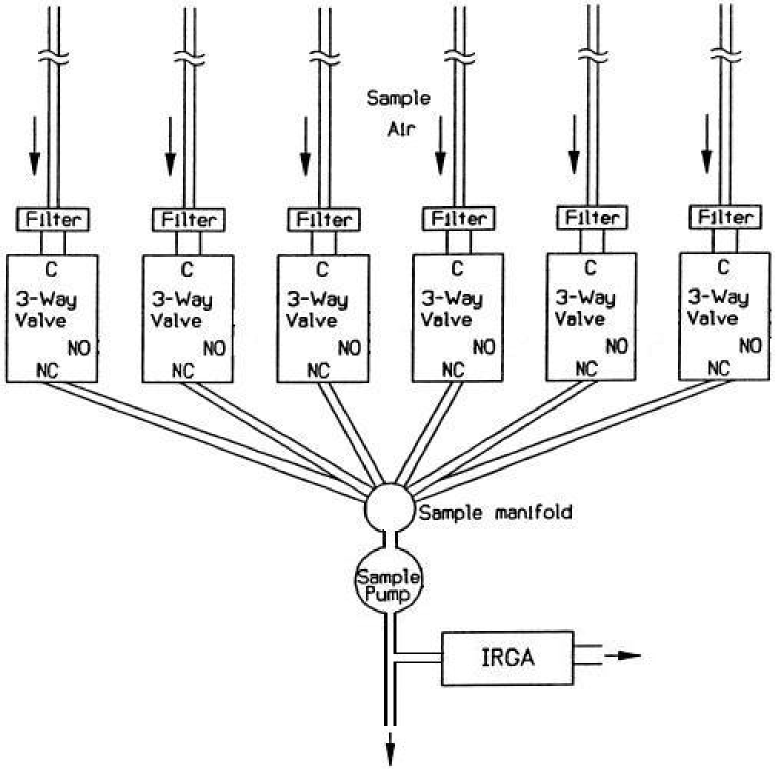
Sampling strategy for CO_2 sampling

Bernard Heinesch

Outline

- Aim of [CO_2] sampling
- Temporal sampling
- Spatial sampling
- Technical description
  - – tubing
  - – flushing time
  - – analyser
  - – intercalibration of analysers



Aim of CO_2 sampling

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

Estimation of storage : temporal variation at a given point

Estimation of vertical advection : spatial variation at a given moment

Estimation of horizontal advection : spatial variation at a given moment

We restrict ourselves to CO_2 (H_20) but a lot of these considerations apply also to other scalars.

Aim of CO_2 sampling

Order of magnitude of $[CO_2]$ differences to be resolved :

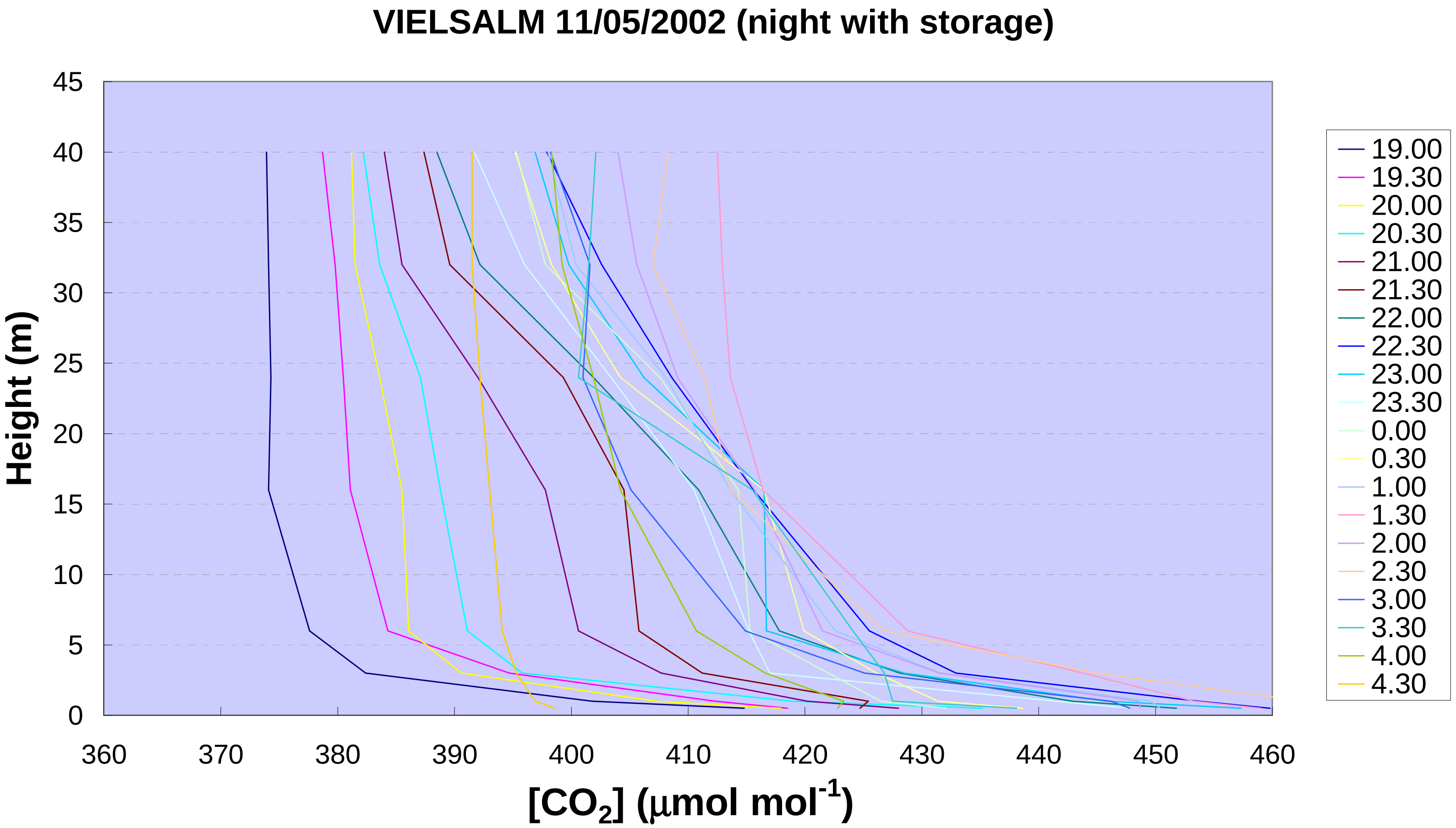
- Temporal differences

  x μmol mol^{-1}

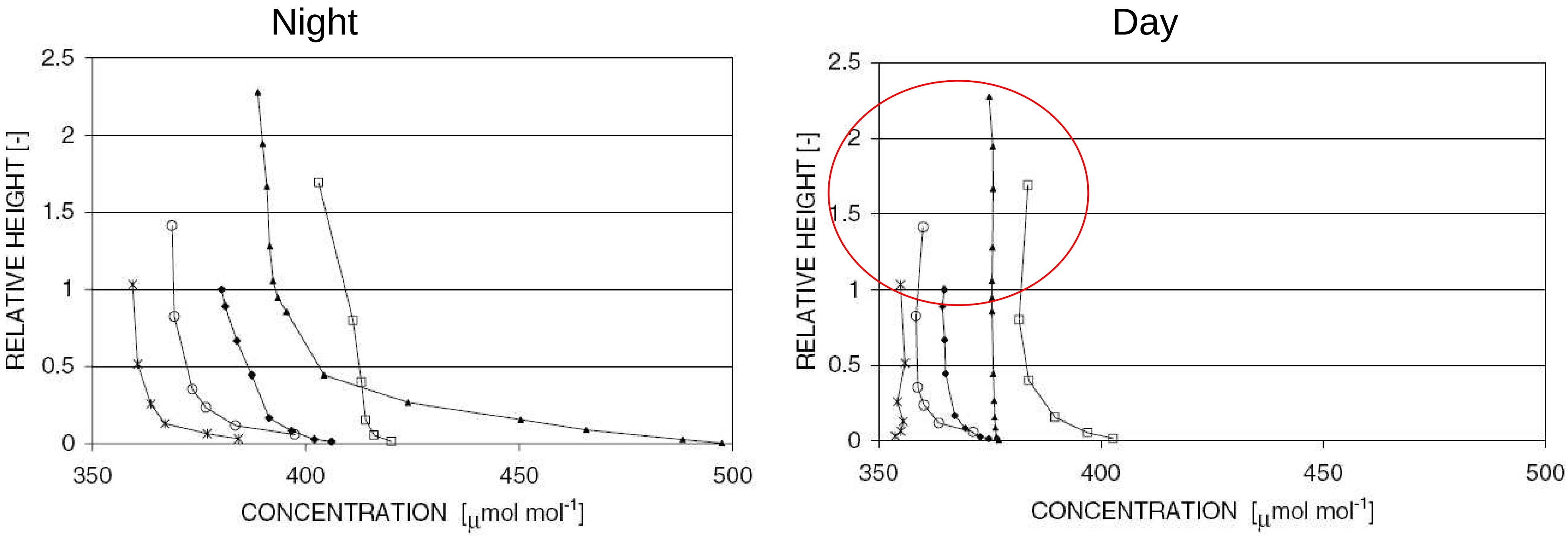
- Spatial differences

  vertical : x μmol mol^{-1}
  horizontal : x μmol mol^{-1}

Example of the time evolution of [CO_2] at night in a forest

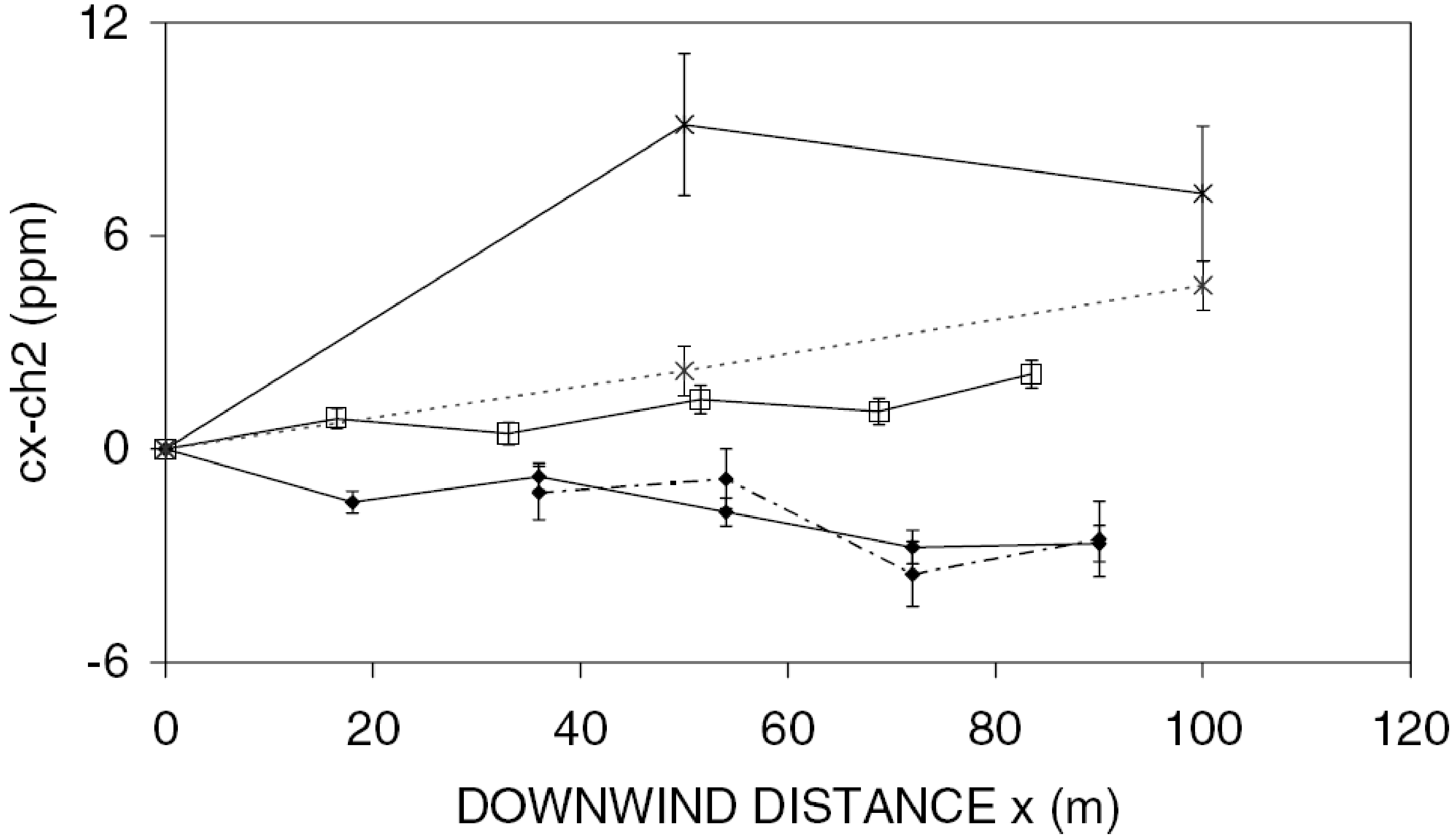


Example of vertical profiles of [CO_2] in forests



(Aubinet et al., BLM, 2005)

Example of horizontal profiles of [CO_2] in forests



(Aubinet et al., BLM, 2005)

Aim of CO_2 sampling

Order of magnitude of $[CO_2]$ differences to be resolved :

- Temporal differences

0-10 ppm

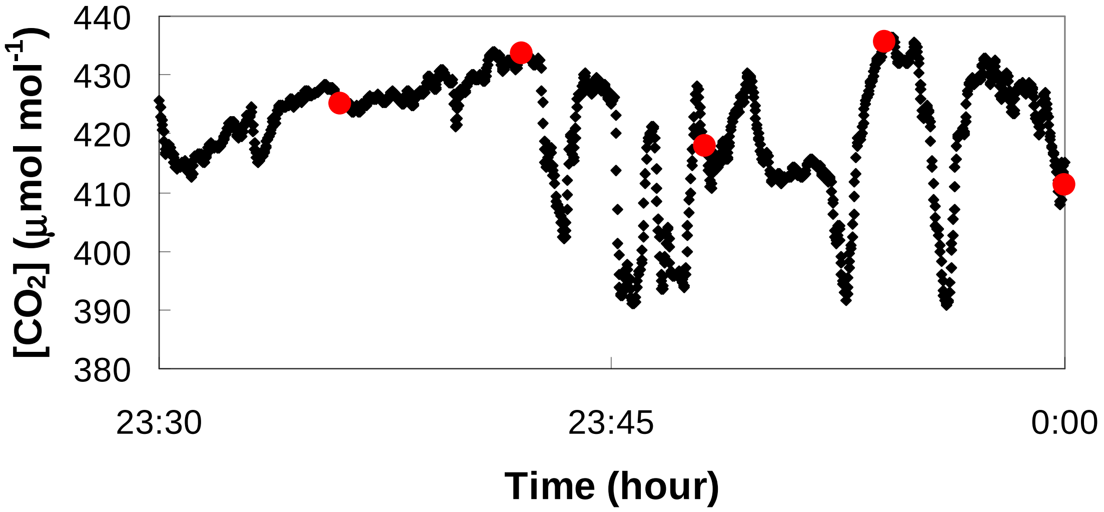
- Spatial differences

vertical : 0-50 ppm
horizontal : 0-10 ppm

To resolve these small differences, any systematic error has to be avoided and minimisation of random uncertainty is necessary.

Temporal sampling : uncertainty

Example of variability of the signal:



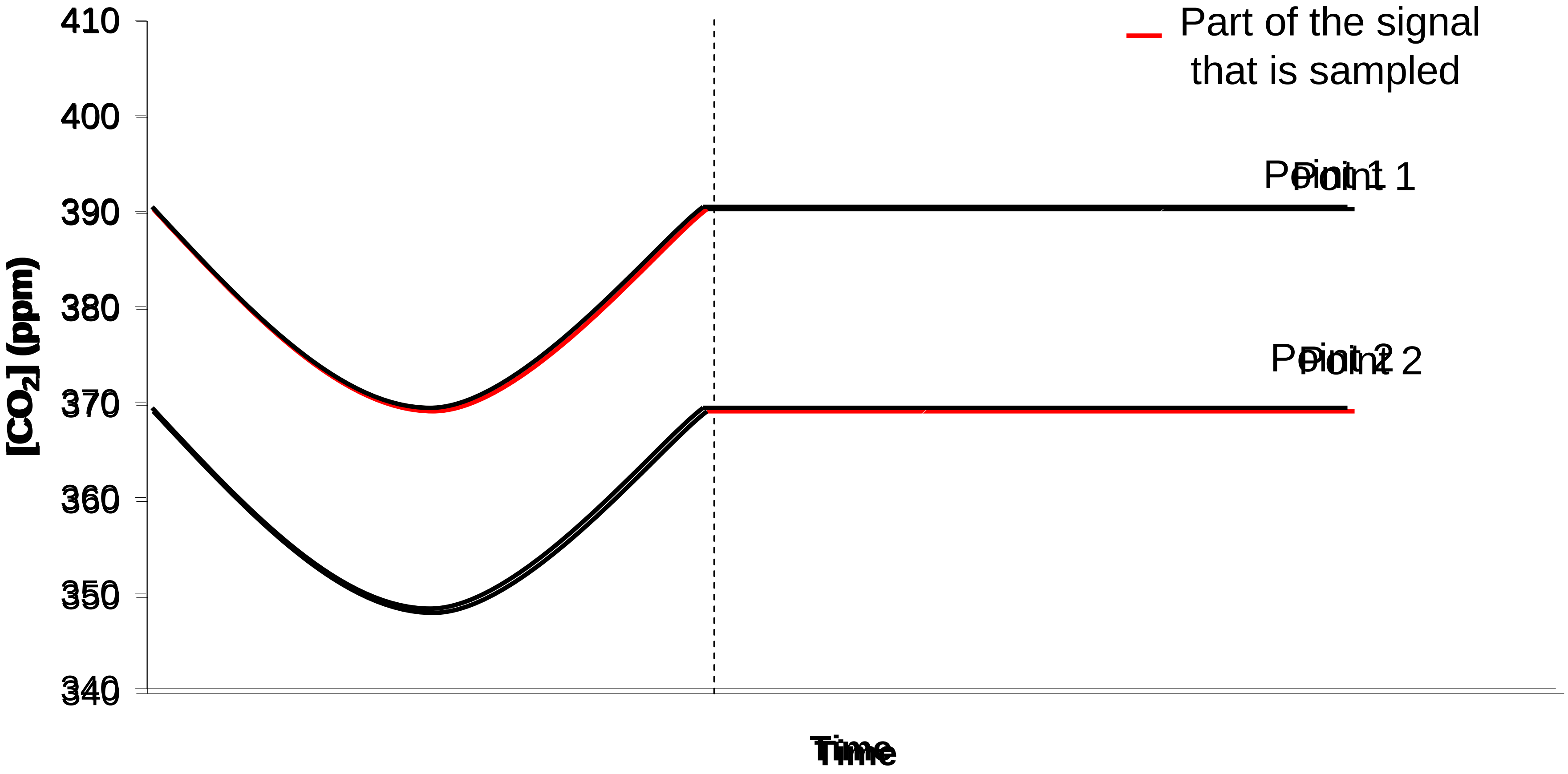
$$\sigma_{\overline{c}} = \frac{\sigma_c}{\sqrt{N}} = \frac{\sigma_c}{\sqrt{T/\Delta t}}$$

T : period of averaging (here 1800s)

Δt : time between two samples

Temporal sampling : uncertainty

Schematic example of sampling error on gradient estimation due non-simultaneity of sampling



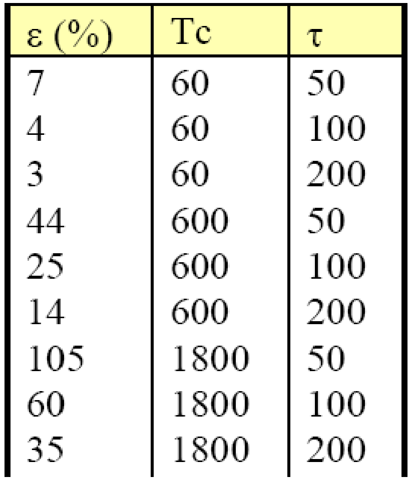
Temporal sampling : uncertainty

Empirical estimation of this uncertainty

Example 1 :

Woodruff (1986) quantified this error by alternately sampling from each of the two continuous temperature time series at each height to simulate the action of intermittent sampling using a single analyzer. The sampling error ε_s was determined as the mean deviation of the intermittent sampling gradient from the "true" gradient as determined from the continuous measurements at each height. The relative error was found to increase monotonically with cycle time T_c

$$\varepsilon = 6\left(\frac{T_c}{\tau}\right)^{0.8}$$



ε (%)	Tc	τ
7	60	50
4	60	100
3	60	200
44	600	50
25	600	100
14	600	200
105	1800	50
60	1800	100
35	1800	200

Temporal sampling : uncertainty

This type of error is random. It will introduce noise.

To reduce this noise :

- Sample as fast as possible
- Make averages on long datasets

Alternative : use of a buffer volume to smooth the signal

Spatial sampling : repartition of inlet points

Vertical repartition :

Better spatial resolution in the sub-layers where concentration variations are important : use of a logarithmic profile (for CO_2)

Height of the lowest level ? :

if close to the soil

+ : better resolution in the layer showing the highest gradients

- : more subject to very local source heterogeneities and difficult to evaluate the height on irregular surfaces

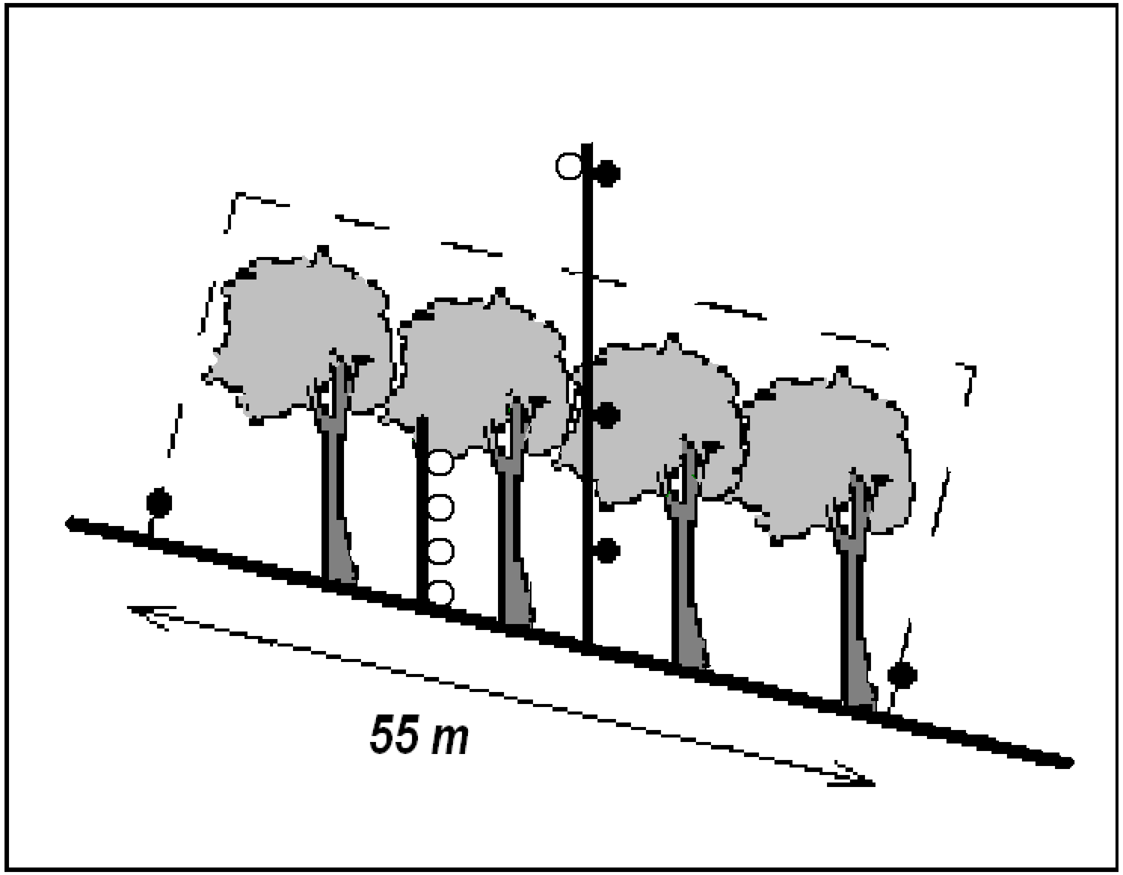
Spatial sampling : repartition of inlet points

Horizontal repartition :

- 2D or 3D ?
- Important to make a horizontal transect to evaluate the horizontal representativity of the measurement
- canopy space ?

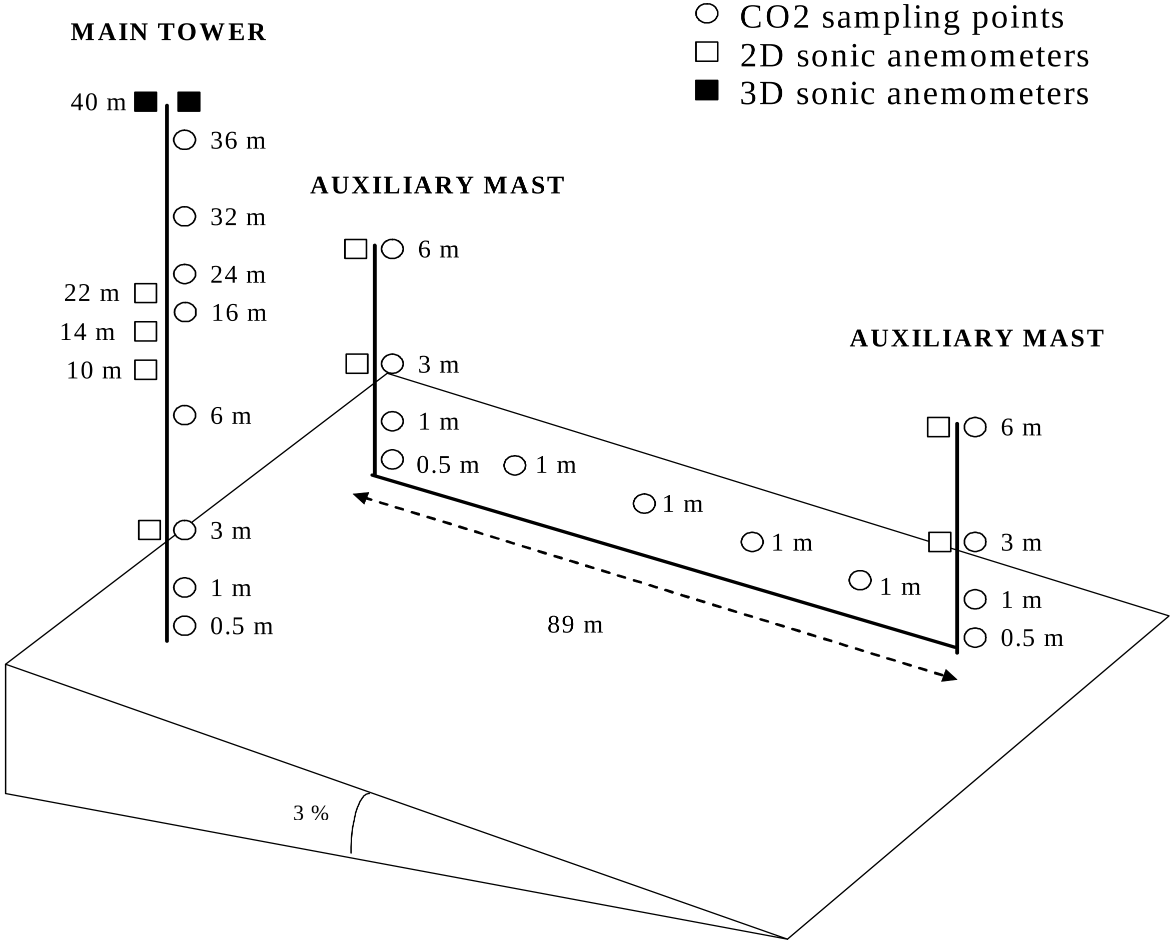
Spatial sampling : repartition of inlet points

Example 1 : Vielsalm 1999



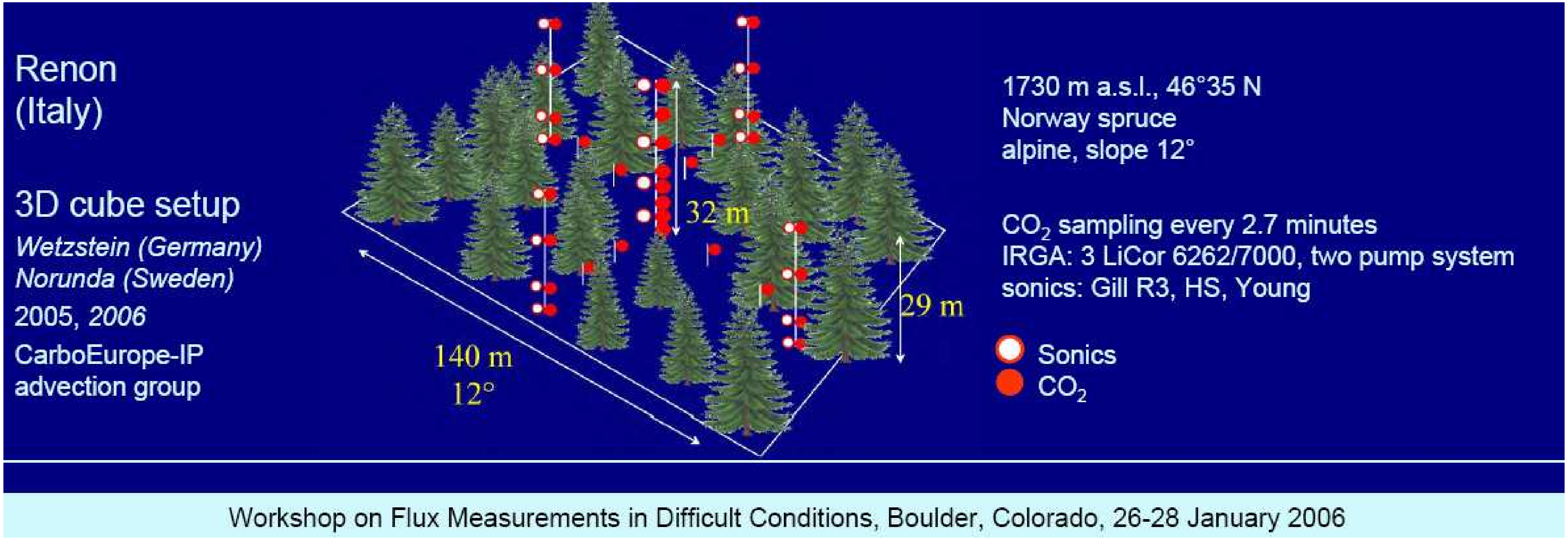
Spatial sampling : repartition of inlet points

Example 2 : Vielsalm 2002



Spatial sampling : repartition of inlet points

Example 3 : ADVEX



Renon
(Italy)

3D cube setup

Wetzstein (Germany)
Norunda (Sweden)
2005, *2006*
CarboEurope-IP
advection group

1730 m a.s.l., 46°35 N
Norway spruce
alpine, slope 12°

CO_2 sampling every 2.7 minutes
IRGA: 3 LiCor 6262/7000, two pump system
sonics: Gill R3, HS, Young

○ Sonics
● CO_2

Workshop on Flux Measurements in Difficult Conditions, Boulder, Colorado, 26-28 January 2006

(from C. Feigenwinter)

Spatial repartition vs frequency of acquisition

« Use a maximum of points and sample as fast as possible »

A compromise has to be found between these two antagonist advices.

What material do you have (number of analysers, flow rates) ?

What is the cycling frequency you can achieve ?

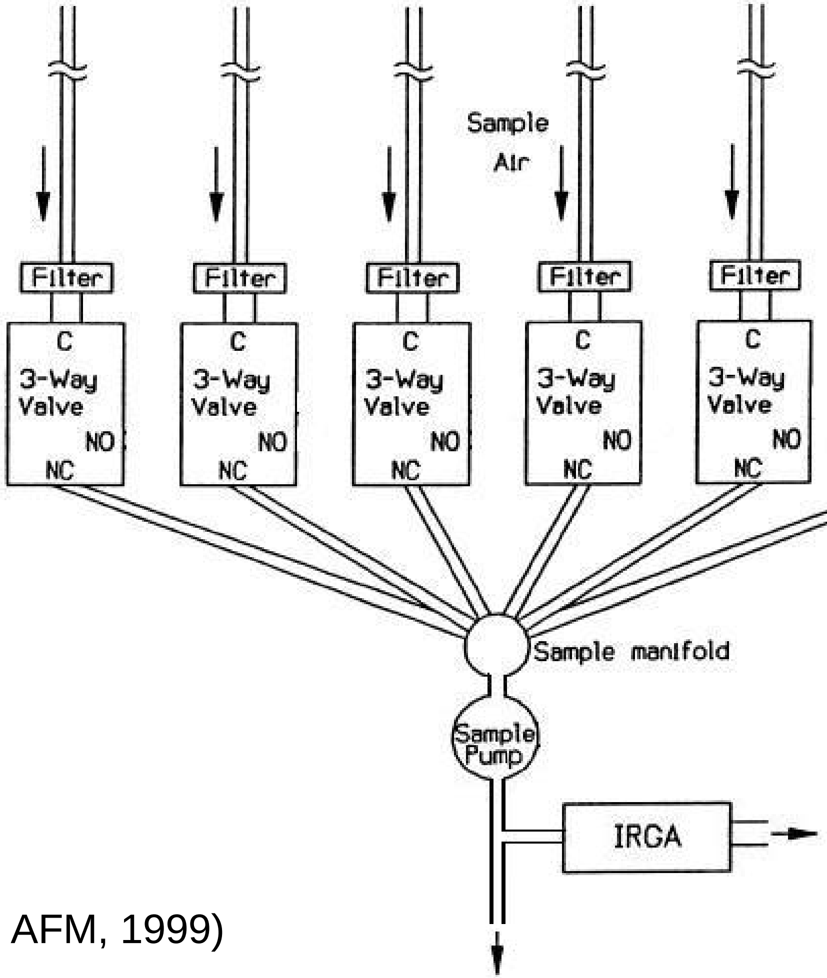
What is the sampling uncertainty you accept ?

⇒ Number of inlet points

In practice : 10 to 20 inlets/analyser with 5-10 measurements/half-hour
on each inlet point

Technical description

Tubing



(modified after Xu et al., AFM, 1999)

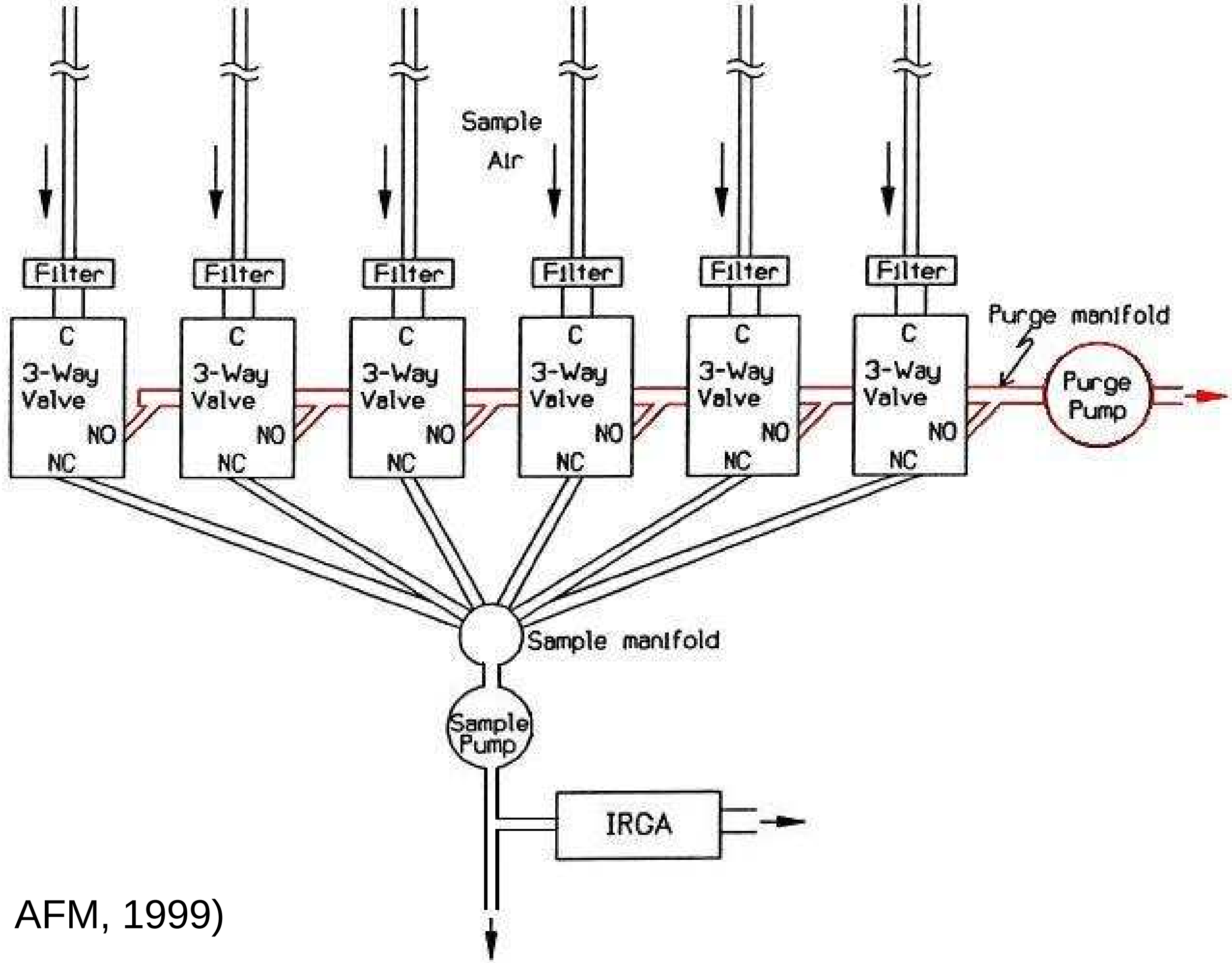
Technical description

Tubing

- Use of a purge pump allows to reduce the flushing time (paths upstream of the valves are constantly flushed)

Technical description

Tubing



(modified after Xu et al., AFM, 1999)

Technical description

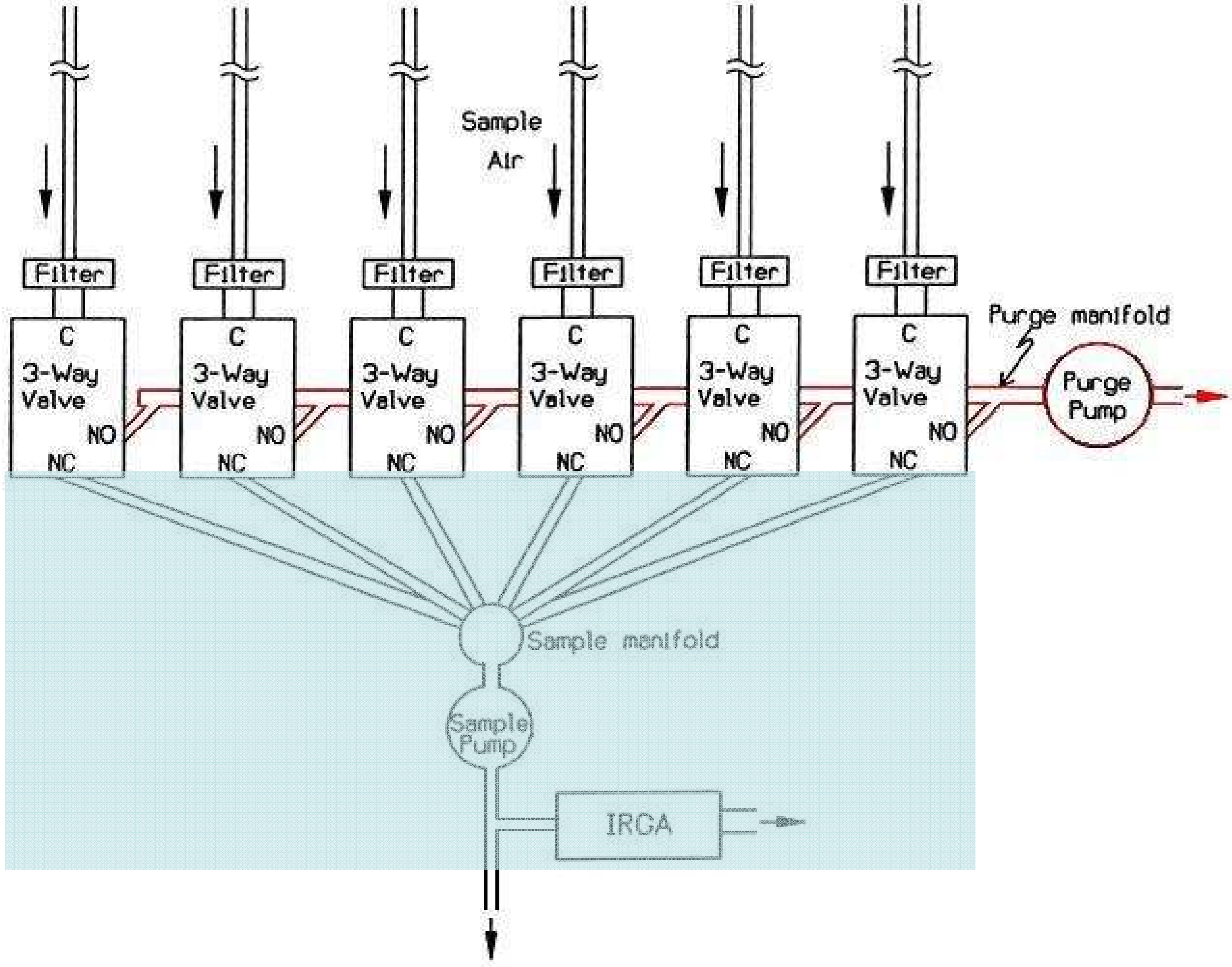
Tubing

- Use of a purge pump allows to reduce the flushing time (paths upstream of the valves are constantly flushed)

- Physical regroupment of valves and IRGA allows to minimise flushing time (paths downstream of the valves – typical values < 10 s)

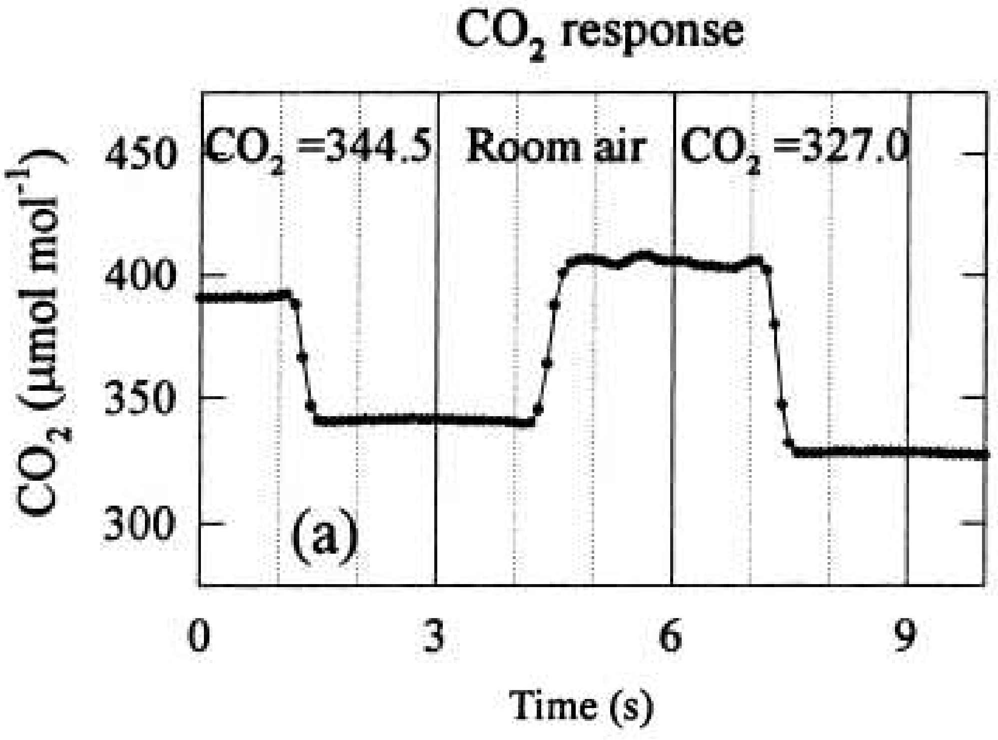
Technical description

Tubing



Technical description : flushing time

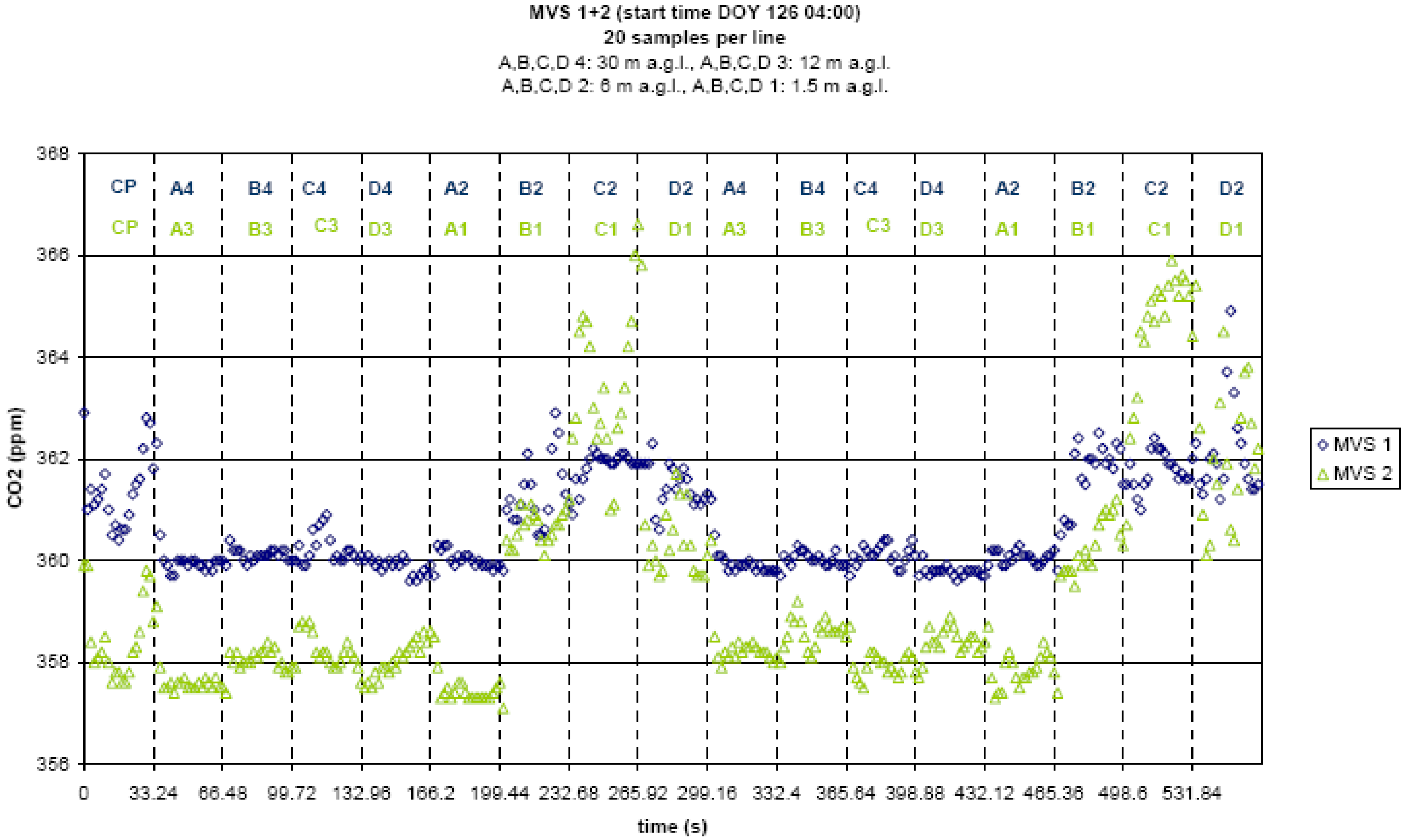
Estimating the flushing time is crucial to avoid contamination of one sampling by the previous one



(Xu, AFM, 1999)

Technical description : flushing time

Estimating the flushing time is crucial to avoid contamination of one sampling by the previous one



MVS 1+2 (start time DOY 126 04:00)
20 samples per line
A,B,C,D 4: 30 m a.g.l., A,B,C,D 3: 12 m a.g.l.
A,B,C,D 2: 6 m a.g.l., A,B,C,D 1: 1.5 m a.g.l.

(Feigenwinter, Boulder workshop, 2006)

Technical description

Tubing

- Use of a purge pump allows to reduce the flushing time (paths upstream of the valves are constantly flushed)
- Physical regroupment of valves and IRGA allows to minimise flushing time (paths downstream of the valves – typical values < 10 s)
- Use of the same tube length for all the lines uniformise flow rates and minimise pressure differences
- Careful check of possible leakages have to be made
- Choice of material for tubing can be important

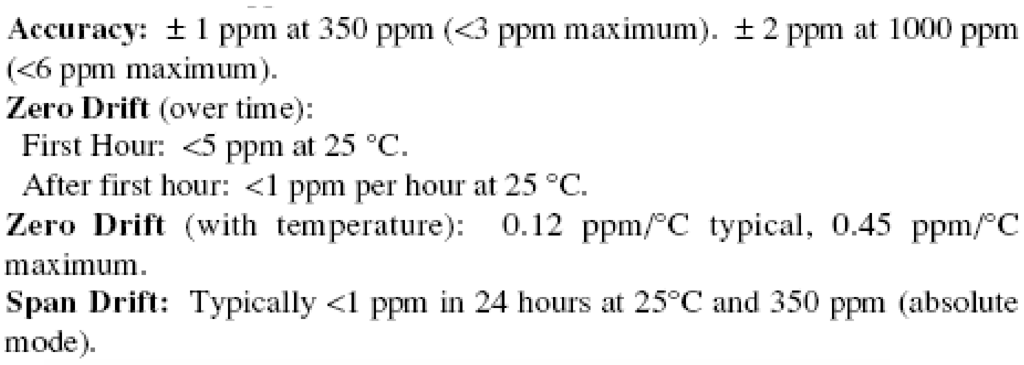
Technical description

Analysers

Measurement is influenced by temperature, pressure and water-vapour content in the IRGA chamber. The chosen type of IRGA must be able to correct for these effects.

Pressure differences between lines are the principal potential cause of systematic error.

LICOR 6262 :


Accuracy: ± 1 ppm at 350 ppm (<3 ppm maximum). ± 2 ppm at 1000 ppm (<6 ppm maximum).

Zero Drift (over time):
First Hour: <5 ppm at 25 °C.
After first hour: <1 ppm per hour at 25 °C.

Zero Drift (with temperature): 0.12 ppm/°C typical, 0.45 ppm/°C maximum.

Span Drift: Typically <1 ppm in 24 hours at 25°C and 350 ppm (absolute mode).

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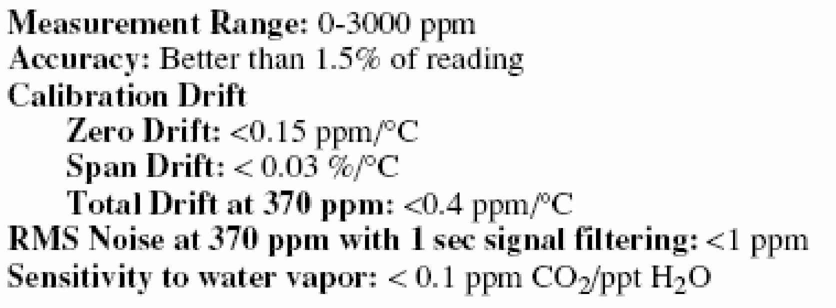
35

LICOR 840 :


Measurement Range: 0-3000 ppm
Accuracy: Better than 1.5% of reading
Calibration Drift
Zero Drift: <0.15 ppm/°C
Span Drift: < 0.03 %/°C
Total Drift at 370 ppm: <0.4 ppm/°C
RMS Noise at 370 ppm with 1 sec signal filtering: <1 ppm
Sensitivity to water vapor: < 0.1 ppm CO_2/ppt H_2O

Technical description

Intercomparison of IRGA

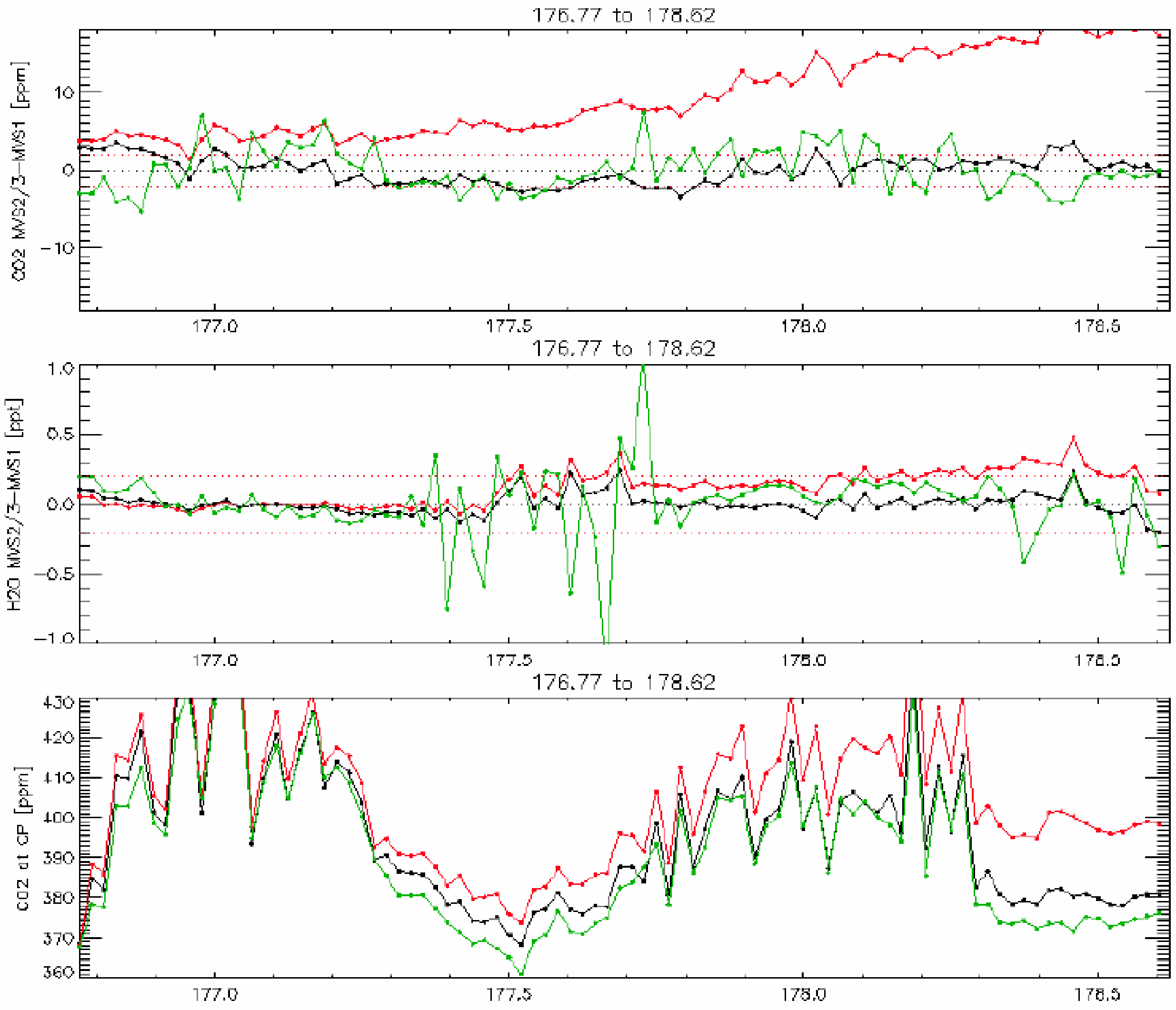
If more than one IRGA is used, intercomparison of IRGA is necessary through simultaneous measurements on co-located inlet points.

Allows to correct for zero drift, temperature and pressure dependence, water sensitivity

adjustment of multiple IRGA measurements

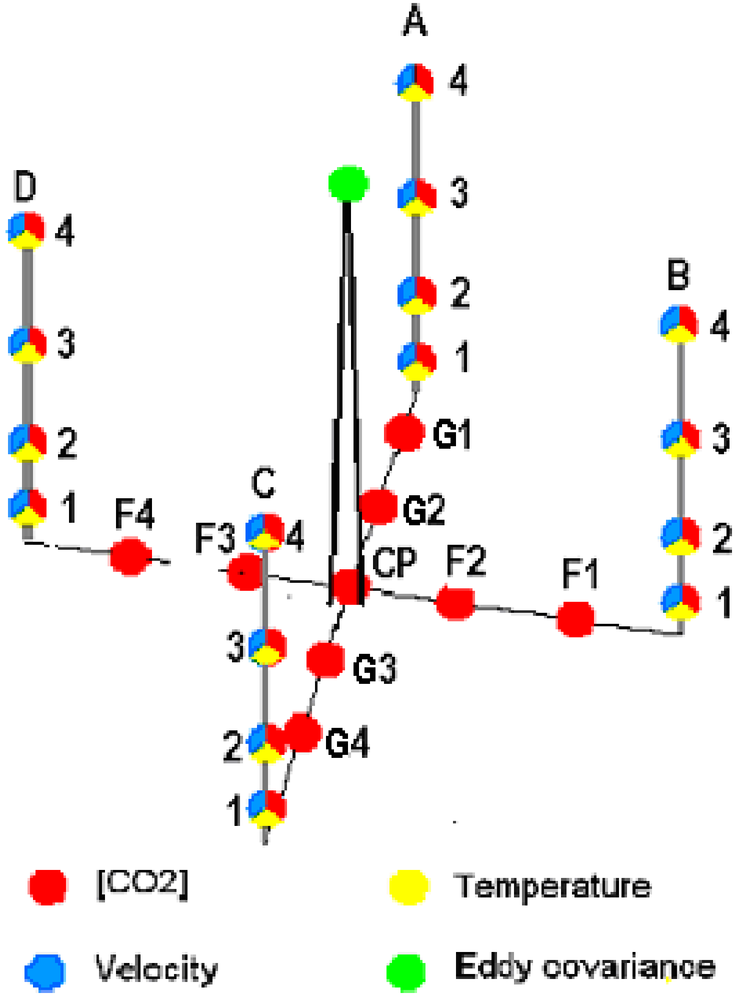
Common point measurements

ref Li 6262 (MVS 1)
🟥 Li 6262 (MVS 2)
⬛ Li 6262 (MVS 2) adj.
🟩 Li 7000 (MVS 3) adj.



(Feigenwinter, Boulder workshop, 2006)

In case of several IRGA, try to make the measurements of the horizontal gradients at a given level with the same IRGA.



Other sampling strategies

$$\int_0^{h_{eco}} \left(\bar{u} \cdot \frac{\partial \bar{c}}{\partial x} \right) \cdot dz$$

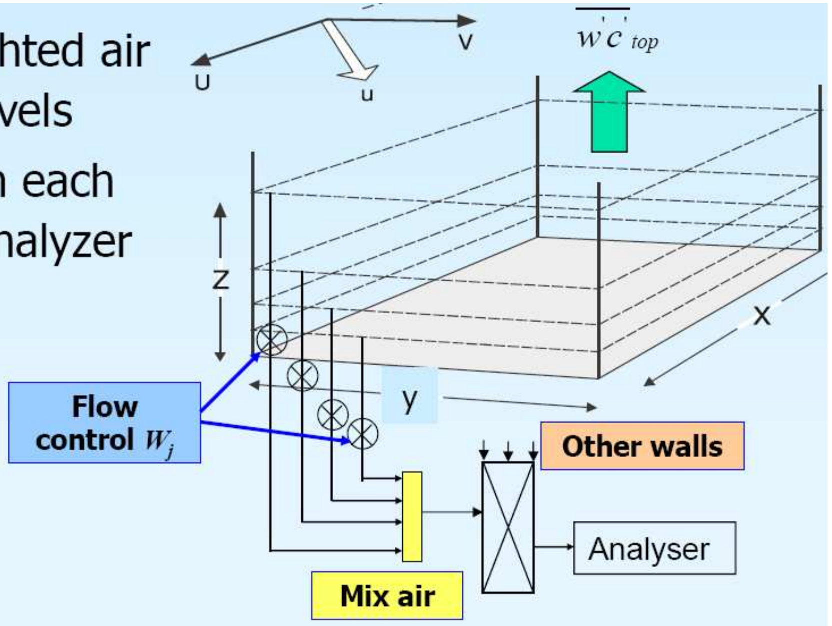
Horizontal advection:
shape & sample weighting factors

$$S(z) = u(z)/u_h = v(z)/v_h$$ Shape factor

$$W_j = S(z)\Delta z$$ Weighting factor

$$F_{adv,hor} = \frac{\bar{c}_d \bar{u}_h}{L}\left[\sum_{j=1}^{6} W_j \overline{\chi}_{c\,yz,j} \Big|_L - \sum_{j=1}^{6} W_j \overline{\chi}_{c\,yz,j} \Big|_0 \right] + \frac{\bar{c}_d \bar{v}_h}{L}\left[\sum_{j=1}^{6} W_j \overline{\chi}_{c\,xz,j} \Big|_L - \sum_{j=1}^{6} W_j \overline{\chi}_{c\,xz,j} \Big|_0 \right]$$

- Mix flow-weighted air (W_j) from 6 levels
- Pump air from each wall to gas analyzer



(Leuning, Boulder workshop, 2006)

Other sampling strategies

(Leuning, Boulder workshop, 2006)

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