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1. Introduction

1.1 Scope

This document describes the current and anticipated relationship and role of the ERS scatterometers in the Global Climate Observing System.

Conclusions and recommendations are provided to further consolidate this relationship and role in order to ultimately improve the visibility and usefulness of the ERS Climate Data Records (CDR).

1.2 Applicable and Reference Documents

Applicable Documents

ID	Reference
AD-1	

Reference Documents

ID	Reference
RD-1	WMO (World Meteorological Organization), "Systematic observation requirements for satellite-based data products for climate", Report GCOS-154, 128 pp., Geneva, Switzerland, 2011.
RD-2	http://www.wmo.int/pages/themes/climate/understanding_climate.php
RD-3	http://www.wmo.int/pages/prog/gcos/
RD-4	WMO Guide to Climatological Practices (WMO-No. 100), http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.html
RD-5	http://www.wmo-sat.info/product-access-guide/domain/ocean/ocean-surface-wind

Acronyms

Acronym	Expansion
ASCAT	Advanced Scatterometer
ASPS	Advanced Scatterometer Processing System
ECMWF	European Center Medium-range Weather Forecast Center
ERS	European Remote Sensing satellite

EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GCOS	Global Climate Observing System
GMF	Geophysical Model Function
KNMI	Koninklijke Nederlands Meteorologisch Instituut
LRDPF	Low bit Rate Data Processing Facility
MARS	Meteorological Archival and Retrieval System
NWP	Numerical Weather Prediction
NOC	NWP ocean calibration
WVC	Wind Vector Cell

2. Executive Summary

Global ERS scatterometer data has been available from 1991 until February 2003, proving essential and unique information on ocean vector winds, land hydrology and sea ice. For the understanding of climate change and climate processes, these backscatter observations are potentially very useful and constitute so-called Essential Climate Variables (ECV), serving several downstream applications, such as for example off-shore wind energy design, production and maintenance.

There are international, as well as national, policy mandates or structures regarding climate and climate change. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to review and provide recommendations to governments regarding the state of knowledge of the science of climate change, the risks associated with human-induced climate change, the social and economic impacts of climate change and possible response strategies. In 2009 the third World Climate Conference (WCC-3) unanimously agreed to develop a Global Framework for Climate Services (GFCS).

Following GCOS principles, is important to derive satellite products in a physically consistent way across ocean, land and atmosphere domains. Fundamental Climate Data Records (FCDR's) and ECV's derived from these imply end-to-end climate information stewardship, consisting of data preservation, data quality, archiving, processing and re-processing, discovery and access, required for CDR production. While some argue that it took more than 40 years to create the end-to-end system that exists today for weather monitoring and forecasting, the climate monitoring end-to-end system profits from these developments.

The continuing importance of long-term climate datasets for climate variability, trend analysis and product inter-comparison is stressed by the GFCS. ERS scatterometer data are at the start of a long record of global C-band scatterometer observations, ranging from 1991 to 2011, complemented by the EUMETSAT MetOp ASCAT scatterometer missions from 2007 onwards. For the production of a seamless ECV it is crucial that the geophysical backscatter observations of the C-band scatterometers are inter-calibrated in a so-called Fundamental Climate Data Record. Standard (Level 2 and higher level) processors for applicable geophysical wind, soil moisture or sea ice products would then be able to provide a stable and truthful record of the changing climate over several instruments.

The development of new integrated data products, especially those produced through reanalyses (data assimilation), has the potential to provide information on climate forcing, which may be useful both in driving climate models and for policy- and decision-makers (e.g., in assessing emissions and fluxes which are regulated by statute and/or treaty). Assuring that such estimates are soundly based and validated under a sufficiently broad range of conditions will be critical if their use is to be accepted. Such reassurance and confidence may be obtained through comparison of reanalyses products, e.g., ECMWF Re-Analysis ERA, with inter-calibrated FCDRs as outlined above.

It is especially important for groups that develop new methodologies for retrievals of physical variables at different centres, agencies and countries to recognise other related developments and compare results. It is essential that common methodologies be developed and applied even if specialized approaches are also taken. The evaluation and vetting of products and their inter-comparison is an essential part of the observational process and should be fully

funded. Hence, the SCIRoCCo project successfully set out to developed new methodology to both linearly and non-linearly inter-calibrate the C-band observations from the ASCAT and ERS scatterometer instruments. Moreover, in the EUMETSAT OSI SAF efforts are ongoing to inter-calibrate C-band and Ku-band scatterometers in order to obtain the desired set of FCDRs outlined above.

Since the calibration has been done in the geophysical measurement domain, the relation with instrument and L0 processing specification remains speculation. This does reduce the confidence in the ERS FCDRs and further investigation in the instrument and L0 processing performance is recommended.

The SCIRoCCo results on the current status of FCDR calibration are documented, but some loose ends exist:

1) FCDR documentation, such as instrument specification, anomaly records, ATBD, user manual, etc., should be accessible by all producers of downstream ECV's and by all users of the FCDR and CDR's. This is currently accommodated on the SCIRoCCo web portal, but maintenance of these pages thus should be assured;
2) This may be done through the provision of digital object identifiers (DOI), which are associated with a so-called landing page; the landing page is maintained and provides references to the necessary documentation and metadata; multiple portals could host a FCDR, but they all would point to the unique DOI, such that the accessibility to each FCDR may be easily checked by specifying the DOI in an internet search engine, as well as its authenticity and responsibility;

Another point of concern is the visibility and provision of information on the ERS scatterometers. In particular, the WMO OSCAR data base lists all past and present space-based instrument capabilities, but no links to satellite and scatterometer instrument specifications are provided. Such specifications are available on the SCIRoCCo pages and WMO should be formally requested to use those links, for example when kept near the maintained pages associated with the ERS1 and ERS2 scatterometer FCDR DOI landing pages.

The SCIRoCCo project elaborated the NetCDF definitions in collaboration with the EUMETSAT OSI SAF and H-SAF projects, the EU Copernicus Marine Environment Monitoring Service (CMEMS), the Copernicus Global Land Service and the International Ocean Vector Winds Team (IOVWST). The resulting community suggestions will be provided to the NetCDF board for endorsement, which may imply further evolution of these definitions and therefore adaptation of the FCDR and ECV data on the longer term. This would require some resources.

3. Global Climate Observing System

Climate monitoring principles, requirements and guidelines for the creation of climate data records (CDR) have been formulated to increase awareness in space agencies to the specific observational and procedural needs for a successful climate monitoring.

The Earth's climate changes slowly relative to the period over which any individual satellite program lasts. Hence, a monitoring of the climate system is difficult unless a whole-system view is taken. Current space-based climate data records are based mainly on the observations of the research and operational satellite systems primarily built to support short-term weather and environmental prediction applications. Thus, past weather and Earth observations, ground-based and space-borne, have left an enormous legacy of data that provides the basis of our current knowledge on climate variability and change. However, there are a number of peculiarities associated with the satellite data which need to be addressed. These include among others instrument calibration, the absence of documented measurement traceability and uncertainty budgets. All of these can introduce artefacts into long-term time series and require careful attention when the resulting climate data record is produced, and consecutive series of satellite observations are integrated over time. In addition, weather observations do not necessarily address all needs for climate studies.

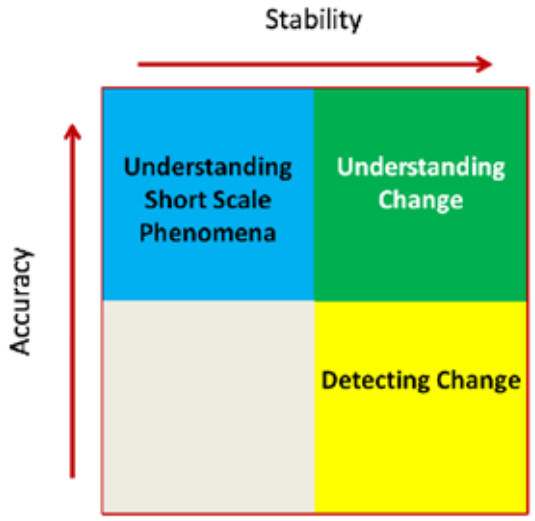

Figure 1 – Accuracy vs. stability diagram following Ohring et al. (2004).

GCOS has been identified as the climate observing component of Global Earth Observation System of Systems (GEOSS). GCOS is a system of observing systems built on the climate-relevant components of the established global observing systems for the atmosphere, ocean, land and surface water. The main components of the observing system are, inter alia, WMO Integrated Global Observing System (WIGOS), WWW Global Observing System (GOS) for atmospheric physical and dynamical properties, IOC/WMO/UNEP/ICSU Global Ocean Observing System

(GOOS) for physical, chemical and biological properties of the ocean, FAO/UNEP/UNESCO/WMO/ICSU Global Terrestrial Observing System (GTOS) for land surface ecosystem, hydrosphere, and cryosphere measurements; and IGBP and WCRP and other research observing networks, which all link to scatterometer FCDRs and thus the SCIRoCCo project. Furthermore, the international climate programs and mechanisms which it supports, and through which it meets its objectives, include, inter alia, the World Climate Programme (WCP), The World Climate Research Programme (WCRP) and related earth system research programmes including the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP) and DIVERSITAS, the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC).

3.1 CDR guidelines

Box 3.4 Summary of GCOS Guideline for Satellite-based Datasets and 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.

Figure 2 – GCOS guidelines (RD-3).

Figure 2 provides a summary of the GCOS guidelines for satellite-based climate data sets and products, which may be compared to the assets of the SCIRoCCo project. A full specification of all processing steps taken in the generation of the FCDR and ECV products, including algorithms and data inputs exists. Moreover, the outcomes of the calibration and validation activities have been described and are publicly available. Moreover, a more minor non-linearity exists in the scaling of the ERS-1 scatterometer measurements with respect to MetOp-A ASCAT. In SCIRoCCo appropriate calibration and validation activities have been performed, notably the inter-calibration with of the ERS-2 scatterometer with MetOp-A ASCAT, which has been absolutely calibrated against accurate transponders. The calibration effort moreover resulted in measures of stability and accuracy of the FCDR record after correction. Moreover, a year of calibrated wind ECV processing has been performed with the ASCAT Wind Data Processor (AWDP), showing that the 25-km sampled product essentially fulfils the GCOS ECV requirements. The non-linear and linear calibration procedures, as (further) developed within the SCIRoCCo project were and are being published in peer-reviewed scientific publications. Scientific publications on the wind (AWDP) and soil moisture processors and their validation are plentiful.

In terms of FCDR version management, the situation is less clear. Some instrument specifications remain unclear, as a non-linear calibration step has been necessary to fully align the measurement distributions of the ERS-1 and ERS-2 scatterometers, but it is not yet clear what hardware or L0 processing specifications cause such non-linearities. Furthermore, although the FCDRs are accessible, they are not well linked to popular user portals (see also next chapter). Furthermore, it is not clear yet how the facility for user feedback on the FCDR will be arranged.

Nevertheless, most components appear in place for the construction of the ERS-1 and ERS-2 CDRs, which is now being planned in the OSI SAF before February 2017, following its high user priority and rather due timeliness. The OSI SAF level 2 CDRs are reviewed by external experts following the GCOS guidelines as of Figure 2, including the availability of a helpdesk (e.g., scat@knmi.nl). DOIs will be obtained and the ECV CDRs will be maintained and kept aligned with the ASCAT 25-km products in the EUMETSAT SAF network. When ready, the landing pages of the CDRs would naturally link to the publicly accessible information (DOI, if available) of the ERS FCDRs. Note that such DOI landing page should ideally cover all of the GCOS guidelines in Figure 2. Higher level (L3 and L4) ERS wind and surface stress products are foreseen in the EU Copernicus Marine Environment Monitoring Service (CMEMS), following an established procedure starting from scatterometer L2 data.

3.2 Standards

The opportunity for standardisation extends beyond climate and includes the whole Earth observation mandate being covered in GEOSS. It is proposed to organize a major effort in concert with the International Organization for Standardization (ISO) and representatives from the various component systems. The WMO Information System (WIS), which is an extension of the WMO Global Telecommunication System (GTS) and GEOSS use the ISO 19115 metadata content standard for geographical information and the ISO 23950 interoperable search service, which can serve for extending the effort as broadly as possible. Because this approach uses well-known, compatible and interoperable standards, it is essential to foster the degree of data and information integration that is so vital to the understanding of climate.

On a higher level, it was noted in the SCIRoCCo project that agencies who fund the production of CDRs should invest in the development of data and metadata standards. As NetCDF is widely used in the EO community, but mainly originates from the earth system modelling community, it appears natural that bodies such as the ESA and EUMETSAT reassure and coordinate that EO expert views are considered in the development of these standards, indeed, on a high level. At the moment, mainly NASA and NOAA have taken up such responsibility on behalf of the EO community. Instead, user communities are elaborating NetCDF definitions and standards, but which need coordination over the different EO themes, such as passive and active sensors, SST, wind, sea ice, hydrology, etc.., since different communities tend to develop their own standards. The SCIRoCCo project thus encourages ESA to take a role of EO NetCDF coordination.

4. WMO requirements and capabilities review

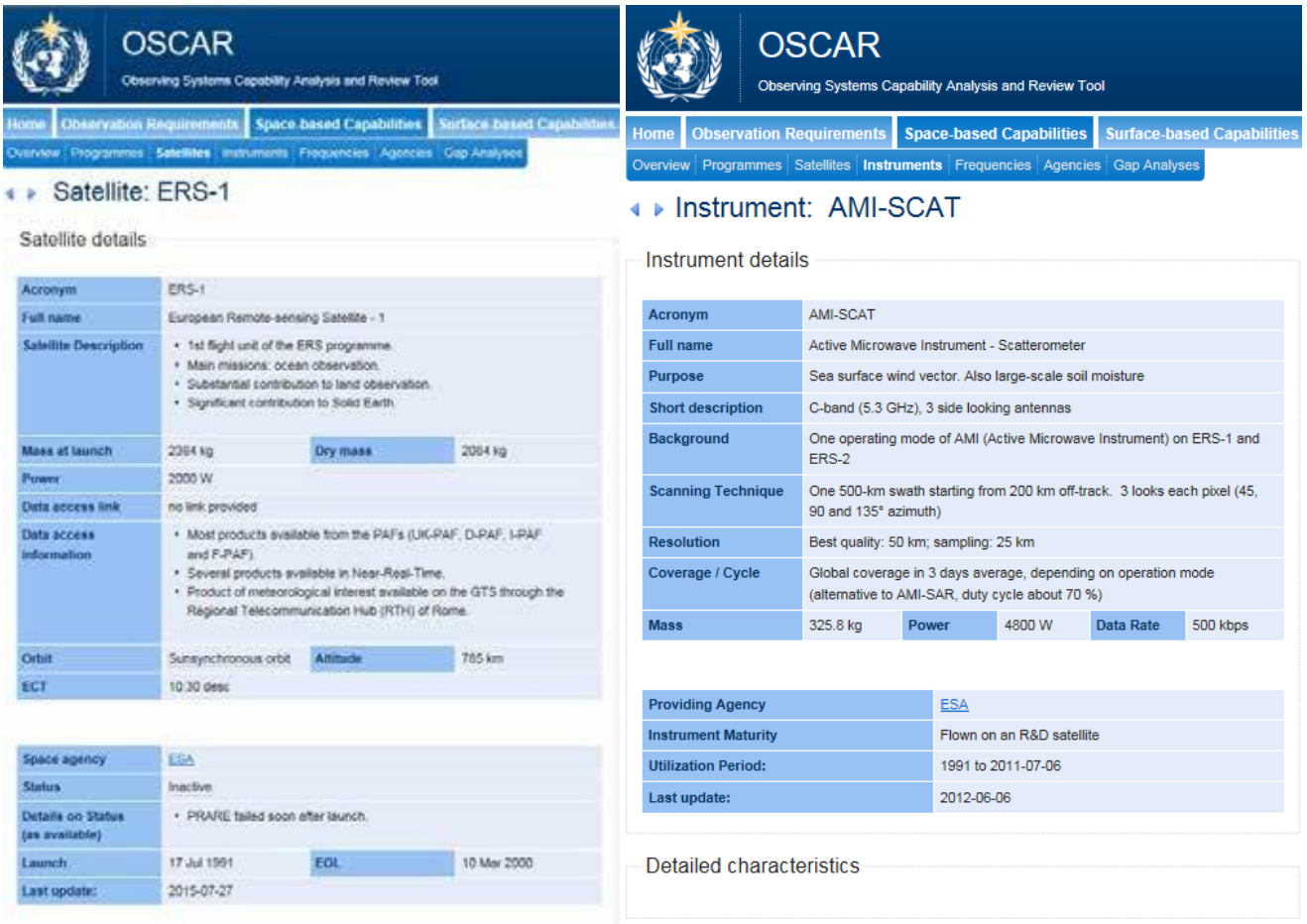

Figure 3 – ERS-1 satellite (left) and scatterometer (right) in the WMO OSCAR data base.

Requirements for and capabilities of past missions and instruments are listed in the WMO OSCAR data base, which serves several EO climate applications (https://www.wmo-sat.info/oscar/). The representation of the ERS scatterometers may be improved. First of all, in the ERS mission description there is a tab for a "Data access link", which is not provided. We suggest that the ESA Earth Online link, https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers, may be provided.

On a next level, OSCAR presents AMI-SCAT, but no link to its detailed characteristics is provided, which appears also as a missed opportunity. Since, OSCAR lists capabilities, a natural link may be https://earth.esa.int/web/sppa/mission-performance/esa-missions/ers-2/scatterometer/sensor-description, but while this page does list some, but not all available ERS CDR products.

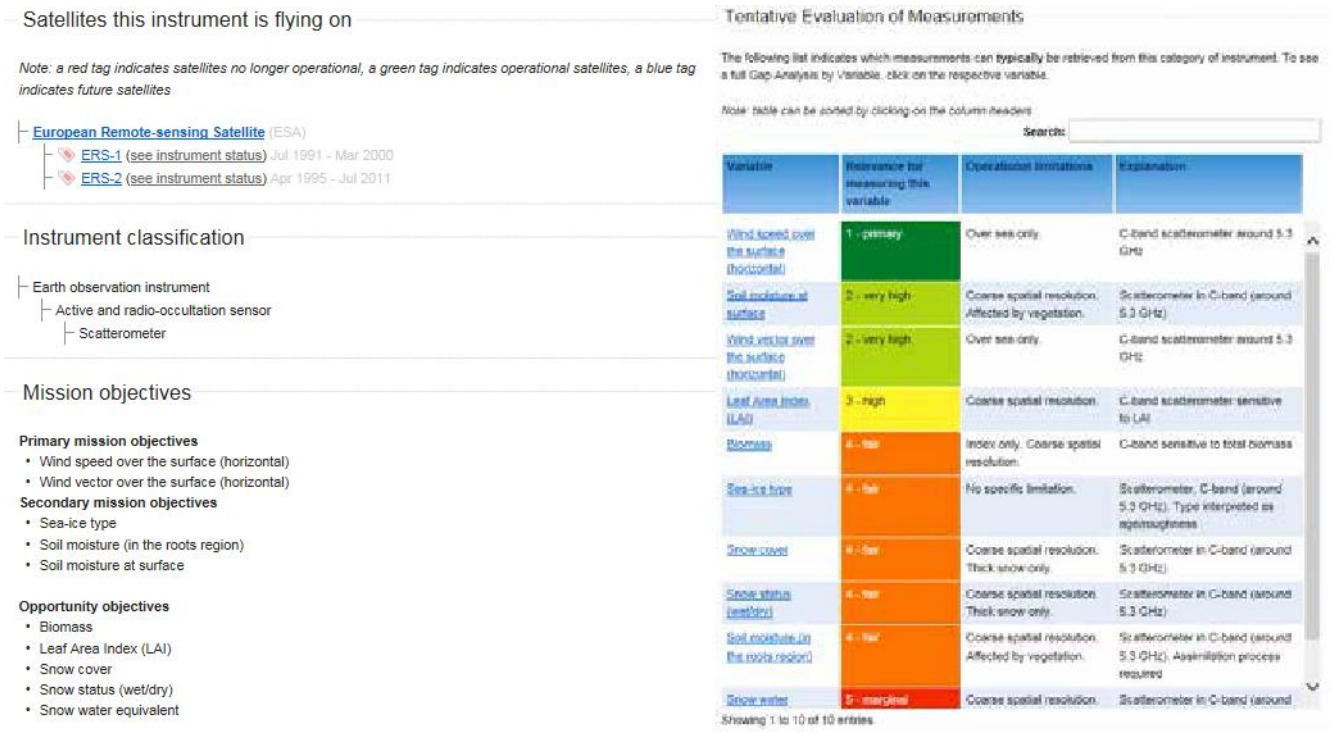

Figure 4 – ERS scatterometer mission objectives (left) and measurement evaluation (right) in OSCAR.

OSCAR lists the mission objectives of an active scatterometer instrument class, as depicted in figure 4, by listing the primary, secondary and opportunity variables that may be measured. This is followed by an evaluation of such measurements in 5 subjective classes. These assessments can be tracked down to a personal level, such that suggestions for improvement can be handled formally by an expert group in a rolling review cycle. Further links allow gap analyses by variable over the years, both in the past and future, by comparing capabilities and requirements, which are both provided in the data base.

The OSCAR variable "sea ice cover" defined as "the fraction of an ocean area where ice is present" has not been activated for scatterometers, whereas all scatterometers are well capable of detection of sea ice edge and cover. Suggestions and omissions should be reported to the WMO Space Programme Office sat-help-desk@wmo.int.

4.1 Visibility and outreach

Users interested in the ERS FCDRs will be mostly producers of L2 geophysical products, which operate in a known circle and are relatively easy to inform of new versions of the product.

However, L2 CDR producers have a limited number (< 100) of registered or known users of these products and guide downstream producers of L3 and L4 products, as for example by the EUMETSAT OSI SAF. Unlike for CDRs, timely L2 products are very popular in real-time applications.

Several portals host L3 and L4 scatterometer products, such as CMEMS and JPL PODAAC, which, indeed are very popular for hydrological, oceanographic, climate monitoring and climate research applications. Scatterometer-only high-quality L3 products are made separately for ascending and descending orbits due to the substantial diurnal cycle over the ocean and land surfaces and for the ERS scatterometer may only be produced on a monthly basis, due to the relatively poor spatial sampling. Despite their popularity, a main R&D task for ocean vector winds and surface stresses remains to provide high-quality L4 products with sufficient time and space resolution by blending scatterometer and reanalyses winds, stresses, or their derivatives, curl and divergence.

In terms of outreach, the goal of the Product Access Guide (PAG) maintained by WMO is to facilitate access to satellite-based geophysical datasets ("level 2" products or higher) for users, and to provide guidance on these products where possible. This is achieved by linking to quality-controlled product collections made available online by data providers. Information on theme-specific international expert groups and training material is also provided, see figure 5. The PAG is simple and distinct from comprehensive data portals such as the GEO portal, the INSPIRE-GEO portal, or the WIS portals. One key target audience are less-experienced satellite data users, in particular from developing countries.

Figure 5 – WMO scatterometer wind access guide (RD-5).

5. Conclusion and recommendations

The document provides a summary of the major outputs/findings of the SCIRoCCo project contributing to the GCOS.

The continuing importance of long-term climate datasets for climate variability and trend analysis and product inter-comparison is stressed by the GFCS. C-band ERS scatterometer data are at the start of a long record of global geophysical products from 1991 to today through the NASA Ku-band QuikScat scatterometer mission from 1999 to 2009 and the EUMETSAT MetOp C-band ASCAT scatterometer missions from 2007 onwards. For the production of a seamless ECV's it is crucial that the geophysical backscatter observations of the C-band scatterometers are inter-calibrated in a so-called Fundamental Climate Data Record. Standard (Level 2 and higher level) processors for applicable geophysical wind, soil moisture or sea ice products would then be able to provide a stable and truthful record of the changing climate over several instruments.

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2) This may be done through the provision of digital object identifiers (DOI), which are associated with a so-called landing page; the landing page is maintained and provides references to the necessary documentation and metadata; multiple portals could host a FCDR, but they all would point to the unique DOI, such that the accessibility to each FCDR may be easily checked by specifying the DOI in an internet search engine, as well as its authenticity and responsibility;

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The SCIRoCCo project elaborated the NetCDF definitions resulting community suggestions which will be provided to the NetCDF board for endorsement, and may imply further evolution of these definitions and therefore adaptation of the FCDR and ECV data on the longer term. This would require some resources.

On a higher level, it was noted in the SCIRoCCo project that agencies who fund the production of CDRs should invest in the development of data and metadata standards. The SCIRoCCo project thus encourages ESA to take a role in EO NetCDF coordination (as well as EUMETSAT and CMEMS).