Analyzing Gross Primary Production and Respiration of Terrestrial Ecosystems Using a Global Carbon Cycle Model That Includes Carbonyl Sulfide

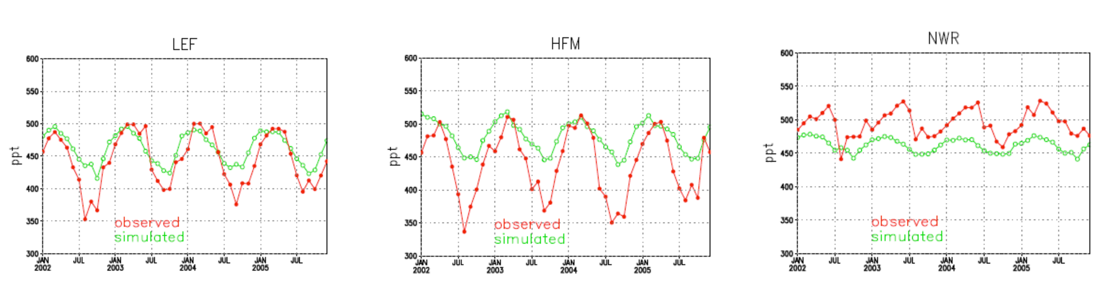
Joe Berry[1], Ian Baker[2], Elliott Campbell[1], S. Randy Kawa[3], A. Scott Denning[2], Zhengxin Zhu[3], Stephen Montzka[4], Adam Wolf[1], Ulrike Seibt[1]
[1]Carnegie Institution, Dept. of Global Ecology, Stanford, CA, [2]Dept. Atmos. Sci. Colorado State Univ. Ft. Collins, CO, [3]NASA, GSFC,Green Belt, MD, [4]NOAA, Global Monitoring Division, Boulder, CO

Introduction

- **Carbonyl sulfide** is an analog of CO_2. It participates in some key reactions of the carbon cycle, and like the ^{13}C and ^{18}O isotopologs of CO_2, monitoring its concentration can provide additional information on carbon cycle processes.
- Its principle source is the ocean and uptake by leaves and soil are its principle sink. There is apparently no significant source from terrestrial ecosystems.
- Atmospheric chemistry and athropogenic sources play a minor role in driving changes in COS concentration.
- The NOAA global monitoring network provides information on the background concentration of COS in the atmosphere.
- Several atmospheric sampling programs have conducted point measurements of COS and CO_2 concentration.
- The goal of this work is to develop a modeling framework for interpreting these data, and to illustrate what COS measurements might tell us

Global Modeling

- **The Parameterized Chemical Transport Model** (PCTM) driven by re-analyzed meteorology from NASA's GEOS-4 model was used to simulate 3-d variation of COS and CO_2 concentration in the global atmosphere.
- **Why use a global model**?
  - A global model does not require atmospheric boundary conditions.
  - Background atmospheric measurements can be used for validation.
  - Kawa et al, (2004) have demonstrated considerable skill in simulating seasonal and synoptic variation in CO_2 with PCTM.
  - PCTM simulations have been widely used for inversions and data assimilation of carbon cycle processes
- **The global budget of COS** presented by Kettle et al., (2002) is the starting point for this model.
  - Simulations with PCTM match the background concentration fairly well but draw-down at continental sites is too small.

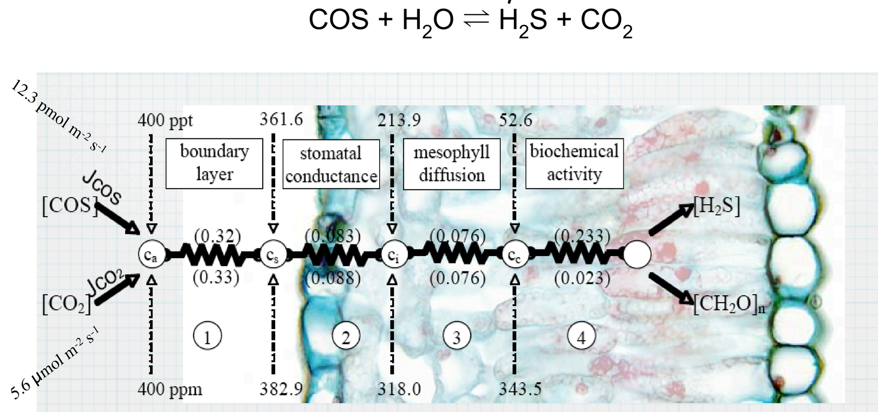


- Work by Kesslemeier and co-workers indicates a larger plant uptake than used by Kettle et al. and identifies the biochemical mechanism of uptake. Opens the way to model COS uptake.

Mechanism of Upatke

- Biochemistry: the uptake is by a hydrolysis reaction catalyzed by carbonic anhydrase (CA), co-located with Rubisco.

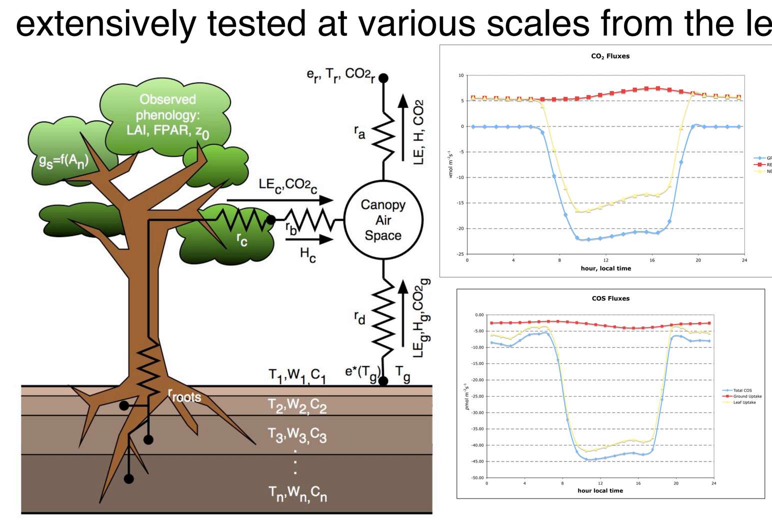
carbonic anhydrase
$$COS + H_2O \rightleftharpoons H_2S + CO_2$$



- Biophysics: Diffusion plays a major role in regulating the rate of uptake. The major control of soil diffusion is by water content, and that of the leaf is regulated by the stomata.

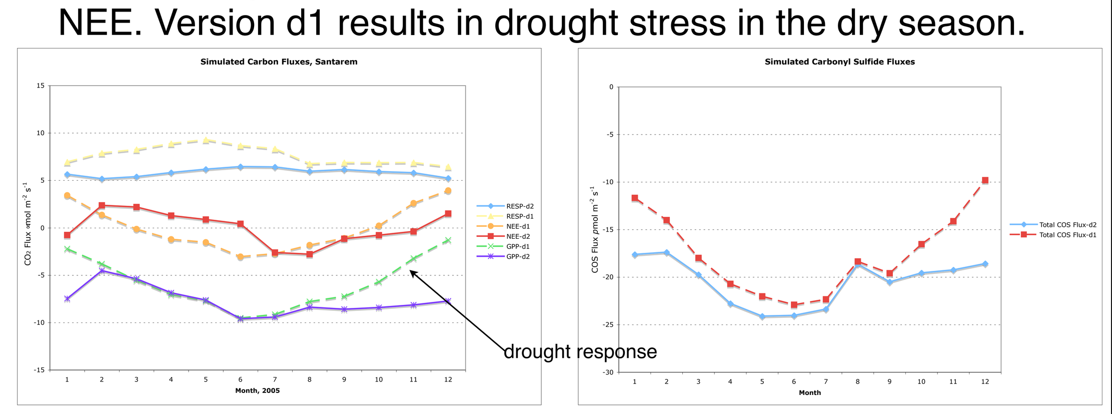
Implementation in SiB - 3.0

SiB-3.0 is a land-surface model that includes the biochemistry and biophysics of CO_2 uptake and respiration. It has been extensively tested at various scales from the leaf to the globe.

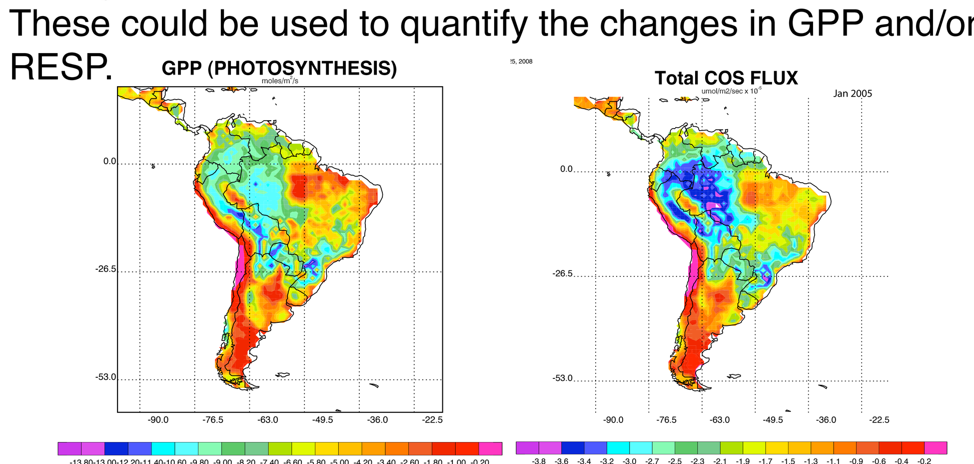


- Amazon Forest
  - Leaf COS uptake parallels photosynthesis (GPP)
  - Soil COS uptake is anti-parallel to respiration (opposite sign).
  - Temperature and water stress responses are assumed to be similar to CO_2.

Yearly Cycles: Figures show simulations with two versions of soil hydrology. Version d2 more closely matches observed NEE. Version d1 results in drought stress in the dry season.



- Un-observable changes in GPP and RESP cause the change in NEE
- Changes in net COS flux occur and could be observed. These could be used to quantify the changes in GPP and/or RESP.



- SiB-3.0-COS was used to simulate fluxes of CO2 and COS hourly at 1x1 degree grid for 2000-2005.
- The spatial patterns of variation in GPP and COS uptake are coherent.

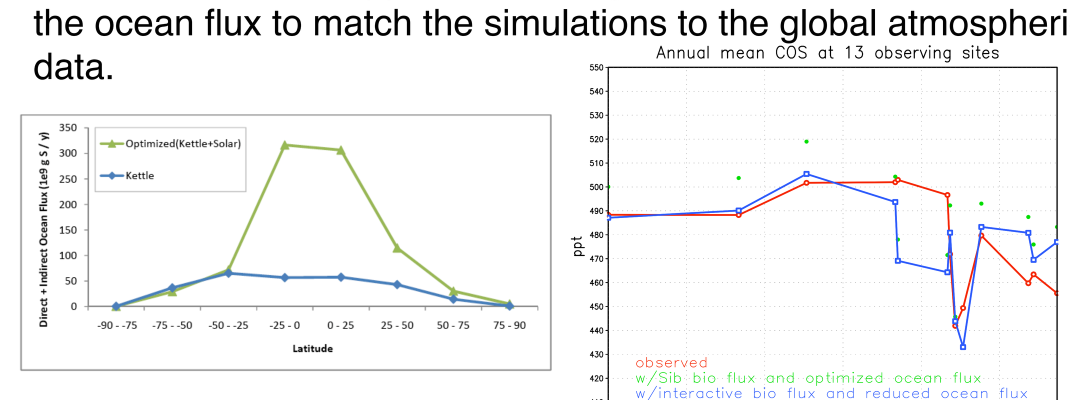
Revisiting the Global Scale

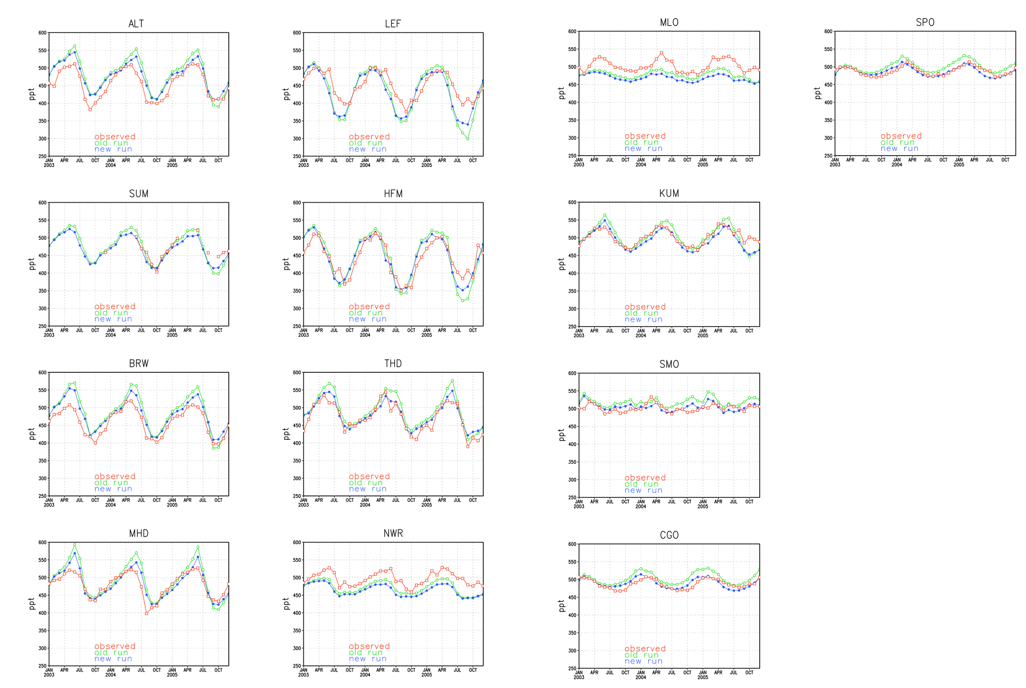
- The new estimates of plant and soil uptake of COS are 3 fold larger and differently distributed than those used by Kettle et al.
  - The sources need to be increased to balance the budget
  - We assume the new source is in the ocean

(unit = 1.0e+09 g Sulfur)

	K2002	This Study
Sources		
Direct COS Flux from Oceans	39	39
Indirect COS Flux as DMS from Oceans	81	81
Indirect COS Flux as CS_2 from Oceans	156	156
Direct Anthropogenic Flux	64	64
Indirect Anthropogenic Flux from CS_2	116	116
Indirect Anthropogenic Flux from DMS	0.5	0.5
Biomass Burning	11	136
Additional Ocean Flux		600
Sinks		
Destruction by OH Radical	-94	-101
Uptake by Canopy	-238	-738.2
Uptake by Soil	-130	-355.8
net total	5.5	-2.5

We used inversion approach varying the latitudinal distribution of the ocean flux to match the simulations to the global atmospheric data.

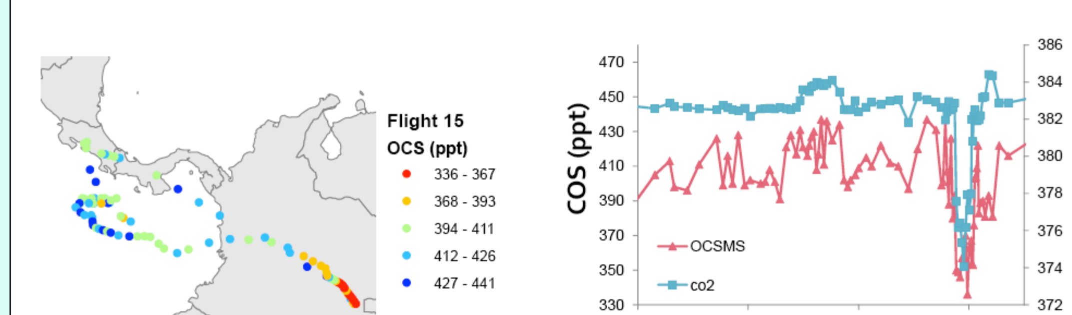




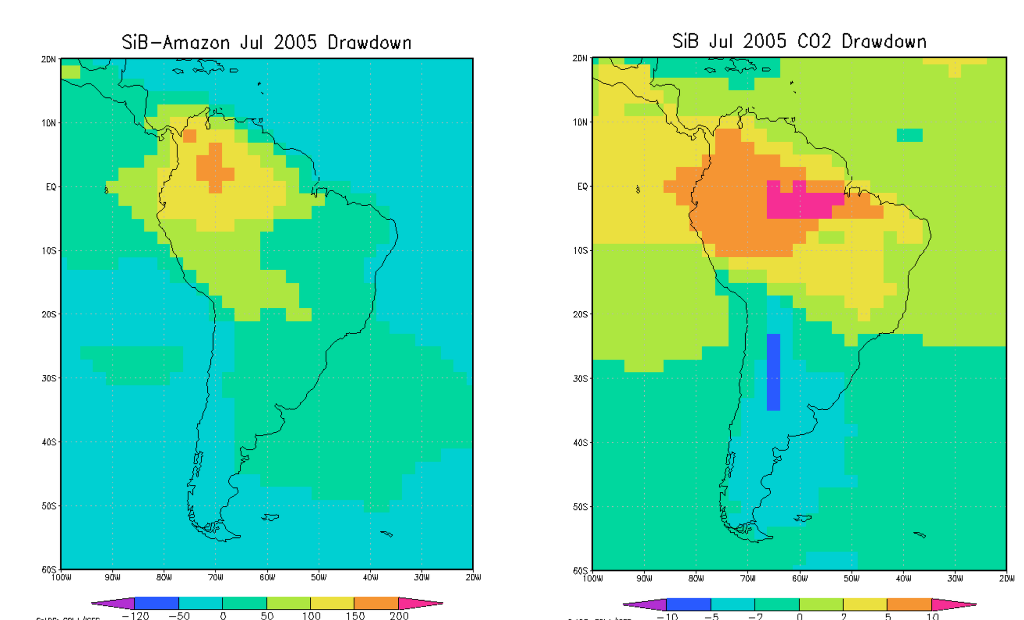
The largest remaining errors are at MLO and NWR..

Predictions of the Model

- If there is a sink for COS at the land surface, the COS concentration should be drawn-down in the boundary layer (ABL) relative to the free troposphere (FT).
- TC4 mission collected samples over the Columbian Amazon. COS and CO2 concentrations (Blake et al., 2007) were lower in the ABL than FT and the change is COS relative to its background concentration was 8 fold larger than that for CO2.

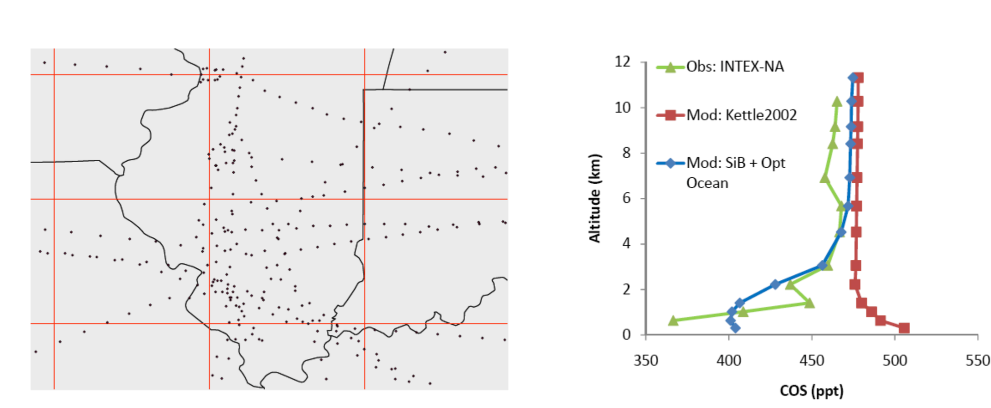


The plots below show simulated difference between mid-ABL and FT for month of July for COS and CO2.



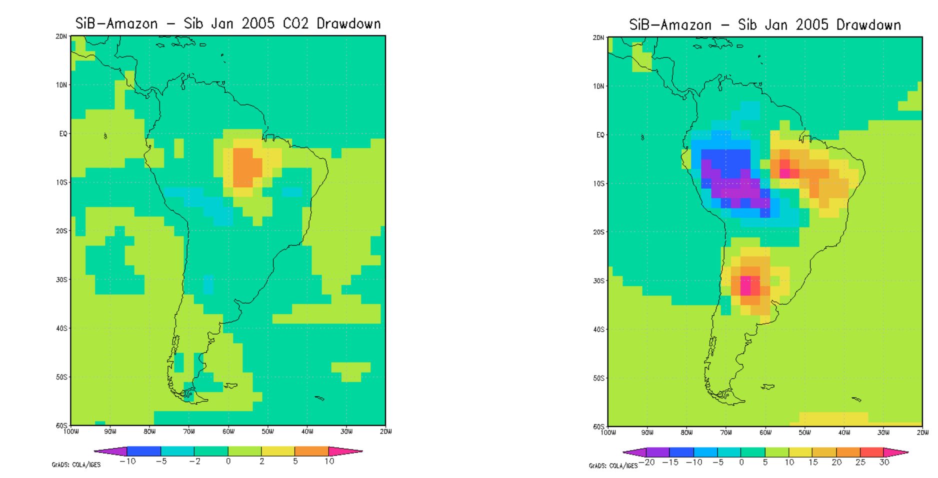
COS CO_2

The INTEX-NA mission collected samples over central N. America in summer. Strong vertical gradients in COS were observed. These matched the gradients using the new SiB-3.0-COS fluxes and were much larger than those simulated with the original Kettle et al., fluxes (NPP).

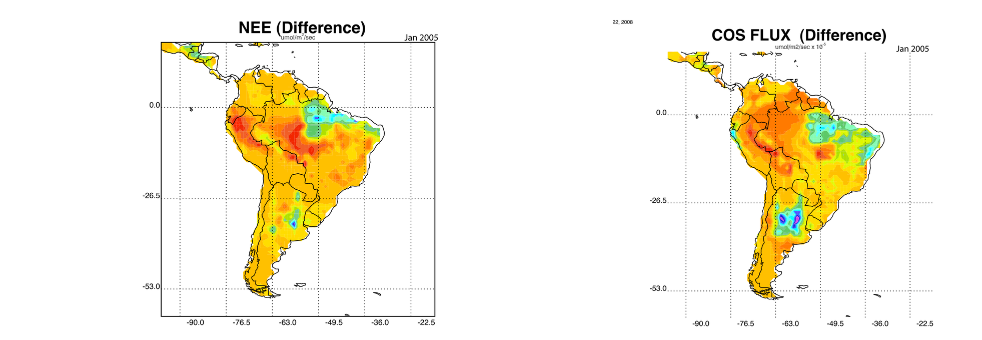


If we could measure COS...

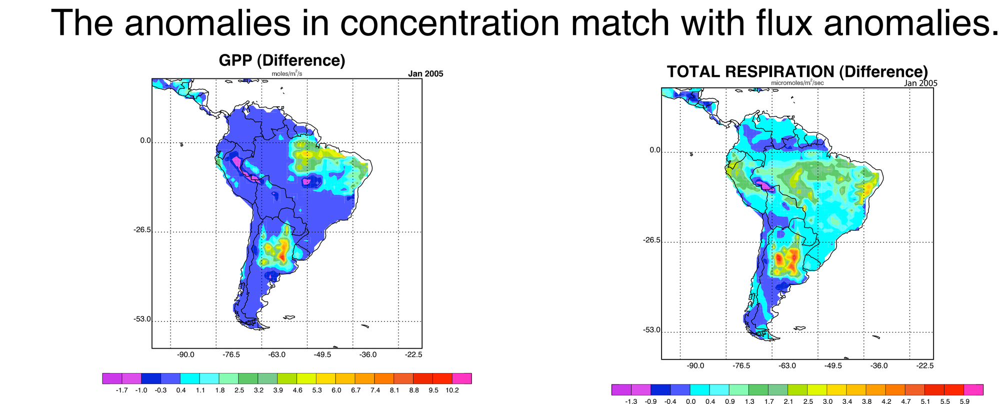
The plots below show the difference in the simulated CO_2 and COS concentration draw-down in the ABL with two different implementations of soil hydrology in SiB-3.0 (d1&d2 at left)



The simulated observations show an enhanced draw-down of CO_2 over the Eastern Amazon(EA) and a corresponding increase in the draw down of COS.. However, there is another area of enhanced COS draw-down over the sub-tropics (ST) with no corresponding increase in CO_2. What causes this?



The anomalies in concentration match with flux anomalies.



Examination of GPP and RESP shows that the improved soil hydrology stimulated photosynthesis but had little effect on respiration in the EA while the change in hydrology stimulated *both* photosynthesis and respiration. Hence COS exchange was increased but not CO_2 (see also site simulation at left).

Conclusions

- The model does a reasonable job of matching the seasonal variation in atmospheric concentration at most background atmospheric sites.
- Large vertical gradients in COS between the boundary layer and free troposphere observed over the continents, are predicted by the model.
- We demonstrated using a "simulation experiment" that COS concentration could provide additional information on the separate responses of respiration and photosynthesis to environmental forcing.
- Simultaneous measurements of CO_2 and COS could provide improved constraints on 4-d data assimilation of carbon cycle processes.

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