A Study of the Carbon Cycle using NASA Observations and the GEOS Model

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Overall Objectives

Show current and planned capabilities of the GEOS model for carbon-cycle studies

Highlight how Piers impacted this work, either indirectly or directly

Key aspects:

- Combined use of complex models and observations
- Pushing frontiers in how this is achieved
- Look at some evaluation and impacts

Themes of GMAO's Research and Products

Weather Analysis and Prediction	Seasonal-to-Decadal Analysis and Prediction	Reanalysis
Global Mesoscale Modeling	Observing System Science	

- These (non-orthogonal) themes span GMAO's main focus areas
- Strong emphasis on NASA's Earth Observations (use, support, planning)
- GEOS is a modular system, encompassing many Earth System components
- Carbon cycle is an integral part of the GEOS system

The CASA Model at NASA GSFC

A version of the Carnegie-Ames-Stanford Approach (CASA) model was used extensively in the in the Biospheric Sciences Lab at GSFC (Jim Collatz)

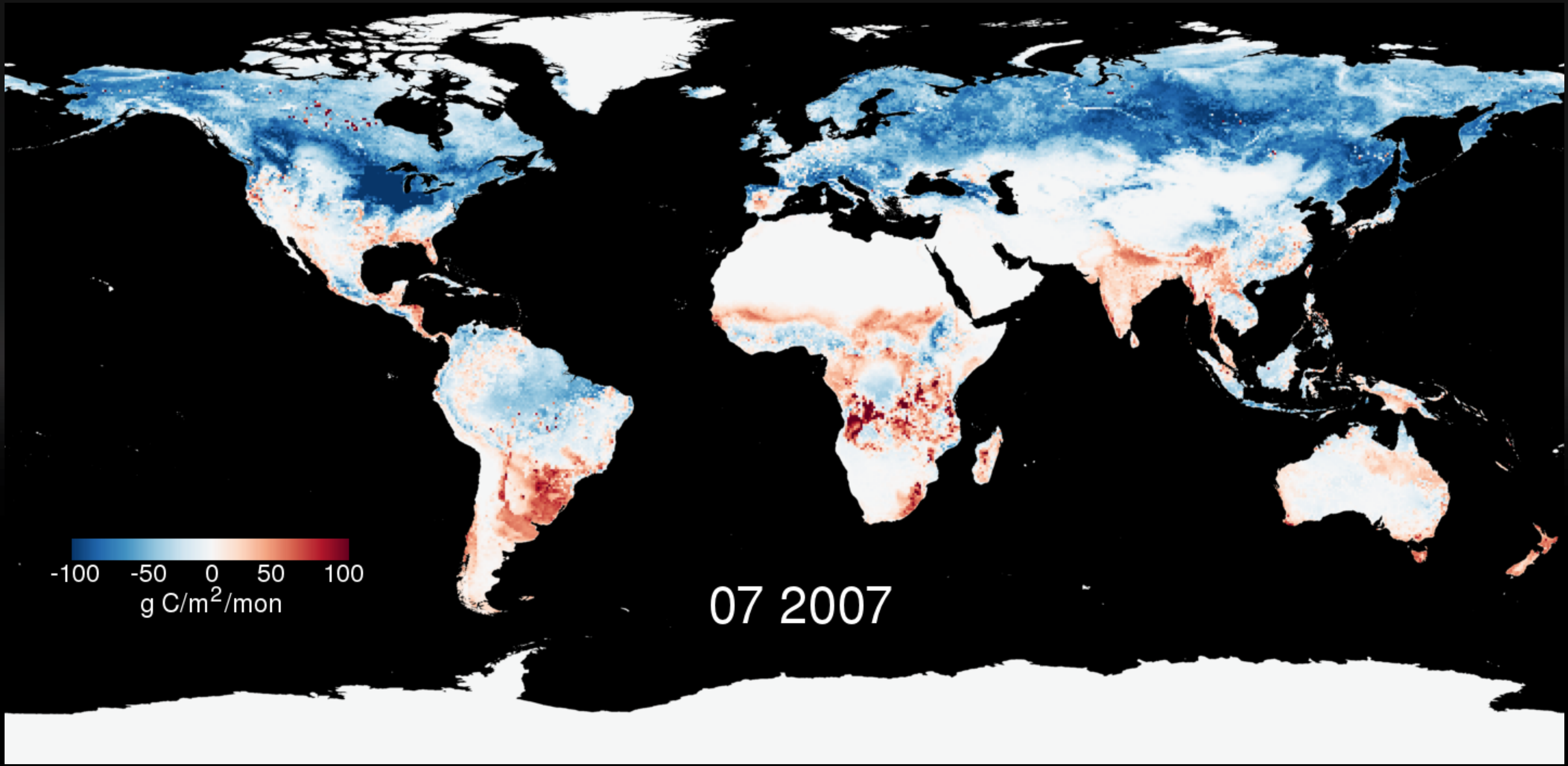
Just as the SiB2 model had made extensive use of observations, CASA used numerous observations from NASA's satellites to constrain the diagnostic computations of land-atmosphere CO_2 exchange

CASA/GFED surface fluxes were used in GSFC's "PCTM" model (Randy Kawa), beginning in the early 2000s

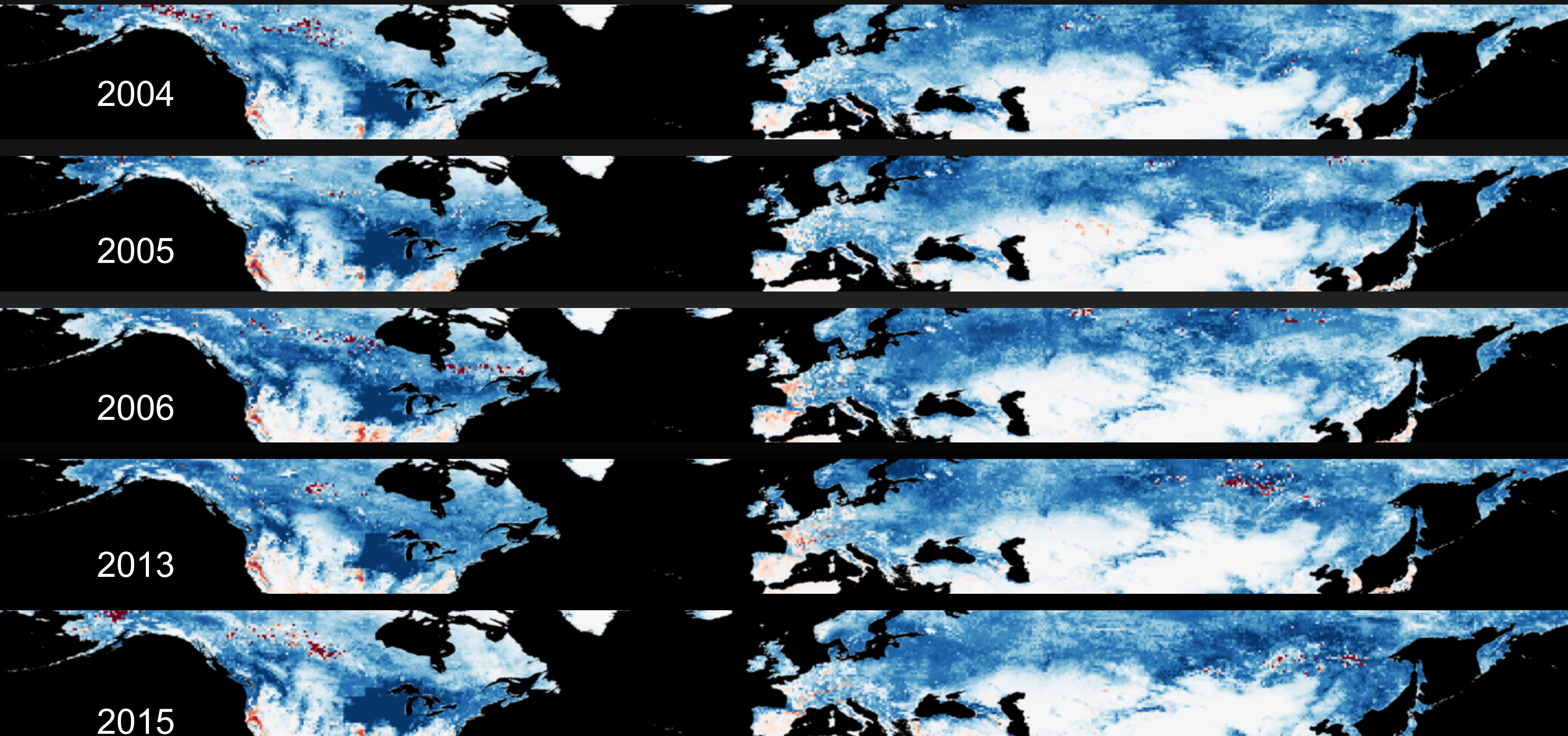
It was a straightforward extension of this work that enabled GMAO to readily import the CASA surface fluxes into the GEOS model

This combination, along with atmosphere-ocean CO_2 fluxes computed from NOBM (Watson Gregg) formed the basis of GMAO's carbon-cycle work

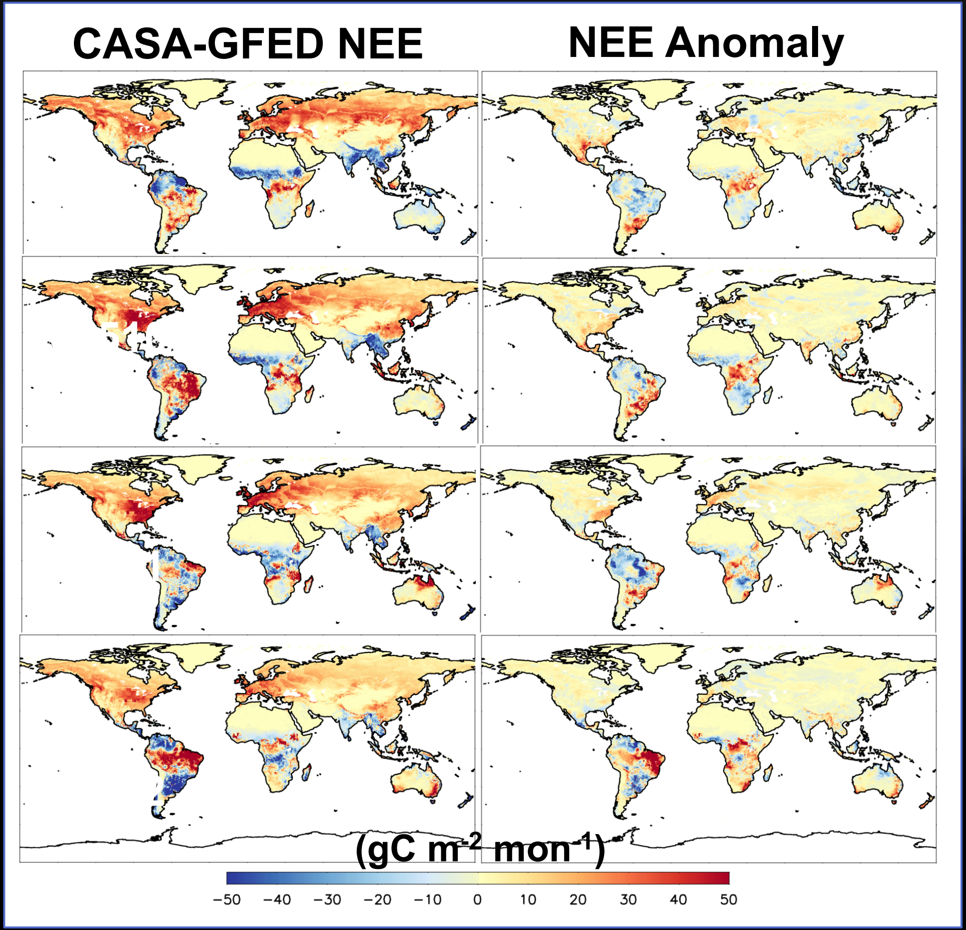
Net Ecosystem Exchange, CASA model: July 2007



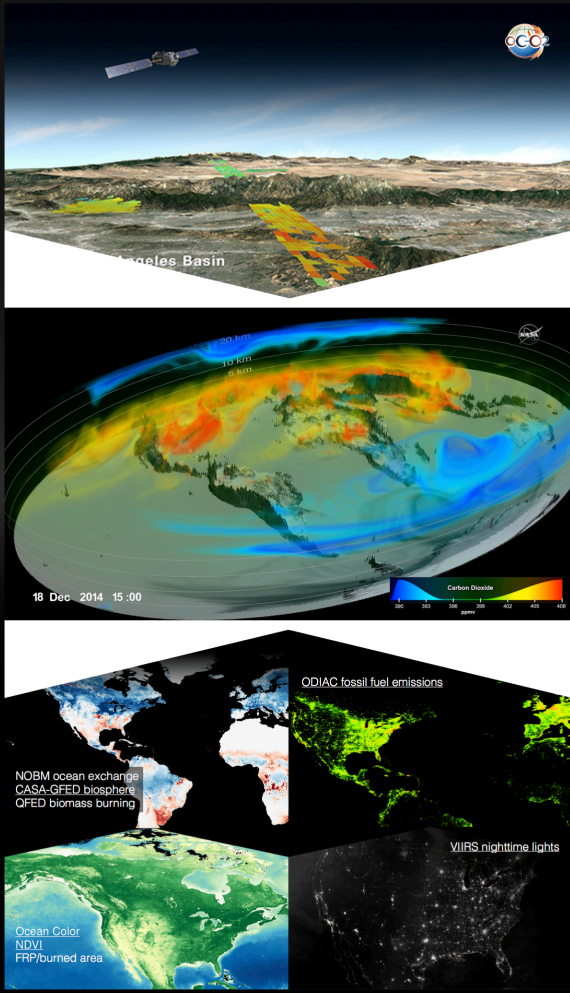
Year-to-Year Variations in CASA fluxes



CASA-GFED ENSO Flux Anomalies



- CASA-GFED NEE fluxes now provide 14 years of observationally-informed land carbon flux estimates, supporting analysis of climate-driven carbon flux anomalies
- During the 2015-16 El Niño CASA-GFED estimates substantial NEE anomalies in Brazil which was strongly influenced by both heavy rains in the western portion of the country and drought conditions in the east.
- CASA-GFED also supports the OCO-2 science team as a prior for a number of inverse modeling systems

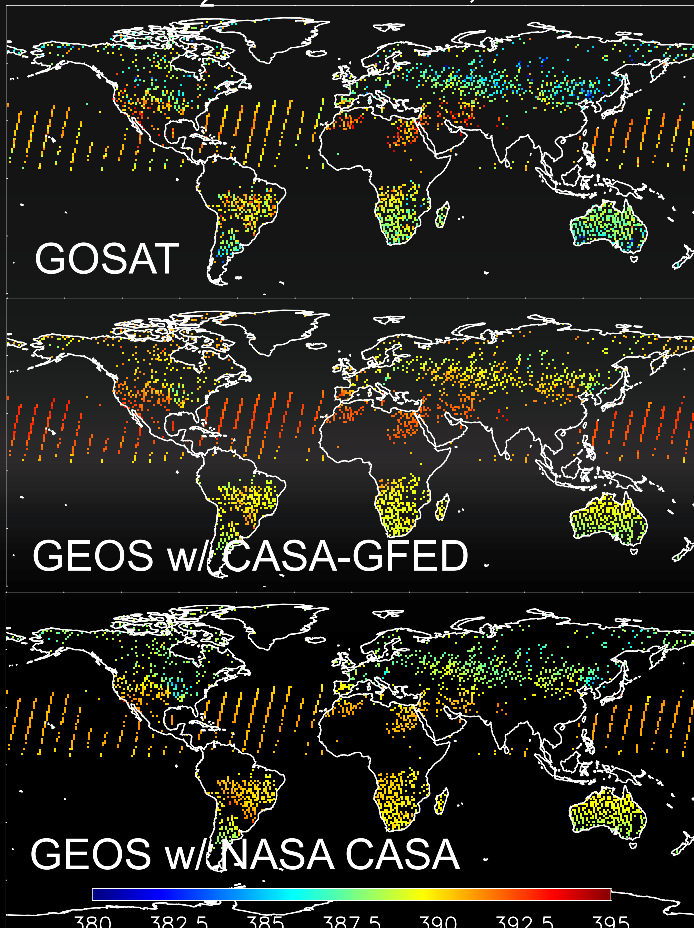


GEOS-Carb

Integrating Top-Down and Bottom-Up Estimates of Carbon Flux

- Using satellite observations to constrain model-based carbon flux estimates
- Ocean color and NDVI informationused with ocean (NOBM) and land productivity (CASA-GFED) models; observations of fire radiative power, burned area, and nighttime lights support high-resolution fire (GFED, QFED) and fossil fuel (VIIRS) emission inventories
- Weather information from MERRA-2 is also used to provide a physically consistent flux dataset
- Bottom-up fluxes are implemented in the GEOS AGCM to provide high quality, high-resolution simulations of CO_2 & CO
- By assimilating atmospheric CO_2 from OCO-2 and GOSAT, the GEOS-Carb system also provides atmospheric carbon reanalyses and insights needed to refine flux estimates

XCO_2 - June 15-30, 2010

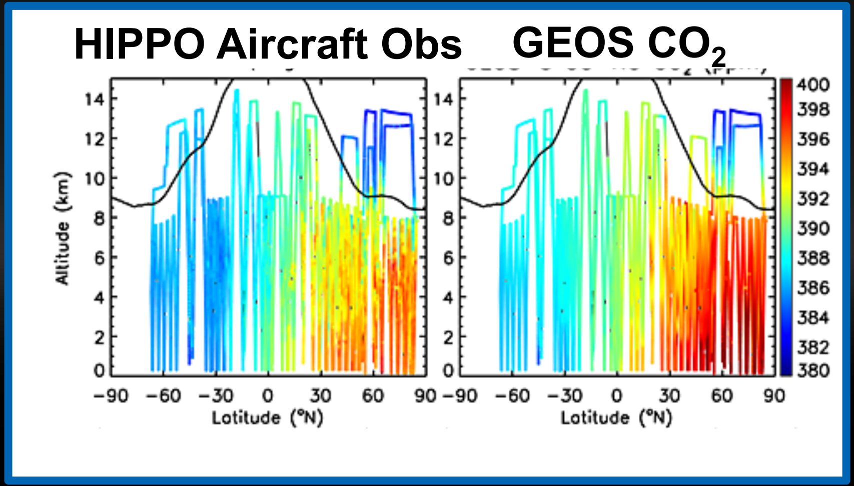


Evaluating bottom-up fluxes through comparison with atmospheric CO_2 observations

- Comparisons of GEOS simulations of XCO_2 with two different land flux models and observations provides insight into land flux processes and observational limitations
- The NASA CASA model begins drawing CO_2 from the atmosphere one month earlier than CASA-GFED which is more consistent with satellite and *in situ* observations
- However, the weaker sink in NASA CASA is inconsistent with the growth rate estimated by oceanic and atmospheric observations
- Different land-carbon models have their own strengths

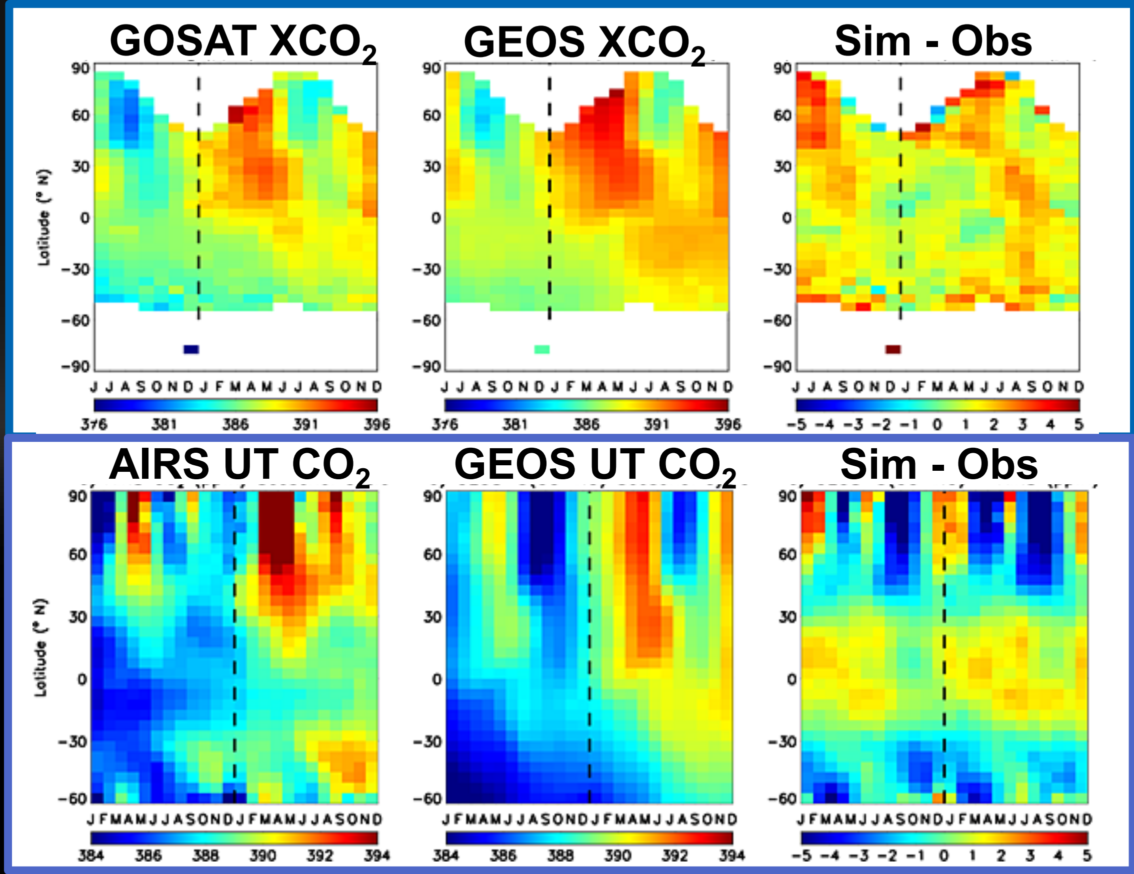
Evaluating GEOS-Carb Concentrations using aircraft data

- Piers was a great proponent of field missions using NASA aircraft
- This slide shows the value of using the in-situ aircraft data from HIPPO in the evaluation of the GEOS-Carb CO_2 concentrations – a unique NASA asset, given the scarcity of free-atmospheric CO_2 measurements
- Comparisons against aircraft data show a tendency to overestimate NH CO_2 due to a weak sink in CASA-GFED, but vertical gradients are well reproduced



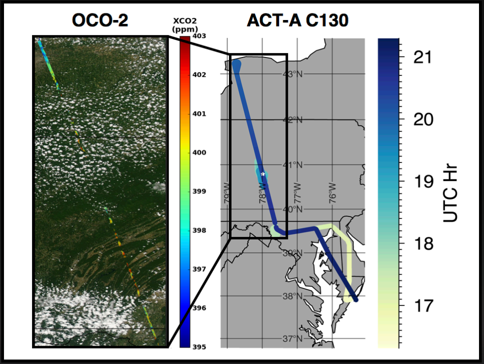
Evaluating consistency of satellite CO_2 observations using GEOS-Carb

- GEOS has also been used to evaluate the consistency of multiple satellite datasets
- Comparisons with GOSAT XCO_2 show a high NH bias that is most notable during spring and summer (and consistent with the bias between GEOS-Carb and HIPPO)
- In contrast, comparison of GEOS with AIRS UT CO_2 data shows a low bias which is difficult to reconcile with other observation types

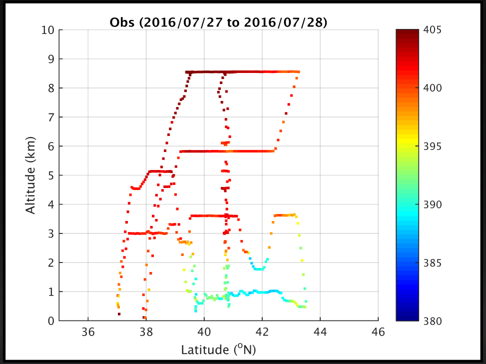


GEOS carbon modeling and analysis in support of NASA missions

OCO-2 overpass and ACT flight path for 27 July 2016

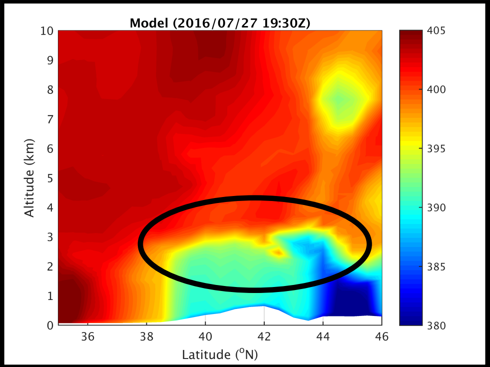


Aircraft CO_2

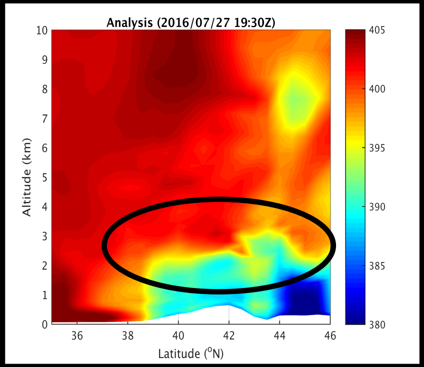


- The GEOS carbon data assimilation system now supports both field campaigns and satellite missions.
- In this example, GEOS is used to facilitate OCO-2 validation by assimilating aircraft CO_2 observations (top)

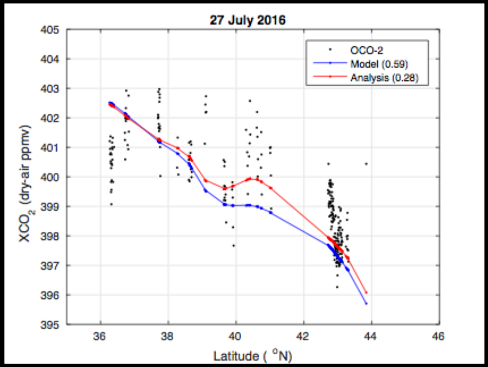
GEOS forecast CO_2



GEOS analysis CO_2



GEOS, OCO-2 XCO_2



- The analysis corrects for a high bias in the model's PBL height, improving the comparison with OCO-2 observations

Moving Ahead – Switching to the Catchment-CN Land Model

The GEOS Earth System model

- Has its roots in weather analysis and forecasting
- Includes many Earth System Components - a modular, seamless system
- Is developed according to priorities set by NASA's satellite observations

SMAP, OCO-2 and other NASA Missions encourage development of the land-surface model (and analysis) components

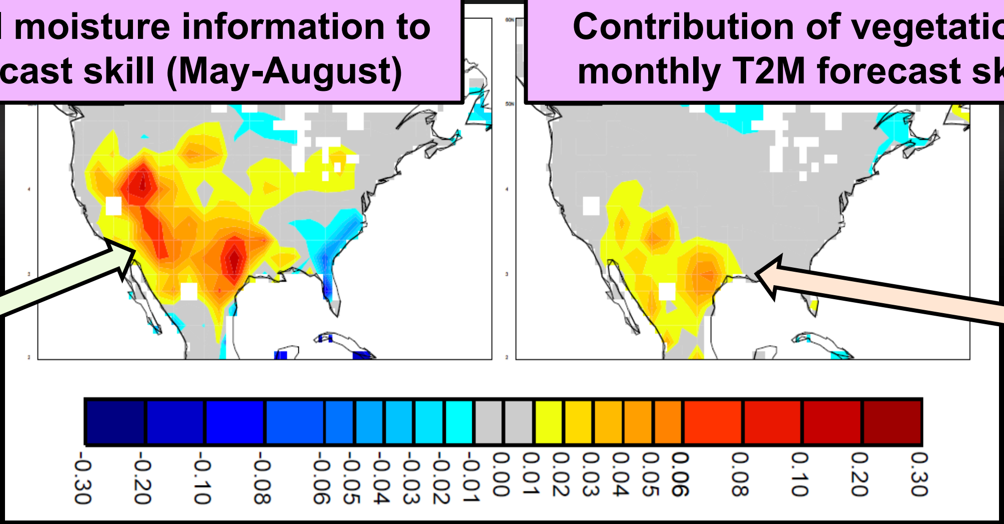
- Catchment model of land physics has been updated in many ways
- Now includes prognostic vegetation and carbon/nitrogen components

Dynamic Vegetation Phenology and Monthly Weather Prediction

Forecast simulations performed with the GEOS-5 atmospheric model fitted with a dynamic vegetation phenology model quantified the separate contributions of soil moisture and vegetation initialization to air temperature forecast skill (measured with an r^2 metric, versus observations).

Contribution of soil moisture information to monthly T2M forecast skill (May-August)

Contribution of vegetation information to monthly T2M forecast skill (May-August)



As established in previous studies, soil moisture initialization does provide skill.

The initialization and modeling of vegetation state also provides some skill!

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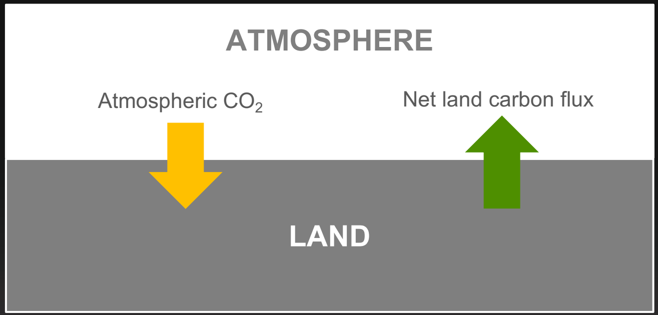
Connecting the Land and Atmospheric Branches of the Carbon Cycle



A new capability in the GEOS-5 system:

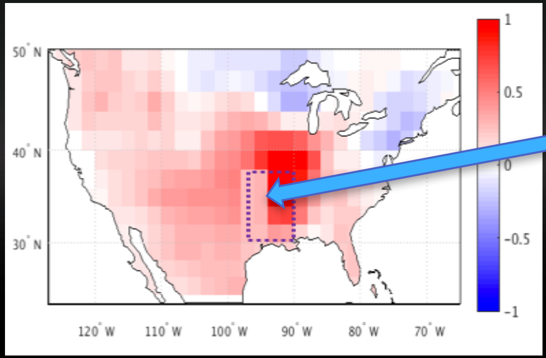
(i) allows the modeled atmospheric CO_2 to affect land surface carbon uptake, and

(ii) uses the modeled net CO_2 uptake at the land surface as a source or sink for the atmospheric CO_2,

(iii) thus enables carbon cycle feedbacks along with water and energy cycle feedbacks

Sample Experiment

ΔCO_2 (ppm, relative to control)



In a GEOS-5 run, imposing a drought here during April to June…

… leads to lower leaf area index (LAI) there in July - September

⇨ reduced net carbon uptake by land

⇨ increased atmospheric CO_2 across the US.

Summary

GMAO's activities in carbon-cycle modeling

Build on the GSFC legacy of CASA-GFED and SiB2

GEOS-Carb modeling activities focus on NASA's observations

Emerging prognostic capabilities in ocean and land, as well as atmosphere

Some important outcomes

Contributions to monitoring of CO_2: multiple diagnostic estimates

Model is used to evaluate consistency of multiple types of observations

Importance of interactive soil moisture and CO_2 in prognostic modeling

Two big things I learned from Piers:

Failure is an option, as long as you learn from it and move forwards

Push on and get things done