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The Effect of Latent Heat Release on Synoptic-to-Planetary Wave Interactions and Its Implication for Satellite Observations: Theoretical Modeling

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SIGNIFICANT ACCOMPLISHMENTS IN PAST YEAR:

The project objectives are as follows:

- Develop simple models to simulate interaction of planetary and synoptic-scale waves incorporating the effects of:
  - a. Large-scale topography
  - b. Eddy heat and momentum fluxes (or nonlinear dynamics)
  - c. Radiative heating/cooling
  - d. Latent heat release (precipitation) in synoptic-scale waves
- Determine the importance of latent heat release in oceanic storm tracks for temporal variability and time-mean behavior of planetary waves.
- Compare the model results with available observations of planetary and synoptic-scale wave variability and time-mean circulation.
- Ascertain the usefulness of monitoring precipitation in oceanic storm tracks by satellite observing systems.

The modeling effort includes two different low-order quasi-geostrophic models:

a. *Time-dependent* version to study intraseasonal variability, anomalous circulations and seasonal cycle. This version will explicitly resolve a few planetary and synoptic waves and their interaction and the transport of water vapor by wave motions.

b. *Climatological mean* version to study response of planetary waves to slow variations in external forcing. This version will explicitly resolve stationary planetary waves only, while parameterizing average effects of transient synoptic-scale waves and latent heat release.

The modeling also includes a low-order primitive equation model. A time-dependent, multi-level version will be used to validate the two-level Q-G models and examine effects of spherical geometry. It will explicitly resolve a few planetary and synoptic waves and include specific humidity as predicted variable, moist convective parameterization and large-scale precipitation.

Since the beginning of the grant in July 1987, we have constructed a two-level model of the extratropical atmosphere which has an arbitrary truncation of meridional and zonal modes. A complete package of diagnostics were developed for the model to examine heat and momentum balances, time-mean fields, energetics, energy spectra, persistent anomalies, etc. Tests with this model form the dissertation of Ph.D. student Enda O'Brien, who was supported by this grant. The results answer outstanding questions regarding the usefulness of low-order models of the general circulation and provide a foundation for our modeling effort. The results are reported in a paper in press for Tellus, a second paper accepted for Tellus and a third paper submitted to J. Atmos. Sci.

The first paper deals with variability within a low-order ("2 by 2" or 2 zonal waves plus a mean flow, 2 meridional modes) version of the model in the presence of planetary-scale topography. We examined the viability of theories of persistent circulation anomalies. We found that the two distinct "weather regimes" (i.e., extremely long-lived configurations of planetary waves) reported by other investigators vanish when realistic physical parameters are used in the model. These regimes are replaced with a more random temporal distribution of the planetary wave in phase space. Persistent anomalies are found that more closely simulate observed anomalies than the weather regimes.

The second paper examines the resolution and processes needed in a low-order model to accurately represent basic features of the extratropical general circulation, e.g., the time and zonal mean circulation, eddy variability and energetics. To achieve this end, the model must have sufficient resolution (at least three wave modes in both the zonal and meridional directions) to represent wave-wave interactions and eddy momentum fluxes, as well as appropriate, but simple, parameterizations to represent radiative driving and dissipation. A "3 by 3" model is capable of representing the mean zonal flow including surface winds, a three-cell meridional circulation, realistic heat and momentum budgets and energy cycle, and a simple K^{-3} energy spectrum where K is total wavenumber. These features are also present in higher resolutions with small quantitative differences. However, a model with only one even and one odd meridional mode is incapable of reproducing the momentum budget, time-mean surface zonal winds and the three-cell structure.

The third paper examines the effect of large-scale topography on the interaction of synoptic and planetary waves in the model, using various truncations. This paper discusses basic elements of stationary wave forcing by topography and the role of synoptic-scale eddies in the variability and time-mean maintenance of the planetary-scale waves. We found that a "5 by 5" truncation provided a reasonable low-order representation of time-mean stationary waves. We also found that wave-wave interactions act to reduce the amplitude of the short stationary waves and alter the phase of the topographically-forced long wave. Stationary waves and persistent anomalies in the model have about one-half the amplitude of observed features. Latent heating appears to be the missing ingredient and, based on satellite-derived observations of diabatic heating over the oceans, will make an order one contribution to the heat budget of the planetary waves.

Thus, a major tool in the project has been developed and tested, using observed atmospheric behavior as a standard. We have also prepared computer code for a low-order, primitive-equations model on a sphere. This model is a subset of the spectral model used by the National Meteorological Center for medium-range forecasts. We have prepared the model for idealized experiments with water vapor and topography and are currently in the testing stage with this model. A complete package of spectral energetics and wave-mean flow diagnostics was developed in the first year. The model includes parameterizations of large-scale condensation and moist convection.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

The results to date demonstrate the usefulness and success of low-order modeling. We are currently working on incorporating moisture effects into the general truncation, quasi-geostrophic model so that the influence of latent heat release on the wave interactions can be examined in that model. During the second year of the grant we will be performing a number of long-term integrations with this model.

In the second year of the project we will examine the effect of moist processes in two different low-order models of the atmosphere, the two-level quasi-geostrophic model with a limited number of zonal and meridional modes in a periodic channel and the multi-level primitive-equations model on a sphere with three or four zonal wavenumbers (3,6,9 and 12) and several meridional modes. These models will include large-scale topography and allow for the development of both planetary and synoptic-scale waves. We will investigate the importance of latent heat release on the synoptic scales in the forcing and variability of planetary-scale waves. In particular, we anticipate that latent heat release in preferred locations (i.e., storm tracks) will be important in organizing or modifying the larger scale waves.

The results will assess the need for observing precipitation over extratropical oceans. In our experiments with the primitive-equations model we will compare the effects of moist convection and condensation by large-scale uplifting. This comparison will provide insights into the nature of the precipitation and its impact on the motion. It is expected that the method of observation of precipitation over the extratropical oceans will depend on the precipitation process. We hope to provide information regarding which type of process is important in the evolution of the large-scale circulation. Comparisons will be made between the behavior in the quasi-geostrophic and primitive-equations models to evaluate the limitations of the simpler, but more efficient quasi-geostrophic model.

PUBLICATIONS:

O'Brien, E. and L. Branscome, 1988: Modes of variability in a low-order, two-level model. In press for Tellus.

O'Brien, E. and L. Branscome, 1988: Minimal modeling of the atmospheric general circulation. Accepted for Tellus.

O'Brien, E. and L. Branscome, 1988: The effect of large-scale topography in minimal general circulation models. In review for J. Atmos. Sci.