MF radar studies on the dynamics of the mesosphere and lower thermosphere

Kiyoshi Igarashi
Laboratory of Radar Atmospheric Science, RISH, Kyoto University

Studies on the dynamics of the mesosphere and lower thermosphere (MLT) received a big boost with the introduction of medium frequency (MF) radar. Compared to other systems MF radar is more economical and other merits such as simple nature of the system, convenient antenna configuration, high efficiency in continuous observation etc. has attracted a number of investigators. As a result, MF radars were installed at various locations around the globe. Combined usage of the datasets opened new avenues in collaborative studies and generated important information on mean winds, atmospheric tides, gravity waves and planetary waves. This thesis mainly deals with the analysis of MF radar data collected at the midlatitude stations Yamagawa (31.2°N, 130.6°E) and Wakkanai (45.4°N, 141.7°E) in Japan, and the high latitude station Poker Flat (65.1°N, 147.5°W), Fairbanks, Alaska, USA (Fig. 1). The Communications Research Laboratory installed these systems in the 1990s and since then has archived valuable datasets. This helped the author to undertake a systematic investigation on various dynamic features of the MLT region.

Analysis of the mean winds over Yamagawa and Wakkanai suggest that the circulation characteristics observed at these midlatitude stations are consistent with other midlatitude stations. Below 90 km, the mean prevailing zonal winds at both sites are dominated by westward/eastward motions in the summer/winter seasons. Meridional circulation at meteor heights is generally southward during most of the year and also extends to lower mesospheric heights during summer. The summer westward jet at Wakkanai is consistently stronger than at Yamagawa. However, the winter eastward winds have identical strength at both locations. Meridional winds also show larger values at Wakkanai. Harmonic analysis of mean zonal winds clearly demonstrates the dominance of annual oscillation over the other periods. Comparison of the observed winds and the HWM93 model winds shows interesting similarities and discrepancies. Climatological comparison of the mean winds at the MF sites and the MU radar site indicates latitudinal dependency of the summer westward jet which is also clearly evidenced in model studies. The analysis also revealed some signs of interannual variability of MLT mean winds.

Studies on the structure and variability of diurnal, semidiurnal, and terdiurnal tides in the midlatitude MLT region generated abundant information. Analysis of the semidiurnal tides indicates reasonable similarities in the variations over Yamagawa and Wakkanai. At both sites, the amplitude generally ranges from 5 to 15 m/s. The multi-year average indicates that the maximum amplitude is observed in August/September at both sites. The summer season is characterized by a large vertical wavelength, while the winter season has a comparatively smaller wavelength. Comparison of the observed semidiurnal tidal amplitude and phase parameters, and the GSWM-98 model values is generally not satisfactory. Diurnal tidal amplitude at Yamagawa and Wakkanai shows significant differences in strength. The amplitude is consistently larger at Yamagawa. Phase structures show better agreement between the sites. As in the case of semidiurnal tide, comparison of the diurnal tidal parameters and the GSWM-98 values reveals less satisfactory results. The interannual variability observed in both the semidiurnal and diurnal tides is larger in the Yamagawa data compared to the Wakkanai data. The semidiurnal and diurnal tidal phases around 90 km generally exhibit a bimodal state with the phase with an almost constant phase near the summer (June) and winter (December) solstices, and mark rapid transitions in the equinoxes. The duration of the winter constant phase is longer in the summer solstice than in the winter solstice. The terdiurnal tidal amplitude observed at Wakkanai exhibits strong day-to-day variability. Short-time variability confirms that the amplitude of terdiurnal oscillation can, on occasion, reach that of the diurnal and semidiurnal tides. The presence of dominant 8-h oscillation is observed in all seasons. However, a strong seasonal dependence is not observed in their amplitude variations. Amplitude values in the winter season are slightly larger than the corresponding values in the summer season. It was found that the terdiurnal amplitudes at Wakkanai are more comparable to the diurnal tidal amplitudes than the semidiurnal values. The dynamical behaviour of 12-, and 24-h oscillations during a time of strong eastward wind was investigated and the result revealed an anticorrelation between the magnitude of eastward mean wind and the zonal amplitude of the diurnal oscillation. It was also observed that the zonal amplitude of the diurnal oscillation is highly correlated with the diurnal oscillation amplitude of the geomagnetic declination, and also shows the strong decrease at the winter solstice.

Observations of planetary waves with quasi-2-day and 16-day periodicities are reported. Analysis of the quasi-2-day wave indicates similar wave features observed at Yamagawa and Wakkanai. The occurrence

of the wave event (probably the same) is seen at both stations during the same days. The wave is found every year with the maximum amplitude in the summer months. The meridional component has a larger amplitude than the zonal component. Comparing the amplitudes at the two stations, the values observed at Yamagawa are larger than those at Wakkanai. The amplitude appears to attain its maximum value at around 90 km at both stations. Substantial year-to-year variations are observed in the 2-day wave amplitude. The average wave period observed at Yamagawa and Wakkanai is roughly 48 hours. The study also explores the dependence of the 2-day wave on the background atmospheric circulation. The 16-day wave climatology observed at Yamagawa clearly shows some seasonal variations. The period from late autumn to spring is marked with larger wave activity, with the strongest waves observed in winter months. The maximum amplitude observed at Yamagawa was about 20 m/s, which is comparatively larger than the amplitudes observed at midlatitude stations. The height dependence of the 16-day wave suggests that the maximum amplitude is observed at altitudes below 80 km. The summer months are characterized by much weaker wave activity. The vertical wavelength appears to be larger in the winter months and shorter in the summer months. The study again confirms that the 16-day wave is highly sensitive to the background mean winds. Eastward motion of the background winds is a more favourable condition for the 16-day wave to penetrate to MLT heights. The wave features show some signs of interannual variability. Overall, the observed features of the 16-day wave at Yamagawa, which is located at the edge of the subtropical latitudes, show some correspondence with the results reported for midlatitude stations. Analysis of the critical frequency of sporadic *E* (*Es*) indicates quasi-periodic oscillations with a period of 2-16 days. The study shows a close relationship between planetary waves and the recurrent cycle of *Es* activity.

The dynamics of the arctic MLT region has been studied using the MF radar wind measurements conducted at Poker Flat, Alaska. The mean wind characteristics observed are fairly consistent with previous wind measurements obtained 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 70-104 km. There is very good agreement between the radar zonal winds and the HWM93 model winds. Comparison of the meridional winds shows some discrepancy. Tidal characteristics observed are also consistent with previous measurements. Semidiurnal tidal amplitude is largest in summer and weakest in winter months. The vertical wavelength is longer during the summer season compared to the winter season. Comparison with the GSWM-00 values produces mixed results. There is reasonable agreement between the observed and modelled phases. Diurnal tide amplitude is comparable in magnitude with that of the semidiurnal tide. Seasonal variation in amplitude is less evident. Again, comparison of the diurnal tidal parameters and the GSWM-00 values reveals some agreement and discrepancies. The overall scenario is that further effort is necessary for improvement of the models. Results of a comparative study of the wind fields in the MLT region over Poker Flat and Davis (69°S, 78°E) are also presented. The study confirms the existence of interhemispheric asymmetry of mean circulation in the high latitude MLT region.

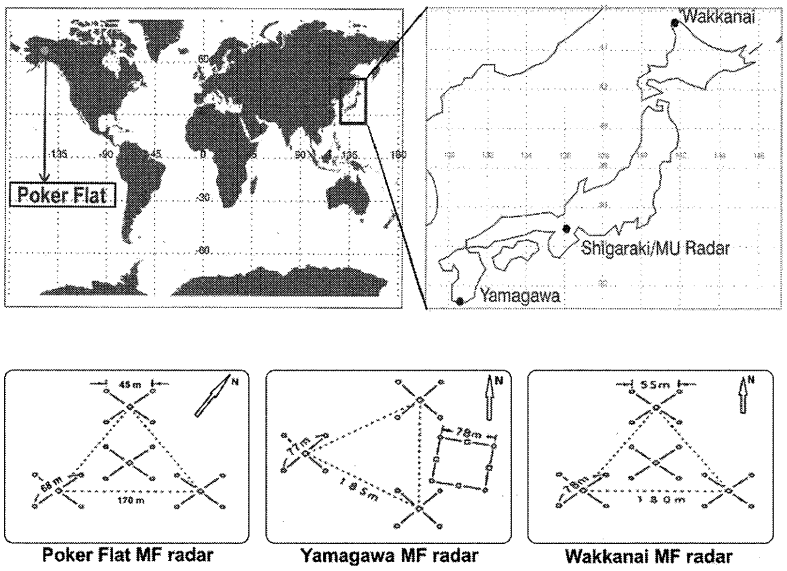

Fig. 1. Locations and antenna configurations of the Yamagawa, Wakkanai, and Poker Flat MF radars, including location of the MU radar at Shigaraki.