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Using the Bering Sea and Typhoon Rules to Generate Long-Range Forecasts II: Case Studies

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1. Introduction

Dynamic weather forecasting using numerical models can be done reliably out to approximately seven days, and has an absolute limit of about 10-14 days. Beyond this point, statistical forecasts are typically made. These limitations are due to the characteristics of the earth and atmosphere, but also the lack of data, knowledge of the physical processes, and measurement error (*e.g.*, Haltiner and Williams 1980; Durran 1999). Error in the initial and/or boundary conditions can render model forecasts as quickly as a few days (*e.g.*, Lorenz 1965), or alternatively two forecasts with slight difference in the initial conditions could evolve in radically different ways over the course of time. This problem is referred to as sensitivity to the initial conditions. One way to mitigate or qualitatively evaluate this problem is ensemble forecasting, a forecasting product that has been available for more than two decades (*e.g.*, Toth and Kalnay 1993, 1997; Tracton and Kalnay 1993).

Forecasting beyond two weeks could also use ensemble forecasting methods, and the Climate Prediction Center (CPC) has developed an experimental product that makes probabilistic forecasts in the three to four week time period[1]. This particular time period has not been forecast for traditionally, as there are monthly and seasonal forecasts made by the Climate Prediction Center. Renken *et al.* (2015) demonstrated the success of temperature predictions in the 6-30 day period for the United States using the Bering Sea Rule (BSR) and/or Typhoon Rule (TR), which showed success over climatology. This skill was especially measurable in forecasting events that were two or more standard deviations above or below climatology. The BSR and TR are based on Pacific and North American (PNA) region teleconnectivity, which was defined statistically by Wallace and Gutzler (1981). Renken *et al.* (2015) further showed that Pacific Region blocking has a strong correlation to weather and climate in the middle part of the USA, via the strong impact on the teleconnection patterns within the PNA region.

The motivation for this work is to demonstrate further the utility of the BSR and TR for prediction in the two-to-four week period. Case studies will be presented in order to demonstrate the capabilities of these indexes. We will also demonstrate that there is a strong degree of autocorrelation in this time frame by examining the PNA index.

2. Data and methodology

a. data

The data used for this work are the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR) re-analyses which are archived in Boulder, CO[2]. These data were the 500 hPa height fields on the 2.5^o x 2.5^o latitude/longitude grid daily from 1948 - present. The daily PNA

[1] http://www.cpc.ncep.noaa.gov/products/predictions/WK34/
[2] http://www.esrl.noaa.gov/psd/data/reanalysis/reanalysis.shtml

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index information was also available from CPC which used the NCEP/NCAR re-analyses and are available from 1 January 1950 - present, which represents a 66 year period as of 31 December, 2015.

b. Methods and definitions

In order to determine if there was predictability in the PNA index time series, autocorrelation was performed by lagging the PNA index from 1 January 2012 to 31 December 2013. Autocorrelation can be used in order to test for chaotic or cyclical behavior in a data set. If a system has limited predictability, then the correlation will fall to zero with further lag and remain there. If there is cyclical behavior, correlation will increase near the time-scale of the forcing function. Additionally, the entire time series was decomposed using Fourier series in order to isolate significant power in the time series.

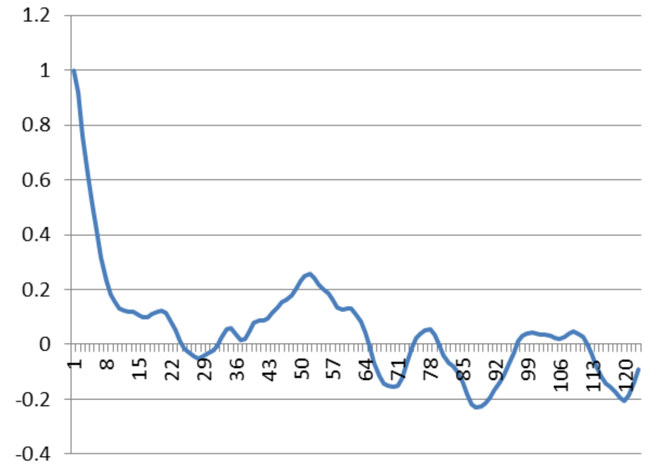

Fig. 1 The autocorrelation of the PNA index from 1 January 2012 to 31 December 2013.

The BSR correlates 500 hPa heights in the Bering Sea Region to three points in the USA which show strong correlation. These three points are in southern Utah, western MO, and near Long Island, using a similar methodology to Wallace and Gutzler (1981). The primary correlation time is in the two to three week time-frame. The TR correlates 500 hPa heights in East Asia to points in the USA, and the primary time-scale in one–to-two weeks.

3. Periodicity in the 500 hPa height field

The results of testing the PNA index derived from the 500 hPa height field using autocorrelation for the two year period of 2012-2013 are shown in Fig 1. The time series was auto-regressed from 1 to 130 days. The correlation falls rapidly, but then increases slightly around 20 and 34 days. There is a strong non-zero peak also found in the 50-55 day period. While this hints at predictability in the three-to-four week time frame and beyond, this test by itself cannot identify recurrence in the desired time frame. Additionally, this period is a small segment of the climatological record for the PNA region. Tests on other parts of the 66 year series reveal similar behavior to that shown in Fig. 1.

Next, the time series of the daily PNA index for the 66 year period were decomposed using Fourier series decomposition (Fig. 2). The entire decomposition is not shown in order to focus on the time period in question. The decomposition shows spectral peaks at several wave numbers, and the period can be determined by dividing the wave number by the spectral peak. For example, in addition to those peaks associated with the annual cycle there were strong peaks around wave numbers 505, 570, and 610, corresponding to a period of about 47, 42, and 39 days (not shown). These peaks probably correspond to a long-period Rossby Wave. This analysis cannot determine if these are different peaks forced by different processes, or more likely, the same

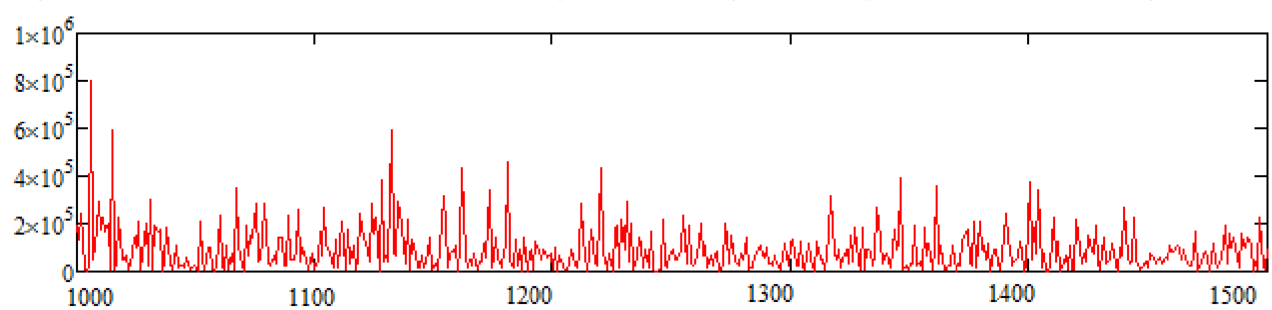

Fig. 2 The spectral decomposition of the 66-year time series of the PNA index. The abscissa is wave number 1000 to 1500, and the ordinate is spectral power.

peak whose period may be modulated by annual cycle, El Nino and Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), or climate change. The latter seemed to be the case when testing different parts of the 66 year time series using auto correlation. Further analysis would be needed to verify this assertion.

The time period of interest is shown is Fig, 2, which shows the spectral peaks from wave number 1000 to 1500, and these correspond to periods of 23 to 16 days. There are peaks found near 1000-1010 and in the 1140-1190 range, which correspond to 24 and 21 days respectively. This analysis, combined with the autocorrelation, hint at predictability in the two - three week time scale, which is similar to the result obtained from autocorrelation.

4. Two case studies

a. 28 April 2014 severe weather

On 28 April, 2014, severe weather occurred across the middle southeast USA, and the St. Louis region. The Storm Prediction Center (SPC) archived several reports of tornadoes, large hail, and strong winds (Fig 3d), and this was associated with a strong trough at 500 hPa located over the plains states (Fig 3c), and this was associated with a well-developed low pressure at the surface. Examining the Bering Sea region about 20 days prior (8 April, 2014) shows a strong 500 hPa low near the Kamchatka Peninsula and the Aleutians (Fig 3a). A figure showing the Bering Sea region on 28 April would show a trough in the same area as in Fig. 3a. Thus there is an approximately two to four week cycle in the PNA index as shown in Section 3. About eight days before the 28 April event, a strong low was located over East Asia (Fig. 3b) which corresponds to the TR.

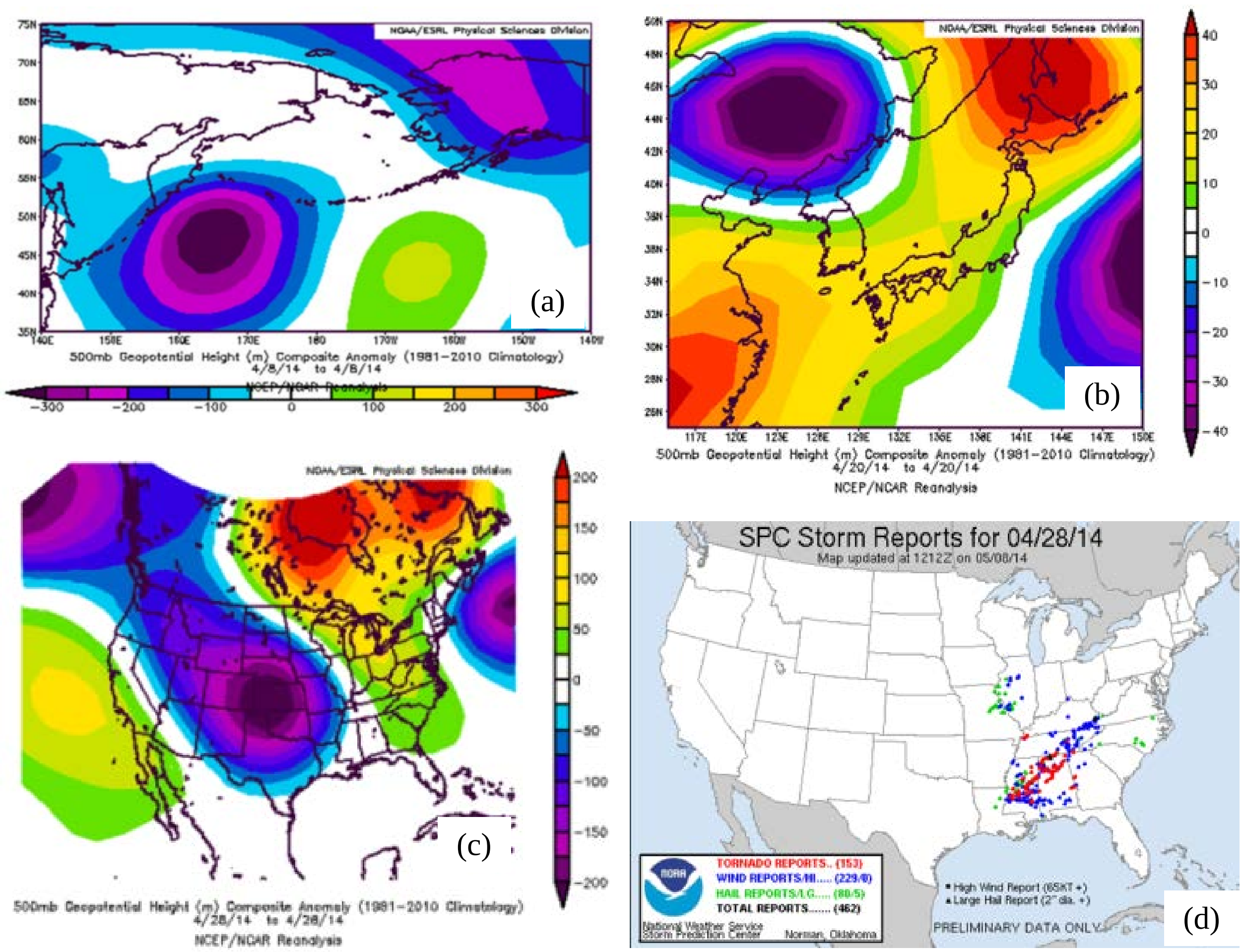

Fig. 3 The 500 hPa height anomalies versus the 1981-2010 climatology over the Bering Sea region for a) 8 April 2014, b) 20 April 2014, and c) over the Continental USA for 28 April 2014. d) The Continental USA severe weather reports.

Also, low pressure would exist in the Bering Sea region again on 28 April (not shown).

b. Typhoon Nuri, November 2014

The case of Typhoon Nuri was cited briefly by Renken *et al.* (2015) as a successful example of the BSR and TR. In early November, 2014, Typhoon Nuri moved poleward in the western Pacific becoming extratropical and deepening to 924 hPa as the strongest North Pacific cyclone ever. This was reflected in the 500 hPa height field as a strong low over the western Bering Sea (Fig. 4a) during the 8-10 November 2014 period. This cyclone was upstream of a weak blocking event, which had onset at 1200 UTC 5 November at about 170^{o} W (see http://weather.missouri.edu/gcc/blocknh.pdf). The cyclone interacted with the blocking event, strengthening the block through the same mechanism shown in Lupo and Smith (1995), Lupo (1997), or Lupo and Bosart (1999). This blocking event induced persistent troughing over North America, which was particularly strong in the middle of and late in the month (Fig. 4c). In this case the, the PNA pattern intensified strongly during the strengthening of the surface cyclone and blocking event. During late November there was also an upstream trough in the Bering Sea region. In the middle of November troughing correlating with the TR was present over East Asia (Fig 4b). There was also strong indication of the mid-November cold event in association with the remnants of Nuri using the TR (Fig. 4a).

5. Discussion, summary, and conclusions

This work furthers the study presented last year which showed that there was skill above climatology in using the BSR or TR for making long-range forecasts in the one to four week time frame, especially for extreme events. The BSR and TR simply use two of the action centers from the PNA index looking at the two positively correlated centers generally (the Bering Sea and the Eastern USA primarily). In this study, the PNA index is used as a surrogate for the 500 hPa height field in the region. Autocorrelation of the PNA time series for 2012-2013 showed cyclical behavior in the correlation series (lagged by up to 130 days), and similar behavior was shown in other parts of the time series. This test suggested that there may be predictability in the 20 and 34 day time period, as well as a strong increase in the correlation peaking at 50-55 days. In our study, the focus is on the three and four week time period. Spectral analysis using 66 years of daily PNA index time series, and there were peaks with a period in the 24 and 21 day time frame.

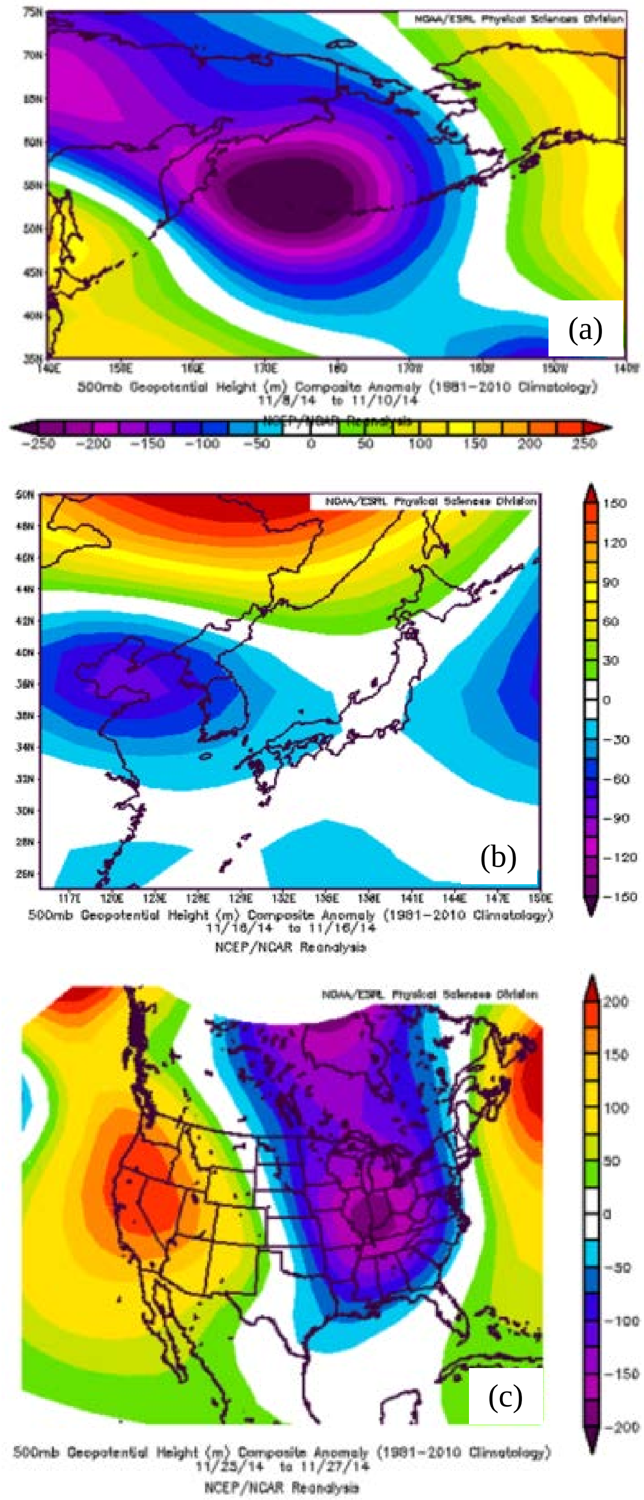

Fig. 4. As in Fig. 3a, 3b, and 3c, except for a) 8-10 November 2014, b) 16 November 2014, and c) 25-27 November 2014.

The predictability implied by the two tests is likely due to a long period Rossby Wave as it propagates through the PNA region on a great circle trajectory (*e.g.*, Hoskins and Karoly, 1981). Here, two case studies were examined and showed about three-week lag between a strong cyclone in the Bering Sea Region and severe weather or very cold weather over some portion of eastern two-thirds of the USA. In both cases, the result is the time period consistent with the BSR. Many studies have shown interaction between the longer-period PNA pattern and synoptic scale eddies (*e.g.*, Lau, 1988, Hall and Derome, 2000, and Reviere and Orlanski, 2007), which seems to be the scenario in the Typhoon Nuri case study. A simple index like the BSR or TR cannot take into account any changes in the intensity of the PNA pattern, nor can the index take into account periods when the PNA exists in an unusual phase or configuration (*e.g.*, Lupo and Bosart). However, the BSR does have forecast skill above climatology, and a simple BSR Index (BSRI) can be created for operational use by simply adding the height anomalies at the action centers. Interpretation of the BSRI does include some interpretation by the forecaster and will be described in a future study, and more information about the BSR and TR are found at: http://www.beringsearule.blogspot.com.

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