Assessment of Discrete Time Filters of Mountaintop CO_2 Observations for Application to Inverse Models

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Motivation

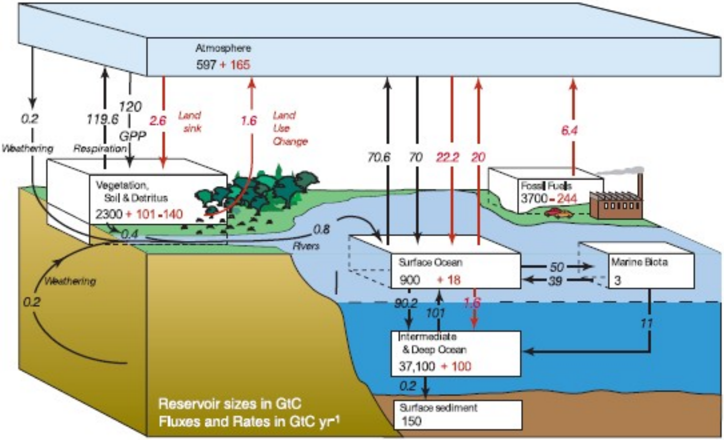
- Complex terrain poses considerable challenges for our ability to measure and predict exchanges of carbon dioxide between the ecosystem and atmosphere
- U.S. Mountain West is undergoing measurable climatic shifts impacting drought, fire, insect outbreaks and the ability of the region to serve as a sink of atmospheric CO_2
- Approaches for quantifying the carbon exchange differ in seasonal magnitudes and timing of peak uptake over various scales.

Motivation

Bark beetle infestation of lodgepole pine (August 2010, Keystone, Colorado)

Motivation

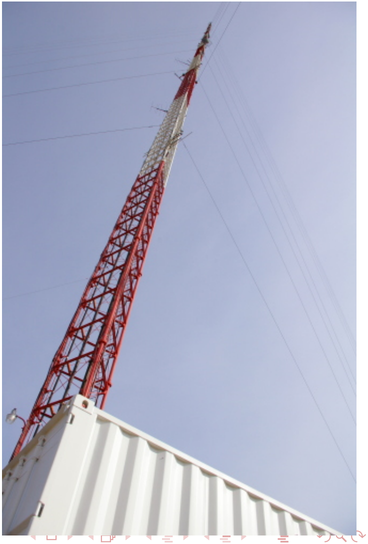
The global carbon cycle for the 1990s, showing principal fluxes in GtC yr^{-1} (taken from IPCC AR4)



Measuring exchanges of carbon

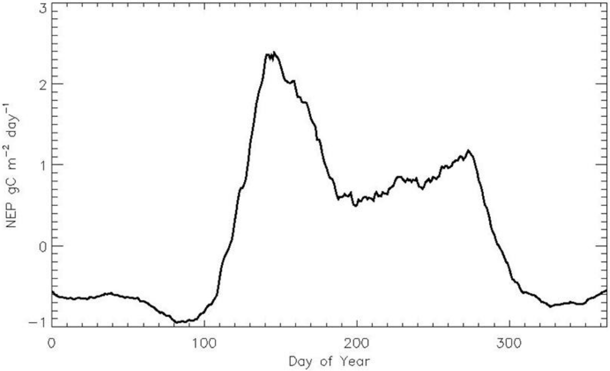
- Direct measurement of net ecosystem exchange (NEE) using the eddy covariance technique is preferred over flat landscapes with relatively homogeneous landcover (e.g. grasslands, wetlands, tree canopies)
- NEE responds strongly to changes in temperature and water availability, making it a useful indicator of carbon uptake

Wisconsin's tall tower at Park Falls



Measuring exchanges of carbon

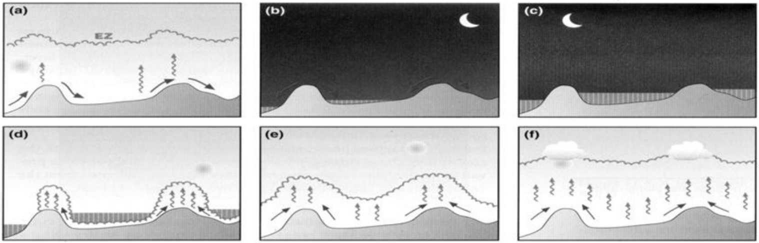
- A derivative of NEE, net ecosystem production (NEP), showing net carbon gained within the tower's footprint over 1 year



AmeriFlux Niwot Ridge (Colorado) tower

Issues with eddy covariance over complex terrain

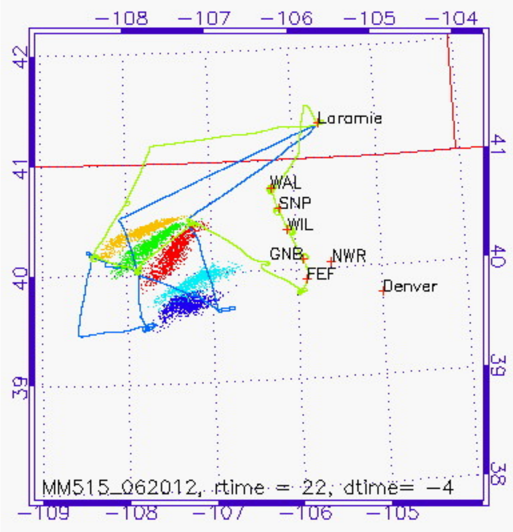
1. Typically land cover is quite variable
2. Frequent terrain and thermally driven (**upslope/downslope**) flows
3. Models are not good at simulating carbon exchange over terrain



Alternatives: Airborne Boundary Layer Budget

Airborne Campaign in the Mountains Experiment '07 (ACME-07)

- Apprx. footprint: north cen. Colorado
- Cost & Not real-time



Alternatives: Process based (bottom-up) Modeling

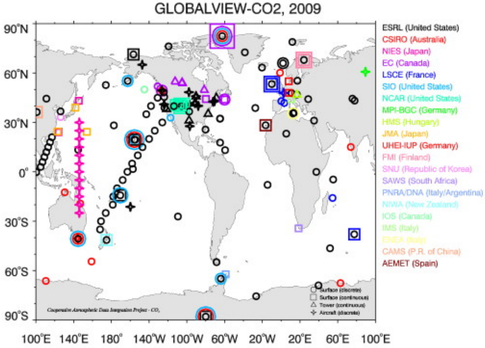
- Bottom-up models such as NCAR's Community Land Model (CLM) and NOAA's LM3V use remotely sensed products (fPAR, LAI) to drive reaction rates and exchanges.
- Remotely sensed observations can be problematic, particularly in terrain that is subject to frequent disturbance

Alternatives: Inversion Modeling to Retrieve Fluxes

Advantages of this approach for modeling over complex terrain

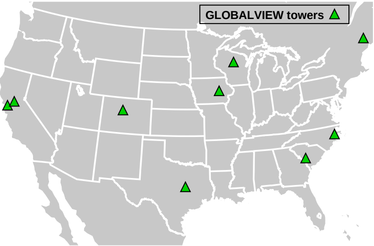
1. Extensive CO_2 concentration monitoring network. Isolated surface stations from the 1950's evolved into sophisticated satellite and *in situ* **observing systems**

2. Infrastructure. Mountaintop monitoring of CO_2 has provided both motivation and infrastructural engineering required to study land–atmosphere carbon exchange



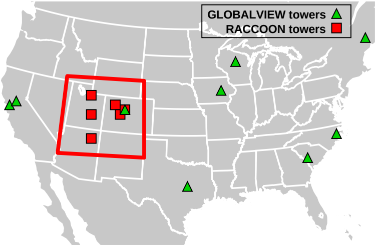
Alternatives: Inversion Modeling to Retrieve Fluxes

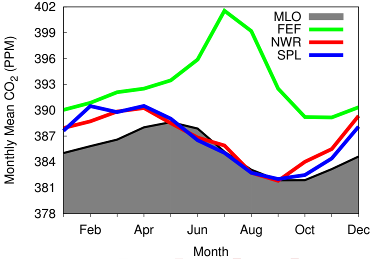
- Over complex terrain flux retrieval is preferred **but** results can be confounded by unresolvable flows that skew CO_2 measurements
- Our ability to obtain accurate CO_2 fluxes is limited by a large gap in the monitoring network over Western US



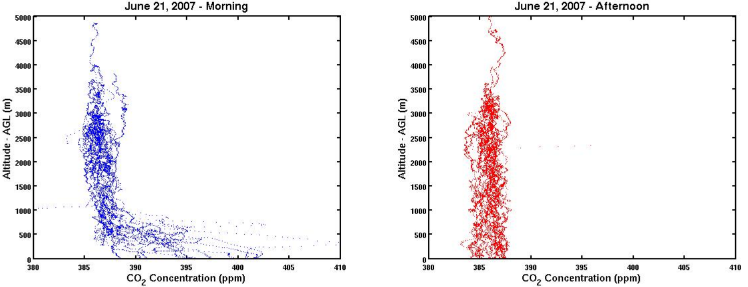
Regional Atmospheric Continuous CO_2 Network (RACCOON) Domain & Seasonal Cycle

- RACCOON covers a missing portion of the CO_2 monitoring network in the Mountain West
- Note the difference in seasonal cycles between Mauna Loa (MLO) and RACCOON towers





Example poorly mixed air (left) from Vertical CO_2 Profile over RACCOON (ACME '07 Campaign)



CO_2 concentration: horizontal axis
Altitude: vertical axis

AIRCOA Design & Network Coverage

- Six RACCOON towers are outfitted with autonomous, inexpensive, robust CO_2 analyzer (AIRCOA) platforms
- Observed CO_2 mole fractions are sampled across multiple inlet heights (3-40 m)

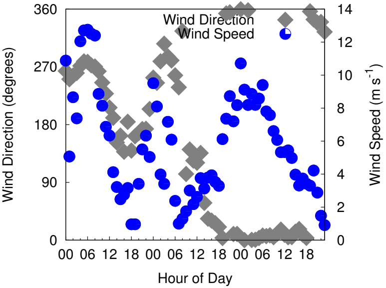
Location and characteristics of the RACCOON towers.

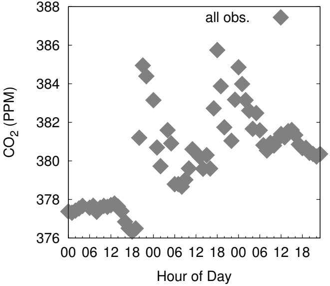
Tower	lat., lon.	Setting
EFS	38.80 N, 109.21 W	marginal plateau
FEF	39.91 N, 105.88 W	alpine valley
RBA	36.46 N, 109.10 W	mountaintop
SPL	40.45 N, 106.73 W	mountaintop
HDP	40.56 N, 111.65 W	mountaintop
NWR	40.05 N, 105.58 W	mountaintop

	Elevation (msl)	tower ht. (m)	Year Installed
EFS	1280	39	2007
FEF	2745	18	2005
RBA	2982	22	2007
SPL	3210	9	2005
HDP	3351	18	2006
NWR	3523	5	2005

Example of Scatter in Tower Data from Niwot Ridge

1. Need for rejecting data representative of upslope/downslope flows, nocturnal spikes, and exaggerated afternoon dips caused by local vegetation
2. Reducing "sampling error" improves flux retrieval representativeness





Motivating Questions

- Can **spatial coherence** and simple evaluation of CO_2 time series be used to identify local or regional air mass?
- How do **statistical CO_2 filters** compare with respect to variances, growth rates, and 'flagged data'?
- What do these filters suggest about the use of mountaintop CO_2 observations in inverse models to estimate regional fluxes?

Discrete Time CO_2 Data Filters

- Detection error (**DE**) filters have effective uses as 'first pass' filters of atmospheric CO_2 data. Used by Gillette and Steele (1983) as a basic filter of flask sample data from Niwot Ridge, and Keeling and others (1976) for South Pole data. Filtered subsets are formed:

$$\{X_{i,h} \in x(t) : \sigma_{X_{i,h}} < 1 \ \ and \ \ |X_{i,h} - X_{i,h-1}| < 0.5\} \quad (1)$$

- Statistical interpolation (**SI**) filters are useful for sophisticated signal processing, including NOAA's MLO tower (Thoning and others 1989). Data points from complete set X_j are used to fit a spline $S(X_i)$ curve. Outliers then rejected during iterative passes. Formation of final subset $x(n)$:

$$\{X_j \in x(n) : |S(X_i) - X_j| < 0.5\} \quad (2)$$

Discrete Time CO_2 Data Filters

- Weighted median (**WM**) filter is designed to adjust for synoptic variability via a dynamically calculated limit l, that is used to form the subset:

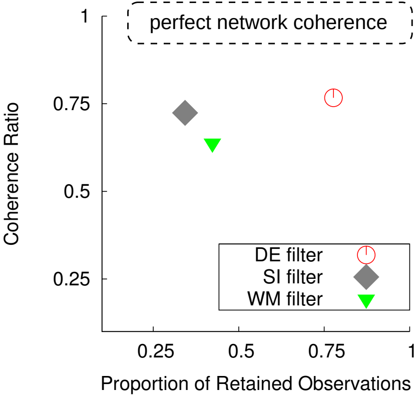
$$\{X_i \in x(n) : |\widetilde{X}(n) - X_i| < l\} \tag{3}$$

- Spatial **coherence** is designed to identify periods when observations from proximal towers (X_i, X_j) are sampling the same air mass:

$$\{X_i \in x(t) : |X_i - X_j| < 1\} \tag{4}$$

Spatial Coherence

$$\{X_i \in x(t) : |X_i - X_j| < 1\}$$



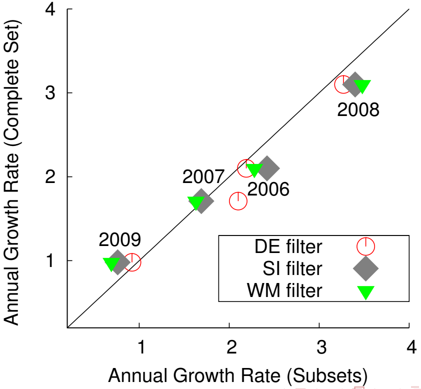
Basic Statistics

Table: Basic statistics for the complete set of observations (**CS**), and filtered subsets (**DE**, **WM**, **SI**) across years 2005-2010. Normalized sum of squares (SS_N) represents average space-time variability.

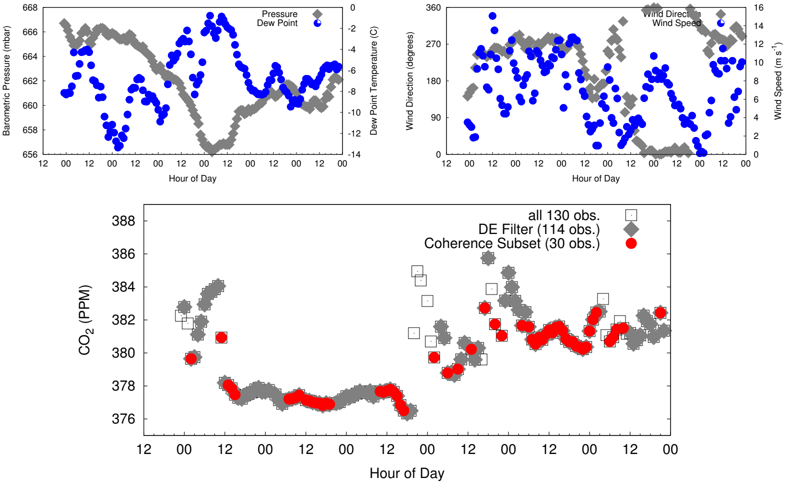
	Retained Fraction	Grand Mean	SS_N
CS	1.000	388.5	50.2
DE	0.777	387.1	17.1
WM	0.423	387.5	9.2
SI	0.343	387.5	8.2

Mean Annual Growth Rates

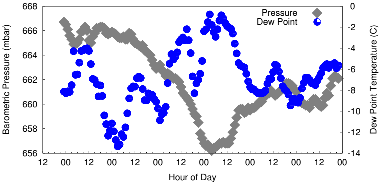
Figure: Mean annual CO_2 growth rates by year. Note that growth rates along the vertical axis greater than 2 PPM/year lie below the 1:1 line.

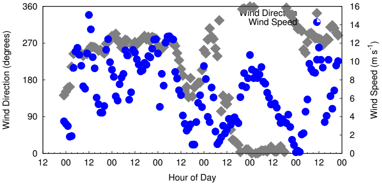


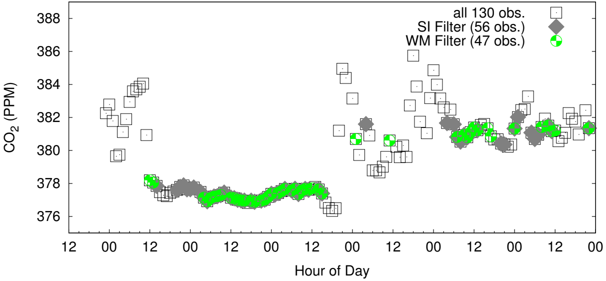
Synoptic Case Studies: DE & Coherence



Synoptic Case Studies: SI & WM

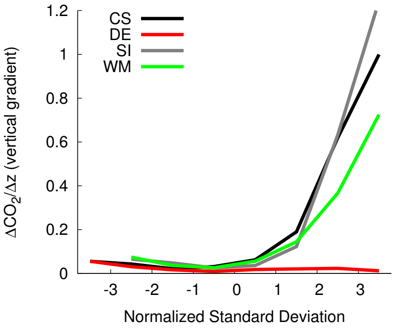






Relationship between vertical CO_2 gradient and standard deviation

Relationship between vertical CO_2 gradient and standard deviation. The $\Delta CO_2/\Delta z$ vertical gradient is plotted for each half-open range of standard deviations $([-4, -3), [-3, -2), \dots)$



Summary

- When used on nearby towers spatial **coherence** filters spurious observations reasonably well, although output can be sporadic. However, **coherence does not distinguish between well-mixed and poorly-mixed CO_2 samples**.
- The **DE** filter is the least stringent, permits the most spurious observations, largely because it **can only account for detection and sampling error across the height of the tower**.
- **SI** & **WM** filters reject more than half of the complete set of observations.
- The **SI** and **WM** filters remove the most spurious (non-synoptic) observations.

Future Work: Experimental Design for Estimating Regional Fluxes

- CarbonTracker (CT) is an inverse tracer transport model that optimizes flux estimates using observed CO_2 mole fractions (www.esrl.noaa.gov/gmd/ccgg/carbontracker/)
- CT branched-run simulations assimilating various collections of RACCOON observations:
    - **Control**. Standard CT simulation assimilating data from 2 RACCOON towers
    - A. **Complete set** from 4 RACCOON towers assimilated
    - B-D. **Filtered subsets** from 4 RACCOON towers
        1. Nocturnal observations only
        2. Nocturnal and daytime observations
        3. Tower elevation adjusted to match model orography (nocturnal and daytime)

Future Work: Multi-model Regional Calibration Study

- In line with AmeriFlux and NACP objectives, carry out a diagnostic evaluation of carbon budgets over US Mountain West from forward and inverse models
  - How much do forward and inverse models differ with respect to time averaged carbon budgets and seasonal cycles over the US Mountain West?
  - Does the mismatch between carbon exchange estimates exceed model error estimates?
- 'Apples-apples' comparison of process based models using the same transport model

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This talk:
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