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3.6.2 PRELIMINARY ESTIMATES OF VERTICAL MOMENTUM FLUX

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INTRODUCTION

The capability of ST radars to provide direct measurements of the momentum flux presents an opportunity for major advances in atmospheric science. Some of the issues, needs, and techniques surrounding the measurement of momentum flux are discussed by FRITTS (1984) and SCHOEBERL (1984), among others. The vertical momentum flux was first measured using the two-beam technique by VINCENT and REID (1983), who used mesospheric observations. They also presented the body force due to the vertical divergence of the vertical momentum flux. CORNISH and LARSEN (1984) examined the vertical momentum flux at 14.5 km over Arecibo, but did not look into the momentum flux divergence. It appears that no other results from the troposphere and stratosphere are available.

The purpose of this paper is to present preliminary results of momentum flux and momentum flux divergence calculations made using data from the Sunset radar. In an attempt to illustrate changing conditions, we present results from a day when the background wind speeds aloft changed abruptly.

DESCRIPTION OF THE EXPERIMENT

The Sunset radar (GREEN et al., 1985) is located in a narrow mountain canyon 15 km west of Boulder, Colorado, and is just east of the Continental Divide. The array antenna of this VHF (ST) pulsed Doppler radar can be steered in the east-west or north-south vertical plane. During the experiment reported here, five antenna beam positions were used: vertical and 15° to the east, west, north, and south. Three consecutive observations were made at each beam position at 90-second intervals and then the beam was moved. A full cycle could thus be made each 20 minutes. The relative locations of the radar volumes are illustrated in Figure 1.

The synoptic situation early in the day chosen, January 28, 1985, was characterized by light winds throughout the height region sampled by the radar (from about 4 to 14 km). After about 15 UT, a weak jet stream sagged southward with winds at 10 km over the radar increasing from 10 m/s to over 30 m/s by 18 UT. Winds at all levels above 4 km were primarily from the west; surface wind data were not available.

The method of VINCENT and REID (1983) was used for this calculation. The vertical momentum flux, $\overline{u'w'}$ or $\overline{v'w'}$, is found from

$$\overline{u'w'}(z) = [\overline{V^2(\theta,R)} - \overline{V^2(-\theta,R)}] / (2 \sin 2\theta)$$

where V is the radial velocity, θ is the antenna beam angle, R is the range and z is the altitude. Altitudes from 4 to 14 km were sampled at 1-km intervals. Decreasing signal-to-noise sometimes rendered the upper level useless.

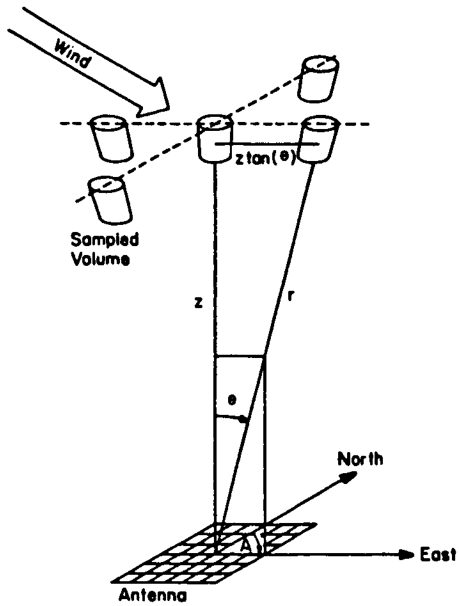

Figure 1. Schematic depiction of the radar beams positions at Sunset.

The calculation was made at a given height only if all beam positions were sampled every cycle during a full hour. Averaging periods of one hour and three hours were used; as the results are similar except that the three-hourly values are obviously smoothed, we have chosen to present the one-hour results in order to capture as much detail of the effects of transients as possible.

Figure 2 shows the hourly momentum flux from 00-18 UT. Values for the meridional component ($\overline{v'w'}$) are typically a few tens of cm^2/s^2 from about 00-09 UT, and then increase in magnitude to on the order of a m^2/s^2 after 09 UT. The most notable event is found below 5 km at 10-12 UT, when $\overline{v'w'}$ reached over $-20\ m^2/s^2$. The values for the zonal component ($\overline{u'w'}$) are usually less than a few m^2/s^2 before 09 UT, although a few magnitudes exceed 10 m^2/s^2. These results can be compared with the aircraft measurements given by LILLY and KENNEDY (1973). They report horizontally averaged momentum flux values of about 8 $dynes/cm^2$ (which corresponds with 2 m^2/s^2 for mean density of $5 \times 10^{-4}\ g/cm^3$); although their traces of integrated momentum flux show large variability, indicating local values range far from the mean. At 10-12 UT a maximum is found in $\overline{u'w'}$ at the same location where a minimum was found in $\overline{v'w'}$. After 12 UT the values of $\overline{u'w'}$ generally exceed 10 m^2/s^2 above 8 km, with a local minimum found at 11 km at 18 UT.

Figure 3 shows the vertical flux divergence of meridional and zonal momentum. These results were computed from the data in Figure 2 by taking differences across layers 1 km apart. No smoothing has been applied in an effort to preserve as much detail in the results as possible. The units used, $10^{-3}\ m/s^2$, correspond to 3.6 m/s/hour (e.g., the contour labelled $10 \times 10^{-3}\ m/s^2$ is the same as 36 m/s/hour). In Figure 3, the large values of zonal and meridional momentum flux divergence occur near 6 km at 10-12 UT. Otherwise, the meridional values are nearly all less than about 3 units. Alternating periods of large zonal values are found above 10 km at 14-18 UT. After about 11 UT, the contours of zero zonal momentum flux divergence slope

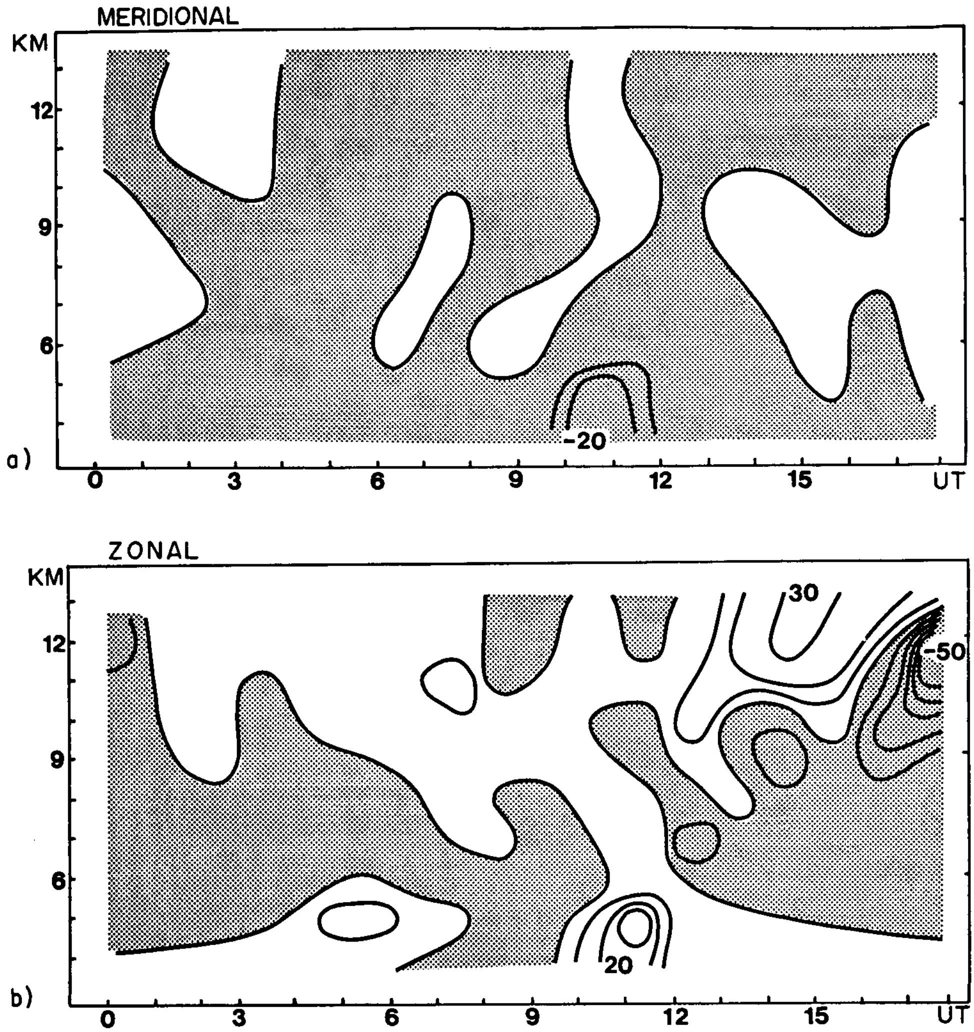

Figure 2. Time-height section of the vertical momentum flux at Sunset on January 18, 1985. Units: m^2/s^2. (a) meridional (b) zonal.

upward to the right, while at the same time the contours of zero meridional flux slope downward to the right. The significance of this pattern, if any, is not yet clear.

CONCLUSION

We have presented preliminary results of the momentum flux and flux divergence during a transient episode, as a jet stream moved over the radar. The zonal and meridional momentum flux and flux divergences displayed remarkable continuity with altitude in time, increasing in intensity as lee waves and other gravity-wave activity developed while the jet stream approached. The momentum flux values observed compare favorably with aircraft measurements made over similar topography, at least during the early part of the day. The accelerations due to the momentum flux divergence seem rather large at first

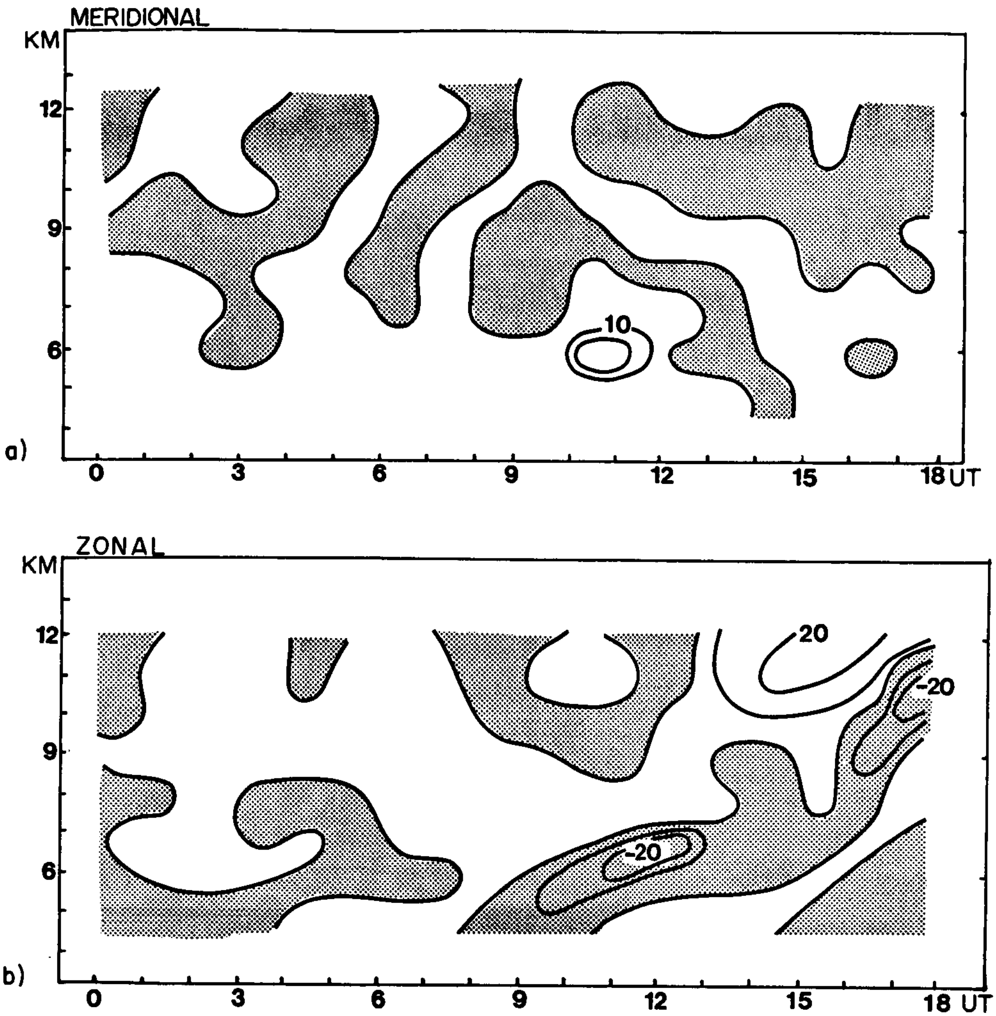

Figure 3. Time-height section of the vertical divergence of the vertical momentum flux at Sunset on January 28, 1985. Units: 10^{-3} m/s^2. (a) meridional (b) zonal.

glance, especially for the late part of the day. However, we note that there may be compensating forces due to effects not considered here, such as transverse circulations or, likely more important, scales of motion too small to be resolved by these data.

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