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Jason-2 OGDR Wind and Wave Products: Random Error Estimation

Saleh Abdalla, Peter A.E.M. Janssen
and Jean-Raymond Bidlot

Research Department

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European Centre for Medium Range Weather Forecasts
Shinfield Park, Reading, Berkshire RG2 9AX, England

Abstract

Triple collocation technique is used to estimate the errors in Jason-2 fast delivery OGDR-BUFR wind and wave products. Significant wave height (SWH) error is estimated by collocating Jason-2 product with buoy and model hindcasts over a period of a year from 1 August 2009 and 31 July 2010. It is estimated that Jason-2 absolute SWH error is about 0.13 m or about 5.4% relative to the mean SWH value. For the collocations considered here, Jason-2 wave height error is the lowest among the other sources of data: ENVISAT RA-2 with about 6.2%, Jason-1 with about 7.8%, the buoys with 8.6% and finally the stand-alone model hindcast with about 9.7%. The wind speed error is estimated by collocating Jason-2 product with buoy and ECMWF model 1-day forecast over the same period. The altimeter wind speed error of Jason-2 turned out to be 1.0 m.s^{-1} (~11.9% of the mean). Although this is not the lowest error among the others, it is not too far from that. For the collocation data used, it is found that wind speed errors of ENVISAT RA-2, Jason-1 altimeter, the buoys and the model 1-day forecast are, respectively: 0.9 m.s^{-1}, 1.0 m.s^{-1}, 1.2 m.s^{-1} and 1.0 m.s^{-1}.

1 Introduction

Abdalla et al. (2010) described the validation and the use of wind and wave products from Jason-2 radar altimeter fast delivery OGDR-BUFR products. It was shown that compared to the ECMWF model products and in-situ (buoy) observations, Jason-2 products are of high quality. However, there was no precise statement about the errors of those products. This statement cannot be reached based on direct comparison against model results and/or buoy measurements. To this end, the triple collocation technique has been used by several researchers. Stofflen (1998) applied this technique to estimate the errors of wind measurements from ERS-1 scatterometer, buoys and model analysis. Caires and Sterl (2003) used the same technique to estimate the errors in the 40-year ECMWF Re-Analysis (ERA-40) wind speed and significant wave height. Tokmakian and Challenor (1999) implemented the same technique to estimate the mean sea level anomalies from the model, ERS-2 and TOPEX/Poseidon altimeters. Freilich and Vanhoff (1999) and Quilfen et al. (2001) used a similar approach with an assumption that the true wind speed is Weibull distributed. Janssen et al. (2007) estimated significant wave height errors in ERS-2, buoy and ECMWF model analysis, first guess and hindcast. They extended the method to include two extra sources of information, i.e. quintuple collocation, to estimate the covariances due to the existence of correlations between the errors in ERS-2 and ENVISAT observations. This was the way out to estimate the errors in ENVISAT RA-2 wave heights in a collocation data set that involves ERS-2 data and model first-guess data. Triple collocation technique was also used by Abdalla and Janssen (2007) in a different context to estimate the error of the total column water vapour from the micro-wave radiometers onboard ENVISAT and Jason-1 as well MERIS onboard ENVISAT and the ECMWF model analysis.

Janssen et al. (2007) also proposed a totally different approach that does not require three estimates for the truth. Instead, they made use of the change of the standard deviation of the difference between the ERS-2 altimeter wave height super-observations and the ECMWF model by varying the number of observations used for the super-observation.

The term “error” is commonly used, in fact, to describe the uncertainty in the measurement or the model output. Strictly speaking the error, or better the instantaneous error, is the difference between the estimate and the “unknown” truth. The standard deviation of the instantaneous errors is what is usually termed as “error”. However, the term “error” as commonly accepted will be used here.

Given three independent estimates, with uncorrelated errors, of the truth, T, it is possible to show that error in each estimate can be found using the “known” variances and covariances of the three data sets in addition to the “unknown” covariances of the errors. Therefore, further assumptions are needed to estimate the error covariances. The assumption that the errors are not correlated is very useful as under such an assumption the error covariances vanish. If the assumption is not correct, the error estimates would not be correct. It is also important to note that although the errors in two data sets may not be correlated directly, it may possible to have a pseudo correlation due to the nonlinear nature of both errors. This is what Janssen et al. (2007) found when they tried to estimate the errors of ERS-2 and ENVISAT altimeters from a collocation that involves both altimeters and the buoys and another collocation that involved ENVISAT, which was not assimilated in ECMWF model at the time, and the model first guess. Contradictory results were obtained. Then with the help of two extra data sets, it turned out that there was a strong correlation between the errors in both altimeters.

Section 2 provides an overview of the data used in the current work. The selection criteria will be discussed as well. An overview on the error estimation using the triple collocation technique is provided in Section 3. The results of the error estimation of the significant wave height are presented in Section 4 while those for wind speed are given in Section 5. Finally, conclusions are listed in Section 6.

2 Data Used

Apart from the covered period, the data sets used for this study are mainly similar to those used by Abdalla et al. (2010). Therefore, only a short description is given here with emphasis on the different aspects.

The first data set used in this study consists of the Ku-band significant wave height (SWH) and surface wind speed within the BUFR (Binary Universal Form for the Representation of meteorological data) version of the Operational Geophysical Data Record (OGDR) of Jason-2 radar altimeter received in near real time (NRT) from EUMETSAT and NOAA. The OGDR product may be of slightly degraded quality compared to the final Geophysical Data Record (GDR) which is not available for operational weather prediction. However, the quality of the SWH and the surface wind speed parameters does not differ between the OGDR and the GDR. It is only the retracker which is of lower quality.

The second data set consists of SWH and wind speed collected by wave buoys or various wave gauges mounted on offshore platforms as disseminated to the weather centres via the Global Tele-Communication System (GTS). It is commonly believed that this type of data represents the ground truth. The total number of in-situ stations is very limited (slightly above 100) and most of them are located in the Northern Hemisphere (NH) around the North American and European coasts including two buoys in the Western Mediterranean. The exceptions are a few buoys in the Tropics (mainly around Hawaii). Therefore, any assessment involving in-situ data would not be of global coverage strictly speaking. The term “buoy” is usually used to refer to this type of data even if it is originated from a different in-situ source. More information about in-situ ocean wave data, including the pre-processing method used for the quality control and averaging, can be found in Bidlot et al. (2002).

The triple collocation technique with the assumption of uncorrelated errors does not work with the model analysis (AN) or the model first-guess (FG). Even short term model forecasts (FC) may not be suitable as well. The SWH from Jason-2, Jason-1 and Envisat RA-2 are all assimilated into the ECMWF ocean wave model. Jason-1 SWH has been blacklisted since late March 2010 following the degradation of the product caused by the instability of the platform. Even if the SWH from one or more of the altimeters are not used, it cannot be considered that the errors in the model AN and FG are independent from that altimeter (Janssen et al., 2007). All altimeters share the same principles of measurements and algorithms. The dependency becomes weaker further along the forecast range. Therefore, altimeter data and the model forecast (FC) can be assumed to have independent errors, especially for forecasts beyond 2-3 days except for any possible systematic errors in the observations. Therefore, it was decided to run a wave model stand-alone experiment without any data assimilation (model hindcast). The model (Janssen, 2004) is configured very similarly to the ECMWF wave model operational configuration that has been in place since late January 2010. The details are given in ECMWF (2010). The experiment used the 6-hour wind vector analysis fields from the high resolution T1279 (16-km horizontal resolution) atmospheric model operational since late January 2010. The wind fields for the period prior to the operational implementation of the high resolution model were obtained from the pre-operational experimental suite (e-suite).

On the other hand, the wind speed data from altimeters are not assimilated in the ECMWF atmospheric model. However, the buoy wind data are assimilated. This leads to a high correlation in error between the model analysis winds and the buoys and the model first-guess winds and the buoys preventing the use of those model fields in triple collocation. An atmospheric model run without the assimilation of buoy winds for a long period of a year, or even few months, is very expensive. Fortunately, the impact of assimilating wind data is short-lived. It is commonly accepted that 24 hours in the forecast is enough for the model to loose the impact of assimilated wind information. Therefore, 1-day forecast fields will be used for wind speed.

The NRT altimeter data from Envisat and Jason-1 are used to form two independent triple collocated data sets. The former data stream is made available by ESA. In particular, Level 2 of RA2 Fast Delivery Marine Abridged Records (FDMAR) product is used. For Jason-1, OSDR product is used here. In fact, the two data sets are not needed here for the estimation of Jason-2 products. Instead, two other triple collocation data sets are constructed each consisting of the altimeter (Jason or Envisat), the buoy and the model. The corresponding errors are estimated independently for each data set ending in three error estimate for the buoys (one from each triple collocation set), three error estimates for the model in addition to single error estimates for each altimeter. If the three error estimates for the buoy are almost equal and similarly for the three model errors, then one can be more confident about the robustness of the approach.

The altimeter data are pre-processed in a way similar to the approach outlined in Abdalla and Hersbach (2004) with slightly modified parameters. The data go through quality control process to remove erroneous and inconsistent observations. The data is then averaged along the track to form super-observations with scales compatible with the model scales of around 75 km. This corresponds to 13 individual (1 Hz) Jason-1 and Jason-2 observations and to 11 individual (1 Hz) Envisat observations.

The data cover the period from 1 August 2009 to 31 July 2010. It should be noted that the model is changed few times a year. Although this may impact the results, it is not the case for this study as the model changes during this period are expected to be of limited impact on wind and waves. However, there was an important change of the Envisat RA-2 processing chain introduced on the 2nd of February 2010. This change has a significant impact as far as the SWH and wind speed are concerned.

Furthermore, Jason-1 suffered a period of instability starting from late March 2010. This was reflected in a degradation of Jason-1 products especially the wind speed.

3 Triple Collocation

Comparisons of pairs of observation products are usually not enough to estimate the error in each product. If enough data products are available, a multiple collocation analysis can be used to give some absolute error estimates of each product. A simplified version of the approach proposed by Janssen et al. (2007) was used here. Three triple collocation exercises were performed. For the first exercise, Jason-2, buoys and model (hindcast for SWH and forecast for wind speed) were collocated. The second and the third data sets are similar to Jason-2 being replaced by Envisat RA-2 and Jason-1, respectively. The collocation is built up by collocating first the altimeter super-observations with the model using proper interpolation. Then the buoy observations are collocated with the model as well. Finally, the altimeter observations (and the model values at the altimeter locations) are collocated with the buoy observations (and the model values at buoy location) within 2 hours and 200 km (this will be adjusted for later). The model values at the altimeter and the buoy locations are used for the triplet selections as will be described later.

Ideally, it is desirable to collocate the altimeter and buoy observations at no spatial or temporal difference. Unfortunately, there would be very few collocations, if any. Figure 1 shows the number of Jason-2-buoy-model triplets in a year for various limitations on the collocation distance. It is clear that the more restricted the distance is the less the number of collocations are and, therefore, the less statistically representative the results are. It will be shown later that the more relaxed this condition is, the more the representativeness errors become. On the other hand, the temporal restriction was not tested as the buoy super-observations are constructed using 5 observations with 1-hour increments. The 2-hour restriction is within the 4-hour duration of the buoy super-observations.

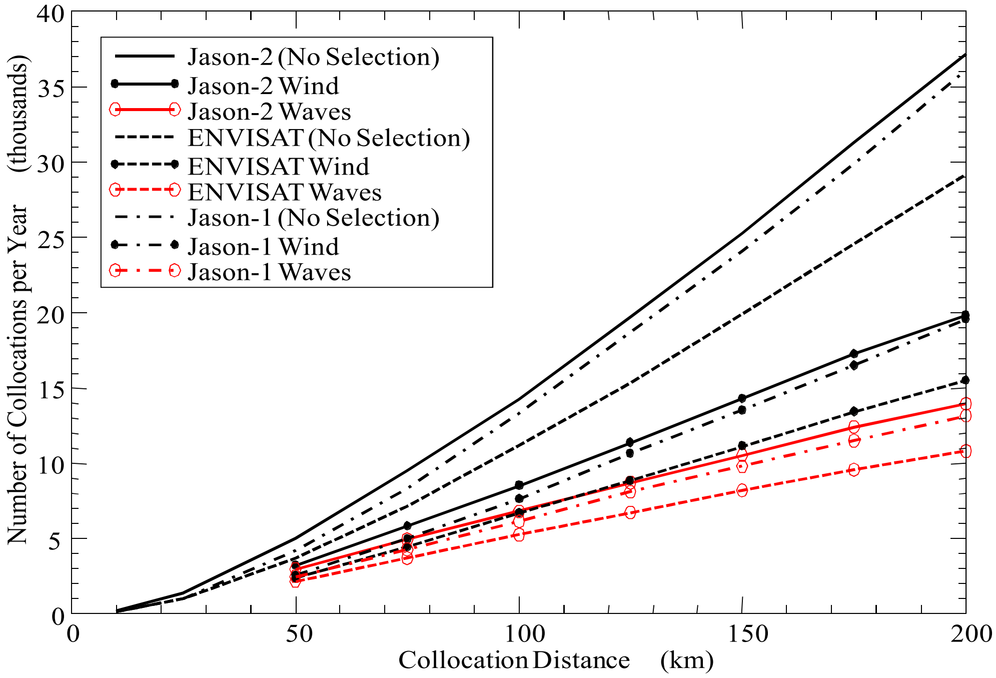

Figure 1: Number of collocations for various restriction conditions for the period from 1 August 2009 to 31 July 2010.

It is essential that assumptions have to be made regarding the relation between model and observations on the one hand and the truth on the other hand. At the same time this gives an implicit definition of the error. Because of an assumed relation between observation and truth it follows that in case that this relation is incorrect the error has both a systematic and random component. Therefore, the assumption of uncorrelated errors is by no means evident, and should, if possible, be tested.

Suppose we have three estimates of the truth, denoted by X_p, p=1,2,3, obtained from observations or from simulations by means of a forecasting system of the same truth, T. In the following all these estimates of the truth will be referred to as measurements. Furthermore, it is assumed that the measurements depend on the truth T in a linear fashion for any triplet, i, as follows:

$$X_{pi} = \beta_p T_i + e_{pi} \tag{1}$$

where e_{pi}, p=1,2,3 denote the instantaneous (or individual) residual errors in the measurements X_p and β_p are the linear calibration constants.

The calibration constants are found by an iterative procedure utilizing a neutral regression (Marsden, 1999) and the errors in the variable X_p using the method described by Janssen et al. (2007). For the simplicity of the formulation below, the variables X_p are divided by the calibration constants; i.e. $X_p = X_p / \beta_p$. By taking mean-square of the differences between each pair in the triplets, it is possible to write for the variance of the unknown error of each product (Janssen et al. 2007) as:

$$\left\langle e_{pi}^2 \right\rangle = 0.5\left[\left\langle \left(X_p - x_{p1} \right)^2 \right\rangle + \left\langle \left(X_p - x_{p2} \right)^2 \right\rangle - \left\langle \left(X_{p1} - x_{p2} \right)^2 \right\rangle \right] \tag{2}$$

Here, X_{p1} and X_{p2} are the other two products in the triplet. It is only possible to reach to Eq. 2 by assuming that there is no correlation between the errors of the triplets. For example, Eq. 2 cannot be used to estimate the errors if the triplet includes a model analysis or first guess together with the observations that have been assimilated into that model. Furthermore, two altimeter products can not be used in a triplet to estimate errors through Eq. 2 due to the intrinsic correlation arising from sharing the same algorithm and nature of error (Janssen et al., 2007). Detailed description of the technique can be found in Janssen et al. (2007).

4 Estimation of SWH Errors

One of the keys to the success of the triple collocation technique as presented above is to ensure the independence of the errors in all data sets used. This was done by selecting the altimeter, the buoy and the model hindcast data. The three data sources are totally independent estimation of the truth and therefore, their errors are expected to be uncorrelated.

The second key of success is the proper selection of triplets. The collocated altimeter and buoy measurements should be very close to each other to represent the same truth and, at the same time this restriction should be relaxed to have enough triplets to yield statistically representative error estimates. Figure 1 shows that the number of collocation triplets of Jason-2, buoy and model within a collocation distance between the altimeter and the buoy over a period of a year is about 37 thousand. With some quality control checks, this number reduces to about 14 thousand. The quality control checks are composed of few basic tests to ensure that all the measurements in the triplet are valid (e.g. SWH values between 0.5 and 20 m). Another selection criterion is to ensure that both the altimeter and the buoy see the same truth. This is done by rejecting any triplet when the model estimates at the altimeter location and at the buoy location differ by more that 5% as was recommended by Janssen et al. (2007).

The assumption here, which is a fair one, is that the model is able to reproduce the true atmospheric variability. Therefore, too different model SWH value is a strong indication of the non-homogeneity of the wave fields and the altimeter and the buoy measurements do not represent the same truth. Furthermore, any triplet with the model mean wave direction at the altimeter and at the buoy locations are different by more than 45 degrees is rejected. This is again another measure for the homogeneity of the field. Reducing the acceptable collocation distance to 100 km, for example, reduces the number of collocations to slightly above 7,000. At 50-km distance, the number of collocations over a year is only few hundreds.

Using Eq. 2 to estimate the SWH error for the three altimeter-buoy-model data set with the dependence of the error on the collocation distance is shown in Figure 2. It was found that the change of error with respect to the collocation distance is linear. Altimeter (at different levels but have more or less same slope) and buoy SWH errors are found to increase by increasing the collocation distance at a rate of about 0.024 m and 0.004 m, respectively, per 100 km. The model error was found to reduce at a rate of about 0.023 m/100 km. More or less the same slopes were found for the other triple collocation data sets; namely: Envisat-buoy-model and Jason-1-buoy-model.

When the collocation data set is binned based on the wave height values or the month in order to estimate the errors at each bin, the number of collocations may not be enough to draw firm conclusions. Therefore, the result above can be utilized to increase the number of collocations by adopting the 200-km restriction of the collocation distance. The error estimates are then adjusted by using the results in Figure 2. An argument can be raised if one needs to adjust for a zero collocation

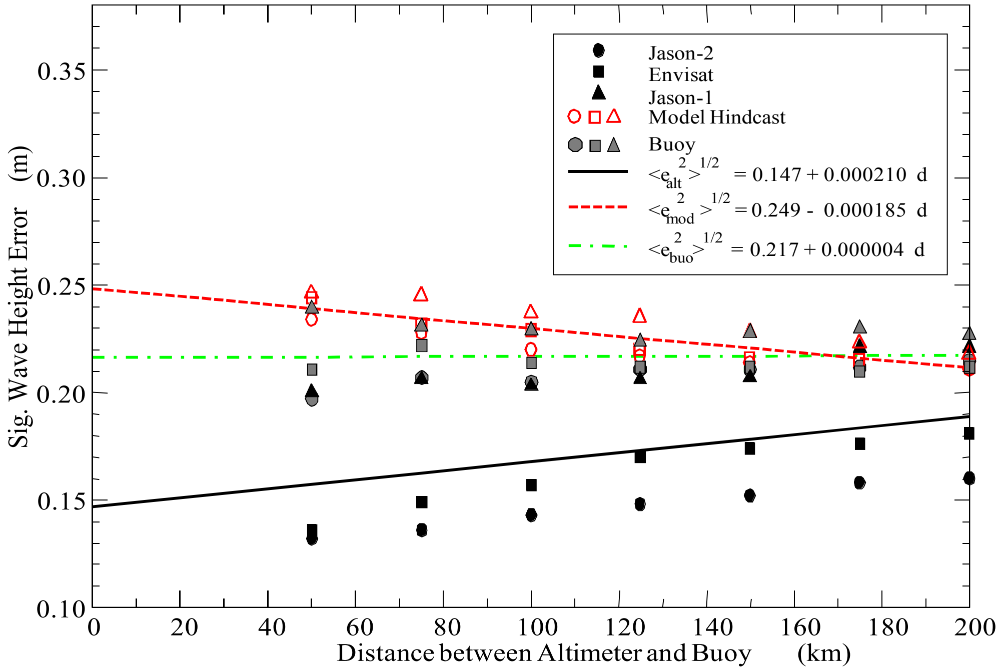

Figure 2: Change of wind speed errors as functions of the maximum allowed collocation distance. The linear regression fits are given. The errors $\langle e_{alt}^2\rangle^{1/2}, \langle e_{mod}^2\rangle^{1/2}, \langle e_{buo}^2\rangle^{1/2}$ *of the altimeters, the model and the buoys are in m while the collocation distance d is in km.*

distance or for a collocation distance depending on the scale of the model and super-observations which is about 75 km in the current data sets. Using the 75-km distance instead of the 0-km distance, would add about 0.018 m and 0.003 m to the altimeter and the buoy errors, respectively, and will reduce the model error by about 0.017 m. It was decided that a collocation distance equals to the scale of the data would be a proper selection here.

The estimated SWH errors, both the absolute values and the relative values with respect to the mean (also called scatter index, SI), in the three altimeters: Jason-2, Envisat and Jason-1, the model hindcast and the buoys are listed in Table 1. The altimeter SWH relative errors (with respect to the SWH mean value) are about 5.4%, 6.2% and 7.8% for Jason-2, Envisat RA-2 and Jason-1, respectively. The model hindcast SWH error is slightly less that 10%, irrespective of the data set used for this estimation, while the buoy SWH error is slightly less than 9%. These values have been adjusted for a maximum collocation distance of 75 km as discussed earlier. It is clear that Jason-2 has the lowest error followed closely by Envisat RA-2. It is important to remind that the Envisat processing has changed in early February 2010 while Jason-1 had few periods of instability. Finally, although the model set-up was very close to the operational ECMWF wave model, it is not exactly the same. The main differences are: The hindcast experiment was forced by 6-hour wind fields compared to changing wind field at each time step in the operational set-up. Furthermore, the impact of gustiness and variable air density was not considered in the experiment. Finally, the operational model assimilates altimeter wave heights and this is not the case for the hindcast experiment used for the error estimation.

	Jason-2 Data Set		**Envisat RA-2 Data Set**		**Jason-1 Data Set**	
Number of collocations	13,920		11,005		13,281	
	Abs. (m)	**SI (%)**	**Abs. (m)**	**SI (%)**	**Abs. (m)**	**SI (%)**
Altimeter Error	0.130	5.4	0.152	6.2	0.192	7.8
Model Hindcast Error	0.234	9.7	0.235	9.7	0.241	9.8
Buoy Error	0.206	8.6	0.203	8.4	0.218	8.9

Table 1: The absolute and relative (SI) significant wave height errors of Jason-2, Envisat RA-2, Jason-1, model hindcast and buoy as estimated using the triple collocation technique using three data sets each involving one of the altimeters in addition to the model hindcast and buoys for the period from 1 August 2009 and 31 July 1010 (mainly in the NH).

To get a better idea about the SWH errors at various regimes of SWH values, the collocated data sets were binned and the triple collocation technique was applied for each bin of wave heights. Figure 3 shows the SWH error at various SWH values. Note that the number of collocations at the bins with high SWH values is very few and may not be representative at those bins. It is clear that the error of Jason-2 SWH is more or less the same at all SWH values while Envisat error is relatively large at low SWH values. The buoy error is lower at higher waves. Finally the model error is high at lower waves and gets better for wave heights above 4 m.

To get an idea about the seasonal variability of the errors or the error variations due to the changes in the model or measurement quality, the triple collocation procedure was applied to the monthly data. The SWH error as a function of the month of the year is shown as 3-monthly running averages in Figure 4. Jason-2 monthly errors show very small variability over the whole year. Envisat RA-2 shows higher errors around October 2009 and during the summer months of 2010. The impact of the problems of Jason-1 can be clearly seen in a form of increased errors during the last 6 months of the considered period. During the early months (summer 2009), the buoy error was higher than the other months. This may be due to the presence of the hurricanes in the North Atlantic during that period. The model error is almost unchanged over the whole period.

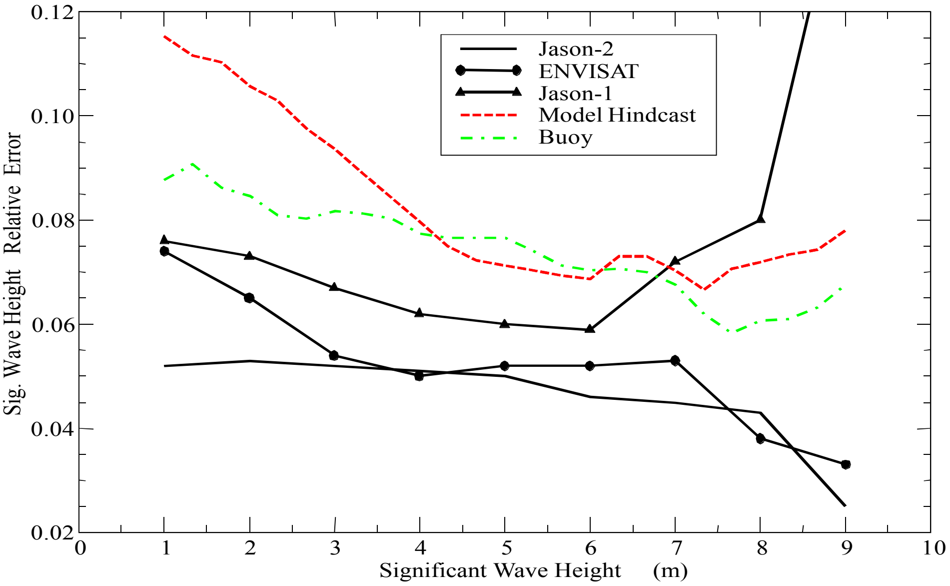

Figure 3: The SWH relative error as a function of the wave height value.

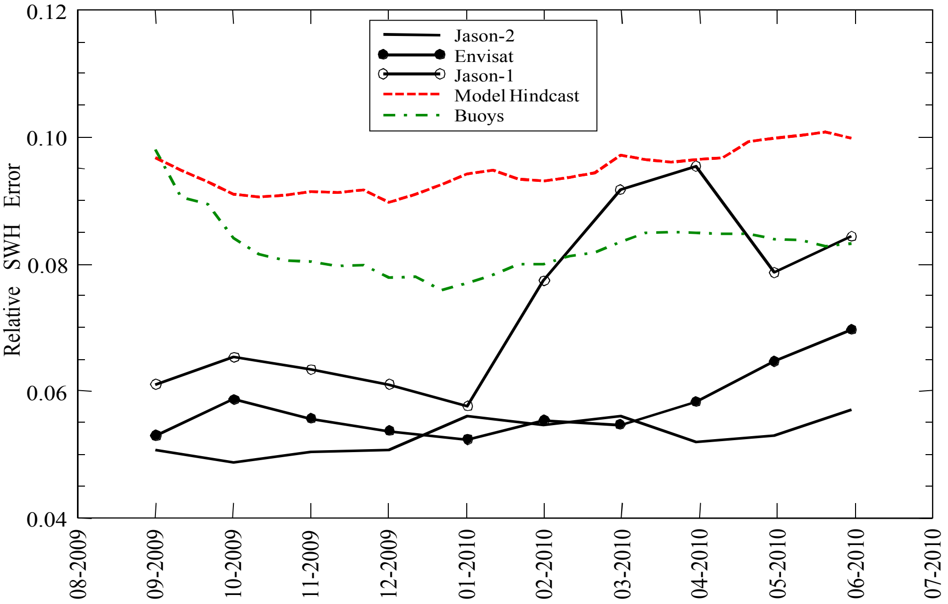

Figure 4: The time series of the monthly SWH errors (3-month running means).

5 Estimation of Wind Speed Errors

The wind speed from the buoys is assimilated into the ECMWF atmospheric model. Therefore, Eq. 2 cannot be used for any collocation data set involving the buoys and the model AN or FG. Therefore, model forecast which is expected to be independent from the buoy measurements during the forecast range after about 24 hours. The 5%-criteria used for wave height cannot be justified for the wind speed. Compared to the SWH, the wind fields show much higher natural variability. Therefore, constraining the difference between model values at altimeter and at buoy location to 5% would be an artificial constraint. Therefore, this criteria was changed into another that restricts the difference between the SWH (not wind speed) values to 50% ensuring a fair amount of homogeneity and allowing for local winds to have their impact with any constraints. On the other hand, the restriction on the model wind direction difference was tightened up. Any triplet with the model wind direction at the altimeter and at the buoy locations with a difference of more than 20 degrees is rejected. Therefore, within a collocation distance of 200 km and during a whole year, the number of the quality-controlled valid collocation triplets of Jason-2, buoy and model after this criteria is reduced to about 20 thousand (out of the original number of 37 thousand) as can be seen in Figure 1. Reducing the acceptable collocation distance to 100 km reduces the number of collocations to about 9,000. At 50-km distance, the number of collocations over a year is only few hundreds.

Similar to what was done for the SWH, the wind speed errors for the triple collocation data set were estimated using Eq. 2 for different collocation distances between the altimeter and the buoy. Figure 5 show those results. Similar to the SWH case, the relation between the error and the corresponding collocation distance is linear. However, the rates of the change of the error with respect to the distance are rather large compared to those from the SWH. The altimetr and the buoy wind speed errors increase by increasing the collocation distance at a rate of about 0.13 $m.s^{-1}$ and 0.17 $m.s^{-1}$, respectively, per 100 km. On the other hand, the model error decreases at a rate of about 0.24 $m.s^{-1}$ per 100 km. Almost the same slopes can be found from the other triple collocation data sets; namely: Envisat-buoy-model and Jason-1-buoy-model. This result is used to relax the collocation distance to 200 km for more triplets in the collocation data set. The estimated errors are then adjusted based on Figure 5.

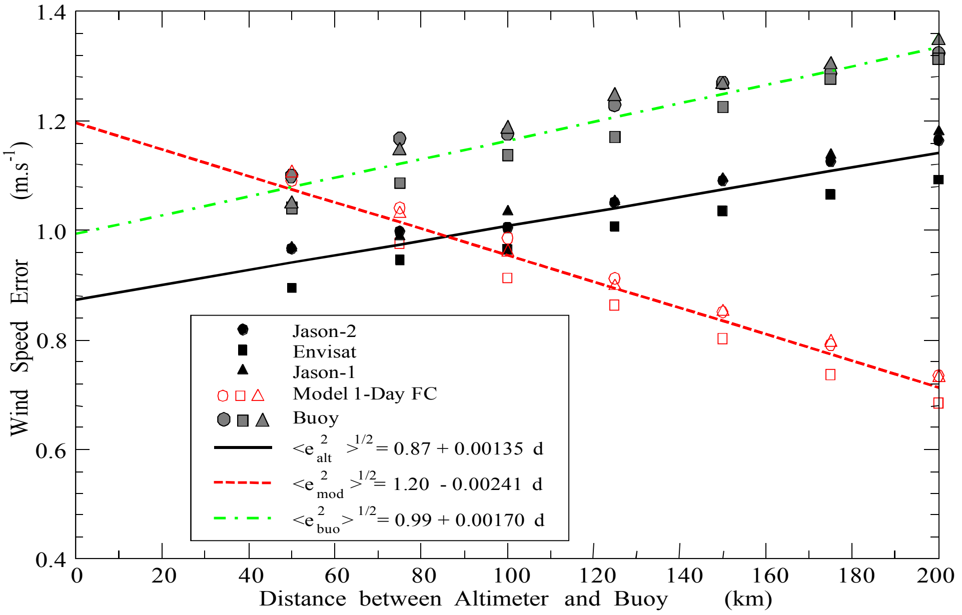

Figure 5: Change of wind speed errors as functions of the maximum allowed collocation distance. The linear regression fits are given. The errors $\langle e^2_{alt}\rangle^{1/2}, \langle e^2_{mod}\rangle^{1/2}, \langle e^2_{buo}\rangle^{1/2}$ *of the altimeters, the model and the buoys are in* $m.s^{-1}$ *while the collocation distance d is in km.*

The estimated errors for all data sources are tabulated in Table 2. The wind speed errors were estimated as 1.00 m.s^{-1} (~11.9%) for Jason-2, 0.93 m.s^{-1} (~11.1%) for Envisat RA-2, 1.01 m.s^{-1} (~12.0%) for Jason-1, 1.15 m.s^{-1} (~13.7%) for the buoys and 0.97 m.s^{-1} (~11.5%) for the 1-day model forecast. These figures were adjusted for a maximum collocation distance between the altimeter and the buoy of 75 km. This was selected to reflect the model scale and the scale used to form the altimeter and buoy super-observations. It should be stressed here that the model error here is the ECMWF 1-day forecast error which is quite higher that the analysis error.

	Jason-2 Data Set		Envisat RA-2 Data Set		Jason-1 Data Set	
Number of collocations	19,856		15,552		19,613	
	Abs. (m.s^{-1})	SI (%)	Abs. (m.s^{-1})	SI (%)	Abs. (m.s^{-1})	SI (%)
Altimeter Error	1.00	11.9	0.93	11.1	1.01	12.0
Model 1-Day FC Error	0.97	11.5	0.94	11.2	0.97	11.6
Buoy Error	1.15	13.6	1.14	13.7	1.17	13.8

Table 2: Similar to Table 1 for wind speed and the model hindcast is replaced by the ECMWF model 1-day forecast.

To find out what is the wind speed error at various wind speed values, the data sets were binned and the triple collocation technique was utilized to estimate the wind speed error for each subset. Figure 6 shows the wind speed relative error as a function of the wind speed itself. Although Figure 6 suggests that the errors are relatively high at lower wind speed values and decreases for higher values, it should be mentioned that the absolute wind speed errors, in fact, increase by increasing the wind speed value (not shown). However, the increase in the error is not fast enough and therefore the relative error appears to be decreasing with wind speed increase. Figure 6 indicates that Jason-2 wind speed is not good at the low wind speed regime. Furthermore, it is clear the error of all instruments, especially the model and the buoys, are very high at low wind speeds with errors of about 16% of the mean for the altimeters and about 25% of the mean for the buoys and the model 1-day forecast. The high buoy error, especially at lower wind speed values, may be a reflection of the fact that the buoy wind speeds communicated through the GTS are reported to the closest 1 m.s-1. An interesting observation in Figure 6 is the relative low wind speed error in the model 1-day forecasts for wind speeds higher that 12 m.s-1.

The temporal variation of the wind speed errors is shown in Figure 7. Jaons-2 wind speed product seems to have suffered some degradation in February 2010 and may be May 2010. Such possible degradations are responsible for the increase of Jason-2 errors seen in Figure 7 in January 2010 as the plot represents the 3-monthly running average. The impact of Jason-1 degraded products can be clearly seen starting from March 2010.

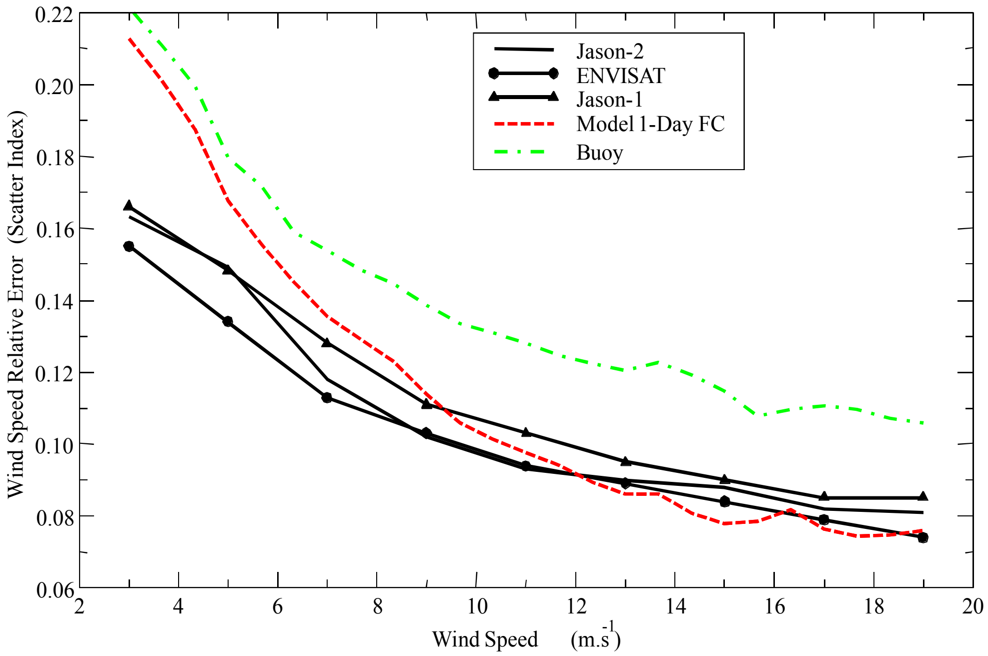

Figure 6: The wind speed relative error as a function of the wind speed value.

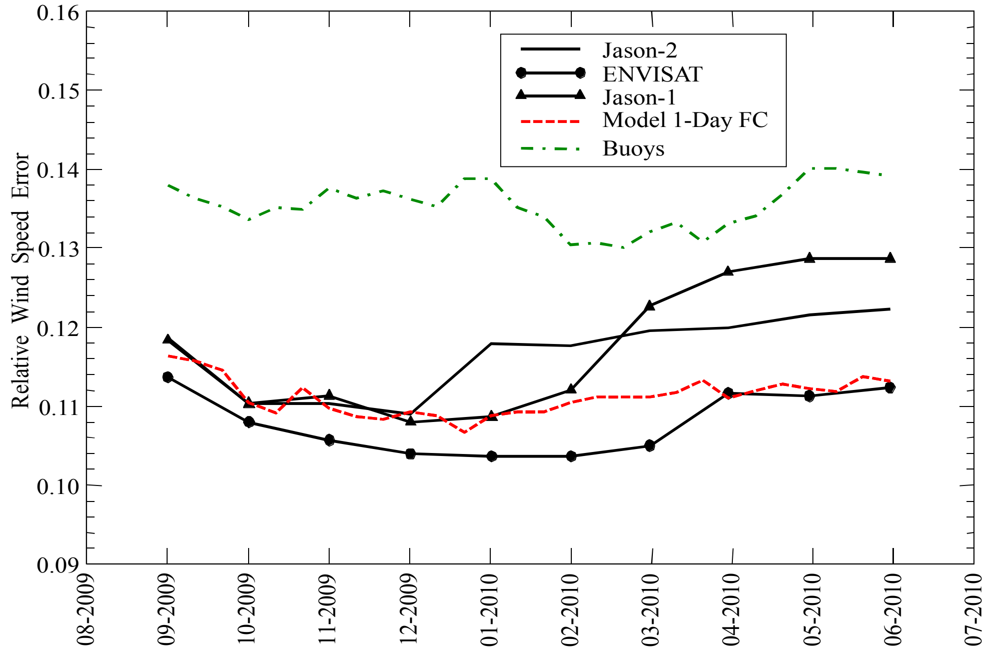

Figure 7: The time series of the monthly wind speed errors (3-month running means).

6 Conclusions

Jason-2 near real time OGDR-BUFR wind and wave products have been analysed to estimate their random errors. The triple collocation technique was utilised for this purpose. Jason-2 Ku-band significant wave height (SWH) product turned out to be of very high quality. The SWH error was estimated to be 0.13 m or about 5.4% of the mean. Its relative error is rather equal at most of the SWH range. Envisat RA-2 SWH, which has some degradation at wave height values lower than 3 m, has a slightly higher error of about 0.15 m. Jason-1, which suffered some stability problems between the end of March and end of summer 2010, showed relatively higher errors especially after March 2010.

On the other hand, Jason-2 wind speed error at a level of 1.00 m.s^{-1} (~11.9%) may not be the lowest compared to the other instruments. Envisat RA-2 wind speed error, which was estimated to be 0.93 m.s^{-1} (~11.1%), is the lowest one. It seems that the error in the wind speed at low wind speed values is relatively high for all instruments especially the buoys and the model. The model 1-day forecast winds seem to be of relatively small error for wind speeds in excess of 12 m.s^{-1}.

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