UNIVERSITY OF BAYREUTH

Department of Micrometeorology

# ATEM Software
# for
# Atmospheric Turbulent Exchange Measurements
# using Eddy Covariance and
# Relaxed Eddy Accumulation Systems
# and
# Bayreuth whole-air REA system setup

**Johannes Ruppert**

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Universität Bayreuth, Abteilung Mikrometeorologie
D-95440 Bayreuth

# Contents

# 1 Introduction

The ATEM software is a LabView® based program package designed to record and manage data of Atmospheric Turbulent Exchange Measurements. Besides recording the raw data of an eddy covariance (EC) system, it is capable of calculating turbulence statistics online. The online assessment of the turbulent exchange is needed for air sample collection with a relaxed eddy accumulation (REA) system (Businger and Oncley 1990). Calculating statistics for the vertical wind velocity (w) and a fast measured scalar (s) used as proxy for the scalar of interest (conditional air sample) allow to further apply a modification of REA, the hyperbolic relaxed eddy accumulation method (HREA) proposed by (Bowling, Delany et al. 1999).

In order to correctly select updraft and downdraft air samples with a REA system, special attention needs to be paid to all time delays in the data processing and handling starting from the actual measurement of air and wind properties and ending with the direction of air samples in the REA reservoirs by valves. As sample selection has to be made on-line with only a short delay in the tube transporting the air to the valves, possibilities of post processing the data for REA measurements are much more limited than for EC data. However by accurately monitoring all events influencing the REA air sample collection, the ATEM software assures that possible failures or errors in the sampling procedure can be identified later. This allows detailed assessment of the quality of the REA measurements.

A second software for the control of two trace-gas profile systems called ATEM_profile_hydra is based on ATEM and the structure, time and data management are equal or at least very similar. This documentation contains notes about ATEM_profile_hydra at points where it seems important.

## 1.1 Instrumentation and Communication

The input to the ATEM software was designed for an eddy covariance system consisting of a METEK-USA-1 sonic anemometer and a LiCor LI7500 open-path $CO_2$ / $H_2O$ detector (see also chapter 4). However, the subroutines reading the RS232 serial input to the computer running ATEM are easily adjusted to other instruments and systems. Refer to the manufactures information on RS232 serial data output, to design a corresponding input routine.

The ATEM_profile_hydra software represents such an adjustment. It was designed to read the data from a LiCor LI820 and a LiCor LI7000 closed path sensors and to manage valve switching in vertical and horizontal $CO_2$ profile systems.

## 1.2 RS232 serial and D I/O communication

ATEM is continuously reading two serial inputs (COM 1 = sonic anemometer or LI 820, COM 2 = open path sensor LI7500 or closed path sensor LI7000)

The digital output can be directed to any output device that can communicate with LabView ®.

In ATEM a subroutine for the digital output and analog input reading is designed to communicate with a BMC PCI 20TR DAQ card. ATEM_profile_hydra has a subroutine for a BMC USB memPIO DI/O module. Again, other subroutines for other devices can be developed and integrated into the software (see also next chapter).

Refer to manufactures manuals to install devices and setup serial communication correctly.

The serial input expected by the existing serial reading subroutines is listed below.

### *1.2.1 USA-1 serial reading.vi*

| | |
|---|---|
| Serial port | COM 1 |
| Baudrate | *19200* |
| Line termination character | A =0xA = '\n' = LF = linefeed |
| expected data line format | M:x =%d y =%d z =%d t =%d |
| Execution interval<br>(retrieval of data if available) | Every 20 ms |

%d stands for a decimal integer format number

### 1.2.2 LI7500 serial reading.vi

| | |
|---|---|
| Serial port | COM 2 |
| Baudrate | *38400* |
| Line termination character | A =0xA = '\n' = LF = linefeed |
| Data string from LiCor 7500 OP: | *Ndx*<br>*DiagVal*<br>~~*(CO2raw)*~~<br>*CO2D*<br>~~*(H20raw)*~~<br>*H20D*<br>*Temp*<br>*Pres*<br>*Aux*<br>*Cooler* |
| expected data line format | %d %d %f %f %f %f %f %f<br>space delimited |
| Execution interval<br>(retrieval of data if available) | Every 20 ms |

%d stands for a decimal integer format number, %f stands for a floating point format number

### 1.2.3 LI820 serial reading.vi

| | |
|---|---|
| Serial port | COM 1 |
| Baudrate | *9600* |
| Line termination character | A =0xA = '\n' = LF = linefeed |
| expected data line format | <li820><data><celltemp>%f</celltemp><br><cellpres>%f</cellpres><co2>%f</co2><br><co2abs>%f</co2abs><ivolt>%f</ivolt><br><raw>%d,%d</raw></data></li820> |

### 1.2.4 LI7000 serial reading.vi

| | |
|---|---|
| Serial port | COM 2 |
| Baudrate | *9600* |
| Line termination character | A =0xA = '\n' = LF = linefeed |
| Data string from LiCor 7000, | *Cellpress*<br>*Celltemp*<br>*Co2a*<br>*Co2b*<br>*Co2d*<br>*H2oa*<br>*H2ob*<br>*H2od*<br>*DiagVal*<br>*Estimated flow* |
| expected data line format | DATA%f %f %f %f %f %f %f %f %f %f<br>space delimited |

### 1.2.5 R3 serial reading.vi

| | |
|---|---|
| Serial port | COM 1 |
| Baudrate | |
| Line termination character | |
| Data string from R3 | R3 continuous mode raw data format |
| expected data line format | |
| Execution interval<br>(retrieval of data if available) | Every 20 ms |

### 1.2.6 BMC PC20TR DAQ card

The Analog In and Digital Out commands of the ATEM software are designed to work with the BMC PC20TR Data Acquisition card in connection to the Bayreuth whole-air REA system (see chapter 4).

**PC20TR Digital out und PC20TR ANALOG IN**

<table>
<tr><td>Port</td><td>PCI</td></tr>
<tr><td rowspan="2">Connection to REA system electronic box</td><td>Digital I/O connector (Channel 1…16)<br>V1…V10, Pump1…Pump5, Pump dir<br>Execution interval<br>(from within ATEM timing)<br>100 ms<br>if port setting (=channel 1…16) changed</td></tr>
<tr><td>Analog Input connector (Channel 1…4)<br>Reading MFM1, MFM2, Pressure, Stop<br>Analog Input Execution interval<br>(retrieval of data if available)<br>Every 20 ms</td></tr>
</table>

### 1.2.7 BMC USB memPIO

The ATEM_PROFILE_HYDRA software is designed to work with the BMC USB mem PIO digital out/input module connected to the Bayreuth trace-gas profile system.

| Port | USB |
|---|---|
| Channels 0-9 | Vertical profile system<br>*H1-H8, H9=CAL1, H10=CAL2* |
| Channels 10-22 | HYDRA system (NCAR, Boulder)<br>*S1-S9, CAL1, CAL2, CAL3, Sx* |

# 2 ATEM setup

The ATEM setup routine reads and writes information needed for program initialization and data management from and to ATEM initialization files (.ati) and to the joint settings global variable file, which contains the settings used by the different ATEM programs and subroutines.

## 2.1 Setup ATEM filenames

Files are created using the information on

*Path to data folder,*
*authors initials,*
*experiment ID,*
A 4 digit *file number* needed for TK2 evaluation
and a *file extension* (.atd = AT EM raw data).

*Filename = author initials+date_time_experiment ID_file number.file extension*

## 2.2 Example for .ati file

.ati files are simple text files containing initialization variable names and values tab separated. You can create them with a text editor or by starting ATEM setup, cancel .ati file reading, continue without settings (several times) and than enter and save new values within ATEM setup:

```
data_directory	H:\data
experiment_id	GRASATEM03_rea
authors_initials	jr
file_no	443
data_file_extension	.atd
pump12_when_locked	0
bag_1_samples_direction	1
ES_duration	35.000000
sampling_frequency	10.000000
op_delay	2
start_filter_calc	4
delay_for_valve_switching	7
filter_length	3600
weighting_function	linear
weighting_function_k	0.500000
wind_hyp_deadband	1
H	1.100000
D	0.600000
planar_fit_rotation	1
p31	-0.013971
p32	-0.019295
p33	0.999749
b0	-0.026000
```

usa1_serial_reading jr USA1 serial reading.vi
li7500_serial_reading jr LI7500 serial reading.vi
daq_card_reading jr PC20TR analog in reading.vi
flush_bags_and_flasksjr flush bags and flasks.vi
eddy_sampling jr eddy sampling.vi
transfere_sample_from_bag1 jr transfere sample from bag 1.vi
transfere_sample_from_bags_to_flasks jr transfere sample from bags to flasks.vi
manual_set jr pc20tr manual set new.vi

## 2.3 Setup ATEM timing

*ES duration [min]* determines when the eddy sampling subroutine automatically stops the sampling procedure. You always can stop the procedure earlier by stopping the subroutine by hand, if necessary. So, the value should be adjusted to the maximum duration expected for eddy sampling (e.g. *40* [min])

*Sampling frequency [Hz]* is adjusting the main sequence loop duration (wait for multiple ms command) in the ATEM software. E.g. a value of *10* Hz makes the main sequence start every 100 ms. All other procedures included in the main sequence like data retrieval and digital output for valve switching are executed once during this 100 ms interval. All letter values reported here regarding the ATEM timing program assume a *sampling frequency* of *10 Hz*

*OP delay [intervals]* determines, to which position in the data array the data coming from the open path instrument is inserted. A value of *2 intervals* means, that the data is put alongside sonic data that is 200 ms old. Use this setting with the Licor 7500 open path $CO_2$ / $H_2O$ sensor in order to compensate a delay due to signal processing between the actual measurement and the RS232 data output (e.g. with a setting of 11 additional delay intervals 138…197 ms, for more details refer to LiCor customers information letter from July 2003)

*Start filter calculation [intervals]* must be set to an interval, in which all data needed for REA air sampling and setting the valves are already present. In REA the valves are set according to the value and sign of vertical air movement. HREA additionally requires the assessment of the value of a proxy scalar used to determine "significant" contributions to the turbulent exchange of the scalar of interest. When open path data is used as proxy scalar *Start filter calculation* needs to be equal or larger than *OP delay*. A default value lying between the usual delay of sensors and the delay of the air sample during transport in the tube is *4 intervals*.

*Delay for valve switching [intervals]* adjusts the actual digital output command driving the valve switching according to the delay of air samples in the tube transported from the inlet of the REA system close to the sonic anemometer to the valves in the REA system. With a *sampling frequency* of *10 Hz* a value of *8 intervals* is equal to a *delay for valve switching* of 800 ms. The actual delay can be determined by a delay experiment, e.g. by performing a differential measurement between REA system inlet und valves based on cross-correlation of a scalar and vertical wind velocity.

Note that during the interval, when a valve is actuated, the ATEM software sets the *event code* and *valves* accordingly. However, this data is inserted to the array at postion 0 like other ‘new measurements’ and therefore appears together with new wind data in the ATEM raw data output (.atd). The *event code* detecting the direction of the sample in an up or down reservoir is related to wind measurements, which are stored e.g. *8 intervals* earlier in the raw data output.

For more detailed information on the ATEM timing refer to the corresponding chapter for this program part and the Excel file: ATEM timing diagram v7.xls

## 2.4 Setup ATEM filter

*Filter length [s]* sets the length of the history of measurements used to calculate means and standard deviations. Be careful with using long filter length, as the recalculation during every interval may lead to interval delays, if the processing time is too long.

In order to allow longer histories of the statistics, a counter was introduced to the ATEM timing main sequence. Instead of every interval the statistics would only be recalculated every 10$^{th}$ interval. However, this option had problems during operation. During the GRASATEM-2003 and WALDATEM-2003 experiments (and with all ATEM program versions from this expermint) the counter did not work due to a wrong logical operation (frame 1 of ATEM timining main sequence, reverse >= to <). Watch if the counter is running correctly during program operation on the front panel. Even with the counter running correctly, limitation in processing time may require, to keep the filter length limited. Watch for interval delay errors. Values of 1800 and 3600 (corresponding to 3 min. and 6 min. without active counter) did not show problems during GRASATEM-2003 and WALDATEM-2003.

*Weighting function* and *k* are form the shape of the weighting function. The slope of the function determines the relative weighting of samples for the calculation of means and standard deviations. These statistics are used to assess, if an air sample shall be sampled or not during REA sampling.

Three different functions can be used:

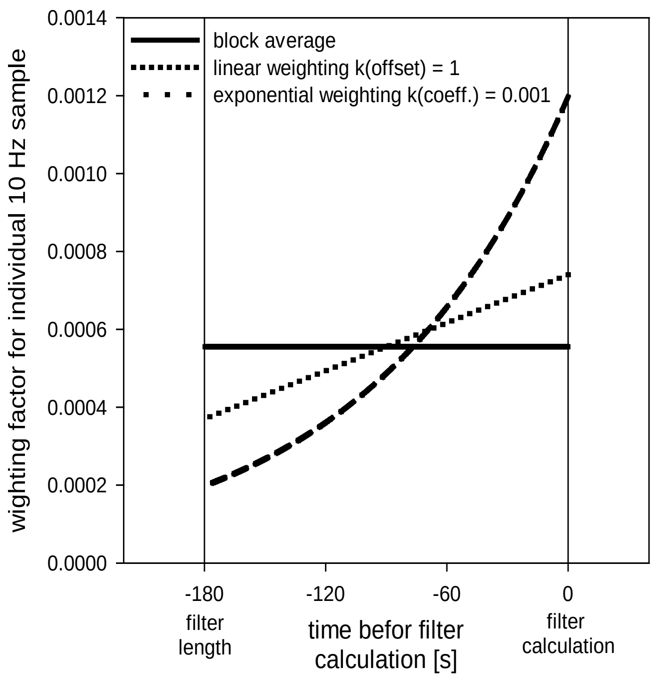
*block* = block average,  all samples are weighted equally

l*inear* = newer samples get more importance than older samples with a linear decrease of the weighting factors. Use the value *k* to add an offset to the weighting function.

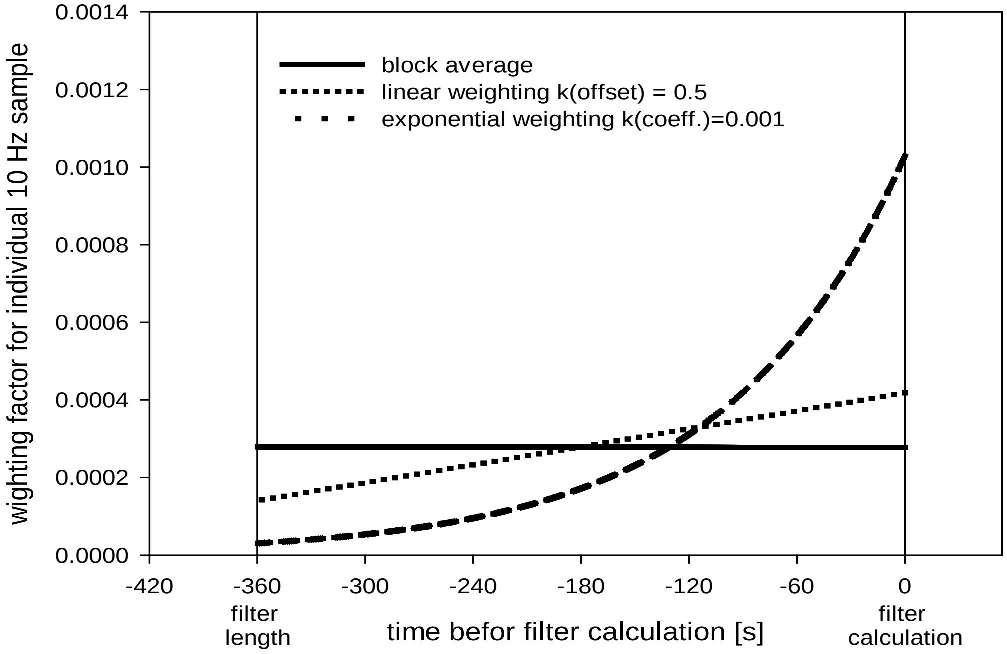
*exponential* = newest samples are the most important when calculating the mean, with an exponential decay of the weighting factor for older samples determined by the *k* value.

A block average corresponds to the weighting in EC data processing, which is the reference for the REA method. However, often an exponential filter is used in REA to give more weight to recent samples and decrease the influence of extraordinary values, which occurred longer ago. A linear filter with an offset is providing an intermediate between the two weighting strategies.

Example 1: GRASATEM-2003 May, 21st and May, 22nd



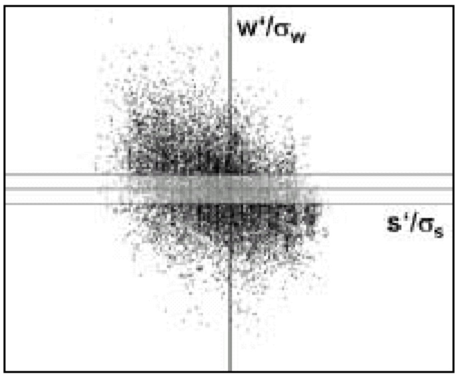
Example 2: GRASATEM-2003 since May, 22nd, 8:00 h



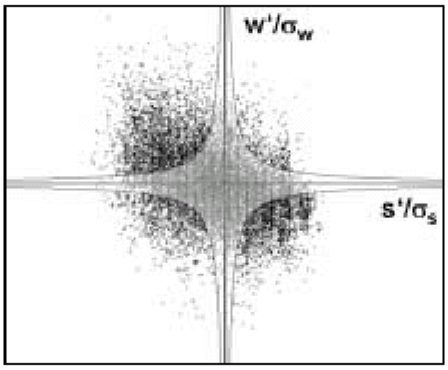

## 2.5 Setup deadband

A switch (*wind or hyperbolic deadband*) allows to select either a wind-deadband or hyperbolic deadband.

$$\left|\frac{w'}{\sigma_w}\right| \leq D$$



$$\left|\frac{w' \cdot s'}{\sigma_w \cdot \sigma_s}\right| \leq H$$




Accordingly the values for *D* and *H* can be set. Air samples are taken, when the corresponding expression shown above is not true. Only then the measurements lie out of the deadband and indicate that the air exchanged at the tube inlet was ‘significantly’ contributing to turbulent exchange. For a detailed comparison of REA and HREA sampling strategies refer to (Bowling, Delany et al. 1999; Ruppert, Wichura et al. 2002).

## 2.6 Setup planar fit matrix

For the calculation of the mean vertical wind velocity you can introduce a planar fit rotation to the vertical wind velocity data (*z*). The planar fit rotation matrix (*p31, p32, p33* and *b0*) must be determined beforehand from data with the same system setup. Online planar fit rotation is performed when copying the raw data vertical wind velocity (*z*) to the REA data (*w*).

## 2.7 Setup subroutines

(Situated on the ATEM setup front panel below the blue box in the window, only for new developments for data input and output or changes in the subroutines for air sample handling)

Subroutines for the serial data reading are called from the ATEM timing main program at startup. You can change to other subroutines by changing the names in ATEM setup. Use the source code of existing subroutines for new developments.

A subroutine called *eddy sampling* sets can be started from the front panel of the main sequence and sets *joint control* variables, so that ATEM timing is transferring the commands for valve switching to the digital output.

Also the transfer of samples from bag reservoirs into glass flasks is organized in a separate subroutine that can be started after sampling dynamically from the ATEM timing front panel.

# 3 ATEM timing, main program sequences

The main sequence in the ATEM timing program assures a stable execution interval according to the *sampling frequency [Hz]* set in ATEM setup by relying on the LabView ® “wait for multiple ms” function.

The timestamp (*time_string*) is generated from the computer clock reading and is rounded to the nearest full 100 ms multiple. Any delays in the sequence start are recorded as "*interval delay*" in the *error code.* The latest sonic and open path data are retrieved from the global variables in ATEM joint control every 100 ms and stored in an array, which is cycled by on position during each interval.

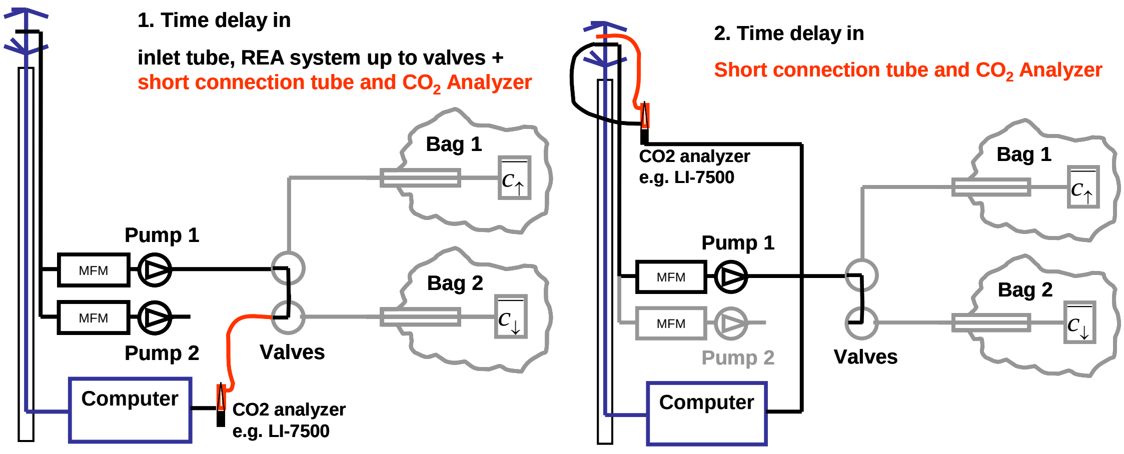
As correct timing is the most crucial aspect in REA sampling, special care was taken to all aspects related to the transfer of data from the sensor to the data in memory and data in the file. See flow charts below and refer to the file ATEM timing diagram v7.xls for more detail.

The largest uncertainty (+/- 100 ms at 10 Hz sampling frequecy) results from the uncertainty related to the time between actual measurement of air and wind properties and the data availability at the RS232 ports. This is a result of different clocks being used in each sensor and the computer and can only be avoided, if either sensors send exact time stamps together with the data or all clocks are exactly synchronized or measurements are polled.

Time shifts between the data can easily be corrected in raw data for EC flux calculations. REA sampling requires fast online evaluation of the data. In order to assure the best possible synchronization in REA, a **time delay experiment** has to be performed before the actual REA measurements. The REA-system design (tube, valve and pump inner volumes) and flow rates need to be controlled and kept constant at the same rates during the ‘time delay experiment’ and during the actual REA measurements. Time delay of the sample in the tube from the sampling inlet up to the valves can be determined by cross correlation of the vertical wind velocity (z, w) and a scalar (e.g. $CO_2$). As any $CO_2$ Analyzer will add internal volume and therefore time delay to the system, a differential measurement must be performed. This means measuring the time delay of

1. inlet tube, REA system up to the valves plus the short connection tube and $CO_2$ Analyzer and

2. short connection tube and $CO_2$ Analyzer only. (see foto in Appendix)




During the first part of the time delay experiment both pumps in the sampling line (pump 1) and in the bypass (pump 2) have to be running at the same flow rate that will be used later during REA measurements. In order to determine the corresponding time delay of the connection tube and $CO_2$ Analyzer, in the second part of the experiment only the flow rate of the sample line provided by pump 1 is needed.

In both parts of the experiment the time shift yielding the maximum cross correlation gives the corresponding time delay. The time delay in the REA system up to the valves and in the inlet tube including additional flow through the bypass with pump 2 is then determined as the difference in time delay measured in both parts of this experiment. By measuring the time delay with this kind of experiment we are able to correct for any delay resulting from the actual experiment setup like it will be used for the measurements in the field. The precision of the measured time delay is only limited by the time resolution of the data record (e.g. 0.1 s corresponding to 10 Hz measurements) and very short delays in data transfer (< 0.1 s). During REA measurements additional delays for valve switching should be kept as short as possible (< 0.1 s).

For all REA measurements it is essential that flow rates through the sample line and the bypass will be kept at the same rate. In our system both flows are monitored by low pressure drop mass flow meters (MFM) and pumps are kept at very steady flow rates using a DC pulse width power supply unit. Tests with mass flow controllers (MFC) were not able to keep flows as constant. The reason was that bigger membrane pumps needed to provide a higher pressure drop at the control valve, introduced more fluctuation in the flow rate.

Slightly reduced covariance between vertical wind velocity (z, w), the scalar of interest (air sample, e.g. $^{13}C$, s) and the proxy scalar ($CO_2$, s_proxy) can result from uncorrected small time shifts. However, in whole-air REA the measurement of multiple gases in the REA updraft and downdraft samples allows to measure the proxy scalar ($CO_2$) additionally to the scalar of interest ($^{13}C$) in the updraft and downdraft air samples. Any reduction in covariance between the air sample and the vertical wind velocity would influence updraft and downdraft values for both scalars in the same way as long as we observe scalar similarity. Therefore, when calculating individual b-factors for each REA measurement from the proxy scalar EC flux results, slightly reduced covariance due to small time shifts during the REA sampling are compensated correctly.

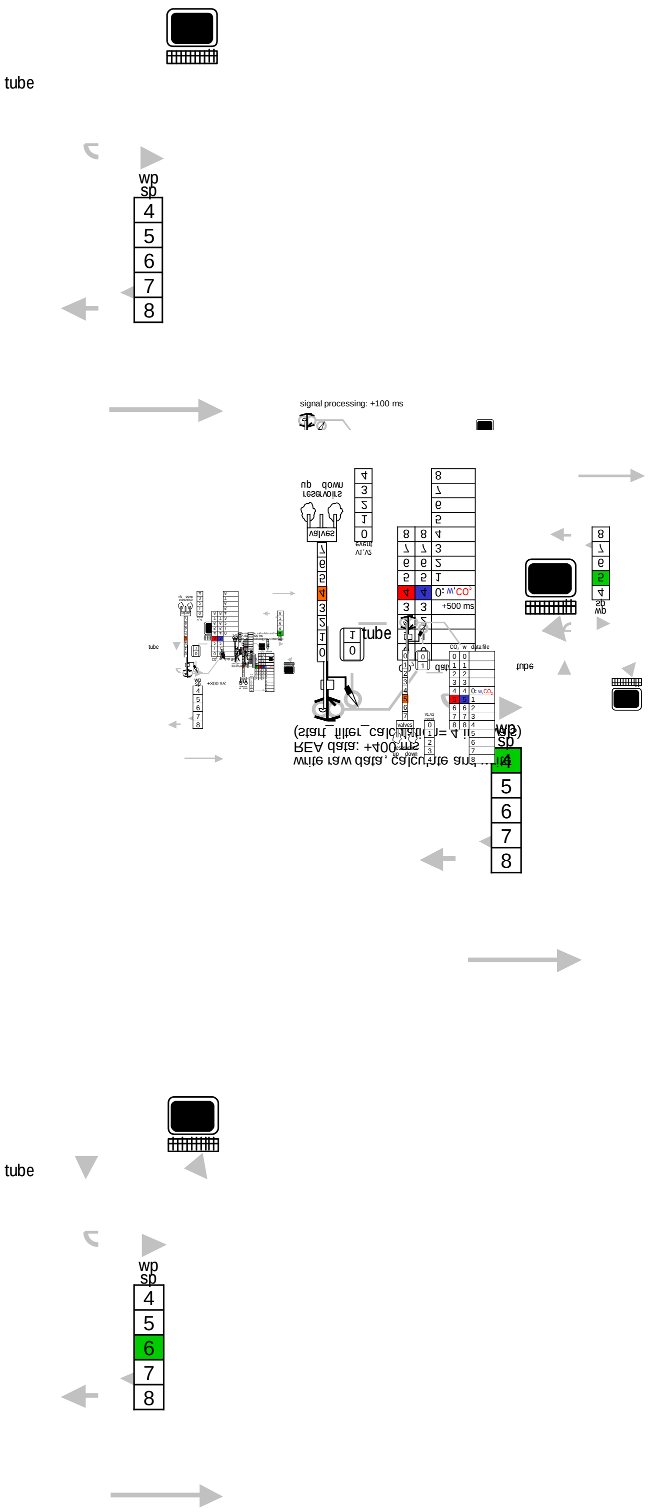
## 3.1 Procedures within one sampling interval

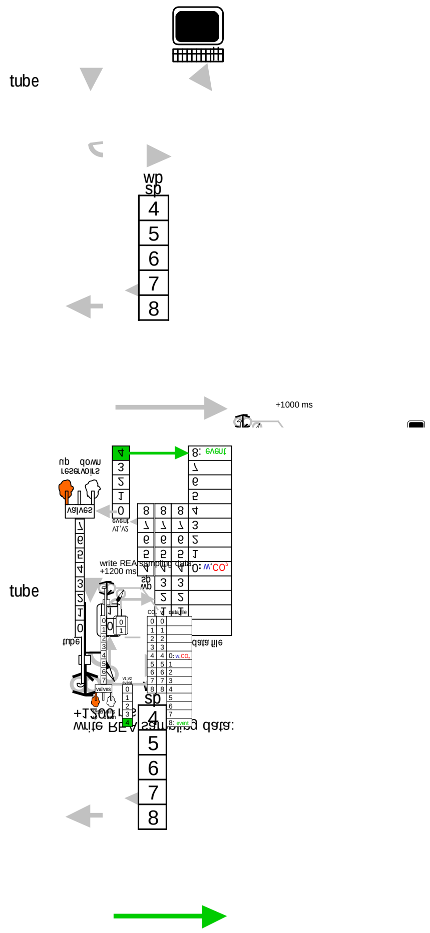
ATEM setup:
*sampling frequency = 10 Hz =100 ms intervals*
*open path delay = 2 intervals*
*start filter calculation = 4 intervals*
*tube delay = 8 intervals*

| | |
|---|---|
| **Timing** | ... Wait for multiple ms stopped |
| **Timing** | generate new timestamp |
| **Valves** | set Digital output according to V1, V2 |
| **raw data** | generate error and event code |
| | cycle raw data arrays |
| | insert latest sonic data in x,y,z,ta(0) |
| | insert latest open path data in co2(2), h2o(2) |
| | insert error(0),event,valve,mfm1,mfm2(0) |
| **REA data** | cycle REA data arrays |
| | planar fit rotate current z data and insert into w(0) |
| | insert current co2 data and instert into s(2) |
| | calculate mean, std |
| | calculate wp(4) from w(4), sp(4) from s(4) |
| | set V1, V2 according to wp(8-1) and sp(8-1) |
| **data rec** | write raw data from arrays(4) |
| | write REA data from arrays(4) |
| **Timing** | wait for multiple ms... |
| | |
| | |
| | |

see also ATEM timing diagram v7.xls

## 3.2 ATEM timing data handling and storage






## 3.3 Data storage

ATEM timing is transferring raw data and REA data as well as all information on the REA sampling process (valve switching, ….) to the .atd raw data file continuously. According to the settings on the ATEM timing front panel, a new data file is started e.g. every 30 min (= when the *time_string* section containing mm:ss.ss matches *00:00.00 or 30:00.00*). The file number contained in the filename is increased by 1.

.atd files are comma separated ASCII files using ten digits (5 before "." 4 after = %10.4f LabView® number format). They can be looked at with a text editor. Compression using e.g. Zip software reduces the size of files by ~ 90%.

**Example of an .atd raw data file (not all columns included):**

```
DOY       ,TIME        ,x          ,y          ,z          ,ta         ,co2        ,h2o        ,op_agc     ,error      ,event      ,
142       ,08:00:00.00,    1.8400,    3.8400,    0.3400,   14.5900,   15.6541,  421.3210,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.10,    1.2000,    3.9400,    0.7500,   14.8400,   15.6631,  421.9840,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.20,    0.8900,    3.7100,    1.0500,   14.6300,   15.6520,  426.3340,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.30,    0.0700,    3.3000,    0.6500,   14.7900,   15.6479,  428.0160,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.40,    0.1600,    3.7900,    0.2100,   14.7300,   15.6353,  426.8570,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.50,    0.4400,    3.9900,    0.5000,   14.7500,   15.6503,  423.8470,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.60,    0.9400,    4.8300,    0.2700,   14.7700,   15.6629,  424.2960,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.70,    0.4700,    4.5000,    0.0400,   14.9000,   15.6422,  419.3680,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.80,    0.3700,    4.8600,   -0.4900,   14.7500,   15.6533,  422.3110,   68.7500,    0.0000,   64.0000,
142       ,08:00:00.90,    0.6500,    5.1700,   -0.5600,   14.8200,   15.6458,  423.0380,   68.7500,    0.0000,   64.0000,
142       ,08:00:01.00,    1.0600,    4.6900,   -0.3100,   14.7400,   15.6561,  423.1490,   68.7500,    0.0000,   64.0000,
142       ,08:00:01.10,    0.0700,    4.5900,   -0.3000,   14.8500,   15.6366,  431.7080,   68.7500,    0.0000,   64.0000,
142       ,08:00:01.20,   -0.0700,    4.7100,    0.8100,   14.7500,   15.6397,  431.0730,   68.7500,    0.0000,   64.0000,
142       ,08:00:01.30,    0.3200,    4.7500,    0.7400,   14.9600,   15.6459,  423.6640,   68.7500,    0.0000,   64.0000,
```

## 3.4 Error code

ATEM timing converts the binary code shown below (0 = false, 1 = true, x = false OR true) to a decimal number, which then is stored in the .atd raw data file.

xxxxxxxxx1 = incorrect data from sonic

xxxxxxxx1x = error during sonic data conversion

xxxxxxx1xx = error during OP data conversion

xxxxxx1xxx = warning from OP diagnostic flag

xxxxx1xxxx = interval delay

xxxx1xxxxx = op_agc > 70%

xxx1xxxxxx = analog in reading error

xx1xxxxxxx = digital out error

x1xxxxxxxx = <not used>

1xxxxxxxxx = user flag

## 3.5 Event code

xxxxxxxxx1 = valve 1 set on

xxxxxxxx1x = valve 2 set on

xxxxxxx1xx = flush bags and flasks

xxxxxx1xxx = Eddy Sampling

xxxxx1xxxx = transfer bag 1 <not used>

xxxx1xxxxx = transfer bags 1+2 to flask 1+2

xxx1xxxxxx = ES system locked

xx1xxxxxxx = bag 1 samples up/down

x1xxxxxxxx = manual set

1xxxxxxxxx = event 10 <not used>

# 4 REA air sampling using the Bayreuth Whole-air REA system

The air sampling („eddy sampling“) is managed from subroutines running independently from the ATEM timing main sequence. However, they can be started from the front panel of the ATEM timing program. ATEM joint control serves as interface for the global variables exchanged between the different subroutines and the main sequence.

Before starting the *eddy sampling* procedure, first *flush bags and flasks* with ambient air to condition them to air, which is similar to the sample that will be stored in it.

At the beginning of each *eddy sampling* period, check and adjust the settings in ATEM setup. By continuously switching the definition of bag 1 as reservoir for either updrafts or downdrafts (*bag 1 samples up/down*) systematic errors originating from e.g. a small contamination in only one sampling path in the REA system can be avoided or at least detected.

An additional data file covering exactly the time of the eddy sampling is stored including the extension "_ES" in the filename instead of the file number.

After the sampling procedure, *transfer samples from bags to flasks.*

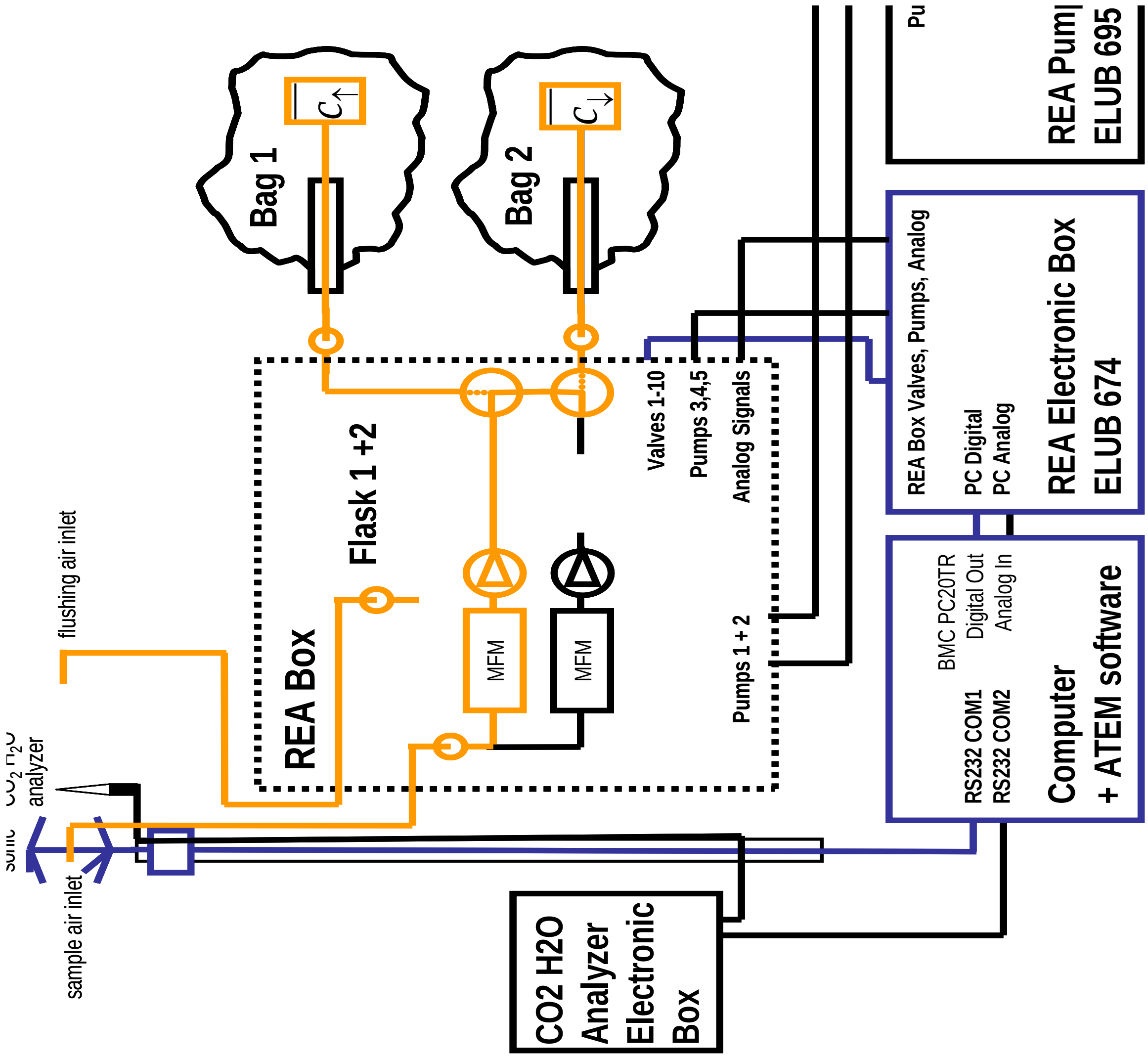
Depending on the pump voltages, pump performance and bag filling, time for the flushing and emptying may vary significantly. You can adjust the times in seconds in the corresponding subroutines on the front panel.

Note:

When using the Bayreuth Whole-air REA system with balloon bags as reservoirs always control the filling processes of the balloons and stop the eddy sampling process by either pushing the stop button on the REA system or stopping the ATEM eddy sampling subroutine. Balloon filling and emptying needs to be monitored also during the sample *transfer from bag to flask* and *flushing bags and flasks* procedures. Sampling, filling and flushing procedures can be stopped at any time by either stopping the corresponding subroutine (press stop button or next button) or pressing the stop button on the REA system box outside.

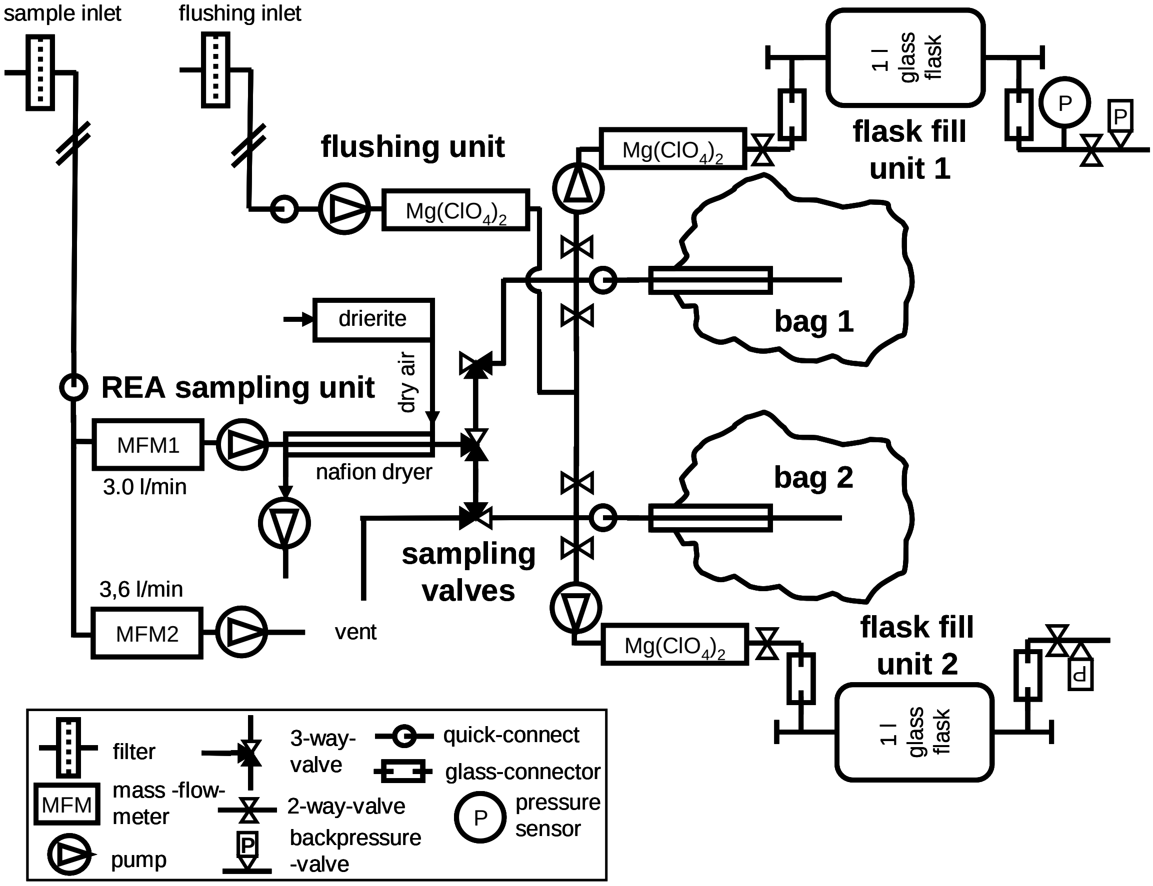
## 4.1 REA system connection setup

Pump 6 needs additional external 16…24 Vdc)



## 4.2 REA system technical components

| REA system part | company | type |
|---|---|---|
| filter | Gelman Sciences Inc., Ann Arbor, MI, USA | ACRO 50, 1.0 µm, teflon® (PTFE) |
| tubing in REA system | | stainless steel |
| inlet tubing | SERTO jacob GmbH, Fuldabrück, Germany | SERTOflex-6 |
| connectors | Swagelock, Solon, OH, USA | stainless steel fittinge<br>quick connects and ultra torr conectors<br>seals: viton® (FPM) |
| connectors | University of Bayreuth, Germany | stainless steel fittinge, seals: viton® (FPM) |
| mass flow meters (MFM1, MFM2) | Bronkhorst Hi-Tec B. V., Ruurlo, Netherlands | F-111C-HA-33-V, 6 ln/min. |
| pumps (P1, P3, P4,)<br>pumps (P2, P5) | KNF Neuberger GmbH, Freiburg, Germany | pump 1, 3, 4: N 86 AVDC, aluminium, viton® (FPM)<br>pump 2, 5: N 86 KVDC, ryton®, viton® (FPM) |
| pump (P6) | FÜRGUT, Aichstetten, Germany | pump 6: DC24/80S |
| nafion gas-dryer | Perma Pure Inc., Toms River, NJ, USA | MD-110-48S-4, stainless steel, nafion® |
| valves (V1, V2)<br>valves (V3, V4, V5, V6, V7, V8) | Bürkert, Ingelfingen, Germany | valve 1, 2 and dummy: 0330, 3/2 way solenoid valve, 3 mm orifice, stainless steel, viton® (FPM)<br>valve 3 to 8: 6011A, 2/2 way solenoid valve, 2.4 mm orfice, version for analytical applications, stainless steel, viton® (FPM) |
| bags (bag1, bag2) | Anagram International, Inc., Eden Prairie, MN, USA | mylar® foil balloons, 45 cm, circle (one bag reservoir consists of two balloons, each balloon is equipped with a stainless steel filler tube through the foil valve of the balloon) |
| drying traps | University of Bayreuth, Germany | magnesium perchlorate granulate in 200 mm x 20 mm ID glass tubes with viton® (FPM) seals |
| pressure sensor | Suchy Messtechnik, Lichtenau, Germany | SD-30, -1…+1.5 bar, stainless steel |
| backpressure valves | Riegler & Co. KG, Bad Urach, Germany | Sicherheitsventile DN 8 +0.5 bar, brass, viton® (FPM) |
| | | |
| pumps (profile system) | KNF Neuberger GmbH, Freiburg, Germany | NMP 830 KVDC, ryton®, viton® (FPM) |




# References


Bowling, D. R., A. C. Delany, et al. (1999). "Modification of the relaxed eddy accumulation technique to maximize measured scalar mixing ratio differences in updrafts and downdrafts." Journal of Geophysical Research D: Atmospheres **104(D)**(8): 9121-9133.

Businger, J. A. and S. P. Oncley (1990). "Flux Measurement with Conditional Sampling." Journal of Atmospheric and Oceanic Technology **7**: 349-352.

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# Appendix

**Example of Tube delay definitions**
**from GRASATEM-2003 and WALDATEM-2003**

All Values are given as number of sampling intervals (= number of data rows). With a sampling frequency of 10 Hz, the length of one sampling interval is 1/10 s. Numbers followed by * are the time lags showing a maximum cross correlation of a scalar signal ($CO_2$ density or event code) and the vertical wind velocity (w). Values in brackets indicate the second most frequent time lag found by evaluating maximum corss correlation for different intervals during a tube delay experiment.

| Experiment Period<br>Days of the year | GA1<br>141, 142 | GA2<br>144, 145 | GA3<br>150 | WA1 - 3<br>177, 179, 187<br>188, 189, 204 |
|---|---|---|---|---|
| Tube length | ~ 4 m | ~ 4 m | ~ 4 m | ~ 6 m |
| Sample air flow (MFM1) | 3.0 l/min | 3.0 l/min | 3.0 l/min | 2.58 l/min |
| Bypass air flow (MFM2) | 3.6 l/min | 3.6 l/min | 3.6 l/min | 3.6 l/min |
| | [1/10 s] | [1/10 s] | [1/10 s] | [1/10 s] |
| Physical tube delay differential measurement = (= 1. – 2., see chapter 3) | 8 | | 7 | 11 |
| 1. inlet tube, REA system up to the valves plus the short connection tube and $CO_2$ Analyzer and | 11 (12) * | | 11 * | 15-16 * |
| 2. short connection tube and $CO_2$ Analyzer only. | 3-4 * | | 4 (5) * | 4-5 * |
| REA settings (.ati file)<br>*delay_for_valve_switching*=<br>software delay used to match valve switching to the correct samples at valves V1 and V2 | doy 141: *8*<br>doy 142: *7* | *7* | *6* | *10* |
| Lag in data record:<br>ATEM_EVAL settings<br>*REA_valve_delay* =<br>used to match w, $CO_2$ data with valve switching recorded in the event code | doy 141: *8 **<br>doy 142: *7 ** | *7* | *6* | *10 ** |

# Note on physical delay vs. delay in data file

There is an **undefined additional delay of about 0.020 to 0.120 s**. This delay arises from the fact that physical measurement take place some time (about –0.020… -120 s) before the data is read from the serial port by the ATEM subroutines during the next cycle of the ATEM main sequence. A detailed analysis is given in “ATEM timing diagram v7.xls”. This delay is indicated in the figure below by the circle (physical measurement) and arrow (submitting data to the serial ports). The time reference 0 ms used here (also see chapter 3.2) corresponds to the start of the ATEM main sequence, in which the data is recived.

In order to **match the physical tube delay to valve switching** and to receive the correct **setting for the software delay (*delay_for valve_switching*)**, decrease the number of the measured physical tube delay by about 0.020… 0.120 s (at 10 Hz sampling frequency i.e. -1 interval, accounting for the additional delay described above). This value also determines the **lag of rows in the data file** between measured data and the event code.

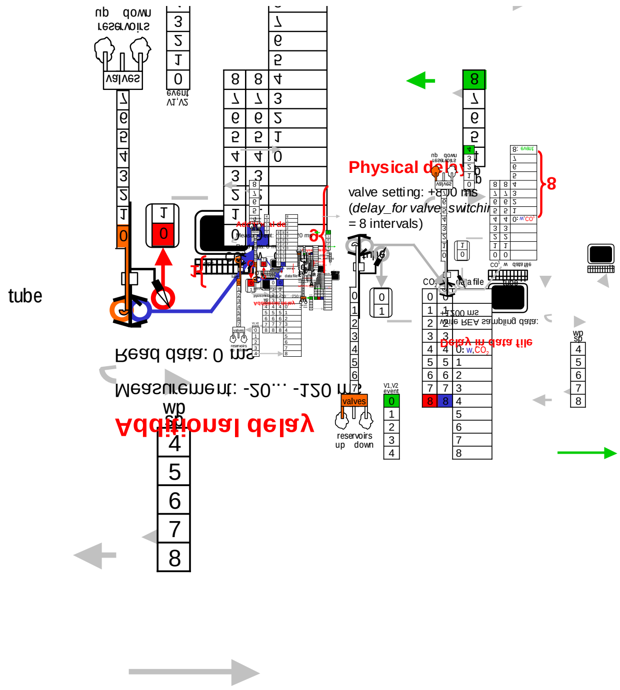
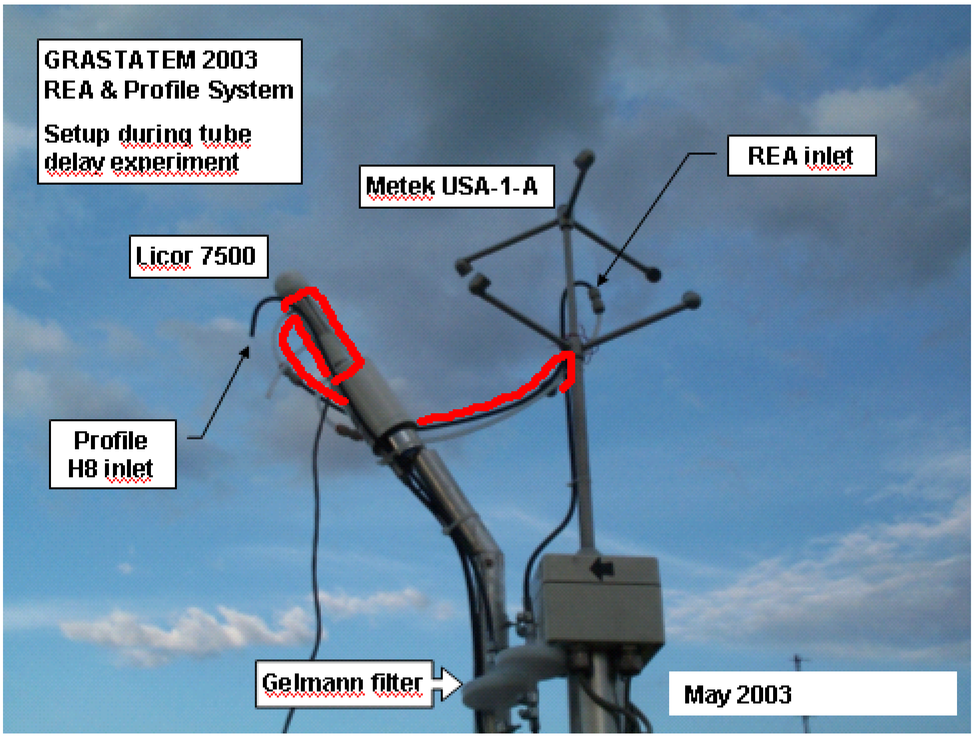


**Foto of Tube delay experiment:**

**2. short connection tube and $CO_2$ Analyzer only.**



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