The Use of Satellite Data in Understanding and Predicting Convective and Large-Scale Dynamical Processes

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Accomplishments in FY-84:

1. Observational Studies of the Index Oscillation

Mr. Robert Schlaak has completed his M.S. Thesis in which he has combined, in a unique way, conventional and NOAA-III and NOAA-IV Earth Radiation Budget (ERB) data to study the pronounced index oscillation of the 1974-75 winter. He has determined that the principal driving mechanism for the oscillation is barotropic wave-mean flow energy exchanges stimulated by the mean westerlies becoming periodically unstable. He has also determined that polar cap radiative processes are phased with the oscillation such as to reinforce it. Variations in mid and high latitutde cloud cover resulting from intrusions of warm air into high latitude regions modulate the net radiative cooling in such a way as to reinforce strong mid-latitude westerlies because of thermal wind balance and thus intensify the oscillation.

2. Theoretical Studies of the Index Cycle and Blocking Phenomena

A two-layer truncated baroclinic spectral model was developed to study the long-term evolution of disturbances to a baroclinically unstable mean flow. Topography and crudely-parameterized radiative processes were accounted for. As a result of Mr. Schlaak's discovery of the underlying barotropic nature of the index oscillation as well as reviewers suggestions about the original manuscript, the model has been revised to allow for barotropic as well as baroclinic wave-mean flow interactions. The form-drag exerted by the topography on the barotropic part of the mean flow is larger than on the baroclinic part and thus we anticipate significant changes from the original calculations on the index oscillation when it is strongly modulated by topography.

3. Numerical Modeling of Index Cycle Variations

We believe that since the index oscillation accounts for a significant portion of atmospheric temporal variance, the long term predictability could be improved if reliable forecasts of the index oscillation were available. Two spectral models of the index oscillation, one barotropic and the other baroclinic, have been developed. The latter allows for moisture, radiation, land-sea temperature contrasts, and energy exchanges with the underlying surface. They are currently being tested for conservation of energy and vorticity.

4. Theoretical and Observational Studies of Cloud Streets

Two manuscripts, Shirer (1984) and Shirer et al. (1984), have been completed recently; these discuss results obtained from a three-dimensional truncated spectral model of moist convection in a shearing environment. In Shirer (1984), two possible cloud street modes arising from a combined Rayleigh/parallel instability were found to be possible--one having orientations for which the Fourier coefficient of the wind shear perpendicular to the roll was nearly zero and the other for which the Fourier coefficient of the shear parallel to the roll was nearly equal to that perpendicular to the roll. These two modes have different horizontal characteristic wavelengths that vary with wind speed at the top of the domain, which is usually taken to be the base of the inversion. In Shirer et al. (1984), analysis of aircraft data taken during 4 cloud street cases from KonTur revealed that in each case the mode for which both shear coefficients were nearly equal corresponded to the observed one.

Work has begun on a three-dimensional spectral model able to represent the convective modes developing as a result of the inflection point instability. In addition, satellite pictures and relevant upper air data have been archived for 30 cloud street days during the 1983-84 winter season; these will be used to assess the results obtained from the above Rayleigh/parallel and inflection point instability models.

Plans for FY-85

1. Observational and Theoretical Studies of the Index Oscillation

We plan to concentrate on the analysis of our six-coefficient baroclinic-barotropic spectral model of the index oscillation. In addition, the blocking phenomenon will be analyzed by seeking low and high index equilibria and examining their stability. Further observational studies are planned which will concentrate on establishing the conditions leading to the establishment of atmospheric blocking patterns and their subsequent maintenance. A mix of conventional and satellite data is anticipated just as in our study of the index oscillation.

2. Modeling of the Index Cycle

It is proposed that the two spectral models be used to produce forecasts from observed fields. The desired prediction quantitiers are the index values, and the points of regime changes. The index values are, of course, calculated directly from the forecast height field. The regime changes may be found by calculating the attractor associated with the forecast fields at certain points in the forecast cycle. If, for example, the associated attractor were calculated every 6 hours and changed after 36 hours, this would indicate a transition to another flow pattern. It is anticipated that several forecasts with slightly different initial conditions will be needed to establish the probability of a regime change. The form of the probability distribution for the change might take the form of a log-normal distribution. This sample stochastic approach also takes into account the possibility of no regime change -- something the single forecast cannot handle.

The calculation of the attractor restricts the number of spectral components to about 60 (or less) for practical reasons of computer time and core. Thus, the initial fields must be restricted to just the larger observed features. Since current satellite observing systems are able to resolve these scales, analyses derived solely from satellite observations should serve as satisfactory initial data.

3. Cloud Streets

The new inflection point instability model will be developed sufficiently that orientation angles and horizontal wavelengths can be predicted for the rolls and these results compared to both the KonTur data and the locally archived data. Development of approximate formulas relating for each possible mode the orientation angles to components of the mean wind shear is one goal of the analysis.

Preliminary work is planned on generalizing the present three-dimensional Rayleigh/parallel instability model to one able to represent the tranisitions from rolls having one wavelength to ones having other, larger ones. Such cell broadening is observed in laboratory models of Rayleigh-Benard convection and in satellite pictures of cloud streets over the ocean, and is modeled well in a new simple spectral model of two-dimensional shallow convection given by Chang and Shirer (1984). The background wind field will likely play a crucial role in determining the details of this cell broadening, and will be an important factor in any usable boundary layer wind-measuring scheme.

Publications

Shirer, H.N. and R. Wells, 1983: Mathematical Sturcture of the Singularities at the Transitions Between Steady States in Hydrodynamic Systems. Lecture Note in Physics, 185, 276 pp.

In review or to appear:

Feldstein, S.B., J.H.E. Clark, 1984: The Hadley and Rossby Regimes on a Sphere, Monthly Weather Review.

Chang, H-R and NH.N Shirer, 1984: Transitions in Shallow Convection: An explanation for cell broadening. Journal of the Atmospheric Sciences.

Shirer, H.N., 1984: On Cloud Street Development in Three Dimensions: Parallel and Rayleight Instabilities. Contributions to Atmospheric Physics.

Shirer, H.N., B. Brummer and A. Grant, 1984: Cloud Streets During KonTur and the Parallel/Rayleigh Instability. Contributions to Atmospheric Physics.

Thesis completed:

Schlaak, R.A., 1984: An Observational Study of the Winter 1974/75 Index Oscillation with Conventional and Satellite ERB Data (in preparation for submission to Monthly Weather Review).