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Quality Control of Eddy-Covariance Fluxes Just-Above and Within the US-NR1 Subalpine Forest

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I. Introduction:

Ecosystem-scale fluxes of mass, momentum, and energy are typically measured using the eddy covariance technique over a 30-min time period (e.g., Aubinet et al., 2012). Our poster focuses on the CO_2 flux F_c measured above and within the US-NR1 subalpine forest by both closed-path and open-path infrared gas analyzers (IRGAs; Fig. 1). When an open-path IRGA is used, additional terms due to air density variations (primarily caused by temperature and water vapor fluctuations in the sample path) need to be included in the calculated F_c flux:

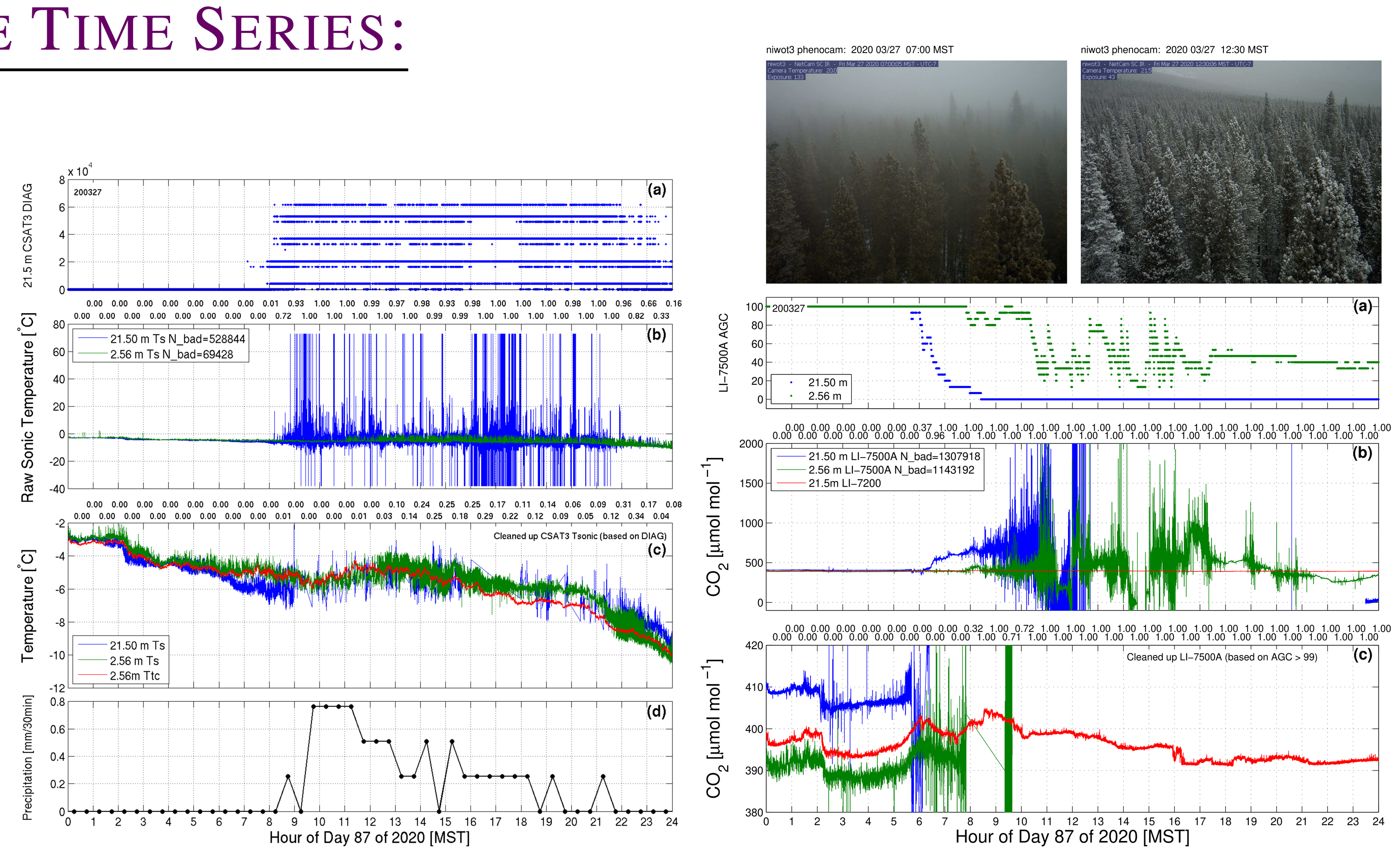
$$F_c = \overline{w'\rho_c'} + \mu \frac{\overline{\rho_c}}{\overline{\rho_a}}\, \overline{w'\rho_v'} + (1+\mu\sigma)\frac{\overline{\rho_c}}{\overline{T}}\, \overline{w'T'}, \qquad (1)$$

where the first term on the right-hand side is the covariance term, the second term is the water vapor term, and the last term is the temperature term (these are typically called the Webb–Pearman–Leuning (WPL) terms after Webb, et al. 1980). For open-path IRGAs heating of the air in the sampling path by the IRGA itself (e.g., Burba et al., 2008; Frank and Massman 2020) also needs to be accounted for. The goals of our study are: (1) to examine the hi-rate statistics of the instrument QC variable (for the CSAT3 sonic anemometer this is DIAG; for the LI-COR IRGAs it is AGC; see (Fig. 2)) with an emphasis on periods with precipitation, (2) compare statistics between the above- and within-canopy IRGAs as well as between closed- and open-path IRGAs (Figs. 3 and 4), and (3) use the dormant winter-time period, and an independent measure of the CO_2 flux by Eosense EOS FD chambers placed at the bottom of the snowpack, to evaluate the "reasonableness" of the US-NR1 F_c measurements (Fig. 5c). Finally, in Burns et al. 2021, an empirical ad-hoc correction was applied to the temperature term to account for IRGA self-heating. This method is tested using the US-NR1 data (Fig. 6).

Figure 1: *Photographs of the instrumentation at the US-NR1 AmeriFlux site.* **(left)** *looking down at the instrumentation deployed at 21.5 m and* **(right)** *the subcanopy flux sensors deployed at 2.5 m (photo inset: an EOS FD Sensor as snow starts to accumulate). The numbered instruments are: ① LI-COR LI-7200 body, ② LI-7200 inlet, ③ and ④ CSI CSAT3s, ⑤ LI-COR LI-7500A, ⑥ LI-6262 inlet, ⑦ Krypton Hygrometer, and ⑧ Vaisala T/RH*

II. QC of Hi-Rate Time Series:

Figure 2: *Example hi-rate (10-Hz, 20-Hz) time series from 27 March 2020 of* **(left) (a)** *DIAG from 21.5m CSAT3,* **(b)** *raw sonic temperature T_s from the 21.5m and 2.56m CSAT3s,* **(c)** *T_s after removing bad data based on the DIAG information, and* **(d)** *precipitation. In the legend of* **(b)** *the number of missing 10-Hz samples over the 24 period are shown. In* **(c)***, the time series from a thermocouple at 2.56m is included. The fraction of missing 10-hz data (based on DIAG) for each 30-min period is shown for the 21.5m CSAT3 (between panels* **(a)** *and* **(b)***) and the 2.56 m CSAT3 (between panels* **(b)** *and* **(c)***). A fraction value of 1.00 means all the 10-Hz data are missing for that particular 30-min period.* **(right)** *A similar time series plot, but shown for the AGC from the 21.5m and 2.56m LI-7500As; Above* **(a)** *are two niwot3 phenocam images that show the conditions at the site.*



III. The Effect of Precipitation on QC and Winter F_c Evaluation:

Figure 3: *The composite diel cycle of the fraction of missing data for the* **(left)** *warm and* **(right)** *winter seasons. The panels shown are:* **(a)** *QC by the CSAT DIAG,* **(b)** *missing data due to instrument or data system issues, and* **(c)** *precipitation for each precipitation state (dDry, dWet, wWet, and wDry). The statistics are calculated for the 21.5 m and 2.56 m CSAT3 (see legend in panel* **(b)***). The diel cycle is calculated from 30 min periods for years 2004–2020 with the approximate number of days (N) used to create each composite shown in panel* **(a)***.*

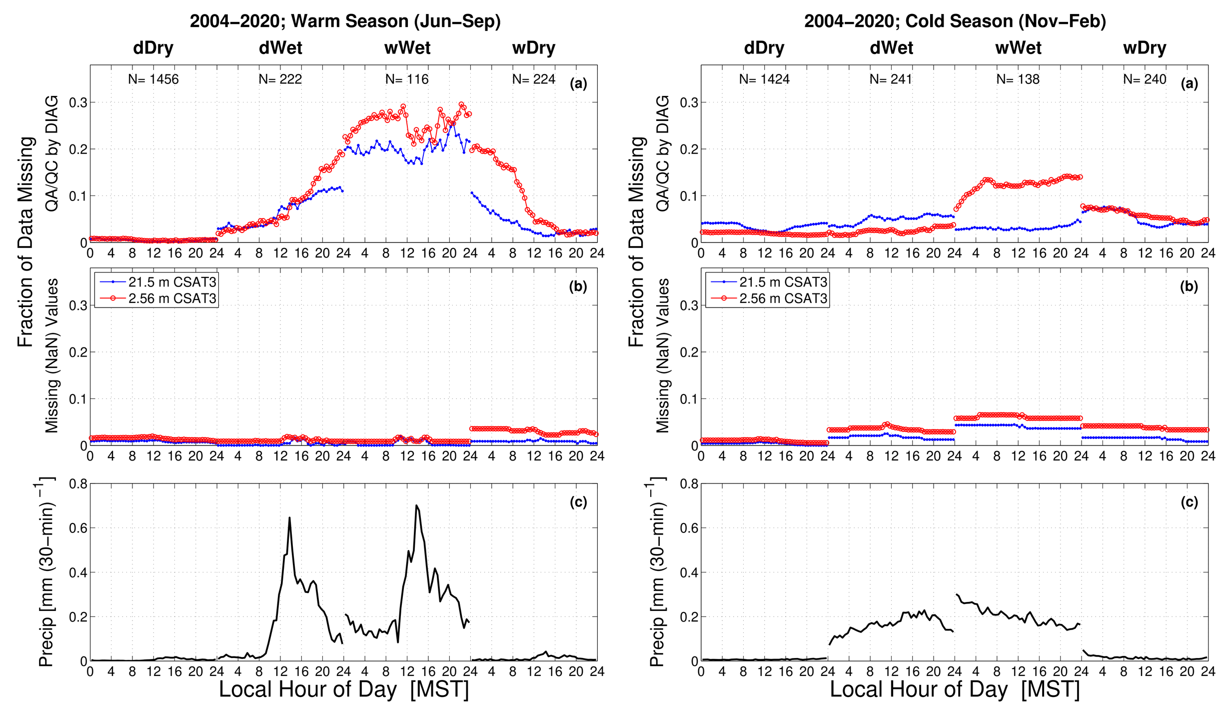


Figure 4: *QC Statistics of CSAT3 (based on DIAG) and LI-7500A (based on AGC) versus relative humidity (RH) (for the warm-season).*

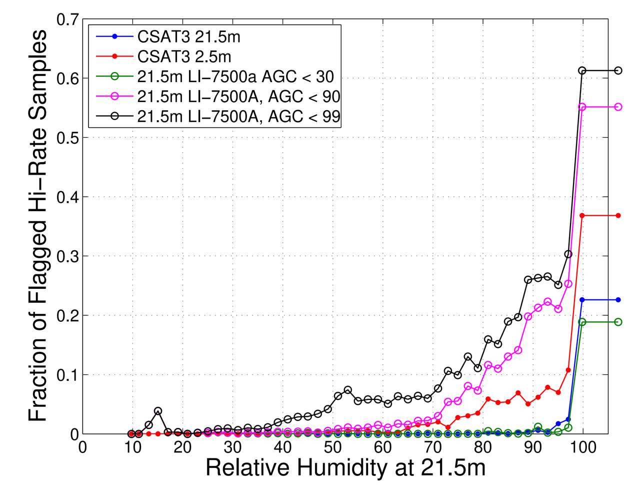


Figure 6: *The mean and median of the daytime (10–14 MST) and nighttime (22–02 MST) dormant-season NEE plotted as a function of an empirical ad-hoc correction to the WPL temperature term.* **(upper)** *results from the GLEES AmeriFlux site (details are in Burns, et al. 2021),* **(lower)** *the same technique applied to the 2.5 m F_c at the US-NR1 site.*

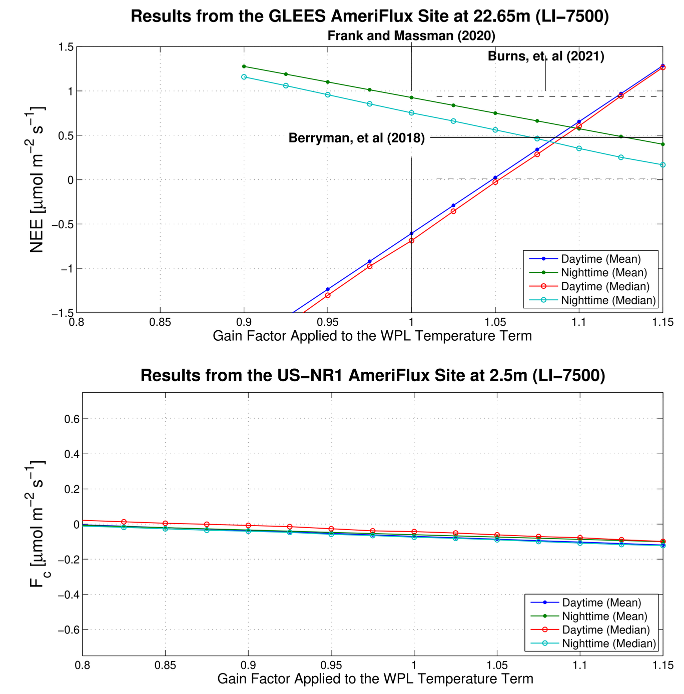
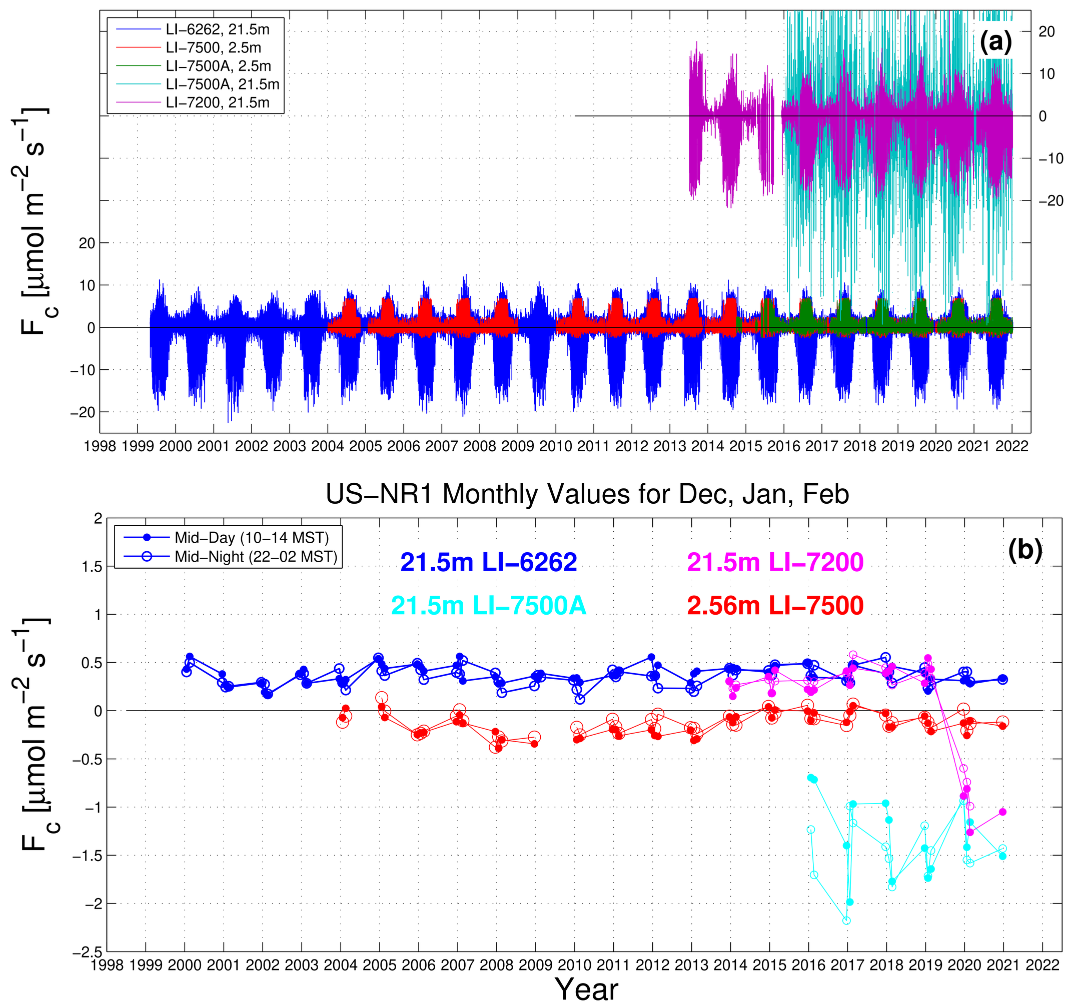
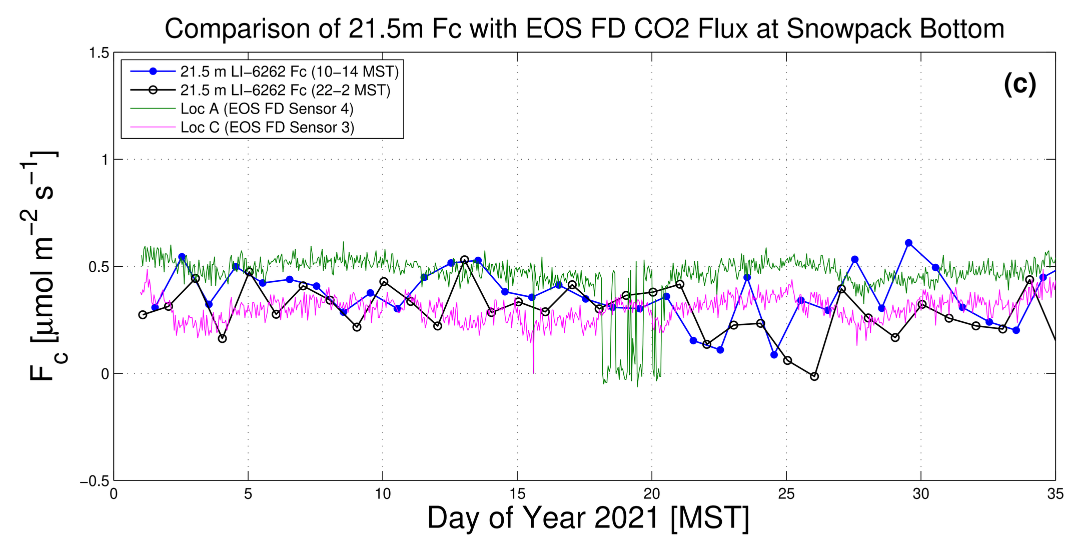


Figure 5: *Time series of* **(a)** *30-min CO_2 flux F_c for the various IRGAs available at the US-NR1 site,* **(b)** *winter-time (Dec, Jan, Feb) monthly averages of F_c for selected IRGAs and levels, and* **(c)** *a comparison between F_c measured by the LI-6262 at 21.5 m and the CO_2 flux measured by two EOS FD sensors at the bottom of the snowpack.*





IV. Main Observations and Conclusions:

- **In wet conditions an open-path IRGA will lose 100% of the the data while a CSAT3 will continue to operate with a smaller percentage of lost data (Fig. 2).**
- **Most hi-rate samples are flagged on wet days. On average, about 20% of the US-NR1 warm-season above-canopy CSAT3 10-hz samples were flagged by DIAG in wet conditions while ≈ 30% of the subcanopy samples were flagged (Fig. 3; left panels). During winter only around 5% of above-canopy CSAT3 samples were flagged (Fig. 3; right panels).**
- **If one considers RH as a proxy for sensor wetness, the percentage of flagged hi-rate samples for the warm-season were as follows: 21.5 m CSAT3 ≈ 20%, 2.5 m CSAT3 ≈ 38%, 21.5 m LI-7500A ≈ 60% (depending on the AGC level used, see Fig. 4). Instrument diags are not enough for full QC (results not shown).**
- **The 2.5 m LI-7500 and LI-7500A and the 21.5 m LI-6262 and LI-7200 F_c fluxes agreed well, but the 21.5 m LI-7500A F_c was highly variable (Fig. 5a) and had a negative mean bias in the winter (Fig. 5b). The 21.5 m LI-7500A was affected by high winds (results not shown).**
- **There was good agreement between the 21.5 m LI-6262 F_c and the CO_2 flux measured by the EOS FD chambers at the bottom of the snowpack in the middle of the winter (Fig. 5c).**
- **The persistent negative 2.5 m LI-7500A F_c (Fig. 5b) could not be explained by the sensor self-heating (Fig. 6), but the 2.5 m CSAT3 sensible heat flux might have an issue (results not shown).**

References:

Aubinet, M., T. Vesala, and D. Papale, 2012: *Eddy Covariance: A Practical Guide to Measurement and Data Analysis*, Springer Atmospheric Sciences, Dordrecht, The Netherlands, 438 pp.

Burba, G. G., et al., 2008: Addressing the influence of instrument surface heat exchange on the measurements of CO_2 flux from open-path gas analyzers *Global Change Biol.*, **14**, 1854–1876.

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