Calibrating altimeter wave height against buoy measurements.

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1 Introduction

Significant wave height ($H_s$) estimated by altimeters need to be checked against buoy data to get good values although the required corrections are usually only a few percent and rarely more than 10%. The calibrations required generally appear to remain constant throughout the life of the altimeter, unless changes are made to the instrument – e.g. change of tracker or transmitter – but Topex wave heights drifted out of initial calibration as the transmitter aged, from 1996 to 1999 (see Fig 1), indicating the need to continue monitoring calibrations.

Figure 1: Differences between ERS-2 and Topex/Poseidon significant wave height from Quefféulou (2000).

This note considers further aspects of calibration techniques.

2 A linear correction

It has been found, over many years with all altimeters, that a linear correction is generally all that is needed. However, the altimeter is not good at measuring $H_s$ less than about 1 m because the slope of the returning pulse is then too steep to be properly estimated from the discrete processing gates; and here, for ERS-2 a quadratic correction is needed.

Another problem arises with such low $H_s$: the 1 Hz values used for calibration are those corrected for instrumental effects which can produce negative $H_s$; these are recorded as 0.
Scharroo (2002) suggested, in para. 2.3.1, that the negative $H_s$ values should be retained in the OPR product; and Scharroo & Lillibridge (2003) repeated this suggestion.

Comparing altimeter and buoy estimates of $H_s$ raises sampling issues, it is usual to take altimeter 1 Hz data when with 50-100 km of the buoy and within 30 minutes of the buoy measurement. Sometimes the 1 Hz record nearest to the buoy is used but usually the mean of all quality controlled records within the 50-100 km circle is used.

A linear relationship:

$$H_{s_{buoy}} = \alpha H_{s_{alt}} + \beta$$

is derived, and $H_{s_{alt}}$ calibrated assuming that the buoy estimate is the correct one.

Originally a linear regression of $H_{s_{alt}}$ on $H_{s_{buoy}}$ was used assuming that all the errors were with the altimeter data - but nowadays an orthogonal distance regression (ODR) is carried out, assuming that the altimeter and buoy errors have similar sized variances. Caires & Sterl (2003) conclude that the variances are indeed similar. Sometimes the geometric mean of the slopes of $H_{s_{alt}}$ on $H_{s_{buoy}}$ and $H_{s_{buoy}}$ on $H_{s_{alt}}$ is advocated, as a good approximation to the ODR result e.g. Cotton et al. (1997), and this works well given the usual high correlation between $H_{s_{alt}}$ and $H_{s_{buoy}}$, but it is unnecessary when the ODR passes through the centre of gravity of the data and the slope can be readily calculated - see e.g. Appendix A to Carter (1998) which shows that the estimated angle, $H_s$, of the ODR line and that of the geometric mean are related by:

$$\tan[2\theta_{ODR}] = r \tan[2\theta_{GM}] \quad r > 0$$

where $r$ is the estimated correlation coefficient.

However, it is better to use, for example, the ODRPack software (Boggs et al., 1989) which not only gives the equation of the ODR but also gives estimates of the errors in $\alpha$ and $\beta$.

Tolman et al. (2006) are on their own when they argue that errors in $H_{s_{alt}}$ are smaller than in $H_{s_{buoy}}$ (which are around 8%) so they use the linear regression of $H_{s_{buoy}}$ on $H_{s_{alt}}$.

All the above methods of analysis assume that the errors on estimates of $H_s$ are from one distribution, while the errors are in fact proportional to $H_s$. Perhaps a model should be used in which the data are weighted inversely proportional to $H_s$, but this would downgrade the highest measurements which are already invariably few in number - a practical rather than statistical argument for the status quo.

3 Choice of buoys

Comparisons against buoys are often carried out using data from the US NDBC buoys because these data are readily accessible and have been in operation over many years. Other buoys are sometimes used e.g. the some Canadian and UK buoys (data provided by the Canadian Marine Environment Data Service and the UK Met. Office) but differences in resulting calibrations have been found, indicating variations between different nations buoy measurements (Challenor & Cotton, 2001; Cotton et al., 2003; Cotton et al., 2005; Queffelec, 2006; Durrant & Greenslade, 2007). Until the differences between buoy measurements have been sorted out it would seem sensible to calibrate altimeters using the US NDBC buoy.
4 Use of wave models

Some comparisons have been carried out using altimeter wave heights and model estimates, as well as buoy data. Differences between an altimeter and a model do not provide altimeter calibration, but such comparisons have been useful in identifying problems in the altimeter algorithms. For example during the ERS-1 cal/val period in 1991 the global mean altimeter Hs was about 1 m higher than the ECMWF model cured by updating the altimeter processing algorithm (Janssen et al., 1997). Janssen et al. (op cit) were also able to compare differences in Hs between altimeter and buoy as a function of the model root mean square slope, suggesting that the altimeter Hs are biased low for wind seas, with large slopes. They conclude that “This underestimation may be as much as 50 cm”, but I am not aware of further investigation of this possibility.

Another use of model data has been to provide three data sets of Hs at the same time and location: altimeter, buoy and model, and to analyse these to obtain estimates of the error variance of each but the analysis does not provide any information on which of the data sets is the true measure. See e.g. Tokmakian & Challenor (1999), Caires & Sterl (2003), Janssen et al. (2003), Cotton et al. (2005).

5 Lack of agreed calibrations

It should be pointed out that many of the papers referenced in this paragraph give values for the coefficients (usually the slope and intercept, α and β in Eq. 1) required to calibrate altimeter Hs data; but there are differences between authors which need to be addressed if agreed values are to be derived.

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