4D.6 TROPICAL CYCLONE TRACK PREDICTABILITY LIMITS

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1. INTRODUCTION

Tropical cyclone track forecasts have steadily improved during recent decades (e. g. Aberson 2001, McAdie and Lawrence 2000) and skill, as measured by comparison of forecasts to those from a simple statistical technique based on climatology and persistence (CLIPER), has steadily increased. For example, in the North Atlantic basin, the average 48 h model absolute track forecast errors in 1976 were larger than current 72 h absolute forecast errors, and average 24 h model absolute track forecast errors in 1976 are comparable to current 48 h absolute track forecast errors (Aberson 2001). However, this has not necessarily translated to improvements in forecasts of the landfall location and time (Powell and Aberson 2002).

Due to the improvements in general track forecasts in the short-range, some operational centers will soon begin to provide track forecasts operationally to five days. This requires knowledge of the limit of the accuracy of these forecasts. The current study shows the limits that have been calculated in the Atlantic, East and Central Pacific, northwestern Pacific, and Australian basins using the technique of Fraedrich and Leslie (1989). The ranking of the basins by predictability are compared with the previous work of Pike and Neumann (1987) who, by ranking CLIPER forecast track errors by tropical cyclone basin, have shown the forecast difficulty in each of the basins studied here.

The pertinent question is the potential predictability of tropical cyclone tracks in the various basins given a perfect model. Small differences in initial conditions are known to become large in time in nonlinear dynamical systems such as the atmosphere. Given a perfect model, a model that can perfectly predict the future given perfect initial conditions, the predictability of the system can be measured by finding the rate at which small initial differences grow. Thus, the divergence rate of initially close tracks can be used. Fraedrich and Leslie (1989) estimated the predictability of tracks in the Australia basin by calculating the this divergence rate, and the same technique was used in the North Atlantic basin (Aberson 1998). The same method is used here for the northwest and northeast Pacific basins, and the relative predictability time scales of the various basins are compared.

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2. METHODS

All tropical cyclone tracks are assumed to start at a common location for simplicity. The distance between two independent tropical cyclone tracks with m successive positions

$$X_m(i) = [X(t_i), ..., X(t_i + (m-1)t)] \quad (1)$$

where $X(t) = (x(t), y(t))$ is a position vector at time t, is represented by

$$d_{ij}(k) = [\{x(t_i + kt) - x(t_j + kt)\}^2 + \{y(t_i + kt) - y(t_j + kt)\}^2]^{1/2} \quad (2)$$

where t_i and t_j are the initial times of the two trajectories i and j, x and y are the longitude and latitude, respectively, t is the time step (6 h), and k is the number of time steps used. The number of pairs whose distance $d_{ij}(k)$ remains below a threshold value, l, is counted ($N_m(l)$), leading to the probability that the trajectories remain within a certain distance of each other. This value, the correlation integral, is given by

$$C_m(l) = N_m(l)/(N_m - 1)^2 \quad (3)$$

where N_m is the total number of independent track pairs under consideration (Grassberger and Proccacia 1984). The number of independent tropical cyclone track pairs remaining within a fixed distance of each other decreases with increasing time. The ratio of C_m to C_{m+1} measures the rate at which close trajectory pairs diverge. The order-two entropy given by

$$K_2 = (1/t) exp(C_m(l)/C_{m+1}(l))$$

$$for \quad l \to 0 \quad and \quad m \to \infty \tag{4}$$

provides a lower bound for the Kolmogorov-Sinai entropy, which is itself a predictability bound. The inverse of K_2 in the region of the constant slope of correlation integral with distance defines the e-folding divergence rate of initially close tracks.

As in previous studies, the correlation integral for various values of m versus distance l are plotted. When the slopes of the lines stop changing as m increases, the correlation integral is said to saturate. The constant slope region at saturation corresponds to the length scale. A similar plot of K_2 shows that the value stops changing with increasing m, and this value corresponds to a predictability time scale.

3. RESULTS

Fraedrich and Leslie (1989) showed that the predictability time scale for tropical cyclone tracks in the Australia region is about 24 h, and Aberson (1998) found that it is near 60 h in the Atlantic. In the northwest and northeast Pacific basins, it is calculated to be 60 h and 42 h, respectively. This suggests that the Atlantic and northwest Pacific basins have the longest predictability time scale (are the most predictable), whereas the Australia region is the least predictable. This disagrees somewhat with Pike and Neumann (1987) who suggested that the Atlantic and Australia region were the most difficult regions in which to make tropical cyclone track forecasts, and that Eastern Pacific was the easiest.

Because tropical cyclone tracks are serially correlated (Aberson and DeMaria 1994), the above calculations were redone using only those tracks which are 24 h apart from each other, with no change in the results in any of the basins. This provides further evidence of the stability of these calculations given the relatively small sample size. As in any study of this type, the small amount of data prevents the tropical cyclone tracks from completely covering the attractor (ie. all possible tracks), and thus makes the values calculated only estimates of the true predictability time scales. Fraedrich and Leslie (1989) suggest that the predictability time scale calculated in this manner is an upper bound to the expected ability of deterministic forecast models to predict tropical cyclone tracks, given perfect initial data. The practical predictability time scales would be considerably shorter due to the inability to produce such perfect initial conditions.

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