Application of Dual-Frequency Satellite Altimeter Data to Improved Global Measuremetns of Sea State

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1. A SEMI EMPIRICAL MODEL OF THE NORMALISED RADAR CROSS SECTION (NRCS)

The NRCS model consists of 2 parts:

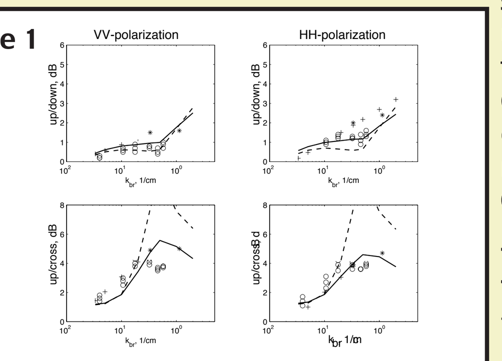
1. The Description of the Statistical Properties of the Sea Surface Itself

This description is based on the physical model of short wind wave spectrum (from a few millimetres to a few metres) developed by Kudryavtsev et al. (1999), and on the model of statistical characteristics of wave breaking events proposed by Philips (1985). Symbiosis of these two models gives a description of all the statistical properties of the sea surface (spectrum, mean square slope, wave breaking parameters), that are needed for radiowave scattering problems.

2. Calculations of Radar Backscattering from the Surface

The NRCS has been modeled as a superposition of "regular" sea surface (where backscattering is supported by the Bragg mechanism) and surface areas with enhanced roughness produced by breaking waves. It was assumed that although these areas are small, their very high local NRCS significantly contributes to the total NRCS. The model of non-Bragg scattering is presented as a sum of high scattered areas (radar targets), with unknown NRCS which is the main tuning parameter. This parameter is a function of incidence angle only. It has been specified so that total NRCS model (accounting for both Bragg and non-Bragg scattering) reproduces the observed mean polarized ratio (averaged over azimuth). Validation of the model has been performed on the empirical K_u and C band NRCS models CMOD_IFR and NSCAT.

Figure 1



Ratio (in dB) of the upwind to downwind NRCS (upper plots) and of the upwind to crosswind NRCS (lower plots) as a function of inverse Bragg scattering wavelength, for VV and HH polorisation, and at an incidence angle 30 deg and wind speed 8 to 12 m/s. Dashed lines are results of the composite Bragg scattering model, solid lines are results of the total NRCS model accounting for the non-Bragg scattering. Symbols refer to radar observations: open circles are from Unal et al (1991), crosses are from Jones and Shroeder (1978), and stars are from Masuko (1986).

The model was then extended to use it in the radar-wave MTF (Modulation Transfer Function) problem. Extension mainly concerns the description of the modulation of the radar scattering by long waves.

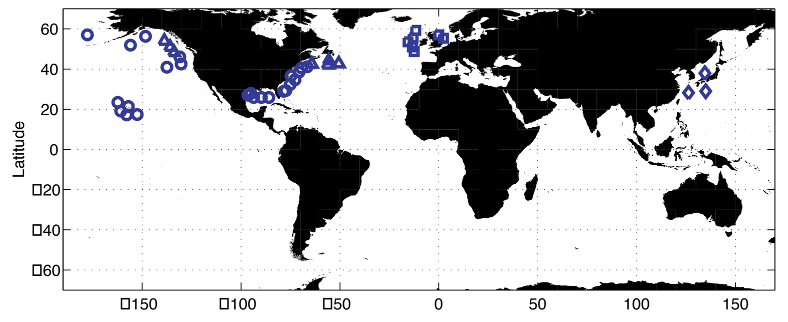
Variations of the NRCS result from modulations of Bragg scattering waves, slopes of tilting waves and modulations of wave breaking supporting non-Bragg scattering. This latter effect has never been taken into account before. We have shown that the modulation of wave breaking plays a crucial role: even if the contribution of non-Bragg scattering to the total NRCS is not very large, the large modulations in wave breaking significantly contributes to the radar MTF.

Model predictions of radar MTF are consistent with results from radar observations either taken from the literature or obtained for the present study.

2. IMPROVED WIND/SEA STATE ALGORITHMS

In recent years, much effort has been applied to improving altimeters sea surface height estimates, but empirically-based algorithms for wind speed and significant wave height have remained practically unchanged. Here, we explore the possibility to extract better sea state information from altimeter data through the use of dual frequency and sea state dependent algorithms. We report here on our progress for the retrieval of wind speed and wind stress.

Figure 2

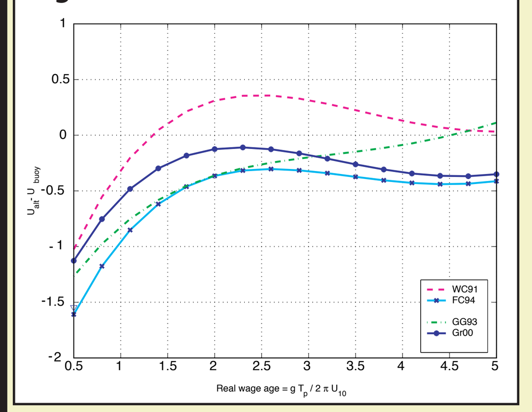


Wind speed

A dataset of colocated buoy/altimeter measurements was collated to develop and validate altimeter wind retrieval algorithms (Gommenginger et al, 2002). The colocated Topex/buoy dataset is the largest collocated altimeter/buoy dataset to date and made use of a network of 41 moored buoys selected for their location in open water and their proximity to Topex tracks (Figure 2). The final dataset included 4444 data points obtained by collocating buoys with Topex data within 1 hour and 50 km.

Single-frequency, dual-frequency and sea state dependent wind speed algorithms were tested using this dataset. We found that dual-frequency (K_u and C band) algorithms do not improve on the performance of single-frequency K_u band models, in accordance with theoretical work by Karaev et al. who suggest that the backscatter at K_u and C band dependence on wind speed are not sufficiently different to yield any improvements in terms of wind speed retrieval.

Figure 3



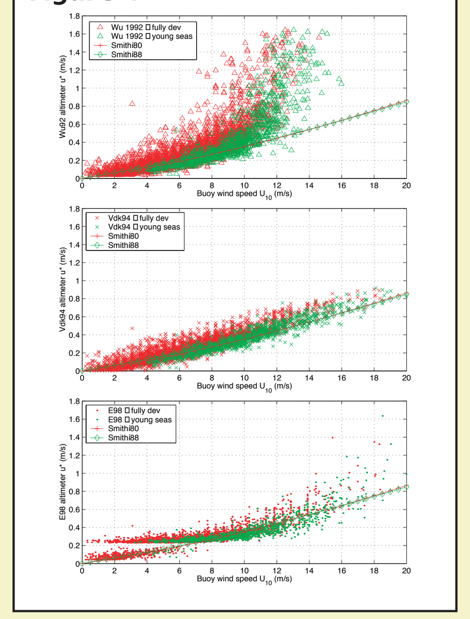
The addition of altimeter significant wave height (SWH) on another hand causes a small but significant reduction of about 10% in root-mean-square error to the wind speed. A residual dependence on sea state persists however in all algorithms (Figure 3), suggesting that the use of SWH is not sufficient to account fully for sea state developement effects. All current algorithms were found to underestimate winds in young sea conditions on average by 1 to 1.5 m/s.

Closer examination of the regional dependence of the wind speed residual suggests the need to include region specific information on sea state climate. Using altimeter wind speed and significant wave height for an a-priori sea state classification, and an iterative approach allows a correction to be derived and further improvement of the wind speed retrieval (Karaev et al., 2002).

Wind stress

The retrieval of wind stress from nadir altimeters is not as well recognised as for scatterometers. However, there are a small number of algorithms in the literature which propose to retrieve wind friction velocity directly from the altimeter backscatter. Here, we consider the single-frequency models by Wu (1992; hereafter Wu92) and Vandemark et al. (1994; hereafter V94) and the dual-frequency model by Elfouhaily et al. (1998; hereafter E98).

Figure 4



A small dataset of in-situ wind stress measurements was available in the mid-North Atlantic for collocation with Topex. The collocated dataset consisted of 46 points when using the time/space separation criteria of 1hr and 100km. Both V94 and E98 models showed good quantitative agreement with in situ measurements (Smith 1984/1988), with correlation coefficients of 0.85 and 0.89 respectively. Further testing using the collocated Topex/buoy dataset revealed a strong discontinuity around 0.23 m/s for the E98 model (Figure 4), due to the two-branch formulation of the model (Gommenginger et al, 2002).

OVERVIEW

INTAS and CNES have jointly funded a 3-year programme to improve the utilization of dual-frequency satellite altimeter data by reconsidering the modelling of sea surface roughness and radar's interaction with it.

The first task has been to develop improved models representing the sea surface roughness over a wide range of scales and thence the radar scattering from it. These advances in modelling have given us insight into the expected sensitivity and dependence on polorization and incidence angle.

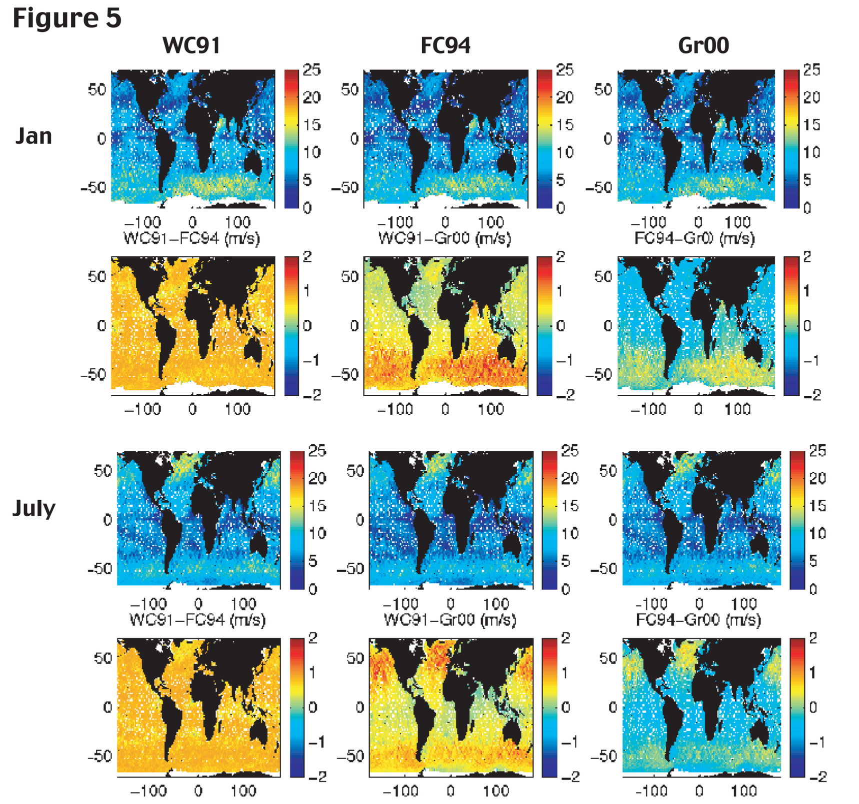
The second step has been to evaluate various altimeter algorithms using a large dataset of buoy matchups. Algorithms for wind speed, wind stress and wave period have been tested, although only the first two are shown here.

The third stage is the routine processing of TOPEX data to develop climatologies of these new validated fields.

3. CLIMATOLOGIES

Accurate description of the wind and sea state climate is of significant importance for numerous socio-economic domains (e.g. transport, offshore exploration, coastal defenses).

Figure 5



Monthly climatology of altimeter derived wind and sea state parameters were produced for Topex. We present here typical climatology results for the wind speed and wind stress models validated in section 2.

Wind speed

The monthly wind speed climatology are shown in Figure 5 for January and July 1994 using three models: the single-frequency altimeter wind speed algorithms by Witter & Chelton (1991; WC91) and Freilich & Challenor (1994; FC94) and the two-parameter (SigKu, SWH) model by Gourrion et al. (2000; Gr00). The other rows represent the wind speed difference between the different models. We find that WC91 displays a positive bias with respect to both FC94 and Gr00. The differnce between FC94 and WC91 illustrates the effect of the SWH parameterisation in Gr00 for wind speed retrieval.

Wind stress

Accurate global wind stress measurements are a vital input to estimates of global air-sea fluxes, which in turn are of central importance to climate studies. The monthly wind stress climatology are shown in Figure 6 for January and July 1994 for the three models described in section 2: the single-frequency models by Wu (1992; Wu92) and Vandemark et al. (1994; Vk94) and the dual frequency model by Elfouhaily et al (1998; E98).

For comparison, figure 7 represents the SOC wind stress climatology used routinely as forcing for ocean circulation and climate models. We find that many seasonal features are well represented (e.g. Monsoon in Indian Ocean, storm track in North Atlantic) and that the Vk94 wind stress model provides the most realistic estimates.

Figure 6

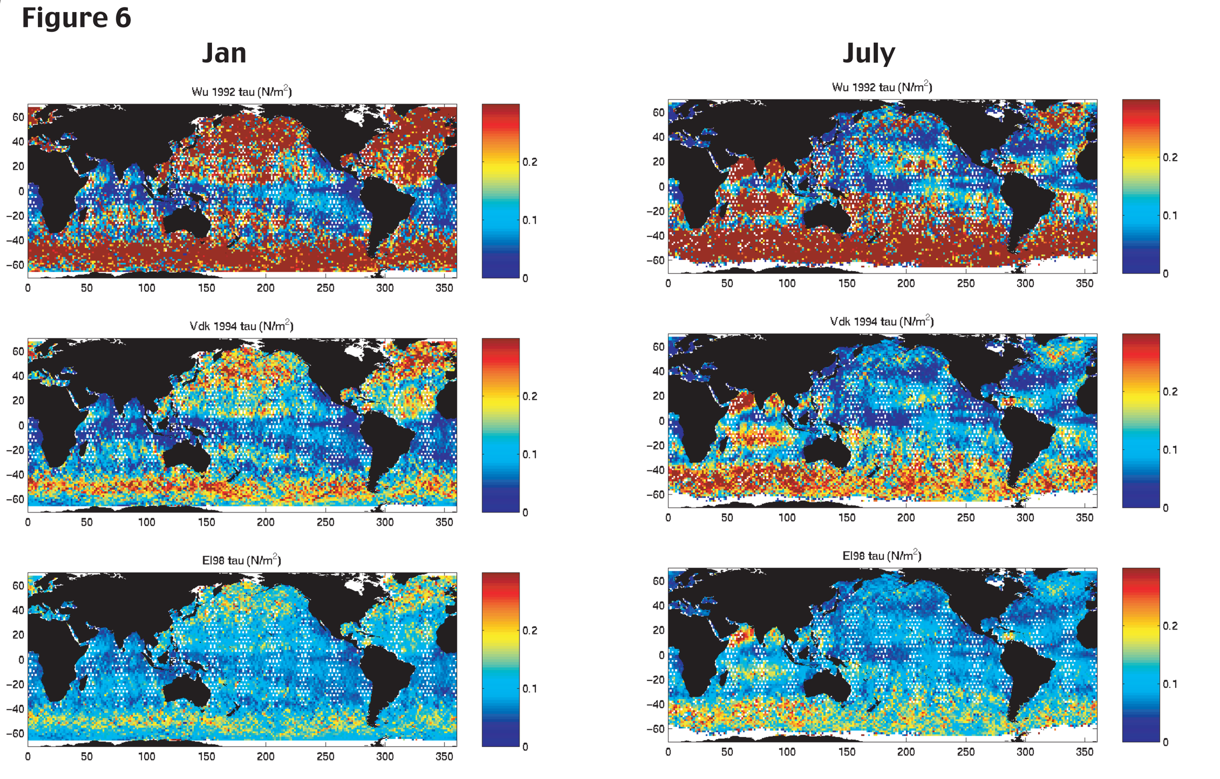
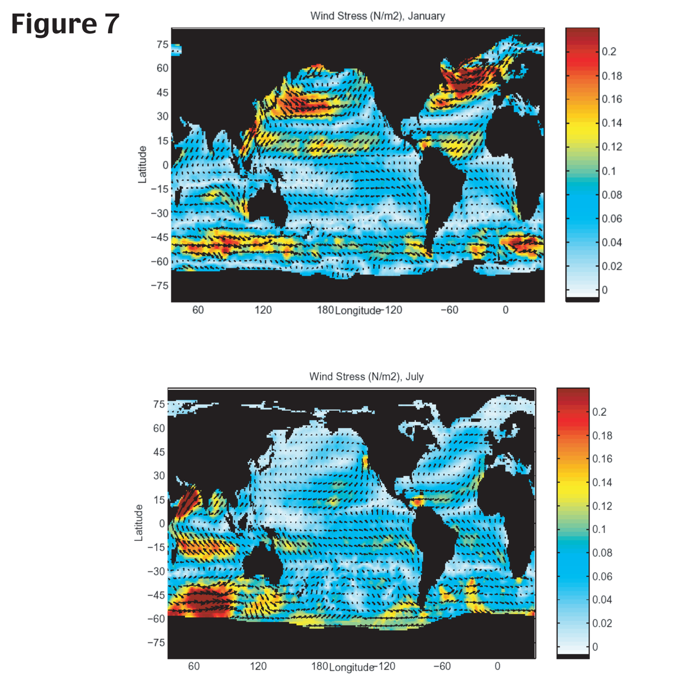


Figure 7



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