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Ministry of Infrastructure and the Environment

EUMETSAT OSI SAF OCEAN AND SEA ICE

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SAF/OSI/CDOP2/KNMI/TEC/RP/278

ERS L2 winds Data Record validation report

25 km wind products (OSI-152)
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Contents

1 Introduction

The EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) produces a range of air-sea interface products, namely: wind, sea ice characteristics, Sea Surface Temperatures (SST) and radiative fluxes, Surface Solar Irradiance (SSI) and Downward Long wave Irradiance (DLI). The Product Requirements Document [1] provides an overview of the committed products and their characteristics in the current OSI SAF project phase, the Service Specification Document [2] provides specifications and detailed information on the services committed towards the users by the OSI SAF in a given stage of the project.

This report contains validation information about the ERS-1 and ERS-2 scatterometer wind Climate Data Record (CDR), produced in the OSI SAF. It was decided to use backscatter from archived near-real time Active Microwave Instrument (AMI) BUFR data for reprocessing. Reprocessing of ERS-2 AMI backscatter data is being done in the SCIRoCCO project (European Space Agency SCatterometer InstRument Competence Centre, http://scirocco.sp.serco.eu/) and reprocessing of ERS-1 data is done by ESA outside the SCIRoCCO project. However, at the time of wind reprocessing, data were available only for ERS-2 and not yet for ERS-1. Moreover, it was shown that the data characteristics of the reprocessed backscatter data were not significantly different from the original data [3]. The data have been processed using the ASCAT Wind Data Processor (AWDP) software version 3.0, as available in the Numerical Weather Prediction (NWP) SAF [4]. More information about the processing and the products can be obtained from the Product User Manual [5].

The quality and stability of the ERS wind CDR has been assessed by looking both at backscatter and wind data. Section 2 describes the checks on the backscatter stability over time. Section 3 assesses the Quality Control applied in the products. In section 4, the winds are compared with NWP model data and with wind data from in situ buoys. Section 5 describes triple collocation experiments to assess the quality of winds from scatterometer, NWP model and buoys separately. Section 6 summarises the main conclusions.

Acknowledgement

We are grateful to Jean Bidlot of ECMWF for helping us with the buoy data retrieval and quality control.

2 Backscatter data stability

A very important task when creating climate data records is to check the stability over time of the used instruments. In the scope of this work we have limited ourselves to looking at the radar backscatter (σ^0) on selected locations of the Earth which are known to have stable geophysical properties. Kumar et al. [6] have looked at SeaWinds backscatter responses over deserts, rain forests and snow covered areas. They found that particularly the snow covered areas show a very stable backscatter with very small standard deviations over time (they studied the 2005-2006 period) and little azimuthal variations. We have looked into the backscatter data over the entire period from March 1992 to June 1996 (ERS-1) and from March 1996 to January 2001 (ERS-2) in a snow covered area also used in [6]: a 2° × 2° box centred at 77 S, 126 E (Antarctica). We consider the Antarctica region to be more stable in time than the Greenland region used in [6]. Long and Drinkwater describe Antarctic backscatter conditions and their anisotropy in [7]. In Greenland melting events occur regularly during the summer which will definitely influence the radiometric properties of the snow cover.

In order to monitor the instrument, we have taken the backscatter data on 25 km Wind Vector Cell (WVC) level for all overpasses in each month. This has been done for the fore, mid and aft beams of WVC 7 (close to the middle of the swath). The data for each month, i.e., all backscatter data acquisitions located within the selected box, have been averaged. In this way, we average out diurnal variations and variations due to different flight directions in multiple orbits over one month. Still we can very well establish the backscatter variations over longer time scales. During the ERS-1 and ERS-2 missions, several events and anomalies occurred which have led to changes in backscatter calibration, see the section on this in the Product User Manual [5]. As described in the PUM, the backscatter changes were corrected for and the backscatter stability over ice was assessed after applying these corrections.

Figure 1 shows the backscatter variations over time in the Antarctica area. We see σ^0 values that are very constant over time with only small seasonal variability. There appear to be differences between the beams and WVCs which can be attributed to anisotropy and different incidence angles. Apart from this, we see some seasonal variation in the backscatter signals, but only very small long term trends, of less than 0.05 dB over 4 to 5 years. Only the ERS-1 mid beam and ERS-2 fore beam appear to have a slightly larger long term trend.

A rule of thumb is that a change of 0.1 dB in backscatter corresponds to a change of 0.1 m/s in wind speed. Hence we conclude that wind speed trends due to instrument drift are very likely to be smaller than 0.05 m/s over the respective 4 to 5 years periods, corresponding to a wind speed drift of less than 0.1 m/s per decade.

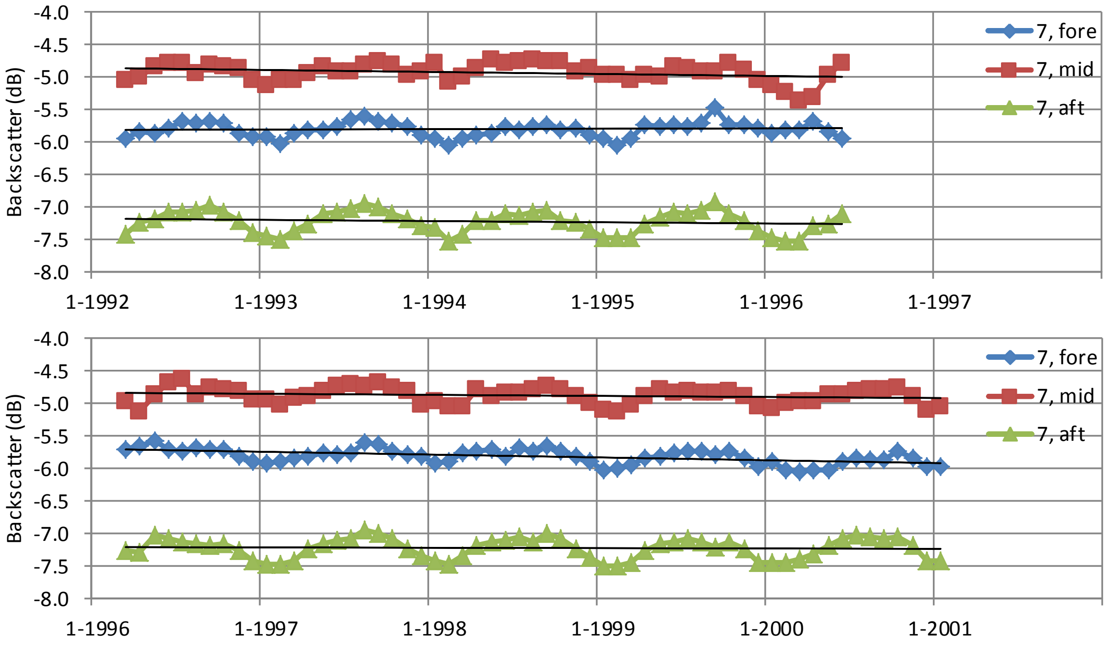

Figure 1: Temporal variation of ERS-1 (top) and ERS-2 (bottom) WVC 7 fore, mid and aft σ^0 over Antarctica (77 S, 126 E).

3 Quality Control characteristics

A good assessment of the information content of scatterometer winds is particularly important in order to use them in weather and climate analysis. Elimination of poor quality data is therefore very important for the successful use of the wind data. Besides retrieval problems in cases of a confused sea state, another problem of scatterometry is the sensitivity to rain, although the C-band ERS AMI instrument is much less sensitive to rain than Ku-band instruments like SeaWinds. Lin et al. [8], [9] established that ASCAT is in fact sensitive to the wind variability (downdrafts) near rain and much less so to direct effects of rain. The MLE is a good measure of local wind variability, but is also used for QC. As part of the ERS data record validation, we have investigated the geographical distribution of the rejection fraction of WVCs. We have done this for the year 1993 and for the year 2000. In this way we can see if the rejection rates have logical patterns which can be associated with rainy areas or areas where downbursts are likely; and if there are any changes over time which can be attributed to instrument drifts.

Inspection of Figure 2 reveals that the main areas with high MLE rejection rates can be associated with east-west oriented bands in the tropics, most notably in the western Pacific. These are regions known to have strong convection, rain and thus wind downbursts. The bands with high rejection rates near the edges of the Arctic and Antarctic sea ice shelves can be associated with the freezing seasons. When the ice edge rapidly moves due to freezing, there may be areas already covered with sea ice which are not yet assigned as ice by the Bayesian ice screening. These WVCs are still rejected by the Quality Control but they are assigned as ‘rain’ rather than ‘ice’. It is also clear that the patterns in 1993 and 2000 only differ marginally.

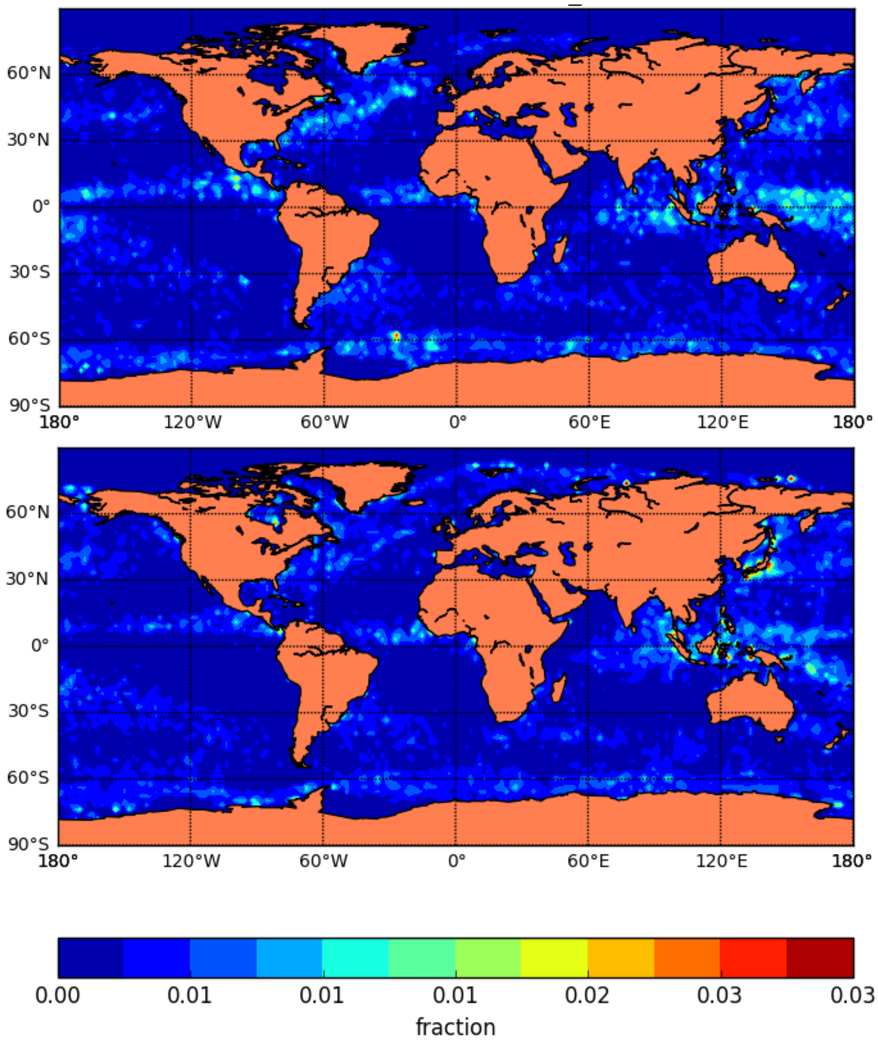

Figure 2: Number of WVCs with KNMI Quality Control flag set as a fraction of WVCs where land flag and ice flag are not set. Results are for the entire year 1993 (ERS-1, top) and for the entire year 2000 (ERS-2, bottom).

4 Comparison of winds with NWP model and buoys

4.1 NWP model wind comparisons

The ERS scatterometer winds have been collocated with ECMWF re-analysis (ERA) Interim wind data [10]. Stress equivalent (U10S) winds have been computed from the real ERA-Interim forecast 10m winds, sea surface temperature, air temperature, Charnock parameter, specific humidity and mean sea level pressure, using a stand-alone implementation of the ECMWF model surface layer physics [11]. The model wind data have been quadratically interpolated with respect to time and linearly interpolated with respect to location and put into the level 2 information part of each WVC. These model winds have been used both to initialise the Ambiguity Removal step in the wind processing and to monitor the scatterometer winds.

Figure 3 shows the monthly averages of wind speed bias and standard deviations of the zonal and meridional wind vector components over the entire period of the reprocessed data set. The wind speed bias is constant within 0.2 m/s over time; no long term trends are visible in the wind speed bias. The wind vector component standard deviations gradually decrease with time, indicating that scatterometer and model winds are getting closer together. The quality of the ERA-Interim winds gradually improves with time due to the availability of more and more satellite observations which are successfully assimilated into the model. When the model winds improve with time and the scatterometer winds keep the same quality, it can be expected that the standard deviations decrease.

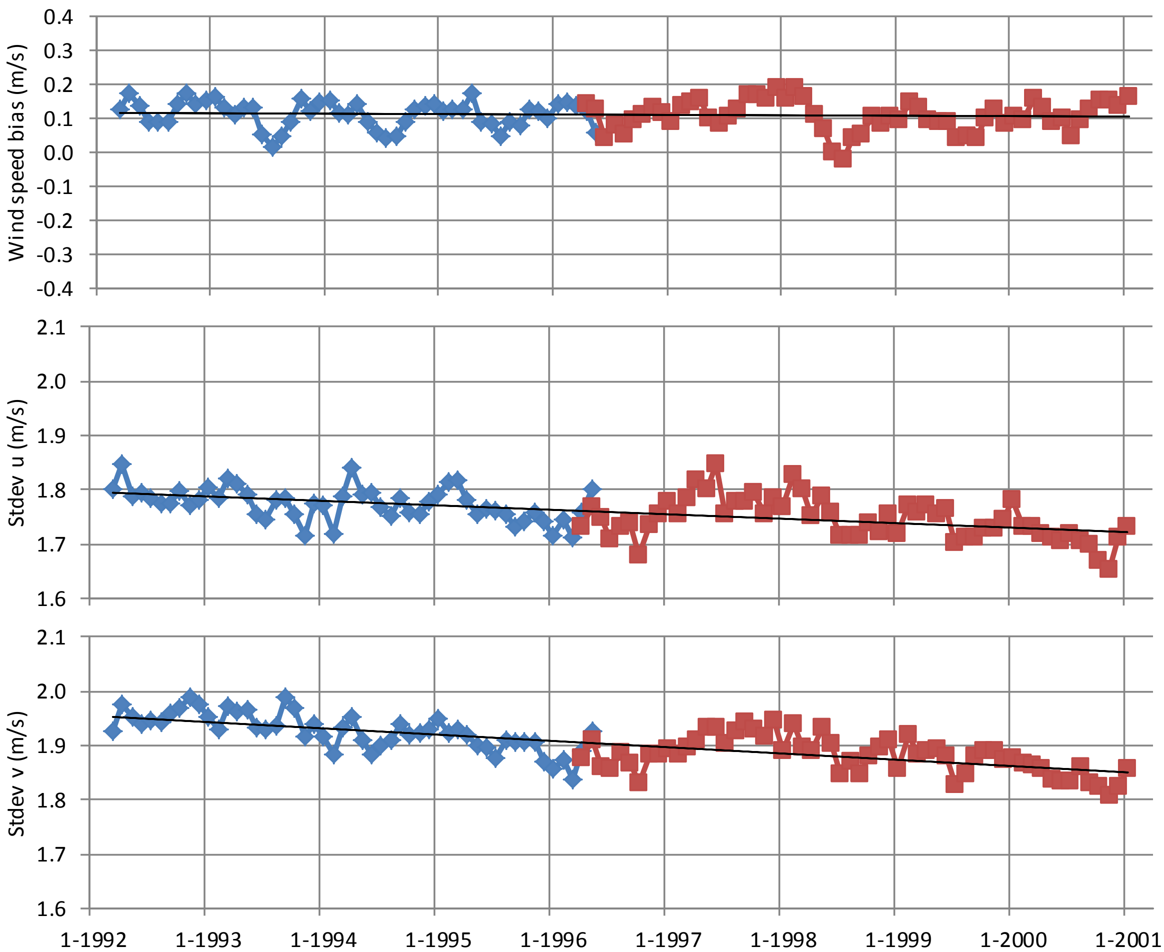

Figure 3: Wind speed bias (top), standard deviation of zonal wind component (middle) and standard deviation of meridional wind component (bottom) of ERS-1 (blue) and ERS-2 (red) winds versus ECMWF ERA-Interim model wind forecasts. The plotted values are monthly averages.

For the SeaWinds reprocessed winds we also observed decreasing wind component standard deviations (i.e., improving model winds quality with a constant scatterometer winds quality), mainly in the period 1999 to 2005, and rather constant values in the period 2005 to 2009 [12]. This is consistent with what we obtain for ERS. It is also clear from these results that the ERS-1 and ERS-2 winds match very well.

In order to isolate any variations in wind speeds, we have plotted the monthly averages of the scatterometer and model wind speeds separately in Figure 4. It is clear that both ERS and ERA-Interim winds increase by approximately 0.1 m/s from 1992 to 2001, leading to no net change in wind speed bias, as confirmed by Figure 3 (top). Note that the model winds are collocated winds and hence the plot does not represent all ERA-Interim winds, but only those at the time and location of ERS overpasses.

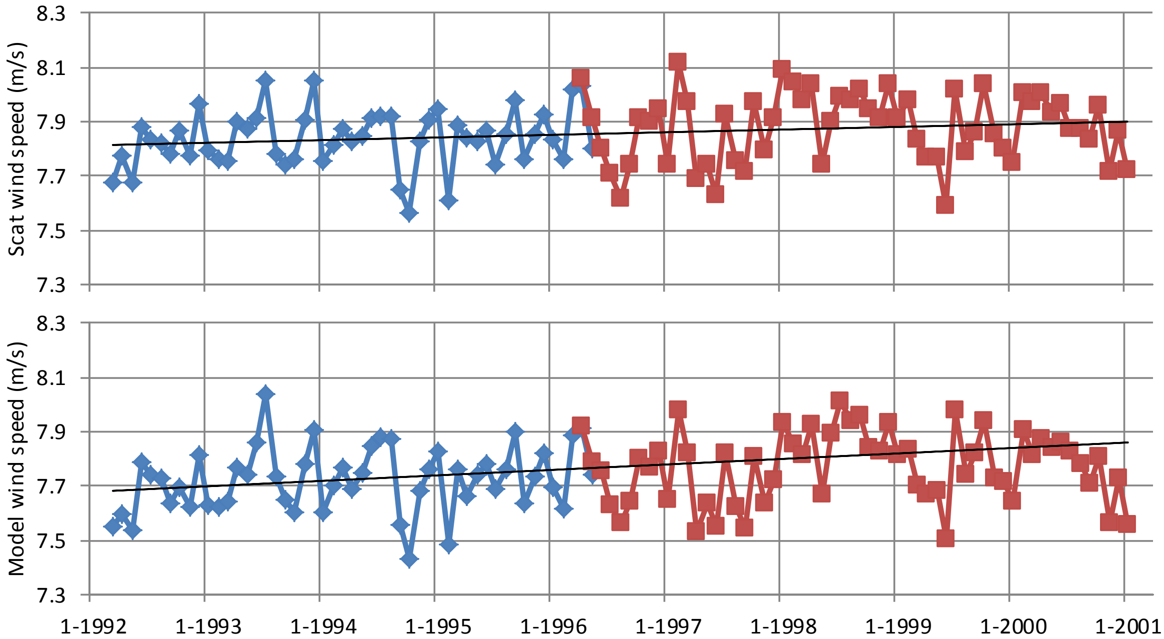

Figure 4: Average ERS wind speed (top) and collocated ERA-Interim wind speed (bottom) of ERS winds. The plotted values are monthly averages.

4.2 Buoy wind comparisons

In this report, scatterometer wind data are compared with in situ buoy wind measurements. The buoy winds are distributed through the Global Telecommunication System (GTS) and have been retrieved from the ECMWF MARS archive. The buoy data are quality controlled and (if necessary) blacklisted by ECMWF [14]. The buoy winds are measured hourly by averaging the wind speed and direction over 10 minutes. The real winds at a given anemometer height have been converted to 10-m equivalent neutral winds using the Liu, Katsaros and Businger (LKB) model ([14], [15]) in order to enable a good comparison with the 10-m scatterometer winds. Note that the difference between equivalent neutral winds and stress equivalent scatterometer winds is very small [16] so that both may be directly compared.

A scatterometer wind and a buoy wind measurement are considered to be collocated if the distance between the WVC centre and the buoy location is less than the WVC spacing divided by $\sqrt{2}$ and if the acquisition time difference is less than 30 minutes. Note that the collection of available buoy data changes over time: buoys are removed, temporarily or permanently, whereas on the other hand new buoys are deployed on new locations. In order to rule out variations in representativeness, we have taken a sub-set of the available buoys, containing only buoys that have produced wind data in seven out of nine years between 1992-2000. The 37 used buoys are listed in Appendix A and a map of the buoy locations can also be found there. Compared to the buoy collections used for the validation of SeaWinds [12] and ASCAT [13] reprocessed data records, the lack of data in the tropical seas is clear. Those buoys were not yet deployed in the ERS era.

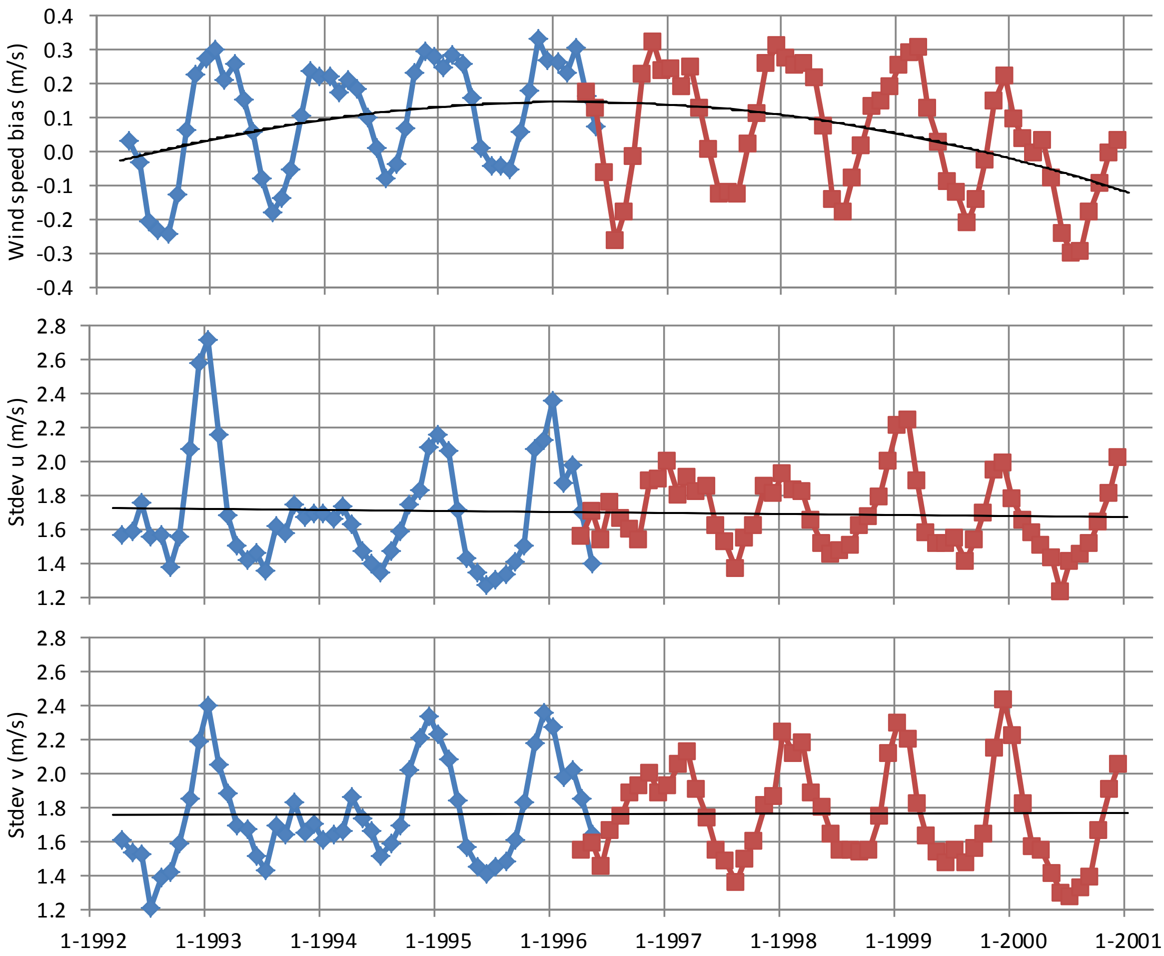

Figure 5: Wind speed bias (top), standard deviation of zonal wind component (middle) and standard deviation of meridional wind component (bottom) of ERS-1 (blue) and ERS-2 (red) winds versus buoy winds. The plotted values are averages over three months.

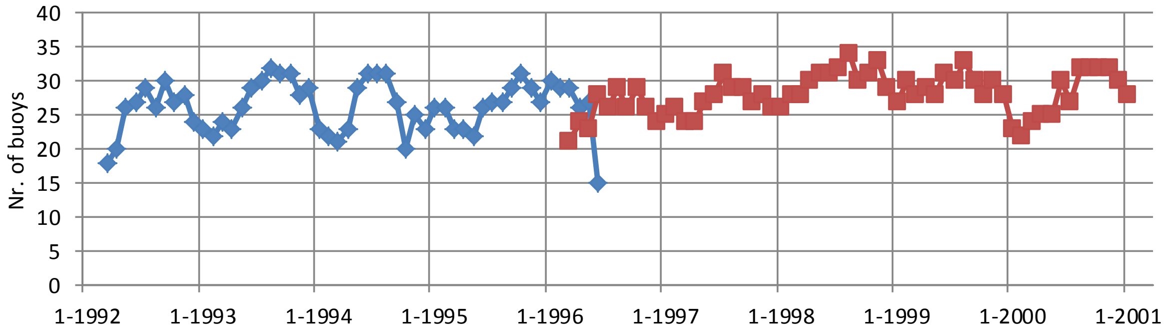

Figure 6: Number of buoys used in the buoy collocations per month.

Figure 5 shows the wind statistics of ERS winds versus buoy winds and Figure 6 shows the monthly number of buoys available for collocations, which is fairly constant over time as expected. A clear yearly oscillation is visible for the wind speed bias and wind component standard deviations. Seasonal weather variations cause differences in the probability distribution function of wind speeds. These differences cause variations in the spatial representativeness errors associated with the scatterometer wind validation and thereby variations in the difference statistics.

The seasonal oscillations are significantly less prominent in the comparisons with model wind data in the previous section. From our previous work on ASCAT and SeaWinds [17], we know that such oscillations are much stronger in the extratropical areas than in the tropical areas due to larger yearly variations in the weather conditions . However, due to the low number of tropical buoys available in the ERS collocations (see the map in Appendix A), we can't provide separate buoy statistics for extratropical and tropical buoys. Still we believe that the oscillations in the buoy verifications are connected with seasonal variations in specific regions.

The wind component standard deviations in Figure 5 are quite constant over the long time, indicating that the wind quality of both observing systems does not change much. The average ERS zonal (*u*) and meridional (*v*) component standard deviations are 1.7 and 1.8 m/s, respectively. This is comparable with the results for ASCAT (1.7 and 1.7 m/s) and SeaWinds (1.8 and 1.7 m/s) for extratropical buoys.

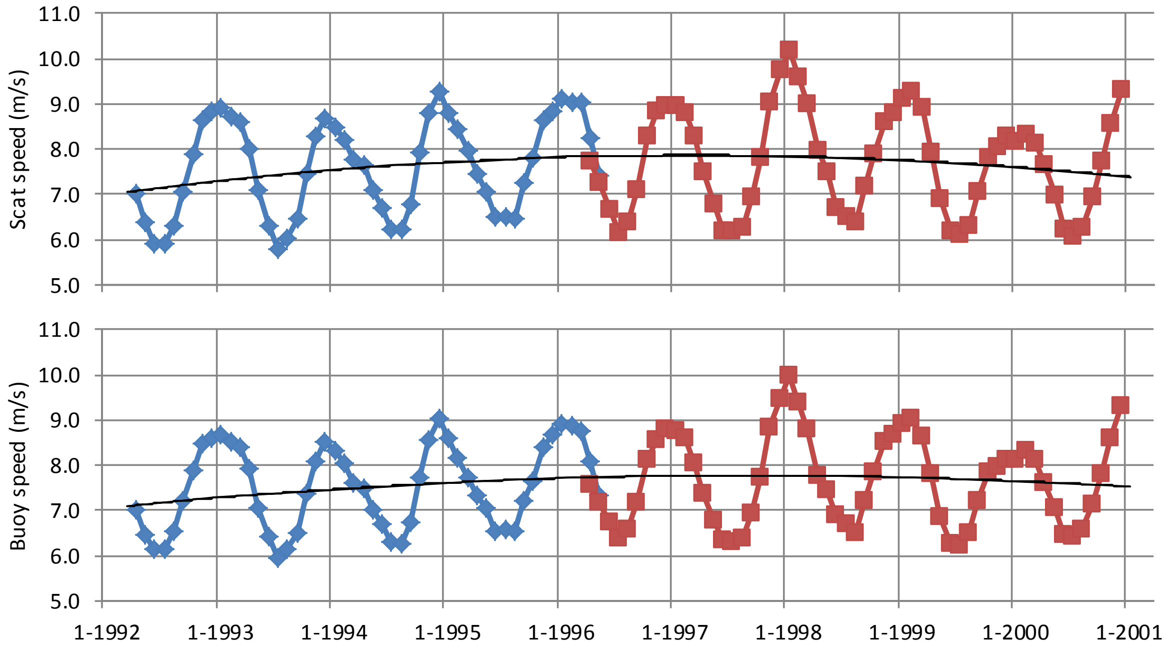

Figure 7: Average ERS wind speed (top) and collocated buoy wind speed (bottom). The plotted values are averages over three months.

It is clear from the top plot in Figure 5 that the wind speed bias of scatterometer winds versus buoy winds first increases and then decreases over the reprocessing period, unlike the wind speed bias versus ERA-Interim winds which does not show significant long term trends (Figure 3).

Analogous to Figure 4, we have plotted the monthly averages of the scatterometer and buoy wind speeds separately, see Figure 7. From these plots it is clear that wind speeds show the same trends in both observing systems: a gradual increase followed by a gradual decrease. The trend appears to be slightly stronger in the scatterometer wind speeds than in the buoy wind speeds, leading to a net effect as shown in Figure 5 (top). The long term trends in the extratropical locations have not been further investigated in the scope of this report, we attribute them to year-to-year changes in local weather conditions.

5 Triple collocation results

A triple collocation study was performed to assess the errors of the ERS, ECMWF and buoy winds independently. The triple collocation method was introduced by Stoffelen [18]. Given a set of triplets of collocated measurements and assuming linear calibration, it is possible to simultaneously calculate the errors in the measurements and the relative calibration coefficients. The triple collocation method can give the measurement errors from the coarse resolution NWP model perspective or from the intermediate resolution scatterometer perspective, but not from the fine resolution buoy perspective without further assumptions on the local buoy measurement error. A wind signal present in buoy measurements but not in scatterometer measurements is therefore contained in the buoy error. This matter is extensively introduced by Vogelzang et al. [19].

Collocated data sets of ERS, ECMWF and buoy winds spanning the whole period of reprocessing were used in the triple collocation. Table 1 lists the error variances of the buoy, ERS and ECMWF winds from the intermediate resolution scatterometer perspective.

The scatterometer errors for ERS-1 and ERS-2 are quite comparable, it is remarkable however that for ERS-2 both the buoy errors and ECMWF errors are larger than those for ERS-1. We have no explanation for this, the increase in ECMWF errors from the ERS-1 era to the ERS-2 era is contrary to the results in e.g. Figure 3 which suggest that the ECMWF errors reduce over time.

The ASCAT errors are significantly lower than those from ECMWF. This can partly be attributed to the instrumental improvements in ASCAT but it may also result from the different spatial distribution of the buoys used for the ASCAT triple collocation. The ASCAT buoy data set contains much more tropical buoys and the wind speed probability function is different in the tropics as compared to the extratropics. In the tropics generally less high wind speeds are observed. This has an impact on the triple collocation errors for all three observation systems.

In general, the ERS scatterometer winds are of good quality: at 25 km scale the error in the wind components is less than 0.9 m/s as is shown in Table 1.

	Scatterometer		Buoys		ECMWF	
	ε_u (m/s)	ε_v (m/s)	ε_u (m/s)	ε_v (m/s)	ε_u (m/s)	ε_v (m/s)
25 km ERS-1	0.67	0.84	1.36	1.38	1.43	1.52
25 km ERS-2	0.66	0.82	1.44	1.46	1.54	1.60
25 km ASCAT	0.48	0.57	1.19	1.23	1.55	1.58

Table 1: Error standard deviations in *u* and *v* wind components from triple collocation of ERS and ASCAT [13] 25 km wind products with buoy and ECMWF forecast winds, seen from the scatterometer perspective.

From the triple collocation analysis, we can also determine the calibration of the scatterometer winds. The calibration coefficients a and b relate the observed scatterometer wind w to the 'true' wind t according to $t = a \times w + b$. This is done separately for the u and v wind components, but an overall calibration coefficient can be obtained by forcing $a_u = a_v$. The calibration coefficients indicate whether the scatterometer and ECMWF winds are underestimated ($a > 1$) or overestimated ($a < 1$). We see values quite close to 1, although ERS winds appear to be slightly too high ($a < 1$).

	Scatterometer	ECMWF
25 km ERS-1	0.974	0.974
25 km ERS-2	0.980	0.974
25 km ASCAT	0.994	1.031

Table 2: Scatterometer and model wind calibration coefficients from triple collocation of ERS and ASCAT [13].

6 Conclusions

The quality and stability of the ERS CDR has been assessed by looking both at backscatter and wind data.

The backscatter values appear to be very constant in time over a selected area on Antarctica. We obtain time series with long term trends of less than 0.1 dB. From these very stable results, we conclude that the observed ERS backscatter drifts appear negligible after appropriate correction for calibration changes during the missions.

The scatterometer wind biases against ERA-Interim do not show any trend but biases against buoy winds show some long term trends, a gradual increase followed by a decrease. Those trends appear to be within 0.2 m/s and we attribute them more to changes in local weather circumstances at the buoy locations than to instrumental drifts. Recall that only 37 buoys can be used having data over the whole ERS-1 and ERS-2 period. It is also clear that ERS-1 and ERS-2 wind characteristics match seamlessly.

Nevertheless, the analysed backscatter and wind changes suggest variations in instrumental bias of well less than 0.1 dB (equivalent to 0.1 m/s) in nine years. As such, the produced ERS wind data record meets the requirements set by the World Climate Research Programme (WCRP) [20]: accuracy better than 0.5 m/s, stability better than 0.1 m/s per decade. From the figures in section 4, we conclude that the OSI SAF product requirements ([1], better than 2 m/s in wind component standard deviation with a bias of less than 0.5 m/s in wind speed on a monthly basis) are also well met.

The triple collocation results show that the scatterometer winds are of good quality and well calibrated.

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8 Abbreviations and acronyms

2DVAR	Two-dimensional Variational Ambiguity Removal
AMI	Active Microwave Instrument
ASCAT	Advanced Scatterometer
AWDP	ASCAT Wind Data Processor
CDR	Climate Data Record
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA	ECMWF re-analysis
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GTS	Global Telecommunication System
KNMI	Royal Netherlands Meteorological Institute
LKB	Liu, Katsaros and Businger
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OSI	Ocean and Sea Ice
QC	Quality Control
QuikSCAT	US Quick Scatterometer mission carrying the SeaWinds scatterometer
SAF	Satellite Application Facility
SCIRoCCO	ESA SCatterometer InstRument Competence Centre
u	West-to-east (zonal) wind component
v	South-to-north (meridional) wind component
WCRP	World Climate Research Programme
WVC	Wind Vector Cell

9 Appendix A: List of used buoys

These are the buoy identifiers of the 37 buoys used in the validations and triple collocations in sections 4 and 5. The buoy locations can be looked up on http://www.ndbc.noaa.gov/ and are shown in Figure 8. Only buoys yielding data in at least six out of seven years between 1994 and 2000 have been used.

41001	42019	44014	46132	51003		
41002	42020	46001	46147	51004		
41004	42036	46002	46184	62105		
41009	44004	46004	46205	62108		
41010	44005	46005	46207	64045		
42001	44008	46006	46208			
42002	44009	46035	51001			
42003	44011	46036	51002			

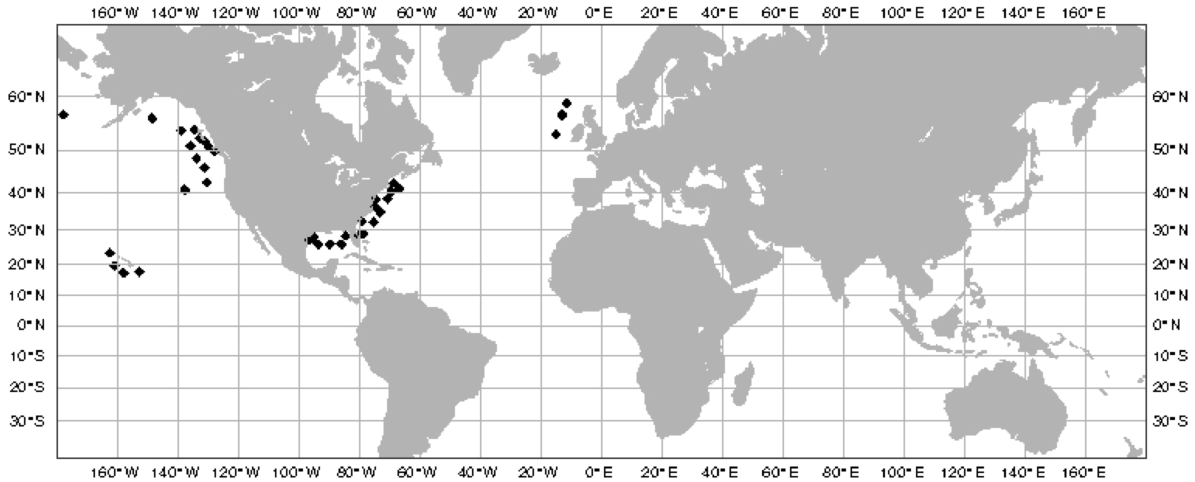

Figure 8: Location of the used buoys.