SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2019
Project Title:	The different effects of heavy rain on the development of ocean waves.
Computer Project Account:	SPITWM
Principal Investigator(s):	Luciana Bertotti
Affiliation:	ISMAR, Venice, Italy
Name of ECMWF scientist(s) collaborating to the project	(not officially) Jean Bidlot
Start date of the project:	2017
Expected end date:	2019

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Current year		**Next year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	600000	0	---	---
Data storage capacity	(Gbytes)	200		---	

Summary of project objectives

In the long term development of both weather and climate models, the atmosphere-ocean interface, with all the related exchanges, appears more and more as a key element for the proper final quantification of the results. Rain, presently a side product of the meteorological model, affects heavily the characteristics of the sea surface. The aim of the project is to analyse the related physical implications.

Summary of problems encountered

Technically no particular problem has been encountered. As the previous year, a practical aspect is that, because of the heavy access to the archive, the large volume of storage of the intermediate data, and the required interaction with local staff, large part of our work needs to be conveniently done at ECMWF.

Summary of results of the current year

1 – The situation we started from

Following the logical course of actions of the first two years of the project, we are tackling the problem of the effects of rain on the physics of the atmosphere-ocean interface. From the perspective of wave modelling, the immediate problem is the influence of rain on the generation and dissipation of ocean waves. This problem is complicated, involving not only wind waves, but also meteorological modelling. Rain is presently an "output" of the meteorological model, without any mechanical feed back into the system. However, rain may affect the sea surface at a substantial level in so doing affecting the air-sea exchange processes at the interface. There are both dynamical and thermodynamic aspects involved. We are tacking these aspects one by one.

In the past year we reported and carried on in defining the modelling formulation for the attenuation of ocean waves by rain. Then we have focused our attention on a more dynamical aspect of the problem.

Our approach has been rather unconventional. After highlighting the basic physics and the data available that lead to the problem we are tackling, we have taken for granted the present models, more specifically one of them, and run a reference test. We have assume this to be correct. Then we introduced some substantial modifications suggested by the evidence we have available and we show how, notwithstanding these changes, we can reproduce with good approximation the original results. The logical principle behind this is to stress that good results are a necessary, but not sufficient, condition to state that the model, hence the embedded physics, we use are correct.

The modifications we have used are not meant to be the solution. They are potential, physically sound possibilities showing the directions along which in our opinion it is necessary to work. Granted the present accuracy of wave forecast (see the statistics at http://www.ecmwf.int/en/forecasts/charts/obstat/?facets=Parameter,Wave%20Height), we must acknowledge that problems often exist and appear, especially in rapidly changing or rather extreme situations. The repeated simulations of the worst typhoons and hurricanes looking for a good fit are a classical example.

Our previous activity in this Special Project (as reported in the first two yearly reports) was focused on a passive reaction by waves to the falling rain. Waves are duly attenuated, but no attention was given to the dynamics of the system, in practice generation by wind. Indeed, to be able to derive from the ECMWF wave model results the attenuation of swell by rain, we had to work on areas with no rain at all. Following our previous experiments with Jean Bidlot (Cavaleri et al., 2015) and a remarkable event with one of us (L.C.) on the ISMAR oceanographic tower during a mild storm (see Cavaleri et al., 2018), it became clear that rain does have a direct effect on the interaction between wind and waves. The smoothing of the surface (i.e. the canceling of the spectral tail) in strong rainy conditions implies that both input and white-capping (a direct evidence) are strongly reduced.

Following the direct experience on the tower, our arguing is as follows. By direct evidence, by and large white-caps disappear during a downpour (only to reappear as soon as the rain is over). This is practically instanteneous (matter of seconds). So the energy drain by white-capping is no longer present. The fact that the wave height did not grow rapidly strongly suggests that also the input by wind was strongly reduced. Were this not the case, given the wind speed, a direct estimate of the overall energy balance shows that the significant wave height H_s would have grown about 15 %. We have also considered different possible attenuation sources, as the previously cited mechanical attenuation by rain or the sink of energy in the tail of the spectrum where energy is transfered by non-linear interactions. Direct estimates exclude also these possibilities. Using the previous results of this project Cavaleri and Bertotti (2017), given the local conditions, the former attenuation is estimated at less than 0.5 % (wave height). For the non-linear possibility, a full (EXACT-NL) calculation using the Zakharov approach indicates an initial exponential decay with about one hour time constant. This implies that the related energy change in the three minutes (or less) of the downpour was less than 5 %. Therefore we can confidently assume that wind input was (almost) absent during the downpour.

In this situation we have set-up and run a few numerical experiments to show, at a possibly naive but quantitatively instructive level, how much the sea would grow if the wind input were still present when white-capping disappears or is strongly reduced. More in general, the action of rain on the two processes, generation by wind and dissipation by breaking, is modulated by the rain rate and the wind speed (soon to be detailed). We have tested different modulations although, as we discuss later, we physically favor the solution of similar, not necessarily identical, modulations of the two processes. Being the test comparative with respect to the present operational formulation, in our tests we have not introduced any further process not considered in the present ECMWF set-up.

2 – The experiments and their results

To summarize the situation: 1) we consider that a sufficiently strong rain will strongly reduce the loss by white-capping $S_{w\text{-}c}$ and input by wind S_{in}; 2) at the same time, guided also by the very enlightening paper by Holthuijsen et al. (2012), we assume that a sufficiently strong wind (typically in a typhoon or a hurricane) will, partly at least, counteract the effects of rain. Given this basic idea, on purely intuitive and experimental ground we have parameterized $S_{w\text{-}c}$ and S_{in} as follows:

$$S_{w\text{-}c} = S^*_{w\text{-}c}\,[1\text{-rain/r1}\ (1\text{-}U_{10}/U1)] \qquad (1)$$

$$S_{in} = S^*_{in}\,[1\text{-rain/r2}\ (1\text{-}U_{10}/U2)] \qquad (2)$$

where $S^*_{w\text{-}c}$, S^*_{in} are the standard source functions used in the ECMWF wave model, 'rain', r1, r2 are in mmh^{-1} and wind speeds U_{10}, U1, U2 are ms^{-1}. 'rain' and U_{10} are the actual conditions, r1, r2, U1, U2 are the modulating parameters. In actual coding suitable checks have been used to avoid unrealistic results for 'rain'>r1, r2 and U_{10}>U1 or U2. (1) and (2) imply that $S_{w\text{-}c}$ and S_{in} are nullified for 'rain' >=r1 and r2 respectively, but this rain effect decreases with increasing wind speed and is in turn nullified if U10>=U1 and U2.

We have carried out six experiments with different modulation by rain of the wind input and loss by white-capping with respect to a standard run with the standard source functions. The period considered is 13-23 October 2016, that includes hurricane Nicole and typhoons Sarika and Haima.

Figure 1 shows their respective tracks (the one of the maximum significant wave height H_s) at each hourly step. All the three tropical storms were up to category 4 or 5.

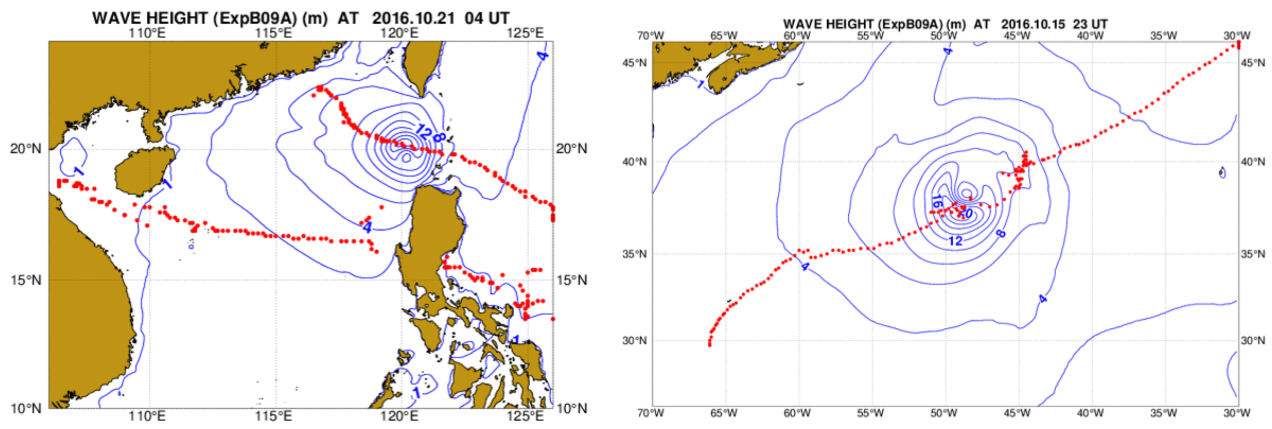

Figure 1 – Left panel: tracks of typhoons Sarika (left) and Haima (right, acting in the panel). Right panel: as left panel, but for hurricane Nicole. The respective areas are the ones considered for their analysis.

Looking at the paper (Cavaleri and Bertotti, 2018) and at the details of the overall results, the key point we want to stress here for the purpose of this project is that a full modulation with rain of the inout by wind and loss by white-capping leads in practice to the same results (as significant wave height is concerned) as the standard, operational model formulation.

We itemize as follows our main conclusions :
- there is experimental evidence that rain, more in general, or together with, a high frequency smoothing of the surface, affects (strongly decreases) white-capping and input by wind,
- the consequences can be large, especially in very rainy conditions, that however we have assumed (on pure physical, albeit intuitive, ground, but based on documented literature) wind can counteract if strong enough,
- a purely "order of magnitude" guess of the related quantification, as implemented in the tests, provides results practically in full agreement with the "regular" ones,
- on more general terms, as dealt more in detail in the cited paper, all these results and experience cast some doubts on the physics that is presently at the base of our wave modeling.

References and papers published

Cavaleri, L., and L Bertotti, 2017. The attenuation of swell waves by rain, Geoph. Res. Let., 44,7pp, https://doi.org/10.1002/2017GL075458.
Cavaleri, L., and L Bertotti, 2018. Rain on generative seas, Geoph. Res. Let., 45,8pp, https://doi.org/10.1029/2018GL078006.
Cavaleri, L., L.Bertotti, and J.-R.Bidlot, 2015. Waving in the rain, J. Geophys. Res., 13pp, doi:10.1002/2014JCO10348.
Cavaleri, L., T.Baldock, L.Bertotti, S.Langodan, M.Olfateh, and P.Pezzutto, 2018. What a sudden downpour reveals about wind wave generation, IUTAM Symposium on Wind Waves, 4-8 September 2017, London, U.K., Elsevier, Science Direct.
Holthuijsen, L.H., M.D.Powell, and J.D.Pietrzak, 2012. Wind and waves in extreme hurricanes, J. Geoph. Res., 117, C9, 11pp, DOI :10.1029/2012JC007983.