Air-sea CO_2 flux estimates from two data-constrained ocean models for the NASA Carbon Monitoring Study Flux Pilot Project

Holger Brix[1,2]

D. Menemenlis[2], W. Gregg[3], K. Bowman[2], S. Dutkiewicz[4], J. Fisher[2], M. Follows[4], C. Hill[4], O. Jahn[4], M. Lee[2], J. Liu[2], L. Ott[3], and D. Wang[4]

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[4] Massachusetts Institute of Technology, Cambridge, MA

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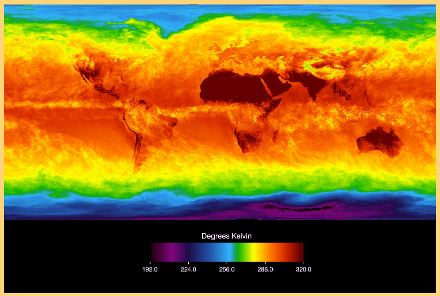
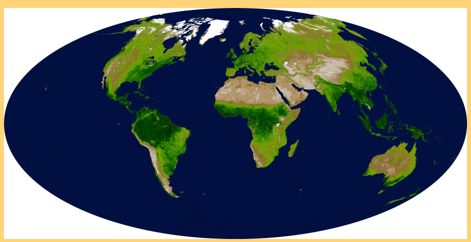
NASA Carbon Flux System

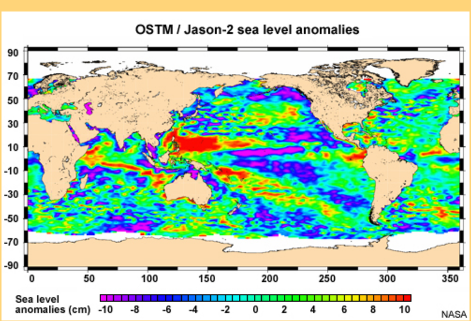
NASA satellites



T, q, p,.. (AIRS)



EVI, FPAR,.. (MODIS)



chlorophyll, altimetry, … (MODIS, JASON)

NASA models/ assimilation

Atmos
GEOS-5

winds (u,v)

Terrestrial
CASA/ CASA-GFED

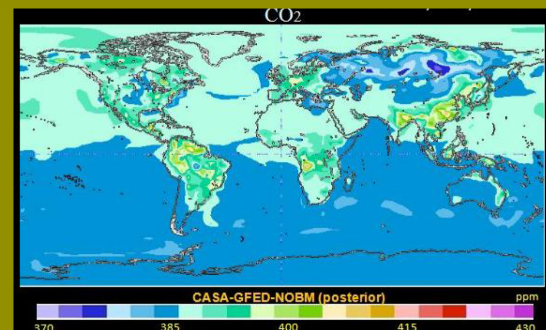
NEE

Ocean
NOBM/ ECCO2-Darwin

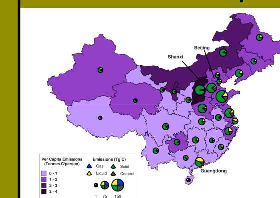
Air/sea CO2 exchange

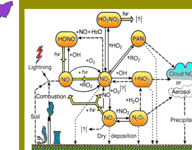
NASA inverse modeling

Inverse
GEOS-Chem



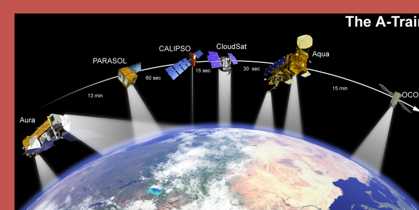
Anthropogenic





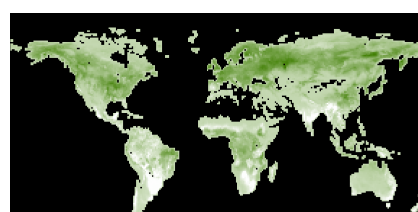
FF, land-use, chemical production

$$\min_{\mathbf{x}_0} C(\mathbf{x}) = \left\{ \sum_i (\mathbf{y}_i - \mathbf{F}_i(\mathbf{x}))^\top (\mathbf{S}_n^i)^{-1} (\mathbf{y}_i - \mathbf{F}_i(\mathbf{x})) + (\mathbf{x}_0 - \mathbf{x}_a)^\top \mathbf{S}_a^{-1} (\mathbf{x}_0 - \mathbf{x}_a) \right\}$$

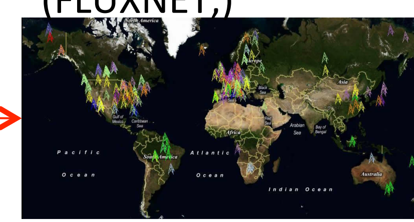


Satellite CO2 sensors (GOSAT, TES, AIRS)

Optimal flux (gC/m^2/day)



Independent tests (FLUXNET,)



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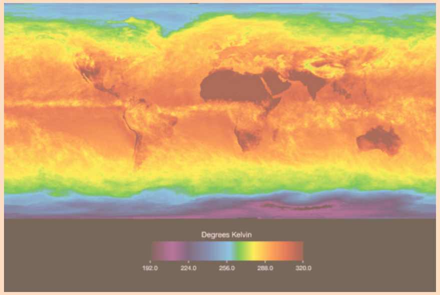

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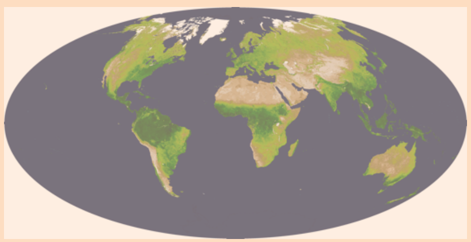

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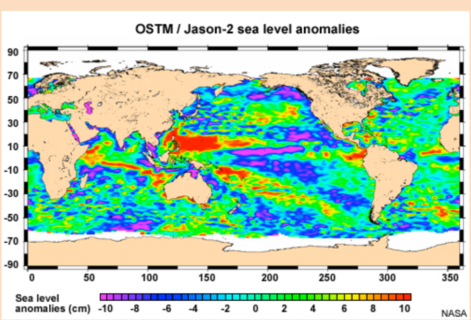

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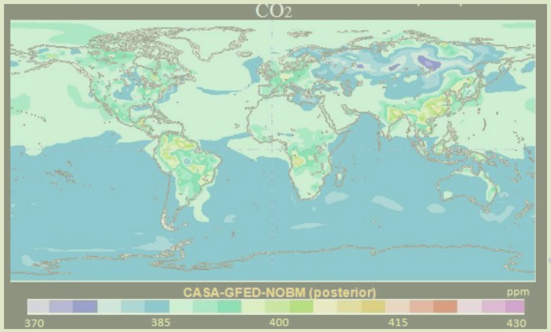

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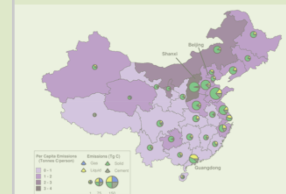

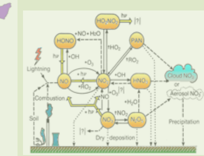

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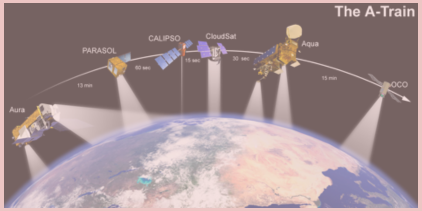

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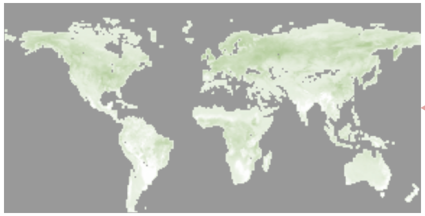
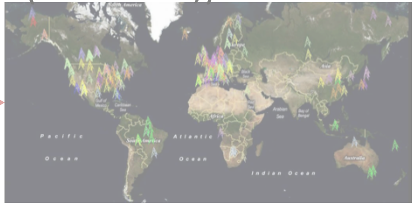




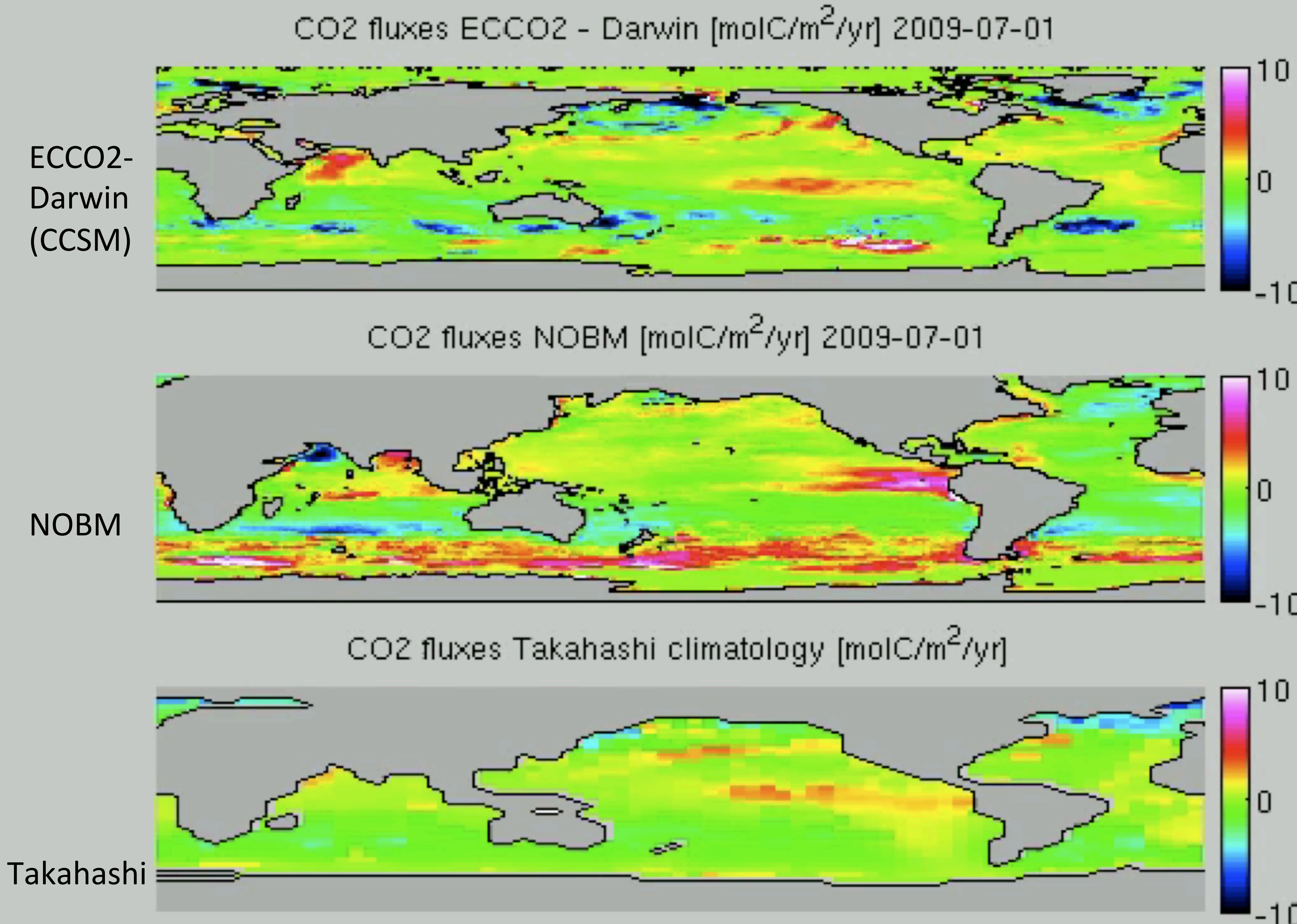
NOBM and ECCO2-Darwin

NASA Ocean Biogeochemical Model (NOBM):

- A biogeochemical processes model, coupled to the
- Poseidon ocean model
- Driven at the surface by the Modern Era Retrospective-analysis for Research and Applications (MERRA)
- Ocean color data is assimilated using MODIS-Aqua chlorophyll.

Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2):

- ECCO2 data syntheses are obtained by least squares fit of a global full-depth-ocean and sea-ice configuration of the Massachusetts Institute of Technology general circulation model (MITgcm), coupled to the
- MIT ecosystem model (Darwin), and
- a marine carbon chemistry model
- The ECCO2 ocean solution assimilates a variety of satellite and in-situ data, including Jason altimetry, AMSRE-E sea surface temperature, and Argo temperature and salinity profiles.


CO2 fluxes ECCO2 - Darwin [molC/m^2/yr] 2009-07-01
ECCO2-Darwin (CCSM)
10
0
-10
CO2 fluxes NOBM [molC/m^2/yr] 2009-07-01
NOBM
10
0
-10
CO2 fluxes Takahashi climatology [molC/m^2/yr]
Takahashi
10
0
-10

Data Assimilation Approach

Least squares method based on computation of model Green's functions.

Previously used for, e.g., ocean circulation estimates (Stammer and Wunsch, 1996; Menemenlis et al., 1997; 2005), atmospheric tracer inversions (Enting and Mansbridge, 1989; Tans et al., 1990; Bousquet et al., 2000), ocean carbon inversions (Gloor et al., 2003; Mikaloff Fletcher et al., 2006; 2007), and joint ocean-atmosphere carbon dioxide inversions (Jacobson et al., 2007a; 2007b).

GCM: $\mathbf{s}(t+1) = M[\mathbf{s}(t), \mathbf{x}]$

s(t) is the ocean model state vector at time t
M represents the numerical model
x is a set of control parameters,
here the weight of different initial conditions

Data: $\mathbf{y} = H[\mathbf{s}] + \mathbf{n} = G[\mathbf{x}] + \mathbf{n}$

y is the available observations
H is the measurement model
G is a function of *M* and *H*
n is additive noise

Cost function: $J = (G[\mathbf{x}] - \boldsymbol{y})^T (G[\mathbf{x}] - \boldsymbol{y})$

J is an unweighted cost function,
i.e., it is assumed that $\langle \mathbf{n}\mathbf{n}^T \rangle = \mathbf{I}$

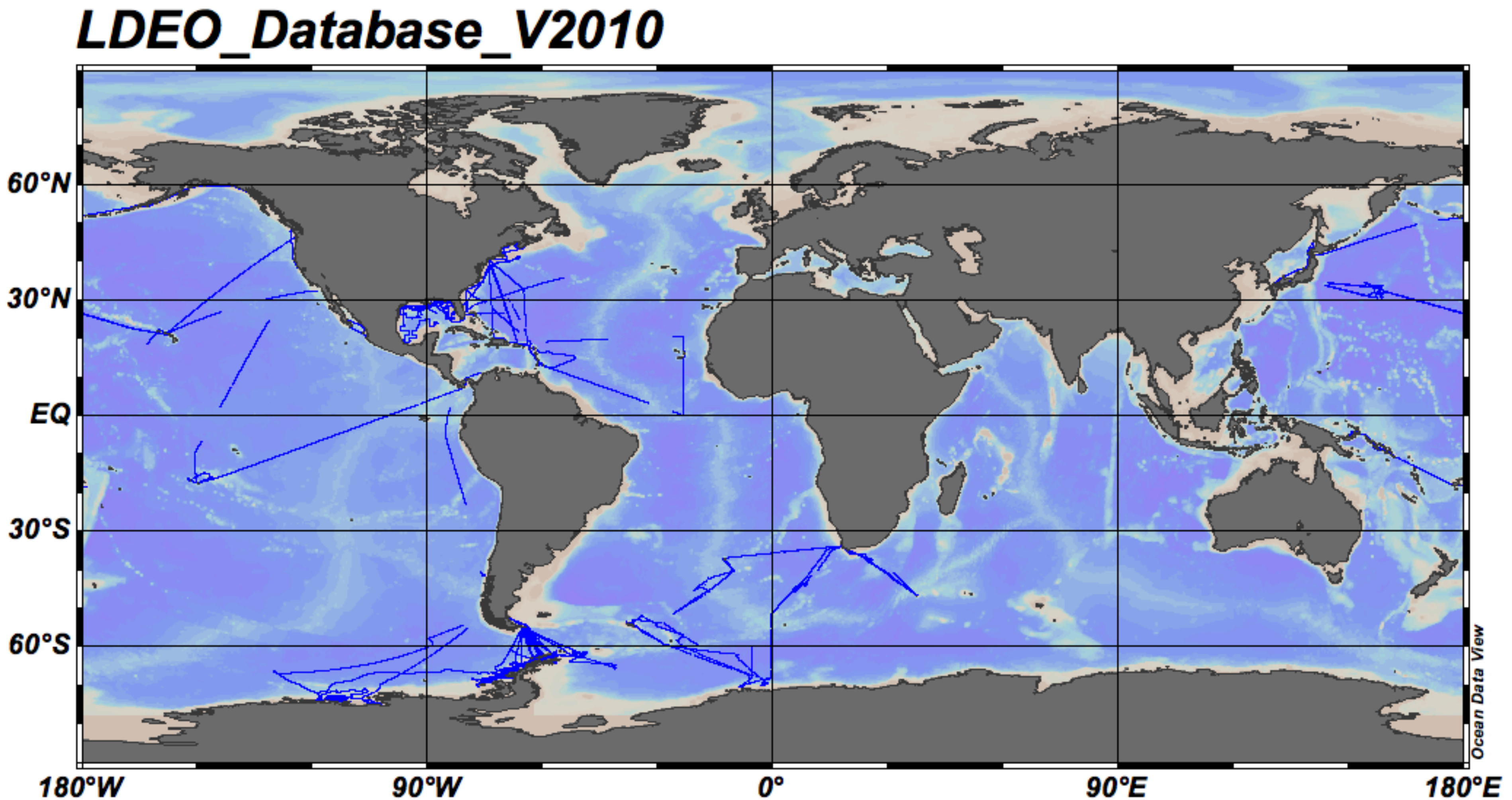
Linearization: $\boldsymbol{y} - G[\mathbf{x}_b] \approx \mathbf{G}(\mathbf{x} - \mathbf{x}_b) + \mathbf{n}$

G is a kernel matrix whose columns are computed using a GCM sensitivity experiment for each parameter in vector **x**.
Subscript "b" represents baseline GCM integration used to linearize problem.

Solution: $\tilde{\mathbf{x}} = \mathbf{x}_b + (\mathbf{G}^T\mathbf{G})^{-1}\mathbf{G}^T(\boldsymbol{y} - G[\mathbf{x}_b])$

Control parameters that minimize cost function *J*

A first proof-of-concept assimilation of LDEO pCO_2 data for 2009-2010



ECCO2-Darwin sensitivity experiments

(or model Green's functions)

The four ECCO2-Darwin integrations differ in their initial conditions (IC) for dissolved inorganic carbon (DIC), alkalinity (Alk), and oxygen:

CCSM: From previous integration with CCSM biogeochemical model

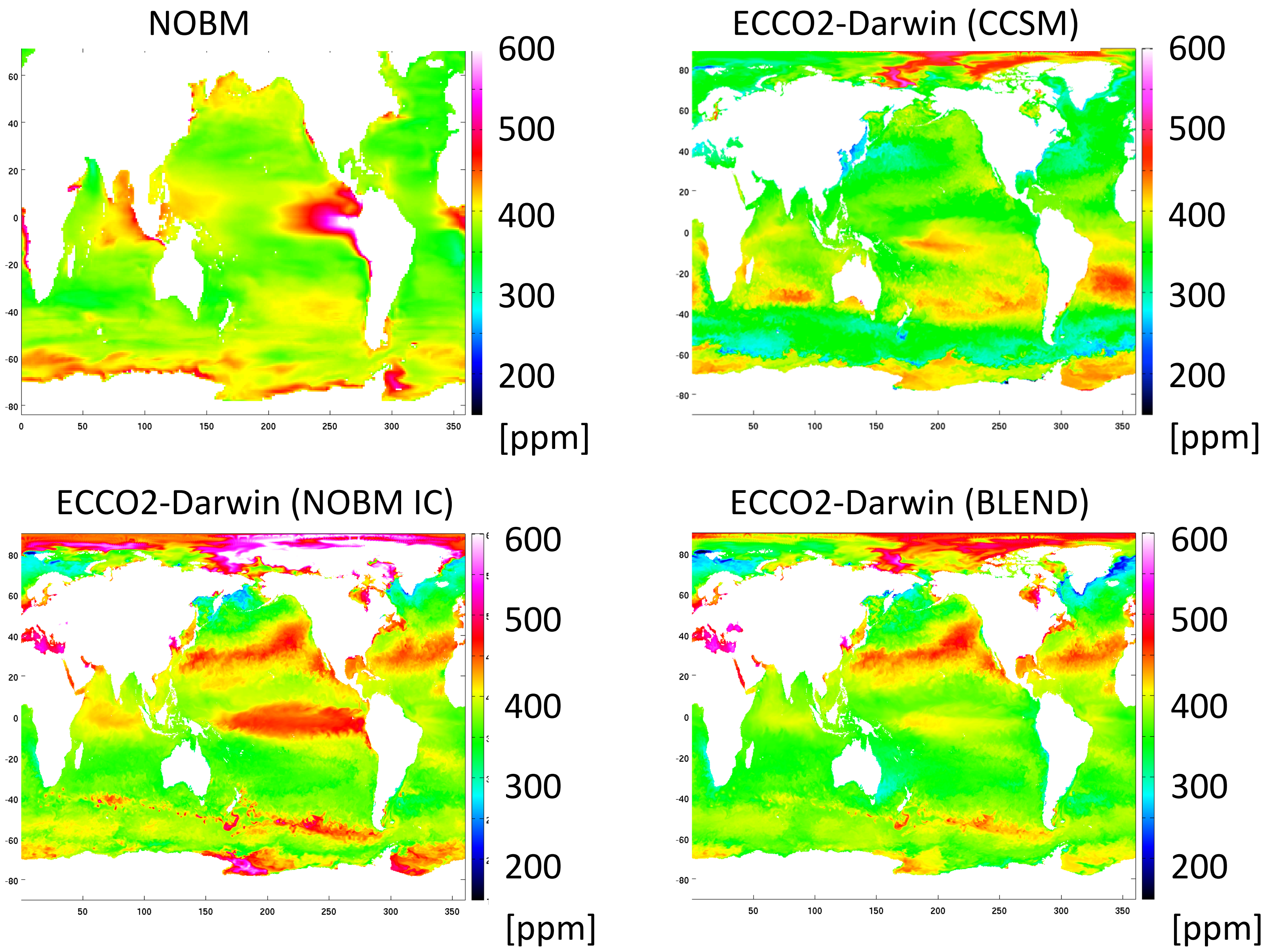
KS: DIC blended from Key et al. and Sabine et al. data sets, Alk from GLODAP, O_2 from World Ocean Atlas 2009

BLEND: Blend of modified **CCSM** and **KS** initial conditions

NOBM IC: DIC and DOC from NOBM, Alk and O_2 from **BLEND**

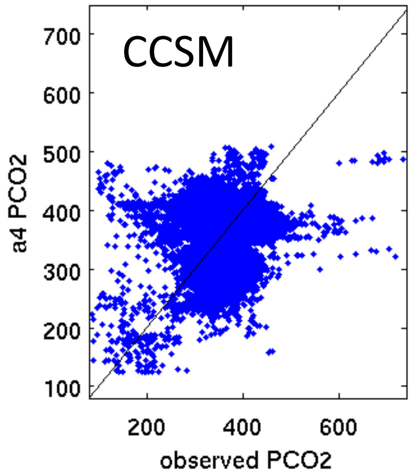
Each column of the kernel matrix **G** is computed as the difference between perturbed and baseline integration (CCSM) sampled at the location and time of the observations (blue lines in previous slide)

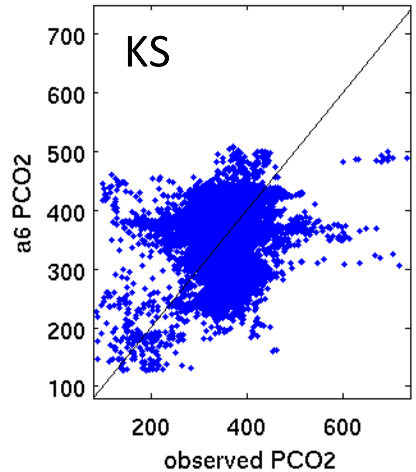
Simulated surface pCO_2 (monthly mean July 2009)

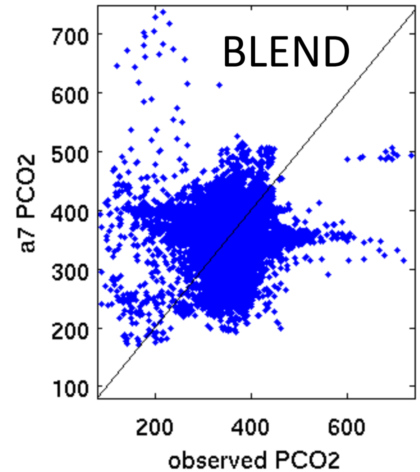


Model (ECCO2) vs. Data: pCO_2

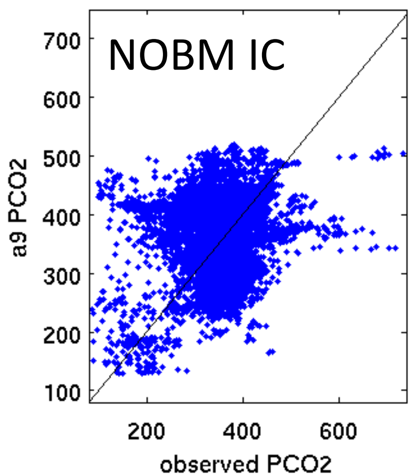
Cost: *J* = 74.6 *J* = 69.1 *J* = 75.7





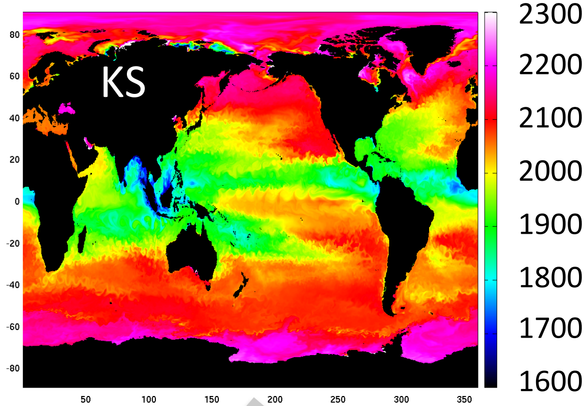


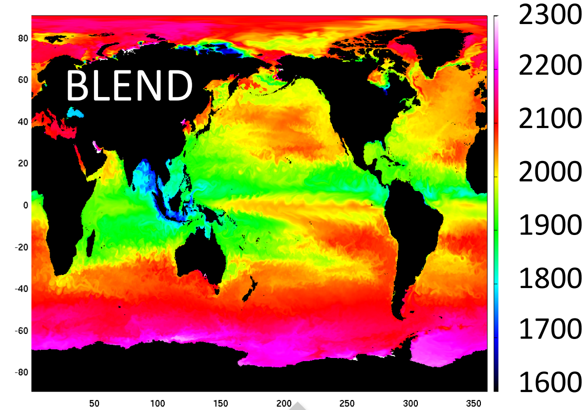
Cost: *J* = 78.2

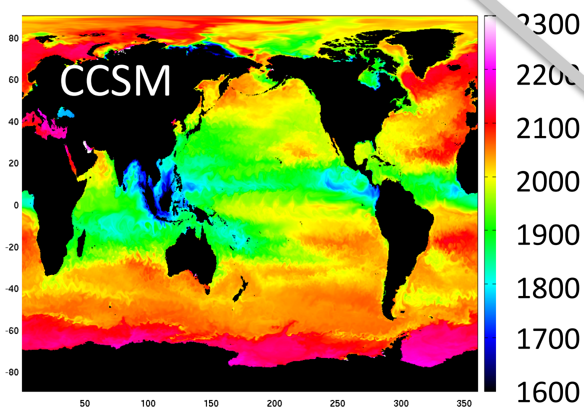


Four different realizations of ECCO2-Darwin compared to LDEO pCO_2 data for 2009 and 2010.

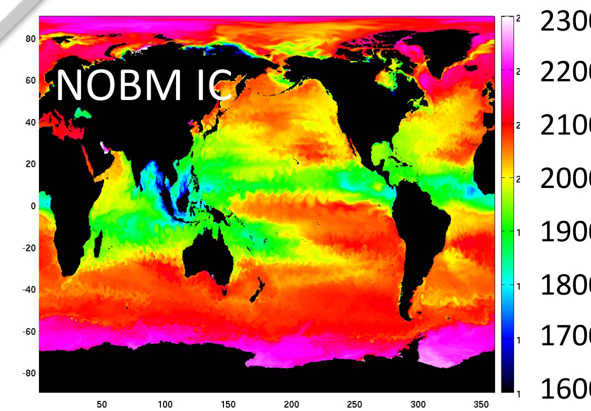
Optimizing biogeochemical initial conditions

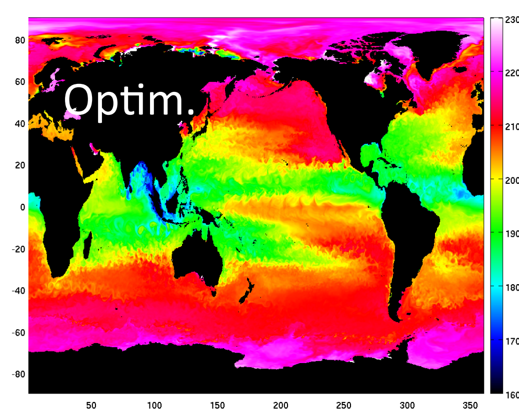






Optimized =
-0.35 * CCSM +
1.19 * KS +
0.38 * BLEND +
-0.23 * NOBM IC



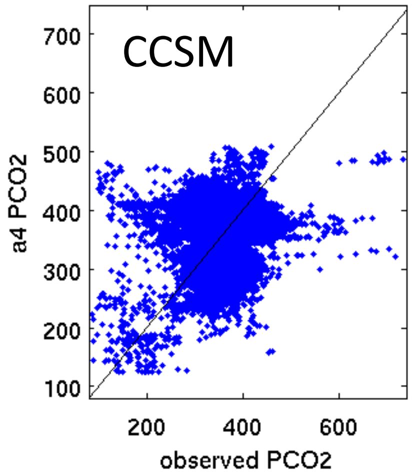


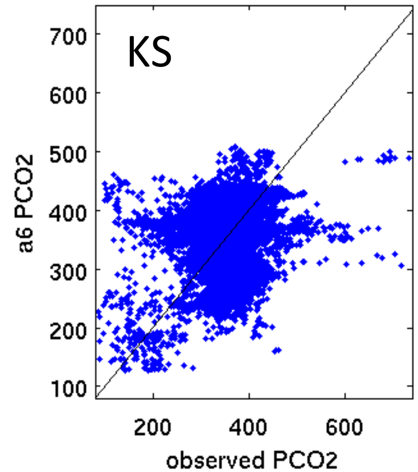
Shown:
Surface DIC
[mmolC/m^3]

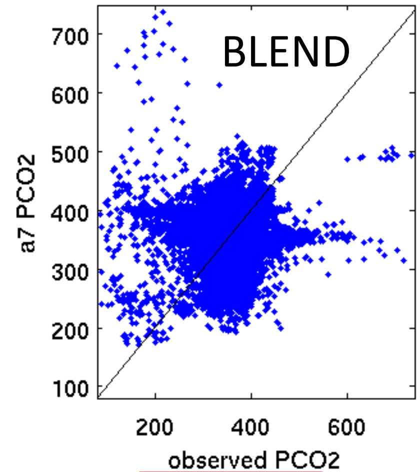
The model physics of the optimized run are identical to the original runs, i.e., all runs have identical physical fields.

Model (ECCO2) vs. Data: pCO_2

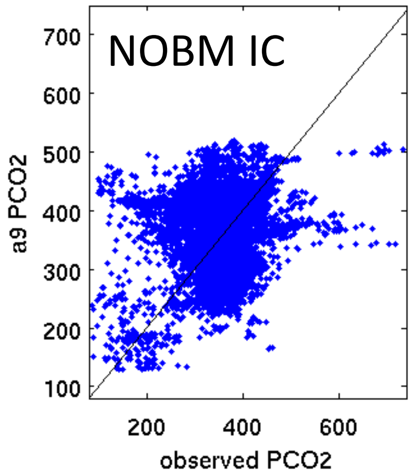
Cost: *J* = 74.6 *J* = 69.1 *J* = 75.7







Cost: *J* = 78.2 *J* = 62.7



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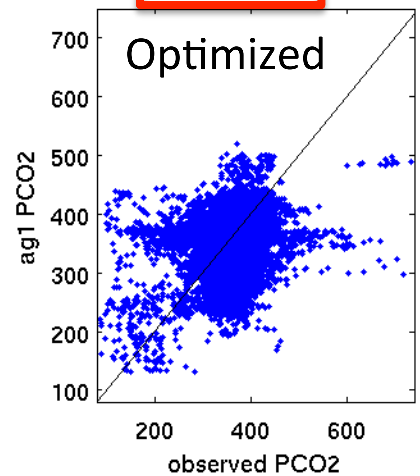
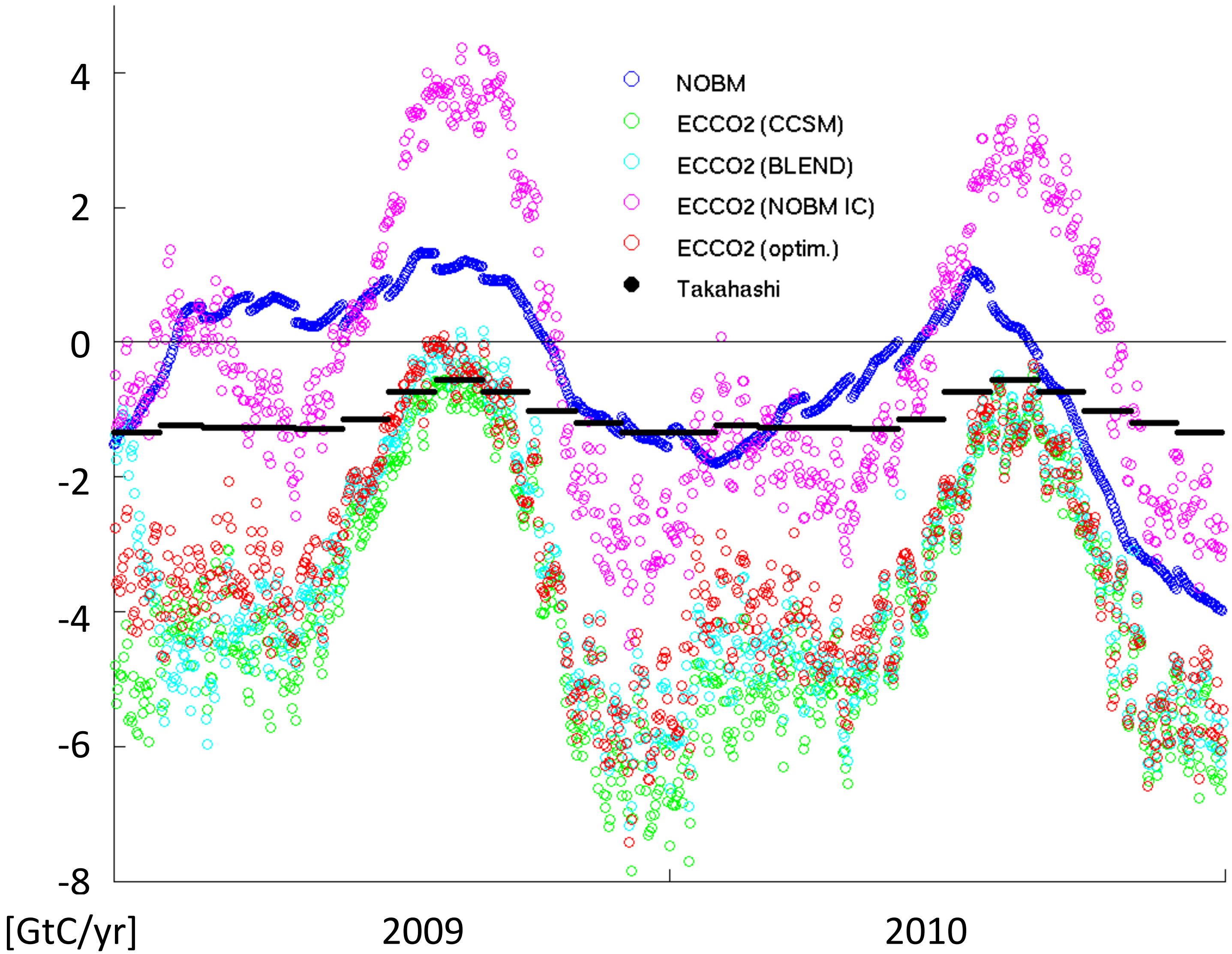


Simulated air-sea CO_2 fluxes (global integral)



Mean flux during 2009—2010 in GtC/yr:

NOBM IC: -0.2
NOBM: -0.5

Takahashi: -1.1

Optimized: -3.4
BLEND: -3.5
CCSM: -4.0

Summary and Planned Work

- Long spin-ups of high-resolution ocean biogeochemical models are problematic because of computational cost and model drift.
- This leads to unrealistic air-sea carbon flux estimates.
- A simple, physically-consistent data assimilation approach based on model Green's functions (forward sensitivity experiments) has been used to reduce model-data mismatch.
- Ongoing work:
  - Computation of additional model Green's functions is underway.
  - Use additional in situ and satellite (e.g., color) data constraints.
  - Use adjoint method to increase number of control parameters.