Understanding data from the Campbell Scientific Krypton hygrometer

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The Krypton hygrometer responds to two lines in the ultraviolet. Absorption of light in these lines is determined by the concentration of both water vapor and O_2. This response is given by (from Appendix C of a Cambell report)

$$V_q = V_{01} e^{-x(k_{w1} q + k_{o1} \rho_o)} + V_{02} e^{-x(k_{w2} q + k_{o2} \rho_o)} \tag{1}$$

which can be simplified to

$$V_q = V_0 e^{-x k_w q} e^{-x k_o \rho_o} \tag{2}$$

assuming $V_{01} \gg V_{02}$ and $k_{w1} \simeq k_{w2}$. Taking the logarithm yields

$$\ln V_q = \ln V_0 - x k_w q - x k_o \rho_o \tag{3}$$

or in terms of q

$$q = \frac{\ln V - \ln V_0}{-x k_w} - \frac{k_o}{k_w} \rho_o. \tag{4}$$

The present calibration routine computes the first quantity on the right-hand side, i.e.

$$q_m = \frac{\ln V - \ln V_0}{-x k_w} \tag{5}$$

which ignores the contribution of O_2. The following values were used based on calibrations of the Kryptons done by Campbell:

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FLAT90   4m     kw = -0.103     Vo = 2946     x = 1.005
ARM91    4m     kw = -0.122     Vo = 3725     x = 1.052
ARM91   10m     kw = -0.103     Vo = 2946     x = 1.005
SJVAQS91 5m     kw = -0.159     Vo = 4673     x = 1.008
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Note that the ARM 4m instrument was borrowed from the Colorado School of Mines. In the field, the calibration routine was called by:

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FLAT90   4m  c=q_kh20_1(-0.103,7.9882)          [7.9882 = ln(Vo=2946)]
ARM91    4m  c=q_kh20_2(-0.122,8.2227,1.052)  [8.2227 = ln(Vo=3725)]
        10m  c=q_kh20_2(-0.103,7.9882,1.005)  [7.9882 = ln(Vo=2946)]
SJVAQS91 5m  c=q_kh20_2a(-0.159,8.4495,1.008) [8.4495 = ln(Vo=4673)]
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Note that the pathlength of 1.005 was set in the FLAT90 calibration routine, q_kh20_1. The ARM91 calibration routine, q_kh20_2 uses an A/D gain of 2.0 and an offset of 5.0V. The SJVAQS91 calibration routine, q_kh20_2a uses an A/D gain of 1.0 and an offset of 0.0. Both routines use a A/D conversion factor of 10V/65536 counts. Since the Krypton outputs an analog voltage in the range 0 to 5 V, it is better to use a gain of 2.0 and an offset of 5.0V, as in ARM91, to optimize use of the A/D. Thus, the calibration routine q_kh20_2 should be used in the future.

To evaluate the effect of oxygen, Campbell assumes that the concentration of oxygen has a constant value, C_o of 21% throughout the atmosphere (a good assumption according to Bert Tanner) and varies according to the ideal gas law

$$\rho_o = \frac{C_o M_o P}{RT}. \tag{6}$$

Combined with Equations 4 and 5, this yields

$$q = q_m - \frac{k_o C_o M_o P}{k_w RT} \approx q_m - 0.047\frac{P}{T} \tag{7}$$

using the values $k_o \approx k_{o2} = -0.00714\mathrm{m}^3/\mathrm{gcm}$ (from a Tanner paper), $M_o = 32\mathrm{kgO}_2/\mathrm{kmole}$, $R = 8314\mathrm{J/kmoleK}$, and $k_w = -0.122\mathrm{m}^3/\mathrm{gcm}$ with q in $\mathrm{g/m}^3$. For ARM91, $P \sim 84000$ Pa and $T \sim 270$ K making the oxygen correction 14.6 $\mathrm{g/m}^3$ - a large correction when $q \sim 4$ $\mathrm{g/m}^3$!

To determine the effect of oxygen on fluctuation measurements, Equation 6 can be differentiated to yield

$$\rho_o' = \frac{C_o M_o P'}{RT} - \frac{C_o M_o P T'}{RT^2}. \tag{8}$$

Taking the ratio of the two right-hand side terms yields

$$\frac{P'T}{PT'} = \frac{(3\mathrm{Pa})(300\mathrm{K})}{10^5\mathrm{Pa})(0.5\mathrm{K})} \approx 2\% \tag{9}$$

thus the first term may be neglected. Differentiating Equation 4 yields:

$$q' = \frac{V'}{-xk_wV} + \frac{k_o}{k_w}\rho_o' = \frac{V'}{-xk_wV} + \frac{k_o C_o M_o P T'}{k_w R T^2}. \tag{10}$$

Again, the constants may be substituted to yield

$$q' \approx q_m' + 0.047\frac{PT'}{T^2}. \tag{11}$$

This equation may be multiplied by w' to yield a water vapor flux correction due to sensible heat flux

$$w'q' \approx w'q'_m + 0.047\frac{Pw'T'}{T^2}. \tag{12}$$

Here, the correction is not as important as for mean q. For ARM91, $w'T' \sim$ 0.1 C m/s making the oxygen correction 0.005 - about 50% of the typical value for $w'q' \sim 0.01$ g/m^3 m/s. During SJVAQS91, the ratio of heat flux to water vapor flux (the Bowen ratio) was much smaller so this correction should be negligible (though this has not been checked). Campbell suggests that the oxygen correction may be significant when the Bowen ratio is greater than 0.5.

Similarly, the humidity variance works out to

$$q'^2 \approx q'^2_m - 2(0.047)\frac{PT'q'_m}{T^2} \tag{13}$$

according to the Campbell document.

Note for this instrument that a Webb correction also is necessary for fluxes since it measures density, rather than mixing ratio. According to Webb, Pearman, and Leuning (QJRMS, 1980, 85-100) this correction is given by

$$E = (1 + \mu\sigma)\{\overline{w'\rho'_v} + (\bar{\rho}_v/\bar{T})\overline{w'T'}\} \tag{14}$$

where $\mu = M_{air}/M_{water}$ and $\sigma = \bar{\rho}_{water}/\bar{\rho}_{air}$.

Use Notes:

In SJVAQS, A one-day comparison of Krypton to psychrometer means showed a bias of about -12 g/m^3. Also during this period, the nighttime values were higher by 1-2 g/m^3, presumably due to dew formation on the window.