

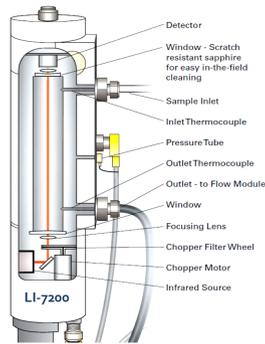
FAST MIXING RATIO COMPUTATIONS OF CO₂ AND H₂O EDDY COVARIANCE FLUXES FROM AN ENCLOSED GAS ANALYZER

G. Burba^{*1}, A. Schmidt², R. Scott³, J. Kathilankal¹, B. Law², G. Fratini¹, D. McDermitt¹, C. Hanson², and D. Anderson¹

¹LI-COR Biosciences, Lincoln, NE (*george.burba@licor.com); ²College of Forestry, Oregon State University, Corvallis, OR; ³ARS-USDA, Tucson, AZ

INTRODUCTION

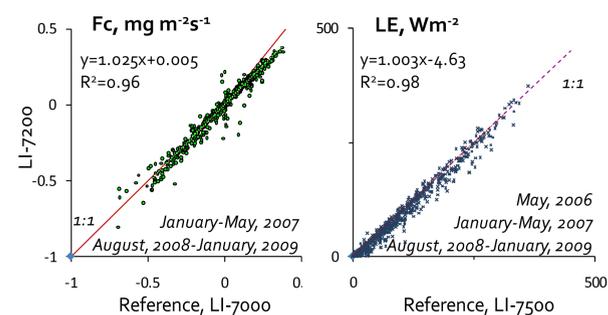
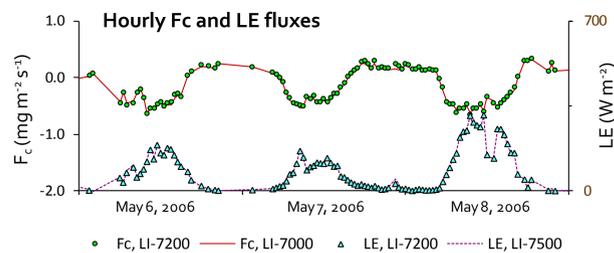
- New fast CO₂/H₂O analyzer LI-7200 is made for low power operation, when used with short intake tube [1]
- Two fast air temperatures and one air pressure are measured in the cell synchronously with CO₂ and H₂O
- This provides an ability to compute fast mixing ratio (MR), or dry mole fraction, on-the-fly
- 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 mixing ratio from LI-7200 to compute fluxes, field data should be examined to verify the following:



- Density-based fluxes from LI-7200 match the standards
- Mixing ratio-based fluxes match 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 CO₂ and H₂O 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



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 (4%) 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 affect 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?

CONCEPT OF MR & WPL

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

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

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 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 – H₂O vapor density; C_p – specific heat; T_a – air temperature in K; μ – ratio of mol. masses of air to water

MR could be 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):

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

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 T_a 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 T_a are attenuated, so calculating fluxes using MR from such an instrument requires validation

FIELD EXPERIMENTS

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	Measurement 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	4.8	21.1	14-Jul	21-Jul
NE	Nebraska	40 51 22 N; 96 39 37 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 22 5 W	70	ag. grassland	0.05	3.0	7.9	5-Mar	22-Mar

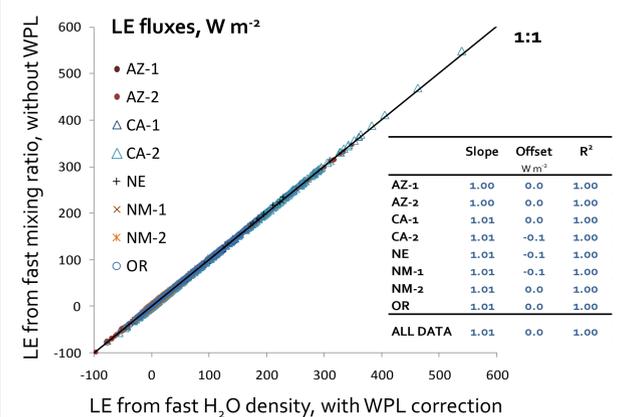
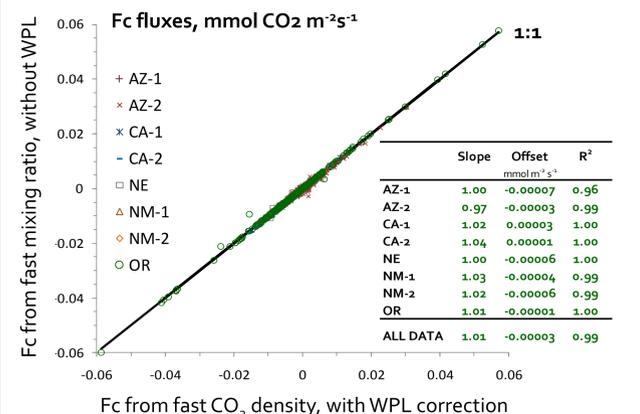
* data from 2009; the rest in the table are from 2010

REFERENCES

- Burba G, D McDermitt, D Anderson, M Furtaw, and R Eckles, 2010. Novel design of an enclosed CO₂/H₂O gas analyzer for Eddy Covariance flux measurements. *Tellus B: Chemical and Physical Meteorology*, 62(5): 743-748
- Webb E, G Pearman, and R Leuning, 1980. Correction of flux measurements for density effects due to heat and water vapour transfer. *Quart. J. Roy. Meteorol. Soc.*, 106: 85-100
- Leuning R, 2004. Measurements of trace gas fluxes in the atmosphere using eddy covariance: WPL correction revisited. In: *Handbook of Micrometeorology* (eds X. Lee, W. J. Massman and B. Law). Kluwer Academic Publishers, Dordrecht, Boston, London, 119-132.
- Massman W, 2004. Concerning the measurement of atmospheric trace gas fluxes with open- and closed-path eddy covariance system: the WPL terms and spectral attenuation. In: *Handbook of Micrometeorology* (eds X. Lee, W. J. Massman and B. Law). Kluwer Academic Publishers, Dordrecht, Boston, London, 133-160.

MIXING RATIO-BASED FLUXES

- Mixing ratio-based fluxes without WPL are plotted below vs. traditional density-based fluxes at 8 different deployments for Fc and LE
- Mixing ratio-based CO₂ flux was within 0%-4% of the density based flux at all 8 sites
- The site with largest difference of 4%, CA-2, had measurement height 7-18 times taller than the any other site, highest LE flux affecting WPL terms, and least number of available data hours
- Water vapor fluxes were within 1% at all 8 sites



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 at the same time
- 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:
 - The density-based fluxes from LI-7200 compared well with open-path and closed-path standards
 - MR-based fluxes from 8 experiments matched well the 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

ACKNOWLEDGEMENTS

Authors deeply appreciate access to LI-7200 data, help and support provided by all members of AmeriFlux Roving Intercomparison Station and by owners of respective field sites, by USDA field site in Arizona, and by LI-COR LI-7200 Team.

We also are very grateful to Drs W. Massman, Lianhong Gu, R. Clement, A. Suyker, D. Zona, and B. Gioli for important discussions and related to the topic of mixing ratio-based flux calculations.

We thank a number of research groups and individuals who tested early prototypes of LI-7200, and suggested important additions and improvements to its design.

Particularly, we would like to thank Dr. R. Clement and Prof. J. Grace; Dr. J. Schedlbauer and Prof. Steve Oberbauer; Mr. Z. Nestic, Dr. C. Brummer, Prof. T. Andrew Black and Mr. D. Lessard; Drs. D. Papale and N. Arriga, and numerous other individuals in the flux community.