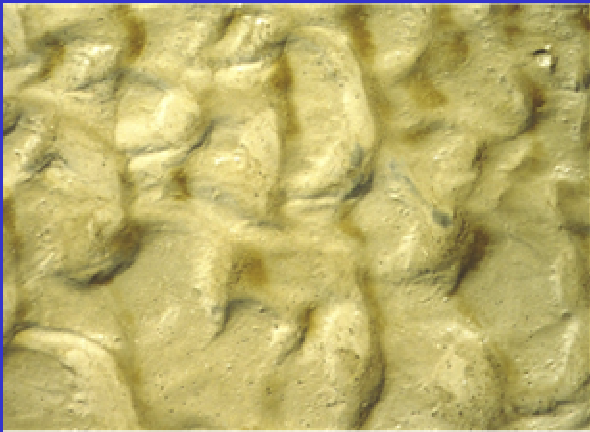


Eddy Correlation – An effective technique for measuring oxygen exchange between the seafloor and the water column



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Hans Røy²
Volker Meyer²**

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2) Max Planck Institute for Marine Microbiology, Germany



Oxygen exchange is a key variable

- Measure for benthic primary production and respiration
- Indicator of eutrophication status
- Measure for organic matter mineralization
- One of the most commonly measured variables in benthic marine ecology/biology



benthic oxygen exchange

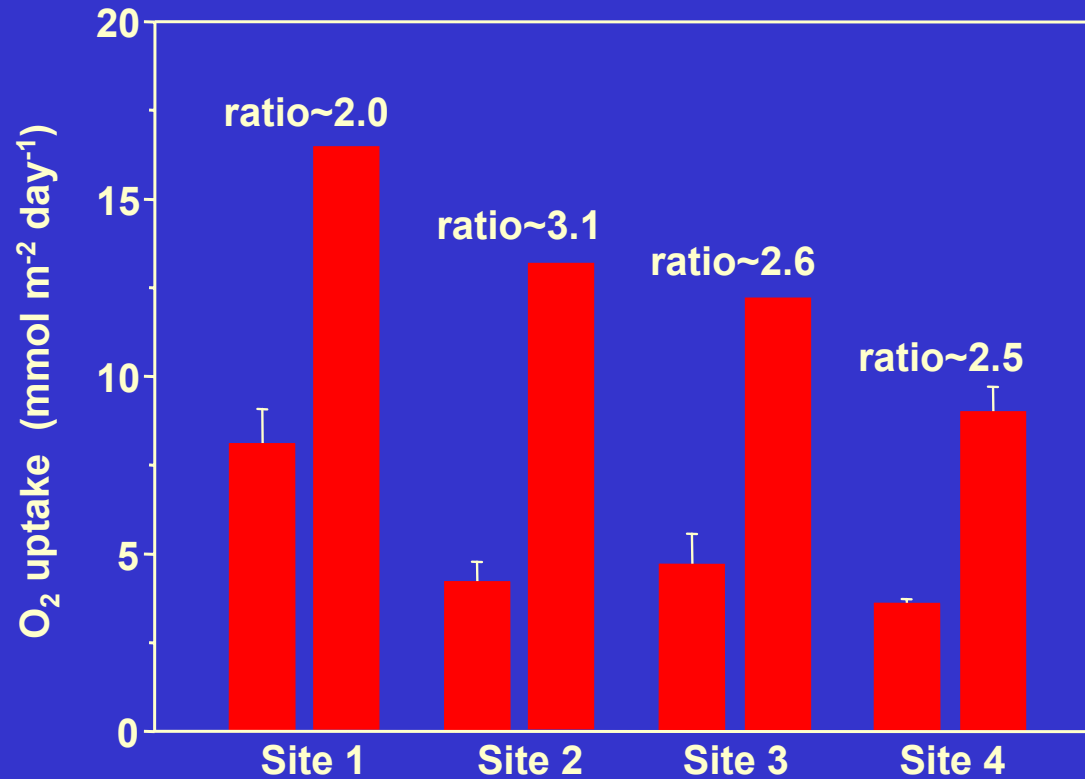
Search

~ 10,400 publications

Traditional methods – cores and *in situ* chambers

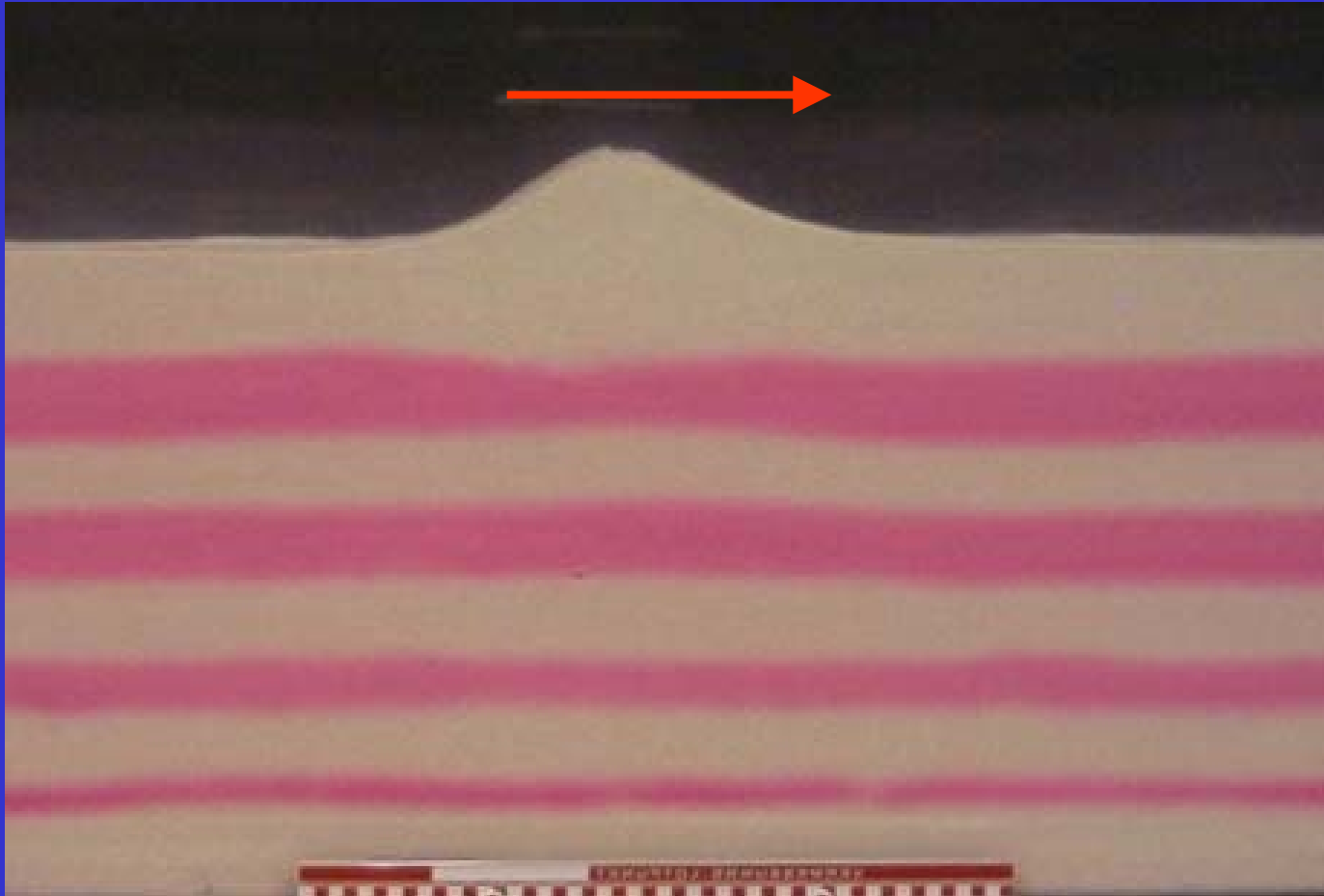


Cores in lab vs. *in situ* chambers



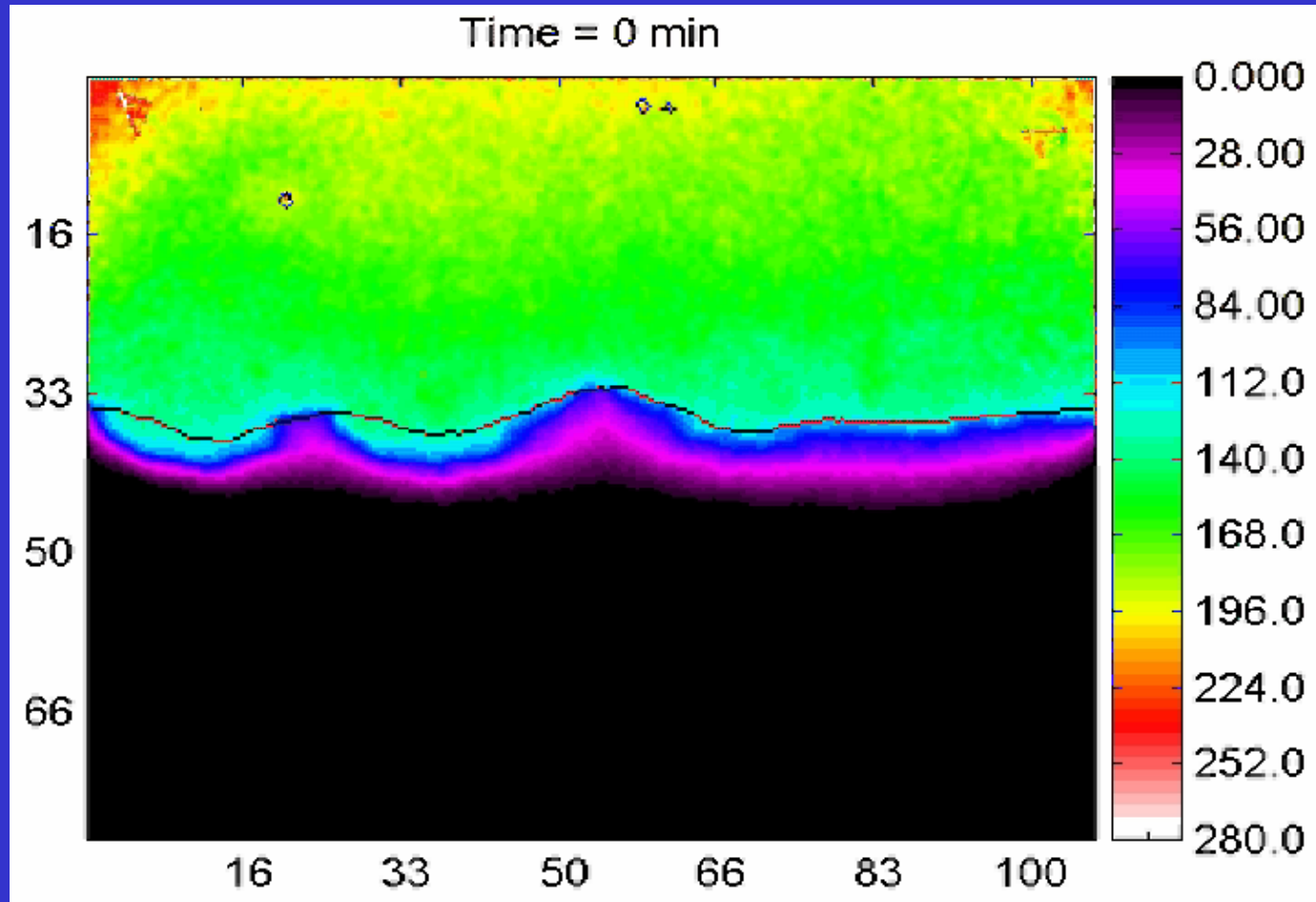
From Glud et al. (1998)

Induced flow in permeable sediments



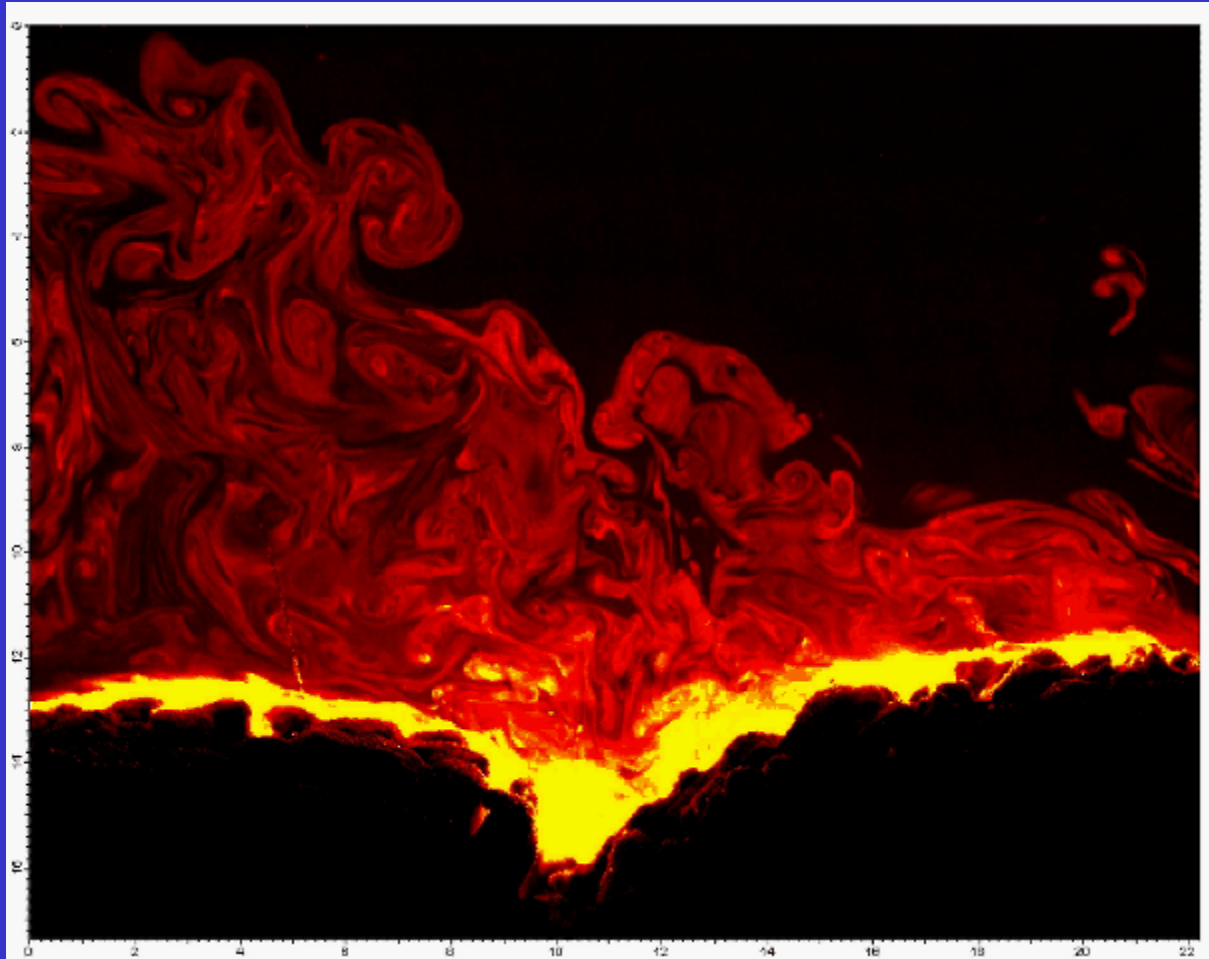
From Huettel and Hammerich (2002)

Induced flow in permeable sediments



From Franke et al. (unpubl.)

Eddy correlation – basic principles



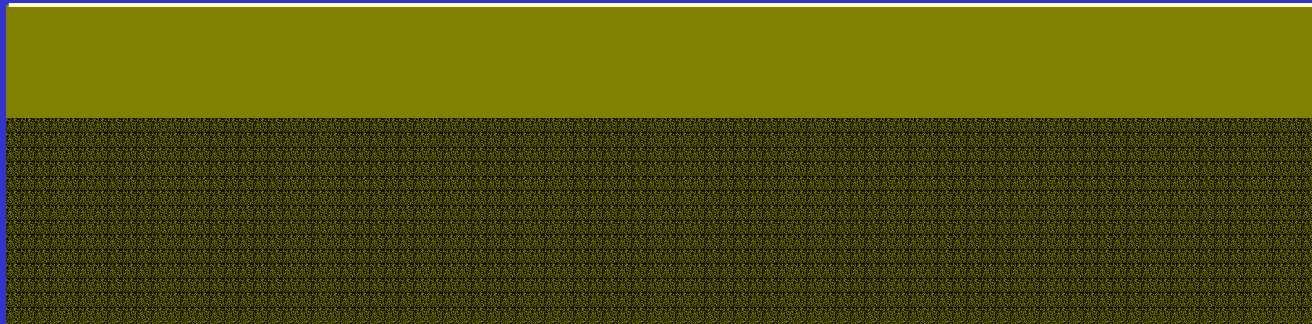
From Reidenbach et al. (2006)

Eddy correlation – basic principles

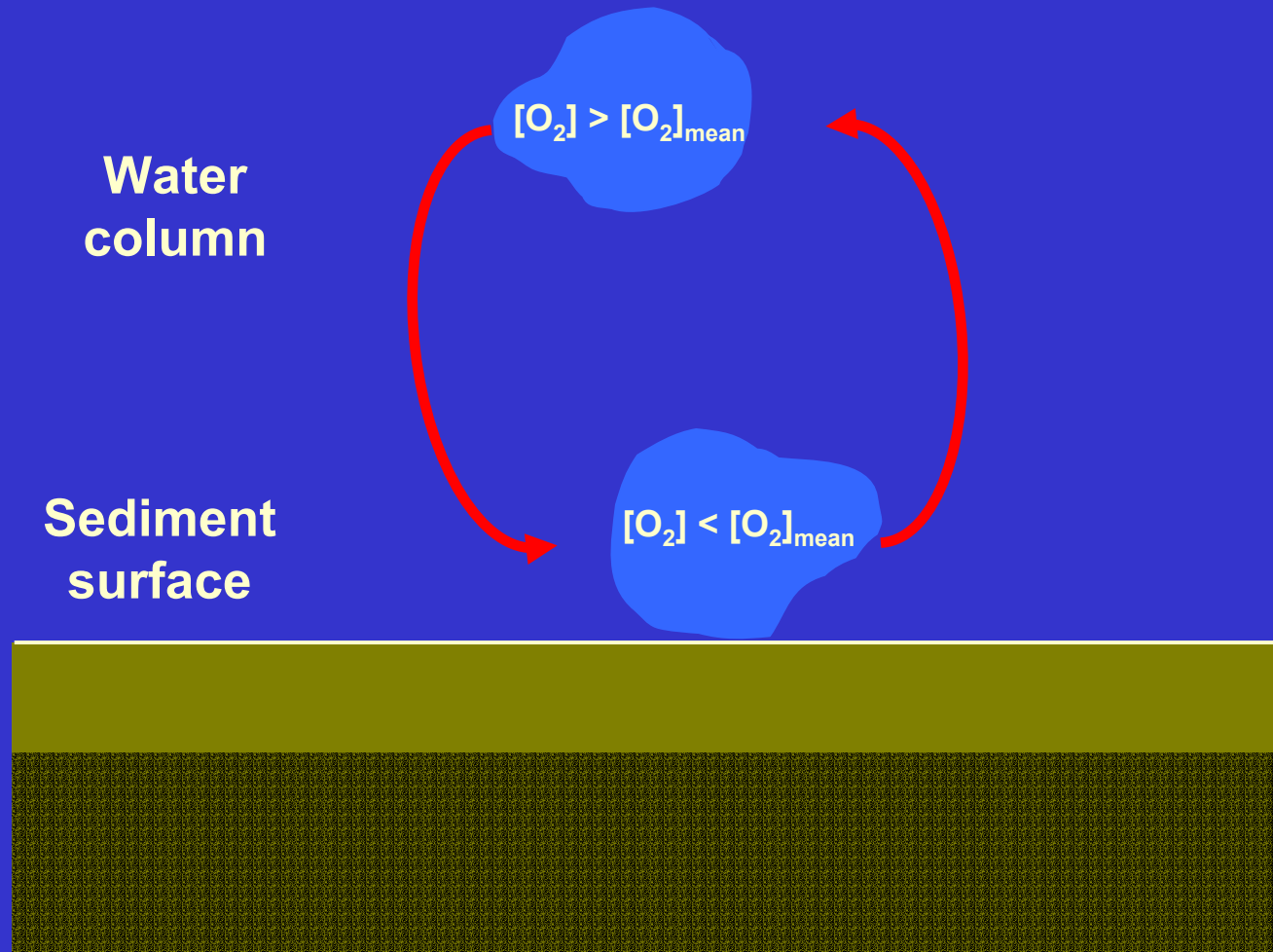
Water
column

Sediment
surface

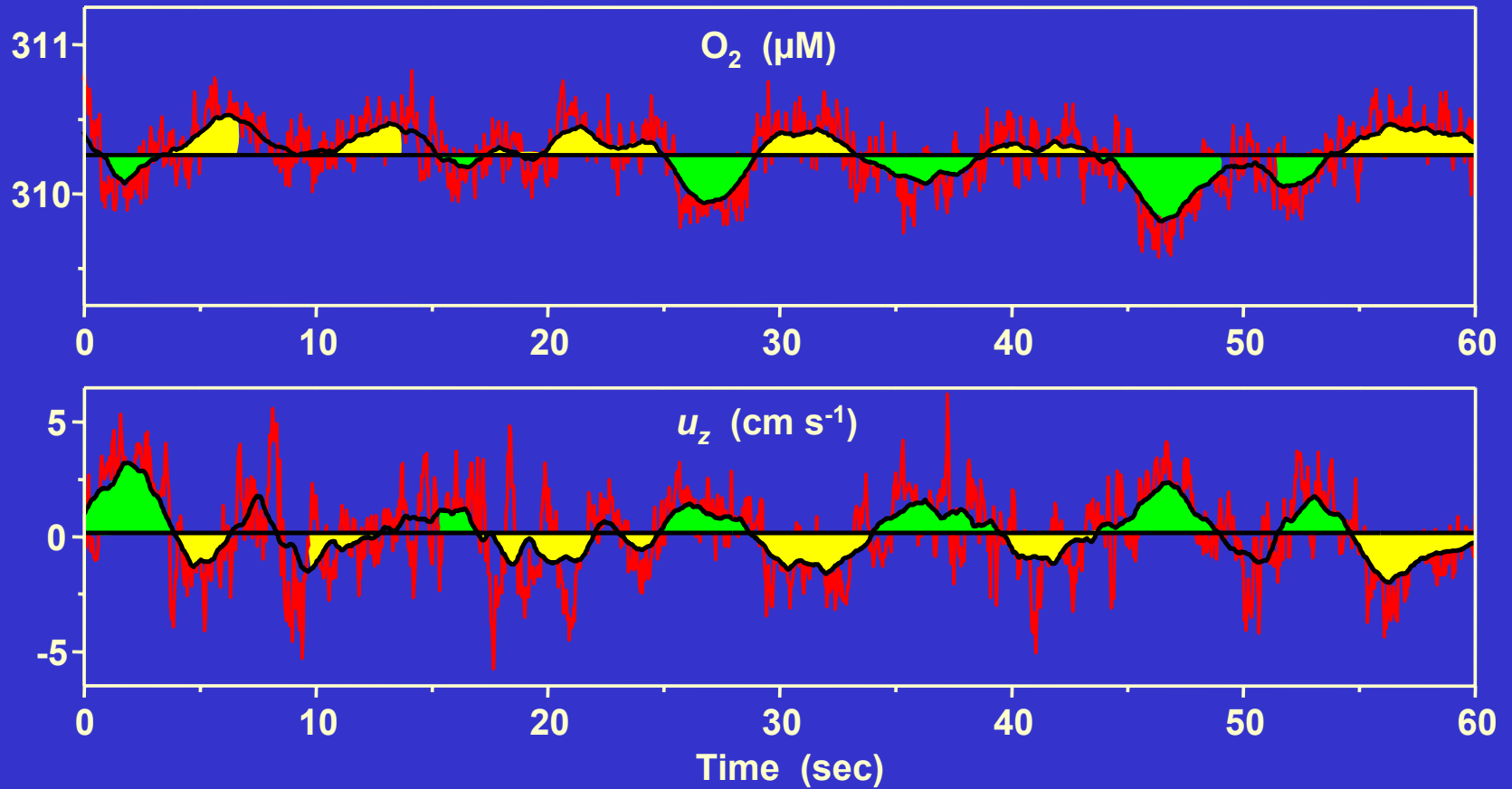
O₂ uptake



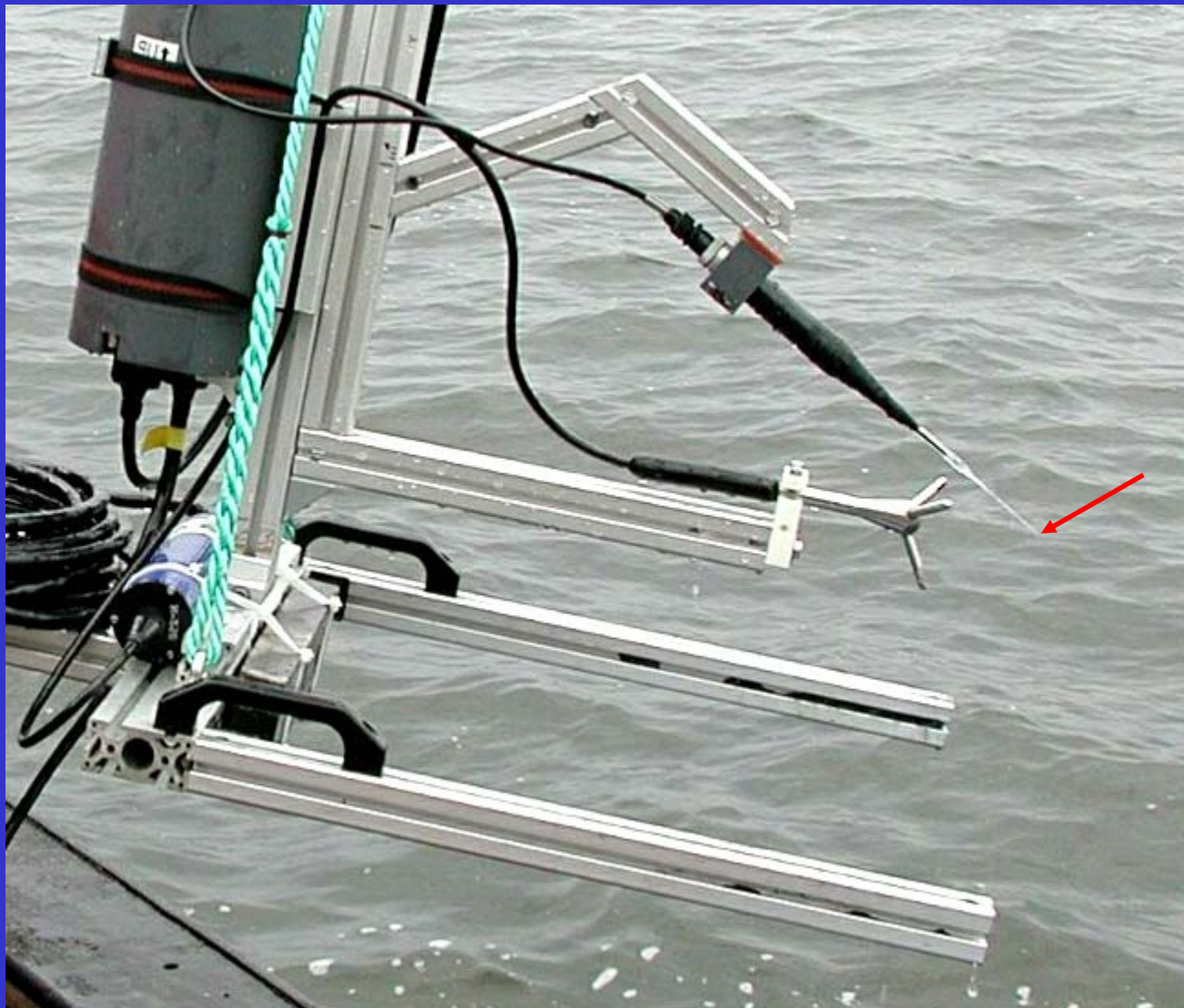
Eddy correlation – basic principles



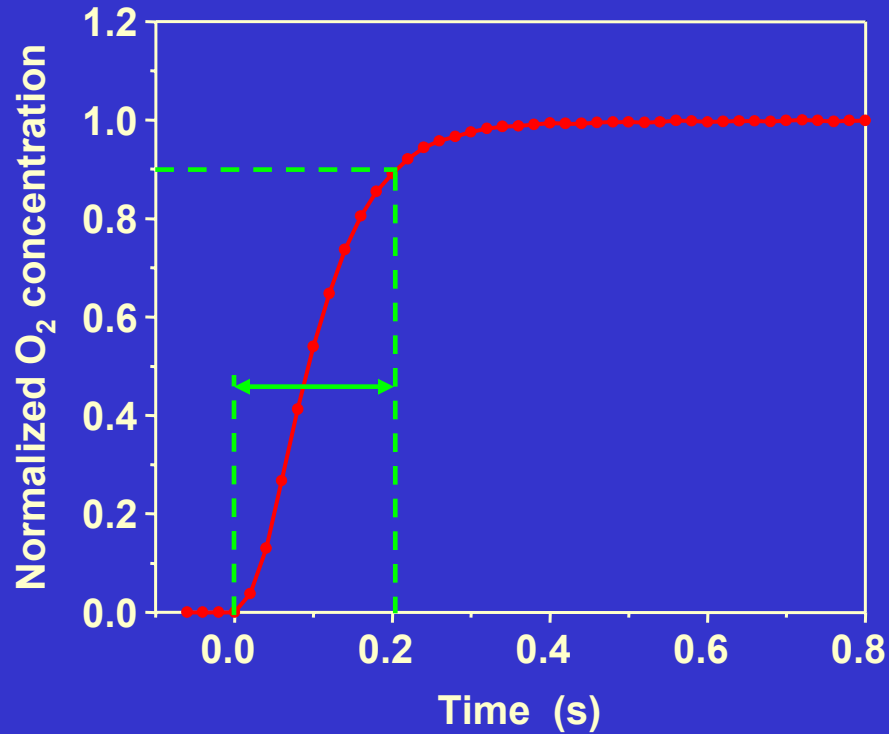
Eddy correlation – basic principles



Instruments



Instruments



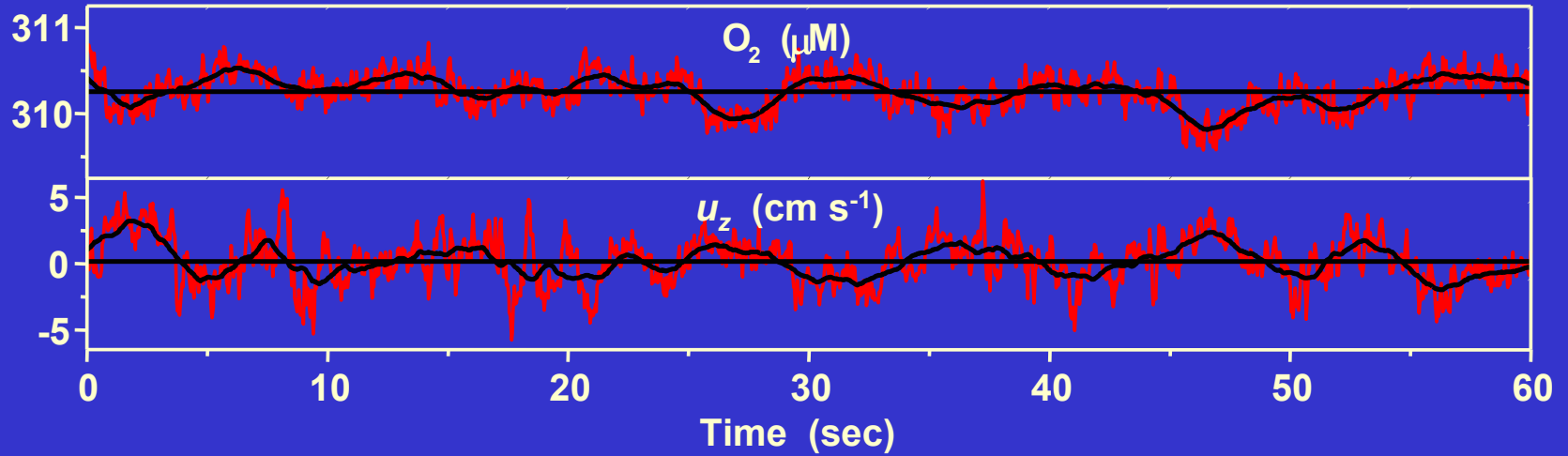
- O₂ microelectrode – 90% response time ~ 0.2 s

Data from Unisense

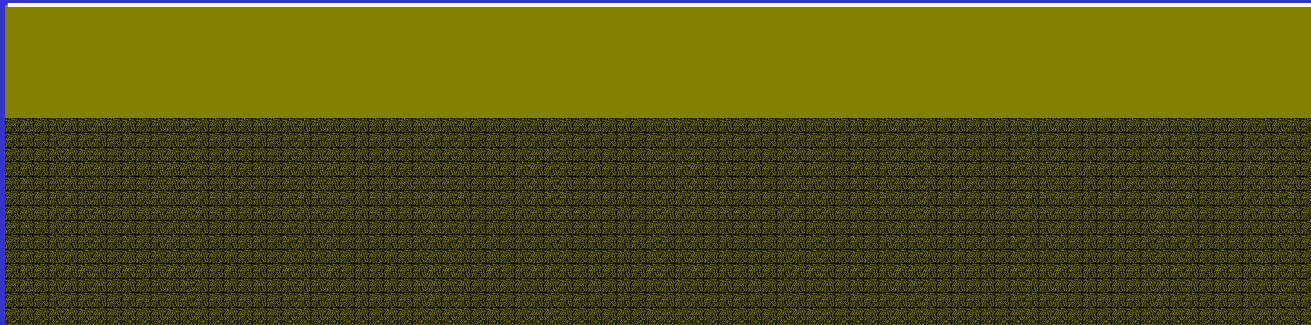
Instruments



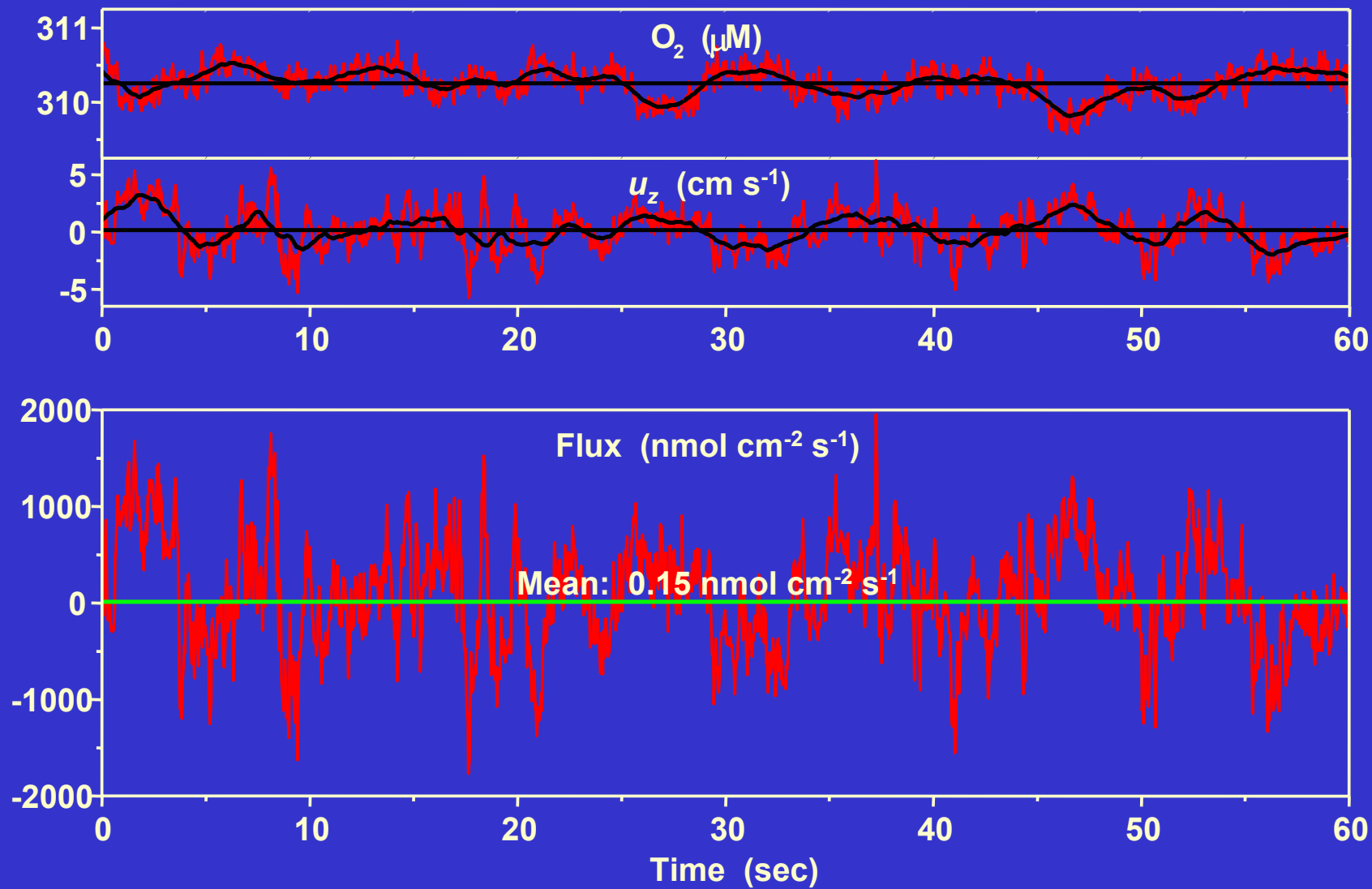
Eddy correlation – flux calculation



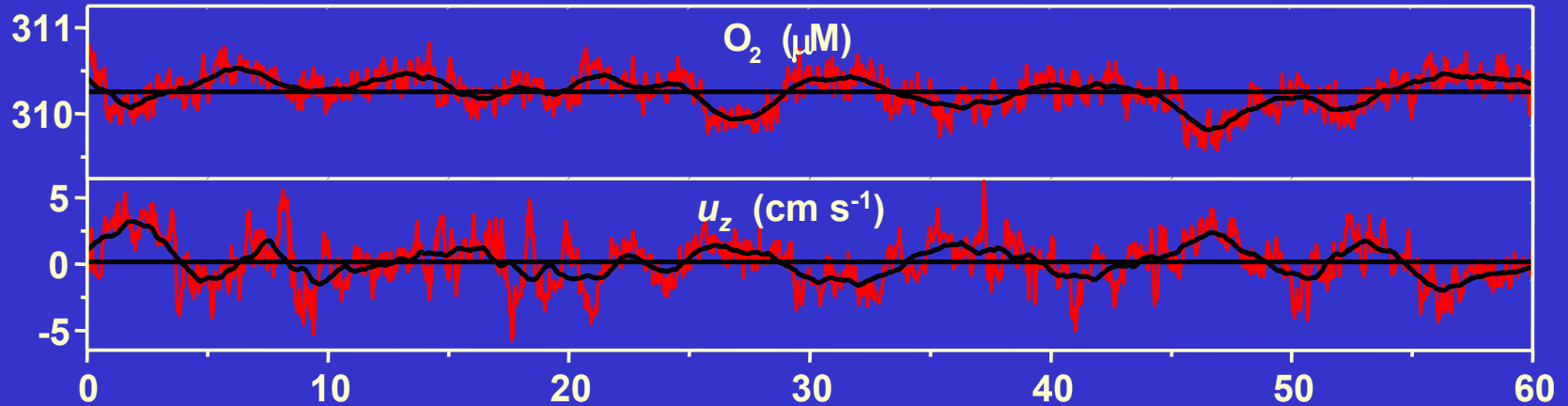
$$\text{Vertical flux} = u_z C - D \frac{dC}{dz}$$



Eddy correlation – flux calculation



Eddy correlation – flux calculation



- Reynolds decomposition:

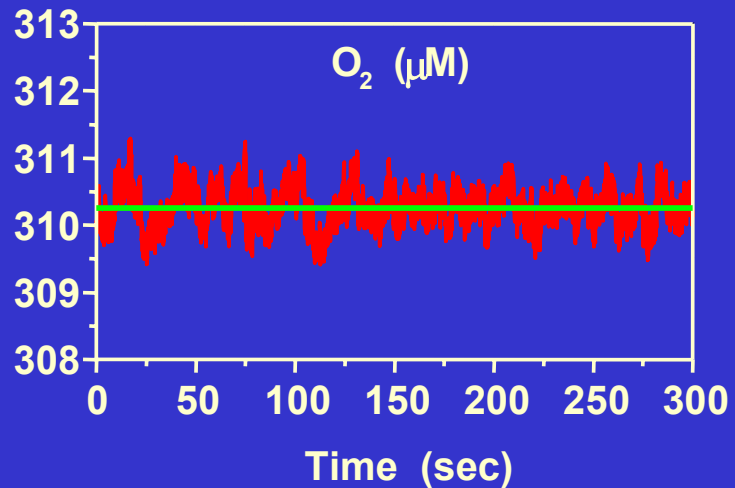
$$C = \bar{C} + C' \quad \text{and} \quad u_z = \bar{u}_z + u_z' \quad \text{where} \quad \bar{C}' = 0 \quad \text{and} \quad \bar{u}_z' = 0$$

- Averaged vertical flux = $\overline{u_z C} = \overline{\cancel{u_z C} + \cancel{u_z C'} + \cancel{u_z' C} + u_z' C'}$

Eddy correlation – flux calculation

- Mean removal:

\bar{C} ~ simple mean of all data



- Reynolds decomposition:

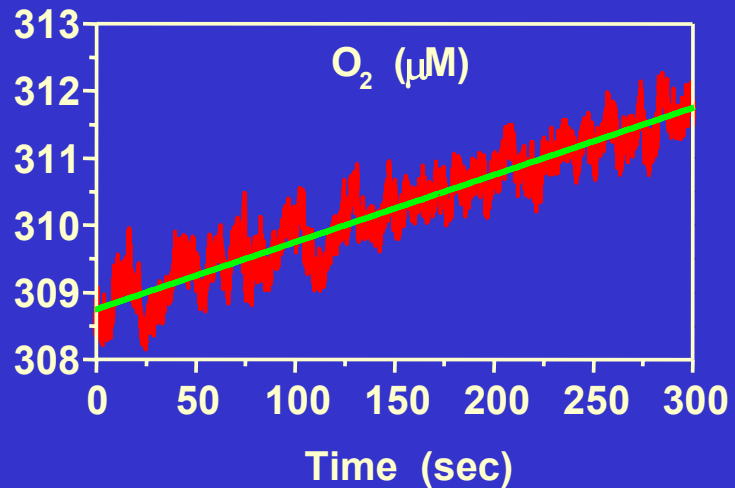
$$C = \bar{C} + C' \quad \text{and} \quad u_z = \bar{u}_z + u'_z \quad \text{where} \quad \bar{C}' = 0 \quad \text{and} \quad \bar{u}'_z = 0$$

- Averaged vertical flux = $\overline{u_z C} = \overline{u_z \bar{C}} + \overline{u_z C'} + \overline{u'_z \bar{C}} + \overline{u'_z C'}$

Eddy correlation – flux calculation

- Linear detrending:

$\bar{C} \sim$ Linear fit to all data



- Reynolds decomposition:

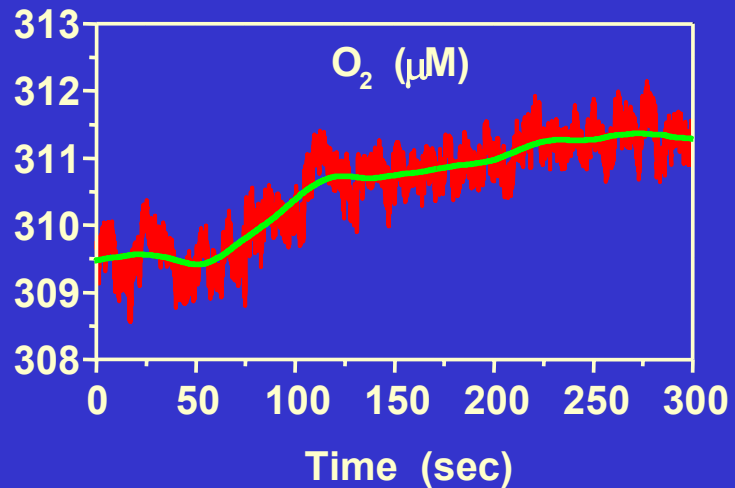
$$C = \bar{C} + C' \quad \text{and} \quad u_z = \bar{u}_z + u'_z \quad \text{where} \quad \overline{C'} = 0 \quad \text{and} \quad \overline{u'_z} = 0$$

- Averaged vertical flux = $\overline{u_z C} = \overline{u_z \bar{C}} + \overline{u_z C'} + \overline{\bar{u}_z C} + \overline{\bar{u}_z C'}$

Eddy correlation – flux calculation

- Filtering:

\bar{C} ~ Dynamic filtering

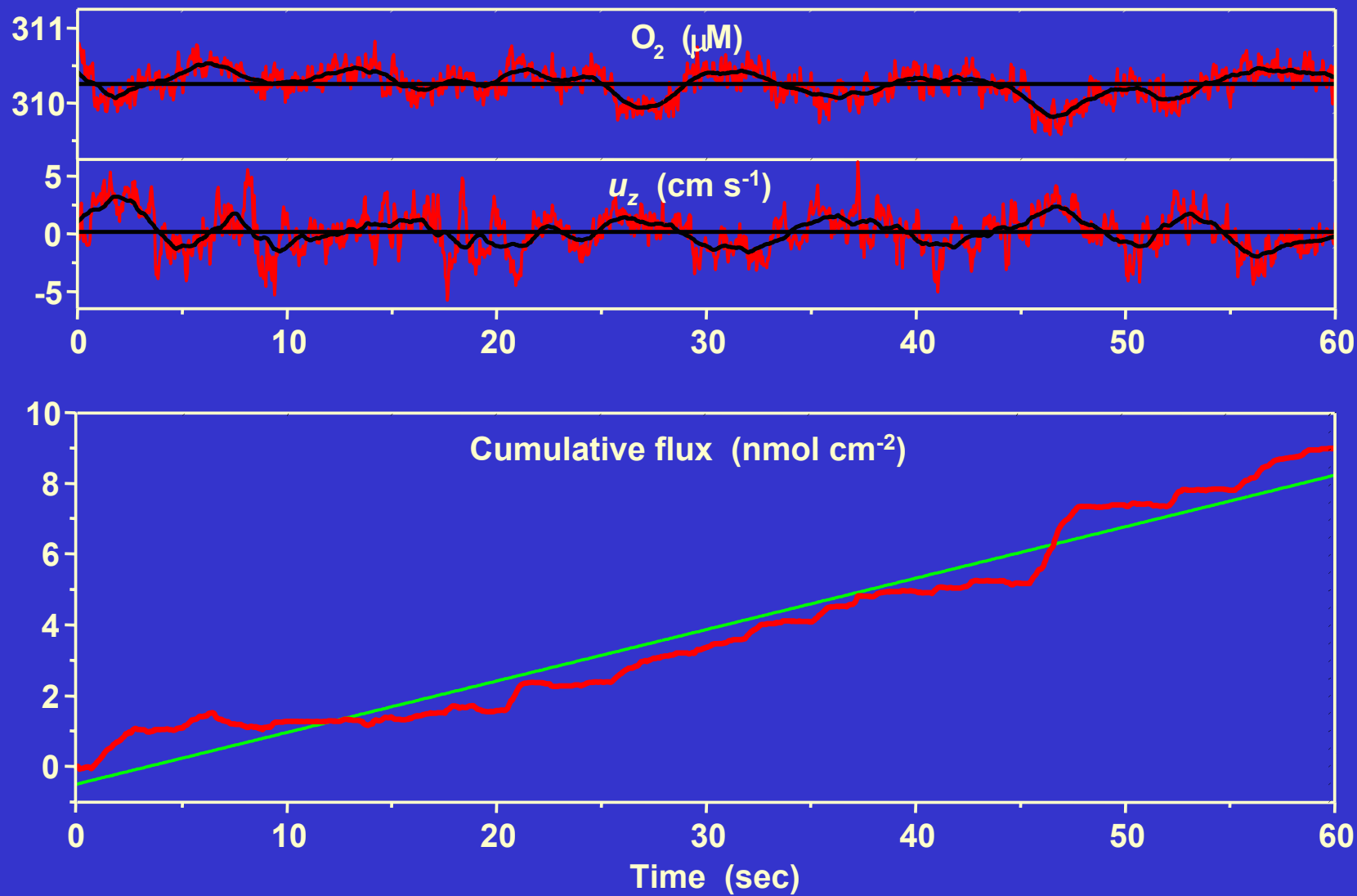


- Reynolds decomposition:

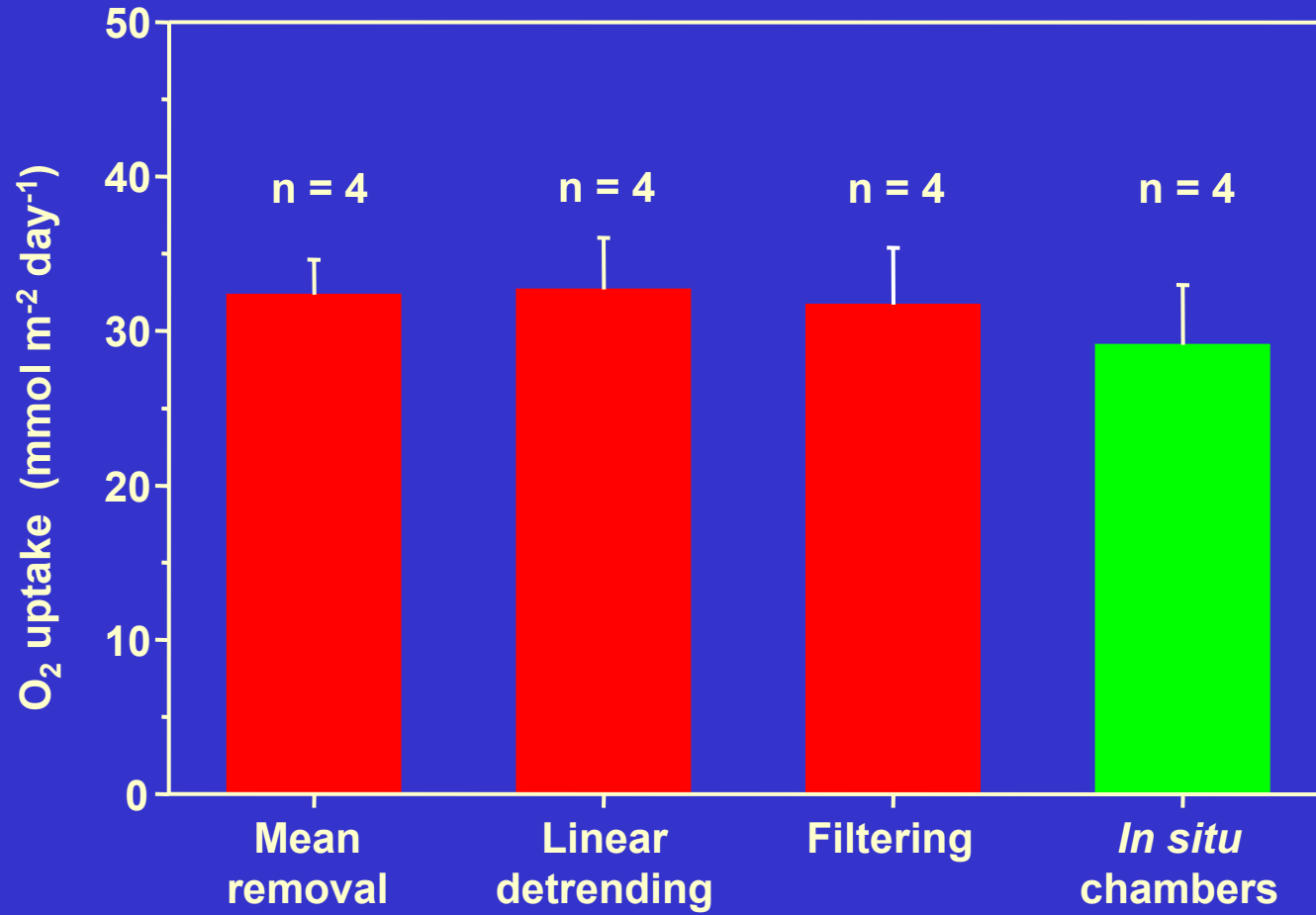
$$C = \bar{C} + C' \quad \text{and} \quad u_z = \bar{u}_z + u'_z \quad \text{where} \quad \overline{C'} = 0 \quad \text{and} \quad \overline{u'_z} = 0$$

- Averaged vertical flux = $\overline{u_z C} = \overline{u_z \bar{C}} + \overline{u_z C'} + \overline{\bar{u}_z C} + \overline{\bar{u}_z C'}$

Eddy correlation – flux calculation

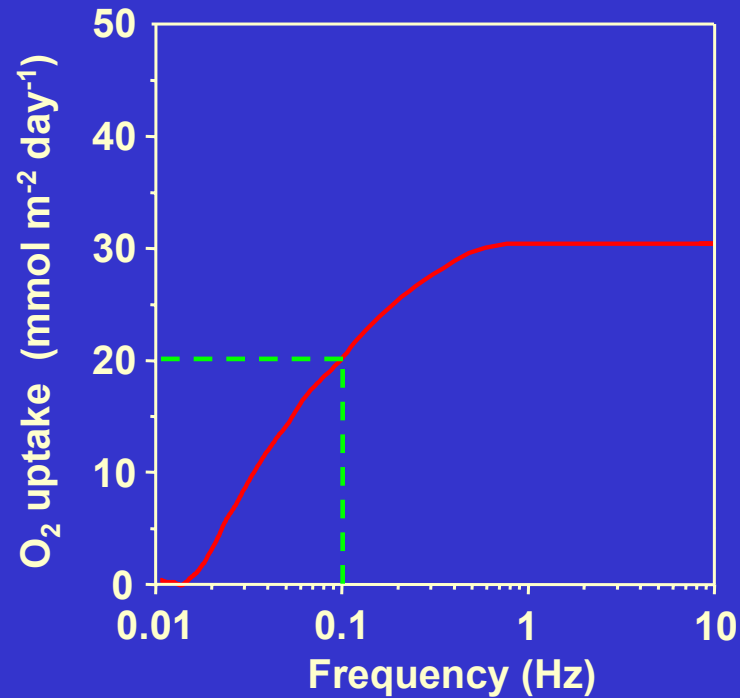


Validation



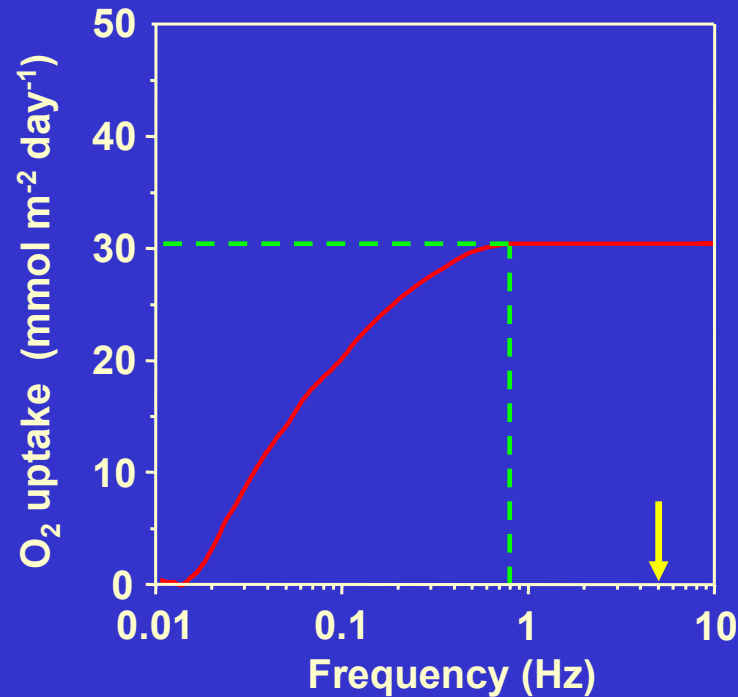
Frequencies of turbulent eddies

- Calculate flux repeatedly while including higher and higher frequencies

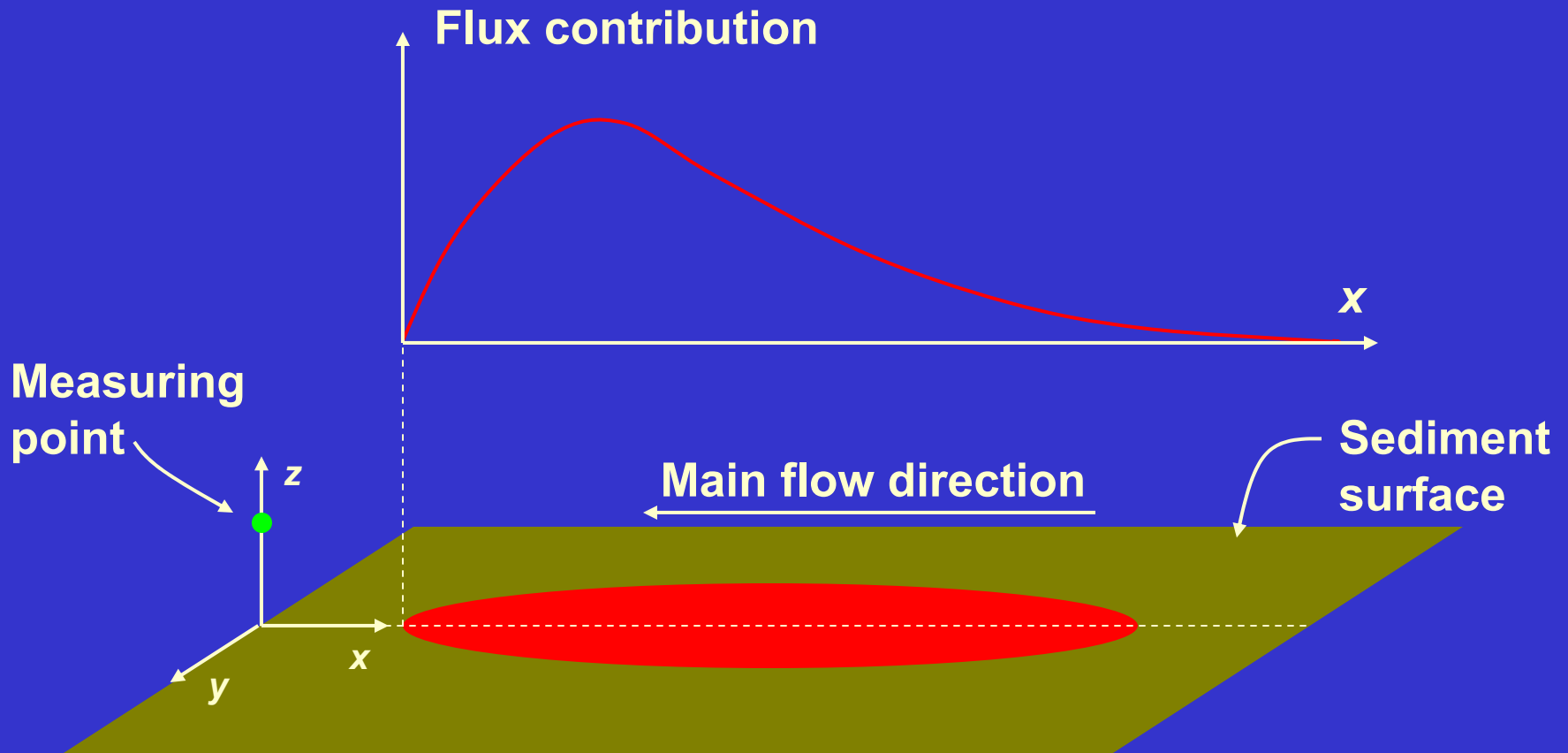


Frequencies of turbulent eddies

- Calculate flux repeatedly while including higher and higher frequencies



Areal integration



- Definition of the foot print: area that contributes with 90% of the flux

Foot print prediction – 3D modeling

- Molecular and “turbulent” diffusion included in all directions
- Advection included in x-direction

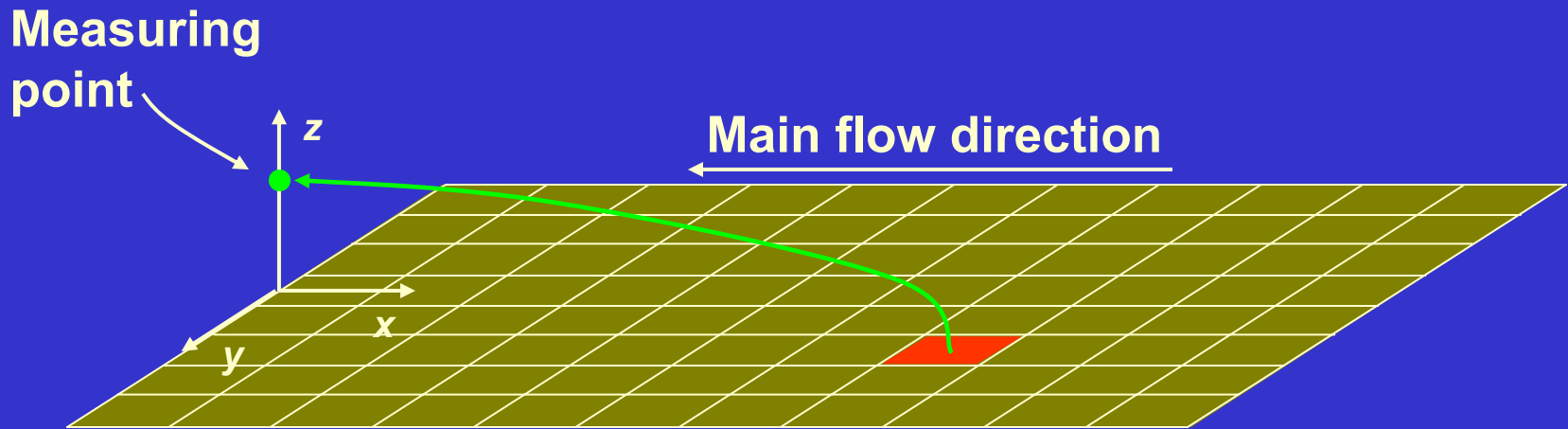
$$\frac{\partial \bar{C}}{\partial t} = \frac{\partial}{\partial x} \left((D + E_x) \frac{\partial \bar{C}}{\partial x} \right) + \frac{\partial}{\partial y} \left((D + E_y) \frac{\partial \bar{C}}{\partial y} \right) + \frac{\partial}{\partial z} \left((D + E_z) \frac{\partial \bar{C}}{\partial z} \right) - \bar{u}_x \frac{\partial \bar{C}}{\partial x}$$

- Eddy diffusivities and velocity are functions of z

$$E_x = E_y = E_z = \kappa u_* z$$

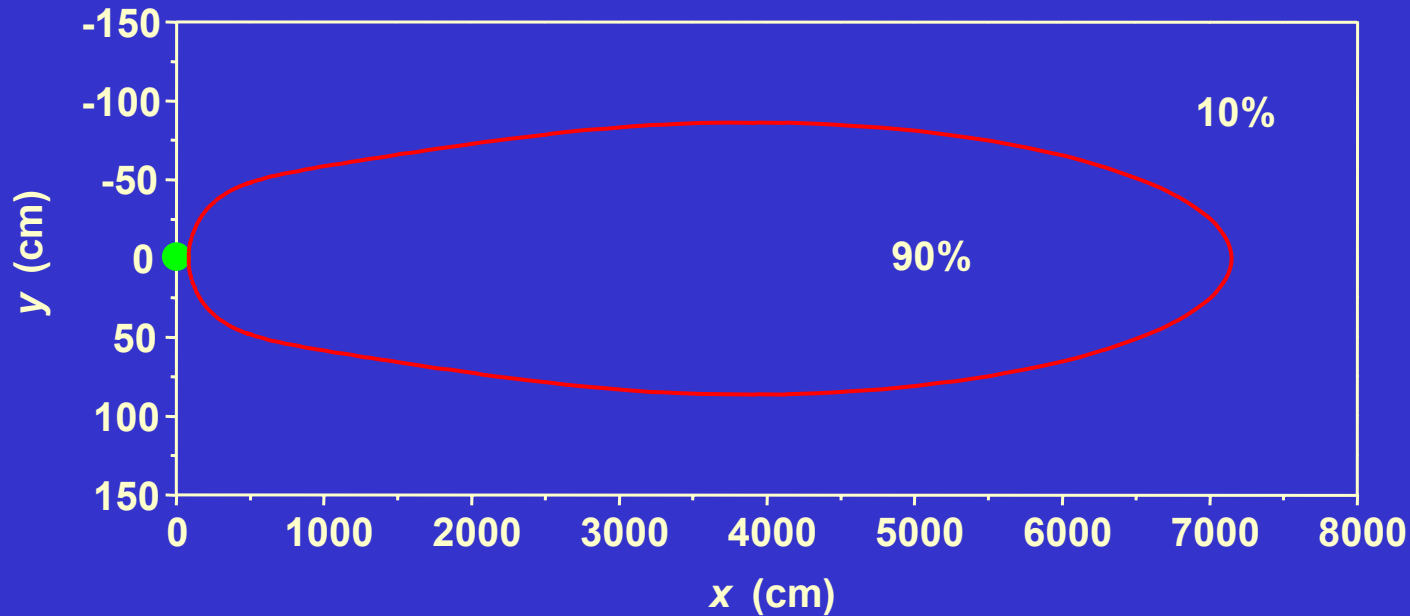
$$\bar{u}_x = \frac{u_*}{\kappa} \ln \frac{z}{z_0}$$

Foot print prediction – 3D modeling



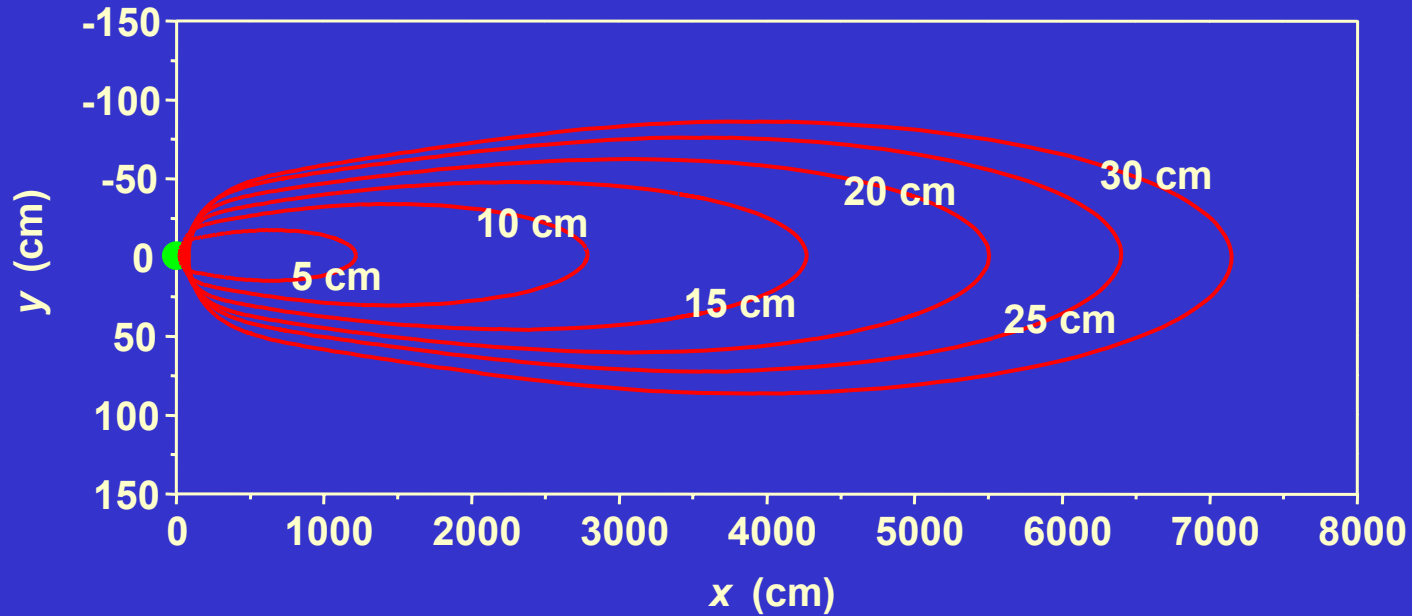
- Number of control volumes $\sim 200 \times 100 \times 100 = 2000,000$

Foot print prediction – 3D modeling



- Relatively smooth sediment surface ($z_0 = 0.1$ cm)
- $\bar{u}_x = 1$ cm s⁻¹ at 30 cm above sediment
- Measuring height over sediment surface: $h = 30$ cm

Foot print prediction – 3D modeling



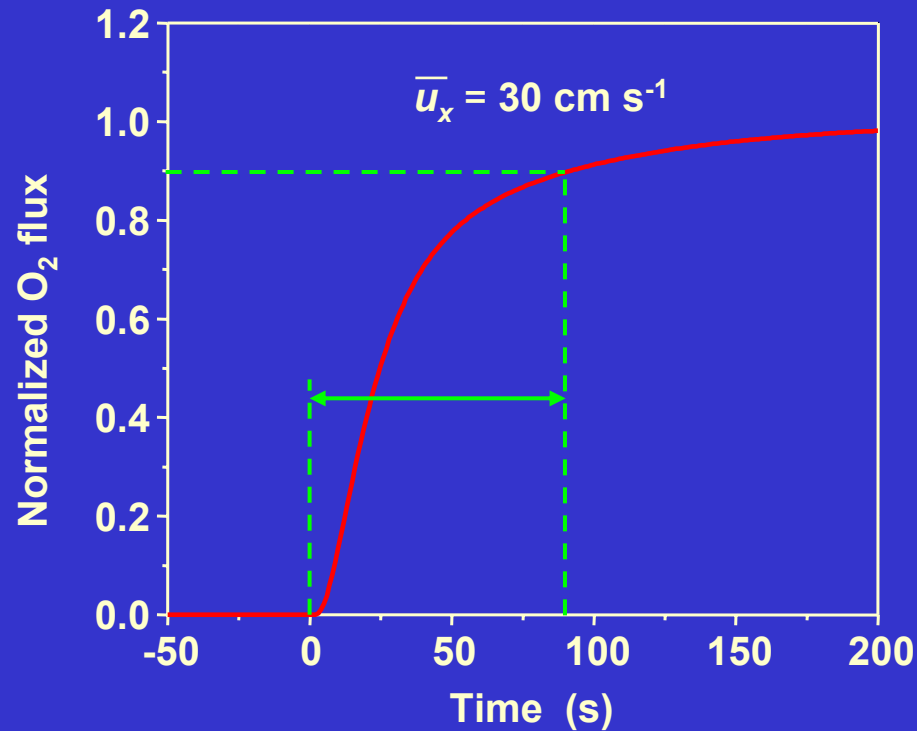
● Length of foot print: $L = -277 + 77.71h + 1.80h^2 - 121h \log(z_0)$



Response to changes in O₂ exchange – 3D modeling

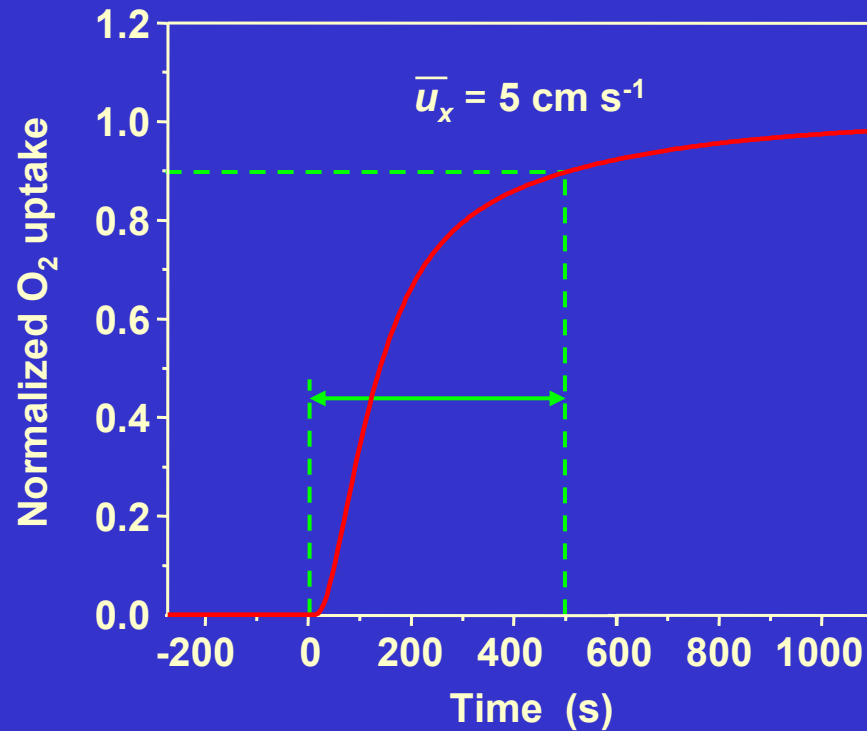


Response to changes in O₂ exchange – 3D modeling



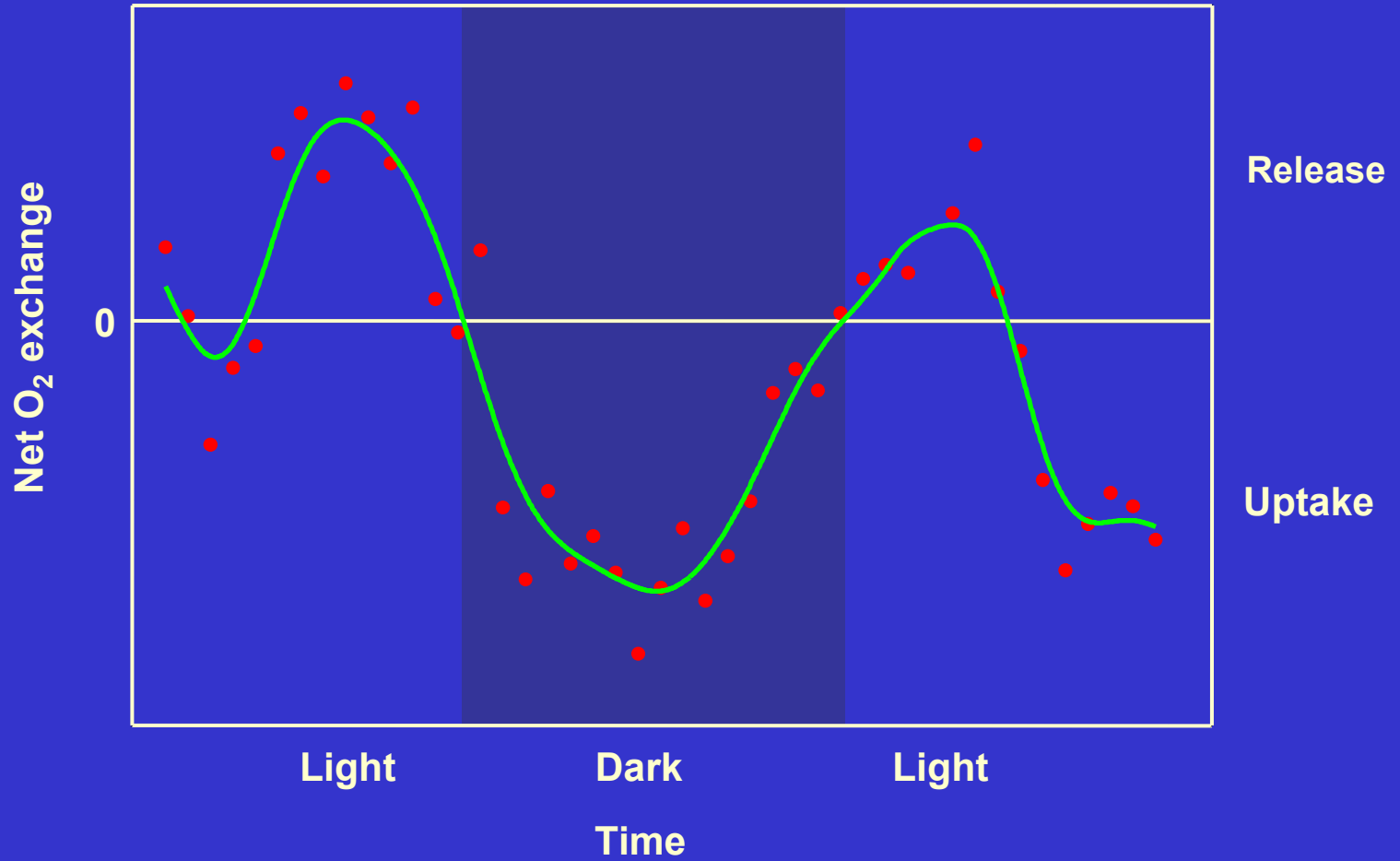
- 90% response time ~ 90 s ($h = 10 \text{ cm}$ and $z_0 = 0.1 \text{ cm}$)

Response to changes in O₂ exchange – 3D modeling

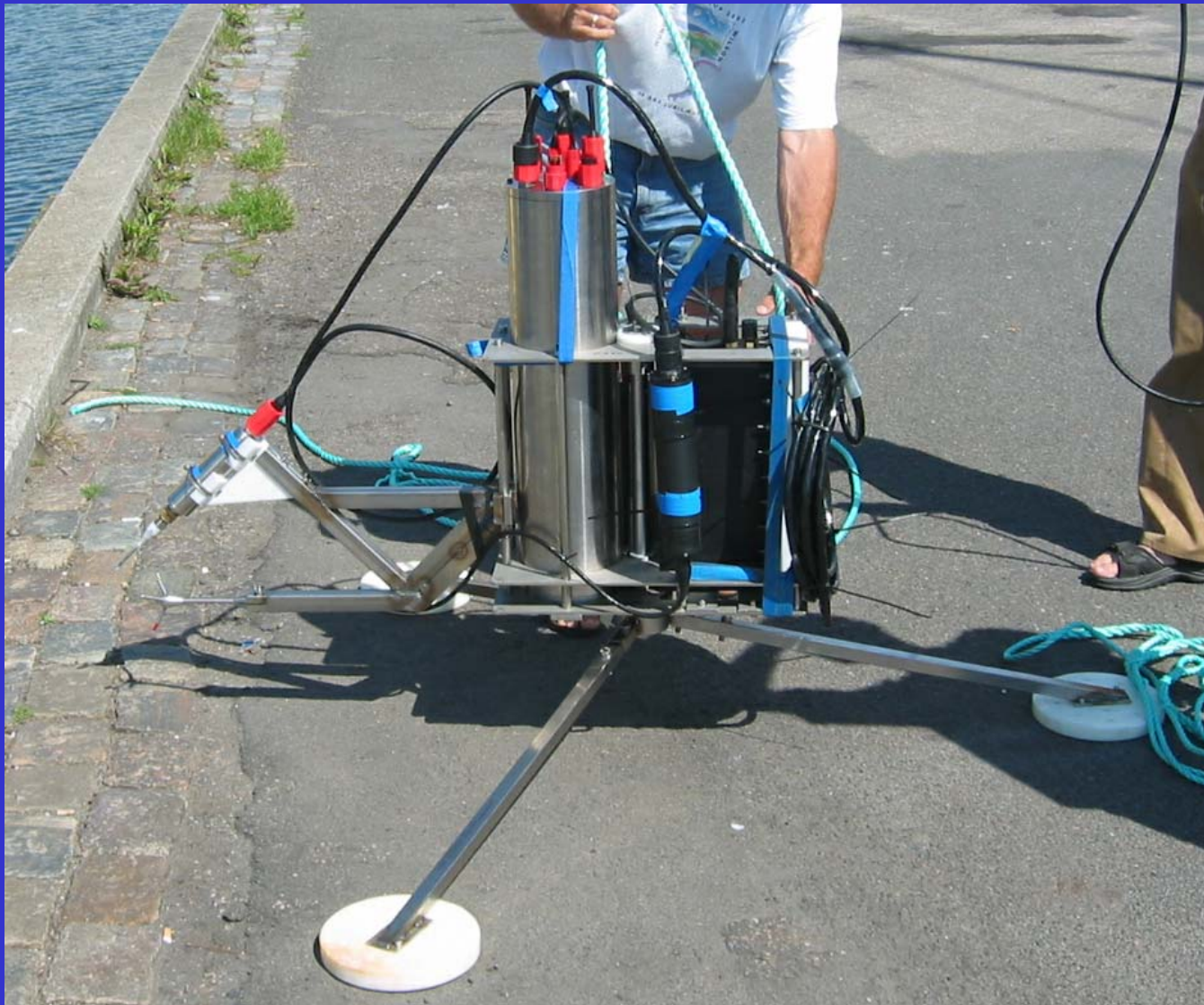


- 90% response time $\sim 500 \text{ s}$ ($h = 10 \text{ cm}$ and $z_0 = 0.1 \text{ cm}$)

Results – Day night cycle



Instruments



Conclusion

- **The new technique is superior to conventional methods:**
 - **True *in situ* measurements without any disturbance of the sediment and under the natural hydrodynamic conditions**
 - **Can be used for highly porous sediments or bio-irrigated sediments where conventional methods often fail**
- **Can be applied to other solutes or quantities that can be measured at sufficiently high temporal resolution**

Deployment

