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WINDS AND WAVES (4 MIN - 11 YRS) IN THE UPPER MIDDLE ATMOSPHERE (60-110 KM) AT SASKATOON, CANADA (52°N, 107°W): M.F. RADAR (2.2 MHZ) SOUNDINGS 1973-1983

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INTRODUCTION

The Saskatoon MF Radar has been operating since ~1968, but in its present continuous-sounding, real-time processing mode since June 1978: 2.2 MHz; 50 kw, 20 μs pulse; 7.5 Hz pulse rate; 1 profile every 5 min; 32 heights, 49, 52 ---- 142 km. The real-time "full correlation analysis" is made possible by converting the 8-bit amplitudes to binary (0,1) with respect to the mean in ~30 sec blocks: partial correlations formed by the AND instruction are accumulated continuously for the whole record; cross-correlograms and autocorrelations result. In a second microcomputer the "proper" peaks are selected and their amplitudes and positions are found; these data plus the mean autocorrelogram are then used to calculate the velocities and pattern parameters -- the method is efficient and of high quality (MEEK and SOIFERMAN, 1979; MEEK, 1980; MEEK et al., 1979, GREGORY et al., 1979).

Most of the atmospheric data shown here were obtained since 1978. Prior to that time the limitations of computing systems usually allowed only noon data (1 hr) each day -- our interest has always been on the full climatology of the region. However now that we operate continuously each day, waves with periods from ~10 min to 5 years are available for study: gravity waves (GW), tides, planetary waves (PW) and circulation effects. We will show examples of all of these.

MEAN WINDS AND LONG PERIOD (≳10d) OSCILLATIONS

The basis for most analyses are 1h mean winds at 3 km intervals (Figure 1): such plots reveal th mean wind and its variations, the 24- 12-h tides, and G.W. fluctuations. The basic analysis is to fit a mean, and 24- 12-h harmonics to each 24-h of data; and then obtain means for monthly (30-d) and (sometimes) 10-d intervals.

Zonal and meridional cross-sections (10-d averages) are available for all years, but we show 1980 (Figure 2). Comparisons with CIRA (1972) demonstrate the need to update that model: e.g. October, May, June (EW) are usually stronger than CIRA; December weaker. Magnitudes may differ by factors of 2-3 within the vortex (GREGORY et al., 1981; MANSON et al., 1981a). Important differences from an expanded data set (GROVES, 1969) also exist: his reversed zonal flow above ~90 km appears too strong, probably due to tidal contamination. More seriously the meridional flow at Saskatoon is inconsistent with Groves and also simple circulation models that require poleward/equatorward flow above ~80 km in winter/summer to be consistent with the thermal winds. The role of gravity waves in depositing momentum and balancing the coriolis torque is being actively studied at Saskatoon -- winter is a puzzle because of the equatorward flow above ~85 km.

The 12-, 6-, 3-mth oscillations (Figure 3) are consistent with the zonal cross-sections, and are stable from year to year (MANSON et al., 1981b). Our results (12-6-mth) are consistent with CIRA below ~100 km, but differences above are probably due to tidal contamination in CIRA. By using good quality noon data the strengths of the summer and winter mesospheric vortices have been

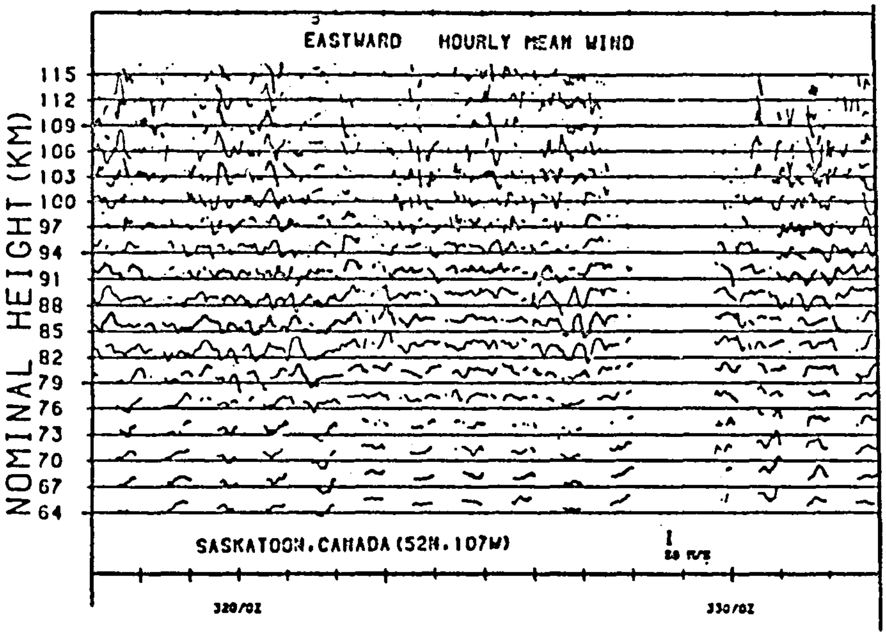

Figure 1. Winds during the November 1981 ICMUA Tidal campaign (~5 km).

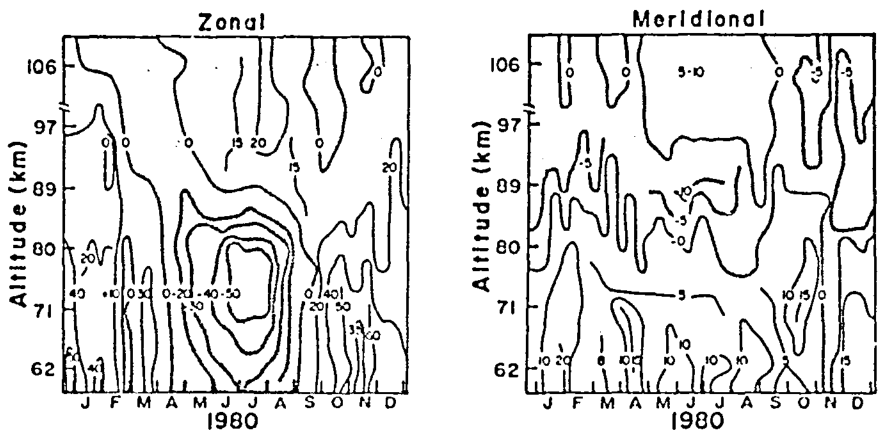

Figure 2. Zonal and meridional winds (10-d averages used): 1980.

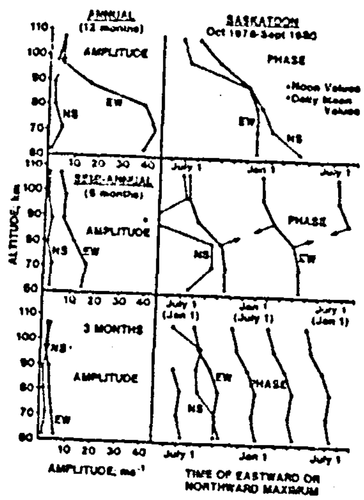

Figure 3. Long period oscillations.

studied from 1974 -- the vortices have strengthened by factors of >2, largest in winter, as the sunspot number has increased (GREGORY et al., 1981). This effect is believed to be independent of, or not caused by, tidal fluctuations.

Finally fluctuations of the mean winds and tides occur during STRATWARMS (MANSON et al., 1981a,c; SMITH et al., 1982). There are frequently oscillations with periods of several days up to ~100 km, as well as strong reversals of the zonal flow below ~80 km. We are involved with DYNAMICS/SWAMP of MAP.

Comparisons of hourly and monthly mean winds from the Radar and from rocket data (e.g. GREGORY et al., 1981) obtained from Primrose Lake (340 km NW), show excellent agreement. These data, and the nature of the wind field discussed here, demonstrate the quality of the winds data from the M.F. radar.

SPECTRAL ANALYSIS (10d - 6h)

Various forms of analysis have been applied to the continuous hourly data, divided into ~30d (monthly) sets. The result of a swept-frequency covariance calculation is shown in Figure 4, for a typical winter month (February 1981). The 12-h tide is dominant, and 24-, 8-, 6-h tidal oscillations grow with altitude. There are strong oscillations of 16d period also, possibly associated with the STRATWARM of 1981. Seasonal variations are shown in the Fourier analysis for 89 km (Figure 5): the 24-/12-tide becomes larger/smaller in summer months; and 2.1, 5-d oscillations are evident especially, but not exclusively, in summer. These oscillations and others with periods of 1.25 - 16d are frequently observed; these are consistent with the planetary normal modes investigated by SALBY (1981). Careful study of the spectra also show the presence of 16h (16.2±.7) and 10h (9.7±.4h) oscillations which may be due to the modulation of the 12-h tide by the 2.1d wave (MANSON et al., 1982).

The P.W. oscillations are being compared with meteor-radar winds from Monpazier (France) during 1979/1980, and there is excellent agreement between the occurrence of such oscillations, and also their amplitudes and vertical wavelengths (J. L. Fellous - private communication, to be published).

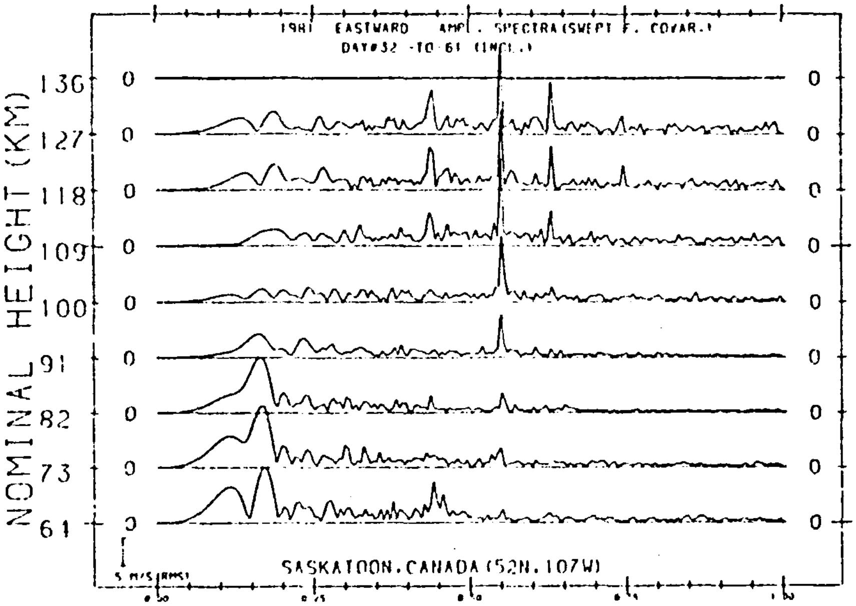

Figure 4. Spectra for February 1981 — during STRATWARM (-5 km).

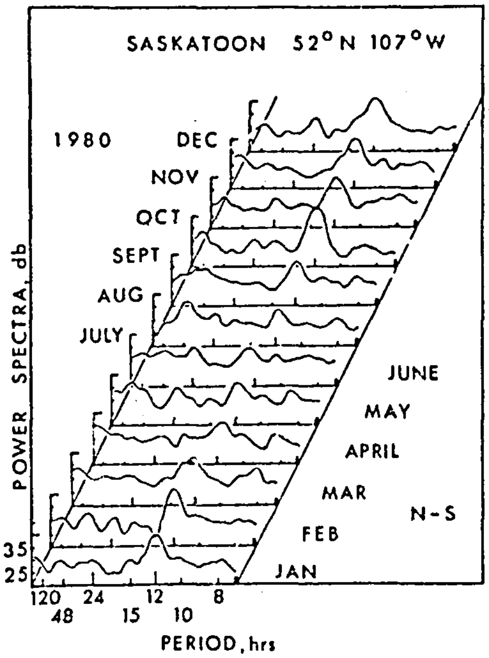

Figure 5. Fourier analysis for 89 km.

TIDES (12- 24-h)

The monthly semi-diurnal tides evidence a clear seasonal variation in their characteristics (MANSON et al., 1981a,c). Figure 6 shows the so-called spring-equinoctial months of March, April, May. March is typical of a winter month, with short vertical wavelengths and large amplitudes (Nov-March are winter-like). May is summer-like in phase, and its wavelength is usually intermediate between winter (43±6 km) and summer (180±90 km) (MANSON et al., 1982; MANSON et al., 1983). The transitions from winter to summer-like states (June-August) are very regular and rapid being centered on March 30 and November 1-10 and requiring only 15d. A summary of these features is shown in Figure 7. Sophisticated non-classical theoretical models like that of WALTERSCHEID and DEVORE (1981) and FORBES (1982b) produce some of these features, e.g., longer wavelengths in summer (2,2 mode dominant) and shorter in winter ((2,3)-(2,5) modes effects); but their phases and the magnitudes, rapidity and regularity of the seasonal changes are not explained. Comparisons with French (J. L. Fellous) and New Zealand (M. J. Smith, G. J. Fraser) data show basically similar behaviour to the Saskatoon 12-h tide. The daily tidal fluctuations are discussed elsewhere (MANSON et al., 1982): possible causes are non-migrating tides, local tidal forcing and gravity-wave coupling.

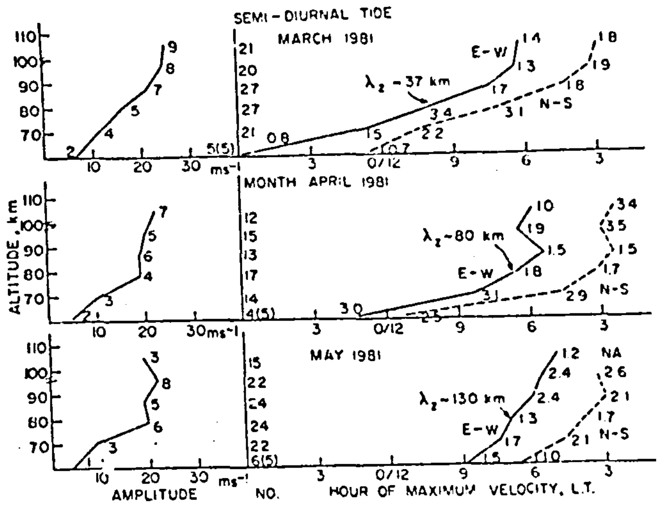

Figure 6. Semi-diurnal tides (amplitudes are arithmetic means; s.d. shown.

The 24-h tide is more irregular on a daily or monthly basis. Theory (e.g. FORBES 1982a) suggests that modes such as the evanescent S_{-1}^{1}, S_{-2}^{1} and propagating S_{1}^{1} should be prese- There is actually a seasonal variation, with longer wavelengths in summe months, and a distinct phase variation (Figure 8), which theories have not successfully predicted. The New Zealand data for 1978-1980 (M. J. Smith, G. J. Fraser - private communication, to be published) shows a similar seasonal morphology closely involved in ATMAP (MAP) and the ICMUA Tidal Working Group.

GRAVITY WAVES (4 min - 6 h)

Ever since the elegant and perceptive paper of C. O. HINES (1960) on

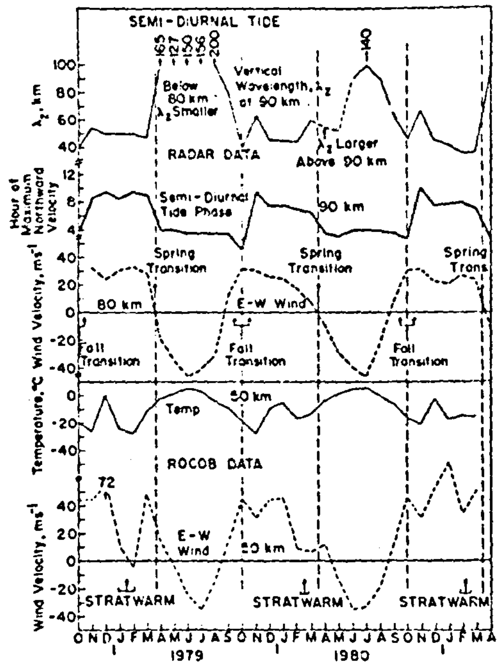

Figure 7. Semi-diurnal tidal variations.

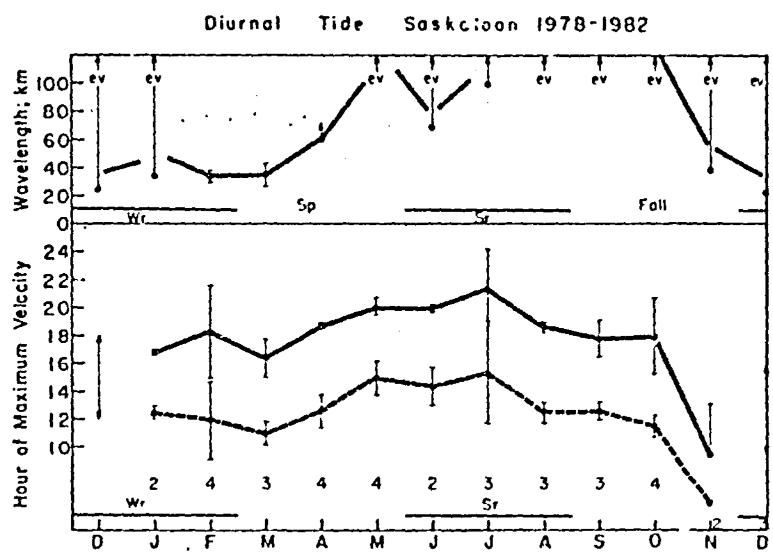

Figure 8. Diurnal tide variations.

gravity waves their presence and importance in the atmosphere has become increasingly obvious. At Saskatoon plots of the 5 min wind vectors reveal fluctuations clearly related to internal gravity waves: the use of 1-h means to filter out the shorter periods is therefore very important.

Special observations were carried out in 1978/1979: six 3h campaigns with 1 min sampling times (MANSON et al., 1981d). These data showed that short period waves (5 min $\leq \tau \leq$ 90 min) were present in all seasons; the wave oscillations also revealed polarization, consistent with the absorption or reflection of G.W. with phase velocities parallel to the mean flow. We show in Figure 9 (right) profiles of the r.m.s. gravity wave oscillations, the energy scale heights h_o, and the corresponding energy dissipation (ϵ_μ)/group velo-

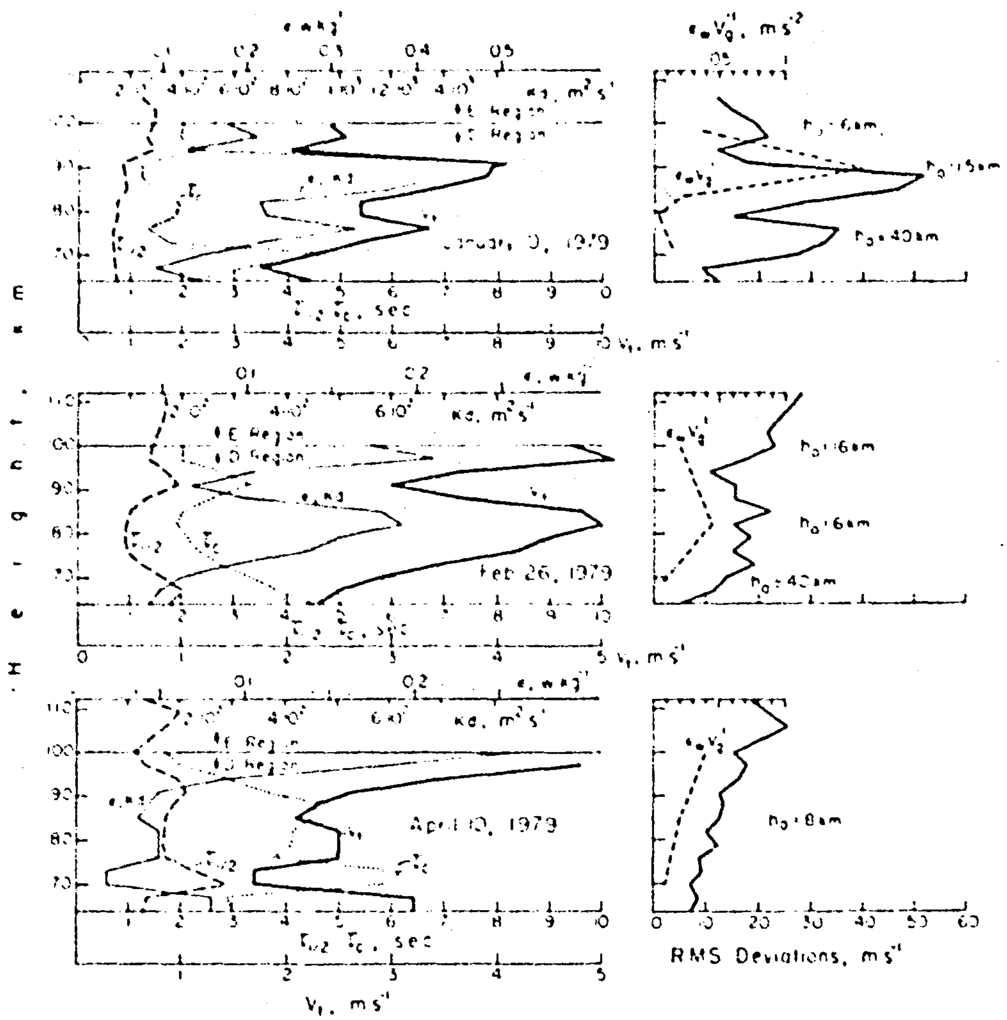

Figure 9. Energy dissipation by turbulence (ϵ_μ) and eddy diffusion (Kd).

city (V_g): $1<V_g<10$ m/s. The profiles of ϵ_{μ} ($\sim$0.05–0.3 W/kg) agree well with those derived independently from t_c (fading time seen by a moving observer): V_t is the s.d. of the random velocity of the scatterers assuming isotropic turbulence; and ϵ, Kd the energy dissipation by turbulence and eddy diffusion respectively (ZIMMERMAN and MURPHY, 1977). Values of Kd (200–600 m^2/s) compare well with other observations.

We have earlier data, which also illustrates interactions between the G.W. and the mean flow. Variations of the heights of maxima for the r.m.s. deviations of the wind correlate very well with heights of reversal of the mean flow, on a monthly basis, 1972–74 (MANSON et al., 1975, 1976). This is consistent with G.W. whose phase velocities are antiparallel to the direction of the main vortex (40–80 km), which reach the reversal height, and then experience critical levels. Large amplitudes and eventual dissipation result, and their momentum is deposited into the flow. The importance of such a process has only recently become evident, as zonal and meridional cross-sections from observation (Figure 2) and circulation models have appeared. As discussed by LINDZEN (1981) and others, some momentum deposition is required to close off the summer and winter vortices and balance the considerable coriolis torque. As noted before, the winter equatorward flow (>80 km) is a problem, as its torque would be additive to any GW momentum deposition!

Finally for several years we have compared the energy densities of PW, Tides and GW (MANSON et al., 1981a,c). Near 80 km all waves are comparable, with GW (<1h) largest; but by 100 km their order (increasing) is PW; tides; GW (>1.5h), GW (<1.5h): values are largest in winter and late summer. Estimating vertical group velocities, the values of ϵ are $\sim10^{-3}$–10^{-4}; <0.05; $\sim$0.1 W/kg, respectively.

Considerable effort is now going in to measuring GW characteristics with a spaced winds system (GRAVNET), to contribute to the MAP GRATMAP project. This should help our understanding of all scales of motion in the upper middle atmosphere.

REFERENCES

Forbes, J. M. (1982a), J. Geophys. Res., 87, 5222.

Forbes, J. M. (1982b), J. Geophys. Res., 87, 5241.

Gregory, J. B., C. E. Meek, A. H. Manson and D. G. Stephenson (1979), J. Applied Met., 18, 682.

Gregory, J. B., C. E. Meek and A. H. Manson (1981), Atmosphere-Ocean, 19, 24.

Gregory, J. B., C. E. Meek and A. H. Manson (1981), Report No. 5, Dynamics Group, I.S.A.S., University of Saskatchewan, Saskatoon, Canada

Groves, G. V. (1969), J. Brit. Interplanet. Soc., 22, 285.

Hines, C.O. (1960), Can. J. Phys., 38, 1441.

Lindzen, R. S. (1981), J. Geophys. Res., 86, 9707.

Manson, A. H., J. B. Gregory and D. G. Stephenson (1975), J. Atmos. Sci., 32, 1682.

Manson, A. H., J. B. Gregory and D. G. Stephenson (1976), J. Atmos. Terr. Phys., 38, 143.

Manson, A. H., C. E. Meek and J. B. Gregory (1981a), J. Geophys. Res., 86, 9615.

Manson, A. H., C. E. Meek and J. B. Gregory (1981b), J. Geomag. Geoelectr. 33, 613.

Manson, A. H., J. B. Gregory and C. E. Meek (1981c), Planet. Space Sci., 29, 615.

Manson, A. H., J. B. Gregory and C. E. Meek (1981d), J. Atmos. Terr. Phys., 43, 35.

Manson, A. H., C. E. Meek, J. B. Gregory and D. K. Chakrabarty (1982), Planet. Space Sci., 30, 1283.

Manson, A. H., C. E. Meek and J. B. Gregory (1983), J. Atmos. Sci. (in press).
Meek, C. E., A. H. Manson and J. B. Gregory (1979), J. Atmos. Terr. Phys., 41, 251.
Meek, C. E. and J. Soiferman (1979), A real time ionospheric drift system, Dynamics Group Report, ISAS, University of Saskatchewan, Saskatoon, Canada
Meek, C. E. (1980), J. Atmos. Terr. Phys., 42, 835.
Salby, M. L. (1981), J. Atmos. Sci., 38, 1827.
Smith, M. J., J. B. Gregory, A. H. Manson, C. E. Meek, R. Schminder, D. Kurschner, and K. Labitzke (1982), Space Research, COSPAR, Ottawa.
Walterscheid, R. L. and J. G. DeVore (1981), J. Atmos. Sci., 38, 2291.
Zimmerman, S. P. and E. A. Murphy (1977), Dynamical and chemical coupling, D. Reidel, Holland, p. 35.