Carbon Balance in the Rocky Mountains: Integrating multi-scale information to develop process based understanding of regional carbon fluxes.

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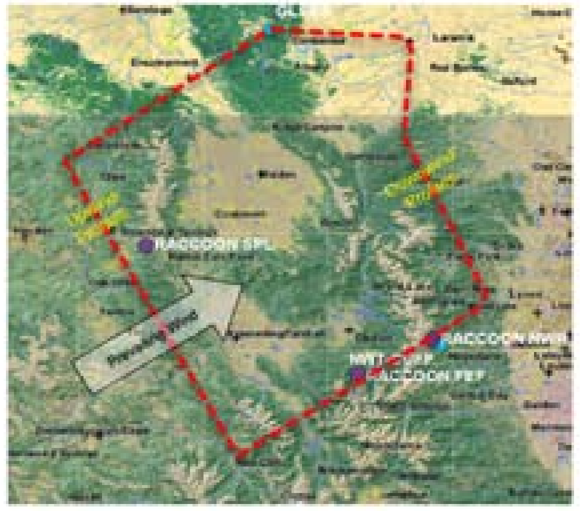
1. Direct Measurements on multiple scales



ACME: Airborne Carbon in the Mountains Experiment. This is the first attempt to measure carbon exchange in mountainous terrain using airborne techniques. ACME evaluates the use of budget, profiling, flux and multiple tracer (13C, 14C) approaches.

Rocky RACCOON

Regional Atmospheric Continuous CO_2 Network in the Rocky Mountains

We have deployed three (Automated Inexpensive Robust CO_2 Analyzers) AIRCOAs (1) at Niwot Ridge, above tree line, (2) at the Storm Peak Lab at the top of Steamboat Mountain ski area in Northwestern Colorado, and (3) at the base of the USFS Forest Service Fraser Experimental Forest.

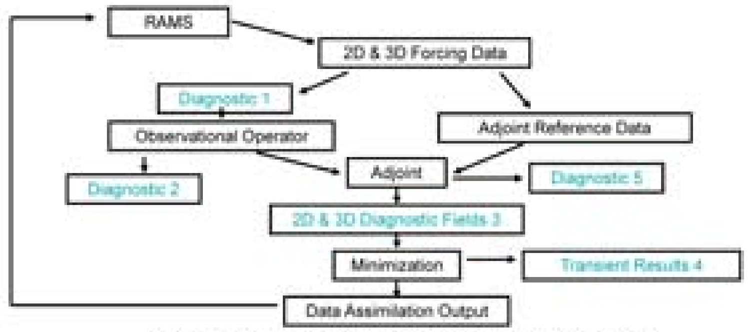
Tower eddy covariance array

The array consists of tower sites throughout the Front Range of the Rocky Mountains. These sites provide direct estimates of Net Ecosystem Exchange (NEE) at high temporal resolution. These measurements inform our understanding of the temporal controls of NEE from minutes to years. They also provide direct inputs to the SIPNET model which allows us to de-convolve the fluxes into their components.

2. Integration using data assimilation

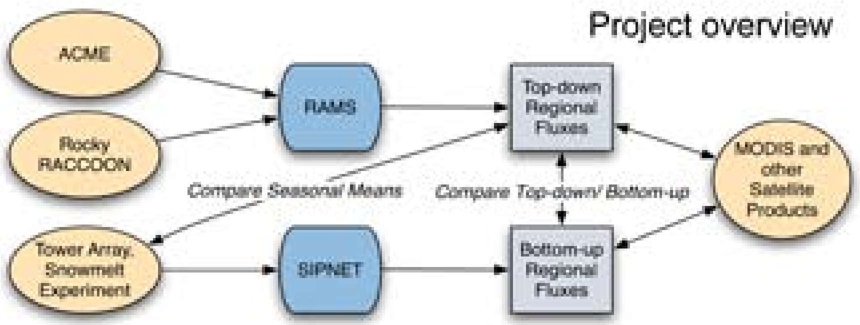
CO_2 measurements will be combined using regional and local data assimilation methods using the RAMS and SIPNET models, incorporating topology, vegetation cover and high resolution weather data to produce top down and bottom up estimates of net carbon uptake and release in the Rocky Mountains.

RAMS We use the Regional Atmospheric Modeling System (RAMS) to integrate the air transport and mixing processes which affect the spatial distribution of CO_2. We use the near continuous data from Rocky RACOON and tower experiments to inform the model. The model's grid averaged surface flux can be compared to the ACME flight results.



Above: *Overview of the Regional Atmospheric Modeling Data Assimilation System (RAMDAS) illustrating how the of the optimization are used to guide model structural changes.*

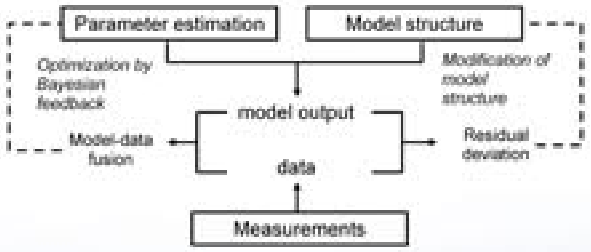
Project overview



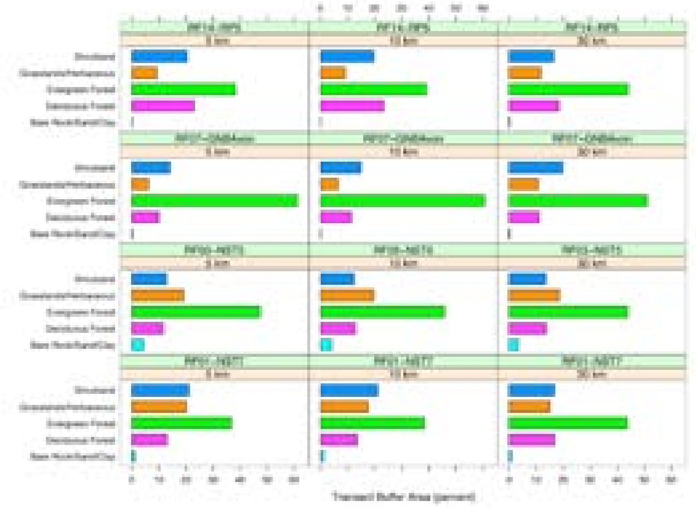
SIPNET The Simple Photosynthesis EvapoTranspiration (SIPNET) model is based on the PnET family of models developed by Aber et al. We use SIPNET with half-daily daytime and nighttime time steps. In each step, eight climate variables drive the flux dynamics: (1) average air temperature, (2) average soil temperature, (3) precipitation, (4) flux density of photosynthetically-active radiation, (5) atmospheric vapor pressure, (6) atmospheric vapor pressure deficit, (7) vapor pressure deficit between the soil and the atmosphere and (8) wind speed.

- SIPNET uses Metropolis simulated annealing algorithm to find both the single best parameter set and an estimate of the posterior distribution of the parameters.
- Basic concept: maximize likelihood,
- SIPNET can use CO_2 and/or H_2O fluxes in the optimization

$$L = \prod_{i=1}^{n} \frac{1}{\sqrt{2\pi\sigma}} e^{-(x_i-\mu_i)^2/2\sigma^2}$$



Above: *Overview illustrating the parameter optimization approach, and showing how the results of the optimization are used to guide model structural changes.*



The diagram above shows the vegetation cover sampled by a set of AMCE flights in 2004. Accurate comparison and scaling of flight CO_2 fluxes require robust quantification of the contribution of different vegetation types to the fluxes

3. Findings and future directions

Progress so far

By assimilating the carbon fluxes measured at the Niwot Ridge flux site in CO, we were successful in separating Gross Ecosystem Exchange (GEE) and ecosystem respiration (R_E), but less successful in accurately partitioning R_E into its autotrophic and heterotrophic components (Sacks et al 2006). Our groups have found that predicting the carbon balance in arid montane forests hinges on the understanding of fundamental physiological processes during a critical period of snow melt in early spring. We found that longer growing seasons at Niwot Ridge were correlated with <u>less</u> net annual CO_2 uptake, possibly because of a decrease of available snow-melt water during the late springtime photosynthetic period. We also found strong evidence for non-arrhenius temperature controls of respiration caused by changes in the microbial population (Monson et al. 2006)

Simulations of the ACME semi-Lagrangian budget technique using the RAMS model were done comparing flux estimates over actual Rocky Mountains with idealized simple terrain. These simulations showed that fluxes may be retrieved very accurately over idealized terrain, and that flux estimates over real mountains converge to mean tower based estimate.

Further integration

We plan to determine a regional 'bottom up' estimate of NEE based on a spatially explicit version of the SIPNET model which can be compared with a 'top down' regional estimate derived from combining RAMS, tower CO_2 meaurements and ACME flight data.

We hope that integrating phenology of gross primary productivity extracted from satellite data with process level information derived from ground measurements and models optimized using data assimilation will lead to a greater predictive understand of carbon balance in mountain regions.

References: Monson RK, *et al.* (2006) ***Nature*** 439: 711-714; Sacks, WJ *et al.* (2006) ***Global Change Biology*** 12: 240-259.