Reply to Reviewers

Reviewer-1

I'm really torn by this paper. I'm all in favor in showing the impact of coupling but I was extremely disappointed that the authors have barely acknowledged that the work they present here has already been done and has been at the core of the operational forecasting system from the European Centre for Medium-range Weather Forecasts (ECMWF) since 1998. Peter Janssen and his team have shown through the years the benefit of such approach. Peter even has a book dedicated to that (Janssen 2004: The Interaction of Ocean Waves and Wind, Cambridge University Press). Moreover, Peter was awarded this year the Nanssen medal in physical oceanography, in greater part because of his work on this topic. Even more disappointing is to note that this work was carried out during the MyWave project, in which Peter was also involved in showing that coupling waves to the ocean circulation (on top of the wave-atmosphere coupling) was also beneficial (Oyvind Breivik, Kristian Mogensen, Jean-Raymond Bidlot, Magdalena Alonso Balmaseda, Peter A.E.M. Janssen, 2015:Surface Wave Effects in the NEMO Ocean Model: Forced and Coupled Experiments Journal of Geophysical Research:Oceans 04/2015; DOI:10.1002/2014JC010565).

Reply: The main aim of this manuscript is to present the approach adopted to develop a fully coupled atmosphere-ocean wave model for supporting regional research and operational activities. Obviously there are many other similar works published during the last decades at global scale (ECMWF, NOAA/GFDL, CNRM-CM5) or at regional scale (coupling with limited area models). In particular, ECMWF has developed an advanced, state-of-the-art system based on a two-way coupling of the IFS spectral atmospheric model and the ECMWF version of WAM ocean wave model (ECWAM). Its superiority has been proved through a number of publications for a decade or even more. Following reviewer's comment we added an extensive paragraph (P4L5-19) describing the development and the main features of the ECWAM. We could not include the work of Breivik et al. (2015) because it was published after manuscript initial submission in the GMD (March 2, 2015). However, it is included in the revised version of the manuscript.

The description of the method used to couple the wave model to the atmospheric model does not indicate anything really novel with respect to what was done by ECMWF. The model parallelisation is different but the essence is still the same.

Reply: The method used to couple the wave model to the atmospheric model is based on the Multiple Program Multiple Data (MPMD). We decided to follow MPMD because it handles on a flexible way the two modelling components and it is very efficient and manageable with the load balancing on the processors. However, the OASIS coupler (versions 3 and 4), which is used to support the UK Met Office Unified Model and having as components the UM atmosphere, the NEMO ocean and the CICE sea-ice models, is also based on the MPMD architecture (https://wiki.cc.gatech.edu/CW2013/index.php/Experiences_and_Decisions_in_Met_

Office_Coupled_ESM_Development). As for the physics of coupling we admit that we followed a method very similar to ECMWF approach but with a totally different atmospheric model implemented on a very high resolution domain.

Moreover, it looks to me that the WAM code used does not contain certain adjustment to the numerical code that was necessary when the original WAM code was adapted at ECMWF (see ECMWF IFS documentation Chapter 7 and Bidlot J.-R. 2012: Present status of wave forecasting at ECMWF.Proceeding from the ECMWF Workshop on Ocean Waves, 25-27 June 2012. ECMWF, Reading, United Kingdom), now called ECWAM.

Reply:
Computer code: The source code of WAM has been extensively revised because it is initially based on the serial code of WAM Cycle 4, which is parallelized using OpenMP directives (P6-7, P11L1-13). To this end, a new MPI communicator has been defined in WAM in order to exchange information with the atmospheric model, which is fully MPI parallelized and using MPI_COMM_WORLD as a global communicator. The cross talking between the two models wasn't the only tricky milestone, since the two models have different grid structure, indexing, sea masks and domain edges. Therefore, numerous modules have been developed for homogenize and handle the data exchange between the atmospheric and the ocean-wave components.
Physics: The reviewer is referring to the following adjustments introduced since CY38R1 version of IFS (IFS Documentation – Cy38r1).

- Reduction of z_a value to 0.008 (from 0.011). We use 0.011 as it also appears in other versions of WAM model (for example WAM Cycle 4.5.4 available through MyWave project web page).
- Adjustment of the wave dissipation source function in order to obtain a proper balance at the high frequencies (Eq. 3.14 of IFS Documentation – Cy38r1). In the present version of WEW we use the original dissipation source term of WAM Cycle 4 (although this has been adjusted in WAM Cycle 4.5.4).

ECWAM contains the same sea state dependent Charnock parameterisation but also the impact of gustiness and air density on wave growth. One might argue that ECMWF focuses on global scale application, whereas this paper interest was the Mediterranean basin. But I will argue that all these effects might actually be more important over the Mediterranean Sea.

Reply: WAM receives the near surface wind components from the atmospheric model and returns the Charnock parameter, similarly with ECWAM, for the estimation of the roughness length and the friction velocity in the surface layer parameterization scheme. The coupling frequency has been set on the WAM timestep which is 360 sec while the timestep of the atmospheric model is 15 sec (P12L14-20). In the abovementioned paper of Breivik et al. (2015) the coupling timestep between IFS/ECWAM and NEMO model is 10800 sec. The coupling timestep of WEW is in line with its native horizontal resolution, which is 0.05°x0.05°. Therefore WEW has the ability to resolve additional mesoscale features since the non-hydrostatic motions of the atmosphere become very important on a resolution of 0.05° or even finer. In general, the atmospheric local circulations, the etesian winds, the sea breezes and the convective systems over an area with complex sea-land physiographic characteristics, such as the Aegean Sea or the Mediterranean Sea, can be resolved by regional non hydrostatic models on very fine horizontal resolutions. Additionally, the parameterization of the impact of gustiness and air density on wave growth has been introduced only to the ECWAM model and it is not freely available to the community of WAM users.

The paper would have constituted a nice contribution the field, had the authors gone beyond reproducing what had already been done (by ECMWF and others). For instance explore the behavior of the heat and moisture flux on sea state Jassen 1997: Effect of surface gravity waves on the heat flux, ECMWF Technical Memorandum http://old.ecmwf.int/publications/library/do/references/show?id=83780 or fluxes specification for short fetches and/or under influence of bora like winds,...

Reply: We would like to thank the reviewer for his/her very interesting and challenging recommendation. It is clear that the work presented in this manuscript describes our efforts to develop a coupled atmosphere – wind waves modelling system and implemented in a very high resolution model domain. Our intention is to use this modelling tool to further study interactions at the air-sea interface and their possible impact on the sea state as the reviewer suggests. We are currently working on the development of a new hybrid surface layer parameterization based on the Mellor-Yamada-Janjic (MYJ) and the Janssen schemes that operate in the atmospheric and ocean wave components of the WEW respectively (Katsafados et al., 2015). In this case the roughness length depends on the wave age instead of the Charnock parameter following the formulation proposed by Vickers and Mahrt (1997). Moreover, the physical processes related to the rainfall and the droplet diameter impacts on the SWH and the ocean wave spume will be incorporated in the updated version of WEW by the end of this year.

List of the works cited in our reply

Katsafados P., Papadopoulos A., Varlas G., and Korres G., 2015: "A hybrid surface layer parameterization scheme for the two-way fully coupled atmosphere-ocean wave system WEW". *European Geosciences Union (EGU), General Assembly 2015*, 12-17 April 2015, Wien, Austria, 12752.

Vickers D. and L. Mahrt, 1997: "Fetch limited drag coefficients". *Bound.-Layer Meteor.*, 85, 53-79.

Reviewer-2

This paper presents a coupled atmosphere-ocean wave limited area model setup for the Mediterranean Sea.
Although the topic is an important one and one which I consider of general interest to the readers of GMD, unfortunately, I cannot recommend publication in its present form. The work presented is sloppily put together with little regard for the work which has been done earlier in this field. Indeed, the work is wholly based on the work by Peter Janssen and his co-workers at ECWMF, but the only reference is to his earlier work (Janssen, 1991). The fact that ECMWF has operated a coupled atmosphere-wave forecast system since 1998 is not mentioned, and I find this inexcusable.

Reply: It was not our intention to exclude or ignore the work done by ECMWF research team (P. Janssen and co-workers) on coupling the atmospheric with the wind wave models in their IFS system. It is true that no proper reference was given in the previous version of the manuscript on this issue. The paragraph describing the work which has been done in ECMWF has been extended in the revised paper (P4L14-30).

What is more important for the general reader is that the system presented does not appear to provide much (if any) improvement over the uncoupled model (Fig 12). Although I can understand the need for publication of a new model setup, even one which offers only marginal improvement, I do not think it is ready in its current form.

Reply: In general, the coupling between the atmospheric and the wave models offer a progressively more realistic representation of the atmosphere-ocean system in terms of the momentum (mainly), heat and moisture exchanges at the air-sea interface. In our paper we present the newly developed technique for the fully coupling between WAM and the ETA atmospheric model. The versions of the models used in this study, constitute numerical components of the POSEIDON forecasting system. On the basis of a long operational period (since 1997) the POSEIDON forecasting system has been evaluated demonstrating its ability to describe quite satisfactorily the sea-state and weather conditions (Papadopoulos et al., 2008). In the current work and as a proof of the proper coupling of the two numerical components we present an evaluation of the coupled system for a high-impact weather and sea state event, in which an overall RMSE improvement of 11% has been achieved for the wave forecasts, while less but not a marginal improvement has been also accomplished for the wind field. This is in agreement with the results of Bao et al. (2000), Desjardins et al. (2000) and Lionello et al. (2003) who also reported limited improvements. This may be partially attributed to the location of the buoys, since the majority of the Mediterranean buoys are lying near the coast, where both the atmospheric and the ocean wave models have difficulties to simulate local circulations and the shallow water waves especially in complex coastal areas. Moreover, we would like to note that the majority of the surface layer parameterization schemes in atmospheric models have been configured using formulas with a constant Charnock coefficient. In the new coupled modeling system we introduce the use of the spatiotemporal variability of the Charnock coefficient. To derive a physically-based variation of this parameter, the WAM model-generated field of Charnock coefficient is ingested into the atmospheric model at every WAM model timestep. Furthermore, and beyond the aim of the current study we are working on the development of a new hybrid surface layer parameterization based on the Mellor-Yamada-Janjic (MYJ) and the Janssen schemes that operate in the atmospheric and ocean wave components of the WEW respectively (Katsafados et al., 2015). In this work, we attempt to investigate if better results can be obtained when the roughness length depends on the wave age instead of the Charnock parameter, following the formulation proposed by Vickers and Mahrt (1997).

Figures are generally of poor quality and should be redone with more intelligible captions.

Reply: The entire figures follow the standards of GMD discussions (300dpi, jpg format).

To salvage this paper I would want to see a much more thorough discussion of the quality of the control and coupled runs. This may require a longer integration.

Reply: The main aim of this manuscript is to present a newly developed, fully coupled atmosphere-ocean wave model. The sensitivity of the new model and the resolved air-sea interactions are also tested in a case study of a high impact weather and wave event. The incident of 4–11 January, 2012 (7 days) has been selected due to the severity of the prevailing atmospheric conditions characterized by an explosive cyclogenesis over the Ligurian Sea. In this phase of the development, longer integrations could not considered as useful ones in order to exploit the impact of coupling in the aerodynamic drag over rough sea surfaces or how it modifies the roughness length. We believe that the impact of the new coupling system should be assessed in a metocean case study including high and time-varying winds. Monthly or even longer integrations include a sufficient number of calms, in which the sea surface stress is negligible, making difficult to figure out the coupling efficiency. However there is a plan of a daily integration of the system in the framework of the next operational POSEIDON forecasting system at HCMR. This would provide the opportunity to investigate the performance of the system in multiple cases.

Proper referencing of earlier work, especially by the group at ECMWF is mandatory. The English needs to be corrected by someone proficient in professional English.

Reply: A paragraph acknowledges the work which has been done at ECMWF is now included in the revised manuscript (P4L14-30). Additionally the use of English in the original manuscript has been substantially refined.

p 4088 l 18: Unintelligible formula involving sin φ

Reply: Sanders and Gyakum (1980) defined an extratropical cyclone as a meteorological bomb when the mean sea-level pressure of its center falls by at least 1hPa per hour for 24 hours at 60°N. An equivalent rate is obtained for a latitude φ by multiplying this rate by the dimensionless number sinφ/sin60°. Sanders and Gyakum (1980) denote this threshold rate as one bergeron. It is also clarified in the revised manuscript.

Fig 12: No explanation to what is found in the various sub panels (a and c). Are these different buoys?

Reply: The first panel (a and b) displays the scatter plots of the near surface wind speed and the significant wave height against the relevant measurements from the network of the Mediterranean buoys presented in the Fig.8. On a similar way, the second panel (c and d) displays the scatter plots of the near surface wind speed and the significant wave height against the remote sensed retrievals. The caption of Fig.12 is corrected accordingly.

List of the works cited in our reply

Bao, J. W., Wilczak, J. M., Choi, J. K. and Kantha, L. H.: Numerical simulations of air-sea interaction under high wind conditions using a coupled model: a study of hurricane development, Mon. Wea. Rev., 128, 2190-2210, 2000.

Desjardins, S., Mailhot, J. and Lalbeharry, R. (2000). Examination of the impact of a coupled atmospheric and ocean wave system. Part I, atmospheric aspects. J. Phys. Oceanogr., 30, 385–401.

Katsafados P., Papadopoulos A., Varlas G., and Korres G., 2015: "A hybrid surface layer parameterization scheme for the two-way fully coupled atmosphere-ocean wave system WEW". *European Geosciences Union (EGU), General Assembly 2015*, 12-17 April 2015, Wien, Austria, 12752.

Lionello, P., Martucci, G., Zampieri, M.: Implementation of a Coupled Atmosphere-Wave-Ocean Model in the Mediterranean Sea: Sensitivity of the Short Time Scale Evolution to the Air-Sea Coupling Mechanisms, Glob. Atmos. Ocean Syst., Vol. 9, Iss. 1-2, 65-95, 2003.

Papadopoulos A. and P. Katsafados, 2009: "Verification of operational weather forecasts from the POSEIDON system across the Eastern Mediterranean". *Natural Hazards and Earth System Science*, **9**, 4, pp. 1299-1306.

Sanders, F. and J.R. Gyakum, 1980: Synoptic-dynamic climatology of the bomb, Mon. Wea. Rev., 108, 1589-1606.

Sanders, F. and J.R. Gyakum: Synoptic-dynamic climatology of the bomb, Mon. Wea. Rev., 108, 1589-1606, 1980.

Vickers D. and L. Mahrt, 1997: Fetch limited drag coefficients. *Bound.-Layer Meteor.*, 85, 53-79.