SCOR Working Group Proposal

# Title: Atmosphere-waves-current interactions and oceanic extremes

Acronym: **EXTREMES**


## Abstract

Both observations and climate predictions anticipate that, although possibly decreasing in the mean, atmospheric and oceanic extreme events will move towards a substantial intensification. This change is connected to the greater amount of energy (increased temperature and humidity) contained in the atmosphere with climate change. A proper analysis of the extreme events and their future development and impacts can only be done employing fully coupled atmosphere-wave-ocean models, as the research of the last ten years has clearly demonstrated. While in recent years remarkable progress has been achieved on modeling capabilities, many crucial aspects of coupling are still to be explored and defined, both in terms of physics and more so as implementation in operational models (Cavaleri et al. 2007). In this SCOR Working Group we plan to bring together some of the leading experts in this field to frame and clarify some of the critical aspects still limiting the accuracy of the present analyses and forecasts. The problem has many facets. We will focus mainly in two directions: "freak waves" in the ocean and in shallow coastal waters, and a deeper coupling between atmospheric and oceanic models towards a better operational system for: a) understanding and forecasting the conditions for the possible appearance of freak waves, and b) a fully coupled coastal system providing improved forecasts of the coastal extremes (especially under storm and surge flooding conditions). At the same time, we will monitor the present trends derived from satellite data using the data available in the next four years.


## Scientific Background and Rational

Atmospheric and oceanic modeling have been separated for a long while. Starting from the research and operational models of the 1960s, for about three decades, using the words of Erik Mollo-Christensen, "meteorologists considered the ocean as a wet surface, oceanographers considered the atmosphere as a place where wind blows". It was only at the end of the 1980s and early 1990s that cooperative efforts between oceanographers and meteorologists led to the realization that interactions at the sea surface are much more complex than previously supposed. It was obvious that a tight coupling between atmospheric and wave models would lead to better predictions of the immediate future for both types of models. However, the ocean was, and partly still is, mostly used in climatic terms as only a boundary condition to the atmosphere.

Today, more than ever, a tight coupling between atmospheric, global circulation and wave models is needed. This is due to various aspects, including the growing concern about climate change and the consequent need of secular projections; the evidence from long-term measured time series of a growing level of the extreme conditions; the longer term projections of the operational meteorological systems (towards seasonal forecasts); the increased vulnerability of the coasts, and the more intensive use of the ocean (ship traffic and oil rigs are obvious examples). All these aspects demonstrate the need for a better fundamental understanding of the first principles governing the coupling between the ocean and atmosphere. This understanding should then be followed by an advanced operational forecast of atmospheric and oceanic conditions for the short term, as well as for climate projections.

Wind waves and the flow of water and air by their moving surfaces are appearing more and more as a key element for all the above-mentioned targets. This comes in view of the fact that sea surface conditions control, within orders of magnitudes, the intensity and the integrated amount of all the exchanges (energy, momentum, heat, gas, solid particles, water, aerosol, etc.) between the atmosphere and ocean. Hence, wind waves are a crucial component in that they determine the physics and, via their modeling, our capability to provide medium-term forecasts, as well as climatic projections.

Among the advancements in atmospheric and oceanic prediction, accurate forecasting of extreme weather events is of specific interest due to their great potential to inflict loss of life and property. Unfortunately, the trends derived from recent observations show that there are reasons for concern. A detailed analysis of altimeter data over the last 30 years has shown that there has been a global increase in the magnitudes of the higher values of both wind speeds and resulting wave heights. In particular, it is the extreme events which are increasing most rapidly (Young et al., 2011). A corresponding analysis of hurricanes and typhoons, in the past and in climate projections, shows that the average intensity of tropical cyclones is increasing. It is predicted that by 2100 the mean intensity of tropical cyclones will increase from Category 3 (today) to Category 4 (Mei et al., 2015). A key global problem is the high concentration of human populations near the coast and in low-laying coastal areas (40-50% of the population). It is mandatory to quantify, in a reliable manner, wave energy and forces acting on the coast. As sea level rises and climate change impacts coastal areas and coastal cities (and mega-cities), extreme events will become more common (more surge-driven flooding and thus more urban infrastructure exposed to waves).

The U.S. East, Gulf of Mexico, and north European coasts provide alarming examples for this trend. In the last 10 to 20 years these coasts have been affected by severe storms that caused serious damages in the coastal zones (e.g., Hurricanes Katrina, Ike, and Sandy in the United States). Additionally, different human activities, such as the offshore wind power and oil industries and coastal recreation, necessitate information about the sea state in the coastal ocean with high resolution in space and time. There seems to be a consensus that high-quality predictions of extreme events like storm surge and flooding caused by storms could substantially contribute to avoiding or minimizing human and material damages and losses (see, among others, Brown et al., 2001 and Wolf et al., 2011). Therefore, reliable forecasts and long-term statistics of extremes are of utmost importance for coastal areas. This cannot be achieved by further neglecting wind-wave-current interactions, both in the open and coastal ocean operational forecasting.

A different, but growing aspect of concern are “freak waves”, that is, the anomalously large waves that sometimes seem to appear out of nowhere in the ocean and also in coastal zones. While related measurements are unavoidably limited, a deeper knowledge has now been achieved based on the nonlinear processes of wind waves. However, at the same time it is becoming clearer that a proper estimate of the conditions favorable to their appearance can be obtained only with the use of deeply coupled atmospheric-wave-ocean models. The interaction between waves and current is obvious, and its relevance for freak waves has been extensively shown by analyzing cases reported along the Agulhas Current (see Peregrine, 1976; White and Fornberg, 1998; Lavrenov and Porubov, 2006; and Toffoli et al., 2015). However, the other classical area for these events, the North Sea, has no such strong current, and here freak waves seem to be related uniquely to the nonlinearity of wave processes, once the combined atmosphere-wave action has created the conditions suitable for the events.

On the whole, there is a strong need for a deeper, more detailed coupling, in terms of the physics, between the atmospheric, wave and ocean models and in monitoring the global trends in surface winds and wave conditions (see Toffoli et al., 2005, for the warning criteria for ships). The need for this is clearly reflected in past and present SCOR Groups, from WG 83 “Wave Modeling”, WG 101 “Influence of Sea State on the Atmospheric Drag Coefficient”, WG103 “The Role of Wave Breaking on Upper Ocean Dynamics”, WG 110 “Intercomparison and Validation of Ocean-Atmosphere Flux Fields”, WG 111 “Coupling Waves, Currents and Winds in Coastal Models to the present WG141 “Sea-Surface Microlayers” and WG 143 “Dissolved N2O and CH4 Measurements”. Especially the two last groups cannot really sort out the proposed problems if the crucial effects on wind and wave interactions are not considered. Indeed, there seems to be a lack of a solid approach towards a better definition of the physical processes at the interface, of the reciprocal interactions between the actors at play, that is, wind, waves and currents, and of the derived role for both the problems cited above and the ones dealt with in the present SCOR working groups.

## Terms of References

The problem is multi-faceted and it would be absurd to suggest a full solution in the next four years. We plan to focus on the presently most urgent and crucial aspects. The main points of our actions will be

1. Develop a more refined physical description of the interaction between waves and

ocean currents to quantify their reciprocal influence. Currents affect waves and waves affect currents. This description will be published in a peer-reviewed journal.

2. Develop observational and theoretical approaches to describe the presence of vertically sheared currents and their influence on the characteristics with which waves and their energy propagate on the ocean. Vertically sheared currents are not presently considered aspect in observations and theory. The related description will be published in a peer-reviewed journal
3. Develop coupled atmospheric-waves-current-surge models suitable for coastal zones. The models will be made openly available.
4. Improve the understanding of the physics of freak waves, i.e of wave of anomalous height believed to be the reason of many ship losses.
5. Verify this physics hindcasting (i.e., re-evaluating a posteriori) the storms of historical large freak events and verify that indeed we would have been able to forecast the conditions suitable for a freak event. All these findings (ToR 4 and 5) will be published in peer reviewed journals
6. Update the altimeter database of wind and waves over the oceans providing to the world community a cross-validated highly verified dataset, with also estimates of long term climate trends in wind and waves. Results to be published in peer reviewed journals.

## Working plan

The Group will act according to the field of expertise of each person, but with a strong continuous interaction to obtain, along the way and at the end, a set of self-consistent and self-supporting results. The necessary expertise is suitably distributed throughout the Group and the proposed Working Group Members have a long history of cooperation in scientific and operational activities.

In the following description of the Working Plan we refer to the ToR (Terms of Reference) above and the names of the different Members listed in Table 1 shown later. The Working Plan is distributed over 4 years. For each Year and ToR the participants are listed in the order of the Members list.

<u>Year 1</u>

ToR1 – refinements for wave and current interactions (Fan, Qiao, Breivik, Smith, Bidlot),
ToR2 – development of theory (Toledo),
ToR3 – definition of new physics in the atmosphere-wave-current interactions. Special reference is done to the action of rain and on its implications for the physics of wind wave generation and dissipation. (Cavaleri, Fan, Breivik, Bidlot),
ToR4 – development of theory, experimental work using optical approach with focus on both open ocean and coastal shallow waters (Onorato),

ToR5 – collection of data of the main documented freak wave historical events (Cavaleri, Breivik, Bidlot, Onorato),
ToR6 – collection of data (Cavaleri, Young, Bidlot)

<u>Year 2</u>
ToR1 – implementation of theory into operational models – application to the Gulf of Mexico, North Sea, and Mediterranean Sea (Fan, Qiao, Breivik, Smith, Bidlot),
ToR2 – development of theory and laboratory experiments – report of results (Breivik, Toledo),
ToR3 – implementation of the new physics into the coupled modeling system in the North Atlantic Ocean and the Mediterranean Sea – results of the experiments (Cavaleri, Fan, Qiao, Breivik, Smith, Ocampo-Torres, Bidlot),
ToR4 – validation of the theoretical approach – paper (Cavaleri, Onorato),
ToR5 – application of the coupled system to the hindcast of the storms in connection with the selected freak events – results of the experiments (Cavaleri, Breivik, Bidlot, Onorato, Monbaliu),
ToR6 – collection of data – statistics of the trends (Cavaleri, Young, Bidlot)

<u>Year 3</u>
ToR1 – hindcast of selected storms in the Gulf of Mexico, North Sea and Mediterranean Sea (Fan, Breivik, Staneva, Smith, Bidlot),
ToR2 – validation of theory - paper (Breivik, Toledo),
ToR3 – intercomparison of the results obtained with the previous approach and the one derived from the new physics - papers (Cavaleri, Fan, Qiao, Breivik, Staneva, Smith, Ocampo-Torres, Bidlot, Monbaliu),
ToR4 – further testing of theory and possible further theoretical developments – paper (Cavaleri, Onorato),
ToR5 – use of the hindcast results for freak wave simulation and check of the related probability - paper (Cavaleri, Breivik, Bidlot, Onorato, Monbaliu),
ToR6 – collection of data – update of the database and of the trends – paper (Cavaleri, Young, Bidlot)

<u>Year 4</u>
ToR1 –intercomparison of the results obtained with the previous and new coupling – paper – results and theory available (Fan, Qiao, Breivik, Staneva, Smith, Bidlot),
ToR2 – final framing of the basic results – paper – theory and method available (Breivik, Toledo),
ToR3 – examples and results available – papers (Cavaleri, Fan, Breivik, Staneva, Smith, Ocampo-Torres, Bidlot, Monbaliu),
ToR4 – final framing of the basic results – paper – theory and method available (Cavaleri, Onorato),
ToR5 – final framing of the basic results – paper – theory and method available (Cavaleri, Breivik, Bidlot, Onorato),
ToR6 – collection of data – new database and possible trends available – paper (Cavaleri, Young, Bidlot)

**Deliverables**

The list of Deliverable is strictly connected to the above Terms of References

D1 (ToF 1) – A more advanced physics of the interaction between waves and current, in particular for what concerns the evaluation and the effects of Stokes drift and Coriolis effects – one or two papers will be produced.
D2 (ToF 2) – Experimental results on the effect of a vertically sheared current on the propagation of surface waves – development of the related theory – two papers will be produced.
D3 (ToF 3) – A coupled atmosphere-waves-current-surge model – examples of its application to the North Sea – two papers will be produced – when available and verified the model will be available to the scientific community.
D4 (ToF 4) – Improved theory of freak waves and two papers.
D5 (ToF 5) – Meteorological and oceanographic reconstruction (hindcast) of at least two historical storms during which exceptionally high freak waves have been measured - application of the theory developed at ToF 4 – verification of the capability of forecasting, in operational conditions, the possibility and the probability of freak waves – two papers.
D6 (ToF 6) – Cross-validated and verified long-term data base of altimeter wind and waves on the whole world with estimate and updating of the climate trends – one paper.

**Capacity Building**

The final and lasting results of the four-year activity of the EXTREMES SCOR working group are represented by the (final) results listed in the above Working Plan and Deliverables. These can be summarized in the following basic, but very important, points:

1. We will provide the basis for a more detailed theory of the interactions between waves and currents with the possibility of better forecasts of the meteorological and oceanographic conditions on the ocean and in coastal areas.
2. The application of these results to the operational models will produce better forecasts, in particular in coastal areas, with a better anticipation, as quality and forecast time, of potential floods, hence earlier warnings to the population. The model will be applied, among others, by FIO (China) and CICESE (Mexico) (see the Full Members list) to improve the local modelling, particularly in extreme (hurricane and typhoon) conditions..
3. One of the Members meeting, during the third year of the project, will be held in China (FIO, see Full Members list), combining it with the periodic oceanographic and climate course there held. In this way the many attending students from developing countries will be able to take advantage of the new findings.
4. There will be a better understanding of the physics of freak waves and of the conditions under which their appearance may become more likely. There will be a better capability of issuing warning to ships and open sea oil platforms of the possibility of anomalously large waves in an incoming storm, particularly during hurricane and typhoon conditions,

respectively in the Gulf of Mexico and Caribbean Sea, and in the South China Sea respectively..

**Working Group composition**

We have included in the proposed Group major experts and active players in the discipline of atmosphere-wave-ocean coupled systems, satellite data and their use for long-term analysis, and freak waves. The geographical distribution is spread throughout four continents (Italy, Belgium, China, Norway, Germany, Israel, Great Britain, USA, Mexico, and Australia). No scientific discipline is associated to a single Member, but we have carefully distributed the tasks and responsibility reflecting the competence in also the different countries. Attention has been given to the gender distribution that reflects, with increased female participation, the distribution of the researchers and experts in the considered field. Two valuable scientists from transition economy countries (Mexico and China) will contribute to the final results.

Table 1 – Full Members

| **Name** | **Gender** | **Place of work** | **Expertise relevant to proposal** |
|---|---|---|---|
| 1 – Luigi Cavaleri<br>Chair | M | ISMAR, Venice, Italy | wave modeling, coupled system, hindcast, measured data |
| 2 – Yalin Fan<br>Vice-chair | F | U.S. Naval Research Laboratory, Stennis Space Center, MS, USA | air-sea interactions and their effects in coupled models |
| 3 – Fangli Qiao | M | First Institute of Oceanography, Qingdao, P.R China | non-breaking waves induced mixing and their influence in circulation and climate models |
| 4 - Oyvind Breivik | M | Norwegian Meteorological Institute, Bergen, Norway | fully coupled atm-wave-cur systems |
| 5 – Johanna Staneva | F | Institute for Coastal Research, HZG, Germany | coupled wave-current system in coastal waters, forecast systems |
| 6 – Yaron Toledo | M | Tel-Aviv Univ., Tel Aviv, Israel | basic wave theory, nonlinear processes in wind waves |
| 7 – Jane Smith | F | US Army Eng, Res. Develop. Center, Vicksburg, MS, USA | fully coupled systems and oceanic extremes, physics and applications, non-linear waves |

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|---|---|---|---|
| 8 – Ian Young | M | Univ. of Melbourne, Vic 3010, Australia | basic physics of wind waves generation and dissipation, long term data sets, long term climatology of wind speeds and wave heights on the oceans |
| 9 – Francisco Ocampo-Torres | M | Dpt.Phys.Oceanogr., CICESE, Ensenada, Mexico | physics of wind waves, waves-current interactions, generation and dissipation of wind waves |
| 10 – Jean-Raymond Bidlot | M | Research Dpt, ECMWF, Reading, U.K. | operational global and coupled models, physics of atmosphere-wave –current interaction, long term use of satellite data |

Table 2 – Associate Members

| **Name** | **Gender** | **Place of work** | **Expertise relevant to proposal** |
|---|---|---|---|
| 11 – Miguel Onorato | M | Univ. Torino, Turin, Italy | freak waves, non-linear processes in waves |
| 12 – Jaak Monbaliu | M | Univ. of Leuven, Leuven, Belgium | coastal wave modeling, freak waves in coastal waters |

### Working Group contribution

**Luigi Cavaleri** – strong experience (by direct experience in the field and with theory) in the physics of wind waves, their generation and dissipation. Long-term experience in wave and coupled modeling.

**Yalin Fan** – strong theoretical and modeling experience in air-sea interactions (momentum and energy fluxes, Langmuir turbulence) and their effect in coupled models, Wave modeling and LES modeling.
**Fangli Qiao** – he developed the non-braking surface wave-induced mixing theory and dramatically improved the crucial vertical mixing of ocean general circulation models and climate models.
**Oyvind Breivik** – attention to both observing and modeling systems. Very strong experience in fully couple systems both in deep and coastal water conditions.
**Johanna Staneva** – experience of wave modeling, wave-current interactions and coupled systems. Intensive model application in coastal and regional modeling.
**Yaron Toledo** – extensive experience in the mathematical modeling of nonlinear wave-bottom and wave-current interactions. Strong experience both in physical oceanography and in its practical aspects as marine measurements and laboratory experiments.

**Jane Smith** – long-term experience on the physics and applications of wind waves. Modeling in both open and coastal shallow water conditions. Solid basis on fully coupled systems and freak waves.
**Ian Young** – long-term experience in wave modeling, remote sensing, air-sea interactions and the statistics of environmental extremes. Handling and validation of satellite data and development of a related database with related statistical analysis of long-term trends.
**Francisco Ocampo-Torres** – Interest in the dynamic of ocean surface waves and the related interaction processes, both with the atmosphere and oceanic currents. Interest and expertise in the processes governing the transfers between the ocean and the atmosphere.
**Jean-Raymond Bidlot** - At the core of the developments of the atmosphere-wave-ocean coupled system of ECMWF. Validation of model performance against in-situ and altimeter data, including freak waves parameters.
**Miguel Onorato** – long-term experience in the field of freak waves in the ocean. Solid basis on the related theory and also in laboratory experiments for their simulation.
**Jaak Monbaliu** – long-term experience in wave modeling in coastal waters. Interest in the impact of extreme waves on marine constructions and in the design of offshore structures.

## Relationship to other international programs and SCOR Working Groups

All the activities and the expertise gained in the past by the Working Group Members has been obtained via international cooperation, large national and international projects. For instance Oyvind Breivik has been working for some years at the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, U.K.), cooperating with Jean-Raymond Bidlot and acting on the coupling between wave and ocean models, an activity he is now carrying and applying in his institute in Norway. ECMWF is the most competent operational centre at the global level in coupled atmosphere-wave-ocean modeling. Several of the participants took part to the MyWave EU sponsored project, ended one year ago, with the aim of framing the European wave modeling in the best way to optimize the coupling with ocean models. This activity has a follow up in the present Wave2NEMO project aiming at further improving the coupling, with also a specific attention to the coasts and coupling with storm surge modeling.

As mentioned above at the end of Scientific Background and Rationale, the proposed activity is a natural follow-up in time of some SCOR Working Group of the past, as WG 83 “Wave Modeling”, WG 101 “Influence of Sea State on the Atmospheric Drag Coefficient”, WG103 “The Role of Wave Breaking on Upper Ocean Dynamics”, WG 110 “Intercomparison and Validation of Ocean-Atmosphere Flux Fields”, WG 111 “Coupling Waves, Currents and Winds in Coastal Models”. Two present WGs that will take advantage of our proposed activities are WG141 “Sea-Surface Microlayers” and WG 143 “Dissolved N2O and CH4 Measurements”. These last two subjects, extremely interesting in themselves, may lack the specific know-how we aim to bring into the system concerning the dynamics and the tuning role of the sea surface (under wave conditions) in modulating all the exchanges at the interface. There we believe that our WG will enhance the capability of some of the existing ones. We look forward to active cooperation, as it is necessary between different, but parallel, disciplines to achieve the best overall results.

## Key references

**Bolaños**, R.; Brown, J.M.; Souza, A.J.: 2014. Wave-current interactions in a tide dominated estuary. Continental Shelf Research, 87. 109-123. 10.1016/j.csr.2014.05.009.

**Brown** J.M., Bolaños R., and Wolf J., 2013. The depth-varying response of coastal circulation and water levels to 2D radiation stress when applied in a coupled wave-tide-surge modeling system during an extreme storm, Coast Eng., 82:102–113.

**Cavaleri**, L., J.-H. Alves, F. Ardhuin, A. Babanin, M. Banner, K. Belibassakis, M. Benoit, M. Donelan, J. Groeneweg, T.H.C. Herbers, P. Hwang, P.A.E.M. Janssen, T. Janssen, I.V. Lavrenov, R. Magne, J. Monbaliu M. Onorato, V. Polnikov, D. Resio, W.E. Rogers, A. Sheremet, J.M. Smith, H.L. Tolman, G. van Vledder, J. Wolf, I. Young. 2007. Wave modeling -- the state of the art. *Progress in Oceanography*, **74(4)**, 603-674.

**Hewson**, T., Magnusson, L., Breivik, O., Prates, F., Tsonevsky, I., and de Vries, H. J. W. (2014). Windstorms in northwest Europe in late 2013. ECMWF Newsletter, 139:22–28. www.ecmwf.int/sites/dafault/files/Newsletter_139_smaller. pdf.

**Lavrenov**, I. & Porubov, A. V. 2006 Three reasons for freak wavegeneration in the non-uniform current. Eur. J. Mech. (B/Fluids) 25,574–585.

**Mei**, W., et al., 2015, Northwestern Pacific typhoon intensity controlled by changes in ocean temperatures, Sci. Adv. 2015;1:e1500014.
**Peregrine**, D. H. 1976 Interaction of water waves and current.In Advances in Applied Mechanics, pp. 9–117
**Roland** A., and Ardhuin F.: On the developments of spectral wave models: numerics and parameterizations for the coastal ocean. Ocean Dyn 64, 6, 833–846, 2014.
**Toffoli**, A., Lefevre, J. M., Bitner-Gregersen, E. & Monbaliu, J. 2005. Towards the identification of warning criteria: analysis of a shipaccident database. Appl. Ocean Res. 27, 281–291.
**Toffoli**, A., Waseda, T., Houtani, H., Cavaleri, L., Greaves, D., & Onorato, M. 2015. Rogue waves in opposing currents: an experimentalstudy on deterministic and stochastic wave trains. Journal of FluidMechanics, 769, 277-297.
**White**, B. S. & Fornberg, B. 1998 On the chance of freak waves at the sea. J. Fluid Mech. 255, 113–138.
**Wolf**, J., and Prandle, D.: Some observations of wave-current interaction, Coast. Eng. 37, 471–485, 1999.
**Young** et al (2011) have shown that over the last 30 years, there has been a global increase in the magnitudes of wind speeds and resulting wave heights. In particular, it is the extreme events which are increasing most rapidly. Mei et al (2015)
**Young**, I.R., Zieger, S. and Babanin, A.V., 2011, Global trends in wind speed and wave height, Science, 332, 451-455, doi:10.1126/science.1197219.

## Appendix

List of publications for each Full Member

**Luigi Cavaleri** –

**Cavaleri** L., L.Bertotti, L.Torrisi. E.Bitner-Gregersen, M.Serio and M.Onorato, 2012. Rogue waves in crossing seas: The Louis Majesty accident, *Journal of Geophysical Research*, Vol. 117, C00J10, 8pp. doi:10.1029/2012JC007923
**Cavaleri** L., B.Fox-Kemper, and M.Hemer, 2012. Wind waves in the coupled climate system, *Bull.Amer.Meteor.Soc.*, November 2012, pp.1651-1661.
Toffoli A., L.Fernandez, J.Monbaliu, M.Benoit, E.Gagnaire-Renou, J.-M.Lefevre, L.**Cavaleri**, D.Proment, C.Pakodzi, C.Y.Stanberg, T.Waseda, and M.Onorato, 2013. Experimental evidence of the modulation of a plane wave by oblique perturbation and generation of rogue waves in finite depth water, *Physics of Fluids*, 25, doi:10.1063/1,4821810.
V A. Toffoli, T. Waseda, H. Houtani, L. **Cavaleri**, D. Greaves and M. Onorato, 2015. Rogue waves in opposing currents: an experimental study on deterministic and stochastic wave trains, *Journal of Fluid Mechanics*, **769**, pp 277-297.
**Cavaleri**, L.Bertotti, and J.-R.Bidlot, 2015. Waving in the rain, *Journal of Geophysical Research*, doi:10.1002/2014JCO10348.

**Yalin Fan** –

**Fan**, Y., W. E. Rogers, and T. Jensen, 2016: Correlations between Interannual SST Oscillations and Modeled Swell Impacts on Turbulent Mixing. *J. Clim*. DOI: 10.1175/JCLI-D-15-0455.1

**Fan**, Y. and S. M. Griffies, 2014: Impacts of Langmuir turbulence and non-breaking wave mixing in global climate simulations. *J. Clim*. DOI: 10.1175/JCLI-D-13-00583.1

**Fan**, Y., I. Ginis, and T. Hara, 2010: Momentum Flux Budget Across Air-sea Interface under Uniform and Tropical cyclone winds. *J. Phys. Oceanogr*. Vol. 40, 2221-2242

**Fan**, Y., I. Ginis, T. Hara, C. W. Wright, and E. J. Walsh, 2009: Numerical simulations and observations of surface wave fields under an extreme tropical cyclone. *J. Phys. Oceanogr*. Vol. 39, 2097-2116

**Fan**, Y., I. Ginis, and T. Hara, 2009: The Effect of Wind-Wave-Current Interaction on Air-Sea Momentum Fluxes and Ocean Response in Hurricanes. *J. Phys. Oceanogr*. Vol. 39, No. 4. 1019-1034

**Fangli Qiao -**

**Qiao**, F., Y.Yuan, Y.Yang, Q.Zheng, C.Xia, and J.Ma, 2004, Wave-induced mixing in the upper ocean: Distribution and application in a global ocean circulation model. *Geophysical Research Letter*, 31:L11303, doi:10.1029/2004GL019824.

**Qiao**, F., Y.Yuan, T.Ezer, C.Xia, Y.Yang, X.Lü, and Z.Song, 2010, A three-dimensional surface wave-ocean circulation coupled model and its initial testing. Ocean Dynamics, 60(5): 1339-1355, doi: 10.1007/s10236-010-0326-y.

**Qiao**. F., C.Huang, 2012, Comparison between vertical shear mixing and surface wave-induced mixing in the extratropical ocean. *J. Geophys. Res.,* **117**,C00J16, doi:10.1029/2012JC007930.

**Qiao**, F., Z.Song, Y.Bao, Y.Song, Q.Shu, C.Huang, W.Zhao, 2013, Development and evaluation of an Earth System Model with surface gravity waves. *J. Geophys. Res. Oceans*, 118, 4514-4524, doi:10.1002/jgrc.20327.

**Qiao**, F.,, Y.Yuan, J.Deng, D.Dai, and Z.Song, 2016, Wave turbulence interaction induced vertical mixing and its effects in ocean and climate models. *Philosophical Transactions of the Royal Society of London Series A - Mathematical Physical and Engineering Sciences*, doi:10.1098/rsta.2015.0201.

**Oyvind Breivik–**

**Breivik, Ø**, OJ Aarnes, S Abdalla, J-R Bidlot and PAEM Janssen (2014b). Wind and Wave Extremes over the World Oceans from Very Large Ensembles, *Geophys Res Lett*, **41**, 5122-5131, doi:10.1002/2014GL060997, arXiv:1407.5581

**Breivik, Ø**, J-R Bidlot and PAEM Janssen (2016). A Stokes drift approximation based on the Phillips spectrum, *Ocean Model,* **100**,*49-56,* doi:10.1016/j.ocemod.2016.01.005, arXiv:HYPERLINK "http://arxiv.org/abs/1601.08092" 1601.08092

**Breivik, Ø**, Y Gusdal, B R Furevik, O J Aarnes and M Reistad (2009). Nearshore wave forecasting and hindcasting by dynamical and statistical downscaling, *J Marine Syst*, **78**, pp S235-S243, doi:10/cbgwqd, arXiv:1206.3055

**Breivik**, **Ø**, K Mogensen, J-R Bidlot, MA Balmaseda and PAEM Janssen (2015b). Surface Wave Effects in the NEMO Ocean Model: Forced and Coupled Experiments, *J Geophys Res: Oceans*, **120**, pp 2973-2992, doi:10.1002/2014JC010565, arXiv:1503.07677

Reistad, M, **Ø Breivik**, H Haakenstad, OJ Aarnes, B R Furevik, and J-R Bidlot (2011). A high-resolution hindcast of wind and waves for the North Sea, the Norwegian Sea, and the Barents Sea, *J Geophys Res*, **116**, C05019, doi:HYPERLINK "http://dx.doi.org/10/fmnr2m" 10/fmnr2m, arHYPERLINK "http://arxiv.org/abs/1111.0770" XHYPERLINK "http://arxiv.org/abs/1111.0770" iv:1111.0770

**Johanna Staneva**–

**Staneva** J., Wahle K. Günther H. and Stanev E., 2015. Coupling of wave and circulation models in coastal-ocean predicting systems. OS-2015-86, 12, 3169–3197, 2015.
Kourafalou V., De Mey P., **Staneva** J., Ayoub N., Barth A., Chao Y., M Cirano M, et al. (2015), Coastal Ocean Forecasting: science foundation and user benefits, Journal of Operational Oceanography8, 147.,
**Staneva**, J., A. Behrens and Wahle K., 2015. Wave modeling for the German Bight coastal-ocean predicting system, Journal of Physics, 633, pp 233-254, doi:1211, 0.1088/1742-6596/633/1/012117, ISBN: 978-3-939230-28-1
Wahle K., **Staneva** J., Guenther H., 2015. Data assimilation of ocean wind waves using Neural Networks. A case study for the German Bight, Ocean Modeling (2015), pp. 117-125
Stanev, EV, J Schulz-Stellenfleth, J **Staneva**, S Grayek, J Seemann, 2011. Coastal observing and forecasting system for the German Bight–estimates of hydrophysical states, Ocean Sci 7, 569-583

**Yaron Toledo**–

Vrećica T., **Toledo** Y. Consistent nonlinear stochastic evolution equations for deep to shallow water wave shoaling. *J. of Fluid Mech*. (in press)
Groeneweg J., van Gent M., van Nieuwkoop J., and **Toledo**, Y. Wave propagation into coastal systems with complex bathymetriesJ. of Waterway, Port, Coastal, and Ocean Engng. 04015003-1, 2015
**Toledo, Y.** The oblique parabolic equation for free-surface gravity waves. *J. of Fluid Mech.* 715, 103-133, 2013
**Toledo** Y., Hsu T.-W. and Roland A. Extended time-dependent mild-slope and wave action equations for wave-bottom and wave-current interactions. *Proc. of the Royal Soc. A.* 468, 184-205, 2012
**Toledo, Y.** and Agnon Y. Nonlinear refraction-diffraction of water waves: the complementary mild-slope equations. *J. of Fluid Mech*. 641, 509-520, 2009

**Jane Smith**–

**Smith**, J.M., M.E. Anderson, and T.V. Wamsley. 2016. Wetland Buffers: Numerical Modeling of Wetland Wave Dissipation. Earth Surface Processes and Landforms, DOI: 10.1002/esp.3904.
Jensen, R.E., A. Cialone, T.J. Hesser, and J.M. **Smith**. 2016 Regional wave modeling and evaluation for the North Atlantic Coast Comprehensive Study, Journal of Waterway, Port, Coastal, and Ocean Engineering, accepted.
**Smith**, J.M., A.A. Taflanidis, and A.B. Kennedy. 2014. Surrogate modeling for hurricane wave and inundation prediction, Series on Coastal and Ocean Engineering Practice, Vol 2, World Scientific, doi: 10.1142/9789814611015_0007, 185-213.

Anderson, M.E., and J.M. **Smith**. 2014, Wave attenuation by flexible, idealized salt marsh vegetation. Coastal Engineering, 83, 82-92.
Atkinson, J., J.M. **Smith**, and C. Bender. 2013. Sea level rise effects on storm surge and nearshore waves on the Texas coast: Influence of landscape and storm characteristics, J. Waterway, Port, Coastal, and Ocean Engineering, 139(2), 98-117.

**Ian Young**–

**Young**, I.R., 2006, "Directional spectra of hurricane wind-waves", J. Geophys. Res., 111, C08020, doi:10.1029/2006JC003540.
Vinoth, J. and **Young**, I.R., 2011, "Global estimates of extreme wind speed and wave height", J. Climate, 24, 6, 1647-1665, doi: 10.1175/2010JCLI3680.1.
**Young**, I.R., Zieger, S. and Babanin, A.V., 2011, "Global trends in wind speed and wave height", Science, 332, 451-455, doi:10.1126/science.1197219.
**Young**, I.R., Vinoth, J., Zieger, S. and Babanin, A.V., 2012, "Investigation of trends in extreme value wave height and wind speed", J. Geophys. Res.,117, C00J06, doi:10.1029/2011JC007753.
Zieger, S., Babanin, A.V. and **Young**, I.R., 2014, "Changes in ocean surface winds with a focus on trends of regional and monthly mean values", Deep Sea Res. Part 1, 86, 56-67. doi:10.1016/j.dsr.2014.01.004.

**Francisco Ocampo-Torres**–

García-Nava, H., F. J. **Ocampo-Torres**, P. A. Hwang (2015). Reconciling discrepancies between airborne and buoy-based measurements of wind stress over mixed seas, Boundary-Layer Meteorol. DOI 10.1007/s10546-015-0007-y
Esquivel-Trava, B., F. J. **Ocampo-Torre**s, P. Osuna (2014). Spatial structure of directional wave spectra in hurricanes. Ocean Dynamics, 65:65-76 DOI 10.1007/s10236-014-0791-9
**Ocampo-Torres**, F. J., H. García-Nava, R. Durazo, P. Osuna, G. M. Díaz Méndez, H.C. Graber (2011). The intOA Experiment: A study of ocean-atmosphere interactions under moderate to strong offshore winds and opposing swell conditions, in the Gulf of Tehuantepec, Mexico. Boundary-Layer Meteorol. 38(3), 433-451. DOI: 10.1007/s10546-010-9561-5
PA Hwang, H García-Nava, FJ **Ocampo-Torres**, 2011. Observations of Wind Wave Development in Mixed Seas and Unsteady Wind Forcing, Journal of Physical Oceanography 41 (12), 2343-2362
PA Hwang, H García-Nava, FJ **Ocampo-Torres**, 2011. Dimensionally Consistent Similarity Relation of Ocean Surface Friction Coefficient in Mixed Seas, Journal of Physical Oceanography 41 (6), 1227-1238

**Jean-Raymond Bidlot** –

Hersbach H. and **J.-R. Bidlot**, 2008: The relevance of ocean surface current in the ECMWF analysis and forecast system. Proceeding from the ECMWF Workshop on Atmosphere-Ocean

Interaction, 10-12 November
Janssen, P. and **J.-R. Bidlot**, 2009: On the extension of the freak wave warning system and its verification. ECMWF Tech. Memo. 588. ECMWF, Reading, United Kingdom, 42pp.
Breivik, Øyvind, Ole Johan Aarnes, **Jean-Raymond Bidlot**, Ana Carrasco, Øyvind Saetra, 2013: Wave Extremes in the Northeast Atlantic from Ensemble Forecasts. J. Climate, 26, 7525–7540. doi: http://dx.doi.org/10.1175/JCLI-D-12-00738.1
Øyvind Breivik, Kristian Mogensen, **Jean-Raymond Bidlot**, Magdalena Alonso Balmaseda, Peter A.E.M. Janssen, 2015Surface Wave Effects in the NEMO Ocean Model: Forced and Coupled Experiments Journal of Geophysical Research: Oceans 04/2015; DOI:10.1002/2014JC010565
Xavier Bertin, Kai Li, Aron Roland, **Jean-Raymond Bidlot**. 2015:The contribution of short-waves in storm surges: Two case studies in the Bay of Biscay. Continental Shelf Research 96, 1-15.

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Venice, 06 April, 2016