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Constraining regional carbon fluxes in complex terrain: The Airborne Carbon in the Mountains Experiment 2007 (ACME07)

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Introduction

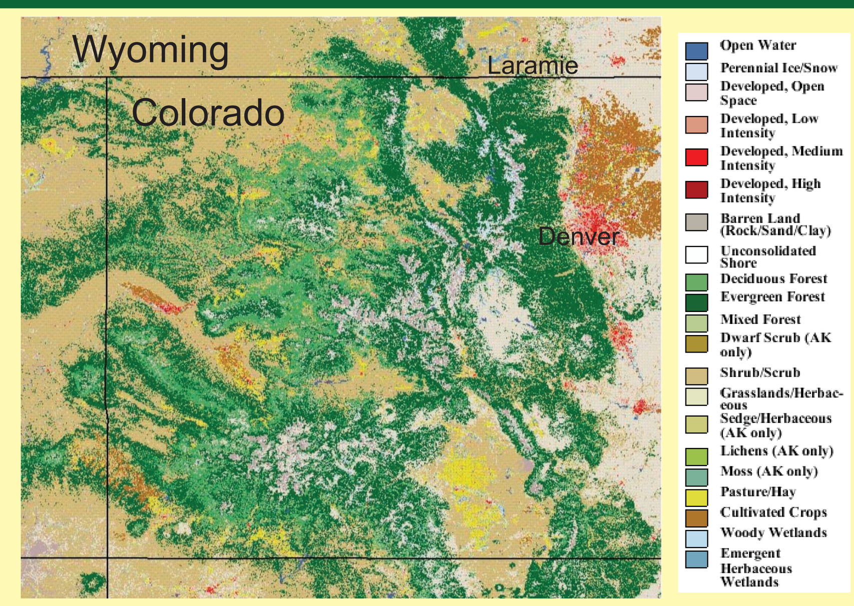


Figure 1. National Land Cover Database 2001 land cover for the ACME07 domain. Flights were launched from Laramie, WY and most sampling occurred in the NE quadrant of forested area (Source: USGS).

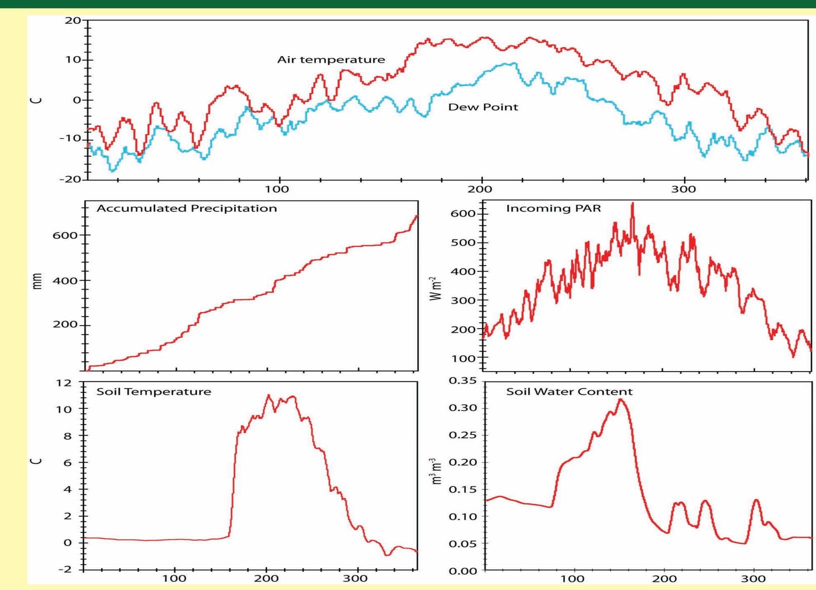


Figure 2. Five-day smoothed daily tower meteorology observations for 2007 from the Niwot Ridge Ameriflux tower located in subalpine forest (3050 m MSL). The site is one of few forest observations in the region. Soil moisture and snow melt dynamics play an important role in the seasonal cycle.

Montaine environments contain significant quantity of forests that are poorly constrained in regional and global estimate of land-atmosphere carbon exchange (Schimel *et al.*, 2002). In the north central Rocky Mountains, forests are primarily found at higher elevation (Fig. 1) and observations of forest productivity are few and far between.

The **Airborne Carbon in the Mountains Experiment 2007** (ACME07) occurred March-August 2007 as a follow-on to the ACME04 project. The goals of the project were to:

- Quantify variations in CO_2, CO, O_2, H_2O, and micrometeorology in the north central Rocky Mountains with the U. Wyoming King Air
- Constrain regional exchange of CO_2 in montaine environments using atmospheric-tracer and ecosystem-modeling approaches
- Understand dynamics of valley cold pools and their relationship to basin-scale ecosystem respiration
- Assess climate, fire, and pest disturbance sensitivity of montaine ecosystem productivity

Smoothed 2007 daily meteorology at Niwot Ridge Ameriflux tower (Fig. 2) reveals major seasonal cycles driven in spring by timing of soil thaw and snow melt, in early summer by onset of drought (lower precip, higher VPD), and late summer by onset of monsoon flow.

Airborne Observations

Morning upwind and afternoon downwind CO_2 profiles were sampled using a receptor based sampling framework (Figs. 7 and 8) across 18 flights from April-August 2007.

Particle models (Flexpart and STILT) coupled to an ensemble of nowcast wind forecasts (WRF, MM5, NAM, ...) reveal complexity that terrain adds to receptor-based inversions due to valley pools, vertical shear, and inhomogenous boundary layer mixing.

Reanalysis boundary layer depth, forecast particle trajectories, and mean paired morning-afternoon profiles (e.g., Figs. 7 and 8) were used to compute simple boundary layer budget CO_2 drawdawn estimates (Table 1).

Computed flux compares well to regional ecosystem model and flux tower daily flux estimates (Fig. 9), except aircraft flux shows increasing uptake over the summer in contrast to ecosystem model and flux tower observations. Ensemble data assimilation approach required to accurately quantify flux.

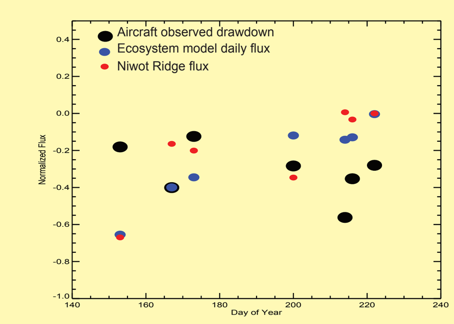


Figure 9. Comparison of normalized anomalies in aircraft drawdown budget, ecosystem model flux, and Niwot Ridge flux tower.

	Morning		Afternoon			
Day	Zi (m)	CO_2 (ppm)	Zi (m)	CO_2 (ppm)	Δ t (h)	Change (ppm m s^{-1})
1-Jun	2377	379.9	3301	375.2	4.21	-1.0
15-Jun	2754	383.5	3811	371.1	5.75	-2.3
21-Jun	3425	389.4	4348	386.2	5.59	-0.7
18-Jul	2674	383.2	3277	373.5	5.47	-1.6
1-Aug	2350	407.9	2861	384.9	5.76	-3.2
3-Aug	2659	396.6	3214	385.0	5.20	-2.0
9-Aug	2944	393.4	3175	383.3	5.64	-1.6

Table 1. Comparison of upwind and downwind mean CO_2 and morning vs. afternoon mean North American Regional Reanalysis (NARR) PBL depth. Entrainment and particle model divergence are ignored in budget calculation. Calculations show reasonable estimates of uptake that is minimum in late June and maximum in early Aug.

June 21, 2007

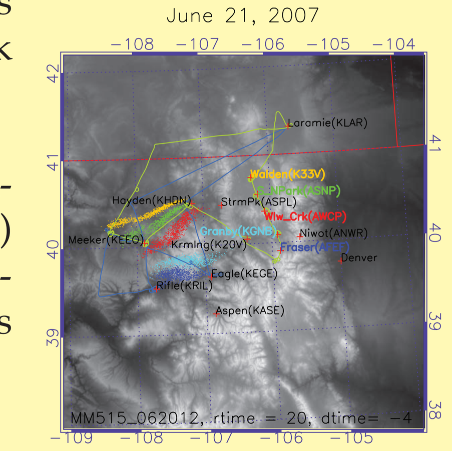
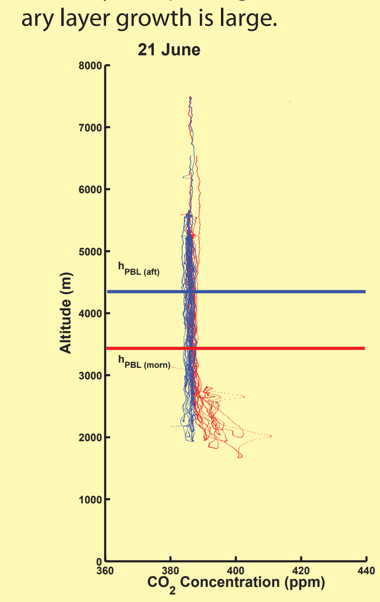


Figure 7. Case Study 1 - June 21 with flight paths and particles for five receptors (top) and subselected upwind and downwind CO_2 profiles (bottom). Southern receptors have less shear and different wind direction. Daytime pooling is small and boundary layer growth is large.



August 09, 2007

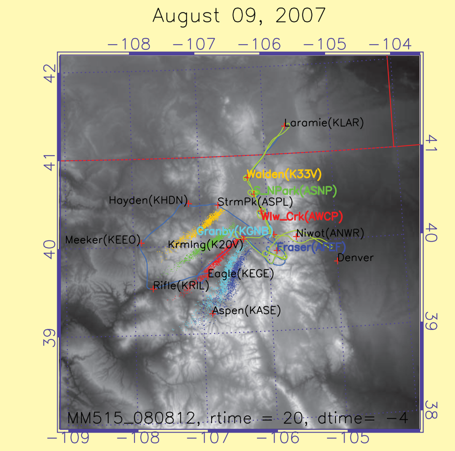
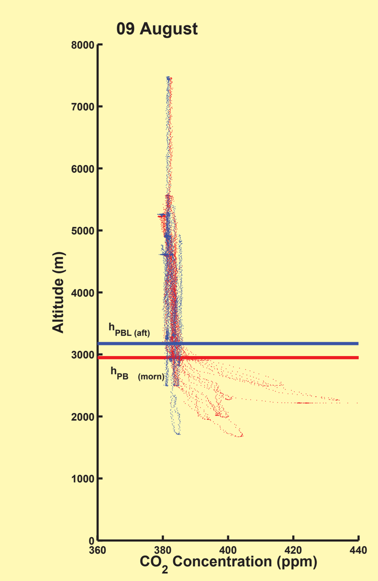


Figure 8. Case Study 2 - Aug 9. Here particles have high shear, but similar wind directions (top). Valley CO_2 pools were found to be much larger, while daytime boundary layer growth appears to be relatively small.



Ecosystem Modeling

Snow melt and drought process influence annual course of net ecosystem exchange (NEE) at the Niwot Ridge Ameriflux tower (Fig. 3) The two processes lead to the observed dual uptake peaks in daily mean flux. Project year NEE (2007, dark gray) was not significantly different from mean of prior years (light gray) with the exception of a small period of increased uptake in early July.

The Sipnet ecosystem model (Sacks *et al.*, 2006) parameterized using Markov Chain Monte Carlo techniques can successfully simulate regional CO_2 fluxes at Niwot Ridge. These parameters were used to define a spatial model across the ACME07 domain.

Model inputs were spatialized at 32x32 km² resolution with North American Regional Reanalysis (NARR) meteorology, NASA MODIS LAI observations, and National Land Cover Database land cover. Additional spatial variation of biophysical parameters was derived from Bradford *et al.* (2008). The regional fluxes in a 3 x 1.125 degree box around Niwot Ridge show close similarity to observed NEE at Niwot Ridge (Fig. 3, green line).

Domain monthly NEE (Fig. 4) shows broad pattern of CO_2 uptake in May, onset of drought-related CO_2 release at lower elevations in June, and expansion of drought and warmer temperatures to higher elevations in July and August. Annual NEE (Fig. 5) shows highest uptake at mid and high elevation locations where forest cover is greatest (Fig. 6).

Even on a square meter basis, annual NEE is more negative at higher elevations (Fig. 6) due to temperature sensitivity of decomposition and photosynthesis. These results also suggest that climate warming may shift the elevation zone of highest productivity for subalpine forests.

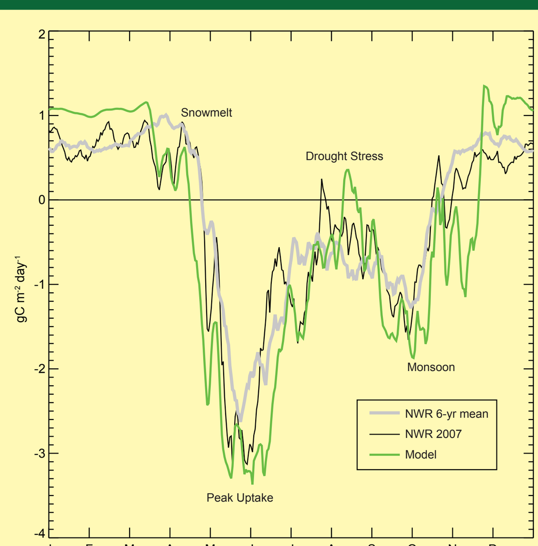


Figure 3. Five-day smoothed daily total NEE at Niwot Ridge 2007 (dark gray), average 1999-2004 (light gray), and the spatial ecosystem model (green), revealing typical uptake pattern.

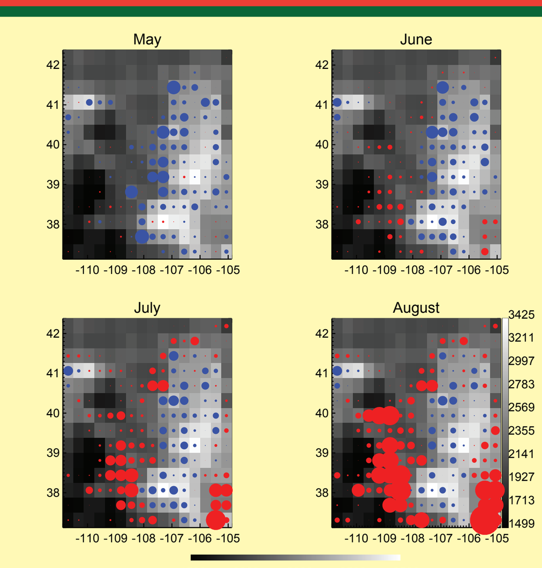


Figure 4. Spatial variability in model monthly NEE from May-Aug. Blue is uptake, red is source. Gray image is elevation. Peak uptake in May is slowly eroded by drought and higher temperatures.

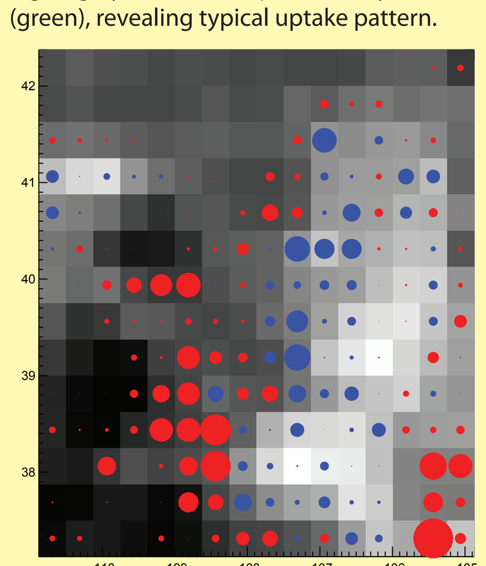


Figure 5. Same as Fig. 4 but for annual NEE revealing pattern of highest NEE in mid-elevations and source of CO_2 on the western slope and at lower elevations.

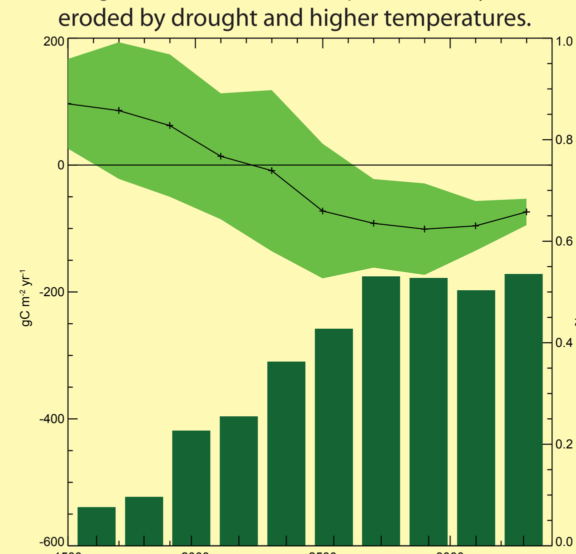


Figure 6. Evergreen forest NEE anomaly on a square meter basis with elevation in ACME07 domain (black line + green standard deviation). Also shown is fraction of elevation zone vegetated (dark green)

Disturbance and Climate Change

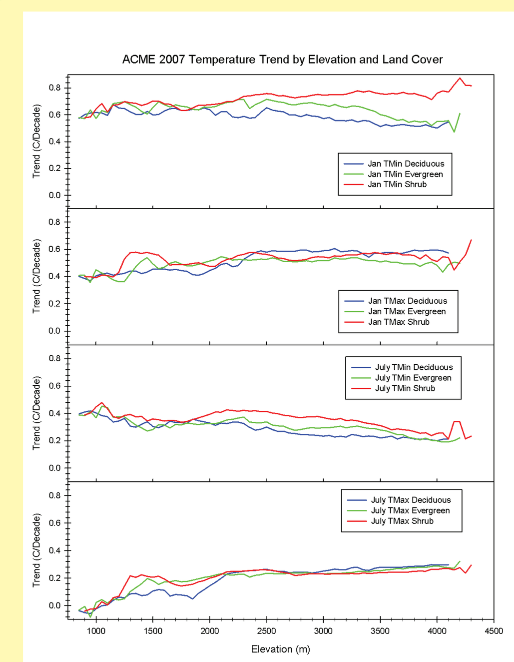


Figure 10. 1970-2007 trends in maximum and minimum monthly temperature binned by elevation and land cover in the ACME07 domain for January and July. All trends are positive, and most trends increase with elevation and with decreasing forest cover.

Regional climate trends over past 37 years, derived from PRISM downscaled meteorology database and NLCD land cover, reveal general pattern of increasing monthly temperatures in both summer and winter (Fig. 10). Higher elevations are warming faster than lower elevations, especially for winter temperatures, and shrublands are warming faster than forest. Effect of changes in snowmelt and drought timing likely to significantly affect regional NEE.

Warming climate allowing for bark beetle infestation to increase in severity and extent. Fraser valley CO_2 observations from Rocky RACCOON *in situ* tower show decline in buildup of nocturnal CO_2 during period of active infestation, suggesting a decline in ecosystem respiration (Fig. 11).

Future work with ACME07 data will attempt to quantify climate and disturbance sensitivity of forest carbon exchange and project changes to future montaine ecosystem fluxes due to climatic warming, recurring pest invasions, and fires.

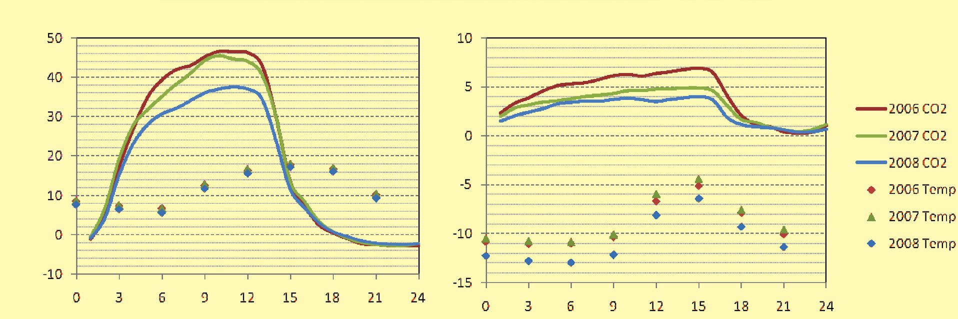


Figure 11. Ensemble mean diurnal pattern of CO_2 concentrations in the Fraser Experimental Forest after removing background CO_2 in summer (left) and winter (right). Nocturnal CO_2 buildup has been decreasing over the years during which significant quantity of forests have died in the valley (source: P. Wilkes, King's College-London).

References

Bradford, J.B., *et al.*, 2008. Tree age, disturbance history, and carbon stocks and fluxes in subalpine Rocky Mountain forests. *Global Change Biology*, 14(12): 2882-2897.

Sacks, W.J. *et al.*, 2006. Model-data synthesis of diurnal and seasons CO_2 fluxes at Niwot Ridge, Colorado. *Global Change Biology*, 12(2): 240-259.

Schimel, D.S., *et al.*, 2002. Carbon sequestration studied in western U.S. mountains. *EOS Transactions*, 83(40): 445-449.

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