Extremes and trends in wave climate

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Wind generated waves modify a range of processes controlling the exchange of heat, momentum and mass between the atmosphere and ocean, important to weather and climate. The increased roughness imposed by waves is also relevant for offshore wind power production, as it affects the vertical wind profile above the surface. In addition, waves constitute loads on offshore structures that need to be accounted for in design. Site specific wave measurements are however sparse, often requiring the use of numerical models to obtain adequate data coverage in time and space. In this regard, reanalyses constitute powerful proxies of the real climate, as these model-runs are firmly controlled by historical observations (assimilation). However, as most established reanalyses are run globally, with relatively coarse resolution, there is often need for calibration, or better yet, dynamical downscaling of the global model. The PhD work of Ole Johan Aarnes has been focused around limitations and side effects associated with significant wave height (Hs) data obtained from reanalyses, particularly related to their ability to represent extremes and recreate trends. The main motivation has been to overcome these deficiencies by investigating alternative datasets in order to obtain better estimates of return values and trends.

The Norwegian Meteorological Institute (MET) has produced a wind and wave hindcast at 10 km resolution covering the northeast Atlantic – the Norwegian reanalysis 10 km (NORA10). This model-run is a downscale of the global reanalysis ERA-40, covering the period September 1957 through August 2002, but has been prolonged to the present date using operational analyses from the European Centre for Medium-Range Weather Forecasts (ECMWF). NORA10 shows significant improvements in its wave climate representation, especially in terms of extreme events, thus forming a solid foundation for extreme value analysis. Based on different, but commonly applied extreme value models, 100-year return value estimates of Hs have been established within Norwegian waters, illustrated in Figure 1. For the most part, these estimates are within ±5% at any given location.

Like NORA10, most time series of Hs do not extend much further than 50 years implying extremes with a recurrence rate

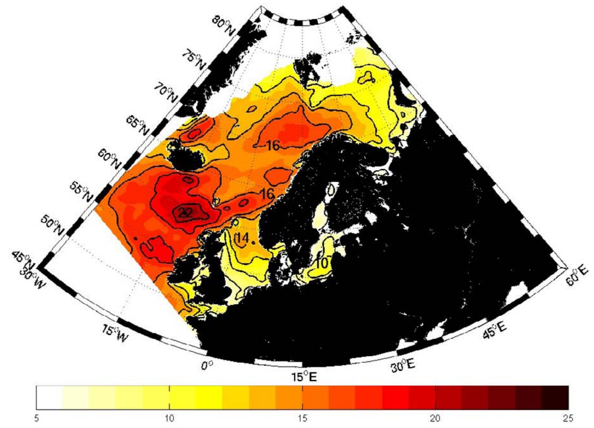

Figure 1: 100-year return value estimate of significant wave height based on NORA10, representative of 1-hour mean sea states.

of 100 years are rarely represented in the data. In an effort to overcome this limitation, this PhD-study investigates the possibility of utilizing archived wave ensemble forecasts (ENS) from ECMWF to obtain vast datasets. By running 50 perturbed versions of the deterministic model at lower spatial resolution, plus a control run initialized from a "best guess" of the atmospheric state, the main purpose of ensemble forecasting is to assign confidence estimates to deterministic forecasts. In general, the spread of the ensemble is increasing with forecast range, reflecting the uncertainty in the forecast. Beyond day 6, the forecast skill is low. At day 10, the 51 ensemble members are sufficiently uncorrelated to be considered independent draws from the model climate. Here, we aggregate historic ENS data, run twice daily, over a period of ~10 years. By assuming each 10-day member being representative of a 6-h mean sea state, the aggregated dataset is equivalent to more than 220 years of data, i.e. the dataset should contain more than 2 events, on average, exceeding the 100-year return value. In this way, 100-year estimates may be obtained directly from the data without resorting to extrapolation of some theoretical extreme value model, presented in Figure 2. This approach is new and should be applicable to other meteorological parameters.

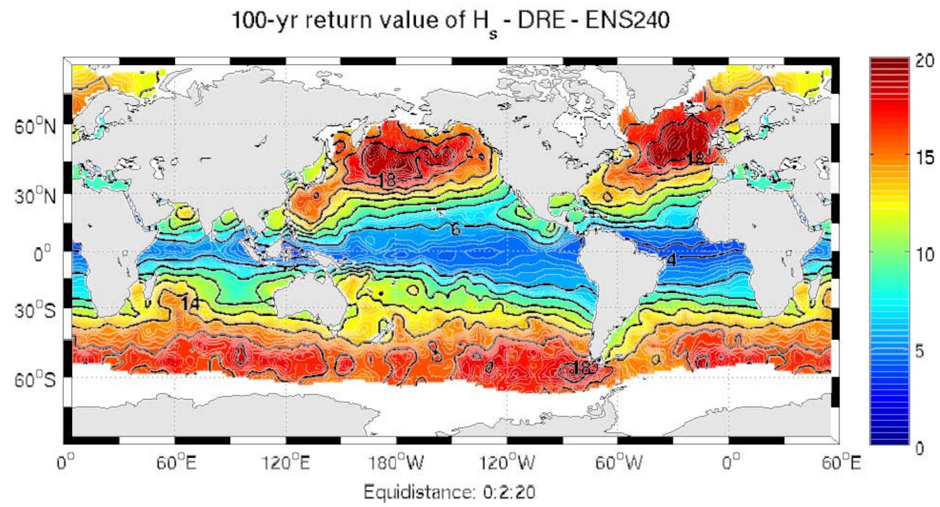

Figure 2: 100-year return value estimates of significant wave height based on aggregates of historic ensemble data, representative of 6-hour mean sea states.

Reanalyses are extensively used for climatic studies and in many cases considered baseline representations of the recent past. It is therefore imperative that a reanalysis is able to recreate realistic trends. An obvious concern is how reanalyses may be affected by the ever growing observational system, especially related to the advent of satellite data. ERA-Interim is a state-of-the-art reanalysis produced at ECMWF, which also comprises prognostic fields, i.e. the model is run as forecasts up to 10 days every 12 hours. This enables the comparison of trends in Hs based on data obtained at the time of analysis against trends obtained at increased forecast range. The purpose of doing such an exercise is to investigate effects of assimilation on trends, an effect that is gradually lost when the model is integrated forward in time. This study reveals that more realistic trends in Hs are obtained from prognostic data, rather than the more often applied reanalyzed data. This applies especially to Hs data, but also seems to have some relevance to wind data. The different Hs-trends obtained with ERA-Interim at the time of analysis and the 48-hour forecast range is presented in Figure 3.

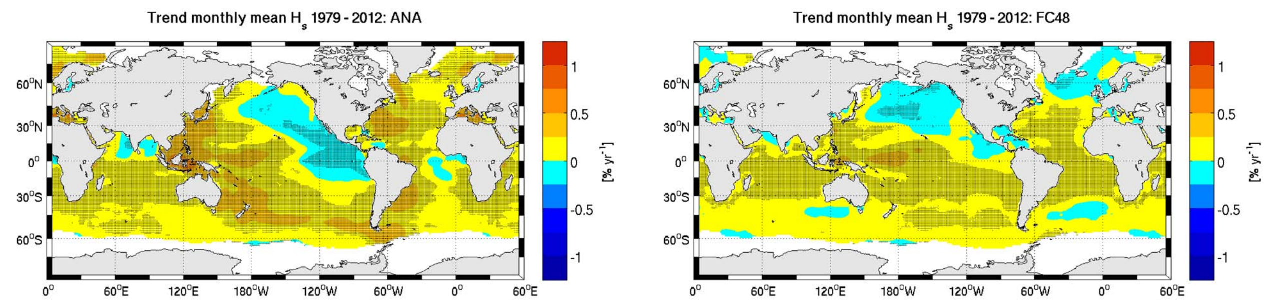

Figure 3: Linear trends in monthly mean Hs obtained from ERA-Interim presented in percentage per year over the period 1979-2012. Left: estimates based on data obtained at analysis: Right: estimates based on data obtained at the 48-hour forecast range.