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Final Report

NAGW-1127 Waves and Instability in the Atmosphere of Mars

NASA Planetary Atmospheres Program

July 1, 1987 - December 31, 1990

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(NASA-CR-192381) WAVES AND INSTABILITY IN THE ATMOSPHERE OF MARS: NASA PLANETARY ATMOSPHERES PROGRAM Final Report, 1 Jul. 1987 - 31 Dec. 1990 (Oregon State Univ.) 8 p

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Brief Summary of Research

The studies carried out under NAGW-1127, "Waves and Instability in the Atmosphere of Mars", have addressed a broad range of phenomena including: (i) polar warming, (ii) forced stationary waves, (iii) gravity waves, (iv) transient baroclinic eddies, and (v) radiative-dynamical instabilities. A variety of numerical models have been employed in these studies, as well as analytical approaches. Some of the most significant results from this work are very briefly summarized below.

Polar warming

Possible transports of dust and water to high northern latitudes during a polar warming (and global dust storm) event were investigated, using a relatively simplified β-plane model. Transports resulting from a planetary wave warming, as well as from such a warming without such large-scale wave activity, were examined. The simplified modeling showed that substantial transports of dust, and possibly also water, could take place in a warming/dust storm event. Planetary waves provide a strong quasi-horizontal mixing that is very effective at transporting dust or water poleward in the presence of a sharp latitudinal gradient (as exists during winter). The mean circulation can also transport large amounts of dust or water poleward during a warming, if large amounts are present in lower latitudes at relatively high levels (above ~10-20 km). The transport study indicated that polar warming events may be a time when substantial quantities of dust and water can be readily transported to very high latitudes - in particular, to the vicinity of the residual cap and the layered terrains - and deposited on the surface.

Dynamical studies of the polar warming phenomenon were also pursued further, using a significantly more realistic model than had been employed in earlier work on this problem. In particular, a spherical wave-mean flow model was developed and utilized to examine a forced planetary wave mechanism for the polar warming. A sizeable set of numerical experiments have now been performed with this model. The results show that a planetary wave mechanism is indeed a highly viable one (as indicated by earlier work with a highly simplified model), that can produce a warming with many of the observed properties. The actual latitudinal distribution of topography in the northern hemisphere appears to provide a potentially adequate forcing for the planetary waves, and both planetary wavenumbers 1 and 2 appear to be able to induce large warmings.

Forced stationary waves

A general study of forced stationary waves in the winter hemispheres of Mars has been pursued. This study has employed a linear primitive equation model developed for this task. A large set of calculations have been made with this model, investigating the stationary response to mechanical and thermal forcings associated with topography. The influence of dissipation and the basic state flow on the stationary wave amplitudes and structures has been examined, using the observed topography (as given by the Mars Consortium data set) to determine the wave forcing. The results show that the topography in both hemispheres should force large-amplitude stationary waves in the winter extratropics. The longest waves, of planetary wavenumber 1 and 2, propagate latitudinally and vertically up into the intense polar jet and reach large amplitudes at very high levels (above ~25-30 km). Thermal forcing may be significant in the winter hemisphere, given the very large topography in low latitudes. A very interesting aspect of the linear results is that the amplitude of the response at upper levels can be extremely sensitive to the structure of the mean flow. Relatively strong and high latitude jets appear to yield very large-amplitude stationary waves, something that may be quite significant in relation to the polar warming phenomenon.

Gravity waves

Several studies of breaking internal gravity waves have been carried out. In one study, a simplified numerical model was employed to investigate the possible effects of such waves in the middle atmospheric region of Mars. In the second study, a nearly-analytic model of the interaction of gravity waves and mean flow in middle atmospheres was constructed, and applied to the Earth as well as to Mars.

The numerical study focused on the possible role of internal gravity waves in "driving" the middle atmosphere thermal field away from radiative equilibrium - as suggested by Earth-based temperature measurements (of the ~50-80 km region). Using a parameterized representation of the momentum drag and diffusion due to the breaking waves, it was shown that topographically-forced gravity waves in the winter hemisphere may indeed exert a very strong influence on the mean circulation in this altitude region. Similar waves may also play a role in the summer hemisphere, though probably at somewhat higher levels (as a result of the "filtering" effects of lower-level winds). The numerical study briefly addressed the possible role of breaking gravity waves in the polar warming phenomenon, finding that very large-amplitude waves would be required to produce effects at such relatively low levels (~20-30 km).

The nearly-analytic model shows the basic parameter dependence of a simple gravity wave driven mean flow. The parameters include both mean flow (e.g., the equilibrium shear and the radiative time constant) and gravity wave (e.g., the momentum flux at a lower boundary) parameters. The solutions are shown to agree very well with those from a more complete numerical model. Applied to Mars, it is found that for relatively large gravity wave fluxes the structure of the mean flow is very similar to that found on Earth. The intensity of the mean circulation is significantly stronger, however, as a result of the short radiative time constants.

Transient baroclinic eddies

Most of the effort related to transient baroclinic eddies has been in connection with related projects in which the P.I. has been involved. These include both the Mars GCM project and the Mars Climate Model project at NASA-Ames, as well as an NSF-sponsored study of nonlinear baroclinic instability. Several reviews of previous work on baroclinic eddies in the Martian atmosphere were carried out, for a book chapter and a review paper presented at the 1989 IAMAP meeting. The work on baroclinic eddies in the related projects has helped to raise a number of basic questions/issues that strongly warrant further investigation.

Radiative-dynamical instability

A study of radiative-dynamical instability in the Martian atmosphere was pursued. This work was initially motivated largely by consideration of the summer polar cyclones observed by Viking, disturbances that have been suggested to be manifestations of radiative instability. A key question that the work attempted to address was the influence of vertical wind shear and baroclinic instability on radiative instability. A relatively simple numerical model was utilized to perform a range of instability calculations, directed primarily at the high-latitude summer atmosphere.

The radiative-dynamical instability calculations yielded a number of very interesting and potentially significant results, but some of these seem to be at odds with recent work on the fundamental dynamics of radiative-dynamical instability. In particular, the calculations evidenced strong growth at long wavelengths as well as shorter ones. The reasons for this behavior have not yet been ascertained; additional calculations are needed to reconcile the results with the recent fundamental work.

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