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Validation of imaging Doppler interferometer winds using meteor radar

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[1] There has been some debate over the years concerning the accuracy of mesospheric wind observations made using the imaging Doppler interferometer (IDI) technique. The high potential and increasing use of IDI wind data in joint studies with spaced-antenna MF and meteor radar systems make it important to quantify the IDI results. This paper presents a novel comparison of wind measurements between a dynasonde implementation of IDI and winds derived from an all-sky meteor radar system, a widely-accepted standard for such measurements. Both radars were located at the USU Bear Lake Observatory and operated almost continuously for a four-month period. The winds and tides derived from IDI were found to closely match those measured by meteor radar, not only during the day but also at night, and at all overlapping heights from 80–95 km. *INDEX TERMS:* 3384 Meteorology and Atmospheric Dynamics: Waves and tides; 3360 Meteorology and Atmospheric Dynamics: Remote sensing; 3332 Meteorology and Atmospheric Dynamics: Mesospheric dynamics; 6952 Radio Science: Radar atmospheric physics; 6994 Radio Science: Instruments and techniques; *KEYWORDS:* IDI, MF radar, Mesopheric winds, Meteor radar. **Citation:** Jones, G. O. L., F. T. Berkey, C. S. Fish, W. K. Hocking, and M. J. Taylor, Validation of imaging Doppler interferometer winds using meteor radar, *Geophys. Res. Lett.*, *30*(14), 1743, doi:10.1029/2003GL017645, 2003.

1. Introduction

[2] Initial implementations of the IDI technique for making drift measurements in the lower ionosphere were restricted to short campaigns at Colorado [*Adams et al.*, 1986], Saskatchewan [*Meek and Manson*, 1987] and Arecibo [*Brosnahan and Adams*, 1993]. Of these, the measurements at Arecibo during the AIDA campaign were the most comprehensive. These early results suggested that discrepancies might sometimes occur between the amplitude of the wind derived from IDI and the more accepted standard of incoherent scatter radar (ISR) winds, particularly above 80 km altitude [*Hines et al.*, 1993]. However, subsequent analysis of the AIDA dataset by *Turek et al.* [1998] has shown that the IDI results agree well with ISR winds over the full overlapping height range from 70 to 97 km. Despite this reassessment, uncertainty has remained regarding the reliability of wind measurements using IDI.

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[3] The introduction of IDI has also led to numerous modeling studies by the radar community in which various analysis methodologies were investigated by simulating atmospheric radar backscatter [*Briggs*, 1995; *Holdsworth and Reid*, 1995; *Roper and Brosnahan*, 1997]. However, there have been few experimental applications of the IDI method until recently. The IDI technique has now been adapted for use with the NOAA HF radar (or dynasonde). Mesospheric measurements have been conducted in this way at Halley (76°S, 26°W) since 1996 [*Jones et al.*, 1997; *Charles and Jones*, 1999] and at the Bear Lake Observatory (41.9°N, 111.4°W) since 1999 [*Berkey et al.*, 2001]. This paper focuses on results from Bear Lake during a period when both IDI and the meteor wind radar technique (MWR) were operated simultaneously.

[4] At Bear Lake, a novel adaptation of the IDI algorithm was used whereby radio waves at 2.2 MHz were transmitted during night-time (00-13 UT) and 3.8 MHz during daytime. Such frequency-agility optimizes the number of detectable echoes by reducing the effects of D-region absorption and local radio interference. This has countered the night-time reduction in MF radar echoes and has resulted in the Bear Lake IDI measurements often being as prolific at night as during the day. This frequency-flexibility also illustrates a major advantage of the IDI approach in that it is not necessary to use antennas or hardware tuned to a specific transmission frequency. IDI soundings of 90 s duration were recorded every 5 minutes to provide continuous coverage of mesospheric winds. For each sounding a horizontal wind vector was fitted to height bins, 3 km wide, over the whole sampled height interval of 70–115 km. Suitably numerous echoes were identified to evaluate winds in most height bins between 75 km and 105 km giving almost complete diurnal coverage at these heights.

[5] A VHF (SKiYMET) MWR, on loan from the University of Western Ontario, was deployed at the Bear Lake Observatory for mesospheric wind and temperature studies. Concurrent observations with the IDI radar were made over a 4-month period between November 2000 and March 2001. The SKiYMET system is an all-sky interferometric MWR that employs a high pulse repetition frequency to detect meteor echoes in the 82–98 km altitude region [*Hocking et al.*, 2001]. Range-timing and spaced receiving antennas allow the height and azimuthal direction of each meteor to be derived. The MWR was configured for operation at a fixed frequency of 35.65 MHz but sometimes experienced external co-channel interference from propagated signals during the day (14-00 UT) thereby reducing the expected meteor detection rate during these times. Nevertheless, the standard processing software was able to produce estimates of the wind in 3km height bins at

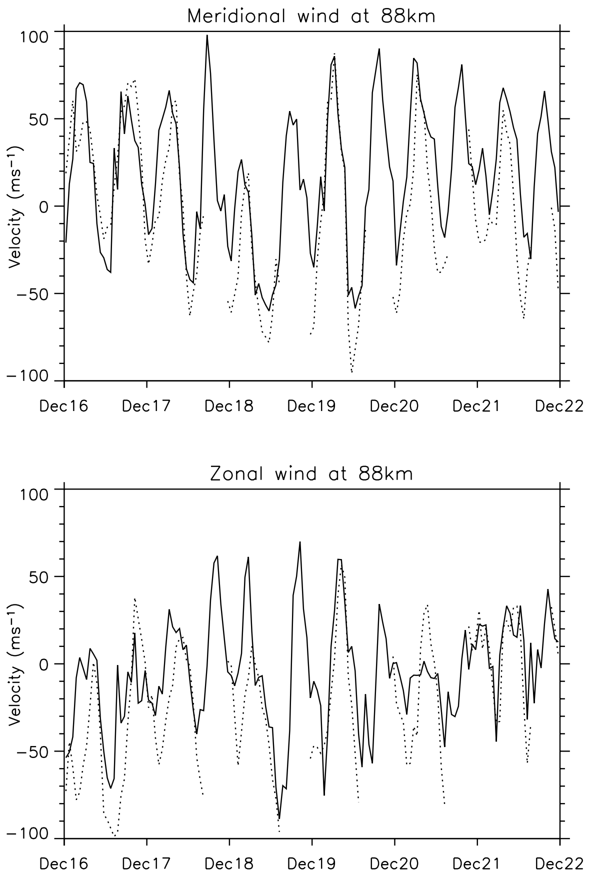

Figure 1. Comparison of hourly mean winds at 88 km as measured by IDI (solid line) and MWR (dotted line) during December 2000.

most hours between 23 and 17 UT. It is generally accepted that the MWR measurements represent the best estimate of the neutral wind in the upper mesosphere [e.g., *Liu et al.*, 2002]. Therefore, they are used here as a reference to evaluate the accuracy of the IDI winds.

2. Hourly Wind Comparison

[6] The standard data products from the MWR are hourly values of the meridional and zonal components of mesospheric wind at 3 km vertical resolution. Similar hourly averages were derived from the 5-minute IDI wind estimates to provide a convenient time series for comparison. A typical set of winds from the two techniques is shown in Figure 1 from 16 December to 22 December, 2000. During this interval there was strong tidal activity producing large amplitude winds suitable for comparing the two measurement techniques. The height bin at 88 km was chosen because it was where meteor echo numbers reached a maximum. The upper panel of Figure 1 shows the meridional wind component (+ve velocities are northwards) and the lower panel the zonal wind (+ve eastwards); the IDI wind (solid line) was almost continuous whilst the MWR wind (dotted line) has short data gaps around midday due to the local interference effect described earlier. Both data sets have similar error bars of ±10 ms^{-1} in their hourly means.

[7] The agreement between the IDI and MWR winds is striking. Both techniques show the dominant semi-diurnal variation with reversal-times matching closely. Indeed, on several occasions the agreement is so good that it is masked in the figure by the two measurements overlying each other. The amplitudes of the wind also agree very well; this is clearer in the meridional component which has a larger amplitude during the interval shown. There is a slight tendency for the IDI winds to underestimate those of the MWR, as will be discussed later. However, the overall comparison shows that both techniques measure almost identical day-to-day wind variations.

[8] Some differences between the wind estimates are to be expected due to the different areas of the sky from which the measurements originate. In the case of MWR, the meteor trails are predominantly detected at low elevations and represent the average wind over a horizontal region up to 300 km in diameter; for IDI the main scattering region lies closer to overhead relying on Doppler echoes within 40° of the zenith. However, by averaging over an hour, any localized effects or short-term gravity wave motion should

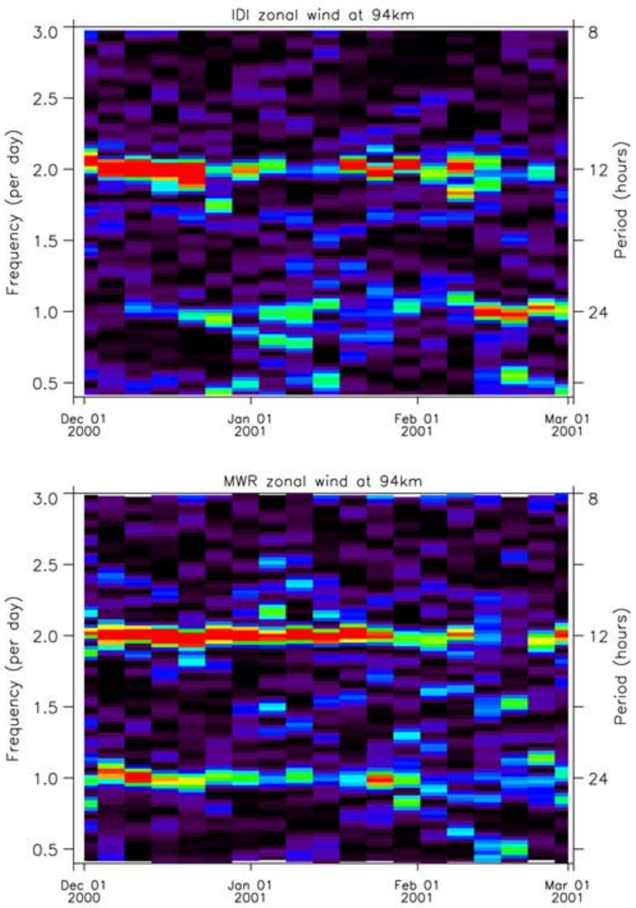

Figure 2. Lomb-normalised periodograms of the zonal wind at 94 km as measured by IDI (upper panel) and MWR (lower panel). Each periodogram (vertical stripe) is derived from a 10-day sequence of hourly mean winds. The colour scale represents relative spectral density (blue = low, red = high).

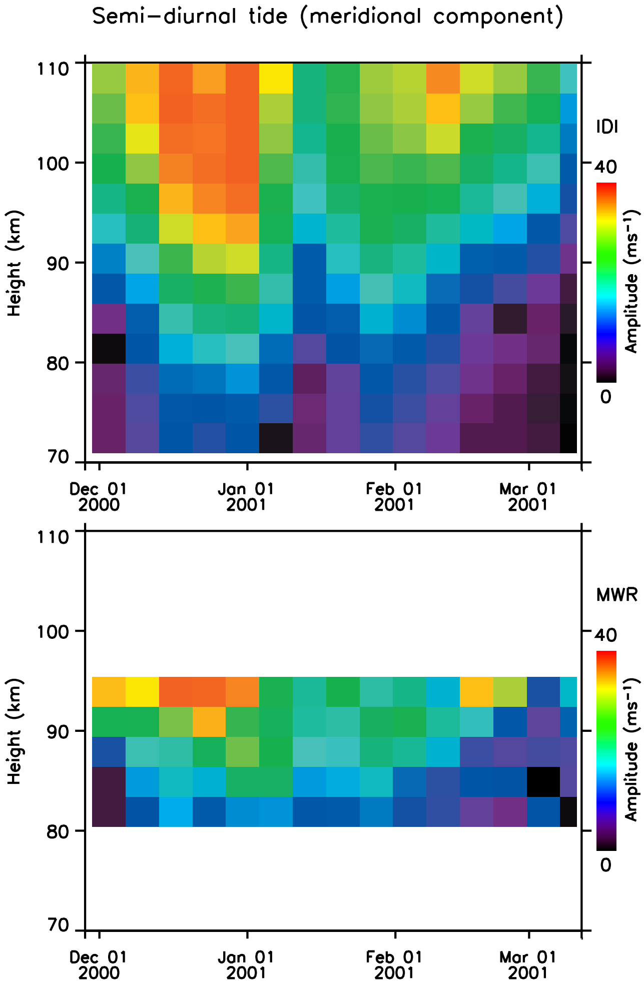

Figure 3. Amplitude of the meridional component of the semi-diurnal tide for IDI (upper panel) and MWR (lower panel). The results are based on sine-wave fitting to the main tidal periods.

be minimized so that both the IDI and MWR datasets represent the large-scale horizontal wind motion.

3. Spectral Analysis

[9] Spectral analysis provides a convenient way to extract tidal variations in the wind flow. Figure 2 shows Lomb-normalized periodograms for 10-day sliding sections of data. A height bin of 94 km was selected, towards the upper end of the MWR dataset, because the tidal amplitudes were larger. The upper panel of Figure 2 shows the dominant periods in the IDI wind between December 2000 and March 2001. It is clear that the semi-diurnal tide dominates for most of the time with a smaller and more variable contribution from the diurnal tide. There is also some evidence of longer-period, planetary wave activity (e.g., during mid- to late-February). The lower panel of Figure 2 shows the equivalent periodograms for the MWR dataset, plotted with identical axes to aid comparison. The tidal activity is remarkably similar. The clear consistency of the main tidal components between the IDI and MWR observations serve, once again, to illustrate the high degree of agreement between the two radar-wind techniques. Once the main tidal periods are known, a more quantitative comparison is achieved by sine-wave fitting to the specific periods identified, thus allowing a better interpretation of the tidal variations.

4. Tidal Fitting and Wind Amplitudes

[10] Fitting a sine-wave function to the main tidal periods makes it easier to quantify changes in the tidal amplitude and phase with time and with height. A multi-parameter, least-squares, sine-wave fit was applied to the hourly IDI and MWR data according to the equation:

$$f = A_0 + A_{48}\sin(2\pi t/48 - \Phi_{48}) + A_{24}\sin(2\pi t/24 - \Phi_{24}) + A_{12}\sin(2\pi t/12 - \Phi_{12}) + A_8\sin(2\pi t/8 - \Phi_8) \quad (1)$$

where A represents the amplitude and Φ the phase of the sine wave component indicated by its subscript (in hours). The fitting was performed using 14-day intervals of data - sufficiently long to provide reliable estimates of the main tidal amplitudes - and were calculated every seven days in

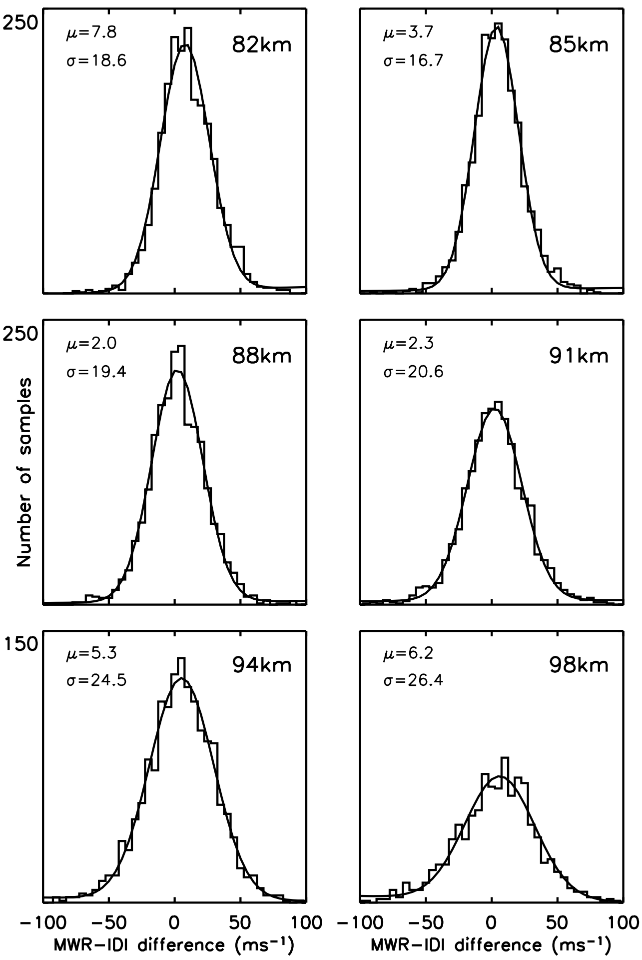

Figure 4. Histograms and Gaussian fits of wind speed differences (MWR-IDI) between December 2000 and March 2001 at various heights. Mean and standard deviations are shown for each fitted Gaussian.

order to monitor changes in the tidal amplitude from week to week.

[11] Figure 3 shows the amplitude of the meridional component of the fitted semi-diurnal tide for IDI and MWR. Results are displayed for IDI up to 110 km, above which the maximum range restricts echo arrival directions, and for MWR up to 96 km. The uppermost MWR height gate at 98 km is omitted due to the small number of meteor detections resulting from daytime interference. As expected, the tide is seen to increase in amplitude with height, and shows considerable variability with time. There are two intervals when the semi-diurnal tide is particularly strong: the first in mid-to-late December when the amplitude reaches over 40 ms^{-1} above 95 km, and a weaker interval during mid-February. In both cases there is very good agreement between the times and strengths of the tide as seen simultaneously by both radar techniques. Significantly, while the MWR tidal fit is restricted to the meteor region near 90 km, the IDI measurements extend upward and show that the tidal amplitude continues to increase up to heights above 100 km.

[12] Previous published studies comparing meteor radar winds with those measured using MF spaced-antenna systems (e.g., *Cervera and Reid*, [1995]; *Hocking and Thayaparan*, [1997]) have suggested that the wind estimates at medium frequencies tend to underestimate the true (MWR) wind speed at heights above 90 km, but the differences were found to vary and depend on season, levels of gravity wave activity and system configuration. Figure 4 summarizes the differences in wind speed between IDI and MWR over the full 4-month study period by displaying histograms of the hourly wind differences (MWR-IDI) at the overlapping heights. This representation is similar to the analysis by *Cervera and Reid* [1995]. The best-estimate Gaussian fits show very little offset from zero with only small asymmetries (visible in the tails of the distribution) confirming the absence of any serious bias between the winds measured by these two techniques. At heights between 82 km and 91 km there is a small tendency for +ve differences (MWR > IDI) indicating that MWR wind speeds are systematically larger than those measured by IDI (similar to comparisons with other MF radars). However, by 94 km the skew in the Gaussian fit has reversed, and the IDI winds are slightly larger than the MWR winds. The widening distributions at 94 km, and particularly 98 km, indicate the larger random measurement errors as echo numbers for both IDI and MWR decrease. An iterative refit of Gaussian curves using various ratios of wind amplitude (MWR/IDI) found that the systematic asymmetries could be removed by small corrections to the IDI wind amplitude of <10 %. A more detailed study of such differences is beyond the scope of this paper. However, the discrepancies are not significant when other systematic influences, such as the different radar viewing areas, are considered.

5. Conclusions

[13] This comparison study shows that there is very good overall agreement between IDI and MWR winds. This is true over a range of heights in the mesosphere and under different tidal influences. Any discrepancy in wind speeds is typically <10 % and comparable to that found for other MF radar techniques. This is a very important result for the ongoing use of IDI winds, particularly in collaborative, multi-site measurements of mesospheric winds and tides. Bearing in mind the other advantages of the IDI technique, such as its flexible implementation on non-dedicated radar systems, and its extended height coverage, these results demonstrate that IDI measurements can provide a valuable contribution to synoptic studies of mesospheric dynamics.

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