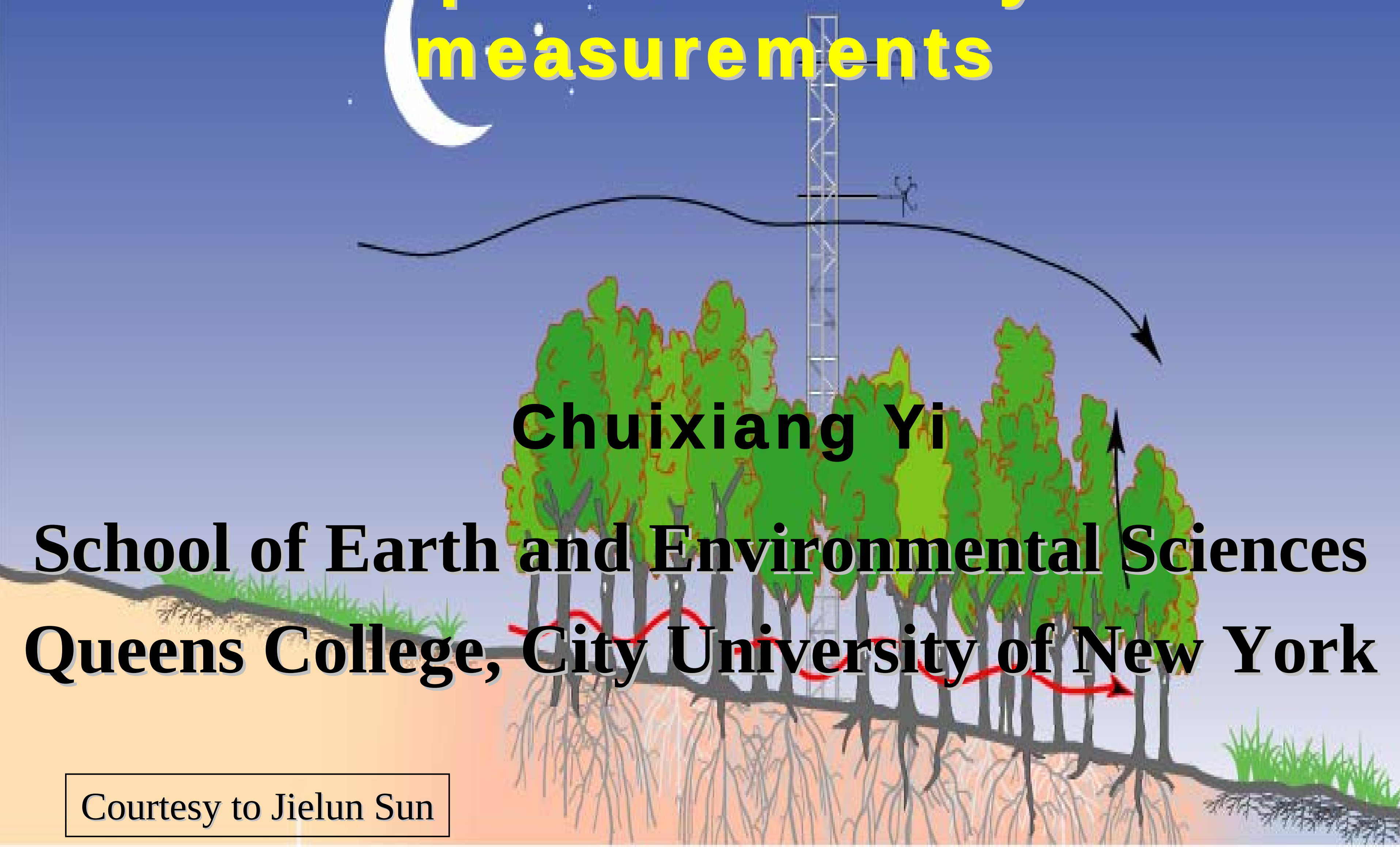
Advection issues and recent developments in eddy-flux measurements

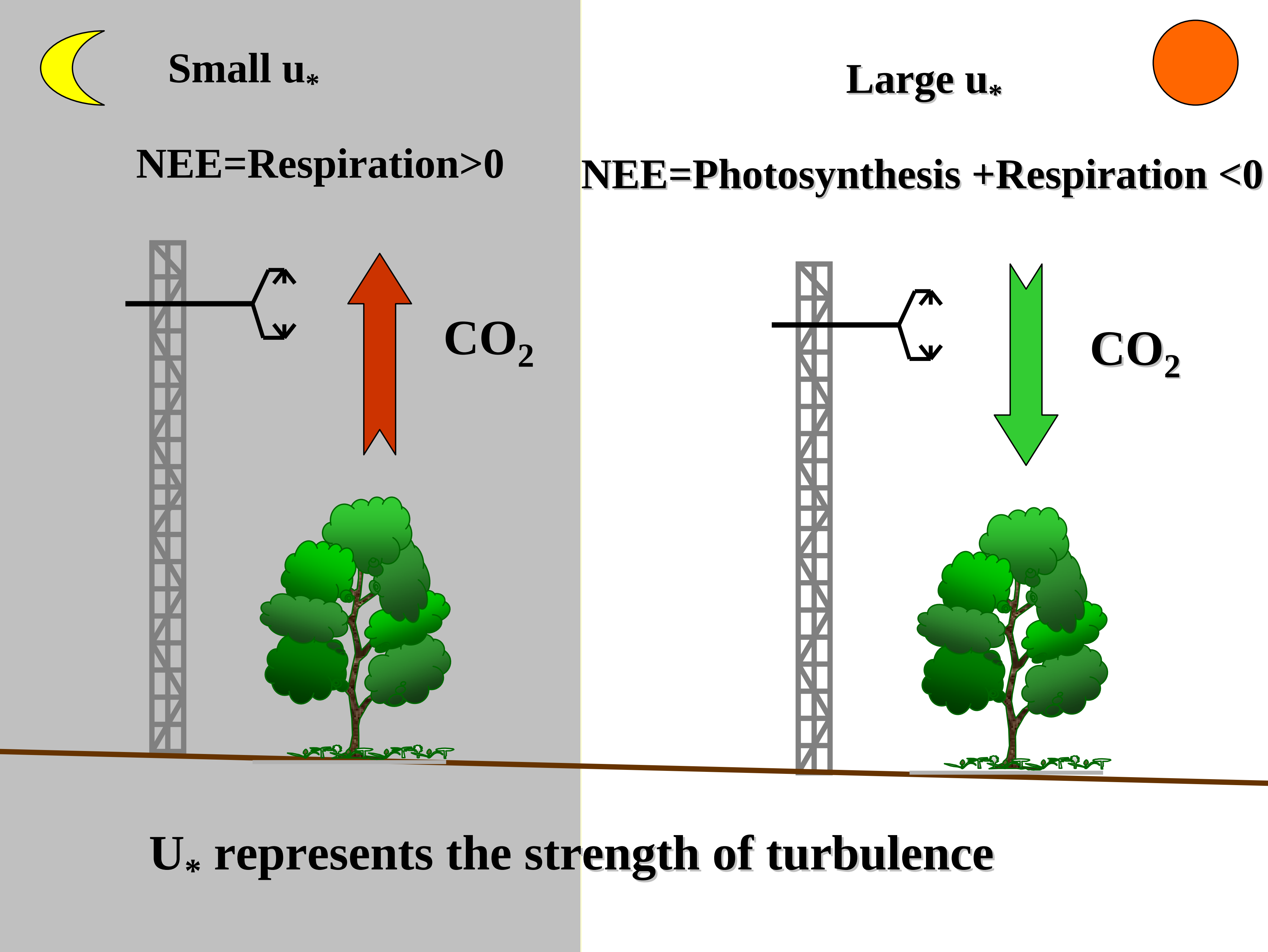


Chuixiang Yi

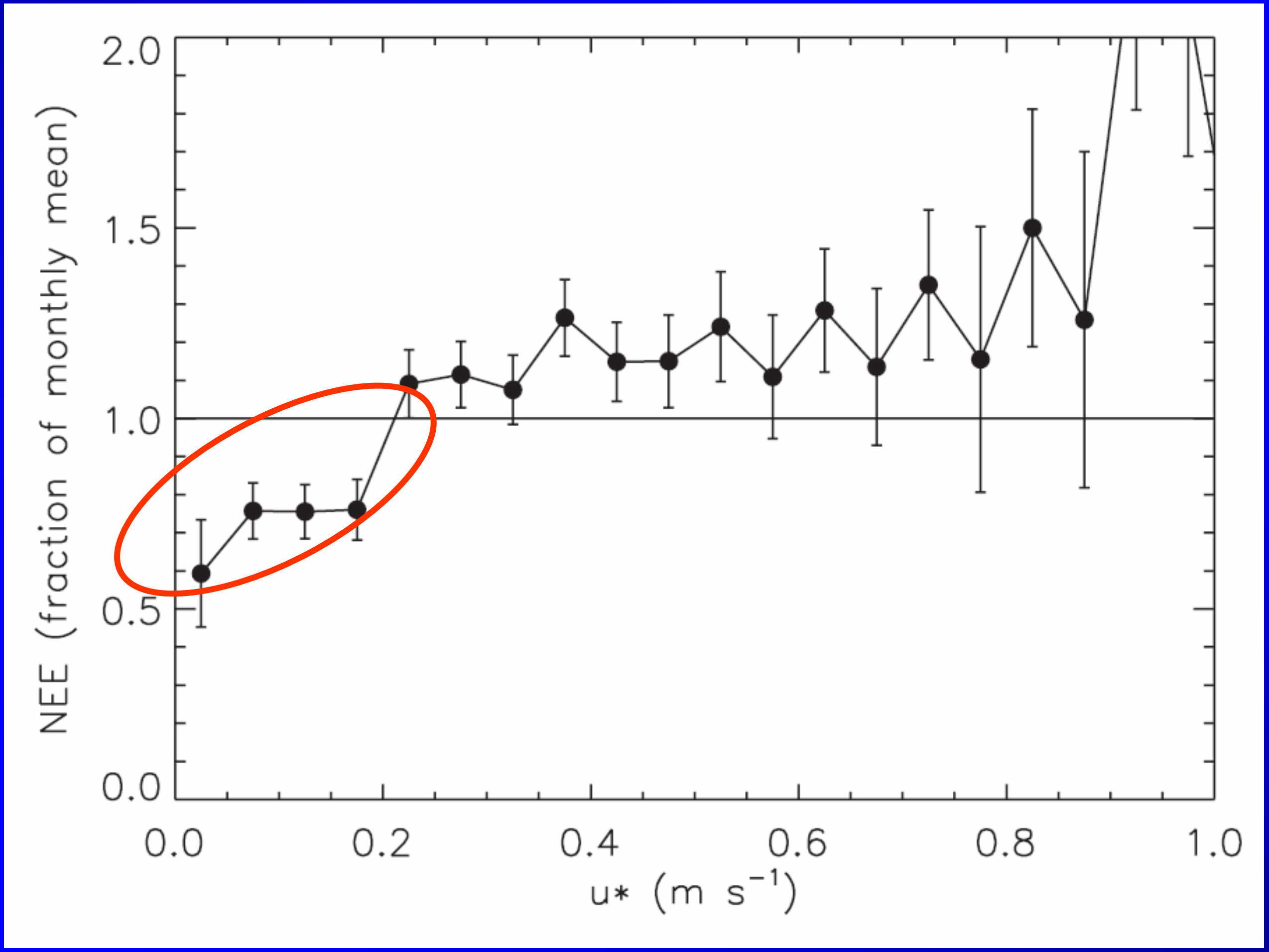
School of Earth and Environmental Sciences

Queens College, City University of New York

Courtesy to Jielun Sun

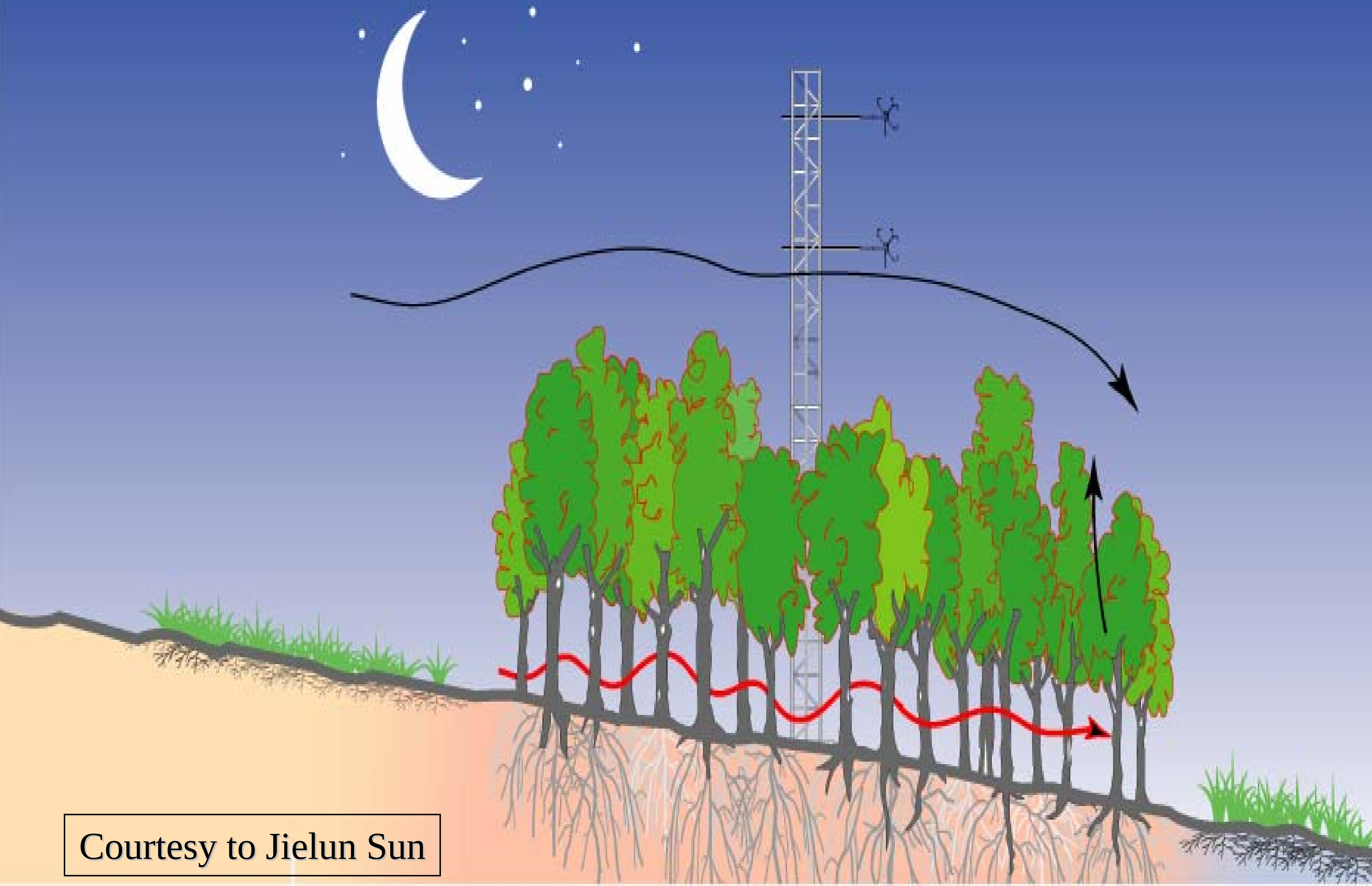

Small u*
NEE=Respiration>0
CO_2
Large u*
NEE=Photosynthesis +Respiration <0
CO_2
U* represents the strength of turbulence

Problems: Nighttime Nee is negative in calm conditions



Davis et al. 2004

Advection issues on eddy flux measurements



Courtesy to Jielun Sun

Mass conservation law

Yi et al., 2000

$$\left[\frac{\partial \bar{c}}{\partial t}+\bar{u}\frac{\partial \bar{c}}{\partial x}+\bar{w}\frac{\partial \bar{c}}{\partial z}+\frac{\partial \overline{u'c'}}{\partial x}+\frac{\partial \overline{w'c'}}{\partial z}\right]=\bar{S}_c$$

Integrate above equation from 0 to Z_r

$$\int_0^{Z_r}\left[\frac{\partial \bar{c}}{\partial t}+\bar{u}\frac{\partial \bar{c}}{\partial x}+\bar{w}\frac{\partial \bar{c}}{\partial z}\right]dz+\int_0^{Z_r}\frac{\partial \overline{w'c'}}{\partial z}dz=\int_0^{Z_r}\bar{S}_c dz$$

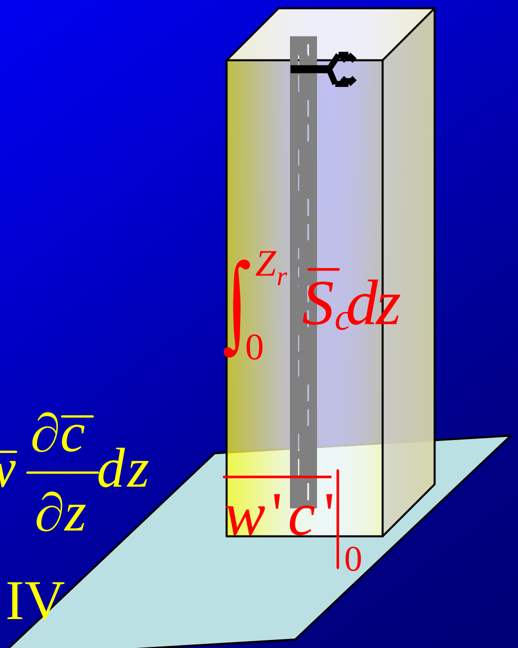
$$\int_0^{Z_r}\left[\frac{\partial \bar{c}}{\partial t}+\bar{u}\frac{\partial \bar{c}}{\partial x}+\bar{w}\frac{\partial \bar{c}}{\partial z}\right]dz+\overline{w'c'}\Big|_{Z_r}-\overline{w'c'}\Big|_0=\int_0^{Z_r}\bar{S}_c dz$$

NEE definition

$$NEE \equiv \int_0^{Z_r}\bar{S}_c dz+(\overline{w'c'})_{z=0}$$

$$=\int_0^{Z_r}\frac{\partial \bar{c}}{\partial t}dz+(\overline{w'c'})_{Z_r}+\int_0^{Z_r}\bar{u}\frac{\partial \bar{c}}{\partial x}dz+\int_0^{Z_r}\bar{w}\frac{\partial \bar{c}}{\partial z}dz$$

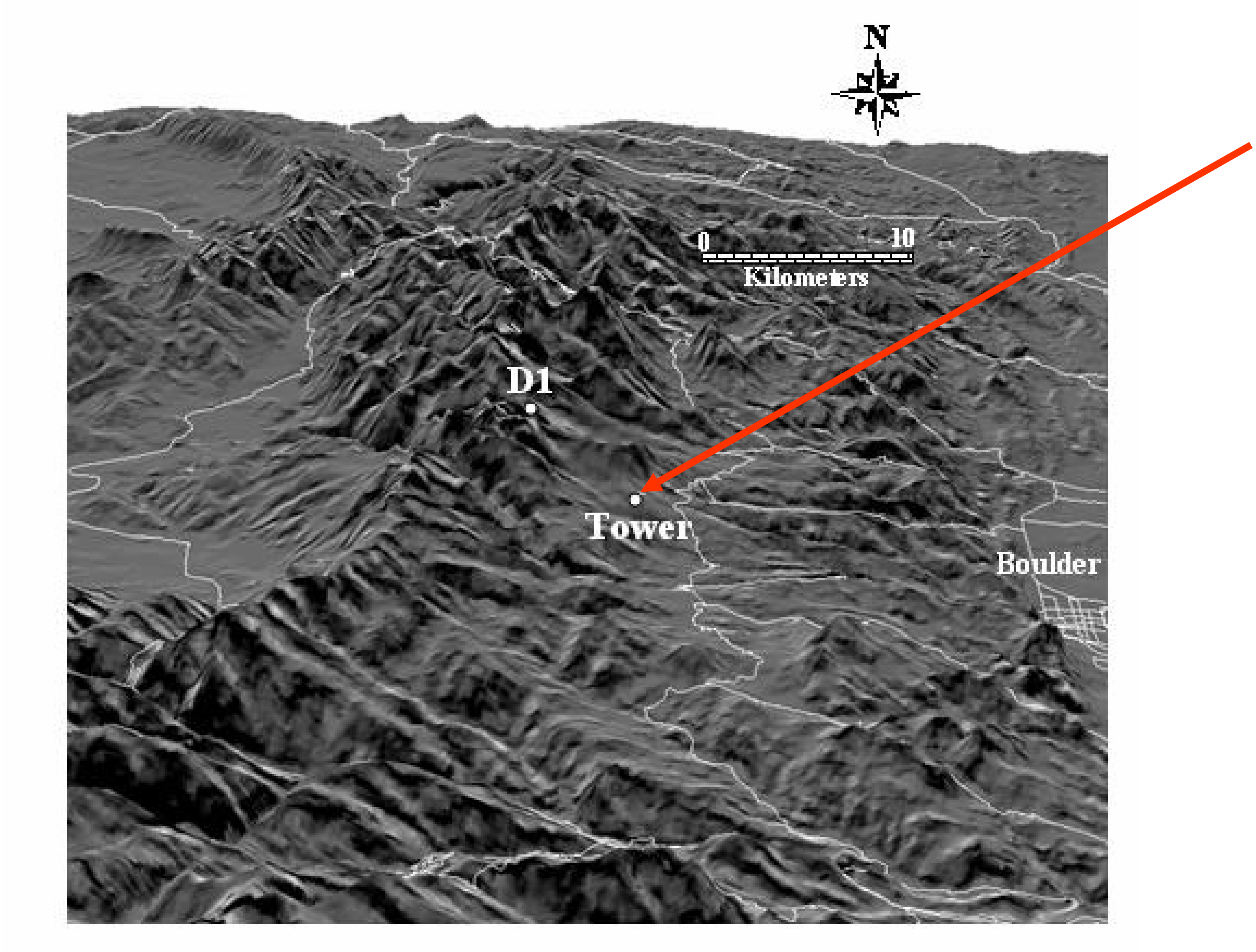
I II III IV



$$NEE = \int_0^{Zr} \frac{\partial \overline{c}}{\partial t} dz + (\overline{w'c'})_{Zr} + \int_0^{Zr} \left\{ \overline{u} \frac{\partial \overline{c}}{\partial x} + \overline{w} \frac{\partial \overline{c}}{\partial z} \right\} dz$$

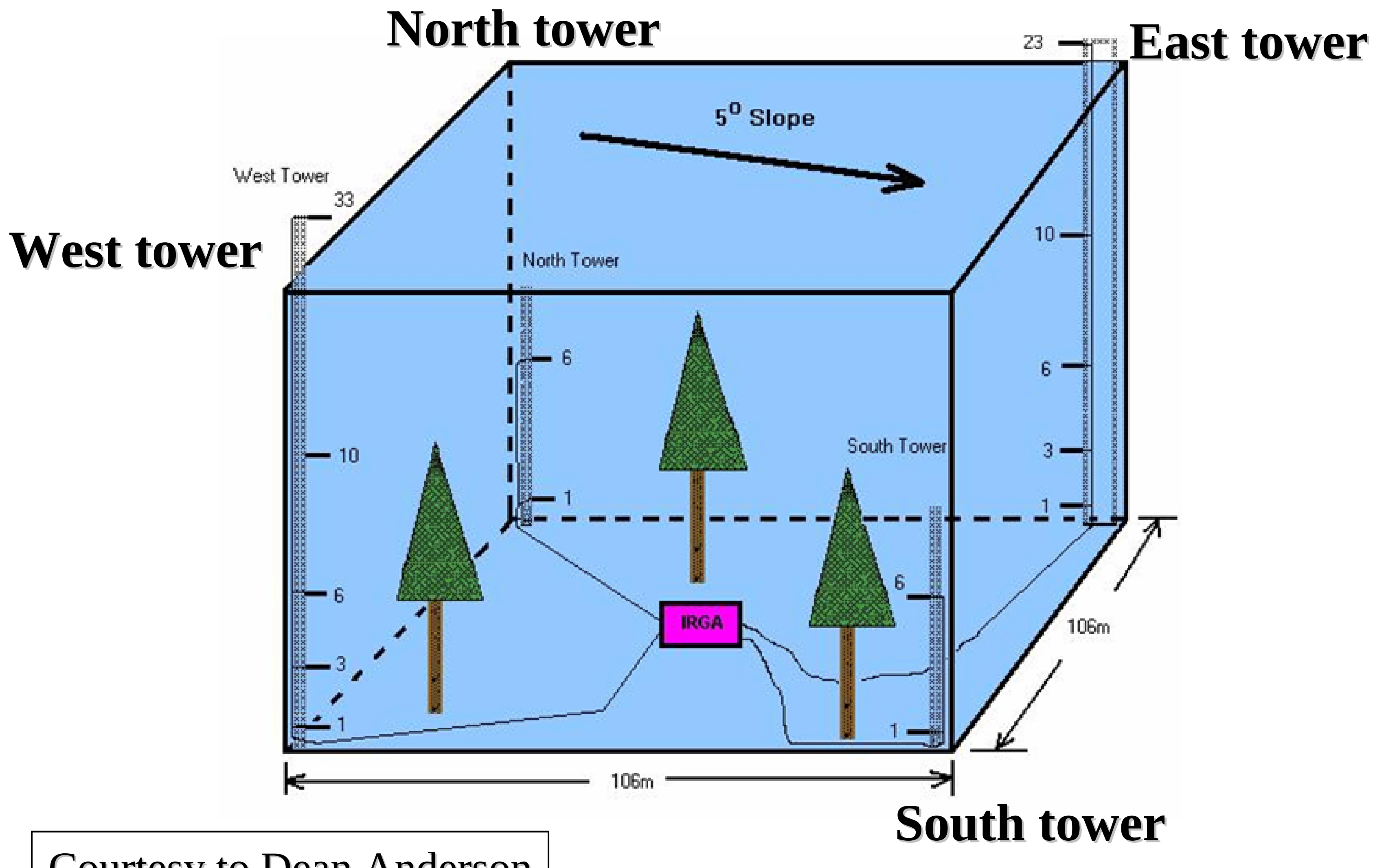
⇕	⇕
Eddy flux	Advection terms
⇕	⇕
Measured	Neglected

Examining advection issues at Ameriflux Niwot Ridge site



Niwot Ridge AmeriFlux Site

3-D measurement system



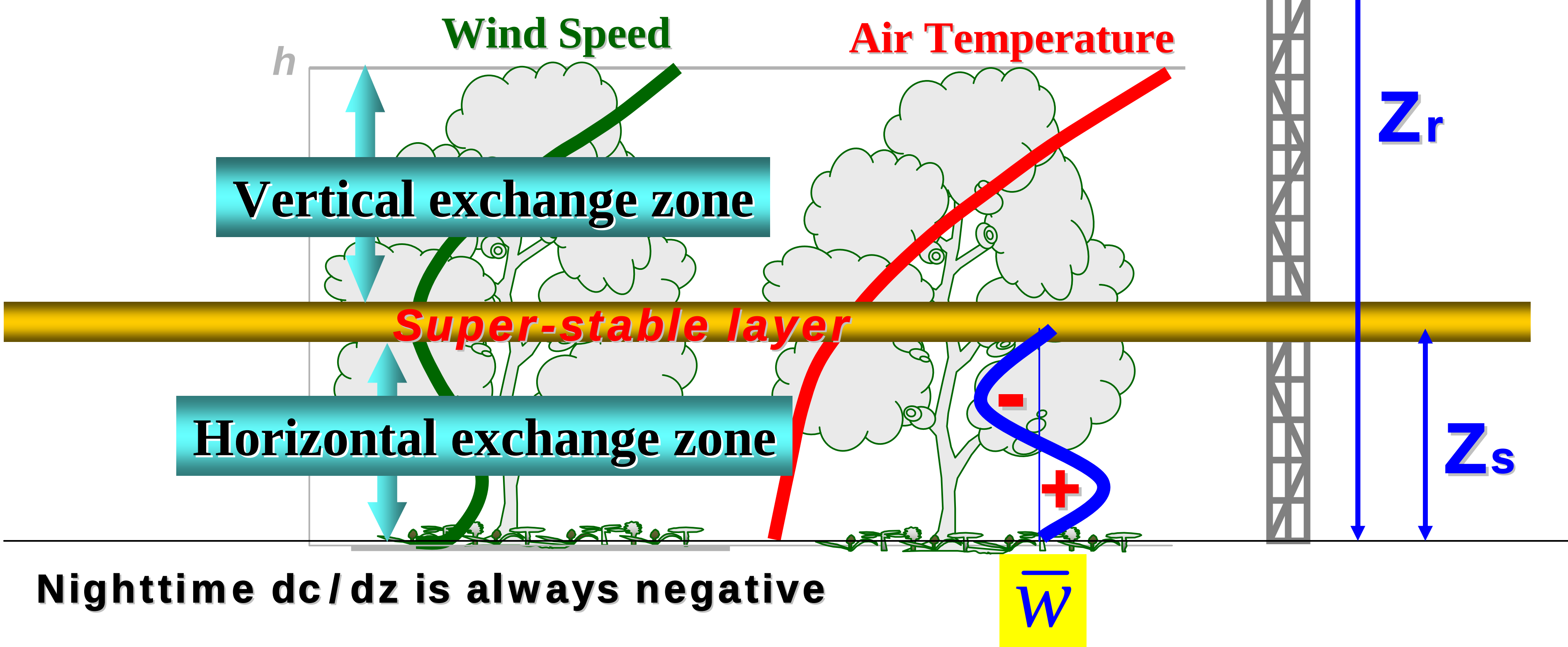
Courtesy to Dean Anderson

Vertical advection

Yi et al., 2007

$$F_{vadv} = \int_0^{Z_r} \overline{w}\frac{\partial \overline{c}}{\partial z}dz = \int_0^{Z_s} \overline{w}\frac{\partial \overline{c}}{\partial z}dz + \int_{Z_s}^{Z_r} \overline{w}\frac{\partial \overline{c}}{\partial z}dz$$

0



Nighttime dc/dz is always negative

Vertical advection

Yi et al., 2007

$$F_{vadv} = \int_{Z_s}^{Z_r} \overline{w}\frac{\partial \overline{c}}{\partial z}dz = \int_{Z_s}^{Z_r} \frac{\partial \overline{w}\,\overline{c}}{\partial z}dz - \int_{Z_s}^{Z_r} \overline{c}\frac{\partial \overline{w}}{\partial z}dz$$

$$F_{vadv} = \overline{w}_{Z_r}\overline{c}_{Z_r} - \overline{w}_{Z_s}\overline{c}_{Z_s} - \frac{\overline{w}_{Z_r} - \overline{w}_{Z_s}}{Z_r - Z_s}\int_{Z_s}^{Z_r}\overline{c}dz$$

Lee's assumption

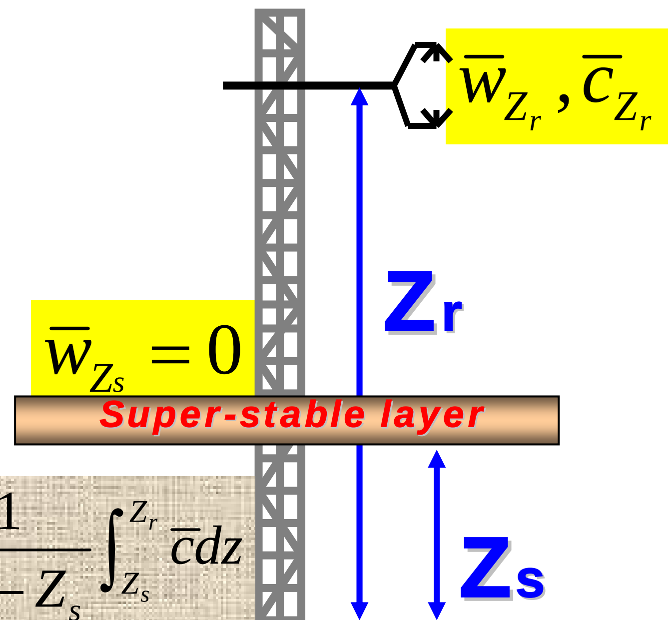
$$\frac{\partial \overline{w}}{\partial z} = \frac{\overline{w}_{Z_r} - \overline{w}_{Z_s}}{Z_r - Z_s}$$

$\overline{w}_{Z_s} = 0$ at super-stable layer

$$F_{vadv} = \overline{w}_{Z_r}\overline{c}_{Z_r} - \frac{\overline{w}_{Z_r}}{Z_r - Z_s}\int_{Z_s}^{Z_r}\overline{c}dz$$

$$= \overline{w}_{Z_r}\overline{c}_{Z_r} - \overline{w}_{Z_r}\langle\overline{c}\rangle$$

$$= \overline{w}_{Z_r}(\overline{c}_{Z_r} - \langle\overline{c}\rangle)$$



$$\langle\overline{c}\rangle = \frac{1}{Z_r - Z_s}\int_{Z_s}^{Z_r}\overline{c}dz$$

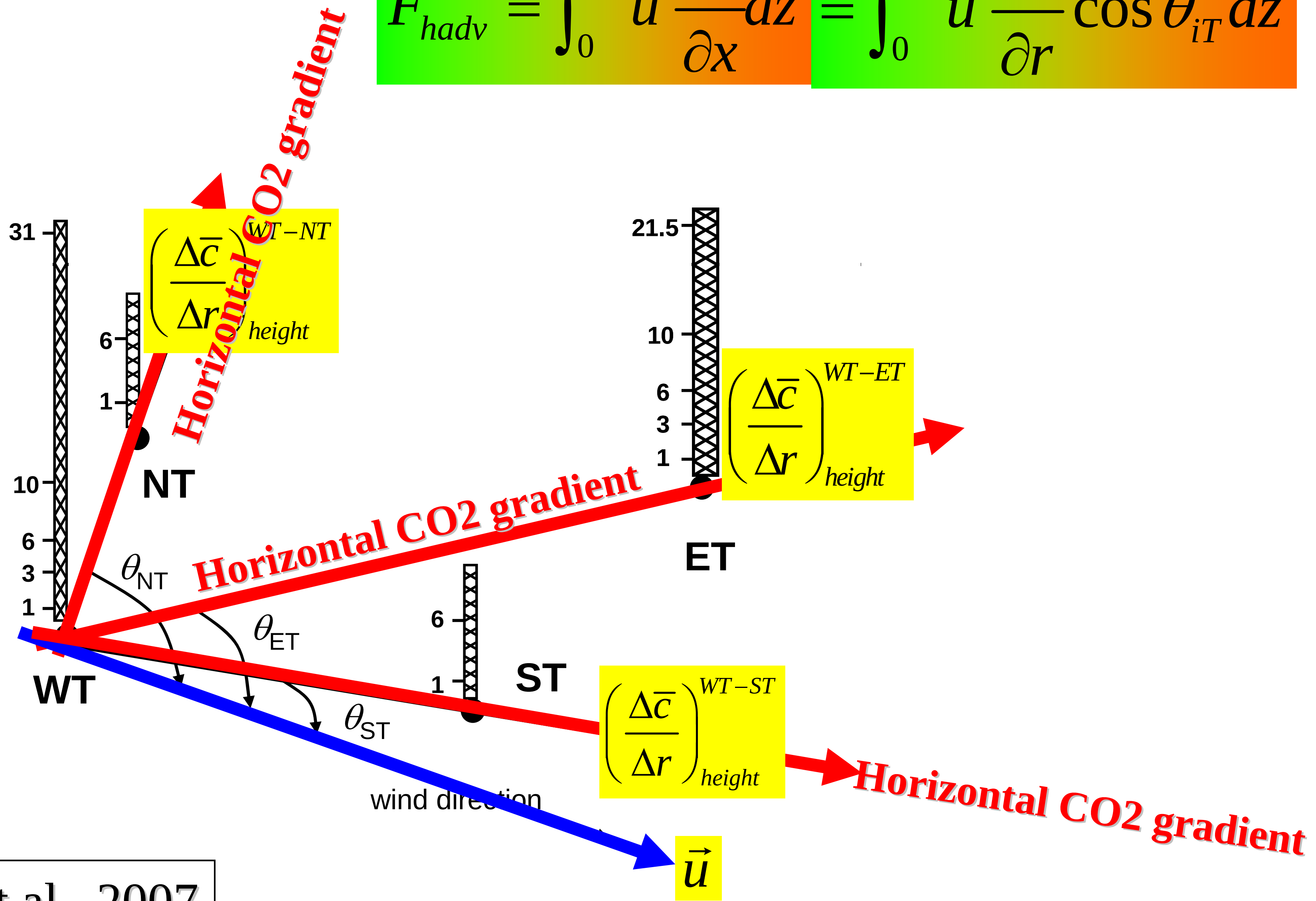
$\overline{w}$ Algorithm

Wilczak, J.M., Oncley, S.P., and Stage, S.A. 2001. Sonic anemometer tilt correction algorithm. Boundary-Layer Meteorology 99: 127-150.

Turnipseed, A.A., Anderson, D.E., Burns, S., Blanken, P.D., and Monson, R.K. 2004. Airflows and turbulent flux measurements in mountainous terrain. Part 2. Mesoscale effects. Agricultural and Forest Meteorology 125: 187-205.

Horizontal advection calculation

$$F_{hadv} = \int_0^{Z_r} \bar{u} \frac{\partial \bar{c}}{\partial x} dz = \int_0^{Z_r} \bar{u} \frac{\partial \bar{c}}{\partial r} \cos\theta_{iT} dz$$



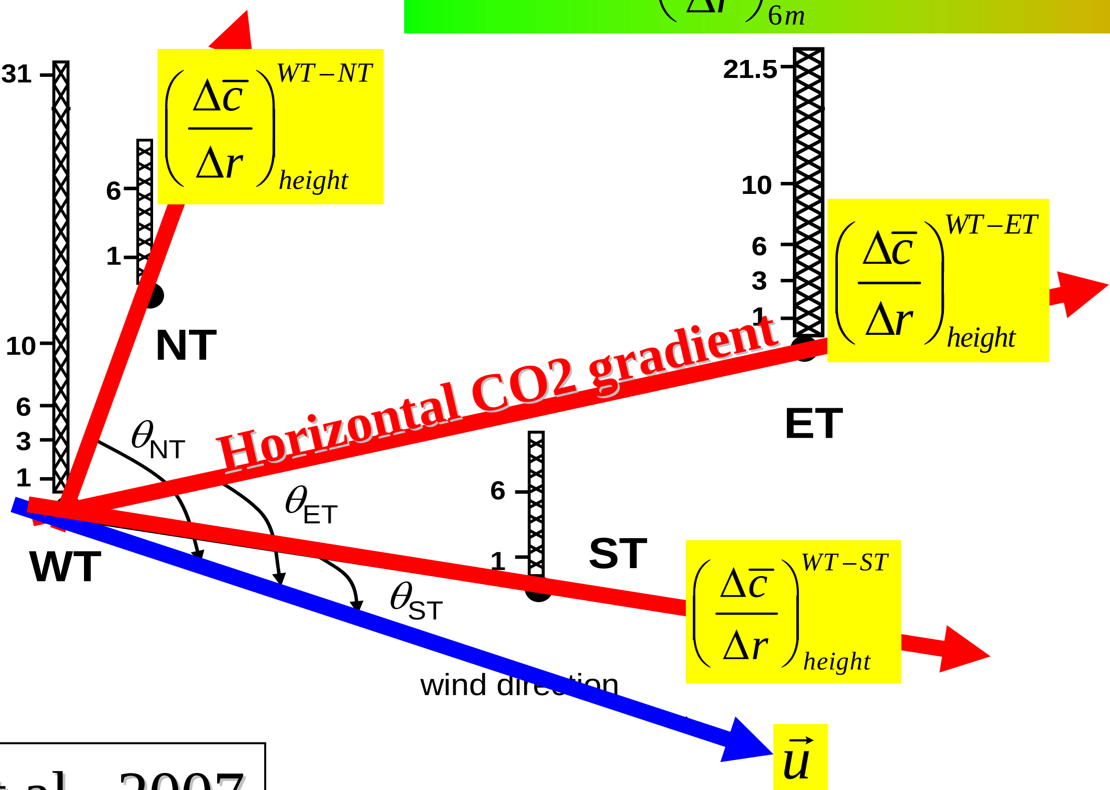
Yi et al., 2007

Horizontal advection calculation

$$F_{hadv} \approx \int_0^{12} \bar{u} \left. \frac{\partial \bar{c}}{\partial r} \right|_{\mathrm{iT}} \cos\theta_{\mathrm{iT}} \, dz$$

$$\approx \bar{u}_{1m} \left(\frac{\Delta c}{\Delta r} \right)_{1m}^{WT-iT} \cos\theta_{iT} * 2 + \bar{u}_{3m} \left(\frac{\Delta c}{\Delta r} \right)_{3m}^{WT-ET} \cos\theta_{ET} * 2$$

$$+ \bar{u}_{6m} \left(\frac{\Delta c}{\Delta r} \right)_{6m}^{WT-iT} \cos\theta_{iT} * 4 + \bar{u}_{10m} \left(\frac{\Delta c}{\Delta r} \right)_{10m}^{WT-ET} \cos\theta_{ET} * 4,$$



The CO_2 gradient that is closer to wind direction is first choice to use. For example, the angle can be limited by $|\cos\ \theta| \geq 0.8$

Yi et al., 2007

Another horizontal advection calculation

Projection of CO2 gradient into wind direction

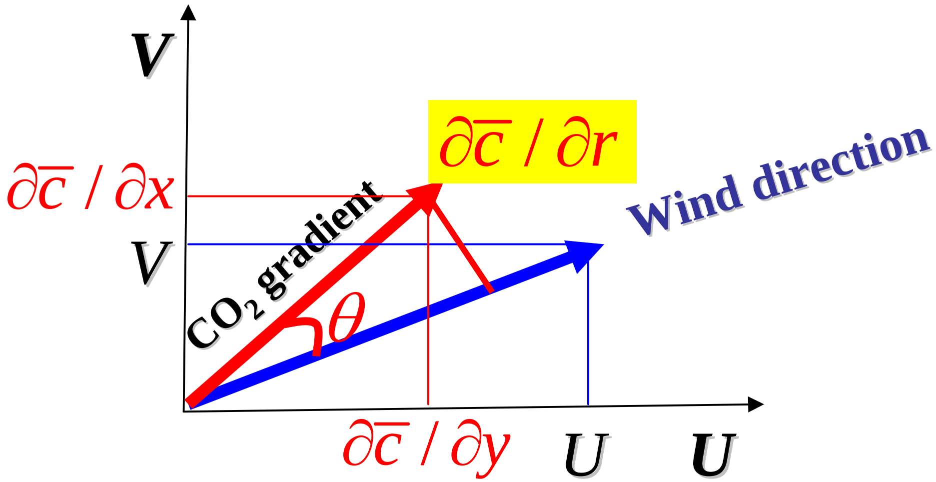
$$\mathbf{U}\cdot\nabla\overline{c} = \overline{u}\,\frac{\partial\overline{c}}{\partial r}\bigg|_{iT}\cos(\theta_{iT})$$

dc/dr is CO2 gradient along a pair towers

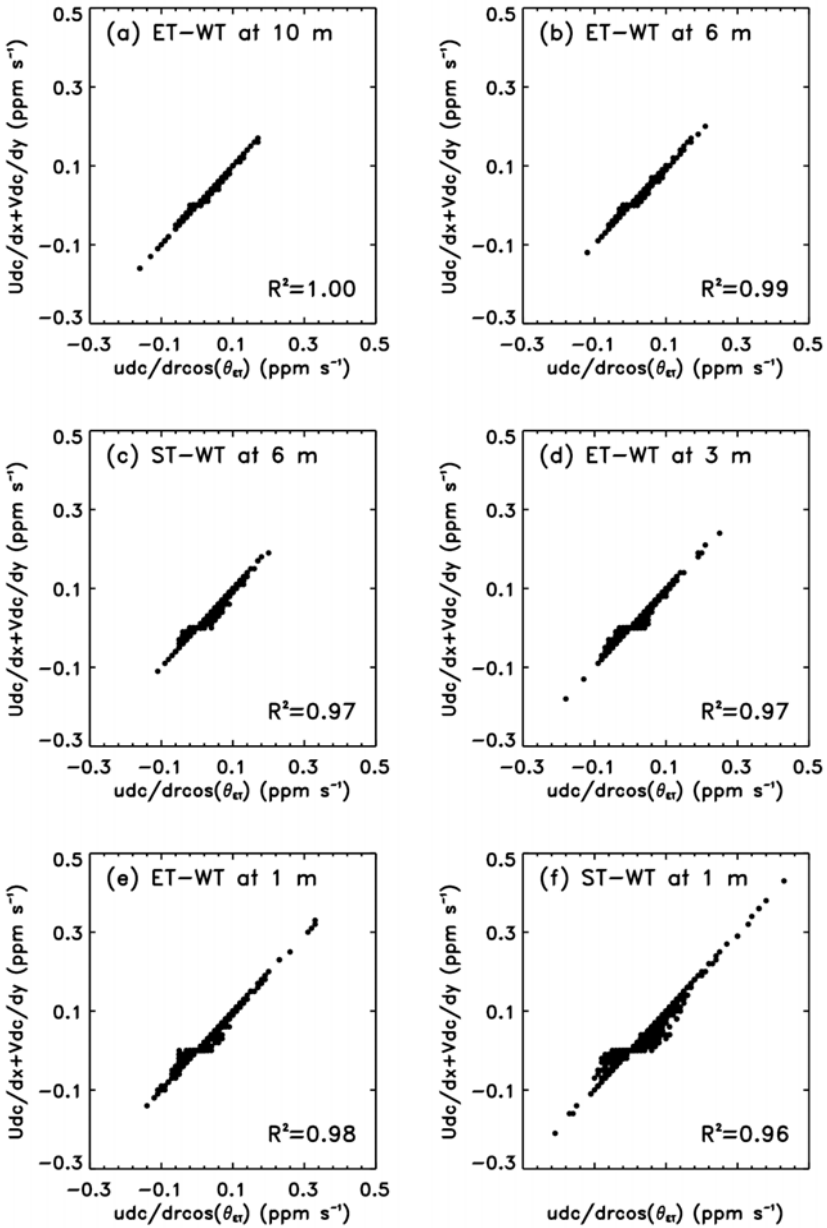
Projection of CO2 gradient into x and y directions

$$\mathbf{U}\cdot\nabla\overline{c} = (U\vec{i} + V\vec{j})\cdot(\frac{\partial\overline{c}}{\partial x}\vec{i} + \frac{\partial\overline{c}}{\partial y}\vec{j}) = U\frac{\partial\overline{c}}{\partial x} + V\frac{\partial\overline{c}}{\partial y}$$

x-y coordinate system is fixed on an instrument



Yi et al., 2007



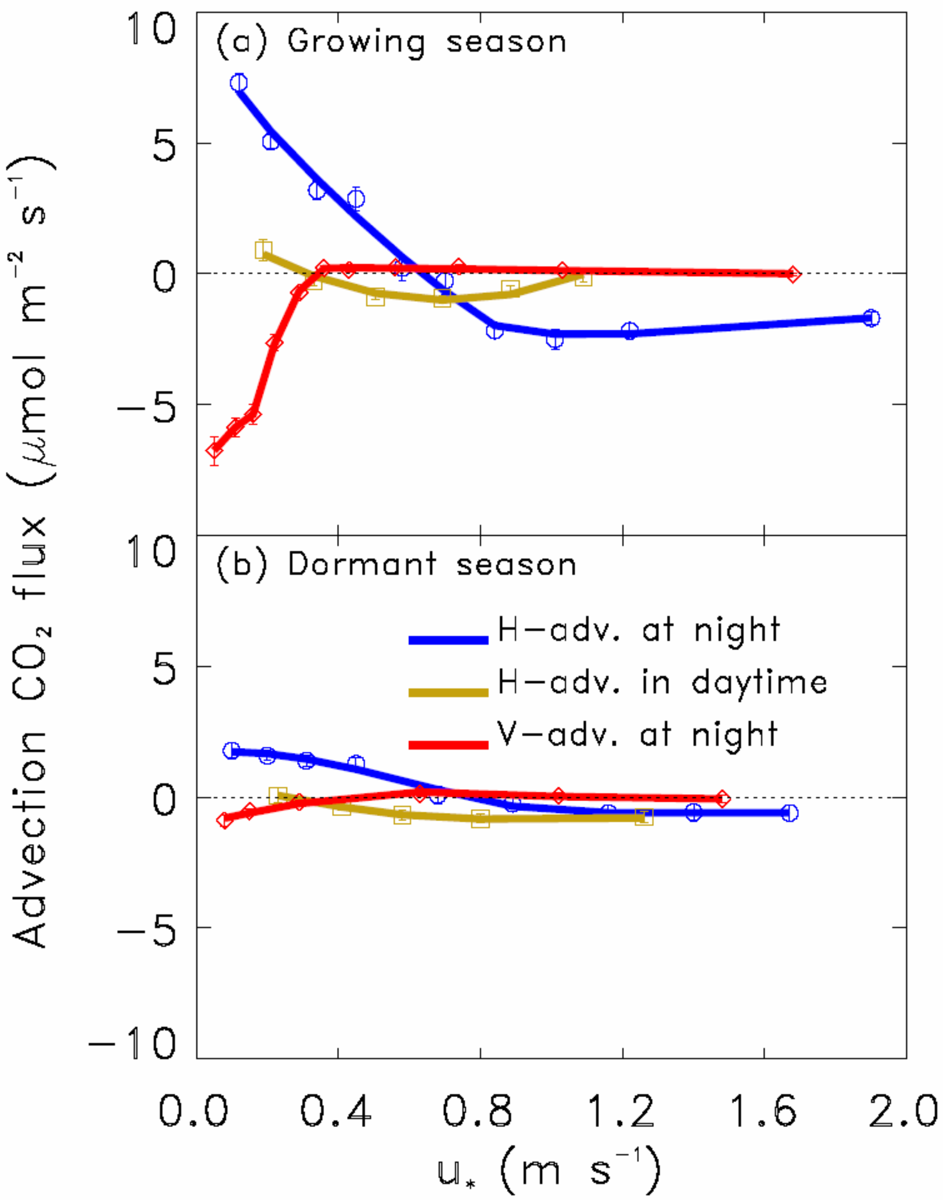
Udc/dx+Vdc/dy

udc/drcos(θ)

Comparison between two methods

Good agreement between Two algorithms

Yi et al., 2007



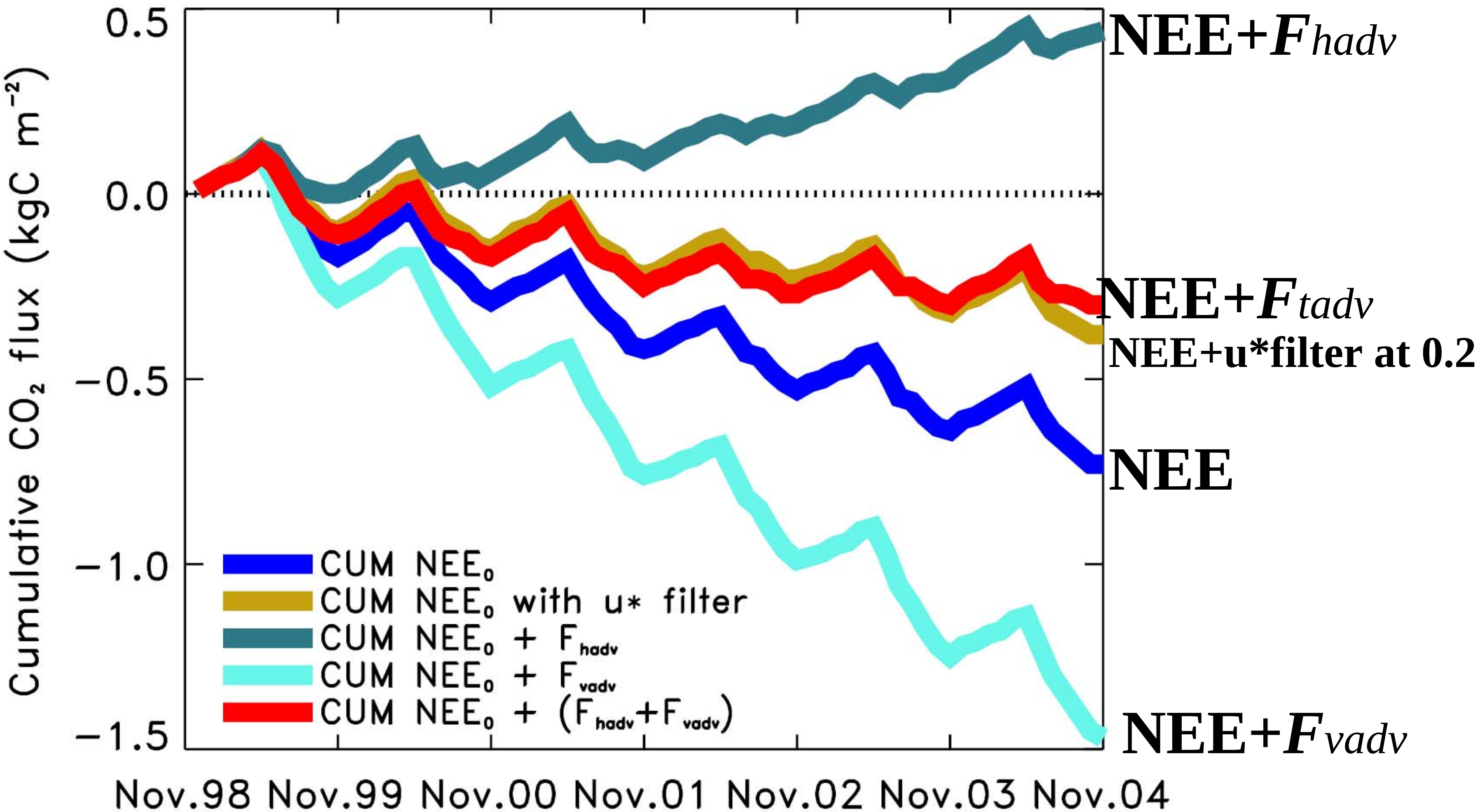
Advection correction is dependent on u*

Vertical advection is opposite to horizontal advection

Correction in summer is much larger than in winter

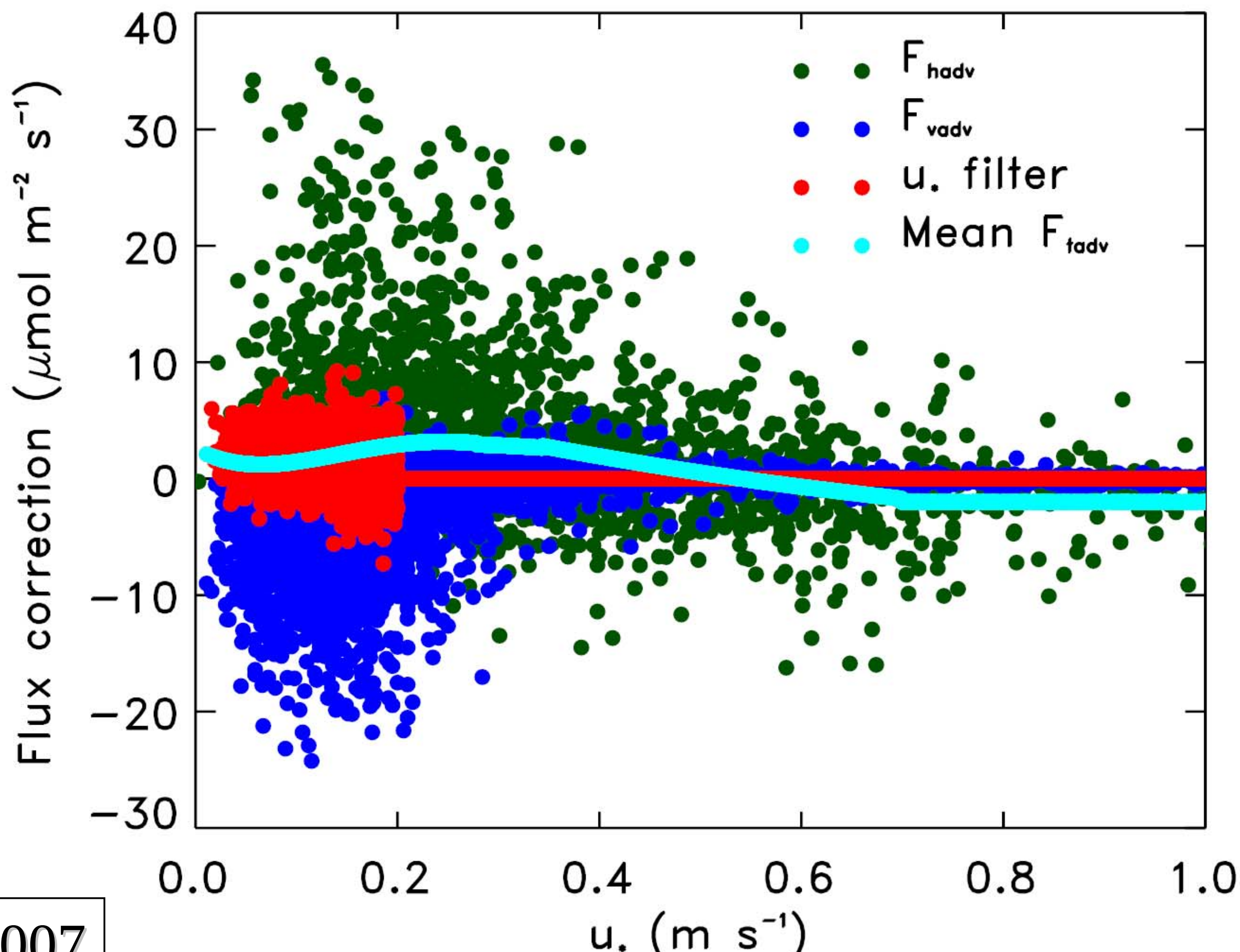
Yi et al., 2007

6-year cumulative NEE



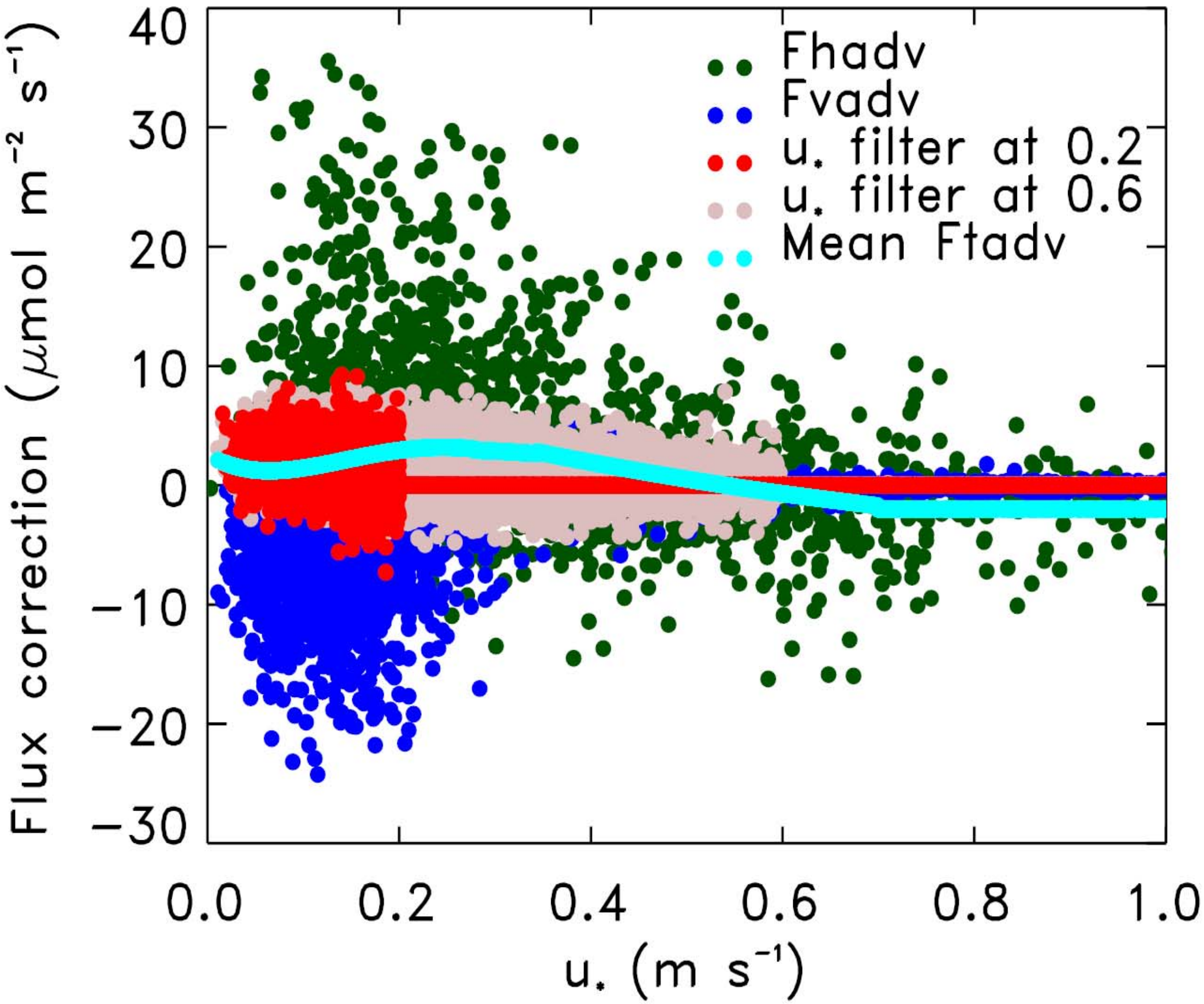
Yi et al., 2007

Comparison to u* filter at 0.2



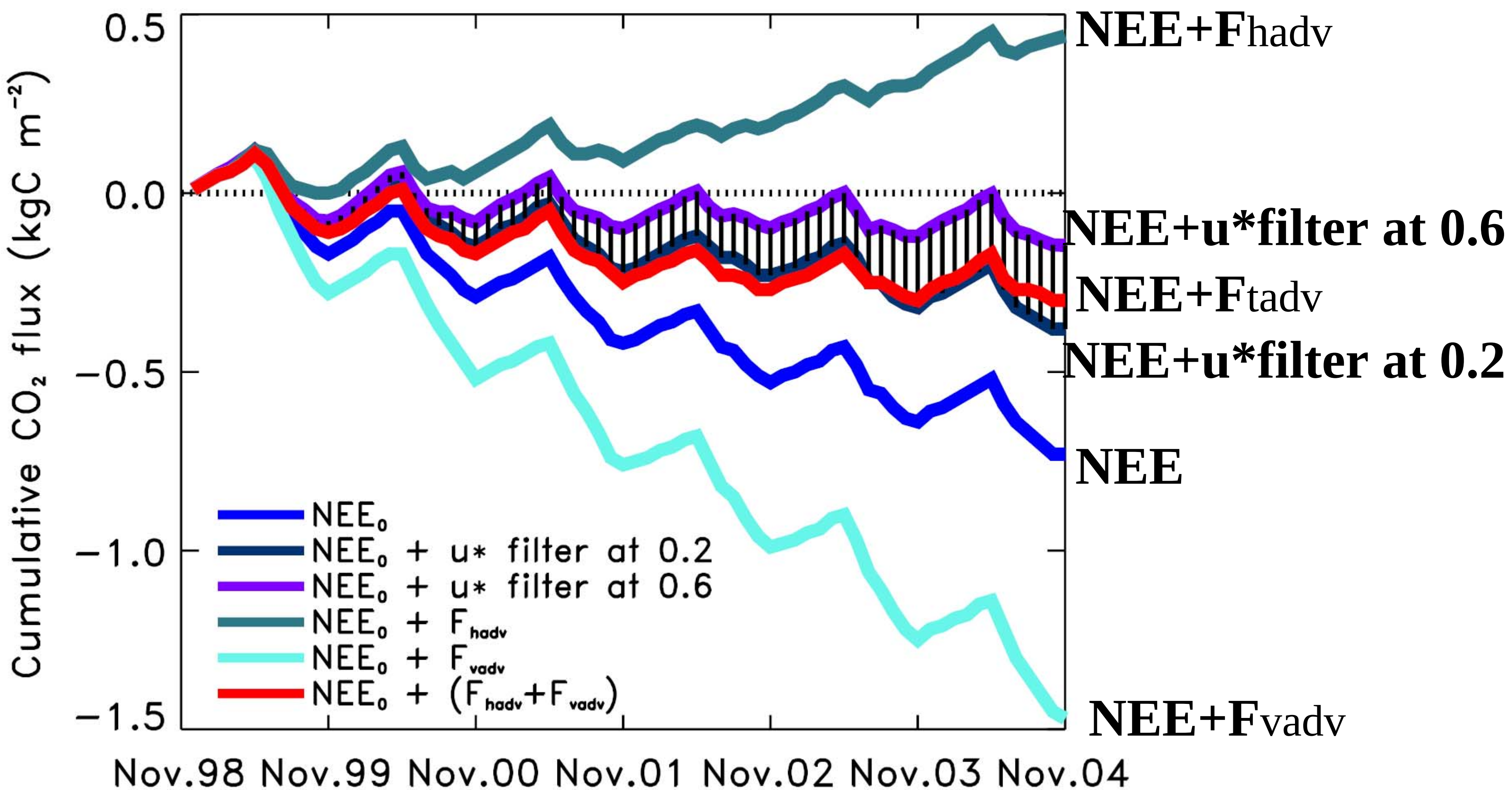
Yi et al., 2007

Comparison to u* filter at 0.6



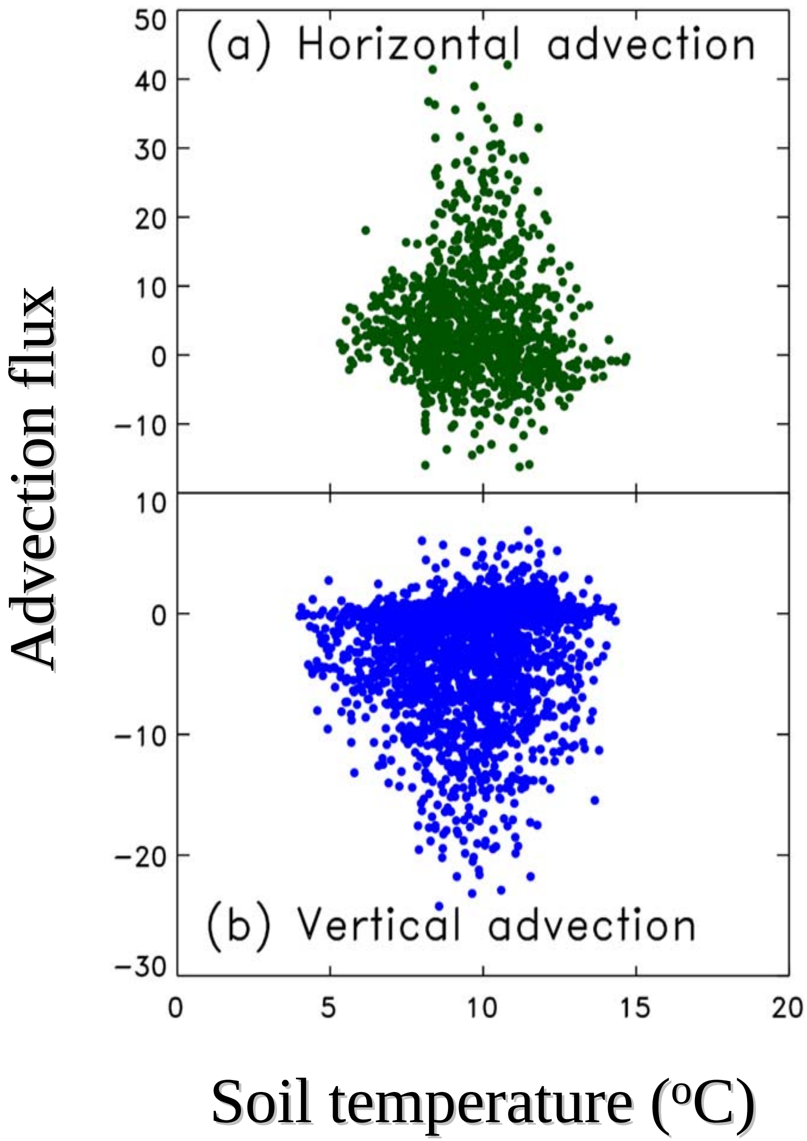
Yi et al., 2007

6-year cumulative NEE

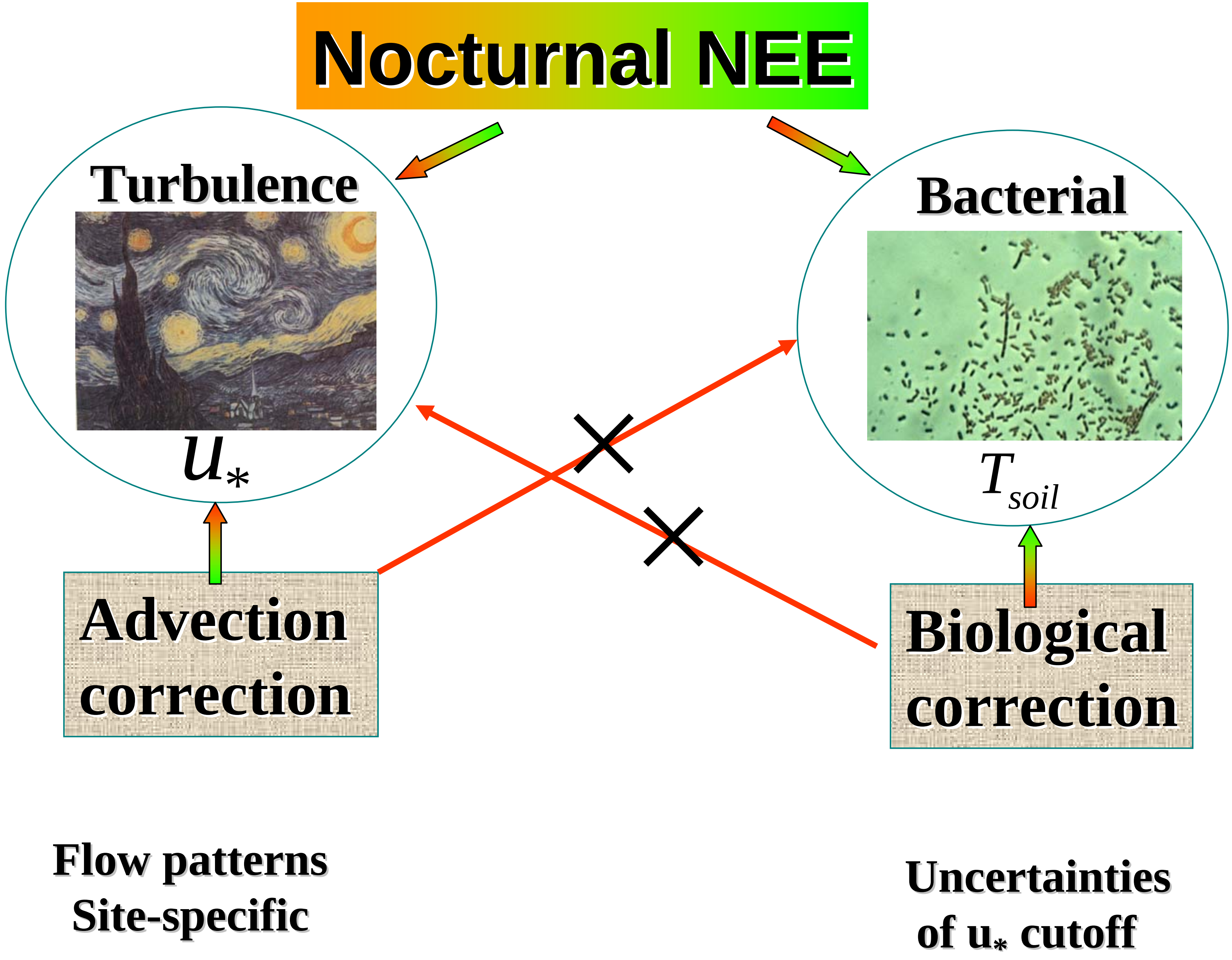


Yi et al., 2007

Advection flux is not a function of soil temperature



Yi et al., 2007


Nocturnal NEE
Turbulence
u_*
Bacterial
T_{soil}
Advection correction
Biological correction
Flow patterns
Site-specific
Uncertainties
of u_* cutoff

Summary & Conclusions

- **Advection fluxes are functions of u*, but not functions of temperature.**
- **The sign and magnitude of advection fluxes are related to the convergence/divergence of terrain-induced flows.**
- **Ecological correction is a function of temperature but not a function of u*.**
- **Ecological correction has no physical base to account for the advection components.**

Contact information

Chuixiang Yi
Assistant Professor
School of Earth and Environmental Sciences
Queens College, City University of New York
65-30 Kissena Blvd
Flushing, New York 11367
Phone: 718-997-3366
Fax: 718-997-3299
Email: cyi@qc.cuny.edu
http://www.essc.psu.edu/~cxyi
http://qcpages.qc.edu/EES/pep/yi.html