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Title: Life Cycles of Transient Planetary Waves

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Background

In recent years there has been an increasing effort devoted to understanding the physical and dynamical processes that govern the global-scale circulation of the atmosphere. This effort has been motivated, in part, from i) a wealth of new satellite data, ii) an urgent need to assess the potential impact of chlorofluorocarbons on our climate, iii) an inadequate understanding of the interactions between the troposphere and stratosphere and the role that such interactions play in short and long-term climate variability, and iv) the realization that addressing changes in our global climate requires understanding the interactions among various components of the earth system.

The research currently being carried out represents an effort to address some of these issues by carrying out studies that combine radiation, ozone, seasonal thermal forcing and dynamics. Satellite and ground-based data that is already available is being used to construct basic states for our analytical and numerical models.

Significant Accomplishments (1991-1992)

Ozone-Dynamics Interaction

During the past year we have been examining the role of radiative transfer and ozone-dynamics interaction in the genesis, maintenance and decay of free waves in the atmosphere. Our studies have employed both analytical and numerical methods. We have shown, for example, that meridional ozone advection may produce wave growth or decay depending on the wave and basic state vertical structures, whereas vertical ozone advection is locally (de)stabilizing when the vertical ozone gradient is (positive) negative, *irrespective* of the wave or basic state vertical structures. For all of the cases considered we have found that photochemically accelerated cooling, which predominates in the upper atmosphere, augments the Newtonian cooling and is stabilizing.

Using zonal mean basic states constructed from satellite and ground-based data characteristic of each season, we have shown that ozone heating generated by ozone-dynamics interaction in the stratosphere can reduce (enhance) the damping rates due to Newtonian cooling by as much as 50% for planetary waves of large vertical scale and maximum amplitude in the lower (upper) stratosphere. For waves with relatively large vertical scale and maximum amplitude in the lower to mid stratosphere and small Doppler shifted frequency, we have obtained the particularly striking result that ozone - dynamics interaction in the stratosphere can significantly influence the zonally rectified wave fluxes in the troposphere!

For the summer basic state, adiabatic eastward and westward-propagating neutral modes having the same zonal scale were shown to emerge; both are confined to the lower stratosphere and troposphere. For these modes ozone heating dominates over Newtonian cooling, and the modes amplify with growth rates comparable to those of baroclinically unstable waves of similar spatial scale.

Periodic Local Forcing and Low Frequency Variability

In a medium that is unbounded in the horizontal and subjected to localized, time periodic forcing, disturbances may amplify downstream from the source. In such situations the flow is said to be spatially unstable. In the atmosphere, tropical convection and wind fluctuations over mountains have been suggested as possible sources of spatial instability.

In this study the linear and nonlinear stability characteristics of spatially growing, long, low frequency baroclinic waves were examined in a continuous atmosphere on a β-plane channel in the presence of Ekman friction and Newtonian cooling. For the low frequency waves considered in this study, the ratio of mechanical energy flux to baroclinic energy conversion was shown to decrease in direct proportion to β. The convergence of mechanical energy flux was shown to be maximized in the mid-troposphere, whereas the baroclinic energy conversion was shown to be maximized in the lower troposphere where it becomes increasingly dominant as the ratio of the surface wind to β increases.

The nonlinear evolution of the wave amplitude and (time-averaged) mean field were shown to be characterized by either a damped oscillatory approach to a steady (space - independent) state or a weak finite amplitude destabilization. Irrespective of the form of the dissipation, the spatial vacillations and corresponding wave fluxes, which are maximized near the source, were shown to increase with forcing frequency. For sufficiently large Newtonian cooling, it was shown that the wave amplitude is maximized in the far field where the wave asymptotically approaches an equivalent barotropic structure.

Steady Forcing and Low Frequency Variability

In recent years several studies have presented evidence suggesting that topographic instability may be one of several potentially important mechanisms by which low frequency motions can be generated at middle latitudes in the Northern Hemisphere. We have recently demonstrated using a two-layer baroclinic model of the atmosphere that zonally asymmetric potential vortcity (PV) forcing can produce dramatic changes in the baroclinic topographic instability properties of the flow. The PV forcing may act to enhance, suppress, or catalyze the topographic instability depending on the phase of the PV forcing with respect to the topography. These changes result from the alteration of the zonal mean flow produced by the interaction between the resonant wave and the stationary (PV) forcing. To the extent that the PV forcing mimics the diabatic heating in a continuous atmosphere, land-sea heating contrasts may play a more important role in the dynamics of topographically induced low frequency instabilities than previously thought.

<u>Focus of Current Research and Plans for Next Year</u>

Current research:

1. *Examination of the nonlinear interactions among radiation, ozone, and dynamics.* A self-consistent set of equations governing the weakly nonlinear interactions between ozone and the dynamical circulation has been developed. These equations are currently being analyzed to provide a better understanding of zonally rectified transports of ozone, heat, and vorticity in a continuously stratified model of the troposphere-stratosphere coupled system.

2. *Examination of the role of seasonal forcing in short-term climate variability.* A two-layer, nonlinear baroclinic model was recently developed in order to study the combined effects of topography, zonal mean and zonally asymmetric seasonal forcing, and wave-wave and wave-mean flow interactions on short - term climate variability.

Plans for next year:

1. We plan to examine the linear stability of free planetary waves in the presence of radiative - photochemical feedbacks for two different cases: 1) using *instantaneous* rather that climatological distributions of wind, temperature and ozone; and 2) using ozone distributions based on recent WMO projections of reduced ozone in the stratosphere.

2. We plan to continue work on the role of seasonal forcing in short-term climate variability. Particular emphasis will be placed on examining the influence of seasonal variations in land-sea heating contrasts.

<u>Publications</u> (1991-1992)

1. Barcilon, A., and T. R. Nathan, 1991: Effects of wave-wave and wave-mean flow interactions on the evolution of a baroclinic wave. *Geophys. Astro. Fluid Dyn.*, **56**, 59-79.
2. Nathan, T. R., and L. Li, 1991: Effects of ozone and Newtonian cooling on the linear stability of transient planetary waves. *J. Atmos Sci.*, **48**, 1837-1855.
3. Nathan, T. R., 1991: Nonlinear spatial evolution of baroclinic waves in a continuous atmosphere on a β-plane. *Eighth Conf. on Atm. and Oceanic Waves and Stability, Am. Met. Soc.*, 285-288.
4. Nathan, T. R., 1992: The role potential vorticity forcing in topographically induced instabilities. Submitted to *Trends in Atmospheric Sciences* (Invited Paper).
5. Nathan, T. R., 1992: Nonlinear evolution of spatially growing baroclinic waves. Submitted to *Geophys. Astro. Fluid Dyn.*
6. Finley, C., and T. R. Nathan, 1992: On radiating baroclinic instability of zonally varying flow. Submitted to *Tellus*.