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A comparison of mean winds and gravity wave activity in the northern and southern polar MLT

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Abstract. Mean winds and waves observed in the mesosphere and lower thermosphere with MF radars located at Davis (69°S, 78°E) and Poker Flat (65°N, 147°W) are compared. Measurements covering the period from 1999 to mid 2000 show differences in the strength of the horizontal wind fields. In the southern hemisphere the zonal and meridional winds reach their maximum values near the summer solstice, but are delayed by 2-3 weeks in the northern hemisphere. Gravity wave variances also show significant differences, as do the strength of vertical velocities.

Introduction

The polar middle atmosphere is one of the least understood regions of the Earth's atmosphere, with the summer polar mesopause the coldest place in the Earth's environment. The cold temperatures lead to the formation of such phenomena as polar mesospheric summer echoes (PMSE), polar mesospheric clouds (PMC) and noctilucent clouds (NLC).

A recent issue is whether PMSE are weaker in the southern polar mesosphere than they are at northern polar latitudes [*Huaman and Balsley*, 1999]. One explanation is that the Antarctic summer mesopause is warmer than the Arctic mesopause. Recent rocket observations show, however, that the thermal structure of the two regions are surprisingly similar [*Lübken et al.*, 1999], suggesting that other factors, such as lower water vapor concentrations in the southern hemisphere, might explain the difference.

If we are to understand hemispheric differences then all factors, including dynamics, need to be considered. Theoretical and experimental studies show that internal gravity waves play an important role in the middle atmosphere. This is particularly true for the polar region where the Arctic mesopause is ~60 K colder in summer than in winter [*Lübken and von Zahn*, 1991]. Gravity wave driving produces a mean meridional circulation from the summer to the winter hemisphere, and the associated rising and sinking motions lead to strong departures from radiative equilibrium [*Garcia*, 1989; *McIntyre*, 1989].

Radars provide one way of studying possible hemispheric differences in the mesosphere. *Vincent* [1994] discussed MF radar observations made at Mawson Base (67°S, 63°E). Comparisons with MST radar observations from Poker Flat (65°N, 147°W) and Andoya (69°N, 16°E) suggested hemispheric differences in mean winds and gravity wave amplitudes. However, the relatively small height coverage and limited duration of the MST radar observations made direct comparisons difficult.

In 1994 the Mawson MF radar was moved to Davis (69°S, 78°E) and upgraded. In October 1998 a similar MF radar was constructed at Poker Flat (PF) by Communications Research Laboratory. The conjunction of similar systems at complementary latitudes allows us to explore possible hemispheric differences in more detail. The focus of this paper is on the summer polar mesopause.

Observations

Data Collection and Analysis

The Davis and Poker Flat MF radars operate at frequencies of 1.94 MHz and 2.43 MHz, respectively. Both radars use a pulse length of ~4 km, but data are oversampled at 2 km height intervals every 2 min. In order to remove outliers caused by poor signal-to-noise the raw wind data were median filtered. The filtered data were then averaged to produce the zonal and meridional wind fields in 10-min intervals at each height.

Mean wind structure

Figure 1 shows time series of the zonal (EW) and meridional (NS) winds for Davis and PF at heights of 80 and 88 km, respectively. These heights were cho-

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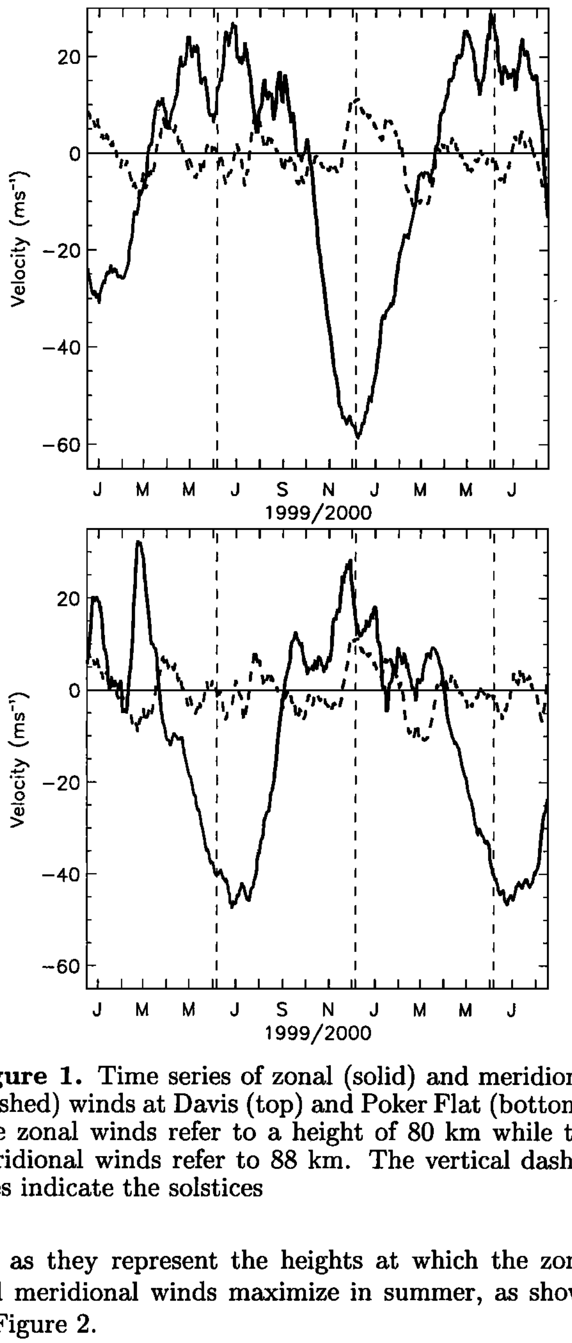

Figure 1. Time series of zonal (solid) and meridional (dashed) winds at Davis (top) and Poker Flat (bottom). The zonal winds refer to a height of 80 km while the meridional winds refer to 88 km. The vertical dashed lines indicate the solstices

sen as they represent the heights at which the zonal and meridional winds maximize in summer, as shown in Figure 2.

The time series show interesting differences. In particular, the time of maximum westward and equatorward flow at Davis both occur within a few days of the December solstice. At PF, however, the wind components reach their maximum values 14-21 days after the June solstice. Best estimates of the dates at which the components reach their maximum values are shown in Table 1.

The vertical profiles shown in Figure 2 consist of 10-day averages around the dates shown in Table 1. The westward winds at Poker Flat increase more slowly with height than at Davis and the maximum value is some 10 ms^{-1} weaker. The meridional winds, however, peak at both stations at the same height of $\sim$88 km, which is the height of maximum zonal shear. It is noteworthy that the peak meridional flow of $\sim$18 ms^{-1} at Poker Flat is a stronger than at Davis ($\sim$13 ms^{-1}), and is stronger at all heights between 80 and 100 km.

Given the rołe that gravity wave drag plays in closing the zonal jet and driving the meridional circulation the differences in the EW and NS winds at the two stations suggests that the wave driving may be different between hemispheres.

Gravity wave variances

The good time resolution available means that gravity wave energy fluxes can be estimated down to periods of a few minutes. Total horizontal wind variances, $\overline{u'^2} + \overline{v'^2}$ were found by computing power spectra of the EW (u') and NS (v') perturbation velocities. At periods shorter than 12 hr the spectra have an approximately $f^{-1.5}$ trend with increasing frequency, f. At high frequencies (periods less than $\sim$1 hr), however, the spectra flatten due to the effects of noise and uncertainties in the wind measurements. The spectra were Wiener filtered by computing the noise floors and subtracting

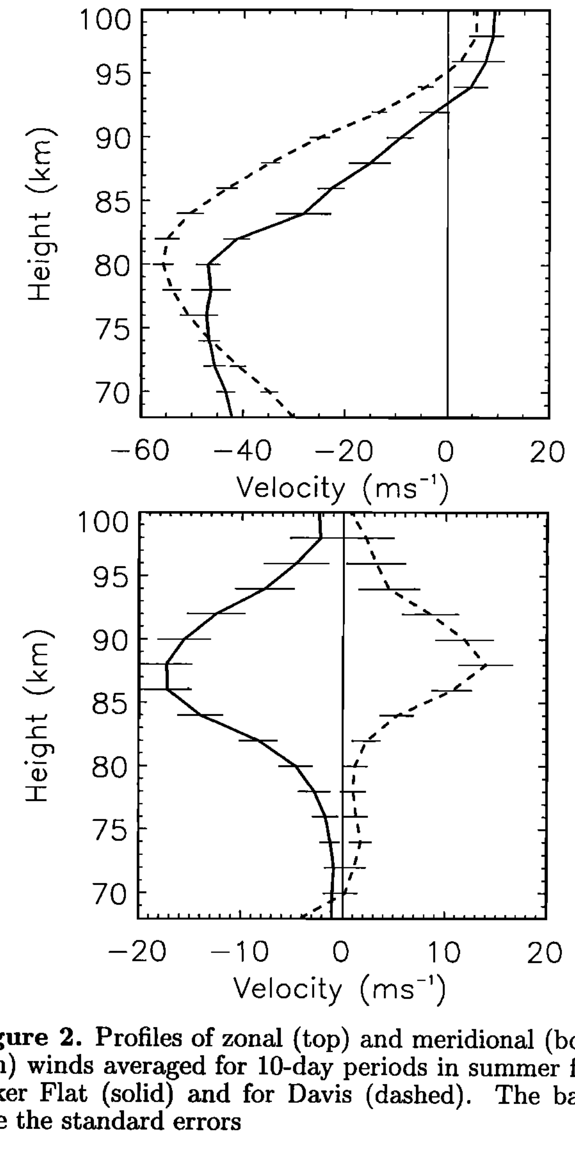

Figure 2. Profiles of zonal (top) and meridional (bottom) winds averaged for 10-day periods in summer for Poker Flat (solid) and for Davis (dashed). The bars give the standard errors

Table 1. Dates of Maximum Westward and Equatorward Flow

	Zonal	Meridional
Davis	17 Dec (351)	28 Dec (362)
Poker Flat	12 Jul (193)	5 Jul (186)

Numbers in brackets are day of year

them from the spectra at each height [*Press et al.*, 1992]. Finally, the spectra were integrated to derive the variances for different period bands.

Vertical profiles of wave variance in the 20-min to 8-hr period band averaged for a 30-day period around the respective summer solstice in each hemisphere are shown in Figure 3. The variances grow steadily with height at Poker Flat. The growth is much slower than the approximate $\exp(-z/2H)$ growth expected for waves that are not breaking or dissipating. The density scale height, H, is about ~ 5 km in July [*Lübken*, 1999], which means that wave variances should grow by a factor of about 20 over the 70-100 km height interval. The vertical structure is more complicated at Davis, with a minimum in wave variances at 80 km. Inspection of the data shows that this is a real feature and not an artifact caused by data of poorer quality at lower heights.

Discussion

Comparisons of the dynamics of the southern and northern polar MLT using similar MF radars located at Davis and Poker Flat show interesting differences around the time of the respective summer solstices. The strongest zonal and meridional winds occur closer to the summer solstice at Davis than at PF, similar to the offset in temperature peaks from HRDI data presented by *Huaman and Balsely* [1999].

The long-term variations in temperature and wind are controlled by the seasonal variations in solar insolation and dynamics. The radiative relaxation times are only a few days in the mesosphere, whereas the time scales representing wave forcing are significantly longer [e.g. *Andrews et al.*, 1987]. Hence, the greater symmetry of MLT winds and temperatures around the austral summer solstice suggest that radiative effects are stronger in the southern hemisphere and wave driving effects are more important in the northern hemisphere in determining the state of the summer polar MLT.

The stronger summer zonal winds and weaker meridional winds at Davis compared with PF suggest that gravity wave effects are weaker in the austral summer, consistent with the results in Figure 3. Wave variances show a slow monotonic growth at PF, but there is much stronger growth at Davis. The height structure of the Davis variances, with a minimum at the same height as where the zonal westward winds are strongest (c.f. Figure 2), may indicate a different wave spectrum between hemispheres. Wave breaking constrains wave amplitudes to $u' \sim |\overline{u} - c|$ [*Fritts*, 1984], which suggests that the wave spectrum at Davis contains waves with substantial westward phase velocities, c. Whether these differences are due to differences in wave sources and/or the filtering effects of the background winds is unknown.

Temperatures in the summer polar MLT are partly determined by the strength of rising motions (upwelling) over the pole and the consequent adiabatic cooling. The observed differences in meridional velocities $\overline{v}$ imply hemispheric differences in the strength of the upwelling. At heights near 88 km the time series of $\overline{v}$ at PF shows a strong anti-correlation with temperatures observed at Andoya and the times of maximum occurrence of NLC and PMSE [see Figure 10 of *Lübken*, 1999], suggesting that $\overline{v}$ can be used as a proxy for gravity wave driving in computing the strength of the mean vertical motions, $\overline{w}$. This should be a valid assumption in the summer MLT since forced planetary waves are excluded by the westward winds at lower heights and transient waves, such as the 2-day wave, appear to induce equatorward winds of only ~ 1 ms^{-1} [*Lieberman*, 1999].

Assuming that $\overline{v}$ is zonally symmetric and, following the notation of *McIntyre*, [1989], the horizontal momentum equation is

$$-f\overline{v} = F(y,z) \approx -\frac{1}{\rho_o}\frac{\partial(\rho_o\overline{u'w'})}{\partial z} \qquad (1)$$

where $F(y,z)$ is the vertical gradient of the Eliassen-Palm flux. This assumes that $\partial\overline{u}/\partial t$ is negligible. Substituting $-f\overline{v}$ for $F(y,z)$ in the mass-continuity equation gives

$$\overline{w}(y,z_o) = \frac{1}{\rho_o(z_o)cos\phi}\frac{\partial}{\partial y}\left\{cos\phi\int_{z_o}^{\infty}\rho_o\overline{v(z)}dz\right\} \qquad (2)$$

The integral means that the $\overline{w}$ at a given level z_o is controlled from above (i.e. "downward-control") [*McIntyre*, 1989]. Since we have observations at only one

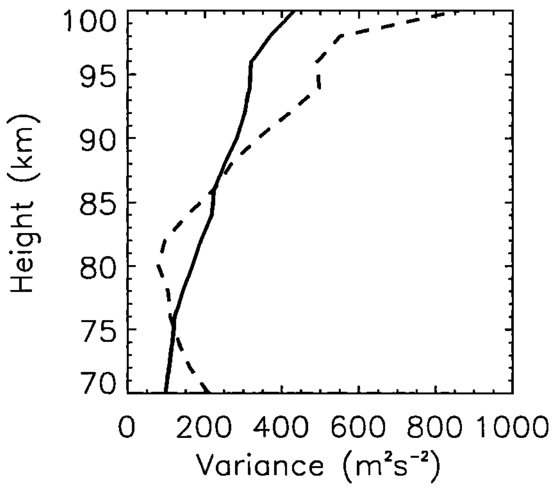

Figure 3. Profiles of variances in the 20 min to 8 hr period band averaged for 30 days around the summer solstice for Poker Flat (solid) and Davis (dashed)

latitude, ϕ, in each hemisphere, the meridional divergence term in (2) is taken as a finite difference between the latitude $\phi = 65°$ for PF and $\phi = -69°$ for Davis and the respective pole, where the cosine factor is zero. The results will refer to an intermediate distance $\overline{y}$ from the pole, corresponding to a mean latitude $|\overline{\phi}| \sim 78°$ ($\sim 80°$) for PF (Davis).

$$\overline{w}(\overline{y}, z_o) \approx -\frac{\cos\phi}{\rho_o(z_o \cos\overline{\phi})\Delta y}\left\{\int_{z_o}^{\infty} \rho_o \overline{v(z)} dz\right\} \quad (3)$$

where Δy is the distance of the radar site from the pole, taken as positive(negative) in the NH(SH).

Using the observed $\overline{v(z)}$, (3) was integrated using densities for 1 July taken from *Lübken*, [1999], with values above 93 km extrapolated to an altitude of 100 km. Figure 4 shows resultant vertical profiles of $\overline{w}$ at Davis and Poker Flat. It should be noted that the results at lower heights are insensitive to the density values above 93 km.

The values agree remarkably well with modeled results [*Garcia*, 1989], although this may be a coincidence given the relative crudeness of our calculations. The peak value of $\overline{w}$ in the SH is 25% smaller than in the NH and is similar in magnitude above 90 km. At lower heights the vertical motions are up to ~ 50% smaller in the SH. This suggests that the adiabatic cooling rates will be smaller by a similar factor.

Adiabatic cooling is an important factor in determining MLT temperatures. If the smaller SH $\overline{w}$ values are confirmed then this means that other factors, such as radiation and chemistry, are required to explain observations showing the Antarctic summer mesopause to be as cold as the Arctic [*Lübken et al.*, 1999]. However, smaller $\overline{w}$ values could account for the apparent lack of PMSE from the Antarctic summer MLT [e.g. *Huaman and Balsely*, 1999] since they would mean reduced upward transport of water vapor. Smaller upward velocities probably mean smaller residence times for ice particles and will therefore affect the formation and growth of the particles.

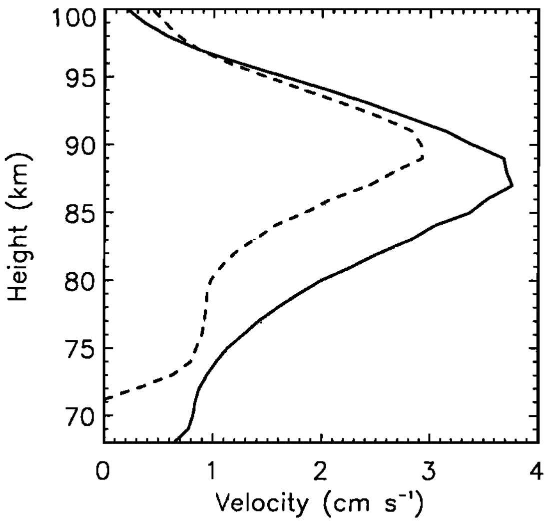

Figure 4. Profiles of vertical velocities in summer for Poker Flat (solid) and Davis (dashed)

These interpretations are based on single station measurements which are assumed to represent zonally symmetric motions. Circumpolar radar networks now evolving around both poles, together with upcoming TIMED satellite observations, will provide the zonally averaged quantities that are required to determine the factors that control the state of the summer polar MLT.

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