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	2018
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)	600000.00	289502.77	600000.00	–----------
Data storage capacity	(Gbytes)	200		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

Technically 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.

For the first aspect, granted the present clear H_s overestimate of the operational wave model in rainy conditions (see report of last year), we have succeeded in providing the analytical expression for direct implementation in the ECMWF wave model. As described in the last year report, 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° 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

$E_{sat} = E_0 \exp(-\alpha R/T^2)$

we have split 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.

The rain effect, although statistically obvious (see the Figure in last year report), is small compared to the usually found differences between model and measured data. This implies a wide range of possible results about the actual attenuation with rain that again must be interpreted in statistical terms. This is shown, and evident, in Figure 1 where we show the statistical distribution of the

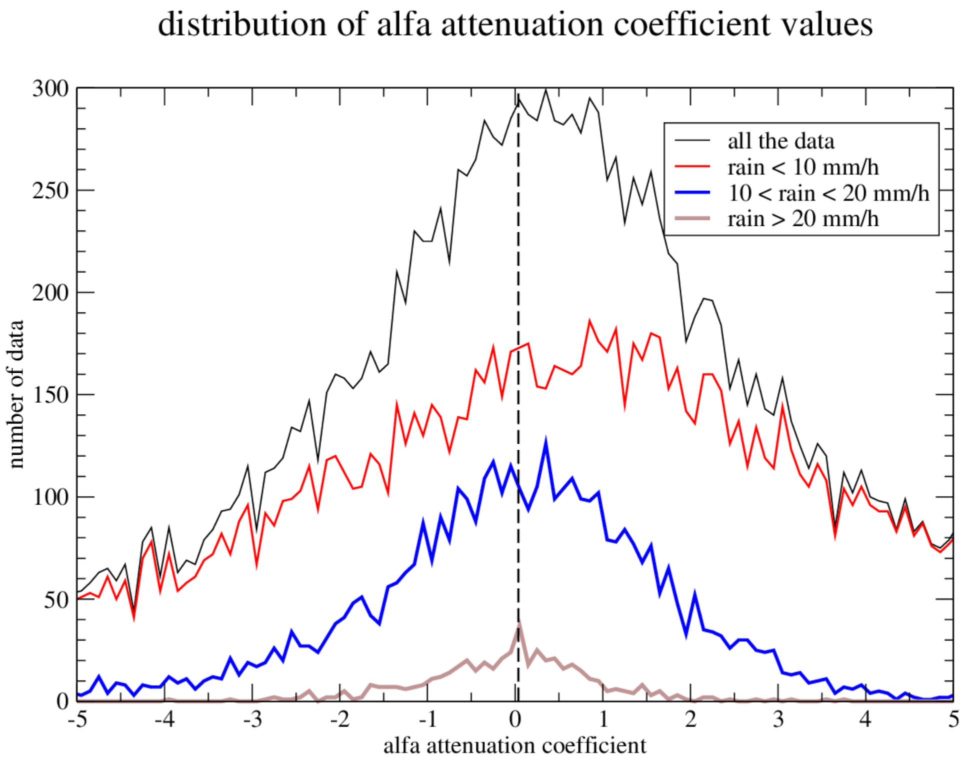

Figure 1 - Distribution of the estimated value of the α attenuation coefficient as a function of the rain encountered by the wave system. The vertical dashed line indicates the mean value of the distribution (0.036), not distinguishable at this scale (after Cavaleri and Bertotti, 2017).

derived α attenuation coefficient as a function of the rain rate. While, as expected, the distribution is very wide for low rain rates, the distribution progressively shrinks and converges with increasing rain rates. The final formula, suitable for direct applications, is given by

$$\exp(-0.036\ R/T^2) \qquad (1)$$

with R the overall amount of rain (mm) and T the wave period (sec). The noteworthy fact in (1) is that the attenuation does not depend on the rain rate, but, with very good approximation, it is a function of only the overall rain amount.

The implications are made clear in Figure 2 where we plot the actual overall attenuation for different periods of ocean waves. It is evident that, negligible for small rain amounts and more so for large wave periods, the attenuation becomes appreciable for large rain rates (hence amounts) and lower wave periods.

The results have been published in the cited reference. We are presently tackling the more dynamical aspects of the rain-sea surface-waves interaction with strong implications on the dynamics of the system.

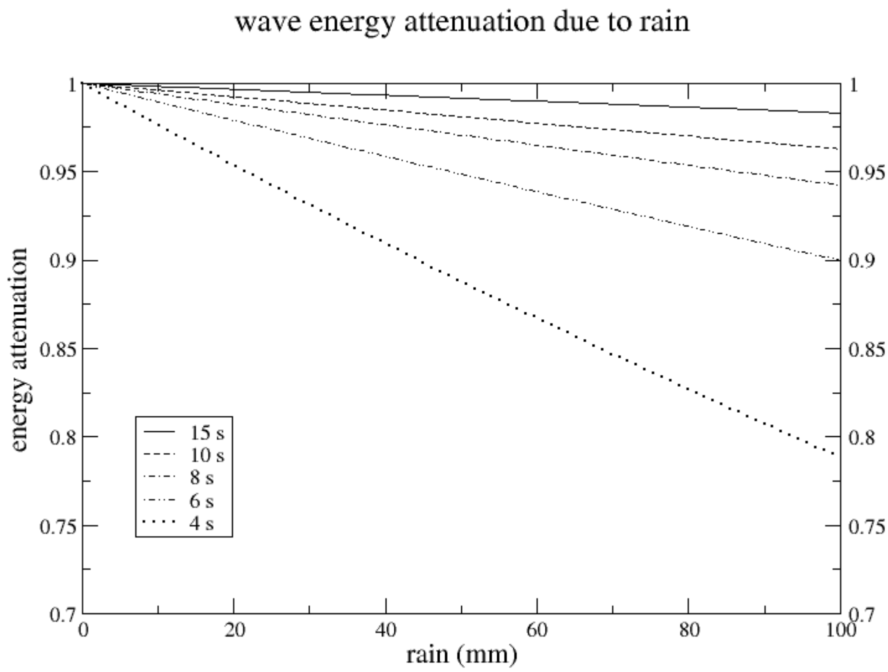

Figure 2 – Attenuation, according to formula (1), of the energy of waves with different period (4, 6, 8, 10 and 15 s) as a function of the encountered rain (after Cavaleri and Bertotti, 2017).

List of publications/reports from the project with complete references

Cavaleri, L., and L.Bertotti, 2017. The attenuation of swell waves by rain, *Geoph. Res. Letters*, 44, 1-7, https://doi.org/10.1002/2017GL075458.