Investigating the Accuracy of Surf Forecasts Over Various Time Scales

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ABSTRACT

Whether or not surfable waves appear in a certain place and time depends upon many factors, some of which can be predicted by mathematical models. Typical outputs available to the public are significant wave height, mean wave direction, peak period, wind speed and wind direction. Wind inputs to wave models depend upon mean sea-level pressure (MSLP) values predicted by atmospheric models, and many surfers still prefer using MSLP charts for 'manual' surf predictions. As a simple test of the accuracy of these forecasts, a hindcast was performed using 27 sets of nine North-Atlantic MSLP charts, each giving predictions at 24-hour intervals between one and eight days ahead. The North Atlantic Oscillation (NAO) index, to which the surf in Europe is closely linked, was used to quantify in a simple way the situation on each chart. The root-mean-square (r.m.s.) error in NAO index across 18 sets of forecasts was noted as a function of forecast horizon. An increase in error with increasing forecast time was best described by an exponential regression model of the form $y = ae^{bx}$. The r.m.s. error of 6 hPa for a 1-day forecast was considered acceptable for surfing forecasts based on these charts, whereas the r.m.s. error of 19 hPa for an 8-day forecast was not. For a particular r.m.s. error, a steady lengthening of forecast horizon is expected as computing power continues to increase.

ADDITIONAL INDEX WORDS: *Forecast, MSLP, NAO, Surfing*

INTRODUCTION

From a surfing point of view, the characteristics of the waves arriving on a coast depend on the combination of many factors. These include swell size, swell direction, swell quality (spectral width and peak period), wave-grouping characteristics (number of waves in a set, wave-height distribution within the set and time between sets), wind direction and wind strength. Surfers, more than anyone else, are acutely aware of these factors – an otherwise good surfing day could be ruined if just one of them is not quite right. Wave-prediction models such as the NOAA Wavewatch III (e.g. TOLMAN *et al.*, 2002) publish a restricted series of outputs on the internet, for use by the general public. These include significant wave height, 'swell' wave height, mean wave direction and peak period at a large number of grid points around the globe, together with spectral information at a much smaller number of points. This has greatly improved the ability of the average surfer to predict mainly the arrival time of a swell and the height of the waves.

The accuracy of wave models such as the Wavewatch III (WW3) depend upon the accuracy of inputs of wind speed and direction, ultimately derived from mean sea-level pressure (MSLP) values predicted by atmospheric models. Charts of MSLP analyses and forecasts have been available for longer than wave predictions, and many surfers still prefer to perform 'manual' wave forecasting from MSLP charts, together with local knowledge, experience and intuition. Therefore, in the present study, it was decided to focus on MSLP charts rather than outputs of wave models such as the WW3.

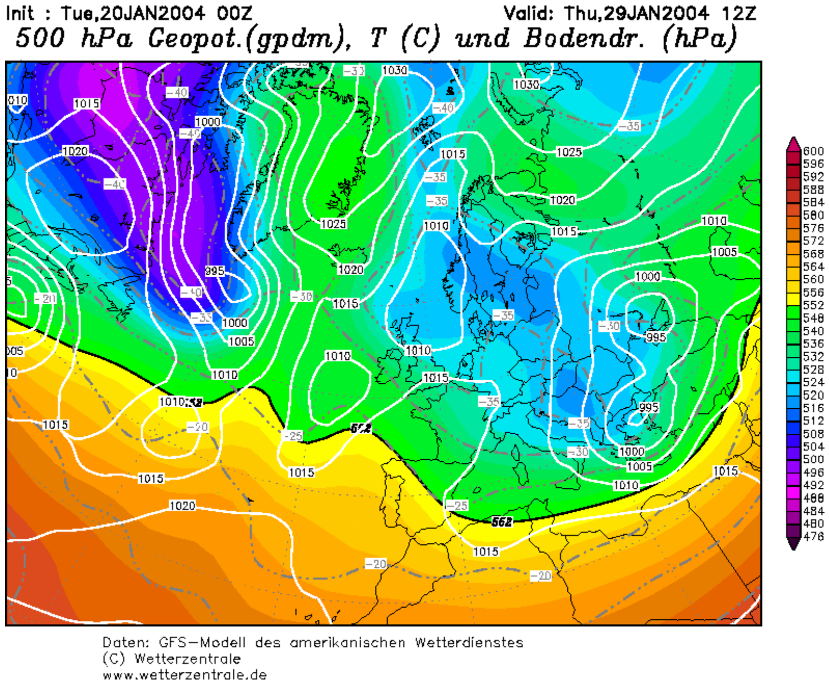

Figure 1: Nine-day North-Atlantic MSLP and 500 hPa geopotential height forecast chart for Thursday 29th January, 2004.

Care must be taken when making longer-term surf forecasts from MSLP forecast charts. The following example illustrates how successive forecasts of the same target day can vary considerably, especially with forecasts for more than five days ahead. The charts in Figures 1 to 4 show the MSLP field, together with 500 hPa geopotential height contours, for the North Atlantic, derived from outputs of the National Centers for Environmental Protection (NCEP) Global Forecast System (GFS) model (e.g. KANAMITSU, 1989). In the present study we focus only on the MSLP contours.

The expected weather over the British Isles for the target day of Thursday 29th January, 2004 is shown to vary as the forecast horizon shortens. The 9-day forecast generated on 20th January (Figure 1) shows calm weather over the British Isles with light and variable winds everywhere. Two days later, the 7-day forecast (Figure 2) shows a large area of low pressure expected to form just west of Ireland, giving gale-force south-westerly winds over most of the U.K. and Ireland. Another two days later, the 5-day forecast (Figure 3) shows the low pressure no longer expected to form. Instead, weak low pressure was now expected to form over the European continent, driving moderate northerlies over the British Isles. Finally, the analysis chart for the target day (Figure 4) shows a similar situation to that predicted five days earlier, with light northerlies over the U.K. and Ireland.

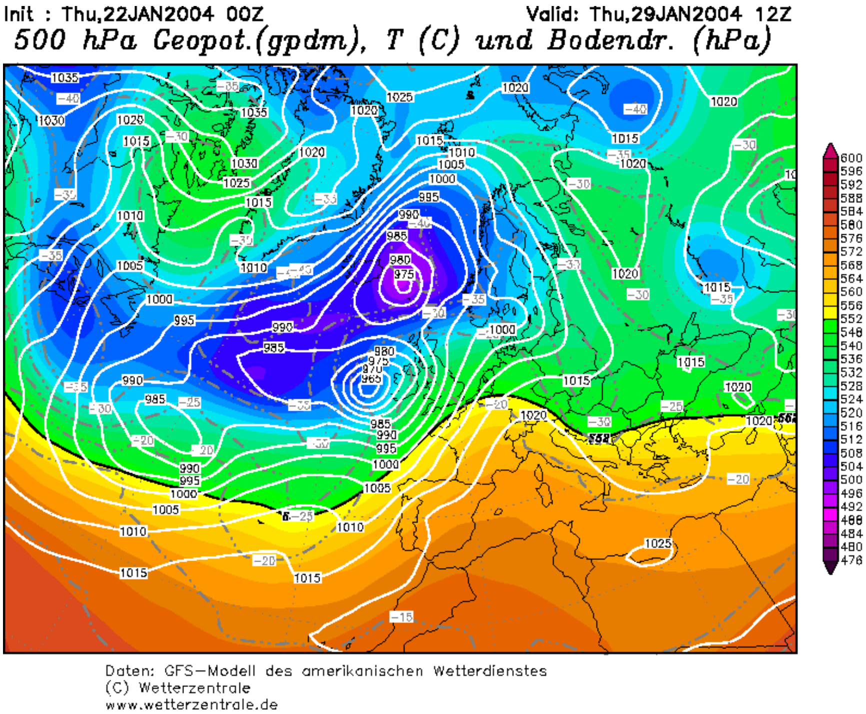

Figure 2: Seven-day North-Atlantic MSLP and 500 hPa geopotential height forecast chart for Thursday 29th January, 2004.

A surfer living in Southwest Ireland, for example, basing his surf predictions on these charts would come up with wildly differing expected conditions for 29-30th January, ranging from small, clean surf with light winds, to large, out-of-control surf with strong onshore winds. He might be disappointed if he planned a day off work with seven days notice. In the present study, we use MSLP charts to further examine the decrease in reliability of surfing predictions with increasing forecast time, and investigate the idea that surfing predictions of more than a few days ahead still contain too many uncertainties to be reliable.

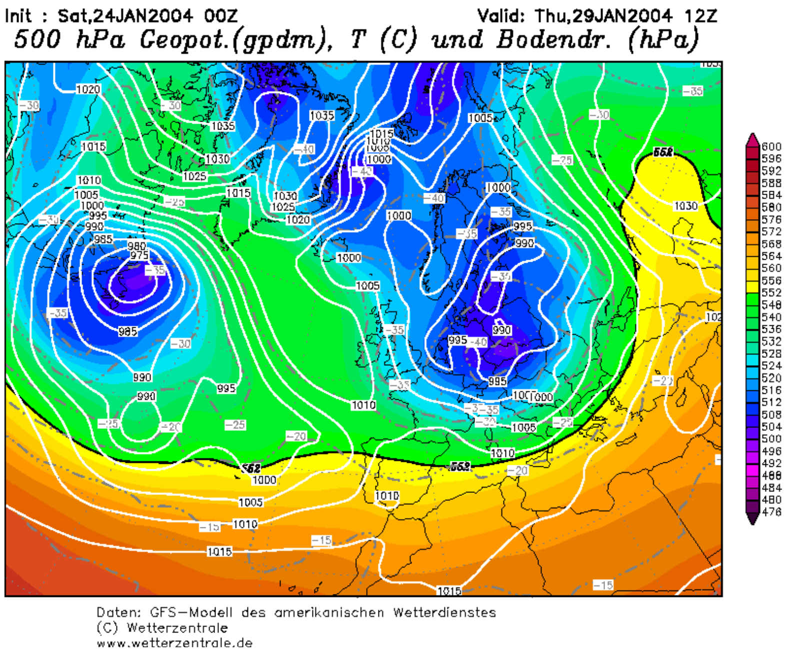

Figure 3: Five-day North-Atlantic MSLP and 500 hPa geopotential height forecast chart for Thursday 29th January, 2004.

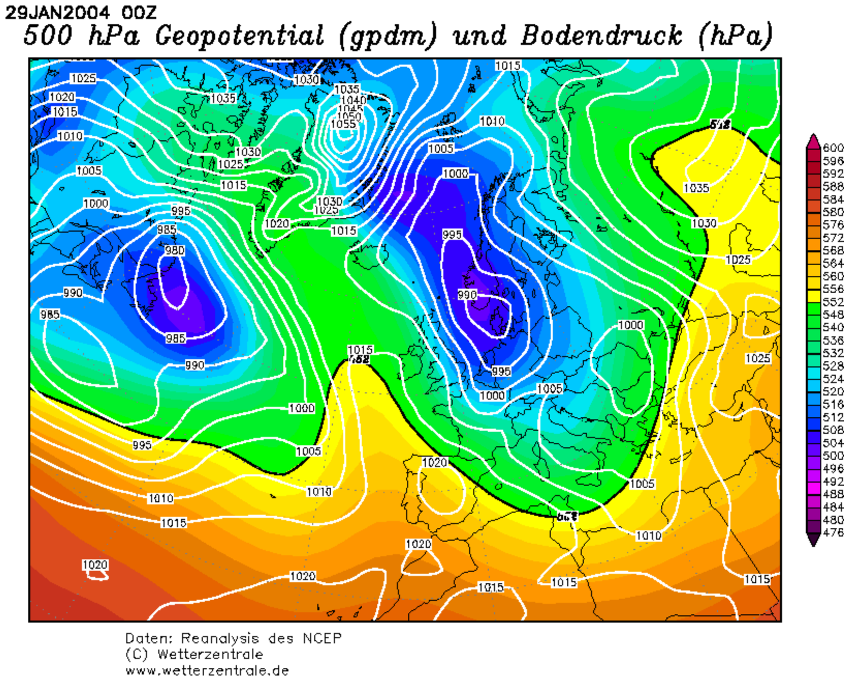

Figure 4: North-Atlantic MSLP and 500 hPa geopotential height analysis chart for Thursday 29th January, 2004.

HINDCAST

As a simple test of the accuracy of MSLP forecasts as a function of forecast time, a hindcast was performed using 27 sets of nine Atlantic MSLP charts, similar to those in Figures 1 to 4. One set of nine charts was collected each day for 27 days, each set consisting of an analysis chart and a forecast chart for each of up to eight days ahead. To enable a comparison between charts to be made, a parameter needed to be found which would quantify, in a simple way, the expected 'state' of the North Atlantic shown by each chart. The North Atlantic Oscillation (NAO) index was considered the best parameter to use in this case. The NAO (e.g. HURRELL *et al.*, 2003) is climatological cycle upon which the weather and, particularly, the surf, in Europe is highly dependent. During one phase of the cycle, the North Atlantic Ocean contains a large, static, high pressure system known as a blocking anticyclone, which impedes the formation of mid-latitude depressions, and therefore means small or no surf on the west coasts of Europe. The other phase of the cycle is characterised by a strong westerly air stream over the North Atlantic which encourages the formation of mid-latitude depressions. This, in turn, means large, consistent surf on west or north-west facing beaches. The current position within the NAO cycle can be quantified using various forms of the NAO index. In the present study we use the MSLP anomaly between Iceland and the Azores. More negative values imply a more 'blocking' state with little chance of surf, whereas more positive values imply a more 'fluid' state and hence a greater chance of surf. Note that the NAO is an accepted surrogate for wave height variations in the North Atlantic (Woolf *et al.*, 2002).

The data set consisted of a 27-row by 9-column matrix of NAO index values. The NAO-index value corresponding to the analysis chart on the ninth data-collection day was noted, and then compared with the NAO-index value for the one-day forecast from day eight, then with the two-day forecast from day seven, the three-day forecast from day six, and so on, until the eight-day forecast from day one. In this way, working backwards from a target day, the deviation from the 'true' value of the NAO index could be found for each of the one to eight day forecasts. The usefulness of the forecast could then be inferred by the NAO-index error value for that particular forecast day.

The same exercise was then repeated for 18 target days and 18 sets of forecast charts. Root-mean-square (r.m.s.) error values for the NAO index, using the data from the 18 sets, were then found for forecast days 1 to 8. The r.m.s. error (σ) is given by

$$\sigma = \sqrt{\frac{1}{8}\sum_{d=1}^{d=8}\left(I_d - I_0\right)^2} \tag{1}$$

where I_d is the NAO index [hPa] for forecast day d and I_0 is the NAO index for day 0, corresponding to the analysis chart. Values of σ as a function of forecast time are shown in Figure 5. An increase in error with increasing forecast time can clearly be seen, supporting the idea that the predictions become less accurate with increasing forecast time. The line running through the points on Figure 5 is a least-squares fit of the form $y = ae^{bx}$, with a Pearson r^2 correlation coefficient of 0.87. For practical purposes, the exponential shape of the function in Figure 5 means that the day-to-day variation in predictions decreases as one gets nearer to the target day. For example, if one is looking at seven or eight-day forecasts there could be wild swings between one day and the next, whereas, within about three days of the target day, predictions settle down and do not vary so much between days.

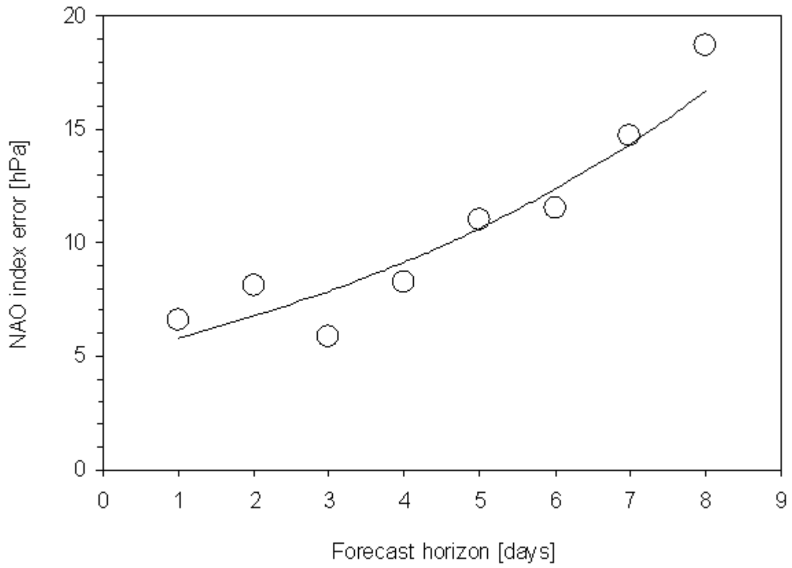

Figure 5: Root-mean-square error in predicted NAO index as a function of forecast horizon. The line represents an exponential regression model.

DISCUSSION

In Figure 5 it can be seen that the r.m.s. error in the NAO index for a one-day forecast is about 6 hPa, whereas the r.m.s error for an eight-day forecast is about 19 hPa. Referring back to the definition of the NAO index used in the present study, this means that the MSLP difference between the Azores and Iceland could turn out to be 6 hPa different from that forecast one day before, but 19 hPa different from that forecast eight days before. From a surfing point of view, a difference of 6 hPa would probably make little difference, whereas a difference of 19 hPa could make a considerable difference to the waves arriving on the north-west facing coasts of Western Europe. For example, the central pressure of a mid-latitude depression centred over Iceland might be forecast to be 980 hPa. If the forecast turns out to be accurate then reasonable surf might be expected on the coasts of Western Europe, with fairly small conditions in southern-most areas such as Portugal. However, assuming the pressure over the Azores is constant, the low over Iceland could actually turn out to be 19 hPa lower, at 961 hPa, which would mean much larger surf and possibly blown-out conditions in northern-most areas such as Northwest Ireland. The low could also turn out to be 19 hPa higher, at 999 hPa, which would mean little chance of surf anywhere except perhaps the Western Isles of Scotland.

North-Atlantic MSLP forecast charts for up to 16 days ahead are published on the internet. An interesting exercise is to find out the expected NAO-index error for a 16-day forecast by extrapolating the regression model computed from the data in the present study. The least-squares fit in Figure 5 is represented by

$$\sigma = 5.02e^{0.15d} \qquad (2)$$

where d is the forecast day, or forecast horizon. Evaluating (2) for d = 16 days yields $\sigma \approx 55$ hPa. Using the argument above, this implies a clearly unacceptable uncertainty in expected surfing conditions for forecasts of this length.

The chaotic nature of the ocean-atmosphere, and the fact that the present state of any physical system cannot be described perfectly (e.g. LORENZ, 1993) shows that the precision with which the future state of a system can be estimated for the same forecast horizon will improve at a diminishing rate. However, a steady increase in the forecast horizon of a forecast with a given precision has been observed over the past 20 years. For example, the U.K. Meteorological Office have analysed MSLP error predictions over a large area including the North Atlantic Ocean. The same r.m.s. error associated with a 1-day forecast in 1980, is observed for a 3.2-day forecast in 2004, with a fairly linear increase in forecast time between the two dates. It is interesting to note that the increase in computing power used by the U.K. Met Office between these two dates has been highly nonlinear, with a 100-fold increase in the approximate number of floating-point operations per second between 1980 and 1992, and a 10,000-fold increase between 1992 and 2004.

The required precision of any forecast depends upon the purpose for which that forecast is intended. The results of the simple test performed in the present study suggest that the Iceland-Azores MSLP anomaly can be predicted to within certain limits, those limits increasing exponentially with forecast time. It has been illustrated that, if one is concerned with making surfing forecasts based upon MSLP predictions, the precision of a 1-day forecast is acceptable whereas an 8-day forecast is not. The threshold above which the forecast precision ceases to be consistently useful for this purpose is, therefore, somewhere between these limits. A reasonable upper acceptable limit to the NAO-index error for surfing forecasts might be around 10 hPa, which corresponds to a forecast horizon of about 4 days.

Much longer-term surfing forecasts are possible, but with information in the forecast being of a different nature and necessarily less precise than prescribing the MSLP field over an ocean on a particular day. For example, from long-term statistics of NAO-index values (GLUECK and STOCKTON, 2001; WOOLF *et al.*, 2002), the average NAO index for the entire winter ahead could be estimated empirically, which could then be used to infer the expected storminess of the North Atlantic and, in turn, give a general estimate of how much surf might be expected in Europe for the coming winter.

CONCLUSIONS

In the present study, the decrease in usefulness of surfing predictions as a function of increasing forecast time has been investigated using North Atlantic MSLP charts. A 1-day forecast shows an r.m.s. error of 6 hPa in the MSLP anomaly between Iceland and the Azores (an NAO index), which is considered acceptable for surfing predictions for the west coast of Europe. An 8-day forecast, however, shows an r.m.s. error of 19 hPa, which is considered too high. The threshold above which the NAO-index error becomes too high to make surfing predictions reliable, lies somewhere between the two. An upper limit of about 10 hPa is suggested, which corresponds to a forecast horizon of about 4 days.

It must be remembered that surfing conditions can turn out better than those forecast, as well as worse. We can be pleasantly surprised as well as disappointed. For example, the six, five and four-day forecasts for a certain target day might suggest no possibility of good surf, then the 3-day forecast might suddenly show a large depression in mid-ocean for the same target day, and a good chance of surf. The uncertainty of surfing predictions, and the continued endeavour for their improvement despite the knowledge that a perfect forecast is impossible, adds an extra facet of interest to surfing, rarely found in other activities.

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