

	<h1>ERS Scatterometer Evolution Report</h1>	Ref:	SCI-RPT-15-0001
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		Date:	14/03/2017
		Proj:	SCIRoCCo Scatterometer Instrument Competence Centre

Prepared by:
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Change register

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2.0	04/11/2016	Revision by RMA	Executive Summary
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3.0	21/12/2016	Major rewriting for Final Review Meeting (MBR coordinating)	All Sections
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Document Approval

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1. Introduction

1.1 Scope

This document provides the recommendations issued by SCIRoCCo, the Scatterometer Instrument Competence Centre, established by ESA in 2014, for the exploitation and valorisation of ESA’s legacy ERS-1 and ERS-2 scatterometer (hereafter ESCAT) data. It indicates the developments needed to bring ESCAT products to the level of ASCAT and SCA.

The main results from the project are listed and discussed, to support the recommended evolutions for ESCAT.

An Executive Summary is provided as a separate chapter.

1.2 SCIRoCCo and the ERS Scatterometer. Data and applications.

The ESCAT Fundamental Climate Data Records (FCDR) and Thematic Climate Data Records (TCDR) are a major component of an over 40 years long dataset from C-band scatterometers, resulting from the ERS legacy and from ESCAT’s successors, i.e., the Advanced SCATterometer (ASCAT) flying on the Metop satellites of the EUMETSAT Polar System (EPS), and the EPS Second Generation Scatterometer (Eps-SG SCA), now being build. SCA is keeping the ESCAT C-band static fan-beam concept and extends the C-band measurements into the polarimetric domain.

ESCAT thus forms the start of a unique, long and stable instrumental record, providing Essential Climate Variables (ECV) over the ocean, land and cryospheric domains [RD-12].

SCIRoCCo has brought together experts in the field of microwave with the objective of exploiting and re-investigating the capabilities of ERS ESCAT data. New insights into the ESCAT data archive were elaborated with respect to data quality and calibration, highlighting the importance of an “active” preservation of this heritage EO data archive.

Ocean Winds and Soil Moisture products have been thoroughly investigated, to identify shortcomings, make upgrades to the current processing, generate new products, and propose new activities to improve exploitation of ERS legacy data.

1.2.1 Ocean Winds

Scatterometers measure the radar backscatter from wind generated cm-size gravity-capillary waves and provide high-resolution global vector wind fields over the oceans (OVWs). Accurate knowledge of surface winds is important to obtain a precise description of the surface fluxes and the initial state used by numerical weather-prediction models, ocean circulation models, storm surge and surface wave models. All-weather scatterometer observations have proven

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relevant for the forecasting of dynamical and severe weather events, such as polar front disturbances and tropical or extra-tropical cyclones. They have been assimilated into meteorological models like that of ECMWF and used for now-casting applications like storm warning. Scatterometer winds have also proved relevant in driving ocean circulation models, as well as for climate studies that focus on the role of wind forcing in ocean-atmosphere interaction phenomena, such as El Nino-Southern Oscillation (ENSO), the modelling of the Antarctic circumpolar current, or the global variability in storm occurrence. A continuous OVW time series of high temporal and spatial resolution will provide much needed help in understanding the inter-annual variability of these phenomena. Finally, scatterometer winds contribute to the creation and validation of a suite of wind resource maps destined to civil protection and the design of offshore wind energy farms. Note that although higher resolution satellite products (such as from SAR) are used to verify local flow conditions for this kind of application, they lack the accurate calibration, temporal coverage and reliable wind direction information of wind scatterometers.

1.2.2 Soil Moisture

The main users of the ESCAT soil moisture products are research organizations. Besides, higher or secondary education institutions, the public body, non-profit organizations and private companies are users of the products, resulting in a large number of applications in various fields. The fields of application include: runoff forecasting, numerical weather prediction, landslide monitoring, vegetation monitoring, agricultural monitoring, rainfall estimation, epidemiological prediction, greenhouse gas (GHG) budget, climate studies, ground water hydrology, flood monitoring, fire monitoring, forestry applications, drought monitoring, carbon cycle modelling, etc. Different users with different application targets require soil moisture products in different data formats and spatial resolutions. SCIRoCCo has provided such products.

1.3 Document Structure

Chapter 1 provides an Introduction to the ERS Scatterometer data

Chapter 2 provides the Executive Summary.

Chapter 3 provide a summary of the results from the project.

Chapter 4 provides an analysis of the status of the Scatterometer products, identifying needs coming from the User's communities involved.

Chapter 5 provides the Recommendations from SCIRoCCo for the continuing exploitation of the ERS dataset. .

Chapter 6 provides the conclusions.

Chapter 7 provides a list of the main references in the field of Scatterometry.

1.4 Applicable and Reference Documents

Applicable Documents

ID	Reference
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ID	Reference
AD-1	

Reference Documents	
ID	Reference
RD-1	Belmonte Rivas, M., Stoffelen, A., Verspeek, J., Verhoef, A., Neyt, X., Anderson, C., “Cone metrics: a new tool for the inter-calibration of scatterometer records”, IEEE JSTARS Special Issue on Advances in Scatterometry, doi: 19.1109/JSTARS.2017.2647842, 2017 (Also known as SCI-TNO-16-0040-v01)
RD-2	Belmonte Rivas, M., “Temporal stability of the linear and non-linear corrections to ERS ESCAT data from Cone Metrics”, SCI-TNO-16-0053-v01, 2016.
RD-3	Reimer C., “Soil Moisture Re-Processing Plan”, SCI-PLA-15-0018-v01
RD-4	Reimer C., “Soil Moisture Product Verification Report”, SCI-RPT-16-0046-v01
RD-5	Reimer C., “ERS-2 mid Beam nonlinearity”, SCI-TN-14-0001-v-01
RD-6	Ko D., “Scirocco Master's Report”,SCI-RPT-16-0052-v01
RD-7	Fascetti F., “Scirocco Master's Report”,SCI-RPT-16-0049-v01
RD-8	Rossicone I., “Scirocco Master's Report”,SCI-RPT-16-0050-v01
RD-9	Messner R., “Scirocco Master's Report”,SCI-RPT-16-0051-v01
RD-10	Reimer, C., 2014. Calibration of space-borne Scatterometers: Towards a consistent climate data record for Soil Moisture Retrieval (Master Thesis). Vienna University of Technology, Vienna.
RD-11	Anderson, C., Bonekamp, H., Duff, C., Figa-Saldana, J., Wilson, J. J. W., 2012b, Analysis of ASCAT Ocean Backscatter Measurement Noise, IEEE Transactions on Geoscience and Remote Sensing 50(7), 2449 - 2457
RD-12	Bojinski, S., M. Verstraete, T. Peterson, C. Richter, A. Simmons, and M. Zemp, 2014: The Concept of Essential Climate Variables in Support of Climate Research, Applications, and Policy. Bull. Amer. Meteor. Soc., 95, 1431–1443, doi: 10.1175/BAMS-D-13-00047.1.

Acronyms	
Acronym	Expansion
ASCAT	Advanced Scatterometer
ASPS	Advanced Scatterometer Processing System
AWDP	ASCAT Wind Data Processor (EUMETSAT)
CDR	Climate Data Record
ECMWF	European Center Medium-range Weather Forecast Center



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Acronym	Expansion
ECV	Essential Climate Variable
EPS	EUMETSAT Polar System
ERS	European Remote Sensing satellite
ESCAT	ERS Scatterometer
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record: Single sensor type re-calibrated and inter-satellite calibrated Level 1 data
GCOS	Global Climate Observing System
GMF	Geophysical Model Function
KNMI	Koninklijke Nederlands Meteorologisch Instituut
LRDPF	Low bit Rate Data Processing Facility
Metop	Meteorological Operational Platform (EUMETSAT)
NASA	National Aeronautics and Space Administration (USA)
NWP	Numerical Weather Prediction
NOC	NWP ocean calibration
OVW	Ocean Vector Wind
TCDR	Thematic Climate Data Record: Geophysical variables associated with GCOS ECV based on FCDRs
WCRP	World Climate Research Programme
WVC	Wind Vector Cell

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2. Executive Summary

2.1 The C-band Scatterometer Climate Data Record (FCDR/TDCR)

The European Remote Sensing satellites, ERS-1 and ERS-2 have provided one of the longest continuous datasets available today, spanning the two decades from 1991 to 2011. Level 1 (calibrated sensing data) backscatter observations from the on-board Scatterometer (hereafter ESCAT) constitute a so-called Fundamental Climate Data Record (FCDR). The Level 1 products support the production of Level 2 products, also called Thematic Climate Data Records (TCDR) of Essential Climate Variables (ECV), such as ocean vector winds (OVW), soil moisture and sea ice extents. Stable, accurate, global, consistent and long-term instrumental FCDRs are crucial to verify trends, variability and biases in climate reanalyses and climate model runs [RD-12].

SCIRoCCo has demonstrated that C-band scatterometers do contribute to the above mentioned FCDRs for the benefit of a broad user community in the meteorological, oceanographic, hydrological and cryospheric domains. Inter alia, wind energy resource, drought, sea ice drift, coverage and type, ocean circulation, wave climate and storm surge assessments, would all much benefit from a high-quality C-band FCDR.

ESCAT is at the origin of a continuous C-Band backscatter data record running through today and continued into the next decades through the EUMETSAT Metop C-band ASCAT and SCA missions, from 2007 onwards. ESCAT thus forms the start of a unique, long and stable instrumental record, providing Essential Climate Variables (ECV) for ocean winds, soil moisture and sea ice [RD-12]. The ASCAT and SCA missions assure the continuous improvement of the services provided, based on evolving user requirements and priorities. For an optimal exploitation and valorisation of ESCAT, developments are deemed necessary, as summarized in the table below, to bring ESCAT products at the same level as ASCAT and SCA.

These developments are discussed in the sections below, where we also address the user requirement for seamless C- and Ku-band scatterometer CDRs, the development of scatterometer data user platforms and a continued system of grants for students to familiarise themselves with the scatterometer data, following the success of SCIRoCCo.

ESA has reprocessed all ERS-2 Scatterometer data and is now reprocessing ERS-1 data. In terms of the above-noted evolving requirements, it is important that these reprocessing campaigns are maintained, in order to keep the available dataset in line with the ongoing improvements in instrument calibration and retrieval algorithms.

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	ESCAT	ASCAT	SCA
FCDR			
Instrument knowledge	Non-linearity issue, seen in Instrument and Processors		
Stability of Instrument Calibration	Still unavailable, in Regional Mission Scenario(2003-2011)		
Coastal processing	Not yet available.		
TCDR/ECV			
Full Product range: Ocean Vector Winds, Soil Moisture, Sea-Ice extents etc...	Only main products available. These ECV's support Climate Change research.		

Table 1 Continuity of ESCAT with ASCAT and SCA. C-band Climate Data Records

2.2 Improving FCDR (L1 products) for C-Band Scatterometers

2.2.1 Improving ESCAT instrument knowledge

SCIRoCCo revealed inconsistencies between the ASCAT and ESCAT calibrations by comparing the distribution of backscatter measurements over the ocean through a novel method called Cone Metrics. Particularly ERS-2 showed non-linear calibration features that are not understood in terms of instrument parameters. Further work is needed to identify the anomalous instrument characteristics that cause non-linearity (and that seem likely related to the noise-floor subtraction scheme) in the ESCAT backscatter data to enhance confidence in the ESCAT FCDR. Tracing the root cause of the non-linearities back to specific ERS instrument and/or ASPs L1B processor settings need to be performed to assess whether the non-linearity can be understood and solved at the L1 processing level, or whether ad-hoc corrections remain needed as a L1 post-processing step. The former increases the confidence in the ESCAT FCDR.

2.2.2 FCDR stability: Improving the Calibration Model

SCIRoCCo has proven that a seamless transition from ERS-1 to ERS-2 ESCAT and from ESCAT to ASCAT ocean backscatter distributions requires new (non-linear) corrections be applied to calibration, producing more accurate Level-1 products. The non-linear ERS-2 corrections clearly improve the ESCAT winds.

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Improving calibration model and understanding the sources of the residual diurnal and seasonal variability seen both in the ERS and ASCAT linear biases will be needed to derive a calibration model for existing as well as future scatterometers; Instrument artifacts, such as antenna flexing due to temperature gradients, may produce the small seasonal and diurnal cycle seen in the linear corrections. Geophysical seasonal or diurnal changes, such as in wind variability may also contribute to this. A novel approach (Cone Metrics) can be applied to analysing residual diurnal and seasonal biases as a function of latitude and solar angle, so that instrumental and atmospheric effects may be separated and their effects clarified;

The regional mission of ERS-2 (2003-2011) has not been evaluated yet and, due to the rather biased geographical sampling, sampling tests on the global mission need to be performed in order to interpret the Cone Metrics of the regional mission, such that a regional FCDR is obtained.

2.2.3 Coastal processing for ESCAT. FCDR

The original data processors were not developed for analysing interface areas such as sea-land (coasts) or peculiar areas such as cities or lakes. These areas are now attracting much attention due to their importance in the analysis of coastal flooding forecast, storm surge prediction, wind farms siting, fish catch enhancement, etc. This leads to the development and implementation of ASCAT “coastal” products, having a reduced spatial filtering extent, thus able to provide wind information closer to the coast and with a higher spatial resolution due to the reduced spatial filtering. As these products are heavily used, the development of an ESCAT coastal FCDR product is recommended, including an accurate assessment of the fraction of the WVC that is covered by land, to aid more advanced wind and land processing near water boundaries leading to the applications described above.

In addition, the usability of the developed calibration tools (and in particular Cone Metrics) for those coastal products needs to be assessed.

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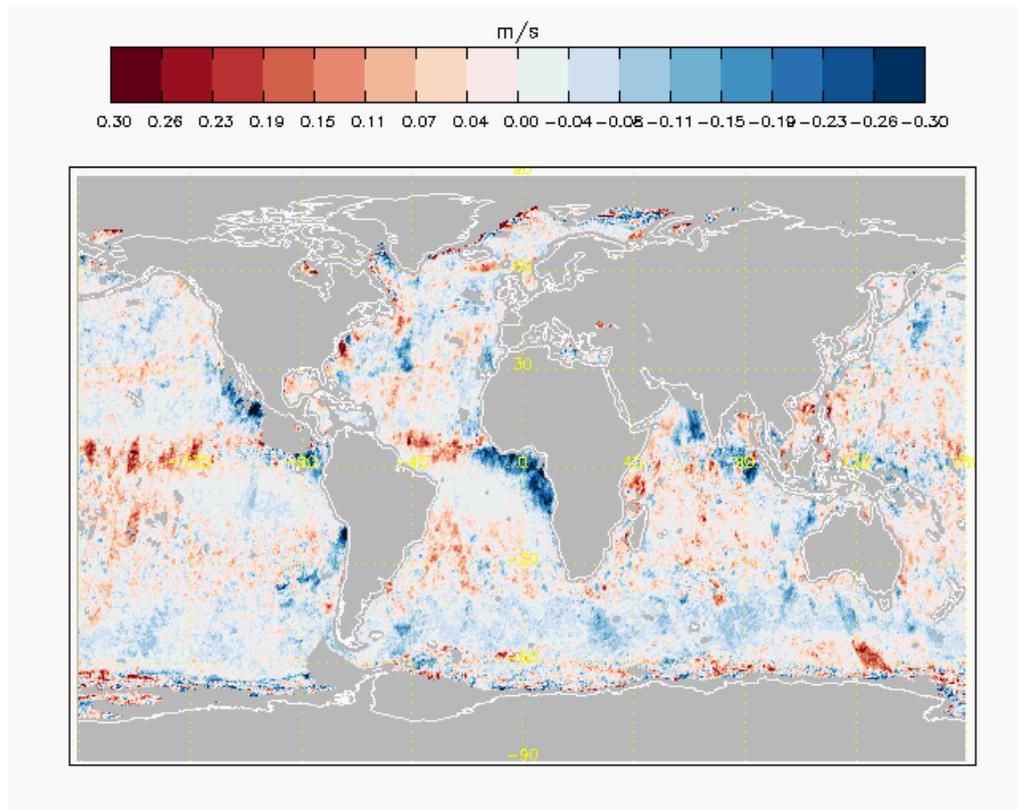


Figure 2.5-1: Impact of ERS backscatter non-linearity on mean annual ocean wind speeds (ERS-2 for year 1997): regional biases exceed the GCOS stated accuracy requirement of 0.1 m/s for the provision of ocean surface winds (WMO, 2011).

2.3 Creating full TCDR/ECV for Climate Research

The availability of improved C-band scatterometer FCDR, as discussed above, will provide a unique opportunity to create geophysical ECVs to support climate change research. Inter-calibrated ESCAT and ASCAT observations can be used together as an input to a single soil moisture, wind and sea ice processor for computing consistent retrievals. Achieving this goal is feasible and requires investigating the effects of overlapping missions on the estimation of processing model parameters and consequently on the final geophysical retrievals.

In SCIRoCCo, the goal of a consistent ASCAT and ERS backscatter dataset has been achieved by mapping the backscatter distributions onto each other [RD-1], which is something that had been long overdue.

Following this major step forward, the Consortium makes the following recommendations for the evolution of geophysical retrievals to support climate change research:

2.3.1 Creating a C-band Sea-Ice data record

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The latest improvements in sea ice detection for ERS, developed within SCIRoCCo, make the generation of a consistent long-term record of sea ice extent and sea ice age (i.e. sea ice type classification) for ERS, Quikscat and ASCAT possible, and the first of its kind. For a continuous and seamless record of sea ice properties from scatterometer data dating from 1991 to present date, additional effort would be necessary to understand the changing signatures of sea ice age at C-band and Ku-band, as the underlying backscatter mechanisms differ;

2.3.2 Geophysical Model Functions: Improving ocean wind retrievals

The mismatch between the geophysical model function (GMF) used for wind retrieval and the backscatter distributions observed for ERS and ASCAT suggests novel means towards improving the GMF, e.g., by ingesting corrections into the ocean backscatter model as a function of wind speed and direction. A reprocessing of ocean winds (at L2 level) should test the effects of the improved GMF on wind retrieval statistics and quality scores for ERS and ASCAT;

2.3.3 Local Wind variability characterization

Characterize the local wind variability [RD-11] is required in order to improve the geophysical retrievals (extraction of wind speed). Analyse consistency of error estimates between different C-band scatterometers is also essential.

2.3.4 Validation of non-linear corrections on geophysical retrievals

The effects of non-linear corrections on geophysical retrievals (Figure 2.5-1) for winds and soil moisture, shall be validated and then tested over sea ice, using the latest ocean wind, soil moisture and sea ice processors which are publicly available and valid for ASCAT and ERS. This will confirm whether no other artefacts are introduced. A review of the TU Wien inter-calibration methodology [RD-10] is recommended to support the radiometric alignment of ESCAT and ASCAT backscatter by Cone Metrics.

2.3.5 Validation of the new TCDR's

Standard validation of the L2 product consistency needs to be performed, to assess the effects of resolution enhancement, coastal processing and regional calibration scenarios, including error analysis, after the coastal FCDR and the regional FCDR enhancements to L1 products have been applied.

2.3.6 Extend Copernicus Service to ERS

For ASCAT, climate data records are produced on L3 and L4 in the EU Copernicus Marine Environment Monitoring Service, which should be extended backwards to the ESCAT era.

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2.4 Consistent Ku-band to C-band CDRs

Complementary sources of Ku-band scatterometer data are the NASA QuikScat mission, from 1999 to 2009, the ISRO Oceansat-2 mission from 2009 till 2014, the JPL ISS RapidSCAT mission from 2014 to 2016 and the Chinese HY scatterometer missions. For an optimal exploitation of scatterometer data in the meteorological, oceanographic, hydrological and cryospheric domains by the broad user community, it is crucial that international efforts are concerted and resources spent to achieve consistent FCDRs and TCDRs across all scatterometer instruments, be it at C, Ku or L-band.

2.5 Create and maintain a technical hands-on Forum.

To promote the use of scatterometer data, a forum where young researchers can get help from more experienced researchers and experts is a necessity. Note that the forum would not duplicate what is already performed by the EO Help Desk.

2.6 Outreach and Education: fostering a new generation of Researchers

The SCIRoCCo project has been very successful in attracting students to work on ESCAT processing and interpretation topics. The Consortium regards Outreach and Education activities as an essential contribution to continuing exploitation and improvement of ESA legacy data. The content of the SCIRoCCo website (scirocco.sp.serco.eu) should be integrated, maintained and referenced through the ESA SPPA portal (earth.esa.int/web/sppa). This website should be referenced in the WMO (OSCAR) and CEOS data bases.

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3. Main results from the SCIRoCCo Project

We summarize in the following sections the main results achieved by SCIRoCCo during its two-years of operations, from 2014 to 2016. SCIRoCCo has provided ERS-1/ERS-2 sensor inter-calibration, sensor characterization and data validation.

3.1 Intercalibrating ERS and ASCAT Missions. Linear and non-linear analysis.

ERS-1 and ERS-2 scatterometer instruments were originally calibrated using transponders, but the quality and coverage of their measurements has been limited. Therefore, the newly reprocessed ERS-2 (ASPS) dataset has been calibrated assuming an isotropic gamma0 over the rainforest. This does not guarantee inter-calibration of the two instruments and in practice differences that are now regarded as non-negligible are found between the available datasets.

Inter-calibration of scatterometers is not trivial, as instrumental calibration by transponders and other vicarious calibration techniques, such as rain forest or Numerical Weather Prediction (NWP) Ocean Calibration (NOC), have proven limited though sufficient to allow accurate wind and sea ice retrievals.

SCIRoCCo has thus addressed this fundamental issue of inter-calibration and inter-comparison between heterogeneous datasets, focusing on ERS-1, ERS-2 and ASCAT. Main output from SCIRoCCo in these areas is:

- New calibration coefficients have been computed, optimizing inter-calibration between ERS-1 and ERS-2 scatterometer instruments. These Coefficients have been delivered to ESA, which is using them in the reprocessing of ERS-1 data.
- Inter-calibration of the ERS and ASCAT measurements has been performed with a novel inter-comparison approach developed within the SCIRoCCo project, the so-called Cone Metric analysis, to assess the non-linearity and long-term stability of the backscatter record. The new analysis has highlighted some further improvements on inter-calibration between the two sensors.

The newly developed level 1 backscatter FCDR with Cone Metrics corrections produce more consistent and standardized geophysical products, as demonstrated for winds processed with the ASCAT Wind Data Processor (AWDP) [OSI SAF, 2017].

A detailed report describing Cone Metrics Analysis has been delivered to ESA and is available as a Technical Report from the SCIRoCCo web portal.

3.2 New Soil Moisture retrievals from ERS

Within the framework of the SCIRoCCo project, ESCAT soil moisture retrievals were revitalised by making use of a re-processed Level 1 backscatter data archive and state of the art soil moisture processors. With the launch of Metop-

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A (ASCAT) in 2007, retrievals from ESCAT had been discontinued. The new products, available from TU Wien's archives, and SCIRoCCo ftp server (scirocco.sp.serco.eu) benefit from the following major improvements:

- Algorithmic updates incorporated specifically for the retrieval of soil moisture from ASCAT have been adopted in the processing software to be applicable for ERS ESCAT retrievals. With respect to these updates, a number of ESCAT soil moisture products with different spatial resolutions and in diverse data formats were generated to satisfy the needs of the user community in this historical data archive. Furthermore, these products are the first consolidated release of ERS ESCAT soil moisture retrievals deduced from a consistent and harmonised set of Level 1 input data with respect to all known major mission events.
- All generated products have been complemented by up-to-date documentation with the objective of closing the gap of information between ERS ESCAT and Metop ASCAT products. Documentation is available through the SCIRoCCo website: scirocco.sp.serco.eu

Table 2 Soil moisture data available from the SCIRoCCo ftp server

Dataset	ftp scirocco.sp.serco.eu/scirocco_team	Description
Soil Moisture orbits (HR)	ERS-soil-moisture-orbits/high_resolution	ERS soil moisture orbit at high resolution
Soil Moisture orbits (NR)	ERS-soil-moisture-orbits/nominal_resolution	ERS soil moisture orbits at nominal resolution
Soil Moisture time series (HR)	ERS-soil-moisture-time-series/high_resolution	ERS soil moisture time series at high resolution
Soil Moisture time series(NR)	sERS-soil-moisture-time-series/nominal_resolution	ERS soil moisture time series at nominal resolution

3.1 ERS ASPS products in NetCDF format

SCIRoCCo has generated NetCDF ASPS data. ERS-2 L1/L2 scatterometer data has been available until about 2001 in the UWI format (and L2 BUFR format). Reprocessed ERS-2 L1/L2 scatterometer data is now available from ESA in the ASPS format. The general trend in the scientific community is to the use of generic data formats. More specifically, the consensus seems to go towards NetCDF owing to its self-describing structure. As an example, EUMETSAT is distributing most Level 1 and Level 2 Metop products in that format.

NetCDF data have been delivered to ESA and are available through ESA's usual distribution channels.

The ASPS to NetCDF converter software is also available through ESA and may also be run on ESA's cloud computing platform GPOD upon registration to the service.

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3.2 New Geophysical products

The newly generated wind, sea ice and soil moisture time-series products are expected to provide major inputs for climate change studies and other related research activities. The ESCAT orbit products fulfil the requirements of the climate community supporting meteorological re-analysis activities.

3.3 Standardization of NetCDF format for Scatterometer products

SCIRoCCo has elaborated NetCDF definitions 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. The Technical Note has been made available to ESA and is also available through the SCIRoCCo's website.

3.4 Harmonization of Scat resources. GCOS, WMO and other entities.

A point of concern for the exploitation of ERS Scatterometer data is the general lack of visibility and provision of information. Resources provided by bodies such as WMO OSCAR fail to provide links to satellite and scatterometer instrument specifications. SCIRoCCo has analysed these issues and produced a Technical Note for ESA with recommendations on liaising with international organizations providing global climate data.

3.5 Outreach: The SCIRoCCo Web Portal

A web portal, currently hosted at: scirocco.sp.serco.eu provides documentation, data analysis and processing software, academic and technical publications in support of calibration and many diverse applications and research in Land (e.g. Soil Moisture), Oceanography (Ocean Winds, Sea, Ice), Climatology to Users.

A Handbook on Scatterometry, has been published on the web portal, providing in a single publication, a knowledge base on Scatterometry data processing, focused on its major applications over Land and Ocean. It describes ERS Scatterometer Processing, explaining in full details the processing from instrument measurement to Level-1 products, and all issues related with instrument calibration and cross-calibration. References to the relevant literature are provided, guiding the User to through the wealth of information available on-line and in the scientific literature.

SCIRoCCo-funded Grants on calibration, L1 processing, soil moisture, ocean winds, and sea ice have been conducted at the partnering institutions (KNMI, TUW and RMA). The capabilities of the ERS ESCAT missions and their data archives was promoted towards young scientist through knowledge transfer by dedicated online lectures, how-to tutorials and four hosted student grants.

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4. Status of Scat products: an analysis from SCIRoCCo.

4.1 Issues with the available data/processors

The Global Climate Observing System (GCOS) program defines guidelines for the provision of satellite-based essential climate variables (ECVs), prescribing a stability requirement of 0.1 m/s per decade for the provision of ocean surface winds (WMO, 2011), which roughly translates into a relative beam stability of 0.1 dB for C-band backscatter. Historically, the stability of scatterometer data has relied on vicarious calibration techniques that depend on external references, such as backscatter from the rain forest, ground transponder data, or the ocean winds from a NWP model (for NWP Ocean Calibration, NOC). The accuracy of these methods, which is limited by the intrinsic variability of the reference used, is estimated to be about 0.1-0.2 dB, which is only marginally acceptable under the GCOS guidelines. It is also important to note that all of these calibration methods operate under the assumption of a linear calibration bias.

Using Ocean Calibration, it has been known that the original LRDPF backscatter is subject to a number of sudden calibration jumps, the most notable of which are a decrease of about 0.1 dB in the fore beam of ERS-1 on January 1994, and a decrease of about 0.2 dB in all beams of ERS-2 between 4 August 1997 and 18 June 1997 linked to a switch in the scatterometer calibration subsystem. These calibration anomalies are corrected at L2 level in the reprocessed KNMI wind record using ad-hoc linear calibration tables. Separate analyses have also indicated the presence of non-linear calibration biases in the ERS record: for low backscatter, the ERS-1 and ERS-2 backscatter distributions differ, while differences of up to several dBs with ASCAT have also been noted (Anderson et al., 2012a). Beam calibration non-linearities, which cannot be handled by any of the existing calibration techniques, result in irreversible non-linear wind retrieval biases and thus require the development of specialized inter-calibration approaches.

4.1.1 The SCIRoCCo Approach

As a short term solution and despite the nonlinear concerns discussed above, an improved alignment of ERS-1 and ERS-2 data was thought important, considering that the ERS-2 scatterometer data was already reprocessed. It was proposed to consider calibration coefficients (antenna patterns) for ERS-1 such that a better alignment with ERS-2 would result. In practice, the calibration coefficients are computed such that the responses over the rainforest measured by the two instruments during the same cycle are the same.

As a longer term solution, a novel inter-calibration approach termed Cone Metrics has been developed within the SCIRoCCo project to assess the non-linearity and long-term stability of the ERS backscatter record [RD-1]. The new approach is capable of measuring linear and non-linear calibration biases by monitoring changes in the location and shape of the backscatter distributions collected by one instrument (ESCAT in ERS-1 or ERS-2) with respect to those collected by a another instrument that serves as reference, which is taken to be ASCAT due to its superior stability and absolute calibration from transponder data. The application of Cone Metrics, whose estimated accuracy is estimated to be on the order to 0.02 dB, demonstrates that the ERS scatterometer design and operation has been

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prone to systematic small linear and non-linear calibration biases that affect the ECV CDRs and must therefore be addressed in any attempts towards the homogenization of the C-band ERS and ASCAT backscatter records.

4.1.2 New data/analysis from SCIRoCCo

For a better alignment between ERS-1 and ERS-2, calibration coefficients based on the rain-forest response have been delivered, allowing to start the reprocessing of ERS-1 data. In parallel, the application of the Cone Metrics inter-calibration approach has produced a number of interesting results conveniently summarized here as:

- 1) Cone Metrics has measured and characterized the non-linear biases that affect the original LRDPF backscatter record, which reach up to 0.2 dB at moderate to high winds, typically increasing with incidence angle and largest (up to several dBs) at low backscatter levels. Non-linearity is significantly larger for ERS-2 than for ERS-1;
- 2) For ERS-1, the non-linearity is removed after introducing backscatter-dependent corrections in the beams. The beam and WVC-dependent non-linear correction curves for ERS-1 are consistent with and indicative of an issue with noise-floor subtraction;
- 3) For ERS-2, the non-linearity is removed after introducing WVC and backscatter-dependent corrections in the beams. The non-linear correction curves are slightly different than for ERS-1, indicating that aside from problems with noise-floor subtraction, other issues may linger of yet unspecified origin;
- 4) Cone metrics has characterized the temporal stability of the linear beam biases left over after non-linear correction of the LRDPF backscatter record. Linear beam biases appear in connection with sudden instrumental anomalies, but also show distinct seasonal and diurnal variabilities of about 0.06 dB, whose root causes (be it atmospheric effects or thermo-elastic flexing of the beams) has not been determined at this point;
- 5) Cone Metrics has characterized the differences between the ocean backscatter distributions observed by the reference instrument, ASCAT, and the geophysical model function (GMF) used for wind retrieval, suggesting novel means towards improving the GMF beyond the latest CMOD7 release;
- 6) Cone Metrics has determined the relation between the original LRDPF and the new ASPS backscatter records. Both records are affected by the same amount of non-linearity relative to ASCAT, but slightly different linear biases arise after a small antenna pattern update and an improved scheme to calculate observation angles in the ASPS data. Regarding temporal stability, the most notable instrumental anomaly in the original (LRDPF) ERS-2 record, a decrease of roughly 0.2 dB measured from August 1996 to July 1997, has been successfully repaired in the newer (ASPS) record, although other smaller anomalies (e.g. November 1998) persist that need attention.

In summary, by monitoring changes in the location and shape of the ocean backscatter distributions, Cone Metrics has established the linear and non-linear corrections necessary to homogenize the ERS and ASCAT backscatter records down to 0.06 dB, a residual figure that is due to diurnal and seasonal variabilities alone and well in compliance

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with the GCOS stability requirement. In order to consolidate and fully understand the ERS backscatter and climate records (for ocean vector winds, sea ice and soil moisture), it would be advisable to trace the root cause of these non-linearities back to specific ESCAT instrument settings. The functional form of non-linear corrections suggest that nonlinearities are likely related to insufficient noise-floor subtraction in the ERS-1 case, while a more complex combination of noise-floor subtraction with other effects is likely to affect ERS-2.

4.2 Soil Moisture

Within the SCIRoCCo project, a set of ESCAT soil moisture products in different formats and spatial resolutions have been produced by TU Wien to serve the needs of the different user groups. The ERS missions are the start of the series of space-borne European C-band scatterometer missions, see Figure 4.2-1, providing valuable information for NWP reanalysis projects and climate change research. The consistency of the ESCAT Level 1 and higher level data set has to be guaranteed as well as the consistency to successor C-band scatterometer missions such as Metop ASCAT and Metop-SG-B SCA.

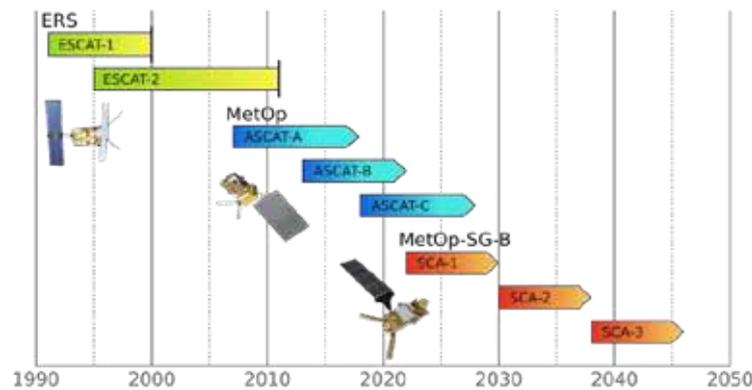


Figure 4.2-1: Overview of European C-band scatterometer missions

European C-band scatterometer missions play a vital role in the generation of a Fundamental Climate Data Record (FCDR), Thematic Climate Data Records (TCDRs) as well as in the creation of Essential Climate Variables (ECVs), comprising a data archive of almost 25 years of continuous global observations starting with the launch of ERS-1 ESCAT in 1991. The SCIRoCCo project was one big step in this direction by reprocessing the Level 1 ERS-2 ESCAT data with an up-to-date scatterometer processing facility (ASPS). Nevertheless, some issues have been identified by the project consortium during the project lifetime which will be addressed in the following.

4.2.1 Issues with available data/processors

A radiometric calibration methodology for European C-band scatterometer missions was developed at TU Wien to monitor the stability of the C-band backscatter measurements in support of land applications and to ensure consistent backscatter observations from scatterometer missions (Reimer, 2014). This intra-calibration of ERS-2 ESCAT ASPS data was performed before carrying out the soil moisture retrieval, revealing several calibration

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anomalies (see Figure 3.5.1-1). One anomaly was detected in 2001/2002 affecting the aft-beam antenna with a deviation of about -0.21 dB from the calibration reference. This anomaly was already reported during the project lifetime. In addition, calibration anomalies in all three antenna beams have been detected during the regional mission scenario (from August 2003 onwards), which highlight the need to investigate this anomaly more in detail.

It should be noted that the ERS-1 ESCAT data archive is a major component of the long-term ESCAT data record (FCDR and TCDR), because it comprises a unique time series of at least 6 years of global observations not covered by any other comparable active microwave instrument. It is recommended to reprocess the entire ERS-1 ESCAT archive with ASPS to derive Level 1 backscatter observations consistent with ERS-2 ESCAT. Especially the ESA funded project ESA CCI Soil Moisture will strongly benefit from this activity by incorporating a consistent ERS-1/2 ESCAT soil moisture data archive for the creation of the corresponding Essential Climate Variable.

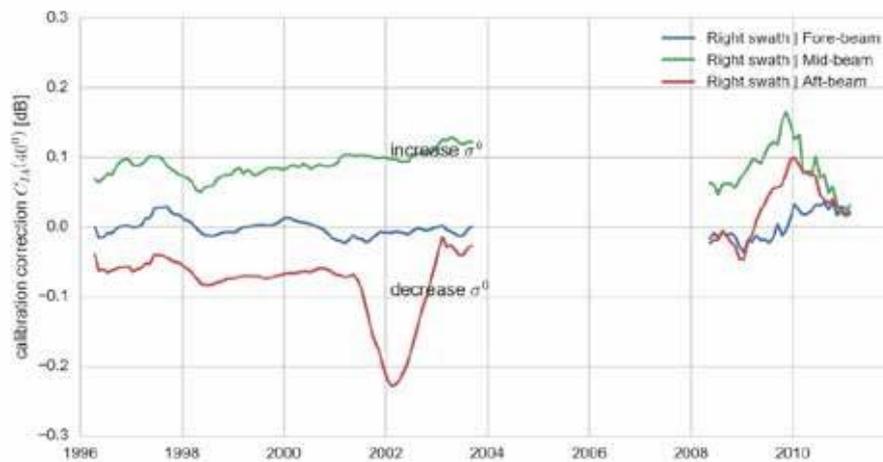


Figure 3.5.1-1: Detected calibration anomalies of ERS-2 ESCAT ASPS nominal/high resolution data.

Non-linearities in ERS-2 ESCAT data had been reported in (Anderson et al., 2012a) and were analysed over land surface within the SCIRoCCo project. The non-linearity of the ERS-2 ESCAT mid-beam antenna was investigated in terms of a comparative analysis with ERS-1 and ERS-2 ESCAT LRDPF data and Metop-A ASCAT data. The analysis verifies the discrepancy between ERS-2 ESCAT and the reference datasets of ERS-1 and Metop-A, suggesting that nonlinearity may not be attributed exclusively to the mid-beam antenna of ERS-2 ESCAT. It was concluded that ERS-2 ESCAT non-linearities may also be related to errors in the fore- and aft-beam antennas of the scatterometer. This was further revealed in the cone metrics approach during SCIRoCCo. Further analysis is recommended to clarify the cause of these non-linearities and to correct for such by adapting the Level 1 processing configuration.

4.2.2 The Scirocco Approach

Within the SCIRoCCo project, the focus has been on the consolidation and revitalisation of the ESCAT soil moisture archive. One of the main objectives was the creation of the most complete and consistent ESCAT soil moisture

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archive re-processed with the latest soil moisture retrieval algorithms. Therefore, reported calibration anomalies have been corrected for using the TU calibration approach (Reimer, 2014) and the radiometric aligned ERS-2 ESCAT Level 1 backscatter archive was used in the final soil moisture retrieval. The provided soil moisture products are complemented by up-to-date documentation about the product generation process, the products themselves and the quality of the products to close the gap of information between the ESCAT research products and the currently operational disseminated products from Metop ASCAT. Moreover, one objective was to revitalise the usage and to advertise the capabilities of ESCAT data for young scientist through knowledge transfer by dedicated online lectures and how-to tutorials.

4.2.3 New data from SCIRoCCo

The latest of ESCAT soil moisture products were released earlier in 2016 using the most recent version of the processing software, referred to as WARP 5.6. These products make exclusive use of the reprocessed backscatter data provided by ESA through the Advanced Scatterometer Processing System (ASPS) (De Chiara et al, 2007). The overall objective of the newly released ESCAT soil moisture data has been the creation of a high quality, long-term consistent ESCAT data record covering the entire ERS-1/2 periods after taking into account all known major mission events. The consolidation of the Level 1 backscatter data from various ground stations during the regional mission scenario by the ASPS processing facility is seen as a big step forward in terms of data quality in comparison to the data of the ESA rolling data archive. Furthermore, the scientific Level 1 backscatter product with enhanced spatial resolution (25 km) satisfies the demand of higher resolution scatterometer products for land and sea ice applications, this in addition to the nominal resolution product (50 km) of ESCAT. The ASPS Level 1 backscatter dataset is the first dataset released by ESA providing backscatter observations during the 2001 and 2003 period, when ESCAT operations were changed to zero-gyro mode and data dissemination was discontinued. The latest ESCAT soil moisture release comprises four products in two spatial resolutions (25 and 50 km) and two data formats (Time series and Orbit products), covering soil moisture observations from March 1996 until the mission end of ERS-2 in July 2011 (see Table 3.5.3-1). These newly released ESCAT soil moisture products address user requirements by providing products at different spatial resolutions and data formats, especially for NWP; note that these products are based on the TU-Wien calibration (Reimer, 2014), and do not include the non-linear corrections of Cone Metrics.

Release Date	WARP Version	Level 1 Input Data	Temporal Coverage	Spatial Coverage
2002	WARP 4.0 (Time Series Product)	ERS-1/2 Wind Fields	1991-2000	Global
2007	WARP 5.0 (Time Series Product)	ERS-1/2 Wind Fields and ERS-2 ESCAT fast delivery UWI	1991-2007	Global, regional from 2003 onwards
2016	WARP 5.6	ERS-1/2 ESCAT ASPS	1996-2011	Global,

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	(Time Series Product)	nominal resolution		regional from 2003 onwards
2016	WARP 5.6 (Time Series Product)	ERS-1/2 ESCAT ASPS high resolution	1996-2011	Global, regional from 2003 onwards
2016	WARP orbit (Orbit Product)	ERS-1/2 ESCAT ASPS nominal resolution	1996-2011	Global, regional from 2003 onwards
2016	WARP orbit (Orbit Product)	ERS-1/2 ESCAT ASPS high resolution	1996-2011	Global, regional from 2003 onwards

Table 3.5.3-3: Overview of ERS ESCAT soil moisture products

4.3 Outreach and Education: The SCIRoCCo web portal

Data analysis and processing software, academic and technical publications in support of calibration and many diverse applications and research in Land (e.g. Soil Moisture), Oceanography (Ocean Winds, Sea, Ice), Climatology have been collected and prepared for being served to Users through a web portal, currently hosted at: scirocco.sp.serco.eu.

With the goal of also help fostering the next-generation scatterometry experts, SCIRoCCo has established an Educational Network through its member institutions (KNMI, RMA, TU Wien, SERCO Europe), where students have been hosted through funded Research programs, working on novel lines of application for Scatterometer data.

4.3.1 Soil Moisture

Educational material about soil moisture has been made available via the SCIRoCCo webpage linked to the corresponding code and data package hosted at <http://esa-scirocco.github.io/SCI-Education/> and can be categorized into “Course Materials” and “Exercises”. Course materials intend to give an overview on soil moisture in general, retrievals from space-borne missions, applications of soil moisture and a detailed description of the TU Wien soil moisture retrieval model. The theoretical course materials are complemented by 6 hands-on exercises (<https://github.com/ESA-SCIRoCCo/sci-sm-tutorials>) with the aim to provide insights into theoretical models related to soil moisture, data handling and visualisation and soil moisture validation. These exercises are written in the open source programming language Python and are available as so called jupyter notebooks enabling interactive learning by doing.

4.3.2 Ocean winds and Sea Ice

A compilation of links providing material from general scatterometry to current weather and climate applications has been made available at <http://scirocco.sp.serco.eu/education/ocean-winds>:

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Scatterometer winds and case studies (EUMETrain video presentations):

- Scatterometer winds (Ad Stoffelen, 2011)
- Assimilation of scatterometer winds (Ad Stoffelen, 2011)
- Satellite Derived Ocean Surface Winds (Josef Sienkiewicz, 2012)
- Measuring Winds from Space – Scatterometers (Ad Stoffelen, 2013)
- Hurricanes over the Atlantic (Mills and Bradley, 2005)
- The Xynthia Storm by ASCAT (Moreira and Lourenco, 2012)

Other resources (COMET/MetEd, site requires registration):

- Introduction to scatterometry (Michael Freilich)
- Advances in Microwave Remote Sensing: Ocean wind speed and direction (Lee and Jelenak)
- Using ASCAT wind and other data in marine forecasting
- Using scatterometer wind and altimeter wave estimates in marine forecasting
- Winds in the marine boundary layer: a forecaster's guide
- Introduction to tropical meteorology
- Tropical cyclone intensity analysis

Applications of Satellite Wind and Wave products for Marine Forecasting:

- EUMETSAT/IODE Training Course

A general lecture on sea ice has also been made available at <http://scirocco.sp.serco.eu/education/sea-ice>:

- Sea ice: processes, observations and models (Belmonte Rivas, 2015)

4.3.3 The Scirocco Web: Available material – Calibration and L1 processing

The following lectures have been made available:

- ERS scatterometer L1 processor
- ERS cross-calibration
- State-less sea-ice discrimination

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4.3.4 Master's Projects Reports

SCIRoCCo-funded Grants on calibration, L1 processing, soil moisture, ocean winds, and sea ice have been conducted at the partnering institutions (KNMI, TUW, SERCO and RMA). These are all available through the SCIRoCCo website.

Author	Title
Tim Bijsterbosch (2016)	“Examining the validity of ERA-Interim for tropical hurricanes over the course of time”
Federica Aveta (2016)	Comparison of ERS-2 ESCAT sea backscattering coefficients with electromagnetic models of sea surface scattering and other empirical models under challenging geophysical conditions
Ines Otosaka (2017)	A historic record of sea ice extents from scatterometer data
Khaoula Hmamouche (2015)	Neural-network based sea-ice discrimination using ERS scatterometer data”
Dorothea Ko (2016)	Daily vegetation modelling to improve the ERS ESCAT soil moisture retrieval
Fabio Fascetti (2016)	Comparison of satellite soil moisture products, models and on-site observation by triple/quadruple collocation including ERS-ESCAT data over H-SAF region (Europe) and "globally" (for ESCAT regional scenario)”
Ivano Rossicone (2016)	Comparison of satellite soil moisture products, models and on-site observation by inter-comparison of ERS-ESCAT vs SMOS over the USDA Watershed in the period Jan-2010 / Jul-2011
Romina Messner (2016)	Daily vegetation modelling to improve the ERS ESCAT soil moisture retrieval

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5. Recommendations from the SCIRoCCo Project

From the work performed during the course of this Project, summarized in the previous Chapters, some lines of evolution have emerged as important for the future continuing exploitation of the ERS data, to the benefit of the many diverse users' communities revolving around the Scatterometer records. We discuss in the following sections those lines which we believe are the most important in the short and medium term (two to five years from now). The Table below provides a summary of what discussed.

Table 4 Bringing ESCAT capability towards ASCAT and SCA

Area	Goal	Need	Development proposed
Fundamental Climate Data Record (L1 Products)			
ESCAT Instrument Knowledge	Enhance confidence in the ESCAT FCDR. Assessing whether the non-linearity can be understood and solved at L1, or whether ad-hoc corrections remain needed as a L1 post-processing step.	Identify the root cause of the non-linear effect, particularly pronounced in ESR-2.	Tracing the root cause of the non-linearities back to specific ERS instrument and/or ASPs L1B processor settings.
Stability	Produce a calibration model for existing as well as for future scatterometers;	Separate instrumental and atmospheric contributions and clarify their effects; Understand residual diurnal and seasonal variability as seen both in the ERS and ASCAT linear biases (instrument artifacts, geophysical variability etc.). Apply non-linear corrections to calibration <i>Not available after 2001 (SPECIFY?)</i>	Further develop the new methods (e.g. Cone Metrics) to analysing residual diurnal and seasonal biases, as a function of latitude and solar angle.
Coastal Processing	Generation of a consistent ERS-ASCAT long-term record	Unavailable for ERS, while it is for ASCAT and SCA. Coastal processing is a new development, originally not foreseen for ERS/ESCAT	Use the available knowledge on ASCAT to develop new Coastal Processing algorithms for ERS/ESCAT
Thematic Climate Data Record/Essential Climate Variable (L2 Products)			
Ocean	Generation of geophysical Ocean	Assess the impact of non-linear	Improve geophysical model

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Vector Winds	Wind Vector ECVs to support climate change research. (Only the main products are currently available)	corrections on geophysical retrievals	function (GMF). Validate L2 product consistency after non-linear corrections, regional , coastal calibration and other enhancements have been implemented on L1. Verify consistency of error estimates across C-band scatterometers
Sea Ice extents	Generation of geophysical Sea-Ice ECVs to support climate change research. Generate a consistent long-term record of sea ice extent and sea ice age for ERS, Quikscat and ASCAT. (Only the main products are currently available)	Assess the impact of non-linear corrections on geophysical retrievals	Validate L2 product consistency after non-linear corrections, regional , coastal calibration and other enhancements have been implemented on L1. Apply improvements in sea ice detection for ERS made in SCIRoCCo to understand the changing signatures of sea ice extent and age across different Scat technologies (Ku)
Soil Moisture	Availability of geophysical Soil Moisture ECVs to support climate change research. (Only the main products are currently available)	Assess the impact of non-linear corrections on geophysical retrievals	Validate L2 product consistency after non-linear corrections, regional , coastal calibration and other enhancements have been implemented on L1.

5.1 Preserving ERS data Legacy

ESA's primary asset comes from the archives of ERS-1 and ERS-2 scatterometer data. Preserving them, the knowledge involved with scatterometer data calibration and processing capabilities, following up with the requests for new, higher resolution and better quality products, coming from an evolving and widening Users' Community is held as a primary goal to pursue.

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5.2 Scatterometer inter-calibration

For climate applications it is important to have long-term homogeneous datasets, free from instrument instabilities or calibration changes. The World Climate Research Program (WCRP) guidelines for the production of FCDRs must therefore be addressed by scatterometer inter-calibration. Further research and development work is thus highly recommended. Many users are interested in accurate and homogeneous backscatter measurements for several type of analyses. ECMWF, for example, would use a more stable, homogeneous and continuous backscatter dataset for reanalysis purposes. Operational ERS-1 and ERS-2 data have been used so far for the ECMWF reanalysis projects (ERA-40, ERA-Interim, ERA-5) with big gaps of data in 2001-2003 due to the gyroscope problems. A more accurate reprocessed dataset covering the mentioned gap, and possibly with higher resolution, would be of great interest for the next reanalysis project.

5.3 ERS-1/ERS-2 Ocean winds vectors

From the results produced within the SCIRoCCo project, it is clear that a long-term record of ocean winds from the current LRDPF or newer ASPS backscatter records will be suboptimal, most remarkably because of the unsolved non-linearity and left over instrumental anomalies. The SCIRoCCo results and corrections on non-linear calibration suggest that certain hardware or characterization components in the ERS-1 and ERS-2 scatterometers are not well understood, resulting in a backscatter record that does not conform to the World Climate Research Programme (WCRP) guidelines for the production of FCDRs. Further work to identify the anomalous hardware characteristics that cause non-linearity (and that seem likely related to the noise-floor subtraction scheme) would enhance confidence in the ERS FCDR, the derived ECV CDRs and its climate applications.

Understanding the sources of the residual diurnal and seasonal variabilities seen both in the ERS and ASCAT records will also be very useful knowledge in order to derive a calibration model for existing as well as future scatterometers.

Meteorological, oceanographic and hydrological applications have great interest in more accurate measurements and possibly with enhancement resolution. Besides the production of FCDRs on the originally set product resolution (50 km), advancements in processing and resolution have been performed for the evolved coastal and higher resolution soil moisture ASCAT products. Enhancing the resolution of the ERS FCDR and of the subsequent ECV CDRs in line with these ASCAT developments is thus highly valuable. The availability of higher resolution ERS data as part of the ESA's ASPS project, brings renewed opportunity to study aspects of climate variability that may only emerge at the smaller spatial scales, such as along the coastal zones. For example, civil protection and wind energy applications in the coastal zones require coastal wind climatologies to design and maintain the associated infrastructure in this era of man-made climate change.

The application of Cone Metrics within the SCIRoCCo project has highlighted the importance of the refinement of the GMF used for ocean surface wind retrieval, in order to provide a better fit to the distribution of observed backscatter in the future. The agreement between the geophysical model function used for wind retrieval (CMOD5n) and the backscatter distributions observed is currently limited by differences of up to 0.3 dB. The observed mismatch between the GMF and the actual backscatter distributions calls for new models that could ingest parametric GMF corrections as a function of scatterometer wind speed and direction.

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Finally, preliminary results obtained within SCIRoCCo indicate that the generation of a historic record of sea ice extents and ice age from ERS data that is consistent with the ASCAT and Quikscat sea ice records is a possibility. Further work is still necessary in order merge the different Ku-band and C-band signatures of sea ice age into a unique, continuous and seamless sea ice record based on the ERS, Quikscat and ASCAT scatterometers dating from 1991 to present date.

5.4 Soil Moisture

To take full advantage of ESCAT data towards the generation of a C-band backscatter FCDR, several iterations of data re-processing will be demanded to continuously improve the quality of the data by adopting and incorporating state of the art Level 1 algorithm improvements.

Calibration requirements of scatterometers may change over time, because the currently gained knowledge of radiometric calibration and instrument stability is based on the most recent missions (ASCAT). With the launch of SCA, the follow-on mission of ASCAT, probably a new radiometric calibration reference will be defined, demanding a full re-processing of all scatterometer heritage missions at this point in time (ESCAT and ASCAT).

Furthermore, higher level scatterometer algorithms, such the soil moisture retrieval model, evolve over time by incorporating new scientific advancements to improve the quality of the retrievals. Current algorithmic developments in the soil moisture retrieval from C-band scatterometers mainly focus on the ASCAT; while some of these improvements can be applied immediately to ESCAT data, adapting others like the new slope-computation (which relies on the improved temporal resolution of ASCAT) will be quite challenging. In addition, new application areas of scatterometer data have been investigated over land surface. For instance, a method to estimate vegetation optical depth from scatterometer data using a water-cloud model has been developed in (Vreugdenhil et al., 2016). Consequently, accessibility of the ESCAT data is essential to transfer algorithmic improvements and new algorithms in order to derive enhanced soil moisture products or even extend the ESCAT product suit for new application areas.

Efforts undergone to obtain a better understanding of the existing vegetation correction in the TU Wien soil moisture retrieval model resulted in a vegetation optical depth (VOD) product as published in (Vreugdenhil et al, 2016). This product complements vegetation products (NDVI, FAPAR, etc.) from optical sensors, providing new physical perspectives to characterise and monitor vegetation phenology. Vegetation characterization with a VOD product from ESCAT may open new fields of applications for scatterometry supporting the visibility of the mission.

The majority of application areas employing scatterometer data demand Level 1 backscatter observations regularly sampled at fixed locations on the Earth's surface to allow time series analyses. Level 1 scatterometer data are traditionally stored and geo-located on an instrument defined orbit grid, hampering the usage of this data for time series analyses as required for climate change research. Providing Level 1 scatterometer data on a Discrete Global Grid (DGG), fixed with respect to the Earth's surface, is anticipated to broaden the user community of ESCAT data to pave the way for new application areas and the valorisation of the data.

The discussed prospects and opportunities for ESCAT are foreseen to foster the awareness of the importance of this data record. To accomplish this, it will be necessary to join the forces of the various expert groups in microwave scatterometry in a collaborative and interactive manner. This cooperation may be facilitated by working on a

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dedicated scatterometer platform, understood here as a shared IT infrastructure where the scatterometer data reside in shared data pool(s) and access to the data and application specific software is provided through cloud accounts. Such a scatterometer platform could be understood as a realisation of a mission exploitation platform as discussed within ESA’s strategy paper on “EO Innovation Europe”. The benefit of such scatterometry platform is seen in shared code libraries among expert groups to enhance Level 1 and Level 2 algorithms in collaboration, a quick response to re-processing demands of these products and direct access to historic and the latest data sets of ESCAT for users.

Hosting of the scatterometer platform may be performed by the EODC Earth Observation Data Centre for Water Resources Monitoring GmbH (EODC GmbH, <https://www.eodc.eu>) which is a public-private partnership (PPP) between the Vienna University of Technology, the Austrian Meteorological Service ZAMG, the companies GeoVille Information Systems GmbH and Catalysts GmbH, and several private individuals. The mission of the EODC is to work together with its shareholders and multi-national partners from science, the public and private sectors in order to foster the use of earth observation (EO) data.

EODC IT infrastructure can be used to archive, preserve and re-process ESCAT data records to maintain the visibility and serviceability of the data. Expert groups can work together, improve algorithms, share them and build services to meet user demands and to ensure accessibility to the data archive for users in the long run.

5.5 NetCDF Standardization

The SCIRoCCo project elaborated the NetCDF definitions resulting in 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 resources in order to follow these developments.

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).

5.6 Scatterometer data and documentation availability on a global scale. GCOS, WMO and other resources.

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

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- 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.

5.7 Outreach and Education

The Consortium regards Outreach and Education activities as an essential contribution to continuing exploitation and improvement of ESA legacy data. Therefore, the content of the SCIRoCCo website (scirocco.sp.serco.eu) should be integrated and made available through the ESA SPPA portal (earth.esa.int/web/spa), to ensure it is preserved and maintained also in the future.

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6. Conclusions

The ESA Sensor Performance, Products and Algorithms (SPPA) section has been actively raising awareness of Earth Observation (EO) data capability and performance within the EO user community being the focal team for data quality control and algorithms evolutions (<https://earth.esa.int/web/sppa>). Within this scope and mandate, the Scatterometer Instrument Competence Centre (SCIRoCCo, <http://scirocco.sp.serco.eu>) was established by ESA in 2014, as an interdisciplinary cooperation of international scatterometry experts aiming at promoting the continued exploitation and valorisation of ERS Scatterometer data (ESCAT) at medium (25 km and 50 km) spatial resolution, and improving the quality of available and future scatterometry data. This document reports on the results and recommendation of SCIRoCCo on the long-term exploitation of the ERS Scatterometer data.

The SCIRoCCo project has been a great initiative and experience to all its participants, teaming up expertise focusing on the exploitation of ERS data. A large potential for future applications and evolutions has resulted from gluing specialised resources and as result of the knowledge achieved. Climate research is the broadest scope, the goal being the production of long-term series of ocean winds, soil moisture and sea ice retrievals (TCDRs) to be consistent with and connected to ASCAT's. This large potential for improvement is possible and has been indicated in this document as way forward after the closure of this project. In order to achieve this potential, some specific lines of action have been highlighted: backscatter non-linearity being a major one, affecting all applications and preventing a proper merging of ERS data records with ASCAT; longer data series achievable reveal shortcomings in retrieval algorithms (e.g. no land change assumption in soil moisture retrieval, ocean wind GMF improvements), which have to be addressed. Newly available high resolution products while opening new scenarios and possibilities (coastal zones), highlight the need for improving the evaluation of data quality. Accessibility to Level 3 products should be also explored. A summary table is provided in section 2.

The SCIRoCCo Team is grateful to ESA for having funded such a coordinated effort, which has resulted in new and deeper understanding of the ERS Scat dataset and its high potential. In line with the pressing expectations of a growing User Community, SCIRoCCo solicits ESA to promote all efforts leading to the preservation and improvement of Scatterometry data, supporting reprocessing campaigns, improved calibration, new algorithms and outreach activities.

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