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OSI SAF
OCEAN AND SEA ICE

ScatSat-1 wind validation report

25 km (OSI-112-a) and 50 km (OSI-112-b) wind products

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1. Introduction

The OSCAT scatterometer instrument is mounted on the ScatSat-1 satellite which was launched on September 26th, 2016 by the Indian Space Research Organisation (ISRO). The Ku-band pencil beam OSCAT instrument has some enhanced features compared to OSCAT on Oceansat-2 which was launched in 2009. The level 1b files from ISRO are processed by KNMI into 25 km and 50 km level 2 wind products.

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 OSI SAF delivers development status level 2 wind products with 25 and 50 km Wind Vector Cell (WVC) spacing in near-real time [3], based on the ScatSat-1 scatterometer level 1b products, kindly provided by the Indian Space Research Organisation (ISRO). See the ISRO documentation [4], [5] for more information on the level 1b product characteristics.

As part of an international Cal/Val effort the ScatSat-1 scatterometer level 1b products have been intercalibrated with other scatterometers. Nevertheless, KNMI implemented a few backscatter corrections [3] in order for our standard processing to provide wind distributions compatible with earlier and ongoing scatterometer missions, e.g., ASCAT.

In this report, we assess the quality of the OSI SAF wind products. We compare the scatterometer wind data with ECMWF model data in section 2 and with in situ wind data from moored buoys in section 3. A triple collocation exercise is done as well and presented in section 4. Section 5 summarises the main conclusions.

The results presented in this report are encouraging and warrant the release of the 25 and 50 km wind products.

1.1. Acknowledgement

ISRO kindly provides the ScatSat-1 level 1b data which are used as input for the OSI SAF wind products. We are grateful to Jean Bidlot of ECMWF for helping us with the buoy data retrieval and quality control.

2. Product characteristics and comparison with NWP model wind data

Figure 1 shows an example of a ScatSat-1 wind field, as visualized on www.knmi.nl/scatterometer. It is clear that the Quality Control (QC) mechanism is well capable to flag rainy WVCs: the orange dots generally well correspond to the cloudy areas where heavy rain can be expected. Some winds near the centre of the cyclonic structure are considered as meteorologically inconsistent and flagged by the variational QC flag (orange coloured arrows). The QC optimizes misses and false alarms to keep high-quality winds and reject winds of inferior quality.

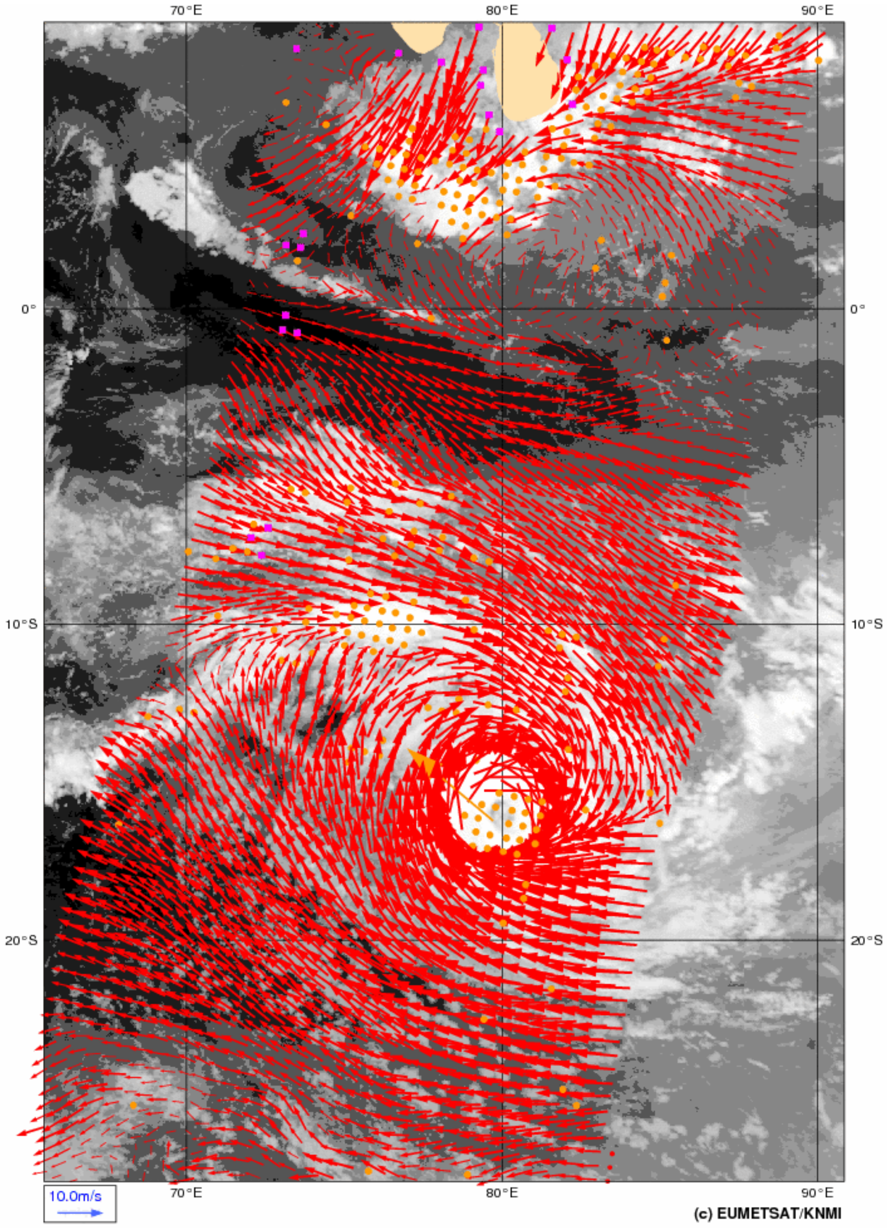

Figure 1: Example of 25 km ScatSat-1 product, thinned to 50 km, over the Indian Ocean at 30 January 2018 3:30 UTC, overlaid on a Meteosat 8 IR satellite image at 2:45 UTC. The purple squares correspond to WVCs where the land flag is set, but where reliable winds can still be computed, the orange dots correspond to WVCs that have been rejected by QC due to inconsistencies between backscatter data and wind GMF, and the orange arrows correspond to WVCs where the variational QC flag is set due to spatial inconsistencies.

Figure 2 shows two-dimensional histograms of the retrieved winds versus ECMWF 10 m wind background for the 25 km wind product, after rejection of Quality Controlled (KNMI QC flagged) wind vectors. The data for these plots are from 29 consecutive orbits from 4 to 5 April 2018. Due to the large daily number of collocations with the model data, two days is sufficient to obtain reliable statistics. The seasonal oscillations are also known to be quite small for these type of comparisons [6].

The top left plot corresponds to wind speed (bins of 0.5 m/s) and the top right plot to wind direction (bins of 2.5°). The latter are computed only for ECMWF winds larger than 4 m/s. The bottom plots show the *u* and *v* wind component statistics (bins of 0.5 m/s). The contour lines are in logarithmic scale. The ECMWF winds are stress equivalent 10 m winds to best represent the retrieved scatterometer winds. Figure 3 shows the comparisons of 50 km ScatSat-1 winds with ECMWF winds in the same way as in Figure 2.

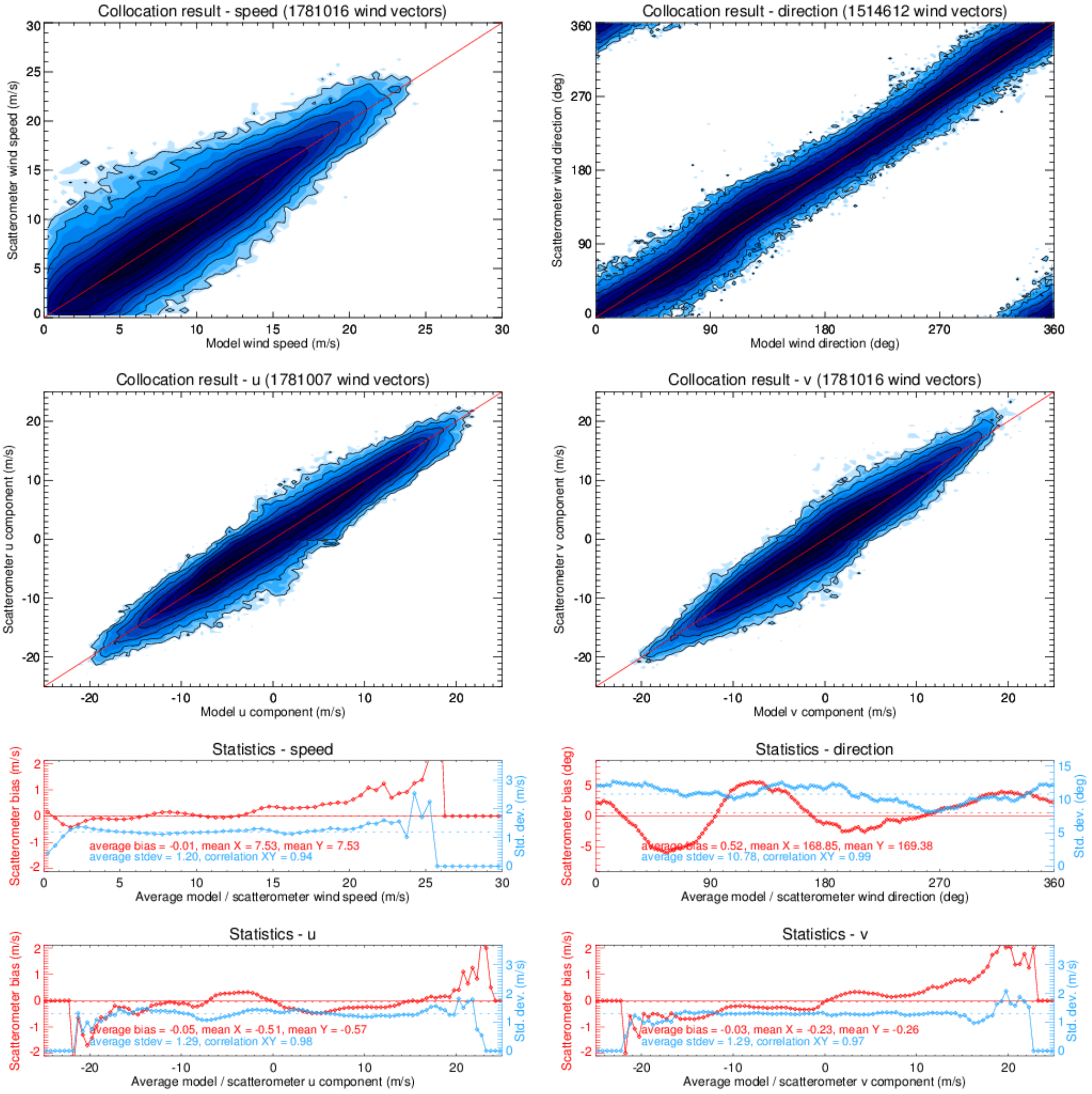

Figure 2: Two-dimensional histograms of wind speed, direction (w.r.t. wind coming from the North), u and v components of 25 km ScatSat-1 wind product versus the ECMWF model forecast winds from 4-5 April 2018 (top panels). The corresponding biases (red) and standard deviations (blue) as a function of the average scatterometer and model winds are shown in the bottom. The bias is set to 0 for empty bins, and standard deviation is set to 0 if bins contain less than two data points.

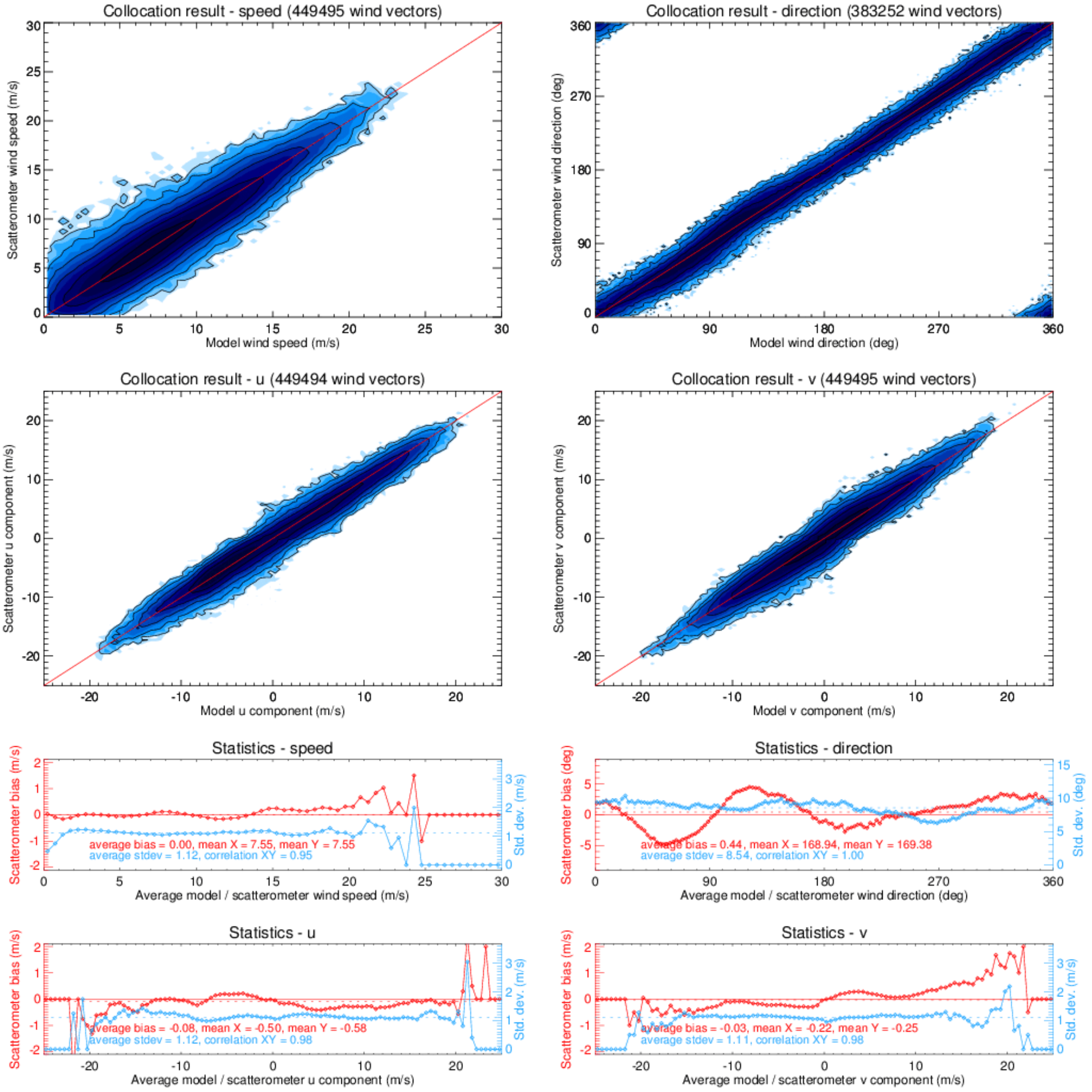

Figure 3: Two-dimensional histograms of wind speed, direction (w.r.t. wind coming from the North), u and v components of 50 km ScatSat-1 wind product versus the ECMWF model forecast winds from 4-5 April 2018 (top panels). The corresponding biases (red) and standard deviations (blue) as a function of the average scatterometer and model winds are shown in the bottom. The bias is set to 0 for empty bins, and standard deviation is set to 0 if bins contain less than two data points.

We note two remaining limitations in these plots. First, the wind direction bias modulation of about 10 degrees, which is partially related to systematic biases in global NWP models for stable stratification. On top of that, there are shortcomings in the wind direction modulation of the NSCAT-4 Geophysical Model Function, leading to systematic wind direction errors. There are also wind direction retrieval difficulties in the nadir swath due to poor beam azimuth separation. This leads to wind direction 'attractors' in the retrievals. Research is ongoing to reduce these errors.

The second limitation is that, although we apply a correction for backscatter values above -19dB, correcting winds above 15 m/s, positive zonal wind component biases remain for high winds. These issues are addressed in current developments, but do pose a major problem to the value of current ScatSat-1 wind data.

The results in terms of wind speed bias and *u* and *v* wind component standard deviations are summarised in Table 1 for the 25 km and 50 km wind products. As reference, the statistics of the OSI SAF QuikSCAT/SeaWinds wind product (25 km) and Oceansat-2/OSCAT wind product (50 km) from comparable periods in 2009 and 2012 are shown as well. The ScatSat-1 wind speed biases are close to the expected value of 0.00 m/s. The 50 km ScatSat-1 wind components compare slightly better to ECMWF than the 25 km ScatSat-1 wind components. This is in line with the relatively coarse effective resolution of the ECMWF model data [11].

It is also clear from Table 1 that the wind component standard deviations are smaller for ScatSat-1 than for SeaWinds and for OSCAT. This is most probably due to the better quality and higher resolution of the ECMWF operational model winds used in the ScatSat-1 comparisons. The reprocessed QuikSCAT and Oceansat-2 winds have been compared with ECMWF ERA-Interim winds on a lower spatial resolution and made with an older version of the Integrated Forecasting System. So it is hard to directly compare the numbers in Table 1, but they clearly indicate that ScatSat-1 winds show at least similar or even better overall statistics as compared to those of earlier Ku-band instruments.

The ScatSat-1 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.

	# of wind vectors	speed bias	stdev *u*	stdev *v*
25 km ScatSat-1	**1,781,016**	**-0.01**	**1.29**	**1.29**
25 km Oceansat-2	1,782,786	0.03	1.50	1.53
25 km SeaWinds	1,666,001	0.02	1.41	1.41
50 km ScatSat-1	**449,495**	**0.00**	**1.12**	**1.11**
50 km Oceansat-2	445,188	0.02	1.36	1.37
50 km SeaWinds	411,368	0.02	1.27	1.29

Table 1: ECMWF comparison results of ScatSat-1 25 km and 50 km wind products from 4 to 5 April 2018, compared with OSI SAF Oceansat-2 reprocessed wind products from 4 to 5 April 2013 [7] and with reprocessed SeaWinds wind products from 4 to 5 April 2009 [6].

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 [8]. We used a set of approximately 160 moored buoys spread over the oceans, most of them in the tropical oceans and near Europe and North America. These buoys are also used in the validations that are routinely performed for the OSI SAF wind products; see the links on http://www.knmi.nl/scatterometer/osisaf/. 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 ([8], [9]) in order to enable a good comparison with the 10-m scatterometer winds.

See Figure 4 for the locations of the buoys used in the comparisons. 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 √2 and if the acquisition time difference is less than 30 minutes.

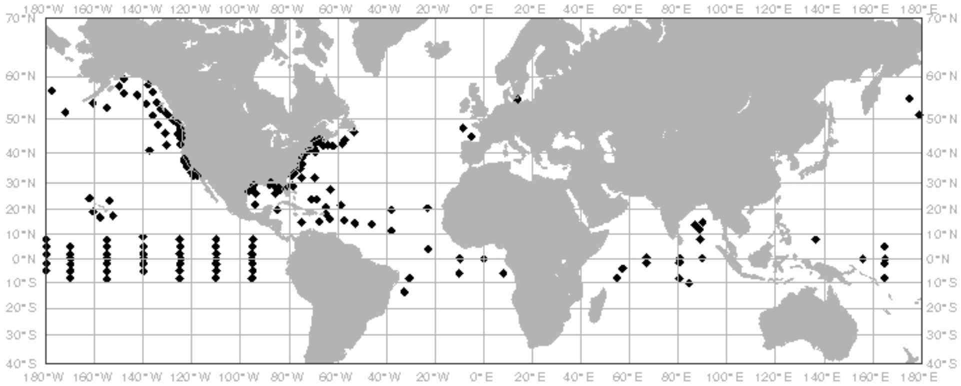

Figure 4: Locations of the moored buoys used in the comparisons.

	# of wind vectors	speed bias	stdev *u*	stdev *v*
25 km ScatSat-1	**23148**	**0.13**	**1.83**	**1.76**
25 km Oceansat-2	36985	-0.09	1.85	1.82
25 km SeaWinds	39240	-0.16	1.72	1.68
50 km ScatSat-1	**23405**	**0.16**	**1.85**	**1.80**
50 km Oceansat-2	37126	-0.03	1.84	1.83
50 km SeaWinds	41558	-0.14	1.73	1.70

Table 2: buoy comparison results of ScatSat-1 25 km and 50 km wind products from October 2016 to July 2017, compared with reprocessed Oceansat-2 wind products from October 2012 to July 2013 [7] and reprocessed SeaWinds wind products from October 2008 to July 2009 [6].

In Table 2 we show the wind speed bias and wind component standard deviations of the 25 km and 50 km ScatSat-1 wind products, obtained from an off-line ISRO v1.1.3 dataset. For comparison, we also show the results of the OSI SAF reprocessed Oceansat-2 and SeaWinds winds. The same autumn/winter/spring period was chosen for Oceansat-2 and SeaWinds as for ScatSat-1, but for different years.

Some differences in wind speed biases are evident when comparing ScatSat-1 with the other instruments. The ScatSat-1 wind speed biases are higher by approximately 0.2 to 0.3 m/s. There may be several reasons for this. Firstly, the buoy set used in this comparison is different from the sets used for Oceansat-2 and QuikSCAT. Regional weather variations cause differences in the probability distribution function of wind speeds. These differences are associated with variations in the spatial representativeness errors of the buoy winds for scatterometer wind validation over a WVC and thereby variations in the difference statistics for different regional samplings. Secondly, there may be small remaining intercalibration differences between the instruments and also some small instrumental variations over time.

The table shows that the ScatSat-1 wind component standard deviations for 25 km are slightly lower than those for 50 km. The higher resolution 25 km winds contain more small scale features and hence better mimic the local point measurements of the buoys. The wind component standard deviations are lower for ScatSat-1 than for Oceansat-2, probably due to the improvements in the instrument characteristics. Both ScatSat-1 and Oceansat-2 show higher wind component standard deviations than QuikSCAT, we attribute this to the lower instrument noise in the SeaWinds instrument.

4. Triple collocation results

A triple collocation study was performed to initially assess the errors of the ScatSat-1, ECMWF and buoy winds independently. The triple collocation method was introduced by Stoffelen [10]. 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 introduced by Vogelzang et al. [11].

Collocated data sets of ScatSat-1 25 km and 50 km, ECMWF and buoy winds spanning nine months were used in the triple collocation. Table 3 lists the error variances of the buoy, ScatSat-1 and ECMWF winds from the intermediate resolution scatterometer perspective. When we compare the 50 km ScatSat-1 product with the 25 km ScatSat-1 product, 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 product, which contains less small scale information and in this respect resembles better the ECMWF winds and resembles worse the local buoy winds. The errors of the 25 km ScatSat-1 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.

For comparison, some triple collocation results from reprocessed Oceansat-2 and SeaWinds are shown in Table 3 as well. Note that the reprocessed data sets contain ECMWF reanalysis ERA-Interim model winds which are on coarser resolution and from an older ECMWF model version than the operational model winds used in the ScatSat-1 data. This results in somewhat higher (by ~0.2 m/s) model wind error values in the reprocessed wind data sets. It appears that the error values for ScatSat-1 are lower than the corresponding errors for Oceansat-2. The ScatSat-1 scatterometer winds are 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 0.6 m/s.

	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 ScatSat-1	**0.77**	**0.60**	**1.37**	**1.40**	**1.10**	**1.13**
25 km Oceansat-2	0.80	0.71	1.44	1.45	1.33	1.40
25 km SeaWinds	0.64	0.54	1.39	1.41	1.28	1.35
50 km ScatSat-1	**0.60**	**0.44**	**1.45**	**1.50**	**0.99**	**1.00**
50 km Oceansat-2	0.61	0.48	1.53	1.54	1.20	1.29
50 km SeaWinds	0.46	0.40	1.50	1.49	1.20	1.28

Table 3: Error standard deviations in u and v wind components from triple collocation of ScatSat-1 25 km and 50 km wind products with buoy and ECMWF forecast winds, seen from the scatterometer perspective. The results were obtained for the period of October 2016 to July 2017. The Oceansat-2 results over 2009-2014 [7] and the SeaWinds results over 1999-2009 [6] are shown for comparison.

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 results in Table 4 show that the ScatSat-1 winds are well calibrated, with *b* values close to 0 and a_u coefficients close to 1. The a_v coefficients are a bit lower, close to 0.93, suggesting a slight overestimation of the wind *v* components by ScatSat-1. The reason for this is not clear and is under investigation.

	a_u	a_v	b_u (m/s)	b_v (m/s)
25 km ScatSat-1	0.994	0.934	-0.059	-0.019
50 km ScatSat-1	0.979	0.929	-0.049	-0.025

Table 4: Calibration coefficients a and b for u and v wind components from triple collocation of ScatSat-1 25 km and 50 km wind products with buoy and ECMWF forecast winds. The results were obtained for the period of October 2016 to July 2017.

5. Conclusions

The OSI SAF ScatSat-1 25 km and 50 km wind products have been validated. They provide wind quality well within the OSI SAF product requirements ([2], 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). The results in this report show that ScatSat-1 winds have overall better quality than Oceansat-2 winds and that ScatSat-1 is a good successor of SeaWinds on QuikSCAT and OSCAT on Oceansat-2. It is critical to extend the Ku-band scatterometer data record over a longer period.

Moreover, due to its particular orbit characteristics, ScatSat-1 provides abundant collocations with the ASCAT scatterometers, which will be useful for improvements in intercalibration and wind processing of all these systems. Detailed analysis of the GMF and wind retrieval properties is ongoing in the EUMETSAT OSI SAF and shared with ISRO, most likely leading to further improvement and reduction of the remaining minor wind direction and wind component anomalies reported here.

6. References

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7. Abbreviations and acronyms

ECMWF	European Centre for Medium-Range Weather Forecasts
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GTS	Global Telecommunication System
ISRO	Indian Space Research Organisation
KNMI	Royal Netherlands Meteorological Institute
LKB	Liu, Katsaros and Businger
MARS	Meteorological Archival and Retrieval System from ECMWF
NWP	Numerical Weather Prediction
OSI	Ocean and Sea Ice
PenWP	Pencil Beam wind Processor
QC	Quality Control
QuikSCAT	US Quick Scatterometer mission carrying the SeaWinds scatterometer
SAF	Satellite Application Facility
u	West-to-east (zonal) wind component
v	South-to-north (meridional) wind component
WVC	Wind Vector Cell