N85-32508 D42

4.5A MOMENTUM FLUX MEASUREMENTS: TECHNIQUES AND NEEDS

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The vertical flux of horizontal momentum by internal gravity waves is now recognized to play a significant role in the large-scale circulation and thermal structure of the middle atmosphere. This is because a divergence of momentum flux due to wave dissipation results in an acceleration of the local mean flow towards the phase speed of the gravity wave. Such mean flow accelerations are required to offset the large zonal accelerations driven by Coriolis torques acting on the diabatic meridional circulation. Thus, a detailed observational knowledge of momentum flux climatology and variability is essential to a more complete understanding of the role of gravity waves in middle atmosphere dynamics.

Ideally, the momentum flux due to a random field of gravity waves would be determined from simultaneous and co-located measurements of vertical and horizontal velocities made with high vertical and temporal resolution. In practice, however, such measurements are not possible at present and other techniques must be employed. Vertical and approximate horizontal wind measurements can be made using Doppler radars with vertical and oblique beam orientations, but high frequency oblique motions are badly contaminated by vertical velocities and large phase errors occur for horizontal wavelengths that are not much larger than typical beam separation distances. Thus, such systems are only suited for measurements of momentum fluxes due to wave motions with large horizontal wavelengths ($\lambda_h \gtrsim 200$ km). These problems can be avoided, in principle, by using a phase-coherent, spaced antenna system to infer co-located horizontal and vertical motions (FRITTS et al., 1984). Another approach which does not rely on individual horizontal and vertical velocity measurements is that of VINCENT and REID (1983). This technique provides an estimate of the momentum flux in the plane of two Doppler radar beams inclined at equal and opposite angles off vertical based on the average rms velocities observed. Because all of these techniques depend on the velocity fluctuations about some mean, however, the contribution to the momentum flux due to quasi-stationary waves is likely to be largely excluded in each. In general, the wave periods for which a particular measurement applies are those that are less than the data collection interval.

Other more general problems with existing systems relate to spatial and temporal resolution; if these are not sufficiently fine, then observed motions may be aliased to other (larger) scales or overlooked altogether. Fortunately, we do not expect motions with small vertical wavelengths ($\lambda_z \lesssim 4$ km) to contribute significantly to the momentum flux and divergence on theoretical grounds (LINDZEN, 1981). On the other hand, high-frequency gravity wave motions ($T \lesssim 20$ min), which may account for significant momentum fluxes, may be excluded or substantially reduced by excessive temporal averaging.

Relatively little is known at present about the distribution and variability of gravity-wave momentum flux in the middle atmosphere, yet these determine, to a large extent, the gross features of the middle atmosphere circulation and structure. The distribution of momentum flux depends on a variety of factors. Perhaps the most significant are (1) the strength and location of important gravity wave sources (wind shear, topography, convection, etc.), (2) the filtering and evolution of the gravity-wave spectrum due to wave-turbulence, wave-wave, and wave-mean flow interactions, and (3) the characteristics of those gravity waves that contribute most to drag and diffusion processes.

Both gravity wave sources and filtering contribute to the temporal and geographic variability of wave amplitudes, scales, and fluxes and may act to polarize the gravity-wave spectrum and align the momentum flux in preferred directions. Significant topographic sources are quite localized on a global basis, and wind shear and convective sources tend to be rather transient in nature. Of the primary gravity wave sources, wind shear and topography are expected to lead to wave spectra that may be strongly polarized, whereas convection is likely to produce a more isotropic distribution of gravity waves. The recent studies by SCHOEBERL and STROBEL (1984) and DUNKERTON and BUTCHART (1984) suggest that filtering processes can also act to modulate or polarize a gravity-wave spectrum anti-parallel to the local mean flow. A tendency for gravity waves in the middle atmosphere to be polarized has been noted by HAURWITZ and FOGLE (1969), HERSE et al. (1980), MANSON et al. (1981), and VINCENT and REID (1983), among others.

Of major importance in the study of the gravity wave and momentum flux distributions in the middle atmosphere are the characteristics of those motions that contribute most to saturation processes. This is because gravity waves with small propagation angles ($\lambda_x >> \lambda_z$) and/or small vertical wavelengths (small intrinsic phase speeds $c-\bar{u}$) may propagate or be advected large distances horizontally between sources in the lower atmosphere and regions of strong dissipation in the stratosphere or mesosphere. Such propagation would tend to homogenize the wave field in the middle atmosphere, independent of geographically local sources and filtering effects. On the other hand, gravity waves with large propagation angles ($\lambda_x \gtrsim \lambda_z$) and large vertical wavelengths will reach the stratosphere and mesosphere rapidly, relatively unattenuated, and in close proximity to the source or filtering environment that determined the wave character. In this case the momentum flux distribution in the middle atmosphere would reflect the spatial variability of the underlying atmosphere. On the basis of the observed spectrum of atmospheric wave motions (CARTER and BALSLEY, 1982), it appears possible that the transport of momentum could be accomplished primarily by relatively high-frequency gravity waves (FRITTS, 1984), consistent with the observations of VINCENT and REID (1983) and SMITH and FRITTS (1983). Other observations suggest that the saturation of gravity waves at a wide range of scales is a nearly continuous process throughout the middle atmosphere (SATO and WOODMAN, 1982; PHILBRICK et al., 1983; BALSLEY et al., 1983; VINCENT, 1984).

Because of the considerable uncertainties regarding the momentum flux distribution in the middle atmosphere, many types of observations are required. Those observations that appear to be important in light of the above discussion include:

(1) the mean geographical and seasonal distributions of momentum flux (and divergence) throughout the middle atmosphere,

(2) those gravity wave scales and frequencies that contribute most to momentum transport,

(3) the degree and causes of polarization and variability of the gravity-wave spectrum, and

(4) the response of the middle atmosphere to changes in momentum flux divergence caused by variable gravity wave sources or filtering conditions.

Studies that address these topics will make important contributions to our knowledge of the role of gravity waves in middle atmosphere dynamics.

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