COMPARISON BETWEEN DIFFERENT QUIKSCAT PRODUCTS, CROSS-CALIBRATED MULTI-PLATFORM OCEAN WIND VECTORS AND BUOY WINDS ALONG THE IBERIAN PENINSULA COAST

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Abstract

Ocean surface wind data extracted from different QuikSCAT products and the Cross-Calibrated Multi-Platform (CCMP) database were compared to measured winds along the Iberian Peninsula coast to assess which one of these databases allows for higher accuracy in describing the wind regime characteristics of the area under study. For this, QuikSCAT swath (L2B 25 km and L2B 12.5 km slice composites) and gridded data (L3) together with CCMP were compared with measurements taken from five buoys located along the Iberian Peninsula coast (Galician coast and Gulf of Cadiz).

The results show that QuikSCAT L2B 12.5 km slice composites product is the one with the best ability in representing the temporal variability of the wind speed and the amplitude of the wind direction, while CCMP shows significant improvements in terms of wind direction phase and wind speed amplitude accuracy. Moreover, CCMP is able to bring important improvements on some of QuikSCAT's known problems, mainly those related to the lower accuracy in representing low wind speeds and to the QuikSCAT land masking limitations. Furthermore, the fact that CCMP is a gridded dataset, with a higher temporal sampling and complete data availability when compared to QuikSCAT, is also an advantage.

These features can make of CCMP an interesting ocean wind database, mainly for offshore wind energy applications where wind speed amplitude accuracy plays the key role, and also for oceanic modelling forcing conditions, where gridded wind data with good temporal sampling and data availability is vital.

INTRODUCTION

Data regarding ocean surface wind is normally available in the form of observations from buoys, ships, etc.. However, these measurements are usually very sparse, both in time and space, and often suffer from long periods of missing and/or invalid data. Therefore, observational data can be insufficient to accurately describe localized wind regimes in ocean areas.

The development of satellite-derived wind data allowed for the first time the observation of the ocean surface wind field on a near-global scale showing their utility in the ocean surface wind assessment, both for climatic studies and offshore wind energy projects.

NASA's SeaWinds scatterometer installed aboard the QuikSCAT satellite platform (QuikSCAT) is one of the most popular in terms of ocean wind data sources. The Cross-Calibrated Multi-Platform Ocean Surface Wind Vectors (CCMP) uses as background a first guess analysis of U and V gridded wind vectors and assimilates multiple sources of observed data (satellites, ships, buoys, etc.), all combined in a 6-hourly globally gridded analysis of ocean surface winds.

Ocean surface wind data derived from 3 different QuikSCAT products (L2B with 25 and 12.5 km of resolution, and L3) and from CCMP were compared to wind speed and direction measurements, in order to assess which one of these databases has higher accuracy and ability to describe the local wind regime characteristics.

DATA AND METHODS

QuikSCAT data

QuikSCAT wind vectors are available in three different forms: Level 1B, Level 2A & 2B and Level 3. A detailed description about these products is available in Dunbar et al. (2006). In this work the following three QuikSCAT products were tested and evaluated: the Level 2B (L2B) swath product with 25 km of horizontal resolution (QL2B-25), the L2B swath slice composite product with 12.5 km of horizontal resolution (QL2B-12.5), and the Level 3 (QL3) gridded product with 25 km of horizontal resolution. All the QuikSCAT products used in this study were subject to a detailed quality control, as all the data marked with rain flags or marked as null/invalid was discarded. All QuikSCAT wind data corresponds to 10 m above sea level (a.s.l.) considering a neutrally stable atmosphere.

CCMP data

CCMP data consists in a 6-hourly gridded ocean surface winds analysis with a horizontal resolution of 25 km. This dataset uses as a background field the ECMWF ERA-40 Reanalysis and Operational Analysis, and assimilates into this background field measurements of ocean wind data, and also data retrieved from several satellites: TRMM TMI, QuikSCAT, WindSat, SSM/I, SSMIS, AMSR-E among others. More information about CCMP is available in Atlas et al. (2011). Like QuikSCAT, CCMP wind data corresponds to 10 m a.s.l. considering a neutrally stable atmosphere.

Measured data

Measured wind data taken from five oceanographic buoys moored off the Galician northern and western coast and the Gulf of Cádiz were considered. These buoys are operated by the Puertos del Estado Spanish Agency and their location is shown in Figure 1. The period from January 1, 2008 to December 31, 2008 was used to validate QuikSCAT and CCMP.

***Figure 1* – Buoys locations**

Statistical methods

The statistical analysis performed in this study considers only the simultaneous and valid records between QuikSCAT products, CCMP and measured data. Taking into account that QuikSCAT data is obtained through satellite swaths, it is necessary to perform a temporal and spatial collocation between QuikSCAT L2B data and CCMP, QuikSCAT L3 and measured data, which have records constant in time and space.

A pre-analysis of QuikSCAT L2B swath records showed that the great majority of QuikSCAT L2B swaths passed in the area under study around 6 A.M. (ascending pass) and 6 P.M. (descending pass). QuikSCAT L2B records that were inside a temporal window of plus and minus 1 hour of 6 AM/PM and at a maximum distance of 25 km (for the QL2B-25) and 12.5 km (for the QL2B-12.5) were selected. As for the QL3, CCMP and measured wind data, all the records corresponding to 6 AM and 6 PM that are closest from the buoys were extracted. By doing this, all datasets share the same temporal collocation, sampling rate and distance to buoys.

This analysis assesses the quality of the simultaneous records, both in terms of spatial and temporal accuracy by using the following statistical parameters: the Root Mean Squared Error (RMSE),

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(\theta_i')^2\right]^{1/2}$$

where

$$\theta_i' = \theta_i^x - \theta_i^{obs}$$

represents the deviation between the QuikSCAT/CCMP wind speed (Θ^x) and the measured speed in the buoy (Θ^{obs}), being N the total number of pairs of simulation/observed records. The wind direction is a circular variable, and not a linear one. Therefore, *Θ'* takes a different expression since the absolute deviation of the wind direction cannot exceed 180º in module:

$$\theta_i' = (\theta_i^x - \theta_i^{obs}) * \left[1 - 360/\left|\theta_i^x - \theta_i^{obs}\right|\right], if \left|\theta_i^x - \theta_i^{obs}\right| > 180^o$$

The bias,

$$Bias = \frac{1}{N}\sum_{i=1}^{N}\theta_i'$$

And the Standard Deviation of the Error (STDE), defined as

$$STDE = \sigma(\theta_i') = [RMSE^2 - Bias^2]^{1/2}$$

In addition to these statistical metrics, also the correlation coefficients (R^2) were used.

Moreover, it is known that QuikSCAT data quality is highly diminished in the presence of low winds (below 5 m.s^{-1}) and strong winds (above 25 m.s^{-1}). Therefore, it becomes interesting to assess QuikSCAT performance in the presence of different wind speeds and to check if CCMP is able to overcome these QuikSCAT limitations in the presence of low and strong winds. To analyze these issues, it will be assessed if QuikSCAT and CCMP wind speed representation errors vary with the observed wind speed. For this, QuikSCAT and CCMP wind speed RMSE and Bias will be binned into four categories: when the buoys wind speed are below 4 m.s^{-1}; between 4 and 8 m.s^{-1}; between 8 and 12 m.s^{-1} and when buoy wind speeds are above 12 m.s^{-1}.

RESULTS AND DISCUSSION

Table 1 shows the RMSE, Bias, STDE and R^2 computed between the buoys and the respective QuikSCAT and CCMP data. N is the number of simultaneous and valid pairs of 6 A.M. and 6 P.M. records between QL2B-25, QL2B-12.5, QL3, CCMP and the respective buoy. The lowest error scores for each statistical parameter are highlighted (bolded and underlined) in the weighted average results. Table 1 shows that:

For the wind speed, all QuikSCAT databases show a better ability in representing the temporal variability of the wind speed (higher R2, lower RMSE and STDE), when compared to CCMP. CCMP shows the best error scores in what is related to the mean state of the wind speed (lowest bias).

Among QuikSCAT databases, and although no major differences were found, the L2B-12.5 was the one with the best overall scores in terms of RMSE, STDE and R^2, while QL2B-25 was the one with the lowest bias. The worst results are obtained with QuikSCAT L3 gridded product.

For the wind direction, the opposite is seen: CCMP presents the highest R^2, lowest RMSE and STDE, while QL2B-12.5 presented the lowest bias.

It is noticeable a tendency for all databases to overestimate the wind speed, due to the positive biases detected in all buoys for all databases. However, it is also clear that CCMP overestimation of the wind speed is significantly lower than the one produced by QuikSCAT.

Errors, in particular for the wind speed, are clearly worst for Peñas buoy. This buoy is the one closest to the shore and the only one located inside QuikSCAT's coastal masking area, indicating that this can be related with the scatterometers known issues in representing coastal winds due to land contamination effects. CCMP is able to partially mitigate these problems, mainly in what is related to the bias since on these statistics this database shows clearly better results than QuikSCAT. CCMP bias scores for Peñas are similar to the remaining buoys, implying that land masking effects have less impact in CCMP.

It would be expected that the increased resolution of QL2B-12.5 could bring improvement to the results, in particular at those buoys closest to shore. Although this is true, due to the fact that QL2B-12.5 is the one with the lowest average errors among QuikSCAT databases for the wind speed, for the buoy closest to shore (Peñas), QL2B-12.5 is the database with the worst error scores for the wind speed.

Buoy	Product	RMSE		Bias		STDE		R^2		N
		Speed (m.s^{-1})	Direction (º)	Speed (m.s^{-1})	Direction (º)	Speed (m.s^{-1})	Direction (º)	Speed (m.s^{-1})	Direction (º)	
Peñas	QL2B-12.5	2.42	54.86	1.21	-0.96	2.10	54.85	0.85	0.58	144
	QL2B-25	2.10	59.41	0.87	-8.49	1.91	58.80	0.88	0.60	
	QL3	2.10	59.83	0.88	-9.21	1.91	59.12	0.88	0.61	
	CCMP	2.05	51.06	0.04	-2.74	2.05	50.99	0.83	0.70	
Bares	QL2B-12.5	1.13	44.60	0.22	-12.93	1.11	42.68	0.96	0.73	138
	QL2B-25	1.29	37.50	0.34	-12.28	1.24	35.43	0.95	0.81	
	QL3	1.29	37.08	0.33	-12.01	1.25	35.08	0.95	0.79	
	CCMP	1.54	36.31	0.04	-8.35	1.54	35.34	0.92	0.82	
Villano	QL2B-12.5	1.40	44.87	0.50	2.79	1.31	44.78	0.94	0.84	178
	QL2B-25	1.41	40.30	0.60	-1.97	1.28	40.25	0.95	0.86	
	QL3	1.48	40.12	0.59	-0.79	1.36	40.11	0.94	0.86	
	CCMP	1.49	40.81	0.13	1.04	1.48	40.80	0.92	0.89	
Silleiro	QL2B-12.5	1.32	57.71	0.26	4.83	1.29	57.51	0.95	0.67	125
	QL2B-25	1.52	57.62	0.15	7.02	1.51	57.19	0.92	0.68	
	QL3	1.45	58.92	0.10	4.90	1.45	58.72	0.93	0.67	
	CCMP	1.41	47.36	-0.08	-1.65	1.41	47.33	0.93	0.78	
Cádiz	QL2B-12.5	1.13	54.80	0.32	1.32	1.08	54.78	0.96	0.63	118
	QL2B-25	1.31	49.35	0.35	9.08	1.26	48.51	0.95	0.73	
	QL3	1.34	49.13	0.59	8.45	1.20	48.40	0.95	0.74	
	CCMP	1.64	42.93	0.08	4.43	1.64	42.70	0.90	0.81	
Weighted average	QL2B-12.5	**1.50**	50.81	0.52	**-0.95**	**1.39**	50.37	0.93	0.70	-
	QL2B-25	1.53	48.26	0.48	-1.88	1.44	47.50	**0.93**	**0.74**	
	QL3	1.54	48.42	0.51	-2.15	1.44	47.72	**0.93**	**0.74**	
	CCMP	1.63	**43.55**	**0.05**	-1.49	1.62	**43.29**	0.90	0.80	

Table 1 **- Statistics of the comparison between QuikSCAT, CCMP and buoy wind data**

Next, Table 2 show the QuikSCAT and CCMP wind speed RMSE and Bias binned according to the measured wind speed by the buoys. Again the lowest error scores for each statistical parameter are highlighted (bolded and underlined) in the weighted average results.

It is visible in the results presented in Table 2 that all QuikSCAT databases show higher errors in the presence of low (below 4 m.s^{-1}) and strong (above 12 m.s^{-1}) wind speeds. This was expected, due to the scatterometers know problems in the presence of low and strong wind speeds. These errors are significantly higher for strong wind speeds than for low wind speeds.

CCMP shows the highest errors for strong wind speeds, while the lowest are seen for low wind speeds, mainly in terms of RMSE. CCMP does not show better performance than QuikSCAT for low and strong wind speeds. Oppositely to QuikSCAT, it is not visible in CCMP error scores any clear over or underestimation tendency for the wind speed. However, it appears to be present a tendency to overestimate wind speeds below 4 $m.s^{-1}$ and to underestimate wind speeds above 8 $m.s^{-1}$.

Measured wind speed		**< 4 $m.s^{-1}$**			**4-8 $m.s^{-1}$**			**8-12 $m.s^{-1}$**			**> 12 $m.s^{-1}$**		
Buoy	**Product**	RMSE ($m.s^{-1}$)	Bias ($m.s^{-1}$)	N	RMSE ($m.s^{-1}$)	Bias ($m.s^{-1}$)	N	RMSE ($m.s^{-1}$)	Bias ($m.s^{-1}$)	N	RMSE ($m.s^{-1}$)	Bias ($m.s^{-1}$)	N
Peñas	**QL2B-12.5**	2.64	1.91	53	2.21	1.08	53	1.67	0.00	28	3.66	1.59	10
	QL2B-25	2.07	1.22		2.14	0.97		1.50	-0.25		3.23	1.65	
	QL3	2.08	1.23		2.14	0.97		1.50	-0.27		3.19	1.70	
	CCMP	2.32	1.07		1.78	0.13		2.12	-1.61		1.64	-1.31	
Bares	**QL2B-12.5**	1.31	0.69	39	0.93	-0.01	44	0.97	0.02	42	1.60	0.21	13
	QL2B-25	1.29	0.43		1.37	0.25		1.10	0.24		1.52	0.73	
	QL3	1.29	0.44		1.37	0.25		1.12	0.20		1.53	0.73	
	CCMP	1.40	0.60		1.48	-0.06		1.15	-0.24		2.75	-0.40	
Villano	**QL2B-12.5**	1.39	0.80	53	1.33	0.38	56	1.35	0.22	49	1.71	0.72	20
	QL2B-25	1.39	0.83		1.19	0.31		1.48	0.52		1.77	1.03	
	QL3	1.52	0.90		1.21	0.29		1.58	0.46		1.75	0.90	
	CCMP	1.38	0.73		1.59	0.11		1.50	-0.40		1.48	-0.04	
Silleiro	**QL2B-12.5**	1.19	0.40	63	1.20	0.19	30	1.57	-0.20	23	1.83	0.71	9
	QL2B-25	1.43	0.41		1.62	0.24		1.44	-0.45		1.87	-0.38	
	QL3	1.44	0.40		1.31	0.07		1.43	-0.50		1.87	-0.36	
	CCMP	0.97	0.33		1.35	-0.11		1.76	-0.90		2.63	-0.74	
Cádiz	**QL2B-12.5**	1.05	0.49	48	1.08	0.22	39	1.29	0.01	22	1.35	0.63	9
	QL2B-25	1.02	0.27		1.15	0.28		1.92	0.33		1.43	1.09	
	QL3	1.22	0.70		1.35	0.53		1.52	0.35		1.44	0.80	
	CCMP	1.46	0.70		1.56	-0.14		2.03	-1.03		1.80	0.38	
Weighted average	**QL2B-12.5**	1.52	0.86	-	**1.40**	0.42	-	**1.33**	**0.04**	-	1.97	0.74	-
	QL2B-25	**1.46**	**0.64**		1.50	0.44		1.44	0.16		1.92	0.87	
	QL3	1.52	0.74		1.50	0.46		1.42	0.12		**1.91**	0.79	
	CCMP	1.49	0.68		1.58	**0.01**		1.62	-0.72		1.99	**-0.37**	

Table 2 **- Statistics of the comparison between QuikSCAT and CCMP wind speed error per buoy wind speed bin**

CONCLUSIVE REMARKS

This study analyses and compares the performance of three QuikSCAT products with the CCMP ocean surface wind database, aiming to determine which of these products is closest to measured ocean surface winds. One year of wind data from CCMP, QuikSCAT L2B (12.5 and 25 km resolution), QuikSCAT L3 and measurements from five buoys located along the Iberian Peninsula shore (Galician coast and Gulf of Cádiz) were selected for this comparison. The main conclusions drawn from this study can be summarised as follows:

For the wind speed, QuikSCAT databases showed the best results in terms of accuracy in representing the wind magnitude temporal variability, with the high-resolution QuikSCAT product showing the highest R^2 and lowest RMSE and STDE. Oppositely, CCMP clearly showed the best performance in depicting the mean wind state due to the lowest biases. The worst results are obtained with QuikSCAT L3 gridded product.

For the wind direction, CCMP showed the best results in representing the temporal variability (in average, highest R2, lowest RMSE and STDE) and the high-resolution QuikSCAT product presented the lowest average bias.

All QuikSCAT databases overestimate the wind speed. CCMP overestimation of the wind speed is significantly lower than the one produced by QuikSCAT.

QuikSCAT limitations in the presence of low and strong wind speeds are not overcome by CCMP. However, CCMP is able to partially mitigate QuikSCAT land masking issues.

The results presented in this work show that QuikSCAT products have their strength in representing the temporal variability of the wind speed and the mean state of the wind direction. This can be important for applications that require ocean wind data with temporal accuracy, such as meteorological and oceanographic modelling studies.

However, CCMP is able to bring significant improvements in terms of wind direction temporal variability and wind speed mean state. Moreover, CCMP is a gridded dataset with a higher temporal sampling and complete data availability when compared to QuikSCAT. These features, all together, can make of CCMP an interesting and valuable database for offshore wind energy assessment studies, where the mean wind speed representation accuracy plays a key role, and also for meteorological, oceanic and climate modelling applications where gridded wind data with good temporal sampling and data availability is vital to force numerical simulation models.

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