Assimilation of Synthetic-Aperture Radar Data into Navy Wave Prediction Models

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LONG-TERM GOAL

To develop methods utilizing synthetic aperture radar (SAR) data to improve predictions for the littoral zone obtained from Navy wave forecasting models — in this case the SWAN model of Booij, Ris & Holthuijsen (1999).

OBJECTIVES

There are three basic objectives to this program: (1) to develop a forward prediction capability for the expected value of the SAR-image spectrum, with the SWAN wave-spectrum prediction as input; (2) to develop methods to bring the SWAN-based SAR-spectrum prediction into agreement with satellite-based SAR observations by adjusting the SWAN model inputs; and (3) to validate the improvement in the results from the SWAN model against ground-truth data.

APPROACH

The accuracy of the predictions obtained from the SWAN model is limited by (among other things) inaccuracies in the specification of the model inputs (initial conditions, boundary conditions, and forcing). The information contained in SAR images of ocean waves can potentially be used to improve the predictions, by guiding modifications to the model inputs so as to obtain the best agreement between the observed SAR-image spectrum and the SAR-image spectrum predicted from the wave spectrum output from the SWAN model. For the calculation of the SAR-image spectrum corresponding to a given SWAN prediction of the wave spectrum, the approaches used are the fully nonlinear mapping approach of Hasselmann & Hasselmann (1991). The approach used to bring the predicted SAR-image spectrum into agreement with the observed SAR-image spectrum relies on the variational framework outlined by Le Dimet & Talagrand (1986) which corresponds to the strong-constraint formalism of Bennett (1992). This procedure is iterative in nature and is applied until the difference is minimized.

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14. ABSTRACT
To develop methods utilizing synthetic aperture radar (SAR) data to improve predictions for the littoral zone obtained from Navy wave forecasting models - in this case the SWAN model of Booij, Ris & Holthuijsen (1999).

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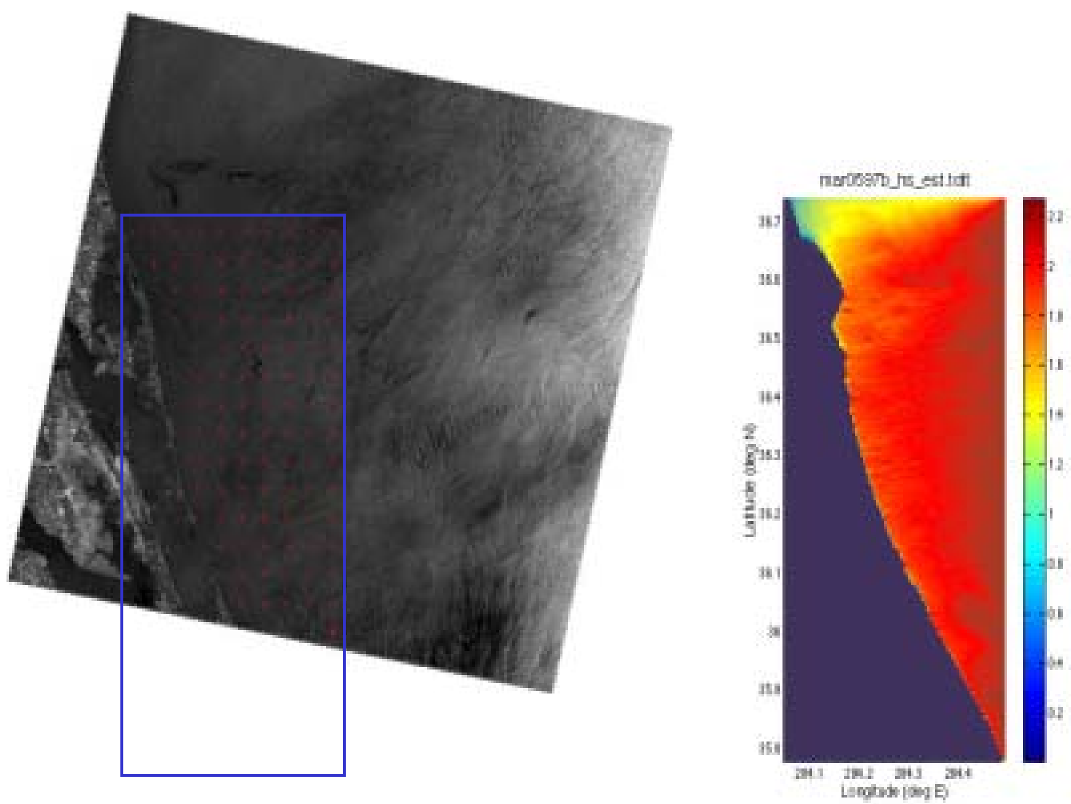
WORK COMPLETED

A variational approach for assimilating wave spectrum observations into the SWAN model was developed and validated for a spatially uniform incident wave spectrum. A variational SAR assimilation algorithm was implemented as well. This required development and implementation of adjoint to both the SWAN model (Booij *et al*. 1991) and the SAR-image spectrum model of Hasselmann & Hasselmann (1991).

RESULTS

In the current fiscal year, the changes to the original SWAN code which allow solution of the adjoint to the SWAN model were ported to the NRL SWANX code. Changes were also made to the adjoint solver to include the nonlinear source terms in the solution of the SWAN adjoint equations. The assimilation code was also modified to allow for a spatially varying incident wave spectrum. Finally, data sets for validation of the SAR assimilation procedure were identified. The improvements outlined above are currently being tested prior to application of the methodology to the validation data sets.

The assimilation procedure consists of a number of steps. First, the SAR image is decomposed into a number on non-overlapping sub-images and their respective energy spectra are calculated. Next, a



a) b)

Figure 1 a) SWAN computational grid overlaid on an ERS SAR image for 05 March 1997; b) Estimated significant wave height distribution obtained via assimilation of SAR data into the SWAN model.

first guess for the wave spectrum over the entire region is made, and the wave spectra corresponding to the sub-image location are extracted. Then, using the forward SAR spectrum model (Hasselmann & Hasselmann 1991), predictions of the SAR-image spectra are made. The following sequence is then followed: 1) The difference between the predicted SAR-image spectra are input to the adjoint SAR spectrum model (Lyzenga 2001) which estimates the effective difference between the predicted and true wave spectrum at those locations. 2) This result is input to the adjoint SWAN model, the solution of which is used to estimate the change needed in the incident wave spectrum to reduce the error between the predictions and observations. 3) The incident wave spectrum is adjusted and the forward SWAN model is run using the 'improved' incident wave spectrum. 4) The improved wave-spectrum predictions are used as input to the forward SAR spectrum model to calculate improved estimates of the SAR-image spectra. Steps 1–4 are repeated until the difference between the predicted and observed SAR-image spectrum is minimized, and the incident wave spectrum ceases to change.

Figure 1 shows the results of the SAR assimilation procedure applied to a set of ERS SAR data collected on 05 March 1997 near the USACE Field Research Facility in Duck, NC. Figure 1a shows the SAR image with the SWAN computational grid overlaid on it while Figure 1b shows the estimated significant wave distribution for the region. This result was obtained assuming a spatially uniform incident wave spectrum and neglecting the non-linearities in the adjoint SWAN model. When the assimilation results are compared to ground truth data, the significant wave height is over-estimated; this appears to mainly due to the requirement that the incident wave spectrum be uniform along the boundary. Reasonably good agreement was obtained between the estimated directional spectrum and ground truth data, and this is expected to improve as a result of the recent changes to the algorithm.

Porting of the adjoint solver modifications and other improvements to the NRL SWANX code involved the addition of several arrays and modifications to the solver sweep directions. As had been the experience in the past, this was made difficult by the complicated data structure of the SWAN model.

Allowing spatial variation in the incident wave spectrum estimated from the assimilation procedure is one of the new features added to the code, and will results in more flexibility, especially in regions of complex bathymetry. This can however, result in too much flexibility and an underdetermined problem. The issue that has arisen is how to ensure uniqueness in the resulting estimated incident wave spectrum; the appropriate approach to constraining the incident wave spectrum to ensure uniqueness is currently under investigation.

IMPACT/APPLICATION

Achieving the overall objectives of the program will result in an improved prediction capability for near-shore waves, allowing readily available remote sensing data to be used effectively.

TRANSITIONS

As the data assimilation capability for the SWAN model is refined, its use may be extended to other data types by other participants in the BE effort.

RELATED PROJECTS

This project is related to other efforts under the AWPP program. The SAR adjoint model described above has been extended under Contract No. N00014-98-C-0363 for use in determining wave coherence from SAR image data for application to mobile offshore base design.

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