What is the optimal level of time-averaging for radar-derived wind-profiles?

D. A. Hooper[1] and C. Gaffard[2]
[1]STFC Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, UK
[2]Met Office, Department of Meteorology, University of Reading, Reading, RG6 6BB, UK

Publication details

book title	Proceedings of the Twelfth International Workshop on Technical and Scientific Aspects of MST Radar
pages	99 - 102
year	2010
editors	N. Swarnalingam and W. K. Hocking
publisher	Canadian Association of Physicists, Ottawa, Ontario, Canada
ISBN:	978-0-9867285-0-1
url	http://www.cap.ca/en/publications/conference-proceedings

1. Introduction

The (UK) Met Office currently assimilates wind-profile data from a number of European radars. The quality of the data for an averaging period of 30 minutes can be comparable to that of radiosonde-derived winds, i.e. with random measurement errors of up to a few m s^{-1} (e.g. *Dibbern et al.*, 2003). As ever-increasing computing power allows numerical weather prediction models to be run at increasingly-high resolutions, there is a corresponding need to increase the resolution of the assimilated data. However, by reducing the period over which radar-derived wind-profiles are averaged, the effects of random measurement errors will become more significant. This is demonstrated in the left panel of Figure 1, which shows the root mean square (RMS) differences between the eastward wind components, derived from Doppler Beam Swinging (DBS) observations made by the MST Radar at Aberystwyth, at adjacent times. The RMS differences represent a combination of the random measurement error and of the natural degree of variability of the wind. The latter is expected to increase with increasing time separation between the estimates. Note that the RMS differences between wind components estimated from just a single cycle of observation (orange line), i.e. at separations of 4.7 minutes, are considerably larger than those estimated for 30 minute averages (blue line). This suggests that the variability between single cycle estimates is dominated by the random measurement error. Moreover, as will be shown here, much of this random measurement error can be attributed to geophysical effects which fundamentally limit the accuracy of single cycle measurements.

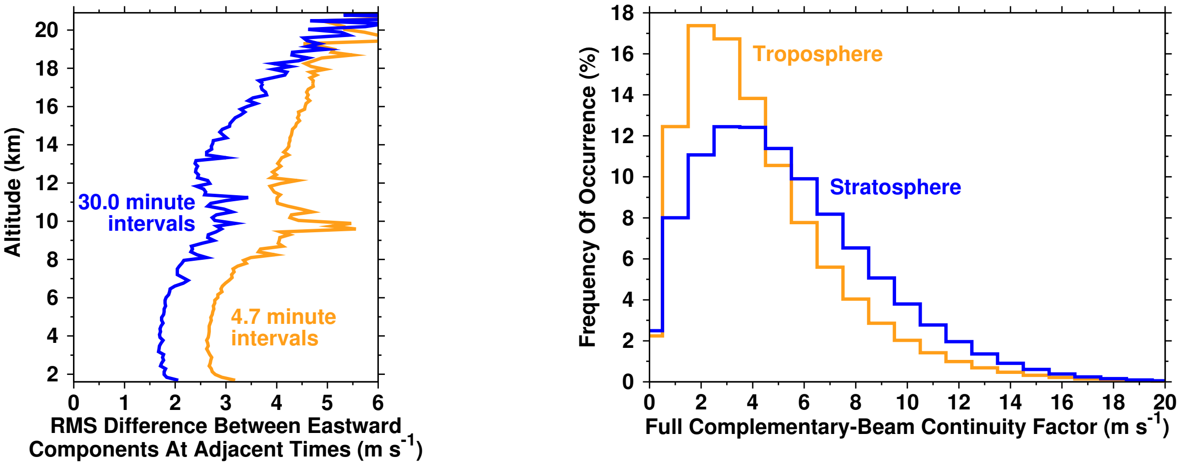

Figure 1: The results of statistical analyses which show (left panel) that the RMS difference between wind components at adjacent times is greater for single cycle data than it is for 30 minute averaged data, and (right panel) that the distribution of the full complementary-beam continuity factor is shifted to larger values for the stratosphere compared to the troposphere.

2. The Complementary-Beam Continuity Factor

The statistics shown in Figure 1 relate to observations made by the Aberystwyth MST Radar during the period 1st July 2006 - 31st January 2007. Each cycle of observation followed an enhanced five-beam sequence, i.e. one which includes dwells in the Vertical direction and at four off-vertical directions which share the same zenith angle, θ, and which have azimuth angles, ϕ, at intervals of 90°. The radial velocity derived from the Vertical beam dwell is interpreted as representing the upward wind component, w (the convention used here is for a positive radial velocity to represent motion away from the radar). This allows the horizontal wind component along the azimuth of each of the off-vertical beams, $v_H(\phi)$, to be inferred from its radial velocity, $v_R(\theta, \phi)$:

$$v_H(\phi) = \frac{v_R(\theta, \phi) - w \cos\theta}{\sin\theta} \tag{1}$$

The availability of complementary (off-vertical) beam pointing directions, i.e. those separated in azimuth by 180°, allows two quasi-independent estimates (albeit with opposite signs) to be made of the horizontal wind component along each of two orthogonal azimuths. These are averaged in order to give a single estimate along each of the two orthogonal azimuths. What is of particular interest here is the use of the difference between the two estimates (after taking the change of sign into account) to give a measure of the reliability of the averaged value. The complementary-beam continuity factor, $\Delta v_{HC}(\phi)$, is defined as:

$$\Delta v_{HC}(\phi) = v_H(\phi) + v_H(\phi + 180^\circ) \tag{2}$$

Attention will be confined here to the full complementary-beam continuity factor, $\Delta v_{HC}(full)$, which is defined as the root of the sum of the squares of the values for the two orthogonal azimuths.

The details of the enhanced five-beam sequence are as follows: NE6.0°, Vertical, SW6.0°, Vertical, SE6.0°, Vertical, NW6.0°, Vertical, W4.2°, Vertical, Mesospheric-Vertical, Vertical. The names for off-vertical beam directions represent first the azimuth and then the zenith angle. Each dwell represents almost 21 s worth of observations made at 300 m range resolution, albeit sampled at 150 m intervals. Note that every other dwell is in the Vertical direction, which provides estimates of the upward wind component every 48 s (taking the 3 s gaps between dwells into account). This was originally introduced for studies of convection, which can give rise to absolute changes in the upward wind in excess of 1 m s^{-1} over this time scale (*Hooper et al.*, 2005). Nevertheless, as will be demonstrated shortly, such an observation strategy is desirable for regular wind-profiling activities. For each off-vertical beam dwell, the upward wind velocity from the Vertical beam dwell which is closest to it in time is used in deriving the corresponding horizontal wind component. Note that complementary (6° off-vertical) beams are grouped together, albeit separated by a single Vertical beam observation. The total cycle time was 4 minutes 43 s.

The right panel of Figure 1 shows the probability distributions of $\Delta v_{HC}(full)$ values for single cycle data at tropospheric (orange line) and stratospheric (blue line) altitudes. The altitude of the tropopause, which is predominantly between 8.0 and 12.5 km, is derived from the profile of Vertical beam signal power. Values of $\Delta v_{HC}(full)$ are calculated only where all four 6° off-vertical beam observations have passed radial- and time-continuity quality control tests, as described by *Hooper et al.* (2008). Nevertheless, values in excess of 10 m s^{-1} occur for a significant proportion of the time. Such large values are inconsistent with the fundamental DBS assumption of the wind field being stationary over the time scale required to make a full cycle of observation and over the horizontal scale separating the different radar observation volumes.

It seems likely that discrepancies between complementary-beam estimates of a horizontal wind component are primarily caused by variations in the upward wind over the time scale separating the dwells. Atmospheric oscillations which are close to the Brunt-Väisälä period (around 10 minutes in the troposphere and around 5 minutes in the lower stratosphere) are predominantly evident in the vertical direction. However, it is possible that some apparent variations are caused by roughness in the nominally-horizontal scattering layers and are not related to changes in the upward velocity. Moreover, actual

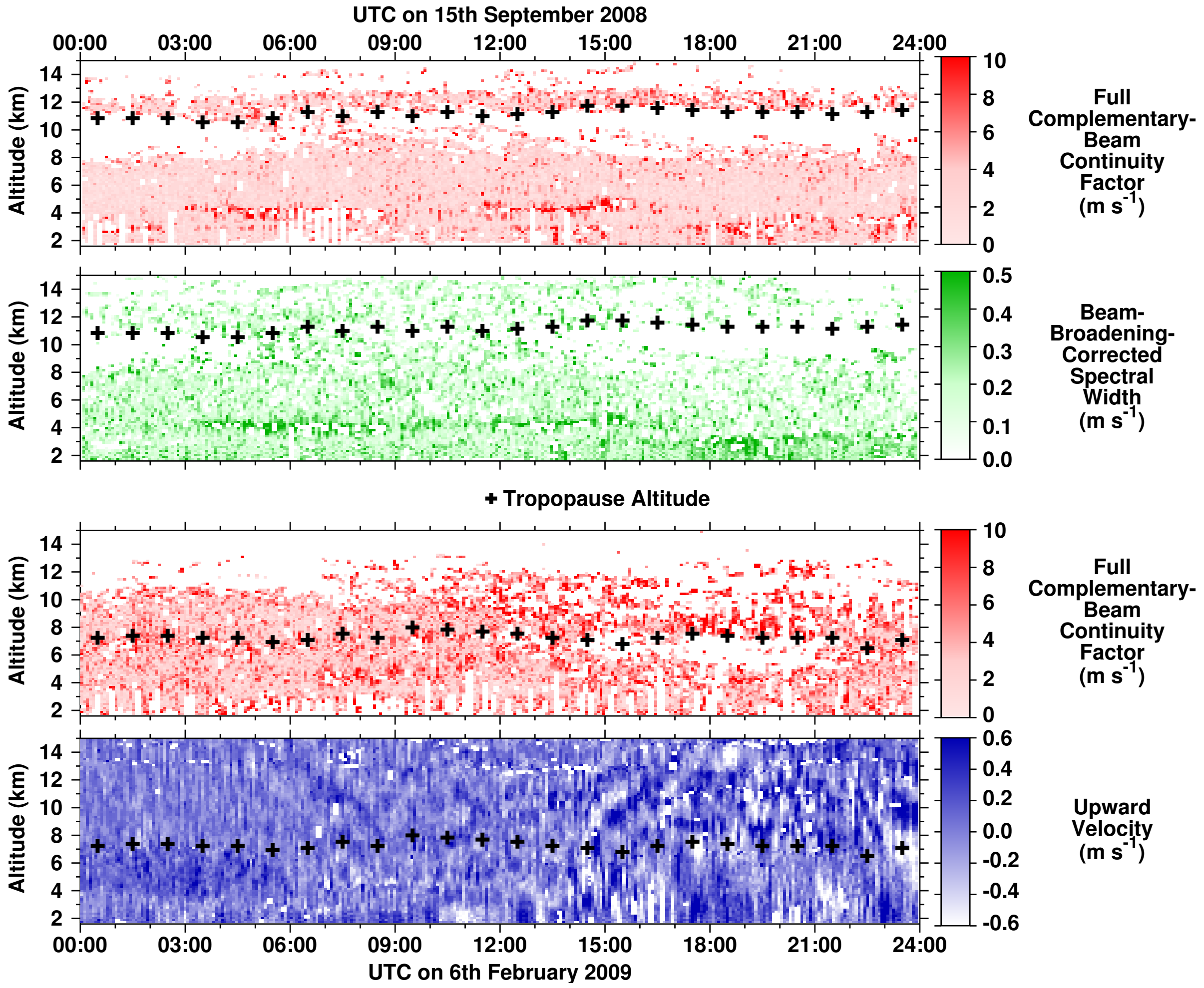

Figure 2: Examples of enhancements in the value of the full complementary-beam continuity factor associated with (upper panels) turbulent layers, and (lower panels) mountain wave activity.

variations in the horizontal wind, e.g. caused by turbulent motions (which will be evident at time scales of less than the Brunt-Väisälä period), cannot be ruled out as a cause.

3. Case Studies Of Reduced Complementary-Beam Continuity

The top panel of Figure 2 shows the (single cycle) values of $\Delta v_{HC}(full)$ for a day characterised by low wind speeds (< 10 m s^{-1}) over most of the troposphere. There is a weak background of upward wind velocity activity (not shown), which is typical at Aberystwyth owing to its close proximity to mountains. Enhanced values of $\Delta v_{HC}(full)$, at altitudes of around 3 and 4, clearly correspond to enhanced values of the beam-broadening-corrected (Vertical beam) spectral width (second panel). The expectation that these layers are turbulent is supported by the the accompanying large values of vertical wind shear (not shown). Correlations between large values of $\Delta v_{HC}(full)$ and large values of corrected spectral width have been seen in a number of similar situations.

The lower two panels of Figure 2 relate to a day characterised by moderate mountain wave activity. It can be seen that enhanced values of $\Delta v_{HC}(full)$ (third panel) are more-widely-spread in the troposphere than they are in the first case study (top panel). Moreover they become particularly prevalent in the lower stratosphere after 12:00 UT, when the amplitude of the upward wind velocity activity (bottom panel) becomes well-established at these altitudes. Enhanced values of $\Delta v_{HC}(full)$ are commonly associated with mountain wave activity. However they are not obviously correlated with any particular characteristic of the waves, e.g. their amplitude, their apparent period of oscillation, or their phase.

The probability distributions shown in the right panel of Figure 1 indicate that, unsurprisingly, large values of $\Delta v_{HC}(full)$ are more common in the stratosphere than in the troposphere. Complementary-beam observation volumes for a zenith angle of 6.0° are separated by a horizontal distance of only 1 km at an altitude of 5 km but by over 3 km at an altitude of 15 km. Consequently there is greater potential for spatial variations in the three-dimensional wind field to become apparent in the stratosphere. The horizontal wavelength of convectively-generated gravity waves can be just 10 km (e.g. *Hauf*, 1993) and that of mountain waves tends to be just a few 10s of km. Moreover, the the Brunt-Väisälä period approaches the interval encompassing two complementary beam dwells (1 minute 13 s) much more closely in the stratosphere (5 minutes) than it does in the troposphere (10 minutes).

4. Discussion and Conclusions

The short-term variations between upward wind components are expected to be more-reliable than those between horizontal wind components. This is partly owing to the fact, mentioned above, that the highest-frequency oscillations are predominantly in the vertical direction. Moreover, the upward wind components are derived from observations made during a single dwell. This minimises the potential for the measurements to be affected by spatial or temporal variations in the three-dimensional wind field. Nevertheless, no attempt has yet been made to fully exploit the availability of the Vertical beam observations at every other dwell (i.e. at intervals of 48 s) in the Aberystwyth dataset. For example, a test needs to be made as to how the values of the complementary-beam continuity factor will vary if the upward wind values used to derive horizontal wind components are not taken from a Vertical beam dwell which is adjacent in time to the off-verical beam dwells. Data from a recent set of special observations, during April 2009, suggest that they will increase. However, this was based on a comparison between 150 m resolution observations, which followed the dwell sequence described in Section 2, and 300 m resolution observations, which made use of a restricted 5-beam sequence for which only a single Vertical beam dwell was available. Incidentally, Met Office monthly model-comparison statistics for April 2009 (see *"The diagnosis of a range gating problem suffered by the Aberystwyth MST Radar"* on pages 123-126 of these proceedings for more details about the use of such statistics) do not suggest any degradation in the quality of the 30 minute averages of the 300 m resolution data. This is in spite of the fact that only 3 single cycle wind-profiles were available for each 30 minute period, as opposed to 6 for standard observations.

In conclusion, geophysical phenomena, including mountain wave activity and turbulence, can reduce the reliability of single DBS cycle wind-profile estimates. The optimal level of time averaging needed to minimise the random measurement error remains to be determined.

5. References

Dibbern, J., D. Engelbart, U. Goersdorf, N. Latham, V. Lehmann, J. Nash, T. Oakley, H. Richner, and H. Steinhagen, Operational aspects, in *EUR 20614 - COST Action 76 - Development of VHF/UHF wind-profilers and vertical sounders for use in European observing systems - Final report*, edited by J. Dibbern, W. Monna, J. Nash,, and G. Peters, pp. 133–224, European Commission, Luxembourg, 2003.

Hauf, T., Aircraft observation of convection waves over southern Germany - a case study, *Mon. Wea. Rev.*, *121*, 3282–3290, 1993.

Hooper, D. A., A. J. McDonald, E. Pavelin, T. K. Carey-Smith, and C. L. Pascoe, The signature of mid-latitude convection observed by VHF wind-profiling radar, *Geophys. Res. Lett.*, *32*, L04808, doi:10.1029/2004GL020,401, 2005.

Hooper, D. A., J. Nash, T. Oakley, and M. Turp, Validation of a new signal processing scheme for the MST radar at Aberystwyth, *Ann. Geophys.*, *26*, 3253–3268, 2008.

This version of the document was produced on January 26, 2011.