Nonlinear Processes in Geophysics (1994) 1: 41 - 44

Nonlinear Processes in Geophysics

Empirically derived climate predictability over the extratropical northern hemisphere

J.B. Elsner[1] and ALA. Tsonis[2]

[1] Dept. of Meteorology, Florida State University, Tallahassee, FL 32306, USA
[2] Dept. of Geosciences, University of Wisconsin-Milwaukee, Milwaukee, WI 53201, USA

Received 1 December 1993 - Accepted 16 February 1994 - Communicated by A.D. Kirwan

Abstract. A novel application of a technique developed from chaos theory is used in describing seasonal to interannual climate predictability over the Northern Hemisphere (NH). The technique is based on an empirical forecast scheme-local approximation in a reconstructed phase space-for time-series data. Data are monthly 500 hPa heights on a latitude-longitude grid covering the NH from 20°N to the equator. Predictability is estimated based on the linear correlation between actual and predicted heights averaged over a forecast range of one- to twelve-month lead. The method is capable of extracting the major climate signals on this time scale including ENS0 and the North Atlantic Oscillation.

1 Introduction

The Earth's global atmosphere displays a tremendous amount of variability on many space and time scales. As a result of sensitive dependence on initial conditions, all forecasts of this atmospheric variability are accompanied by error growth which leads to limits on accurate predictions. The question of just how predictable the weather and climate are can be addressed using observations or numerical model simulations. The present study examines the problem of seasonal to interannual climate predictability using a nonlinear time-series model on observed data. The approach centers on building a model from earlier data and comparing model predictions with data later in the record. Predictability is assessed by deterioration of forecast skill as predictions are made further into the known future. The appealing aspect of this approach is that it is independent of forecasting method, at least in theory.

2 Data and Methodology

Consider 522 consecutive maps of monthly-averaged 500 hPa geopotential heights over the extratropical Northern Hemisphere, where each map consists of a latitude-longitude grid (18 latitude points between 20°N and the pole by 60 longitude points around each latitude circle). Geopotential heights at a given pressure level indicate the density in the underlying atmosphere and horizontal gradients of the height field approximate the horizontal momentum field. Data are from the US National Meteorological Center's (NMC's) initial analyses for the period January 1946 through June 1989. Thus, at each latitude-longitude grid point there exists a univariate time series of geopotential heights for 522 consecutive months. A nonlinear forecast model is trained on the first 480 months (40 years; the training set) of each time series separately and a relative measure of predictability is assessed by examining linear correlations between actual and predicted values over the remaining 42 months (3.5 years; the target set).

The univariate nonlinear prediction model is a version of the Farmer and Sidorowich (1987) and Sugihara and May (1990) interpolative algorithm used in Wales (1991) and is based on the simplex method in phase space. An embedding dimension (E) is chosen and the phase space constructed using the method of time delays. Based on the decay of the autocorrelation function a time delay of two months is used, however, results are not sensitive to the exact choice of a time delay in the range of one

Correspondence to: J.B. Elsner

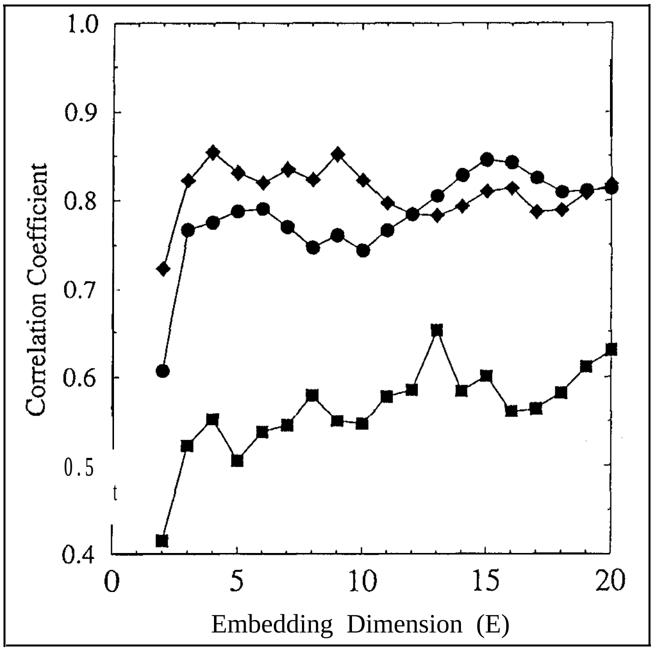

Figure 1. Prediction error versus embedding dimension. The prediction model is a local-linear approximation method in phase space. Prediction error is estimated by the linear correlation between actual and predicted values for a one-month forecast of 500 hPa geopotential heights. Shown are prediction errors for three representive grid points over the Northern Hemisphere (grid point (1,18) with circles, grid point (45,1) with squares, and grid point (31,12) with diamonds).

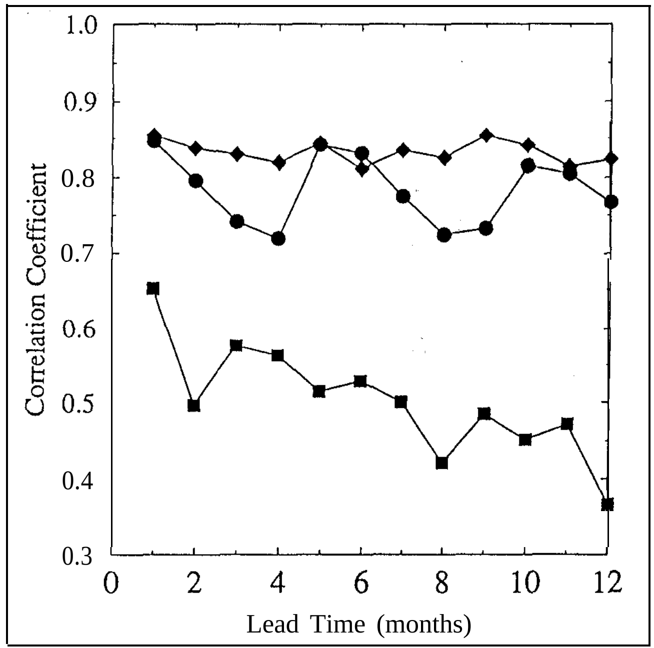

Figure 2. Prediction error versus lead time for the same three grid points used in Figure 1. The prediction model is a local-linear approximation method in phase space with an embedding dimension of five months. Prediction error is estimated by the linear correlation between actual and predicted values for predictions made from one- to twelve-month lead.

to twelve months. For each point in phase space, nearby points are located and a minimal neighborhood is defined such that the sequence containing the target point is located within the simplex with a minimum diameter formed from the E+1 closest neighbors. A one-month prediction is made by keeping track of where the points in the simplex end up after one month into the known future. The Pearson's product-moment linear correlation coefficient is computed over all target points to quantify predictability. The predictability field is then contoured on a map of the extratropical Northern Hemisphere.

The nonlinear prediction model requires the specification of an optimum embedding dimension. To do this Sugihara and May (1990) suggest plotting the one-step (one month) prediction error as a function of embedding dimension. The results of such a procedure for three representative grid points over the NH (the 1, 1 grid point is located at 20°N and 0°E with indices increasing to the north and east) is shown in Figure 1. For all grid points linear correlation between actual and predicted values increase from low embeddings and saturate above embedding dimension four. Therefore, an embedding dimension of five is used for all grid points. Results are not sensitive to embedding dimensions in the range from two to eight.

Predictions over the target set are made at each grid point for lead times from one to twelve months. Examples of forecast skill over this period are shown in Figure 2 for the same points used in Figure 1. Note that a two-month forecast is made by considering the one-month prediction value rather than the known value for that month; and the same procedure is followed for all forecasts out to twelve months. These twelve forecast errors (one error for each month) are averaged to obtain a single prediction error representing how well the time series at each point can be predicted on average over an entire year.

3 Results and Discussion

Linear correlations (X 100) between actual and predicted 500 hPa geopotential heights averaged over the 42-month (January 1986 - June 1989) target set and averaged over lead times of one through twelve months for each grid point are color contoured in Figure 3. Correlations range from 0.5 (violet) to 0.9 (red). Results have been smoothed using a nine-point uniform filter.