

Title: Application of Dynamical Systems Theory to Global Weather Phenomena
Revealed by Satellite Imagery

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Significant Accomplishments in the Past Year:

1) Theoretical studies of low frequency and seasonal weather variability. As part of our effort to treat extratropical weather in terms of stochastic-dynamical systems analysis, we have developed a thermally-forced, low-order model of the atmosphere that seems capable of accounting for many of the statistical properties of the long-wave structure including the main seasonal and planetary-monsoonal variations. In its most simplified form this model can be reduced to a 3-variable forced, dissipative dynamical system exhibiting a "folded resonance" equilibrium structure that admits multiple steady-states in a realistic parameter range. This structure can explain the observed bimodality and vacillation of long-wave amplitude in winter and the more steady monsoonal circulation characteristic of summer (Saltzman, Tang, and Maasch). In other theoretical studies the criteria for "baroclinic adjustment" and the role of interactions between planetary and cyclone-scale waves in accounting for the observed zonal mean and wave structure have been elucidated in a series of three papers (Ebisuzaki).

2) Dynamical properties of observational (e.g., satellite) and GCM-generated records. The newly developed techniques for determining "attractor dimensionality", and the presence of multiple regimes and "jump" phenomena have been used and improved in a series of studies applied initially to paleoclimatic data (Maasch). The ultimate aim is to apply these same techniques to the long, continuous time-series being made available for the first time by satellite borne instrumentation, and being made available theoretically by extended GCM runs. A first order task is to determine the extent to which those series can be ascribed to an identifiable deterministic process (that may however be "fractal" or "chaotic"), having an attractor that can be modelled by a low-order system. Our preliminary results, for example, indicate that the weather variability exhibited by a complex GCM can be modelled with a reduced low-order system containing a minimum of six variables (Maasch and Saltzman).

3) Effects of the hydrologic cycle and latent heat release on extratropical weather. Using a general circulation model we have determined that extratropical Northern Hemisphere weather is extremely sensitive to variations of sea surface temperatures in the Gulf of Mexico which is the most significant source of water vapor fueling the latent heat release in the North Atlantic storm track. The consequences of the cooling of this Gulf region during the deglaciation phase of the last ice age cycle, about 10,000 years ago, are corroborated by the geologic and paleoclimatic evidence available for this period (Oglesby, Maasch, and Saltzman).

4) Earth-system science studies. In a series of papers we have explored the degree to which the major changes in terrestrial climate associated with the Pleistocene "ice ages" can be accounted for internally by complex nonlinear interactions involving the atmosphere, bio-hydrosphere, and cryosphere. In our most recent contribution we show how positive feedback in the global carbon cycle, as controlled by the deep ocean state, can provide the instability to drive the major ice age cycle. When additive external forcing (e.g., due to earth-orbital, Milankovitch variations) is applied much of the inferred global variations of climate over the past 2 million years, including the "jump" about 900,000 years ago, can be accounted for with a relatively small number of adjustable parameters (Saltzman and Maasch).

Focus of Current Research and Plans for Next Year:

1) Continuing Study of Low-Order Weather Systems. We are presently performing numerical calculations to explore the robustness of the results of our 3-variable model described above for a full range of parameters. Our objective will be to establish the relevance of the results of this thermally-forced model as an explanation of the observed bimodality of the long-wave amplitude structure. In addition, the model will be expanded by the successive addition of new features such as wave-wave interactions and orographic forcing. Concerning the former additional considerations, Dr. W. Ebisuzaki will be continuing his promising numerical modelling work on baroclinic adjustment and the interactions of planetary and cyclone scale wave motions; interesting work on the latter, orographic, considerations is already underway by Lionel Pandolfo, in the contexts of both barotropic and baroclinic models. Furthermore, it remains our goal to include hydrology and clouds into these low-order models in order to connect these models more directly with satellite observations.

2) Observational studies. Dimension analysis of satellite OLR and cloud records are being pursued, in conjunction with similar analyses of the output of general circulation models. A more general observational goal will be to use satellite data to help quantify the "cloud and latent heat forcing" in the storm tracks associated with the long baroclinic waves, as embodied qualitatively in our present low-order dynamical model.

Publications Since June 1987:

- 1) Tang, C.-M., 1988: The meridional scale of baroclinic waves with latent heat release. Atmósfera, 1, (in press).
- 2) Saltzman, B. and C.-M. Tang, 1988: Folded resonance and seasonal vacillation in a thermally-forced baroclinic wave model (abstract). Ann. Geophysicae, European Geophysical Society, XIII General Assembly, Bologna, p. 107.
- 3) Ebisuzaki, W., 1988: Dynamical criterion for a marginally-unstable, quasi-linear behavior in a two-layer model. J. Atmos. Sci., 45, (in press).
- 4) Maasch, K.A., 1988: Statistical detection of the mid-Pleistocene transition. Climate Dynamics, 2, 133-143.
- 5) Maasch, K.A., 1988: Dimension from a time series: application to deep sea $\delta^{18}O$ records (abstract). EOS, 69, 376.
- 6) Saltzman, B. and K.A. Maasch, 1988: Carbon-cycle instability as a cause of the late-Pleistocene ice-age oscillations: modelling the asymmetric response. Global Biogeochem. Cycles, 2, (in press).
- 7) Saltzman, B., 1988: Modelling the slow climatic attractor. Physically Based Modeling and Simulation of Climate and Climatic Change (M.E. Schlesinger, ed.), Reidel Publ. Co., Dordrecht (in press).

Manuscripts Submitted for Publication or in Preparation

- 1) Saltzman, B., C.-M. Tang, and K.A. Maasch, Folded resonance and seasonal vacillation in a thermally-forced baroclinic wave model. (submitted for publication).
- 2) Ebisuzaki, W., Interactions between long and synoptic-scale waves: Part I. Instability of a non-zonal flow. (submitted for publication).
- 3) Ibid., Part II. Growth rate of long waves. (submitted for publication).
- 4) Maasch, K.A., On the practicality of calculating dimension from $\delta^{18}O$ records. (in preparation).
- 5) Pandolfo, L. and A. Sutera, The effects of form-drag and wave-wave interactions on the equilibrium solutions of topographically-forced barotropic and baroclinic models of atmospheric planetary waves. (in preparation).
- 6) Oglesby, R., K.A. Maasch, and B. Saltzman, Glacial meltwater cooling of the Gulf of Mexico: GCM implications for Holocene and present-day climates. (submitted for publication).

