Detection of climate-driven terrestrial carbon flux anomalies in the US Mountain West through integration of CarbonTracker with back-trajectory models and mountaintop CO_2 observations

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Introduction

High-elevation forest ecosystems potentially contribute a large fraction of carbon uptake in North America. Carbon balance across the U.S. Mountain West is thought to be significant but highly susceptible to a variety of stressors such as drought, fire, and insect outbreaks. We ask: how sensitive are in situ continental CO_2 concentration observations to climatic extremes in the US West? Are we capable of detecting these changes with the existing CO_2 concentration measurement network? If we can, to what degree and at what locations can we best detect them? We applied Weather Research Forecast-Stochastic Time Inverse Largragian (WRF-STILT) back trajectories to mountaintop observation sites of the Regional Atmospheric Continuous CO_2 Network in the Rocky Mountains (Rocky RACCOON) to test the sensitivity of mountaintop CO_2 mole fraction observations to imposed anomalies (droughts) in simulated biological carbon fluxes from NOAA's CarbonTracker. Carbon surface influence functions over the US Mountain West were calculated by the WRF-STILT model via tracking ensembles of virtual particles released from the model back in time. Back-trajectory particle inverse modeling with mesoscale model (WRF) wind fields were analyzed over 2008 for three days backward in time at three-hour time step. Locations of boundary-layer virtual particle latitude, longitude, and altitude were saved and summed to produce influence functions. CarbonTracker fluxes were numerically manipulated to simulate drought around the US Mountain West and these were convolved with influence functions to generate estimates of sensitivity of carbon mole fraction measurements to modeled flux sensitivity in terrain. The detectability and uncertainty of carbon flux inferred by mountaintop CO_2 were compared for "normal" and "drought" conditions. The results indicate high transport model sensitivity but likely detection of large-scale drought from the Rocky RACCOON network, though the size of drought and the distance between the drought region and an observation site may significantly influence this detectability and sensitivity.

Principles and Methodology

1. WRF-STILT model: Backward time particle simulations enable implementation of a ''receptor-oriented framework'' that defines upstream influences on tracer observations at the receptor. A single backward time release of particles marks out the potential source region $(x{\downarrow}i{\uparrow}, y{\downarrow}i{\uparrow}, z{\downarrow}i{\uparrow})$ that influences the receptor $(x{\downarrow}r, y{\downarrow}r, z{\downarrow}r)$, generating the spatial and temporal dependence of the influence function $I(X{\downarrow}r,$

Framework for Drought Experiment

1. We investigated the effects of drought in the US West on the measurements of CO_2 concentration and tested sensitivities of these measurements to climate-driven terrestrial carbon flux anomalies with back trajectory inverse modeling. Virtual particles were released every hour from the study sites or receptors, and tracked back in time with WRF-STILT model for derivation of influence function (Figure 1)

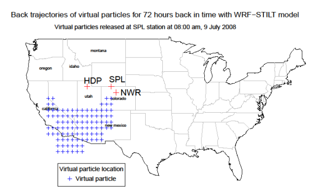

Figure 1 Back trajectories of virtual particles released from SPL at 08:00 am, 9 July 2008 were simulated with WRF-STILT model. The particles were tracked back for 72 hours in time

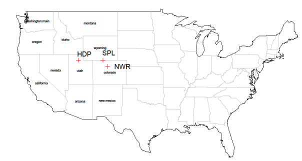

Figure 2 Hiden Peak station (HDP): 40º34' N, 111º39' W, 3351 msl
Storm Peak Laboratory (SPL): 40º27' N, 106º44' W, 3210 msl
Niwot Ridge T-Van (NWR): 40º03' N, 105º 35' W, 3523 msl

2. Study sites: we chose three mountaintop CO_2 concentration measurement stations from Rocky RACCOON as study sites or receptors (Figure 2) to conduct back trajectory inverse modeling and calculate influence functions for the US West area.
3. Drought intensity, size, and domain: During the time period between 2001 and 2010, 2006 is a regular year without major drought, but there were some large droughts occurred in 2008 in the US Mountain West. Figure 3 shows the CO2 concentration differences between our study site SPL and Mauna Loa in 2006 and 2008.

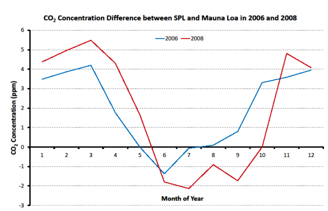

Figure 3 CO_2 concentration differences between the real time measurements at SPL and Mauna Loa in 2006 (a regular year) and 2008 (a drought year)

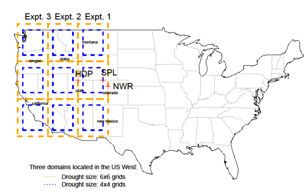

Figure 4 The layout of experimental drought domains in the US West. For Experiment 1~3, there are three domains located in SW, NW, and middle relative to the study sites. Drought may occur in each domain with 4 by 4 and 6 by 6 degrees

4. Simulated droughts occurred in SW, NW, and middle directions relative to the receptor sites with size varying from 4 by 4, 6 by 6, to 10 by 10 degrees (Figure 4-5). Four experiments for drought in the US West were carried out and magnitudes of CO2 concentration change resulted from drought were calculated by multiplying the influence functions of WRF-STILT model and with CarbonTracker biogenic fluxes experimentally suppressed to simulate drought in each experiment region.

Acknowledgements and Major References

1. We are grateful for the funding support from U.S. National Oceanographic and Atmospheric Administration Office of Atmospheric Research (OAR) Climate Program Office (CPO) (grant NA09OAR4310065).
2. Simulation from WRF-STILT model were conducted by Anna Michalak (Carnegie Institute for Global Change) and Arlyn Andrews (NOAA) and provided to us with assistance from Kim Mueller.

*Desai et al. 2011 JGR *Gerbig et al 2003 JGR *Lin et al 2003 JGR *Michalak et al 2004 JGR

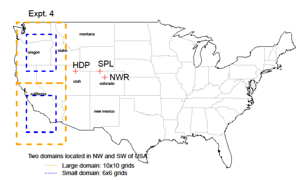

Figure 5 The layout of experimental drought domains in the US West for Experiment 4. There are two large domains located in SW and NW relative to the study sites. Drought size varies from 6 by 6 to 10 by 10 degrees

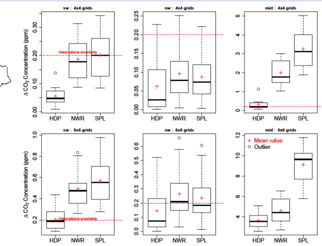

Figure 6 Boxplots for CO_2 concentration differences between the simulated drought year (2008) and a normal year (2006) from different domains and drought size (Experiment 1).

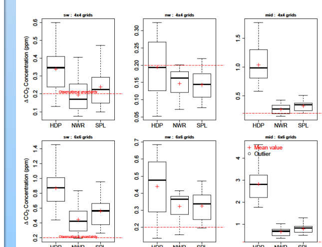

Figure 7 Boxplots for CO_2 concentration differences between the simulated drought year (2008) and a normal year (2006) from different domains and drought size (Experiment 2).

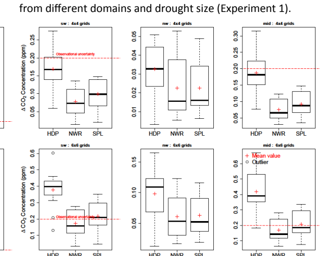

Figure 8 Boxplots for CO_2 concentration differences between the simulated drought year (2008) and a normal year (2006) from different domains and drought size (Experiment 3).

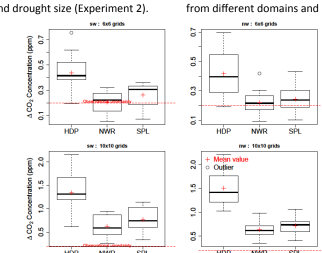

Figure 9 Boxplots for CO_2 concentration differences between the simulated drought year (2008) and a normal year (2006) from different domains and drought size (Experiment 4).

Results and Conclusions

1. Through comparison of CO_2 concentration differences between our study sites and the site in Mauna Loa in 2006 and 2008, we found that drought significantly resulted in more CO_2 releases in the summer and fall of 2008.
2. The experiment results from this study strongly indicate that climatic anomalies such as drought are detectable by CO_2 measurements on the top of Rocky Mountains with typical observation accuracy of 0.2 ppm.
3. The larger the size of drought, the greater the CO_2 concentration increment relative to no drought, but the result is not linear with drought magnitude.
4. Drought in the near-field region are much easier to detect than ones in Pacific U.S.
5. Among these three sites, HDP demonstrated better capability of picking up drought signals from NW, SW, and middle directions relative to the study sites in the US Mountain West. Distance could be an important factor.

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