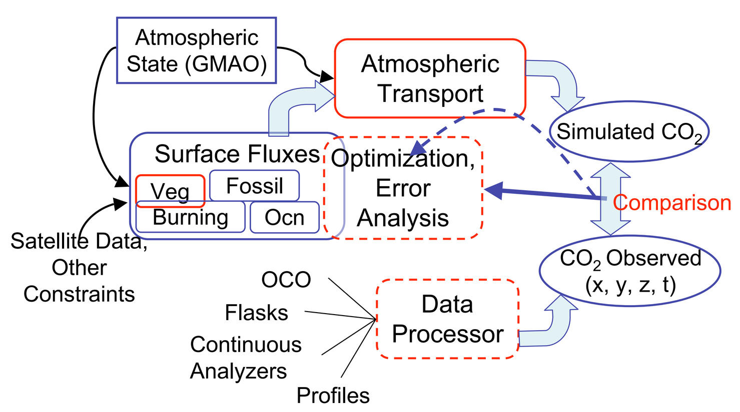
Modeling the Global Atmospheric Carbon Cycle in Preparation for OCO

S. R. Kawa[1], G. J. Collatz[1], A. S. Denning[2], D. J. Erickson[3], S. C. Wofsy[4], A. E. Andrews[5]
[1]NASA Goddard Space Flight Center
[2] Colorado State University Department of Atmospheric Science
[3]Oak Ridge National Laboratory
[4]Harvard University Department of Earth and Atmospheric Sciences
[5] NOAA Earth System Research Laboratory

Abstract and Introduction

As we enter the new era of satellite remote sensing for CO_2 and other carbon cycle-related quantities, advanced modeling and analysis capabilities are required to fully capitalize on the new observations. Model estimates of CO_2 surface flux and atmospheric transport are required for initial constraints on inverse analyses, to connect atmospheric observations to the location of surface sources and sinks, and ultimately for future projections of carbon-climate interactions.



For application to current, planned, and future remotely sensed CO_2 data, it is desirable that these models are accurate and unbiased at time scales from less than daily to multi-annual and at spatial scales from several kilometers or finer to global. Here we focus on simulated CO_2 fluxes from terrestrial vegetation and atmospheric transport mutually constrained by analyzed meteorological fields from the Goddard Modeling and Assimilation Office. Use of assimilated meteorological data enables direct model comparison to observations across a wide range of scales of variability.

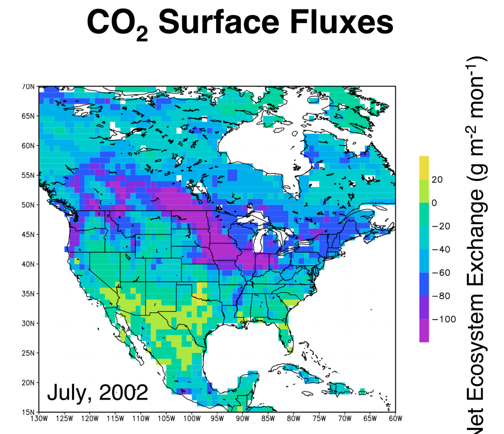
- Goal: Improve characterization of CO_2 source/sink processes globally.
- Approach: Develop and integrate improved formulations for atmospheric transport, terrestrial uptake and release, and observational data analysis.
- Motivation: Incorporate OCO and other data to better infer flux processes, uncertainties, and dependence on weather and climate.

TRANSPORT MODEL AND FLUX CALCULATION

Parameterized Chemistry/Transport Model (PCTM)

- Meteorological fields from the Goddard Global Modeling and Assimilation Office (GMAO), version GEOS-4.
  - 3-hour averages from analysis used in off-line transport
  - Flux-form semi-Lagrangian transport algorithm [Lin and Rood, *Mon. Weather Rev.*, 1996]
  - Model Grid: 1° x 1.25° x 28 levels to 0.4 mbar, hybrid terrain-following coordinate
  - Parameterized convective and PBL diffusive transport in troposphere
  - Global fields output hourly, plus interpolation to selected site locations
  - Runs done for year 1998-2006
- Model evaluation using climatological CO_2 fluxes in Kawa et al., JGR, [2004] and Bian et al., Tellus, [2006].

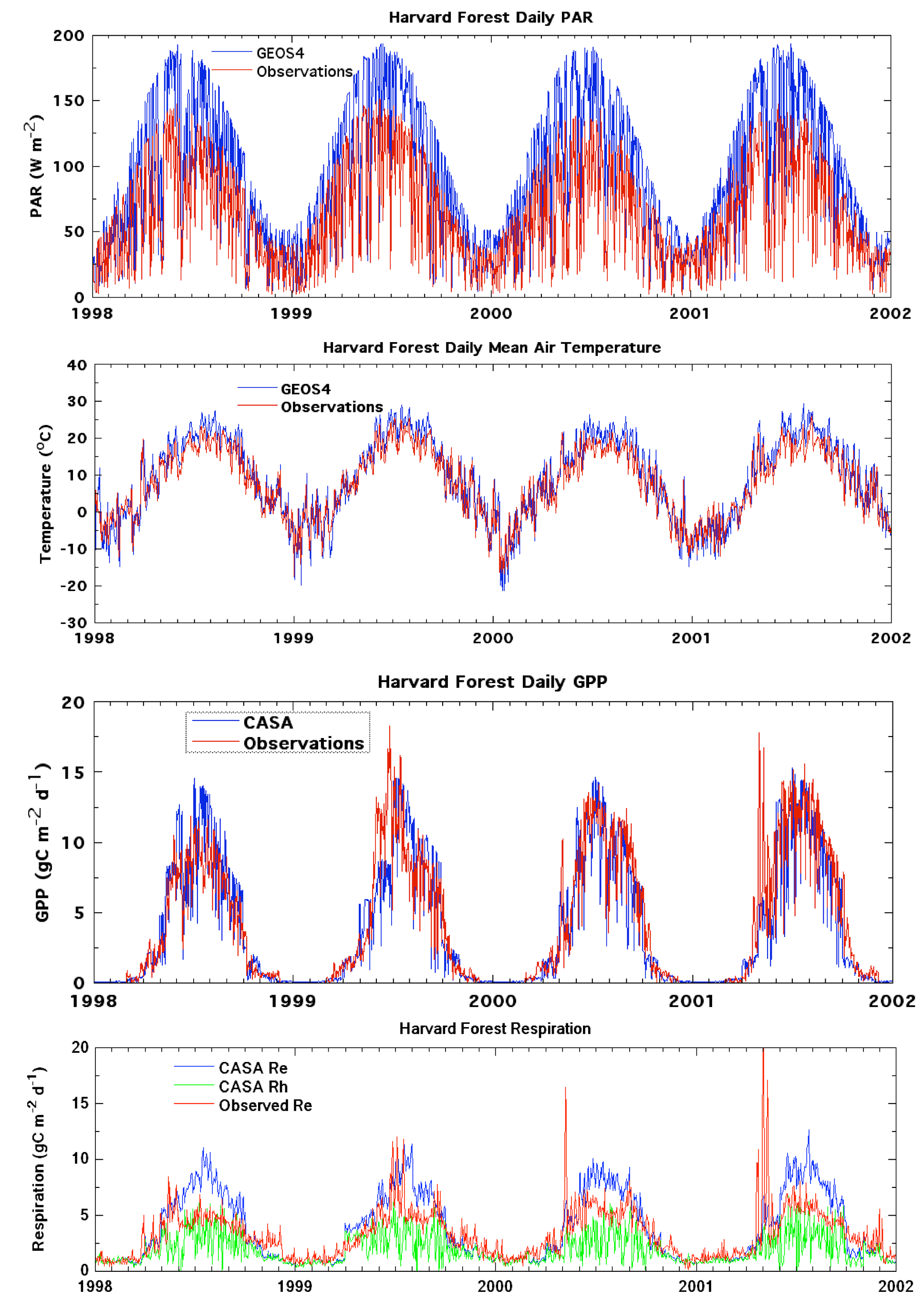
CO_2 Surface Fluxes



- Monthly global biosphere fluxes at 1x1° for 1998-2006 generated from CASA using monthly mean GEOS-4 analyzed meteorology and monthly GIMMS NDVI.
  - Biomass burning from GFED2 included in CASA monthly fluxes.
  - 3-hourly fluxes produced using 3-h analyzed radiation and temperature in the method of Olsen and Randerson, JGR, [2004].
- Fossil Fuel emission fluxes mapped for 1998 at 1 x 1° from CDIAC country data.
- Ocean fluxes based on http://www.ldeo.columbia.edu/res/pi/CO2/carbondioxide/air_sea_flux/fluxdata.txt

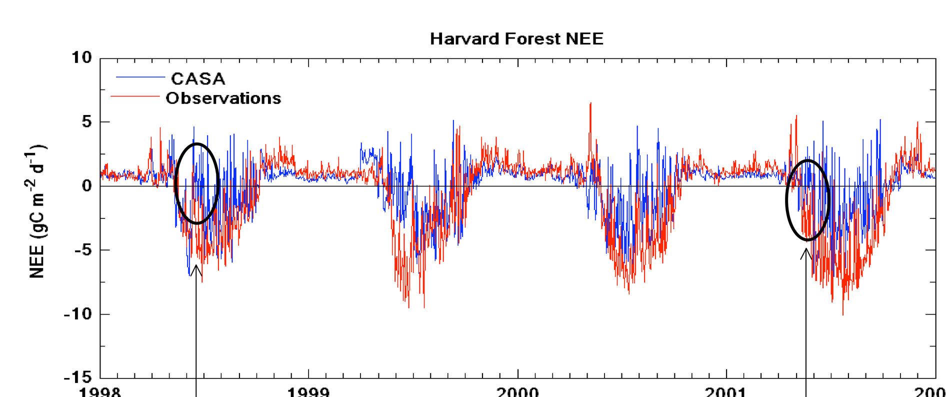
BOTTOM-UP CO_2 FLUXES

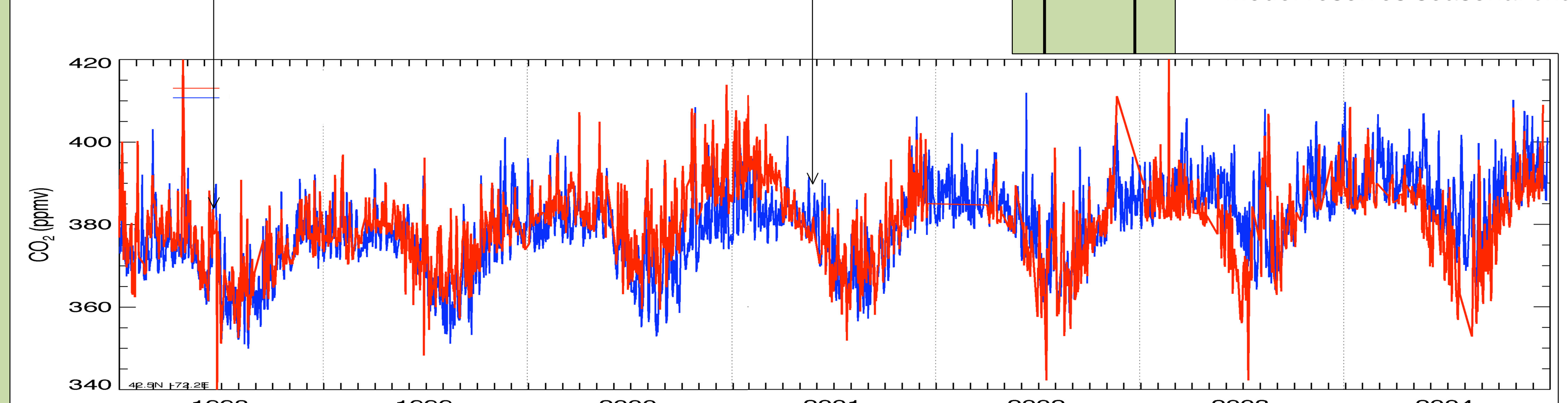
CASA Flux Evaluation



- Time series comparison of flux model forcing data (PAR, T) and CO_2 flux output (GPP, Resp) with tower data at Harvard Forest site shows generally good agreement for seasonal to daily variations. High R_e bias results from light use efficiency compensation in CASA.
- These parameters will be optimized in CO_2 inversion.

Flux Anomalies

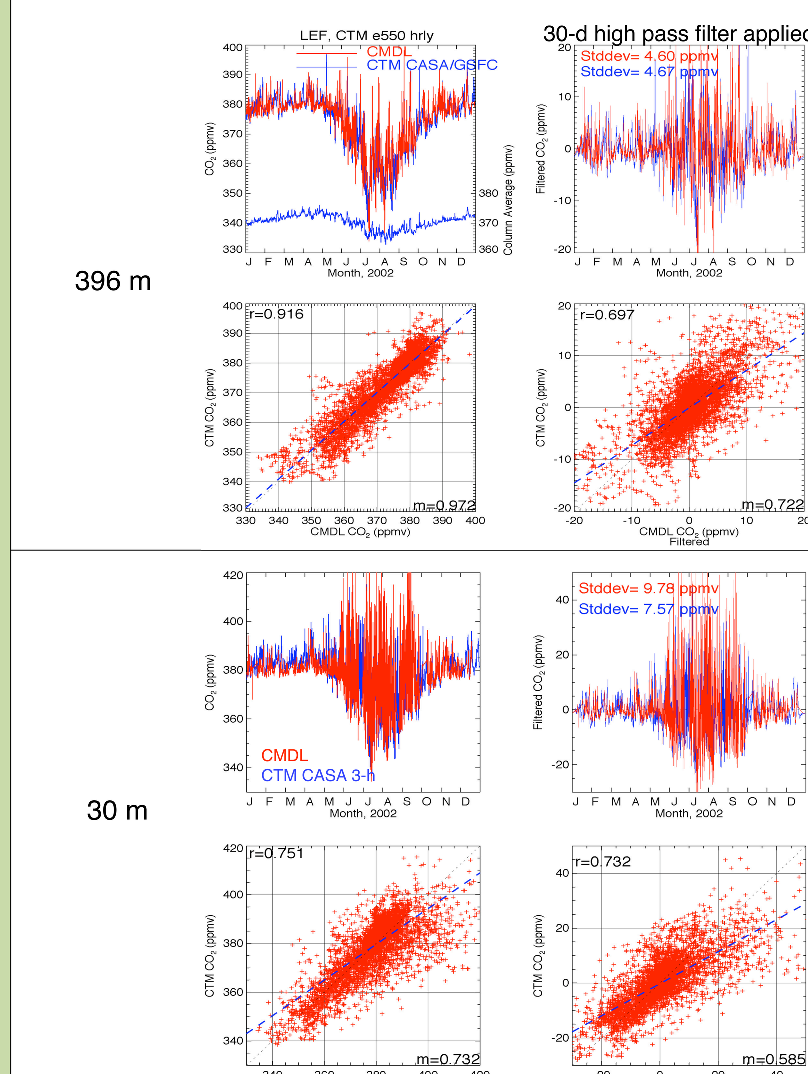




- The phase of the CO_2 flux and mixing ratio seasonal cycle agrees well with observations.
  - Observed CO_2 at this site shows some evidence of an excess sink on top of interannual variability, clearly manifest in the growing season.
- Many specific events involving abrupt changes in NEE are captured in the model and observations.
  - The June 1998 drop in carbon uptake shows up in elevated CO_2. Low par drives low GPP (above) in both CASA and observations.
  - Spring warming event in May 2001 drives enhanced GPP and NEP in observations, but less so in CASA. Inverse modeling will lead to better scalar sensitivity coefficients for CASA.

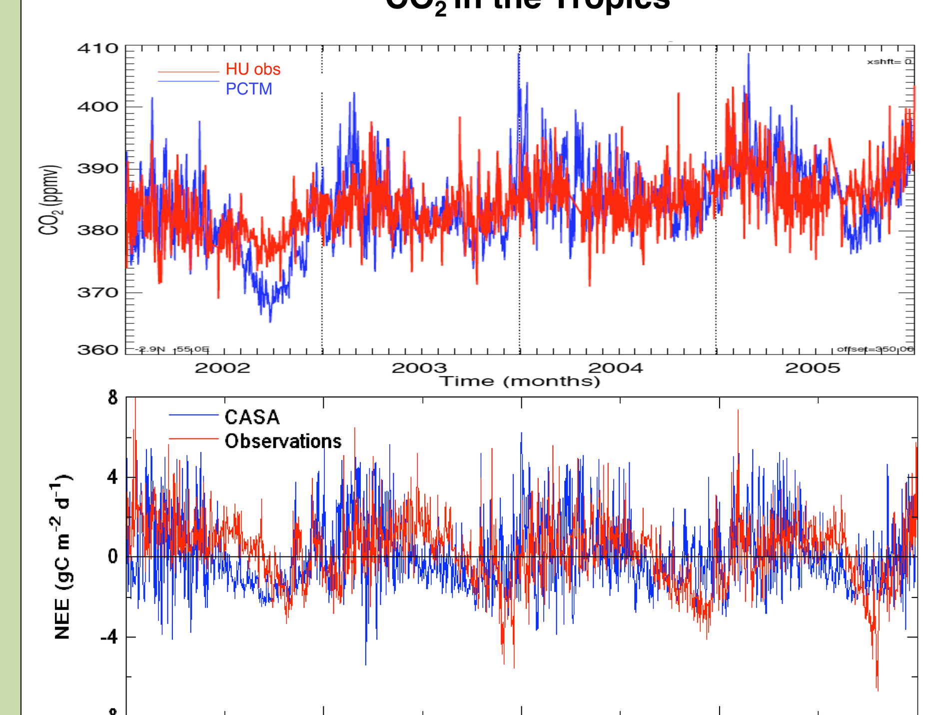
ATMOSPHERIC CO_2 VARIABILITY

CO_2 Mixing Ratio Comparisons

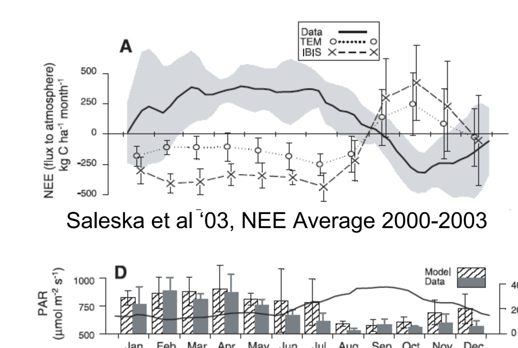


- Comparison of model using 3-hourly fluxes shows significant skill in simulating observed variability over range of time scales at altitudes of 30 to 396 m. Lack of vertical resolution limits ability to resolve very high values in shallow nighttime boundary layers (not shown).
- Column CO_2 variations of several ppmv should be resolved by remote sensing.

CO_2 in the Tropics

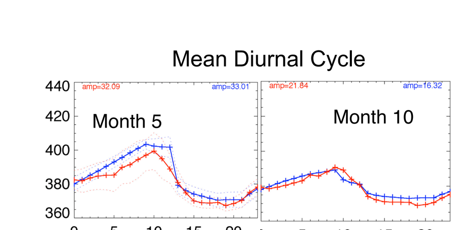


- Model resolves seasonal changes in daily CO_2 at Brazilian forest site (TPJ).



Saleska et al '03, NEE Average 2000-2003

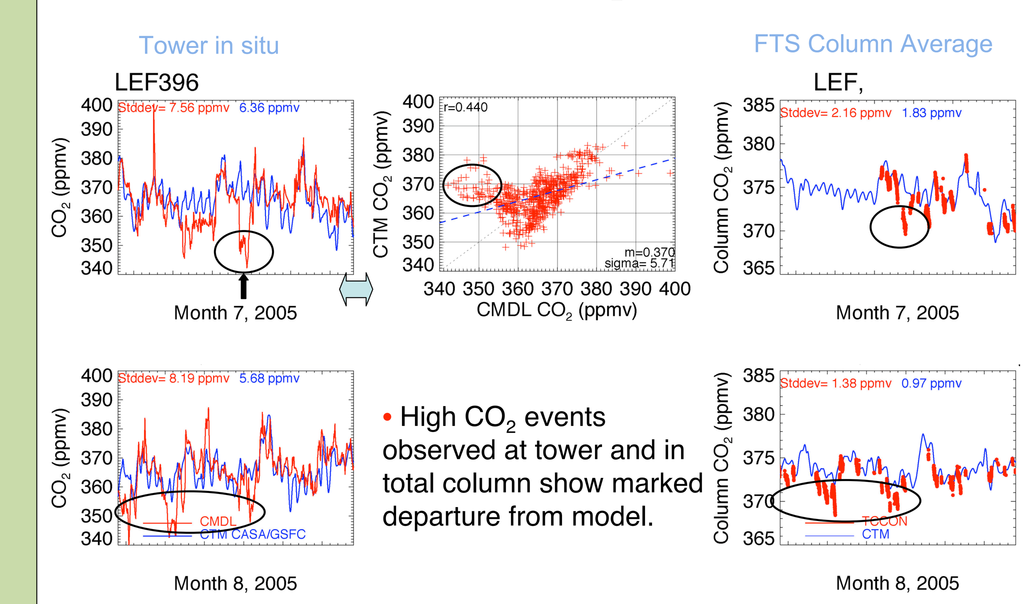
- Previous work (Saleska et al.) showed flux model seasonal cycle out of phase with observations.
- CASA NEE fluxes are shifted in wet-dry season transition, but appear to have correct dependence on meteorological forcing.



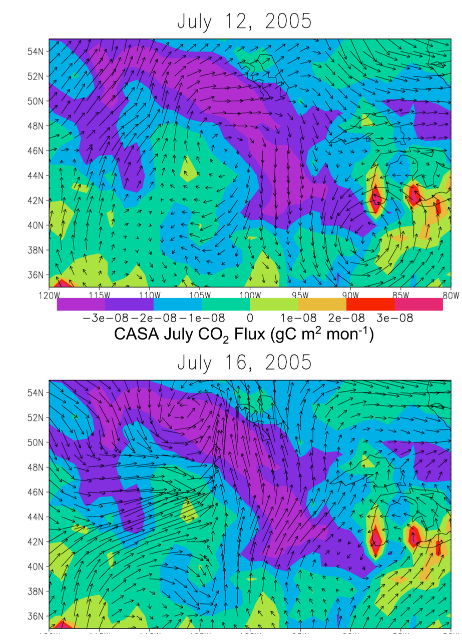
Hourly model output highly correlated with data in most seasons. Seasonal differences in CO_2 daily max and min are consistent with differences in R_e and GPP between model and observations (⇒ day/night inversions?)

CO_2 SYNOPTIC EVENTS

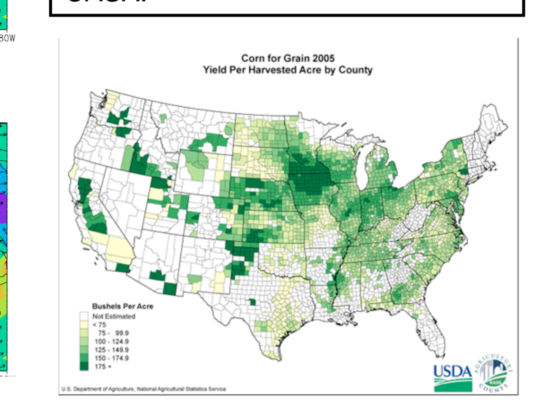
Interpretation of CO_2 Weather

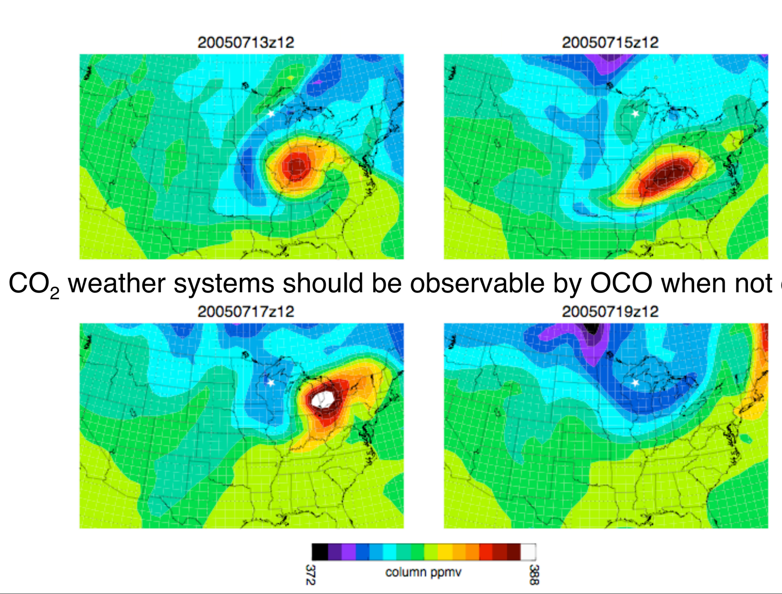


- High CO_2 events observed at tower and in total column show marked departure from model.



- The large CO_2 discrepancies at LEF occur during advection from crop-intensive areas.
- Agricultural uptake can create a large unbalanced sink relative to CASA.

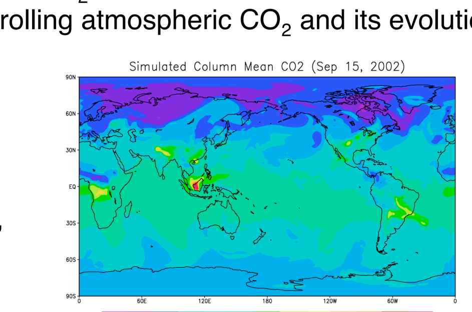




- CO_2 weather systems should be observable by OCO when not cloudy.

Toward Use of Remote Sensing CO_2 Data

- We find that the CO_2 terrestrial flux and transport models constrained by observations (i.e., analyzed met data, NDVI) can resolve much of the hourly to synoptic variability in the observations across a variety of sites. Resolution of these scales is highly desirable to make full use of satellite remote sensing data, e.g., to minimize bias and representation errors.
- The seasonal cycle and its interannual variations generally respond adequately, although globally a "missing sink" is clearly required relative to the CASA. Discrepancies in these comparisons will be addressed with inverse models and will guide refinement of the process simulation in CASA.
- In general, the fidelity of these simulations leads us to anticipate incorporation of real-time, highly resolved OCO and other observations into quantitative analyses that will reduce uncertainty in the terrestrial CO_2 sink and revolutionize our understanding of the key processes controlling atmospheric CO_2 and its evolution with time.



Author Contact Information:
S. R. Kawa (stephan.r.kawa@nasa.gov),
NASA GSFC, Code 613.3,
Greenbelt, MD, 20771

Acknowledgements

NOAA ESRL Carbon Cycle Greenhouse Gases Group
S. Pawson, Z. Zhu (NASA Goddard Space Flight Center)
I. Baker, N. Parazoo, R. Lokupitaya (Colorado State University)
M. Butler (Penn State U)
P. Wennberg, G. Keppel-Aleks (California Institute of Technology)
J. T. Randerson (University of California, Irvine)
NASA Carbon Cycle Science