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Data assimilation of partitioned HF radar wave data into Wavewatch III

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ABSTRACT

In this study the assimilation of HF radar data into a high resolution, coastal Wavewatch III model is investigated. An optimal interpolation scheme is used to assimilate the data and the design of a background error covariance matrix which reflects the local conditions and difficulties associated with a coastal domain is discussed. Two assimilation schemes are trialled; a scheme which assimilates mean parameters from the HF radar data and a scheme which assimilates partitioned spectral HF radar data. This study demonstrates the feasibility of assimilating partitioned wave data into a coastal domain. The results show that the assimilation schemes provide satisfactory improvements to significant wave heights but more mixed results for mean periods. The best improvements are seen during a stormy period with turning winds. During this period the model is deficient at capturing the change in wave directions and the peak in the waveheights, while the high sea state ensures good quality HF radar data for assimilation. The study also suggests that there are both physical and practical advantages to assimilating partitioned wave data compared to assimilating mean parameters for the whole spectrum.

1. Introduction

Observing and modelling waves in coastal regions is important for applications such as shipping, offshore engineering and development of sea defences. Data assimilation is a process by which models and observations are combined to give the best estimate of the true state, known as the analysis. It is a useful tool for initialising forecasts and optimising hindcasts which in turn can improve our understanding of the ocean and coastal conditions.

Data assimilation into wave models is a relatively new subject. While data assimilation into atmospheric models began in the 1950s and 1960s, data assimilation into wave models was not addressed until the 1980s. In the 1980s the higher quality of the wind fields being produced by atmospheric models and the increase in wave observations through the introduction of ocean satellite radars such as the SAR (Synthetic Aperture Radar) were instrumental for the extension of assimilation to wave models. The majority of wave models in operational use are third generation spectral wave models. In general it is not practical to assimilate the whole two dimensional wave spectrum into these wave models. The main reason is due to the difficulty of calculating an analysis for all the spectral components and the high computational cost involved with doing this. The limited availability of full frequency-direction spectra from observations has also restricted the possibility of assimilating the whole spectrum. Furthermore, correlation exists between spectral components and ideally this would need to be specified if assimilating the spectrum directly. This correlation would be difficult to define and would further increase the cost of the scheme. So as an alternative most authors have chosen to assimilate a selection of mean parameters and wind parameters such as significant waveheight (*Hs*), mean period (*Tz*), wind speed and wind direction. But since the wave models are spectral models, an analysis spectrum needs to be generated by adjusting the original model spectrum using the assimilated parameters.

Various schemes have been proposed, some are as simple as scaling the whole model spectrum to the analysis wave height, for example Esteva (1988) and Bauer et al. (1992), while others (Thomas, 1988; Foreman et al., 1994; Francis and Stratton, 1990) consider the windsea and swell parts of the spectrum separately. Lionello et al. (1992) classified a spectrum as either windsea, swell or mixed windsea and applied different techniques for scaling the spectrum dependent on the classification.

By the mid 1990s the idea of assimilating partitioned spectral wave data had been proposed (Voorrips et al., 1997; Hasselmann et al., 1997). The idea was that rather than splitting the wave spectrum into a windsea and swell component using methods for characterising a windsea from the local wind, a more elegant partitioning method based on the topography of the spectrum could be used to identify all the component wave trains present (allowing for more than one swell wave train). It is then assumed

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that each partition within the spectrum represents a different wave train with a unique meteorological origin and thus, that each partition is uncorrelated. The analysis mean wave integrated parameters for each partition can then be calculated and each partition can be adjusted separately.

Voorrips et al. (1997) assimilated partitioned pitch and roll buoy spectra into a North Sea implementation of WAM. The framework for the assimilation was an optimal interpolation method and each partition was scaled in energy and shifted in frequency and direction to obtain the partitioned analysis energy, mean frequency and direction. Hasselmann et al. (1997) also used an optimal interpolation method and assimilated partitioned Atlantic ERS-1 satellite radar data into the WAM model.

To date, most assimilation into wave models has been concerned with global or ocean scale models; there has been little consideration of data assimilation into coastal regions until recently (Siddons, 2007; Siddons et al., 2009; Portilla, 2009; Sannasiraj and Goldstein, 2009). Data assimilation into a coastal model poses specific problems compared to a global model. Wave conditions in regional models vary on much shorter temporal and spatial scales and are sensitive to changes in bathymetry and sheltering from coastlines. The error covariances therefore need to be designed to reflect the complex coastlines and bathymetry of a region. It is important that deep water points are not strongly correlated with shallow water locations to avoid instabilities in the data assimilation results. Much like global models, an important source of error comes from the wind forcing but this will occur at different scales in a regional model and regional models may also expect errors from their boundary conditions.

Siddons et al. (2009) assimilated *Hs* and *Tz* data from an OSCR (Ocean Surface Current Radar) HF (High-Frequency) radar located off the East Coast of England into the SWAN model. He tested three different assimilation techniques; 3D-VAR, an ensemble optimal interpolation (ensemble-OI) and an ensemble Kalman Filter (ensemble-KF). The results showed some overall improvements for the 3D-VAR and ensemble-OI methods, however, results from the ensemble-KF method were inconsistent. Siddons et al. (2009) suggested that incorporating spatially correlated errors and removing biases could improve the performance of the data assimilation schemes. He also stressed the need to apply strict quality control to the HF radar data. Portilla (2009) assimilated data from a single buoy off the Belgium Continental Shelf into a near shore configuration of the WAM model. He assimilated mean parameters (*Hs* and *Tz*) using an optimal interpolation scheme and investigated some different methods for parameterising the gain matrix. The parameterisation of the gain matrix allows for information to be spread in way which is consistent with the wave conditions in the region, but makes it difficult to extend the method to multiple observations. Portilla (2009) found improvements to the scatter index and RMSE and showed that in moderate wind conditions the benefit of assimilation could last for several days. Portilla also discussed assimilation of partitioned data and highlighted that the main task for this application would be the specification of an effective partition cross-assignment scheme.

Sannasiraj and Goldstein (2009) also used the optimal interpolation method to assimilate buoy data into WAM. They considered the Arabian sea region and assimilated significant waveheights from 3 different buoys into their model. They found their method to be computationally efficient and noted that the root mean squared error in the analysis waveheights was reduced by 30–50% in their study.

This study considers the assimilation of both mean parameters and partitioned wave data from an HF radar into a Celtic Sea wave model. An optimal interpolation (OI) method is used to assimilate multiple HF radar observations and a technique based on the Quick Canadian (QC) covariance method (Polavarapu et al., 2005) is used to estimate the wave model background error correlations for the region. The background error covariances are parameterised using these correlation lengthscales and parameterisations based on the bathymetry and climatological conditions of the region. Unlike the studies of Portilla (2009) and Sannasiraj and Goldstein (2009), this study implements data assimilation of wave partitions in a coastal region and compares the results to a twin study which assimilates mean parameters of the whole spectrum.

2. Wave model and observations

2.1. Wavewatch III

The model used in this study is Wavewatch III version 2.22 (hereafter WW3). It is a third generation spectral wind-wave model which solves the action balance equation. The full details of the numerical expressions used in WW3 are provided in Tolman (2002), Booij et al. (1999) and Ris et al. (1999). WW3 uses an explicit numerical scheme and in this study the Tolman and Chalikov (1996) combined input and dissipation source term is applied, the Hasselmann et al. (1973) empirical JONSWAP model is used for the bottom friction and the discrete interaction approximation (DIA) of Hasselmann and Hasselmann (1985) is used to model the quadratic non-linear wave-wave interactions.

For this study the WW3 model was run for the Celtic Sea region using NGDC GEODAS bathymetry data from 9 W to 4 W, 50 N to 55 N, with a resolution of $\frac{1^o}{30}$ (see Fig. 1). WW3 was forced with hourly 12 km resolution analysis winds from the UK Met Office atmospheric model and 12 km current and water level fields from the POLCOMS shelf sea model. The Celtic Sea model was nested within a $\frac{1^o}{6}$ North East Atlantic model, which in turn was nested in a lower resolution North Atlantic model. The North Atlantic model was run from 15/12/2004 and provided hourly boundary conditions for the North East Atlantic model which was run from 11/01/2005. The Celtic Sea model was initialised from zero at 11/01/2005 (the first 2 days were considered as spin up) and was forced with hourly boundary conditions from the North East Atlantic model. The WW3 model used spectra with 25 frequencies

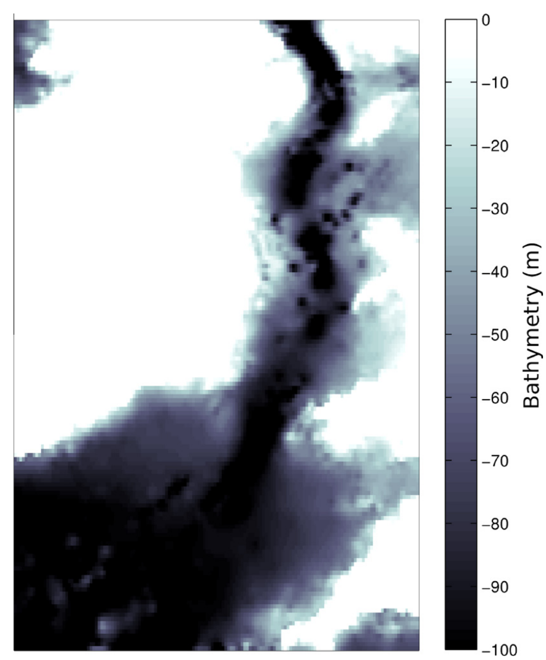

Fig. 1. The Celtic Sea model bathymetry.