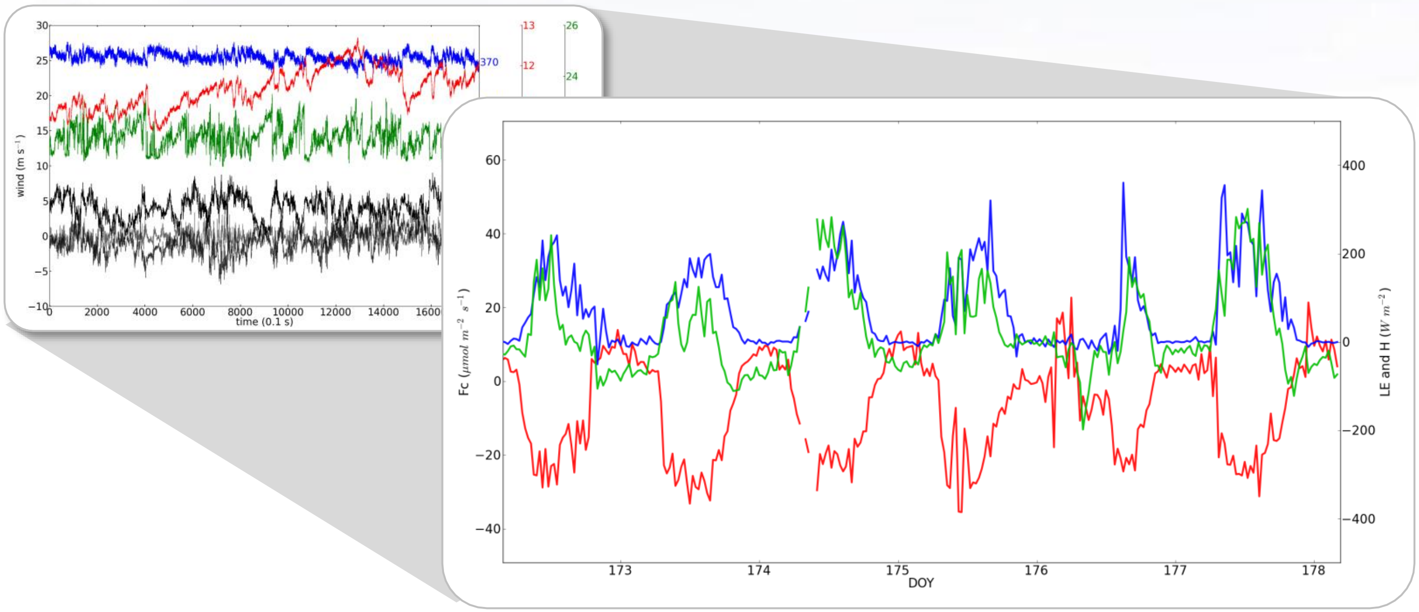
Eddy Covariance Data Processing



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Outline

- Overview of data processing
- Software installation and sample data preparation
- Hands-on EddyPro data processing with guidance
- EddyPro data processing exercise

Basic Data Processing Procedures

Raw data

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Quality check – hard flags

↓

De-spike

↓

Time delay removal

↓

Coordinate rotation

↓

Uncorrected flux computation

↓

Sonic temperature correction

↓

Frequency correction

↓

WPL correction

↓

Corrected fluxes – with QA/AC flags

↓

Footprint

Raw Data Formats

GHG file - .ghg

- High frequency data + metadata
- Biological and meteorological (Biomet) data + metadata
- Updated LI-7550 Analyzer Interface Unit

TOA5 - .txt

- Table Oriented ASCII Format 5
- PC logging

TOB1 - .dat

- Table Oriented Binary Format 1
- Campbell datalogger

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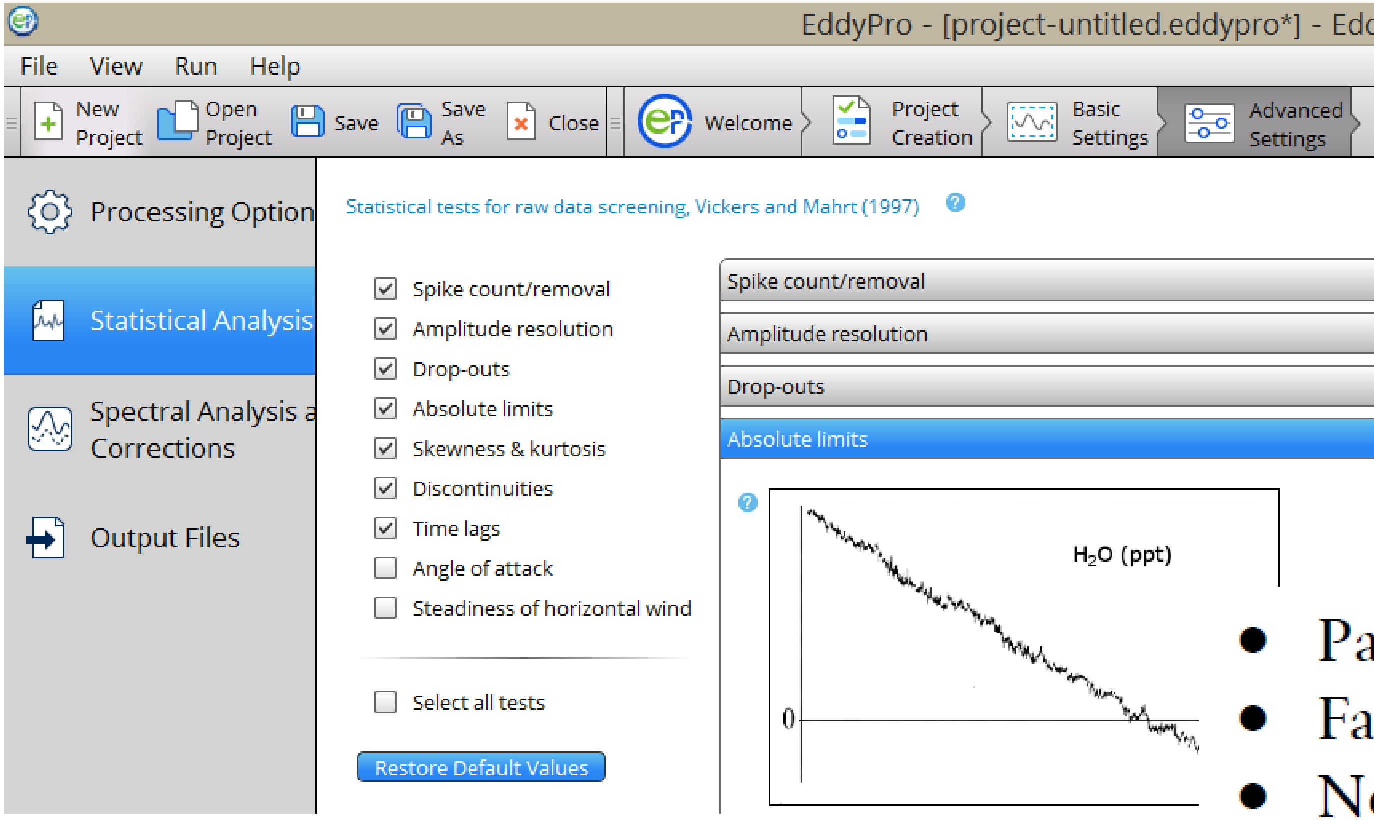
Quality Check – Hard Flags

- Spike detection and removal test
- Amplitude resolution test
- Drop out test
- Absolute limit test
- Skewness and Kurtosis tests
- Discontinuities test
- Time lag tests

Quality Check – Hard Flags

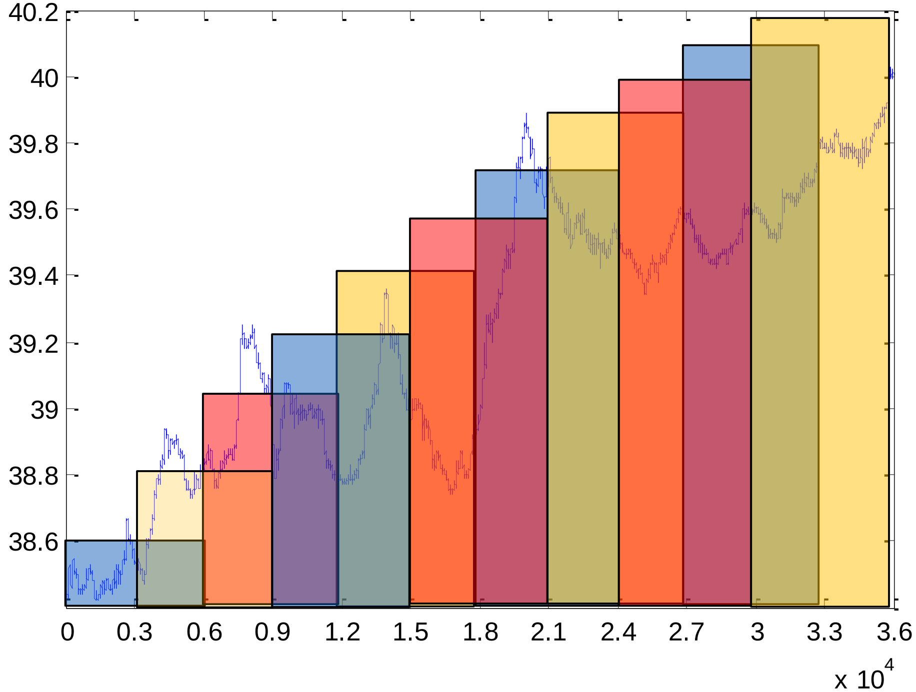


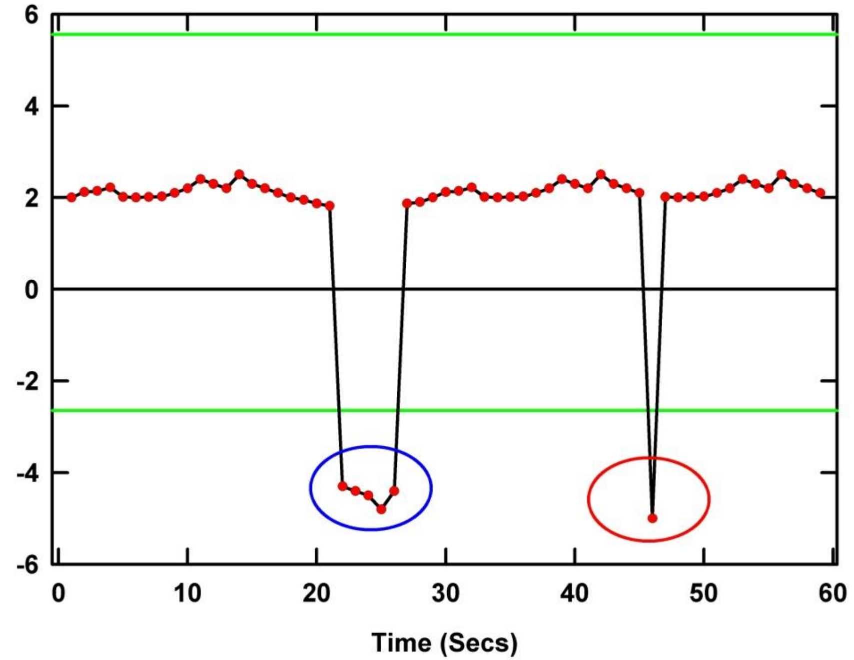
- Passed: 0
- Failed: 1
- Not selected: 9

statistical_flags		
spikes	amp_res	drop_out
HFu/v/w/ts/co2/h2o/ch4/n2o	HFu/v/w/ts/co2/h2o/ch4/n2o	HFu/v/w/ts/co2/h2o/ch4/n2o
HF00000009	HF00000009	HF00000009
HF00000009	HF00000009	HF00000009
HF00000009	HF00000009	HF00000009
HF00000009	HF00000009	HF00000009

Despiking

Spikes - Moving windows (1/6 of flux averaging period with half window overlapped)
Not spikes - 4 or more consecutive points
Spikes are counted and removed.
Replaced through linear interpolation or not

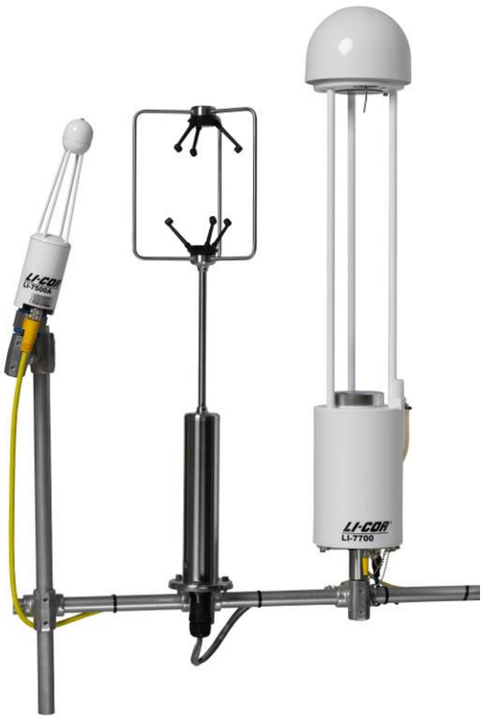


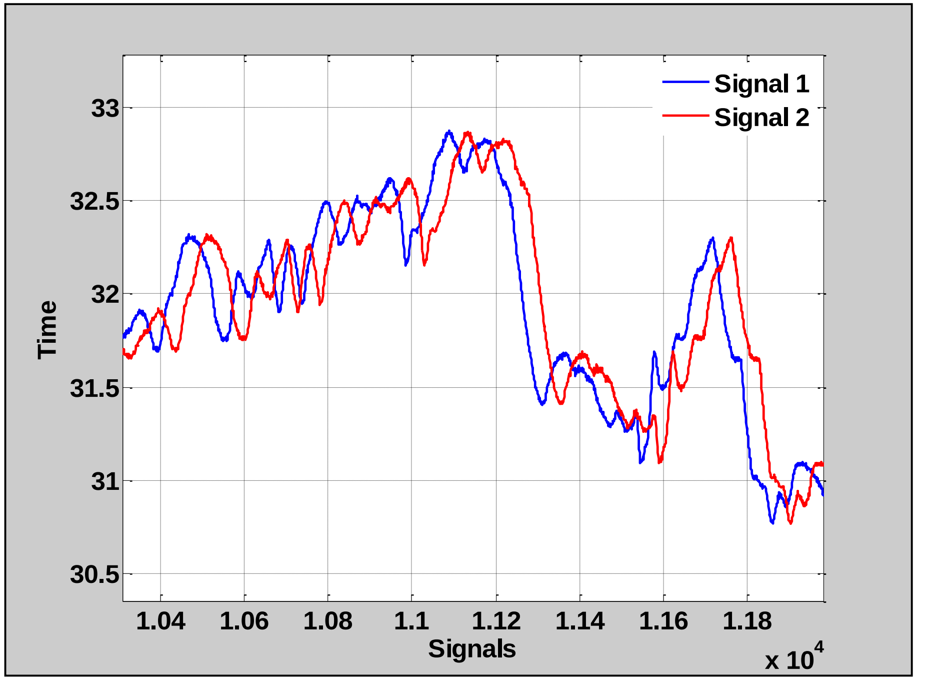


Common σ range for scalars

Variable	Plausibility Range
u, v	window mean ±3.5 st. dev.
w	window mean ±5.0 st. dev.
CO_2, H_2O	window mean ±3.5 st. dev.
CH_4, N_2O	window mean ±8.0 st. dev.
Temperatures, Pressures	window mean ±3.5 st. dev.

Time Delay and Removal





Open-Path

$$\tau_{nom} = 0$$

$$\tau_{min} = \frac{-sensor\ separation}{0.5}$$

$$\tau_{max} = \frac{sensor\ separation}{0.5}$$

0.5 – average wind speed (m/s)

Closed-Path

$$\tau_{nom} = \frac{tube\ length \cdot tube\ \ cross\ \ section}{flow\ rate}$$

$$\tau_{min} = \tau_{nom} - 2$$

$$\tau_{max} = \tau_{nom} + 2 \cdot \tau_{nom}$$

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Coordinate Rotation

- Assumption:
  - Mean vertical wind speed = zero
- Requirement:
  - Level the sonic *perfectly*
- The reality:
  - *Cannot* level the sonic perfectly
- The problem solver:
  - Coordinate rotation

Coordinate Rotation - Methods

I. Natural wind coordinate rotation

- Done every averaging period
- Better for simple topography
- Crop land and grassland

II. Planar fit coordinate

- Long-term (monthly)
- Better for complex topography
- Forest site

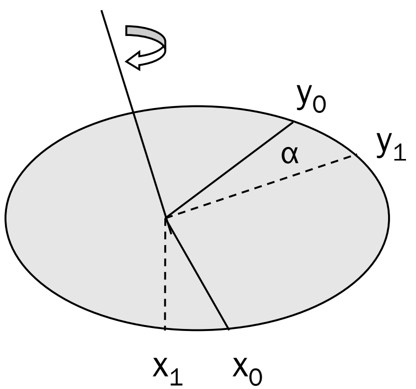
Natural Wind Coordinate Rotation

2D

<u>1^{st} step</u>

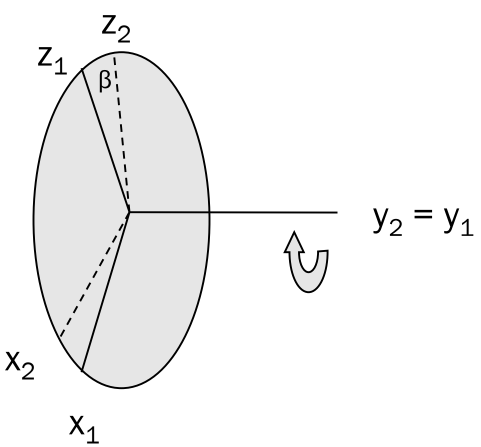
$\overline{v} \longrightarrow 0$

$z_1 = z_0$



<u>2^{nd} step</u>

$\overline{w} \longrightarrow 0$



3D

$\overline{v'w'} \longrightarrow 0$, rotating x axis, not recommended

Planar Fit Coordinate Rotation

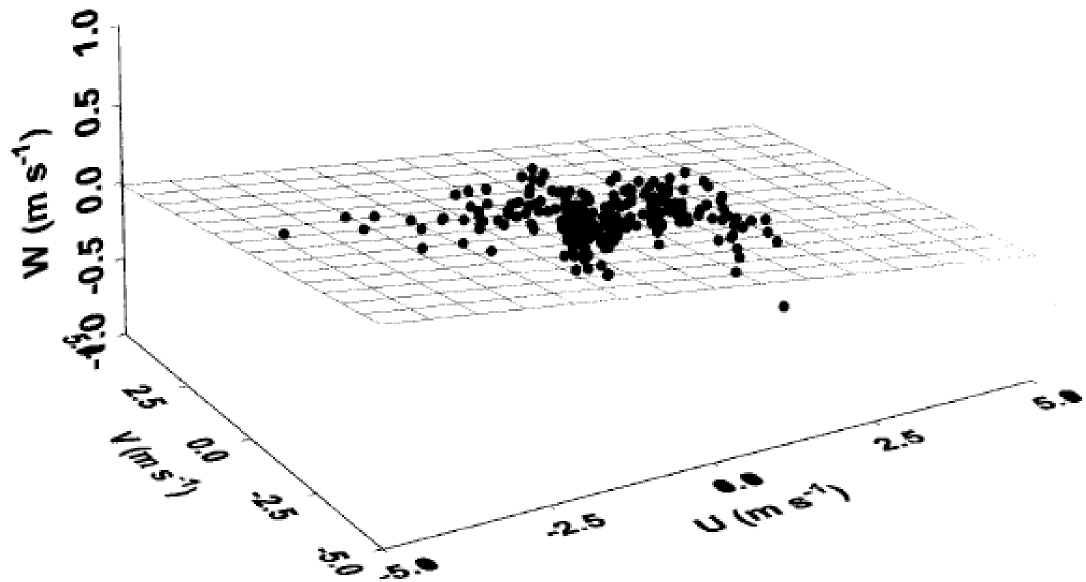
$$\overline{w} = b_0 + b_1 \overline{u} + b_2 \overline{v}$$

b_0, b_1 and b_2
– regression coefficients

z axis is fixed

x and y axis are redefined based on b_1 and b_2 in each averaging period

w = -0.099998 -0.059016*u -0.043260*v



Paw et al. 2000, Bound.-Layer Meteorol. 97: 487-511

Uncorrected Flux Computation

Sensible heat : $$H = \overline{\rho_a}\,\overline{c_p}\,\overline{w'Ts'}$$

CO_2 , H_2O, or CH_4 : $$F = \overline{w'c'}$$

Latent heat : $$LE = \lambda F_{H_2O}$$

H – sensible heat

ρ_a – moisture air density

C_p – specific heat of air

w - vertical wind speed

Ts – sonic temperature

F – uncorrected CO_2 , H_2O,or CH_4 flux

c - CO_2 , H_2O,or CH_4 molar density

λ - specific evaporation heat

F_{H2O} – water vapor flux

Sonic Temperature Correction

$$T_s = T_a\,(1+0.32e/p)$$

$$T_s = T_a\,(1+0.51Q)$$

T_s - Sonic temperature (K)

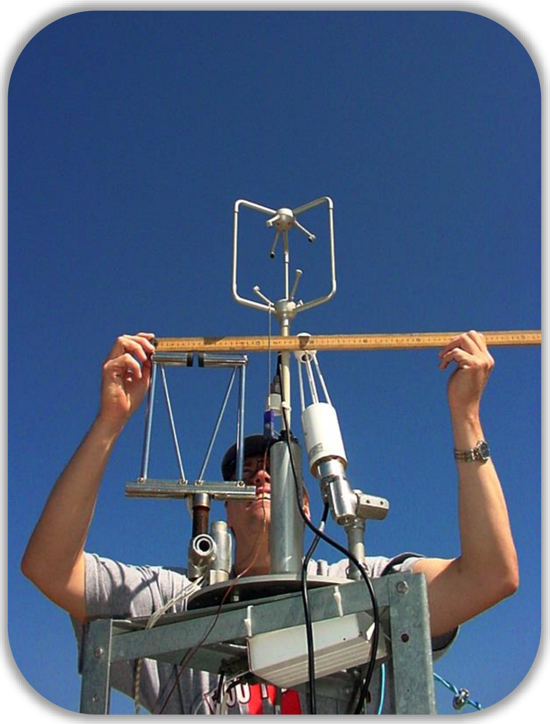
T_a - Air temperature (K)

e - Water vapor partial pressure (kPa)

p - Air pressure (kPa)

Q – Specific humidity (mass ratio of water vapor to dry air)

Frequency Response Correction



- Assumptions:
  - Wind speed and mixing ratio measurements
    Same time, same point
  - *All* the eddies are measured

- The reality:
  - Sensor separation
  - Measurement path length
  - Measurement frequency:
    10 Hz – Loss of *high* frequency eddies;
    30-minute averaging – Loss of *low* frequency eddies

- The problem solver:

  - Frequency response correction

Fourier Data Transfer for Frequency Correction

Time ⟶ Frequency:

$$F(k) = \int_{-\infty}^{\infty} f(x) e^{-2\pi i k x} dk$$

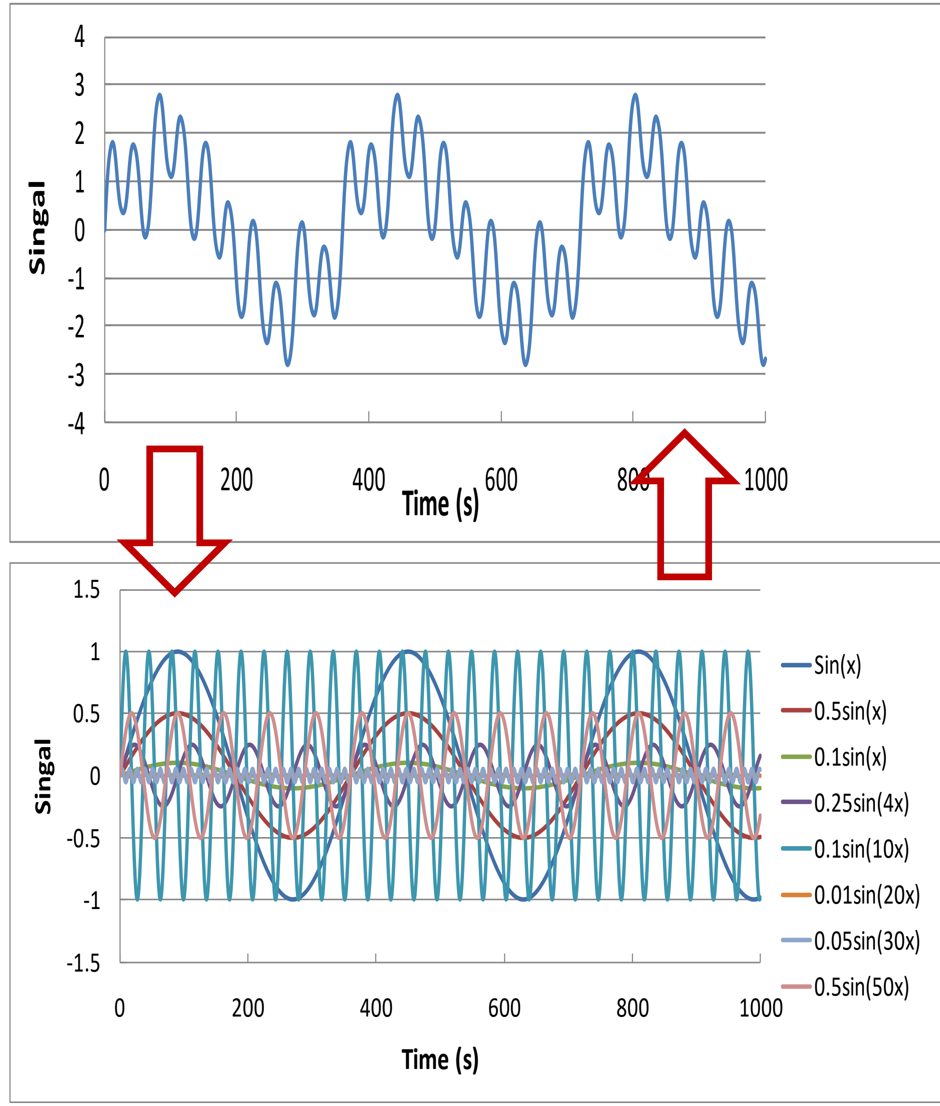
Frequency ⟶ time :

$$f(x) = \int_{-\infty}^{\infty} F(k) e^{2\pi i k x} dk$$

X – time (second)

K – frequency (Hertz)

i – phasor



Frequency Response Correction

Calculation of a true flux spectrum

↓

Estimation of transfer functions:

(Input -> [tran. function] -> output)

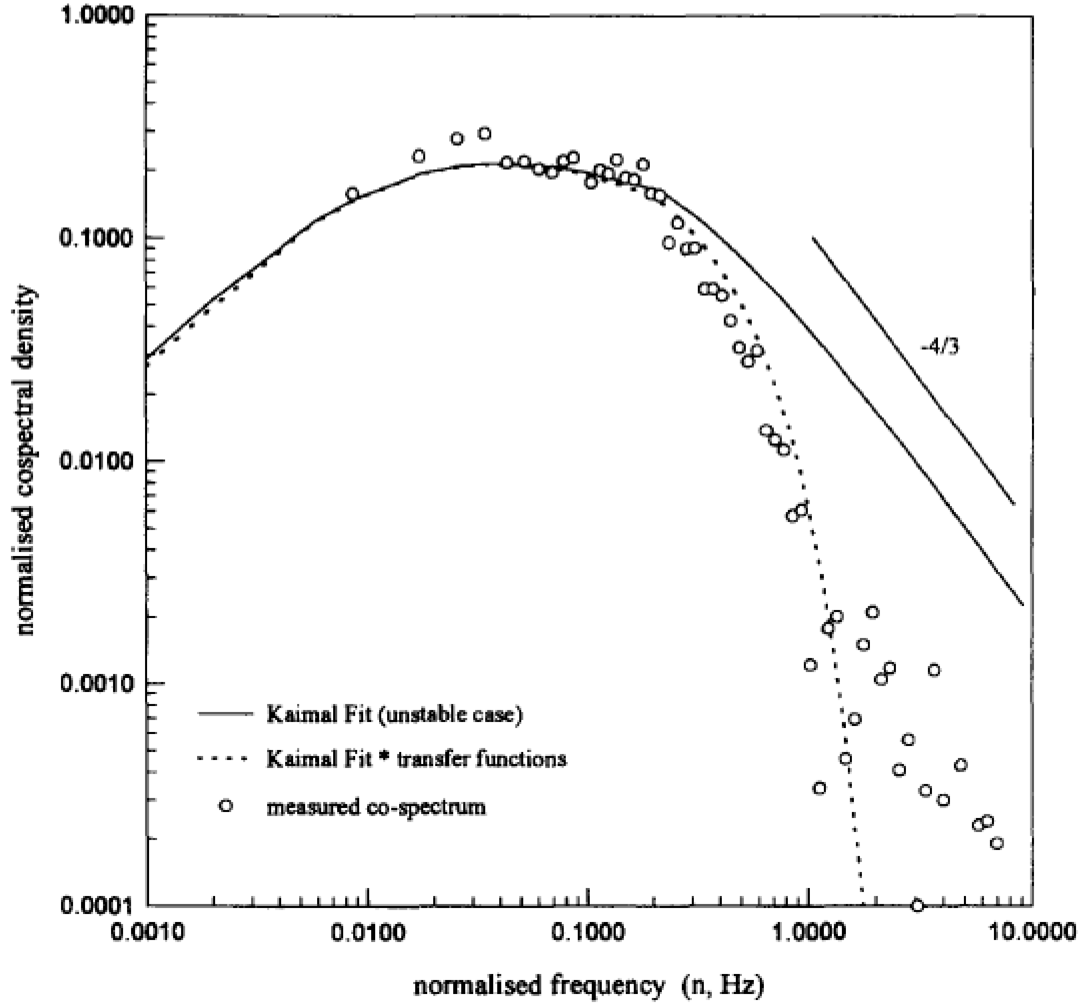
↓

Estimation of flux attenuation

↓

Calculation of the spectral correction factor

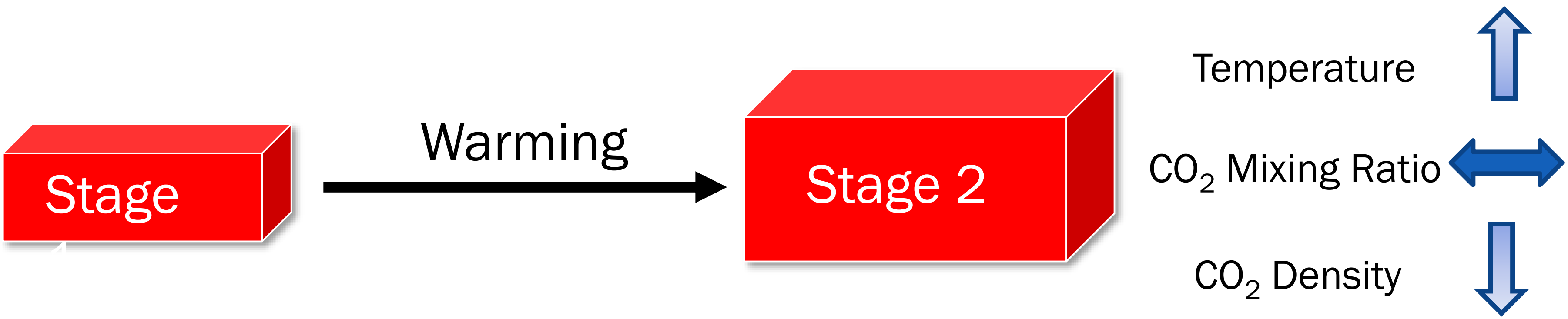
$$\frac{\Delta F_c}{F_c} = 1 - \frac{\int_0^\infty T_{w\rho_c}(n) C_{w\rho}(n)\,\mathrm{d}n}{\int_0^\infty C_{w\rho}(n)\,\mathrm{d}n}$$



- Moncrieff et al, 1997, Journal of Hydrology, 188-189: 589-611

WPL (Webb-Pearman-Leuning) Correction

- **Definition:**
  - Mixing ratio is used in the eddy covariance formula
- **The reality:**
  - Analyzers measure *density* instead of *mixing ratio*
  - Density is affected by variations in temperature and humidity



- **The problem solver:**
  - **WPL correction**

WPL Correction

Open-path system CO_2 and H_2O fluxes:

$$Fc = Fc_o + \mu \frac{E}{\rho_d} \frac{q_c}{1+\mu \frac{\rho_v}{\rho_d}} + \frac{H}{\rho C_p} \frac{q_c}{T_a}$$

Fc – final corrected flux
Fc_o – uncorrected flux
E – evapotranspiration
H – sensible heat flux

q_c – mean CO_2 density
ρ_d – dry air density
ρ_v – H_2O vapor density
ρ – total air density

C_p – air, specific heat
T_a – air temperature in K
μ – ratio of mol. masses of air to water, μ=1.6077

Closed-path system CO_2 and H_2O fluxes:

1) Using H = 0 and uncorrected E;   2) Using mixing ratio (LI-7200)

Open-path system CH_4 flux:

$$F_c = \mathbf{A}\left\{\overline{w'q'_{cm}} + \mathbf{B}\mu\frac{\overline{q_{cm}}}{\overline{q_d}}\overline{w'q_v'} + \mathbf{C}\left(1+\mu\sigma\right)\frac{\overline{q_{cm}}}{\overline{T}}\overline{w'T'}\right\}$$

Flux Quality Flags

I. Steady State Tests ➡ Determine stationarity

$$RN_{cov} = \left| \frac{\frac{\sum \overline{\acute{w}\acute{x}_n}}{n} - \overline{\acute{w}\acute{x}}}{\overline{\acute{w}\acute{x}}} \right|$$

Time series is *steady* when $RN_{cov} < 30\%$

II. Developed Turbulent Conditions tests ➡ Integral Turbulence Characteristics (ITC)

- The normalized standard deviations of turbulent parameters over all frequencies of the turbulent spectrum
- Measured: $\frac{\sigma_x}{X_*}$ Modeled: $\frac{\sigma_x}{X_*} = c_1 \cdot \left(\frac{z}{L}\right)^{c_2}$

$$X_* = T_* = -\frac{\overline{w'T'}}{u_*} \qquad X_* = q_* = -\frac{\overline{w'q'}}{u_*}$$

C_1 and C_2 – constants, Z – measurement height, L – Monin-Obukhov length, u_* - Friction velocity

$$ITC_\sigma = \frac{ITC_{model} - ITC_{measured}}{ITC_{model}}$$

Well developed turbulence when ITCσ < 30%

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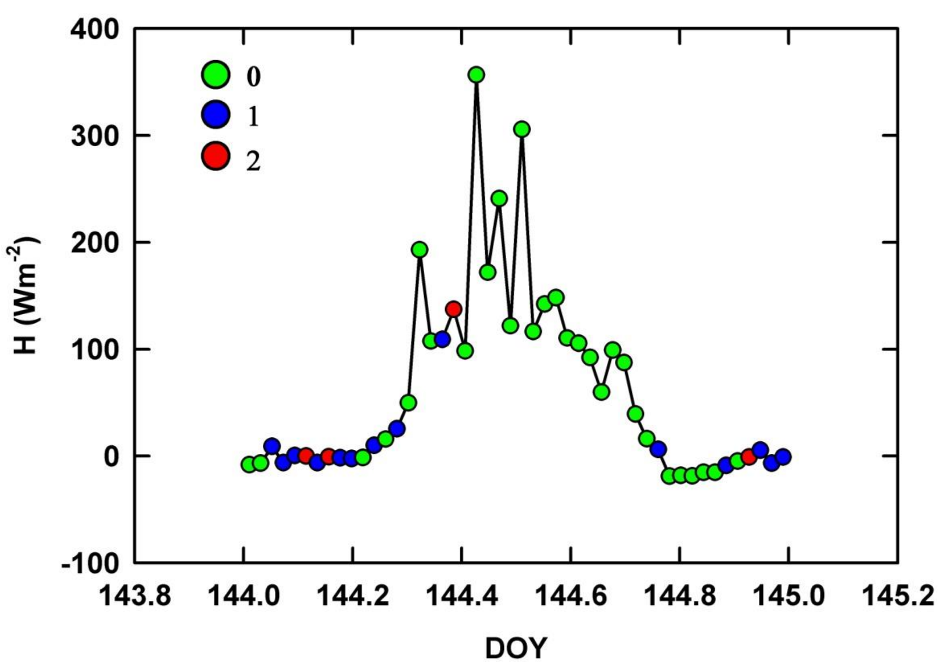
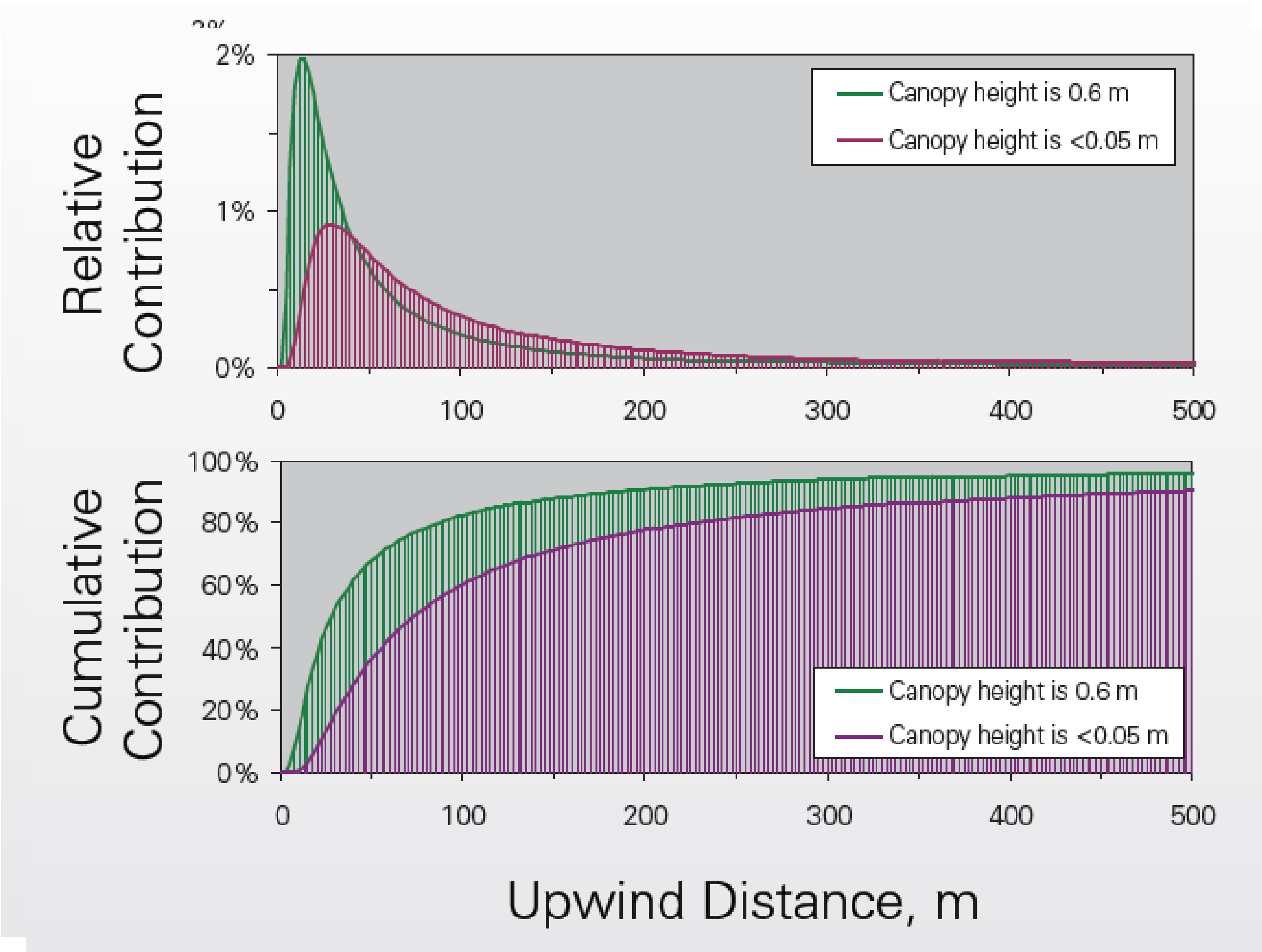
Flux Quality Flags

RN_{cov}	ITCσ	QA/QC FLAG	DATA QUALITY
≤30	≤30	0	High
≤100	≤100	1	Moderate
>100	>100	2	Low

Overall quality flags after Spoleto agreement, 2004 for CarboEurope-IP



Flux Footprint



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Data Processing Software

I. EdiRe, University of Edinburgh, UK

2. ECpack, Wageningen University, the Netherlands

3. TK3, University of Bayreuth, Germany

4. Alteddy, Wageningen University, the Netherlands

5. EddySoft, Max Planck Institute for Biogechemistry, Germany

6. EddyUH, University of Helsinki , Finland

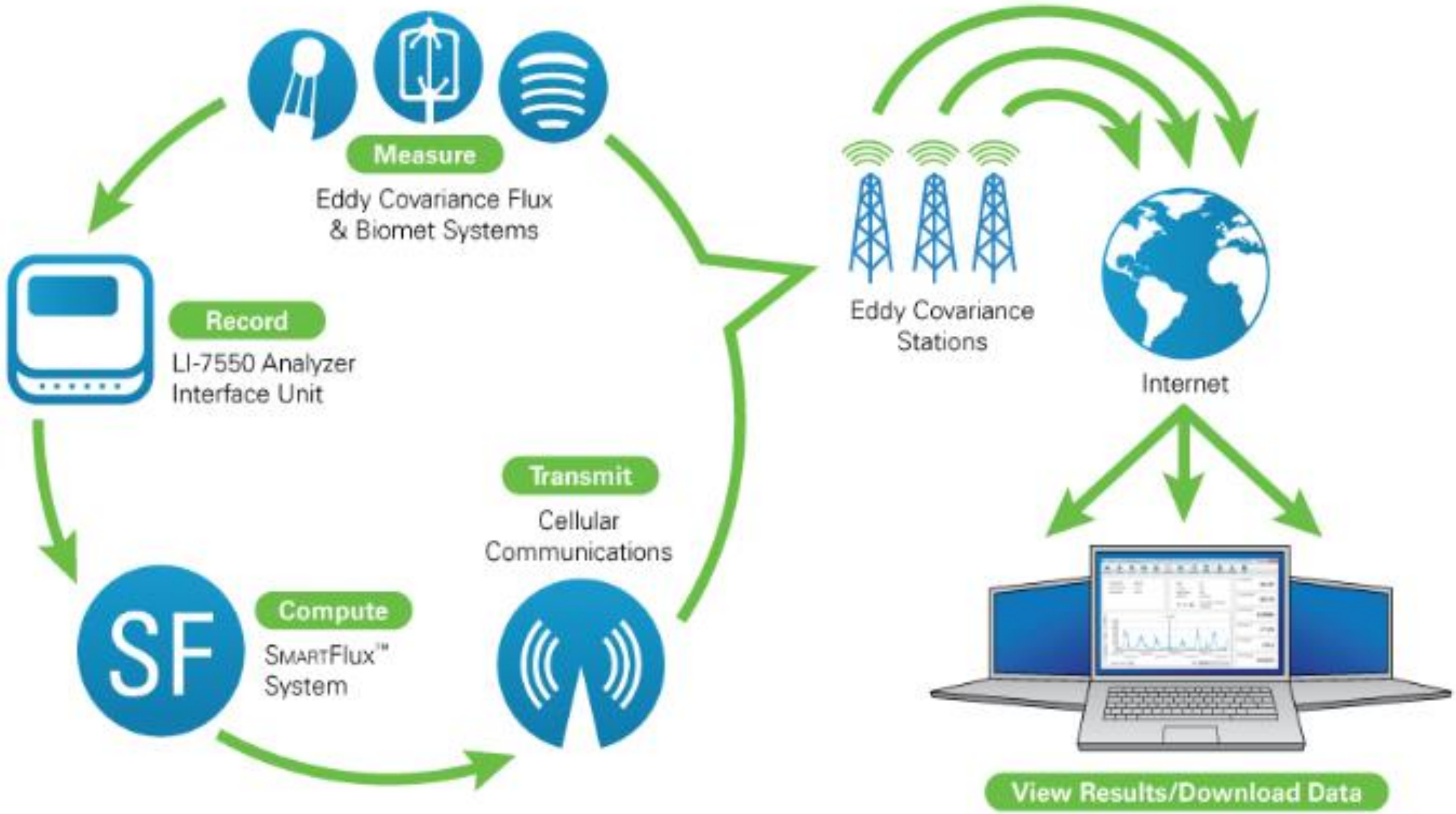
7. Self-written computer programs using Fortran or MATLAB

8. EddyPro , LI-COR Bioscience, released in April 2011

EddyPro Introduction

- Process CO_2, H_2O, CH_4, N_2O, CO… and energy flux data
- Support various raw flux data formats(GHG, ASCII, and TOB1) , including biological and meteorological (Biomet) data (radiation, soil heat flux ....)
- Express and Advanced modes
- Open source and free
- With LI-COR support
- Over 3800 downloads in 155 countries
- Flux networks are adapting EddyPro as a standard software for flux processing

On-site Flux Data Processing - SMARTFlux



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Thank You

Questions?