CALCULATING CO_2 AND H_2O EDDY COVARIANCE FLUXES FROM LOW-POWER GAS ANALYZER USING FAST MIXING RATIO

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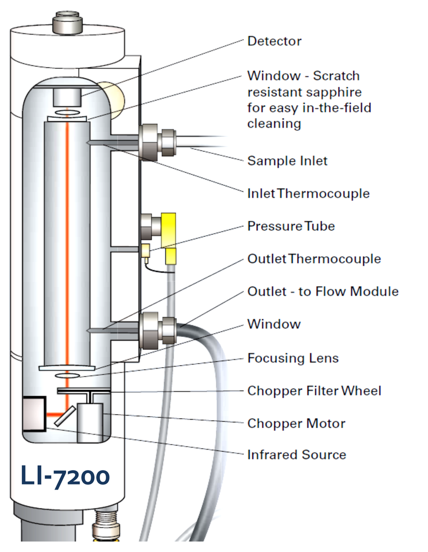
INTRODUCTION

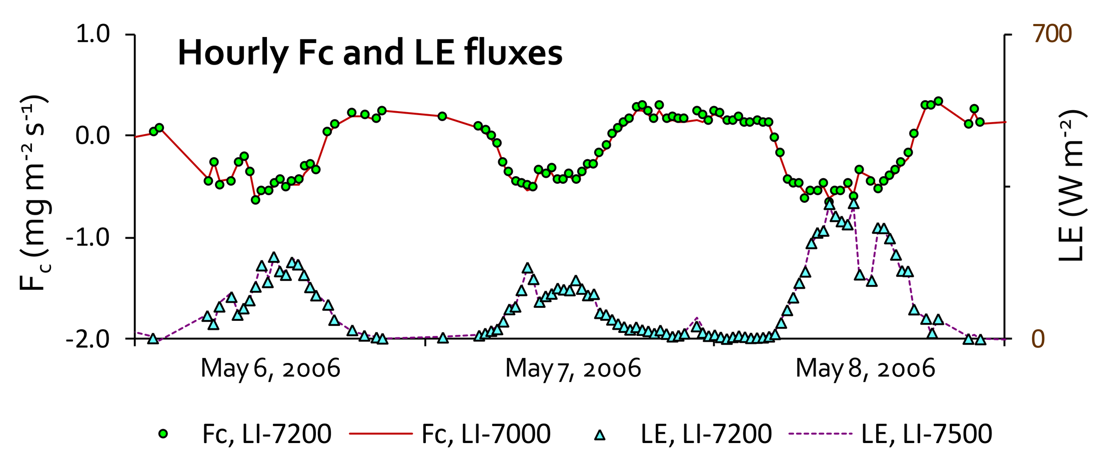
- New fast CO_2/H_2O analyzer LI-7200 is made for low power operation, when used with short intake tube [1]
- Two fast air temperatures and one air pressure are measured in the cell synchronously with gas and water vapor measurements
- This provides an ability to compute fast mixing ratio (MR), or dry mole fraction, on-the-fly

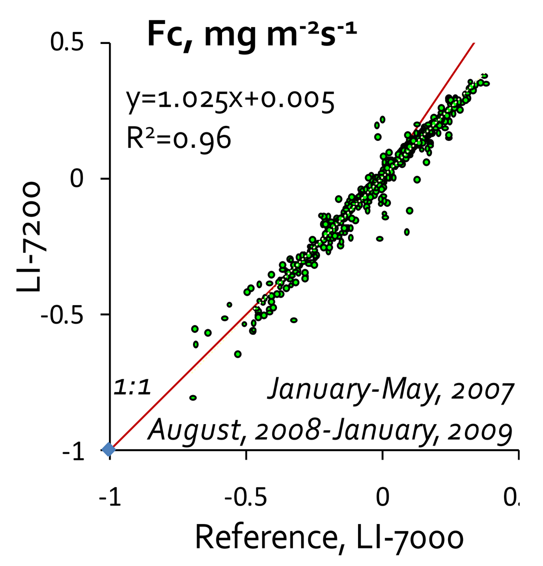


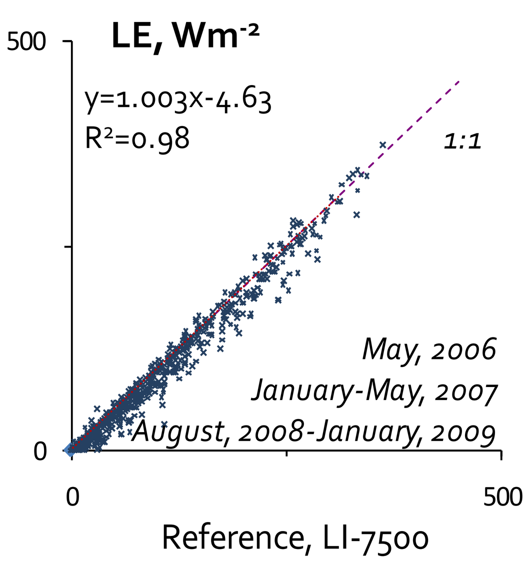
- MR can be used for Eddy Covariance flux calculations without a need for Webb-Pearman-Leuning density terms [2,3,4]
- Such approach may offer substantial advantages in terms of reduced flux uncertainties and minimum detectable flux
- In order to use MR from LI-7200 to compute fluxes, field data should be examined to verify the following:
  - (i) Density-based fluxes from LI-7200 match the standards
  - (ii) MR is computed correctly on-the fly
  - (iii) MR-based fluxes match the density-based fluxes

DENSITY-BASED FLUXES

- Traditional density-based fluxes from LI-7200 were compared to the standards in the field experiments over ryegrass in Nebraska and over wetland in Florida [1]
- The open-path LI-7500 was chosen as a standard for water vapor flux (LE) because it does not attenuate water vapor in the intake tube
- The closed-path LI-7000 was chosen as a standard for CO2 flux (Fc) because it is not a subject of surface heating effect in extremely cold conditions
- Hourly CO_2 and H_2O fluxes were within 2.5% of the standards (LI-7000 and LI-7500, respectively) in all experiments
- Observed 2.5% difference was not statistically significant, for P<0.05
- The data confirms the good performance of LI-7200 in terms of traditional density-based flux calculations and WPL correction







CONCEPT OF MR & WPL

Fundamentally, fluxes could be computed from a covariance between vertical wind speed and gas content following [2,3,4]:

$$Fc = \overline{w\rho S} \approx \bar{\rho}_d \overline{w's'} \quad (1)$$

However, traditional flux calculations usually use density measurements which are native to the gas analyzers:

$$Fc_o \approx \overline{w'q_c'} \quad (2)$$

and then apply density corrections after Webb et al. [2]:

$$Fc = Fc_o + \mu \frac{E}{\rho_d}\frac{q_c}{1+\mu\frac{\rho_v}{\rho_d}} + \frac{H}{\rho C_p}\frac{q_c}{T_a} + 0 \quad (3)$$

Dilution Term: E is computed from water vapor density measured in the cell simultaneously with CO2

Thermal Expansion Term: H in the LI-7200 cell is below 10% of ambient due to 1 m intake; remainder can be computed from in-cell fast temperatures

Pressure Expansion Term: it is usually neglected, but can be computed from fast measurements inside the LI-7200 cell

Fc – final corrected flux; w - vertical wind speed; ρ – total air density; S – wet mole fraction; ρ_d – dry air density; s – mixing ratio (dry mole fraction); Fc_o– uncorrected flux; q_c – gas density; E – evapotranspiration; H – sensible heat flux; ρ_v – H_2O vapor density; C_p – specific heat; T_a– air temperature in K; μ– ratio of mol. masses of air to water

The LI-7200 is capable of fast outputs of both density q_c and mixing ratio *s*. Fluxes from LI-7200 could be computed both in traditional manner from density (Eq. 3), and from mixing ratio (Eq. 1)

Fast MR has been used before with traditional closed-path analyzers, without fast *T* and *P*, because *Ta* was attenuated in the long intake tube, *P'* was small, and water vapor was measured

But in an enclosed LI-7200, when used with short tube, most but not all of the fast fluctuations in *Ta* are attenuated, so calculating fluxes using MR from such an instrument requires validation

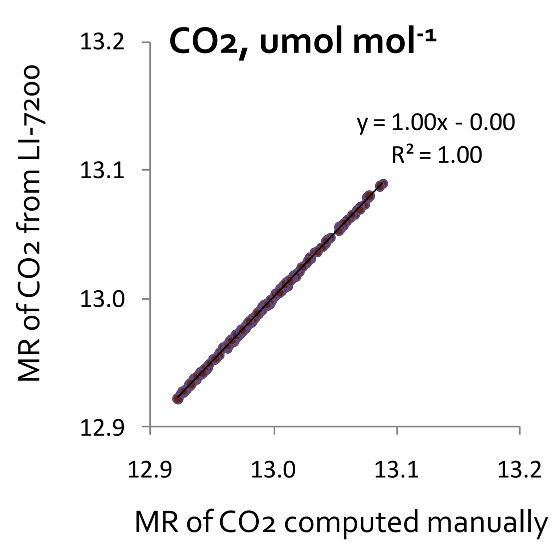
COMPUTING FAST MR

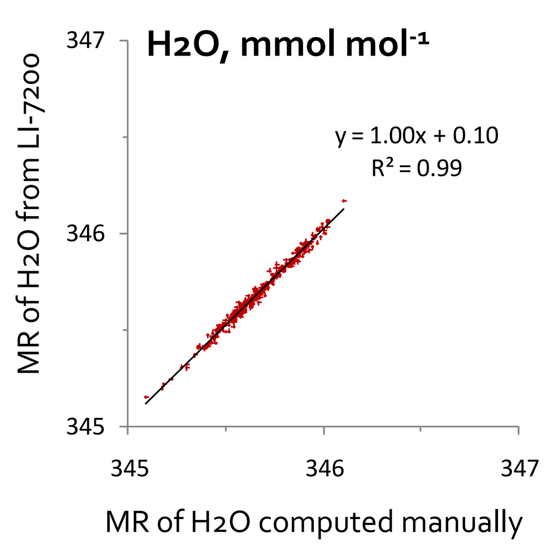
MR is computed in LI-7200 on-the-fly from density, using instantaneous water mole fraction (X_w), two temperatures (*T*) and a pressure (*P*) measured in the cell, and a gas constant (*R*):

$$S = q_c \frac{RT}{P} \Rightarrow s = \frac{S}{(1-X_w)} = q_c \frac{RT}{P(1-X_w)} \quad (4)$$

Plots below show examples of one hour of 10 Hz MR data computed on-the-fly inside the instrument plotted versus those computed from 10 Hz density data by hand for CO2 and H2O

In both cases MR computed on-the fly inside the instrument were not statistically different from those computed manually





FIELD EXPERIMENTS

For comparison of density-based fluxes from LI-7200 to established standards, the data from the field experiments over ryegrass in Nebraska and over wetland in Florida were used [1]

For comparison of MR-based flux calculations to density-based flux calculations, data from a total of eight field experiments were used to cover broad range of set-ups and conditions:

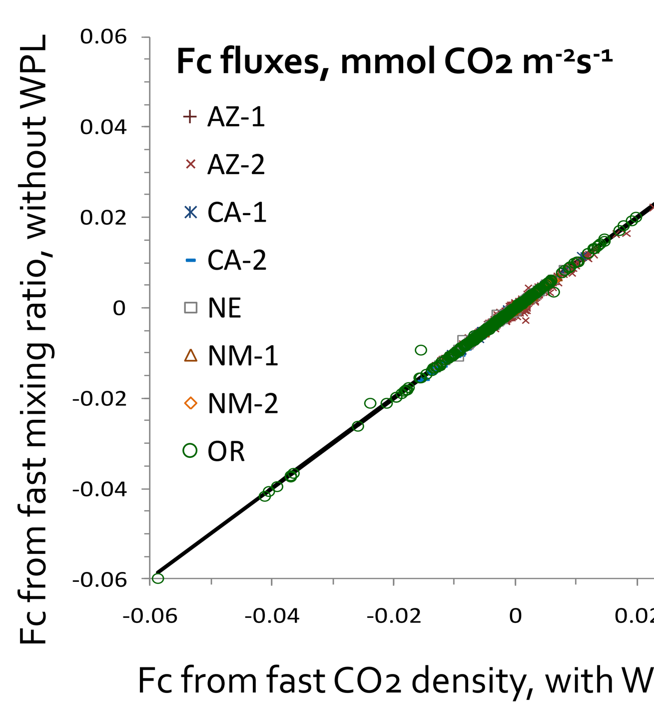
6 experiments from AmeriFlux Roving Station utilizing LI-7200
1 experiment from USDA site in Arizona (AZ-2)
1 experiment from LI-COR field test facility in Nebraska (NE)

Site	Location	Coordinates	Elevation m	Ecosystem	Canopy ht m	Inst. ht m	Average T C	Measurement start	end
AZ-1	Arizona	31 54 30 N; 110 10 22 W	991	shrubland	0.7	3.6	28.3	5-Jul	14-Jul
AZ-2	Arizona	31 82 14 N; 110 86 61 W	1116	savanna	2.5	6.4	24.7	14-Apr	29-Jul
CA-1	California	33 22 38 N; 116 37 22 W	1429	shrubland	0.7	3.0	17.8	26-May	3-Jun
CA-2	California	37 4 4 N; 119 11 40 W	2020	forest	30	48	21.1	14-Jul	21-Jul
NE	Nebraska	40 51 22 N; 96 39 17 W	350	ryegrass	0.1	2.6	17.6	15-Sep	12-Nov
NM-1	New Mexico	34 21 27 N; 106 41 0 W	1590	grassland	0.3	2.9	23.7	27-Jun	5-Jul
NM-2	New Mexico	34 20 6 N; 104 44 39 W	1593	shrubland	0.6	2.8	28.0	18-Jun	25-Jun
OR	Oregon	44 38 5 N; 123 12 5 W	70	ag. grassland	0.05	3.0	7.9	5-Mar	22-Mar

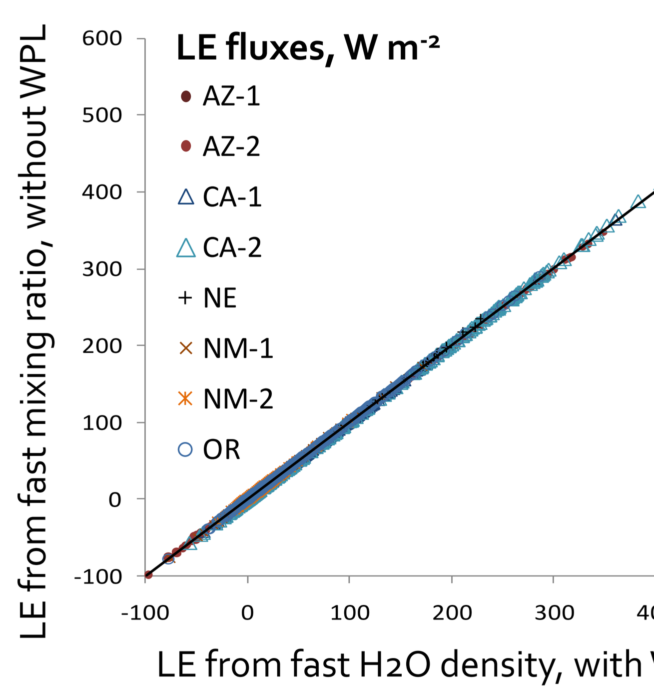
** data from 2009; the rest in the table are from 2010*

FLUXES FROM FAST MR

- MR-based fluxes without WPL are plotted below vs. traditional density-based fluxes at 8 different deployments for Fc and LE
- MR-based CO2 flux was within 3% of the density based flux for 7 sites, and within 6% for CA-2 site
- CA-2 site had measurement height 7-18 times taller than the any other site, affecting frequency corrections, highest LE flux affecting WPL terms, and least number of available data hours
- Water vapor fluxes were within 3% at all 8 sites



	Slope	Offset mmol m^{-2} s^{-1}	R^2
AZ-1	1.00	-0.00007	0.96
AZ-2	0.97	-0.00003	0.99
CA-1	1.03	0.00001	1.00
CA-2	1.06	-0.00002	1.00
NE	1.00	-0.00006	1.00
NM-1	1.03	-0.00006	0.99
NM-2	1.01	-0.00006	0.99
OR	1.01	-0.00002	1.00
ALL DATA	1.01	-0.00004	0.99



	Slope	Offset W m^{-2}	R^2
AZ-1	1.00	0.0	1.00
AZ-2	1.00	0.0	1.00
CA-1	1.03	0.0	1.00
CA-2	1.01	-0.1	1.00
NE	1.01	-0.1	1.00
NM-1	1.01	-0.1	1.00
NM-2	1.01	0.0	1.00
OR	1.01	0.0	1.00
ALL DATA	1.01	0.0	1.00

SUMMARY

- New enclosed gas analyzer LI-7200 can use short intake tube, since fast T and P are measured in the cell with CO2 and H2O
- The analyzer can output both fast gas density and mixing ratio
- This opens an opportunity to compare MR-based fluxes without WPL correction with traditional density-based fluxes with WPL
- Traditional density-based fluxes from LI-7200, on-the-fly MR calculations , and resulted MR-based fluxes were examined:
  - (i) The density-based fluxes from LI-7200 compared well with open-path and closed-path standards
  - (ii) MR computed by LI-7200 on-the-fly matched manual calculations
  - (iii) MR-based fluxes from 8 experiments compared well with density-based fluxes over wide-range of conditions
- The ability to compute MR-based fluxes is important for gas flux measurements, because elimination of density corrections could increase flux data quality and temporal resolution, and may help to reduce the magnitude of minimum detectable flux

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OPEN QUESTIONS

Although MR-based fluxes and traditional density-based fluxes matched quite well in all examined experiments, there are still few open questions related to MR approach, at least theoretically:

- *Which method of flux calculation is more accurate?*

  The only site with significant difference (6%) between the MR-based and density-based fluxes, CA-2, had very tall measurement height and very large LE flux

  Does it mean that MR-based flux is more accurate because uncertainties in frequency response corrections affected both Fc and LE fluxes in density-based flux computations?

- *Is there a difference in frequency response corrections for MR vs. density based flux?*

  Strictly speaking, frequency response for MR should include not only CO2, but also H2O, T and P: is this effect for MR significant or negligible in comparison with density?

- *Does avoiding density corrections help to reduce uncertainties from correcting the product of fast covariances using hourly H and LE, which also come with their own uncertainties?*