SONIC TEMPERATURE SIGNIFICANCE AND LIMITATIONS

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The ATI sonic thermometer measures temperature from transit times t_1 and t_2 measured along the vertical path of the anemometer's probe. They are the times taken by sound pulses to traverse the 15-cm acoustic path in opposite directions; (these same transit times are used also for computing the vertical wind component).

The instrument exploits the strong dependence that exists between the speed of sound in air and temperature, expressed usually in the form

$$c^2 = 403T(1+0.32e/p) \tag{1}$$

where c is the velocity of sound (m s^{-1}) in air, T is the temperature (K), and e and p are respectively the vapor pressure of water in air and absolute pressure. The humidity effect on the measured sonic temperature, T_s [$= T(1 + 0.32\, e/p)$], resembles very closely the virtual temperature T_v defined by meteorologists as the temperature at which dry air has the same density as moist air at the same pressure:

$$T_v = T(1+0.38e/p) \tag{2}$$

Thus,

$$T_s = T_v(1-0.06e/p) \approx T_v - 0.06\left(\frac{T}{p}\right)e \tag{3}$$

Clearly, T_s more closely approximates T_v than it does T, the error being on the order of ±0.01°C in assuming $T_s' = T_v'$, compared to ±0.05°C for $T_s' = T'$ (assuming a typical ($\sigma_e \approx 0.5$ mb at 10 m height).

In many boundary-layer calculations, T_v' rather than T' is needed to include the buoyancy contribution from moisture (e.g., Monin-Obukhov stability parameter, z/L, and buoyant production term in the TKE budget). Since the error in assuming $T_s' = T_v'$ is well within the bounds of experimental uncertainty, that distinction can now be dropped. The sonic temperature equation takes the form

$$1/t_1 + 1/t_2 = (2/d)\left(c^2 - V_n^{\,2}\right)^{1/2} \tag{4}$$

where v_n^2 is the magnitude of the wind vector normal to the acoustic path, and d is the path length.

Assuming c^2 - 403 $T_{v,}$ we now have

$$T_v = \left(d^2/1612\right)\left[(1/t_1)+(1/t_2)\right]^2 + V_n^2/403 \tag{5}$$

The velocity contamination is usually ignored, but it grows in significance as the wind speed exceeds 5 m s^{-1}. (The vertical heat flux is particularly sensitive to this error when the stability is near neutral.) In the ATI sonic anemometer-thermometer v_n^2 is computed in real time from the horizontal wind components V_X and V_Y

$\left(V_n^2 = V_X^2 + V_Y^2\right)$, already corrected for transducer shadow error T_v. The digital output from the instrument is scaled to read directly in degrees centigrade (or Kelvin as in earlier versions of the instrument).

A word of caution is in order for those planning to use the mean T_v readings for vertical gradient measurements. The absolute value of the reading cannot be trusted partly because T_s is not exactly T_v, but more importantly, because t_1 and t_2 include additional delays introduced by the transducers. These delays cause the absolute temperature readings to be underestimated. In the ATI instrument, a time delay of 18.3 µs is subtracted from all measured transit times to compensate for this error. Uncorrected, these delays would cause T_v to be underestimated by 25°C. Corrected, the uncertainty is reduced to about ±1°C. Sample-to-sample variations in the transducers, therefore, impose a limit on the accuracy of mean temperature readings from the sonic thermometer, unless, of course, the bias has been carefully measured for the particular transducer pair, and removed from the readings. Another point to remember is that "spikes" in the data from mistriggering in the received pulses would be larger in the temperature signal than in the vertical velocity signal. Squaring of $\left[\left(1/t_1\right) + \left(1/t_2\right)\right]$ exaggerates the temperature spikes and causes the frequency-weighted temperature spectrum, $f\,S_T(f)$, to turn up at mid-to-high frequencies, when the vertical velocity spectrum shows only a small upturn at the very high end. An f^{+1} slope near the high end invariably spells trouble in the data, a fact easily confirmed by an examination of time series plots. If detected during the course of an experiment, readjustment of the triggering levels is often all that is needed to rectify the problem.