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MF radar observations of mean winds and tides over Poker Flat, Alaska (65.1° N, 147.5° W)

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Abstract. MF radar wind measurements in the mesosphere and lower thermosphere over Poker Flat, Alaska (65.1° N, 147.5° W) are used to study the features of mean winds and solar tides. Continuous observation with the newly installed radar is in progress and in the present study we have analyzed a database of the first 27 months (October 1998–December 2000) of observation. The observed mean wind climatology has been compared with previous measurements and the latest empirical model values (HWM93 model). Similarly, the tidal characteristics are described and compared with the Global Scale Wave Model (GSWM00).

The mean wind characteristics observed are fairly consistent with previous wind measurements by the Poker Flat MST radar. The main feature of the zonal circulation is the annual variation with summer westward flow and winter eastward flow. The annual mean zonal wind has a westward motion at altitudes below 90 km. The annual mean meridional circulation has mainly southward motion at 70–100 km. There is very good agreement between the radar zonal winds and the HWM93 model winds. Comparison of the meridional winds shows some discrepancy. Analysis of two years of data indicated that the year-to-year consistency is preserved in the mean circulation in the mesosphere.

Tidal characteristics observed are also consistent with previous measurements. Semidiurnal tides have the largest amplitudes in summer while the weakest amplitude is observed during the winter months. The vertical wavelength is longer during the summer season compared to the winter season. Comparison with the GSWM00 produces mixed results. There is reasonable agreement between the observed and modeled phases. Diurnal tide amplitudes are comparable in magnitude with that of the semidiurnal tide. Seasonal variation is less evident in the amplitudes. Comparison of the observed tidal parameters with the GSWM00 reveals some agreement and discrepancies.

Key words. Meteorology and atmospheric dynamics (climatology; middle atmosphere dynamics; waves and tides)

1 Introduction

Studies of the arctic middle atmosphere over Poker Flat, Alaska, took a new dimension with the joint research project recently launched by the Communications Research Laboratory of Japan and the Geophysical Institute of University of Alaska, USA. The motivation behind the “Alaska Project” was the complete understanding of the dynamics of the arctic middle atmosphere and ionosphere that contribute to the global environmental and climate changes. It has been found that several of the arctic atmosphere phenomena have direct impacts on the structure or variations of atmosphere over other regions. The main focus of the project is the observation of the middle atmosphere as well as the ionosphere by using various ground-based instruments. As part of the project various optical and radio equipments have been installed and currently the project is undergoing its observational phase. Mesosphere and lower thermosphere (MLT) observations (in the Alaska Project) are mainly conducted by using a medium frequency (MF) radar, a Fabry-Perot interferometer, a sodium lidar and a Rayleigh lidar. It is expected that the combined use of the data based on these collocated instruments will be able to address a number of issues of the dynamics of the high-latitude middle atmosphere.

Information on high-latitude middle atmosphere dynamics is documented through observations at a number of stations in the northern and southern hemispheres. At Poker Flat, previous observations using the MST radar during 1980s were useful to describe various features of the dynamics of the middle atmosphere. The radar relied on backscatter due to turbulent fluctuations in the index of refraction. In addition, meteor echoes have been observed on the radar and have been used to study the mean winds and tides in the 80–

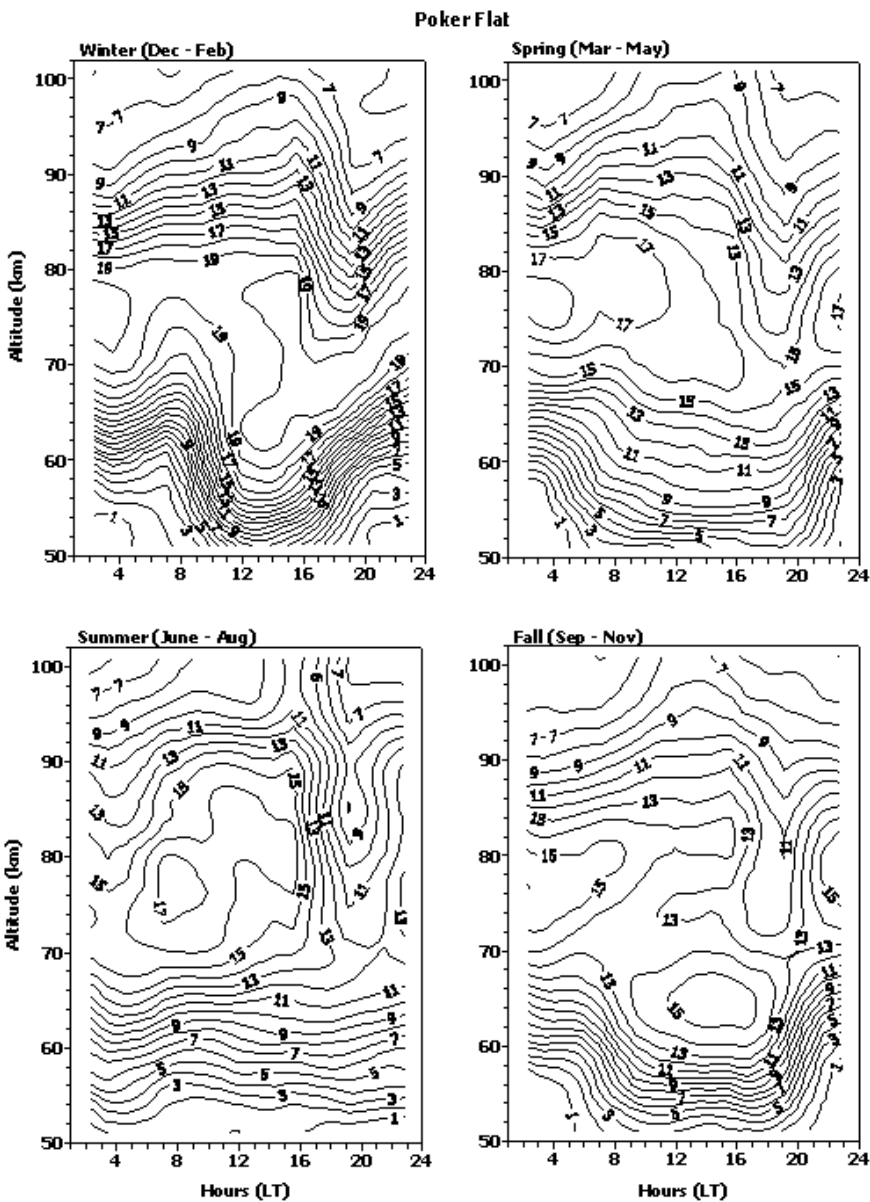


Fig. 1. Average number of wind estimates available per hour at each height gate (between 50 and 100 km) for summer, winter, spring, and fall seasons during 1999. Maximum number possible is 20 estimates/hour.

100 km height range (Avery et al., 1983, 1989; Balsley and Riddle, 1984; Tetenbaum et al., 1986). Various other analyses also provided valuable information on other phenomena such as gravity waves, turbulence, and longer-period motions in the high-latitude mesosphere (Carter and Balsley, 1982; Williams and Avery, 1992).

In this paper, we present an analysis of the wind field over Poker Flat for the first 27 months (October 1998–December 2000) of MF radar observation. The study is primarily concerned with the mean winds and the tidal oscillations in the wind field. The observed results are compared with the latest model results as well as with other earlier observations. We begin by describing the data collection and analysis procedures in Sect. 2. Results and discussion are presented in Sect. 3. The summary of the analysis is presented in the last section.

Table 1. Poker Flat MF radar system specifications

Characteristic	
Location	65.1°N, 147.5°E
Operation frequency	2.43 MHz
Peak envelope power	50 kW
Half-power pulse width	27 μsec
Antenna spacing	170 m
Sampling interval	2 km
Time resolution	3 min

2 Observations and analysis of data

A new MF radar which uses the spaced-antenna (SA) technique was established at Poker Flat, Alaska (65.1°N,

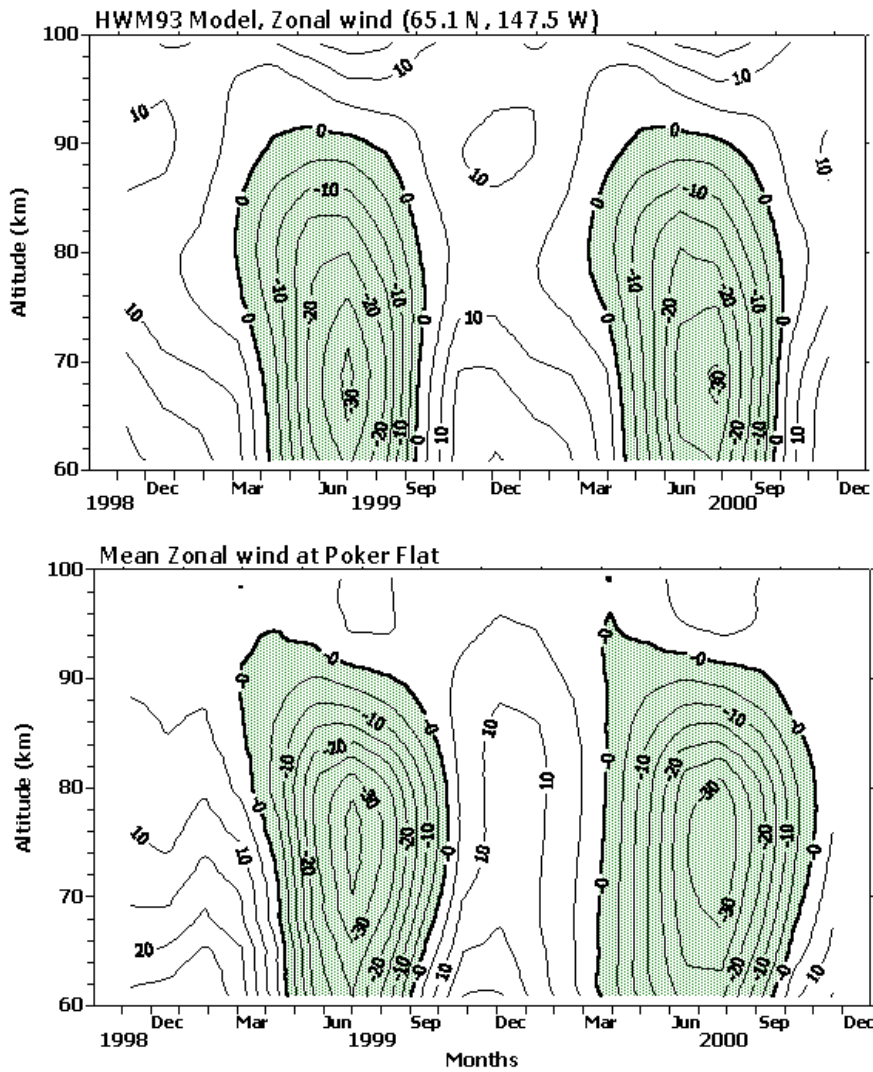


Fig. 2. Time-height cross section of the mean zonal wind component (bottom) observed at Poker Flat from October 1998 to December 2000. HWM93 (Hedin et al., 1996) model contours for Poker Flat are given in the top panel. Shaded regions represent the regimes of westward flow.

147.5° W) in October 1998. Since then, continuous observation of mesosphere lower thermosphere winds has been underway. The radar is almost identical to the two other MF radars installed by CRL, in Yamagawa and Wakkanai in Japan (for details see Namboothiri et al., 2000). Table 1 gives the specifications of the radar. The radar transmits circularly polarized radiowaves at a frequency of 2.43 MHz, which is slightly larger than the frequency (~ 1.95 MHz) used at Yamagawa and Wakkanai. Three sets of crossed dipoles, spaced at 170 m, are used for reception. The radar uses a pulse length of ~ 4 km but data are oversampled at 2 km height intervals and observations taken every 3 min. The analysis is carried out in real-time using the conventional full correlation analysis (FCA) (Briggs, 1984). Seasonal characteristics are studied by classifying the data into winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and fall (September, October, and November).

One significant point concerning the data collection over Poker Flat is the availability of echoes even from altitudes

below 50 km. Figure 1 shows the average number of wind values per hour at each height gate (between 50 and 100 km) for the four seasons of 1999. It should be noted that all of the data presented in the study are plotted against the “virtual height” of reflection. In a recent study, Namboothiri et al. (1993) described the effects of group retardation on 2.2 MHz signals at Saskatoon and predicted the real heights for different seasons and solar activity conditions. They showed that noontime group retardation is not severe during winter for both solar maximum and minimum conditions; for such periods the tidal and winds data are valid up to 111 km without any correction. In summer, however, daytime group retardation is more significant and suggest that, during solar minimum periods, the virtual height may be equivalent to the real height up to 97 km. The corresponding solar maximum height falls as low as 95 km. Generally, similar constraints are applicable to the Poker Flat data. The results presented here are for the period October 1998–December 2000, which was a solar moderate/maximum period. From the figure it can be seen that the data yield is

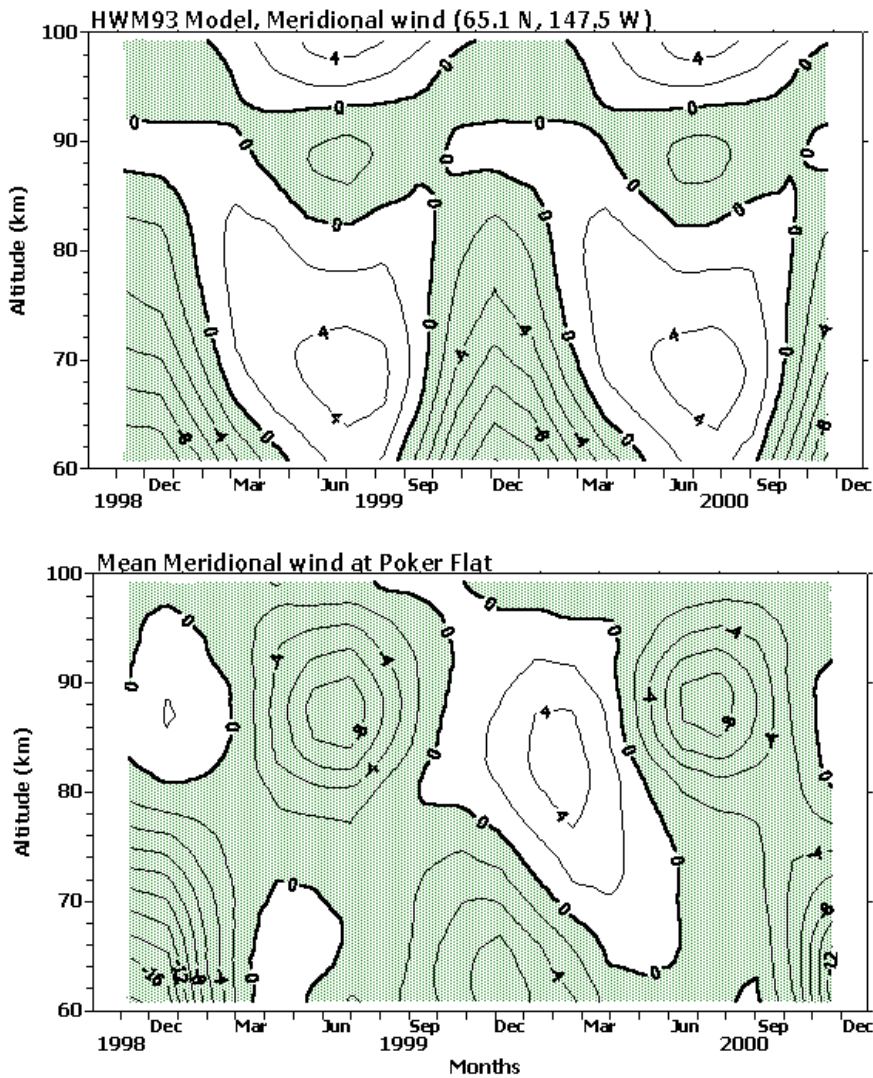


Fig. 3. As in Fig. 2 but for the meridional wind. Periods of equatorward motions are denoted by shaded regions.

low at 50–60 km during nighttime. However, the data yield is much better, even in the altitude range 50–60 km, during daytime. There is a clear seasonal variation in data yield at the lower altitudes where, during the summer, the time of day is larger than during winter. Generally, the maximum data rate is observed in the 70–80 km range. The winter season is characterized by the largest number of wind values; a comparatively lesser data rate is observed in the fall season. The increased data availability in the altitudes near 50 km is due to enhancements in electron density, which may be the effect of aurora and energetic particle precipitation in the polar latitudes. Igarashi et al. (2000) reported larger D-region electron density distributions (compared to the IRI-model and Wakkanai, a mid-latitude station) over Poker Flat. The low altitude echoes are also observed in southern hemispheric high latitudes. MF radar observations at Scott Base, Antarctica (77.9° S, 166.8° E) showed some evidence of ionization, even at altitudes between 40–50 km, and it is suggested that the observed ionization is caused by relativistic electrons penetrating into the upper stratosphere (von Biel,

1992, 1995). Rees (1963, 1989) discusses the production of winds from such an electron flux in connection with auroral ionization.

Harmonic analysis has been performed to derive the prevailing wind and tidal components. Hourly means of winds for each height bin were estimated by averaging all the available wind values for each hour. These hourly mean wind estimates for each height gate are averaged to make the monthly or the seasonal mean of mean winds. For the tidal fitting, we adopt the criterion that there should be at least 16 hours represented in the data for a given height. Also, we weighted the hourly means in the fit according to the number of values therein. Time series of amplitudes and phases were determined and studied the climatological aspects. Considering better data reliability, the analysis is mainly focused on the height range 60–100 km.

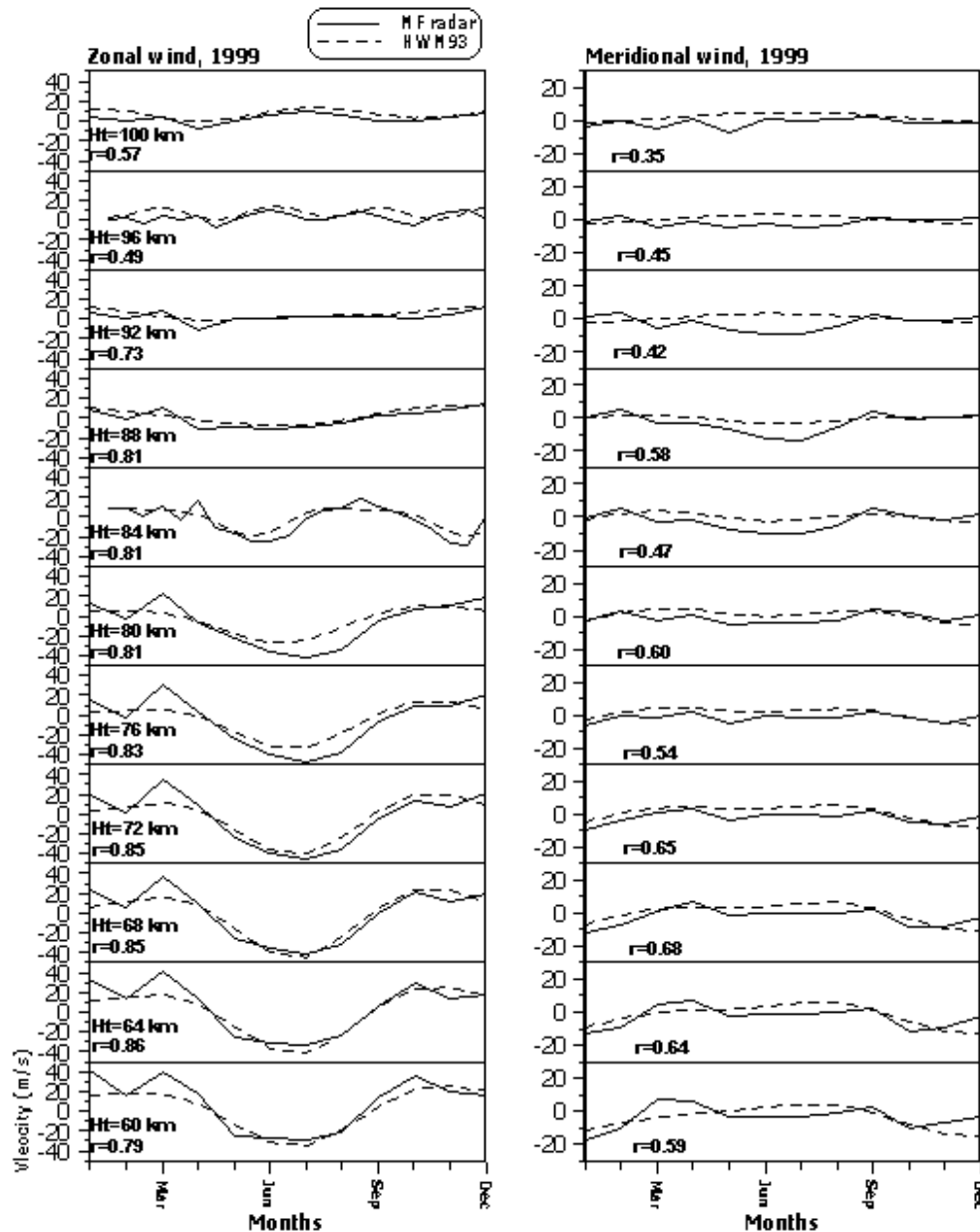


Fig. 4. The observed and modeled wind components for the year 1999. The data are given for 60–100 km (4 km interval). The correlation coefficient is given in each box.

3 Results and discussion

3.1 Mean winds

This section presents measurements of the mean circulation in the MLT region over Poker Flat and compares them with the HWM93 empirical model (Hedin et al., 1996). In Fig. 2, the bottom panel illustrates the time-height contours representing average prevailing zonal wind patterns for the first 27 months of MF radar observations at Poker Flat. The HWM93 empirical model winds for the latitude and longitude of Poker Flat are given in the top panel. Monthly mean values are utilized to develop these mean wind climatologies.

Describing the circulation characteristics, the dominant feature observed is the annual cycle of summer westward and winter eastward winds. The seasonal variation of the circulation is observed mainly at altitudes below 92 km. Two years of wind data presented here show qualitative agreement in the flow patterns. Generally, the spring reversal from eastward to westward occurs in March. The summer mesospheric westward jet maximizes near 75 km at about 35 m/s. This is almost consistent with the past MST radar measurements at Poker Flat (Carter and Balsley, 1982; Tetenbaum et al., 1986; Williams and Avery, 1992). The analysis of five years (1985–1989) of wind data by Tetenbaum et al. (1986)

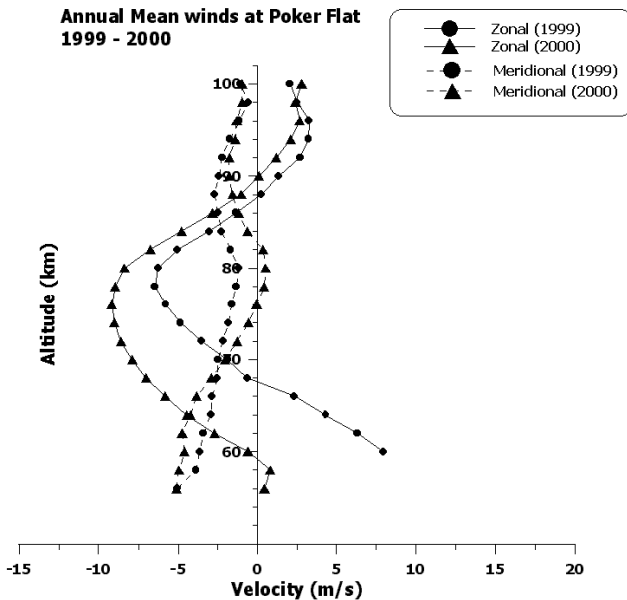


Fig. 5. Annual mean zonal and meridional winds at Poker Flat for the years 1999 and 2000.

has shown that the summer westward jet has a maximum amplitude of 30 m/s located at about 80 km. At 80 km the summer westward winds persist for about 6–7 months. The westward jet maximizes in June or July. The observed similarity, in the strength of the summer westward jet, with the previous MST radar measurements suggests that the interannual variability is less evident in the amplitude of the winds. The peak summer crossover occurs at around 90 km. Above this altitude the wind flow is mostly eastward at all times of the year. The summer to winter circulation commences during September–October. Winter eastward winds appear to have higher variability. The maximum amplitude of the eastward jet is 20–25 m/s. The eastward maximum tends to occur at a lower altitude (around 60 km). This is somewhat different to the behavior at midlatitude sites, where the maximum eastward winds occur at an altitude around 75 km. The spring-time seasonal changes show a more abrupt transition in 2000 than compared to the transition in 1999. The fall transition was comparatively gradual in 1999 and 2000. It occurred over a period of several weeks in the 60–90 km height region.

Comparison of the observed zonal winds and the HWM93 model winds reveals excellent agreement. The summer and winter cells have similar structure. The summer westward jet has approximately similar intensities both in model and observation. The maximum difference observed is only 5 m/s. The time occurrence of maximum westward winds is generally the same in both datasets. The peak summer reversal occurs around 92 km in the model outputs as well as in the observation. The winter eastward winds also have identical strength in both model and observation.

The time-height contours of the meridional wind are presented in Fig. 3 along with the corresponding model (HWM93) winds. The general pattern of the plots is somewhat similar, but there are also some differences. The variability of meridional winds is larger than the zonal winds.

The maximum intensity of southward or northward winds in the model and observation appears to be similar. However, there is some difference in the structure of these southward/northward cells. At altitudes above 92 km, the circulation shown by the model and observation differ in their pattern. At 88 km the observation shows a consistent strong southward winds (>8 m/s) during June/July. The model produces only weak winds at the same height and time of the year. These summer equatorward motions have also been observed at other high latitude stations, for example, Heiss Island, Molodezhnaya, Tromsø, and Scott Base (Lysenko et al., 1979; Fraser, 1984; Manson et al., 1992). The maximum amplitude of southward winds in the observation and model is 12–16 m/s and the corresponding northward wind amplitude is only 4 m/s. Comparison of the observed meridional winds with the earlier MST radar measurements (Tetenbaum et al., 1986) notes some differences. The MST observations basically indicated northward motions at altitudes 80–88 km throughout the entire year. Our observations show evidence of southward motions at similar heights during the summer season. As in the case of zonal winds, the MF and MST radar measurements produce meridional winds of comparable intensity. The observed features of the summer southward jet are consistent in both years. The location (88 km) of the jet is just below the zonal reversal height where the zonal shear is largest.

Comparing the MF radar mean winds at Poker Flat with the earlier Mawson (68° S, 63° E) measurements (Manson et al., 1991, Figs. 7–8), it can be seen that there is reasonable agreement between the two circulations. At both places the zonal winds are of similar strengths and also the circulation features have considerable resemblance. Similarly, the meridional contours also compare well in their structure and intensities of the southward/northward cell. The paper by Manson et al. (1991) extensively discussed and compared the wind contours at the high-latitude stations such as Poker Flat, Tromsø, Mawson etc. It is shown that the circulation at these stations is quite similar.

In order to facilitate the comparison more efficiently, we have calculated the correlation coefficients between the observation and the model values. In Fig. 4 we show the observed winds and the model values for altitudes (4 km interval) from 60 to 100 km for the year 1999. The correlation values are given in each box. It can be seen that the correlation is better in the case of zonal winds. The values are around 0.80 up to 88 km and above this altitude correlation becomes weak. However, the meridional winds show little correlation with the model values throughout the entire altitude. Again, the lower altitudes show comparatively better correlation than the upper altitudes.

The annual mean zonal and meridional profiles for Poker Flat are presented in Fig. 5. It follows from the figure that the average zonal wind has a westward circulation at altitudes below 90 km and above this limit eastward circulation prevails. The westward flow maximizes around 78 km at approximately 6–9 m/s. The meridional profile shows mainly southward motion in the altitude region 70–100 km

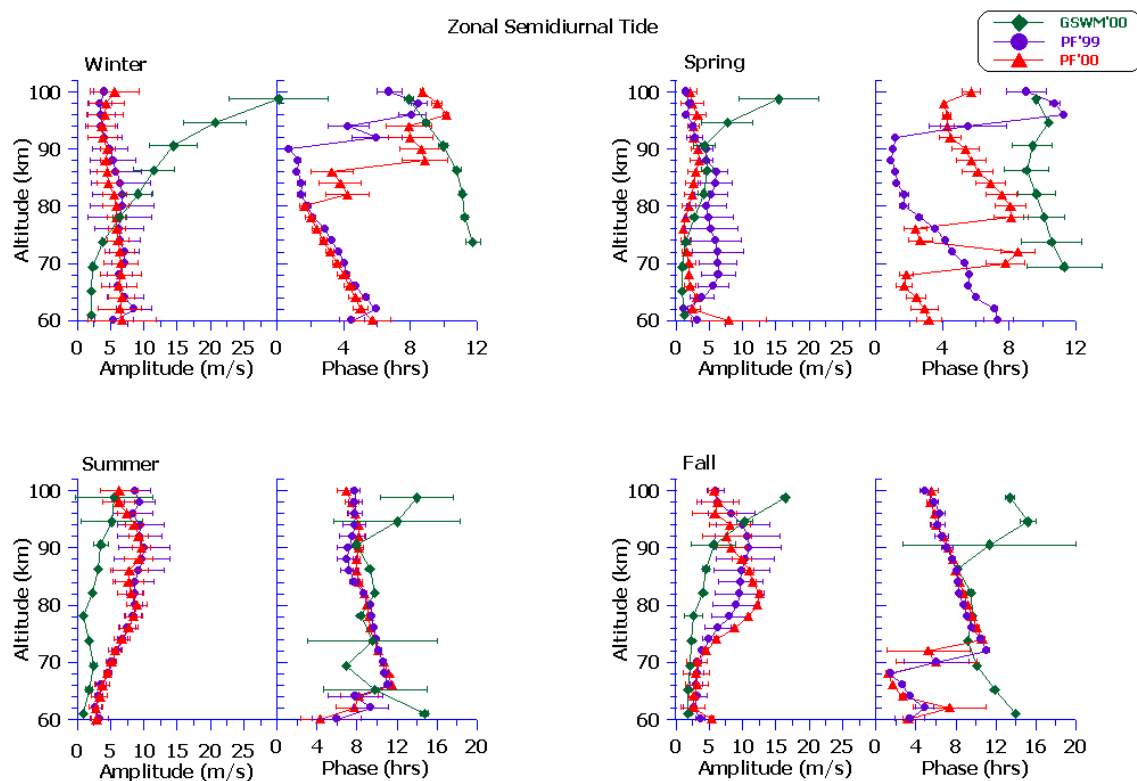


Fig. 6. Semidiurnal seasonal mean for summer, winter, spring, and fall of the Poker Flat radar data (zonal component) and the GSWM00 values. Data shown are for the years 1999 and 2000. Horizontal bars represent the standard errors.

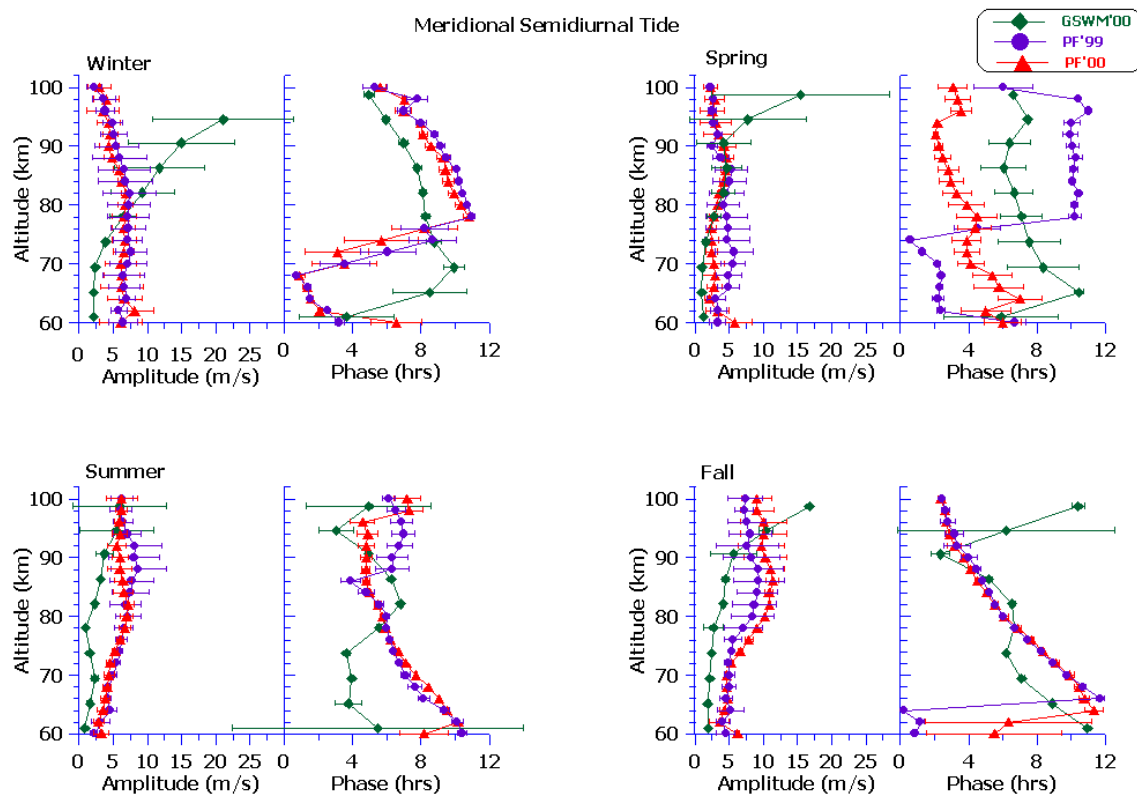


Fig. 7. As in Fig. 6 but for the meridional component.

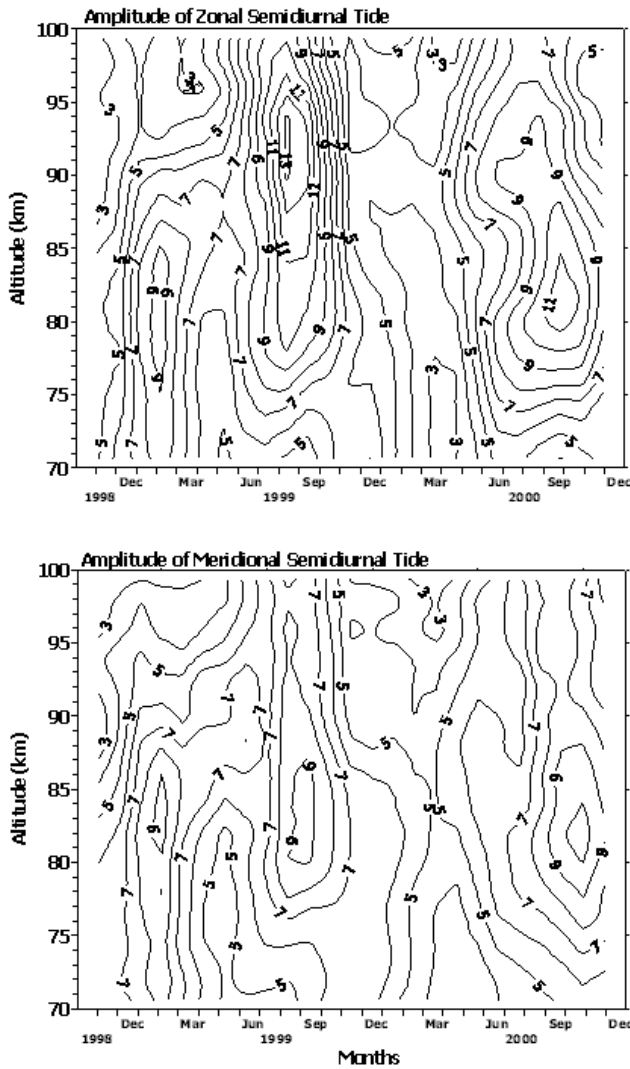


Fig. 8. Height-time cross section of amplitude of the semidiurnal tide of October 1998–December 2000.

and found that the average flow is less than 3 m/s in the same height region.

3.2 Semidiurnal tide

This and the following section present observations of the tidal winds over Poker Flat during 1998–2000. The semidiurnal and diurnal tides are discussed separately and compared with the Global Scale Wave Model 2000 (GSWM00) (M. E. Hagan, Private communication, 2001). The advantage of GSWM00 over the previous versions is that it can provide tidal parameters for each month. The vertical structures of the seasonally averaged semidiurnal tide at Poker Flat for 1999 and 2000, and the GSWM00 values are shown in Figs. 6 and 7. The horizontal bars on the plot represent the month-to-month variability about the average. For the purpose of comparison, the model results were sampled at heights corresponding to those of the radar data, and then the amplitudes and phases of the semidiurnal tide were averaged

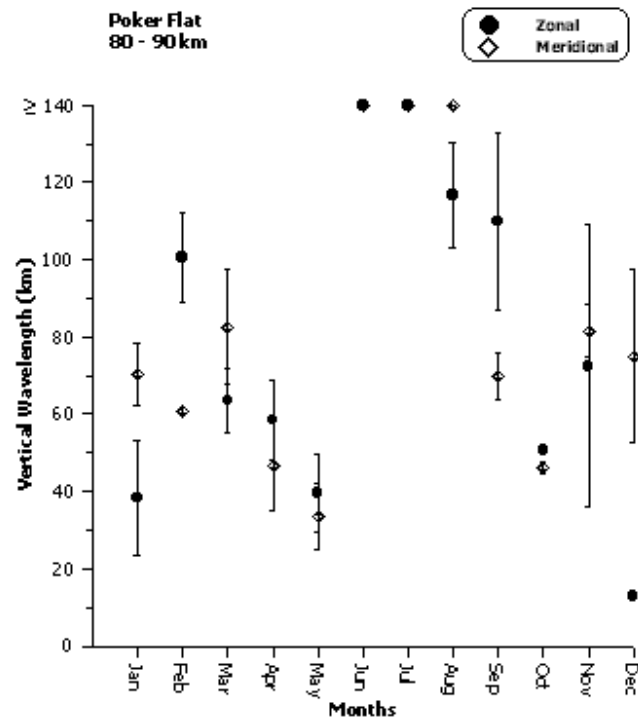


Fig. 9. Two-year averaged vertical wavelengths of the semidiurnal tide at Poker Flat. Vertical wavelengths ≥ 140 km are shown by symbols along 140 km level.

over 3-month blocks to obtain the seasonal means. It seems that each component shows almost year-to-year consistency in the amplitude and phase structures. The amplitudes of the meridional component are comparable with those of the zonal component. Weak seasonal variations of amplitude and phase are seen in both radar data and model. Tidal amplitudes are largest (10–12 m/s) in summer and fall seasons. The weakest amplitude (5 m/s) occurs in spring. Overall, the comparison between the observation and the model is not good, especially in the case of amplitudes. Generally, above 90 km the model overestimates the observed values. Below 90 km, observed values show larger strength than the model values. In almost all the seasons the model amplitude continues to grow with height. Above 80–90 km an abrupt growth in model amplitude is observed. Model amplitudes of values >30 m/s are not shown in the plot. Model profiles show the smallest amplitude in summer while the other seasons have comparatively similar values and variations. The phases of the zonal and meridional components of the semidiurnal tide generally show the downward phase progression during most of the months. Both model and observation display a larger vertical wavelength in summer and a shorter vertical wavelength in winter season. The vertical phase structure generally indicates a propagating wave. Comparison of the model and observed phases suggests that there is reasonable agreement between the two sets of values.

Figure 8 presents contour plots of the zonal and meridional components of semidiurnal tide amplitudes. The important

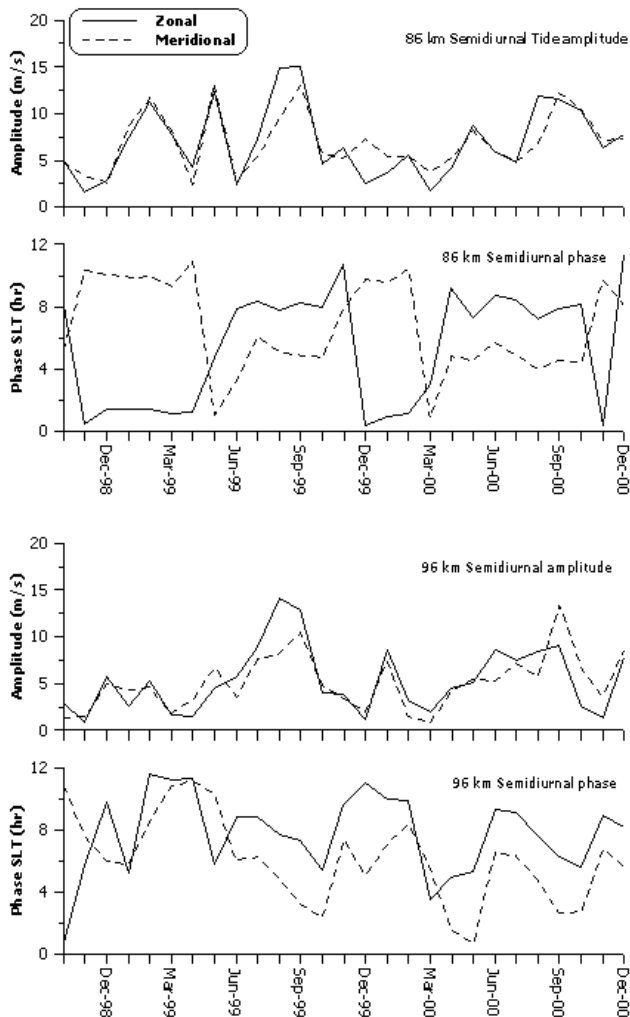


Fig. 10. Semidiurnal tidal amplitude and phase observed at Poker Flat for the heights 86 and 96 kms.

feature is the consistent amplitude maximum in the summer/early fall season. The maximum amplitude observed is 10–13 m/s. The zonal amplitudes are slightly larger than the meridional component. The winter/spring months are characterized by comparatively smaller amplitudes than the amplitudes in the other months.

The seasonally averaged tidal characteristics reported here are often consistently with the previous observations made at Poker Flat (Tetenbaum et al., 1986). However, it should be remembered that the comparison with the previous measurements is not entirely valid considering the interannual variability of tides. For example, Tetenbaum et al. (1986) reported semidiurnal tide contours of maximum strength 20 m/s for the 1983/1984 data. The present measurements indicated the value of the maximum contour as 13 m/s. High-latitude tidal structure shows considerable variations between different stations. Tetenbaum et al. (1986) observed large differences between the semidiurnal tides at Mawson (MacLeod and Vincent, 1985) and Poker Flat. Avery et al. (1989) compared the high-latitude tidal behavior by using

the data from several stations, including Poker Flat. They observed a number of similarities as well as differences between the stations. We plan to conduct more comparative studies using the Poker Flat data and concurrent data from other high-latitude stations.

The two-year (1999 and 2000) average vertical wavelengths of semidiurnal tides at Poker Flat are shown in Fig. 9. Here the height range considered is 80–90 km. It is clear that long vertical wavelengths (>140 km) or evanescent structure are observed during summer and comparatively shorter wavelengths are observed in other seasons. The vertical wavelength (zonal) observed in December is very low (~ 13 km). It is observed that in both years there are pronounced phase jumps which may have contributed to anomalous vertical wavelength. Apart from those phase jumps, the gradients in Fig. 6 for winter have reasonably uniform phase slopes corresponding to vertical wavelengths of about 60 km, comparable with the meridional values. Overall the observed values are similar with the MST radar measurements at Poker Flat (Avery et al., 1989).

Figure 10 shows the monthly amplitudes and phases for 1999–2000 at two selected heights. This plot illustrates the seasonal variations of tidal parameters at 86 and 96 km. It can be seen that the monthly amplitude of the zonal component correlates well with those of the meridional component. The phases also correlate reasonably well. The zonal phase leads the meridional phase by about 3 h, indicating that the tide is circularly polarized. As noted in the contour plots the amplitude maximum is observed in late summer/fall months. At both heights, the amplitude is similar in strength. Summer and winter seasons show distinct phase states. The period of almost constant phase state (especially at 86 km) in summer lasts longer than the period of constant phase state in winter. Phase transition is observed in spring and fall seasons. The analysis of two years of data presented here indicates that the annual pattern of amplitude and phase is repeated in consecutive years.

3.3 Diurnal tide

Turning our attention to the diurnal tides, Figs. 11 and 12 display the mean behavior of height dependencies of tidal parameters for Poker Flat during the four seasons. The data are presented in the same fashion as the semidiurnal tides (Figs. 6 and 7). First discussing the amplitudes, like the semidiurnal tide, the diurnal amplitude is also mainly in the range 5–10 m/s. There is no clear seasonal trend evident in the height profiles. The seasonal profiles shown for the two years suggest that the amplitudes appear to have consistent values in 1999 and 2000. Both the zonal and meridional components have roughly similar strengths, especially in the summer seasons. The zonal amplitude in the winter season is marked with slightly larger values than the meridional amplitude. However, during the spring and fall conditions at some heights, the meridional component tends to have larger (2–4 m/s) amplitude than the zonal component. A linear drop in the amplitude is evident in both components at 74–94 km

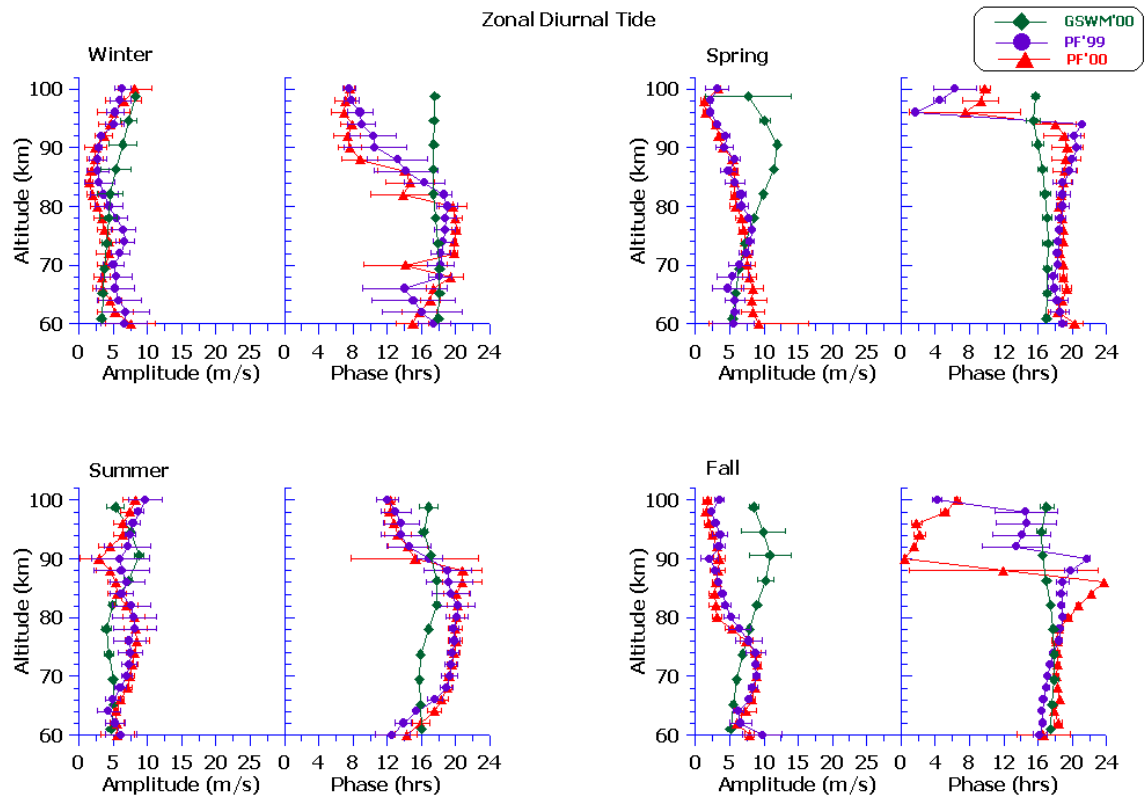


Fig. 11. Height profiles of the amplitudes and phases of the zonal wind component of the diurnal tide during summer, winter, spring, and fall seasons. Data shown are for the years 1999 and 2000. GSWM00 values are also given for comparison.

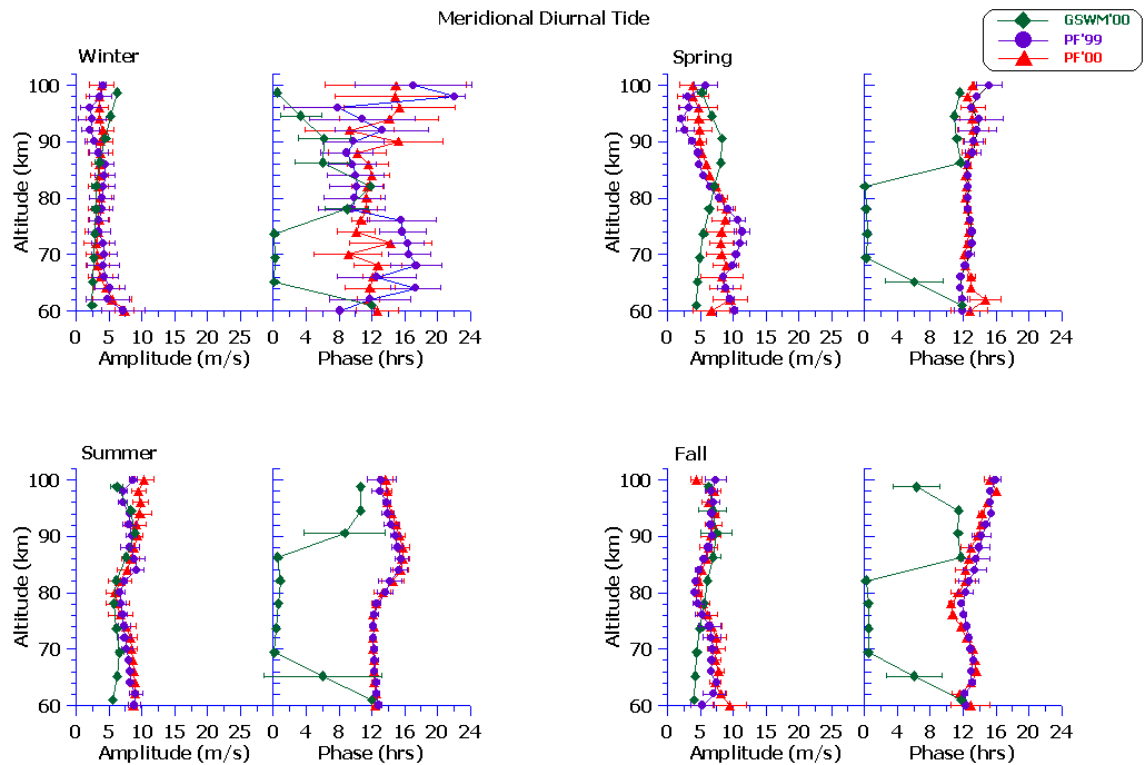


Fig. 12. As in Fig. 11 but for the meridional component.

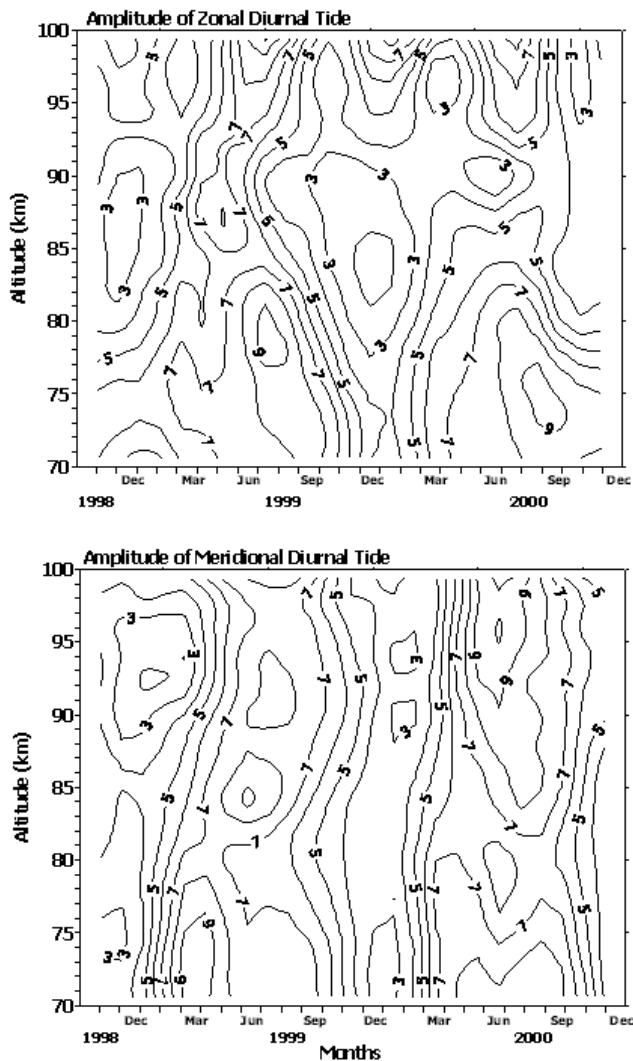


Fig. 13. Height-time monthly contours of the amplitudes of the zonal and meridional components of diurnal tide.

during the spring season. The observed amplitudes generally compare well with the model values during the summer and winter seasons. Mostly the model values are within the standard deviation of the observed values. However, comparison is not promising (particularly for the zonal component) in the case of spring and fall conditions. The model values are larger than the observed values at altitudes above 75–80 km.

The observed phase profiles show consistency in the two years of data analyzed in the present study. The zonal diurnal tide, during summer and winter, shows downward phase propagation at altitudes above 80 km. The large error bars for the meridional component during the winter season demonstrate instability of the phase structure. The spring and fall conditions mainly represent evanescent behavior of the diurnal tide. It is interesting to note that at many heights (generally below 90 km) the phase of the meridional component leads that of the zonal component by several hours in all the four seasons. In spring and fall, sudden changes with height

in the meridional phase are clearly observed. This results from the interference of different tidal modes. The model profiles often show larger vertical wavelengths or evanescence in all the seasons. Comparison of the observed and model tidal phases does not show much agreement. The discrepancy is larger in the case of meridional component.

Figure 13 shows contour plots of amplitude for the zonal and meridional components of diurnal tide at Poker Flat. The cross sections have some differences compared with the seasonal features seen in the previous plots. It appears that the zonal and meridional components have the same amplitudes. In general, a very distinct seasonal variation is not seen in the climatological presentation of amplitudes. However, above 90 km during summer, there is a tendency to attain larger amplitudes for both zonal and meridional components. The maximum amplitude observed is nearly 10 m/s at around 100 km. Similarly, a closer look reveals that the amplitude is smaller (3–5 m/s) during the winter season. The year-to-year variability is least significant in the tidal contours.

Comparing the present climatological features with the previous measurements conducted at Poker Flat (Tetenbaum et al., 1986), some differences can be seen. For example, Tetenbaum et al. (1986) showed that the amplitude of the meridional component is generally larger than the zonal component. The present MF measurement does not match the previous measurements. Our measurements agree with the measurements at Tromsø (Manson et al., 1988), which also reported that the zonal and meridional components have the same amplitudes.

4 Summary

This paper is an attempt to provide the mean wind and tidal characteristics over Poker Flat. We have used two years of data collected by a new MF radar, which is installed as part of a collaborative research project. Seasonal variations of mean winds and tides over the site are constructed and the climatologies are compared with earlier observations as well as the latest model results.

The main feature of the zonal circulation in the MLT is the annual variation with summer westward flow and winter eastward flow. The summer westward jet has a maximum intensity of 35 m/s, which is larger than the winter eastward maximum (20 m/s). Dominant annual variation, with summer southward motions and winter northward motions, is observed in the meridional circulation. The annual mean zonal wind has a westward motion at heights below ~90 km. It maximizes at around 80 km with a strength of 7–10 m/s. The annual mean meridional circulation shows mainly equatorward motions. The model (HWM93) and observations show very good agreement (especially for zonal component) in the wind patterns as well as in the strength.

For the semidiurnal tides, comparison between GSWM00 results and observations shows that model amplitudes (above 80–90 km) are significantly larger than observed amplitudes

during the winter, spring and fall seasons. During the summer, however, observed amplitudes are stronger than the modeled amplitudes. Model and observed tidal phase variations show reasonable similarity. Short vertical wavelength is observed in winter and evanescent or longer vertical wavelengths are observed in summer.

The height profiles of diurnal tides suggest weak evidence of seasonal variation. The summer amplitudes are slightly larger than the winter amplitudes. The GSWM00 amplitudes and the observed amplitudes match well in the case of diurnal tide. The comparison of the phases shows a larger discrepancy particularly in the case of meridional component.

The MF radar observation at Poker Flat is steadily progressing. Creation of an extensive and continuous database is a major priority and such a database would open avenues for promising collaborative studies with other middle atmosphere research groups. Topics like studies on latitudinal/longitudinal dependencies of major dynamical processes in the MLT region can be well addressed through such initiatives.

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