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Mesospheric winds derived from SuperDARN HF radar meteor echoes at Halley, Antarctica

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Mesospheric winds are derived from HF radar observations of meteor echoes at Halley (76°S, 27°W), Antarctica. These meteor echoes are observed within the first range gates of the radar (less than 500 km) and are characterised by lower spectral widths than echoes backscattered from plasma irregularities in the E region of the ionosphere. The derived winds show first order agreement with mesospheric winds measured independently over Halley. Gravity wave signatures (e.g. <2-h period) and smaller-scale structure in the winds are revealed within the spatiotemporal data formed by the 16 beams. A data base of such observations is being built up from existing radar data extending over nearly a full solar cycle from 1988 to the present day.

1. Introduction

The HF radar at Halley (76°S, 27°W), Antarctica, has been operating since 1988. It forms part of the Super Dual Auroral Radar Network (SuperDARN) of HF radars (Greenwald *et al.*, 1985, 1995) located in the northern and southern high latitude regions. The radars predominantly observe echoes from field-aligned plasma irregularities in the E and F regions of the ionosphere which are then analysed to study plasma convection in the auroral oval and inside the polar cap. However, at the closest ranges (<500 km), another type of coherent echo is observed. These were termed "grainy near-range echoes" by Hall *et al.* (1997) who used data from the HF radar at Saskatoon (52°N, 106°W). They showed that these echoes were backscattered from meteor trails at a mean altitude of 94 km. Thus, as with conventional meteor radars, they can be used as tracers to study the motion of the neutral atmosphere, and hence winds, tides and waves in the mesosphere. There are very few mesospheric measurements made in either hemisphere poleward of 70°; thus the HF radar measurements from Halley will be a valuable addition to global observations of mesospheric dynamics. This paper describes the application of the technique based on that described by Hall *et al.* (1997) to the HF radar data from Halley, Antarctica. The implementation of this technique along a single beam is described in Jenkins *et al.* (1998). This current paper compares these single beam observations with independently-derived measurements and demonstrates the potential provided by assimilating the information from all 16-beams of the radar to give spatial information over small scales.

2. Experimental Method

The SuperDARN HF radar at Halley (Baker *et al.* 1989) operates within the frequency range 8–20 MHz, but this range is restricted in practice to 12–14 MHz, the preferred frequency of operation being 12.3 MHz. The radar consists of 16 log-periodic antennas which form a fan of narrow azimuth (~4°) beams, with an angular separation of 3.2°, which is directed approximately polewards. The peak power is 10 kW and the pulse width of 200–300 μs gives a range resolution of 30–45 km. The radar scans through the 16 beam positions remaining in each position for 6 s so that the entire field of view is scanned in under 2 minutes. In the usual operating mode, the first range gate is set to 180 km and a range gate of 45 km is used over 75 range cells. For each beam/range gate cell, an autocorrelation function is calculated and about 50 of these are averaged together over the integration period of 6 s. This means that any temporal variation shorter than the integration period is lost. In the standard SuperDARN analysis, the backscattered power, the Doppler velocity and the spectral width of the echo spectrum are obtained by fitting a Gaussian and a Lorentzian spectral shape to the average autocorrelation function from each range gate cell of each beam. The grainy near range echoes (GNREs) are only observed within the first 7 range gates at Halley. The majority of the observed meteor echoes are underdense in which case the power of the echo backscattered from the trail decays exponentially as the trail radius increases due to diffusion. As the echo spectrum from an underdense meteor trail is Lorentzian this model is used in the SuperDARN fitting procedure to derive the observed parameters. The spectral width $\Delta\nu$ of an underdense meteor echo depends upon the exponential decay time constant, τ, and the radar wavelength, λ:

$$\Delta\nu = \frac{\lambda}{4\pi\tau} \tag{1}$$

and τ depends upon the diffusion coefficient, D:

$$\tau = \frac{\lambda^2}{32\pi D^2}. \tag{2}$$

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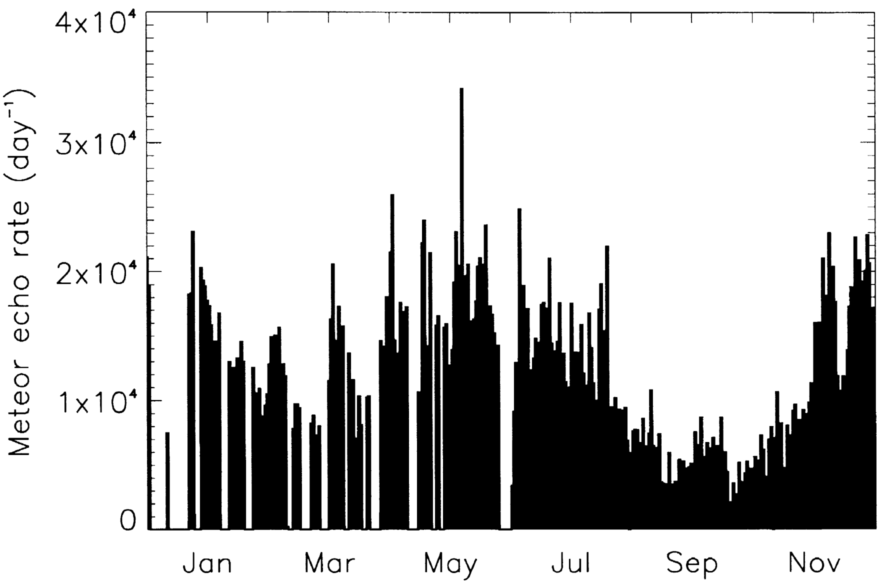

Fig. 1. Rate of meteor echoes observed during 1996 at Halley. Note that data gaps (e.g. during January) are indicated by a thicker time axis.

From this equation, it can be seen that the spectral width depends upon the diffusion coefficient. Thus the spectral width of an underdense meteor echo is thus expected to lie within certain narrow limits; this parameter has therefore been used as a filter to exclude echoes from the first few range gates that do not arise from meteor trails. For compatability, the same operating system and analysis is used at each of the SuperDARN radars, although each may use a slightly different range of frequencies. Different operating frequencies will sample different meteor populations; however, in practice the SuperDARN operating frequency range is so small that it is not expected to significantly alter the mean height of the sample population. Distributions of spectral widths recorded at different operating frequencies did not show any significant differences. In creating the database of mesospheric wind observations from meteor trails the data have been accepted if the spectral width is less than 50 m s^{-1} and greater than 1 m s^{-1}, the range is less than 500 km and the backscattered power is greater than 3 dB above the background. Because there is no height discrimination in this method, results will be averaged over an altitude layer of 10–20 km thickness. This could limit the detection and interpretation of waves with small vertical wavelengths. At high latitudes, the tides and planetary waves have long vertical wavelengths ($>$50 km) so the altitude smearing for these will be small. The GRNEs only appear within the first seven range gates at Halley as the backscattered power from a meteor trail decreases as the radial distance to the radiating source increases. At further ranges echoes from the E and F regions dominate the echo spectrum. At Halley, beam 3 is directed toward the south geographic pole so the line-of-sight velocity as recorded in this beam gives the meridional component of the wind. Since the beams are oriented at an angle to each other meridional and zonal components of the wind can be calculated by assuming a uniform wind field across the 16 beams. The zonal component is less accurate than the meridional component due to the general poleward orientation of the beams.

3. Results

The GNREs are present throughout the year though there is an annual variation as shown in Fig. 1. This represents the daily meteor echo count rate occurring at Halley during 1996. Where there are complete absences of data (represented by a solid line on the x-axis), this is the result of a break in the data series for instrumental reasons. The median hourly rate is 380, the mean hourly rate is 330. This compares to a mean hourly rate of 660 at the Saskatoon HF radar. There is a consistently higher rate at the solstices with a lower rate at the equinoxes. The occurrence pattern has been analysed for all years between 1994 and 1998 inclusive and each year there is a steady reduction of the meteor rate during September. The diurnal variation of the meteor echo rate is as expected for meteors, with a minimum in the afternoon and a peak in the local morning hours.

A typical diurnal variation of the line-of-sight velocity derived from beam 3 (meridional) is shown in the top panel of Fig. 2 for the first 7 range gates. The data presented are from 23 December 1997 which was during a geomagnetically particularly quiet period. The semidiurnal tide is evident with poleward (red) winds in the early morning switching to equatorward (blue) and then back to polewards in the afternoon, before reversing again in the evening. The magnitude of the velocity lies within $\pm$50 m s^{-1} and is thus typical for mesospheric winds; it has a similar amplitude to that observed by Forbes *et al.* (1995) using a meteor radar at South Pole in January 1995. The bottom panel of Fig. 2 shows the meridional velocity as recorded by an Imaging Doppler Interferometer (IDI) at Halley on the same day. This is a recently developed technique at Halley which uses a special operating mode of the dynasonde (Jones *et al.*, 1998). The IDI measurements began in December 1996 so there is, so far, about 18

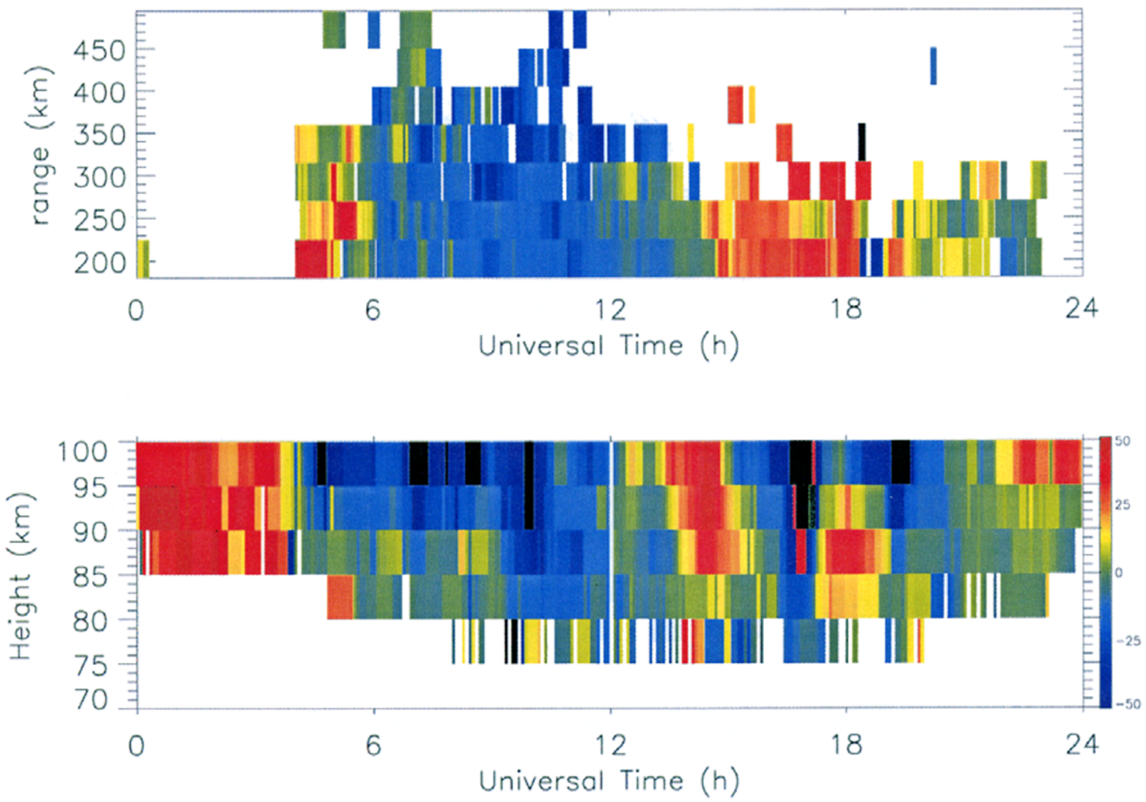

Fig. 2. Top panel: line-of-sight velocity as a function of range and Universal Time from the HF radar beam 3 for Dec 23, 1997. Bottom panel: meridional velocity as measured by the IDI as a function of altitude and Universal Time, also for Dec 23, 1997. Colour indicates velocity in m s^{-1}. At Halley LT = UT-2.

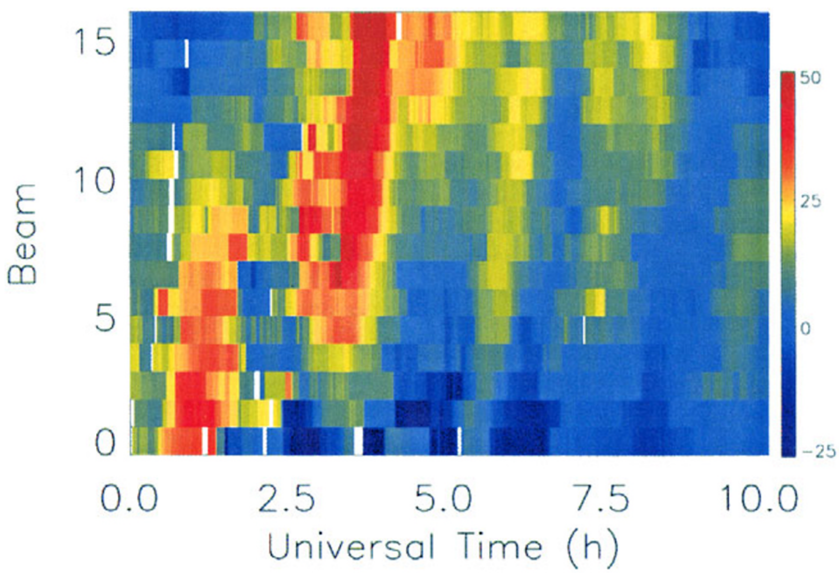

Fig. 3. The diurnal variation of the line of sight velocity in the first range gate across all 16 beams of the HF radar on Jan 5 1995. Colour indicates velocity in m s^{-1}. Lower beam numbers are at earlier Local Time; beam 3 is directed polewards.

months of overlap between the two techniques. Note that with meteor echo elevation angles between $\sim 10^\circ$ and $\sim 20^\circ$ the line-of-sight velocity measured by the HF radar will be between 93% and 98% of the horizontal wind. Note also that the IDI is directed vertically and the HF radar polewards, so the two techniques do not sample a common volume; there is a spatial separation of about 250 km. However, as Fig. 2 shows the comparison between the two techniques is, to a first order, good. A more detailed comparison is presently being carried out.

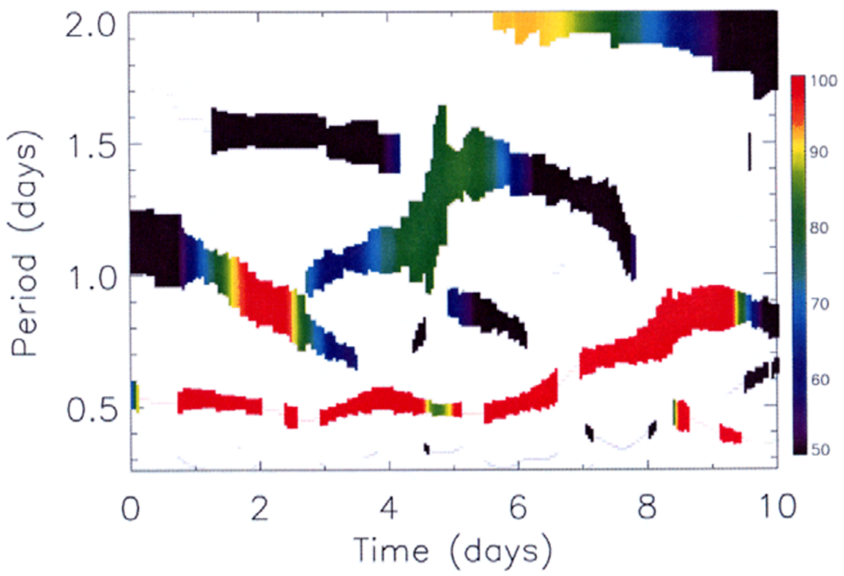

Fig. 4. Waves present during December 18–26 1997, as determined by wavelet analysis of the meridional component. The statistical confidence level is indicated by the colour scale.

A unique advantage of the beam-swinging utilised by the HF radar over other mesospheric radars is that it enables the winds over a spatial extent of ∼200 km (∼3/4-h of time) to be examined with a longitudinal resolution of ∼15 km. The diurnal variation from the first range gate in each of the 16 beams for 5 January 1995 is shown in Fig. 3. (Note: It must be remembered that the beams are not parallel as presented in the figure but in fact are at an angular separation of ∼3.2°.) Waves with a period of about 2 hours are clearly evident in the figure. The beam-swinging technique hence allows small-scale structure to be examined.

To investigate the frequencies of these and other waves wavelet analysis has been applied to the data. Wavelet analysis essentially decomposes a time series into a series of wavelet functions from which the dominant frequency modes can be determined together with how these modes vary with time. Unlike a standard Fourier transform, wavelet analysis provides information in both the time and frequency domains. Assuming a red noise background the statistical significance of each of the frequencies can also be determined (Torrence and Compo, 1998). The disadvantage of wavelet analysis is that the technique requires regularly spaced data and so for mesospheric wind data some interpolation is usually necessary. The alternative Lomb-Scargle periodogram method which can cope with data gaps has the disadvantage that only the significance of the main peak is known. The results of wavelet analysis on the HF radar data are shown in Fig. 4. The statistical significance is plotted in time frequency space. This shows the dynamic analysis of the meridional component during December 1997. The semidiurnal tide is evident at a high confidence level. A quasi 2-day wave is also present; although this wave appears at a low level of confidence the nonlinear interaction between the 12-h tide and the 2-day wave is indicated by the presence of the secondary waves with periods of around 10 hours and 16 hours. As is usually the case, the 16-hour wave is the stronger. When this interaction occurs the power in the semidiurnal tide is much reduced (Manson and Meek, 1986; Kamalabadi *et al.*, 1997).

4. Summary

A technique to derive mesospheric winds from HF radar observations of meteor echoes at Halley, Antarctica has been implemented. The meteor echoes are characterised by their occurrence in only the closest ranges and by their spectral widths when the echo spectrum is fitted to a Lorentzian model. Thus they can be distinguished from echoes that are backscattered from plasma irregularities in the *E* and *F* regions of the ionosphere. Assumptions of a uniform flow across the beams enables the meridional and zonal components of the wind to be determined. Also, the wind field across the 16 beams, covering a horizontal distance of about 200 km, can be examined at a longitude resolution of ∼15 km. This gives the SuperDARN HF radars a unique advantage over other mesospheric radars. There is good first order agreement between the winds derived from the HF radar meteor echoes and the mesospheric winds measured by the IDI at the same site; this is currently being examined in more detail. A wavelet analysis technique has been applied to the data to investigate the temporal behaviour of the tides and waves. In data presented here the quasi 2-day wave was observed and the secondary waves associated with the nonlinear interaction between this wave and the semidiurnal tide were also present. Observations of the mesospheric wind in the high latitude southern hemisphere are scarce and this dataset, which will soon cover a full solar cycle, is expected to resolve, as yet, unanswered questions about the dynamics of the mesopause region.

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