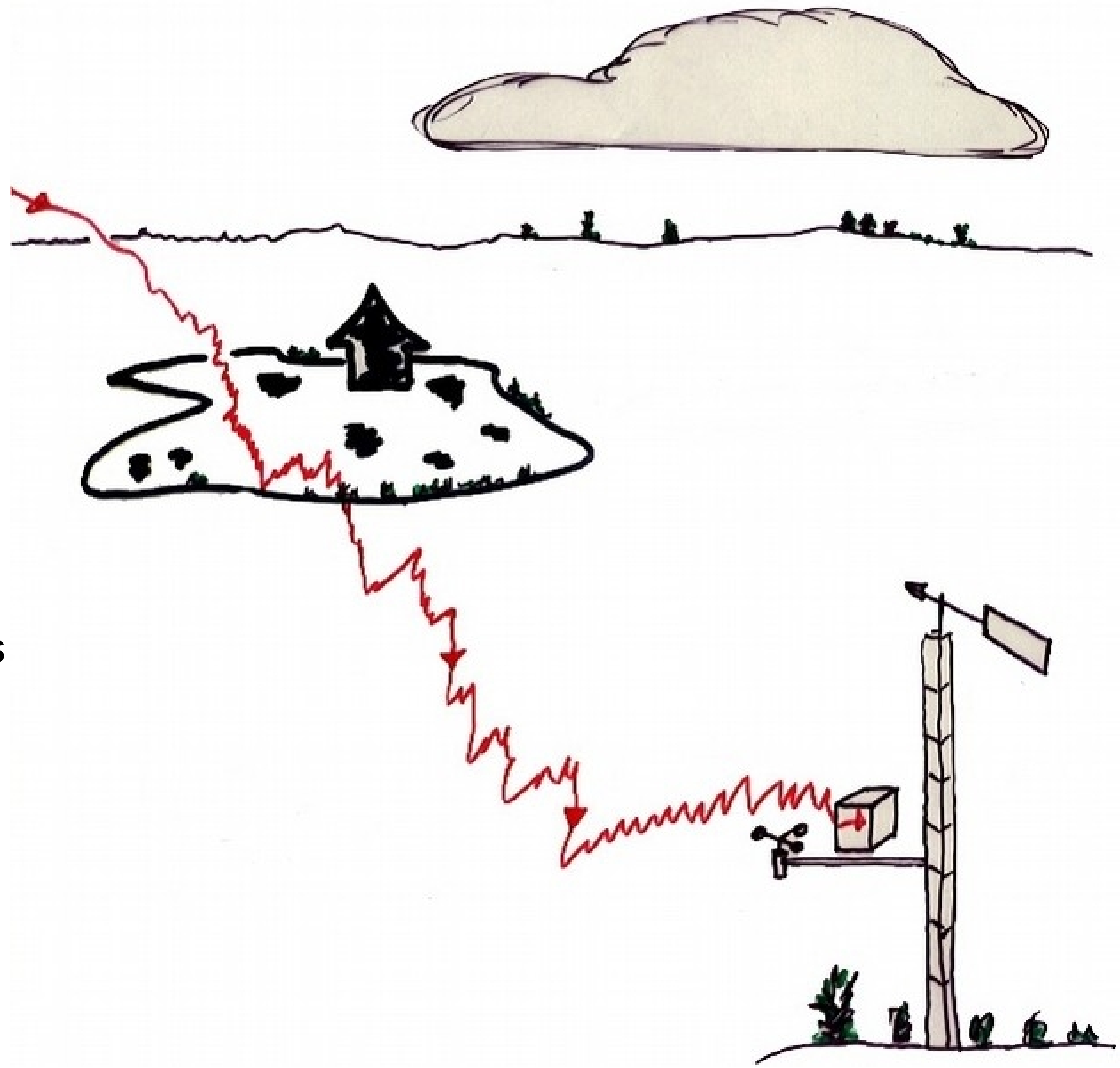
Micrometeorological methods to determine surface-air exchange



- Micromet methods – their basis
- The family of micromet methods
- Inverse dispersion in particular
- Applications

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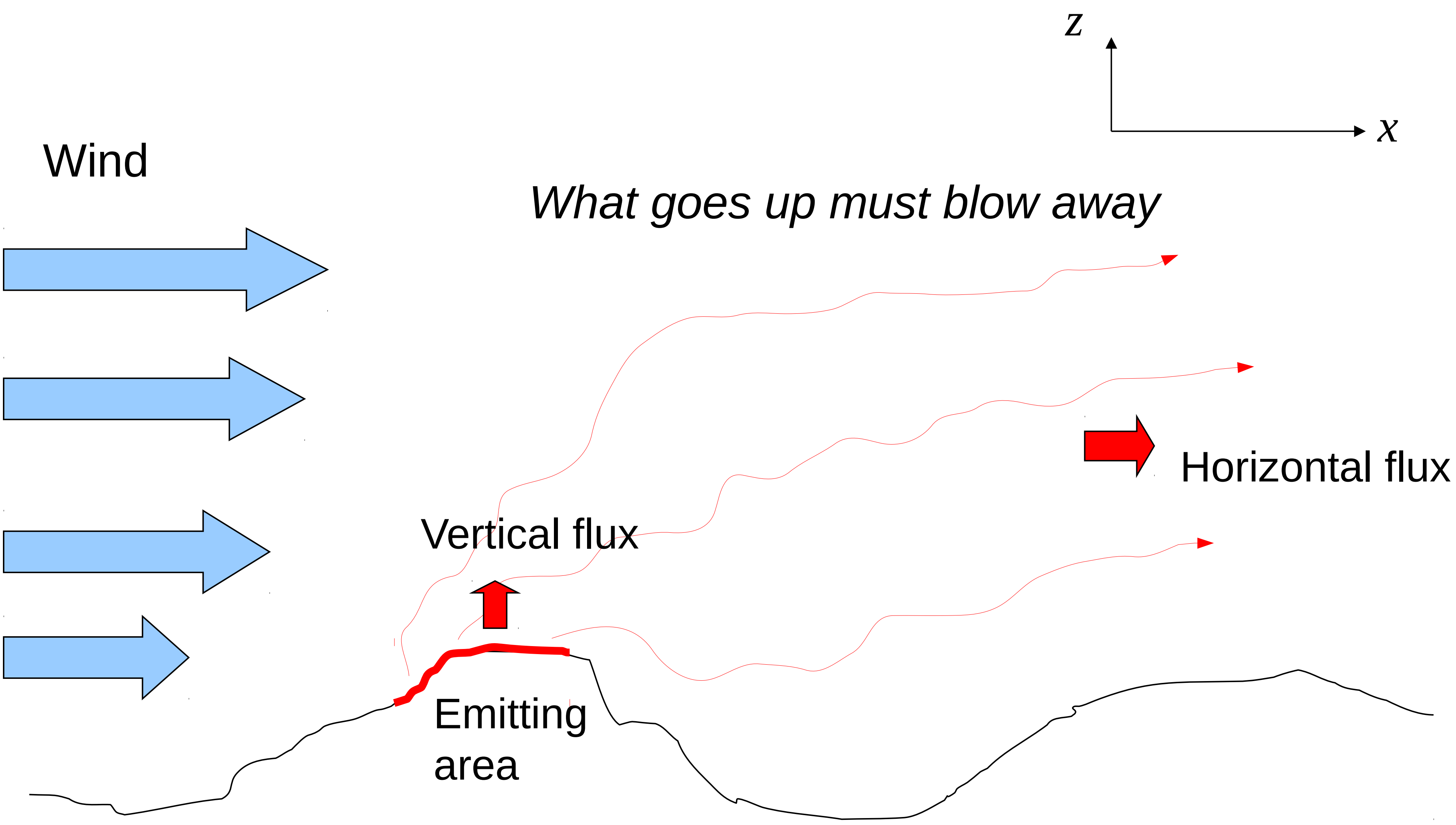
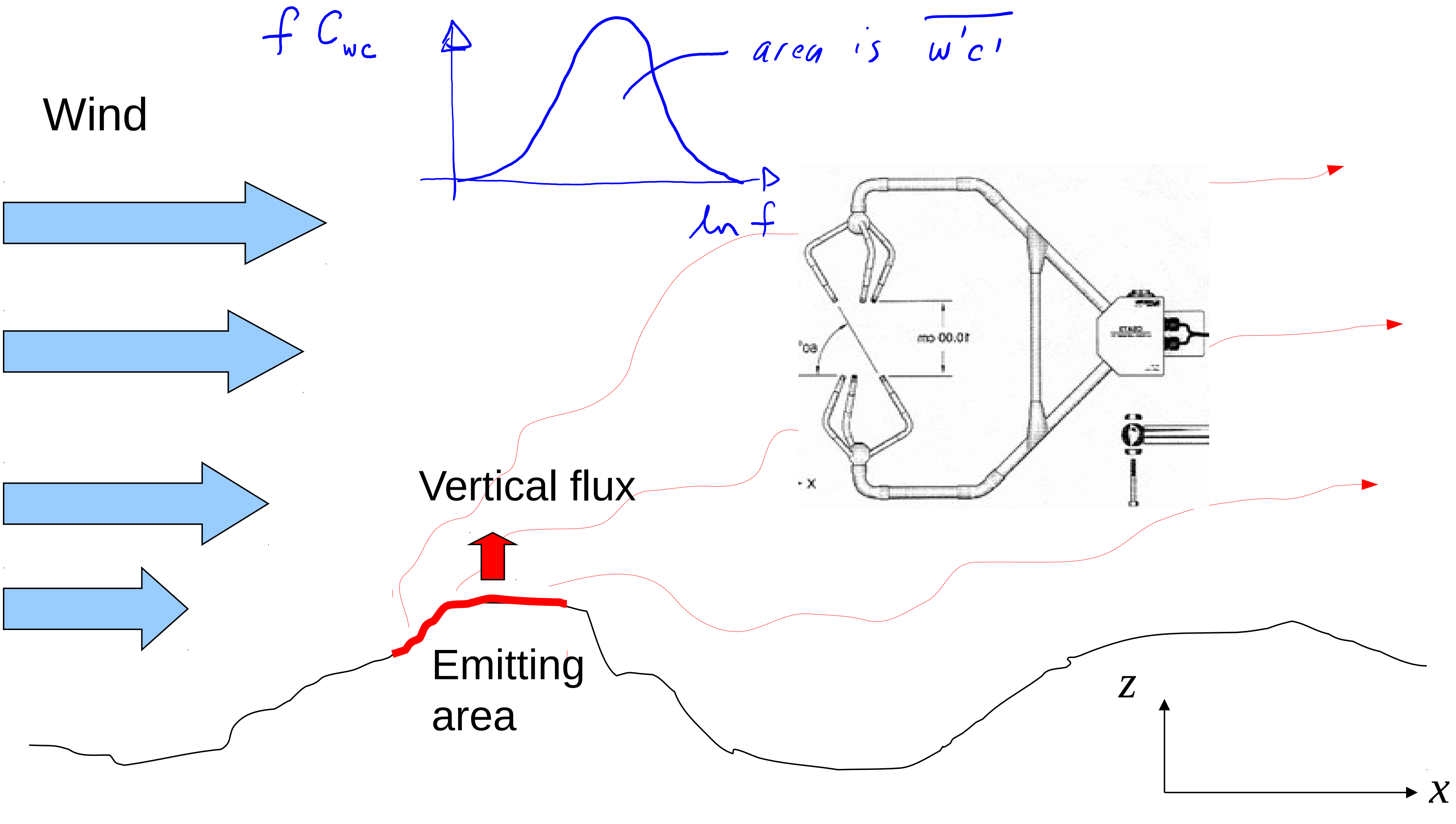
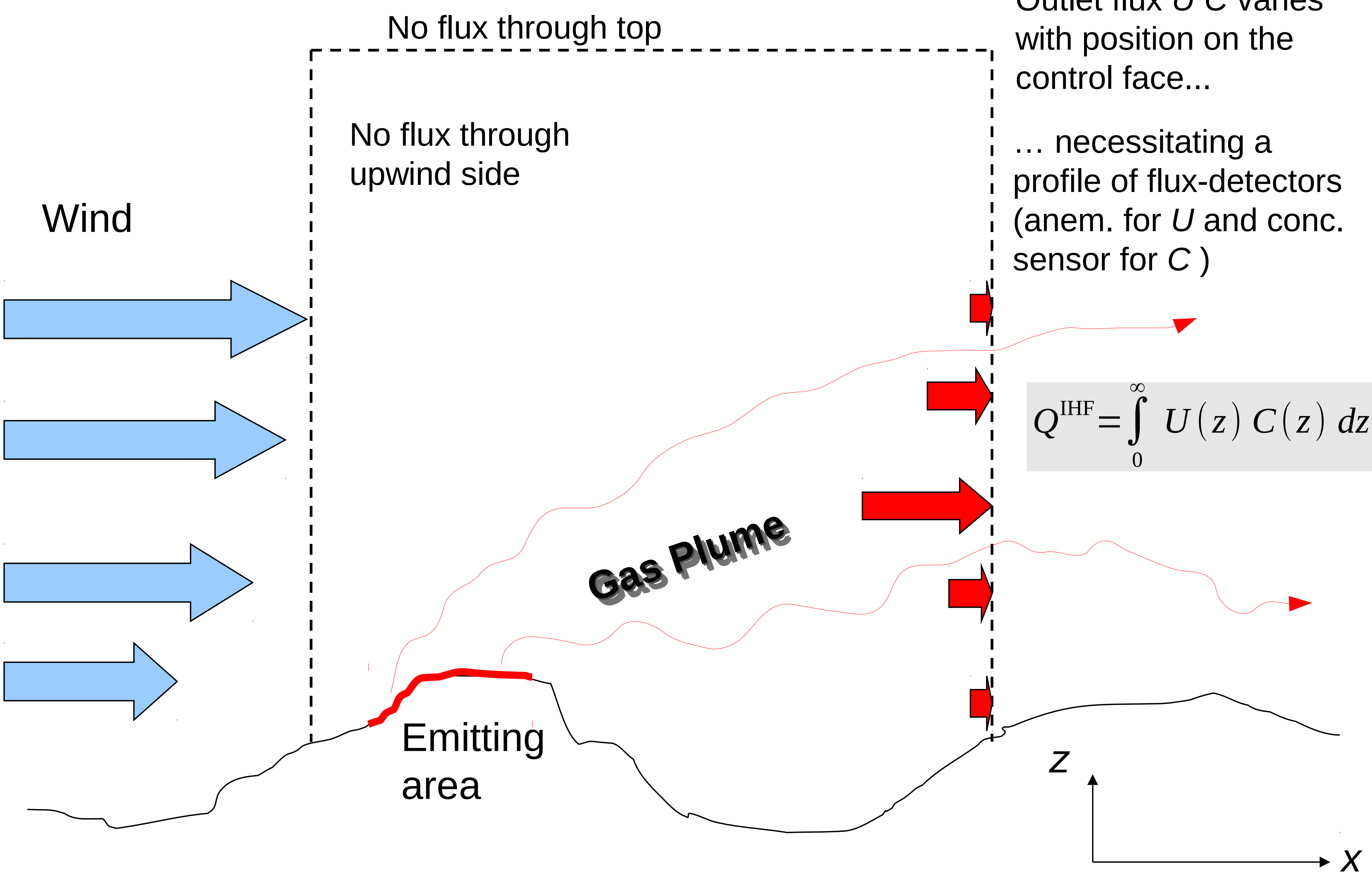
- as opposed to observing what goes missing from the substrate.
- winds and gas fluxes are averaged over periods of order 15 – 60 min.



May focus on measuring the vertical flux, or on measuring the horizontal flux

- e.g. eddy covariance: fast gas detector measuring concentration *c*(*t*) is paired with a sonic anemometer giving *w*(*t*). Processing gives the vertical eddy flux $\overline{w'c'}$
- provisos on site suitability apply – requires large fetch of uniform source





Outlet flux *U C* varies with position on the control face...

… necessitating a profile of flux-detectors (anem. for *U* and conc. sensor for *C*)

$$Q^{\mathrm{IHF}} = \int_0^\infty U(z)\, C(z)\, dz$$

- assume instruments are immersed in a constant flux layer, i.e. $Q = \overline{w'c'}$ is independent of height between ground and z_2
- adopt gradient-diffusion model

$$Q = -K_c \frac{\partial C}{\partial z} \quad , \quad \overline{w'\theta'} = -K_h \frac{\partial \overline{\theta}}{\partial z}$$

- assume the (kinematic) heat flux $\overline{w'\theta'}$ is known (e.g. measured by a sonic anemometer)
- then

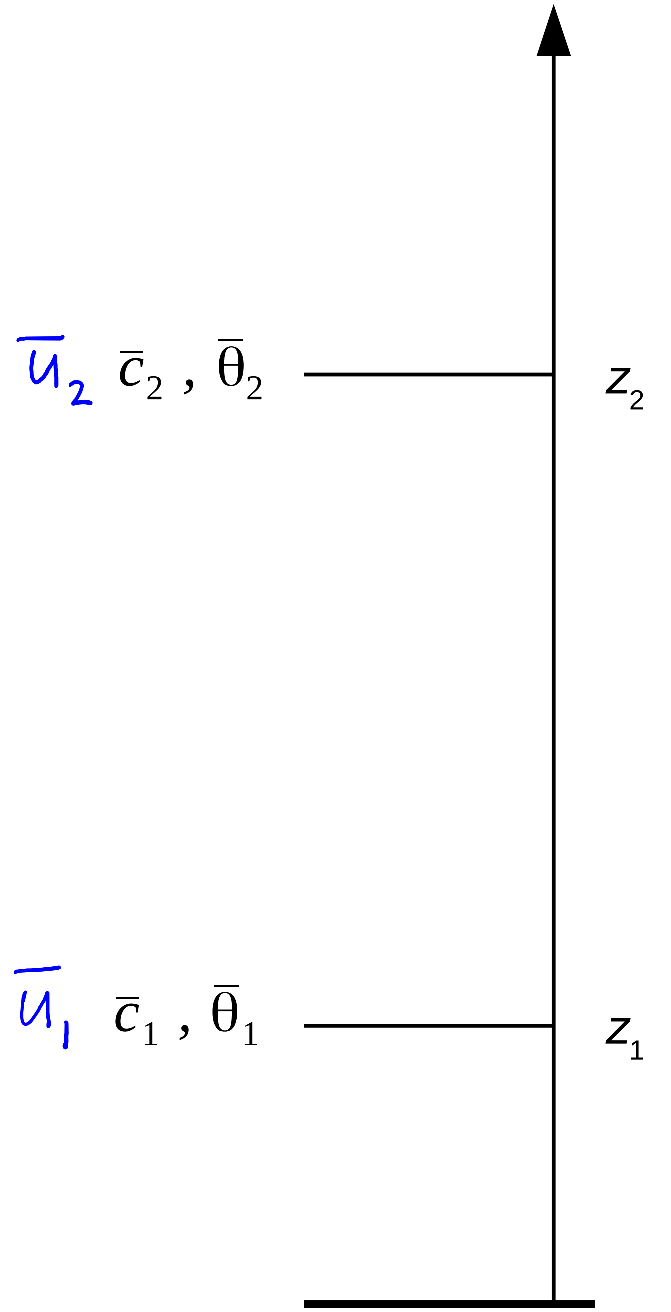
$$\frac{Q}{\overline{w'\theta'}} = \frac{K_c}{K_h} \frac{\overline{c}_2 - \overline{c}_1}{\overline{\theta}_2 - \overline{\theta}_1}$$

- or, assuming MOST applies

$$Q = \overline{w'\theta'} \frac{\phi_h(z_m/L)}{\phi_m(z_m/L)} \frac{\overline{c}_2 - \overline{c}_1}{\overline{\theta}_2 - \overline{\theta}_1}$$

where z_m (mean) is often specified as $(z_1 z_2)^{1/2}$.

- as an alternative to measuring the heat flux and temperature profile, may measure the wind profile and take u_*^2 as the companion flux



$$\overline{u'w'} = -u_*^2 = -K_m \, \partial \bar{u} / \partial z$$

$$\frac{Q}{-u_*^2} = -\frac{K_c}{K_m} \frac{\bar{c}_2 - \bar{c}_1}{\bar{u}_2 - \bar{u}_1} = -\frac{\phi_m(z_m/L)}{\phi_c(z_m/L)} \frac{\Delta \bar{c}}{\Delta \bar{u}}$$

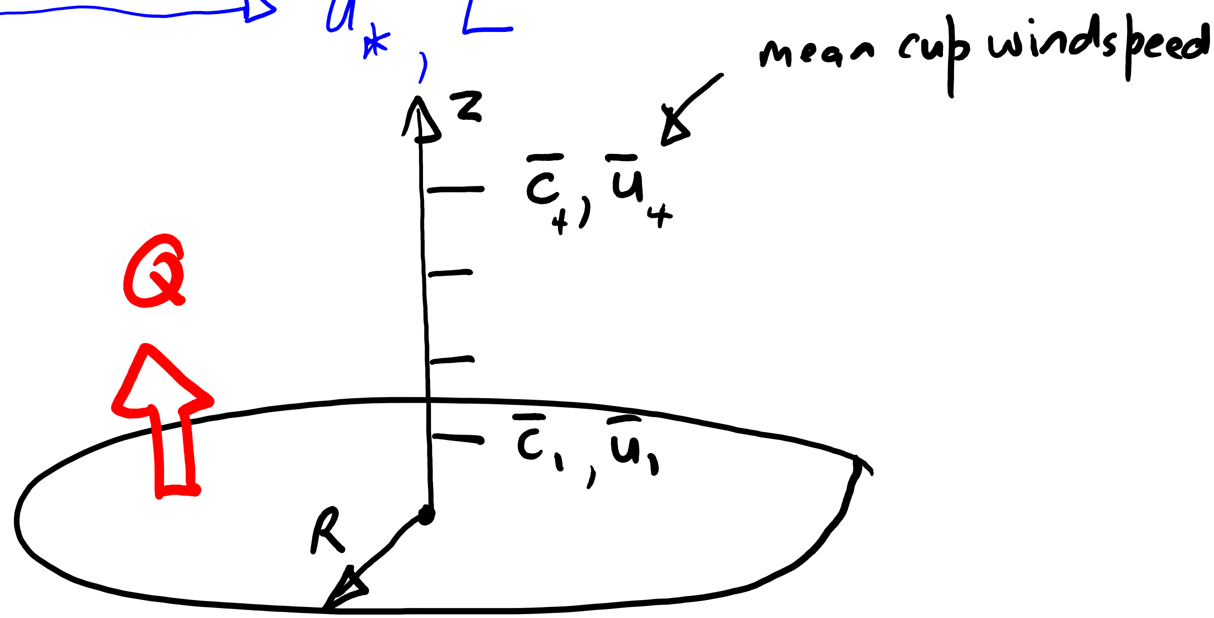
(m: mtm)

Best fit MO profiles of $\bar{u}$ and $\bar{\theta}$ to our

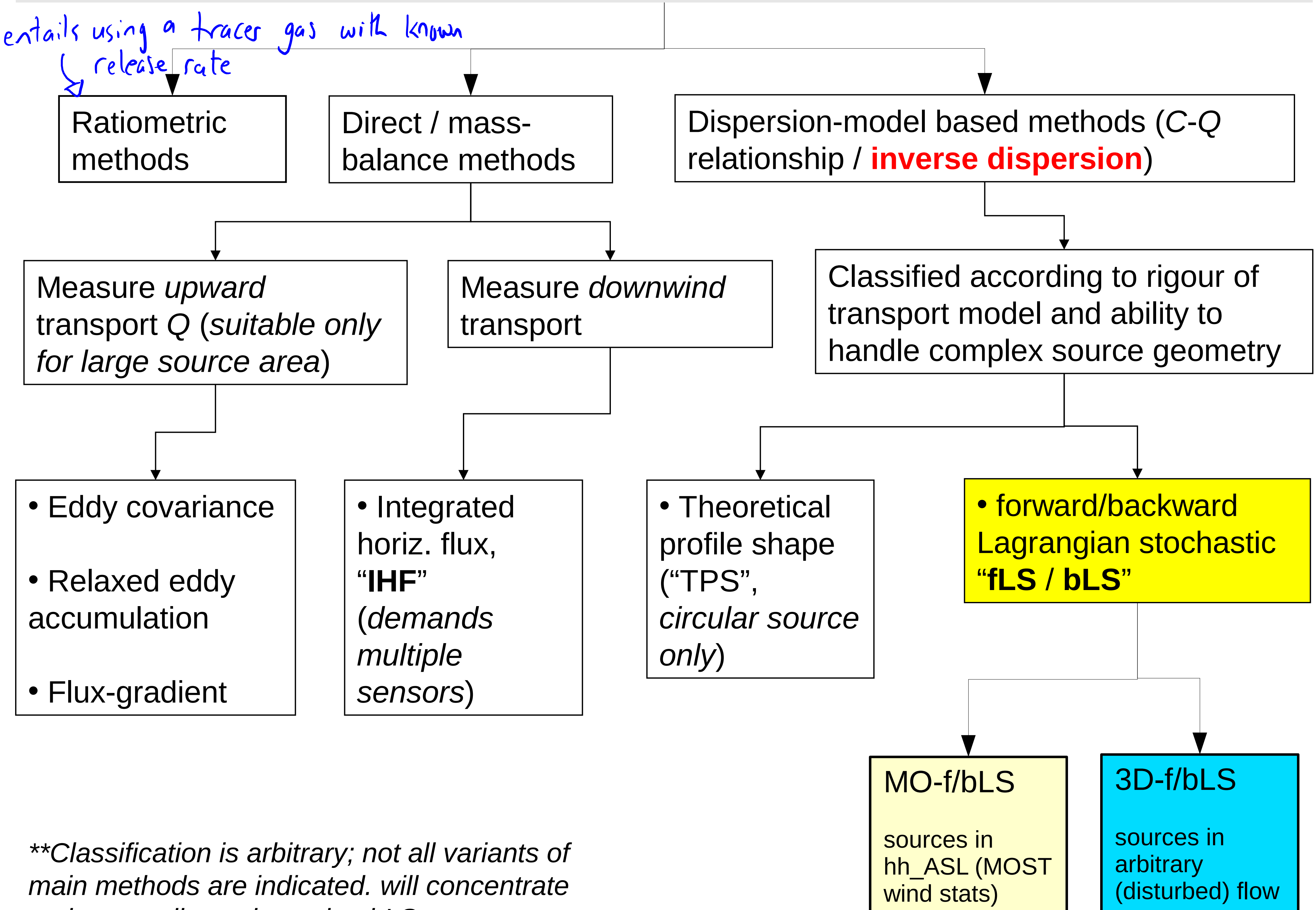
$\bar{u}_1, \bar{u}_2, \bar{\theta}_1, \bar{\theta}_2 \longrightarrow u_*, L$

$$QR = \int_0^\infty \bar{u}(z)\, \bar{c}(z)\, dz$$

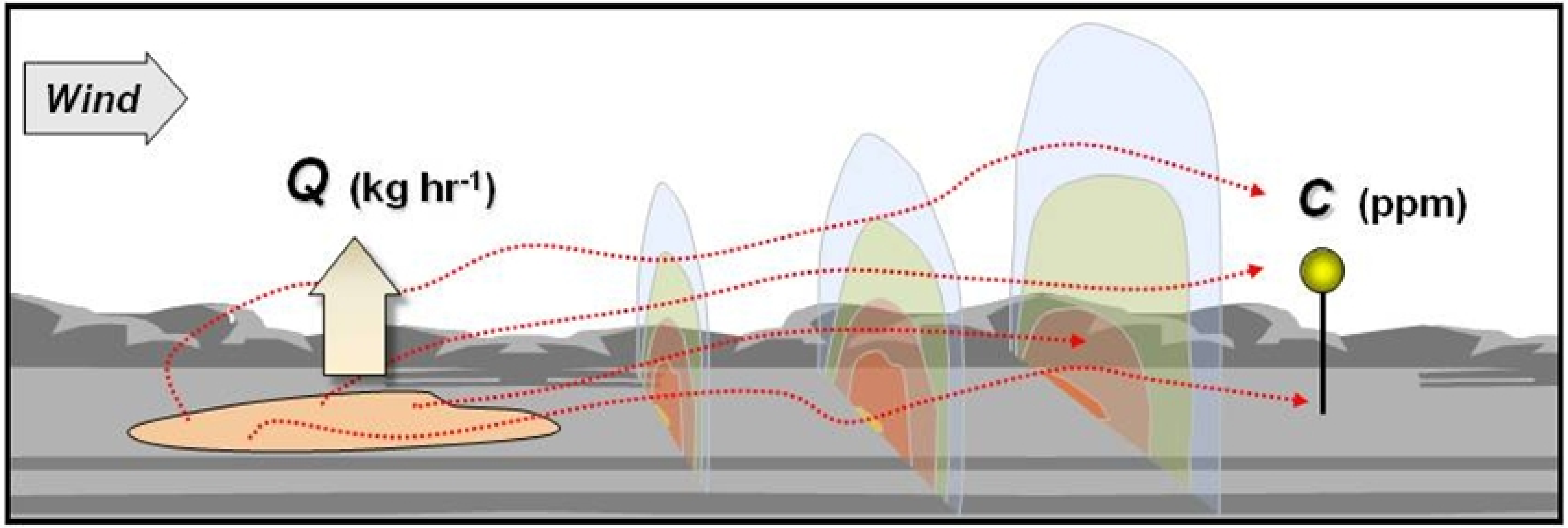
(a variant of IHF)



TPS method reduces exptl input to a single $\bar{u}$ and single $\bar{c}$ at a special height $Z^{INST.}$



***Classification is arbitrary; not all variants of main methods are indicated. will concentrate on inverse dispersion using bLS*



- Atmospheric dispersion model relates downwind concentration *C* to emission rate *Q* for prevailing regime of wind & turbulence

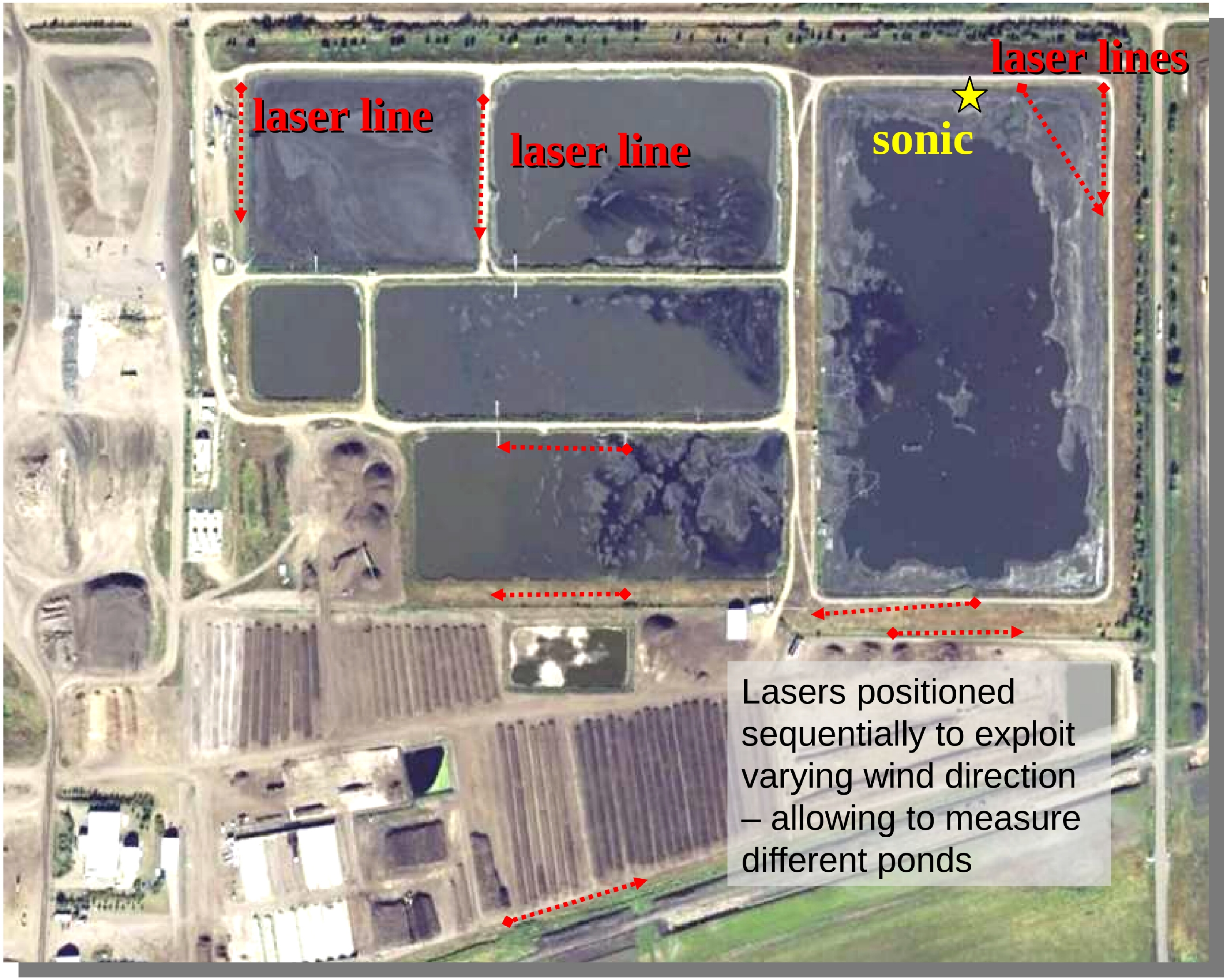
- Measurement of *C* (minus background) + model permits to infer *Q*

- Approach blends data + theory

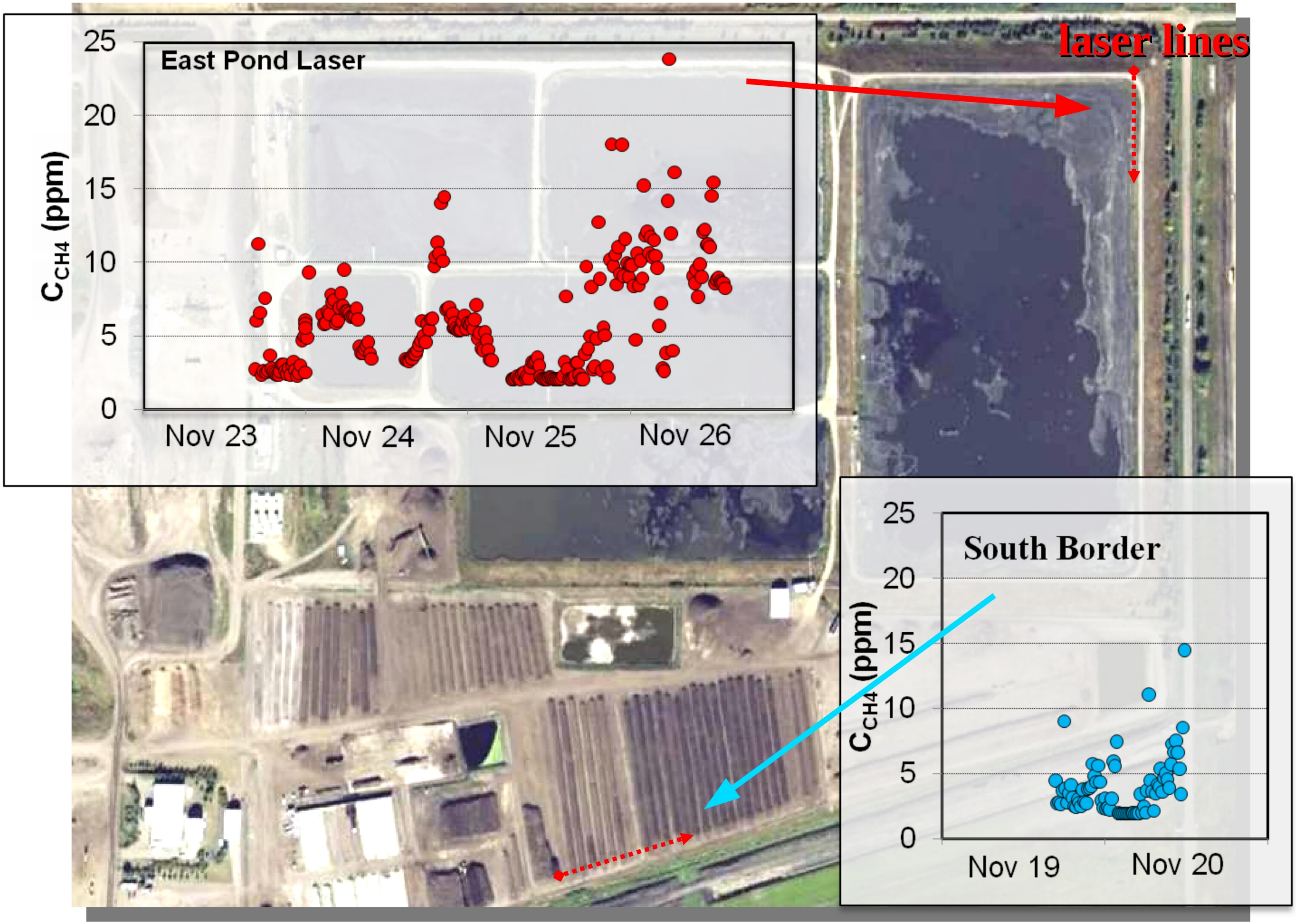
- "WindTraX" is a Lagrangian stochastic (LS) particle trajectory model appropriate for inverse dispersion on the surface layer scale – assumes wind statistics obey MOST


Sonic anemometer
provides wind statistics
(15 min intervals)
Inverse dispersion using bLS to
determine methane emission rate
from a lagoon

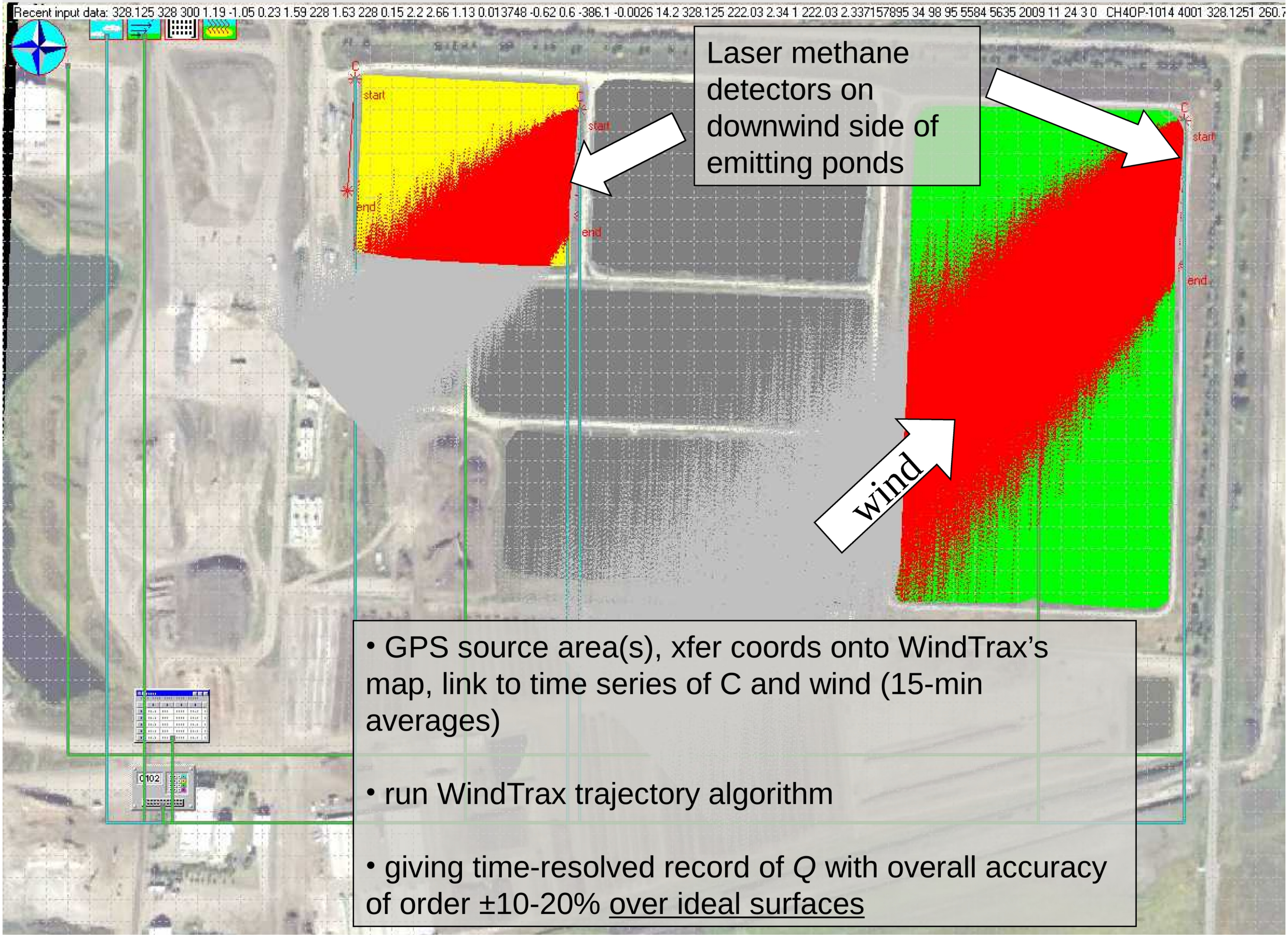

Line-averaging laser methane detector
(pathlength typically ~ 100 m)



Lasers positioned sequentially to exploit varying wind direction – allowing to measure different ponds

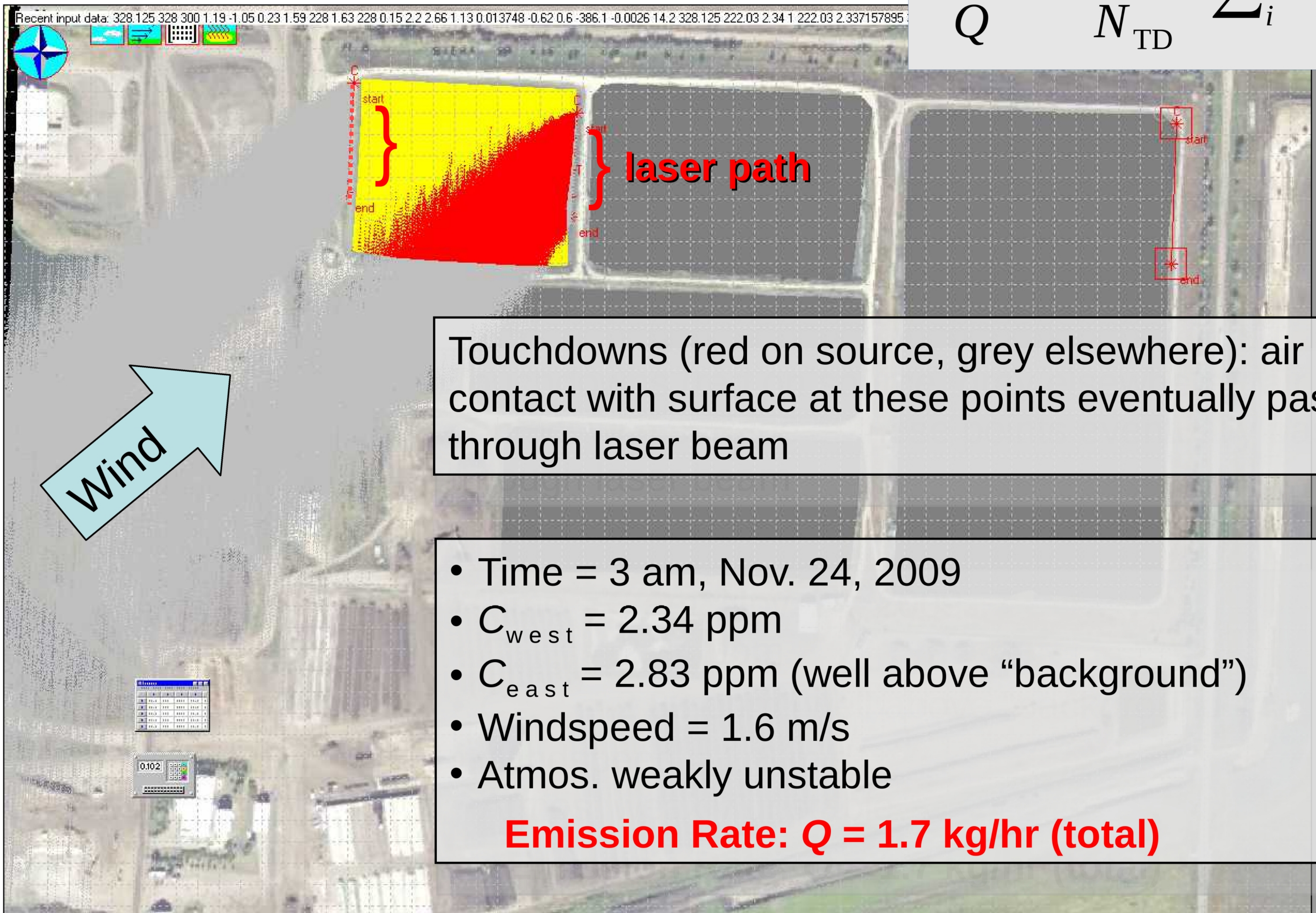

East Pond Laser
25
20
15
10
5
0
C CH4 (ppm)
Nov 23
Nov 24
Nov 25
Nov 26
laser lines
South Border
25
20
15
10
5
0
C CH4 (ppm)
Nov 19
Nov 20

WindTrax facilitates MO-bLS – here showing "touchdown clouds"



- GPS source area(s), xfer coords onto WindTrax's map, link to time series of C and wind (15-min averages)
- run WindTrax trajectory algorithm
- giving time-resolved record of *Q* with overall accuracy of order ±10-20% <u>over ideal surfaces</u>

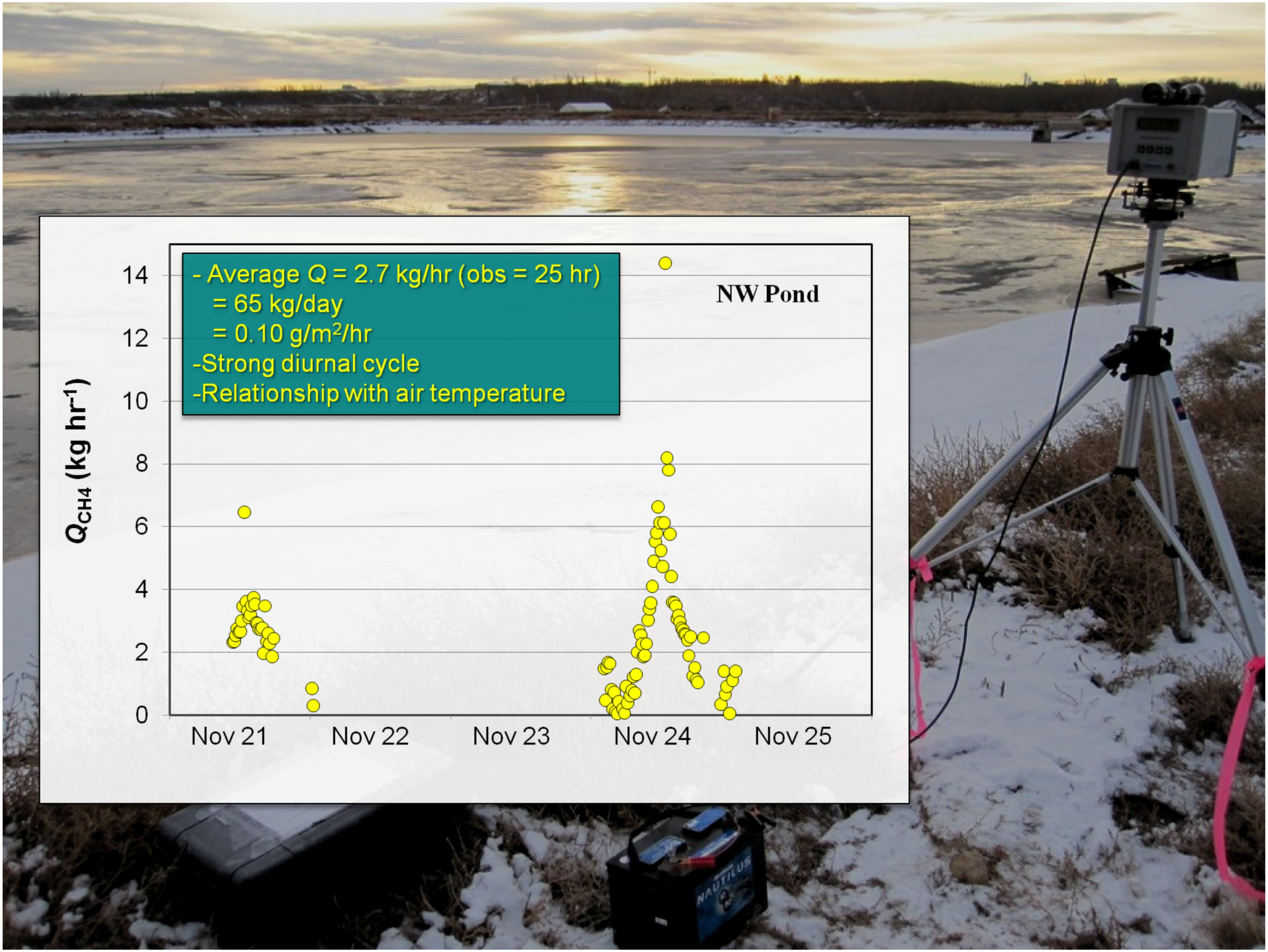
$$\frac{C}{Q} = \frac{1}{N_{TD}} \sum_i \frac{2}{w_i}$$



Touchdowns (red on source, grey elsewhere): air in contact with surface at these points eventually passes through laser beam

- Time = 3 am, Nov. 24, 2009
- C_{west} = 2.34 ppm
- C_{east} = 2.83 ppm (well above “background”)
- Windspeed = 1.6 m/s
- Atmos. weakly unstable

Emission Rate: Q = 1.7 kg/hr (total)


- Average Q = 2.7 kg/hr (obs = 25 hr)
= 65 kg/day
= 0.10 g/m2/hr
-Strong diurnal cycle
-Relationship with air temperature
NW Pond
Q_{CH4} (kg hr^{-1})
0
2
4
6
8
10
12
14
Nov 21
Nov 22
Nov 23
Nov 24
Nov 25
NAUTILUS

CH4 emission rate by eddy covariance (Casandra Brown, EAS MSc thesis) 14a

CH4 emission rate by eddy covariance & inverse dispersion (Casandra Brown) 14b

Inferred CH4 and NH3 emission rates from a Texas feedlot (47,000 cattle)

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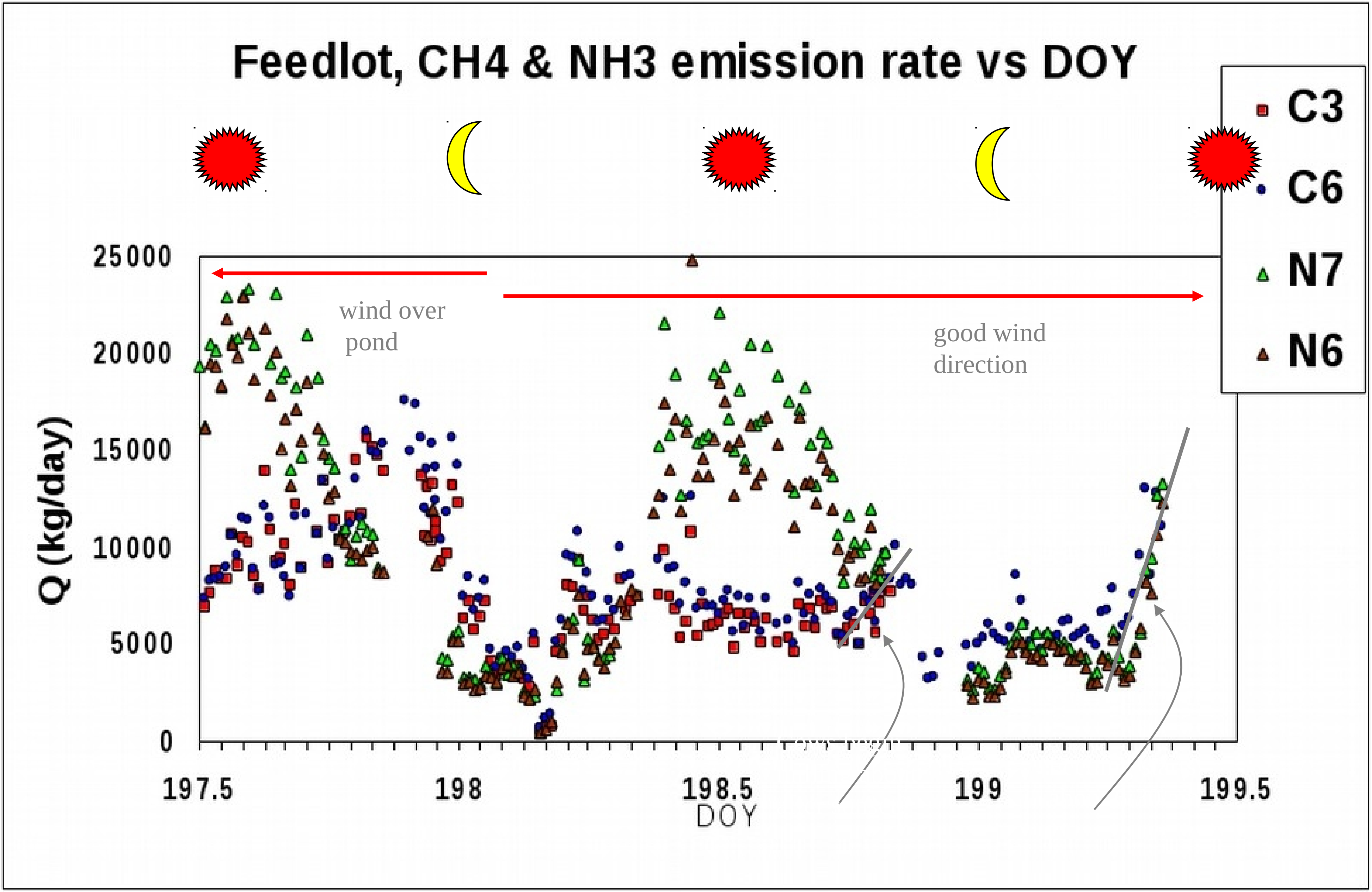
Feedlot, CH4 & NH3 emission rate vs DOY
C3
C6
N7
N6
wind over
pond
good wind
direction
Q (kg/day)
25000
20000
15000
10000
5000
0
197.5
198
198.5
199
199.5
DOY