Analysis of Wave Height Climate Variability from 1° x 2° Gridded Monthly Mean Altimeter Data.

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Introduction

This analysis has employed satellite significant wave height (H_s) altimeter data, covering the period October 1992 to September 1998, to investigate the spatial and temporal characteristics of (inter-annual) variability of wave climate in the North Eastern Atlantic. The intention is to identify the major large scale patterns of variability which may in turn influence the coastal wave climate. The results of this study will then be used to identify patterns which contain links with large scale atmospheric features, and may thus be combined with predictions from large scale climate models to generate predictions of future wave climate close to the UK coast.

Data

The altimeter data are gathered from 3 satellites: ERS-1 (1991-95), TOPEX/Poseidon (1992-98), and ERS-2 (1992-98). Significant wave height data from each altimeter have been extracted, quality controlled and separately calibrated according to linear corrections given in Cotton et al., (1997). These data have then been combined together to generate monthly means on a 1° latitude by 2° longitude global grid. The higher spatial resolution of the grid requires cotemperaneous sampling by two altimeters, hence the time period of this data set is constrained to the period when (at least) two satellite altimeters have been operating simultaneously, October 1992 to the present. The most recent data analysed in this report are from September 1998, hence six full years of data are analysed.

Data Overview

Figures 1 and 2 provide the mean and variance of significant wave height climate for the first and third quarters of the year, together with the number of months in the six year period with valid data (maximum 18) and the mean number of transects per month in each grid square (< 5 transects, blue colours, is regarded as too few for representative sampling). Figures 1 and 2 indicate that none of the grid squares immediately adjacent to the English and Scottish East coast (North of East Anglia) receive adequate sampling. We see a similar lack of coverage for the squares adjacent to

the European coast eastward of (and overlying) the Cherbourg (Cotentin) peninsula to Denmark, and the grid squares in St Georges Channel between N Ireland and Scotland. Therefore, we should not assume that the values in any of these squares are representative of the wave climate therein.
The panels illustrating the mean and variance of the wave height climate clearly illustrate the higher mean and variability that is present in the first three months of the year, and also the decrease in both these parameters in the southern North Sea and eastern English Channel. If we can assume that the shape of the wave height distribution takes a certain form, we can use these values of mean and variance to generate estimates for 50 (and 100) year return values, and the percentage time that selected significant wave height thresholds will be observed to be exceeded.

Annual Cycle

It is important to accurately characterise the annual cycle in wave height, and then remove it from the data, before inter-annual variability can be investigated. A simple sine model has been fitted individually to the monthly mean H_s values in each 1° x 2° grid square, and the cycle thus identified is presented in Figure 3. The annual mean H_s, and the annual range in H_s can both be seen to decrease Eastwards into the English Channel and Southwards into the North Sea (from > 3 m at 20° W , to 1 m or less at the south-eastern tip of Kent). There is a suggestion that the time of maximum wave height is slightly earlier in the southern North Sea, early January, than it is elsewhere, particularly to the north-west, early Feburary (The colour key starts at 0, 1st January, and ends at 2, 1st March). When the percentage reduction in variance achieved by fitting the annual cycle is considered, Figure 4, it becomes clear that the annual cycle describes less of the variability in the gridded and averaged altimeter data in these more sheltered regions (~70% at 15°-20°W, ~30-50% in the southern North Sea). This effect may be genuine, but it may also be a consequence of the poorer sampling of these regions by the altimeter. Remember that the grid squares immediately adjacent to the coastlines in the North Sea do not receive adequate sampling.

Modes of Variability from Empirical Orthogonal Functions

Empirical Orthogonal Analyses identify separate, orthogonal, modes of variability in data sets. EOF analysis was carried out on the gridded altimeter data set, after the annual cycle has been removed. The procedure was carried out on 3 regions, the North Eastern Atlantic (45°-60°N , 20°W -10°,), a reduced British seas area (50°-64° N, 6°W- 10°E), and a North Sea region area (50°-60° N, 2°W to 10°E)

Table 1 gives the variance explained by the first five EOF modes in the various regions. We can see that in the first five modes explain > 70% of the variance in the monthly mean data set covering the whole North Atlantic, and > 80% of the variance in the reduced areas. We are advised that, when considering relatively short time series, one should be wary of allowing too much weight to lower order modes which can be influenced strongly by individual events. It would therefore seem sensible at this stage to discuss only the first two modes in detail. (The features of the EOF modes of the largest area have been discussed in an earlier report, and are not discussed again here).

	Percent Variance explained by EOF			
EOF no.	All N Atl.	20°W to 10°E	6°W to 10°E	2°W to 10°E
1	36.4	55.0	53.9	44.5
2	17.8	16.8	13.2	14.7
3	7.2	4.6	7.8	10.9
4	5.5	3.9	4.8	6.3
5	4.6	2.8	3.1	4.1
1-5	**71.5**	**83.1**	**82.8**	**80.5**

Table 1. Percentage variance of monthly mean gridded significant wave height explained (annual cycle removed) by modes of variability identified in EOF analysis

The most significant EOF mode on the larger scale (Figure 5 - top panel) explains 55% of the inter-annual variance in the altimeter H_s data, and is similar in both spatial and temporal terms to the NAO related time series identified in an earlier JERICHO report. However, the magnitude of this mode is greatest to the north west, and whilst it retains some significance at the south-west English Welsh coasts, its importance decreases in the Southern North Sea. When the area of the data analysed by EOF is reduced (middle and lower panels of Figure 5), the percentage variance explained by this first mode decreases (to 54% and then 45%), and the time series appears to show more high frequency noise. However, the spatial and temporal character of the mode remains broadly the same.

The second EOF mode accounts for 17% of the variance in the north-east Atlantic, 13% and 15% in the reduced areas - Figure 6. In contrast to mode 1, the character of the second mode is completely different in the analyses of the larger (top panel) and smaller (bottom panel) regions. The lower panel appears to show a mode of variability centred in the North Sea, which exhibited a strong minimum in early 1997, and a maximum early in the previous year.

Finally, bearing in mind the lower percentage variance explained by the annual cycle in the North Sea, we carried out an EOF analysis on the raw monthly mean data of the North Sea area, without first removing a fitted annual cycle (Figure 7). The first mode (top panel) explains 77% of the variance, and clearly has a 12 month period. The spatial pattern indicates a uniform change in significant wave height at this frequency. It is particularly interesting to note that the time series suggests that the range of the annual cycle reduced significantly in 1996, and has stayed at this lower level since then. Note that the spatial pattern is negative, hence it is the maximum (winter values) of the annual cycle that has changed. The second and third modes represent 5.3% and 3.7% of the total variability respectively - roughly 24% and 17% of the variability not explained by the first mode with the strong 12 month period. However, it is difficult, at least at first look, to relate the patterns of the second and third EOF modes in Figure

7, to the 1st and second EOF modes of the same area on the lower panels of figures 5 and 6.

Conclusions

The dominant large scale patterns of wave climate variability in the north-eastern Atlantic and North Sea have been characterised as an annual cycle and two EOF modes. It appears that the coastal climates of the regions on the south western English and Welsh coasts are strongly influenced by the larger scale NAO related mode, but that the eastern English coast and southern North Sea are not.

Next steps in the analysis involve feeding these EOF patterns into a CCA analysis with sea level pressure fields, in an attempt to identify connected patterns of variability. If significant patterns do exist, then they can be used to generate hindcast wave fields and (using output from long term forecasting climate models) projected future wave fields. The values of means and variance in significant wave height can be used to generate maps, on this 1° x 2° grid, of 50yr and 100 yr return values, and of other statistical parameters.

References

Cotton P.D., P.G. Challenor, and D. J. T. Carter, An assessment of the accuracy and reliability of Geosat, ERS-1, ERS-2, and TOPEX altimeter measurements of significant wave height and wind speed, proceedings of CEOS wind and wave validation workshop, June 1998, ESTEC, Noordwijk, The Netherlands. ESA WPP-147.

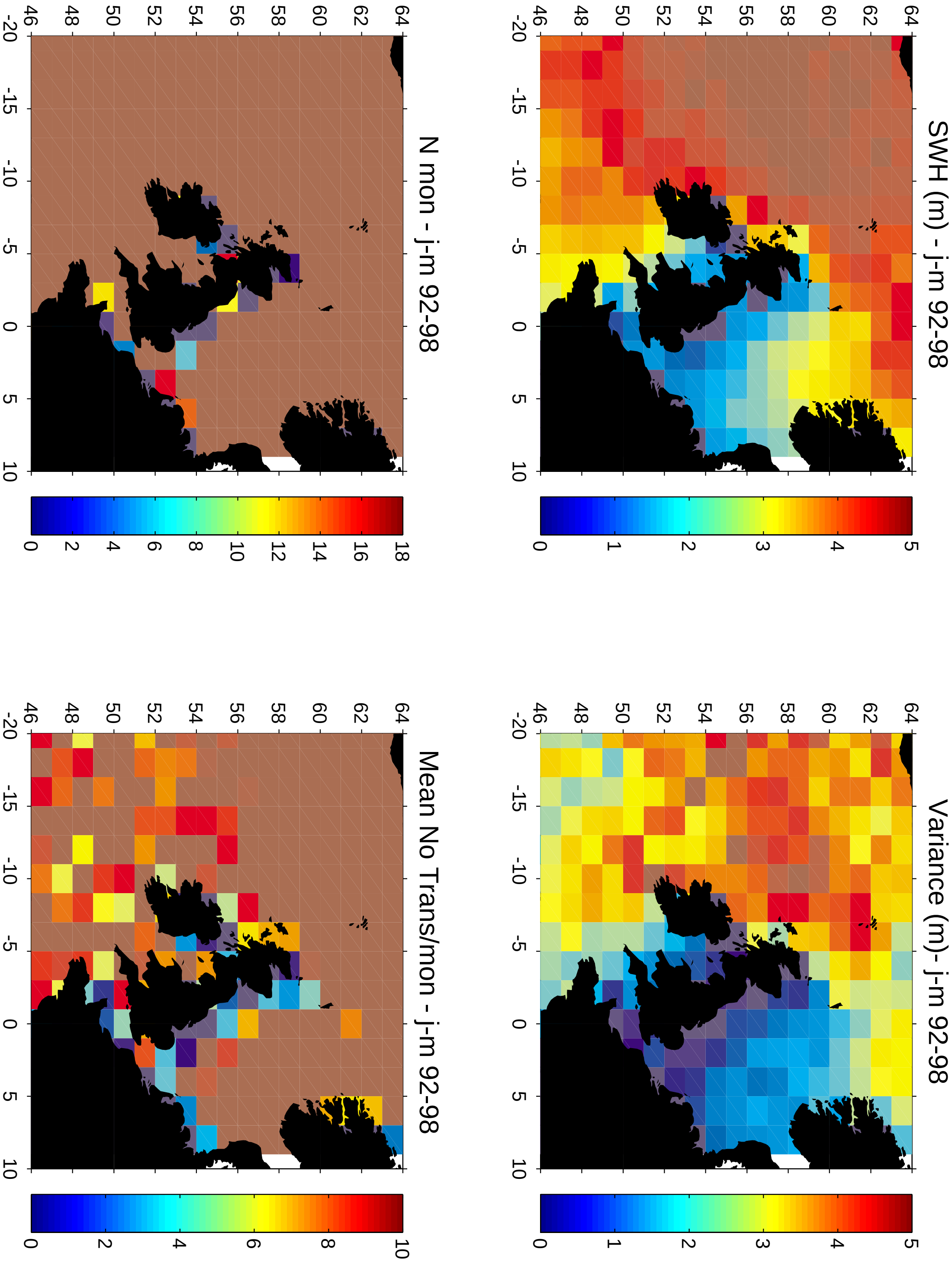

Figure 1. Statistics of the 1° x 2° monthly mean significant wave height data set for January to March. Top left: Mean significant wave height, Top right: mean variance, Bottom Left. No of months with valid data, Bottom Right: Mean number of transects per month (5 is the threshold of useful sampling)

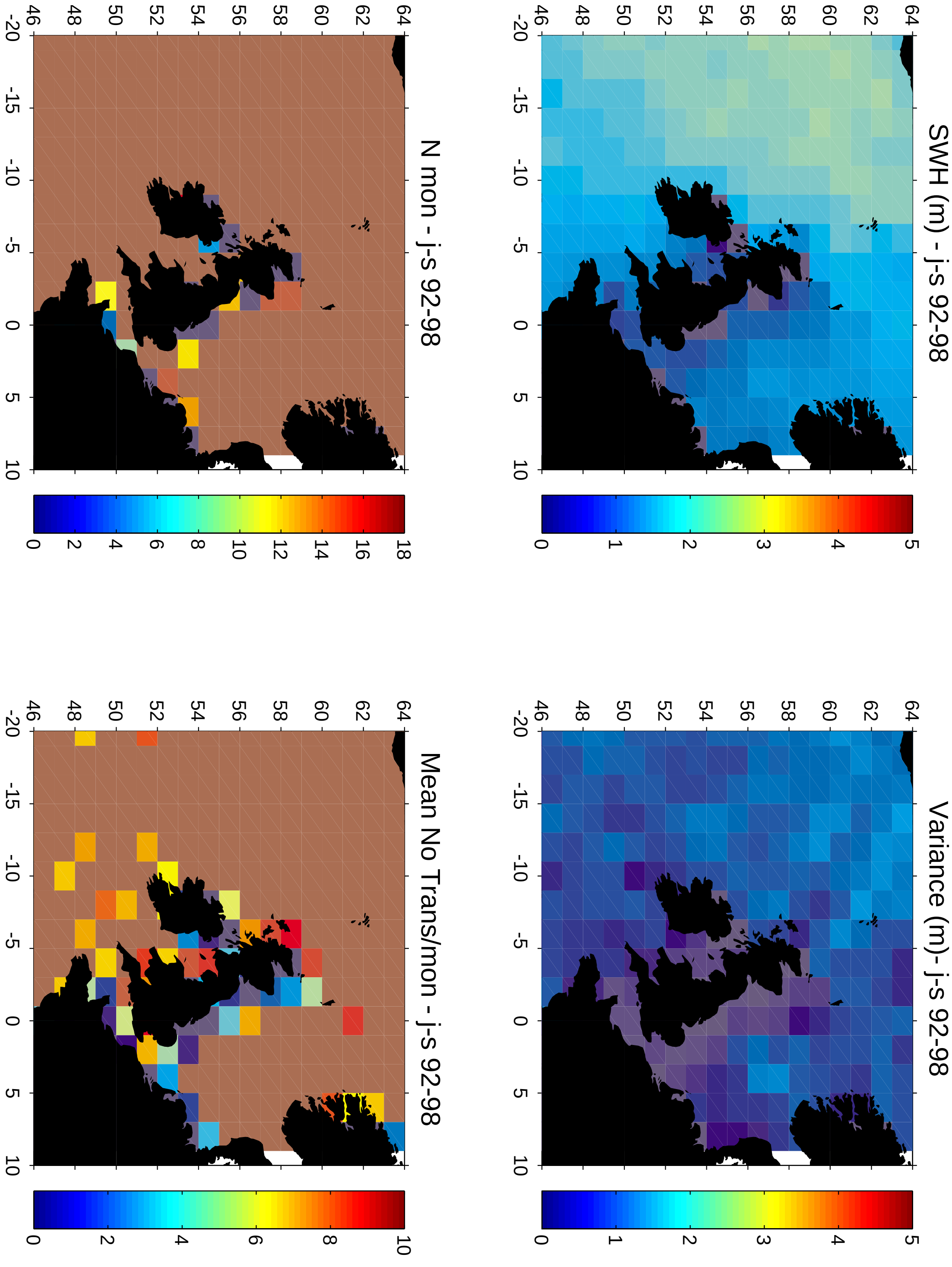

Figure 2. Statistics of the 1° x 2° monthly mean significant wave height data set for January to March. Top left: Mean significant wave height, Top right: mean variance, Bottom Left. No of months with valid data, Bottom Right: Mean number of transects per month (5 is the threshold of useful sampling)

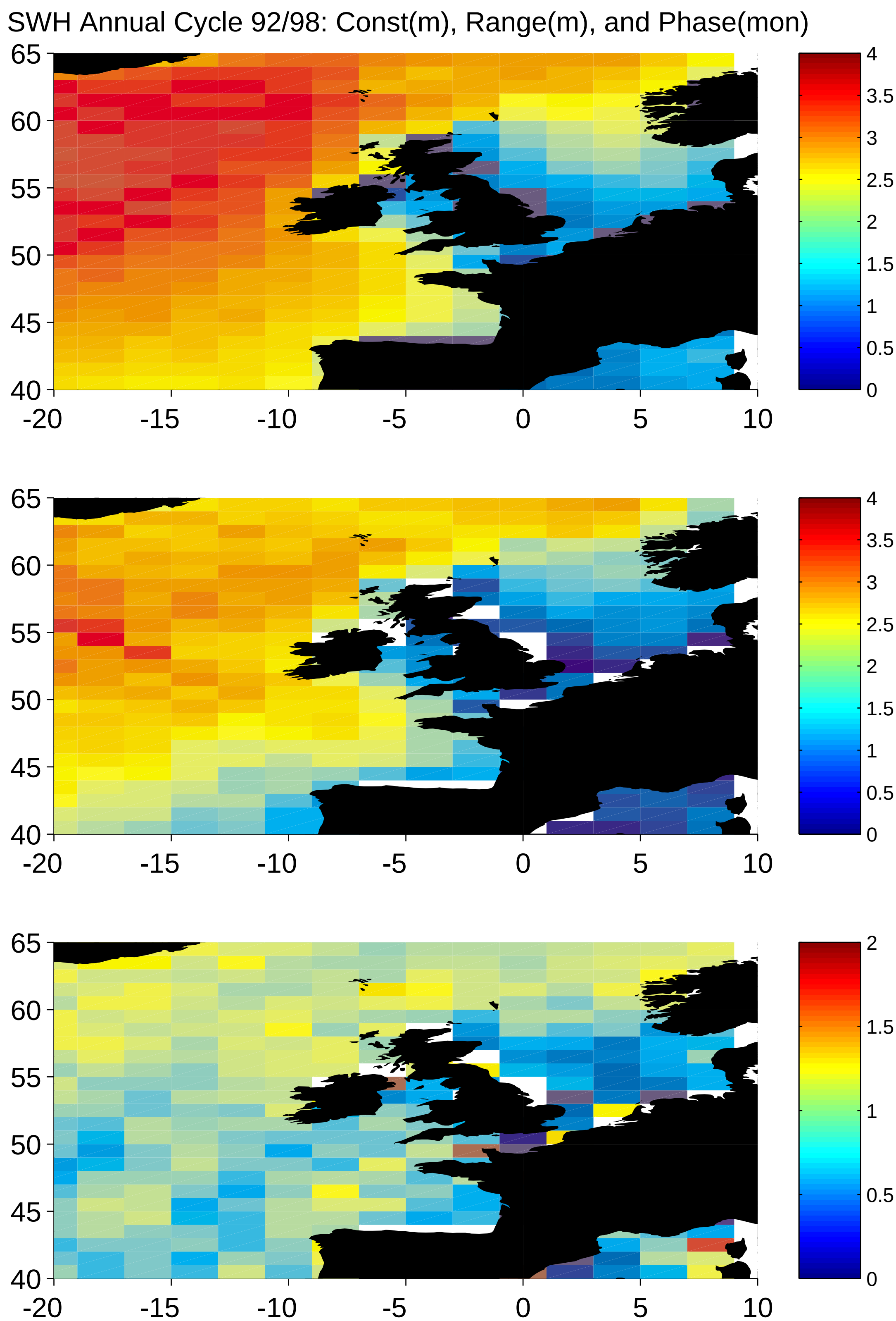

Figure 3. Coefficients of significant wave height annual cycle fitted to monthly mean altimeter data: (top) annual mean H_s, (middle) annual range in H_s, (bottom) month of maximum H_s

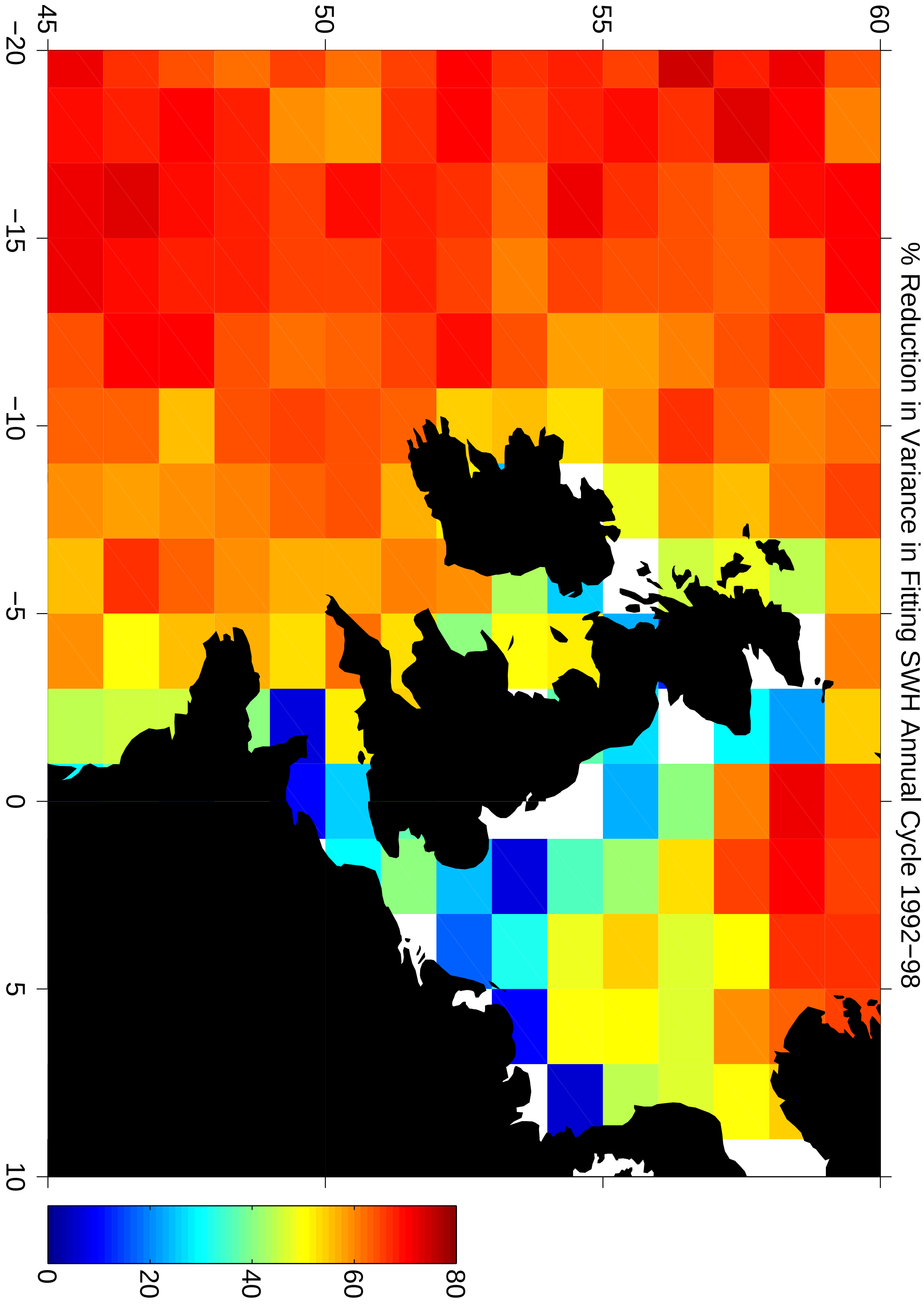

Figure 4. Percentage reduction in variance achieved by fitting annual cycle

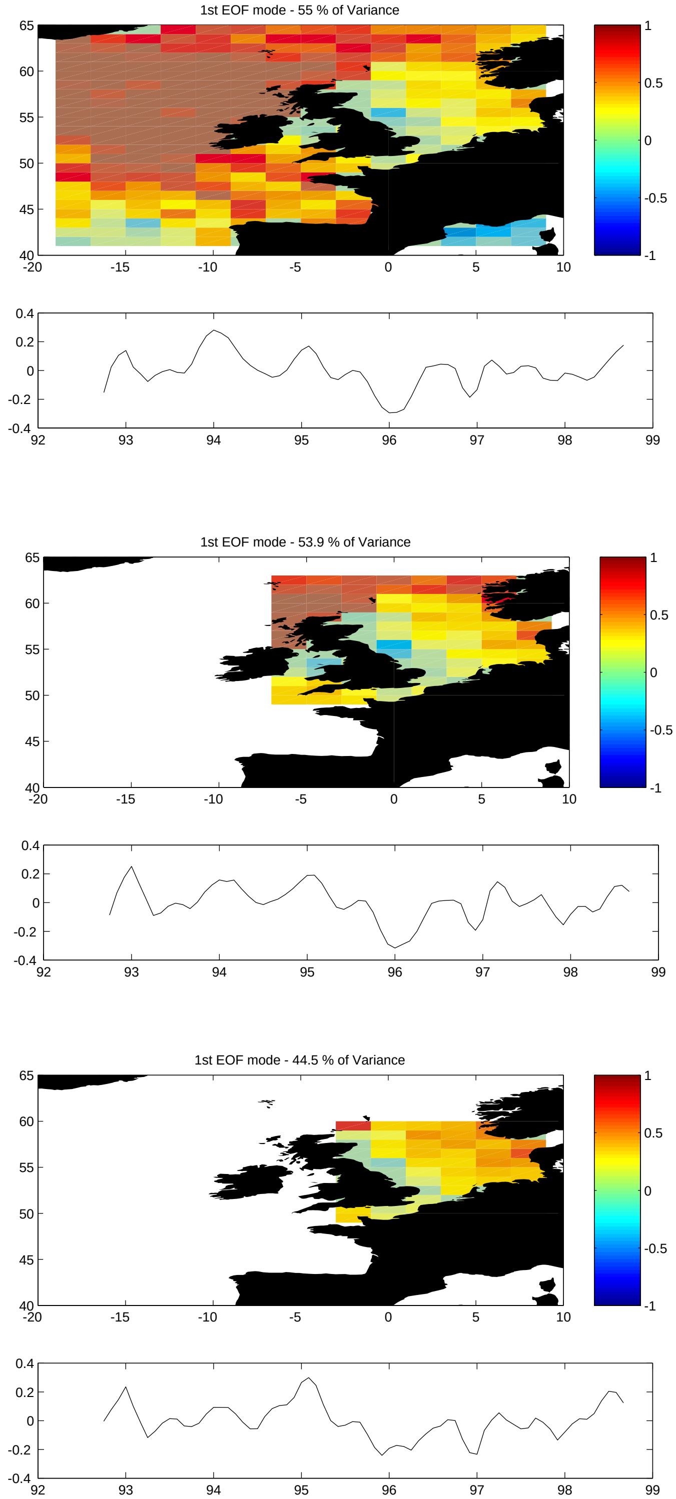

Figure 5. Spatial pattern and time series of 1st EOF mode of interannual variability in altimeter measured significant wave height climate in the North Atlantic (a), (b) and (c).

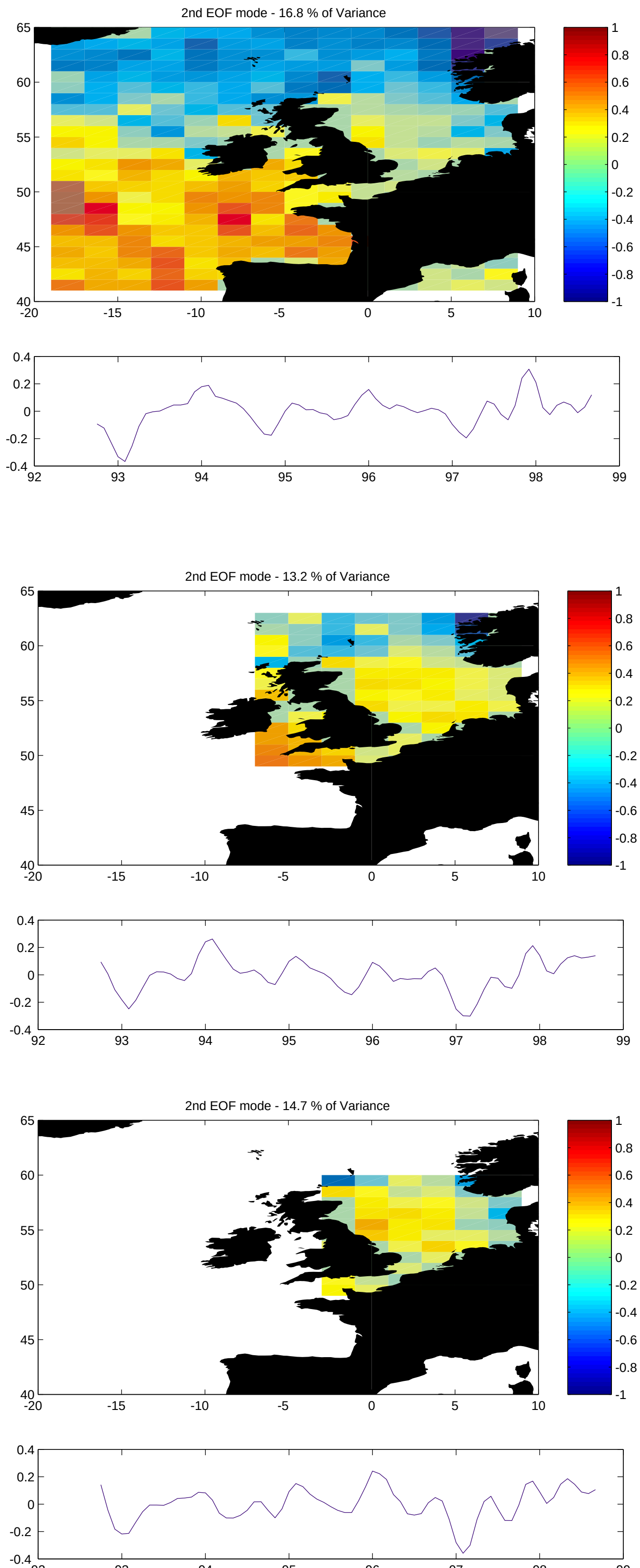

Figure 6. Spatial pattern and time series of 2nd EOF mode of interannual variability in altimeter measured significant wave height climate in the North Atlantic. (a) (b) and (c)