REQUEST FOR A SPECIAL PROJECT 2013–2015

MEMBER STATE: France

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Project Title:

Wind stress in coupled wave-atmosphere models: storms and swells

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ______________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project. For projects started before 2009, please state 2009 as the start year.)	2013	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☒

Computer resources required for 2013-2015: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2013.)	**2013**	**2014**	**2015**
High Performance Computing Facility (units)	7,000,000	8,000,000	8,000,000
Data storage capacity (total archive volume) (gigabytes)	8	10	10

*An electronic copy of this form **must be sent** via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): October 1st 2012

Le Directeur général adjoint

Olivier GUPTA

Continue overleaf

Principal Investigator: Fabrice Ardhuin

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

Project Title: Wind stress in coupled wave-atmosphere models: storms and swells

Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

Summary: Using ECMWF's Integrated Forecasting System (IFS) in near-operational configuration we are planning to perform deterministic forecasts to estimate the sensitivity of the atmosphere and ocean waves on the wind stress parameterizations over the oceans. In the first year this project will focus on high winds in extra-tropical storms of the North Atlantic, for which the stress at a given wind speed is expected to decrease with wave age. That effect that is already taken into account in the IFS by the use of a Wave Model (WAM) to estimate the sea roughness but its magnitude is still debated. In the second and third year the emphasis will shift on low winds and swell-dominated conditions, relevant to the tropical ocean, which are expected to strongly affect the wind stress vector, up to reversing its direction. Parameterizations of these effect will be developped and tested in the IFS, with an effort to make them coherent with the use of WAM.

1) Context

Wind stress over the oceans is determinant for the evolution of storms, both hurricanes and extra-tropical storms (e.g. Emmanuel 2003) . Although it is generally recognized that the wind stress vector is modified by the sea state, both in high wind conditions and in moderate winds in the presence of swells, it is striking that ECMWF is unique in its implementation of a wind stress parameterization that includes some of these effects (Janssen 2008).

a) High winds

Indeed, the parameterization by Janssen (1991, 1994) represents the decrease of wind stress with wave age which is relevant to stoms. That parameterization has given a significant extension of the forecast range (Janssen 2001), and has lead to beneficial results in terms of storm surges (Mastenbroek et al. 1993; Bertin et al. 2012). Large impacts were also found in simulations of hurricanes although the effects of sea spray are still poorly understood (Doyle 2002). Other observations and numerical models of hurricanes have questionned the behaviour of such a parameterization at high winds, suggesting that the drag coefficient may decrease for wind speeds at 10 m above 25 m (Black et al., 2007, Zedler et al. 2009) while storm intensity is further enhanced by the feedback of spray on heat fluxes (Bao et al. 2011). In general, there is no consensus on the range of variability of the wind stress with wave age at a fixed wind speed. Some datasets (Drennan et al. 2005) support a larger variability than Janssen's (1991) parameterization, while others support a more moderate variability (Edson et al. 2007).

Also, this variability of the wind stress is expected to be related to the energy level in the high wavenumber tail of the wave spectrum (Janssen 1991, Donelan 1998). Ardhuin et al. (2010) have proposed a parameterization that generally gives a bettern variability of the high wavenumber tail, compared to Janssen (1991). Evidence of that is given by figure 1, a similar figure in Ardhuin et al. (2009), and routine verification of the operational wave models for the mean wave period Tm02, for which the scatter index in ECMWF analysis is 7.5% for all buoys and 14.0% in the Western Mediterranean, compared with 6.9% and 9.9% with the SHOM-Ifremer forecasting system (these numbers are taken from the May 2012 monthly reports compiled by J. Bidlot as part of the Wave Model Verification project under JCOMM). In spite of that better behavior of high-frequency waves, that parameterization yields a much reduced and probably unrealisting variability of the wind stress, as shown in figure 2. This shows, that it is very difficult to define a proper parameterization of air-sea fluxes by considering only the wave field. Certainly the feedback on the atmosphere, and possibly ocean, has to be taken into account to find a proper wind stress parameterization.

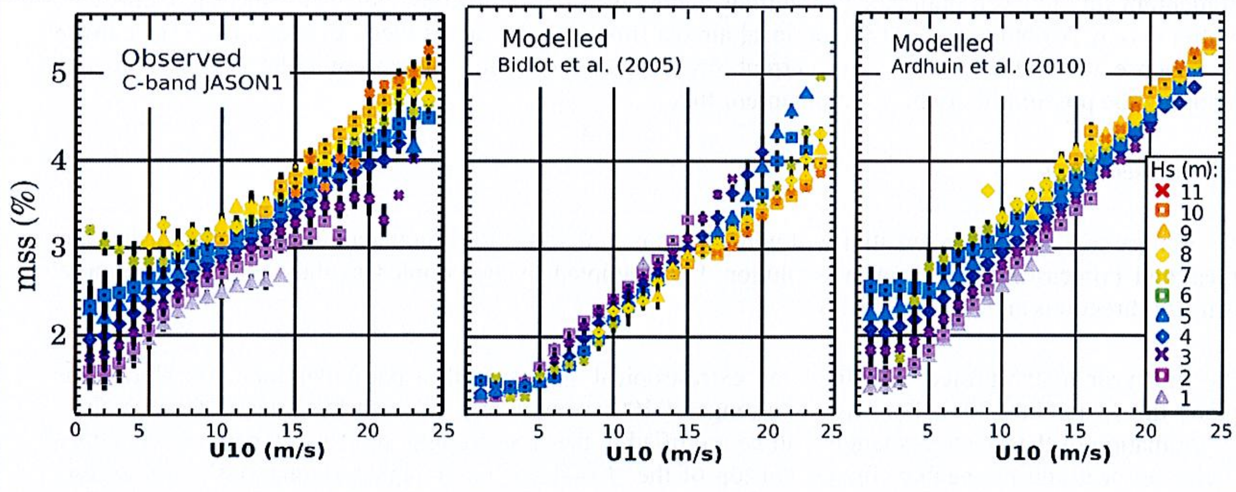

Figure 1: Variation of mean square slope (mss) estimated as 0.64/σ0 averaged over classes of wind speed (x-axis) and wave height (colour). The left panel show the observations from the C-band altimeter on board JASON 1 for the first 6 months of 2007. The right panel show model results at the location of the altimeter measurements using the ECMWF parameterization, and the middle panel show results with the new model.

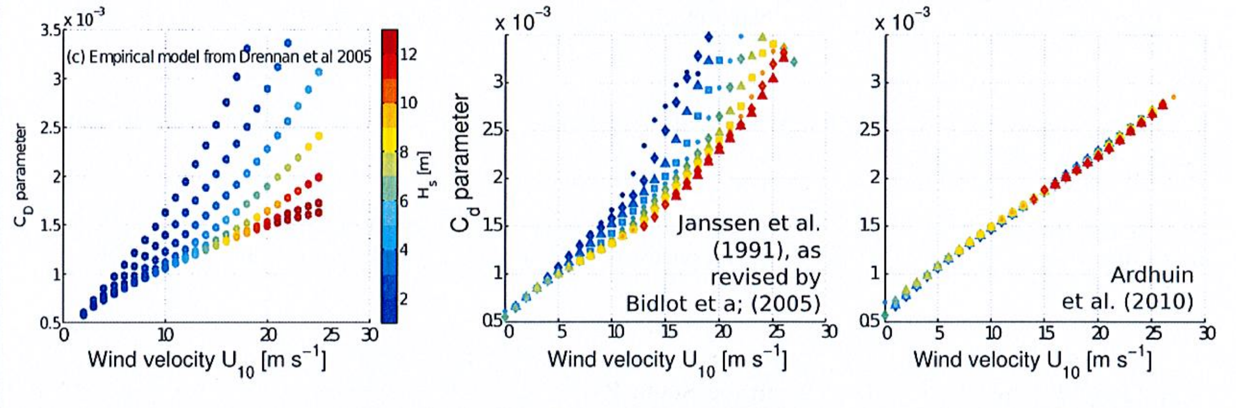

Figure 2: Drag coefficient as a function of wind speed and wave height. Wave height is used here as a surrogate for the wave age. In the left panel, the empirical wave spectral shape by Elfouhaily et al. (1997) has been used. The two other panels are obtained from a 1 month global hindcast using the model WAVEWATCH III.

Our question here is : Is it possible to design a parameterization that will give both a realistic energy level for short wind-waves and a realistic dependence of the drag coefficient with the sea state? And by the way, what is the real dependence of the drag on the sea state?

b) Swells and weak winds

Swells have been observationally known to influence the magnitude and direction of the wind stress (e.g. Drennan et al., 2003; Hogstrom et al. 2009), even leading to a reversal of the stress vector (e.g. Grachev and Fairall, 2003). At low wind speed observations have shown that non-locally generated waves (swell) have a significant impact on momentum transfer, , on the turbulent kinetic energy, and on the structure of the overall marine boundary layer (e.g. Carlsson et al., 2009; Garcia-Nava et al., 2009; Semedo et al 2009). They can reduce the drag in providing momentum to the atmosphere when the wind and swell are aligned. They can enhance the drag when the swell propagates against the wind. Theoretical and numerical approaches also gave interesting results (Hanley and Belcher 2008, Sullivan et al. 2008). The LES of wind-swell interaction (Sullivan et al. 2008) indicate a wave-induced momentum flux divergence and the development of the low-level jet. Global climatology (Hanley et al. 2010) indicates that a wave-driven wind regime is prevalent in tropical regions, where weak winds and mid-latitude originated swell can co-exist.

So far these effects have not been included in weather forecasting. However, the magnitude of the upward momentum flux in swell-dominated conditions is now well constrained by long-range measurements of swell evolution (e.g. Ardhuin et al. 2009) and local air-sea fluxes. Using recent theoretical and numerical advances, we propose to modify and test the current stress parameterization to represent the wave-driven regime, including the possibility of upward momentum flux.

2) Proposed work

We propose to evaluate the sensitivity of wind stress parameterizations on the atmospheric forecasts using the Integrated Forecasting System at a resolution T511 coupled to the coupled to the 55 km resolution WAM using 24 directions and 30 frequencies.

The first year of the project will focus on extra-tropical storms, with a particular focus on North Atlantic winter the years 2009-2011. Forecasts to a range of 10 days will be performed for at least 20 cases. Only the determination of the roughness length will be modified in the IFS, keeping the existing parameterization of its effects on heat and momentum fluxes. On top of the "Control" and "coupled simulations" such as used by Janssen et al. (2001), we will include two more parameterizations: one in which the Charnock coefficient is a function of wind speed alone, and another with a greater sensitivity to wave age than Janssen (1991), i.e. similar to Drennan et al. (2005).

On a few cases, the impact of swells on the roughness predicted by **Cy38r1** will be investigated in relation to recent wind stress measurements (Garcia-Nava et al. 2012) and known parameterization behaviour (Ardhuin et al. 2007).

For all cases, the model accuracy will be verified using 500 mb geopotential correlations, significant wave heights and mean periods, and wind speeds.

In parallel, we will work to modify the current ECWMF stress parameterization to include the wave-driven wind regime. Tests and first evaluations will be performed in one-dimensional atmospheric model, forced by various swell fields.

In the second and third year, more emphasis will be placed upon the tropical ocean and heavy swells with weak wind conditions. Tests will focus on the South Pacific and Atlantic regions where wave-driven wind regimes are expected to be most frequent.

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