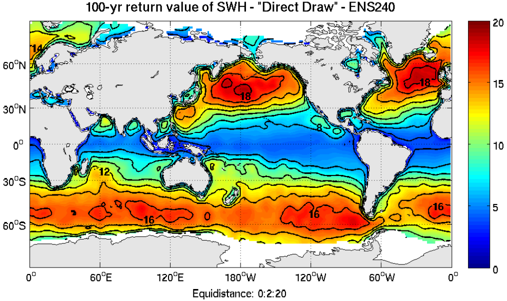
Wind and Wave Extremes over the World Oceans From Very Large Forecast Ensembles

Øyvind Breivik, Ole Johan Aarnes*, Saleh Abdalla and Jean-Raymond Bidlot



ECMWF
* Norwegian Meteorological Institute met.no

Motivation

- Return values for wind and waves are essential to offshore design
- Observational records are short and sparse
- Reanalyses and hindcasts provide geographical cover but are still fraught with large error bars due to insufficient length
- Archived ensemble forecasts are a hitherto unused source of wave and wind climatology
- The amounts are vast - 51 forecast members twice daily since 2003 amount to $> 300,000$ fields

Brief description of methodology

- Ensembles of +240-h forecasts are aggregated from 2003-2012
- The forecasts are checked for intra-ensemble correlations
- The upper percentiles are compared with buoy and altimeter observations
- The forecasts are now assumed independent and identically
- Individual forecasts are assumed to be representative of the sea state and wind speed in a six-hourly interval. Taken together they now amount to the equivalent of 229 "years"
- All values above a threshold of 99.7 per cent are used to compute return values
- The results are compared with the ERA-Interim reanalysis

Conclusions

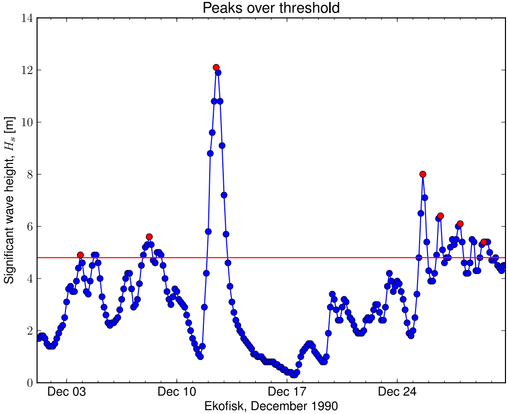
1. The method is general and applicable to a range of geophysical parameters
2. Generally higher 100-yr H_s and U_{10N} return values compared with ERA-I, especially in the extratropics and in the hurricane-prone subtropics, but lower than what is found by Caires and Sterl (2005) and Vinoth and Young (2011)
3. Conversion to an equivalent time period appears to work well
4. Correlations within the ensemble are of negligible importance
5. Return value estimates in a changing climate not well represented as the data sets covers only 9 years - but to handle this requires non stationary extreme value theory
6. Much tighter confidence intervals due to larger data set
7. Upper-percentile biases are hard to assess, but are neither better nor worse than those found in traditional reanalyses and hindcasts

See also Breivik *et al* (2013). Wave Extremes in the North East Atlantic from Ensemble Forecasts, *J Climate*, **26**, pp 7525-7540, doi:10/mpf, `http://arxiv.org/abs/1304.1354`

Generalized Pareto (GP) and Peaks-over-threshold

Peaks exceeding threshold 4.8 m. Generalized Pareto Distribution (threshold exceedances $y = X_i - u,\ y > 0$)

$$H(y) = 1 - \left(1 + \frac{\xi y}{\tilde{\sigma}}^{-1/\xi}\right)$$



Estimating return values from ensemble forecasts

Main assumptions:

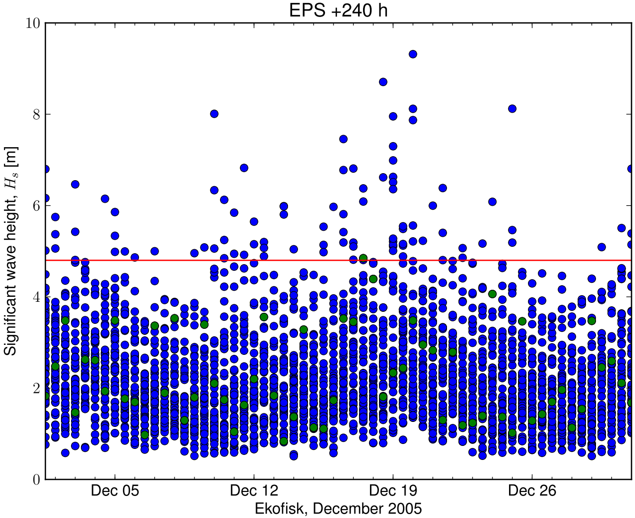
- Each forecast is representative of a time interval (six hours), which makes the total data set equivalent to

$$51\,\mathrm{mem} \times 2\,\mathrm{daily\,forecasts} \times 9\,\mathrm{yr} \times 6\,\mathrm{h} = 229\,\mathrm{yr}$$

- No spurious trend in the mean and the variance due to model updates
- No significant correlation between ensemble members at advanced lead times
- The model climatology distribution is comparable to the observed climatology distribution

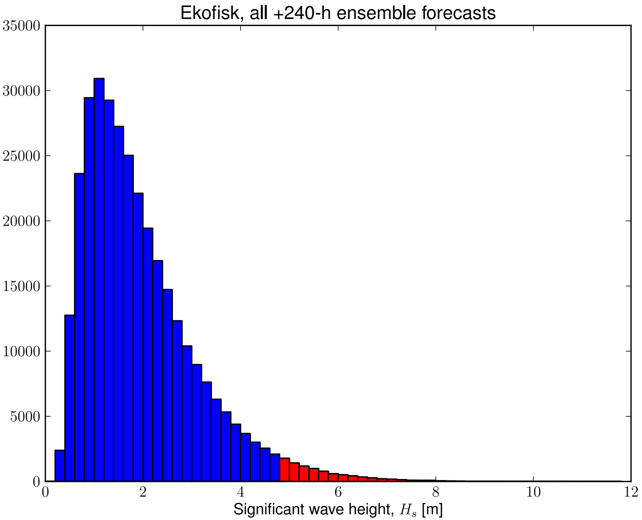
Thresholds applied to ensemble forecasts

Green dots represent member #50.



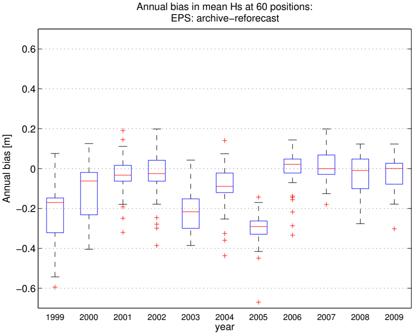
Thresholds applied to ensemble forecasts

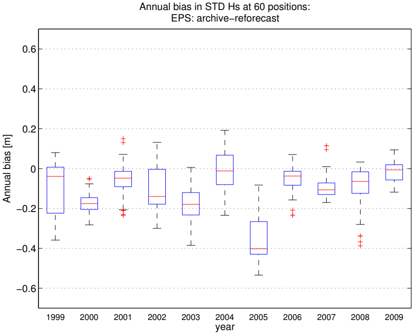
Red exceeds threshold 4.8 m.



Stationarity of errors

- Annual mean and variance *v* reforecast Cy36r4

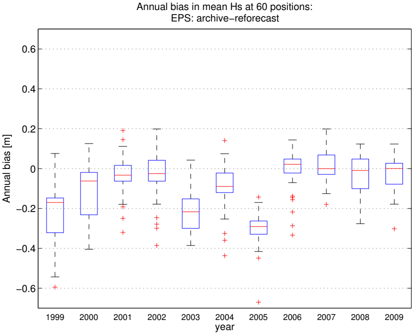


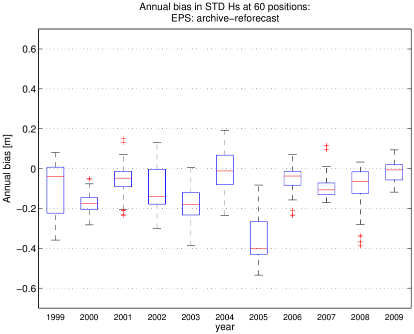


- Is there potential for using the reforecasts for computing extremes?

Stationarity of errors

- Annual mean and variance *v* reforecast Cy36r4





- Is there potential for using the reforecasts for computing extremes?
-

$$\frac{5\,\text{weekly members} \times 18\,\text{yr}}{51\,\text{members} \times 2\,\text{daily forecasts} \times 7\,\text{weekdays} \times 9\,\text{yr}} \approx 0.011.$$

Alas, the data set is too small.

Impact of correlation on return values

- Intra-ensemble correlations reduce the effective ensemble size

$$N^* = \frac{N}{1 + (N - 1)r}.$$

Impact of correlation on return values

- Intra-ensemble correlations reduce the effective ensemble size

$$N^* = \frac{N}{1+(N-1)r}.$$

- How does this affect the tail of the distribution and the return values?

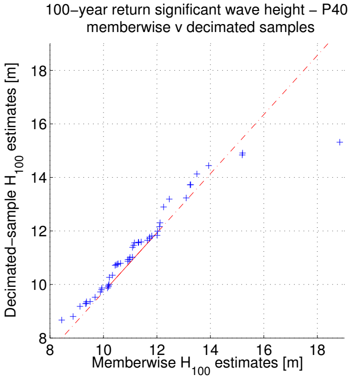
Impact of correlation on return values

- Intra-ensemble correlations reduce the effective ensemble size

$$N^* = \frac{N}{1+(N-1)r}.$$

- How does this affect the tail of the distribution and the return values?

We split the ensemble memberwise and "forecastwise" to find out

- 

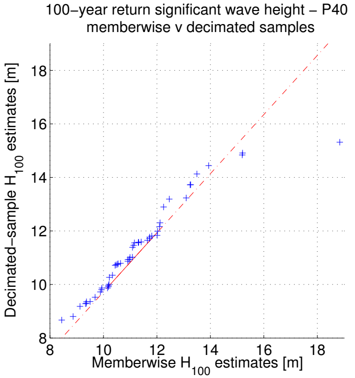
Impact of correlation on return values

- Intra-ensemble correlations reduce the effective ensemble size

$$N^* = \frac{N}{1+(N-1)r}.$$

- How does this affect the tail of the distribution and the return values?

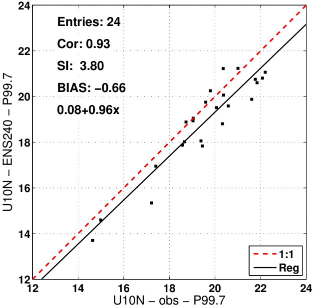
We split the ensemble memberwise and “forecastwise” to find out

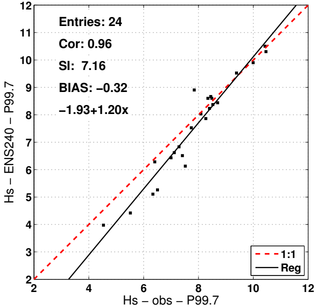
- 

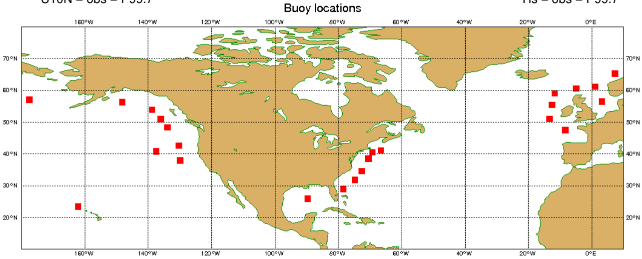
- Conclusion: intra-ensemble correlations have very little impact on return estimates.

Model climatology *v* buoy climatology

Observed *v* modelled $P_{99.7}$ of $U_{10\mathrm{N}}$ and H_s.



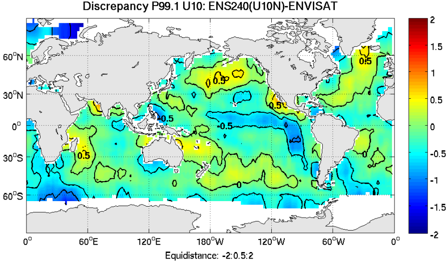




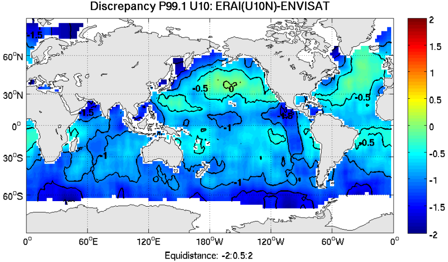
Model U_{10N} climatology v altimeter climatology

$P_{99.1}$ +240-h forecast *v* ENVISAT altimeter measurements.

ENS240

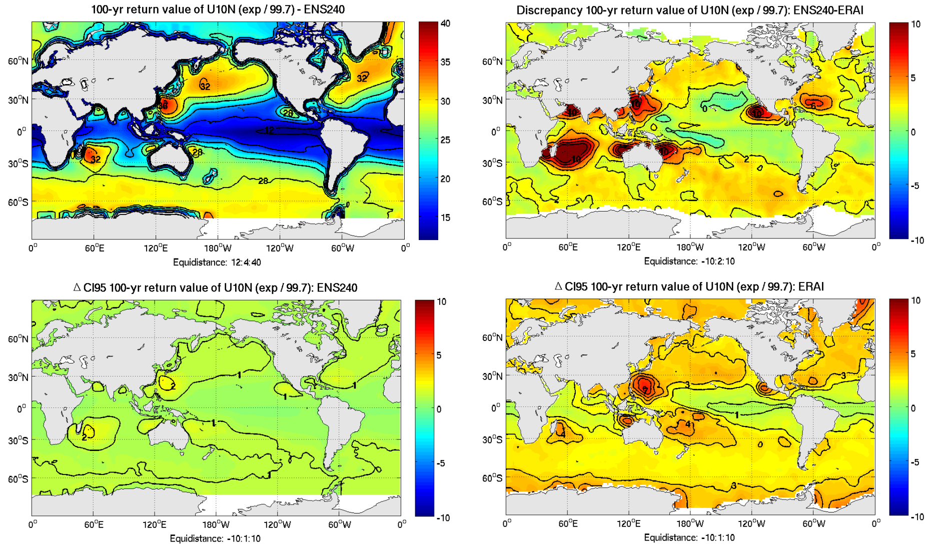


ERA-I

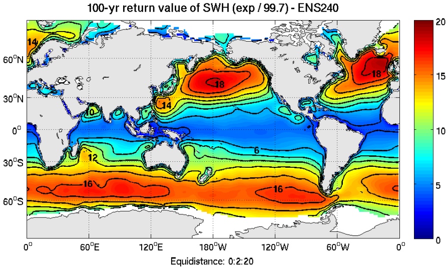


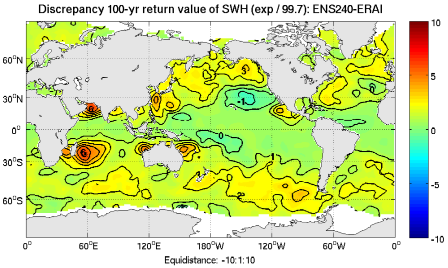
The ensemble is generally closer to ENVISAT wind speed, and ERA-I tends to be biased low.

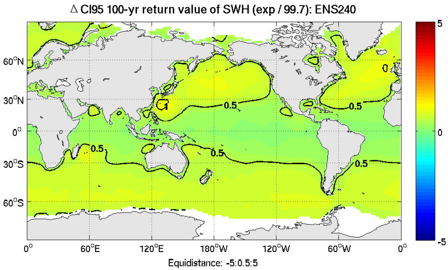
100-yr return values of 10-m wind speed

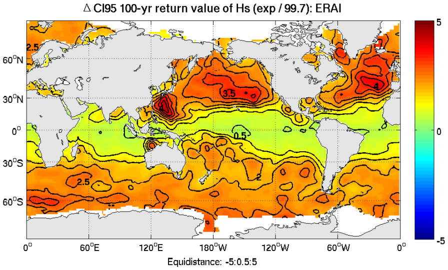


100-yr return values of significant wave height





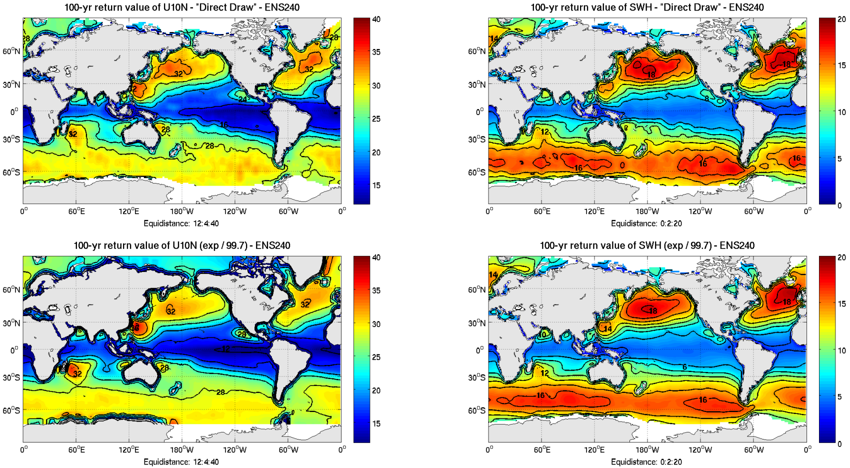




Direct return value estimates

$$X_{100}^{\mathrm{DRE}} = 0.67X_{(2)} + 0.33X_{(3)},$$

where X_{100}^{DRE} is the 100-yr return value, and $X_{(n)}$ is the n-th highest value.
Results are very similar to the exponential threshold estimates



Caveat Emptor

1. Beware of spurious trends caused by model upgrades
2. Check for correlations within the ensemble - not all geophysical parameters will have equally decorrelated upper percentiles
3. Take care when converting to an equivalent time period

Caveat Emptor

1. Beware of spurious trends caused by model upgrades
2. Check for correlations within the ensemble - not all geophysical parameters will have equally decorrelated upper percentiles
3. Take care when converting to an equivalent time period
4. Return value estimates in a changing climate not well represented

Caveat Emptor

1. Beware of spurious trends caused by model upgrades
2. Check for correlations within the ensemble - not all geophysical parameters will have equally decorrelated upper percentiles
3. Take care when converting to an equivalent time period
4. Return value estimates in a changing climate not well represented
5. Upper-percentile biases caused by coarse model resolution and/or inadequate physics

Conclusions

1. The method is general and applicable to a range of geophysical parameters
2. Generally higher 100-yr H_s and U_{10N} return values compared with ERA-I, especially in the extratropics and in the hurricane-prone subtropics, but lower than what is found by Caires and Sterl (2005) and Vinoth and Young (2011)
3. Conversion to an equivalent time period appears to work well
4. Correlations within the ensemble are of negligible importance
5. Return value estimates in a changing climate not well represented as the data sets covers only 9 years - but to handle this requires non stationary extreme value theory
6. Much tighter confidence intervals due to larger data set
7. Upper-percentile biases are hard to assess, but are neither better nor worse than those found in traditional reanalyses and hindcasts

See also Breivik *et al* (2013). Wave Extremes in the North East Atlantic from Ensemble Forecasts, *J Climate*, **26**, pp 7525-7540, doi:10/mpf, `http://arxiv.org/abs/1304.1354`