National Aeronautics and Space Administration

Towards a High-Resolution CO2 Flux Inversion

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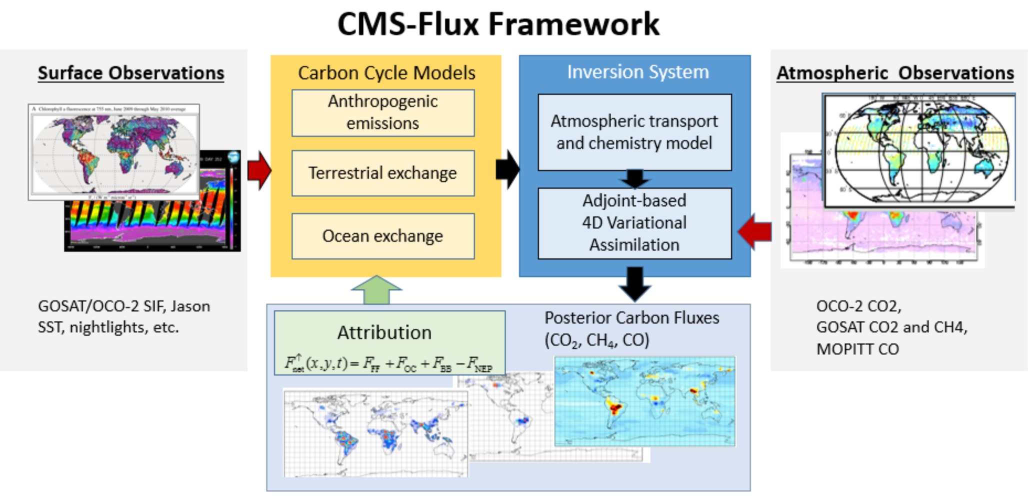
Program:

Project Objective:

Global CO2 monitoring is required for assessing climate agreement target achievement, but trends in flux are driven by natural and anthropogenic factors.



Inverse Problem:
Calculate causal factors from indirect observations – e.g. calculate local CO2 source and sink strengths from observations of atmospheric CO2

NASA's CMS-Flux system currently limited to 2°×2.5° latitude-longitude (rectilinear) grid

GEOS-Chem

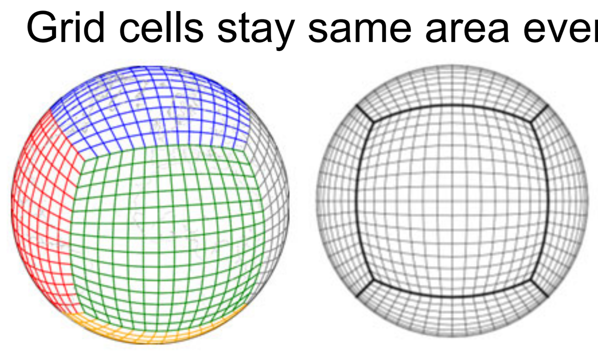
GEOS-Chem is an open-source global chemical transport model with a large development community and research base, currently in its 12th major revision

GCHP

GCHP applies the MAPL implementation of the NASA Earth Systems Modeling Framework (EMSF) to GEOS-Chem's internal chemistry mechanisms

Allows for GEOS-Chem to be run at high resolutions, down to ~10km, using a cube-sphere grid, on high performance computer systems, spreading computation across 100s or even 1000s of cores

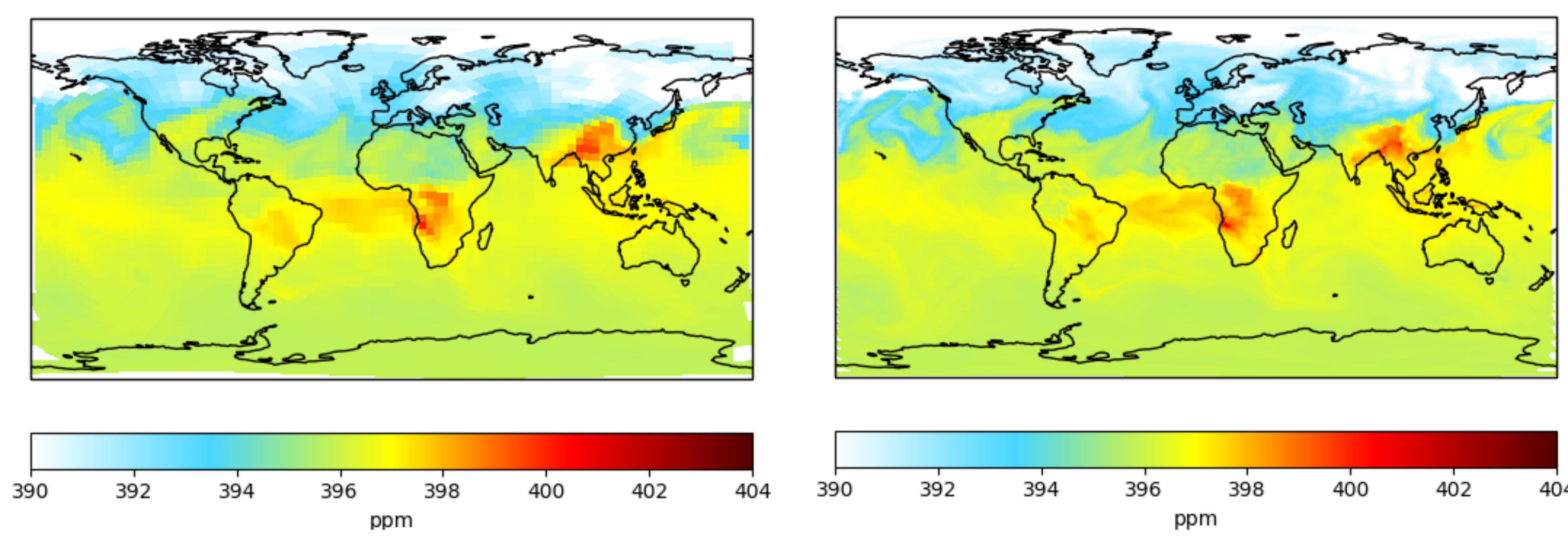
Cubed-Sphere Grid
Grid cells stay same area even in polar regions



https://www.gfdl.noaa.gov/fv3/fv3-grids/

FY18/19 Results:

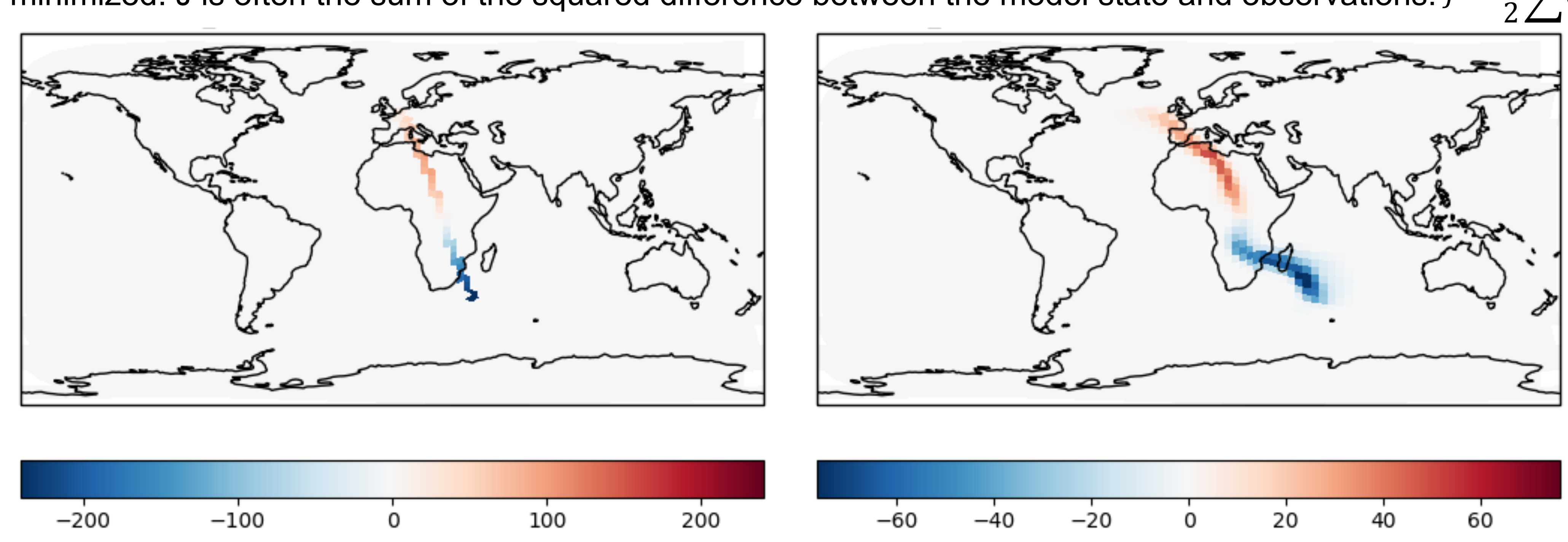
The first important step was to get GCHP to read in the CMS-Flux prior emissions data in order to run the forward model and simulate transport of CO2. The prior emissions data come from a rich set of data and observations about biological activity (CARbon DAta MOdel framework; CARDAMOM), biomass burning (GFED3) and human activities (Open-Data Inventory for Anthropogenic Carbon dioxide; ODIAC).



The left panel shows the GCHP CO2 simulation using CARDAMOM prior emissions data run at C24 resolution (~4°×5°) while the left panel shows the same simulation but at C90 resolution (~1°×1.25°). Although both simulations present broadly similar global distributions, the C90 simulation captures much higher detail synoptic patterns.

Reverse Time Integration

The model is typical integrated backwards in time to solve the inverse problem. A scalar-valued cost function, J, is minimized. J is often the sum of the squared difference between the model state and observations: $J = \frac{1}{2}\sum(c_o - c_a)^2$



The right figure shows artificially generated "forcing" terms, $\frac{\partial J}{\partial c_a^f} = \sum(c_o - c_a^{final})$, and the left shows the "sensitivities", $\frac{\partial J}{\partial c_a^i} = \sum(c_o - c_a^{initial})$ after the forcings are advected backwards in time for 24 hours. Our artificial forcings were generated along a theoretical satellite orbit path and the signs indicate that $c_o > c_a^f$ in the Northern part of the overpass and $c_o < c_a^f$ in the Southern portion. The sensitivities indicate how the models state needs to be altered 24 hours in advance of our simulated overpass to remove the forcing term. I.e., by adding the values in the right panel to the forward model's initial conditions, the model's state 24 hours later would be decreased by up to 200 ppm in the Southern part of the track shown and increased by a similar amount in the Northern section.

Benefits to NASA and JPL (or significance of results):

- With increasing CO2 levels and the onset of carbon-climate feedbacks, there is a critical need to break the current barrier of 4x5 flux inversions to harness the full suite of data from the carbon constellation including the NASA/JPL OCO-2 and OCO-3, as well as the JAXA GOSAT and GOSAT-2.
- This research has demonstrated the capability to calculate an adjoint sensitivity by running the next-generation GCHP "backward" in time. This is a critical step in migrating the inversion capability from heritage CO2 transport models and position JPL to exploit the carbon constellation.

Publications:
None to date

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