CarbonTracker (CTDAS): adding $^{13}CO_2$ constraints to the carbon cycle assimilations

Wouter Peters
based on work by
Ivar van der Velde

Current CT

- CarbonTracker North America (NOAA ESRL, USA) (2007)
- CarbonTracker Europe (Wageningen University, Netherlands) (2008)
- CarbonTracker Asia (KMA Korea) (2008)
- CarbonTracker China (Nanjing University & CAS GSNRR Beijing) (2011)
- CarbonTracker Amazonia (NOAA ESRL, WU, INPE Brazil) (2009)
- CarbonTracker Alpine (ETH Zurich, 2012)
- CarbonTracker Methane I (NOAA ESRL, 2010)
- CarbonTracker Methane II (FMI Finland, 2011)

CTDAS

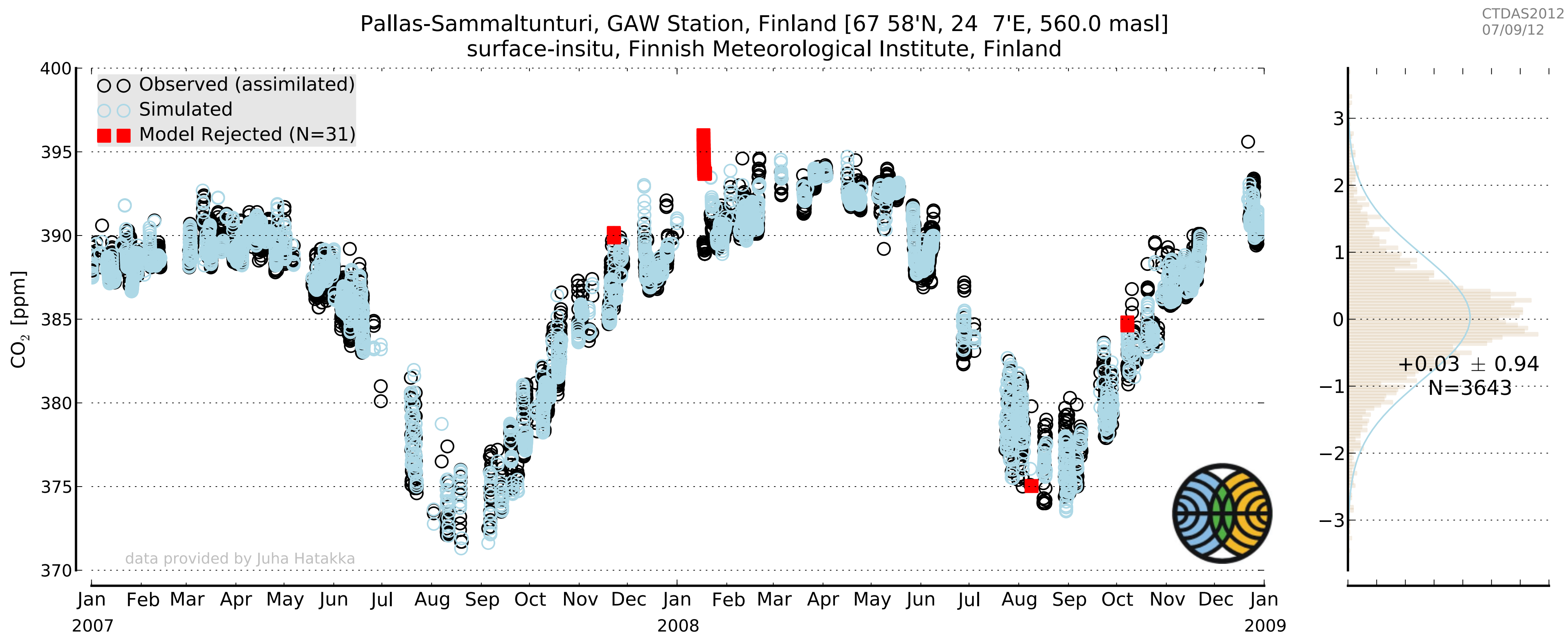
- Developments relevant for TM5 community:
  - ObsPack
  - CarbonTracker & $^{13}CO_2$
  - gridded CarbonTracker

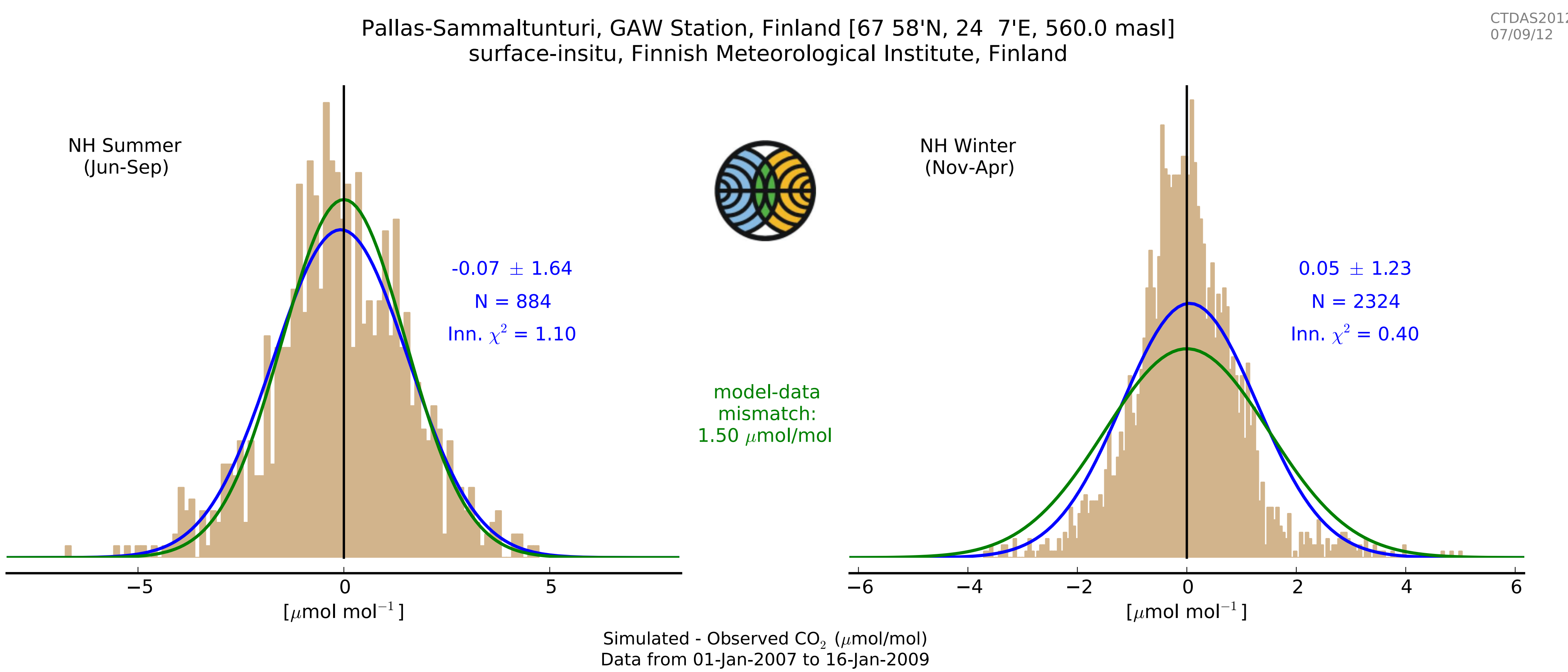
CTDAS

- Developments relevant for TM5 community:
  - ObsPack (courtesy Ken Masarie)
  - CarbonTracker & $^{13}CO_2$
  - ~~gridded CarbonTracker~~

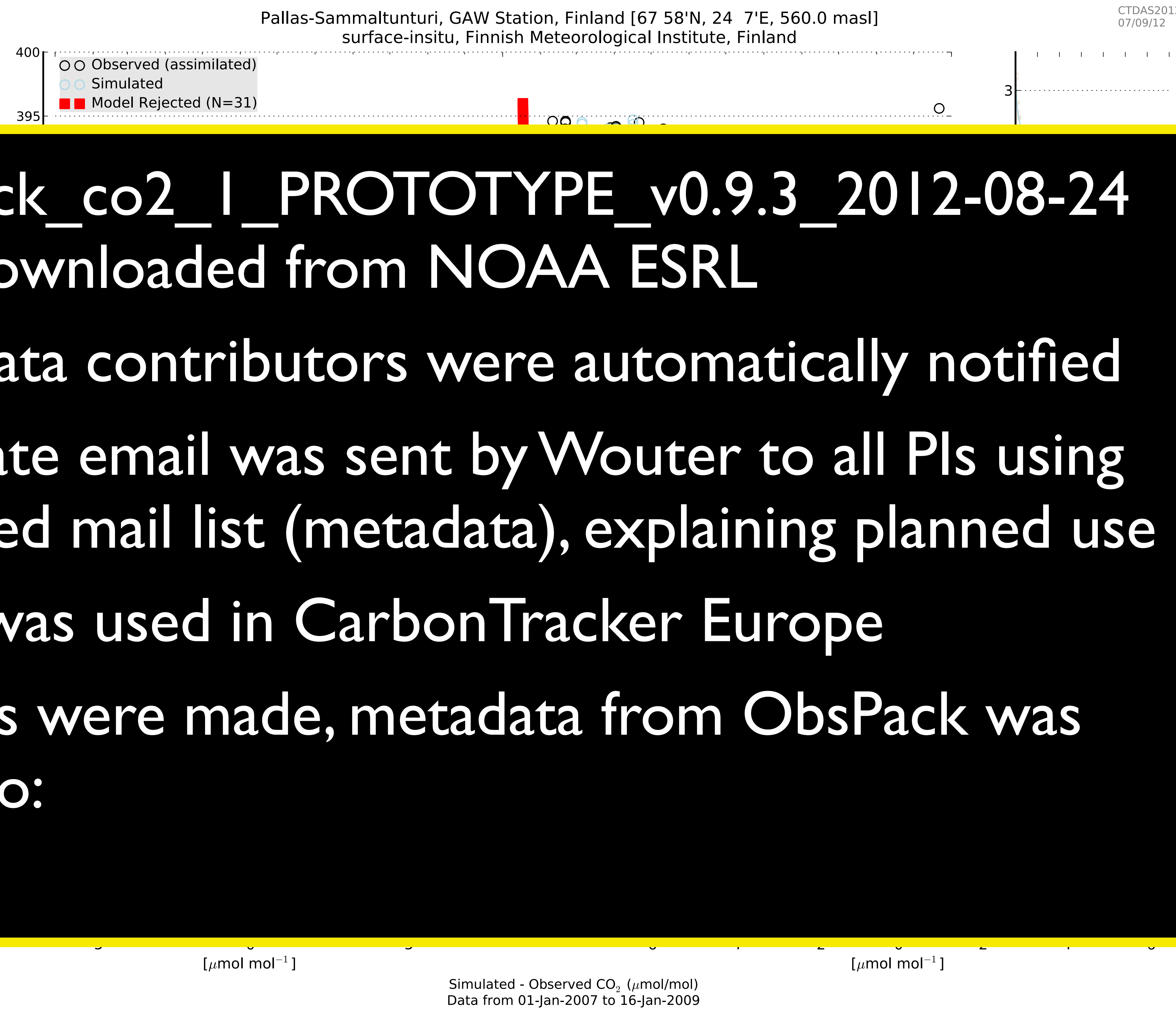
ObsPack

- A new framework to distribute mole fraction observations (CO, CO_2, COS, CH_4, SF_6, (H)CFCs, isotopes) to users
- Successor of GlobalView by K. Masarie
- Advantages:
  - datasets fully traceable
  - datasets fully citable
  - easily acknowledgeable
  - downloads with automatic notification
- Example:





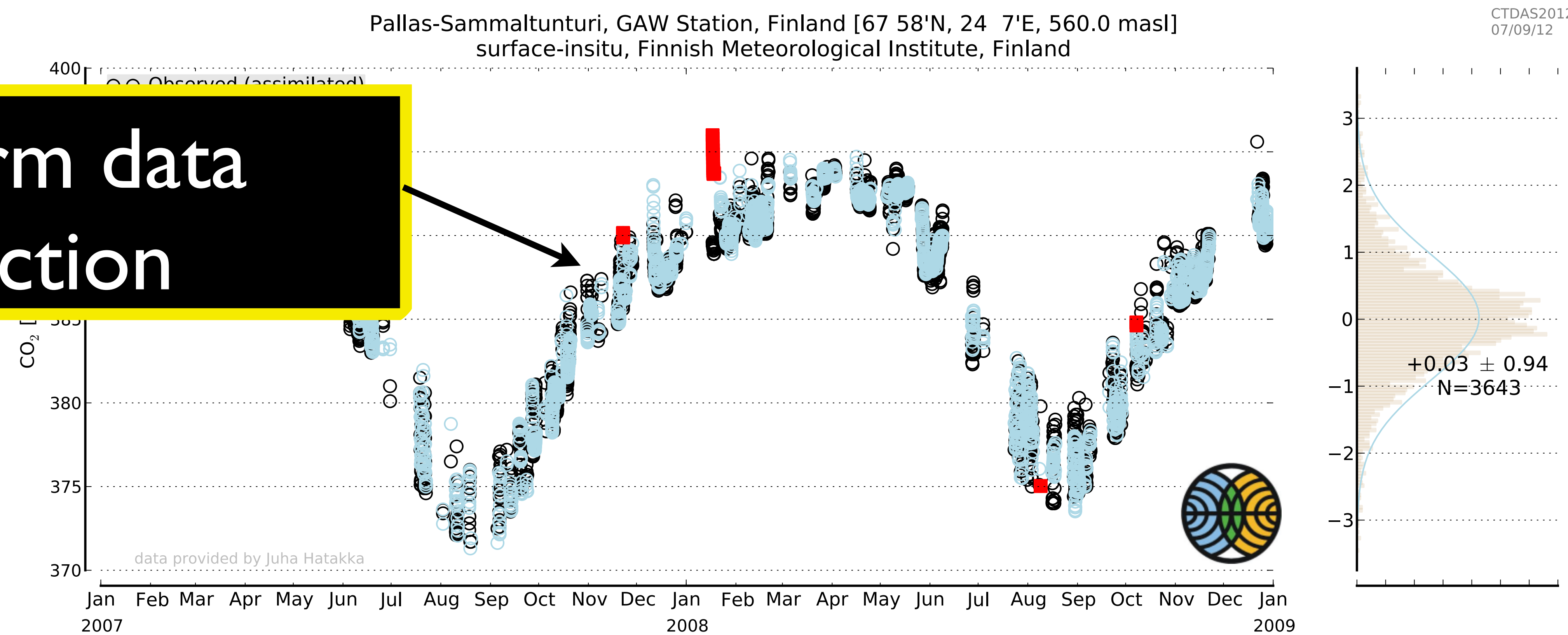
ObsPack used in GEOCARBON

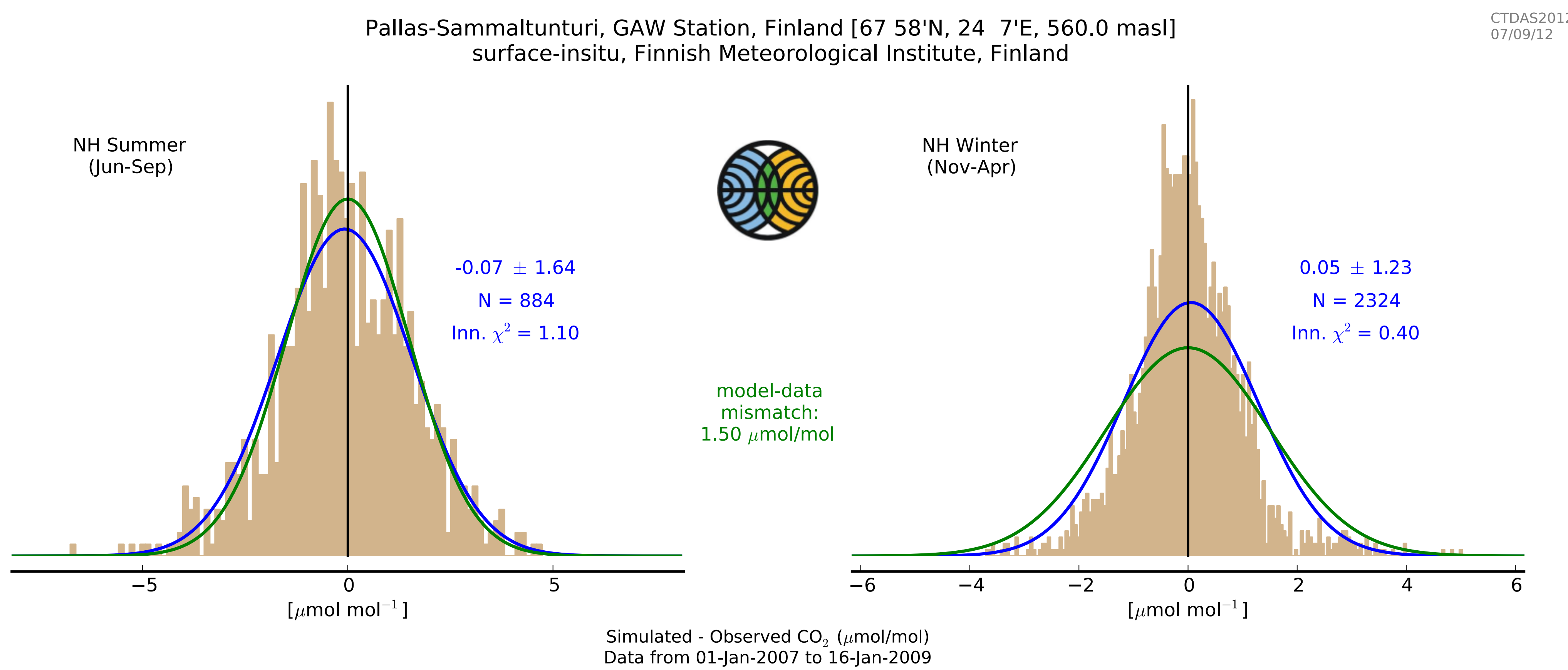


ObsP
usec
GEOCA

- obspack_co2_1_PROTOTYPE_v0.9.3_2012-08-24 was downloaded from NOAA ESRL
- ALL data contributors were automatically notified
- Separate email was sent by Wouter to all PIs using included mail list (metadata), explaining planned use
- Data was used in CarbonTracker Europe
- Figures were made, metadata from ObsPack was used to:

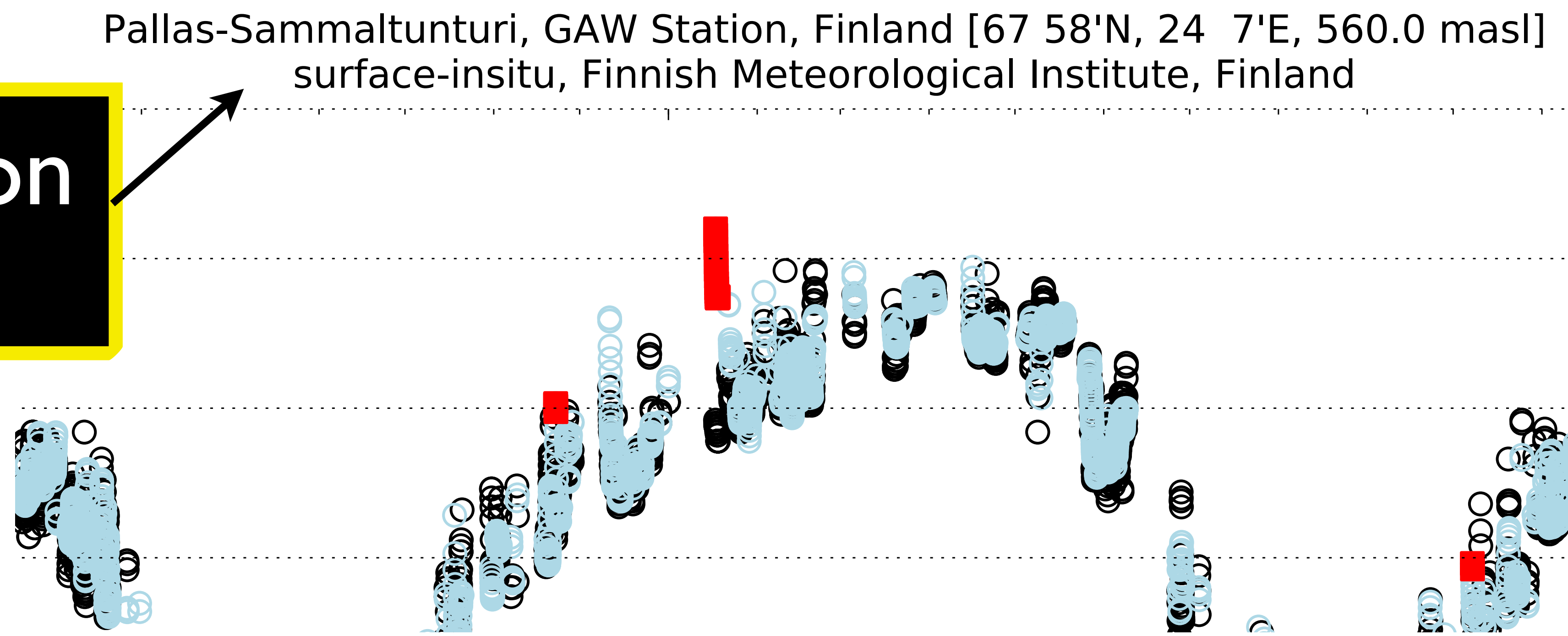
Perform data selection





ObsPack used in GEOCARBON

Describe full station info



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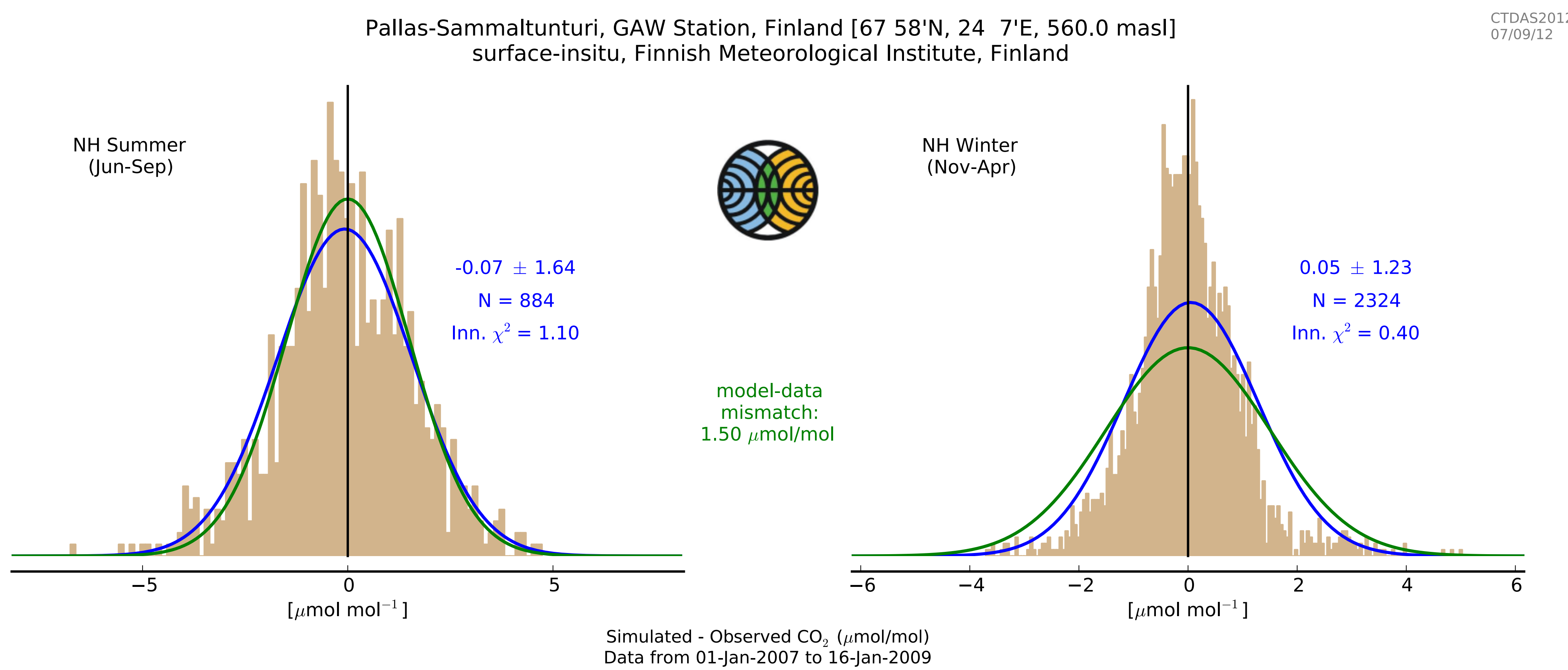

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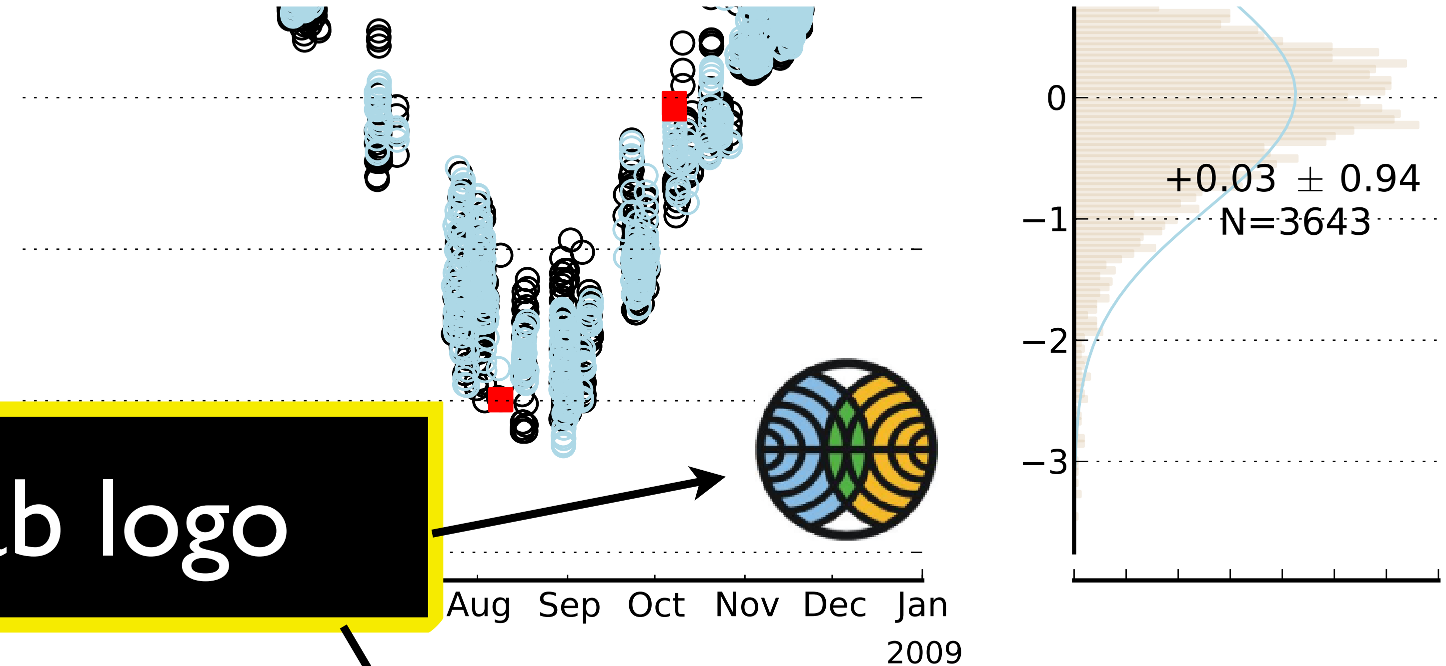
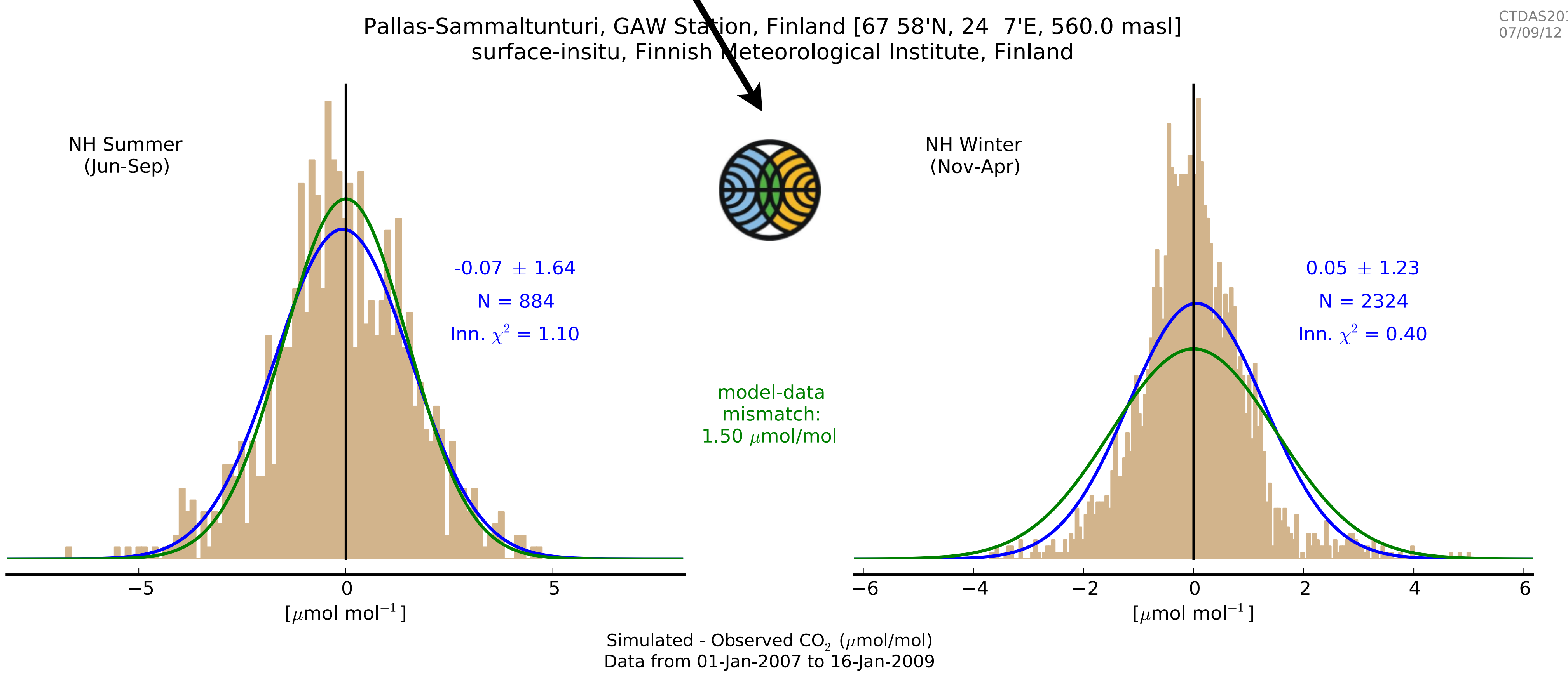
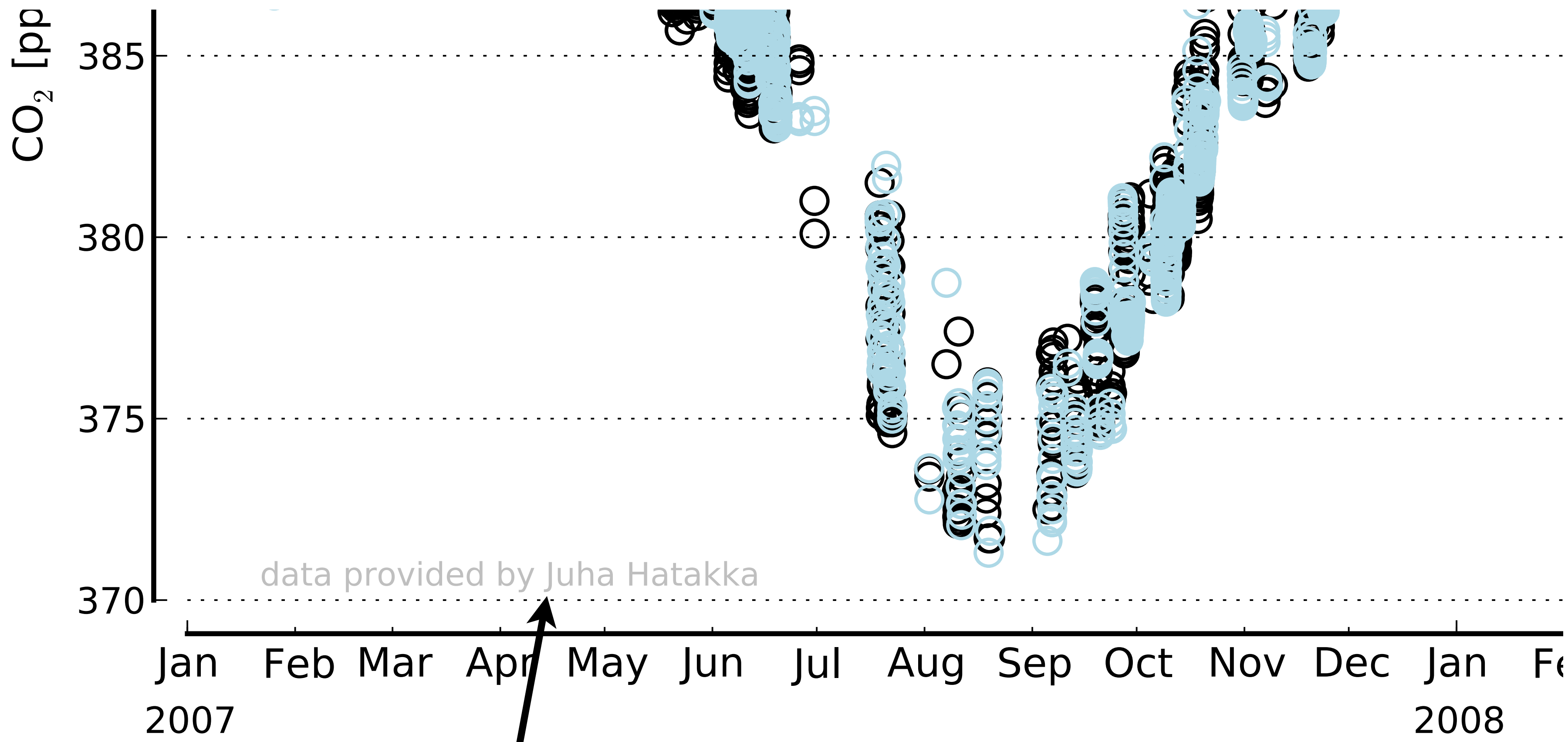


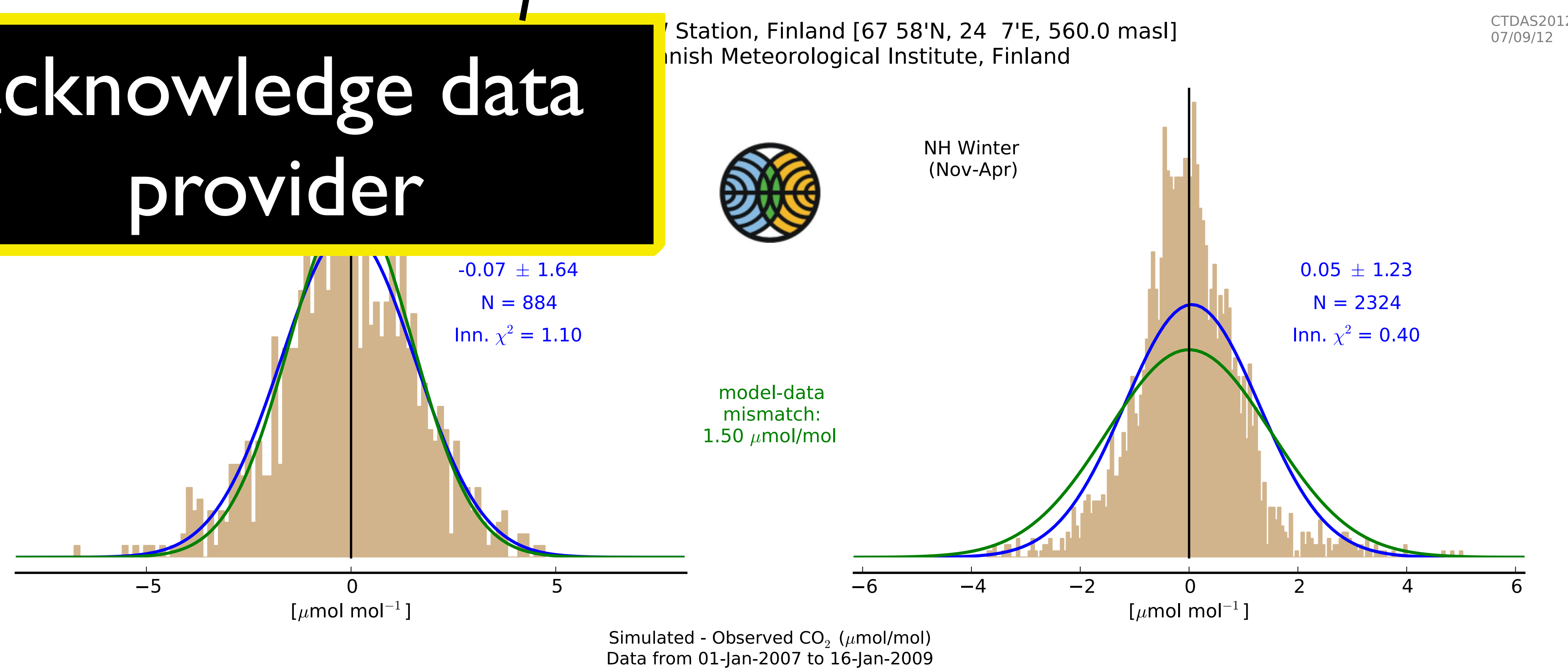
Include lab logo



ObsPack used in GEOCARBON



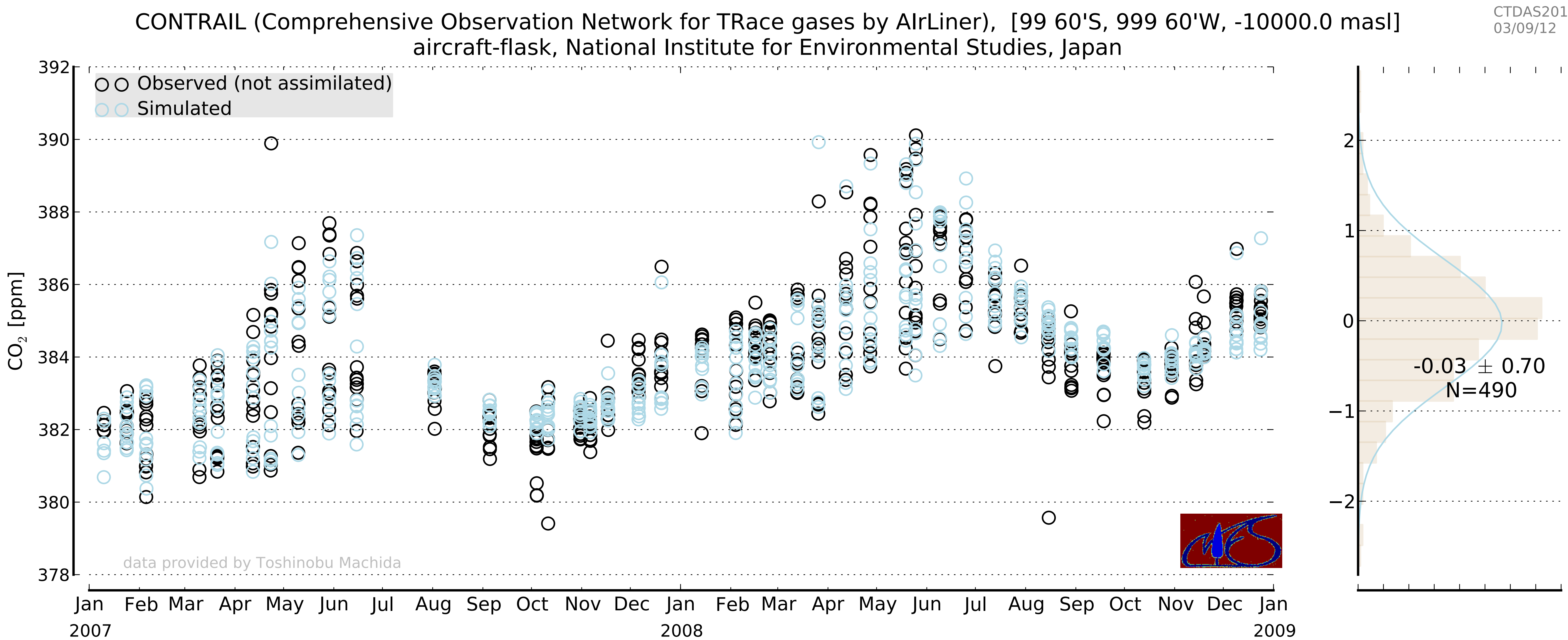
acknowledge data provider



ObsPack

- Publication of ObsPack with all data providers to the prototype
- Prototype now used in EU project "GEOCARBON"
- Creation of targeted ObsPacks for specific projects or user communities
- Creation of ObsPacks for other species (CH4, SF6, $^{13}CO_2$,...)

ObsPack: Independent aircraft data comparison



CONTRAIL aircraft flights on Japan Airlines

$^{13}CO_2$

- We developed a comprehensive system to simulate terrestrial + atmospheric $^{13}CO_2$ cycling
  - Ivar van der Velde
- Based on SIBCASA, hourly photosynthesis, fractionation of C3/C4, cycling through pools, ++
- Implemented in CarbonTracker to interpret (and assimilate) $^{13}CO_2$ observations

δ = signature of a reservoir

Δ = discrimination by a process

$$\frac{d[CO_2]}{dt} = F_{fossil} + F_{fire} + N_{ocean} + N_{bio}$$

$$CO_2 \cdot \frac{d\delta_{13}}{dt} = F_{ff} \cdot (\delta_{ff} - \delta_a) + F_{fire} \cdot (\delta_{bio} - \delta_a) + N_{bio}\Delta_{bio} + N_{ocean}\Delta_{ocean} + D_{bio} + D_{oce}$$

- **Mass balance coupled to CO_2 through the net exchange fluxes (N)**

$$\frac{d[CO_2]}{dt} = F_{fossil} + F_{fire} + N_{ocean} + N_{bio}$$

$$CO_2 \cdot \frac{d\delta_{13}}{dt} = F_{ff} \cdot (\delta_{ff} - \delta_a) + F_{fire} \cdot (\delta_{bio} - \delta_a) + N_{bio}\Delta_{bio} + N_{ocean}\Delta_{ocean} + D_{bio} + D_{oce}$$

- **But one-way exchange of CO_2 also impacts the isotopic ratio**

$$\frac{d[CO_2]}{dt} = F_{fossil} + F_{fire} + N_{ocean} + N_{bio}$$

$$CO_2 \cdot \frac{d\delta_{13}}{dt} = F_{ff} \cdot (\delta_{ff} - \delta_a) + F_{fire} \cdot (\delta_{bio} - \delta_a) + N_{bio}\Delta_{bio} + N_{ocean}\Delta_{ocean} + D_{bio} + D_{oce}$$

δ = signature of a reservoir

Δ = discrimination by a process

D = disequilibrium =

F_{up} (δ_{down} - δ_{up}) of a gross flux

$$\frac{d[CO_2]}{dt} = F_{fossil} + F_{fire} + N_{ocean} + N_{bio}$$

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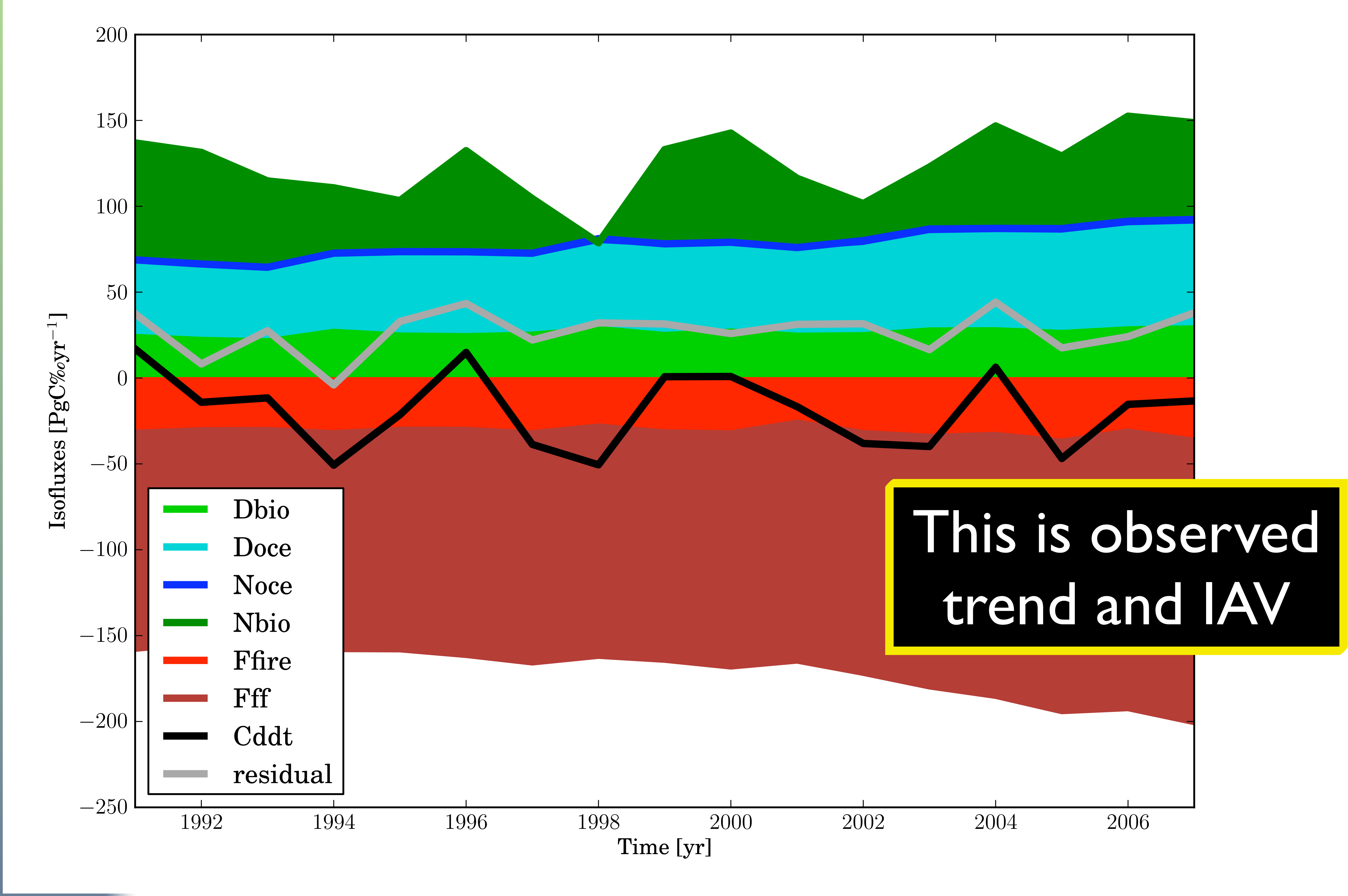
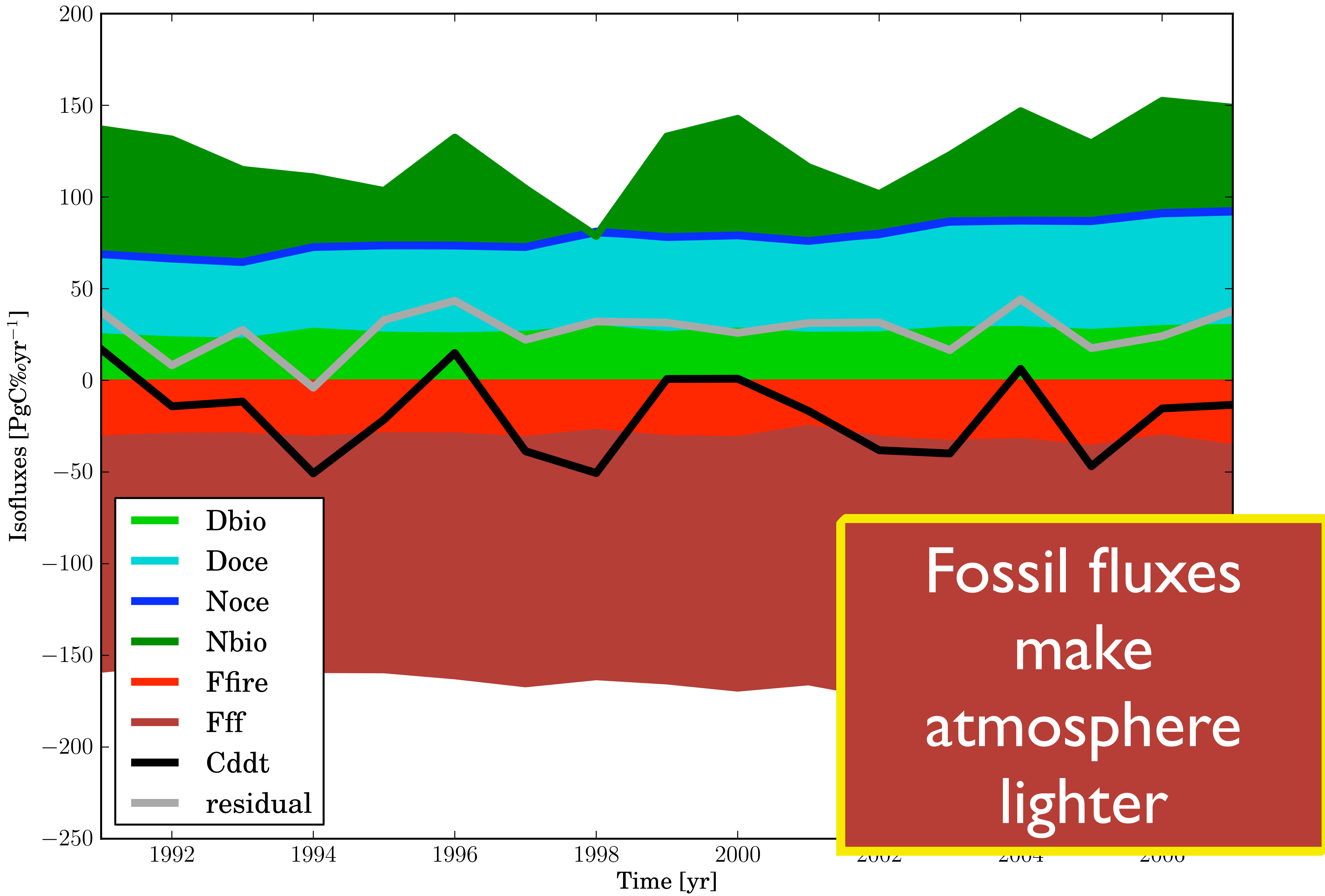
mass balance of $^{13}CO_2$



[13]C observations courtesy of INSTAAR/ U. of Colorado

WAGENINGEN UR
For quality of life

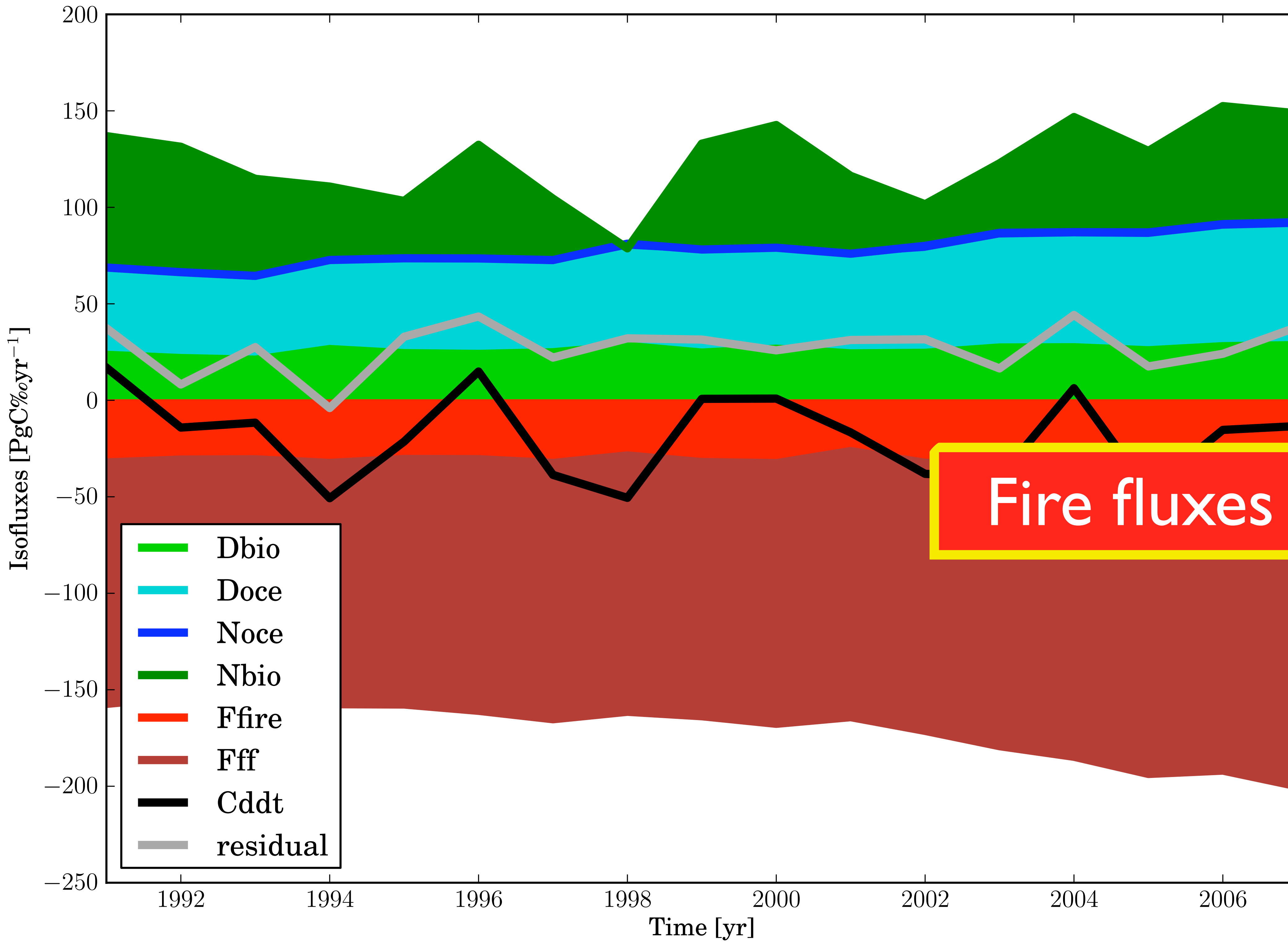
mass balance of $^{13}CO_2$



Fossil fluxes make atmosphere lighter

^{13}C observations courtesy of INSTAAR/ U. of Colorado

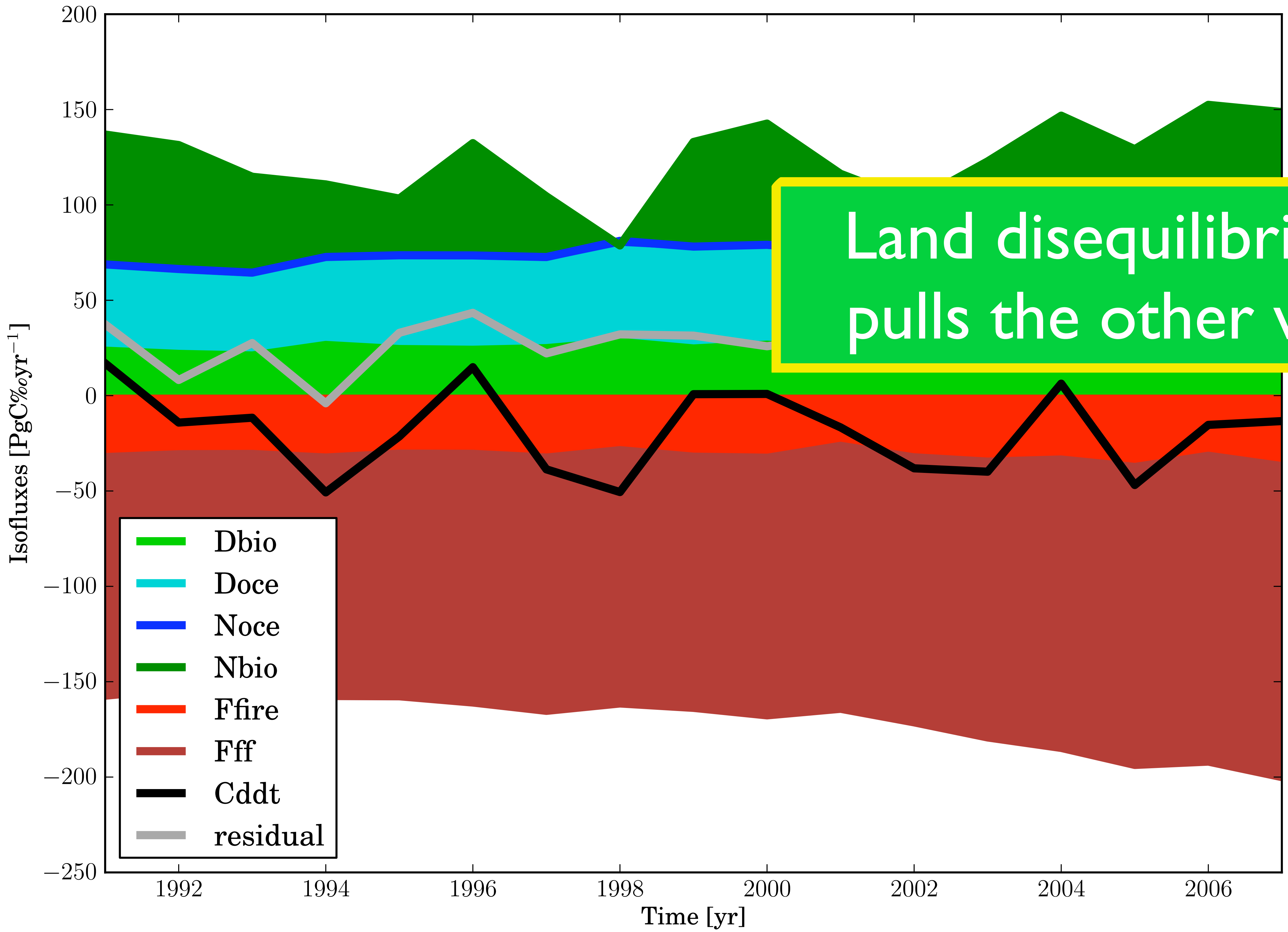
mass balance of $^{13}CO_2$



Fire fluxes too

^{13}C observations courtesy of INSTAAR/ U. of Colorado

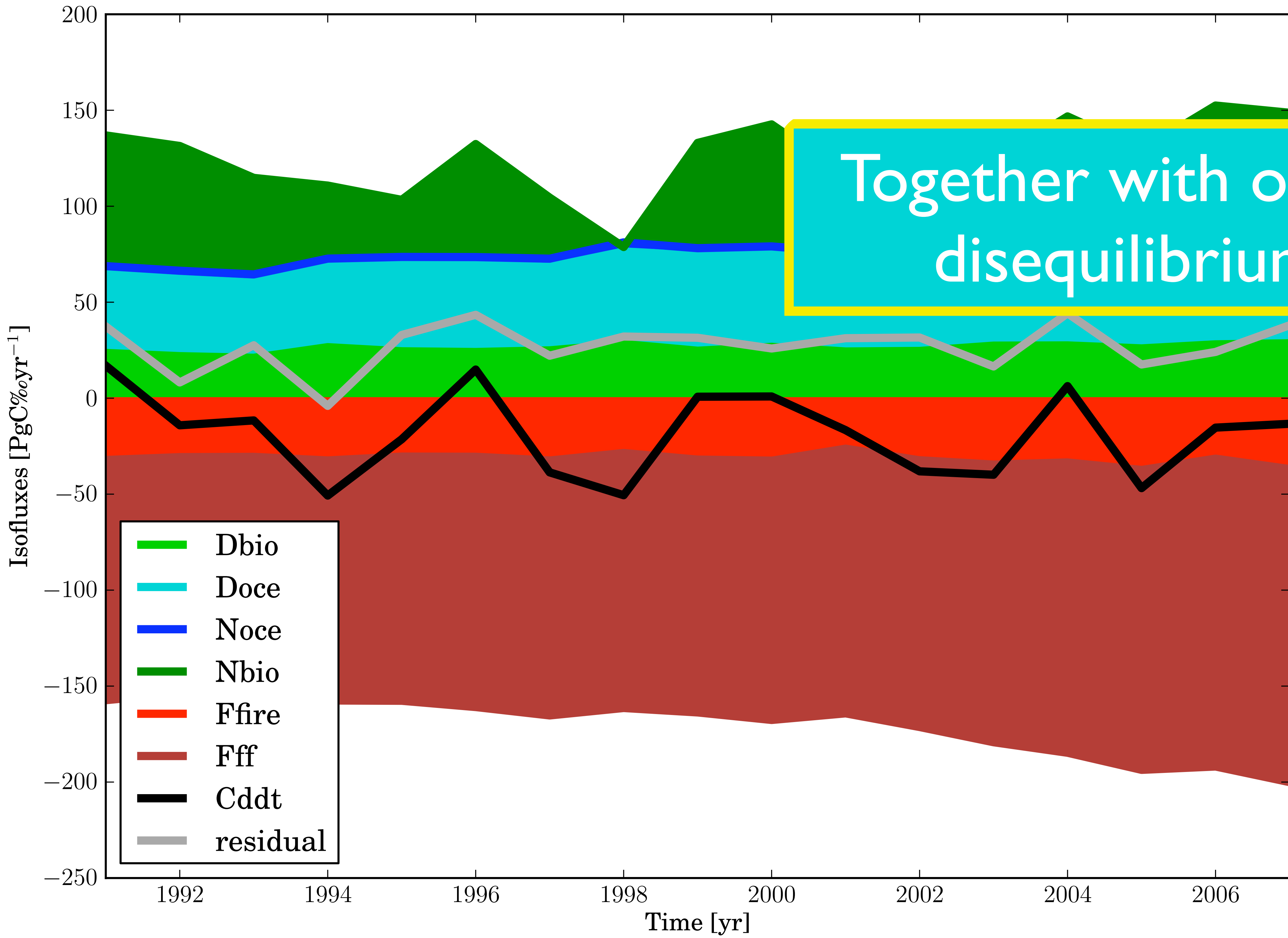
mass balance of $^{13}CO_2$



Land disequilibrium pulls the other way

^{13}C observations courtesy of INSTAAR/ U. of Colorado

mass balance of $^{13}CO_2$

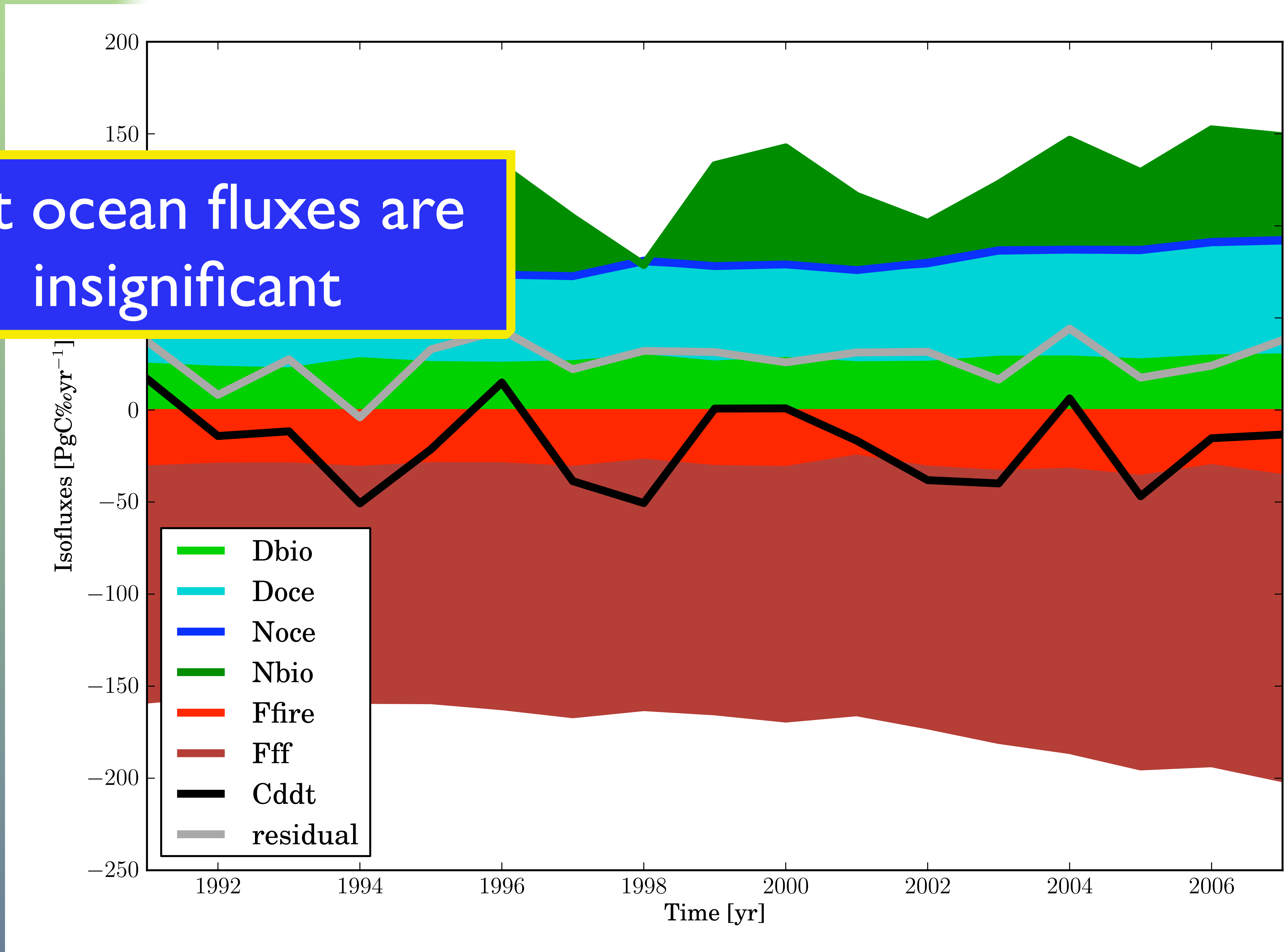


Together with ocean disequilibrium

[13]C observations courtesy of INSTAAR/ U. of Colorado

mass balance of $^{13}CO_2$

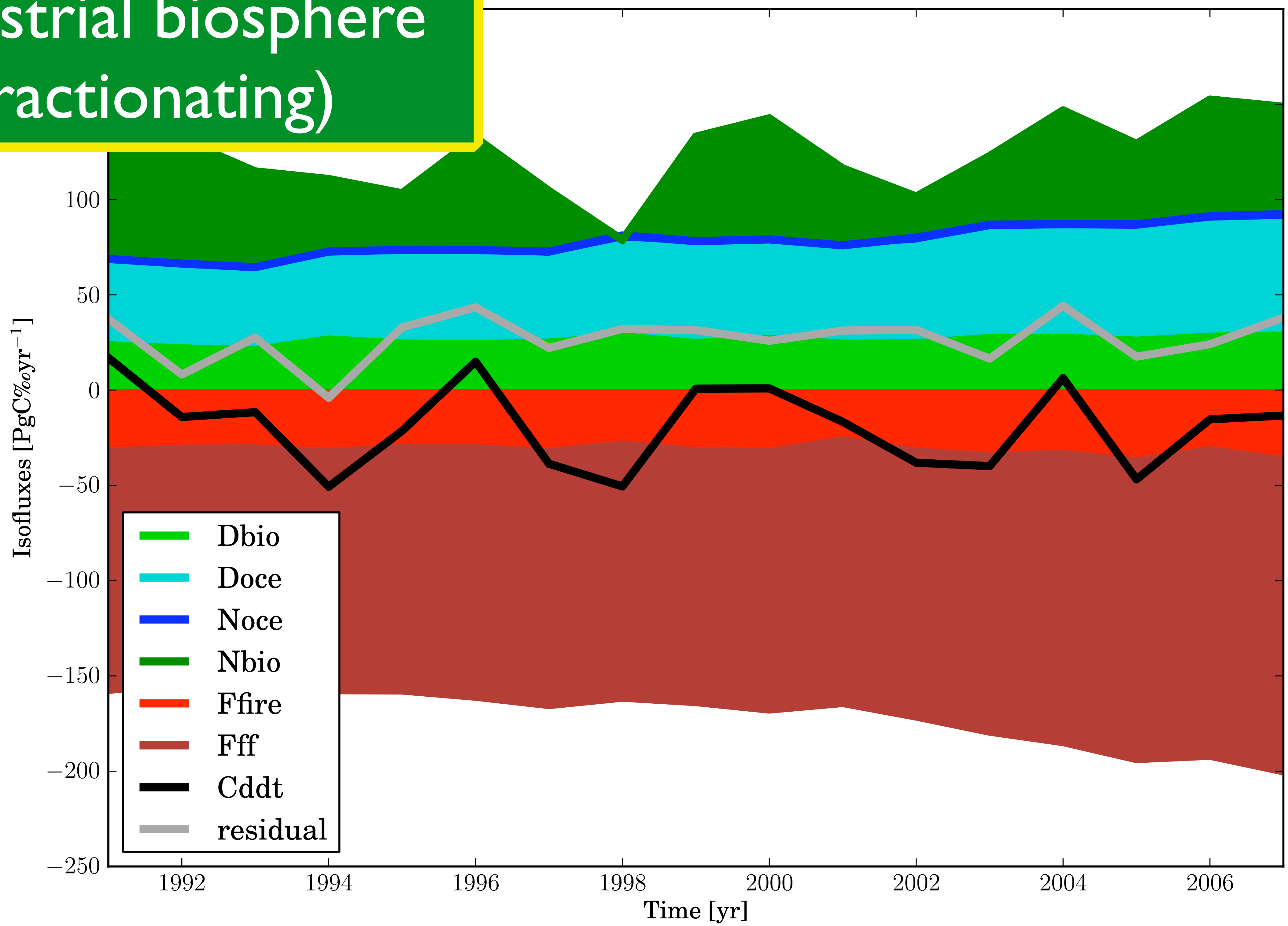
Net ocean fluxes are insignificant



^{13}C observations courtesy of INSTAAR/ U. of Colorado

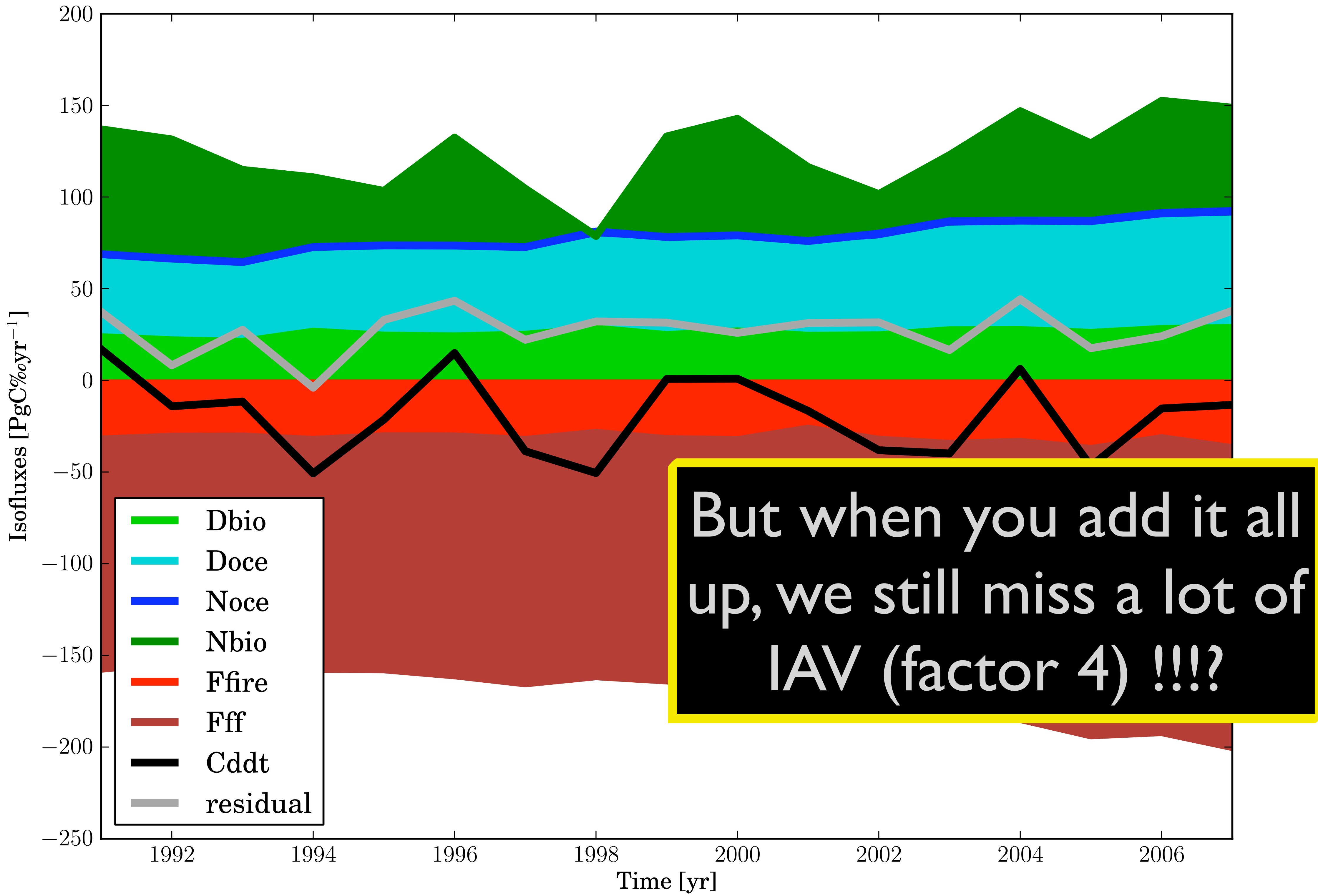
...alance of $^{13}CO_2$

And nearly all IAV comes from the terrestrial biosphere (fractionating)



^{13}C observations courtesy of INSTAAR/ U. of Colorado

mass balance of $^{13}CO_2$



^{13}C observations courtesy of INSTAAR/ U. of Colorado

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d/dt C_a [a]	3.6	PgC/yr
F_{ff} [b]	6.9	
F_{fire} [c]	1.8	
N_{oce} [d]	-2.1	
N_{bio} [e]	-3.0	

δ_a [a]	-8.0 ‰
δ_{ff} [b]	-28.6 ‰
$(\delta_{ab} - \delta_a) = -\Delta$ [i]	-15.2 ‰
$(\delta_{ao} - \delta_a) = \epsilon$ [j]	-2.0 ‰
C_a [a]	779.2 PgC

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C_a [a]	779.2 PgC

	mean
C_a d/dt δ_a [a]	-18.7
$F_{ff}(\delta_{ff} - \delta_a)$	-141.9
$F_{fire}(\delta_{ab} - \delta_a)$	-27.8
$N_{oce}(\delta_{ao} - \delta_a)$	4.2
$N_{bio}(\delta_{ab} - \delta_a)$	45.6
D_{bio} [f]	25.4
D_{oce} [g]	48.7
residual [h]	27.1

d/dt C_a [a]	3.6
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	mean	1σ
C_a d/dt δ_a [a]	-18.7	$\pm$ 21.3
$F_{ff}(\delta_{ff} - \delta_a)$	-141.9	$\pm$ 4.0
$F_{fire}(\delta_{ab} - \delta_a)$	-27.8	$\pm$ 2.3
$N_{oce}(\delta_{ao} - \delta_a)$	4.2	$\pm$ 0.4
$N_{bio}(\delta_{ab} - \delta_a)$	45.6	$\pm$ 18.1
D_{bio} [f]	25.4	$\pm$ 1.5
D_{oce} [g]	48.7	$\pm$ 1.5
residual [h]	27.1	$\pm$ 10.1

d/dt C_a [a]	3.6
F_{ff} [b]	6.9
F_{fire} [c]	1.8
N_{oce} [d]	-2.1
N_{bio} [e]	-3.0

δ_a [a]	-8.0 ‰
δ_{ff} [b]	-28.6 ‰
$(\delta_{ab} - \delta_a) = -\Delta$ [i]	-15.2 ‰
$(\delta_{ao} - \delta_a) = \epsilon$ [j]	-2.0 ‰
C_a [a]	779.2 PgC

WAGENINGEN UR
For quality of life

	mean	1σ	$1\sigma^2$
C_a d/dt δ_a [a]	-18.7	$\pm$ 21.3	454.4
$F_{ff}(\delta_{ff} - \delta_a)$	-141.9	$\pm$ 4.0	16.0
$F_{fire}(\delta_{ab} - \delta_a)$	-27.8	$\pm$ 2.3	5.3
$N_{oce}(\delta_{ao} - \delta_a)$	4.2	$\pm$ 0.4	0.14
$N_{bio}(\delta_{ab} - \delta_a)$	45.6	$\pm$ 18.1	326.5
D_{bio} [f]	25.4	$\pm$ 1.5	2.1
D_{oce} [g]	48.7	$\pm$ 1.5	2.2
residual [h]	27.1	$\pm$ 10.1	102.2

d/dt C_a [a]	3.6
F_{ff} [b]	6.9
F_{fire} [c]	1.8
N_{oce} [d]	-2.1
N_{bio} [e]	-3.0

δ_a [a]	-8.0 ‰
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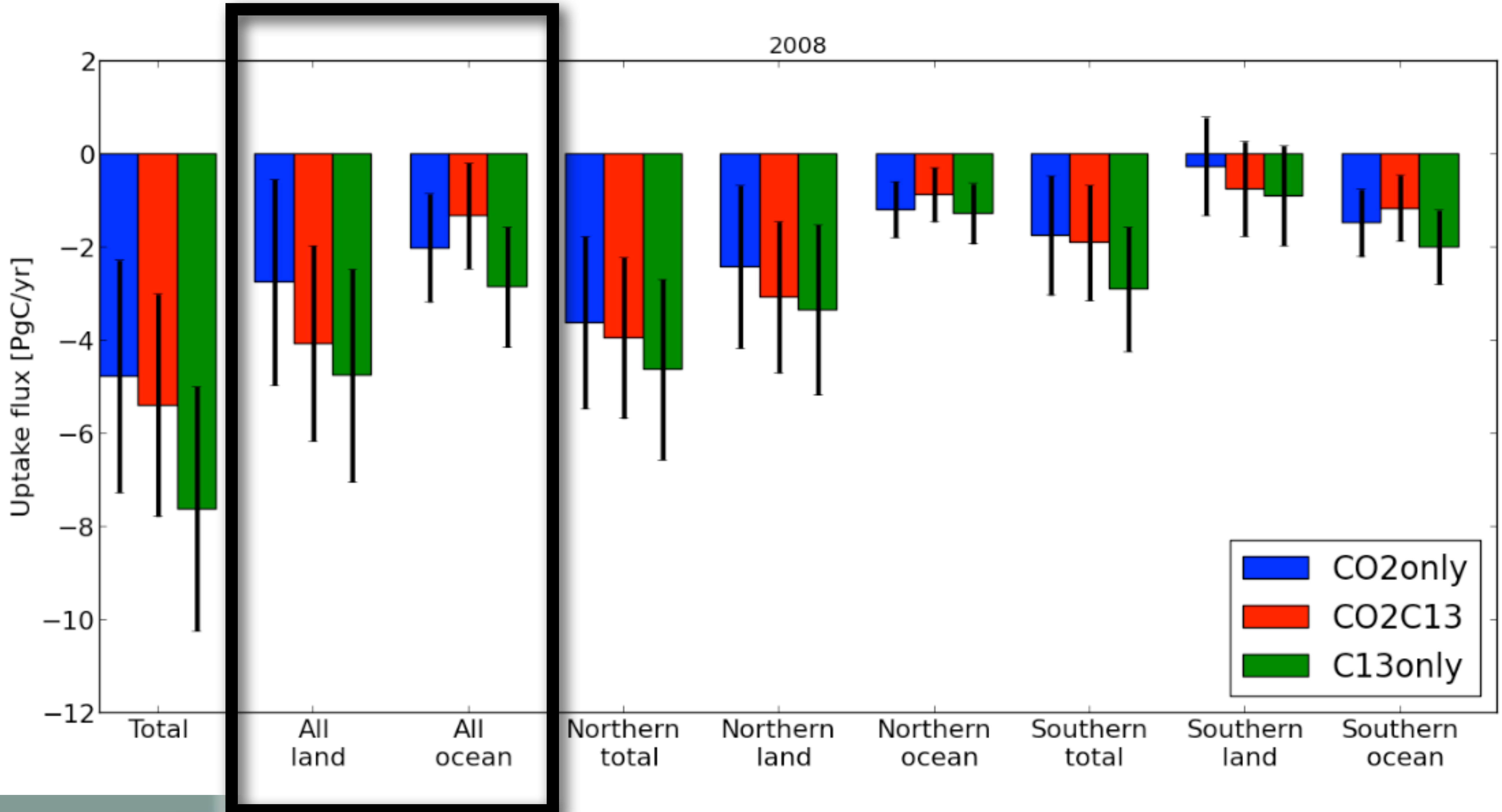
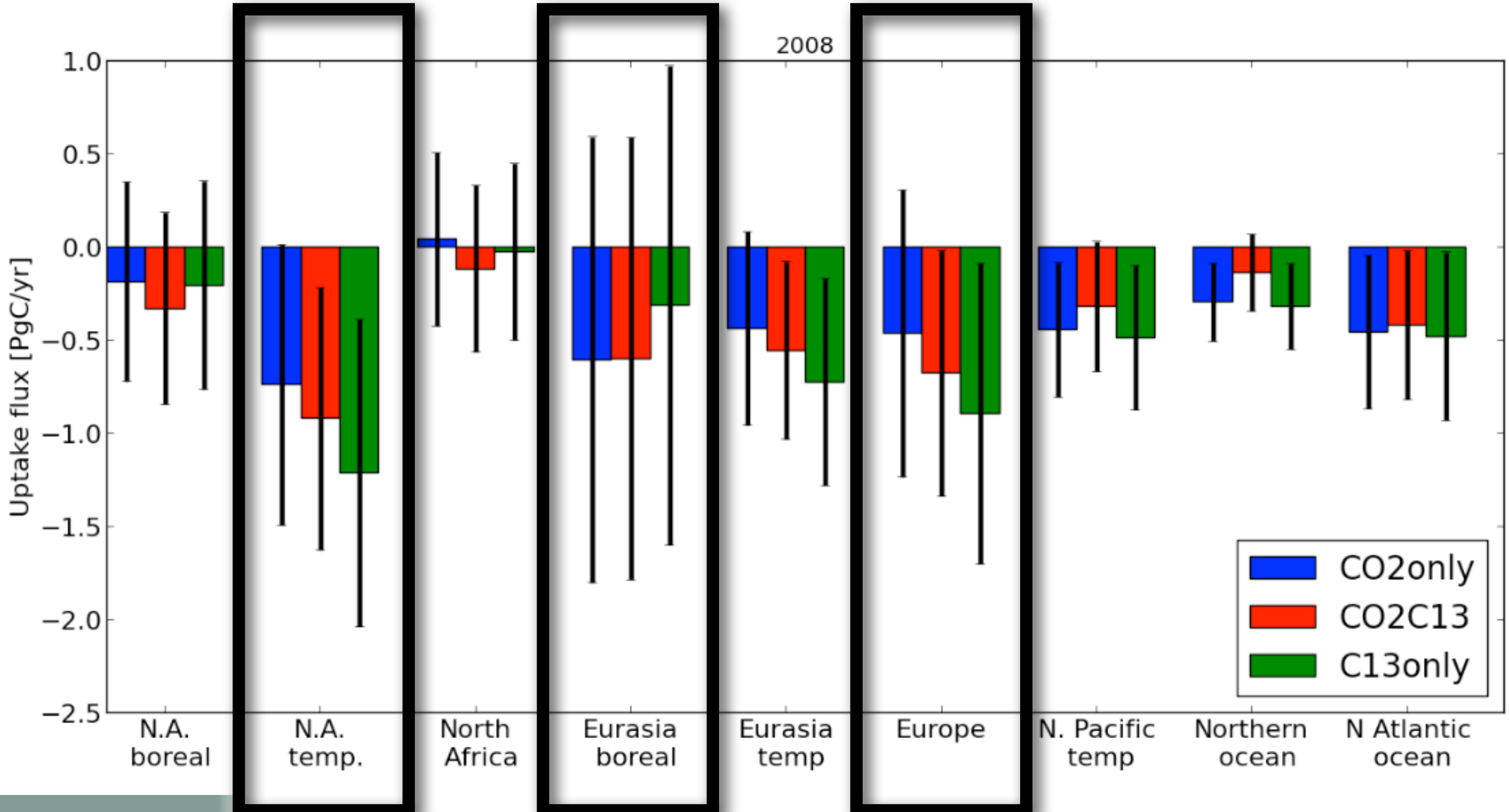
$(\delta_{ab} - \delta_a) = -\Delta$ [i]	-15.2 ‰
$(\delta_{ao} - \delta_a) = \epsilon$ [j]	-2.0 ‰
C_a [a]	779.2 PgC

$^{13}CO_2$

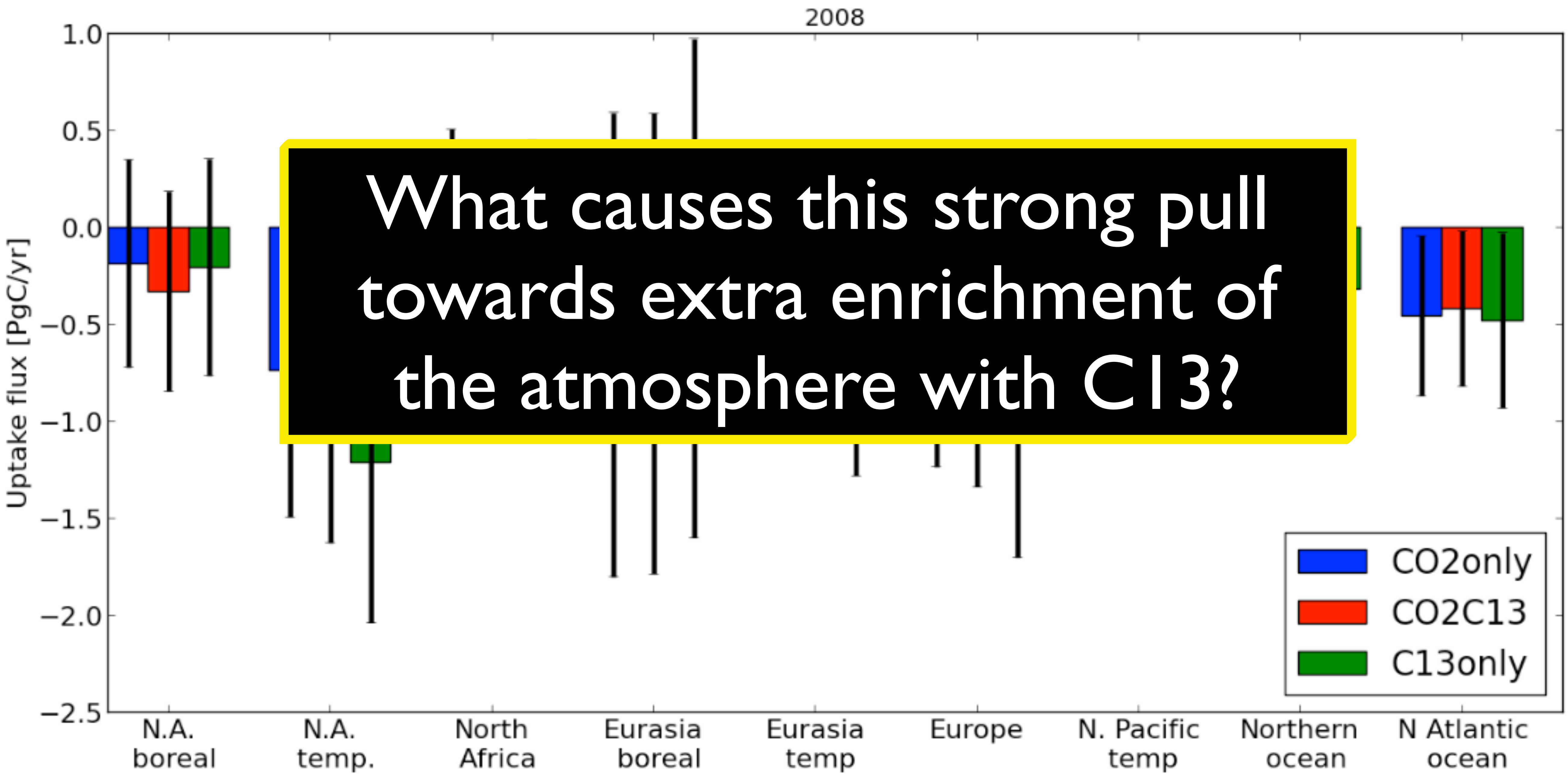
- First analysis indicates:
  - easy to match long-term mean growth rate by scaling disequilibrium fluxes (uncertain terms)
  - very hard to match observed inter-annual variability in $^{13}CO_2$
  - requires (too) large IAV in net terrestrial fluxes, or
  - (too) large IAV in net ocean fluxes, or
  - (too??) large adjustments in fractionation strength by biosphere
  - First flux results:



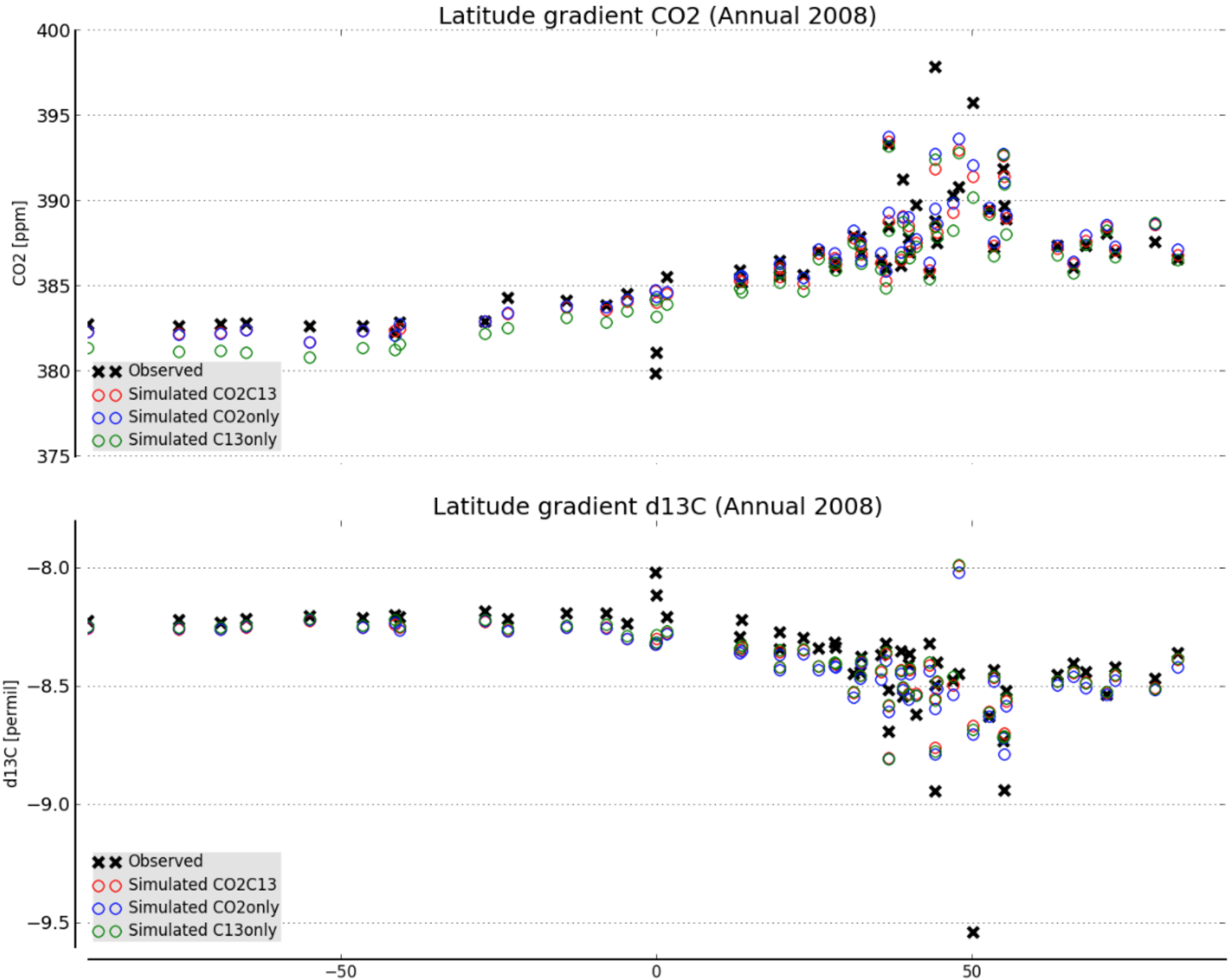
- C^{13} constraint pulls towards more land uptake, and more ocean uptake
- the balance with CO_2 only allows large land uptake with smaller ocean uptake

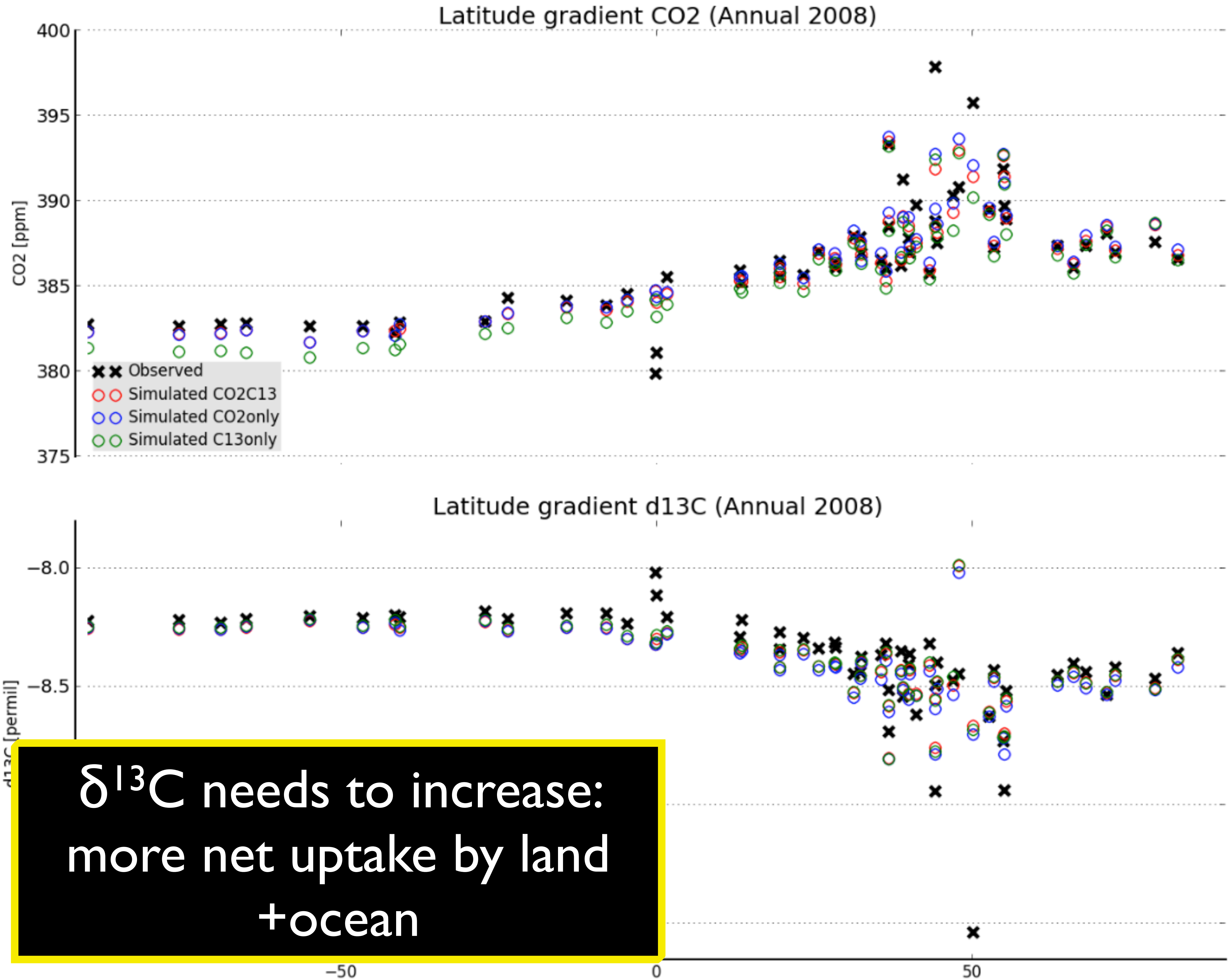


- C^{13} constraint pulls towards more uptake in North America and Europe, and less uptake in Boreal EurAsia
- the balance with CO_2 only allows large land uptake with smaller ocean uptake

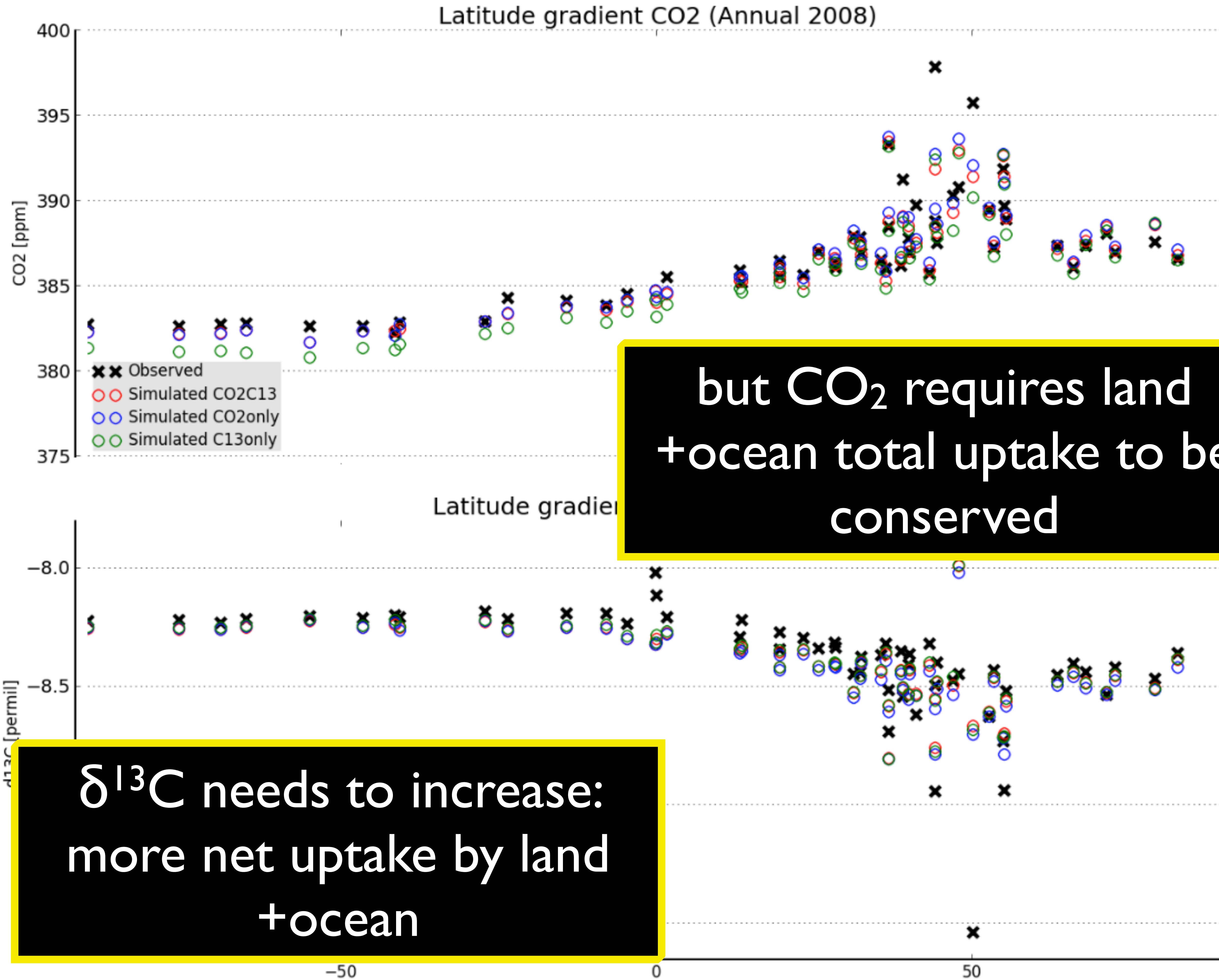


- C^{13} constraint pulls towards more uptake in North America and Europe, and less uptake in Boreal EurAsia
- the balance with CO_2 only allows large land uptake with smaller ocean uptake


Latitude gradient CO2 (Annual 2008)
CO2 [ppm]
400
395
390
385
380
375
Observed
Simulated CO2C13
Simulated CO2only
Simulated C13only
Latitude gradient d13C (Annual 2008)
d13C [permil]
−8.0
−8.5
−9.0
−9.5
Observed
Simulated CO2C13
Simulated CO2only
Simulated C13only
−50
0
50

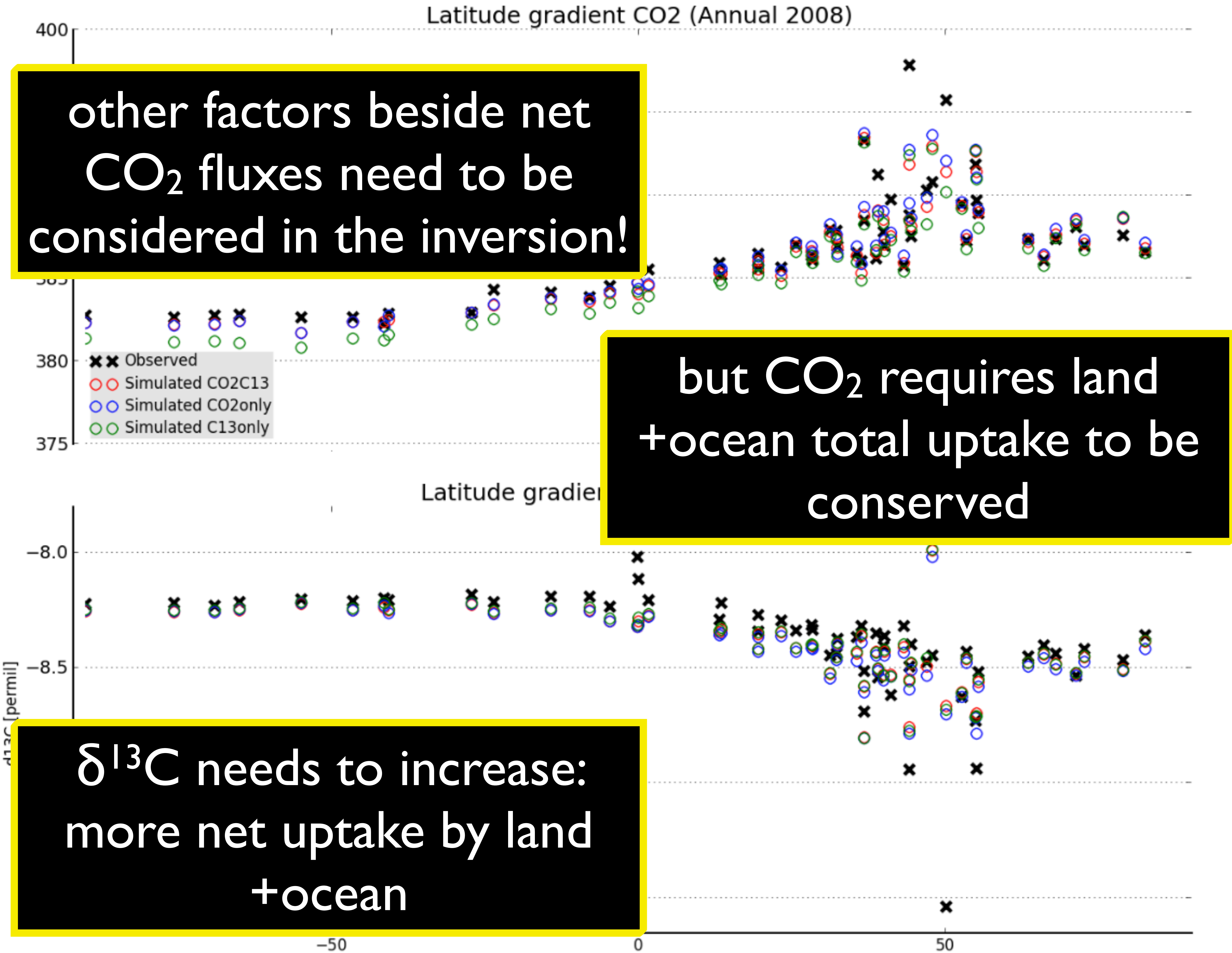


δ[13]C needs to increase: more net uptake by land +ocean

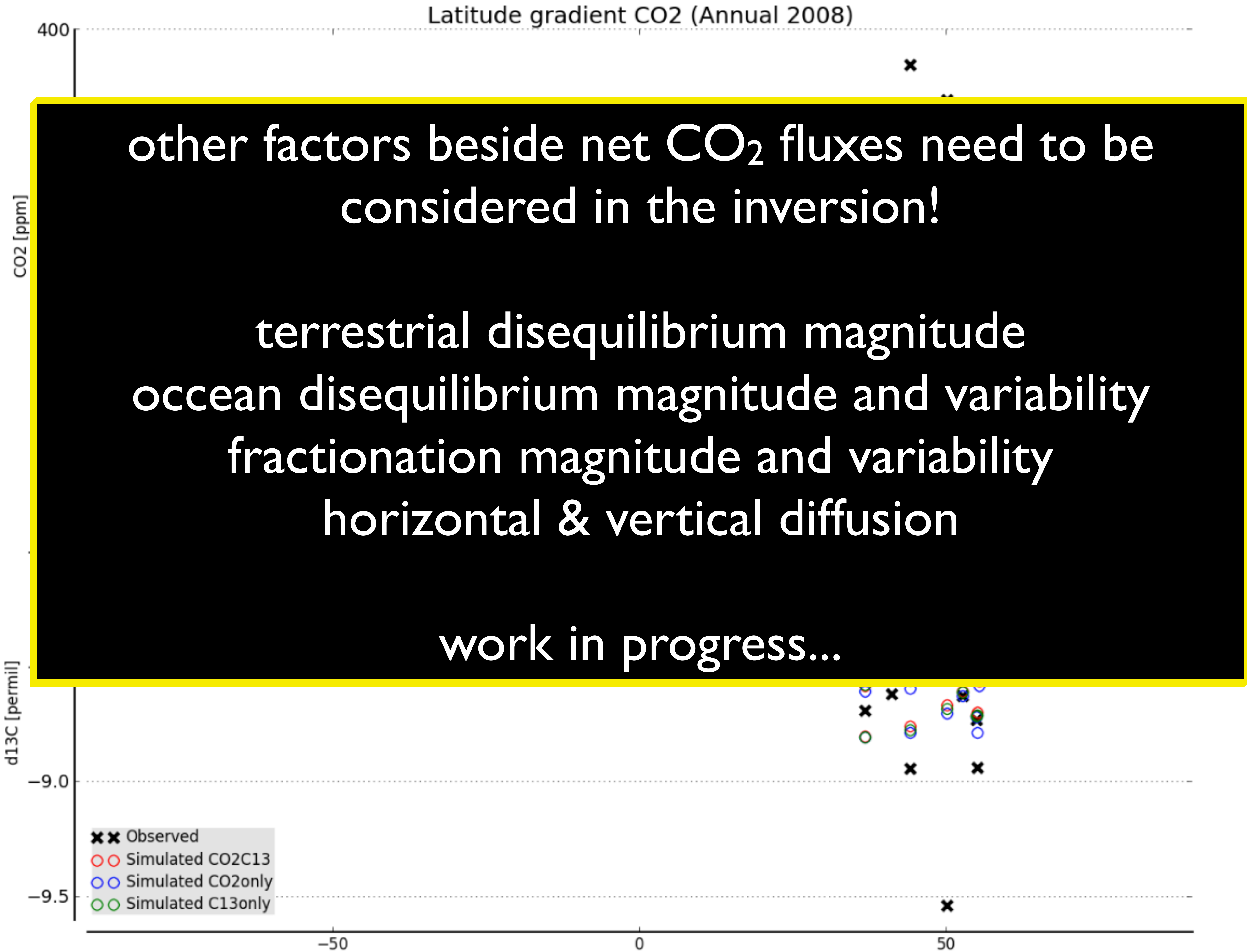


but CO_2 requires land +ocean total uptake to be conserved

$\delta^{13}C$ needs to increase: more net uptake by land +ocean



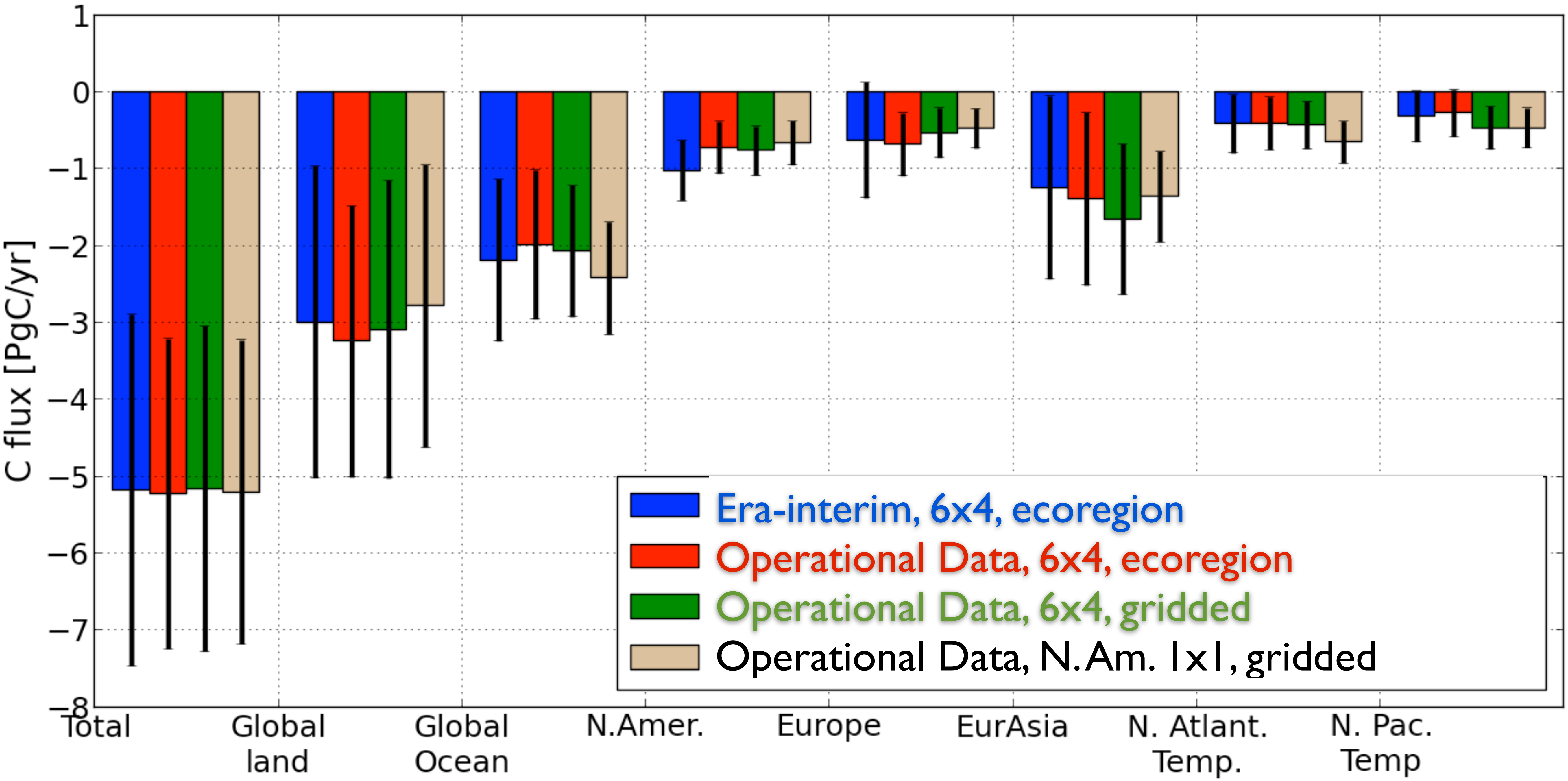
Latitude gradient CO2 (Annual 2008)
400
380
375
Observed
Simulated CO2C13
Simulated CO2only
Simulated C13only
other factors beside net CO_2 fluxes need to be considered in the inversion!
but CO_2 requires land +ocean total uptake to be conserved
Latitude gradie
−8.0
−8.5
[permil]
$\delta^{13}C$ needs to increase: more net uptake by land +ocean
−50
0
50



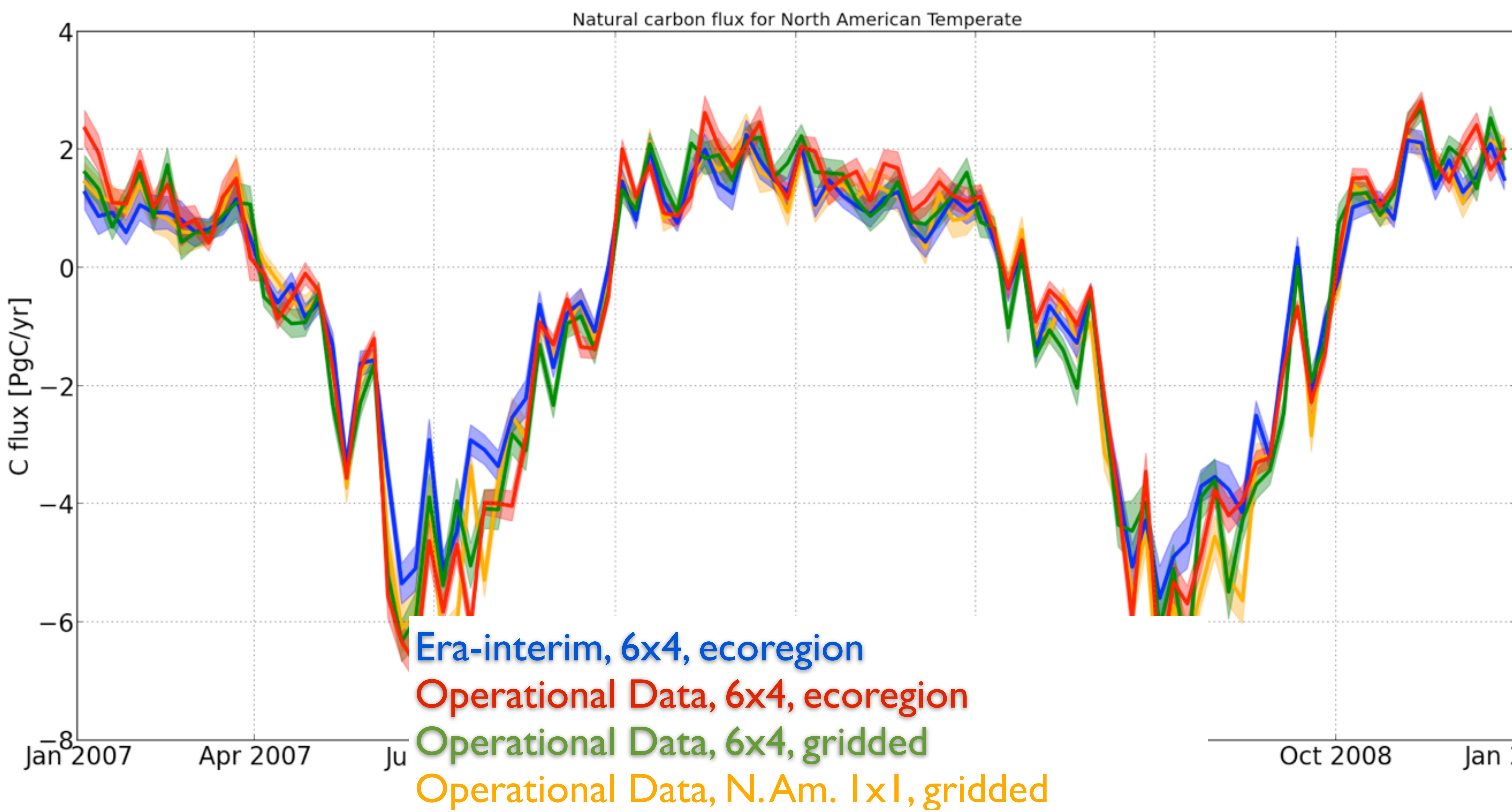
other factors beside net CO_2 fluxes need to be considered in the inversion!

terrestrial disequilibrium magnitude
occean disequilibrium magnitude and variability
fractionation magnitude and variability
horizontal & vertical diffusion

work in progress...



C flux [PgC/yr]
1
0
−1
−2
−3
−4
−5
−6
−7
−8
Total
Global land
Global Ocean
N.Amer.
Europe
EurAsia
N. Atlant. Temp.
N. Pac. Temp
Era-interim, 6x4, ecoregion
Operational Data, 6x4, ecoregion
Operational Data, 6x4, gridded
Operational Data, N.Am. 1x1, gridded


Natural carbon flux for North American Temperate
C flux [PgC/yr]
4
2
0
−2
−4
−6
−8
Jan 2007
Apr 2007
Ju
Oct 2008
Jan
Era-interim, 6x4, ecoregion
Operational Data, 6x4, ecoregion
Operational Data, 6x4, gridded
Operational Data, N.Am. 1x1, gridded

summary

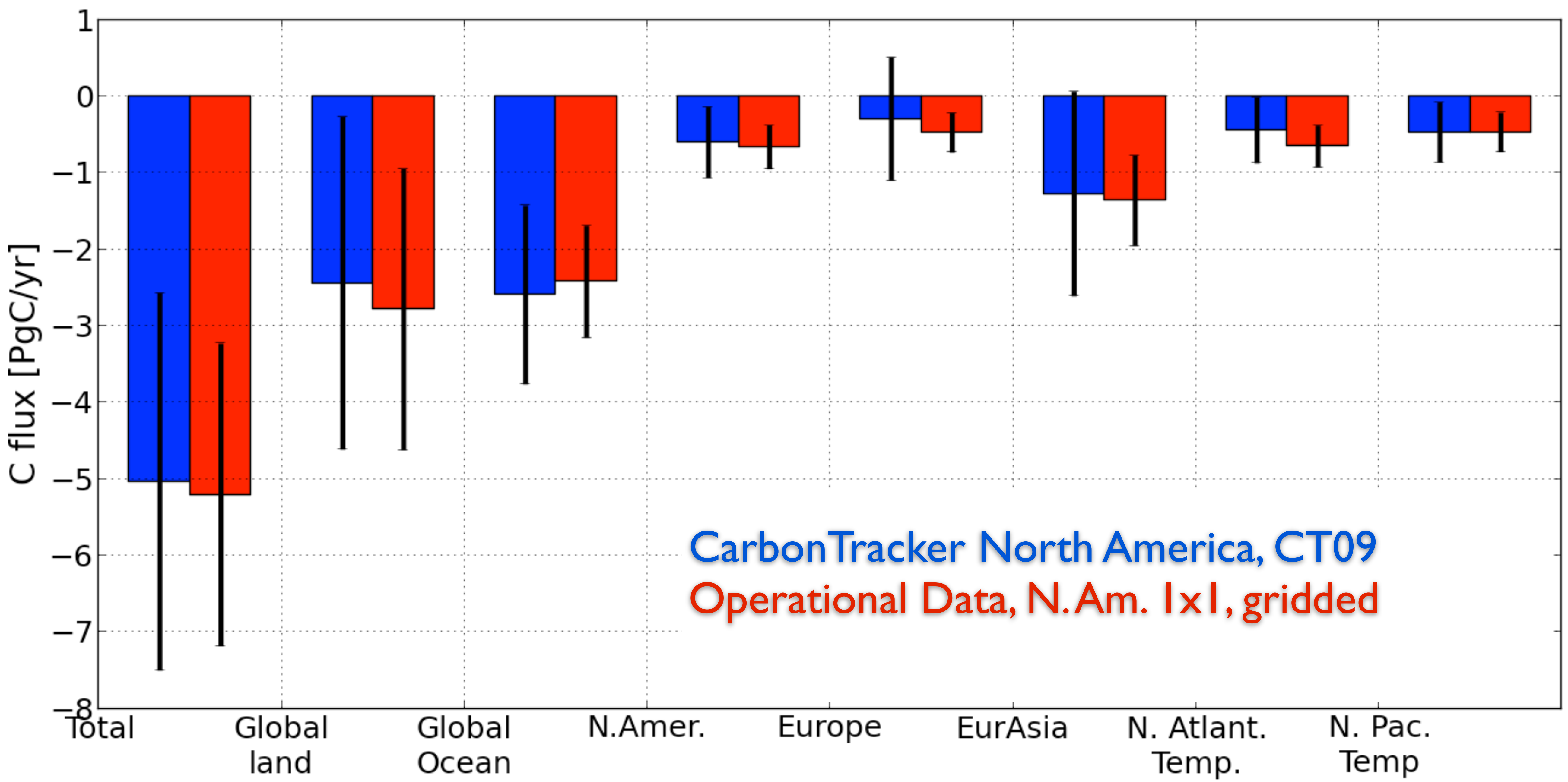
- First multi-species CTDAS system built by Ivar
- Use of ObsPack very convenient
- TM5 details still important: north-south gradients, PBL mixing, use of meteo are all factors in the results

ongoing

- Model development: CTDAS now has a separate Google Group for users
- Plan is to decouple CTDAS from TM5 completely (a dummy transport model will be delivered instead)
- Users still welcome to join TM5 group (!?)
- We'd love to move to TM6 and can offer some hours in assistance
- Following up on horizontal/vertical diffusion issues: Emma's work

to discuss

- The CTDAS group also wants to support an OD archive next to an EI one
- Closer collaboration adjoint/ensemble inversion systems: wanted, needed?
- ...



C flux [PgC/yr]
1
0
−1
−2
−3
−4
−5
−6
−7
−8
Total
Global land
Global Ocean
N.Amer.
Europe
EurAsia
N. Atlant. Temp.
N. Pac. Temp
CarbonTracker North America, CT09
Operational Data, N.Am. 1x1, gridded

HDF/NetCDF (thanks Ivar)

- Tests on huygens (NL HPC system)
- Base TM5 trunk version (10 test tracers)
- 1 month simulated, 5 processors
- Tests for
  - pregridding
  - HDF/NetCDF
  - ~~parallel IO vs serial IO~~
- TM5 used for regridding + conversions, works well!

glb600x400 from 100x100 meteo, no zoom

HDF/ NetCDF (thanks Ivar)

duur: 20070101-20070201
tracers: test tracers (lichte configuratie)
#procs: 5
========================
TM5-EI-HDF met alle meteo data in glb100x100:
cpu: 1027.09 s
cpu/step: 0.66093308 s/step

TM5-EI-NETCDF met alle meteo data in glb100x100:
Nog niet uitgevoerd. Ik mis nog voor ml60 de glb100x100 meteo data in netcdf
========================

WAGENINGEN UR
For quality of life

glb600x400 from pregrid meteo, no zoom

HDF/ NetCDF (thanks Ivar)

duur: 20070101-20070201
tracers: test tracers (lichte configuratie)
#procs: 5
========================
TM5-EI-HDF met pregridded ml60 data in glb600x400:
cpu: 400.43 s,
cpu/step: 0.25767696 s/step

TM5-EI-NETCDF met pregridded ml60 data in glb600x400:
cpu: 434.38 s,
cpu/step: 0.27952381 s/step
========================

glb600x400 from pregrid meteo, with zoom

HDF/ NetCDF (thanks Ivar)

duur: 20070101-20070201
tracers: test tracers (lichte configuratie)
#procs: 5
========================
TM5-EI-HDF met pregridded ml60 data in glb600x400, nam300x200, nam100x10

cpu: 1849.20 s,
cpu/step: 1.18996139 s/step

TM5-EI-NETCDF met pregridded ml60 data in glb600x400, nam300x200, nam100

cpu: 1982.94 s,
cpu/step: 1.27602317 s/step

========================

HDF/ NetCDF (thanks Ivar)

- Pregridded meteo in HDF makes TM5 a factor of ~2.5 faster
- TM5 with HDF4 is faster than with NetCDF4, on our machine (huygens)