EUMETSAT
OSI SAF
OCEAN AND SEA ICE

Scientific Validation Report (SVR) for the Ku-band wind data records

SeaWinds 25 km winds 2nd reprocessing (OSI-151-c)
SeaWinds 50 km winds 2nd reprocessing (OSI-151-d)
Oceansat-2 25 km winds 2nd reprocessing (OSI-153-c)
Oceansat-2 50 km winds 2nd reprocessing (OSI-153-d)
RapidScat (ISS) 25 km winds 1st reprocessing (OSI-159-a)
RapidScat (ISS) 50 km winds 1st reprocessing (OSI-159-b)

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1. Introduction

The complete data records from the Ku-band scatterometers SeaWinds on QuikSCAT (19 July 1999 - 21 November 2009), OSCAT on Oceansat-2 (15 December 2009 - 20 February 2014) and RapidScat on the International Space Station (ISS) (3 October 2014 - 19 August 2016) have been reprocessed using the Pencil Beam Wind Processor (PenWP). ERA5 re-analysis winds from the European Centre for Medium-Range Weather Forecasts (ECMWF) have been used to initialise the ambiguity removal step in the wind processing and for validation and monitoring of the wind retrievals. The resulting Ocean and Sea Ice Satellite Application Facility (OSI SAF) wind Data Records can be obtained from the EUMETSAT Data Centre. The PenWP software is developed within the OSI SAF and can be obtained through the Numerical Weather Prediction Satellite Application Facility (NWP SAF) website. This report contains validation information about these data records. More information about the processing and the products can be obtained from the Product User Manual [3].

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.

The quality and stability of the data records has been assessed by assessing the wind data. The QuikSCAT and Oceansat-2 backscatter stability over time has been checked has been checked before in the validation reports of the previous reprocessing [4], [5]. In section 2 and 3, the winds are compared with NWP model data and with wind data from in situ buoys. Section 4 describes triple collocation results to assess the quality of winds from scatterometer, NWP model and buoys separately. Section 5 summarises the main conclusions.

The results presented in this report are encouraging and warrant the release of the wind products.

1.1. Acknowledgements

The QuikSCAT and RapidScat level 1b data have been obtained from the NASA JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC) web portal.

ISRO has provided the near-real time Oceansat-2 level 1b data which were used as input for the OSI SAF wind products. Alexander Fore of JPL has kindly provided their archived OSCAT data record to the OSI SAF.

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

1.2. Reference and applicable documents

[1] OSI SAF,
Product Requirements Document,
SAF/OSI/CDOP3/MF/MGT/PL/2-001, 2021 (link)

[2] OSI SAF,
Service Specification Document,
SAF/OSI/CDOP3/MF/MGT/PL/003, 2021 (link)

[3] OSI SAF,
Product User Manual (PUM) for the Ku-band wind data records,
SAF/OSI/CDOP3/KNMI/TEC/MA/414, 2022 (link)

[4] Verhoef, A., J. Vogelzang and A. Stoffelen,
Reprocessed SeaWinds L2 winds validation report
SAF/OSI/CDOP2/KNMI/TEC/RP/221, 2016 (link)

[5] Verhoef, A., J. Vogelzang and A. Stoffelen,
Oceansat-2 L2 winds Data Record validation report,
SAF/OSI/CDOP3/KNMI/TEC/RP/298, 2017 (link)

[6] Verhoef, A., J. Vogelzang, J. Verspeek and A. Stoffelen,
Long-Term Scatterometer Wind Climate Data Records,
IEEE Journal of Selected Topics in Applied Earth O, 2017, **10**, 5, 2186-2194,
doi:10.1109/JSTARS.2016.2615873

[7] Hersbach, H, B. Bell, P. Berrisford et al.,
The ERA5 global reanalysis,
Q J R Meteorol Soc. 2020, **146**, 1999-2049, doi:10.1002/qj.3803

[8] de Kloe, J., A. Stoffelen and A. Verhoef,
Improved Use of Scatterometer Measurements by Using Stress-Equivalent Reference Winds,
IEEE Journal of Selected Topics in Applied Earth O, 2017, 10, 5, 2340-2347,
doi:10.1109/JSTARS.2017.2685242

[9] Bidlot J., D. Holmes, P. Wittmann, R. Lalbeharry, and H. Chen
Intercomparison of the performance of operational ocean wave forecasting systems with buoy data
Wea. Forecasting, vol. 17, 287-310, 2002

[10] Liu, W.T., K.B. Katsaros, and J.A. Businger
Bulk parameterization of air-sea exchanges of heat and water vapor including the molecular constraints in the interface
J. Atmos. Sci., vol. 36, 1979

[11] Stoffelen, A.
Toward the true near-surface wind speed: error modeling and calibration using triple collocation
J. Geophys. Res. 103, C4, 7755-7766, 1998, doi:10.1029/97JC03180

[12] Stoffelen, A, J. Vogelzang, G.-J. Marseille
High resolution data assimilation guide, version 1.3
SAF/OSI/CDOP3/KNMI/SCI/GUI/388, 2020 (link)

[13] Global Climate Observing System,
Systematic Observation Requirements for Satellite-based Products for Climate Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC - 2011 Update, December 2011,
GCOS Report 154, (link)

2. Comparison of winds with NWP model

The scatterometer winds have been collocated with ECMWF re-analysis (ERA5) wind data [7]. Stress equivalent (U10S) winds have been computed from the equivalent neutral ERA5 forecast 10m winds, air temperature, specific humidity and mean sea level pressure [8]. The model wind data have been quadratically interpolated with respect to time and bi-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.

It is important to note that scatterometer winds are being assimilated into the ECMWF model and therefore the wind field used for ambiguity removal (i.e., a forecast) is taken to be independent from the scatterometer observation. In ERA5, observations are assimilated in the model up to 3 hours after the analysis time. Therefore, in the processing of scatterometer winds, only forecast winds starting from 3 hours after analysis time are used. In this way the independence between the scatterometer and the ECMWF model winds, used to guide the wind direction ambiguity removal, is guaranteed.

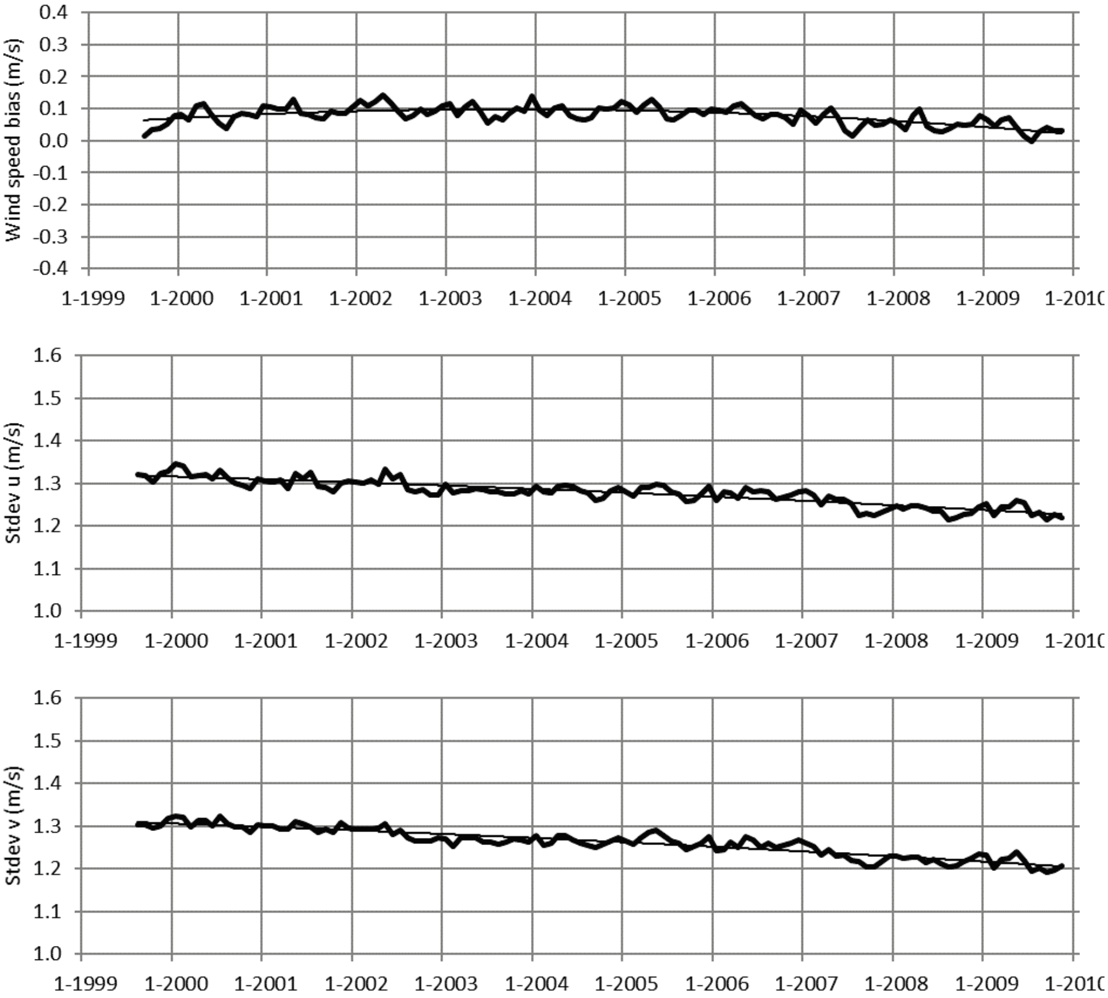


Figure 1: Stress-equivalent wind speed bias (top), standard deviation of zonal wind component (middle) and standard deviation of meridional wind component (bottom) of 25 km SeaWinds winds versus ECMWF ERA5 model U10S wind forecasts. The plotted values are monthly averages.

All validation results in this report only contain the accepted winds, i.e., after rejection of the winds having the KNMI Quality Control (including rain) flag set.

Figure 1 shows the monthly averages of SeaWinds 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 0.1 m/s over time. The wind vector component standard deviations gradually decrease with time, indicating that scatterometer and model winds are getting closer together. The quality of the ERA5 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. The SeaWinds wind component standard deviations with respect to ERA5 are significantly lower (by approximately 0.15 m/s) than those with respect to ERA-Interim as obtained in the previous reprocessing [4]. This is mainly due to the much better quality and higher resolution of the ERA5 winds.

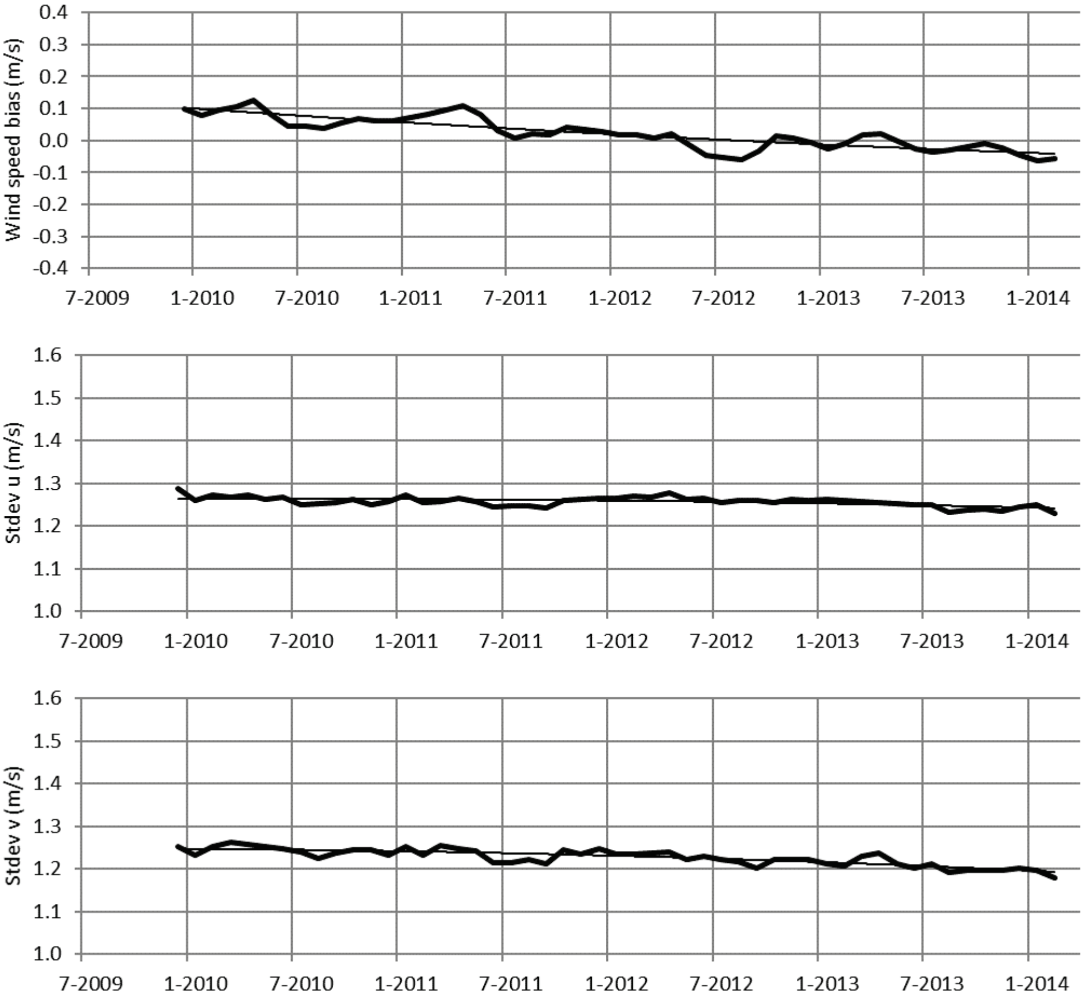


Figure 2: Stress-equivalent wind speed bias (top), standard deviation of zonal wind component (middle) and standard deviation of meridional wind component (bottom) of 25 km Oceansat-2 winds versus ECMWF ERA5 model U10S wind forecasts. The plotted values are monthly averages.

Figure 2 shows the Oceansat-2 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 0.1 m/s over time; with a gradual decrease over time. The decrease is in line with the decrease that we found in the previous Oceansat-2 reprocessing [5]. There may be small instrument drifts, which cause trends in wind climatologies. Contrary to QuikSCAT, a small decrease of the Oceansat-2 backscatter over time appeared in the analysis in [5], this may indicate an instrument drift. The operation period of Oceansat-2 is too short and the trends are too small to conclude about this. The wind vector component standard deviations are slightly decreasing over time, in line with what we found for SeaWinds. We also attribute this to the availability of more and more satellite observations which are successfully assimilated into the ERA5 model. Assuming constant Oceansat-2 wind quality (the wind component standard deviations w.r.t. buoys are rather constant, see Section 3), ERA5 quality appears to slightly increase in this time frame. The Oceansat-2 wind component standard deviations are approximately 0.05 to 0.10 m/s higher than those from SeaWinds in the 2009 – 2010 time frame (where both datasets almost overlap). We attribute this to higher noise levels of the OSCAT instrument. The Oceansat-2 wind component standard deviations with respect to ERA5 are significantly lower (by approximately 0.20 m/s) than those with respect to ERA-Interim as obtained in the previous reprocessing [5]. This is mainly due to the much better quality and higher resolution of the ERA5 winds, but also partly due to improved Oceansat-2 retrievals.

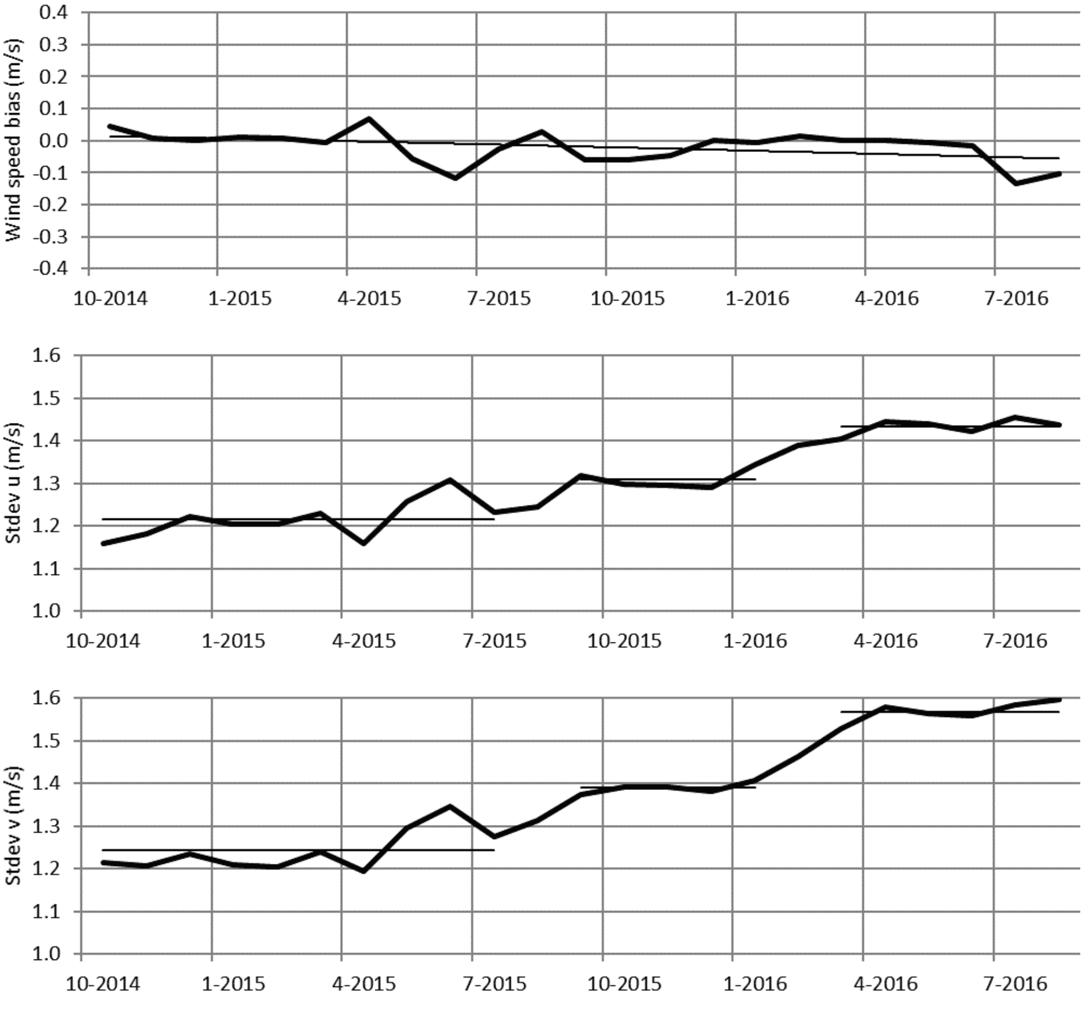


Figure 3: Stress-equivalent wind speed bias (top), standard deviation of zonal wind component (middle) and standard deviation of meridional wind component (bottom) of 25 km RapidScat winds versus ECMWF ERA5

model U10S wind forecasts. The plotted values are monthly averages.

Figure 3 shows the RapidScat 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 0.1 m/s over time, the standard deviations however significantly increase. This is due to the changes in signal levels that RapidScat underwent during its lifetime which resulted in different signal-to-noise (SNR) ratios. Three periods can be distinguished, see also the information on the PO.DAAC website: https://podaac.jpl.nasa.gov/dataset/RSCAT_L1B_V1.3:

1. Data from 10 Oct 2014 to 15 Aug 2015 are high SNR
2. Data from 19 Aug 2015 to 11 Feb 2016 are low SNR period 1
3. Data from 11 Feb 2016 to 19 Aug 2016 are low SNR period 2

The periods are indicated with horizontal bars in Figure 3 which indicate the averages for that period. The standard deviations increase in period 2 and then further in period 3 due to the lower SNR ratios that result in noisier wind retrievals. In Figure 4 the wind component standard deviations for the 50 km RapidScat are shown. Clearly, the standard deviations hardly increase for this product. This is due to the spatial backscatter averaging over a much larger area (four times as large), resulting in less noisy backscatter values and winds.

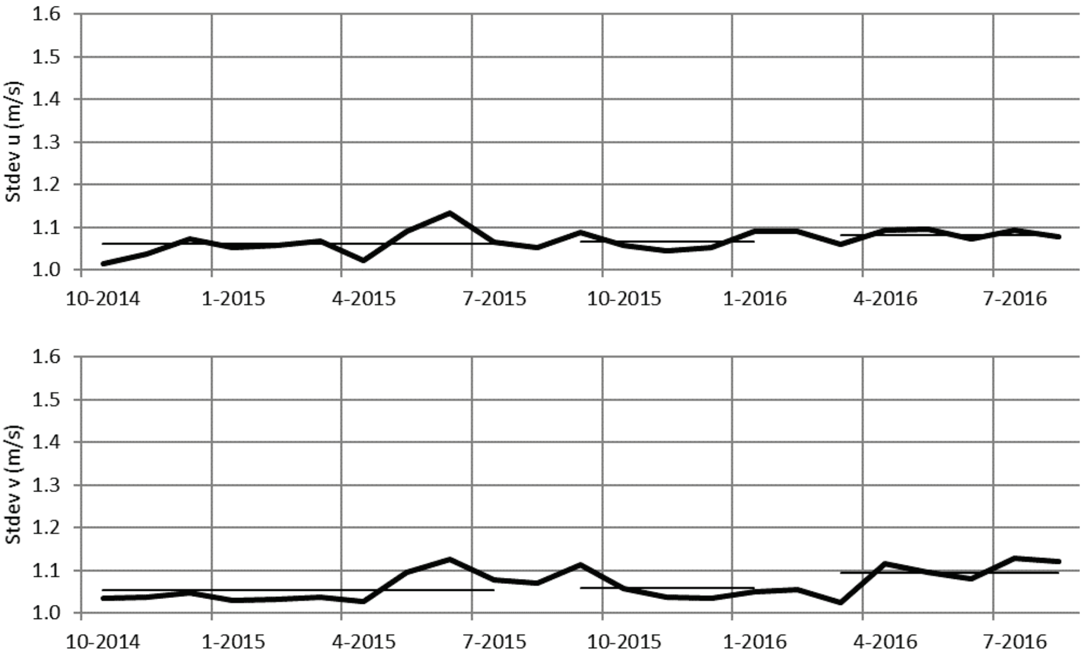


Figure 4: Standard deviation of zonal wind component (top) and standard deviation of meridional wind component (bottom) of 50 km RapidScat winds versus ECMWF ERA5 model U10S wind forecasts. The plotted values are monthly averages.

The plots for the 50 km products are not shown here, apart for the RapidScat result in Figure 4. They generally show the same trends as the corresponding 25 km plots but generally lower standard deviations. These smaller standard deviations are due to the limited effective spatial resolution of the ERA5 winds. The 25 km wind product resolves small scale features which are to a lesser extent present in the 50 km wind product and absent in the NWP model. Hence it can be expected that the 50 km scatterometer winds closer resemble the model winds and that the standard deviations are smaller.

Table 1 summarises the statistics for all 25 km and 50 km products. It is difficult to directly compare the standard deviations of the three missions. They represent different periods in time and as shown above, the quality of the ERA5 winds improves over time. Hence the lower standard deviations of RapidScat (period 1) and Oceansat-2 are probably mainly due to the changes in ERA5 than to difference in scatterometer wind characteristics.

In summary, all wind speed biases and wind component standard deviations are all well within the OSI SAF requirements: better than 2 m/s in wind component standard deviation with a bias of less than 0.5 m/s in wind speed.

	speed bias	stdev *u*	stdev *v*
25 km SeaWinds	0.08	1.28	1.26
25 km Oceansat-2	0.02	1.26	1.23
25 km RapidScat period 1	-0.01	1.22	1.24
25 km RapidScat period 2	-0.03	1.31	1.39
25 km RapidScat period 3	-0.04	1.43	1.57
50 km SeaWinds	0.08	1.12	1.09
50 km Oceansat-2	0.02	1.10	1.07
50 km RapidScat period 1	-0.01	1.06	1.05
50 km RapidScat period 2	-0.02	1.07	1.06
50 km RapidScat period 3	-0.02	1.08	1.09

Table 1: ECMWF comparison results of 25 km and 50 km wind products over their full mission lifetime or over the different SNR periods for RapidScat.

3. Buoy validations

In this section, 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 [9]. 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 ([9], [10]) in order to enable a good comparison with the 10-m scatterometer winds. Unlike the NWP winds, the equivalent neutral buoy winds have not been further converted into stress-equivalent winds since only few buoys always report the necessary parameters (pressure, humidity and air temperature).

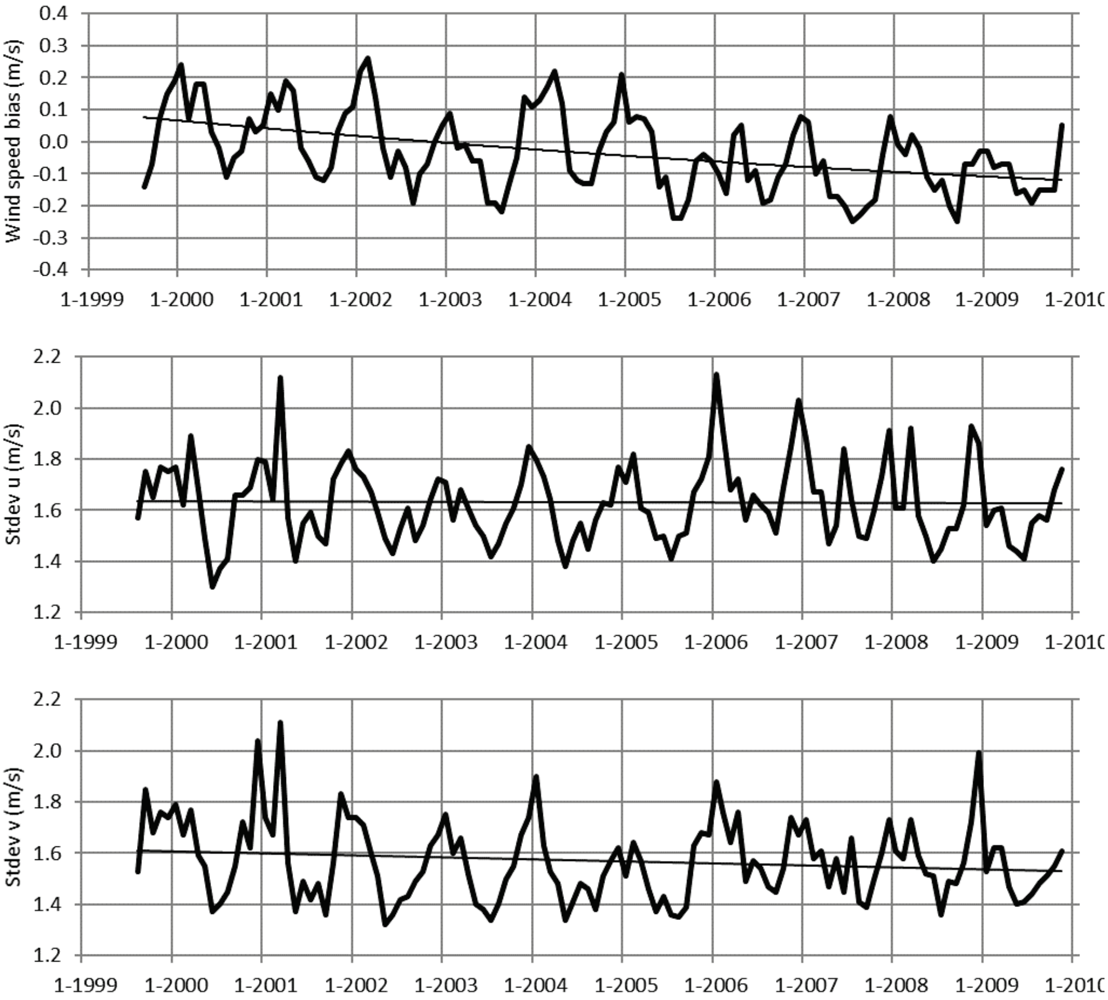
A scatterometer wind and a buoy wind measurement are considered to be collocated if the distance between the WVC centre and the buoy location is less than the WVC spacing divided by $\sqrt{2}$ and if the acquisition time difference is less than 30 minutes. Note that the collection of available buoy data 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, For SeaWinds and Oceansat-2 we have taken a sub-set of the available buoys, containing only buoys that have produced wind data in every year of the mission’s lifetimes. For RapidScat all available buoys were used since this mission spans only two years. The buoys used in the validation of the three missions are listed in Appendix A and maps of the buoy locations can also be found there.

Figure 5 shows the wind statistics of SeaWinds 25 km winds versus buoy winds and the monthly number of buoys available for collocations. A clear seasonal oscillation is visible for the wind speed bias and wind component standard deviations. Seasonal weather variations cause differences in the distribution 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 the previous reprocessing [4] we know that the oscillations appear stronger when we look at the wind speed bias for the extratropical buoys in the northern hemisphere. When we consider the wind speed biases for the tropical buoys only, we see only a very weak seasonal oscillation. So the oscillations are indeed connected with seasonal variations in the extratropic regions.

It is clear from the top plot in Figure 5 that the wind speed bias of scatterometer winds versus buoy winds gradually decreases over the QuikSCAT era, whereas the wind speed bias versus ERA5 winds hardly decreases (Figure 1). In [4] and [6], the QuikSCAT wind speed biases, based on the previous OSI SAF reprocessing, have been further investigated. The average scatterometer, buoy, and ECMWF wind speeds have been assessed separately in the extratropics and in the tropics. It was found that in the tropics, the scatterometer and buoy winds both decrease over time, and that the scatterometer winds decrease stronger than the buoy winds. Such wind speed climatology changes and changes in wind speed distributions may well cause a decrease in the wind speed bias. In the extratropics, the average wind speeds from both systems were quite constant over time.

In 2004 the number of available buoys was quite low as can be seen in the 4th plot of Figure 5, mainly due a lack of tropical buoy data from the ECMWF MARS archive. This has less impact on the number of monthly collocations (bottom plot) and appears to have little impact on the wind statistics. The wind component standard deviations in Figure 5 are quite constant over time, indicating that the wind quality of both observing systems does not change much. Compared to the previous reprocessing, the average wind component standard deviations have decreased from 1.68 m/s to 1.63 m/s for the zonal component (*u*) and from 1.63 m/s to 1.57 m/s for the meridional component (*v*), i.e., an improvement of approximately 0.05 m/s for both components. These numbers are obtained against the same reference observation system and hence we consider this a significant improvement of the wind data record as compared to the previous version.



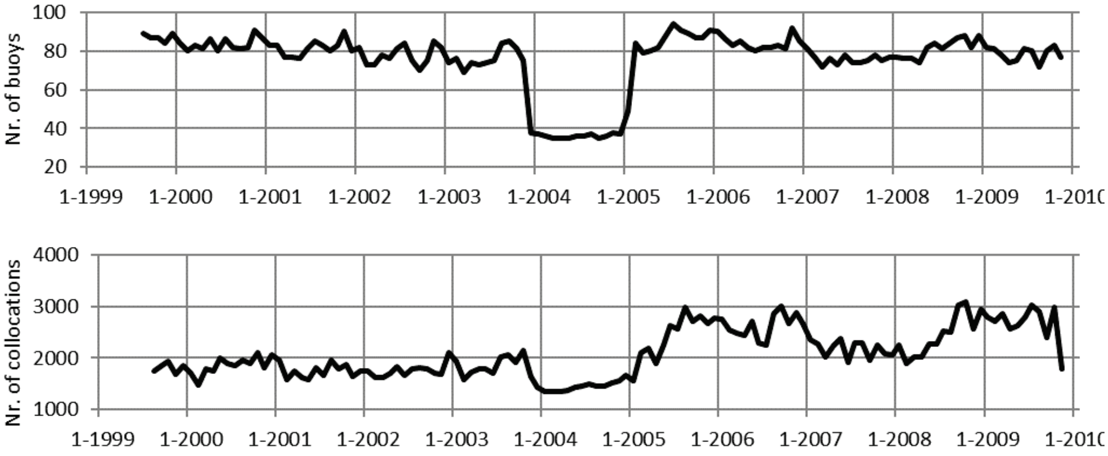
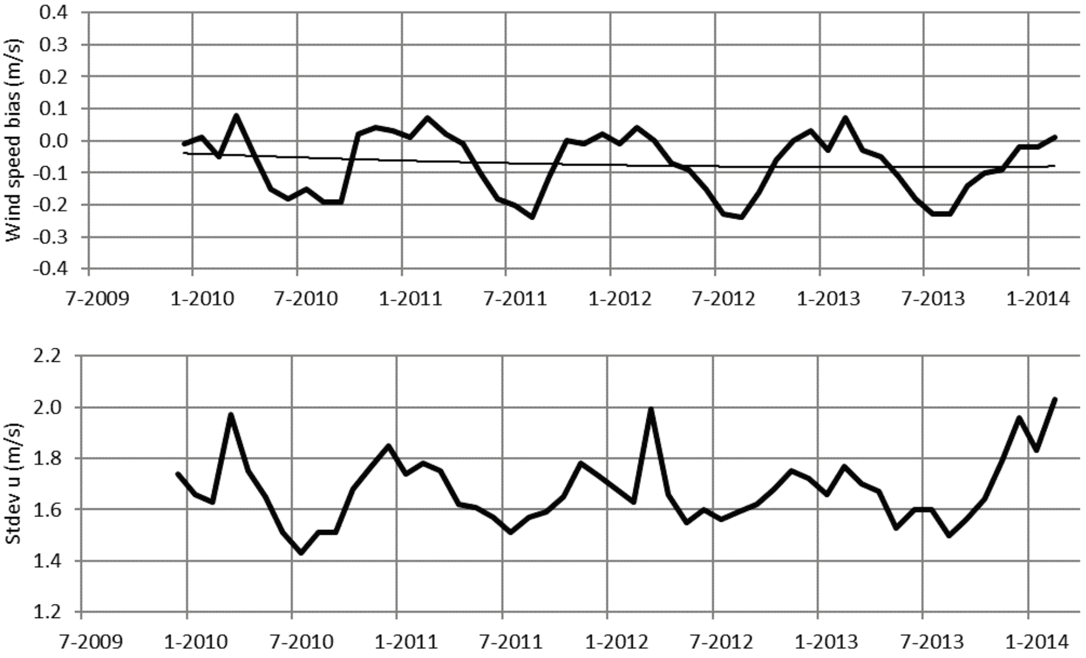


Figure 5: Wind speed bias (top), standard deviation of zonal wind component (2nd plot), standard deviation of meridional wind component (3rd plot), number of buoys used (4th plot), and number of available collocations (bottom) for 25 km SeaWinds winds versus buoy winds. The plotted values are monthly averages or totals.

Figure 6 shows the wind statistics of Oceansat-2 winds versus buoy winds and the monthly number of buoys available for collocations. The number varies by up to 10% over most of the time, except for the last few months of the mission period, where a more significant decrease is observed. A seasonal oscillation is visible which is comparable to what is observed for SeaWinds. The top plot in Figure 6 shows that the wind speed bias of Oceansat-2 winds versus buoy winds slightly decreases over the reprocessing period, but the trend appears to be even smaller than in the wind speed bias versus ERA5 winds (Figure 2 top).



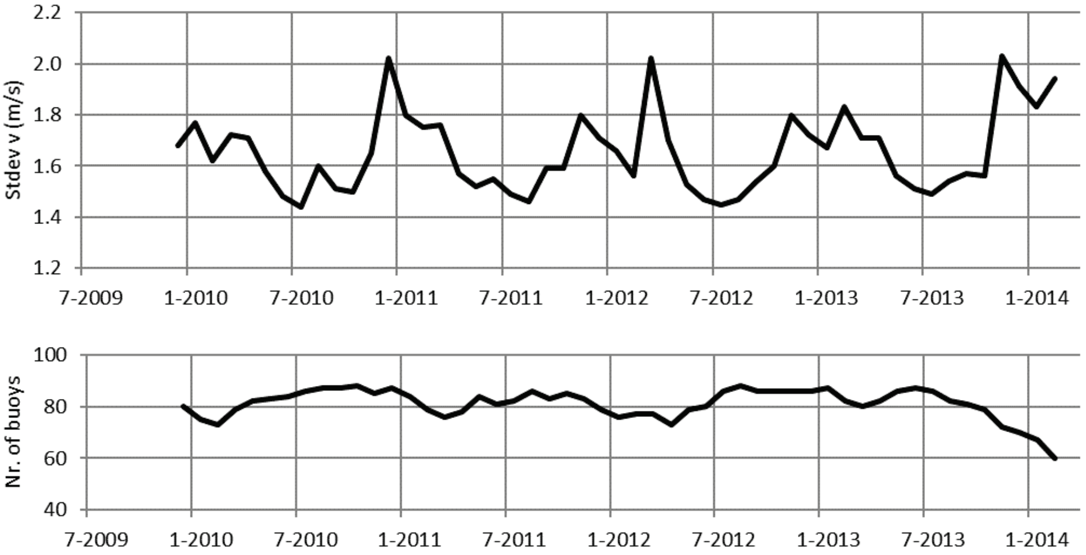
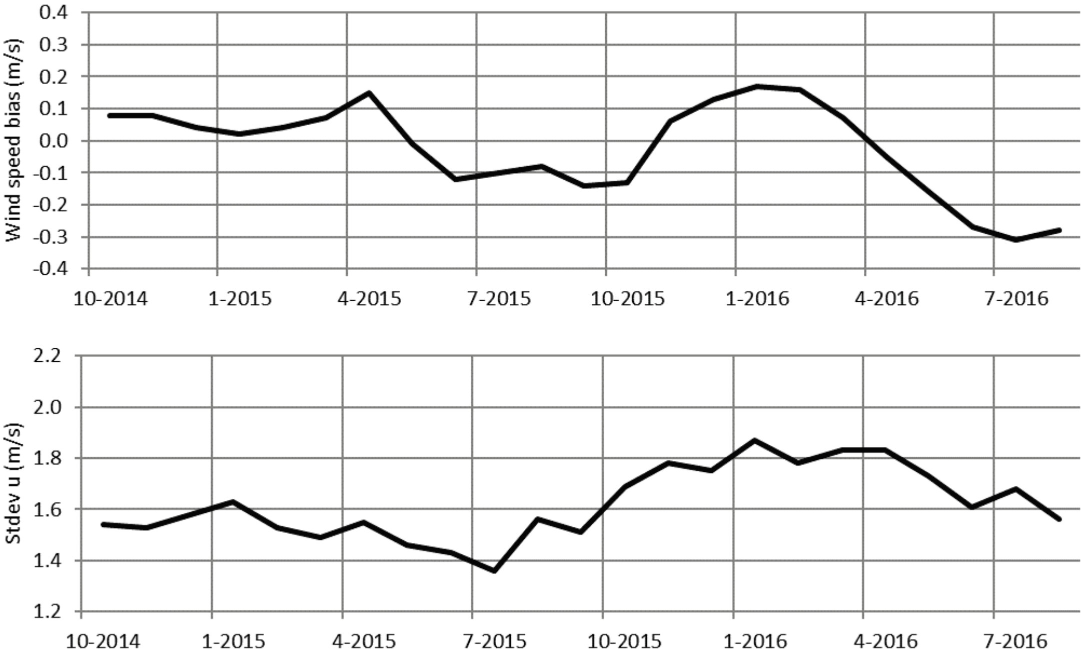


Figure 6: Wind speed bias (top), standard deviation of zonal wind component (2nd plot), standard deviation of meridional wind component (3rd plot), and number of buoys used (bottom) for 25 km Oceansat-2 winds versus buoy winds. The plotted values are monthly averages or totals.

The average OSCAT zonal and meridional component standard deviations are 1.68 and 1.65 m/s, respectively. This is slightly higher than the results for SeaWinds (1.63 and 1.57 m/s), but significantly lower than the standard deviations obtained in the first reprocessing: 1.80 and 1.79. Hence the values in the new data record are lower by more than 0.1 m/s, an even stronger improvement than for SeaWinds.



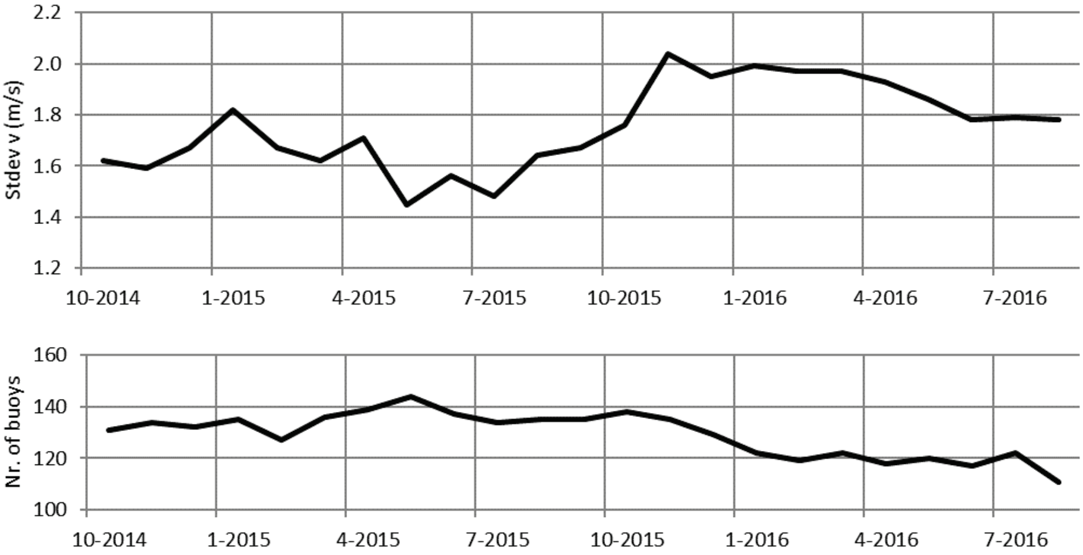


Figure 7: Wind speed bias (top), standard deviation of zonal wind component (2nd plot), standard deviation of meridional wind component (3rd plot), and number of buoys used (bottom) for 25 km RapidScat winds versus buoy winds. The plotted values are monthly averages or totals.

Figure 7 shows the wind statistics of RapidScat winds versus buoy winds and the monthly number of buoys available for collocations. The numbers are higher for RapidScat since no filtering for buoy availability over the mission time span was done. The fluctuations in bias and standard deviations are quite significant, this is partly due to the seasonal oscillations and partly due to the changing instrument characteristics (varying SNR) over the mission lifetime. The wind component standard deviations are clearly higher in the low SNR periods (2 and 3) as of August 2015.

	speed bias	stdev *u*	stdev *v*
25 km SeaWinds	-0.03	1.63	1.57
25 km Oceansat-2	-0.07	1.68	1.65
25 km RapidScat period 1	0.03	1.51	1.62
25 km RapidScat period 2	0.02	1.72	1.88
25 km RapidScat period 3	-0.17	1.71	1.85
50 km SeaWinds	0.01	1.68	1.66
50 km Oceansat-2	-0.03	1.71	1.72
50 km RapidScat period 1	0.07	1.59	1.67
50 km RapidScat period 2	0.06	1.71	1.80
50 km RapidScat period 3	-0.05	1.54	1.64

Table 2: Buoy comparison results of 25 km and 50 km wind products over their full mission lifetime or over the different SNR periods for RapidScat.

In Table 2 the wind speed bias and wind component standard deviations of the 25 km and 50 km products are summarised. The time series for the 50 km products generally show the same trends as those for the 25 km products and are not shown here. The table shows that the wind component standard deviations for 25 km are generally slightly lower than those for the corresponding 50 km products. The higher resolution 25 km winds contain more small scale features and hence better mimic the local point measurements of the buoys. The standard deviations are smallest for RapidScat in its high SNR period (1), but the differences with Oceansat-2 and SeaWinds are small and can probably partly be attributed to the sampling: this period spans less than a year of data and uses a different set of buoys.

4. Triple collocation results

A triple collocation study was performed to initially assess the errors of the scatterometer, ECMWF and buoy winds independently. The triple collocation method was introduced by Stoffelen [11]. 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, from the intermediate resolution scatterometer perspective, or from the fine resolution buoy perspective when using an estimated buoy observation error, mainly constituted by the spatial representativeness error of buoy data for a scatterometer WVC. How to deal with errors of spatial representation is extensively discussed in [12].

Collocated data sets of scatterometer 25 km and 50 km, ECMWF and buoy winds spanning the mission lifetimes were used in the triple collocation. Table 3 lists the error standard deviations of the buoy, scatterometer and ECMWF winds from the intermediate resolution scatterometer perspective. When we compare the 50 km products with the corresponding 25 km products, we see an increase of the buoy wind error standard deviations and a decrease of the ECMWF wind standard deviations. This is due to the coarser resolution of the 50 km products, which contain less small scale information and in this respect resemble better the ECMWF winds and resemble worse the local buoy winds. The errors of the 25 km scatterometer winds are larger than those of the 50 km winds. This is most probably due to the larger noise in the 25 km wind retrievals.

The error standard deviations for RapidScat are significantly higher than those of the corresponding SeaWinds and Oceansat-2 products, in particular for the 25 km products, see Table 3. This is mainly due to the later low SNR periods of the instrument, where we also found higher standard deviations w.r.t. ERA5 winds and buoy winds (sections 2 and 3). Inspection of the detailed results as a function of time reveals that the error standard deviations for 25 km in the high SNR period are around 0.50 m/s, close to those from SeaWinds.

	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 SeaWinds	0.59	0.41	1.26	1.31	1.04	1.10
25 km Oceansat-2	0.69	0.56	1.26	1.31	0.98	1.02
25 km RapidScat	0.74	0.80	1.24	1.32	0.98	0.94
50 km SeaWinds	0.48	0.25	1.38	1.44	0.94	0.98
50 km Oceansat-2	0.54	0.38	1.37	1.43	0.90	0.93
50 km RapidScat	0.48	0.47	1.34	1.41	0.91	0.87

Table 3: Error standard deviations in u and v wind components from triple collocation of scatterometer 25 km and 50 km wind products with buoy and ECMWF ERA5 forecast winds, seen from the scatterometer perspective. The results were obtained for the entire mission lifetimes.

As compared to the products from previous reprocessing, the SeaWinds error standard deviations are lower now by ~0.08 m/s (25 km) and ~0.05 m/s (50 km) [4]. For Oceansat-2, the error standard deviations are lower now by ~0.13 m/s (25 km) and ~0.08 m/s (50 km) [5]. We attribute this to the improvements in the wind retrievals that have been implemented in this reprocessing, see Section 2 in the Product User Manual [3].

The scatterometer winds are all of good quality: at 25 km scale the error in the wind components is less than 0.8 m/s; at 50 km scale it is less than 0.55 m/s. It is clear from Table 3 that the ERA5 wind component standard deviations decrease over time: they are lower for Oceansat-2 products (2009-2014) than for SeaWinds products (1999-2009), and lower for RapidScat products (2014-2016) than for Oceansat-2 and SeaWinds products. We attribute this to the improving ERA5 winds over time due to the availability of more and more satellite observations that have been assimilated in the model.

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. The calibrations have been computed per year to see if there is any trend or glitch visible indicating instrument changes over time, see Figure 8 and Figure 9. The scaling factors *a* indicate whether the scatterometer and ECMWF winds are underestimated ($a > 1$) or overestimated ($a < 1$).

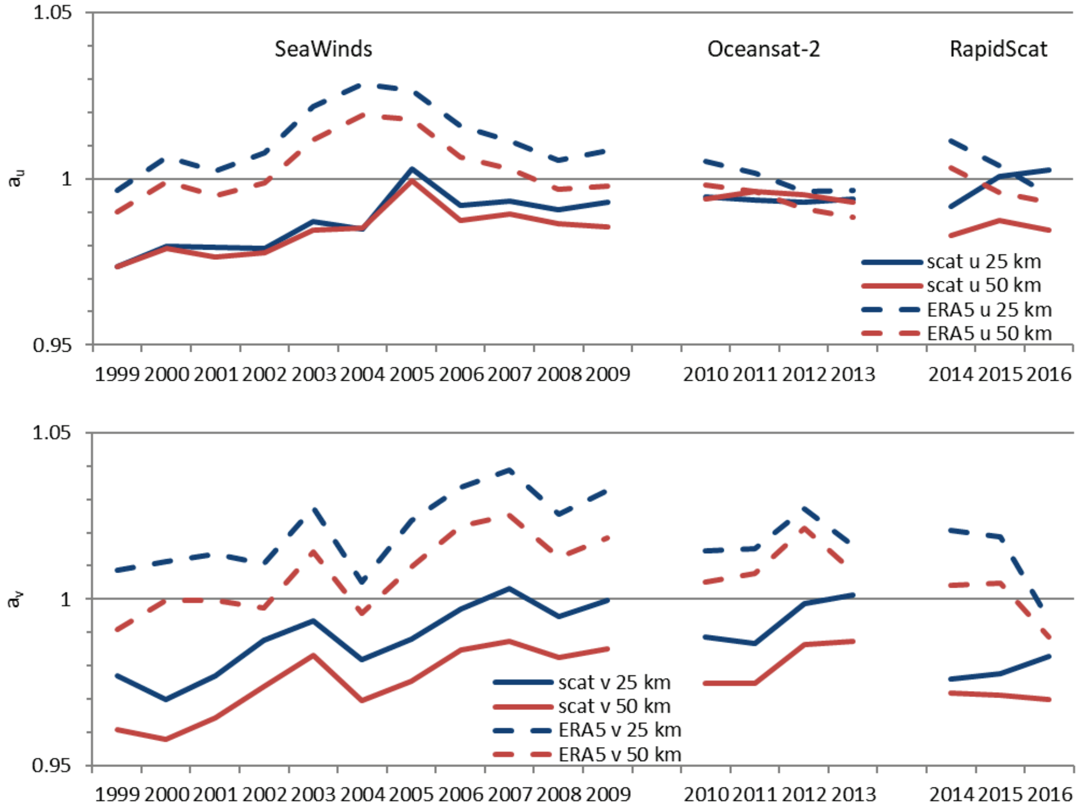


Figure 8: Triple collocation results for the wind component calibration scaling a for zonal wind (top) and meridional wind (bottom) scatterometer and the ECMWF winds relative to the buoy measurements, per year.

For all instruments, we generally see scaling values *a* close to 1. For SeaWinds, apart from some yearly variations, a small increasing trend appears to be present in the calibration coefficients of both ECMWF and scatterometer wind components. This indicates that the ECMWF and scatterometer wind speeds gradually decrease when compared with the buoy winds, that are taken as reference and assumed to be constant over time. This is in line with the results from sections 2 and 3. For Oceansat-2, the years 2009 and 2014 have been neglected here since only few data are available in those years. A small increasing trend appears to be present in the calibration coefficients (mainly of the meridional winds, *v*) of both ECMWF and scatterometer wind components. The bias values *b* are generally close to zero and no significant trends can be discerned in Figure 9.

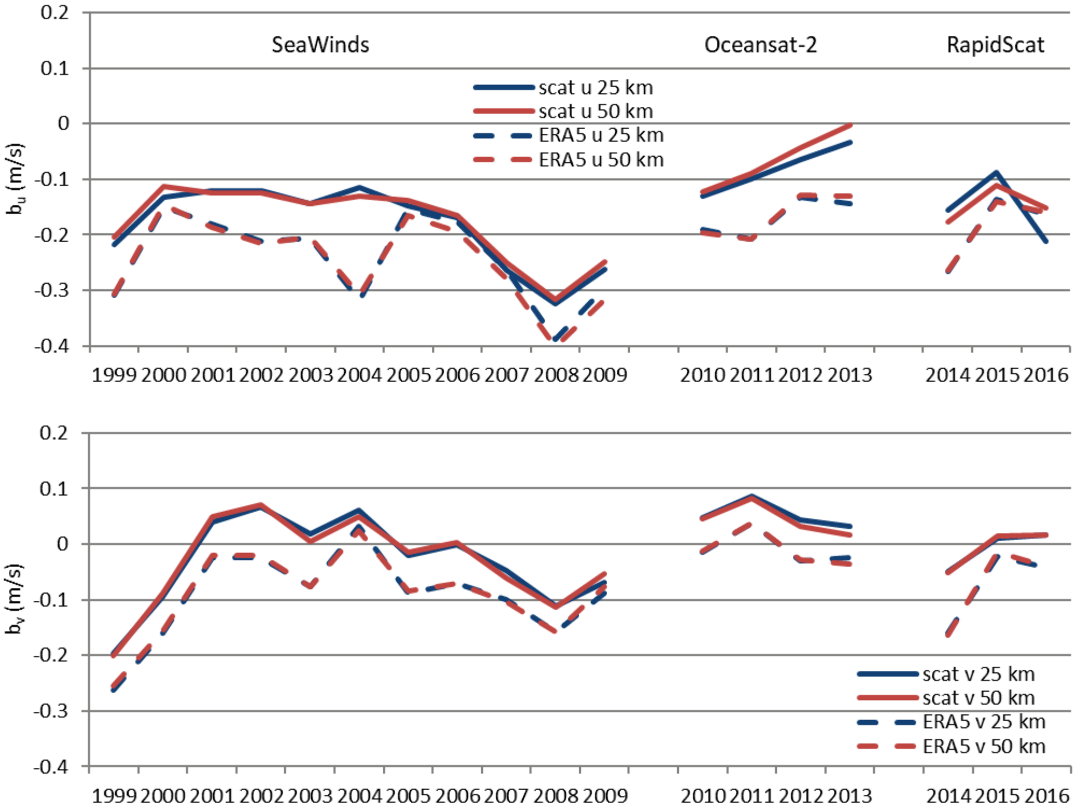


Figure 9: Triple collocation results for the wind component calibration bias b for zonal wind (top) and meridional wind (bottom) scatterometer and the ECMWF winds relative to the buoy measurements, per year.

5. Conclusions

The quality and stability of the OSI SAF Ku-Band 25 km and 50 km wind data records from SeaWinds, Oceansat-2 and RapidScat have been validated. The three missions together provide scatterometer winds almost continuously from July 1999 to August 2016.

The requirements as set by the World Climate Research Programme (WCRP) [13] are: accuracy better than 0.5 m/s, stability better than 0.1 m/s per decade. The accuracy requirement appears to be easily met by all three data records. The SeaWinds scatterometer wind bias against buoy winds shows a gradual decrease of 0.10 to 0.15 m/s over 10 years, however such decrease is not found in the bias against ERA5 winds. The analysed SeaWinds backscatter and wind changes [4] also suggest a drop in instrumental bias of no more than 0.1 dB (equivalent to 0.1 m/s) in ten years, which meets the stability requirement. The Oceansat-2 and RapidScat data records are too short to decide about the stability requirement. Still we think that these data records are a useful contribution to the collection of OSI SAF reprocessed wind data records.

From the figures in sections 2 and 3, 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 RapidScat winds, in particular the 25km data, show a decreasing quality in the low SNR periods (after 15 August 2015 until the end of the mission), however these winds are still within the product requirements.

The triple collocation results show that the scatterometer winds are of good quality, well calibrated and sufficiently stable over the mission period.

6. Abbreviations and acronyms

CDR	Climate Data Record
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA	ECMWF re-analysis
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GTS	Global Telecommunication System
ISRO	Indian Space Research Organisation
ISS	International Space Station
JPL	Jet Propulsion Laboratory
KNMI	Royal Netherlands Meteorological Institute
LKB	Liu, Katsaros and Businger
MARS	Meteorological Archival and Retrieval System from ECMWF
NWP	Numerical Weather Prediction
Oceansat-2	Indian Scatterometer mission carrying an OSCAT scatterometer
OSCAT	Scatterometer on-board the Oceansat-2 and ScatSat-1 satellites (India)
OSI SAF	Ocean and Sea Ice SAF
PenWP	Pencil Beam wind Processor
QC	Quality Control
QuikSCAT	US Quick Scatterometer mission carrying the SeaWinds scatterometer
RapidScat	US scatterometer on-board the International Space Station
SAF	Satellite Application Facility
ScatSat-1	Indian Scatterometer mission carrying an OSCAT scatterometer
u	West-to-east (zonal) wind component
v	South-to-north (meridional) wind component
WMO	World Meteorological Organisation
WVC	Wind Vector Cell

7. Appendix A: Lists of used buoys

This section lists the buoys used in the validations and triple collocations in sections 3 and 4. The buoy locations can be looked up on https://www.ndbc.noaa.gov/ and are shown in the figures. For SeaWinds and Oceansat-2, only buoys yielding data in each year of the mission have been used. For RapidScat, since it had a lifetime of less than two years, all available buoys have been used.

13008
15001
15002
32303
32304
32305
32315
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32317
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32320
32321
32322
32323
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41009
41010
41026
42001
42002
42020
42035
42036
42039
42040
43001
43301
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44008
44009
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44025
44140
44141
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46001
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46132
46147
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46206
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52079
52309
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52315
52316
52321
61001
62001
62029
62081
64046

Table 4: List of 101 buoy identifiers used for SeaWinds validations.

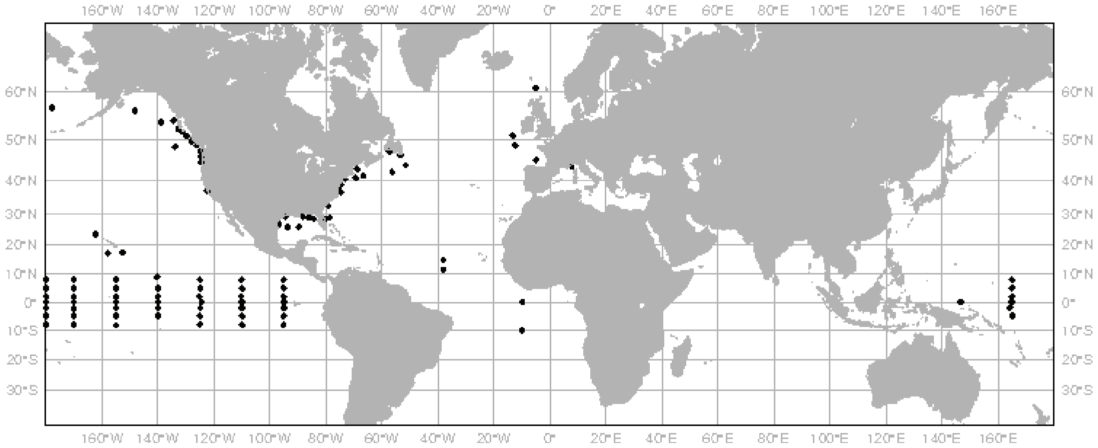

Figure 10: Locations of the moored buoys used for SeaWinds validations.

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13010
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31005
32303
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32316
32319
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42019
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42057
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43301
44009
44024
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44037
44137
44139
44141
44251
44255
46001
46004
46012
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46206
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51009
51015
51021
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51307
51311
52001
52004
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61002
62001
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62094
62105
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64045

Table 5: List of 106 buoy identifiers used for Oceansat-2 validations.

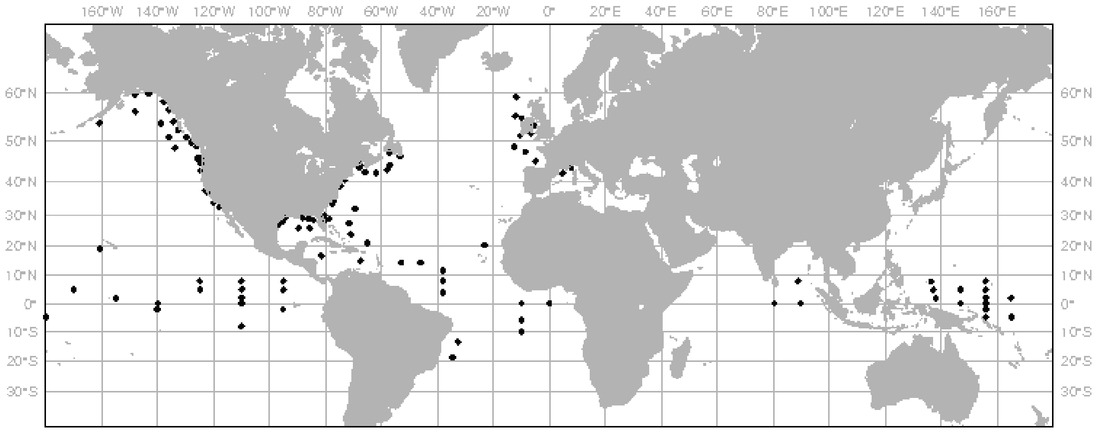

Figure 11: Locations of the moored buoys used for Oceansat-2 validations.

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14046
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15002
15006
23001
23002
23003
23004
23005
23006
23007
23008
23010
23017
23092
23097
23459
23460
31001
31002
31003
31004
32303
32304
32305
32315
32316
32317
32318
32319
32320
32321
32322
32323
41001
41002
41004
41009
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41013
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41043
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41048
41049
42002
42003
42019
42020
42035
42036
42039
42040
42055
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42058
42059
42060
43001
43301
44005
44008
44009
44011
44014
44017
44018
44025
44027
44037
44066
44137
44139
44141
44150
44251
44255
46001
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51002
51003
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61002
62001
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62163
66021

Table 6: List of 188 buoy identifiers used for RapidScat validations.

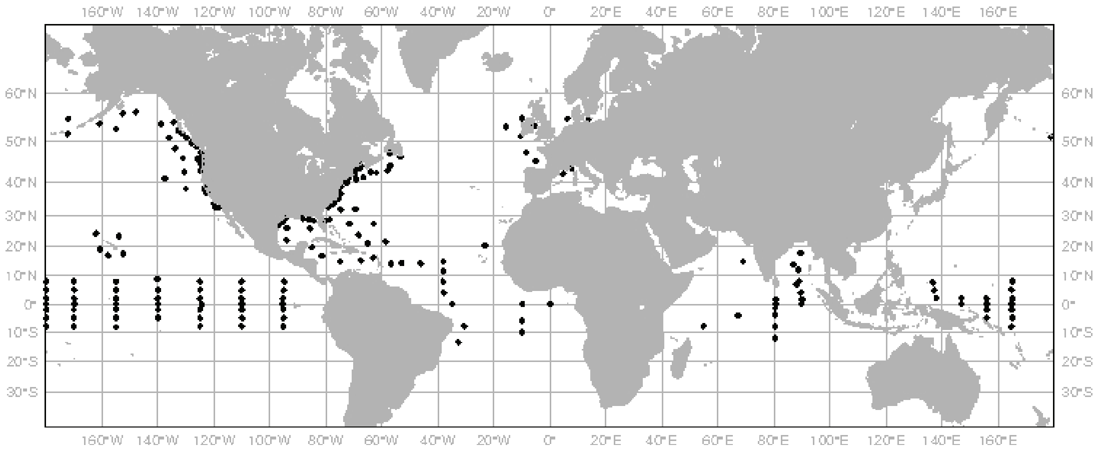

Figure 12: Locations of the moored buoys used for RapidScat validations.