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	2017
Project Title:	The different effects of heavy rain on the development of ocean waves.
Computer Project Account:	SPITWM
Principal Investigator(s):	Luciana Bertotti
Affiliation:	SMAR, 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)	700000.00	532601.02	600000.00	0.0
Data storage capacity	(Gbytes)	200		200	

Summary of project objectives

The aim of the present project, as clearly indicated in the title, is to investigate the influence of rain on the process of growing and developing of ocean waves, analysing all the processes that concur to their development. Last year we had focused on, although not the most relevant, probably the most difficult one, i.e. the attenuation of wind waves by rain while they propagate on the sea. We are presently finalising the work in this direction. At the same time we have explored the sensitivity of the model results for hurricanes to some of the source functions.

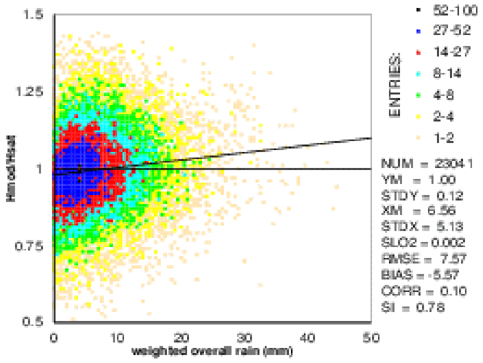
Summary of problems encountered

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

As mentioned in the reports of our previous projects, during these last few years we have tackled the problem of 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 thermodynamical aspects involved. We are tacking these aspects one by one. Our first step has been to clarify and quantify the attenuation of waves by rain.

Wave modeling and the related operational forecasts have reached a satisfactory level. This implies that further progress requires considering what, at least for the quantification of the energy involved, can be defined as second order processes.
Starting from the theoretical approach by Le Mehaute' and Khangaonkar (1990) we made use of the meteorological and wave model results produced by the Centre during a conveniently long period between 2011 and 2016. Using the meteo and wave results we derived an estimate of the wave attenuation with rain.
The first step has been to compare wave height model results with altimeter measurements. The result shows an evident overestimate of the wave model with increasing rain rate. Hence, see the figure below, we have plotted the H_{mod}/H_{sat} values versus the amount of rain encountered by the local wave systems during their approach to the measurement location. We then have traced a best-fit line to the data with an obvious positive slope with increasing rain. This means that the model over-estimates the wave height for larger rain rates. In so doing we see that the wave model neglects the the attenuation by rain.



Because the influence of rain on waves is much smaller than other more dominant processes, we need to consider cases where the dominant energy non-conservative processes (wind input and white-capping) are not at work. We therefore have focused our attention on the tropical zone, from 30^{o}S to 30^{o}N, basically out of the storm belts, where the frequency of convective precipitation and the presence of swell provide more favorable conditions. The basic idea is to compare with altimeter data the wave model results, taking into account how much rain the waves have passed through before reaching the measurement point.
We have used the 12 to 24 hour forecast fields of the ECMWF coupled model system, from December 2011 to February 2016. This corresponds to the use of the T1279 spectral resolution of the meteorological model. During this period we have selected data at 0.5^o resolution, retaining significant wave height H_s, the full 2D spectra, wind speed and direction, and rain rate. Working with forecast fields has avoided the objectivity problems consequent to data assimilation and allowed the availability of fields at one hour interval.
Starting from the basic equation by Le Mehaute' and Khangaonkar

we have splitted the total energy E_o into different , more specifically four, wave systems from different directions, each one with its own history. Therefore at our generic point P we have

$$E_{sat} = \sum_{1}^{4}[E_i^{''}(1-\alpha\frac{R_i}{T_i^2} + \frac{\alpha^2}{2}\frac{R_i^2}{T_i^4})]$$

that can be solved providing the specific value for α. The above procedure is applied to each single altimeter, hence model, value providing different estimates of the α attenuation coefficient.
We are presently analysing the above results.

Parallel to this, but still concerning the rain, we will consider the various effects of rain in the development of a storm, up to the case of hurricanes. The effect cited above of smoothing the surface, hence reducing the wind input to the ocean system, must be considered in the light of the extreme conditions in a hurricane. At wind speed of 200 Km/h or more the sea surface may loose its meaning, transformed into a continuous layer of water bubbles and foam. Hence the effect of rain must be considered as opposite to that of the wind that disrupts the usual structure of the surface. All this has effects also on the temperature of the sea surface.
We have explored all this with devoted experiments, changing the various boundary conditions (state of the surface, surface temperature, smoothing) to explore the sensitivity of the coupled model results to the parametrization of the various mentioned processes. We have explored the cited sensitivity in different cases with different intensities of the event. In practice we have considered both strong and weak hurricanes. This also helped to better understand the limits of the present approach, exploring how the performance of the wave model depends on the class of the hurricane, and implicitly on the conditions (the physics) of the sea surface. Also these results are presently under scrutiny to decide which further experiments need to be done

References
Le Mehaute', B., and T.Khangaonkar, 1990. Dynamic interaction of intense rainwith water waves, J. Physic. Oceanogr., 20, 1805-1812.

List of publications/reports from the project with complete references