Velocity of Winds Aloft from Site Test Interferometer Data

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Abstract

MMA Memo 129 (Holdaway, *et al.* 1995) introduced the basic data reduction pathway for the NRAO site test interferometers. One of the secondary data products derived in Memo 129 was the velocity of the water vapor aloft. We demonstrate two quite independent methods of measuring the wind velocity aloft agree to 5-10%.

Wind Velocity Aloft

In MMA Memo 129 (Holdaway, *et al.* 1995), we showed one method of determining the mean horizontal velocity of the part of the atmosphere which bears the turbulent water vapor, referred to below as the velocity aloft. The temporal structure function of the interferometer phase rises with lag time for times which are short compared to the crossing time and then saturates or turns over for lag times which are long compared to the crossing time. The velocity aloft v is related to the baseline B and the "corner time" t_c (the lag time at which the turnover occurs) by

$$v = s(\alpha) B / t_c, \tag{1}$$

where s_α is a scale factor which depends upon the structure function exponent. We have determined $s(\alpha)$ empirically from atmospheric simulations, and it is found to vary between 0.65 and 1.11 over the observed range in α. Figure 7 of MMA Memo 129 shows a time series of the velocity aloft and the surface wind velocity. The apparent scatter in the velocity aloft led us to estimate its accuracy at about 30%, but some larger systematic errors also seemed to affect the velocity aloft. We indicated that some scatter might be expected since the wind velocity generally increases with height and the water vapor exists over a range of heights.

Another way to determine the velocity aloft is by comparing the temporal and spatial structure functions. Under the frozen screen model, temporal phase fluctuations are due to the spatial fluctuations passing overhead with velocity v (Treuhaft and Lanyi, 1987). Then the temporal and spatial structure functions are related:

$$\bar{D}_\phi(t) = D_\phi(\rho)|_{\rho = vt}. \tag{2}$$

Assuming a power law describes the structure functions accurately,

$$\begin{aligned} a_t t^{\alpha_t} &= a_s \rho^{\alpha_s} && (3) \\ &= a_s v^{\alpha_t} t^{\alpha_t}, && (4) \\ & && (5) \end{aligned}$$

as the exponent of the spatial and temporal structure functions are the same. The velocity aloft is

$$v = (a_t/a_s)^{1/\alpha}. \tag{6}$$

With a single baseline interferometer, we can obtain the temporal structure function of the interferometer phase, which is $\sqrt{2}$ times larger than the single point temporal structure function $\bar{D}_\phi(t)$. The interferometer also measures a single point on the spatial phase structure $D_\phi(\rho)$ at $\rho = 300$ m; a_s can be determined from the 300 m point and the temporal structure function exponent. If the structure function exponent flattens on scales less than 300 m, the calculated velocity will be larger than the true velocity. This method does not rely on any simulations or complicated fitting techniques, and should be very accurate if the constant power law assumption is met.

In Figure 1, we compare the velocity aloft calculated from the temporal structure function turnover with the velocity aloft calculated from the scaling between the temporal and the spatial fluctuations from Chile site test data, 1995 May 10-26. The correlation is very tight. The best fit line is $y = 0.95x + 2.2ms^{-1}$ with an rms of $1.2ms^{-1}$ about this line. The excellent agreement in the velocity aloft as determined the two different methods indicates that either method is in error by at most 5-10%, much better than we previously estimated. Fluctuations of the velocity aloft over 20 minutes (see Figure 7 of MMA Memo 129) are much larger than the estimated error in the velocity aloft. We need to use shorter time series to properly sample the velocity aloft.

There are no instances of the velocity calculated from the temporal-spatial structure function scaling being much larger than the velocity calculated from the temporal structure function turnover, indicating the structure function exponent is fairly constant up to 300 m. The constancy of the structure function exponent out to 300 m is indirect evidence for a thick (>300 m) screen of turbulent water vapor.

In Figure 2, we compare the surface wind velocity and the velocity aloft calculated from the temporal structure function turnover. The velocity aloft is nearly always larger than the surface velocity.

References

Holdaway, M.A., Radford, Simon J.E. , Owen, F.N., and Foster, Scott M., 1995, MMA Memo 129, "Data Processing for Site Test Interferometers".

Treuhaft, Lanyi 1987, "The Effect of the dynamic wet troposphere on radio interferometric measurements," *Radio Science*, Vol 22, No 2, 251-265.

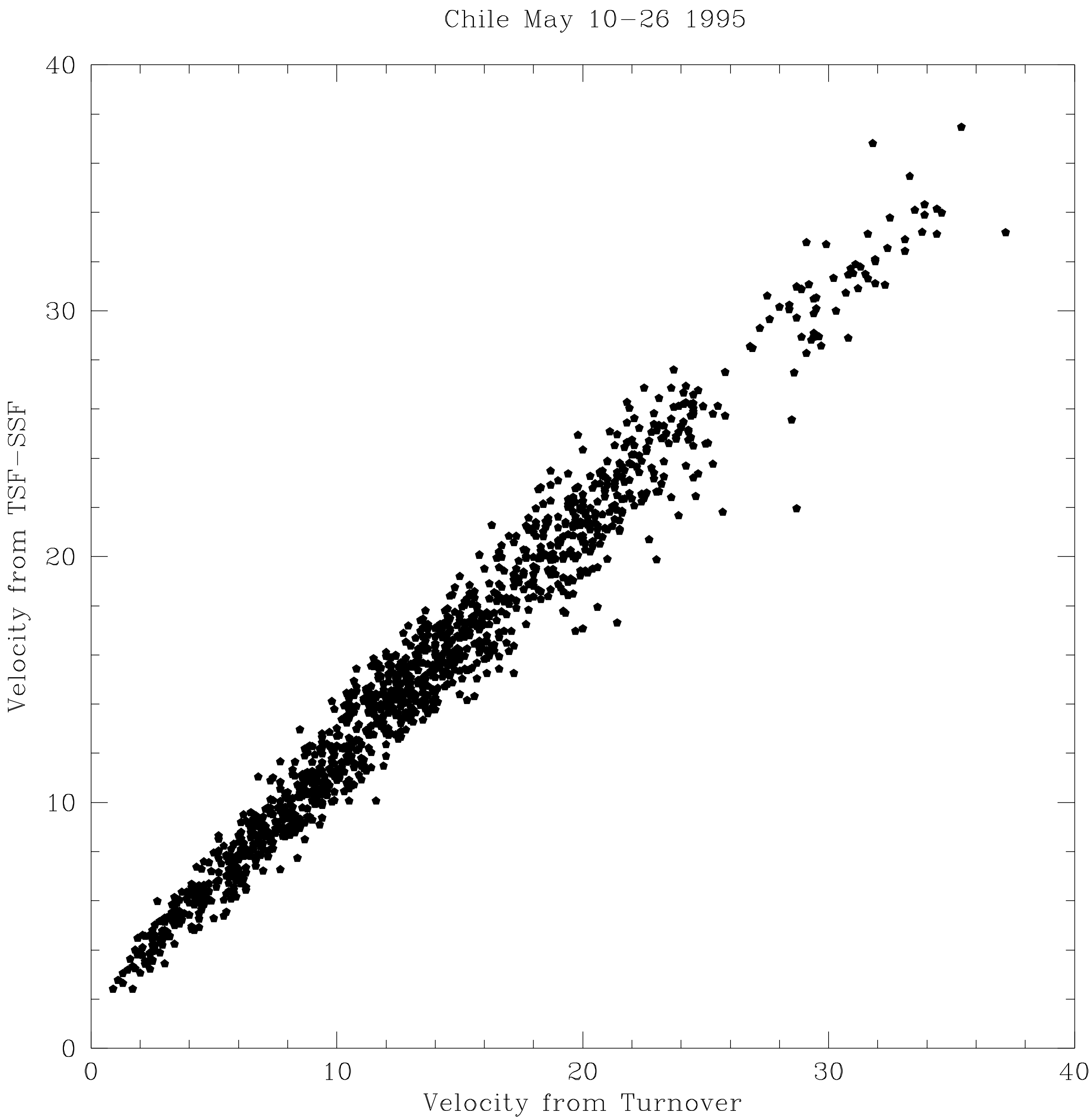

Figure 1: Derived velocity of the winds aloft as calculated from the scaling between the spatial and temporal structure functions, plotted against the velocity calculated from the temporal structure function turnover and simulations.

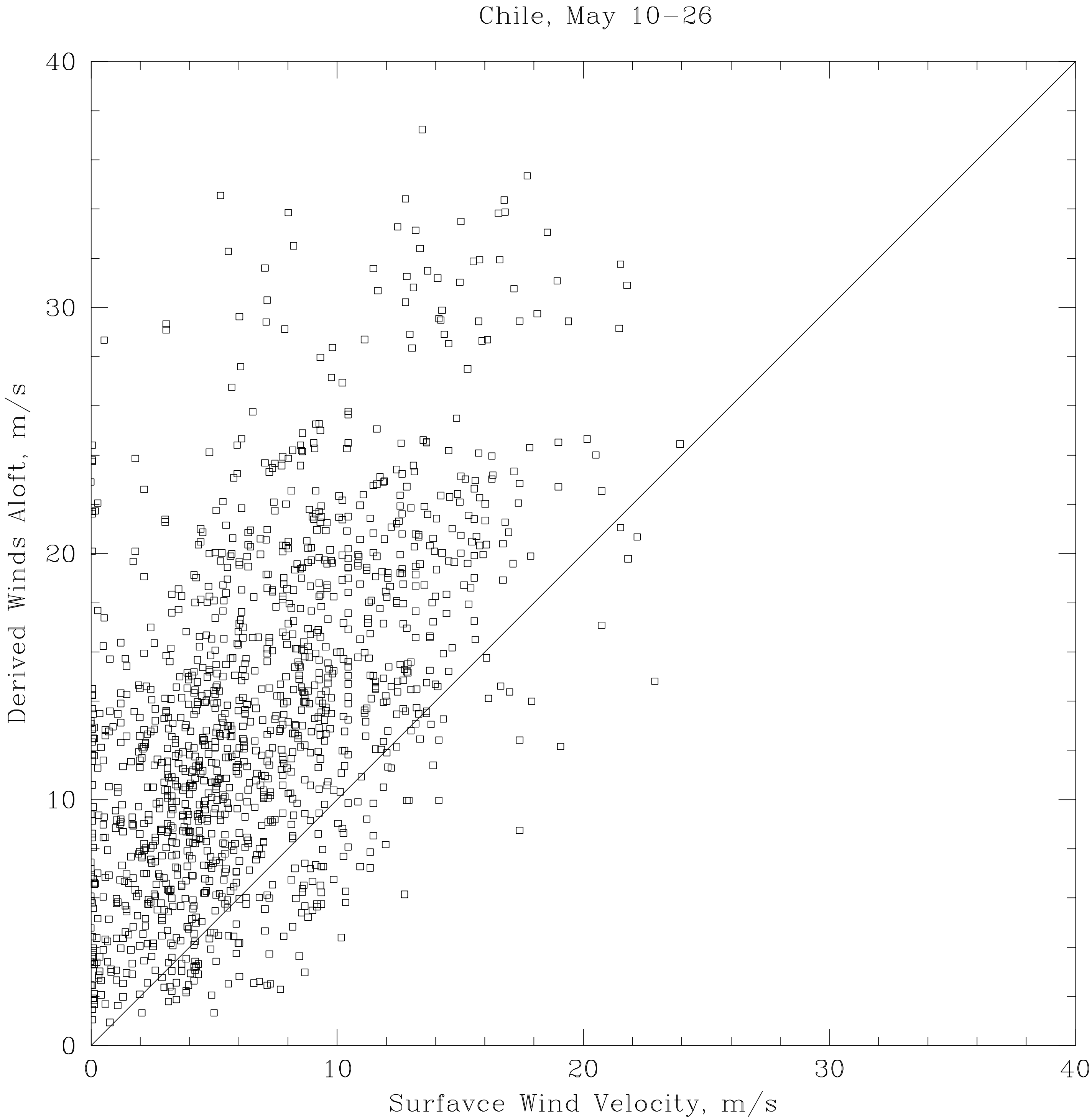

Figure 2: Derived velocity of the winds aloft as calculated from the scaling between the spatial and temporal structure functions, plotted against the surface wind velocity measured at our weather station.