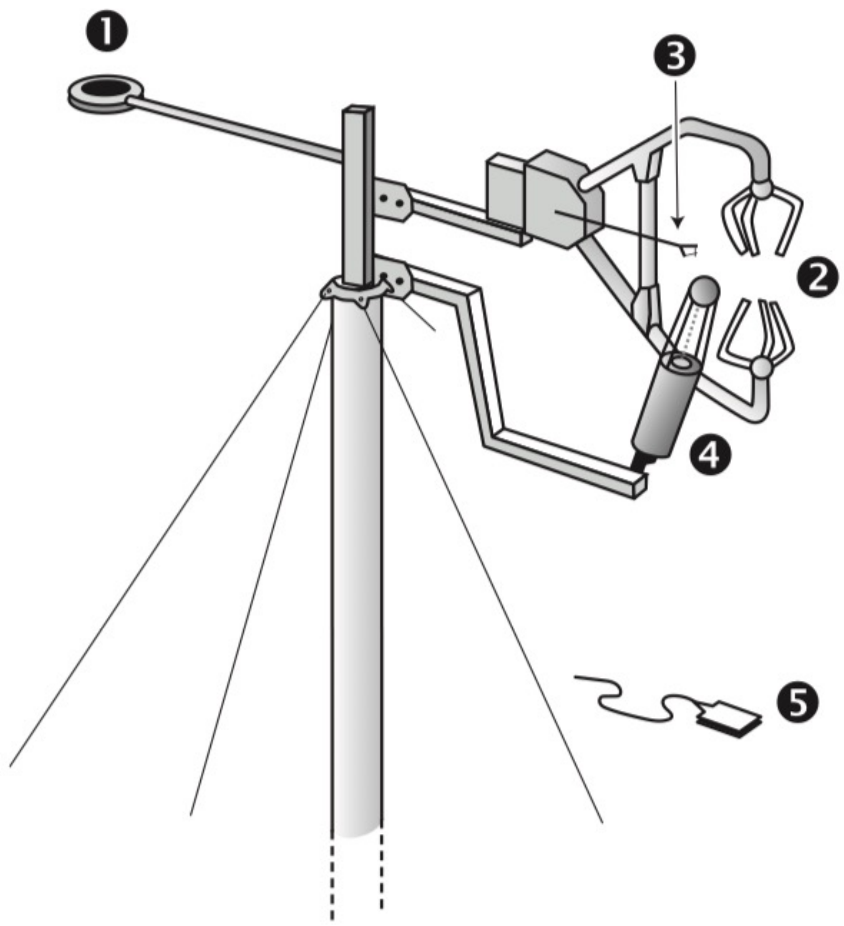
Measuring greenhouse gas fluxes from a salt marsh in Boundary Bay, Delta, BC using the eddy covariance approach. Photo: Tzu-Yi Lu

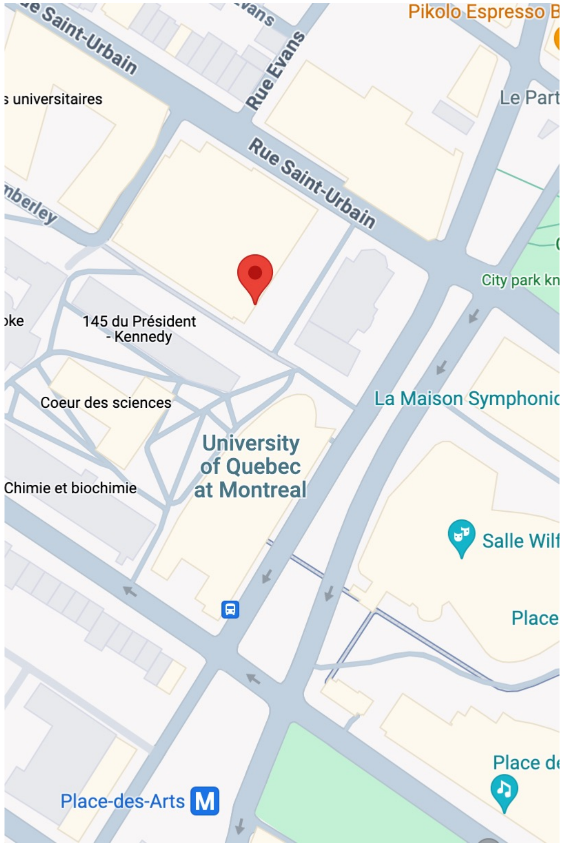
22 Eddy covariance

Lab visit, Tuesday March 19th



[Science Biologique Pavillion, second floor (near the elevators), room **SB-2210**]

141 Avenue du Président-Kennedy, Montreal Quebec
UQAM



Today's learning objectives

- Describe the eddy covariance approach & what observations are required to measure flux densities using this approach.
- Describe the equations used to calculate Q_H, Q_E and trace gas fluxes.
- Be able to interpret eddy covariance observations of Net Ecosystem Exchange (NEE).

Measurement of convective fluxes using the EC technique at a salt marsh in Boundary Bay, Delta, BC (*Photo: Tzu-Yi Lu, UBC*)

Convective transport

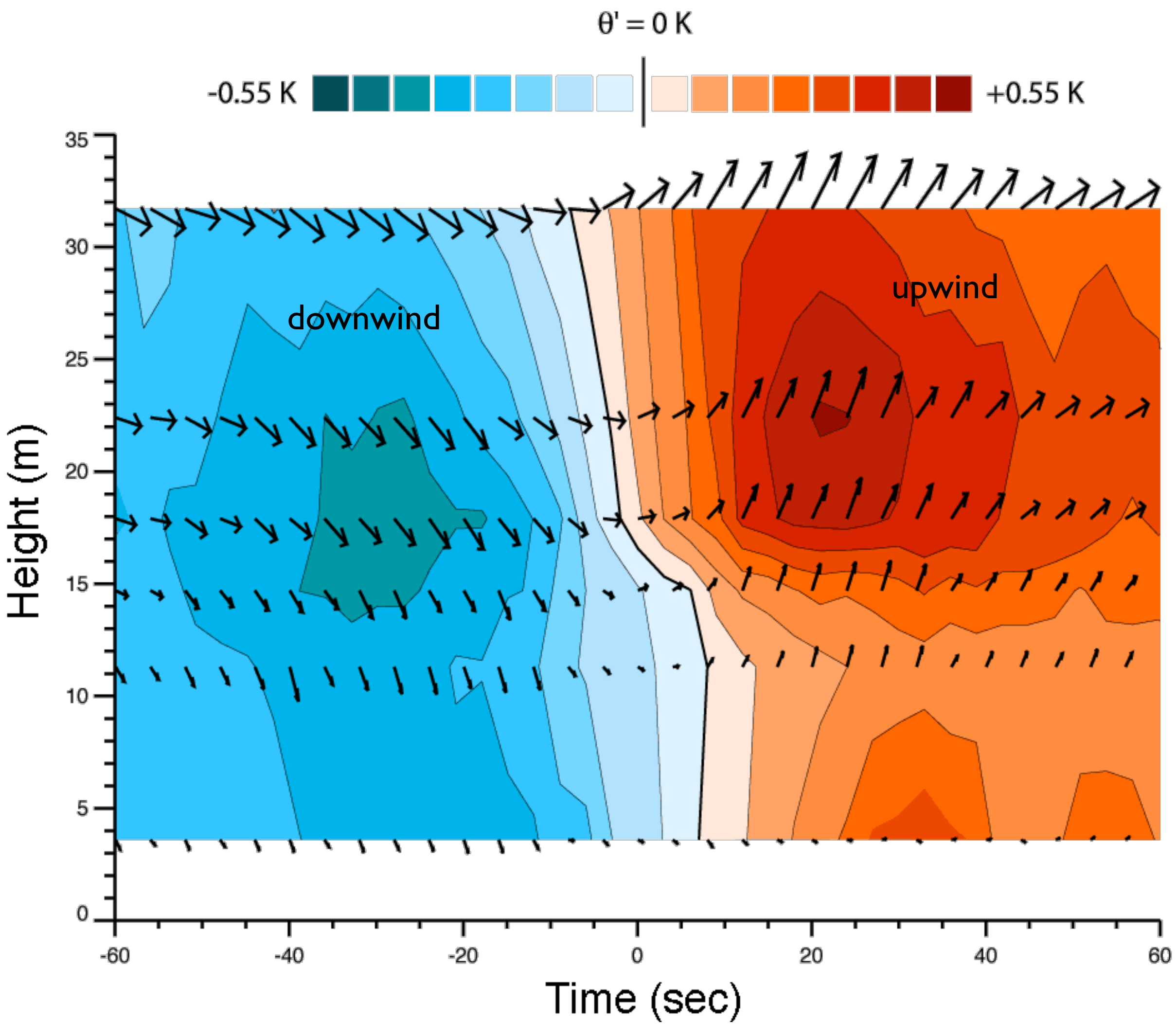
Turbulence and the 'eddies' transport not only momentum but also heat and mass. Turbulence is the most relevant vertical transport mechanism in the ABL.

Tower with eddy covariance instrumentation

Photo: Nick Lee

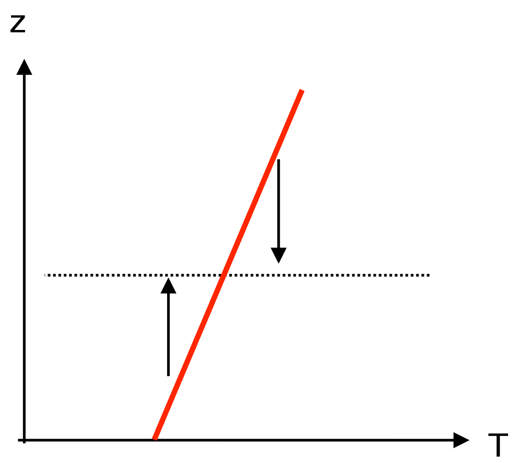
Evidence of convective transport in a time series

Simultaneous measurements at 6 heights on a tower of **wind vector** (arrows) and **temperature** (colors)



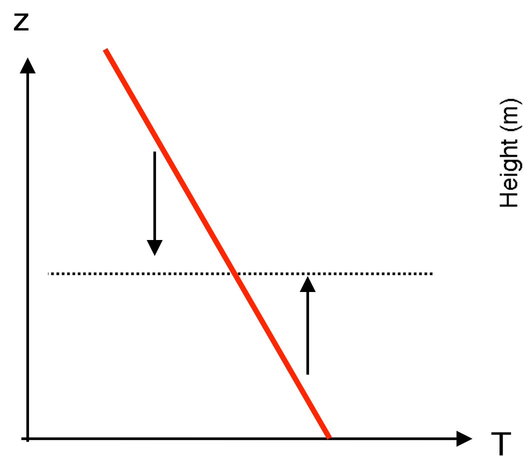
Test your knowledge (slido)

What temperature profile do those observations correspond to?



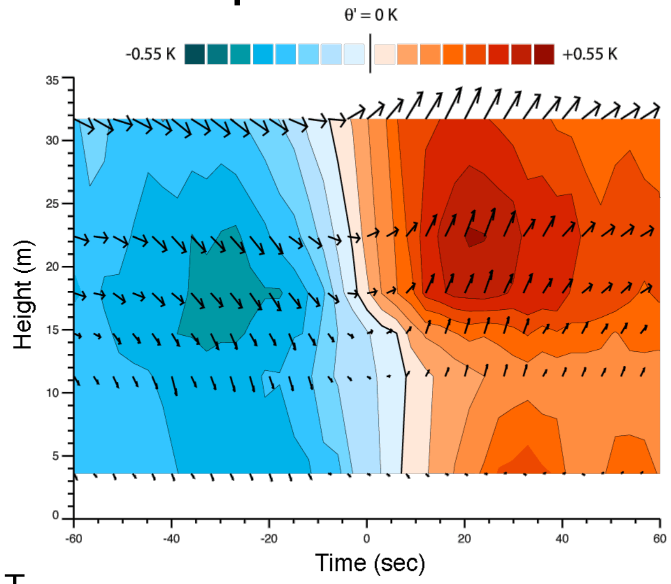
Potential temperature increases with height.

A

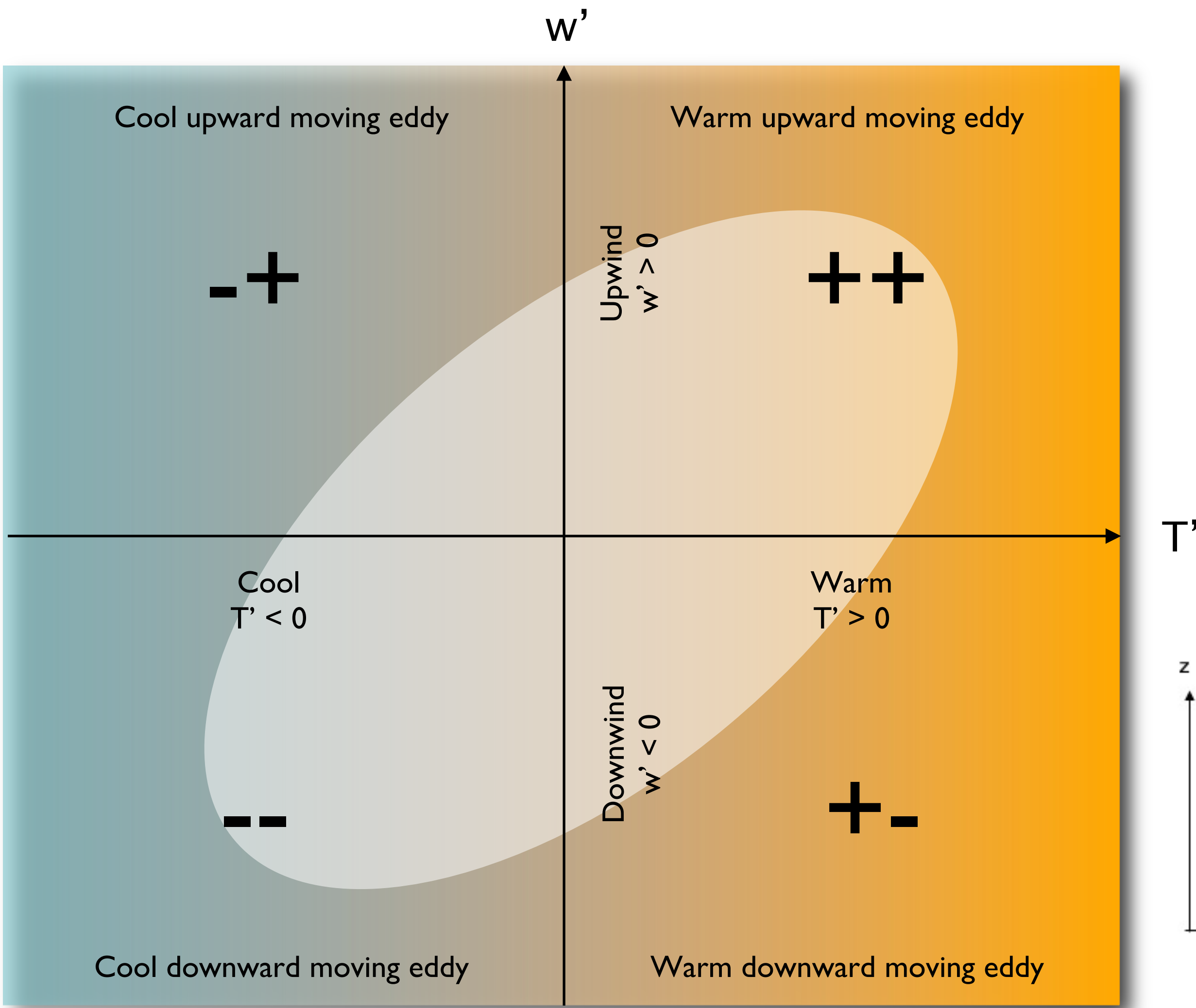


Potential temperature decreases with height.

B

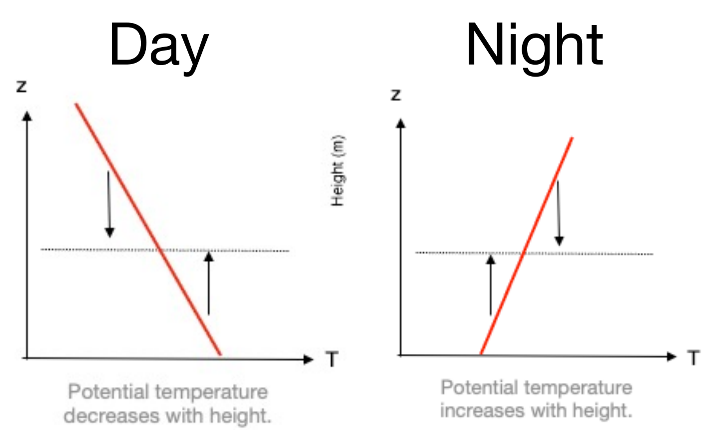


Joint probability density - *w’T’ – Day or night? (Slido)*

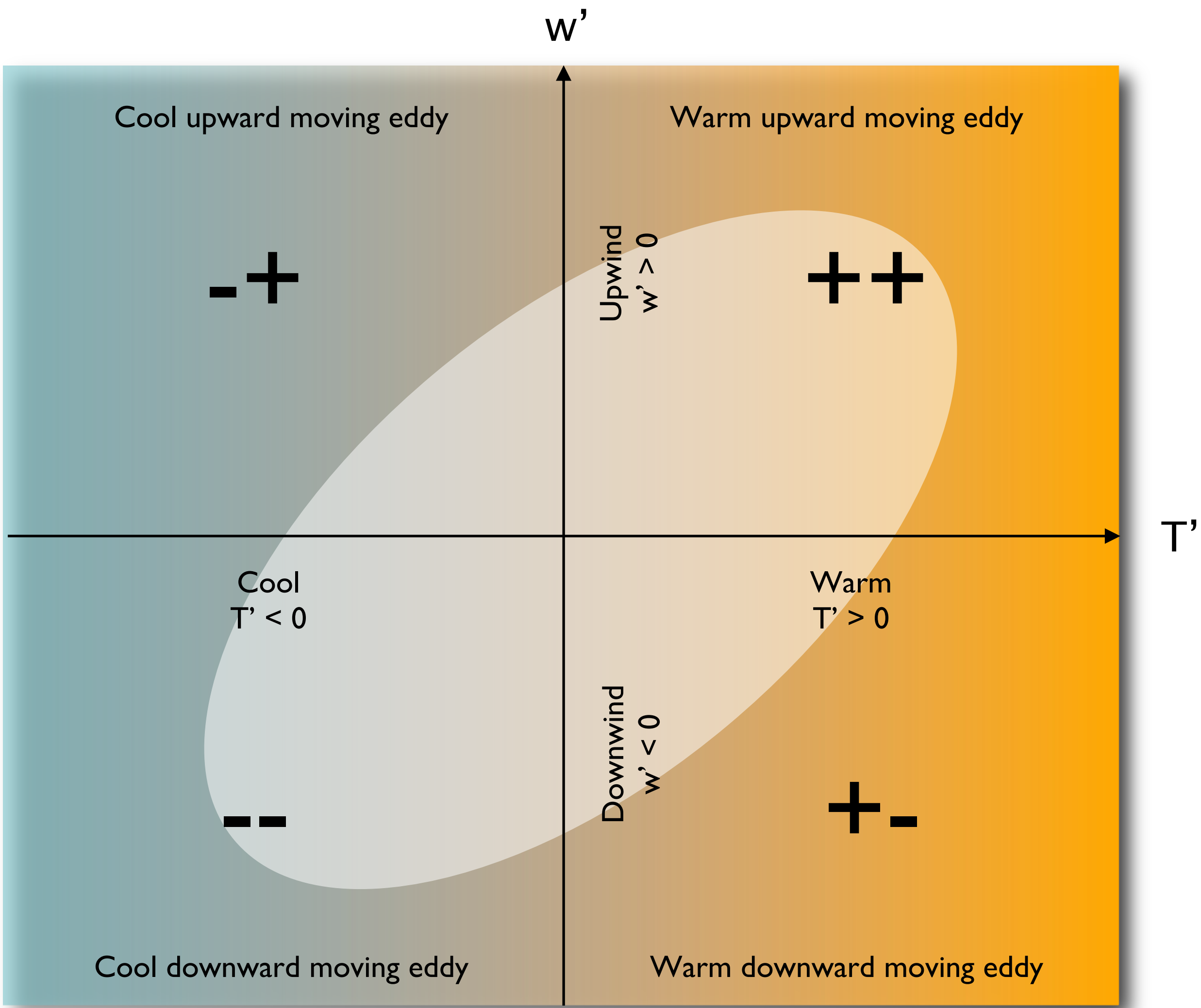


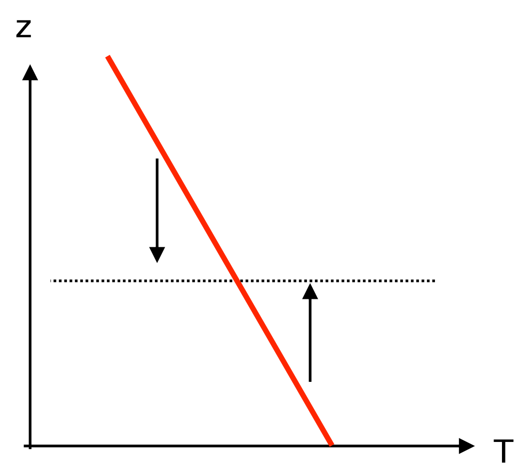
(A) Day

(B) Night



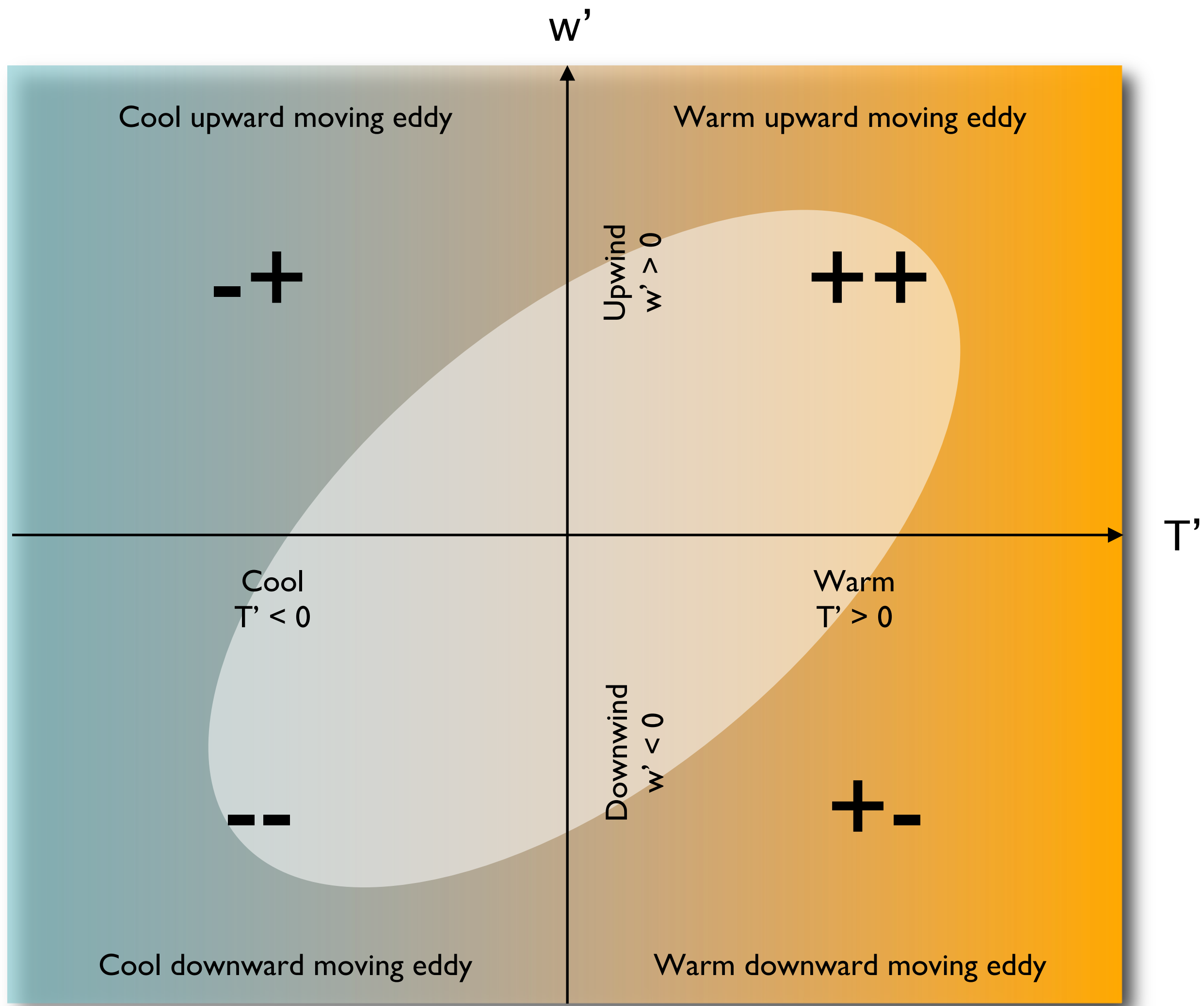
Daytime joint probability density - *w'T'*





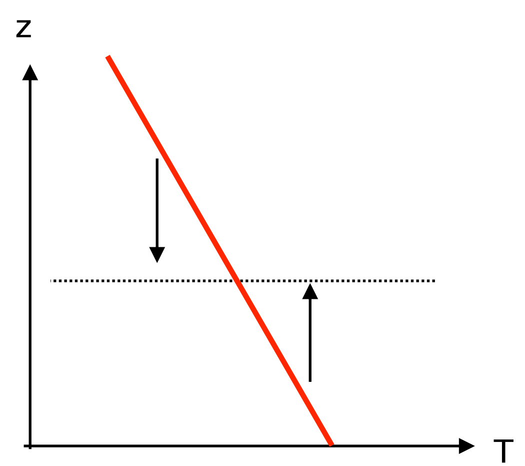
Potential temperature decreases with height.

Daytime joint probability density - *w'T'*



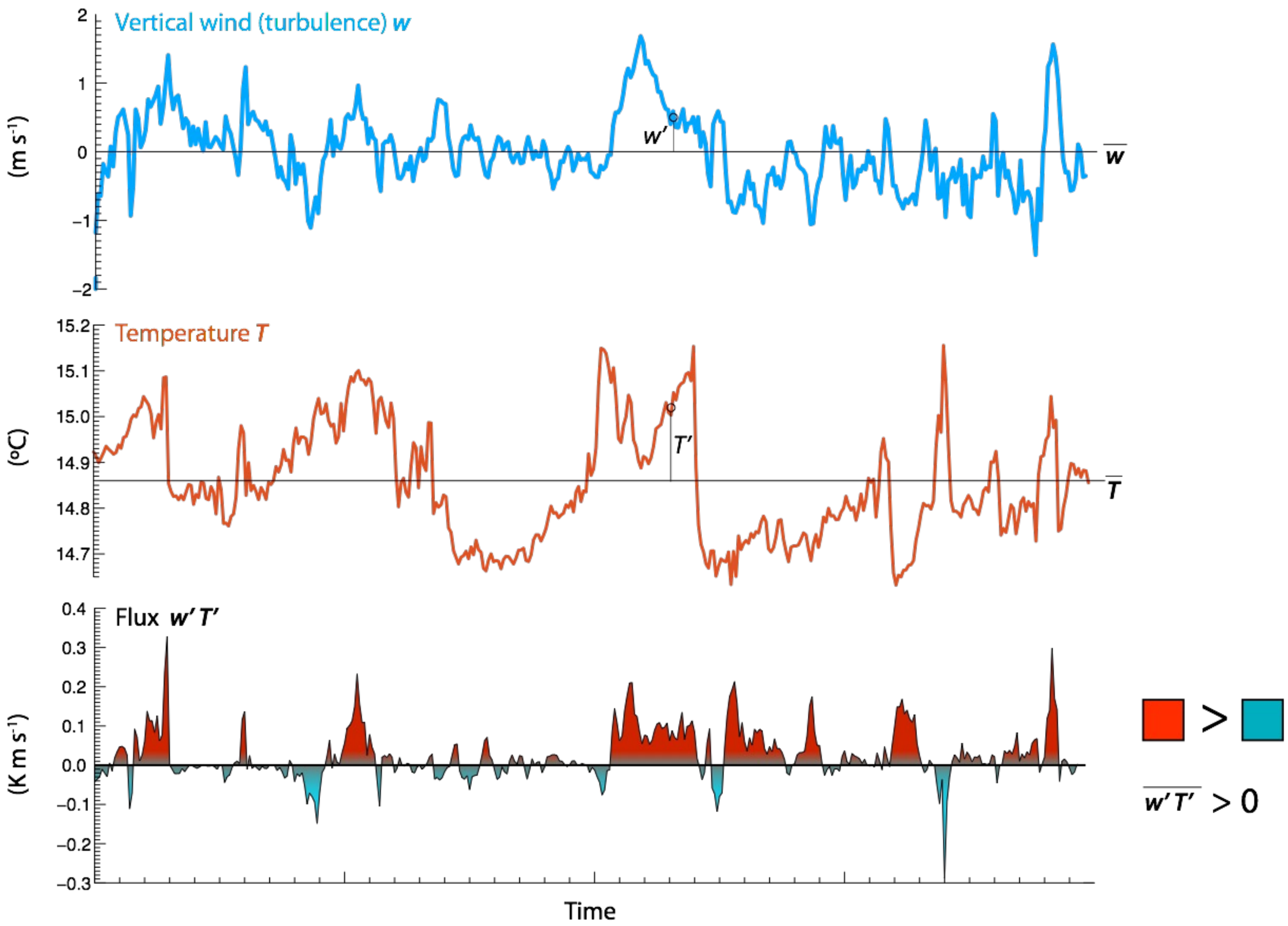
$$\overline{w'T'} > 0$$

sensible heat flux transports energy away from the surface

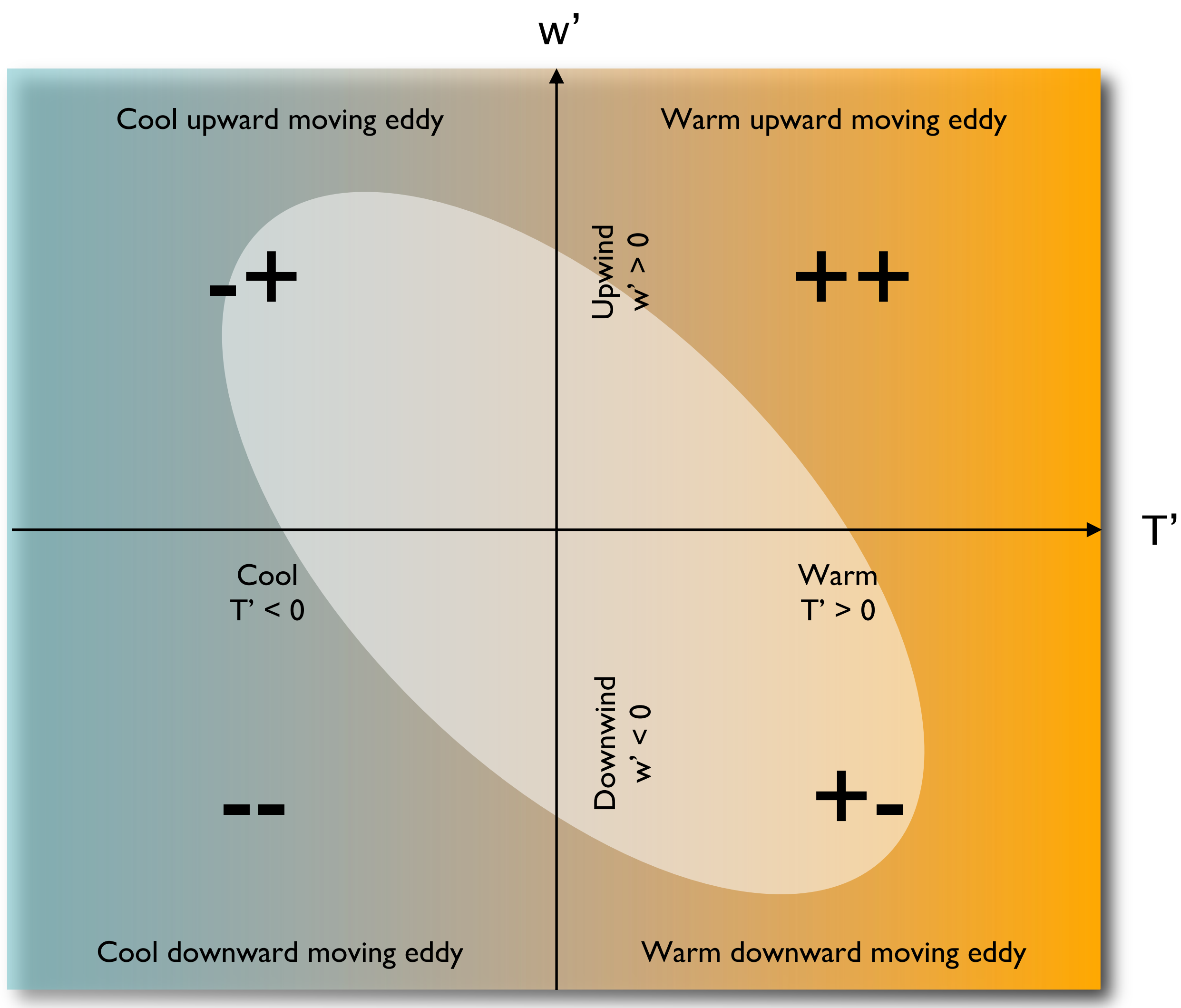


Potential temperature decreases with height.

Fast trace of signals.

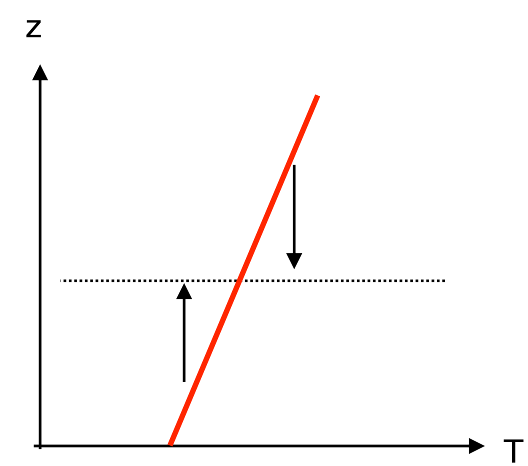


Nocturnal joint probability density - *w'T'*



$$\overline{w'T'} < 0$$

sensible heat flux transports energy towards the surface



Potential temperature increases with height.

Covariance and flux densities (1/2)

The vertical flux density of an entity *s* is defined as

flux density = **air density** x **vertical velocity** x **concentration of *s***

(anything m^{-2} s^{-1} = kg m^{-3} x m s^{-1} x anything kg^{-1})

For some entity s, its *average* flux density is hence

$$Q_S = \overline{\rho w s}$$

Applying **Reynold's decomposition**, and separate mean flow and turbulent fluctuations:

$$\rho = \overline{\rho} + \rho' \qquad w = \overline{w} + w' \qquad s = \overline{s} + s'$$

Covariance and flux densities (2/2)

Close to the surface, $\overline{w} \to 0$ and $\rho' \to 0$ hence

$$Q_S = \overline{\overline{\rho}\, w'(\overline{s} + s')}$$

$$Q_S = \overline{\overline{\rho}\, (w'\, \overline{s} + w'\, s')} =$$

$\overline{\hphantom{xxxxxxxxxxxx}}$ = 0
since constant x *w'* → 0 (see lecture 18).

A flux density can be also expressed in terms of the correlation coefficient:

$$Q_S = \rho\, \overline{w' s'}$$

Covariance and flux densities (2/2)

Close to the surface, $\overline{w} \rightarrow 0$ and $\rho' \rightarrow 0$ hence

$$Q_S = \overline{\overline{\rho}\, w'(\overline{s} + s')} = \overline{\overline{\rho}\,(w'\,\overline{s} + w'\,s')}$$

$$Q_S = \overline{\overline{\rho}\,(w'\,\overline{s} + w'\,s')} = (\underbrace{\overline{\overline{\rho}\,w'\,\overline{s}}}_{=0} + \overline{\overline{\rho}\,w'\,s'}) = \boxed{\rho\,\overline{w's'}}$$

= 0
since constant x *w'* → 0 (see lecture 18).

A flux density can be also expressed in terms of the correlation coefficient:

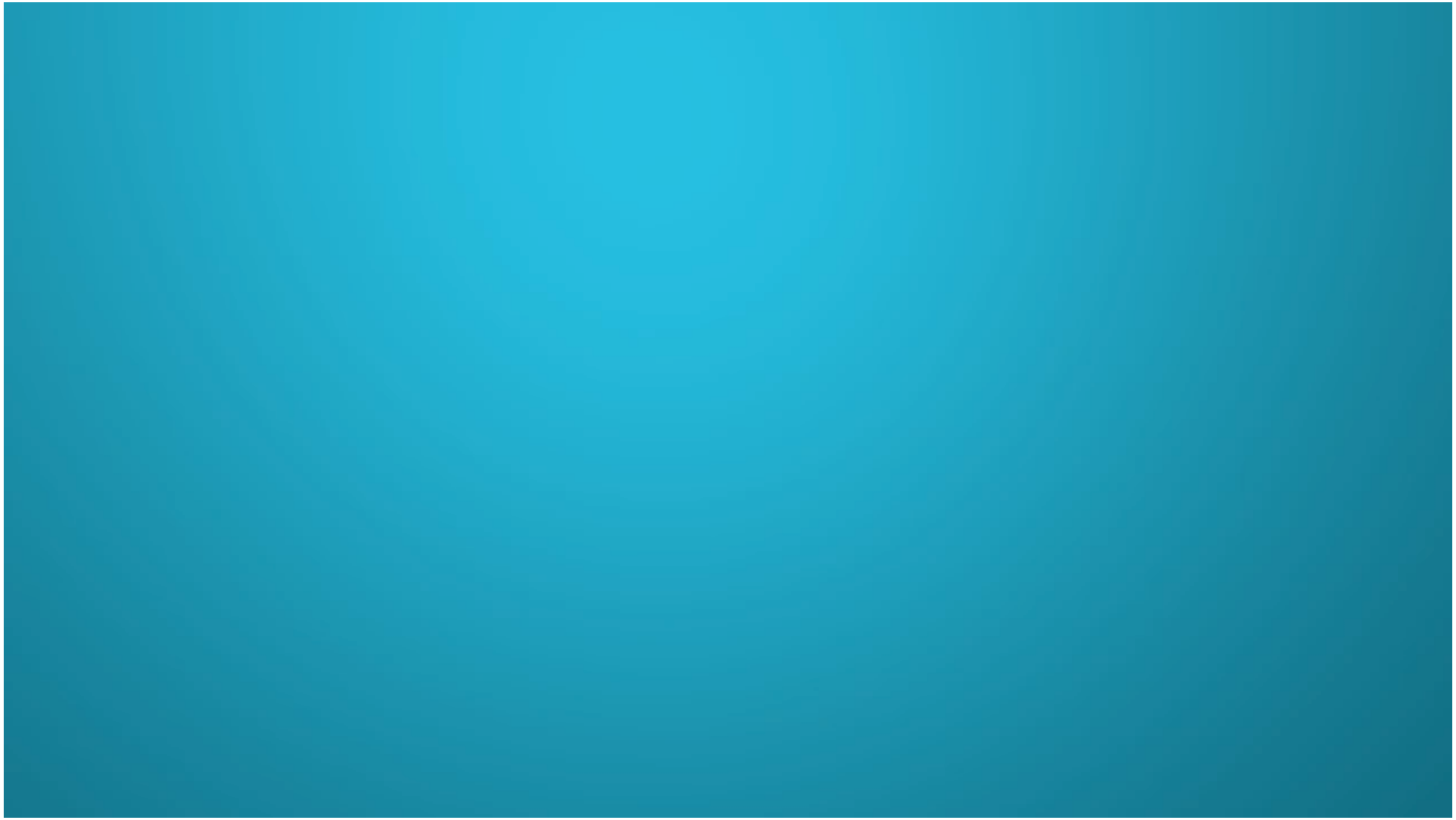
$$Q_S = \rho\,\overline{w's'} = \rho\, r_{ws}\,\sigma_w\,\sigma_s$$

Covariance

$$r_{uw} = \frac{\overline{u'w'}}{\sigma_u \sigma_w} \quad \star$$

Standard deviation

The eddy-covariance approach (EC)



Source: https://www.youtube.com/watch?v=CR4Anc8Mkas

Measuring sensible heat flux density Q_H by EC

The instantaneous sensible heat flux density is (in W m^{-2}):

$$Q_H = C_a \, T' \, w'$$

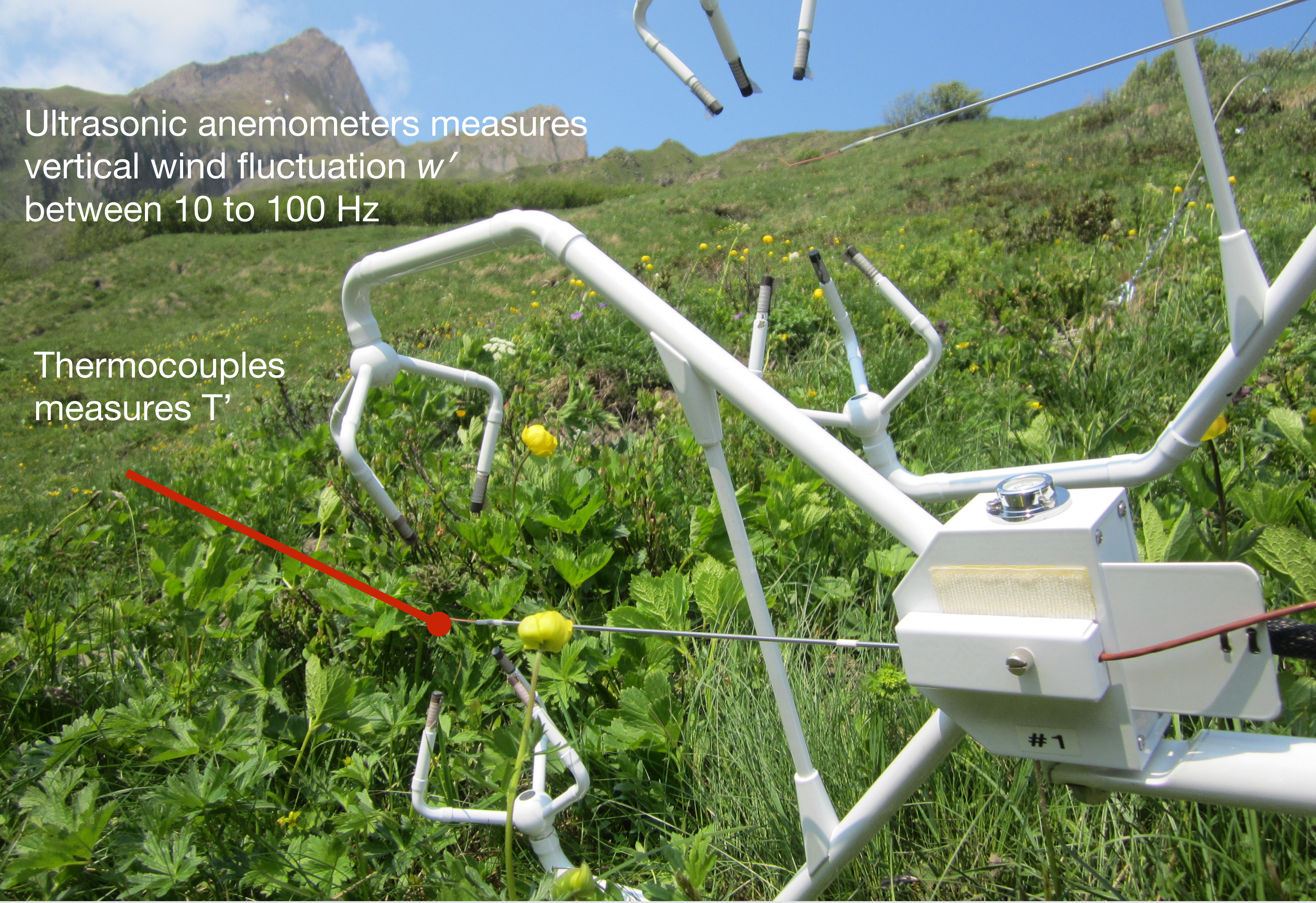
Averaging:

$$Q_H = C_a \, \overline{T'w'} = C_a \, \overline{w'T'}$$

Since $C_a = \rho c_p$ we can write:

$$Q_H = \rho \, c_p \, \overline{w'T'} \quad \star$$

Where c_p is the specific heat of air at constant pressure.


Ultrasonic anemometers measures
vertical wind fluctuation w'
between 10 to 100 Hz
Thermocouples
measures T'
#1


CAMPBELL SCIENTIFIC INC.
CSAT3
3-D SONIC ANEMOMETER


Fine-wire
thermocouple
measures T'

Latent heat flux density Q_E

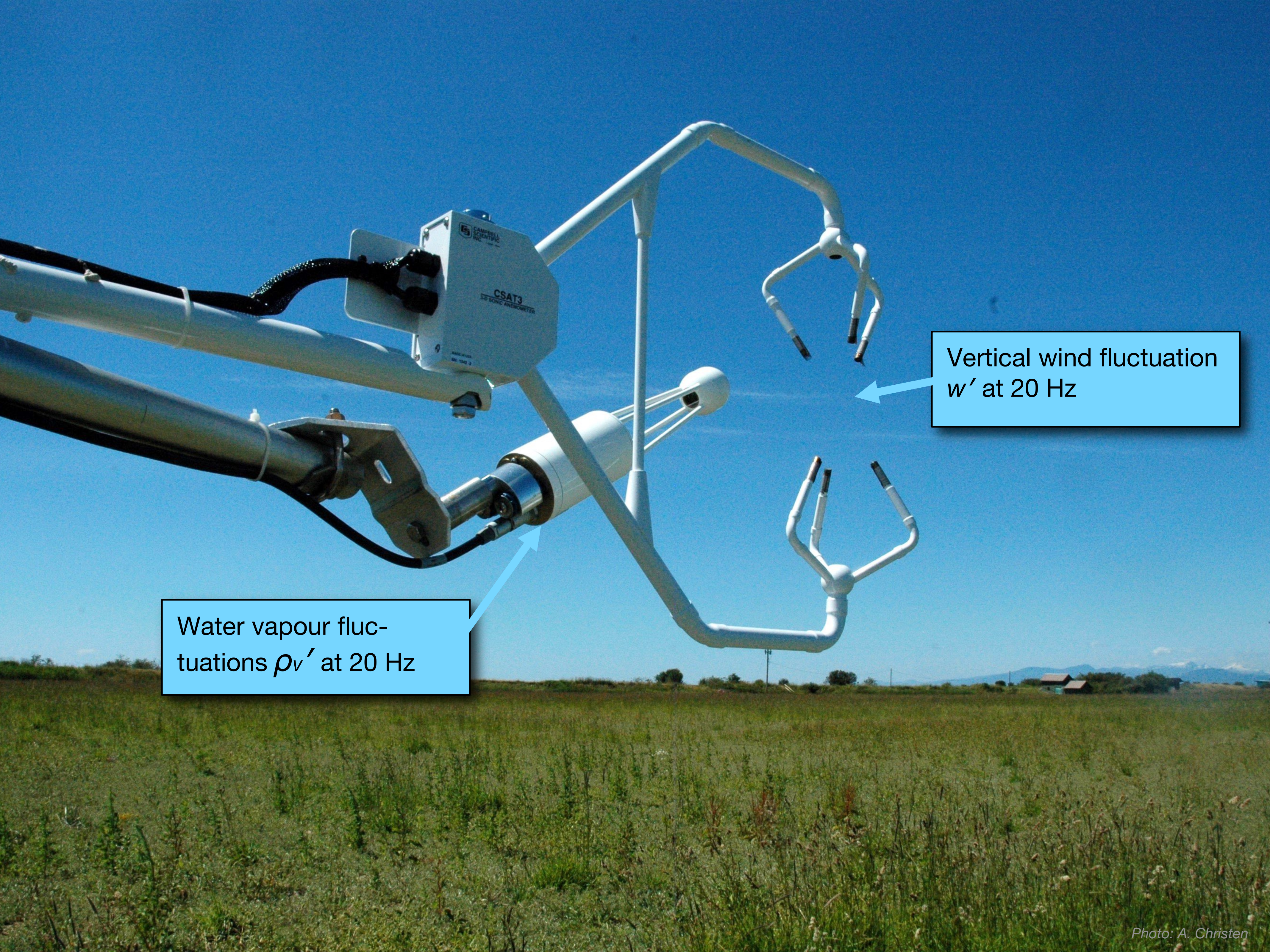
The instantaneous latent heat flux density is (in W m^{-2}):

$$Q_E = L_v w' \rho_v'$$

Averaging over a longer period results in the covariance (L_v ~constant):

$$Q_E = L_v \overline{w' \rho_v'} \quad \star$$

Here, L_v is the specific heat of vaporization (in J kg^{-1}) and ρ_v **partial density of water vapour** (=**absolute humidity**, in kg m^{-3}).


Vertical wind fluctuation
w' at 20 Hz
Water vapour fluc-
tuations $\rho_v{}'$ at 20 Hz
CSAT3
Photo: A. Christen


Vertical wind fluctuation
w' at 20 Hz
Water vapour fluc-
tuations ρ_v' at 20 Hz
Photo: A. Christen

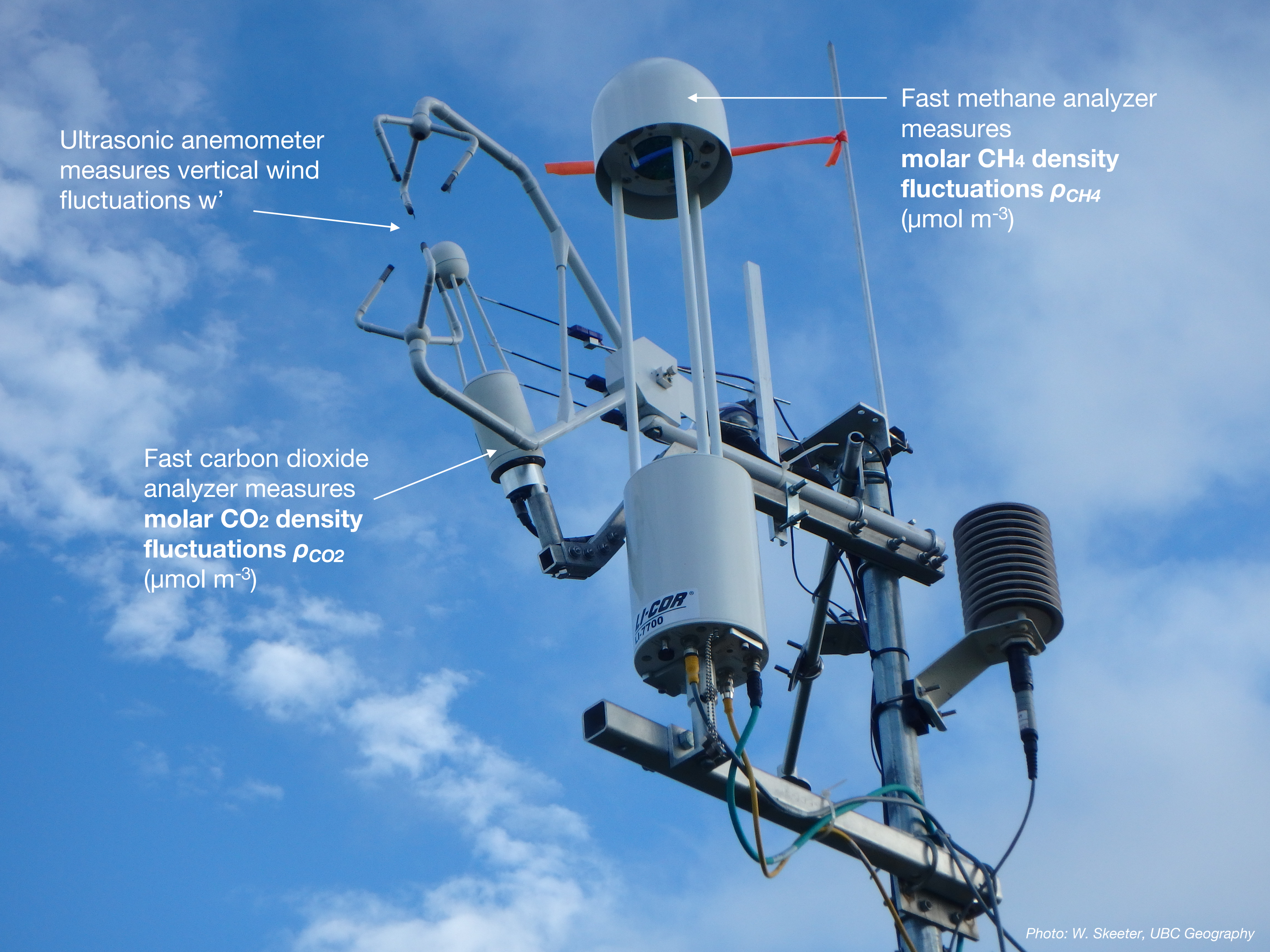
Eddy covariance in Boundary Bay, Delta, BC

https://youtu.be/qhWem_mXyX8

360 video of the Boundary Bay EC system

Check out this link:

https://www.youtube.com/watch?v=63Ho07nCYjY


Ultrasonic anemometer measures vertical wind fluctuations w’
Fast methane analyzer measures **molar CH_4 density fluctuations ρ_{CH4}** (µmol m^{-3})
Fast carbon dioxide analyzer measures **molar CO_2 density fluctuations ρ_{CO2}** (µmol m^{-3})
LI-COR
LI-7700
Photo: W. Skeeter, UBC Geography

Measuring trace gas fluxes

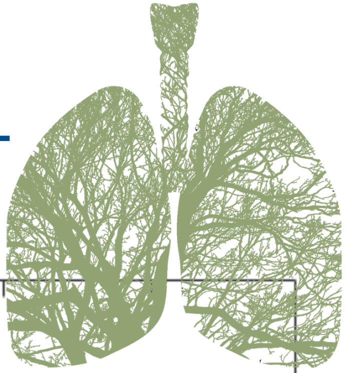
If we equip an eddy covariance system with an analyzer that measures fast fluctuations of the molar density of any **trace gas** ρ_c' (e.g. μmol m^{-3}) we can directly determine the gas-exchange (molar flux) between a land surface and the atmosphere:

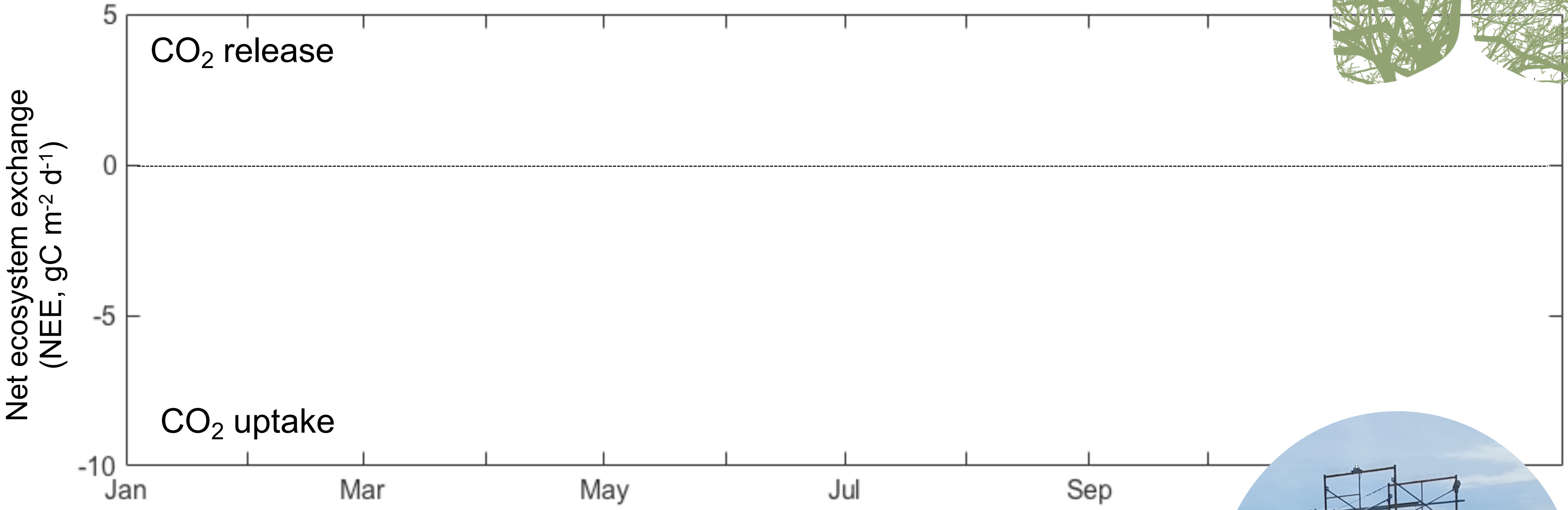
$$\underbrace{F_c}_{\text{Molar trace gas flux (μmol m}^{-2}\text{ s}^{-1})} = \overline{\underbrace{w'}_{\text{vertical wind (m s}^{-1})}\underbrace{\boxed{\rho_c'}}_{\text{molar density (μmol m}^{-3})}}$$ ★

To convert a molar trace gas flux to a mass flux, you multiply by the **molar mass** $\mathcal{M}$ (g mol^{-1}) of the compound:

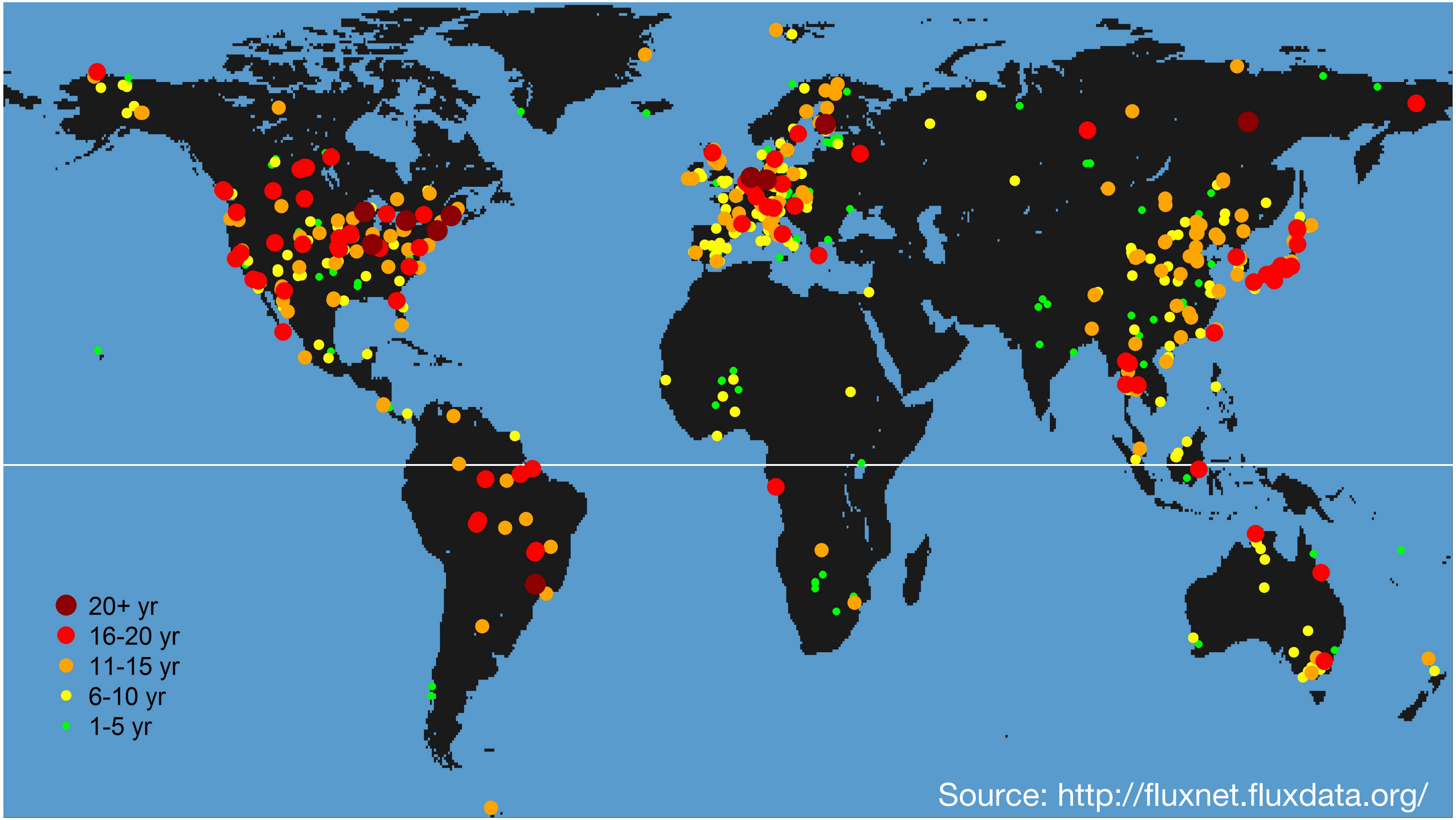
Mass trace gas flux (g m^{-2} s^{-1}) → $F_{m,c} = \mathcal{M} F_c$ ← Molar trace gas flux (mol m^{-2} s^{-1})

Measuring the ‘breathing’ of our biosphere





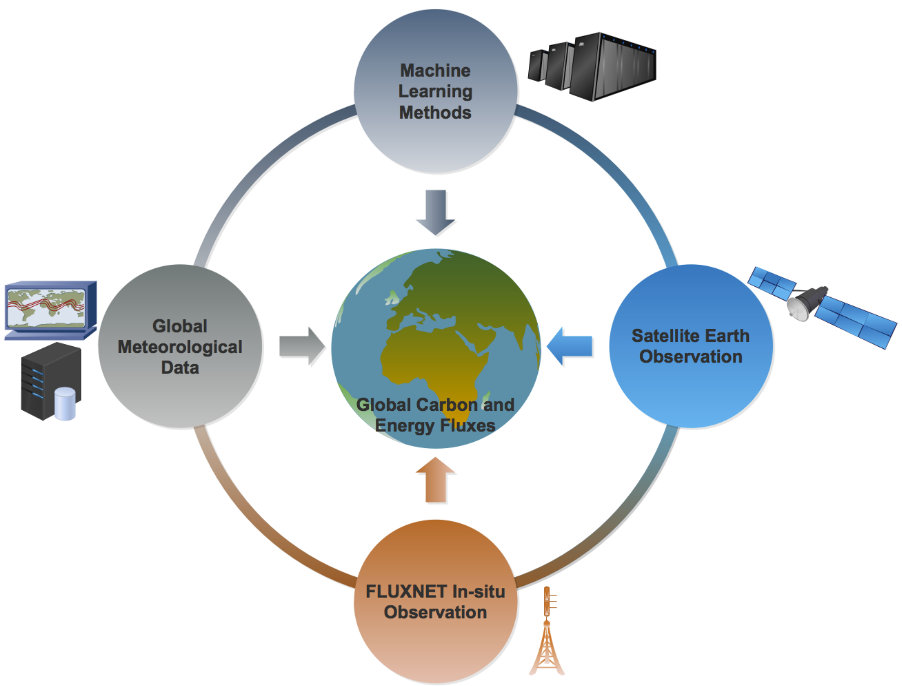
FLUXNET – a global network of EC sites

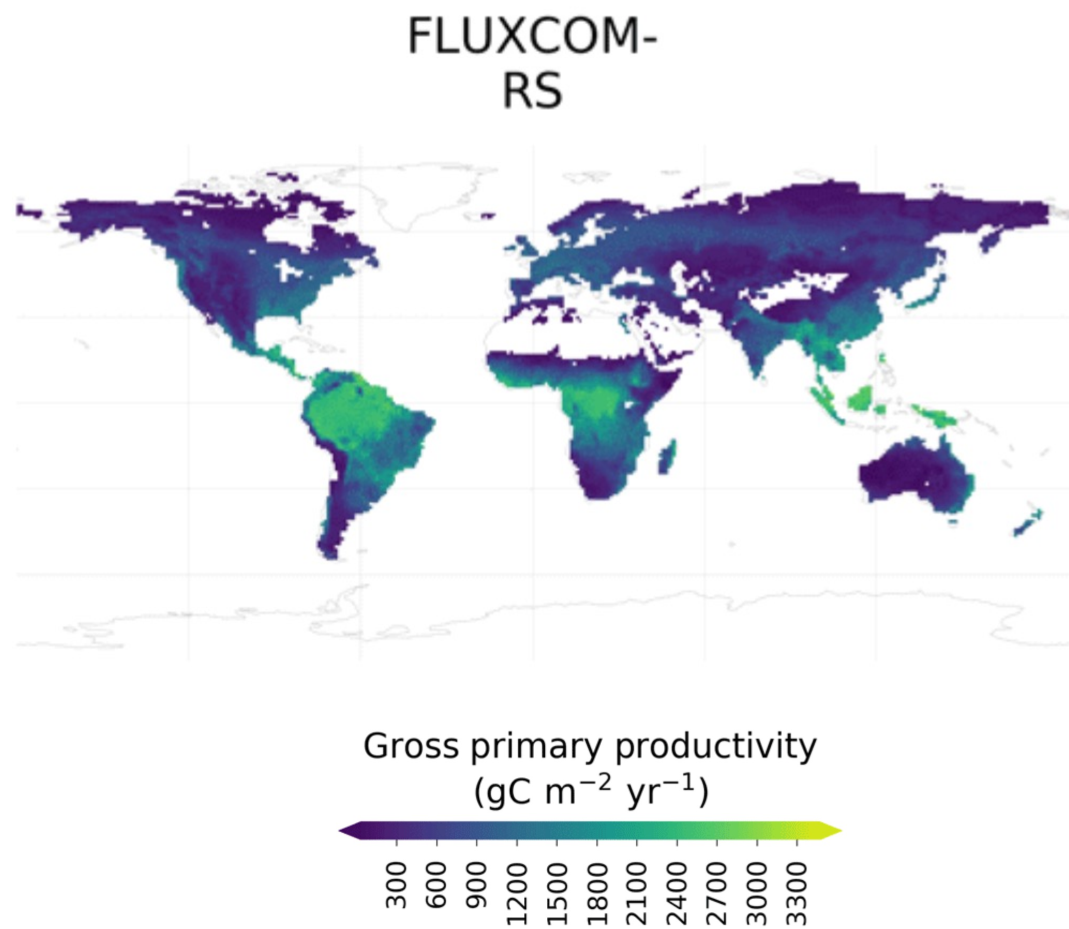


Visualizing eddy covariance data (30 min avg data)

1. Go to: https://ameriflux.shinyapps.io/version1/
2. Select site US-Ha1 & plot CO2_1_1_1 (CO_2 concentration) as the Y-axis variable
    - What do you see?
3. Now change the Y-axis variable to FC_1_1_1
    - What do you observe?
3. Click on ‘All Sites’ & change the Y-axis variable to ‘NEE’
4. Create your own plot(s)

Research example – upscaling EC obs to the global scale





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Take home points

- By simultaneously measuring vertical wind and a concentration, we can measure turbulent fluxes using the **eddy-covariance** technique.
- Eddy-covariance can be used to directly measure the **sensible heat flux density** using $Q_H = \rho\, c_p\, \overline{w'T'}$
- We can track the flux of water vapour and measure the **latent heat flux density** using $Q_E = L_v\, \overline{w'\rho_v'}$
- To measure **traces gas fluxes** we use the covariance between the molar density and the vertical wind $(\overline{w'\rho_c'})$
- Eddy covariance observations can help inform carbon cycle & climate science