Atmospheric LIDAR Provides Insight into Land Surface-Atmosphere Exchange at 3 AmeriFlux Towers

Sonia Wharton*[1], Jennifer Newman[2], Jessica Osuna[1], Siyan Ma[3], Matthias Falk[4], Ken Bible[5], Dennis Baldocchi[3]

*wharton4@llnl.gov; [1]Lawrence Livermore National Laboratory, Livermore, CA; [2]University of Oklahoma, Norman, OK; [3]University of California, Berkeley, CA; [4]University of California, Davis, CA, [5]University of Washington, Seattle, WA

1. INTRODUCTION

This study examines the role of atmospheric shear and turbulence above the plant canopy on CO_2 flux exchange at three distinct flux towers in the Western U.S.

i. Eddy covariance (EC) CO_2 fluxes are often noisy (Fig. 1), particularly at night, leading to large uncertainties in net annual carbon exchange. Research currently cannot fully explain:

1) drivers of turbulence above the canopy because they are rarely measured at EC towers (Figure 2)
2) influence of above canopy or "top-down" forced turbulence on flux exchange
3) solutions for correcting CO_2 flux outliers, including "nighttime photosynthesis"

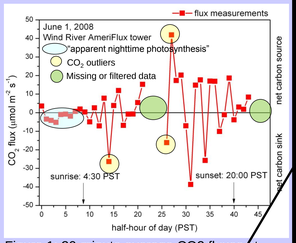


Figure 1: 30-minute average CO2 fluxes at Wind River before extensive post-processing.

ii. Eddy covariance measures flow at the top of the canopy layer while missing complex flow above, which generates turbulence that can penetrate the canopy.

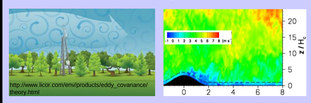


Figure 2: Flow features are captured by EC in the canopy layer (left) but not in the lower PBL (right). This region may provide clues for understanding atmospheric causes of flux outliers.

iii. We test the hypothesis that *above canopy* produced shear and turbulence are accurately measured with LIDAR and that they can play a role in understanding the causes of CO_2 flux outliers at AmeriFlux sites.

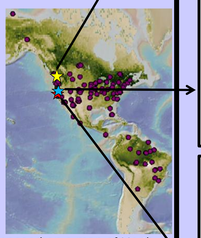


Figure 3: The sites are in Northern California and Southern Washington and are shown superimposed on a map of North and South American FLUXNET locations.

2. METHODS

- Laser Detection and Ranging (LIDAR) Wind Cube v2 was co-located with Ameriflux towers during each field campaign. 2013 campaigns will also use a ZephIR LIDAR which has the advantage of measuring closer to the surface.
- LIDAR measured u, v, and w from 40 m – 200 m with 10 m resolution at 12 user-defined heights at 1 Hz resolution.
- Turbulence kinetic energy was calculated from 1 Hz LIDAR data and 10 Hz sonic data. Flux data were shared by each site.

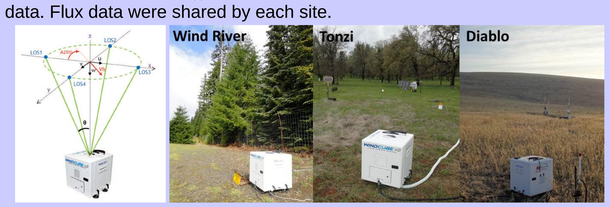


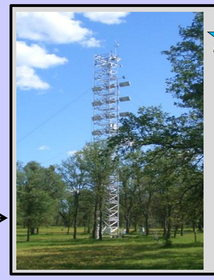
Figure 4: This project used a WindCube v2 LIDAR to measure wind speed, direction and turbulence at AmeriFlux sites in Washington (Wind River) and California (Tonzi and Diablo). The sites represent three different canopy types ranging from old-growth forest to annual grassland.

Field Campaign	Dates	Ecosystem Conditions
Tonzi AmeriFlux: Growing season	April 5-26, 2012; April-May 2013	Leaf emergence in late March, canopy "green-up", high carbon uptake and resp. rates, min. moisture deficit, optimal Ta for photosynthesis
Wind River AmeriFlux	May 1-11, 2012, May – June 2013	Peak carbon uptake, no drought or temp. stress, diffuse radiation for high photosynthesis
Tonzi AmeriFlux: Drought season	August 24 – November 26, 2012	Extreme water deficit until first Autumn rains (October 22) with near neutral carbon balance, leaf senescence, soil respiration pulses after rain events, grasses first emerged in November
Diablo AmeriFlux	November 26, 2012 – June 2013	Dominant dead grass canopy after long summer drought (no rain from April 25- October 22, 2012), grasses first emerged in late November. Canopy photosynthesizes ~ December – May.

3. SITE DESCRIPTIONS

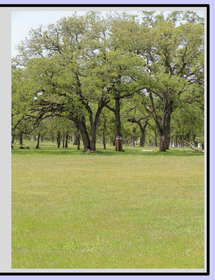
Wind River AmeriFlux
Old-Growth Conifer Forest

- Western Cascade Mtns., Washington, USA
- Tree canopy: max 60 m tall, max ~500 years old
- EC sensor height: 67 m
- Evergreen, needleleaf, vertically complex forest
- Wet, cool climate with summer drought
- No management
- Large coarse woody debris & soil C pools
- Mean PPT = 2338 mm; mean Ta = 8.8 °C



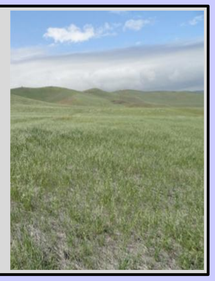
Tonzi AmeriFlux
Mediterranean Oak - Grass Savanna

- Sierra Nevada foothills, California, USA
- Tree canopy: max 10 m tall, max ~ 90 years old
- Overstory EC sensor height: 23 m
- Understory EC sensor height: 2 m
- Deciduous oaks + C3 annual grasses
- Wet, mild winters; hot, very dry summers
- Grazed and actively managed
- Mean PPT = 562 mm; mean Ta = 16.5 °C



Diablo AmeriFlux
Annual Grassland

- Altamont Hills, Diablo Range, California, USA
- Grass canopy: max 0.5-1.0 m tall
- EC sensor height: 2.2 m
- Annual C3 grasses
- Wet, mild winters; hot, very dry summers
- No grazing or agricultural activity since 1953
- Mean PPT = 265 mm; mean Ta = 15.0 °C



4. WIND RIVER RESULTS

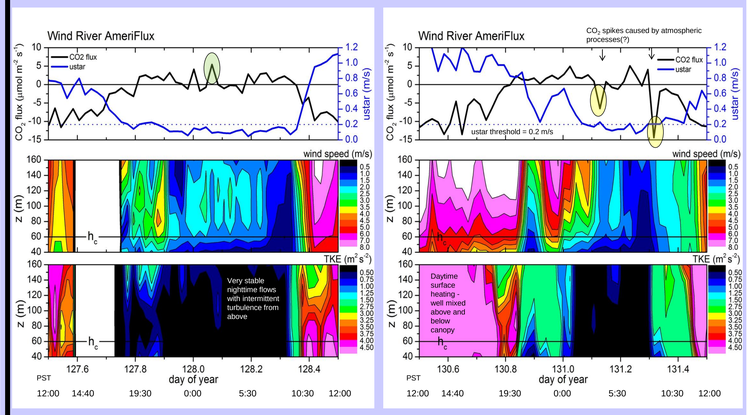


Figure 5: (top panels) 30-min. mean CO_2 fluxes and ustar (friction velocity) measured at the AmeriFlux tower on May 6-7 (left) and May 9-10, 2012 (right). (lower panels) Contour plots of LIDAR 30-minute mean wind speed and turbulence kinetic energy (TKE). Turbulence generated by wind shear aloft periodically penetrates the tree canopy (h_c) at night, breaking up very stable flows within and above the canopy and can result in positive respiration "spikes" (green circle) in the CO_2 data (day 128). CO_2 spikes (yellow circles) were also observed during stability-related transitions on the night of day 131 and are likely from non-stationary conditions during the half-hour periods.

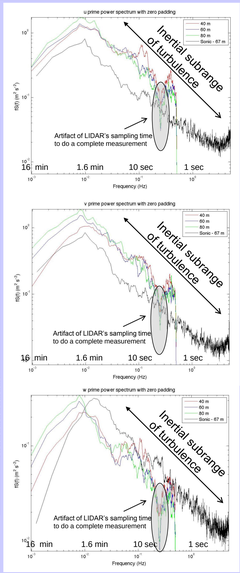


Figure 6: Power spectra of u, v, and w from LIDAR (40-80 m heights) and sonic anemometer (67 m) both show the inertial subrange although LIDAR misses the highest frequencies due to sampling limitations.

5. TONZI RESULTS

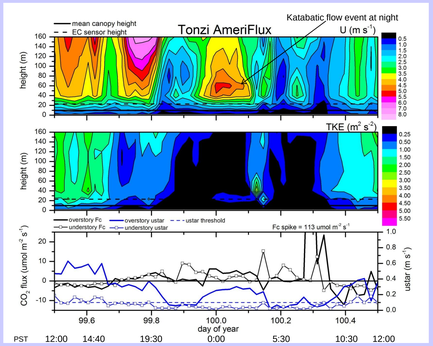


Figure 7: April 8-9, 2012 LIDAR data show evidence of easterly katabatic flows at night from the Sierra Nevada. These create maximum wind speeds around 40-60 m, a layer of higher TKE near the EC sensor (23 m) from mechanical shearing stress underneath the jet, and result in relatively high, positive overstory CO_2 fluxes due to either canopy mixing or the contribution of advective flux (this is still under investigation).

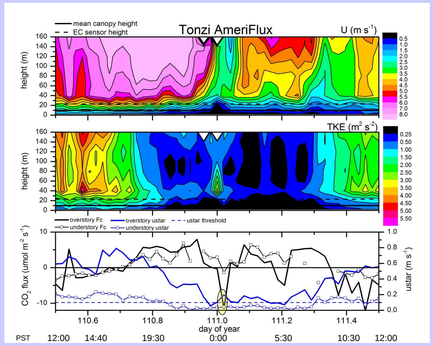


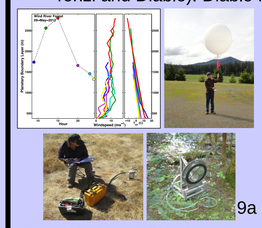
Figure 8: April 19-20, 2012 LIDAR data show "top-down" forced turbulence events at night due to higher wind speeds aloft. TKE is overall higher at night during these non-katabatic flows above the canopy and bursts of TKE are observed penetrating the EC sensor height leading to a more mixed canopy and both positive fluxes and occasional negative CO_2 spikes. For example, the yellow circled CO_2 spike at night may be due to CO_2 poor air entrainment from above.

6. CONCLUSIONS

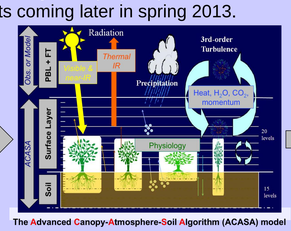
- LIDAR misses highest frequency turbulence but captures most the inertial subrange and thus appears to be ok for measuring profiles of TKE above the canopy.
- Gravity-driven flows from the Sierra Nevada were measured on 40-45% of nights at Tonzi and were related with maximum wind speeds around 40-60 m AGL, higher TKE below the jet at EC sensor height, and relatively high, positive CO_2 fluxes. Katabatic flows were not observed at WR during the short field campaign.
- Ustar may not be the best threshold for determining "adequate" nighttime turbulence because "top-down" and "bottom-up" produced turbulence can have equally high ustar values but can also result in very different CO_2 fluxes as measured by the sensor. "Top-down" turbulence are sometimes associated with negative flux spikes (CO_2 poor air entrainment from above?).
- EC data need to be initially run without a spike filter because it appears that CO_2 spikes often occur during PBL flow or stability-related transitions or during quick turbulence events. Understanding atmospheric causes for spikes may reduce uncertainties involved with gap-filling and lead to more accurate NEE.

7. RELATED AND FUTURE PROJECTS

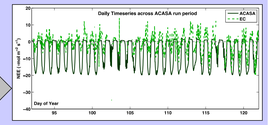
- LIDAR data as well as radiosonde launches and soil resp. fluxes are being used to improve, validate, and apply the Advanced Canopy-Atmosphere Soil Algorithm (ACASA) model to produce accurate CO_2 fluxes for daytime gap-filling and nighttime flux replacement for these FLUXNET sites.
- In 2013 we will have a new LIDAR system (ZephIR) that measures down to 10 m AGL (needed for Tonzi and Diablo). Diablo results coming later in spring 2013.



9a



9b



9c

Figure 9: (9 a) Nearly 50 radiosonde launches were made during field campaigns at Tonzi and Wind River. In addition, soil respiration fluxes were continuously measured at WR and periodically at Tonzi. These data are used to validate the surface layer and PBL layer (when coupled to WRF) TKE and wind shear profiles as well as modeled soil CO_2 fluxes in the land-surface model ACASA (9b). The goal of ACASA is to provide the FLUXNET community with an alternative, accurate gap-filling code which is adaptable to any field site. A preliminary example of using ACASA for gap-filling the Wind River eddy covariance CO_2 measurements is shown (9c). Improvements to the model are in progress.

Acknowledgments: This research was supported by a Laboratory Directed and Research Development Grant (12-ERD-043) at the Lawrence Livermore National Laboratory. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-POST-605972