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MESOSCALE DENSITY VARIABILITY IN THE MESOSPHERE AND THERMOSPHERE: EFFECTS OF VERTICAL FLOW ACCELERATIONS

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A mechanistic one-dimensional numerical (iterative) model has been developed which can be used to simulate specific types of mesoscale atmospheric density (and pressure) variability in the mesosphere and the thermosphere, namely those due to waves (see below) and those due to vertical flow accelerations. i.e., quasi-static flow effects. The model was developed with the idea that it could be used as a supplement to the TGCMs (thermospheric general circulation models) since such models have a very limited ability to model phenomena on small spatial scales. The details of the model formulation can now be evaluated since observations indicate that quite large vertical flow accelerations exist in the disturbed high latitude thermosphere (ROBLE, 1983). The horizontal scales for which such effects are potentially possible have been calculated using the methods of SMITH (1980) and are equivalent to those developed by REVELLE (1987a). Depending on the thermal structure and on the mean horizontal winds, the mesoscale effects can influence a region approaching 500 km across under extreme conditions. More typically, however, the maximum horizontal scale where quasi-static conditions apply, are in the range from 50 to 120 km. Calculations for the mean troposphere using these methods indicate that the corresponding maximum values for the mesoscale regime are in the range from 1 to 50 km, with the latter being an extreme value.

The steady flow, inviscid model equations used satisfy the combined constraints of conservation of mass, linear momentum and of energy on a middle latitude f plane. They represent a set of equations similar to, but more general than, those developed by GHOSH (1970). As discussed in REVELLE (1987a), the equations developed apply not to wave effects on the hydrostatic mean flow, but rather to those of a vertially accelerated mean flow, i.e., a state of quasi-static balance. The corresponding effects of a noninteracting, linearized plane wave model have been calculated in REVELLE (1987b) in the internal acoustic-gravity wave part of the spectrum in the high and low frequency limits, repsectively. In the latter, only wave amplitude was considered and wave sources were parameterized in the tropsophere using a modified form of geostropic adjustment theory.

The simplest case to consider was the integration upward through a time-averaged, height independent, horizontally divergent flow field. This situation was chosen in part because an analytic solution was derived for this case (in height coordinates) which could be used as a check on the validity of the numerical results. This was important since small vertical height steps were necessary in order to reliably integrate the resulting equations. Vertical winds were initialized at the lower boundary using the Ekman pumping theory over flat terrain.

The results of the computations can be summarized as follows:

a) Accelerating updrafts lower the air density (pressure) relative to the static case and vice versa. Nonaccelerated vertical flow does not influence the hydrostatically computed density (pressure) structure.

b) Unless vertical winds are very large, dynamical density (pressure) variations are virtually identical to each other. (See also e) below.)

c) The degree of density (pressure) change predicted with respect to the static reference state depends significantly on the local gas temperature. Vertical flow accelerations produce the maximum effect in regions of minimum atmospheric temperature (See also e) below.)

d) The minimum vertical wind speed necessary to significantly modify the density structure in the mesosphere and the thermosphere is about 50 m/s. For vertical winds approaching 250 m/s, density changes of about ± 20 percent maximum can occur.

e) An instability is predicted as the vertical wind approaches the isothermal acoustic wave speed. This could occur at the point where the vertical kinetic energy/mass equals or exceeds the atmospheric potential energy/mass in an inviscid fluid. Current observations indicate that the latter possibility is highly unlikely to occur.

In the current calcuations, only mechanistic solutions were used, i.e., formal solutions of the energy equation were not used to constrain the results. Such constraints are necessary in general however so that vertical motions can compensate for any net heating/cooling effects in the steady flow limit. In this region of the atmosphere a combination of thermal conduction, radiation, joule heating, horizontal transport of heat and wave dissipation effects, etc. would need to be considered in any realistic thermal balance computation. Instead, the net heating/cooling rate necessary to maintain a steady state with vertical winds was determined. If this net heating/cooling field could be considered realistic in terms of values determined from various energy budget estimates (for example, during a substorm joule heating rates in excess of 1000 deg K/hr have been reported) then the effects of such accelerated flow on the statically computed reference state was considered reliable. Note that in a major heating event the static density (pressure) profile will also change significantly in general. Such effects have not been considered here. The reference state used was the U.S. Standard Atmosphere 1976 which is likely to differ from a mean disturbed state, but especially above about 150 km. Since in this latter region the changes predicted are relatively small due to the elevated gas temperatures, these static changes are probably not of great significance with respect to the currently predicted mesoscale quasi-static changes.

Although much work remains to be done, it would appear that the method is useful with regard to simulating density variability effects in the mesoscale range that cannot currently be addressed using either the TGCMs (see, for example, DICKINSON et al., 1981) or by using modified static diffusion models (see, for example, BARLIER and BERGER, 1983). This work was carried out in support of various NASA projects in this height regime including, but not limited to those of the shuttle, AOTV, Space Station, VARS, etc...

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