ICDC 10
10th International Carbon Dioxide Conference 2017
Interlaken, Switzerland, 21 - 25 August 2017

Fifteen years after TransCom3: are global CO_2 inverse calculations robust?

Benjamin Gaubert[1], Britton B. Stephens[1], Andrew R. Jacobson[2], Sourish Basu[2], Frederic Chevallier[3], Christian Roedenbeck[4], Prabir Patra[5], Tazu Saeki[5], Ingrid van der Laan-Luijkx[6], Wouter Peters[6], David Schimel[7] and the HIPPO Measurements Team

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[2]University of Colorado Boulder and NOAA Earth System Research Laboratory Boulder, CO, USA.
[3]Laboratoire des Sciences du Climat et de l'Environnement, Institut Pierre-Simon Laplace, CEA-CNRS-UVSQ, Gif sur Yvette, France.
[4]Max Planck Institute for Biogeochemistry, Jena, Germany.
[5]Department of Environmental Geochemical Cycle Research, JAMSTEC, Yokohama, Japan.
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Towards robust regional estimates of CO_2 sources and sinks using atmospheric transport models

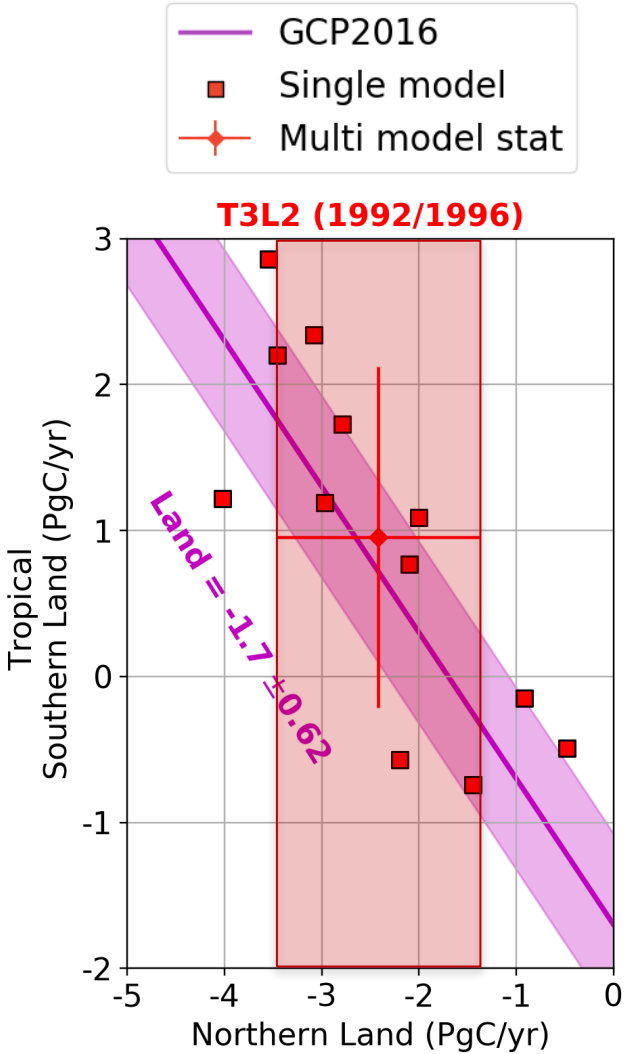
Kevin Robert Gurney*, Rachel M. Law†, A. Scott Denning*, Peter J. Rayner†, David Baker‡, Philippe Bousquet§, Lori Bruhwiler‖, Yu-Han Chen¶, Philippe Ciais§, Songmiao Fan#, Inez Y. Fung☆, Manuel Gloor**, Martin Heimann**, Kaz Higuchi††, Jasmin John☆, Takashi Maki‡‡, Shamil Maksyutov§§, Ken Masarie‖, Philippe Peylin§, Michael Prather‖‖, Bernard C. Pak‖‖, James Randerson¶¶, Jorge Sarmiento#, Shoichi Taguchi##, Taro Takahashi☆☆ & Chiu-Wai Yuen**

NATURE | VOL 415 | 7 FEBRUARY 2002 | www.nature.com

The ensemble approach: the multi-model mean and standard deviation suggest a strong northern land carbon uptake

- Northern Extra-tropical land flux: -2.42 +/- 1.09 PgC/yr

Gurney et al. 2002, 2004



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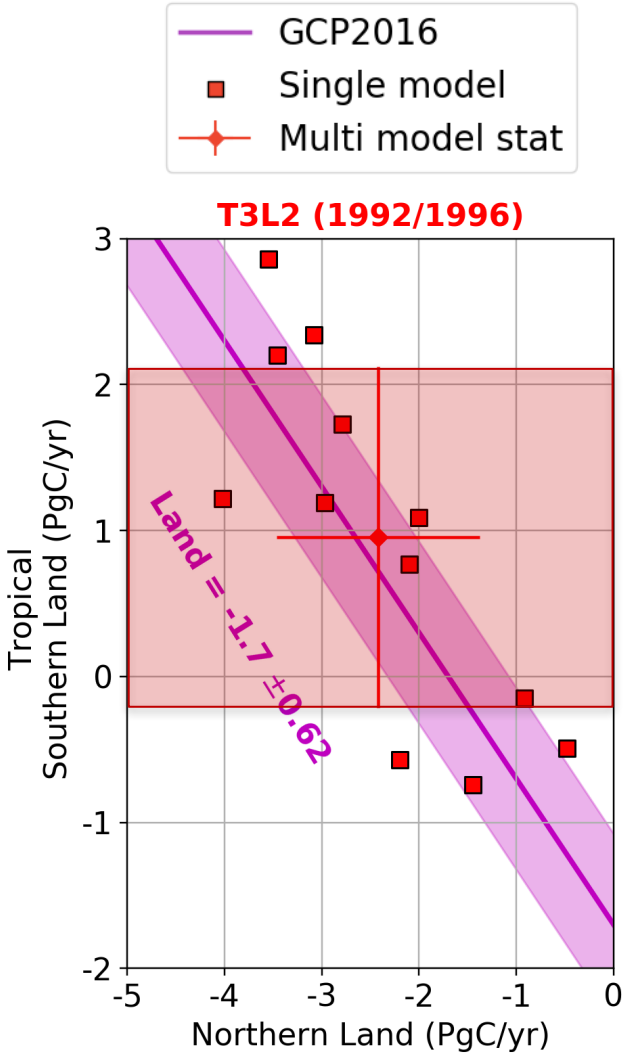


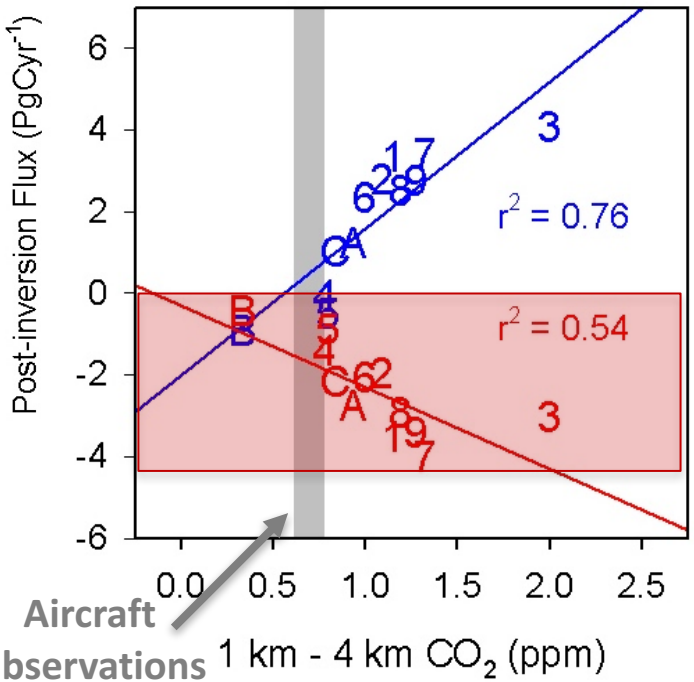
The ensemble approach: the multi-model mean and standard deviation suggest a strong northern and a weak tropical land carbon uptake

- Northern Extra-tropical land flux: -2.42 +/- 1.09 PgC/yr
- Tropical and southern land flux: 0.95 +/- 1.22 PgC/yr

Gurney et al. 2002, 2004

Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO_2

Britton B. Stephens,[1]* Kevin R. Gurney,[2] Pieter P. Tans,[3] Colm Sweeney,[3] Wouter Peters,[3] Lori Bruhwiler,[3] Philippe Ciais,[4] Michel Ramonet,[4] Philippe Bousquet,[4] Takakiyo Nakazawa,[5] Shuji Aoki,[5] Toshinobu Machida,[6] Gen Inoue,[7] Nikolay Vinnichenko,[8]† Jon Lloyd,[9] Armin Jordan,[10] Martin Heimann,[10] Olga Shibistova,[11] Ray L. Langenfelds,[12] L. Paul Steele,[12] Roger J. Francey,[12] A. Scott Denning[13]



22 JUNE 2007 VOL 316 SCIENCE www.sciencemag.org

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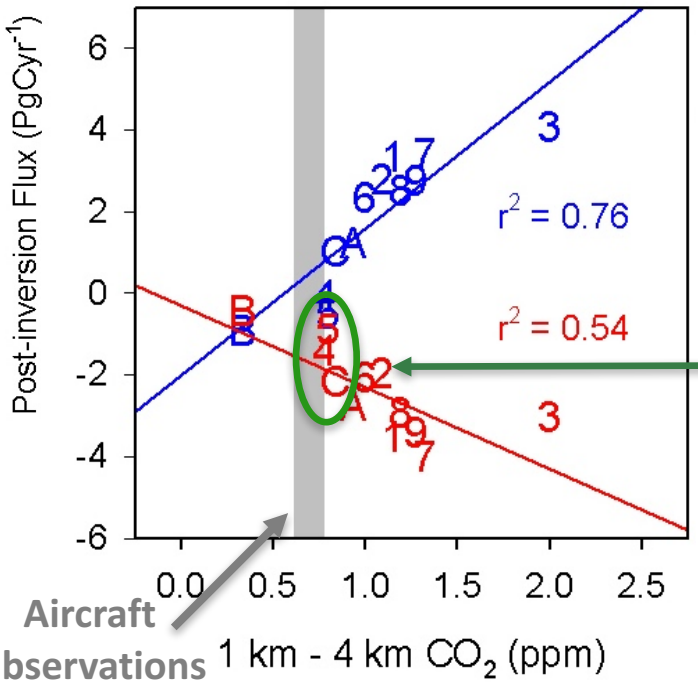
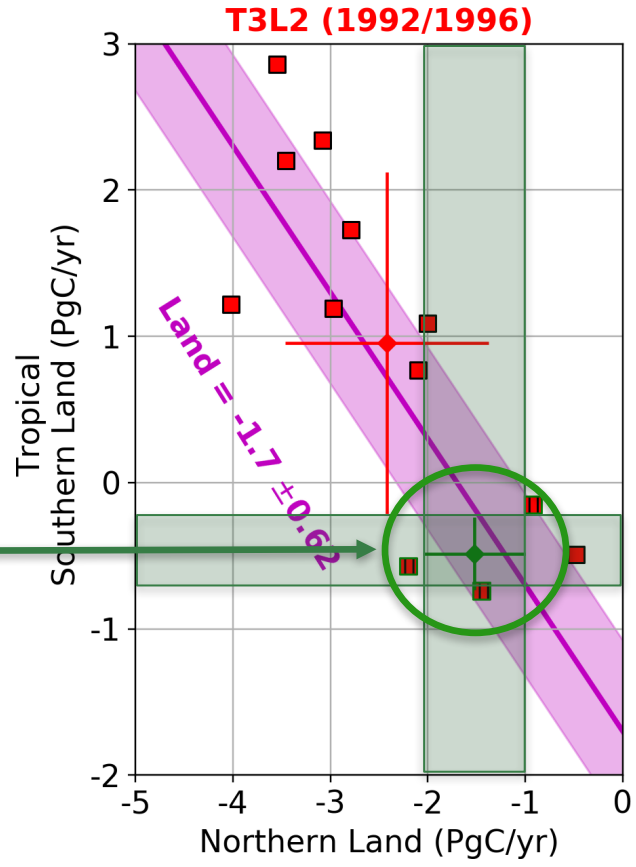
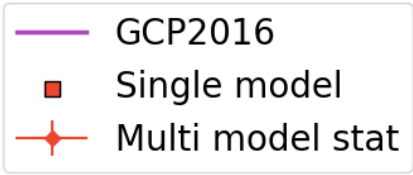






- Northern Extra-tropical land flux: -1.52 +/- 0.64 PgC/yr
- Tropical and southern land flux: -0.49 +/- 0.3 PgC/yr

22 JUNE 2007 VOL 316 SCIENCE www.sciencemag.org

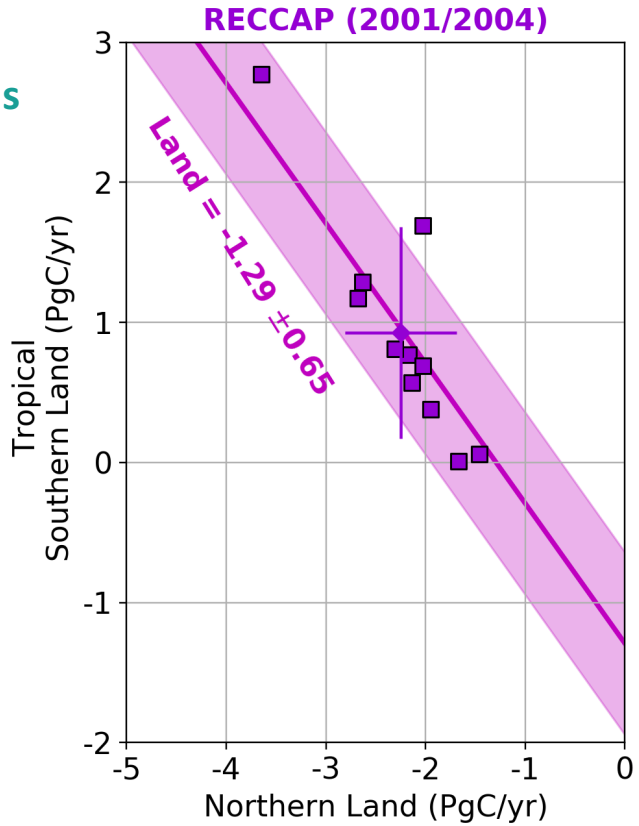
Global atmospheric carbon budget: results from an ensemble of atmospheric CO_2 inversions

Biogeosciences Open Access

P. Peylin[1], R. M. Law[2], K. R. Gurney[3], F. Chevallier[1], A. R. Jacobson[4], T. Maki[5], Y. Niwa[5], P. K. Patra[6], W. Peters[7], P. J. Rayner[1,8], C. Rödenbeck[9], I. T. van der Laan-Luijkx[7], and X. Zhang[3]

"Four-year mean fluxes are reasonably consistent across inversions at global/latitudinal scale"

- Northern Extra-tropical land flux: -2.25 +/- 0.58 PgC/yr
- Tropical and southern land flux: 0.93 +/- 0.9 PgC/yr



Biogeosciences, 10, 6699–6720, 2013
www.biogeosciences.net/10/6699/2013/
doi:10.5194/bg-10-6699-2013

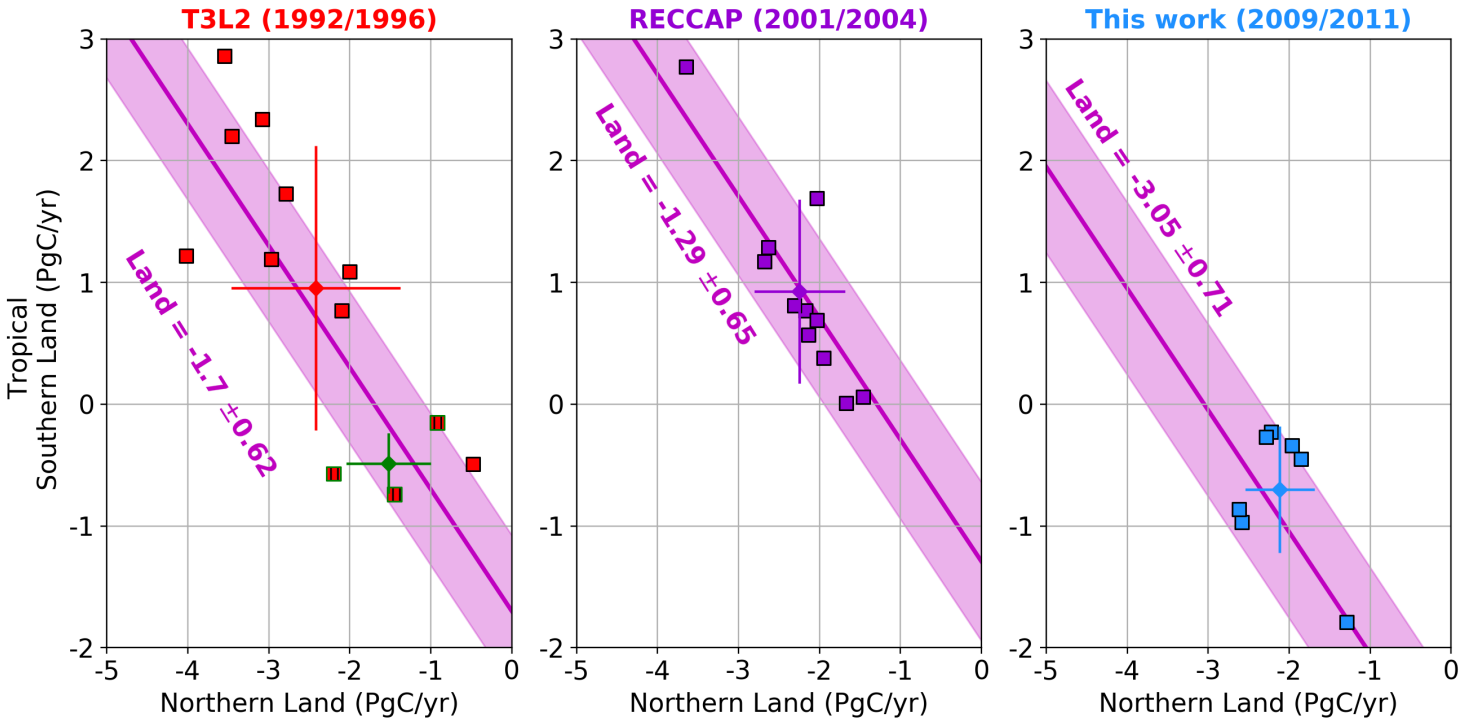
Are inverse models still highly dependent on transport errors and a priori assumptions ?

1. Intercomparison of modelled a posteriori fluxes
   - Large-scale constraints presented by Global Carbon Project included for comparison

2. CO_2 modelled after flux optimisation is compared to HIPPO observations

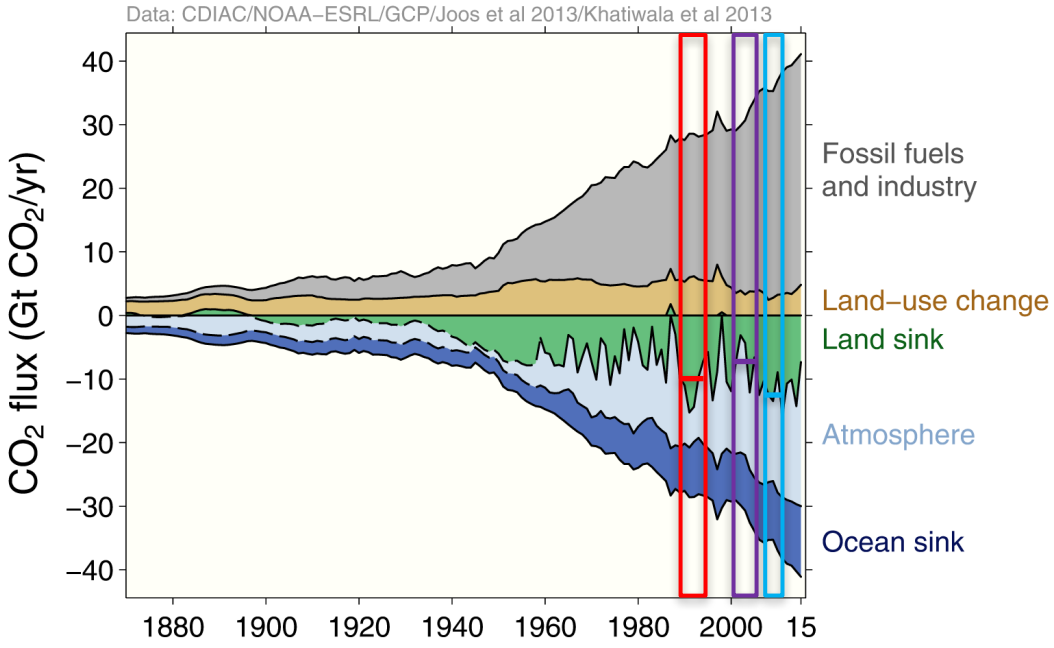
Modelling system	References	Grid Spacing	Transport Model	Meteorological fields
MACC-II (v14r2) CAMS (Copernicus)	Chevallier et al. (JGR 2010; GMD 2013)	3.75° x 1.875°	LMDZ	ECMWF wind
Jena (S04_v4.1)	Rödenbeck (2005)	4° x 5°	TM3	ERA interim
CTE2016	van der Laan-Luijkx et al. (2017)	1° x 1°	TM5	ERA interim
CT2016	Peters et al. (2007) with updates documented at http://carbontracker.noaa.gov	1° x 1°	TM5	ERA interim
ACTM (IEA & CDIAC FF)	Saeki and Patra (2017)	T106 (1.125° x 1.125°)	ACTM	NCEP2
TM5-4DVar	Basu et al. (2013)	3° x 2°	TM5	ERA interim

All units are PgC/yr	Northern extra-tropical flux	Trop + Southern Land flux
T3L2 (Gurney et al. 2004)	-2.42 +/- 1.09	0.95 +/- 1.22
T3L2 subset (Stephens et al. 2007)	-1.52 +/- 0.64	-0.49 +/- 0.3
RECCAP (Peylin et al. 2013)	-2.25 +/- 0.58	0.93 +/- 0.9
This work	-2.12 +/- 0.43	-0.7 +/- 0.52



Global carbon budget

The carbon sources from fossil fuels, industry, and land use change emissions are balanced by the atmosphere and carbon sinks on land and in the ocean



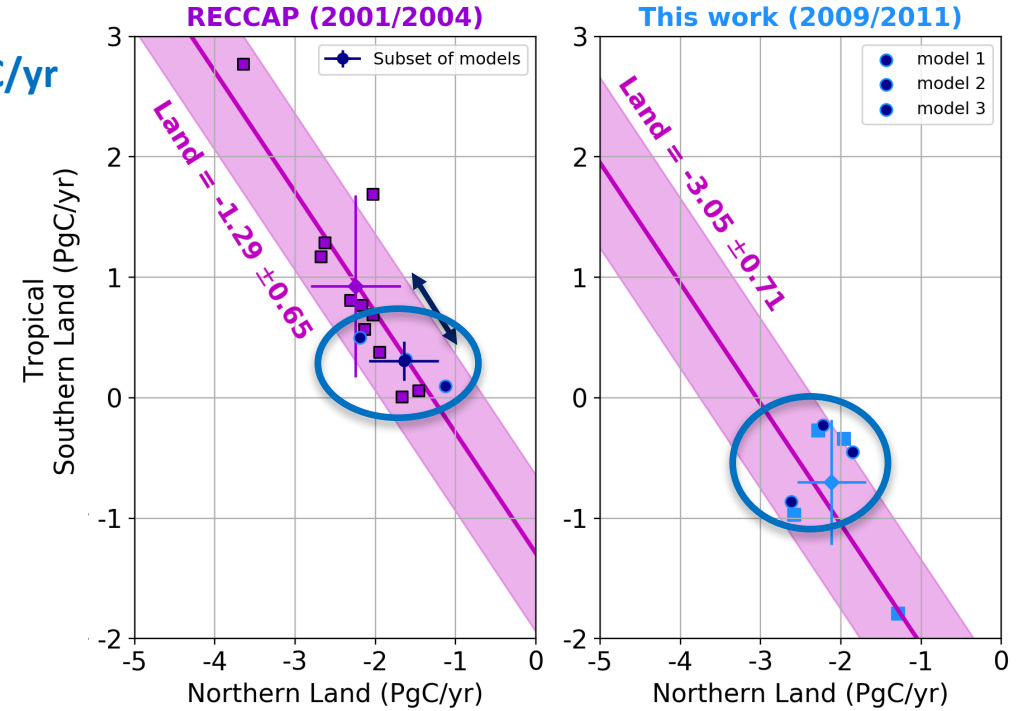
Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Joos et al 2013; Khatiwala et al 2013; Le Quéré et al 2016; Global Carbon Budget 2016

All units are PgC/yr	Northern extra-tropical flux	Trop + Southern Land flux
RECCAP (Peylin et al. 2013)	-2.25 +/- 0.58	0.93 +/- 0.9
This work (RECCAP period)	-1.65 +/- 0.44	0.31 +/- 0.16
This work	-2.12 +/- 0.43	-0.7 +/- 0.52

RECCAP period (2001-2004) with updated 3 models (MACC v14r2, CT2016 and CTE2016)

- Northern extra-tropical flux: -1.65 +/- 0.44 PgC/yr
- Trop + Southern Land flux 0.31 +/- 0.16 PgC/yr

Significant effect of interannual variability and trend of the land flux between the two periods



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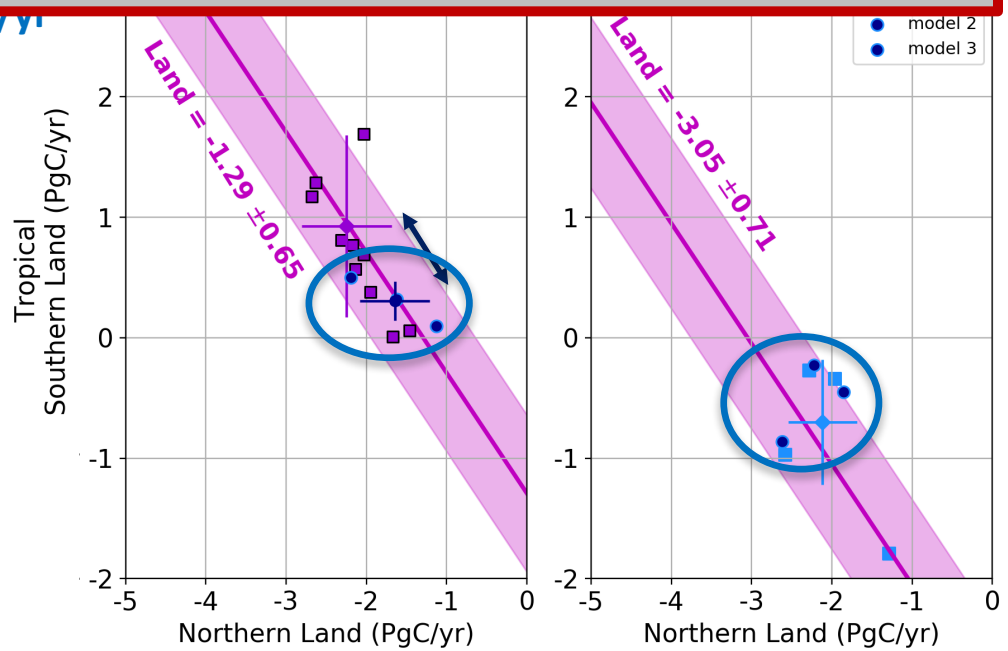
This work	-2.12 +/- 0.43	-0.7 +/- 0.52

➢ **Is the remaining spread still due to transport error ?**

➢ Northern extra-tropical flux: -1.65 +/- 0.44 PgC/yr

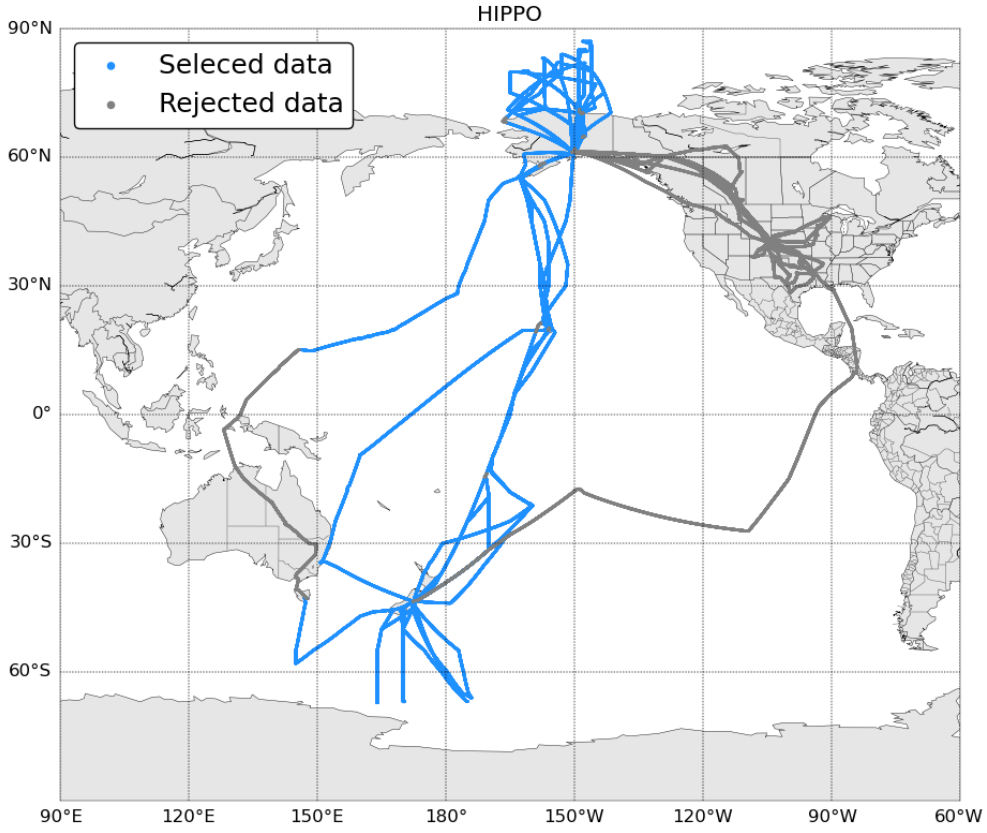
➢ Trop + Southern Land flux 0.31 +/- 0.16 PgC/yr

Significant effect of interannual variability and trend of the land flux between the two periods



Evaluation of posterior CO_2 concentration vs. HIPPO data

- **Provide large scale CO_2 measurements with a good coverage coverage in latitude, time, and vertical gradients**



- Filter out:
  - continental boundary layer,
  - airports local pollution,
  - stratospheric air

HIPPO
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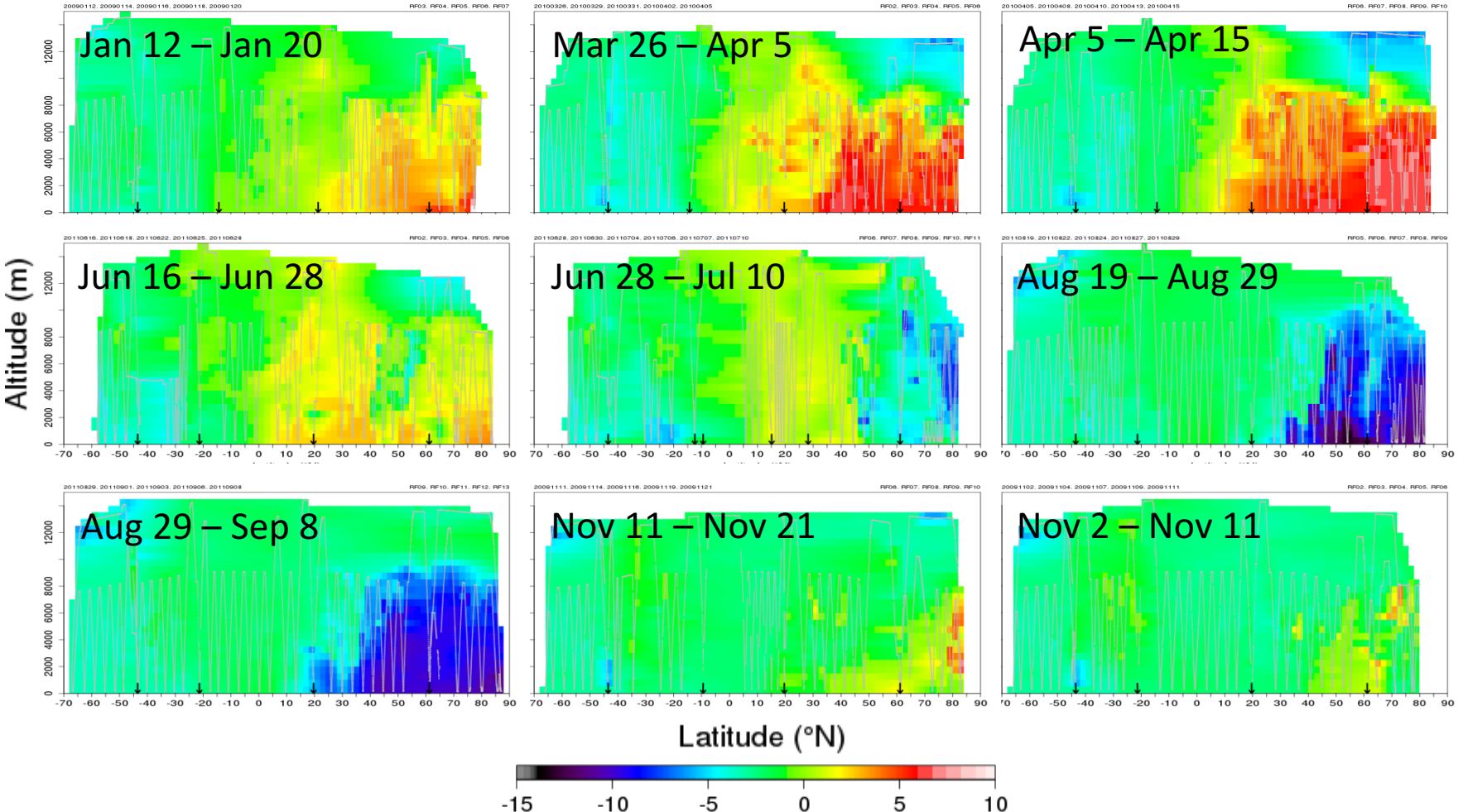
Observations

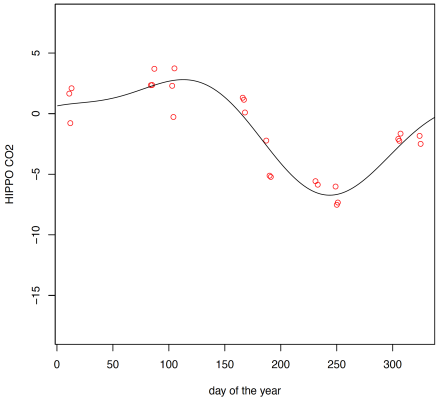
Wofsy SC. 2012. HIPPO Merged 10-second Meteorology, Atmospheric Chemistry, Aerosol Data (R_20121129). Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/hippo_010 (Release 20121129)

1. Detrend the CO2.X mask (recommended) time series using Mauna-Loa trend component

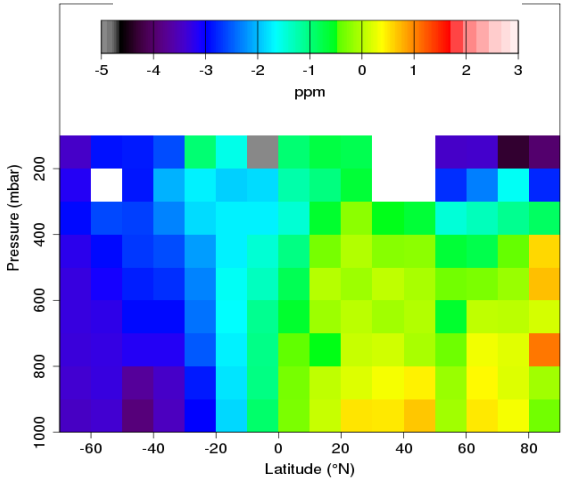
Detrended HIPPO CO_2 Observations



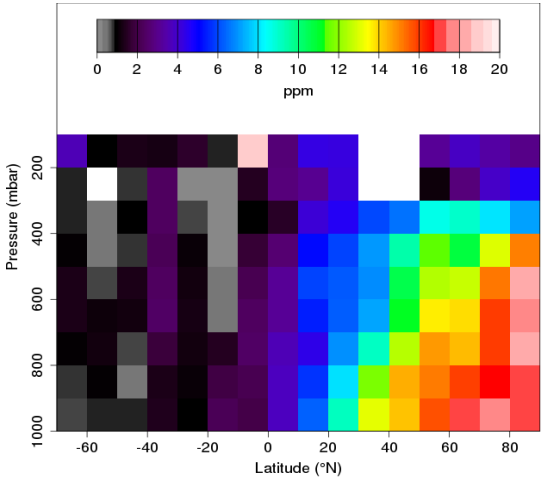
1. Detrend the CO2.X mask (recommended) time series using Mauna-Loa trend component
2. Fit of the time series for each box (**5 degrees latitude** and **100 hPa**), using 2 harmonics



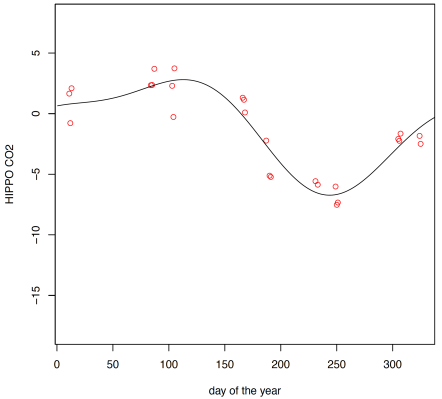
HIPPO CO_2 Annual Mean



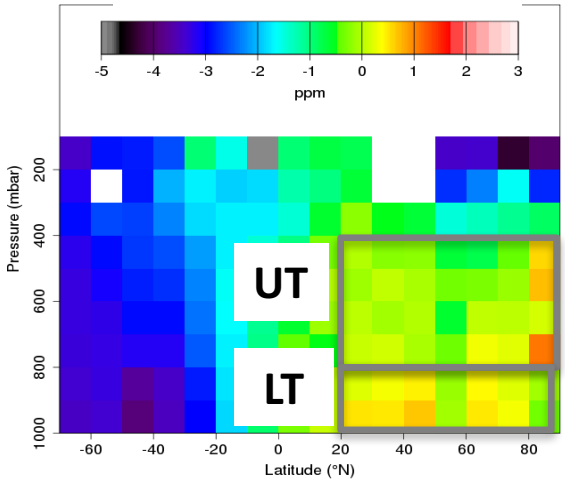
HIPPO CO_2 Seasonal amplitude



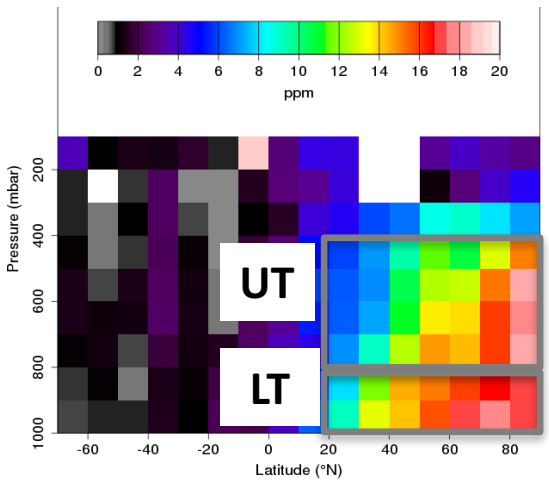
1. Detrend the CO2.X mask (recommended) time series using Mauna-Loa trend component
2. Fit of the time series for each box (5 degrees latitude and 100 hPa), using 2 harmonics
3. Focus on vertical gradients
   - Northern Extratropical Lower Troposphere (LT, surface to 800hPa) and Upper Troposphere (UT, 800hPa to 400hPa)
4. Weighting average using cos(latitude)
5. Repeat this for every model output using CO2.X mask



HIPPO CO_2 Annual Mean

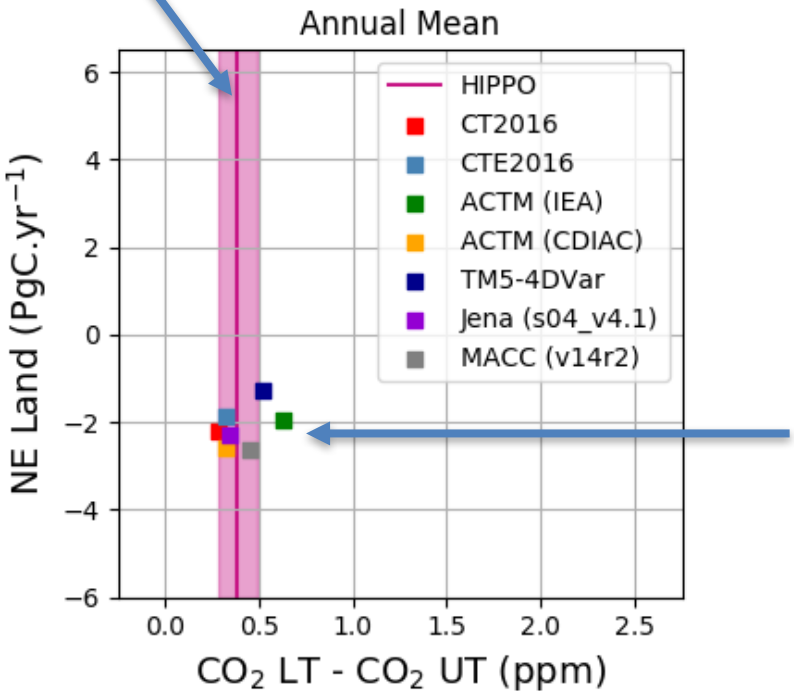


HIPPO CO_2 Seasonal amplitude



CO_2 modelled after flux optimisation is compared to HIPPO observations
NE Land flux versus NE vertical gradients

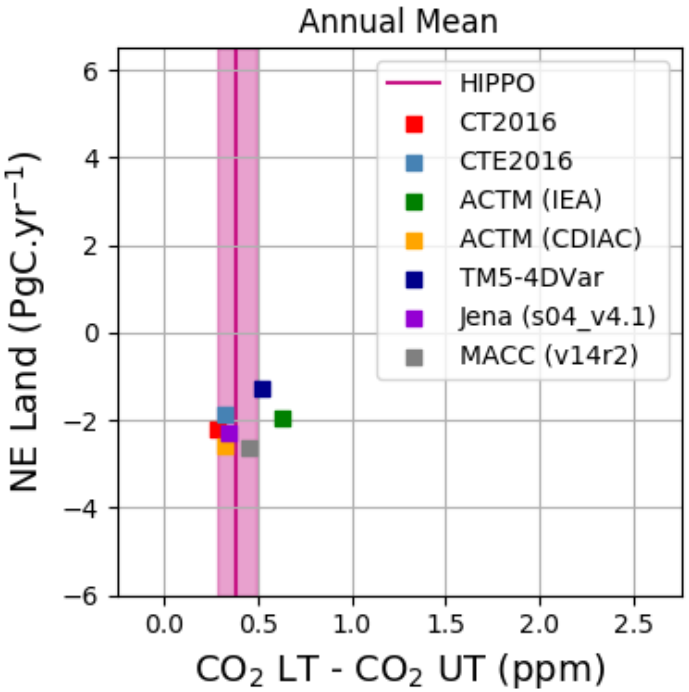
Observations of NE CO_2 vertical gradients

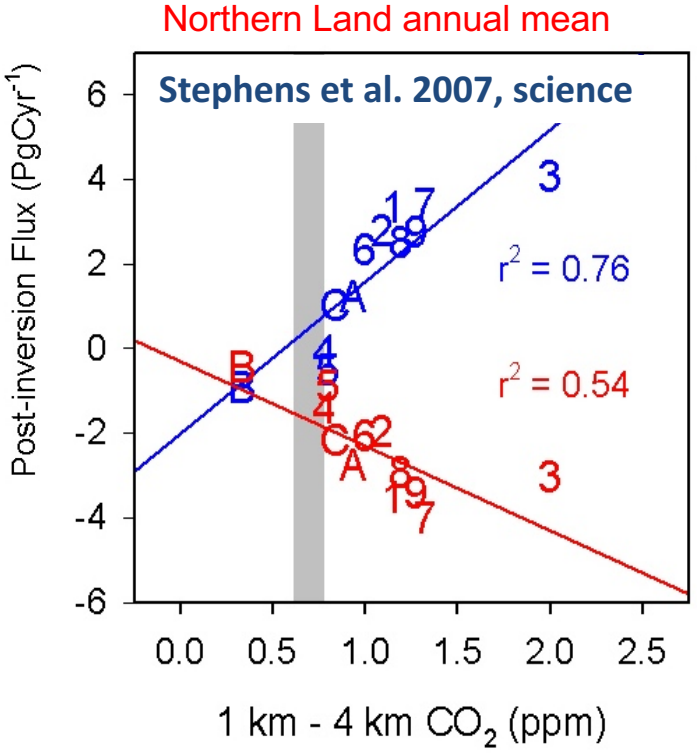


Northern Extra-tropical land flux (PgC/yr)

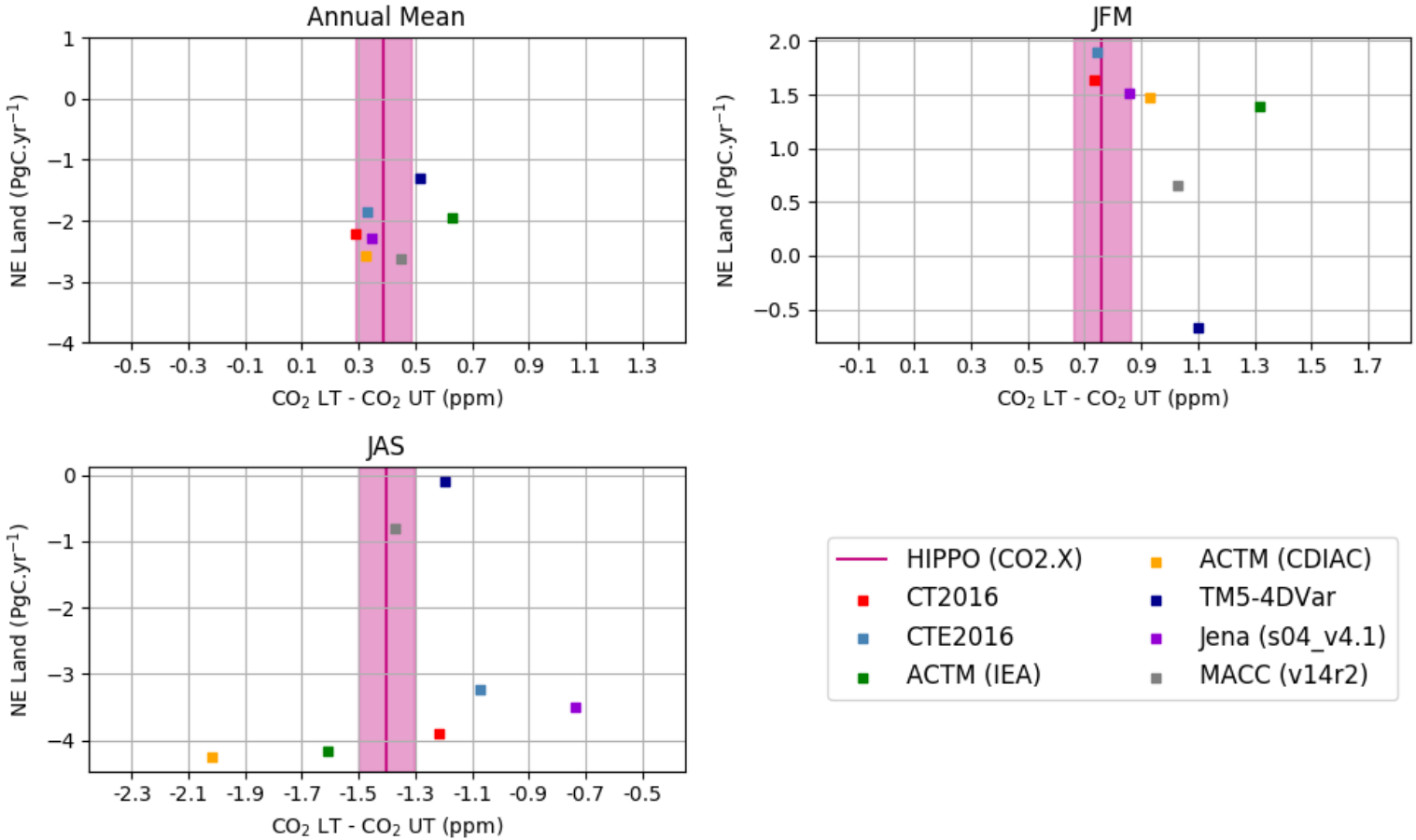
-2.12 +/- 0.43

CO_2 modelled after flux optimisation is compared to HIPPO observations
NE Land flux versus NE vertical gradients





CO_2 modelled after flux optimisation is compared to HIPPO observations
NE Land flux versus NE vertical gradients



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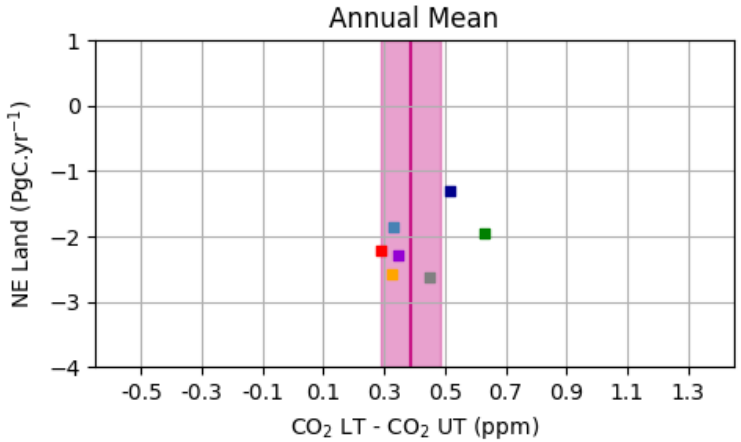
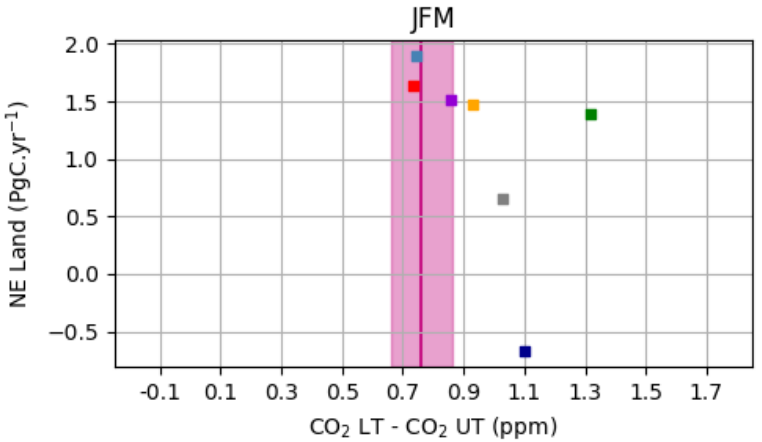
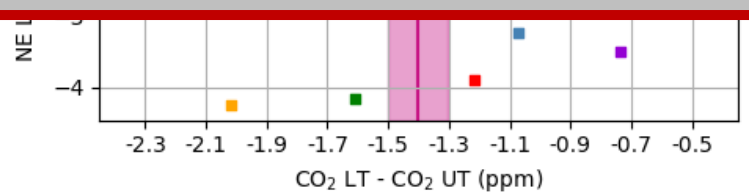
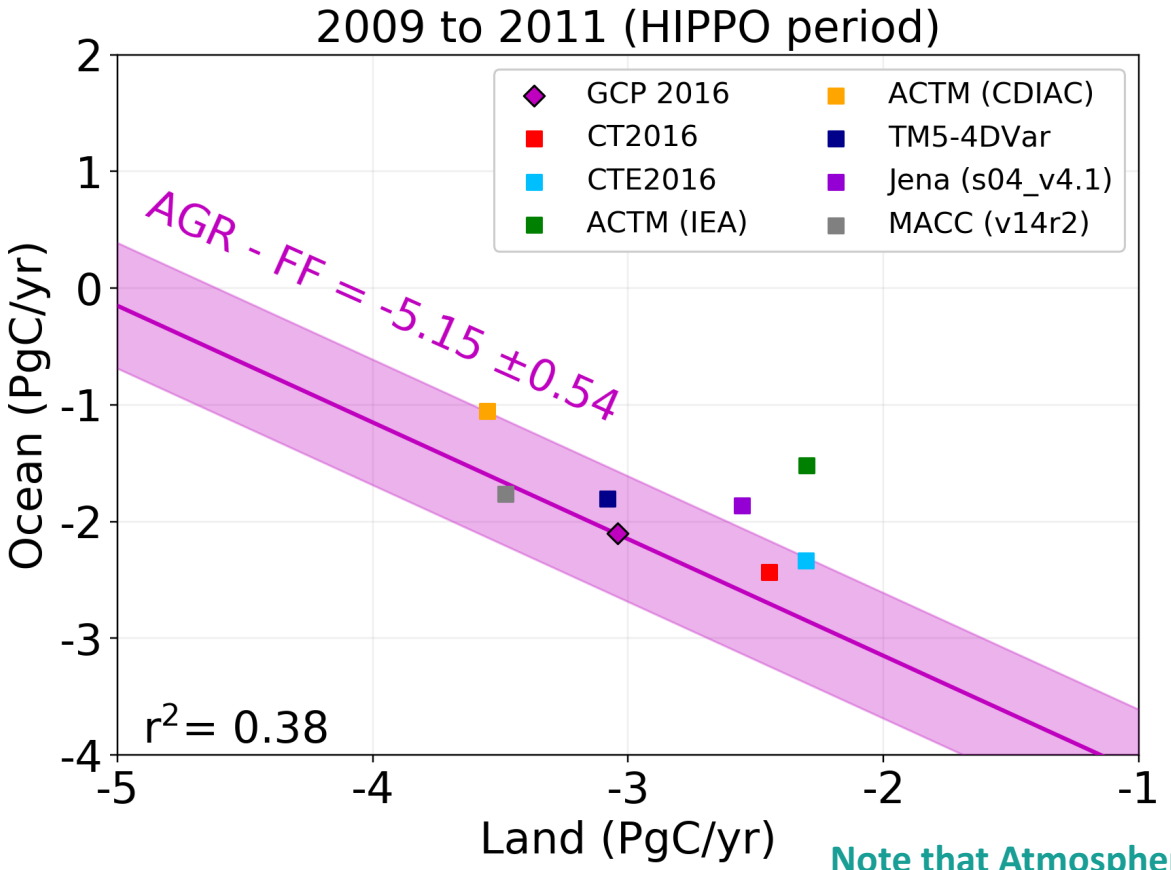




- **Large improvements in representing annual mean CO_2 vertical gradients**
- **Retrieved fluxes do not show vertical error dependence**
  - **what is driving remaining spread in annual mean model estimates?**

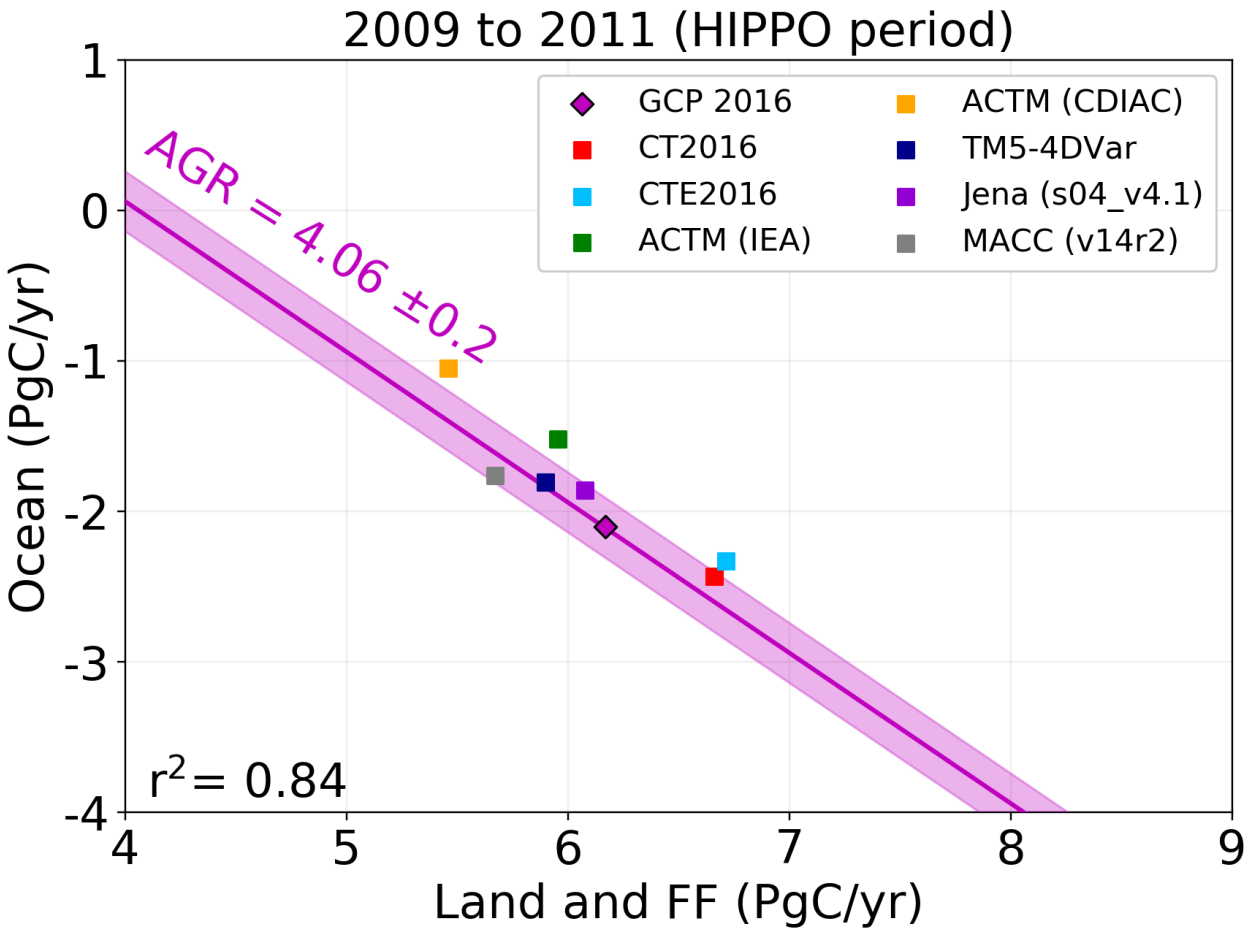


Posterior fluxes and Global Carbon Project



Note that Atmospheric Growth Rate (AGR) is calculated as: AGR = FF - Land - Ocean

Posterior fluxes and Global Carbon Project



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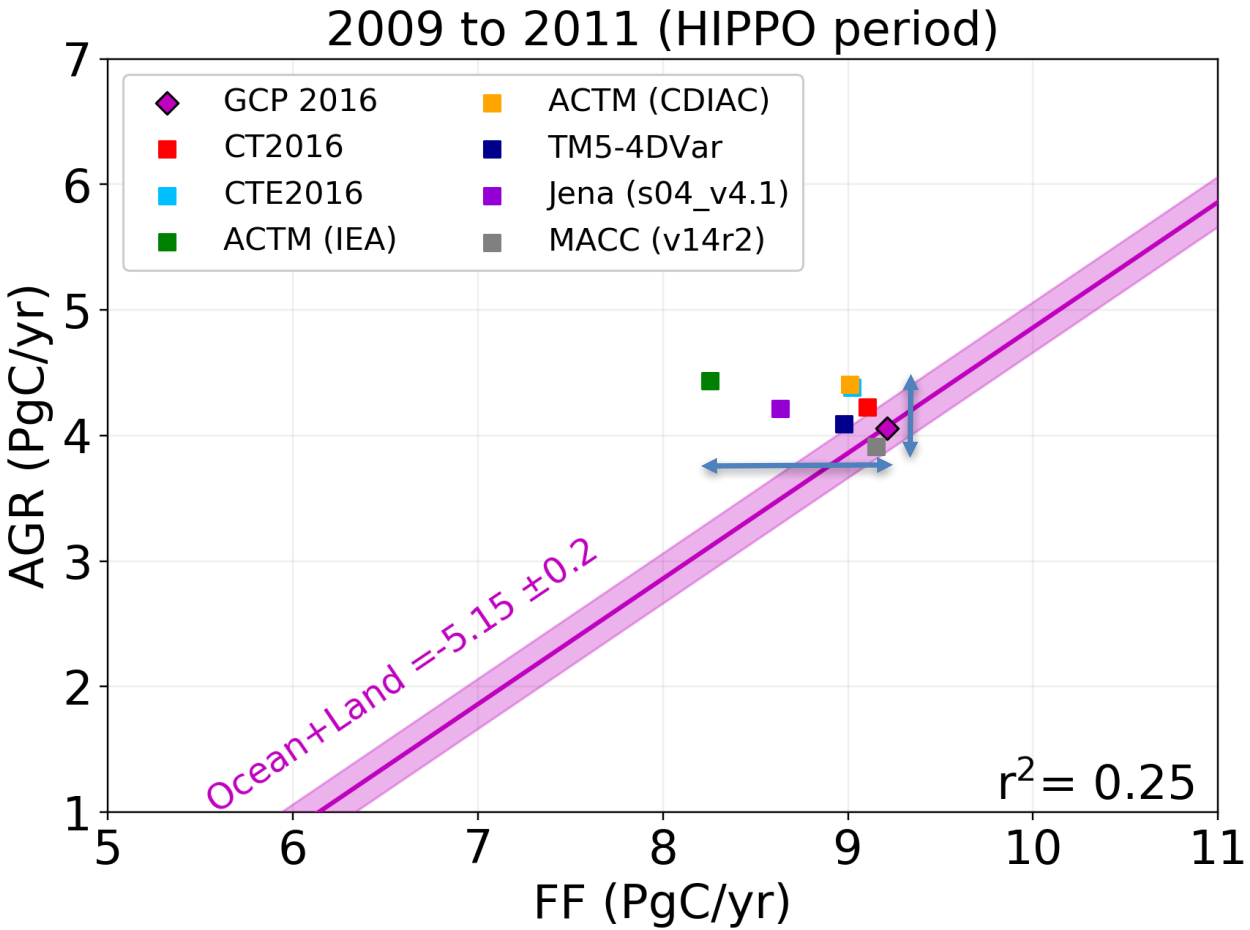

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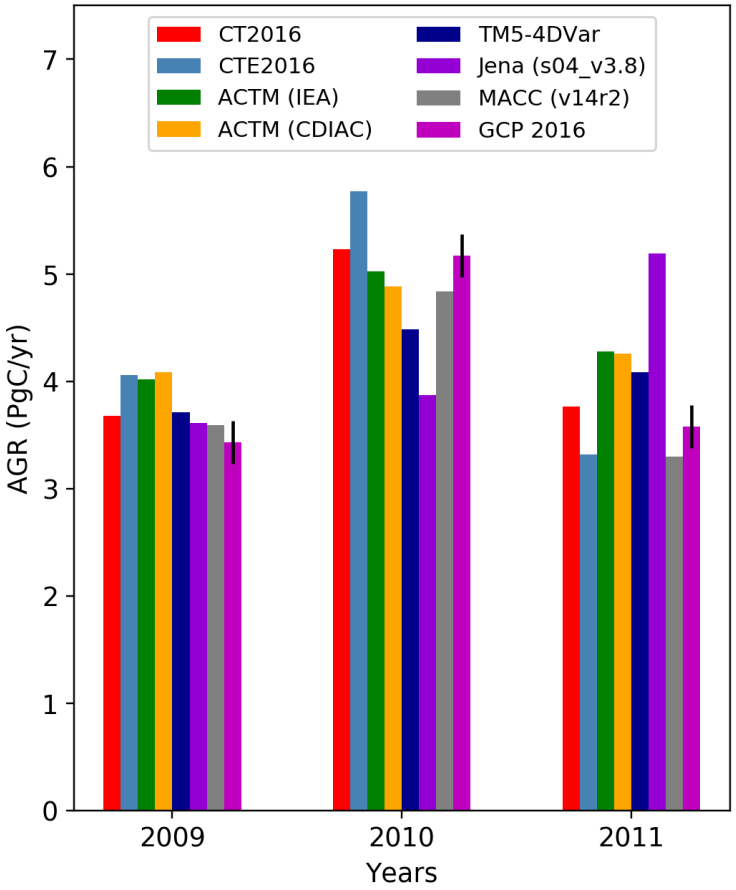
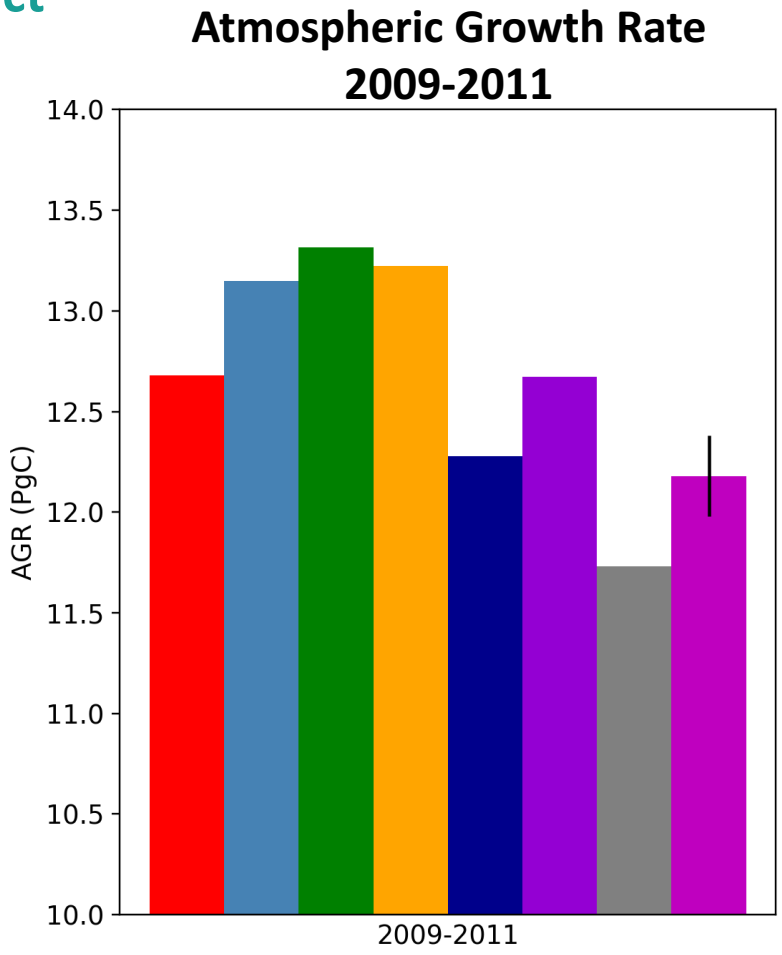
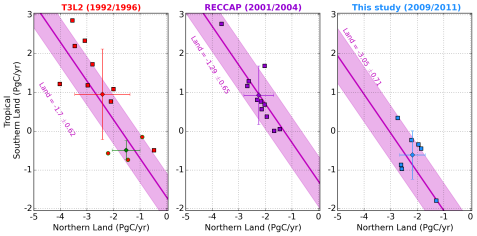


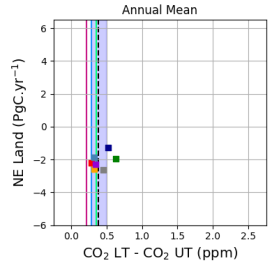


Take home messages

- **Analysis of carbon fluxes estimated by a set of inverse models show convergence on latitudinal distribution NE land flux of -2.12 +/- 0.43 and a tropical + southern land of -0.7 +/- 0.52. Both NE and Trop/SE model spread have been reduce by 60 % since the Transcom experiment**

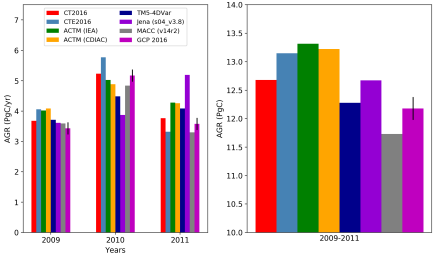


- **The transport errors are not clearly responsible for those fluxes differences**

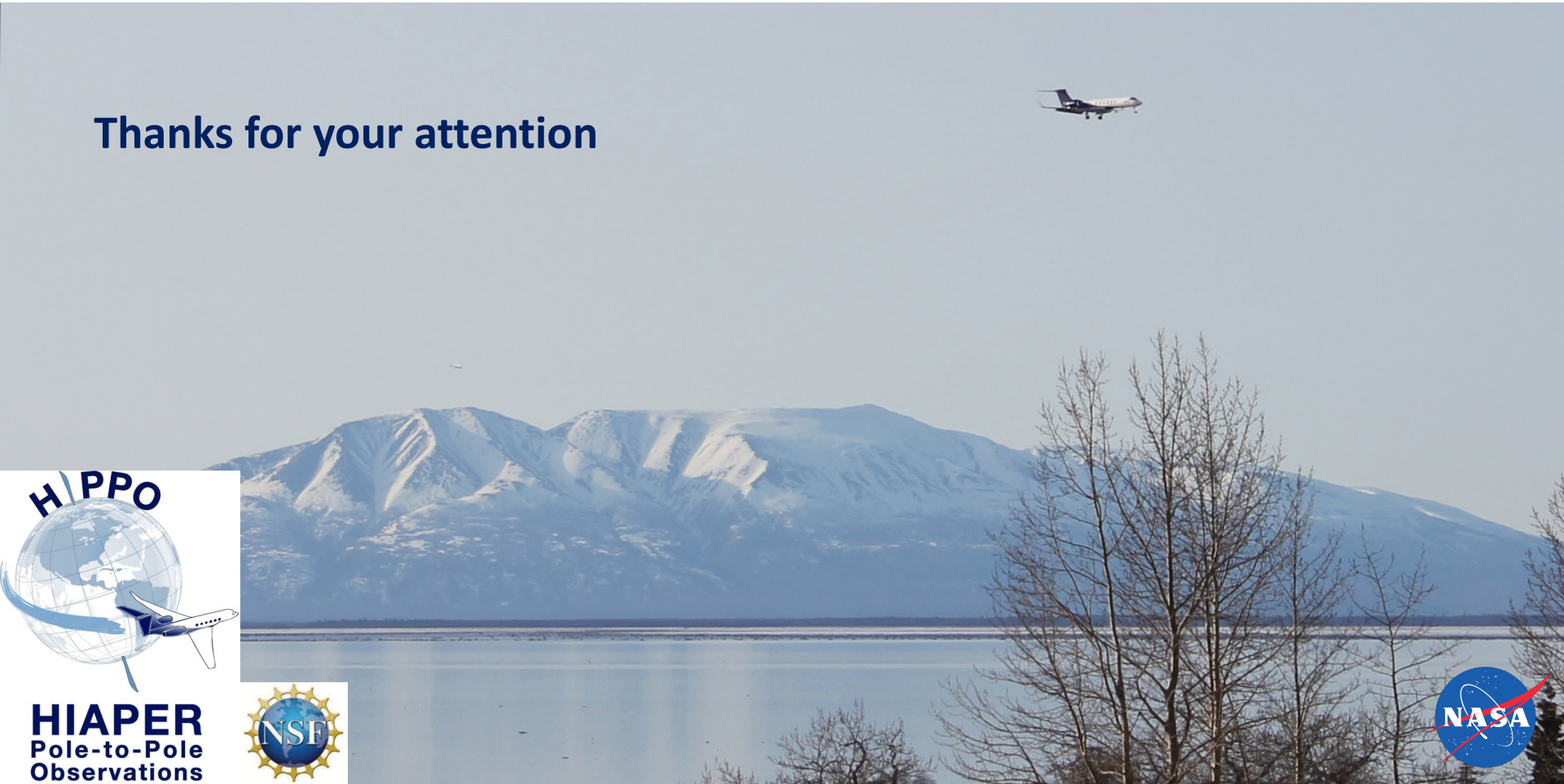


- **Error in prior Fossil Fuel emissions is compensated by changes in other estimates such as AGR, or land sink [Saeki and Patra 2017]**

- **The spread in prior FF emissions and AGR (~1PgC/yr) are larger than GCP uncertainty estimates (~0.5 PgC/yr) and of similar magnitude to spread in land and ocean fluxes**



Thanks for your attention



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Observations

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