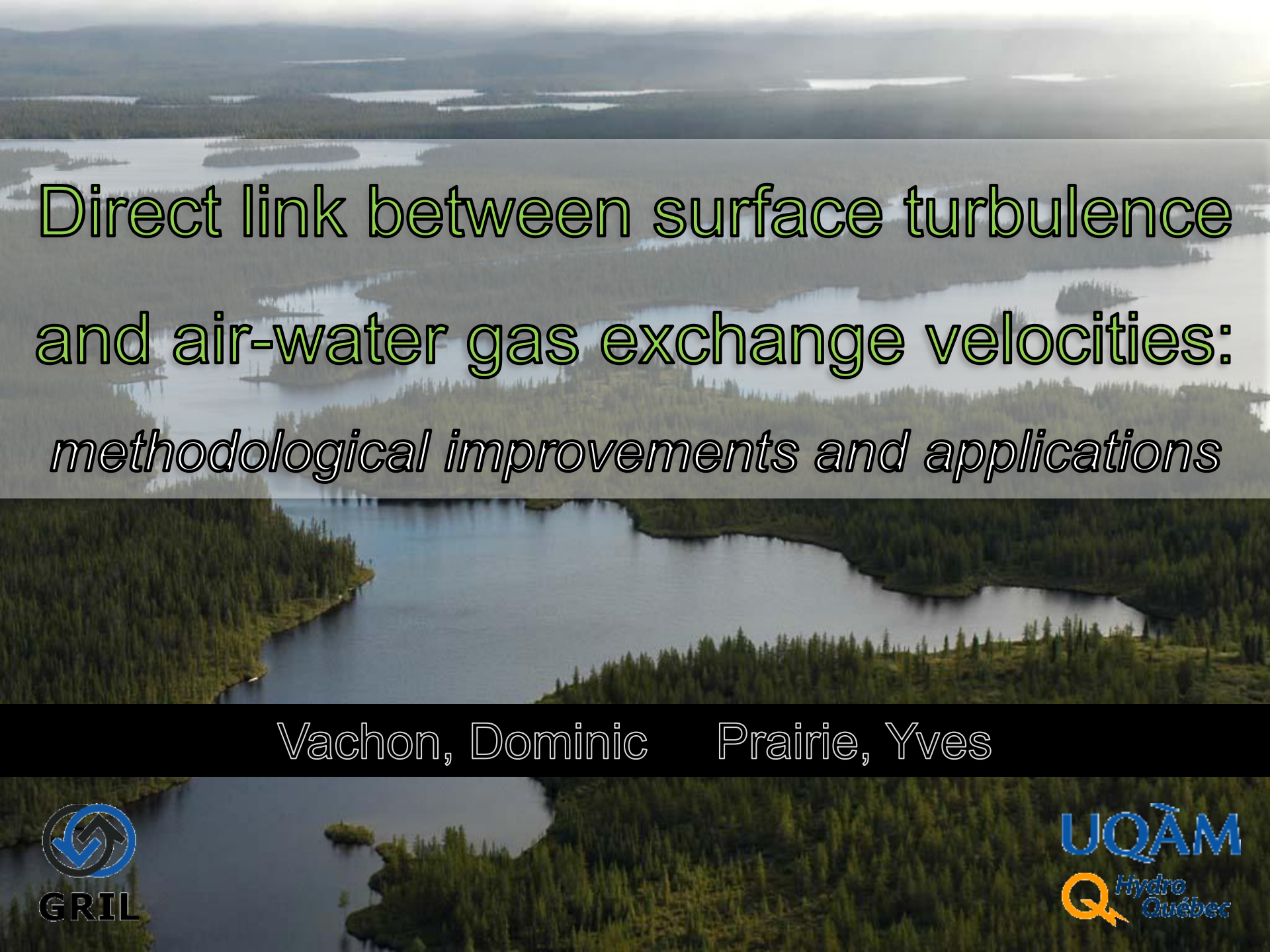


Direct link between surface turbulence and air-water gas exchange velocities:

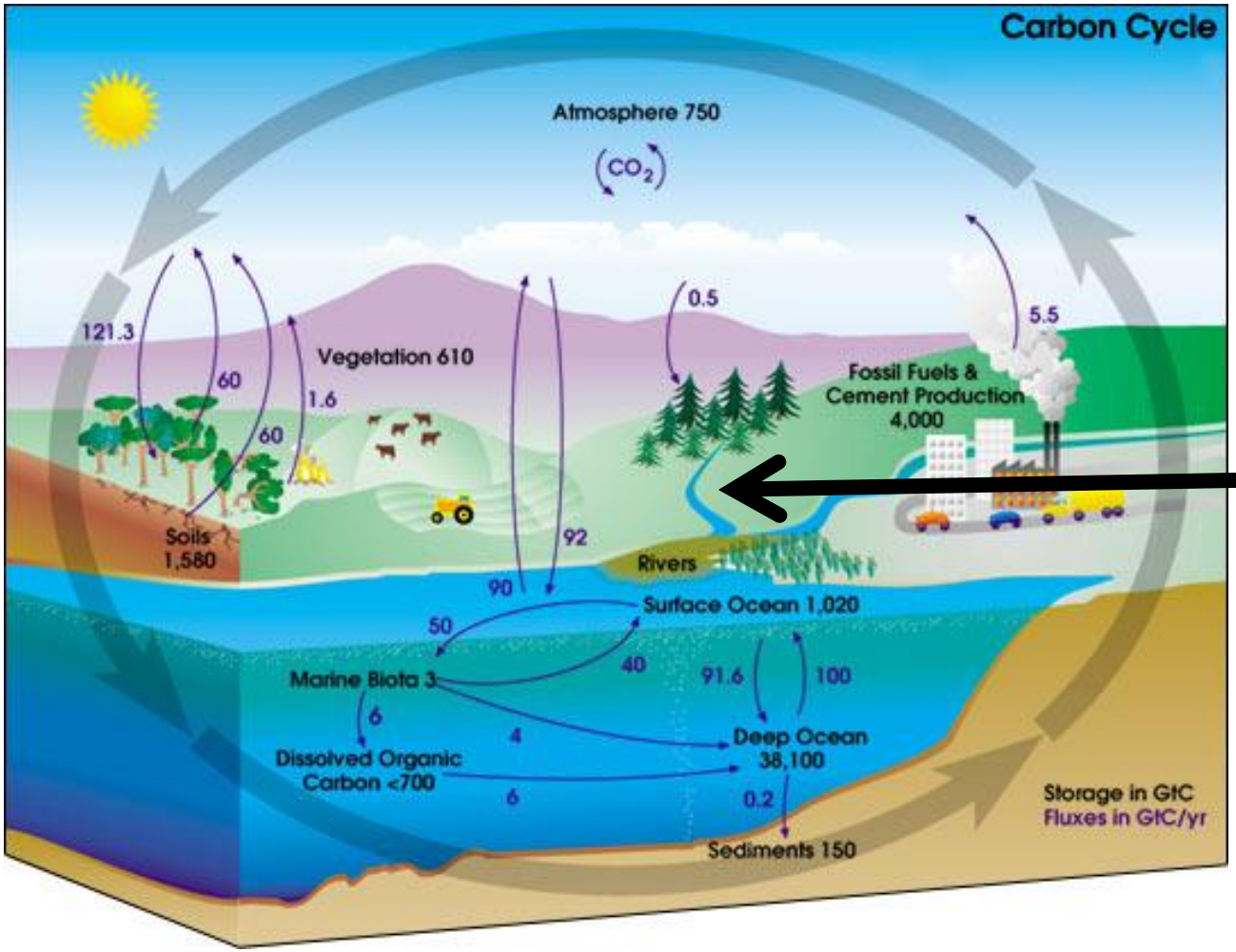
methodological improvements and applications

Vachon, Dominic Prairie, Yves

GRIL

UQÀM

Hydro Québec

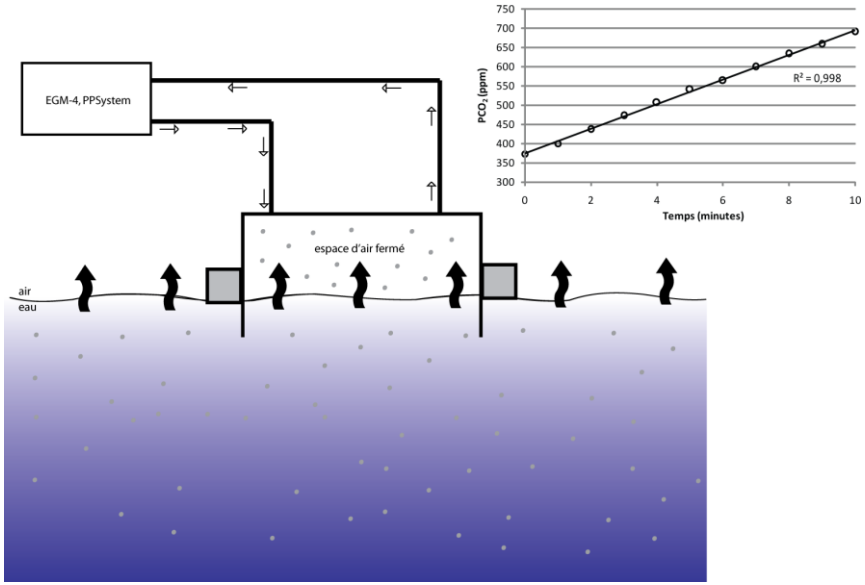


Inland aquatic systems

Source: NASA

Direct way:

Floating chamber Method



Flux= C quantity/surface area/time

Semi-Empirical way:

$$F = k \times Kh(pCO_{2water} - pCO_{2air})$$

k = gas transfer velocity (specific for each gas)

Kh = Henry coefficient (temperature, salinity)

$(pCO_{2\ water} - pCO_{2\ air})$ = partial pressure difference

Than

$Kh * pCO_{2\ water}$ = CO_2 water concentration

$$k_{600} = 2{,}07 + 0{,}215 \times U_{10}^{1{,}7}$$

Cole and Caraco 1998


11.09

Problem with floating chamber (FC) method

Fluxes measured with FC seem higher compared to other methods

(Matthews et al. 2003; Eugster *et al. 2003)*

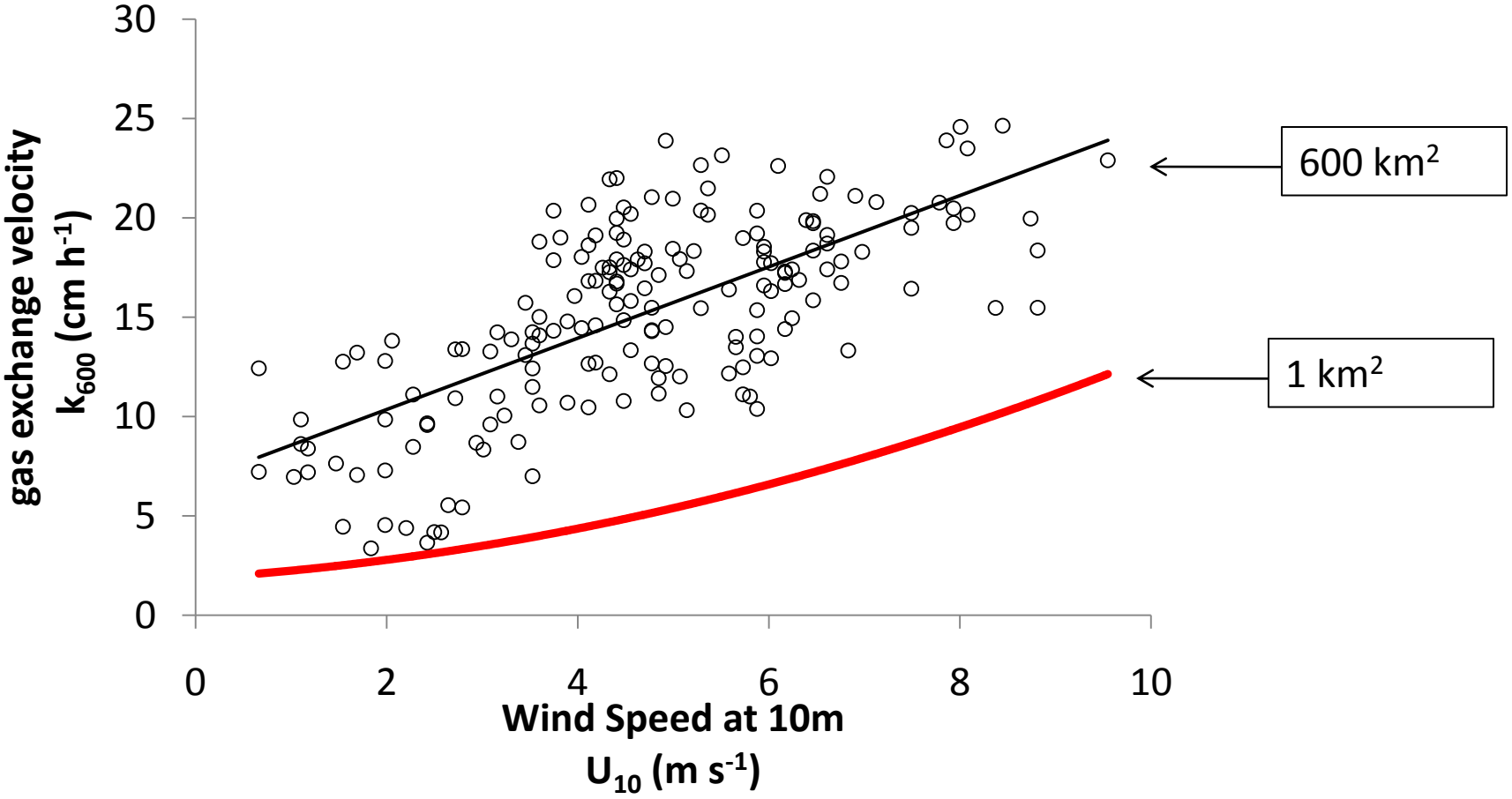
Explanation: FC disturbs the air-water interface

(Lambert and Fréchette 2004; Kremer *et al.* 2003)

FC sides create artificial turbulence inside the sampling surface

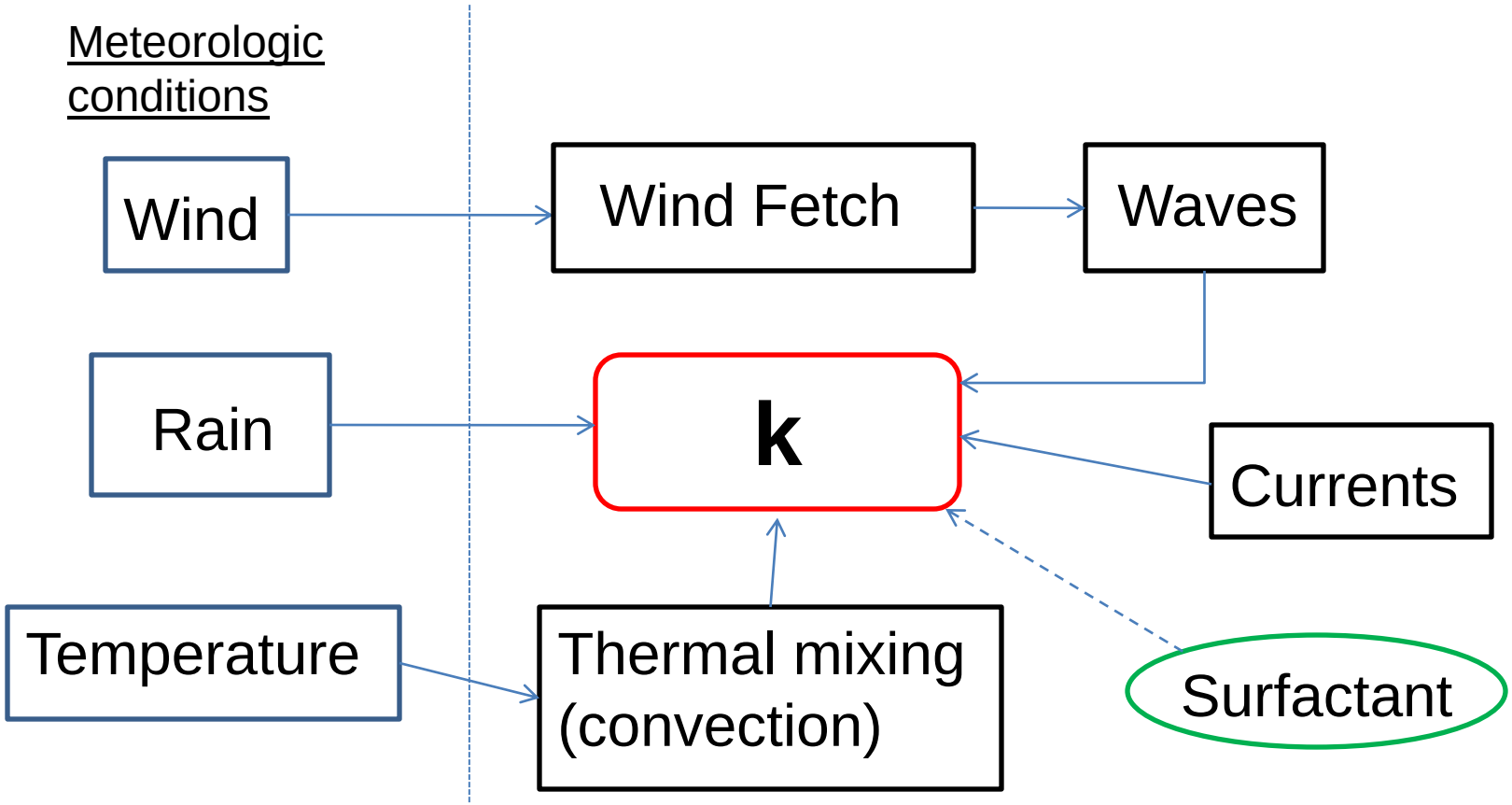
Example of empirical relation based on wind speed at 10 m compared to FC sampled from hydroelectric reservoir

Cole and Caraco 1998 (red line developed on Mirror Lake)



''The primary driving mechanism at low to moderate wind speed is near surface turbulence.''

Zappa *et al.* 2007



Statement 1:

If flux at the air-water interface is indeed a diffusive process driven by surface turbulence, then...

Hypothesis 1:

***In situ* turbulence could be used to estimate gas exchange velocities**

Statement 2:

If FC overestimates fluxes because of artificially created turbulence, then...

Hypothesis 2:

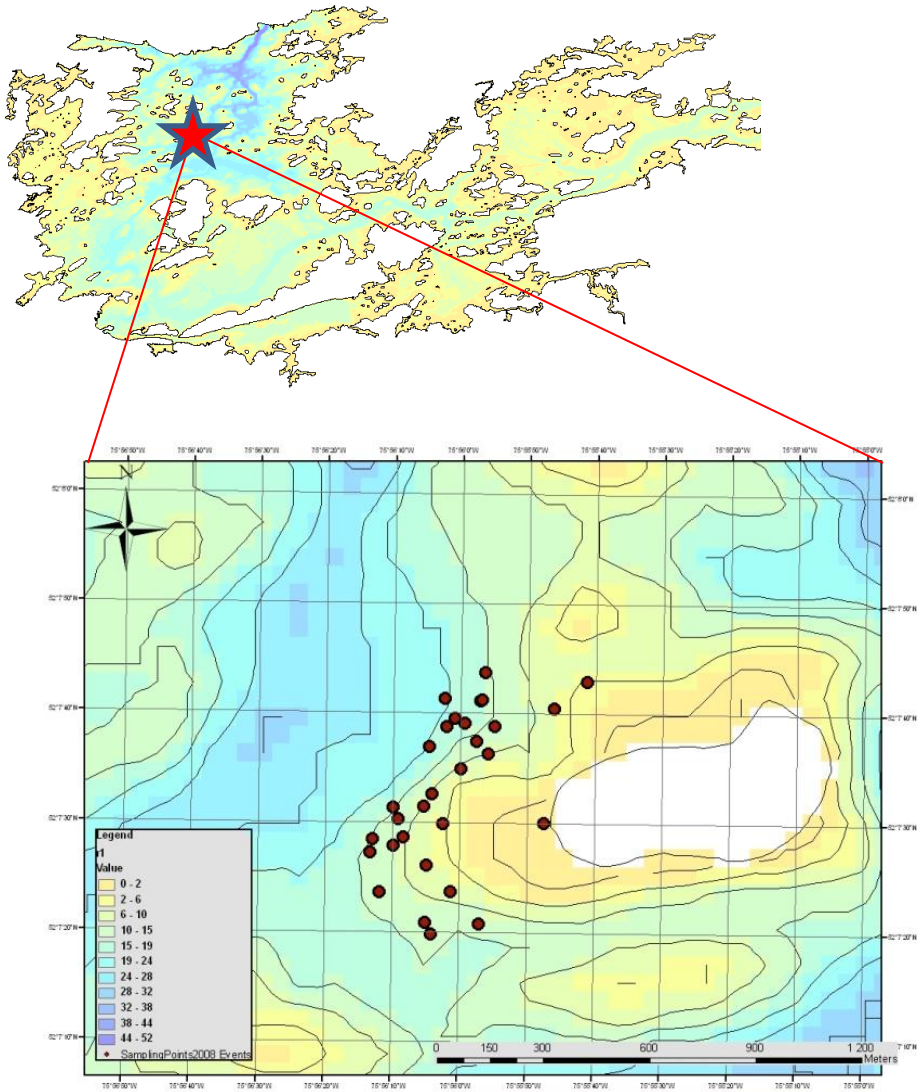
Turbulence inside the chamber should be higher than it would be without FC

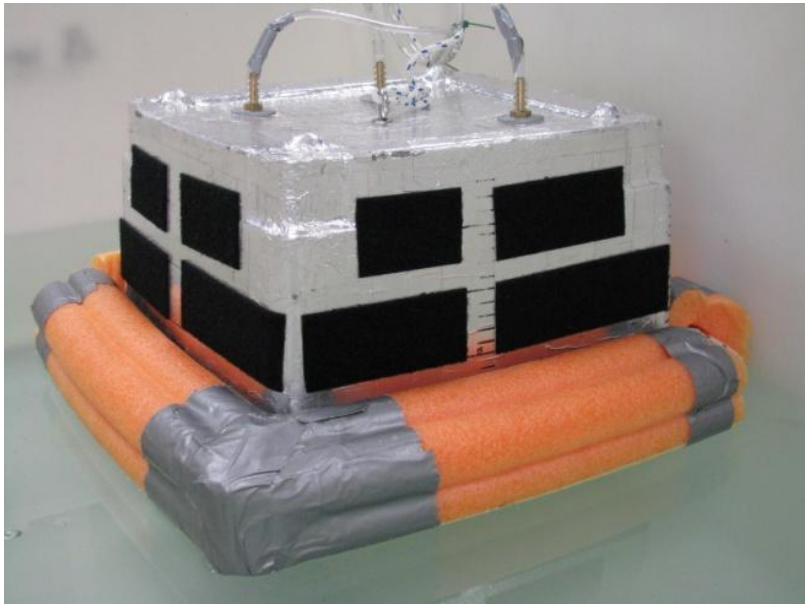
1- Eastmain reservoir

-Hydro-Quebec

2- Eastern Township lakes

-11 random lakes





Volume: 22L

Area: 0.1 m^2

Skirt length: 6 cm

$$F = k \times Kh(pCO_{2water} - pCO_{2air})$$

$$k_{CO_2} = \frac{F}{\Delta pCO_2} \rightarrow \boldsymbol{k_{600}}$$

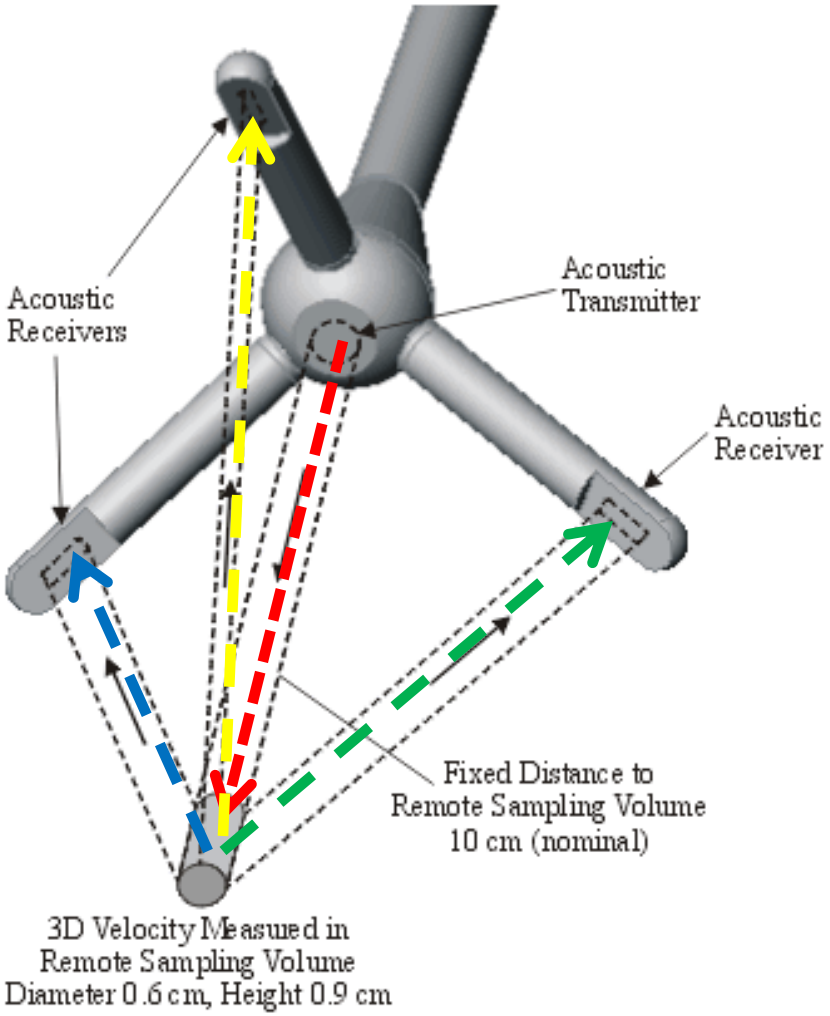
Water turbulence

ADV (*Acoustic Doppler Velocimeter*)

- 3D water velocities with high frequencies (25 Hz)

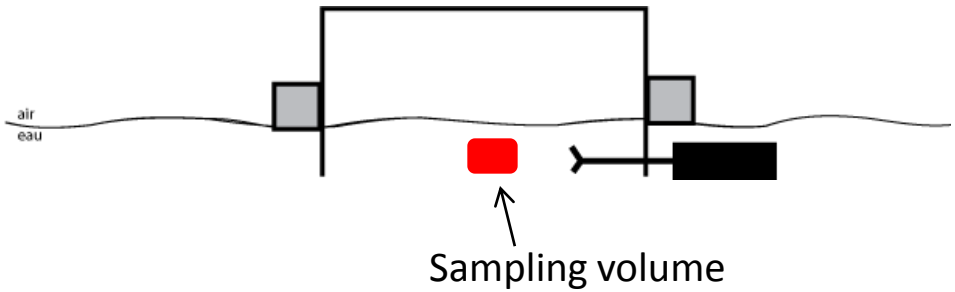
Turbulence index used

- TKE (*Turbulent kinetic energy*) dissipation rate ε

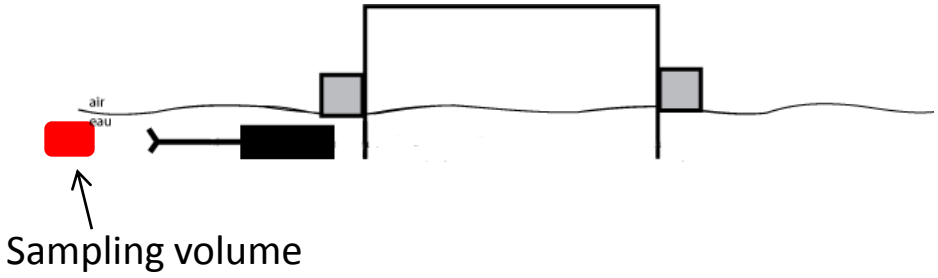


Lagrangian reference frame: moves with a fluid element

Inside the chamber (centered)



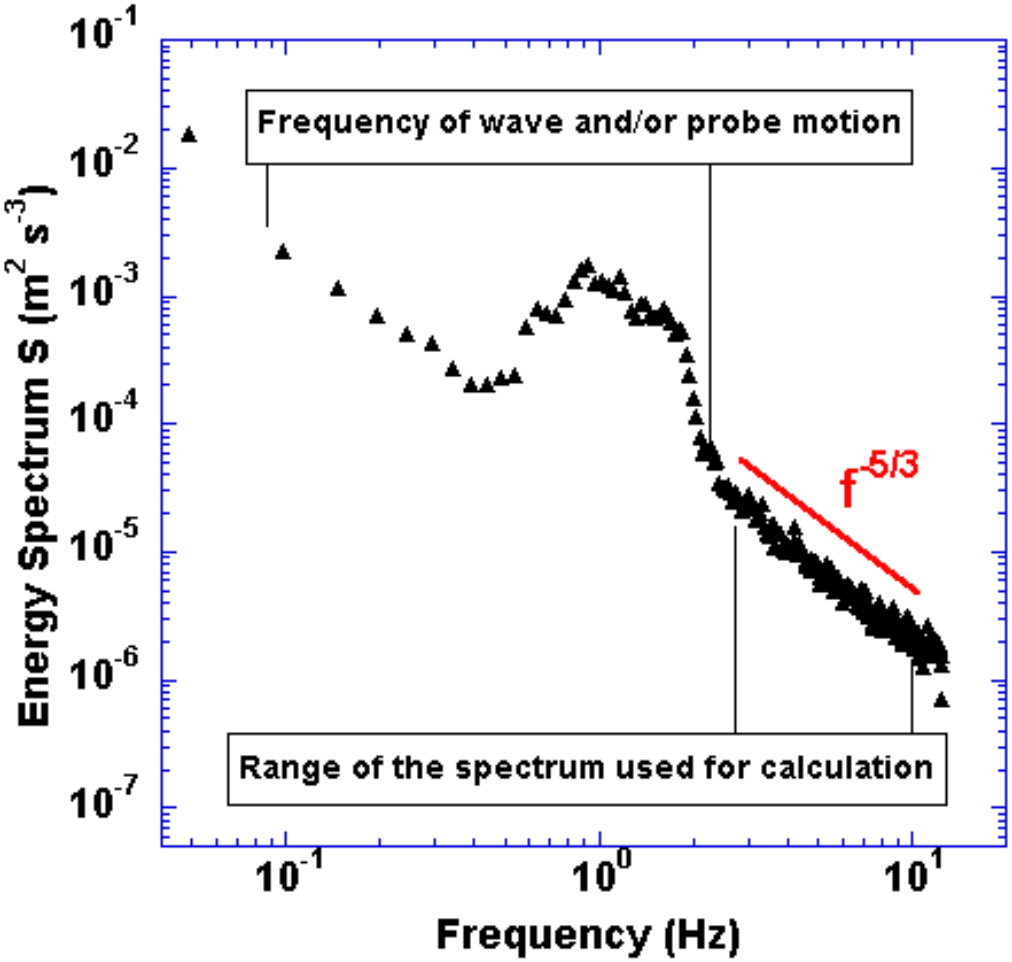
Slightly outside



Sampling depth: 10 cm

Turlulent Kinetic Energy Dissipation Rate ε

Eddy breakup and decay to smaller length scales



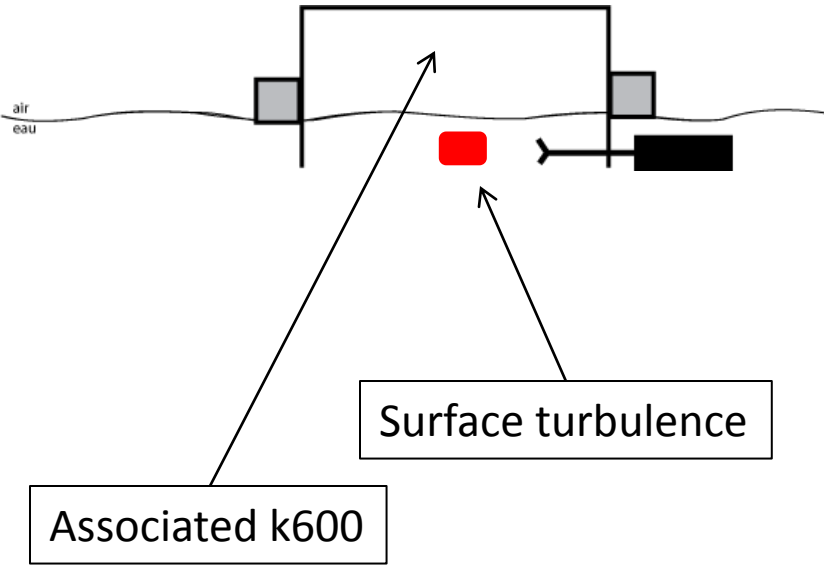
Kolmogorov's law:

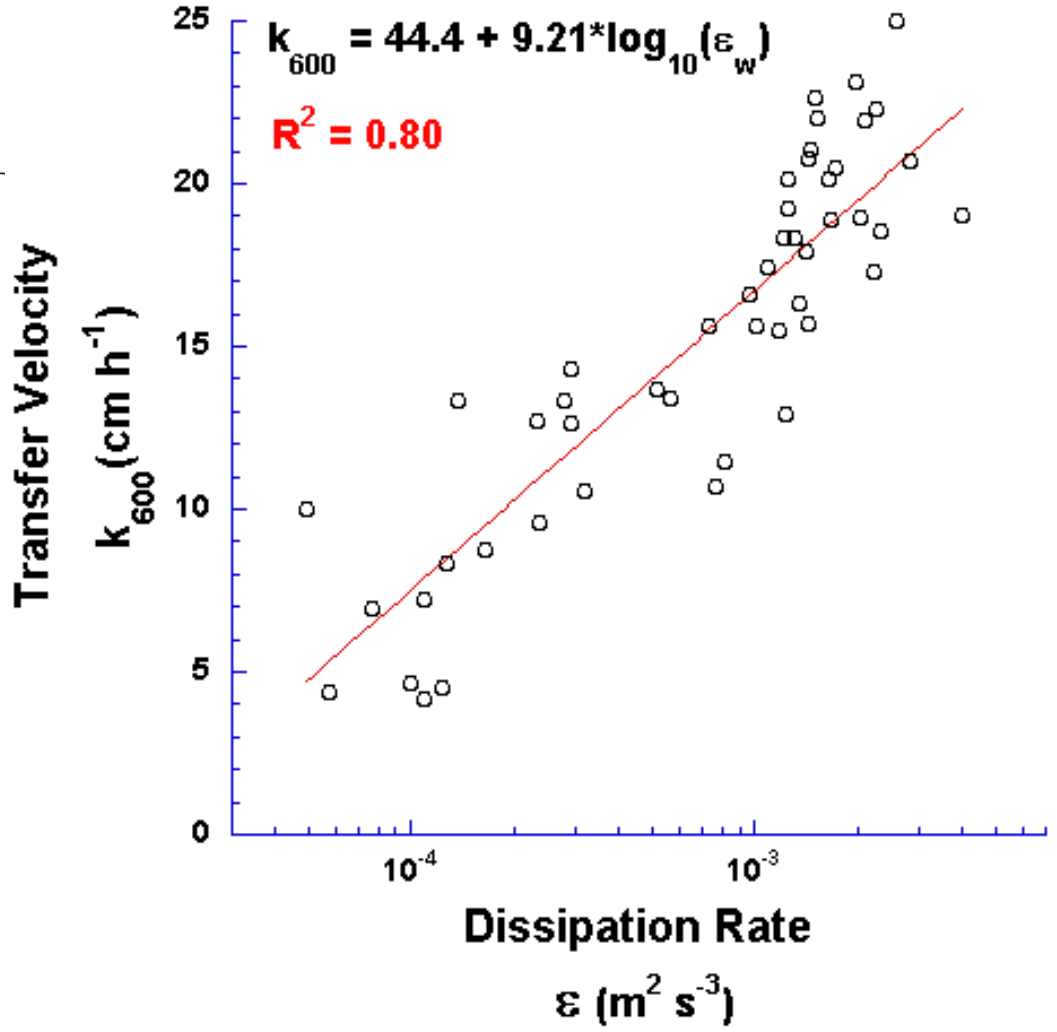
$$S = \alpha \varepsilon^{2/3} \kappa^{-5/3}$$

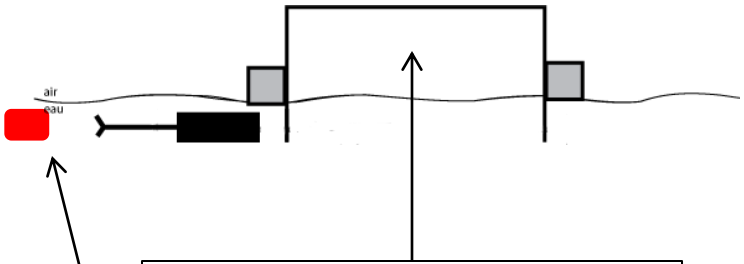
Assumptions:

Isotropic turbulence:
the statistic of the flow have no preferred direction

Building a model using relation of turbulence inside the FC



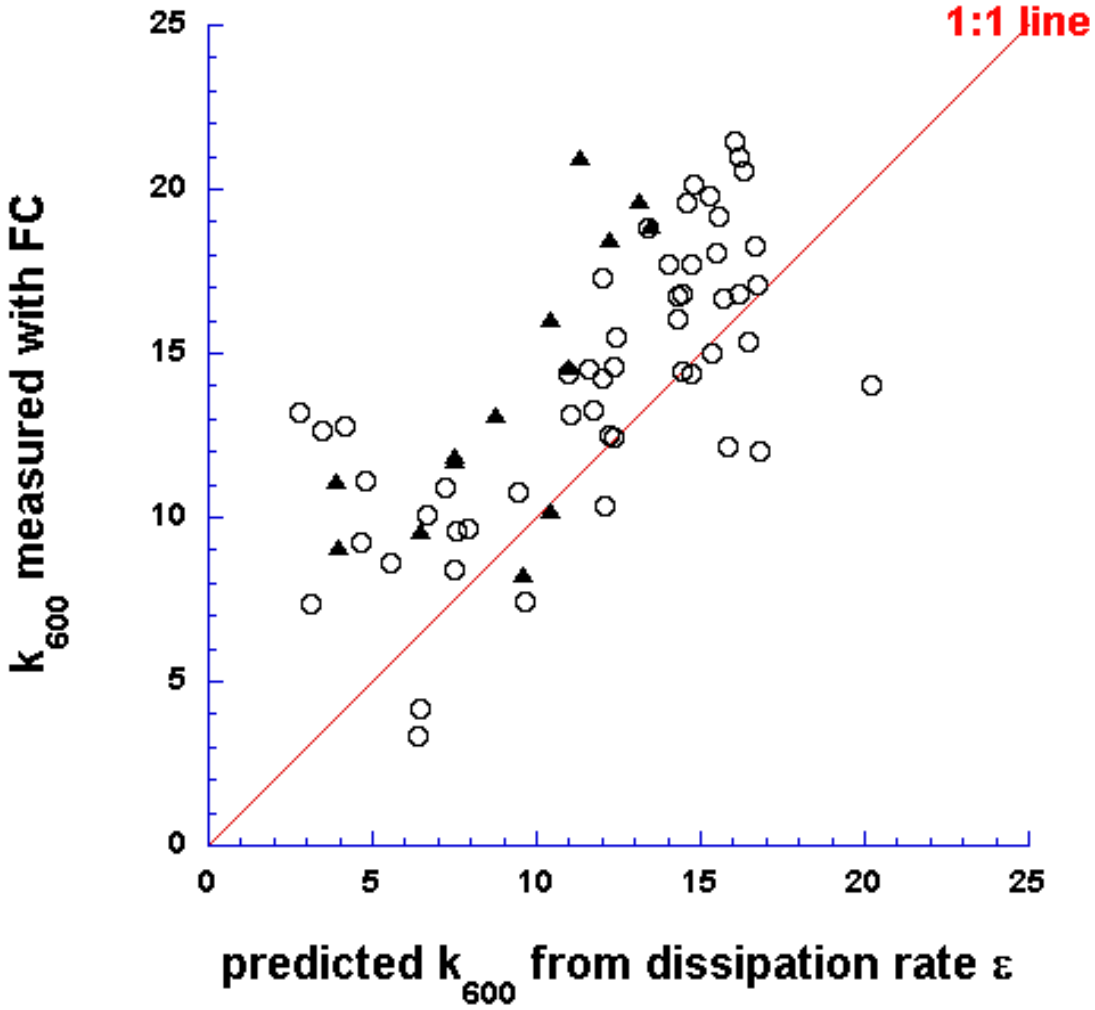




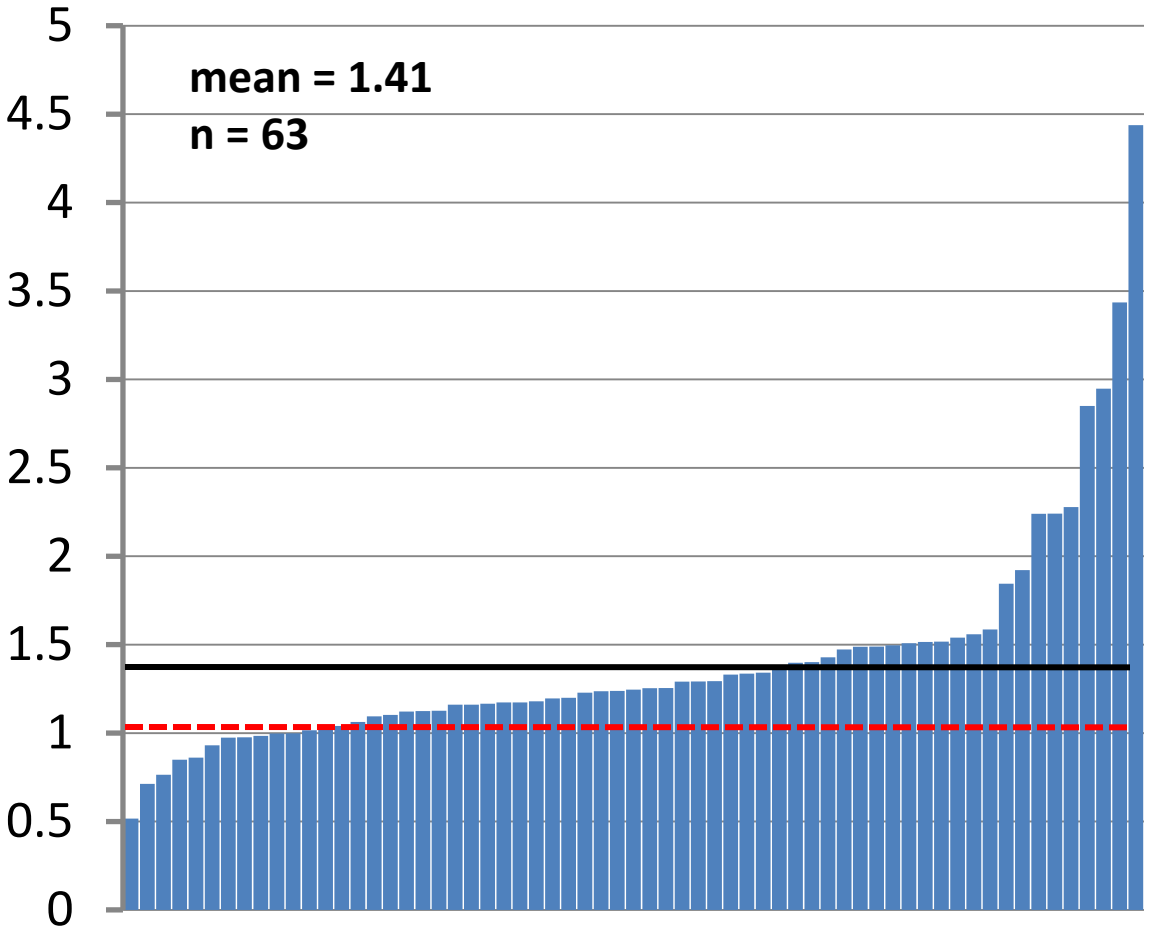
Associated measured k_{600}

Surface turbulence used to predicted ''real'' k_{600}

○ Reservoir ▲ Eastern Township lakes



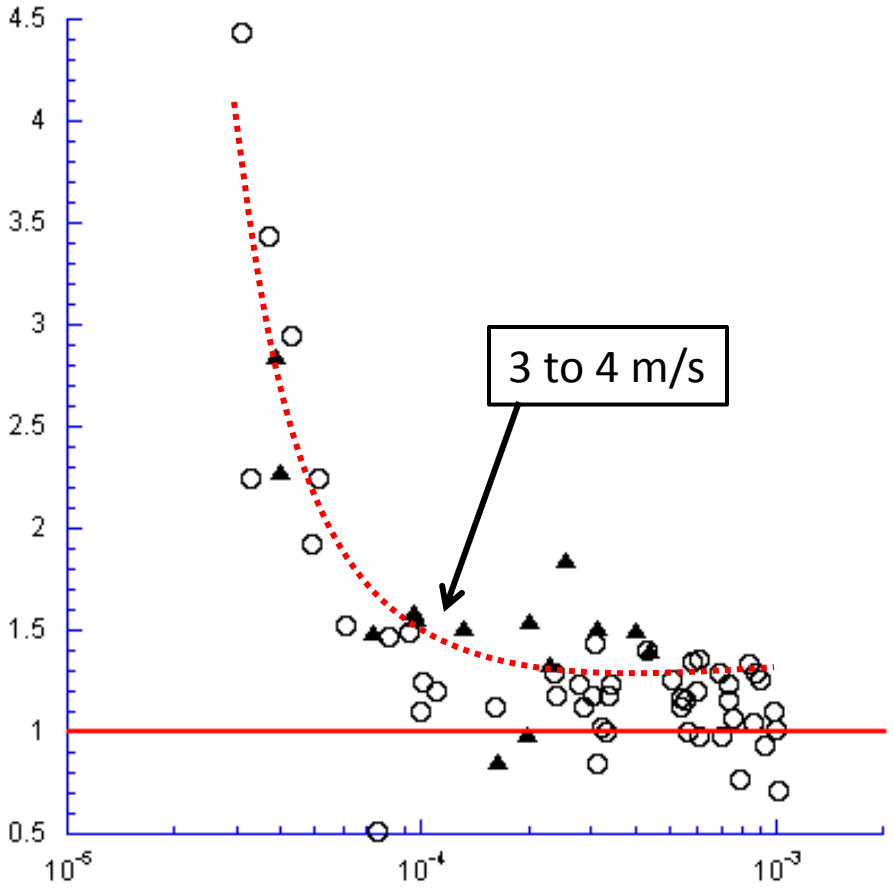
Overestimation Ratio
(measured k_{600}/
predicted k_{600} from ε)



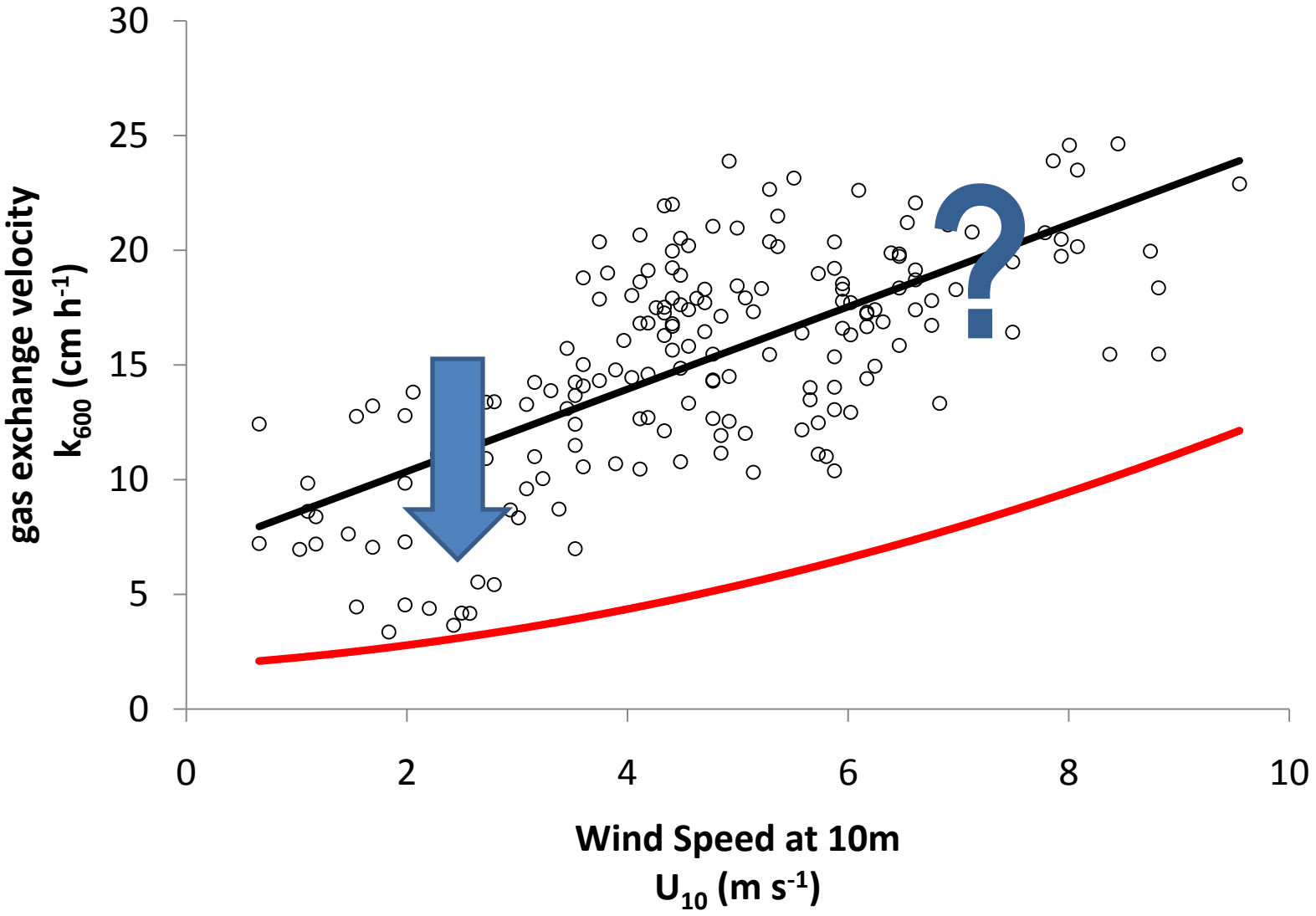
○ Reservoir ▲ Eastern Township lakes

Overestimation ratio

(K_{600} mearured by FC /predicted k600 from ε)



Dissipation rate ε (m^2 s^{-3})

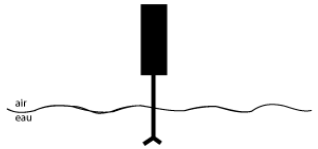

gas exchange velocity
k_{600} (cm h^{-1})
30
25
20
15
10
5
0
0
2
4
6
8
10
Wind Speed at 10m
U_{10} (m s^{-1})
?

Conclusions:

- There is a strong relation between turbulence and exchange velocity
- FC over estimate fluxes because of the artificial turbulence created by the chamber
- The overestimation (up to 4 fold) is larger at low turbulence (less than about 3 to 4 m s^{-1} wind speed)
- At higher wind speed, system size could affect gas exchanges

Applications:

- Possibilities of estimating k from turbulence without the need of any chambers
- Possibility to study other factors that affect k



SPECIAL THANKS TO:

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Geneviève Marquis et Mathieu Roy

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Thank you!

Questions and suggestions ?

GRIL UQÀM Hydro Québec

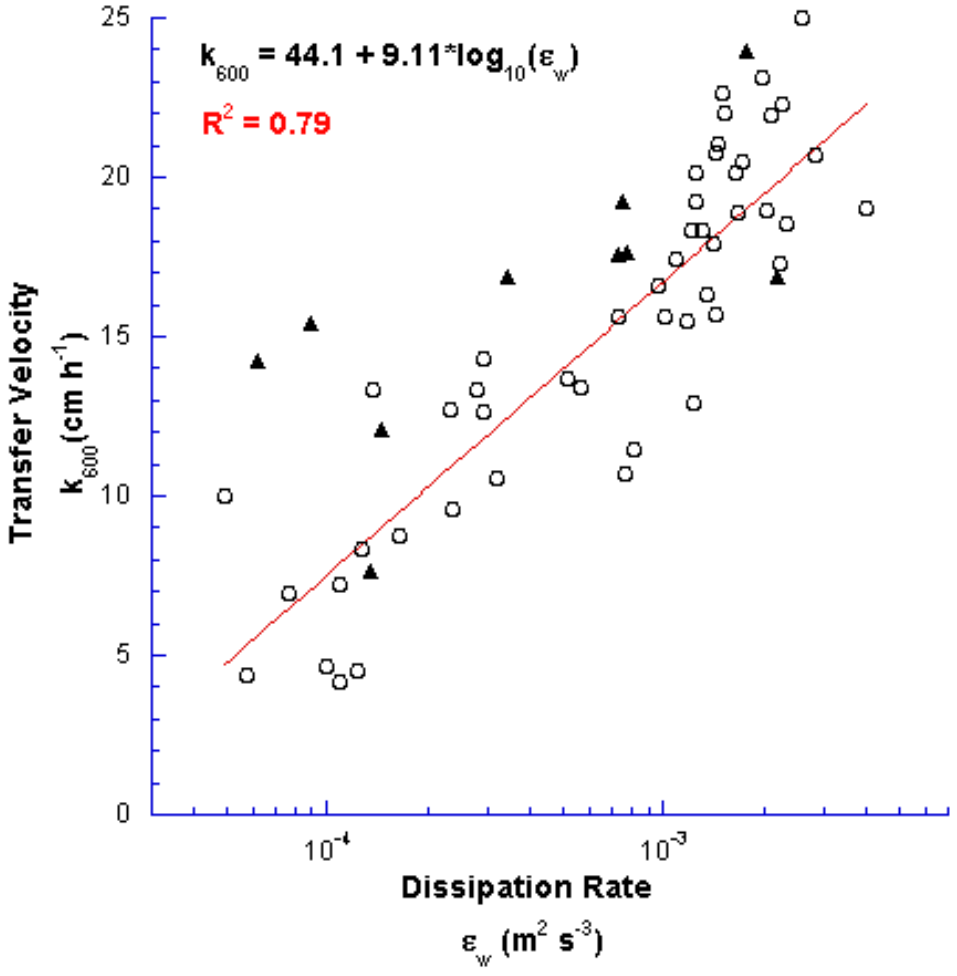
k_{600} normalized

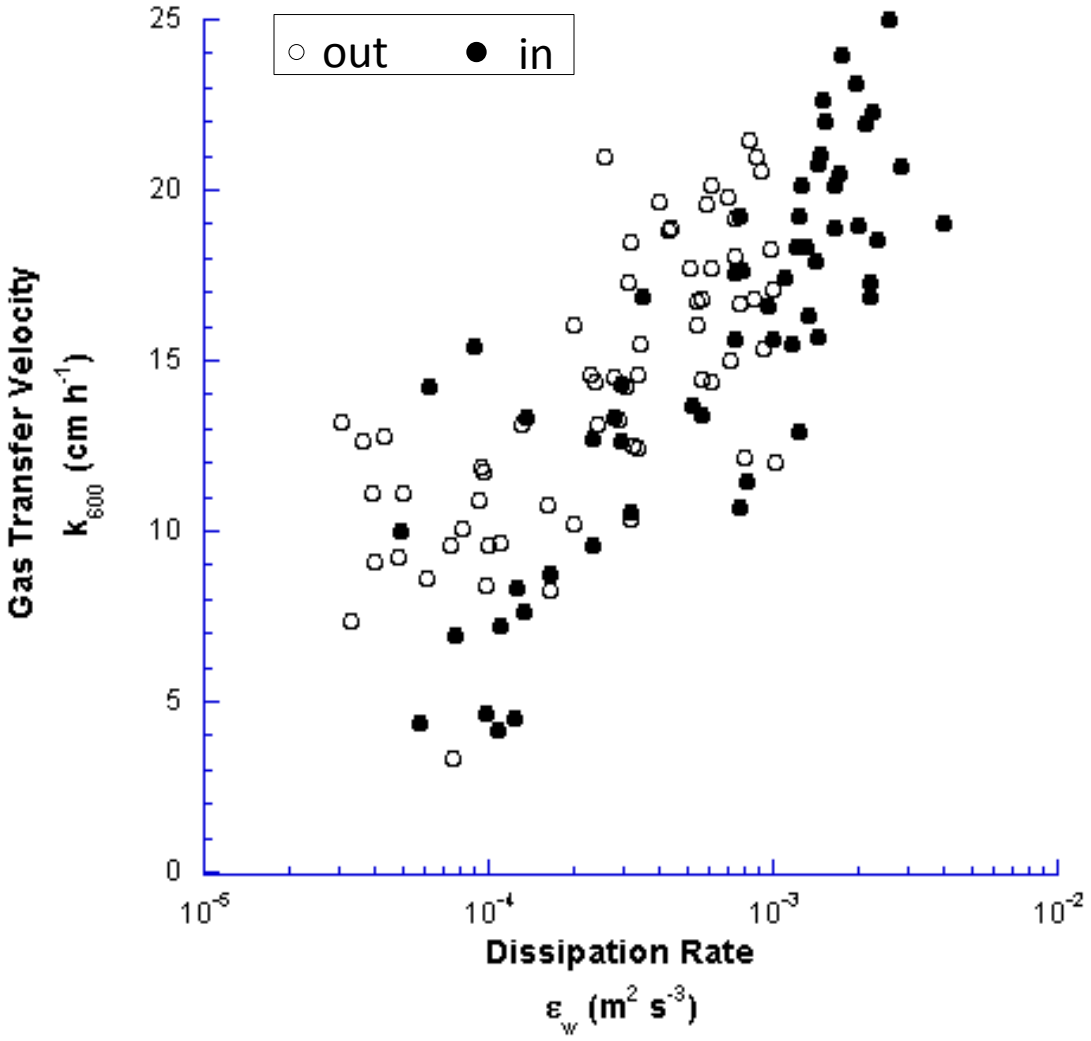
$$k_{CO_2} = k_{600} \times \left(\frac{600}{Sc_{CO_2}} \right)^{2/3 \, or \, 1/2}$$

Schmidt number:

Sc = kinematic viscosity/gas diffusion

U_{10} = Wind speed at 10m


$k_{600} = 44.1 + 9.11*\log_{10}(\varepsilon_w)$
$R^2 = 0.79$
Transfer Velocity
k_{600} (cm h^{-1})
25
20
15
10
5
0
10^{-4}
10^{-3}
Dissipation Rate
ε_w (m^2 s^{-3})

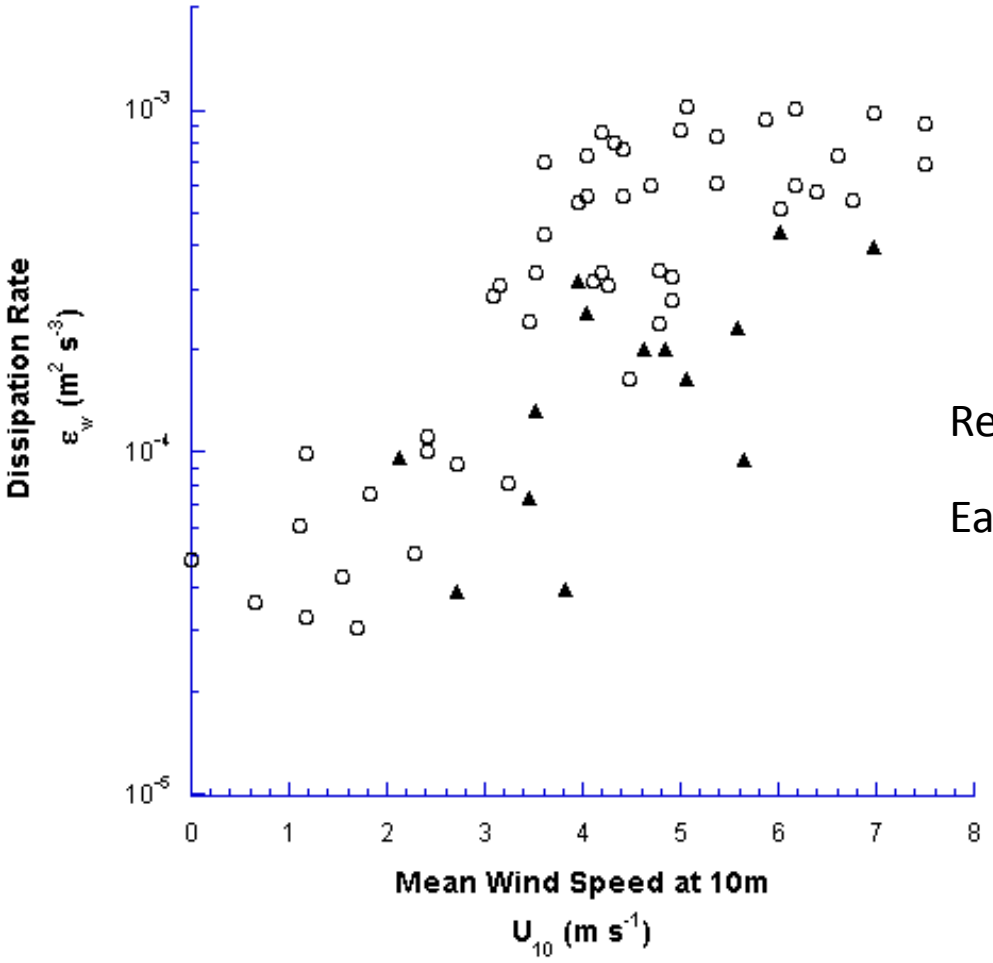


Ancova:

Slope $\rho > 0.05$

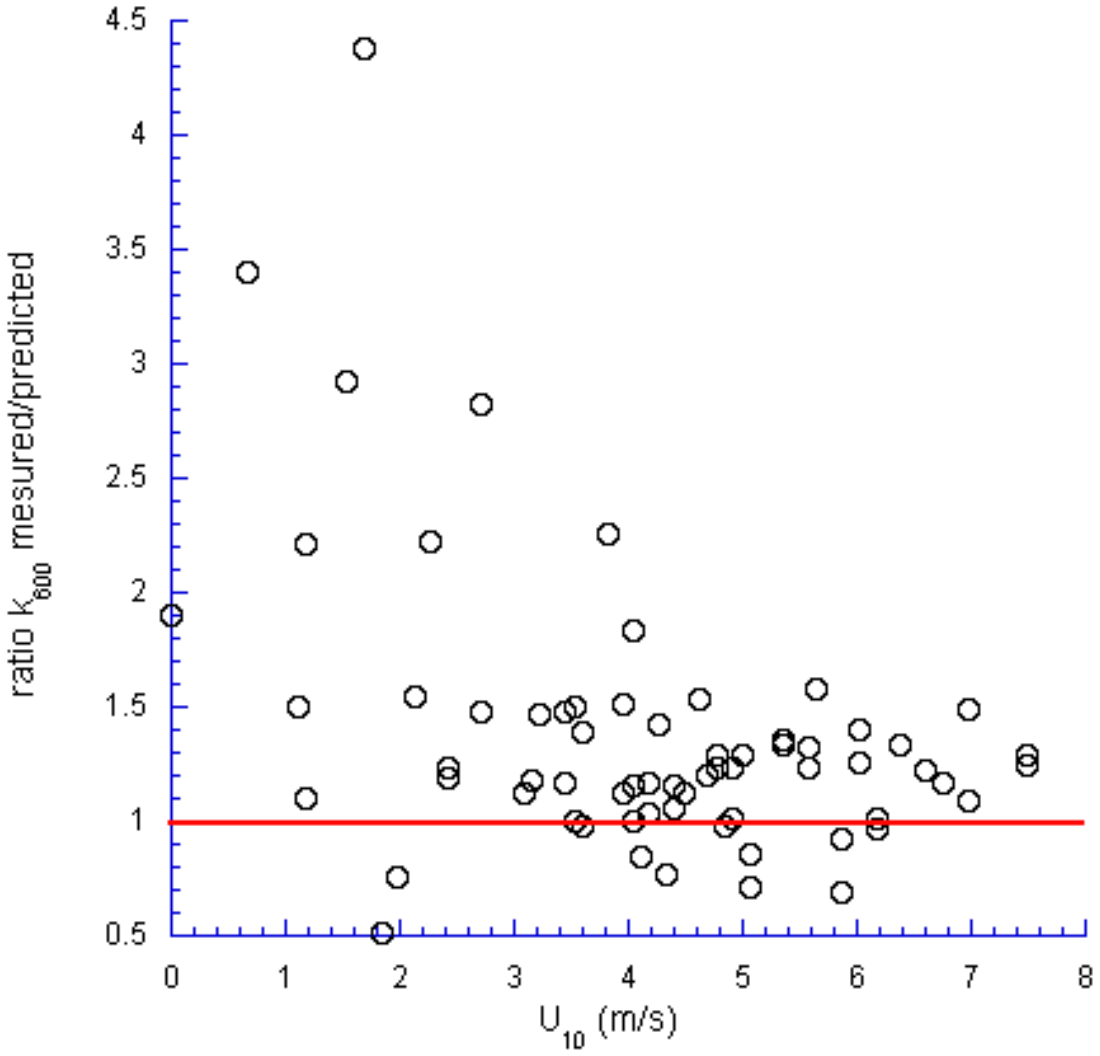
Elevation $\rho < 0.05$

○ Reservoir ▲ Eastern Township lakes



Reservoir area : 600 km^2

Eastern Township lakes mean area: 5 km^2


4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
ratio k_{600} mesured/predicted
U_{10} (m/s)