Air temperature equation derived from sonic temperature and water vapor mixing ratio for the air flow through closed-path eddy-covariance systems

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

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At high frequency, a closed-path eddy-covariance system measures sonic temperature in open space and water mixing ratio in the closed measurement camber with more stable temperature and pressure than in an open measurement space.

Air temperature derived from sonic temperature and water mixing ratio in a closed-path eddy-covariance system has advantages over the temperature probe measured one in reflecting its high frequency fluctuations needed in flux calculations and in minimizing its solar contamination for measurement quality.

T air temperature
T_s sonic temperature
q specific humidity
e water vapor pressure
P atmospheric pressure

$$T = \frac{T_s}{(1 + 0.51q)}$$

Schotanus et al. (1983)

$$T = \frac{T_s}{\left(1 + 0.32\frac{e}{P}\right)}$$

Kaimal and Gaynor (1993)

SND equation

$$T = \frac{T_s}{\left(1 + 0.51\dfrac{\rho_w}{\rho_d + \rho_w}\right)} = T_s\left(1 + 0.51\frac{\chi_w}{1 + \chi_w}\right)^{-1}$$

T air temperature

T_s sonic temperature

ρ_d dry air density

ρ_w water vapor pressure

χ_w water vapor mass mixing ratio

KG equation

$$T = \frac{T_s}{\left(1 + 0.32\dfrac{R_v T\rho_w}{R_d T\rho_d + R_v T\rho_w}\right)} = T_s\left(1 + 0.51\frac{\chi_w}{1 + 1.61\chi_w}\right)^{-1}$$

T air temperature
T_s sonic temperature
χ_w atmospheric pressure

ΔT= |SND equation – KG equation|

$$\Delta T = \frac{0.31 T_s \chi_w^2}{1 + 3.63 \chi_w + 3.20 \chi_w^2}$$

T_s : -30 ~ 57 ^{o}C
χ_w : 0~ 45 g kg^{-1}
ΔT : 0 ~ 0.176 ^{o}C

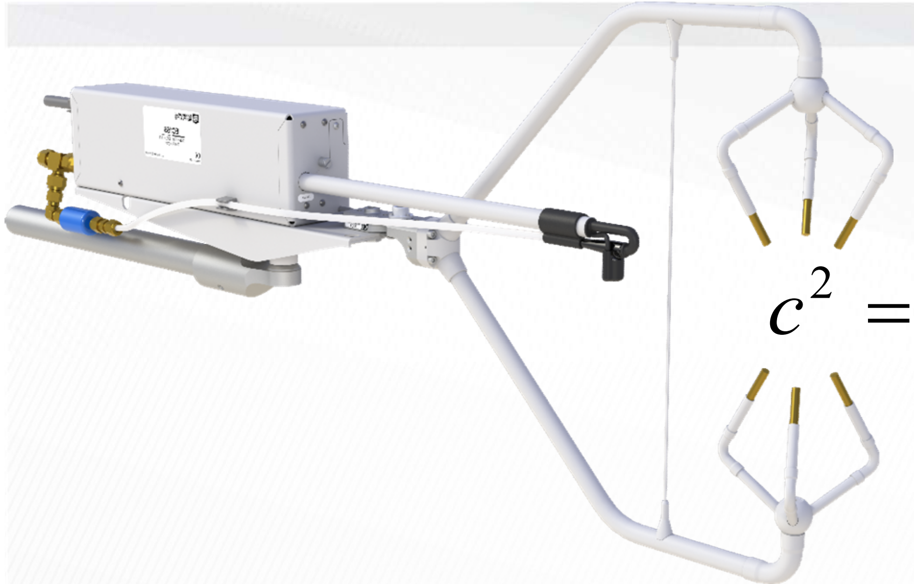
T air temperature
T_s sonic temperature
q specific humidity
e water vapor pressure
P atmospheric pressure

$$T = \frac{T_s}{\left(1 + 0.51q\right)}$$

Schotanus et al. 1983

$$T = \frac{T_s}{\left(1 + 0.32\,\frac{e}{P}\right)}$$

Ishii (1932)
Barrent and Suomi (1949)
Kaimal and Gaynor (1993)



$$c^2 = \gamma \frac{P}{\rho}$$

Barrrett and Suomi (1949)

$$P = R_a \rho T$$

$$T = \frac{c^2}{\gamma R_a}$$

c	speed of sound
γ	ratio of moist air specific heat between constant pressure and constant volume
P	atmospheric pressure
ρ	moist air density
R_a	gas constant of moist air
T	air temperature

$$T = \frac{c^2}{\gamma R_a}$$

$$T_s = \frac{c^2}{\gamma_d R_d}$$

T air temperature

T_s sonic temperature

c speed of sound

γ ratio of moist air specific heat between constant pressure and constant volume

γ_d ratio of dry air specific heat between constant pressure and constant volume (1.400279)

R_a gas constant of moist air

R_d gas constant of dry air (287 J K^{-1} kg^{-1})

Sonic temperature of moist air is the temperature that its dry air component can reach at the same enthalpy as the moist air has.

Equation derived from the first principals without any approximation

$$T = T_s \frac{\left(1+\varepsilon\chi_{H2O}\right)\left(1+\varepsilon\gamma_v\chi_{H2O}\right)}{\left(1+\chi_{H2O}\right)\left(1+\varepsilon\gamma_p\chi_{H2O}\right)}$$

T air temperature

T_s sonic temperature

γ_v ratio of specific heat at constant volume between water vapor and dry air (2.04045)

γ_p ratio of specific heat at constant pressure between water vapor and dry air (1.94422)

ε ratio of molecular mass between water vapor and dry air (0.622).

χ_{H2O} water molar mixing ratio

Error in calculated air temperature

$$\Delta T = \frac{T\left(T_s, \chi_{H2O}\right)}{T_s}\Delta T_s +$$

$$T\left(T_s, \chi_{H2O}\right)\left[\frac{\varepsilon + \varepsilon\gamma_v\left(1 + 2\varepsilon\chi_{H2O}\right)}{\left(1 + \varepsilon\chi_{H2O}\right)\left(1 + \varepsilon\gamma_v\chi_{H2O}\right)} - \frac{1 + \varepsilon\gamma_p\left(1 + 2\chi_{H2O}\right)}{\left(1 + \chi_{H2O}\right)\left(1 + \varepsilon\gamma_p\chi_{H2O}\right)}\right]\Delta\chi_{H2O}$$

T air temperature

T_s sonic temperature

γ_v ratio of specific heat at constant volume between water vapor and dry air (2.04045)

γ_p ratio of specific heat at constant pressure between water vapor and dry air (1.94422)

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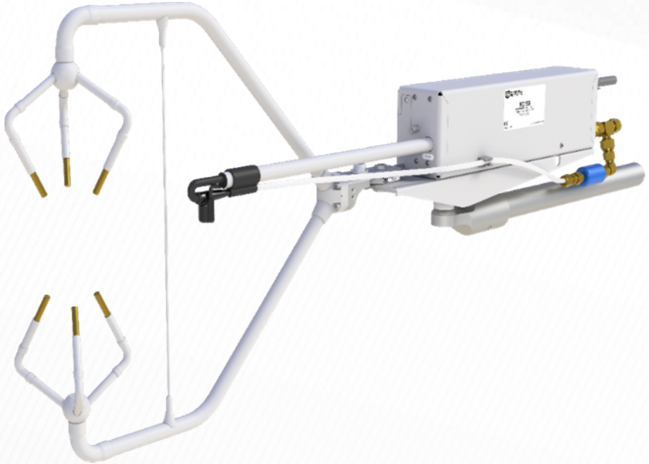
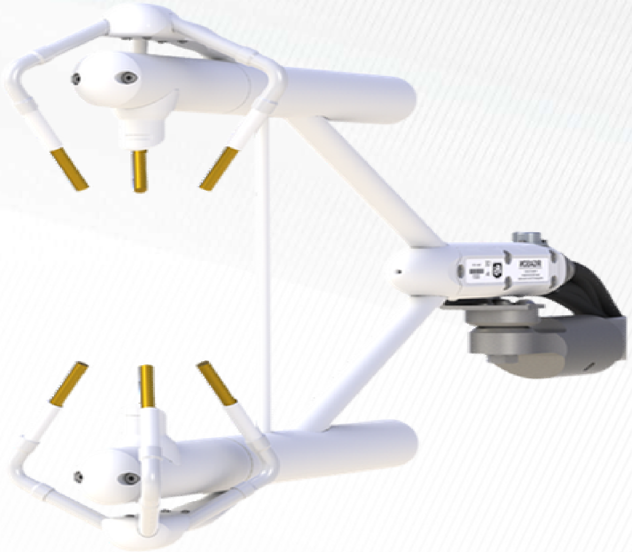
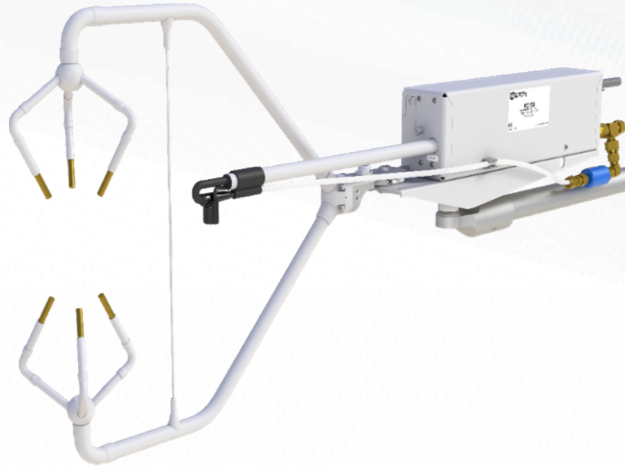
χ_{H2O} water molar mixing ratio





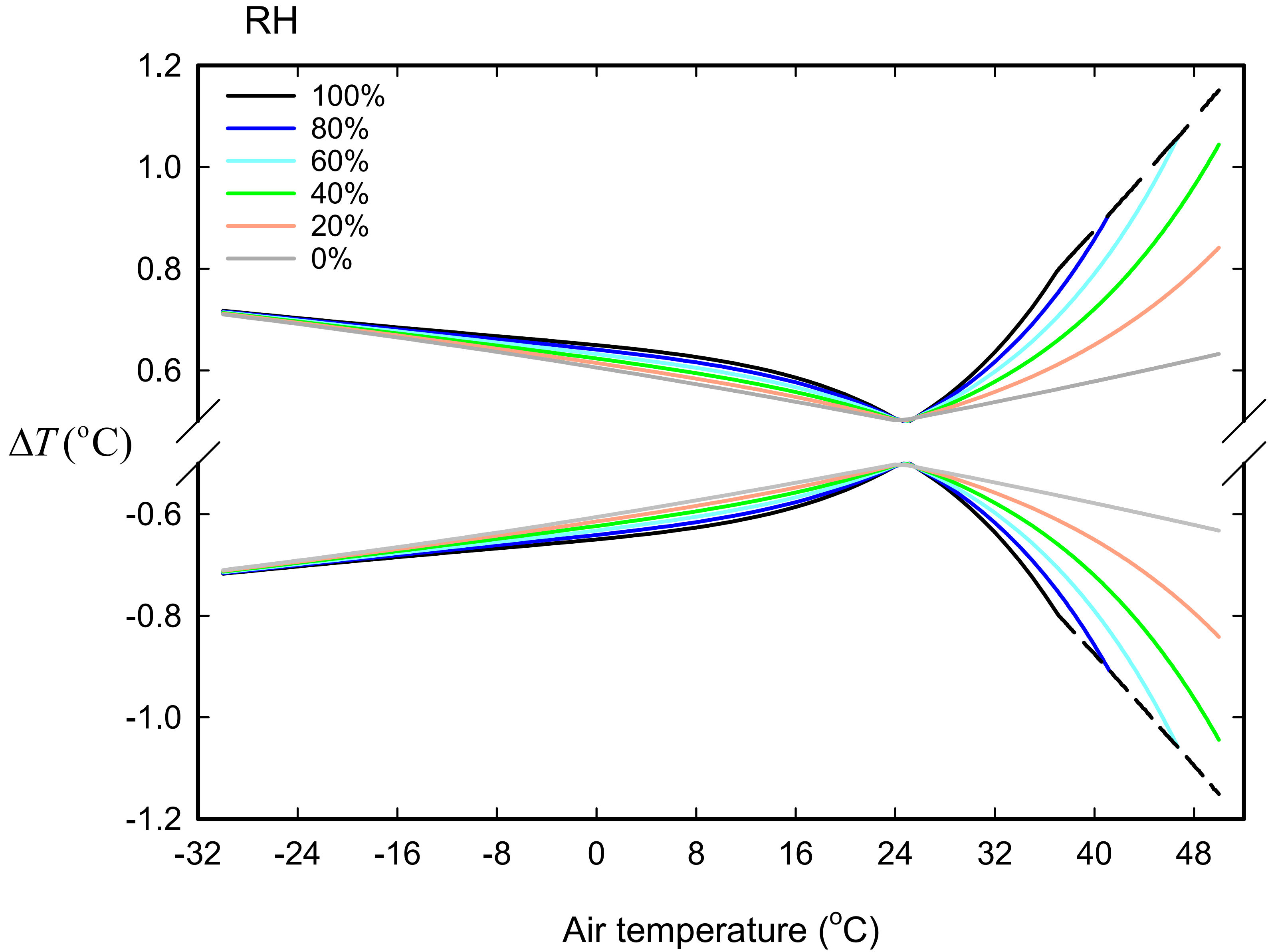
$$\Delta T_s < 0.5\ ^oC$$



$$\Delta\chi_{H2O} = \Delta\chi^{p}_{H2O} + \Delta\chi^{s}_{H2O} + \Delta\chi^{g}_{H2O} + \Delta\chi^{z}_{H2O}$$

precision | sensitivity to CO_2 | gain drift | zero drift

Maximum error ranges of calculated air temperature at different relative humidity



Radiation_LI200X_Avg (R)
T_tmpr_rh_mean (L)
Tc_mean (L)
N40_IRGASON_FLUX_RESEARCH.dat
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25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
900.0
850.0
800.0
750.0
700.0
650.0
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
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2014-08-07 06:00
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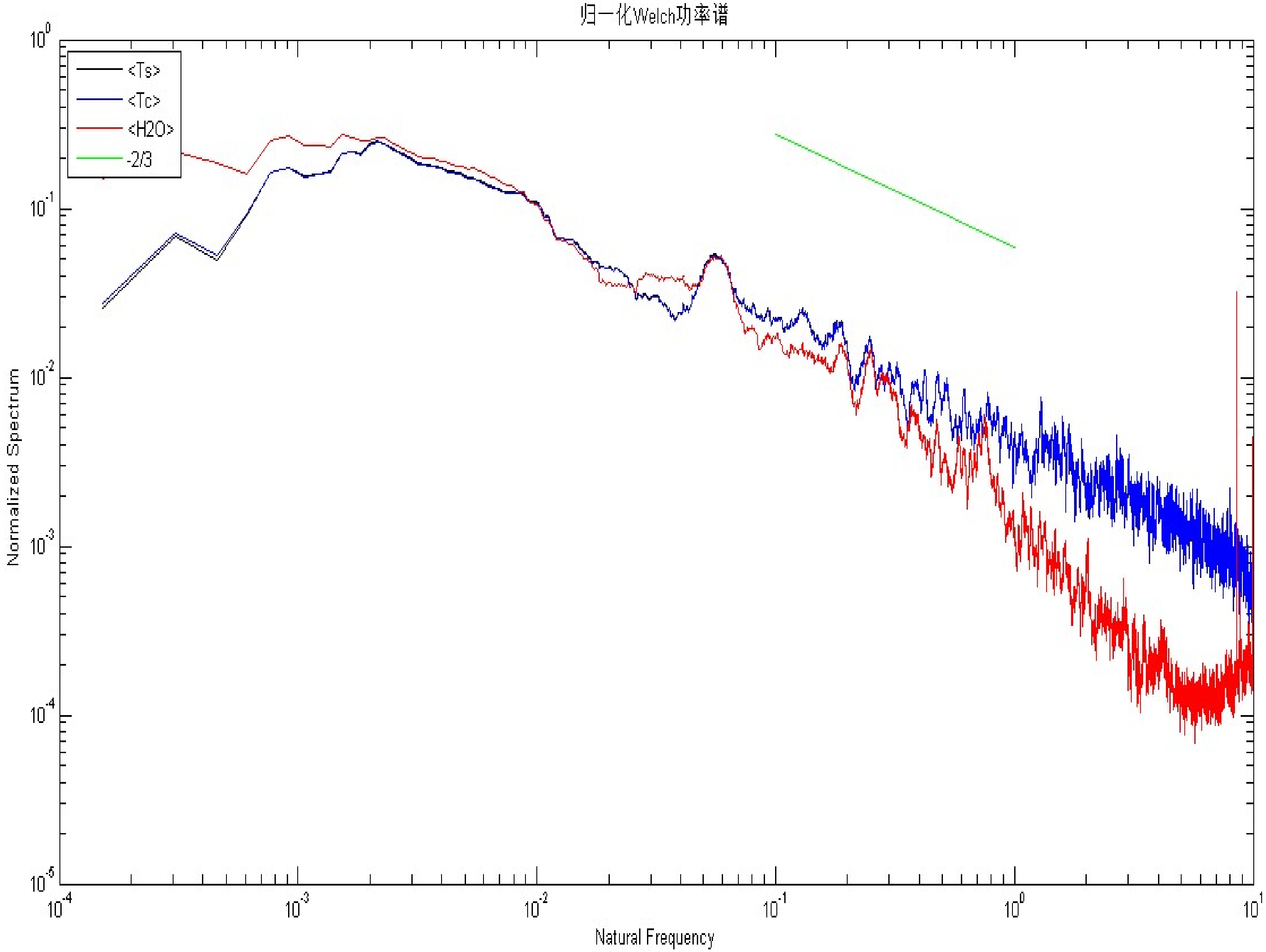

Bruce Bugbee


Questions
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