TRENDS AND POTENTIAL BIASES IN NCEP-DRIVEN OCEAN WAVE HINDCASTS

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1. INTRODUCTION

In this study the NCEP Reanalysis (NRA) surface (10 m) wind fields at 6-hourly intervals were used to drive both a global spectral ocean wave model and a detailed North Atlantic model for the period 1958-1997. The North Atlantic hindcast was based on kinematically reanalyzed NRA wind fields (ENRA). Fifteen statistics were computed for both the resultant wave heights and input wind fields on monthly, seasonal and annual time scales; trend and variability analysis was carried out for each grid point in both hindcasts. In addition, a spatial analysis was carried out for the Northern Hemisphere oceans relating the wave climate to the surface pressure patterns. The results of the two wave hindcasts were compared with each other, and with homogeneous point time series of waves to investigate potential biases in the trend analyses.

2. WAVE HINDCASTS

The global wave hindcast was carried out using Oceanweather's ODGP2 1-G fully discrete spectral wave model with a grid resolution of 2.5° longitude by 1.25° latitude. Wind fields are derived directly from the NCEP Reanalysis surface 10 m winds, updated at 6-hourly intervals, and the model time step is 3 hours. The only modification to the wind fields in the global model was to convert them to effective neutral using the NRA 2 m temperature and sea surface temperature fields. In the global model ice fields were specified on a monthly basis, using long term monthly historical ice concentration data. Details are given by Cox and Swail (1999).

The North Atlantic wave hindcast was carried out using the ODGP 3-G wave model with a grid resolution of 0.625° latitude by 1.25° longitude. The ice edge was based on the actual monthly ice concentration. The NRA wind fields were reanalyzed and enhanced with the aid of analyst-interactive techniques, during which in situ data were correctly re-assimilated, wind fields in extratropical storms were intensified as necessary and tropical cyclone boundary layer winds were included. Swail and Cox (1999) describe the generation of these wind fields in detail, and show the significant improvement in the reanalyzed wave fields, particularly in the specification of storm peaks.

3. CLIMATE ASSESSMENT

A statistical analysis of the wind and wave trends was carried out at each point on the grid. Trends were computed as simple linear trends over the 40 years of each hindcast using least squares fitting techniques; 99% statistical significance levels were also computed. Figure 1 shows the trends in the 99th percentile wave height for the two hindcasts. Increasing trends are most noticeable in the northeast Atlantic Ocean, across the northern edge of the north Pacific Ocean, and along the margins of Antarctica. The Antarctic trends are considered to be rather unreliable due to the data scarcity in the Southern Ocean as a whole, and documented problems in the NRA with the Southern Hemisphere, particularly south of 50°S. Negative trends in wave height are found mostly in equatorial regions, particularly in the Pacific Ocean, and also in the Labrador Sea. Particularly noticeable is the bi-polar nature of the trends in the North Atlantic, with strong increases in the northeast, and strong decreases in the south-central North Atlantic. This pattern follows the dominant mode of the North Atlantic Oscillation.

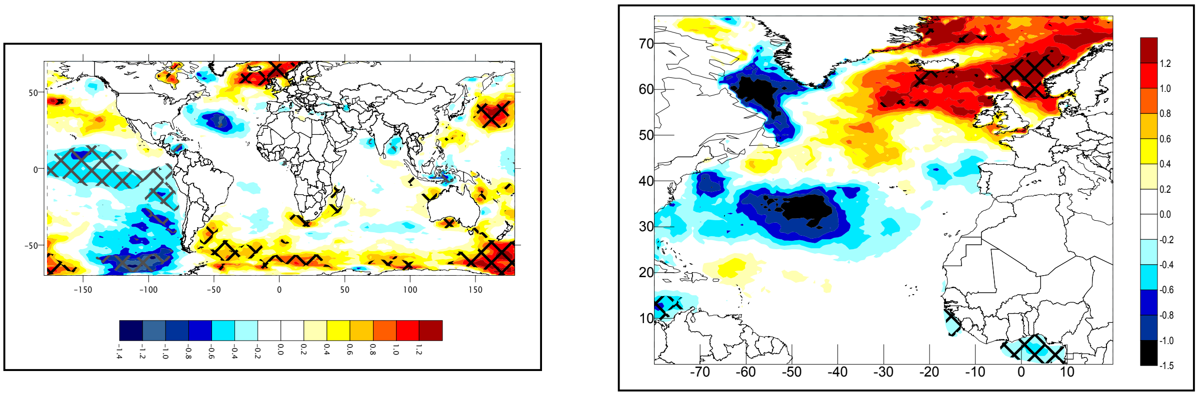

Figure 1 – Inferred change in 99th percentile wave heights 1958-1997 with 99% confidence level.

While the NRA used the same numerical prediction scheme for the 40-year period, thus removing the bias associated with ever-changing operational models, there still remain probable biases due to increased observational densities, and particularly for ocean areas, an increase in shipboard anemometer heights coupled with an increased fraction of measured versus estimated winds. These are often referred to as “creeping inhomogeneities”, and are potentially serious constraints to any attempt to derive long-term trends. Therefore, we would like to verify the trend analyses derived from the two hindcasts against some long time histories of homogeneous measured data at selected points. Unfortunately there exist very few locations in the global ocean where such data are available.

One location for which we do have reasonably homogeneous wind measurements over the 40-year period is at Sable Island, just off the east coast of Canada. We are also able to analyze the surface atmospheric pressure record from Sable Island, along with records from two other sites in Nova Scotia (Halifax, Sydney), to compute pressure triangle wind records. As shown by Schmidt and von Storch (1993), the pressure triangle winds are likely the least biased wind estimator available, since inhomogeneities in pressure records are much less than for most atmospheric variables.

Table 1 shows the trends for the Sable Island area from the hindcasts, Sable Island and the pressure triangle. In both the Sable Island measurements and the triangle winds the trends in the percentiles are decreasing; the magnitude of the decreasing trend is comparable in both analyses, with the triangle wind trend being slightly more negative. The hindcast wind speed trends show a near-zero, but very slightly positive trend. This likely indicates an inhomogeneity introduced into the NRA winds. This could be a result of increased data densities in later years. For the NRA hindcast it could also be a result of assimilating ship wind observations at an anemometer height of 10 m, when in fact the heights have increased from about 20 m at the beginning of the period to more than 30 m by the end of the period, with many observations coming from anemometers at heights exceeding 45 m. Coupled with an increase in the percentage of measured winds from ships, this could induce an artificial positive trend in the winds (and waves). In the 1990’s an increasing volume of moored buoy data would have been included in the NRA winds. These winds are taken at 5-m height, but also assimilated at 10 m into the model. This would have the effect of reducing the wind speed trends, and thereby reducing but not eliminating the positive bias in areas near the buoys, i.e. we would expect the trends to be more positive if the buoy winds were assimilated at the correct heights. This is in fact what we see from the ENRA hindcast where both the ship winds and the buoy winds are assimilated at their actual anemometer heights. The ENRA trends in both winds and waves are consistently higher in this region, dominated by buoy observations in the 1990s, than the NRA trends. The ENRA trends should be a truer indication of the creeping inhomogeneities in the reanalysis process. Table 1 also shows the trends from Comprehensive Ocean-Atmosphere Data Set (COADS) ship observations. These wind speeds have been corrected where possible following the approach of Cardone *et al*. (1990). However, there remains a strong positive trend in wind speeds, particularly at the higher percentiles. Based on the Sable Island and triangle winds, this trend is likely spurious, indicating that even these methods are unable to remove all of the artificial trend introduced by changing observational procedures on ships.

A second area for which "ground truth" information is available for trends is off the Norwegian coast. WASA (1998) computed winds from two pressure triangles: (1) T-B-M (Thorshavn-Bergen-Mike (OWS)); and (2) T-A-B (Thorshavn-Aberdeen-Bergen). Table 2 shows the comparative results of the hindcasts and the WASA triangles. In this area both trends are positive, the hindcast winds being slightly more positive than the triangles. This indicates that the hindcast trends are reasonable, but probably slightly too high, or a good upper bound on real trends. Trends from adjusted ships in these areas similarly show too-strong increases in wind speed, especially in the higher percentiles.

Table 1 Summary of trends (% change/year) in winds and waves near Sable Island 1958-1997.

% ILE	NRA wind	ENRA wind	SABLE IS wind	TRIANGLE wind	SHIP wind	NRA wave	ENRA wave
99	0.01	0.07	-0.12	-0.19	0.31	-0.01	0.15
90	0.03	0.09	-0.11	-0.14	0.13	-0.02	0.01
50	0.05	0.10	-0.24	-0.20	0.05	0.13	0.19

Table 2 Trends (% change/year) in winds and waves for WASA triangles, nearest hindcast points and 2° latitude-longitude adjusted COADS boxes 1958-1997.

	%ILE	NRA wind	ENRA wind	WASA wind	SHIP wind	NRA wave	ENRA wave
TRIANGLE T-A-B	99	0.22	0.26		0.56	0.30	0.40
	90	0.28	0.28	0.23	0.44	0.40	0.44
	50	0.27	0.33		0.56	0.34	0.44
TRIANGLE T-B-M	99	0.29	0.34		0.73	0.45	0.54
	90	0.25	0.27	0.23	0.42	0.42	0.46
	50	0.22	0.30		-0.17	0.29	0.40

Table 3 Trends (% change/year) in winds and waves at selected locations 1958-1997.

	%ile	NRA wind	ENRA wind	SHIP wind	NRA wave	ENRA wave
SCOTIAN SHELF	99	0.01	0.07	0.31	-0.01	0.15
	90	0.03	0.09	0.13	-0.02	0.01
	50	0.05	0.10	0.05	0.13	0.20
GRAND BANKS	99	0.10	0.14	0.58	0.17	0.11
	90	0.13	0.18	0.53	0.07	-0.05
	50	0.14	0.17	0.41	0.09	-0.11
BAY OF BISCAY	99	-0.01	-0.03	0.32	0.03	-0.10
	90	-0.01	-0.04	0.16	-0.02	-0.06
	50	-0.02	-0.03	0.25	0.02	-0.02
MID-ATLANTIC	99	0.15	0.01	-0.05	0.17	0.18
	90	0.13	0.11	0.11	0.20	0.16
	50	0.11	0.11	-0.09	0.14	0.08
OWS BRAVO	99	-0.31	-0.64	-0.51	-0.64	-0.01
	90	-0.22	-0.35	-0.20	-0.35	-0.85
	50	-0.30	-0.30	-	-0.80	-0.99
OWS PAPA	99	-0.01	-	-0.94	-0.17	-
	90	-0.02	-	-0.46	0.06	-
	50	0.08	-		0.25	-

We have compared trends from ship wind observations in other areas with the hindcasts. In addition to the Sable Island box, and a box selected near the Hibernia oil field on the Grand Banks

(47N, 47W), we have arbitrarily selected a mid-Atlantic 2° box (49N, 35W), and a box near the Bay of Biscay (45N, 9W). Table 3 shows that, except for the mid-Atlantic box, the adjusted ship trends show much larger increases than the hindcasts. It is also evident that the ENRA wind and wave trends are less than the NRA trends in the eastern Atlantic, while near Sable Island, where the buoys dominate the later years, the ENRA trends exceed those from the NRA. Trends from the Labrador Sea, away from the influence of the buoys, show the same pattern as the eastern Atlantic. An anomaly appears for the Grand Banks, just outside the northern of the buoy coverage, where the ENRA wind trends exceed the NRA trends, but the ENRA wave trends are less.

Table 3 shows trend results from OWS Papa and OWS Bravo. Unfortunately the overlapping period between the weathership records and the hindcasts is restricted to 24 years (Papa) and 16 years (Bravo). At Bravo, trends are negative for both the OWS and hindcasts. Consistent with a general artificial upward trend in hindcasts, the weathership trend is more negative (i.e. less positive). The same applies at the ship Papa location, although the OWS Papa trend looks somewhat suspicious, particularly the 99^{th} percentile trend.

Redundancy analysis techniques (described by Wang *et al*., 1999) were used to carry out detailed seasonal spatial statistical analyses for both the global and North Atlantic hindcasts. In the North Atlantic hindcast, significant increases in the northeast Atlantic in the 90^{th} percentile wave heights were matched by significant decreases in the subtropical North Atlantic, for the winter (JFM) season. The rates of increase/decrease are generally greater than those found in the global wave hindcast. Linear trends detected for the 99^{th} percentiles are generally less significant than those for the 90^{th} percentiles. The correlation between sea level pressure (SLP) and the 90^{th} percentile wave height (H90) is significant at the 99^{th} confidence level. Both time series possess a significant increasing trend at the 95% confidence level, indicating that the Icelandic low has deepened during the recent decades while the Azores high intensified, and consequently, significant wave height (SWH) extremes have increased in the northeast NA, accompanied by decreases of SWH extremes in the subtropical NA. Both SLP and H90 are highly significantly correlated with the NAO index. Similar results were also found for winter (JFM) 99^{th} percentile wave heights. In the global hindcast changes in North Pacific winter (JFM) SWH are found to be significant at the 90% confidence level; increases in SWH in the central North Pacific are found to be associated with a deepened and eastward extended Aleutian low. For both the North Atlantic and North Pacific no significant trends of seasonal SWH extremes are found for the last century, though significant changes do exist in the last four decades; multi-decadal fluctuations are quite noticeable, especially in the North Pacific. A more detailed description of these results can be found in Wang and Swail (1999) and Swail and Wang (1999).

4. REFERENCES

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