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Top-Down Constraints on Regional CO_2 Flux in Amazonia: Inverse Atmospheric Modeling at Multiple Spatial Scales

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Inverse Modeling

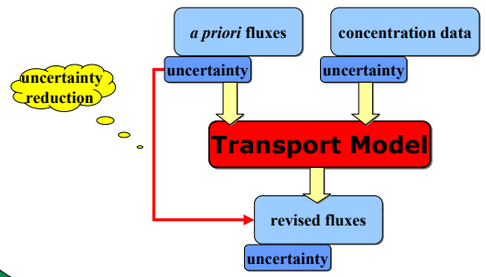
Surface exchange of CO_2 is heterogeneous in space and time, which complicates generalization from tower-based flux data across complex landscapes. Process models can be developed and tested locally against flux data. These models can be extrapolated using imagery and other spatial data products. But how can we know when and how these extrapolated models are wrong?

Variations in atmospheric concentrations and stable isotope ratios of CO_2 contain information about surface fluxes. Quantitative methods have been developed to extract this information using tracer transport models. The mixing properties of the atmosphere allow evaluation of spatially aggregated surface fluxes.

"Inverse modeling" is so named because we estimate causes (fluxes) from effects (concentrations downwind).

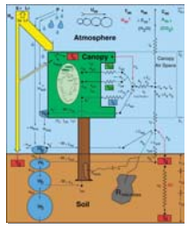
Here we present examples in which atmospheric mass-balance constraints are applied to the study of ecosystem CO_2 exchange through inverse modeling at local, regional, and global scales.

Bayesian Synthesis



Boundary-Layer Simulation

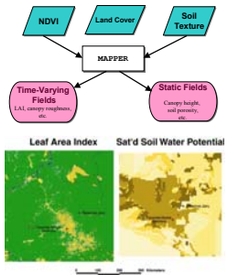
SiB2



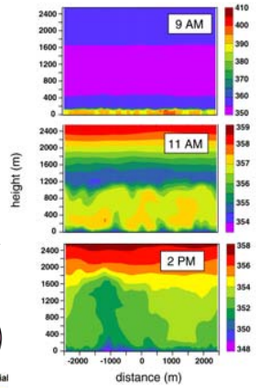
- Ecophysiological process model describing land-air exchanges of radiation, heat, water, momentum, CO_2, and $^{13}CO_2$
- Flexible resolution, stand-alone or coupled to a range of atmospheric models
- Time steps of seconds to minutes for interaction with PBL turbulence

- SiB2 model is parameterized from satellite imagery and other spatial data (soils, vegetation)
- Local-scale simulations driven from observed micromet data (ABRACOS) and coupled to CSU RAMS

Model Parameters



RAMS LES



Elevated CO_2 under stable inversion

Residual layer contains some of "yesterday's" low- CO_2 air

High- CO_2 air "eroded" from above by entrainment of dilute air

Low- CO_2 surface layer introduces plumes of air from forest

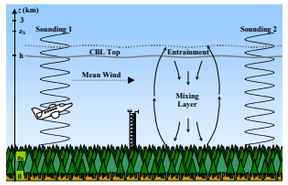
Well-developed "mixed layer" with weak gradients

Significant variability due to coherent turbulent structures

Coupled RAMS-SiB2 simulation of the evolution of a CO_2 mixed layer over Reserva Jaru in February

Boundary-Layer Inversions

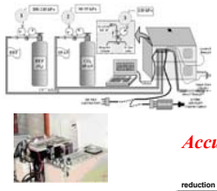
CBL Budget Technique



$$F_{S_1S_2} = \int_0^{z_S} \chi_{S_2} - \chi_{S_1} \, dz$$

Mass-balance of CBL air

Instrumentation



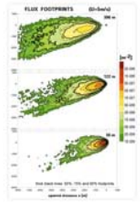
LiCor 6262 with temperature and pressure controls, and frequent on-board calibration

GPS receiver and datalogger

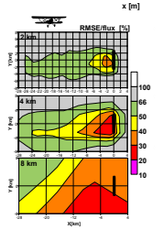
Requires no operator intervention!

Accurate to +/- 0.1 ppmv

Lagrangian Influence Functions



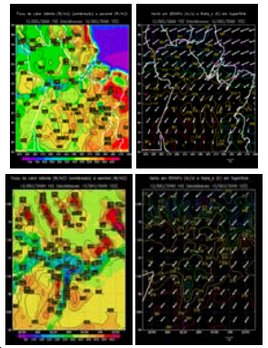
- Massless "particles" are released into a RAMS simulation of atmospheric winds and convective transport by boundary-layer turbulence
- Can be run locally in cloud and eddy-resolving mode, or regionally in mesoscale mode
- Population of particles reaching the detectors carry information about their points and times of origin at the underlying land surface
- Defines "footprints" of tower (or aircraft) data



- Influence functions are calculated from RAMS for a series of samples collected on cross-wind aircraft transect
- Each sample's "footprint" is treated as a basis function for synthesis inversion
- Inversion recovers flux within quantifiable error on a grid of variable sources, even in the presence of turbulent variations

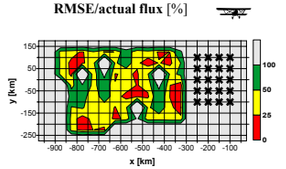
Regional Inversions

Operational RAMS Analysis



- Daily weather analysis and forecast in RAMS at USP
- Nested grid centered at Santarém, within coarse grid covering most of South America
- 28 km and 7 km grids available
- Finer nests during 2001 campaigns
- Lagrangian particle dispersion model

Synthesis Inversion of Pseudo-Data



Bayesian synthesis inversion applied to pseudo-data sampling in a mesoscale run.

The inversion can significantly constrain flux estimates on a 50 km grid.

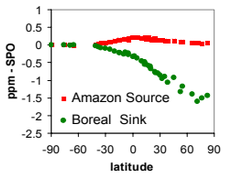
Global Inversions

- Samples are collected weekly, mostly in the remote marine boundary layer
- High precision trace gas analysis in NOAA lab
- No samples over tropical continents!

TransCom 3 Basis Regions

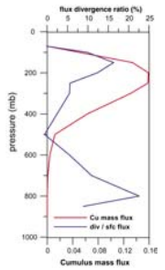
- Annual mean CO_2 fluxes are estimated for each of 22 regions using flask data collected at 67 stations in remote MBL
- Seven global tracer transport models are compared

Simulated Concentrations at flask stations



Concentration response due to a 1 GtC/yr flux in the Amazon is much weaker than response due to a 1 GtC/yr flux in boreal forest

Convective "Leakage"



Photosynthesis and cumulus convection are correlated in time and space in parts of the Amazon

Convective updrafts carry much of the "signal" of ecosystem flux aloft

As much as 30% of the flux due to ecosystem metabolism leaves the atmospheric column in the upper troposphere, but nobody is looking there!

LBA Sampling Impact

A posteriori uncertainty (gtC/yr) for Amazon

	Existing Flasks	+ Weekly LBA profiles
Model 1	0.89	0.08
Model 2	0.89	0.52
Model 3	0.92	0.73
Model 4	0.91	0.25
Model 5	0.85	0.16
Model 6	0.90	0.22
Model 7	0.89	0.47
Mean	**0.89**	**0.35**

- Weekly samples collected by two aircraft profiles near Belem and Santarém were added to synthesis inversions for seven global transport models
- There is a dramatic improvement in the confidence of basin-wide flux estimates from every model

For more information, please email denning@atmos.colostate.edu

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