

NASA-1954

IN-47-CR

273073

4B

The Pennsylvania State University

The Graduate School

Department of Meteorology

PREDICTABILITY OF WEATHER AND CLIMATE IN A
COUPLED OCEAN-ATMOSPHERE MODEL:
A DYNAMICAL SYSTEMS APPROACH

A Thesis in

Meteorology

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 1989

(NASA-CR-186499) PREDICTABILITY OF WEATHER
AND CLIMATE IN A COUPLED OCEAN-ATMOSPHERE
MODEL: A DYNAMICAL SYSTEMS APPROACH Ph.D.
Thesis (Pennsylvania State Univ.) 4 p

N90-21502

Unclas

CSCL 04B G3/47 0273073

ABSTRACT

A dynamical systems approach is used to quantify the instantaneous and time-averaged predictability of a low-order moist general circulation model. Specifically, the effects on predictability of incorporating an active ocean circulation, implementing annual solar forcing, and asynchronously coupling the ocean and atmosphere are evaluated. The predictability and structure of the model attractors is compared using the Lyapunov exponents, the local divergence rates, and the correlation, fractal, and Lyapunov dimensions. The Lyapunov exponents measure the average rate of growth of small perturbations on an attractor, while the local divergence rates quantify phase-spatial variations of predictability. These local rates are exploited to efficiently identify and distinguish subtle differences in predictability among attractors. In addition, the predictability of monthly averaged and yearly averaged states is investigated by using attractor reconstruction techniques.

Activating the oceanic circulation increases the average error doubling time for the short time scales by about 10 percent and decreases the variance of the largest local divergence rate $L(\tilde{x}(t))$ by nearly 40 percent. However, these improvements in predictability are reversed when annual solar forcing is implemented in the model. When the atmosphere and ocean are asynchronously coupled such that the update time for the coupling terms is more than a week, the average error doubling time increases by nearly a factor of four. In addition, the variability of $L(\tilde{x}(t))$ is significantly reduced, and a strong bias towards events with nearly neutral local predictability develops.

The predictability of the monthly averaged states varies in a similar manner as the various changes are implemented in the model. The value of the largest Lyapunov exponent γ_1 suggests a maximum error doubling time of approximately three months for the attractor of the monthly means. The predictability of the yearly averaged states is most affected by the incorporation of an active ocean circulation: both γ_1 and the variance of the largest local divergence rate decrease by approximately 50 percent. However, the values of γ_1 and the variance of $L(\underline{x}(t))$ change little when annual solar forcing is added to the model. The value of γ_1 suggests that some predictability of yearly means may remain beyond two years. Interestingly, the enhancement of predictability attributed to the asynchronous coupling methodology is minimal for the yearly averaged states.

The dimension of the attractor of the instantaneous states decreases slightly when the oceanic circulation is activated, but the decrease is barely discernible from the inherent errors in the calculation. Both the correlation and fractal dimensions remain approximately constant when annual solar forcing is added, but when asynchronous coupling is implemented and the update time for the coupling terms is greater than a week, both dimensions decrease noticeably. Because the Lyapunov dimension d_L depends directly on the Lyapunov exponents, variations in d_L are more pronounced and more closely correlated with variations in the average predictability. In almost all experiments, however, d_L appears to be a significant overestimate of the attractor dimension. The pattern of variation observed for the dimensions of the reconstructed attractors of the

monthly and yearly averaged states is very similar to that observed for the instantaneous states.

In general, the dimensions of the attractors of the monthly and yearly averaged states are not significantly less than the dimensions of the attractors of the instantaneous states. In many cases, the differences are no larger than the uncertainty in estimating the dimensions. For the monthly averages, this result is not altogether unexpected because the variation across the ensemble of monthly mean states is comparable to that across the instantaneous states. Apparently, even an averaging period of a year is too short to induce a reduction in dimension. The present data sets do not provide conclusive estimates of the dimension of decadal- and century-averaged attractors. Nonetheless, a foundation has been laid for a dynamical systems approach to understanding the predictability of time-averaged climatic states.

Arguably a more important contribution of this work to research in predictability is the demonstration that the local divergence rates can provide a concise quantification of the variations of predictability on attractors and provide a basis for comparing their local predictability characteristics. A practical application of this idea is provided in the form of an algorithm for generating a real-time estimate of local predictability to accompany a forecast.