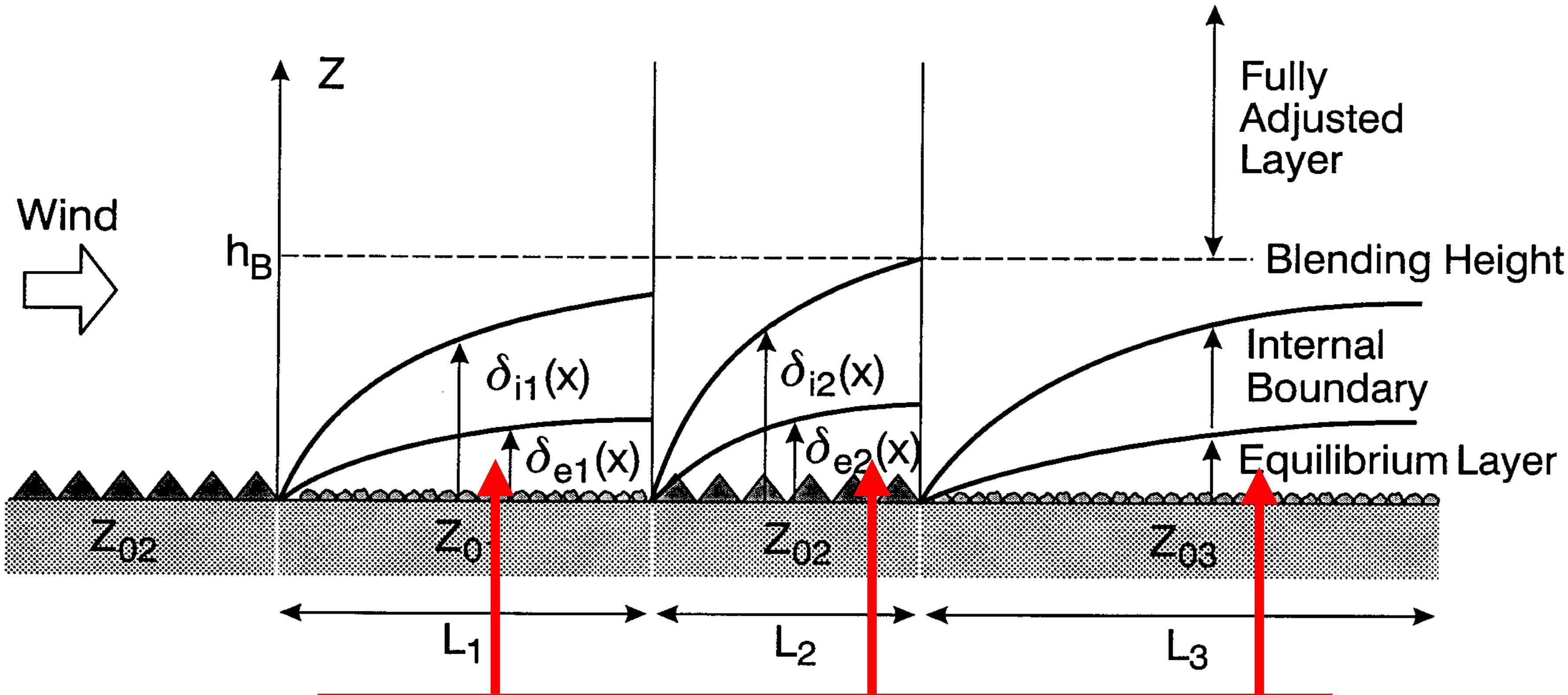
Lecture 4: Site & Measurement requirements

- Site requirements
  - Internal boundary layer
  - Flux footprint
- Measurement requirements
  - Eddy fluxes
  - Profiles
    - Vertical advection
    - Change in storage
- Energy closure

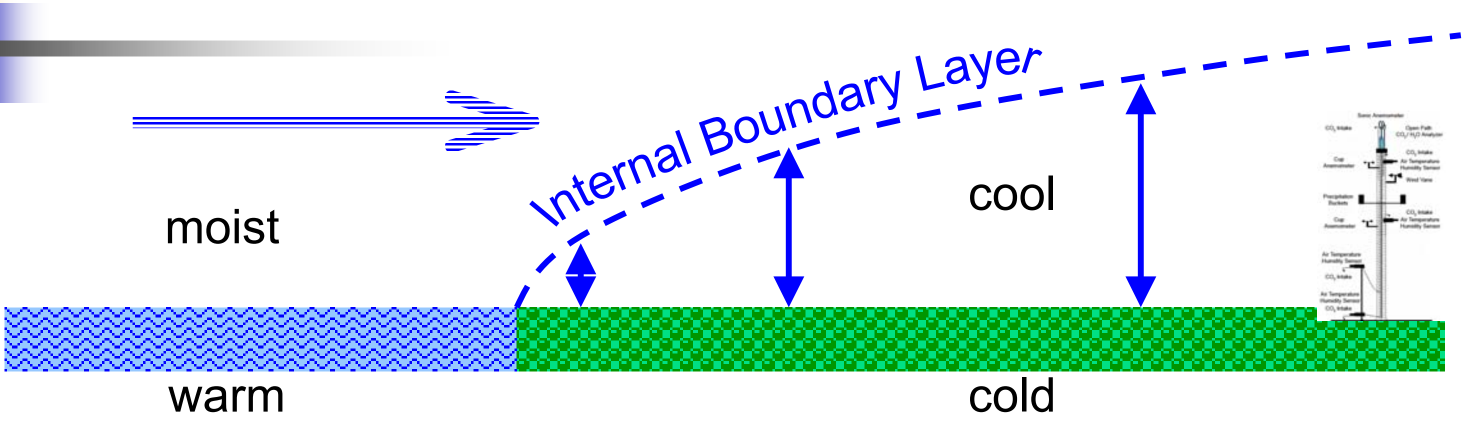
Landscape is a patchwork of surfaces



Equilibrium layer is where we want to measure

Courtesy Dr JJ Finnigan, CSIRO

Internal boundary layer



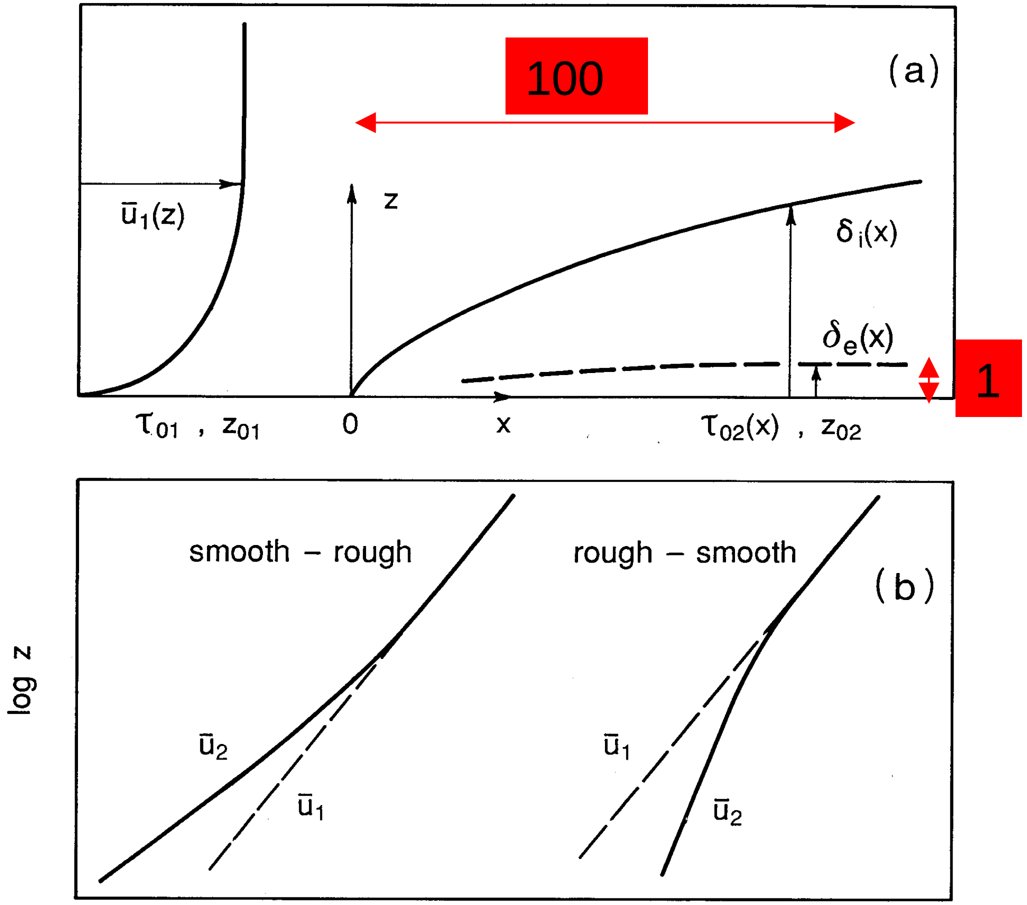
“The depth over which the surface BL adjusts to new surface conditions is related to time it is allowed to do so”

“The strength of a thermal adjustment depends on the magnitude of the thermal forcing”

Courtesy Prof HP Schmid
Indiana University

Windspeed adjustment to change in roughness

- 100:1 fetch rule of thumb
  - Neutral conditions
  - > for stable conditions
  - < for unstable conditions
- there is often a trade-off between a representative footprint and avoiding advective effects

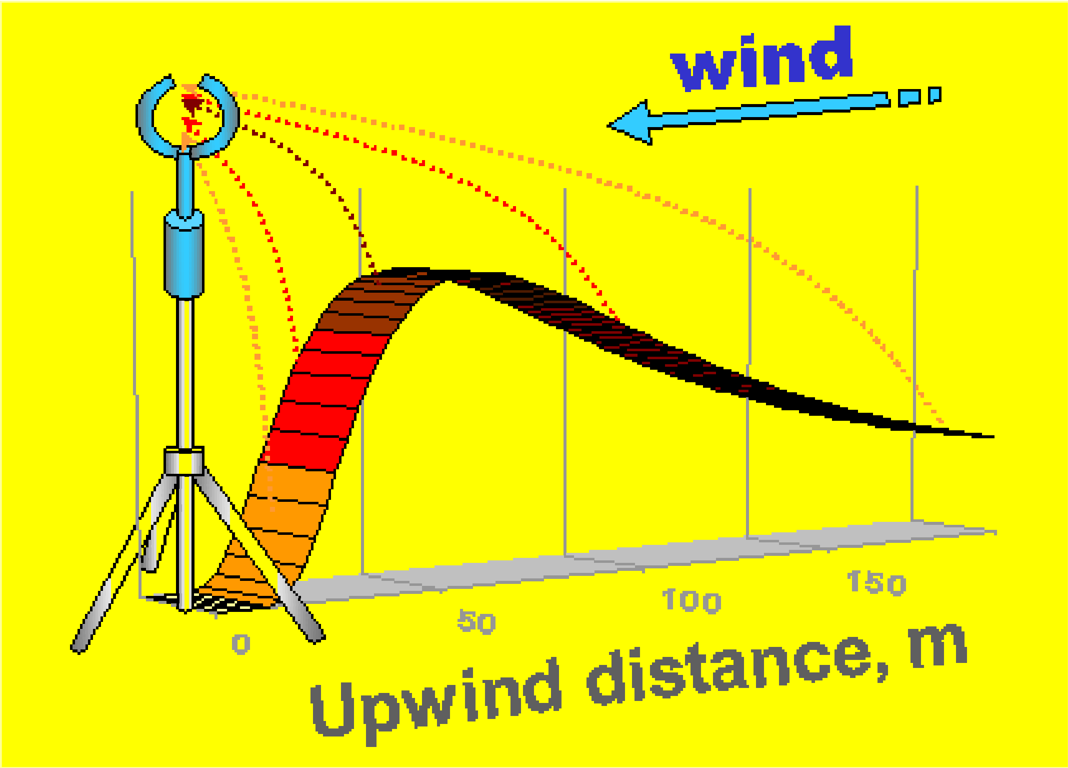


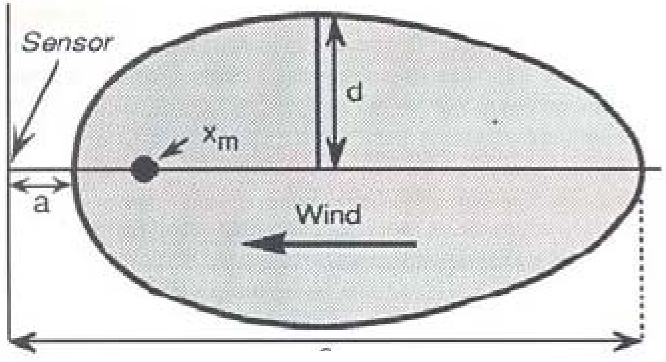
Courtesy Dr JJ Finnigan, CSIRO

Source Footprint

The area under the curve is contribution of source to the flux

Courtesy Prof HP Schmid Indiana University





Upwind distance

Dimensions of the footprint area.

x_m: location of maximum source contibution

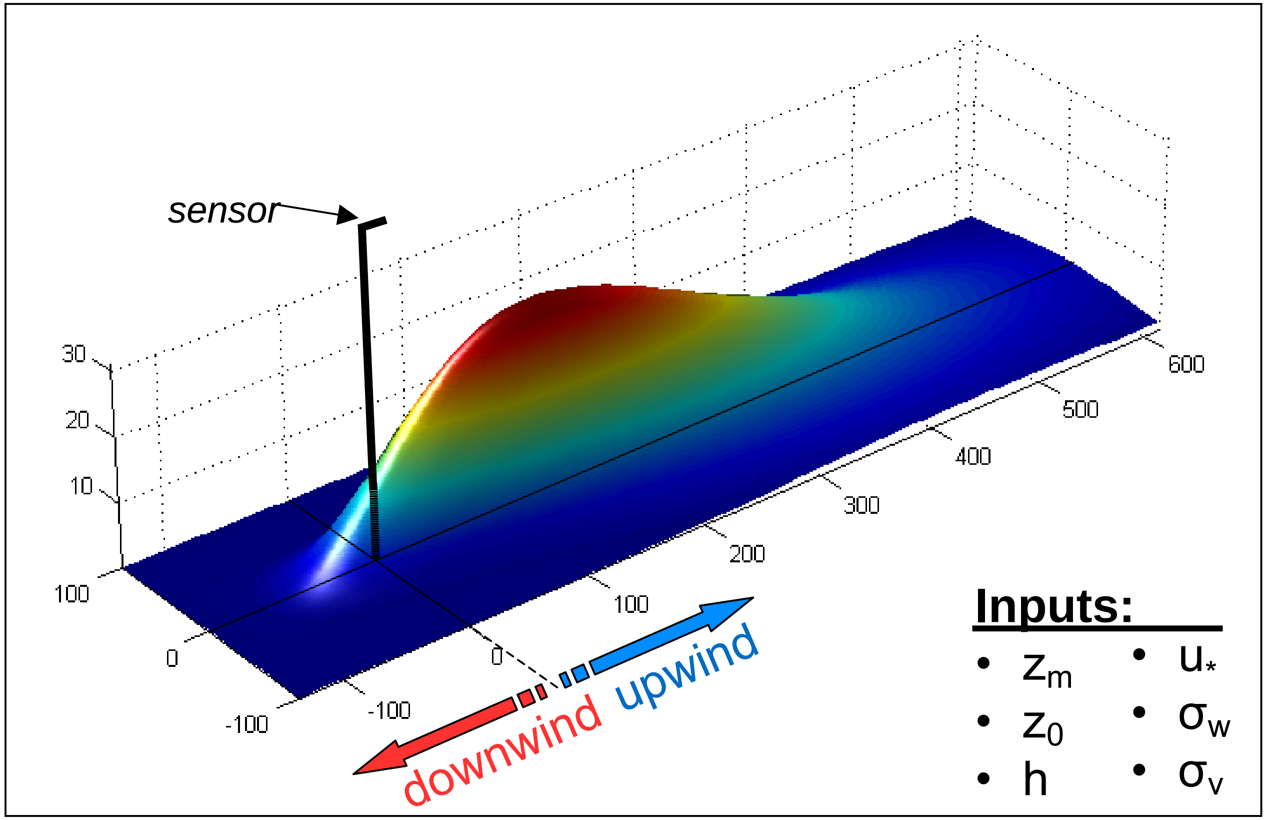
a: downwind edge

d: lateral half-width area

Flux Footprint = spatial filter, “field of view”

$$F(\mathbf{x}) = \iint_{\Re} Q_s(\mathbf{x}') \cdot f(\mathbf{x}-\mathbf{x}') \cdot d\mathbf{x}' = Q_s * f$$

(**Convolution** of the **source distribution,** ***Q*$_S$, **with the **footprint, *f***)



Inputs:

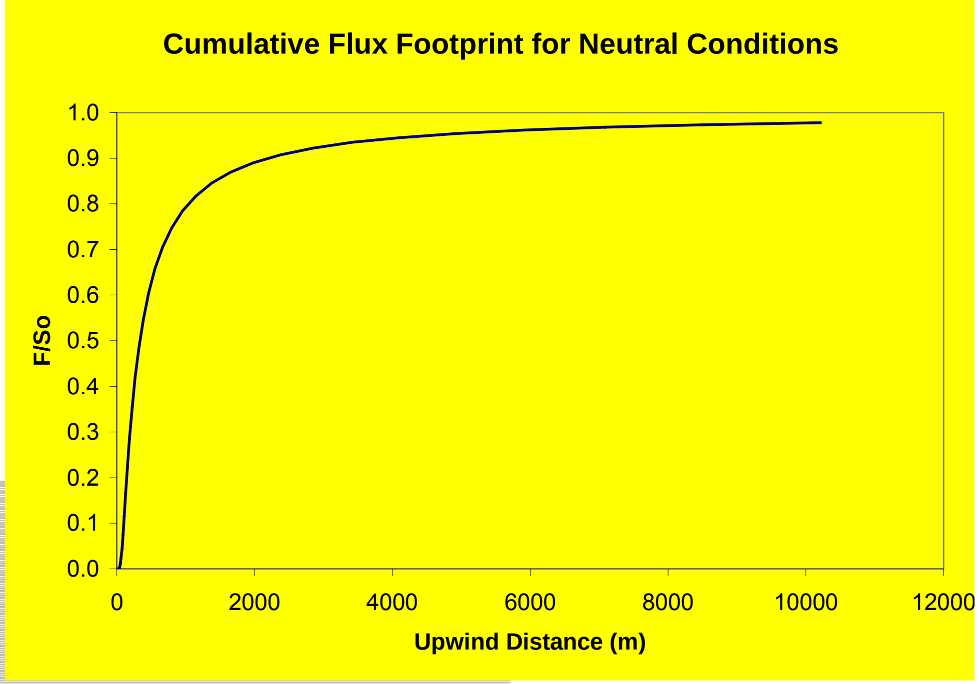
- z_m
- z_0
- h
- u_*
- σ_w
- σ_v

Courtesy Prof
HP Schmid
Indiana
University

Schmid 1994 (*Boundary-Layer Meteorol.*, **67**, 293-318)

Cumulative flux footprint

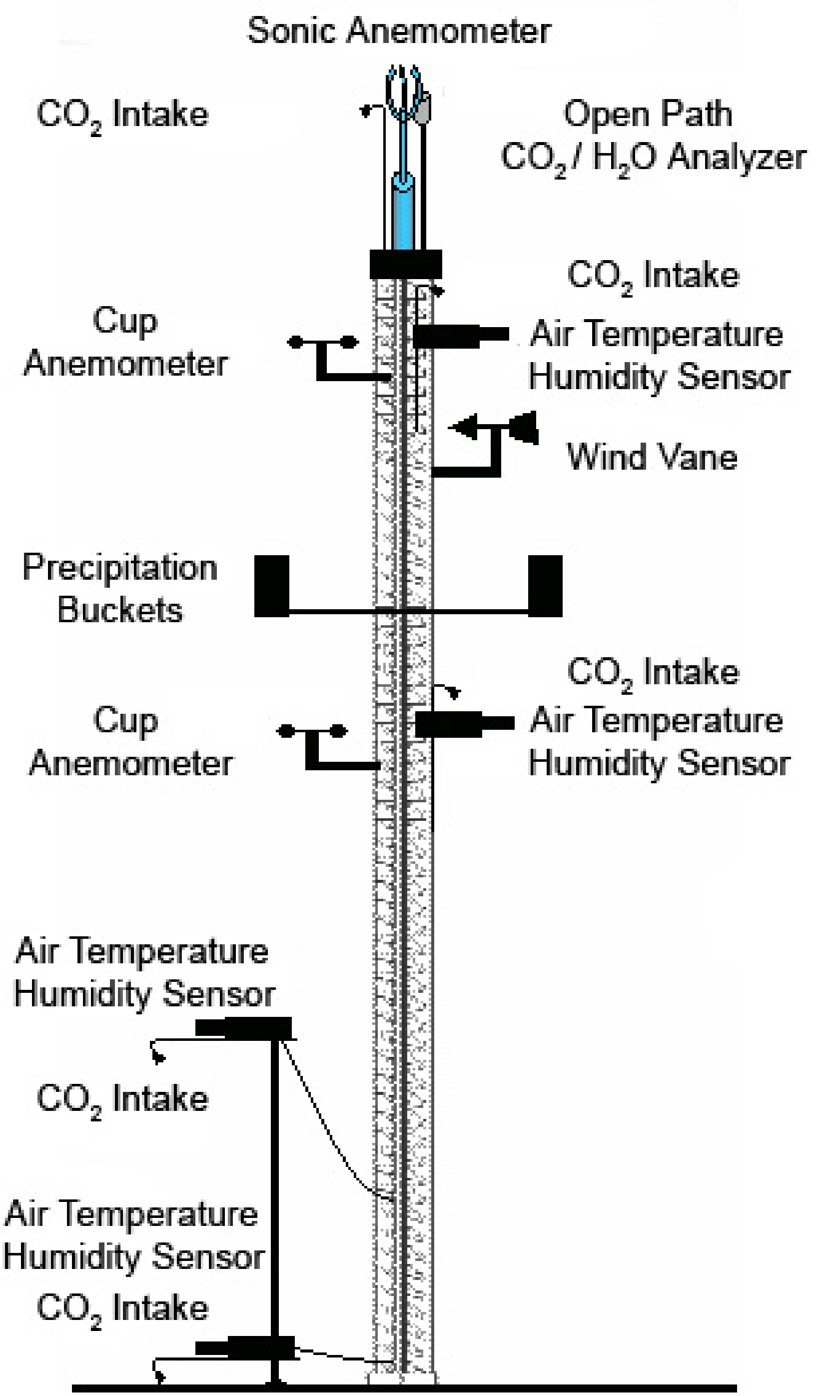
Courtesy Prof HP Schmid Indiana University



$$\frac{F}{S_0} = \exp\left(\frac{-1}{k^2 x} D z^P \left|L\right|^{1-P}\right)$$

F = *measured flux*
S_o = *surface source strength*
x = *upwind distance*, z = *measurement height*
k = *von Karman constant* = 0.4
L = *Monin-Obukhov length*
$D = 0.28$; $P = 0.59$ for unstable conditions ($\xi = z_m / L < 0$)
$D = 0.97$; $P = 1$ for near neutral conditions ($|\xi| < 0.02$)
$D = 2.44$; $P = 1.33$ for stable conditions ($\xi > 0$)

Tower schematic

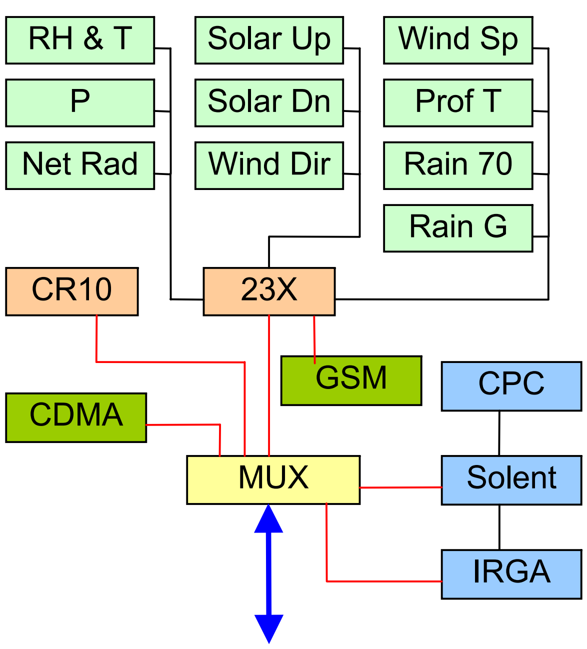


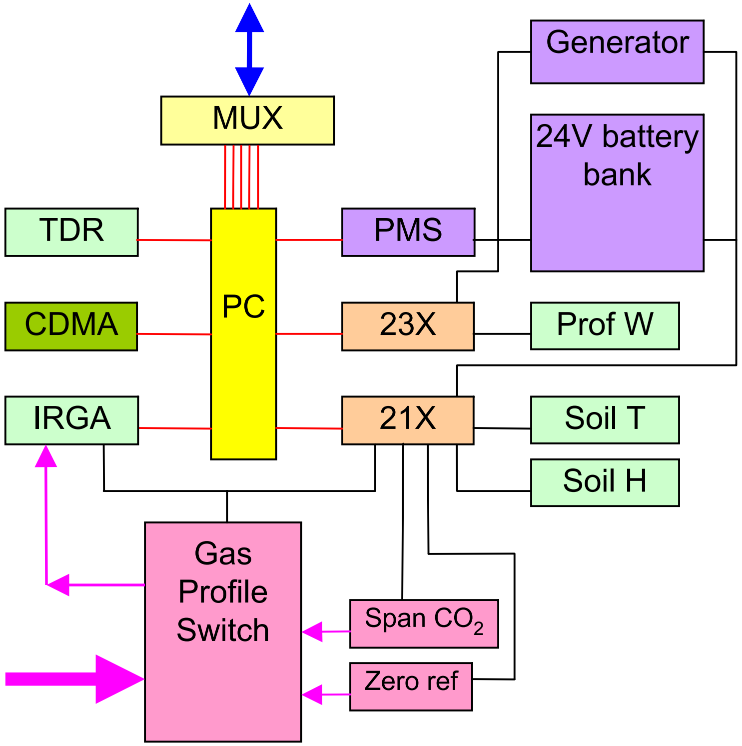
Courtesy Prof Shashi Verma, Univ. Nebraska

Tumbarumba data acquisition

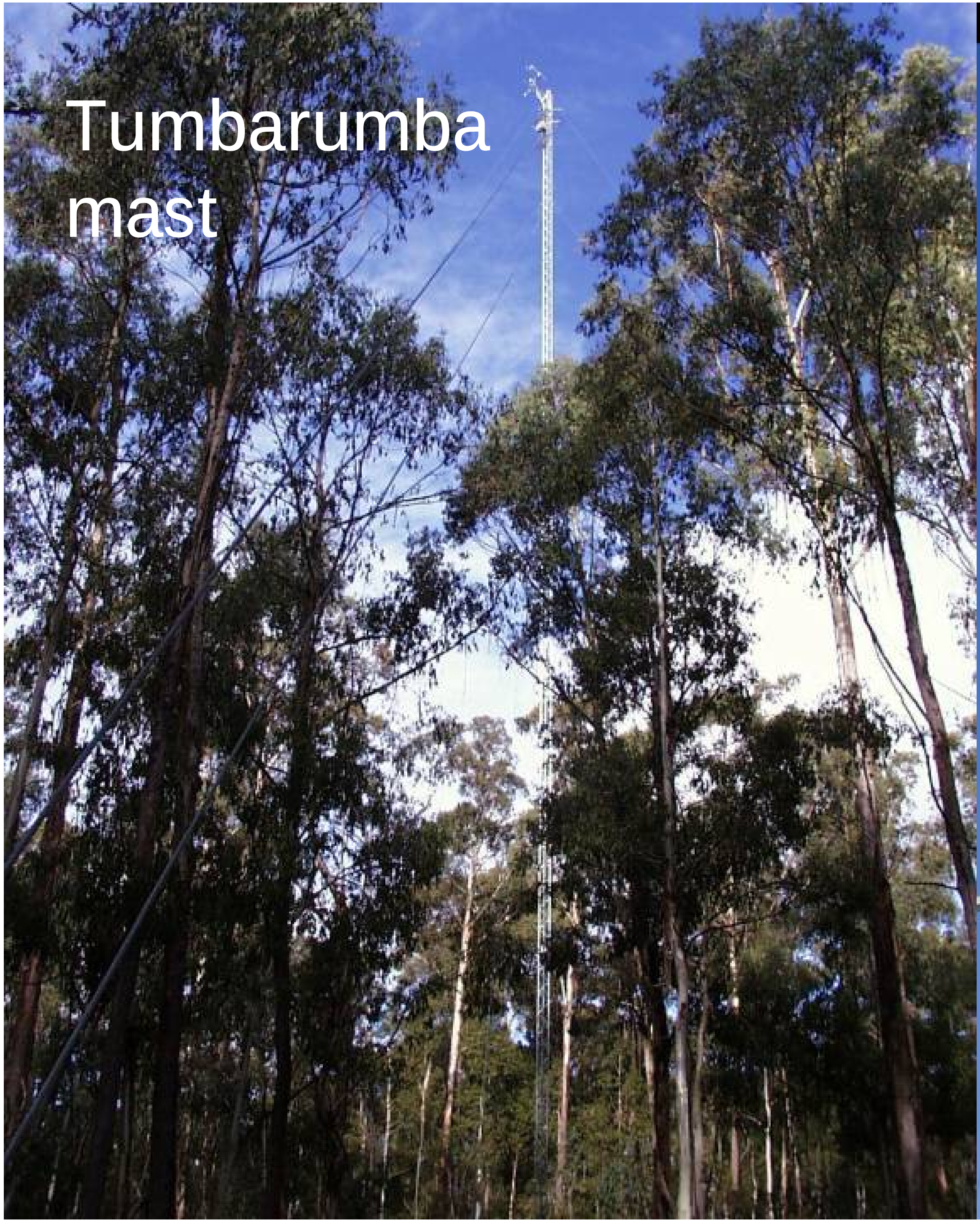
Mast Instruments

Ground Instruments





Tumbarumba mast



Tumbarumba mast instruments

Minimum measurements needed

- Top of mast
  - 3-D wind vector (20Hz)
  - CO_2 and H_2O concentrations (20Hz)
  - Net radiation (15 min average)
  - Incoming and reflected solar radiation (15 minute average)
  - RH and air temperature (15 minute average)
  - Wind speed and direction (15 minute average)
  - Rainfall
- Ground
  - Soil temperature (15 minute average)
  - Soil heat flux (15 minute average)
  - Soil moisture (TDR, hourly)

Minimum measurements needed (cont^d)

- Profiles (multiple levels, 1 Hz)
    - Temperature
    - CO_2
    - H_2O vapor
    - 2- or 3-D wind vectors

Instruments

Optional measurements

- Spectrometer (plant canopy reflectance spectra)
- Particle counter (VOC’s, dust)
- Gas isotope measurements
- Etc., etc., etc.

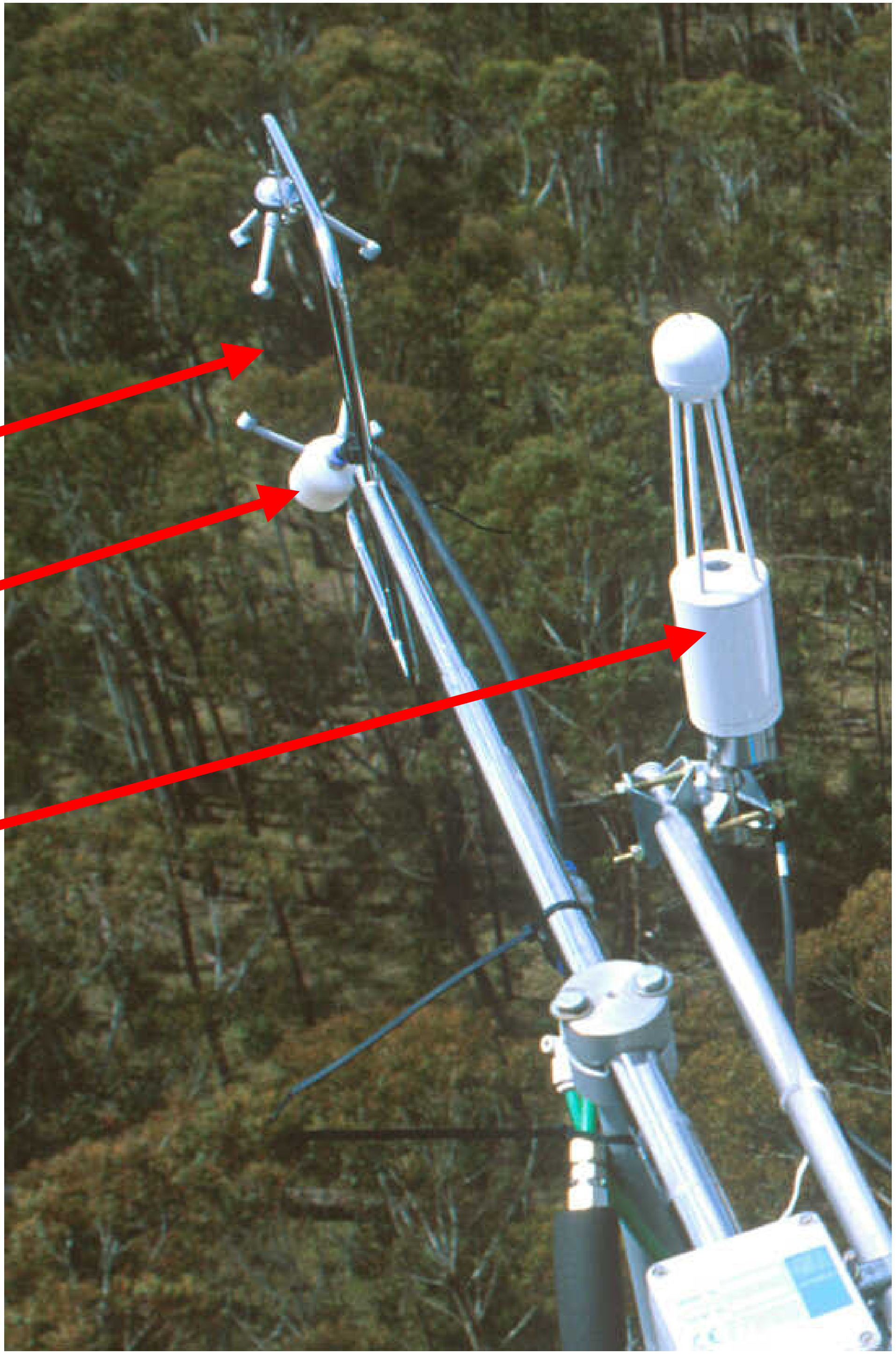
Limitations on instrumentation:

- Power requirements
- Ability to maintain and calibrate the instruments !!

Biological measurements

- Respiration chambers
    - Soil
    - leaves
    - Stems
- Photosynthesis chambers
- Carbon stocks
    - Soil
    - Biomass
- Allometric relationships
    - e.g. leaf biomass vs dbh
    - e.g. stem biomass vs dbh

Instrumentation

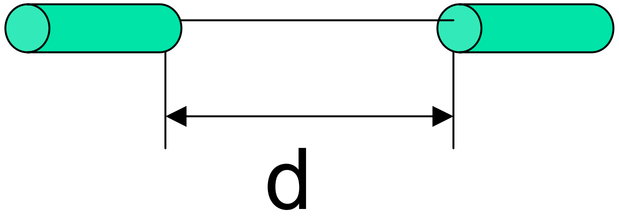


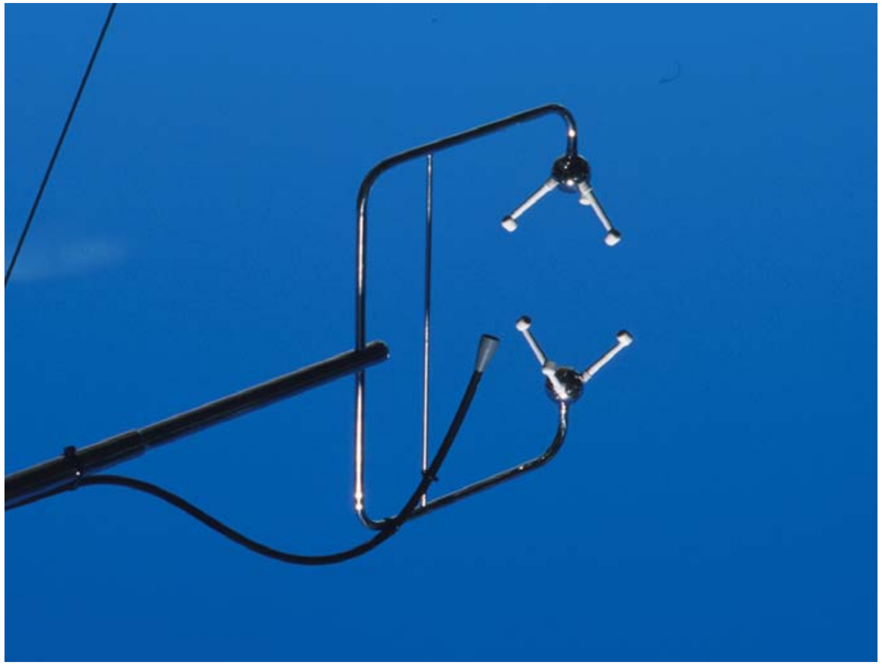
Sonic anemometer

Air intake for closed-path CO_2 & H_2O analyser

Open-path CO_2 & H_2O analyser

Sonic anemometer





Wind speed

$$v_d = \frac{d}{2}\left[\frac{1}{t_1} - \frac{1}{t_2}\right]$$

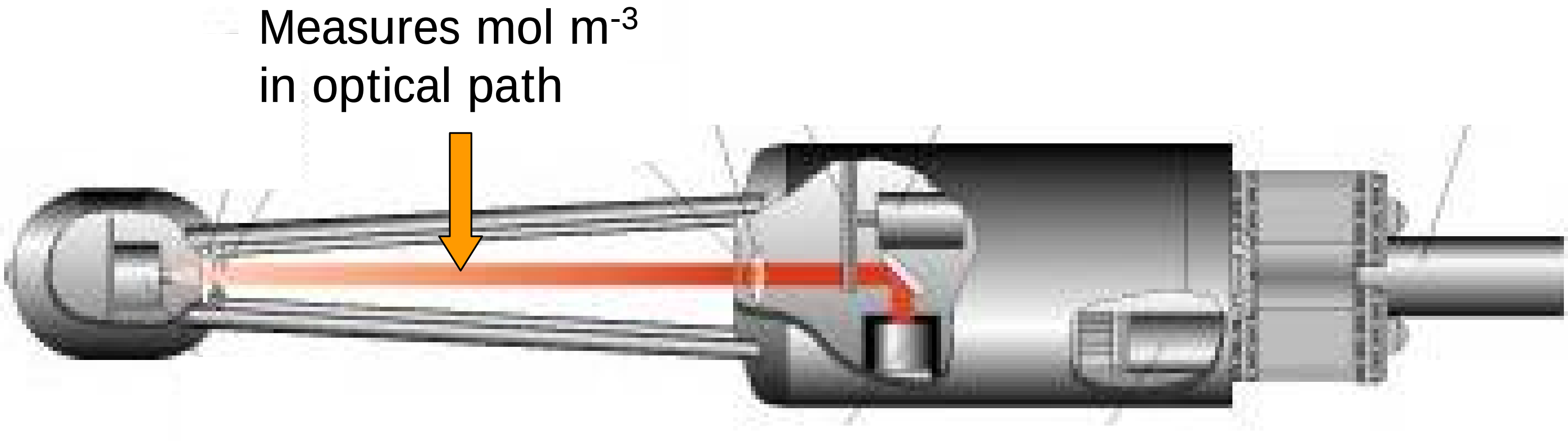
Absolute instrument for v_d

Virtual temperature

$$T_v = \frac{d^2}{1612}\left[\frac{1}{t_1} + \frac{1}{t_2}\right]^2 + \frac{1}{403}\left[v_x^2 + v_y^2\right]$$

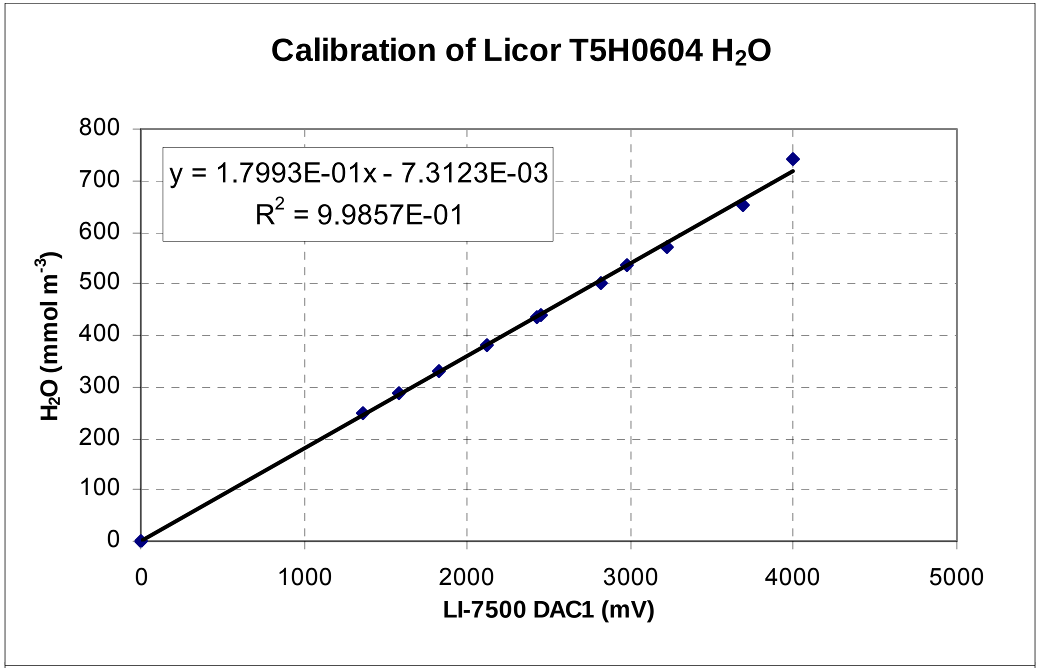
Kaimal & Finnigan, 1994

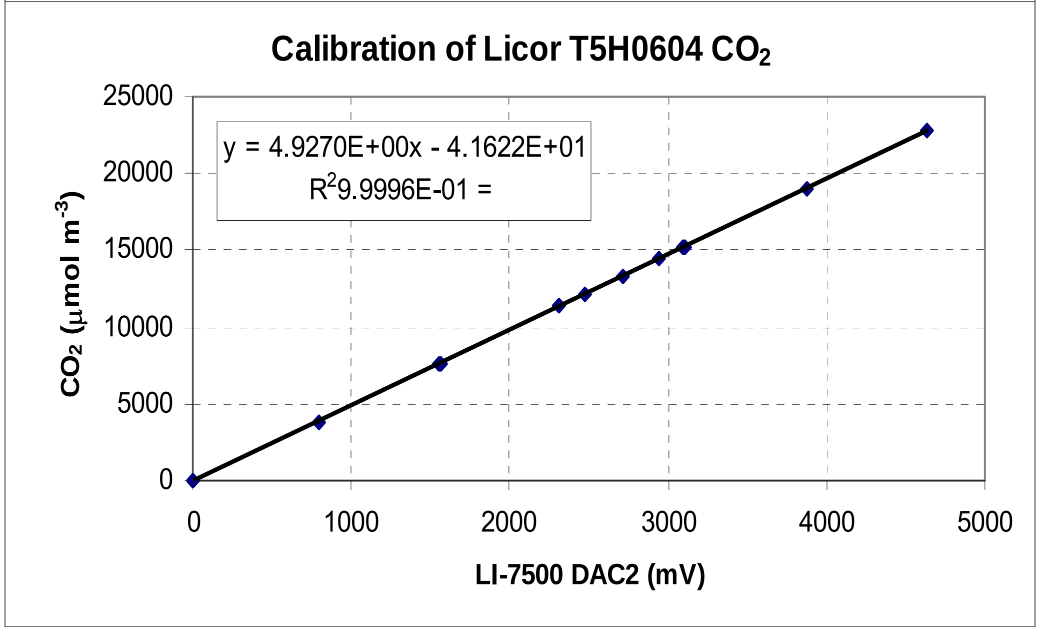
Fast-response CO_2 and water vapor analyser


Measures mol m^{-3} in optical path

LI-7500 Open-path CO_2 and water vapor analyser

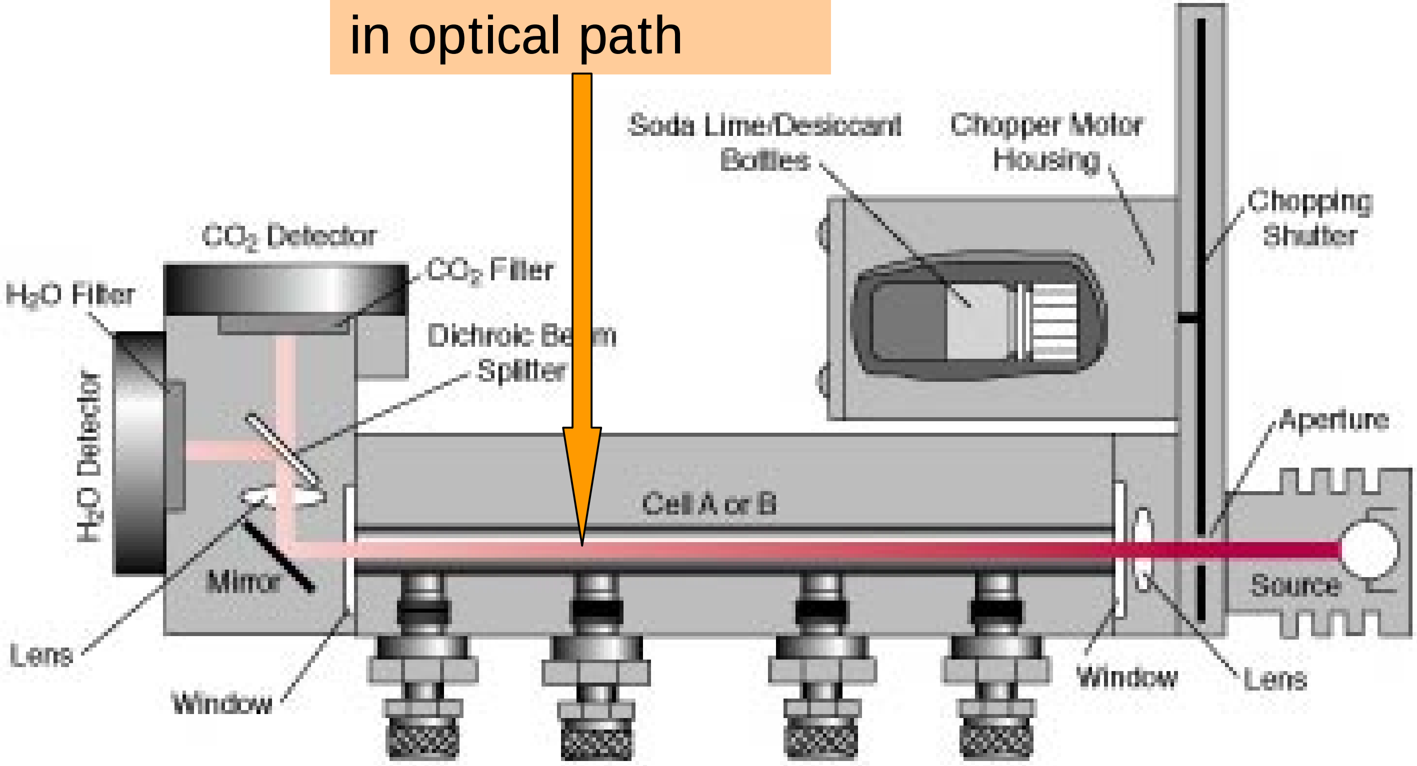
Calibration LI-7500


Calibration of Licor T5H0604 H_2O

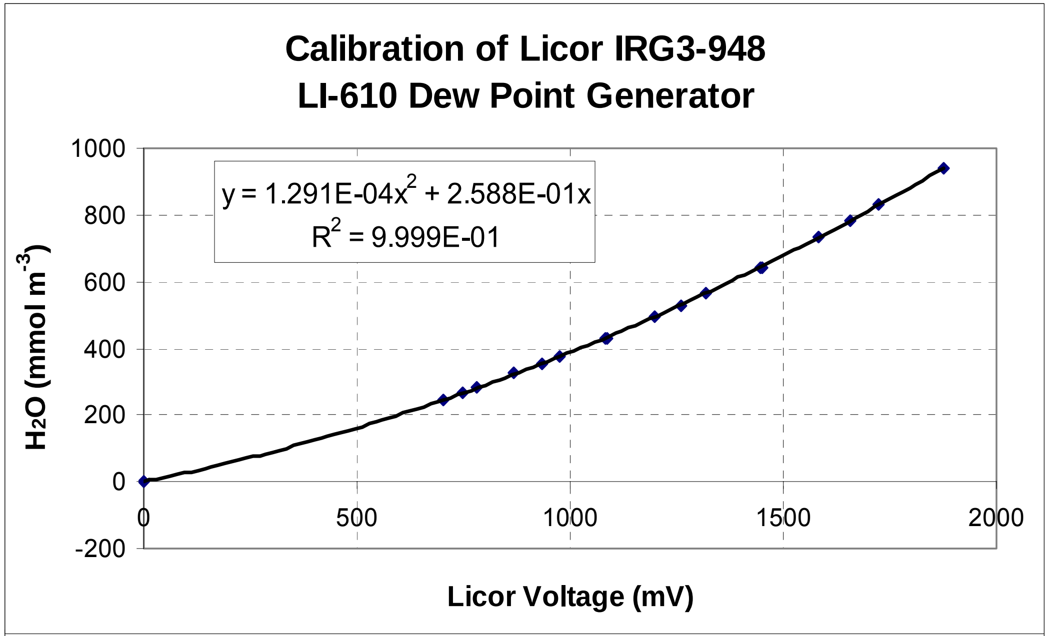

Calibration of Licor T5H0604 CO_2

Licor closed-path analyser

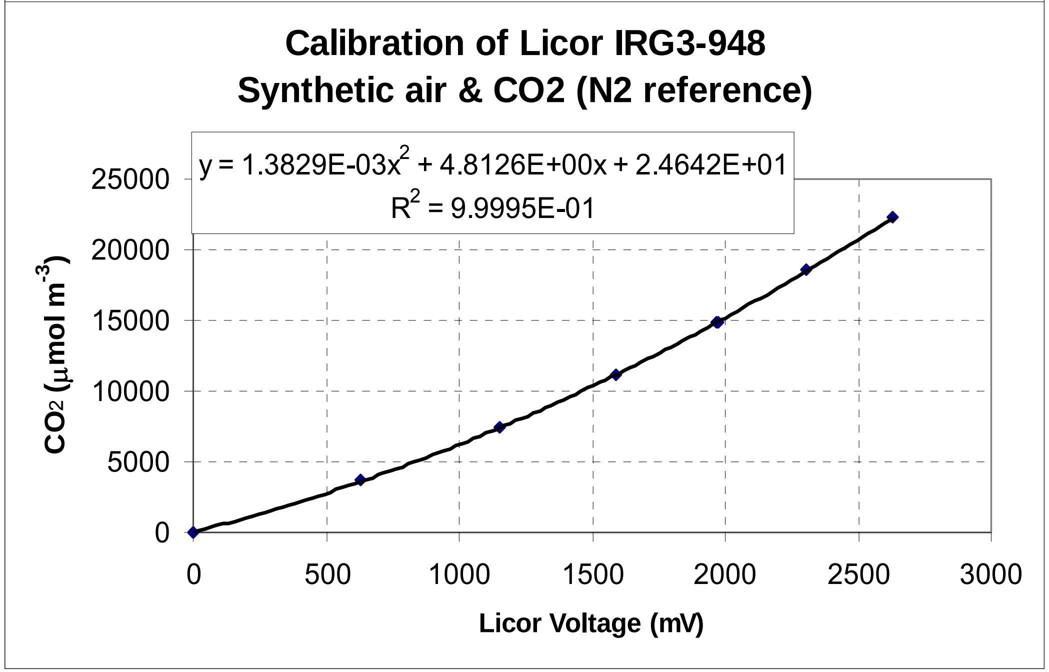
Measures mol m^{-3} in optical path



Calibration LI-6262

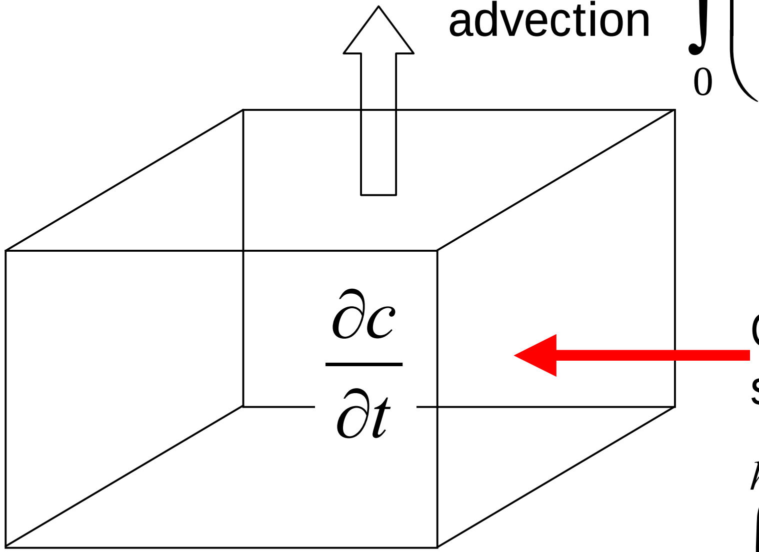


Calibration of Licor IRG3-948
LI-610 Dew Point Generator



Calibration of Licor IRG3-948
Synthetic air & CO2 (N2 reference)

Control volume



$$\frac{\partial c}{\partial t}$$

Vertical advection

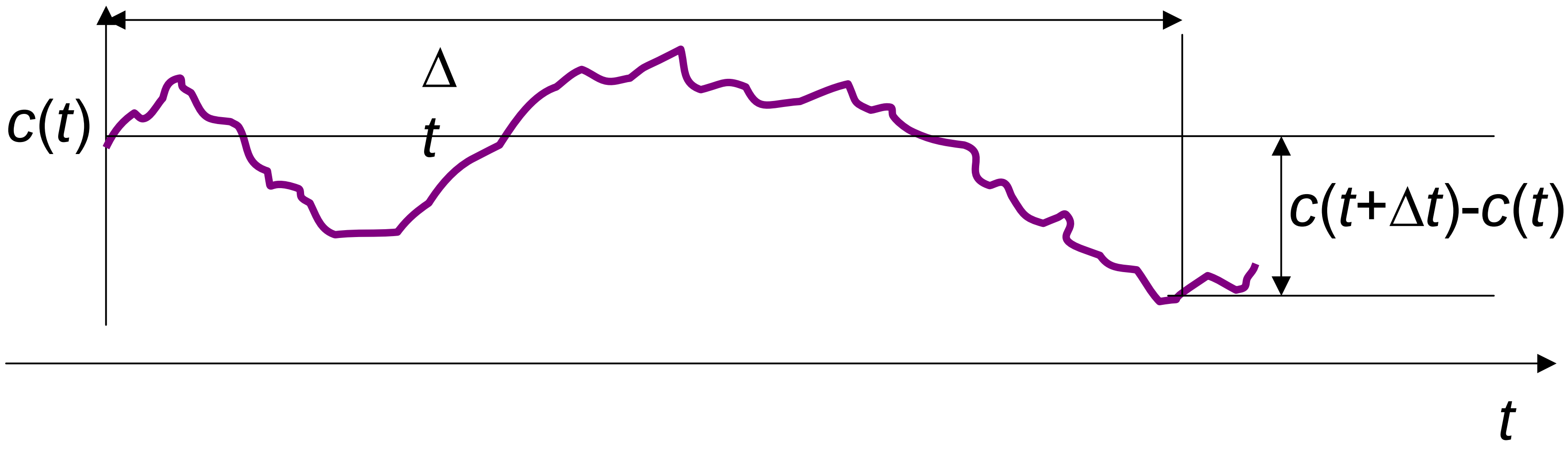
$$\int_0^h \left(\overline{w} \frac{\partial \overline{\chi_c}}{\partial z} \right) dz$$

Change in storage

$$\int_0^h \left[\frac{\overline{\partial c}}{\partial t} dt \right] dz$$

The change in storage term

$$\int_0^h \left[\overline{\frac{\partial c}{\partial t}}dt\right]dz = \int_0^h \left[\frac{1}{T}\int_0^T \frac{\partial c}{\partial t}dt\right]dz = \int_0^h \left[\frac{1}{T}\left(c\left(T\right)-c\left(0\right)\right)\right]dz$$



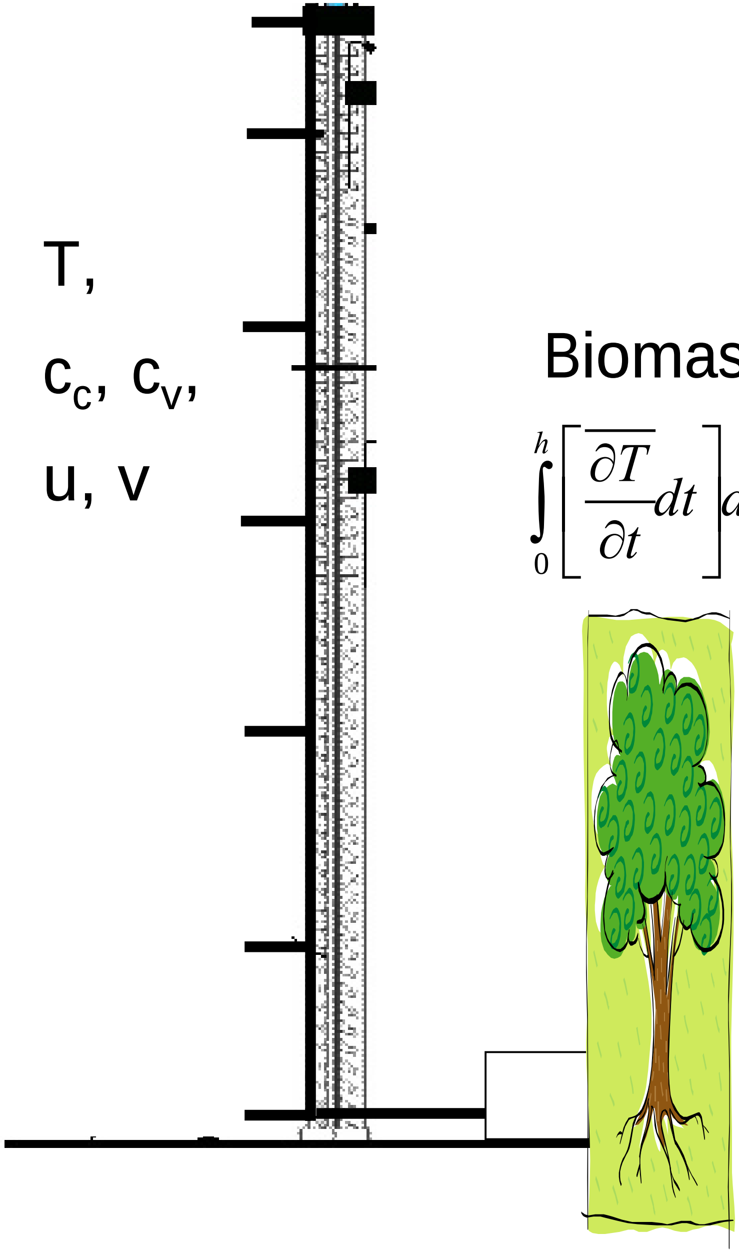
Vertical advection

See lecture 7 for details

$$\int_0^h \left(\overline{w}\frac{\partial \overline{\chi_c}}{\partial z}\right)dz = \overline{w}(h)\overline{\chi_c}(h) - \int_0^h \left(\overline{\chi}_c \frac{\partial \overline{w}}{\partial z}\right)dz$$

$$= \underset{\substack{\uparrow\\ \text{Vertical velocity}\\ \text{at top of CV}}}{\overline{w}(h)}\left[\underset{\substack{\uparrow\\ \text{Mixing ratio}\\ \text{at top of CV}}}{\overline{\chi}_c(h)} - \frac{\int_0^h \overline{\chi}_c(z)u(z)dz}{\underset{\substack{\uparrow\\ \text{Windspeed-weighted}\\ \text{mixing ratio within CV}}}{\int_0^h u(z)dz}}\right]$$

Profiles



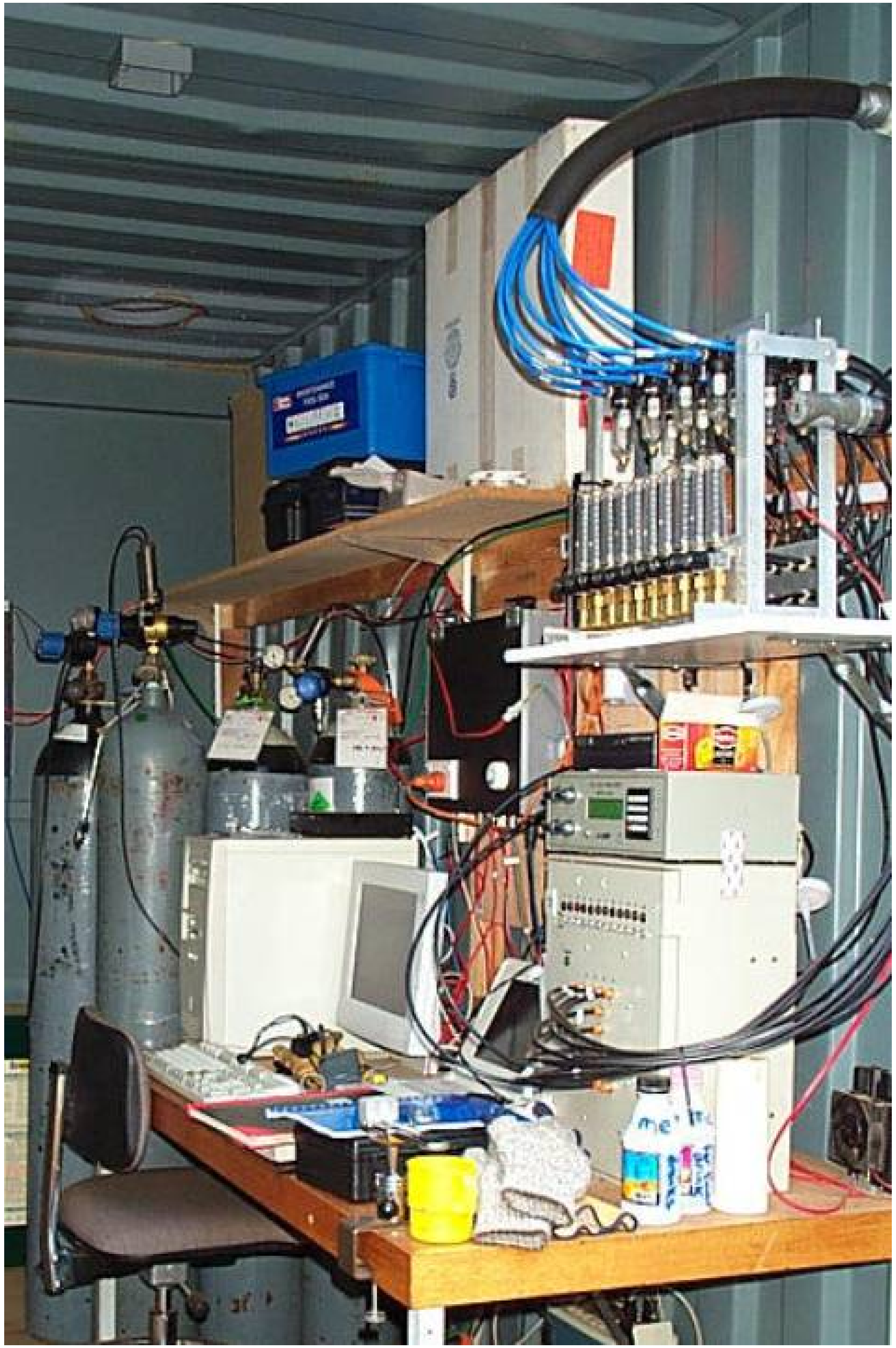
T,

c_c, c_v,

u, v

Biomass

$$\int_0^h \left[\frac{\overline{\partial T}}{\partial t} dt \right] dz$$



Canopy Energy Closure at Tumbarumba

$$R_n - G_0 \left(-\Delta J_c\right) = H + \lambda E$$

$$J_c = J_a + J_e + J_{tr}$$

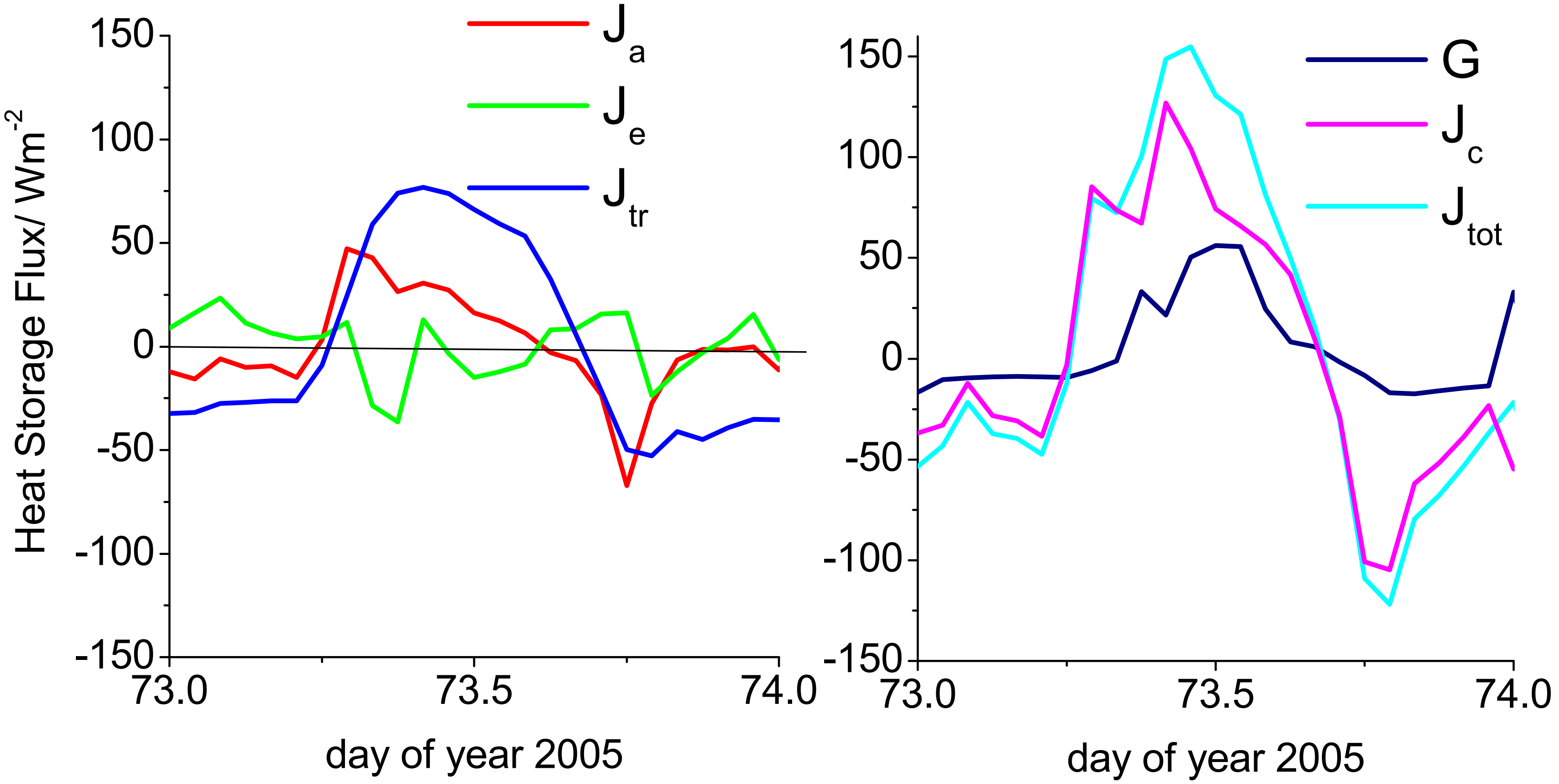
Air

H_2O vapor

Trunks

$$J_{tr} = \int_0^{h_c} m_{tr} c_{tr} \frac{d\overline{T_{tr}(z)}}{dt} dz$$

Magnitude of biomass heat storage term



Canopy Energy Balance

$$R_n - G_0 \left(-\Delta J_c \right) = H + \lambda E$$