating and cooling or other situations of near-surface stratification.

The main limitations on the GHRSST datasets are associated with the removal of atmospheric effects from the satellite radiances, as features such as aerosols, water vapour variability, unidentified clouds and precipitation can affect the retrieval of SST. The estimation of uncertainty in the dataset is being developed through a detailed analysis of individual uncertainties in each element of the product-generation process.

For the future, there is considerable uncertainty about continuity of appropriate microwave instruments in currently-planned satellite missions. With respect to quality control and evaluation of GHRSST SST products, there remain questions about how best to exploit the mix of *in situ* platforms available. Ship-based radiometers have good, traceable calibration and measure skin SST, but are few in number. The much more numerous buoys deliver matches to satellites with broad geographical coverage, but have not so far been deployed with traceable calibration of equivalent accuracy.

Surface winds

Sea-surface wind fields are important for many oceanographic applications such as ocean modelling and reanalysis, as the wind is a dominant driver of the ocean. The fields are also extensively used for numerical weather prediction and for the monitoring of tropical cyclones.

The workshop focused on scatterometer estimates of the surface wind field, where much of the analysis effort has been concentrated on weather rather than climate time scales. The satellite instruments essentially measure surface stress. Moreover, while there has been continuous coverage since 1991, the time series is based on different missions. There are several comparisons of data products from these missions in research studies, but a more comprehensive and definitive effort to set up inter-calibration standards is much needed.

Currently *in situ* buoy data are used for calibration and evaluation purposes, but the relationships between wind, stress, SST and atmospheric stability mean that comparison can be difficult. Moreover the number of suitable sites is very limited globally. The horizontal gradient computed from a two-dimensional wind field (e.g., for vorticity and convergence) that drives vertical mixing is needed in climatic applications. The mixing brings short-term momentum and heat from the surface mixed layer into the deep ocean, where they are stored over time. It also brings nutrients and carbon stored in the deep ocean to the surface, where there is sufficient light for photosynthesis. Computing these gradients has more stringent accuracy and resolution requirements.

In addition to the limitations listed above, there is a need for greater coordination of algorithm development, reprocessing, standardisation of quality metrics, and even the definition of variables. Full documentation would further enhance the transparency of the process and utility of the products. A concerted effort is needed to support appropriate calibration, evaluation and reprocessing activities; an activity similar to the GHRSST community is seen as necessary.

Scatterometer data have been used from USA and European missions, but it would be desirable to acquire similar data from Asia provided routine access and data quality can be assured.

Sea ice

Sea ice datasets are used for a range of practical applications associated with ship navigation at both international and local levels, as well as supporting weather and climate modelling and other research activities. The sea ice analysis is an essential element of global SST analyses.

While greater emphasis tends to be placed on sea ice concentration and extent, other variables such as ice age, ice thickness and ice motion are also important for both practical and research purposes. Sea ice time series are available since the late 1970s, and suitable satellite missions are assured at least until 2020. Several different datasets have been assembled for sea ice, and there have been some inter-comparisons. However, the nature and source of differences have not been fully documented. Indeed the detailed process for generation of each dataset has not been fully documented. The spatial and temporal variability of sea ice makes it difficult to reduce the uncertainties in datasets which are further complicated by variable atmospheric adjustments to satellite radiances. Melt ponds remain a specific problem for satellite retrievals, but greater use of scatterometer data may reduce the problem.

Products such as ice motion, age and concentration are essentially research-level products at this time. Snow cover is a major cause of uncertainty in these products.

4.3 Terrestrial ECVs

Soil moisture

Coarse-resolution (25-50 km) global soil moisture datasets derived from both passive and active microwave remote sensing instruments have increasingly become available in recent years. They comprise soil moisture data derived from multi-frequency radiometers, scatterometers, and the first purposefully designed Soil Moisture and Ocean Salinity (SMOS) mission. Within the 2014-2015 time-frames the Soil Moisture Active Passive (SMAP) mission will be launched which is expected to further improve spatial and temporal coverage as well as the accuracy of the soil moisture retrieval.

It is recognised that most climate users of soil moisture datasets are interested in the soil moisture content over a depth such as the root zone, rather than in surface soil moisture estimated from most satellite instruments. Models are generally used with the surface observations and ancillary data to estimate the soil profile. Such Level 3 or 4 ECV datasets may be of the greatest interest to the climate community.

The workshop participants decided that greater international cooperation would enhance the impacts of the work being done by individual teams on the generation and evaluation of soil moisture datasets. It was recognised that cooperation across agencies will be required to prepare a long-term global soil moisture dataset in order to integrate the individual records. Comparison of Level 1 and 2 CDRs as well as the related algorithms would help ensure consistency and quality in the integrated product. Currently there is a need for reprocessing of a number of Level 1 FCDRs (such as ERS-1 and ERS-2) and for inter-calibration of some datasets (such as ERS and ASCAT, as well as AMSR-E and Windsat). An international working group could facilitate and prioritise such activities, and it could also improve the documentation of soil moisture datasets by compiling an overall compendium of available datasets.

It is clear that the generation and evaluation of the ECV datasets should involve a continuing commitment across agencies, in order to improve algorithms and to reprocess datasets as research advancements are made. A particular issue is the contemporaneous incorporation of active and passive measurements.

The workshop participants agreed that it would be very useful to establish an international assessment of soil moisture datasets to provide a consistent and independent evaluation of current products. Given the relative immaturity of these datasets, it would be appropriate to focus on Level 2 swath data for a limited period (such as 2010). The assessment should be limited to global datasets that are freely available and have a fully-documented generation process. The assessment should involve both comparison with *in situ* observations and inter-comparison among the different ECV datasets. The independence of the assessment would require the work to be carried out by a group that is not involved in the generation of any of the ECV datasets.

The successful completion of the first assessment should lead to a continuing process in which the scope and depth of the assessments are increased. In particular, the period of evaluation could be extended and Level 3 datasets could be considered. The international framework could also be used to conduct specific field experiments to improve the characterisation of aspects such as surface roughness or vegetation.

Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)

GTOS (2009a) gives a detailed assessment of the status of the development of standards for FAPAR, and the workshop participants saw that document providing an adequate evaluation of that ECV at present. This ECV, which represents solar radiation absorbed by a vegetation canopy, is difficult to measure directly, and so it is inferred from models using satellite measurements as constraints. Indeed FAPAR is closely related to the leaf area index (LAI), which represents the ecological driver of FAPAR. It was also recognised that land cover classification is an important aspect of modelling used to derive FAPAR, and a consistent approach to the detection of land cover change would help ensure consistency across a range of terrestrial ECVs.

Activities associated with enhancement of the generation and evaluation processes for FAPAR are currently planned. However, resources are needed to support the required work on reference sites to provide *in situ* evaluation and to support independent assessments of existing datasets.

Snow cover

The ECV “snow cover” is considered to include four categories: snow covered area (SCA), snow water equivalent (SWE), snow depth, and snow wetness (presence of liquid water in the snow cover). There is a remote sensing capability to determine, with varying degrees of accuracy, all four of these parameters. However, the primary monitoring product with the longest time series, and considered to be the most accurate of the four, is a continuous data record of global snow covered area (SCA).

The strengths and weaknesses of snow cover products can be summarized in the following manner: dense forest cover obscures targets for both optical and microwave data; microwave data are all- weather and day/night, while darkness and cloud obscure the optical signal; optical data are limited to surface properties while microwave can estimate total mass for dry snow, although unable to detect the SWE of wet snow. Current spatial resolution of global microwave data is approximately 25 km, while optical data are available at 500 m.

5. General dataset issues

5.1 Introduction

In evaluating the ECV datasets, the workshop participants identified a number of common issues that require action to ensure that datasets continue to improve in quality and utility. Each of the following issues is considered below:

- Reprocessing of FCDRs, to ensure that data are well calibrated and benchmarked
- Independent assessments, as part of the continuing process of dataset evaluation
- Indices of maturity and uncertainty estimates, that provide information on the strengths and weaknesses of datasets
- Interdependence of variables, that impose physical constraints on datasets
- Atmospheric adjustment for satellite retrievals of surface properties which is a common element in the processing of many datasets
- Observational strategies for ECVs, that makes full use of available data.

It is also noted in Section 2.3 that reanalysis provides an emerging technique for the synthesis of global climate datasets, and it is expected to become a key process for the generation of physically-consistent global gridded datasets. Reanalysis (atmosphere, ocean, land, sea ice) is one aspect of the overall utilisation of global climate datasets. It is clear that continuing improvement in the quality and accessibility of climate datasets will be driven by increasing use for climate monitoring and diagnostics as well as modelling and reanalysis.

Each of the functions considered below needs to be carried out by groups generating datasets. However, the effectiveness and efficiency of the overall process is vitally dependent on cooperation and coordination among all the relevant agencies and programs.

5.2 Reprocessing of FCDRs

Key requirements for the utilisation of climate data records (CDRs), involving both space and *in situ* observations are continuity, calibration, accuracy, and benchmarks. The CDRs must be of known quality with uncertainty estimates. Calibration can be provided with a ground-based climate observing system such as GRUAN, with satellite systems such the Climate Absolute Radiance and Refractivity Observatory (CLARREO - now on hold), or through cross-calibration of satellites to a given reference via the Global Spaced-based Inter-Calibration System (GSICS).

Innovative ways to monitor the climate system are needed and one recent example is the use of GPS radio occultation (GPS-RO) to measure the bending angle through limb paths through the upper atmosphere. With current global warming predictions it should be possible to measure expected changes through GPS-RO with fifteen years of data. The major advantage of these data is they are not subject to radiometric calibration, which can introduce biases into the top of atmosphere radiances measured by conventional sounders. Accordingly they are closer to a benchmark measurement and they can be used to help calibrate IR and microwave sounders. The GSICS initiative and the Sustained Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) are also providing valuable constraints on the observed radiances through inter-comparisons among different satellite instruments and between observations and reanalyses. CLARREO was a promising mission for cross-calibrating satellite sensors and tying them to a standard, but has been placed on indefinite hold. It is much needed for improving the accuracy and stability of FCDRs.

Space agencies are encouraged to give sustained attention to activities that ensure the accuracy and consistency of the observational datasets from satellites used to derive ECV products. This begins with the operation of satellite observing systems in accord with the GCOS Climate Monitoring Principles, and the monitoring of system performance. The latter may include utilisation of feedback from the use of the data in numerical weather prediction and reanalysis, particularly from the bias-correction schemes used by their data assimilation systems. First steps in this direction have been taken by GSICS. The FCDRs need to be built up, often from the measurements made from a succession of satellites in a series, and adjustments (which should be well documented) may need to be made to these records to account for instrumental biases (that may drift over time) and for changes in instrumental characteristics from one satellite to the next in the series.

As calibration methods improve there will be a periodic need to reprocess FCDRs and the ECV products that depend on them. This is in addition to the generation of new versions of ECV products due to improvements in the retrieval methods used to derive products from the FCDRs. The need for such periodic reprocessing has been stressed by GCOS and WCRP (see http://www.wcrp-climate.org/documents/ for principles identified by WOAP), and a number of agencies have started activities, often collaboratively, in recent years. This includes the multi-agency GSICS and SCOPE-CM activities and climate reprocessing initiatives by ESA and NASA. It is vital that these activities be continued and indeed expanded to meet the full range of user requirements.

To improve the process of linking the generation of ECV products to needed reprocessing of FCDRs it is recommended that all activities (research and operational) producing ECV CDRs should investigate the sensitivity of the ECV product to the satellite input data and to document any problem that relates to the used FCDR. This will establish a knowledge base that can be used by space agencies to adjust their planning towards FCDR generation and reprocessing.

The inclusion of FCDR reprocessing into the plans of space agencies is complex as each space agency has specific decision processes and funding mechanisms. Very long time series (such as those from MSU/AMSU) may involve data from satellites where different space agencies have responsibility for the raw data archives. To efficiently coordinate a way forward it is recommended that specific needs are communicated via the GCOS co-sponsored panels AOPC, OOPC and TOPC. Coordination bodies of space agencies, such as CGMS and CEOS, respond to needs expressed in the GCOS Implementation

Plan and its Satellite Supplement. One particular route for promoting the requirement for reprocessing capability, and for implementation, is through the CEOS Virtual Constellations.

5.3 Independent assessments

It is well recognised that global climate datasets must be continually evaluated, first as part of the initial generation process and then as an ongoing activity as new applications and information become available. The agencies or groups involved with the generation of ECV datasets invariably carry out a self-assessment of their products, and this is an important part of the overall quality control. However, there are benefits for both the producers and users of global climate datasets if there are also independent assessments by expert groups. An independent assessment is a documented expert opinion on available datasets for a given ECV or set of linked ECVs. The steps involved in a self-assessment should be the same as those carried out for an independent assessment, and those steps are discussed later in this section.

An independent assessment provides the producers of datasets with a transparent quality-assurance of the products in which they have invested. Moreover it enhances the credibility of the product in the broader community and so builds confidence in the product and encourages its application by users. An independent assessment also contributes to the maturity index of the dataset and provides a reference for data availability. The process gives direct feedback to producers and so contributes to their internal operations by giving guidance on priorities to maintain the quality of the dataset, by identifying possible gaps and by highlighting uncertainties that need to be addressed in reprocessing of the dataset.

Independent assessments are of great benefit to users by providing objective documentation on the characteristics of a dataset, so that a user can select the best dataset for their particular application. This selection is important when a dataset is used for say the development or evaluation of a model where clear metrics of uncertainty are needed. Joint assessment of related datasets is useful in deciding the relative strengths and weaknesses of each dataset. Independent assessments invariably lead to the practical results of the datasets being readily accessible and of the producers developing improved datasets.

Experience with the conduct of independent assessments shows that, while very worthwhile, they take an extended period of time especially when they are not properly funded. Thus a key issue for the future is to promote the benefits of independent assessments so that agencies recognise that the associated costs are well worthwhile. Moreover it will be most effective to recognise assessment as a continuing rather than an intermittent process.

Assessments require regular meetings of the participants so that the work continues at an appropriate rate and so that incremental adjustments can be made to the process as results become available. It is important for an assessment to begin with a standardised collection of all the datasets. This first step ensures that any deficiencies in data accessibility are corrected quickly and that a broad group can be involved with the assessment. The step is clearly dependent upon access to proper infrastructure for data handling.

Independent assessments of course involve close interaction with the producers of each dataset. These interactions require communication skills, as people are inherently sensitive to criticism especially of their products prepared diligently over a long period. On the other hand, it is important for both producers and users of observed data to understand and manage their irregularities.

The proposed inventory (Section 3) and the GCOS Guidelines (2010) provide details on the various aspects of an assessment. However, it is useful here to outline some of the key features of an independent assessment. First it needs to provide a list of all the available products for a given ECV or set of related ECVs. It is useful to include in the list datasets that will not be assessed and to note the reason for their exclusion. The assessment then needs to consider the scientific basis and rigour associated with the generation of a dataset. This includes the navigation and calibration processes as well as the retrieval algorithms and models. Evaluation of the generation process allows statements to be made on the basic strengths and weaknesses of a dataset, as well as its fitness of specific purposes. The maturity of each dataset can be estimated at this stage.

Evaluation of ECV products needs to be based on agreed metrics, which are usually much more than average values and which will depend somewhat on the range of applications of a dataset. Where possible, datasets should be evaluated against reference standards or at least independent observations; that is, observations used in generating a dataset (such as for calibration) ideally should not be used for evaluation.

When each dataset has been compared with independent observations, it is useful to compare the estimated metrics from each dataset. Such inter-comparison can provide information on the sensitivity of products to *a priori* assumptions and to ancillary data in the generation process. Outliers within and between datasets can lead to help clarify these sensitivities.

In comparing datasets it is important to develop a measure of the uncertainties in each one. The uncertainties can be derived from comparison with independent data and also from formal error analysis of each step in the generation process. The latter approach is susceptible to structural error, which can lead to unexplained differences in datasets. Indeed the potential for structural error is a major motivation for the generation of more than one dataset for a given ECV. As with numerical models, independent generation of datasets can lead to better estimates of the possible structural errors in each approach.

An independent assessment should conclude with recommendations on the utility of each dataset for its intended applications. The recommendations are based on the results of the overall analysis.

5.4 Indices of maturity and uncertainty estimates

In establishing processes to develop confidence in observed datasets, it is now recognised that there needs to be an agreed vocabulary or lexicon between producers and users so that the strengths and weaknesses of a dataset are clearly understood. A maturity matrix like that of Bates and Barkstrom (2006) provides a foundation for the required dialogue by classifying datasets on an increasing scale from initial (score of 1) through to benchmarked (score of 6) on a number of characteristics, including algorithm stability, accessibility, documentation, engineering aspects, and applications. The estimation of the maturity matrix of ECV datasets is seen as an essential step in the overall evaluation process. While there may be some subjectivity in estimating the precise index score, the range of 1 to 6 means that it is easy to differentiate between mature and immature datasets. It is reasonable to expect a dataset to have a mean score of at least 3 (classified as provisional) before it is considered for general application and assessment.

A continuing issue for data access is the relatively short lifetime of URLs on the Internet: the mean half-life is found to be a few months. There is developing interest in generating persistent identifiers for global climate datasets through the assignment of Digital Object Identifiers (DOIs). The assignment of a DOI might be coupled to a peer-review process of a dataset. The costs and benefits of this approach are still being assessed, but it is likely that the use of DOIs will mark the maturity of future datasets.

Perhaps the most important characteristics of a dataset to convey to the user community are the nature and extent of its uncertainties. More work is needed to develop the lexicon between producers and users that convey these characteristics. The possible trade-offs between precision and accuracy are important aspects of datasets used for the detection and analysis of climate trends. However, for satellite-based instruments where the relationship between the measurement and the inferred physical variable can be remote in many senses, the structural uncertainties in the generation of ECV datasets require a large effort to identify and quantify (Thorne et al. 2005).

Estimates of uncertainties as a result of calibration, inter-calibration, retrieval and mapping procedures can be developed. These estimates need to be validated by independent observations where possible.

Currently, uncertainties are often not properly propagated from the Level 1 to the Level 3 product. In particular, it is found that the mapping of Level 2 data can lead to significant additional biases in the Level 3 dataset. Independent assessment (Section 5.3) can help identify and explain such biases, which can lead to differences in Level 3 datasets based on the same Level 1 and 2 data.

5.5 Interdependence of variables

Some ECVs are defined as a single quantity (such as sea-surface temperature), whereas some are actually diagnostic inferences from a number of measurements (such as surface radiation). Even in the first case, the retrieval of the quantity from satellite observations rarely avoids the need to remove other effects from the measurements; Section 5.6 considers the common example of the removal of atmospheric effects from a measurement of a surface variable. Similarly the retrieval of atmospheric properties is often affected by the nature of the underlying surface. Hence, even most single-variable ECV datasets depend on information from other data products.

An example of the second case is provided by inferences of the surface radiative fluxes: the fluxes are not directly measured from satellites but are calculated using measurements of the properties of the surface and atmosphere. Thus, such "diagnostic" ECVs depend directly on the quality of the other data products and algorithms used in the calculations. One implication is that any potential production system for an ECV that relies on additional information to isolate the quantity in question must ultimately use input data products for variables that may or may not be ECVs themselves. In either case, it is important that all input data have consistent 'climate' quality; that is, they are based on FCDRs.

Interdependence between climate variables is clearly apparent when they can be constrained by some physical process, such as the conservation of energy or water. Such constraints can be used in the simultaneous estimation of a group of variables, or at least to provide uncertainty estimates for each variable in the group. The WOAP Principles for Reprocessing Climate Data Records (Section 5.2) emphasise the need to seek physical consistency among climate data products. In order to achieve the required consistency, it will often be desirable for agencies to coordinate the reprocessing of linked datasets. It is also important for different communities generating complementary datasets (such as FAPAR/LAI and surface albedo) to coordinate the evaluation of their products.

5.6 Atmospheric adjustment for satellite retrievals of surface variables

It is noted in Section 5.5 that datasets associated with surface variables require the removal of atmospheric effects on radiances measured by satellite instruments. Thus, atmospheric adjustments are often made using a range of ancillary datasets. However, there is not a lot of consistency in the use of these ancillary data in deriving atmospheric adjustments for different ECVs. Adjustments are usually made statistically, using data and algorithms that are readily available. The physical and temporal consistency of ECV datasets can therefore be reduced by the use of different atmospheric adjustments.

Analysis of the impacts of ancillary data on the quality of an ECV product (as required under the WOAP Principles for Reprocessing) should help quantify these inconsistencies. However, a better strategy would be to develop a consistent approach to atmospheric adjustment. Such a strategy is probably not feasible while the adjustments are made statistically. On the other hand, the development of an agreed forward model for calculation of retrievals should improve the consistency among ECV datasets. This strategy would also provide a physically-based pathway for continuous improvement in atmospheric adjustments.

5.7 Observational strategies for ECVs

There is a need for climate observations that are global and multi-decadal in coverage with resolution sufficient to examine variations at the process-level. Given the available measurement technology, such climate data records usually have to be assembled from measurements by multiple instruments with limitations of information content and space-time resolution. Thus, the key to constituting a climate observing system is to exploit many different kinds of measurements with different accuracies and sampling characteristics.

The global observing system for climate is an integrated system with two major components. Complementary data are provided by the satellite constellation and the global *in situ* networks in the atmosphere and ocean and on land and ice. While satellites can generally provide global coverage, they cannot measure all the variables of interest and they are often not designed to provide data with long-term stability and homogeneity. The *in situ* observing networks can be used for calibration and evaluation of satellite data, and they are vital for the measurement of variables, such as surface air temperature and sub-surface ocean properties, that cannot be measured from satellites. Most *in situ* networks require independent calibration and evaluation, which can be provided by a third type of network that supplements the main satellite and *in situ* global networks.

The third type of network provides detailed point measurements of several variables in specific climatic zones. At these 'super-sites', high-quality measurements of many variables (often allowing budgets of water, energy and carbon to be closed) are maintained in geographically-representative locations around the world. Observations from these sites (such as the GRUAN) can provide anchor points for global climate datasets, as well as yielding information on the processes controlling the budgets of water, energy and chemical species.

All three components of the global observing system are needed to ensure the quality and comprehensiveness of global climate datasets.

6. Conclusions and actions

A workshop was held in Frascati, Italy in April 2011 with the aim of preparing a report on the evaluation of satellite-related global climate datasets. From consideration of the utility of global datasets, it is concluded that global climate datasets are vital components of climate science, supporting

- monitoring of climate variability and change on a range of time scales
- monitoring of forcing of the climate system
- prediction of climate variability and change
- attribution of causes of climate change
- characterisation of extreme climate events.

To ensure that the quality and utility of global datasets are adequate for these purposes, a rigorous process of development and evaluation is required, and the Guideline of Dataset Generation (GCOS, 2010) lists actions for implementation of that process. It is recognised that different datasets may be fit for different purposes.

In order to develop a framework for future actions, the workshop considered the evaluation of eight ECV datasets against the GCOS Guidelines. Arising from the evaluations, an inventory of the status of ECV datasets has been initiated to provide a consistent and accessible source of information on global climate datasets. The inventory should be maintained and developed to support the activities of data providers and users. It is likely that the inventory will be established at the NOAA Global Observing Systems Information Center (GOSIC), and the admission of new datasets into the inventory will be managed by the GCOS Panels.

The inventory of global ECV datasets will be a resource for users of climate observations to identify and locate data for their particular applications. It will also be of value to producers of datasets in providing a consist evaluation of strengths and weaknesses, and hence a means for determining priorities for further development. Inspection of inventory components can also highlight the vulnerability of specific ECVs to potential gaps in satellite instruments; for example, the risk to continuity of microwave radiometers with low-frequency channels may impact on the global SST record.

The items in the inventory entry for a global dataset align with the GCOS Guidelines. From consideration of the evaluation of the ECV datasets, it is concluded that special attention needs to be given to some issues, in particular:

- observing strategies for ECVs
- reprocessing of FCDRs
- atmospheric adjustment for satellite retrievals
- independent expert-group assessment of datasets
- indices of maturity and uncertainty
- interdependence of variables
- long-term homogeneity of datasets.

Conclusions on each of these issues are summarised below.

The global observing system for climate is an integrated system with two major components: complementary data are provided by the satellite constellation and the global *in situ* networks in the atmosphere and ocean and on land and ice. While satellites can generally provide global coverage, they cannot measure all the variables of interest and they often are not designed to provide data with long-term stability and homogeneity. The *in situ* networks can be used for calibration and evaluation of satellite data, and they are vital for the measurement of variables, such as surface air temperature and sub-surface ocean properties, that cannot be measured from satellites. These global systems are supplemented by 'super-sites', which provide detailed point measurements of several variables in specific climatic zones. Observations from these sites can provide anchor points for global climate datasets, as well as yielding information on the processes controlling the budgets of water, energy and chemical species. All three components of the global observing system are needed and should be maintained to ensure the quality and comprehensiveness of global climate datasets.

Space agencies are encouraged to give sustained attention to activities that ensure the accuracy and consistency of observational datasets from satellites used to derive ECV products. As calibration methods improve there will be a periodic need to reprocess FCDRs and the ECV products that depend on them. It is vital for these activities to be continued and expanded to meet the full range of user requirements. The international activities of GSICS and SCOPE-CM and the climate reprocessing activities of ESA and NASA are important initiatives supporting these needs.

Many surface variables require the removal of atmospheric effects on radiances measured by satellite instruments, and so atmospheric adjustment is a common procedure for climate datasets. These adjustments use a range of ancillary data in somewhat different ways for different ECV datasets. While the adjustments are statistically based, there is little scope to develop an agreed consistent approach. However, research aimed at the development of an agreed forward model for the calculation of retrievals should lead to greater consistency among ECV datasets.

All producers of climate datasets carry out self-assessment of the utility and uncertainties of the products. However, independent expert-group assessments of the datasets associated with ECVs markedly enhance the utility and encourage improvements of individual datasets. This process is time-consuming and needs to be properly resourced in the future, confirming the commitment of agencies to transparency and quality in the generation of global climate datasets. International independent assessments are seen as an important mechanism to enhance and promote the utility and application of these datasets. For example, it would be timely to commence a coordinated international assessment process for global Level 2 soil moisture datasets, with a view to expanding the scope and depth as scientific progress is made.

In order to promote an effective dialogue between users and producers of global climate datasets, an agreed lexicon based on the maturity index will be used in the ECV inventory to articulate the relative strengths and weaknesses datasets for specific applications. More work is required to develop agreed metrics of uncertainty in global datasets that transparently account for the many sources of error in generating a global climate dataset from satellite-based measurements.

Many ECVs represent a number of physical variables and so it is appropriate to account for their interdependence when generating datasets for each variable. Moreover a group of variables is often constrained by physical processes, such as the conservation of energy or water. Such constraints should be used in the generation of the individual datasets, and they can also be used in the evaluation of datasets. To maximise the benefits of accounting for the interdependence of variables, it is often desirable for agencies to coordinate the reprocessing of their datasets.

The specific variables associated with an ECV can evolve with advances in scientific knowledge and instrumentation, and such changes need to be accounted for to assure the long-term record of ECVs. For example, the products being generated by the Group for High Resolution SST (GHRSST) have enhanced the quality and reproducibility of global SST datasets, but work is required to ensure that the climate record can be extended consistently back in time as well as forward; that is, the long-term homogeneity of global climate datasets must be maintained.

The workshop brought together experts from across the geographical domains and found that, while there are specific issues associated with ECVs for each domain, there are many commonalities in the development and evaluation of global climate datasets across domains. Further international cooperation will lead to enhancements in the quality, utility and accessibility of global climate datasets.

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Willett, K.M., Alexander, L.V., and Thorne, P.W., Eds. (2010) Global climate [in "State of the Climate in 2009"]. *Bull. Amer. Meteor. Soc.*, **91**, S19-52.

Appendix 1 – GCOS Guidelines for dataset generation

Guidelines for the generation of datasets and products to meet GCOS requirements were updated in May 2010 (GCOS 2010). They aim to help all producers of climate datasets as they generate, assess and document their products. The following twelve items are highlighted as requirements to help assure the stewardship of datasets of Fundamental Climate Data Records (FCDRs) and Essential Climate Variable (ECV) products.

1. Full description of all steps taken in the generation of FCDRs and ECV products, including algorithms used, specific FCDRs used, and characteristics and outcomes of validation activities

2. Application of appropriate calibration/validation activities

3. Statement of expected accuracy, stability and resolution (time, space) of the product, including, where possible, a comparison with the GCOS requirements

4. Assessment of long-term stability and homogeneity of the product

5. Information on the scientific review process related to FCDR/product construction (including algorithm selection), FCDR/product quality and applications

6. Global coverage of FCDRs and products where possible

7. Version management of FCDRs and products, particularly in connection with improved algorithms and reprocessing

8. Arrangements for access to the FCDRs, products and all documentation

9. Timeliness of data release to the user community to enable monitoring activities

10. Facility for user feedback

11. Application of a quantitative maturity index if possible

12. Publication of a summary (a webpage or a peer-reviewed article) documenting point-by point the extent to which this guideline has been followed.

Appendix 2 – Workshop Participants

Anderson, Craig	Eumetsat	GERMANY
Armstrong, Richard	University of Colorado	UNITED STATES
Asrar, Ghassem	World Meteorological Organization	SWITZERLAND
[1]Bates, John	NOAA NCDC	UNITED STATES
Bennett, Victoria	Harwell office	UNITED KINGDOM
Bodeker, Greg	Bodeker Scientific	NEW ZEALAND
Bojkov, Bojan	ESA/ESRIN	ITALY
Bosilovich, Michael	NASA/GSFC	UNITED STATES
Chadwick, Anne	Harwell office	UNITED KINGDOM
De Jeu, Richard	VU University Amsterdam	NETHERLANDS
Dolman, Han	VU University Amsterdam	NETHERLANDS
Donlon, Craig	ESA	NETHERLANDS
Dowell, Mark	EU – JRC	ITALY
Figa, Saldana Julia	EUMETSAT	GERMANY
Govaerts, Yves	EUMETSAT	GERMANY
Heidinger, Andrew	NOAA	UNITED STATES
Hersbach, Hans	ECMWF	UNITED KINGDOM
Hollmann, Rainer	Deutscher Wetterdienst	GERMANY
Kern, Stefan	University of Hamburg	GERMANY
Kerr, Yann	CESBIO	FRANCE
Key, Jeffrey	NOAA	UNITED STATES
Kinne, Stefan	MPI-Meteorology	GERMANY
Koike, Toshio	The University of Tokyo	JAPAN
Kummerow, Christian	Colorado State University	UNITED STATES
Lecomte, Pascal	European Space Agency	UNITED KINGDOM
Liu, W Timothy	Jet Propulsion Laboratory	UNITED STATES
Loew, Alex	MPI-meteorology	GERMANY
Luojus, Kari	FMI	FINLAND
Manton, Michael	Monash University	AUSTRALIA
Mathieu, Pierre-Philippe	ESA	ITALY
Meier, Walter	National Snow and Ice Data Center	UNITED STATES
Merchant, Christopher	University of Edinburgh	UNITED KINGDOM
Minnett, Peter	University of Miami	UNITED STATES
Phulpin, Thierry	CNES	FRANCE
Pinty, Bernard	JRC-EC/ESRIN-ESA	ITALY
Plummer, Stephen	European Space Agency	UNITED KINGDOM
Podaire, Alain	Mercator Ocean	FRANCE
Pulliainen, Jouni	Finnish Meteorological Institute	FINLAND
Ranga, Myneni	Boston University	UNITED STATES
Rossow, William	City College of New York	UNITED STATES
Running, Steven	University of Montana	UNITED STATES
Ryan, Barbara	World Meteorological Organization	SWITZERLAND
Saunders, Roger	MET OFFICE	UNITED KINGDOM
Schulz, Joerg	EUMETSAT	GERMANY
Simmons, Adrian	ECMWF	UNITED KINGDOM
Stackhouse, Paul	NASA Langley Research Center	UNITED STATES
Stammer, Detlef	Univ. of Hamburg	GERMANY
Stoffelen, Ad	KNMI	NETHERLANDS
[2]Stubenrauch, Claudia	Lab. de Meteorologie Dynamique	FRANCE

1 Unable to participate, but presentation given by Joerg Schulz

Tan, David	ECMWF	UNITED KINGDOM
Trenberth, Kevin	NCAR	UNITED STATES
Van der Linde, Paul	MET OFFICE	UNITED KINGDOM
Wagner, Wolfgang	Vienna University of Technology	AUSTRIA

2 Presentation via video-conference

Appendix 3 – Workshop Program

Day 1 – Mon 18 April 2011

Session Chair: B. Ryan (Big Hall, Blg 14)

0900 Opening (ESA, WCRP, GCOS)
0915 Experiences in using ECV datasets in reanalysis in USA and Japan (M. Bosilovich)
0945 Experiences in using ECV datasets in ECMWF reanalyses including CCI applications (D. Tan)
1015 Experiences in using ECV datasets in modelling (R. Saunders)

1045 Coffee break

1100 Experiences in using ECV datasets for diagnostic studies (K. Trenberth)
1130 Overview of GCOS guidelines (A. Simmons)
1200 Indicators of maturity of datasets (J. Bates)
1230 Indicators of uncertainties in datasets (J. Schulz)

1300 Lunch

Session Chair: P.-P. Mathieu (Magellan Room, Blg 1)

1400 Overview of dataset inventory (J. Key)
1430 Scope and status of cloud properties products (C. Stubenrauch)

1515 Coffee break

1530 Scope and status of sea ice products (W. Meier)
1615 Scope and status of FAPAR products (S. Running)
1700 Dataset access and analysis (T. Koike)
1715 Conclusions and instructions to break-out groups
1730 Close followed by Reception

Day 2 – Tue 19 April 2011

0900 Instructions to break-out groups
0915 Break-out groups (atmosphere, ocean, terrestrial)

1030 Coffee break

1100 Break-out groups continue
1230 Brief report from atmosphere break-out group (C. Kummerow)
1240 Brief report from ocean break-out group (D. Stammer)
1250 Brief report from terrestrial break-out group (H. Dolman)

1300 Lunch

1400 Break-out groups continue

1530 Coffee break
1600 Break-out groups
1700 Brief report from atmosphere break-out group (C. Kummerow)

1710 Brief report from ocean break-out group (D. Stammer)
1720 Brief report from terrestrial break-out group (H. Dolman)
1730 Close

Day 3 – Wed 20 April 2011

Session Chair: M. Manton

0900 Plenary discussion of assessment of cloud properties (C. Stubenrauch)
0930 Plenary discussion of assessment of FAPAR (S. Running)
1000 Plenary discussion of assessment of sea ice (W. Meier)

1030 Coffee break

1100 Plenary discussion of assessment of surface radiation (P. Stackhouse)
1130 Plenary discussion of assessment of sea surface temperature (P. Minnett)
1200 Plenary discussion of assessment of snow cover (R. Armstrong)
1230 Plenary discussion of assessment of surface winds (A. Stoffelen)

1300 Lunch

1400 Plenary discussion of assessment of soil moisture (W. Wagner)
1430 Conclusion and next steps
1500 Close

Appendix 4 – Examples of inventory entries for atmosphere ECVs

Several datasets for cloud properties and surface radiation were considered at the workshop. Two datasets for cloud properties are given in this report as example entries in the ECV inventory. One is the GEWEX cloud dataset ISCCP, and the other is a less mature dataset developed at a research institute (AIRS-LMD).

Inventory entry for ISCCP Version D

1. Date of entry:
20 April 2011

2. Dataset name:
International Satellite Cloud Climatology Project (ISCCP) Version D

3. Lead investigator and agency:
Dr William B. Rossow, Distinguished Professor, City College of New York

4. Geophysical parameters (ECVs):
- FCDR = Visible and Window IR Radiances from all operational weather satellites
- ECV = Cloud Amount, Top Pressure, Top Temperature, Optical Depth, Water Path (Liquid/Ice)

5. Intended uses and users (existing or potential):
Climate and Weather Research Communities to Study Clouds-Dynamics, Clouds-Precipitation, Clouds-Radiation, Any User Needing Basic Cloud Variation Information

6. History and outlook – sustainability:
Currently funded through 2013; about to become operational

7. Availability (restrictions, web/ftp, registered with DOI system):
- No restrictions on availability
- Monthly Mean Products online at 3 sites, All Products available for ftp from two National Archives (NOAA NCDC and NASA Langley DAAC)
- Not DOI registered

8. Maturity (Bates-Barkstrom Index) = 4.75

Sensor Use	5
Code Stability	4
Metadata & QA	6
Documentation	6
Validation	5
Public Release	4 (3 for code, 5 for data products)
Science & Applications	6

9. Adherence to GCOS Guidelines:
Yes to all

10. Strengths and weaknesses or limitations:
Strengths: Global coverage with mesoscale resolution, data record > 25 years with diurnal resolution, basic cloud properties accurate enough to re-construct radiation budget to useful accuracy.

Weaknesses: Incomplete microphysical description (particle sizes only available from twice-daily polar orbiter measurements), incomplete vertical structure information (under-estimate top height for multi-layer clouds, no cloud base information), miss thinnest cirrus and less accurate results in Polar Regions.

11. Uncertainty estimates:

	CA	**CTT**	**CTP**	**COD**	**CWP**
Mesoscale & Instantaneous:	0.10	2-6K	50-200hPa	15-25%	10-30%
Regional Monthly Mean:	0.05	2K	100hPa	10%	10-30%
Global Annual Mean:	0.03	1K	100hPa	5%	10-30%
Accuracy:	0.10	1-2K	100hPa	5%	30%

12. Long-term homogeneity and stability:

13. Self and independent assessments: Yes and Yes
Datasets used in assessments: Cloud Information Derived from Surface Weather Observations and Radiosondes, LANDSAT, SAGE, HIRS, AVHRR, MODIS, AIRS, MISR, MLS, POLDER, ATSR, Calipso, NASA FIRE and ASTEX campaigns, SHEBA

14. Publication of algorithms, FCDR characteristics and assessments:
Website – http://isccp.giss.nasa.gov

Summary Papers:

- Schiffer, R.A., and W.B. Rossow, 1983: The International Satellite Cloud Climatology Project (ISCCP): The first project of the World Climate Research Programme. *Bull. Amer. Meteor. Soc.*, **64**, 779-784.
- Schiffer, R.A., and W.B. Rossow, 1985: ISCCP global radiance data set: A new resource for climate research. *Bull. Amer. Meteor. Soc*., **66**, 1498-1505.
- Rossow, W.B., and R.A. Schiffer, 1991: ISCCP cloud data products. *Bull. Amer. Meteor. Soc.*, **72**, 2-20.
- Rossow, W.B., and R.A. Schiffer, 1999: Advances in understanding clouds from ISCCP. *Bull. Amer. Meteor. Soc.*, **80**, 2261-2287.

Total publications that document and/or evaluate some aspect of ISCCP products = 42

15. Dataset Details:

Time period:	July 1983 – December 2009
Spatial coverage:	Global
Spatial/temporal sampling intervals:	DX = 30 km, 3 hr, D1 = 280 km, 3 hr, D2 = 280 km, Monthly
FCDRs used:	Visible & Window IR radiances from Operational Weather Satellites – FCDR Produced by Project
Ancillary inputs:	NOAA Snow Cover Product, NSIDC Sea Ice Concentration Products, TIROS Operational Vertical Sounder Product (daily, 280 km, global temperature, humidity profiles), Matthews Surface Types
Datasets used in development:	Surface Weather Observations, Operational Radiosonde Observations
Output data products:	Basic Cloud Properties (Amount, Top Temperature, Top Pressure, Optical Depth, Water Path) for All Clouds and 15 Cloud Types Defined by CTP-COD and Phase, Atmospheric Temperature and Humidity Profiles, Ozone Abundance, 9 Surface Types, Topography, Reflectance and Temperature, Cloud Property and Joint CTP-COD Histograms, Retrieval QC Information, Cloud Detection Uncertainty Estimate
Data product formats:	Binary, READ software provided

Inventory entry for AIRS-LMD Version 1

1. Date of entry:
20 April 2011

2. Dataset name:
AIRS-LMD, V1

3. Lead investigator and agency:
Dr Claudia Stubenrauch, Laboratoire de Météorologie Dynamique (LMD) IPSL/CNRS

4. Geophysical parameters (ECVs):
Cloud properties: Cloud Amount, Top Pressure, Top Temperature, Emissivity

5. Intended uses and users (existing or potential):
Climate studies, GCM evaluation, especially high clouds

6. History and outlook; sustainability:
First release, currently 2003 – 2009

7. Availability (restrictions, web/ftp, registered with DOI system):

- No restrictions on availability
- Monthly Mean Products available at http://ara.abct.lmd.polytechnique.fr
- L2 data in preparation to be distributed by CNES-ICARE
- Not DOI registered

8. Maturity (Bates-Barkstrom Index) = 2.5

Sensor Use	3
Code Stability	3
Metadata & QA	3
Documentation	1
Validation	3
Public Release	2
Science & Applications	4 (Cirrus & supersaturation, persistent contrails)

9. Description of adherence to GCOS Guidelines:

Full description of FCDR & ECV:	FCDRs from NASA, ECV L3 from LMD
Validation activities:	Yes (evaluation with Calipso V2)
Description cal/val activities & results:	In progress (GSICS)
Statement of accuracy, stability and resolution, including GCOS requirements:	In progress
Statement of long-term stability and homogeneity:	No follow up of AIRS on other satellites, continued by IASI on Metop (foreseen until at least 2020)
Information on scientific review of construction process, quality and applications:	GEWEX Cloud Assessment, GRP
Global coverage:	Yes
Version management of FCDRs and products:	NASA V5 AIRS Cal Rad L1B
Access to FCDRs, products and all documentation:	http://mirador.gsfc.nasa.gov
Timeliness of data release to the user community:	L3 data released, L2 data in preparation (see above)
Facility for user feedback:	Email
Application of a quantitative maturity index:	See above
Publication of a summary:	Web, article

10. Strengths and weaknesses or limitations:
Strengths: sensitive to thin cirrus, no night-day difference

Weaknesses: noise for low clouds, less accurate results in Polar Regions, no vertical structure available (only in combination with CALIPSO-CloudSat)

11. Uncertainty estimates:

	CA	**CTT**	**CTP**	**CEM**
Regional Monthly Mean:	0.05	2-4 K	40 hPa	0.05-0.20

12. Long-term homogeneity and stability:
No follow up of AIRS on other satellites, continued by IASI on Metop (foreseen until at least 2020)

13. Self and independent assessments: Yes and Yes
Datasets Used in Assessments: CALIPSO (2 years collocated), ISCCP, SAGE, HIRS, AVHRR, MODIS, MISR, POLDER, ATSR (monthly statistics, GEWEX Cloud Assessment)

14. Publication of algorithms, FCDR characteristics, assessments:
Website – http://ara.abct.lmd.polytechnique.fr

Selected Papers:
Stubenrauch, C. J., S. Cros, A. Guignard, and N. Lamquin, 2010: A 6-year global cloud climatology from the Atmospheric InfraRed Sounder AIRS and a statistical analysis in synergy with CALIPSO and CloudSat, *Atmos. Chem. Phys.*, 10, 7197-7214.
Stubenrauch, C. J., S. Cros, N. Lamquin, R. Armante, A. Chédin, C. Crevoisier and N. A. Scott, 2008: Cloud properties from AIRS and evaluation with CALIPSO, *J. Geophys. Res.*, 113, D00A10, doi: 10.1029/2008JD009928.
Stubenrauch C. J., A. Chédin, G. Rädel, N. A. Scott and S. Serrar, 2006: Cloud properties and their seasonal and diurnal variability from TOVS Path-B, *J. Climate*, 19, 5531-5553.
Stubenrauch, C. J., A. Chédin, R. Armante, and N. A. Scott, 1999: Clouds as seen by Infrared Sounders (3I) and Imagers (ISCCP): Part II) A New Approach for Cloud Parameter Determination in the 3I Algorithms. *J. Climate*, **12**, 2214-2223.
Stubenrauch, C. J., A. Chédin, R. Armante, and N. A. Scott, 1999: Clouds as seen by Infrared Sounders (3I) and Imagers (ISCCP): Part I) Evaluation of Cloud Parameters. *J. Climate*, **12**, 2189-2213.

Total Publications that Document and/or Evaluate Some Aspect of AIRS-LMD / TOVS Path-B Products = 7

15. Dataset Details:

Version No.:	1
Time Period:	2003 –2009
Spatial Coverage:	Global
Spatial/Temporal Sampling Intervals:	L2: 15 km, 12h, L3 (monthly): 1°, 12h
FCDR Used:	NASA V5 AIRS Cal Rad L1B
Ancillary Inputs:	T + H2O profiles, Tsurf, MW snow flag (NASA L2: V5), spectral surface emissivity (AIRS + MODIS), TIGR spectral transmissions
Datasets Used in Development:	CALIPSO V2
Output Data Product Contents:	Basic Cloud Properties (Amount, Top Temperature, Top Pressure, Emissivity) L3 as in GEWEX Cloud Assessment data base, L2 in preparation
Data Product Format:	netcdf

Appendix 5 – Examples of inventory entries for oceanic ECVs

Several datasets for sea-surface temperature (SST), sea ice and surface wind were considered at the workshop. Two datasets are given in this report as example entries in the ECV inventory. The examples are the MODIS SST dataset and the NSIDC sea ice dataset.

Inventory entry for MODIS SST Version 5

1. Date of entry:
20 April 2011

2. Dataset name:
MODIS SST Version 5

3. Lead investigator and agency:
Peter J. Minnett & Robert H. Evans
Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science
University of Miami, Miami, USA

4. Geophysical parameter and related ECV:
Skin sea-surface temperature; can be related to foundation temperature and sub-surface temperature with appropriate models.

Foundation temperature defined in Donlon, et al., 2007, The Global Ocean Data Assimilation. Experiment High-resolution Sea Surface Temperature Pilot Project. Bulletin of the American Meteorological Society, 88, 1197-1213.

5. Existing and/or potential users:
NWP centres, operational oceanography centres, ocean modellers, navies, climate researchers, fisheries and wildlife research and management.

Many users coordinated through GHRSST (https://www.ghrsst.org/).

6. History and outlook; sustainability:
Heritage instrument: AVHRR

Other SST fields available from (A) ATSR, TMI & AMSR-E

Sustainability:

- AVHRRs on MetOp polar orbiters
- VIIRS on NPP (2011) and then JPSS series (?)
- SLSTR on ESA Sentinel 3 (A - 2013, B – 2015)
- AMSR-2 on GCOM-W (1 - 2012, 2 -)
- MetImage (VII) on Post-EPS (Eumetsat, 2020)
- Geostationary (GOES-R (?))

7. Availability and DOI registration:

- GHRSST coordinates data processing, assembly and dissemination to the user community
- Parallel (partially linked) efforts: e.g. NAVOCEANO at Stennis Space Center; Ocean Biology Processing Group, NASA GSFC
- Remote Sensing Systems (microwave), Eumetsat OSI-SAF
- No DOI registration

8. Maturity index:

Sensor use:	4
Algorithm stability:	5
Metadata & QA:	6
Documentation:	6
Validation:	4
Public release:	6
Science and applications:	6
Mean maturity index:	5.3

9. Adherence to the GCOS guidelines:

Full description of FCDR & ECV: Largely, through GHRSST

Cal/val activities & results: Yes

Accuracy, stability and resolution, including GCOS requirements: Yes

Long-term stability and homogeneity: Yes

Scientific review of construction process, quality and applications: Yes

Global coverage: Yes

Version management of FCDRs and products: Yes, through GHRSST

Access to FCDRs, products and all documentation: http://mirador.gsfc.nasa.gov, https://www.ghrsst.org/data/data-descriptions/l2p-observations/, https://www.ghrsst.org/data/data-descriptions/l4-gridded-sst/, ftp://podaac-ftp.jpl.nasa.gov/allData/modis/docs/modis_sst.gd.html http://oceancolor.gsfc.nasa.gov/.

Timeliness of data release to the user community: L2 available in near-real time from NASA GSFC - http://oceancolor.gsfc.nasa.gov/. Postprocessed GHRSST data from JPL: L2P swath data - https://www.ghrsst.org/data/data-descriptions/l2p-observations/; L4 gridded SST fields - https://www.ghrsst.org/data/data-descriptions/l4-gridded-sst/.

Facility for user feedback: Email; on-line user forums

Maturity index: See above

Publication of a summary: Web, articles

10. Strengths, weaknesses, limitations:

Strengths:

- Temperature is an SI variable
- Traceability path to SI reference standards (since 1998)
- 30 yr time series, beginning with AVHRR
- Reasonably well defined variable

Weaknesses:

- IR cloud-cover identification problems
- IR errors larger for “anomalous atmospheres” – aerosols, dry-layers…
- Microwave errors in rainfall
- Microwave spatial resolution
- Microwave side-lobe effects close to coasts
- Effective corrections for diurnal variability
- Validation data not uniformly distributed, leaving gaps in time and space

11. Uncertainty estimates:

Determined by comparisons with:

- Drifting and moored buoys (sub-skin SST)
- Ship-based radiometers (skin SST)

For MODIS SSTs, means and standard deviations expressed for each pixel as a function of seven controlling variables. For other data sets, usually expressed as a global mean and standard deviation, thereby hiding regional, seasonal and geophysical effects.

Each processing step is prone to additional error sources – see Cornillon et al. (2010) Sea-Surface Temperature Error Budget White Paper. (http://www.ssterrorbudget.org/ISSTST/).

12. Long-term homogeneity and stability:
Pre-MODIS SST legacy data sets from AVHRR on NOAA-nn polar-orbiters (global at 4-km resolution), going back to 1981 (see http://www.nodc.noaa.gov/sog/pathfinder4km/). Future extension of MODIS-like SSTs on VIIRS on NPP and JPSS.

13. Self and independent assessments:
Comparisons with independent collocated and contemporaneous buoy and ship radiometer measurements. Radiometers are traceable to NIST temperature standards (Rice, J. P., and Coauthors, 2004: The Miami2001 Infrared Radiometer Calibration and Intercomparison: 1. Laboratory Characterization of Blackbody Targets. *Journal of Atmospheric and Oceanic Technology*, **21,** 258-267). Comparisons with SSTs derived from other satellite radiometers.
Matchup Data Bases are available for independent, community analysis.

14. Publication of algorithms, FCDR characteristics, assessments:
www.ghrsst.org; http://www.hrdds.net; ftp://podaac.jpl.nasa.gov/allData/ghrsst/docs/; http://oceancolor.gsfc.nasa.gov/DOCS/atbd_mod25.pdf

Donlon, C., and Coauthors, 2007: The Global Ocean Data Assimilation Experiment High-resolution Sea Surface Temperature Pilot Project. Bulletin of the American Meteorological Society, 88, 1197-1213.

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Minnett, P. J., 2010: The Validation of Sea Surface Temperature Retrievals from Spaceborne Infrared Radiometers. Oceanography from Space, revisited., V. Barale, J. F. R. Gower, and L. Alberotanza, Eds., Springer Science+Business Media B.V., 273-295.

15. Dataset details:

Version number:	5
Time period:	2000-present (MODIS on Terra); 2002-present (MODIS on Aqua)
Spatial coverage:	global (cloud-free)
Spatial/temporal sampling intervals:	
FCDRs used:	Infrared radiances in 3.7-4.1 and 10-12 µm atmospheric transmission windows
Ancillary inputs:	Visible radiances for cloud screening

Datasets used in development:	AVHRR SSTs, Drifting and moored buoy subsurface SSTs, ship-based radiometer skin-SSTs, radiosonde measurements and NWP analyses of atmospheric state.
Output data products:	Skin SST
Data product formats:	GHRSST L2P swath data (see https://www.ghrsst.org/data/data-descriptions/l2p-observations/); L4 gridded SST fields (see https://www.ghrsst.org/data/data-descriptions/l4-gridded-sst/).
File structure is netCDF.	For file readers, see https://www.ghrsst.org/data/ghrsst-data-tools/. Also L2 and L3 available in near-real time from http://oceancolor.gsfc.nasa.gov/.

Inventory entry for NSIDC sea ice

1. Date of entry:
20 April 2011

2. Dataset name:
Sea ice dataset

3. Lead investigator and agency:
W. Meier
National Snow and Ice Data Center (NSIDC)

4. Geophysical parameter and related ECV:
- Sea ice concentration and extent
- Sea ice motion
- Sea ice age, multi-year fraction
- Sea ice thickness

5. Existing and/or potential users:
Climate modelling, NWP, process studies, biology, commercial and military navigation, resource extraction, local communities, educators, media, general public.

6. History and outlook; sustainability:
Based on passive microwave
Sustainability: DMSP, EOS Aqua, GCOM-W through to 2020

7. Availability and DOI registration:
- NSIDC
- DOI registration under consideration for CDRs

8. Maturity index:

	Sea ice	**Motion/age**
Sensor use:	3	3
Algorithm stability:	4	3
Metadata & QA:	3	2
Documentation:	5	3
Validation:	4	4
Public release:	4	5
Science and applications:	6	5
Mean maturity index:	4.1	3.6

9. Adherence to the GCOS guidelines:

	Sea ice	Motion	Age
Full description of FCDR & ECV:	Yes	Yes	No
Cal/val activities & results:	Yes	Yes	Yes?
Accuracy, stability and resolution, etc:	Yes	Yes?	Yes?
Long-term stability and homogeneity:	Yes	Yes	Yes?
Scientific review of construction process, etc:	Yes	Maybe	No
Global coverage:	Yes	Yes	Yes
Version management of FCDRs and products:	Yes	No	No
Access to FCDRs, products etc:	Yes	Maybe	Not yet
Timeliness of data release etc:	Yes	No	No
Facility for user feedback:	Yes	Yes	Not yet
Maturity index:	Yes	Yes	Yes
Publication of a summary:	Yes	No	No

10. Strengths, weaknesses, limitations:

Strengths:

- Long-term record since 1987
- Complete all-sky daily coverage
- Mature algorithms, many validation studies
- Consistent inter-calibration through satellite transitions

Weaknesses:

- Limited documentation of some processing steps
- Errors not characterised on grid cell basis
- Low spatial resolution (ice edge uncertainty)
- Microwave spatial resolution
- Variable surface characteristics (eg snow, melt)

11. Uncertainty estimates:

Sea ice:

- In central Arctic winter, uncertainty is about 5%
- Errors can be much higher in some regions:
  - During melt (under-estimation due to liquid water)
  - Ice edge (due to resolution of sensor)
  - Near land (false ice due to mixed land-ocean emission in IFOV)
  - Thin ice (due to ambiguous emission signature)
- Also errors from atmospheric emission (most relevant near ice edge) and surface roughness

Sea ice motion and Lagrangian age:

- 3-6 km/day, with little bias
- Uncertainties due to:
  - Limited spatial resolution of input data
  - Surface character changes between observations
  - Divergence within grid cell, for age

12. Long-term homogeneity and stability:

13. Self and independent assessments:

14. Publication of algorithms, FCDR characteristics, assessments:

15. Dataset details:

Version number:	
Time period:	1978 - present
Spatial coverage:	12.5 km or 6.25 km
Spatial/temporal sampling intervals:	
FCDRs used:	
Ancillary inputs:	
Datasets used in development:	
Output data products:	Daily and monthly sea ice
Data product formats:	Gridded ascii or binary

Appendix 6 – Examples of inventory entries for terrestrial ECVs

Several datasets for soil moisture, snow cover and FAPAR were considered at the workshop. Example entries in the ECV inventory are listed below for the MODIS snow cover dataset and for the WACMOS soil moisture dataset.

Inventory entry for MODIS snow cover

1. Date of entry:
3 August 2011

2. Dataset name:
MODIS Snow Cover

3. Lead investigator and agency:
Richard Armstrong, National Snow and Ice Data Center (NSIDC)

4. Geophysical parameter and related ECV:
Snow Cover – Global areal extent.

5. Existing and/or potential users:
Climate change, climate modelling, NWP, flood prediction, process studies, albedo studies, biology, transportation, hazard assessment, agriculture, recreation, local communities, educators, media, general public.

6. History and outlook; sustainability:
MODIS sensor on NASA EOS Terra and Aqua platforms

7. Availability and DOI registration:

- Available from NSIDC
- DOI registration under consideration for NSIDC CDRs

8. Maturity index:

Sensor use:	3
Algorithm stability:	4
Metadata & QA:	5
Documentation:	5
Validation:	4
Public release:	5
Science and applications:	4
Mean maturity index:	4.3

9. Adherence to the GCOS guidelines:

Full description of FCDR & ECV:	Yes
Cal/val activities & results:	Yes
Accuracy, stability and resolution, including GCOS requirements:	Yes
Long-term stability and homogeneity:	Yes
Scientific review of construction process, quality and applications:	Yes
Global coverage:	Yes
Version management of FCDRs and products:	Yes
Access to FCDRs, products and all documentation:	Yes
Timeliness of data release to the user community:	Yes
Facility for user feedback:	Yes
Maturity index:	Yes
Publication of a summary:	Yes

10. Strengths, weaknesses, limitations:
Strengths: Global daily coverage, stable sensor, robust, automated algorithm, consistent processing, and appropriate resolution for regional studies.

Weaknesses: Clouds and vegetation obscure target, insufficient spatial resolution for some basin scale studies, and increased uncertainty in complex terrain. Detection of thin snow (< 1.0 cm) can be problematic.

11. Uncertainty estimates:
Overall absolute accuracy is 93%, varying with land-cover type and snow condition (see Hall and Riggs, 2007, below). The most frequent errors are due to snow-cloud discrimination problems.

12. Long-term homogeneity and stability:
Product of NASA EOS Terra and Aqua programs.

13. Self and independent assessments:
Hall & Riggs (2007), see item 14.

14. Publication of algorithms, FCDR characteristics, assessments:
Hall, D. and Riggs, G. 2007. Accuracy assessment of the MODIS snow products. Hydrological Processes, 21:1534-1547.
Hall, D., Riggs, G. and Salomonson, V. 2001. Algorithm theoretical basis development (ATBD) for the MODIS snow algorithm. http://modis-snow-ice.gsfc.nasa.gov

15. Dataset details:

Version number:	Version numbers advance with each re-processing
Time period:	February 2000 – Present
Spatial coverage:	Global
Spatial/temporal sampling intervals:	500m and 0.05 deg. - daily
FCDRs used:	
Ancillary inputs:	
Datasets used in development:	MODIS Level-1B Calibrated Radiance product (MOD02) and Geolocation Fields (MOD03).
Output data products:	Daily, 8-day and monthly snow cover
Data product formats:	HDF-EOS

Inventory entry for WACMOS soil moisture

1. Date of entry:
20 April 2011

2. Dataset name:
WACMOS merged active-passive soil moisture dataset for 1978-2008

3. Lead investigator and agency:
Richard de Jeu, Vrije Universiteit Amsterdam (VUA)
Wolfgang Wagner, Wouter Dorigo, Vienna University of Technology (TU Wien)

4. Geophysical parameter and related ECV:
Soil moisture

5. Existing and/or potential users:
Climate modelling, NWP, hydrology, agronomy, ecology, epidemiology, natural hazards (drought, flood, landslides), greenhouse gas accounting, and military navigation.

6. History and outlook; sustainability:
The WACMOS merged soil moisture data set is the first long term (30+ years) soil moisture data sets obtained by merging C-band scatterometer (active) and multi-frequency microwave radiometer (passive) based Level 2 soil moisture retrievals. Thanks to the operational status of this type of microwave instruments, the sustainability is high.

7. Availability and DOI registration:
- The dataset will become freely available at the beginning of 2012 from TU Wien or VUA.
- No DOI registration yet.

8. Maturity index:

	Active	Passive	Merging Technique
Sensor use:	5	5	
Algorithm stability:	4	4	3
Metadata & QA:	3	3	1
Documentation:	4	4	2
Validation:	4	4	1
Public release:	5	5	1
Science and applications:	3	3	1
Mean maturity index:	4	4	1.5

9. Adherence to the GCOS guidelines:

	Active	Passive	Merged
Full description of FCDR & ECV:	yes	yes	yes
Cal/val activities & results:	yes	yes	yes
Accuracy, stability and resolution, etc:	yes	yes	yes
Long-term stability and homogeneity:	not known		
Scientific review of construction, etc:	yes	yes	no
Global coverage:	yes	yes	yes
Version management of FCDRs and products:	no	no	no
Access to FCDRs, products etc:	yes	yes	no
Timeliness of data release:	yes	yes	no
Facility for user feedback:	yes	yes	no
Maturity index:	yes	yes	no
Publication of a summary:	yes	yes	yes

10. Strengths, weaknesses, limitations:

Strengths:

- Long technological heritage (scatterometers, multi-frequency radiometers)
- High radiometric accuracy and stability
- Robust soil moisture retrieval algorithms
- Error characterisation available

Weaknesses:

- Long-term stability not yet known
- Retrieval impacted or not possible over dense forest, mountainous regions, urban area, water bodies, snow, and frozen soil
- No internationally coordinated assessment has yet been carried out

11. Uncertainty estimates:

Yes, available from error propagation, triple collocation and assessments with independent data sets, e.g. with in-situ measurements from the International Soil Moisture Network (ISMN).

12. Long-term homogeneity and stability:

Individual scatterometer and radiometer data sets are internally homogeneous and stable. Instrument inter-calibration not well enough known to characterise the stability of the merged soil moisture data sets.

13. Self and independent assessments:

Self and independent assessments are available for the individual active and passive soil moisture data sets. For the merged active-passive soil moisture data sets only self assessments are available so far.

14. Publication of algorithms, FCDR characteristics, assessments:

Algorithms have all been published in peer-reviewer journals; FCDR characteristics are rather well understood; no internationally coordinated assessment has yet been carried out.

15. Dataset details:

Version number:	
Time period:	1978-2008
Spatial coverage:	Global
Spatial/temporal sampling intervals:	0.25°/daily
FCDRs used:	Level 1 of ERS SCAT, METOP ASCAT, SMMR, SSM/I, TMI, AMSR-E
Ancillary inputs:	GLDAS
Datasets used in development:	GLDAS, ISMN
Output data products:	Daily images with for each pixel: surface soil moisture, surface soil moisture error, quality flags (e.g. frozen soils, mountains, snow cover), and product(s) used as input.
Data product formats:	Daily images in NetCDF