Title: Use of Satellite Data and Modeling to Assess the Influence of Stratospheric Processes on the Troposphere

Principal Investigator:

Terrence Nathan
Atmospheric Science Program
Department of Land, Air and Water Resources
University of California, Davis, CA 95616
(916)752-1609 (off. #); (916)752-1552 (FAX #)

Significant Accomplishments in the Past Year (1990-1991)

1. **Stability of idealized and realistic atmospheric flows: a mechanism for explaining the origin of observed waves in the atmosphere.**

Over the past forty years hundreds, perhaps thousands of linear stability studies have been carried out in order to explain the origin and structure of observed waves in the atmosphere. Of these studies only a small fraction have considered the stability of time-dependent, zonally varying flow or the influence of radiative-photochemical feedbacks on the stability zonally uniform flow. Yet, as described below, the stability of such flows may yield important information concerning the origin, structure and transient time scales of free waves in the atmosphere.

A. Stability of free planetary waves in the presence of radiative-photochemical feedbacks (Nathan and Li, 1991; JAS)

During the past year we have developed a beta-plane model that couples radiative transfer, ozone advection, and ozone photochemistry with the quasigeostrophic dynamical circulation in order to study the diabatic effects of Newtonian cooling and ozone-dynamics interaction on the linear stability of free planetary waves in the atmosphere. Under the assumption that the diabatic processes are sufficiently weak, an analytical expression was derived for the eigenfrequencies of these waves valid for arbitrary distributions of background wind and ozone volume mixing ratio (γ). That expression reveals the following: 1) the influence of meridional ozone advection on wave growth or decay depends on the wave and basic state vertical structures; 2) vertical ozone advection is locally (de)stabilizing when $d\gamma/dz$ (>0) <0, *irrespective* of the wave or basic state vertical structures; 3) photochemically accelerated cooling, which predominates in the upper atmosphere, augments the Newtonian cooling and is stabilizing.

The one-dimensional stability problem also was solved numerically for a Charney basic state (constant vertical shear and constant stratification) and for zonal mean basic states constructed from observational data characteristic of each season. It was 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, 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 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.

B. Stability of time-dependent zonally varying flows (Manney and Nathan, 1990; JAS)

We have examined the stability of a basic state consisting of a westward - moving wave and a zonal mean jet using a linearized, nondivergent barotropic model on sphere. The sensitivity of the stability of the flow to the strength and structure of the zonal jet was emphasized. We have shown that for certain westward-moving waves, inclusion of a very weak jet in the basic state can dramatically alter the stability of the flow. An examination of the energetics shows that some unstable disturbances depend almost entirely on zonal variations in the basic state for their existence. In cases where meridional variations of the basic state dominate the energy transfer, examination of basic state meridional potential vorticity gradients is useful in understanding the stability characteristics. At subcritical basic state wave amplitudes, addition of a weak jet, which by itself is stable, can change the meridional absolute vorticity gradient to resemble that for a supercritical basic state wave alone. Unstable disturbances then occur that have spatial structures and propagation characteristics similar to those for the supercritical wave alone.

For a basic wave state resembling the observed "two-day" wave alone, inclusion of an easterly (summer) jet in the basic state has a strong stabilizing influence. When a strong easterly jet is included unstable disturbances occur that have structures similar to waves observed concurrently with the "two-day" wave.

We have also shown a seasonal dependence in the stability of several westward - moving basic state waves.

Focus of Current Research

Our current research is focused on the following problems:

1. *Examination of the finite amplitude interactions among radiation, ozone, and dynamics.* The beta-plane model described under 1A above has been extended to provide a self-consistent set of equations governing the weakly nonlinear interactions between the ozone and dynamical fields. 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, weakly nonlinear baroclinic model was recently developed in order to study the combined effects of topography, seasonal forcing, and wave-wave and wave-mean flow interactions on short - term climate variability. Preliminary model results are currently being analyzed.

Plans for Next Year

1. Examine the linear stability of free planetary waves in the presence of radiative - photochemical feedbacks for *instantaneous* rather that climatological distributions of wind, temperature, and ozone.

2. Continue work on the role of seasonal forcing in short-term climate variability.

Refereed Publications (1990-1991)

1. Manney, G. L., and T. R. Nathan, 1990: Barotropic instability of westward-moving waves in realistic stratospheric zonal flows. *J. Atmos. Sci.*, 47, 19 pgs.

2. Howell, P., and T. R. Nathan, 1990: Barotropic instability of zonally varying flow forced by multimode topography. *Dyn. Atmos. Oceans.*, 15, 35-58.

3. 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.

4. Nathan, T. R., and L. Li, 1991: Effects of ozone and Newtonian cooling on the linear stability of transient planetary waves. *J. Atmos Sci.* (in press).

Additional Personnel Involved in the Project (1990 - 1991)

Ms. Cathy Hamann (M.S., 1990. Thesis title: Linear and nonlinear stability of zonally varying flow.)

Mr. Long Li (M.S., 1990. Thesis title: Effects of ozone heating and Newtonian cooling on the stability of transient planetary waves.)

Ms. Mary Parlange (M.S. expected 1992. Thesis title: Influence of seasonal forcing on a multi-wave baroclinic system.)