Inverse modelling of CO_2 , CH_4 and N_2O using JAMSTEC's MIROC4-ACTM

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Kyoto, Japan

MoE
Suishin-hi

Introduction

- Global stocktaking of greenhouse gases emissions is scheduled for the early 2020s
  - Each country will report their progress towards the Nationally Determined Contributions
  - Independent estimation is likely to come from the regional and global inversion of atmospheric observations
- Inverse modelling of CO_2 using MIROC4-ACTM (1998-2017)
  - Comparisons with some other results, as our inversion is almost entirely data driven
  - Contribution to Global Carbon Budget (LeQuere et al., 2018, ESSD, in review)
  - Contribution to TransCom-HIPPO (Gaubert et al., in review)
- Inverse modelling of CH_4 and N_2O using MIROC4-ACTM
  - Explanation of the CH_4 growth rate anomaly in the past 3 decades
  - Attribution of emissions to anthropogenic and natural emission processes
- Use of satellite remote sensing data of atmospheric column CO_2 and CH_4
  - Rapid progress in the recent years
  - Extremely promising for refining sources and sinks estimate by the surface network

Inverse modelling of CO_2: TransCom experiment and modificaion

(Surface Source) (Uptake on surface) (Atmospheric Transport)

$$\frac{dD_{ACTM}(x,y,z,t)}{dt} = S_0(x,y,t) - U_0(x,y,z,t) - \nabla.\Phi_D(x,y,z,t)$$

$$S = S_0 + (G^T C_D^{-1} G + C_{S_0}^{-1})^{-1} G^T C_D^{-1} (D - D_{ACTM})$$

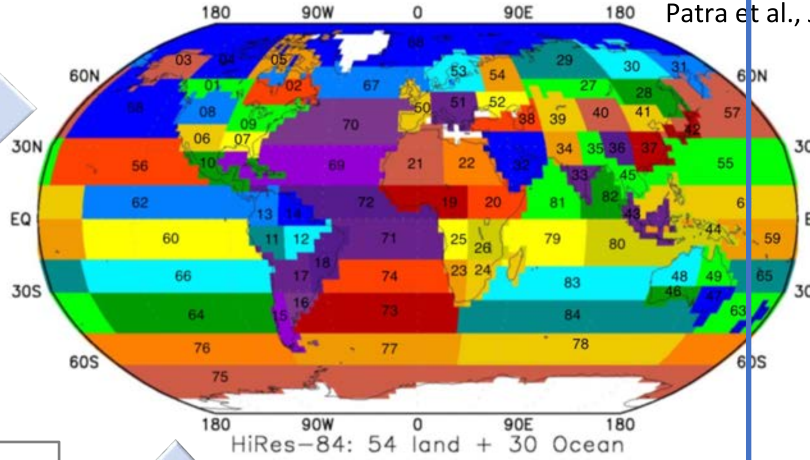
$$C_S = (G^T C_D^{-1} G + C_{S_0}^{-1})^{-1}$$

e.g., Rayner et al., Tellus, 1999

Patra et al., JMSJ, 2016

Forward simulation

Validate model transport using independent species (e.g., ^{222}Rn, SF_6)



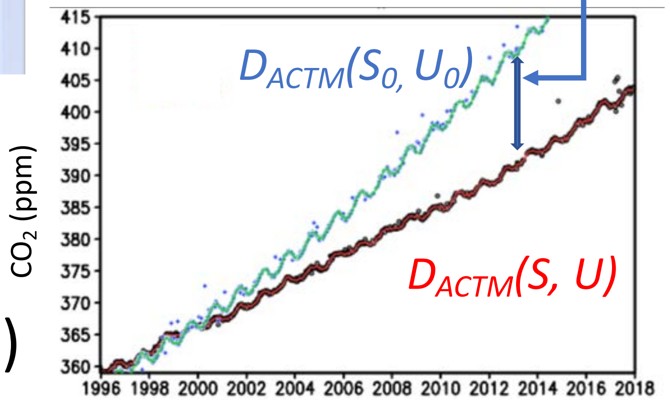
S, U

Emissions (S_0)

1) Fossil fuel and cement (EDGAR v432; JRC)
2) Land biosphere (CASA-3hr; Niwa, MRI)
3) Takahashi ocean (2009)

- S_0, S = prior and predicted sources
- G = Green's functions for regional source-receptor relationships
- C_D = Data covariance = 0.3 ppm + synoptic variability
- C_{S0} = Prior source covariance
- D = Observed atmospheric concentration
- D_{ACTM} = ACTM simulated D

Atmospheric observation (D)



In JAMSTEC:

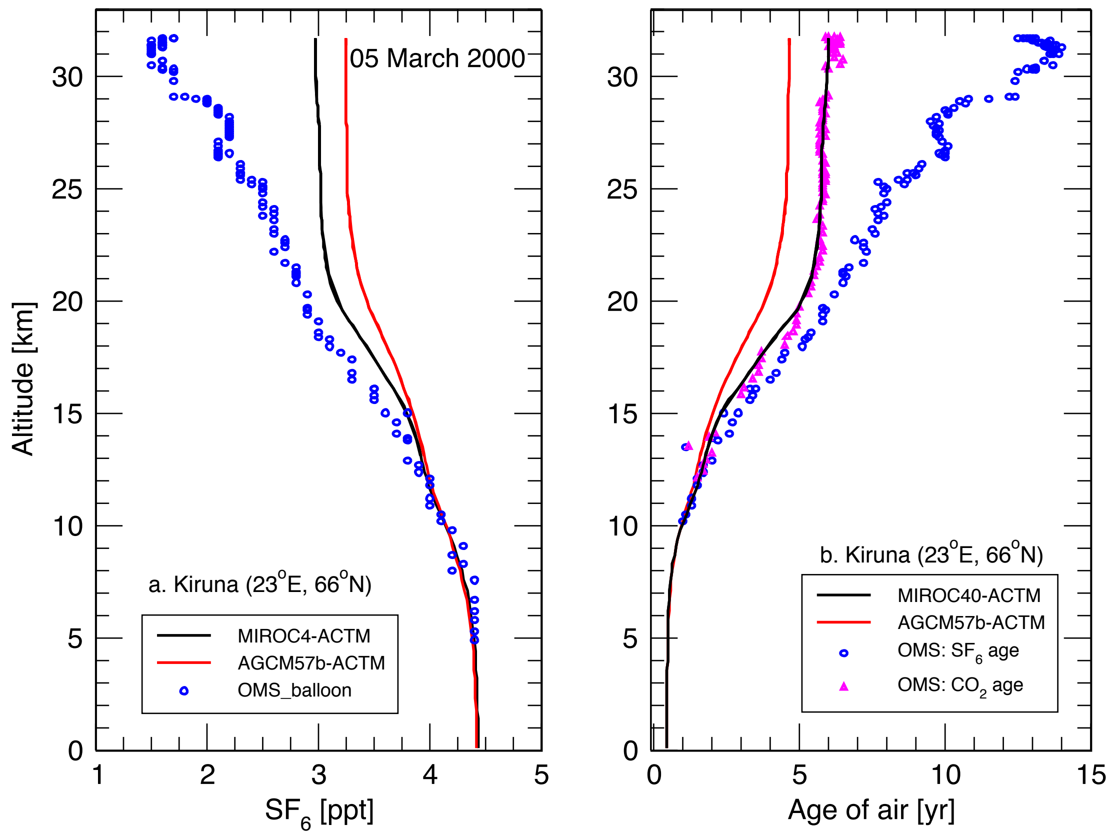
CCSR/NIES/FRCGC AGCM5.7b-based Chemistry-Transport Model (ACTM)

MIROC4-ACTM : has been developed recently (Patra et al., 2018)

Development of MIROC4-ACTM: transport validation using age of air and SF_6

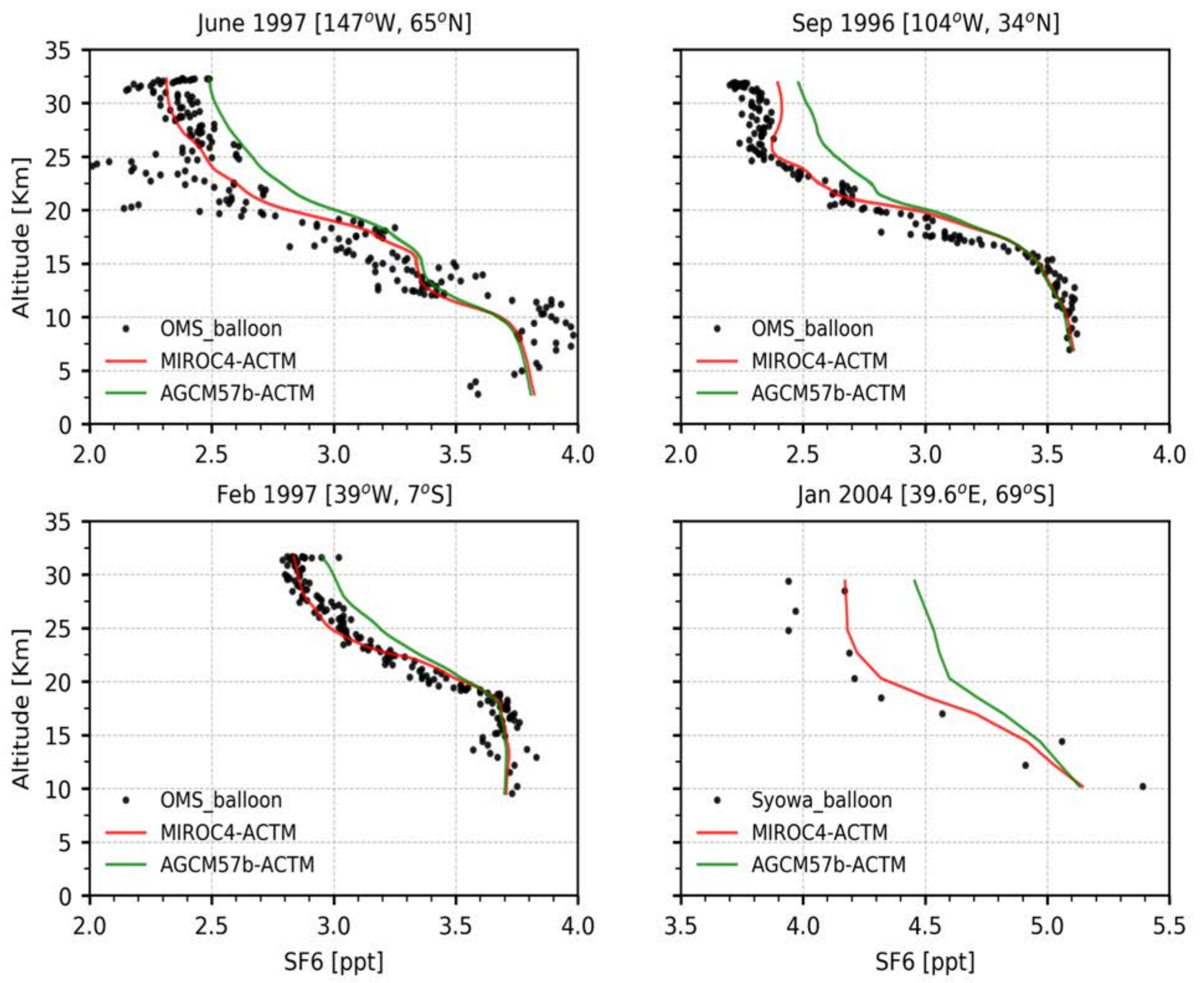
(SF_6 is a dielectric material with no known loss in the troposphere and stratosphere, but some loss in the mesosphere affect polar stratospheric data)

But in the polar stratosphere........



Ray et al., 2017 (CO_2 age of air); Patra et al., revised, SOLA

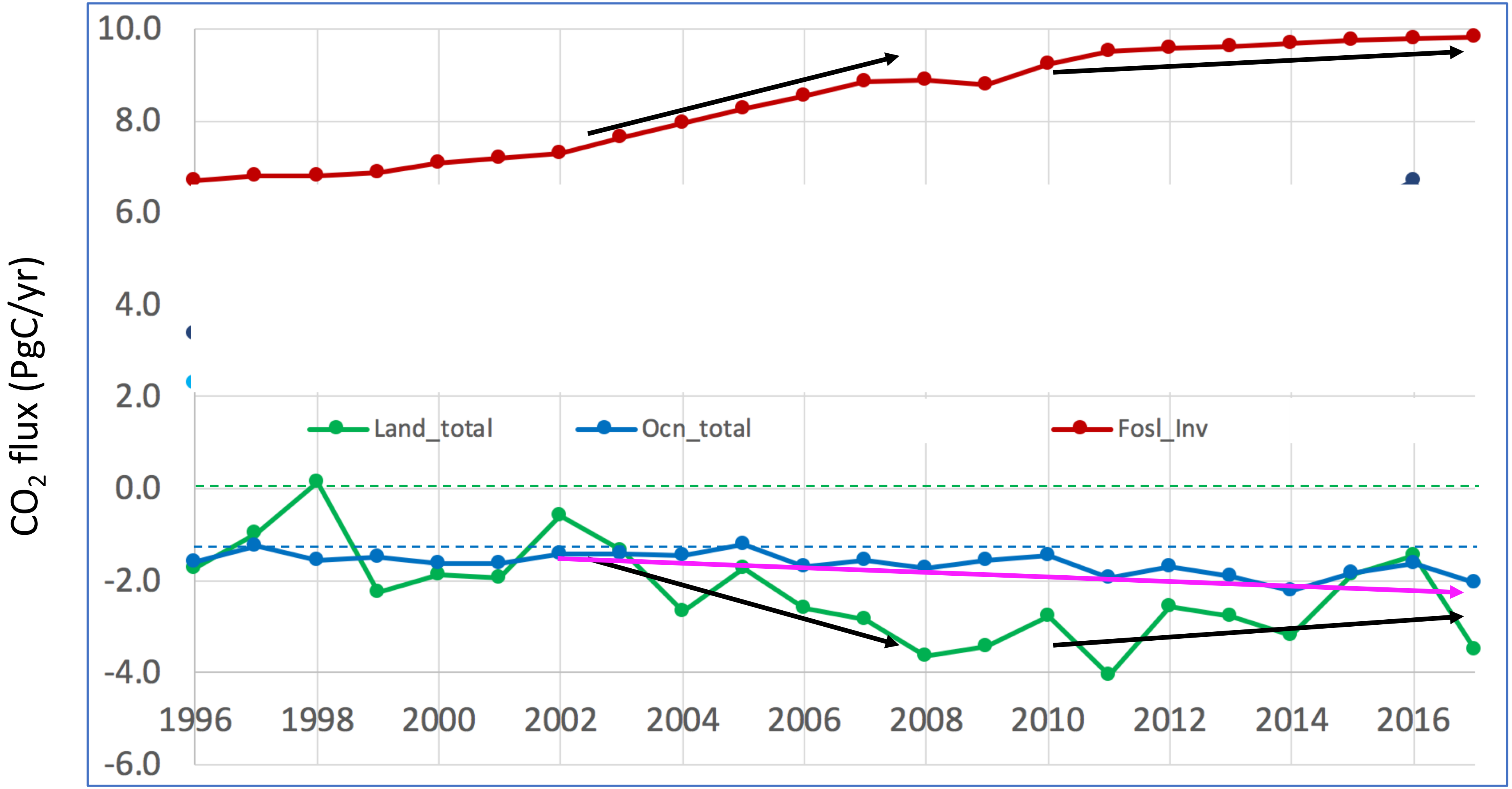
MIROC4-ACTM SF_6 agree quite well with observations, compared to AGCM57b-ACTM

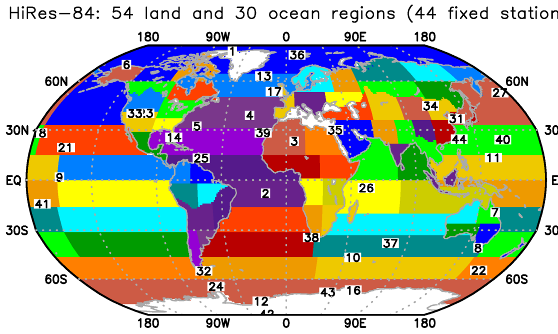


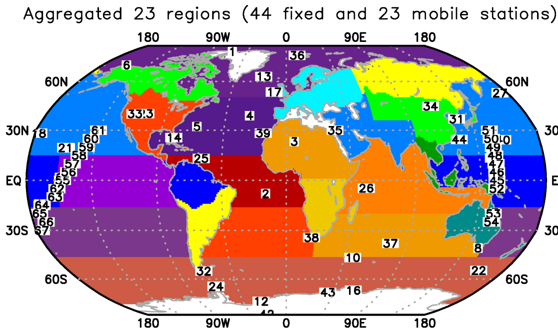
Observations : GMD/NOAA (Daube et al., 2002); NIPR/Tohoku Univ (Goto et al, 2017)

CO2 INVERSION RESULTS

MIROC4-ACTM inversion (TDI84_2017) : global totals







Units:

1 Pg = 10^{15} g

1 Tg = 10^{12} g

… further analysed by GCP-CO_2, Budget 2018

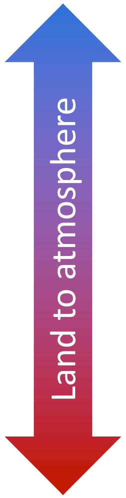
See also: Saeki and Patra, GOSL, 2017

Current understanding (IPCC-2013)

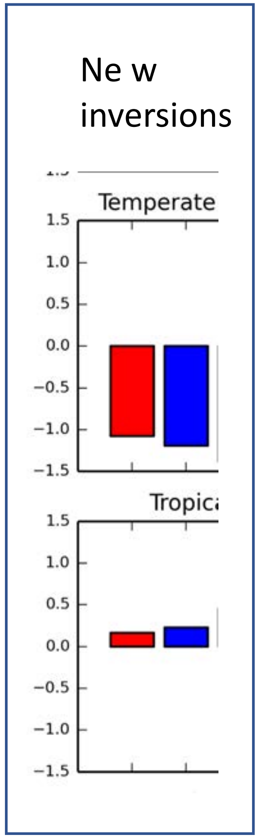
Decadal average CO_2 fluxes for 11 land regions

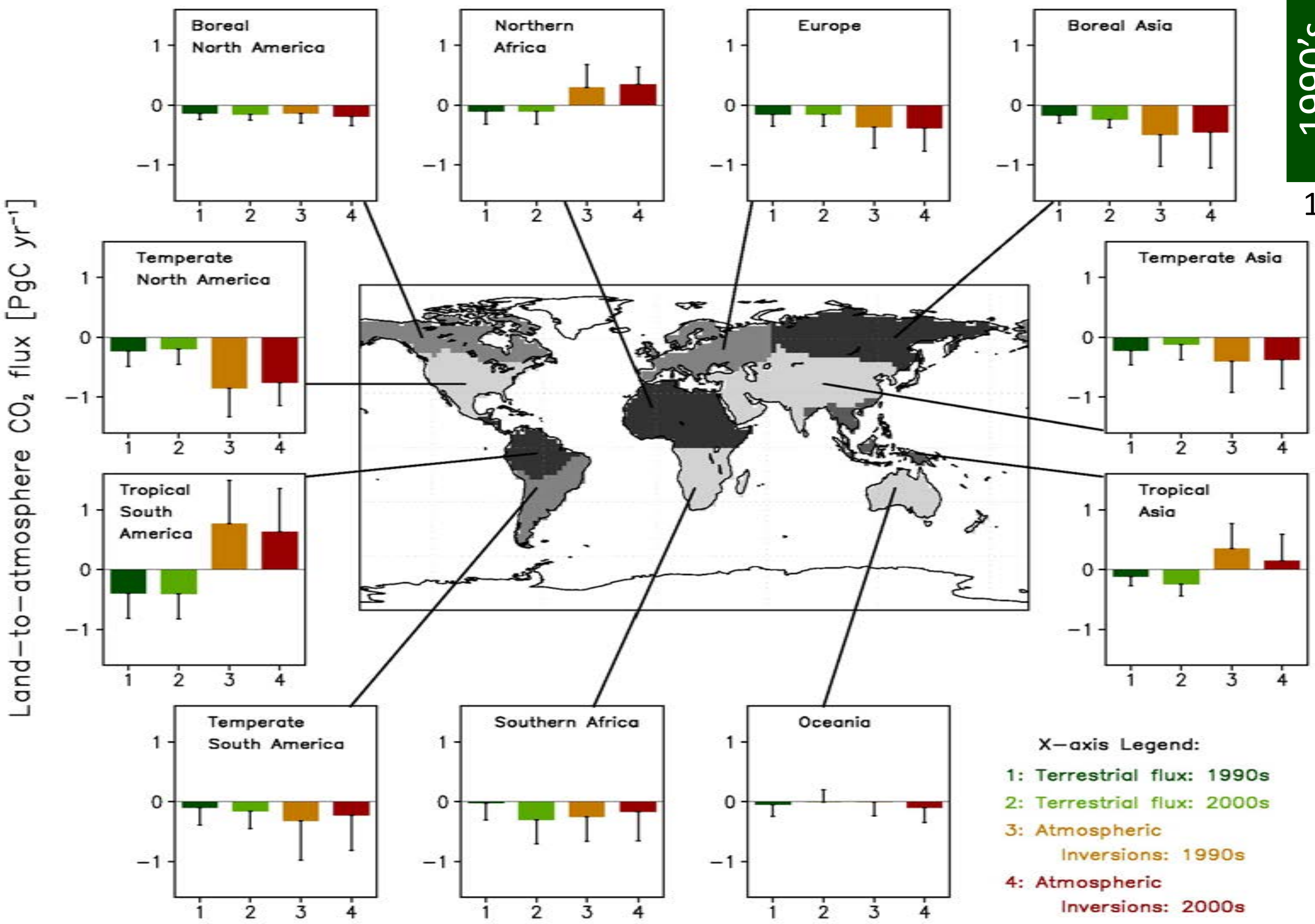
Bottom-up approach : 10 DVGMs (**TRENDY**)
Top-down approach : 10 atmos. Inversions (**TransCom**)

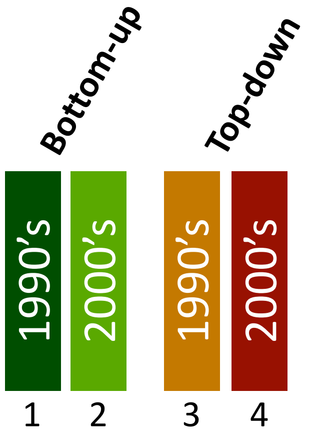
+: source



-: sink

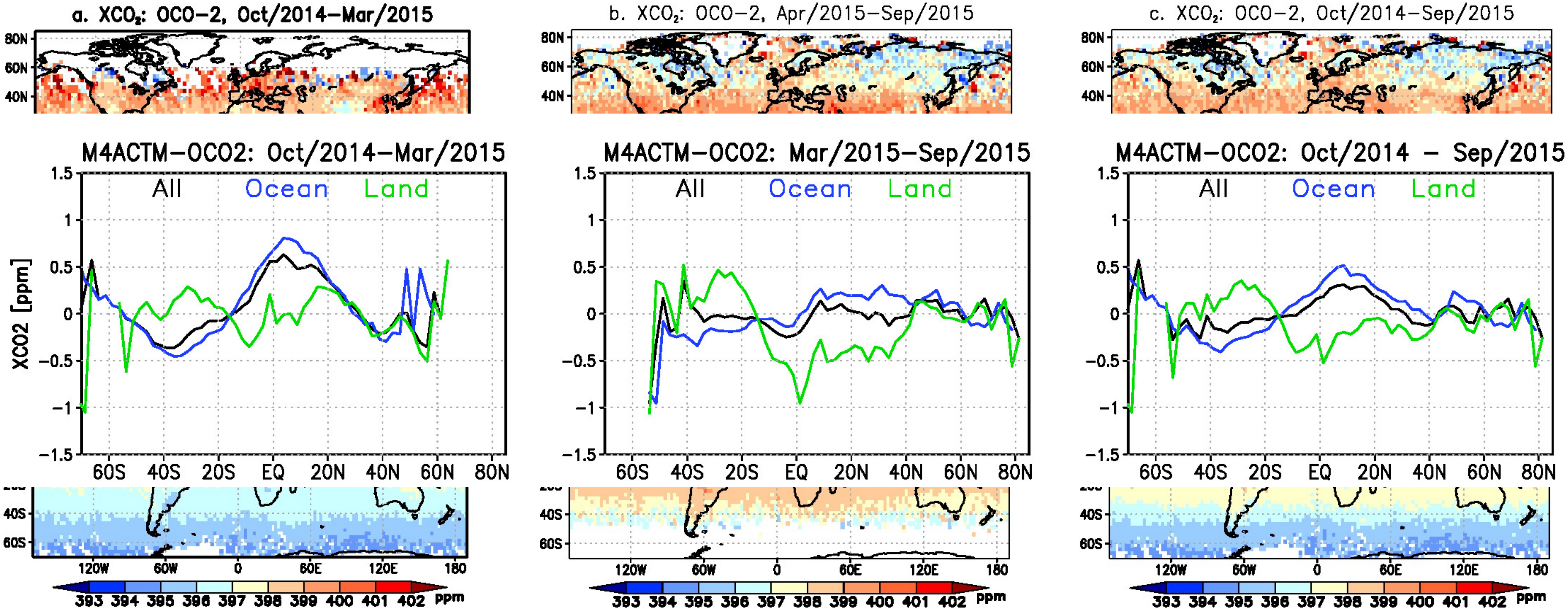






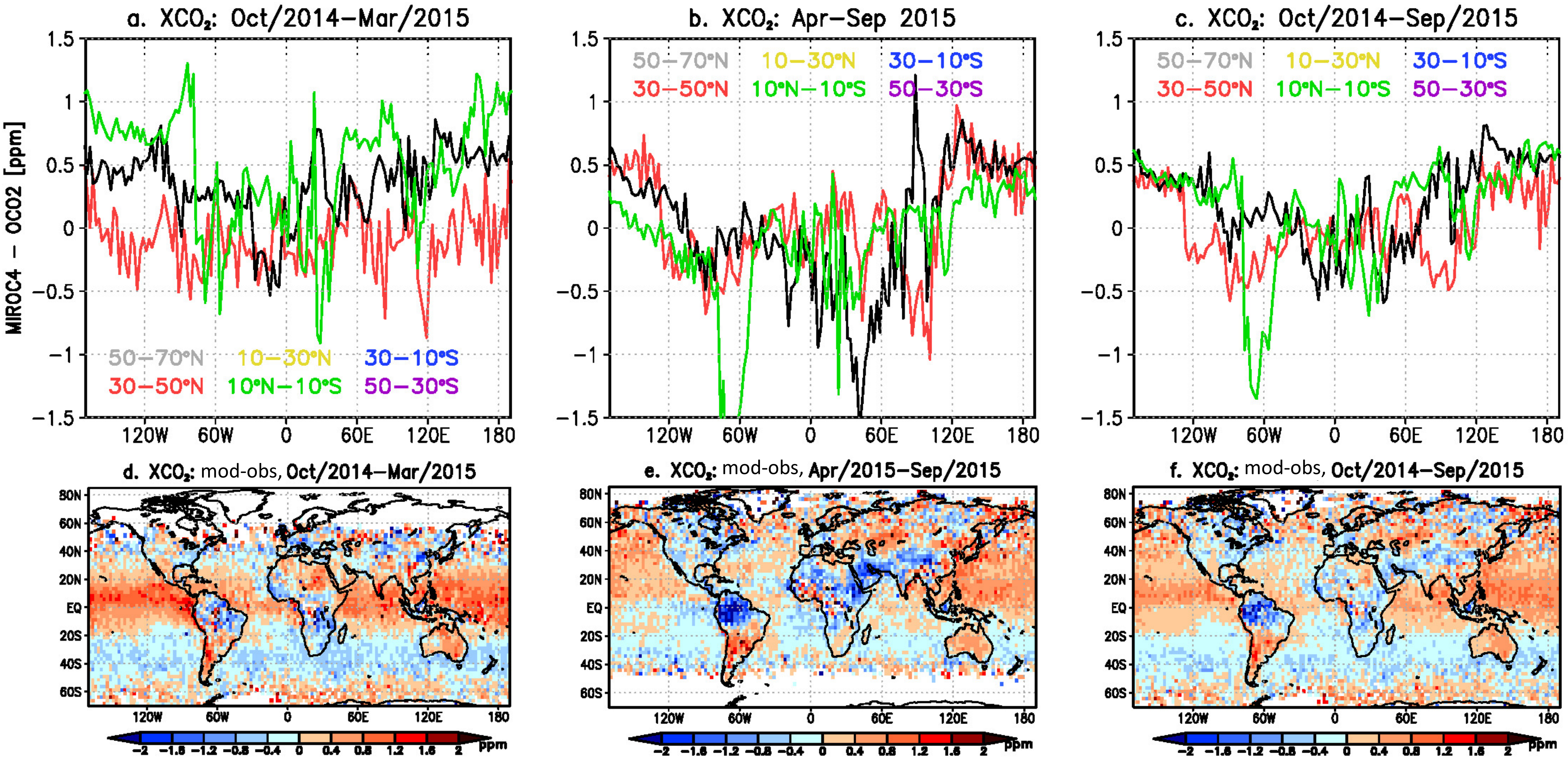
IPCC AR5, 2013
Fig. 6.15 (by P. Patra)

Large increase in data coverage in satellite remote sensing era



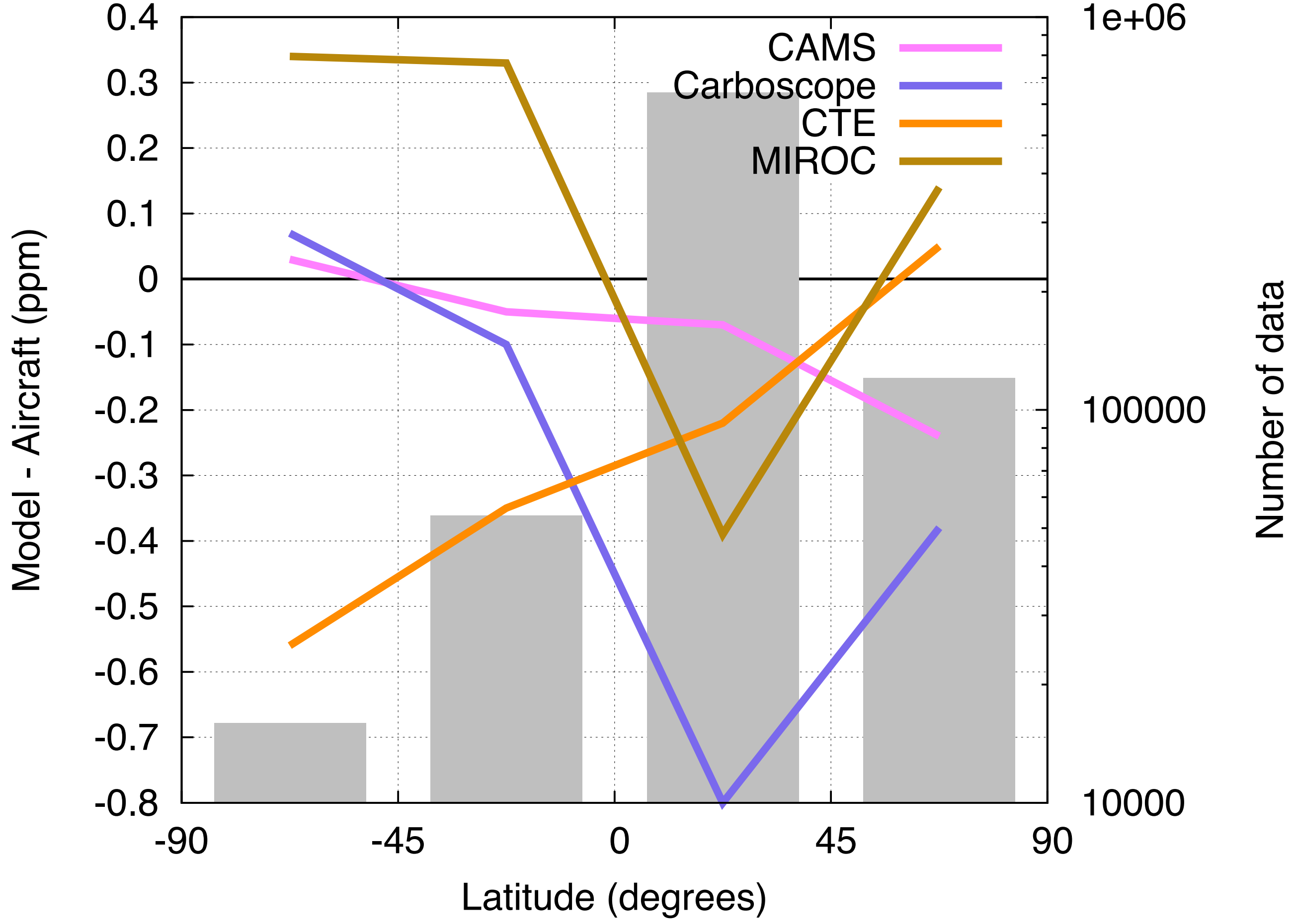
We also achieved improved simulations of XCO_2 within 1 ppm by global (and regional) chemistry-transport models ….

Zonal gradients for latitude band: Is North America sink overestimated?



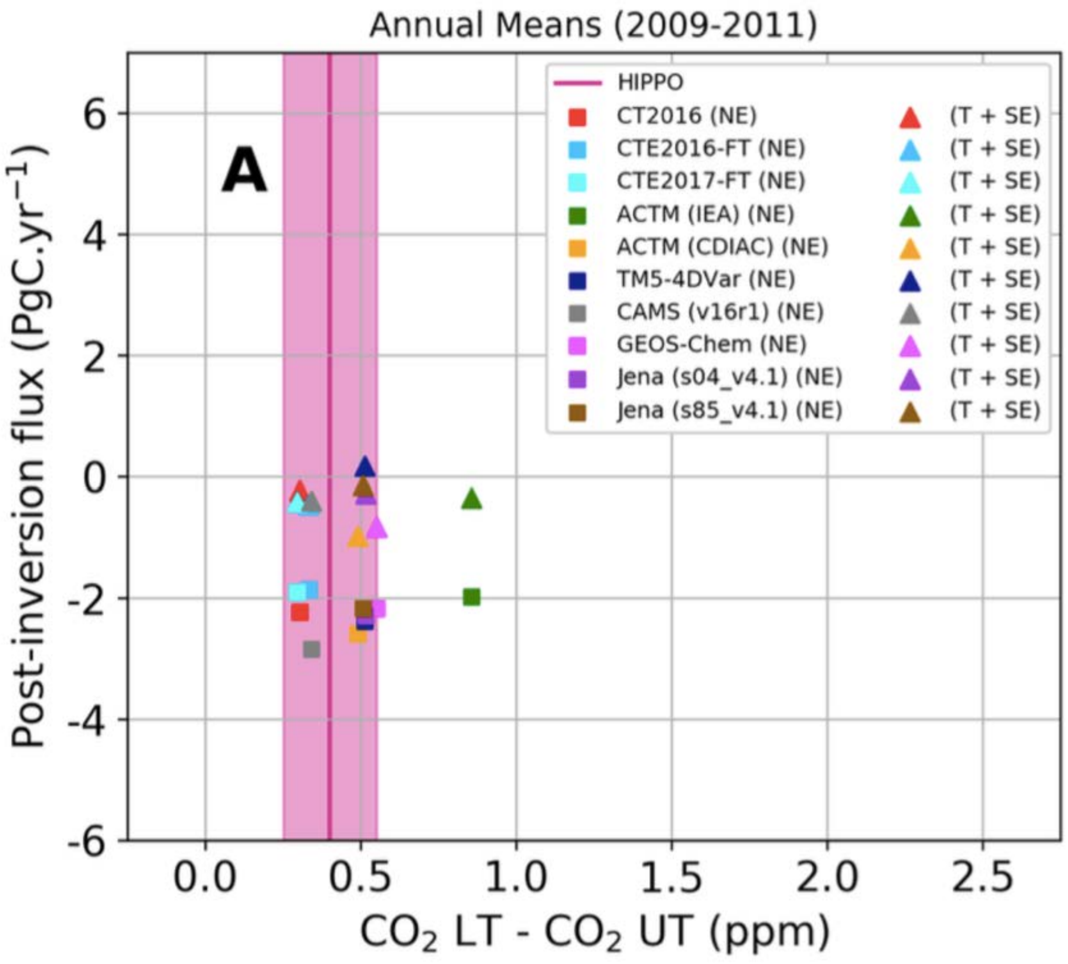
Evaluation of inversion fluxes using aircraft data

Example for the 2008-2016 period (includes CONTRAIL)



GCB2018, Le Quéré et al., ESSD, in review, 2018

Example using HIPPO
(Key results from Saeki & Patra, 2017 are endorsed)

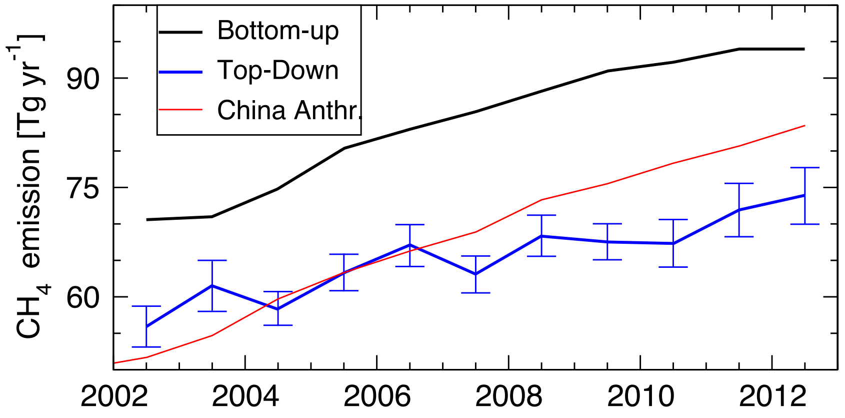


TransCom like, Gaubert et al. BG, in review, 2018

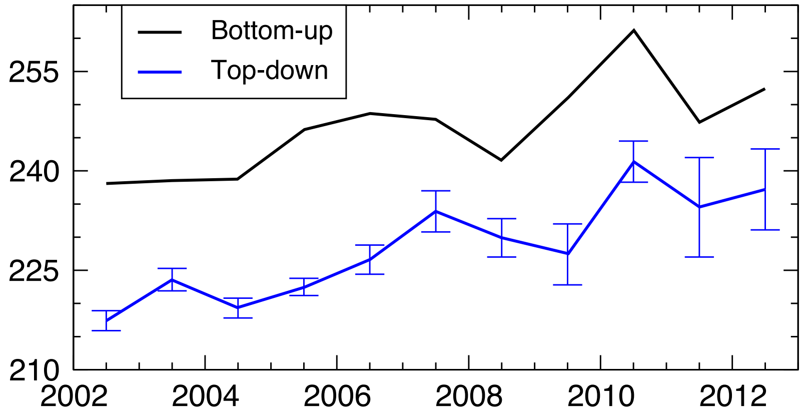
CH4 INVERSION RESULTS

CH_4 emission trends and variability: Validation using Tohoku Univ. data over Sendai

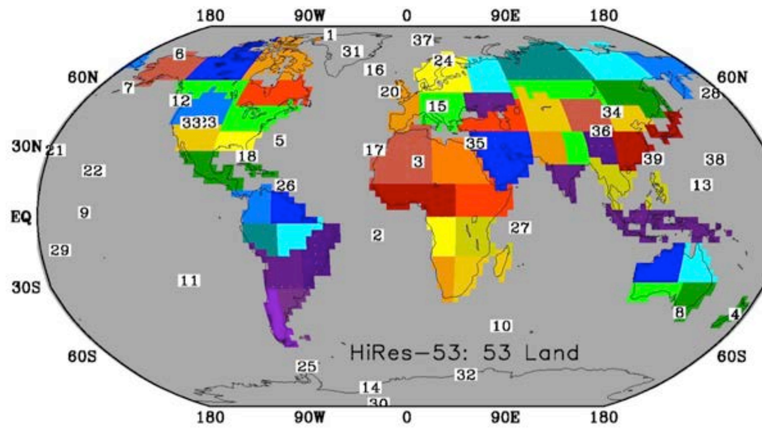
East Asia (China, Japan, Korea)



Tropical Land (Africa, America, Asia)

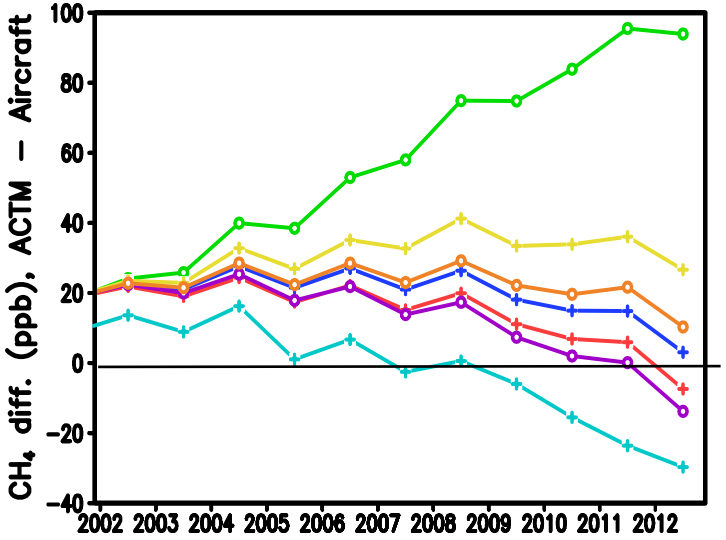


Patra et al., JMSJ, 2016

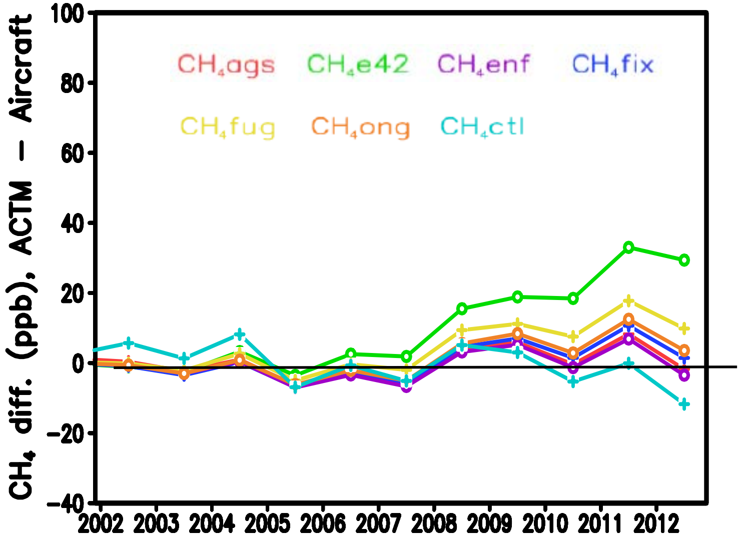


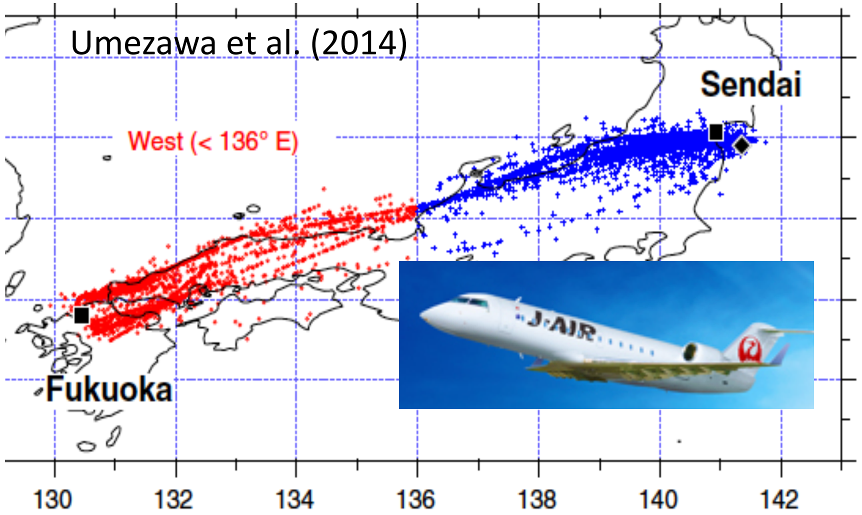
3-5%/yr increase in CH_4 emission of East Asian emission; about half of the prior

a. Sendai (0–2 km); Prior; Ann mean

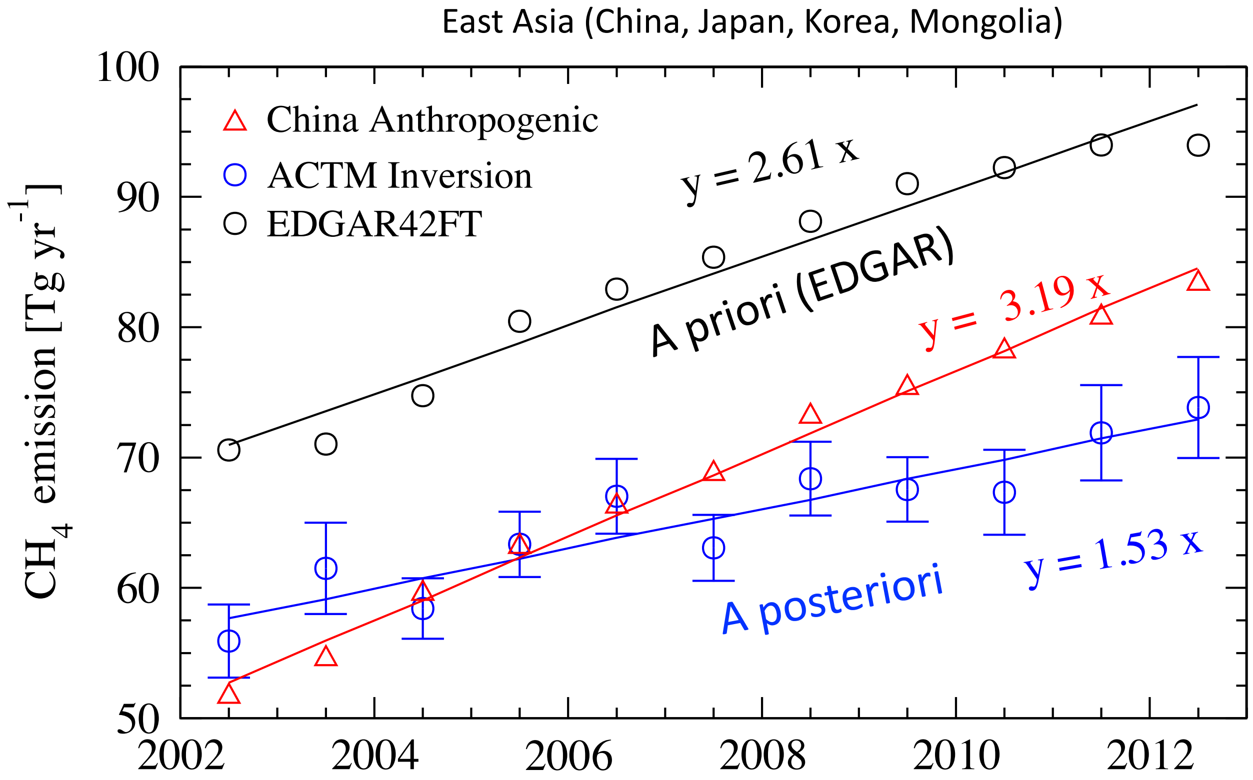


b. Sendai (0–2 km); Poste; Ann mean





CH_4 inversion: application to anthropogenic CO_2 emission



China alone drives the East Asian emission increase. Mostly from coal industry.

Increase rate of **inverted CH_4 emissions** are 22% (9 Tg) lower than that of **EDGAR2012FT inventory**

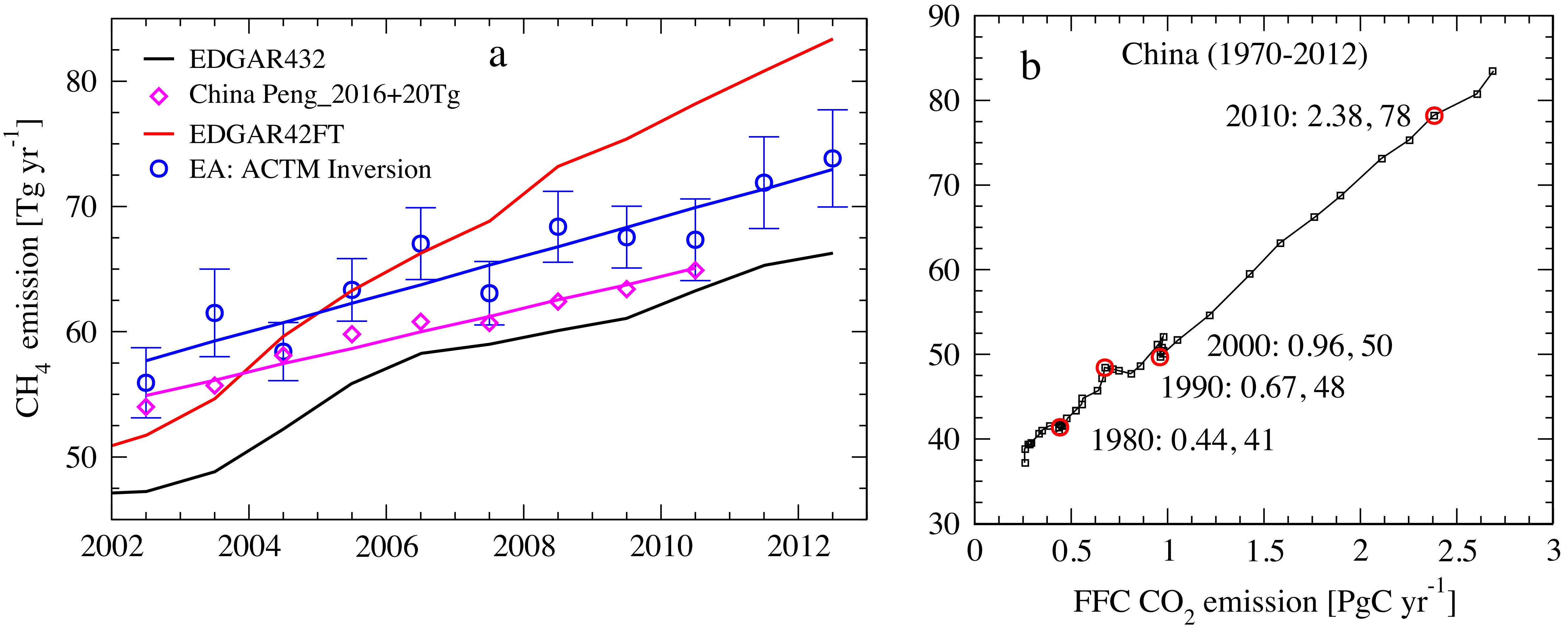
Ratio of slopes
1.53/2.61 = 0.59

We estimated a scaling factor of **0.59** to FFC CO_2 emission "increase rate" for the period 2003-2014, relative to the emissions for 2002 from the inventory emissions.

Saeki and Patra, Geosci. Lett., 2017

Updates in China CH_4 emission: perspective for FF CO_2 emission

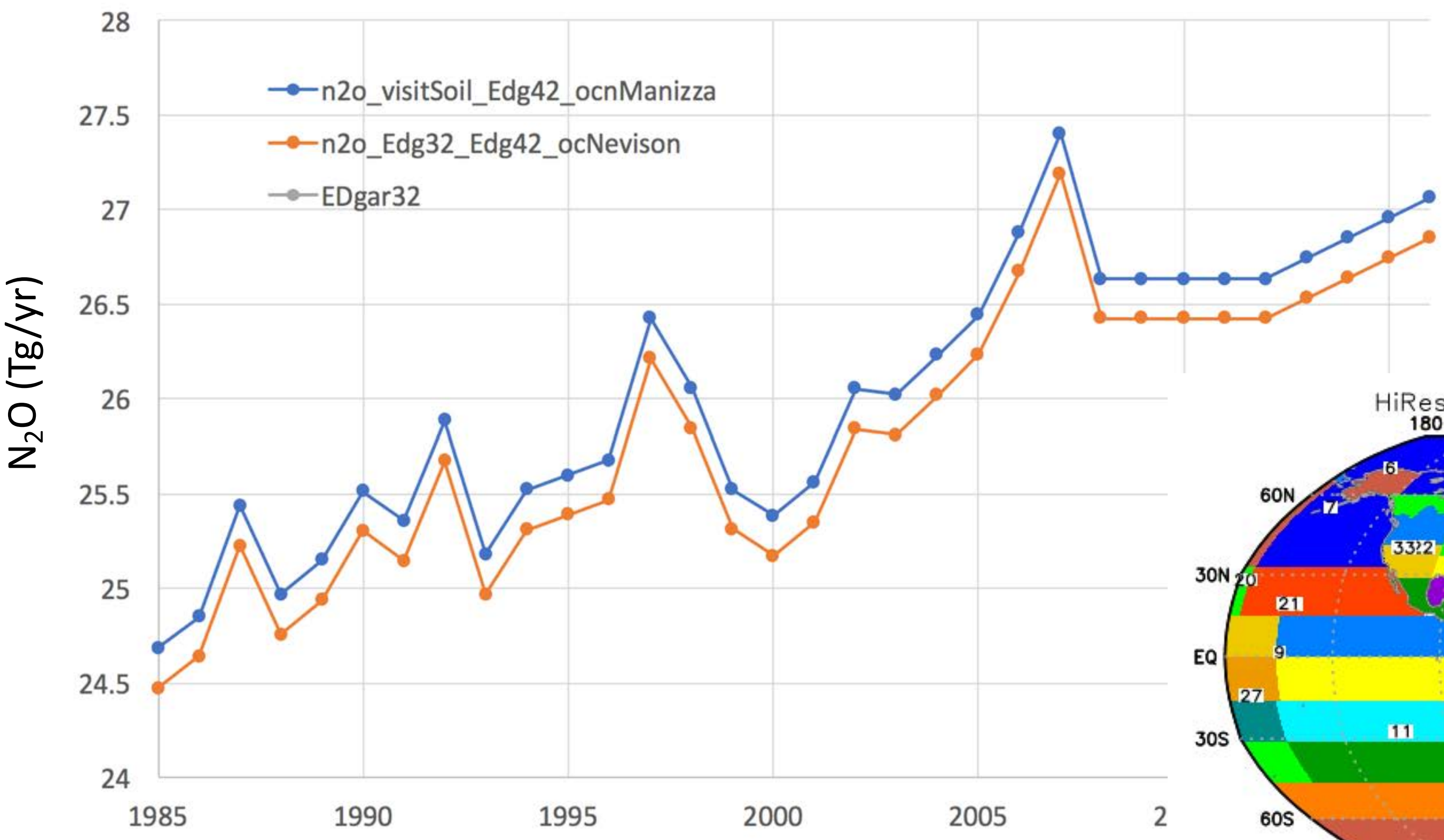
Patra et al., 2016; Peng et al., 2016; Janssen-Maenhout et al., 2017

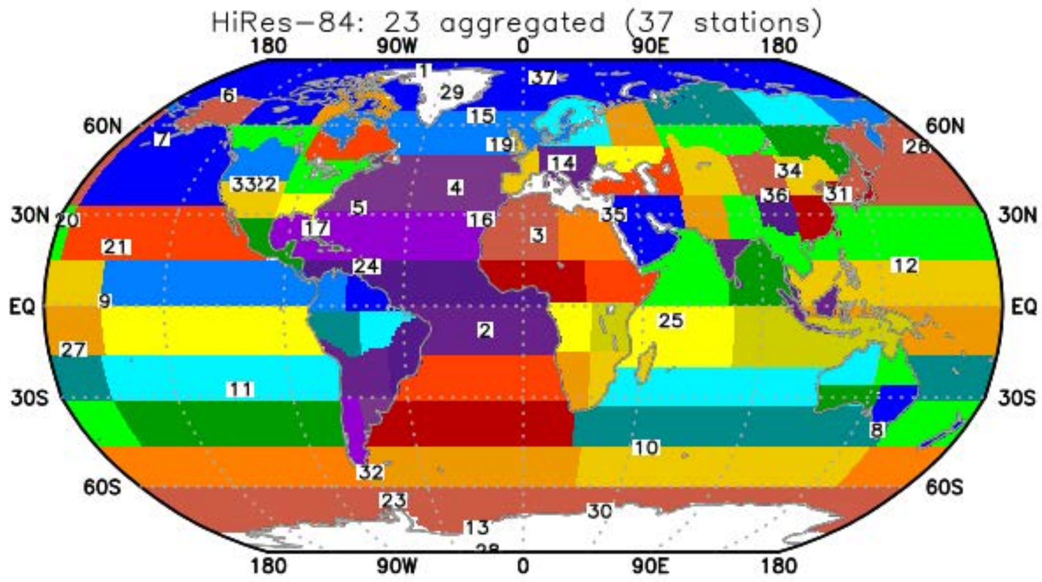


We recommend a scaling factor to FFC CO_2 emission "increase rate", based on CH4 inversion results

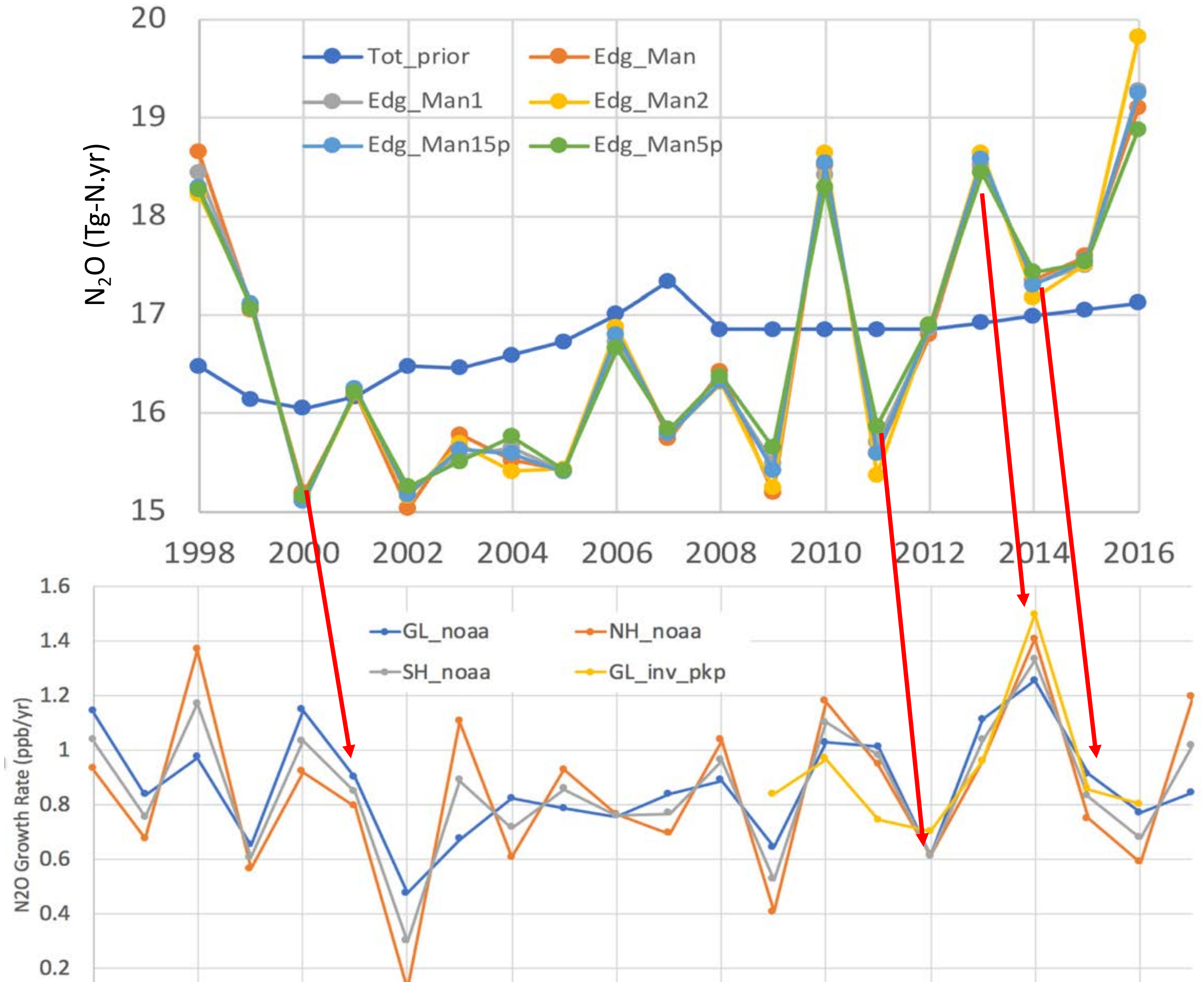
N2O INVERSION RESULTS

Modelling N_2O: emissions using EDGARv42FT, Soil (2), Ocean (2)





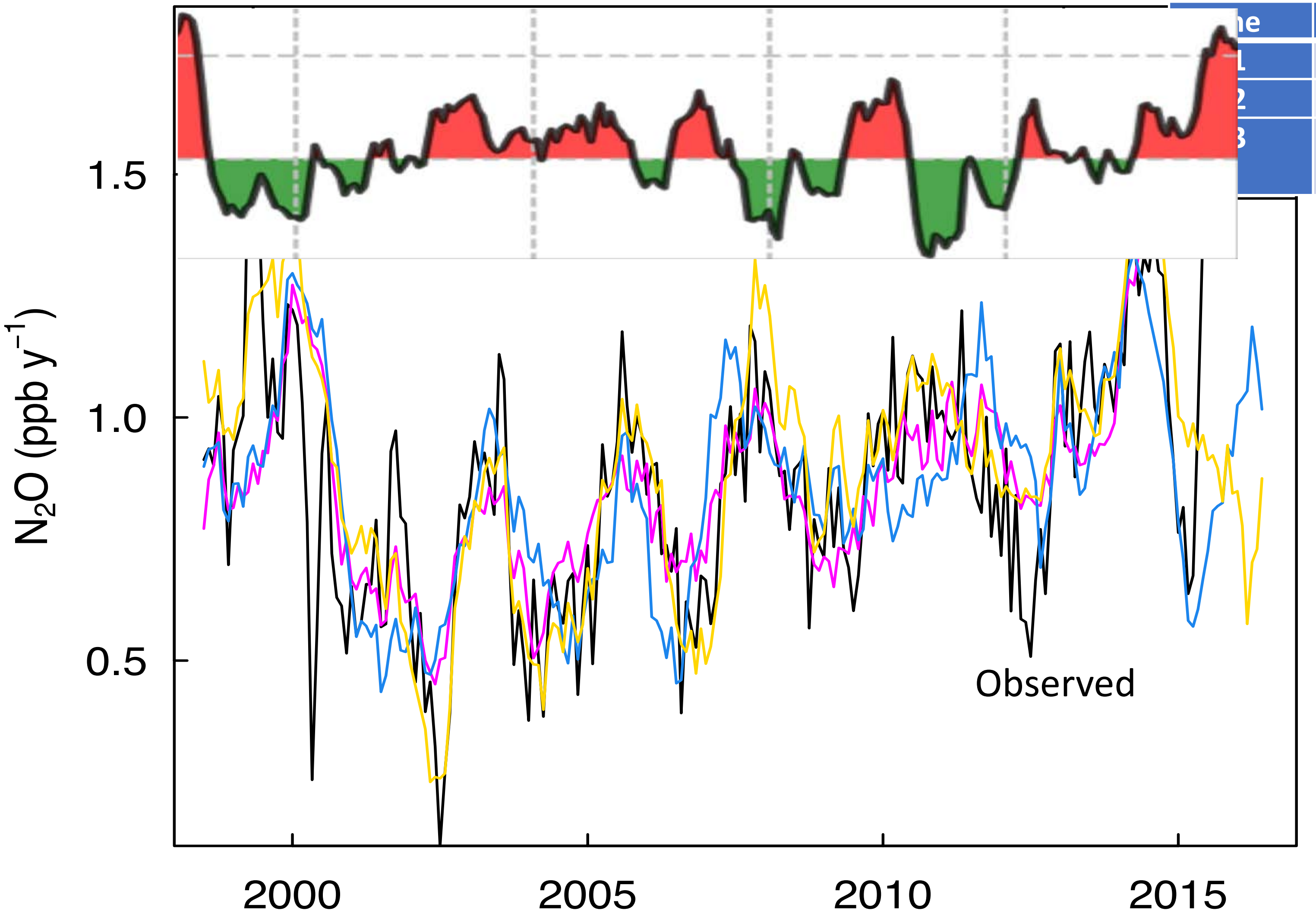
N_2O inversion fluxes (RGO) in comparison with the prior (blue)



Interesting differences between emission variabilities and concentration growth rates (due to the effects of transport in troposphere and the stratosphere-troposphere exchange)

N_2O growth rate plot by:
Kentaro Ishijima

Atmospheric N_2O growth rates, compared between GCP inversions



ne	ACTM	Method	Resolution
1	TOMCAT	4D-Var	5.625°×5.625°
2	LMDz5	4D-Var	3.75°×1.875°
3	MIROC4-ACTM	Bayesian analytical	84 regions

Key conclusions (1998 – 2017):

- Our inversion using MIROC4-ACTM works well, when compared to other inversions
- The concentration IAVs are apparently linked to ENSO, but in opposite phase as that of CO2 and CH4??
    - High growth rate in the La Nina years
- Role of stratosphere-troposphere exchange (STE) is unclear??

Rona Thompson et al.; work in prog

Conclusions

- Investment in developing the model physics is key to interpret the atmospheric concentration measurements

- It encouraging that the 40+ sites and model can simulate the global XCO_2 data, generally within the observational uncertainty
  - A data-rich era for CO_2 has arrived due to JAL/NIES CONTRAIL, HIPPO, GOSAT, OCO2

- CH_4 inversion clearly identified the problems in the China inventory emissions and a closer agreement is now achieved, but further work is needed

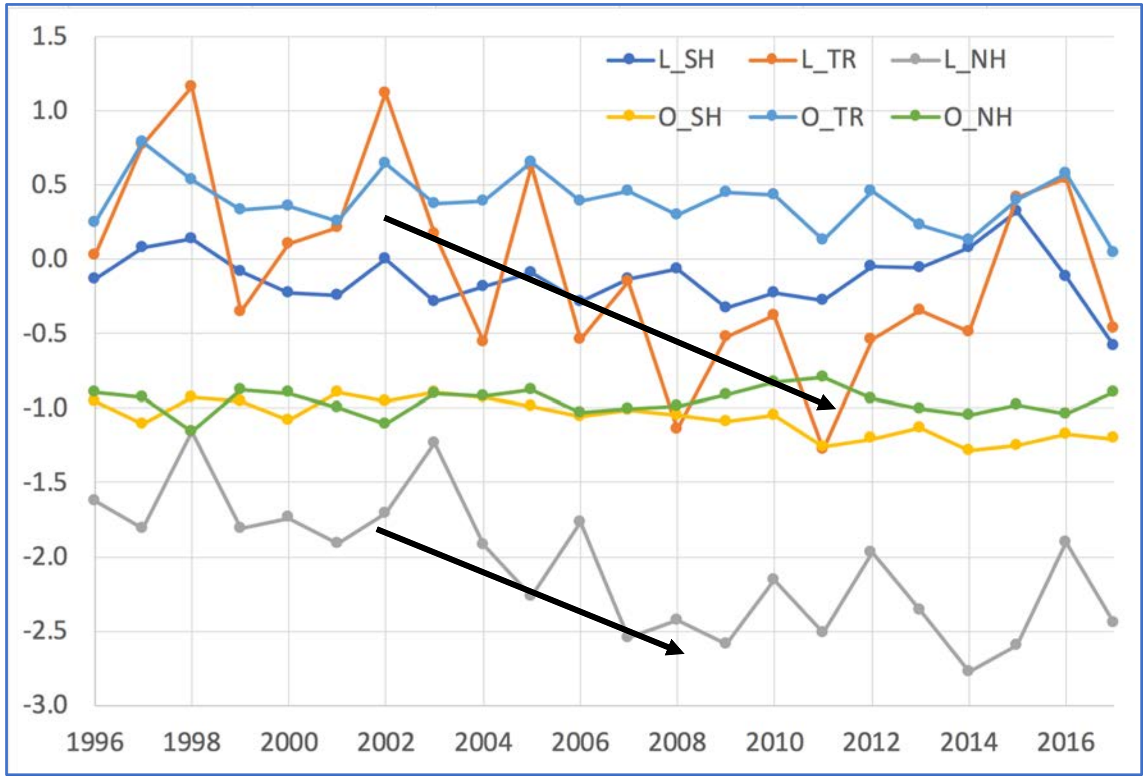
- Emissions of N_2O from anthropogenic sector continued to increase, but the bottom-up estimations do not fully explain the observed concentration variabilities

Thank you

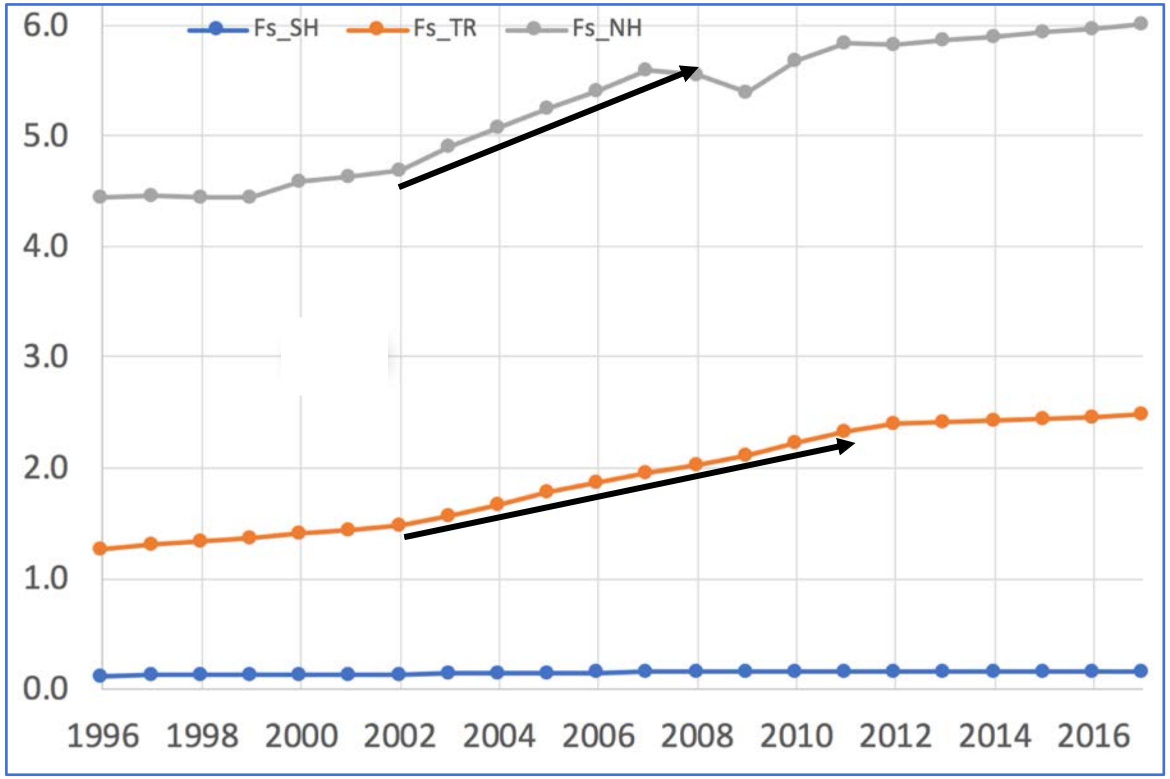
MIROC4-ACTM inversion (TDI84_2017) : hemispheric totals

Latitude bands: SH > 30S; 30S > TR < 30N; NH > 30N

Land and ocean fluxes (Pg/C) for NH, TR and SH

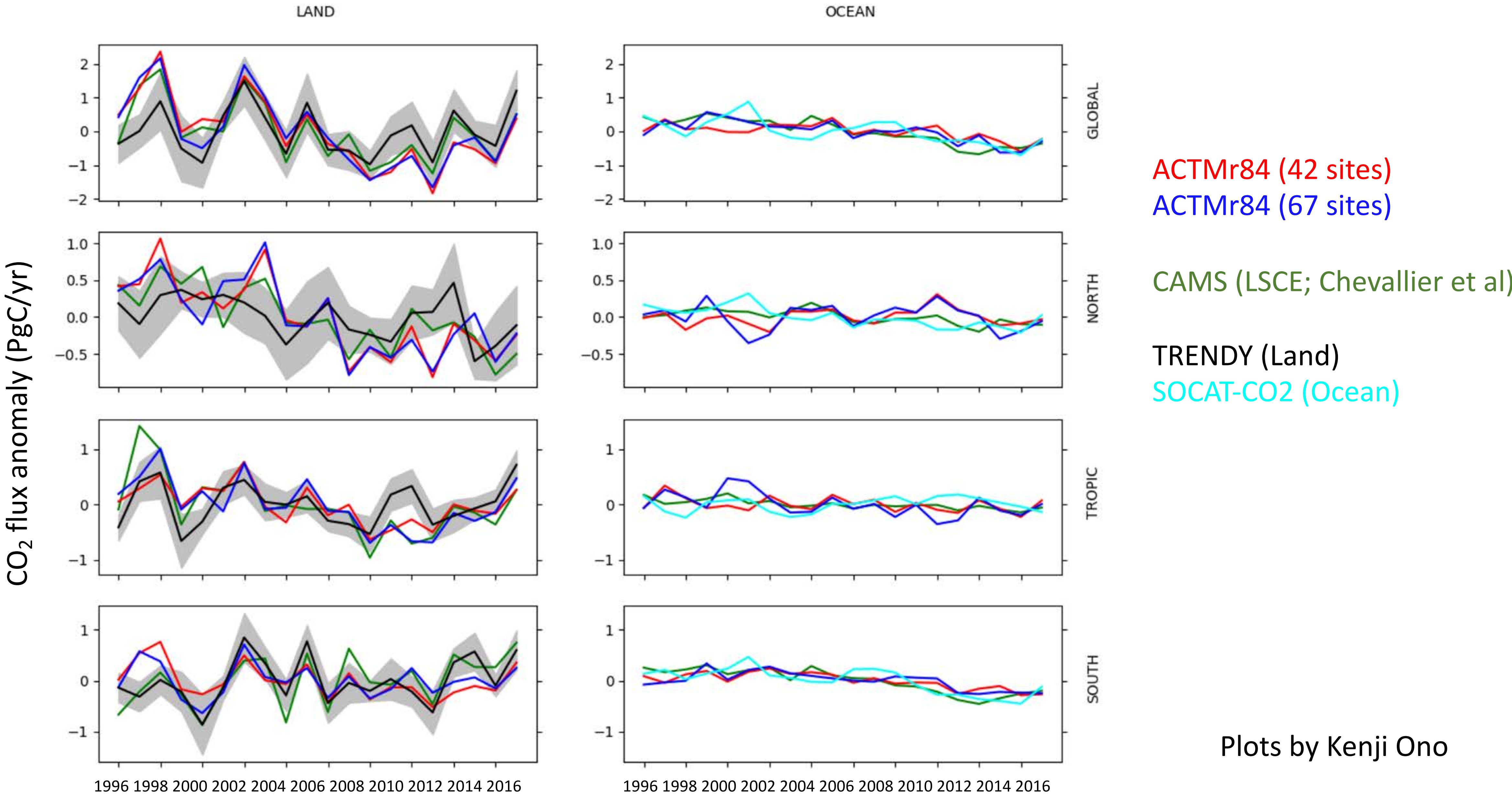


Fossil-fuel emissions (Pg/C) for NH, TR and SH



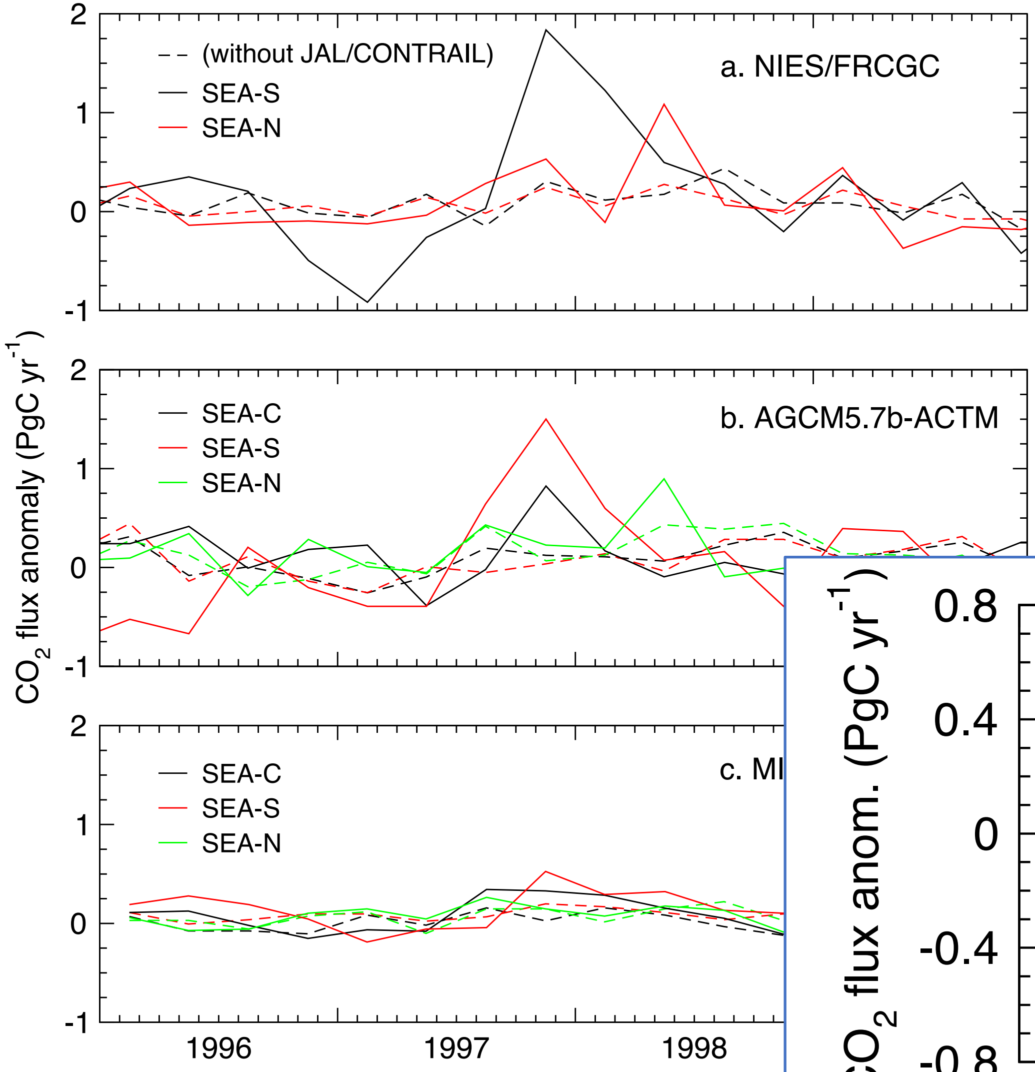
To be further analysed by GCP-CO_2, Budget 2018

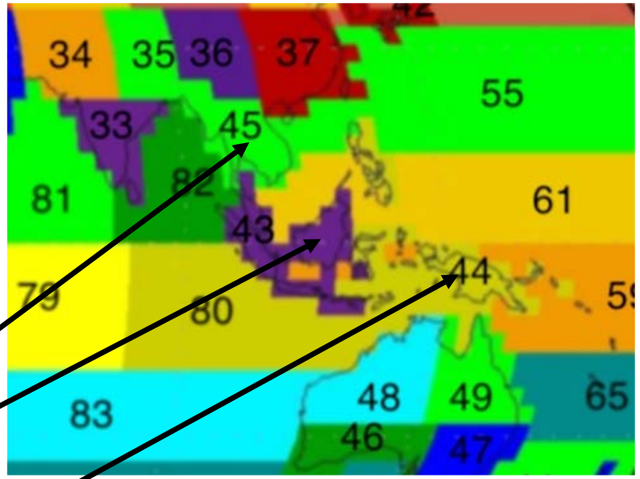
MIROC4-ACTM inversion (TDI84_2017) : hemispheric totals



Plots by Kenji Ono

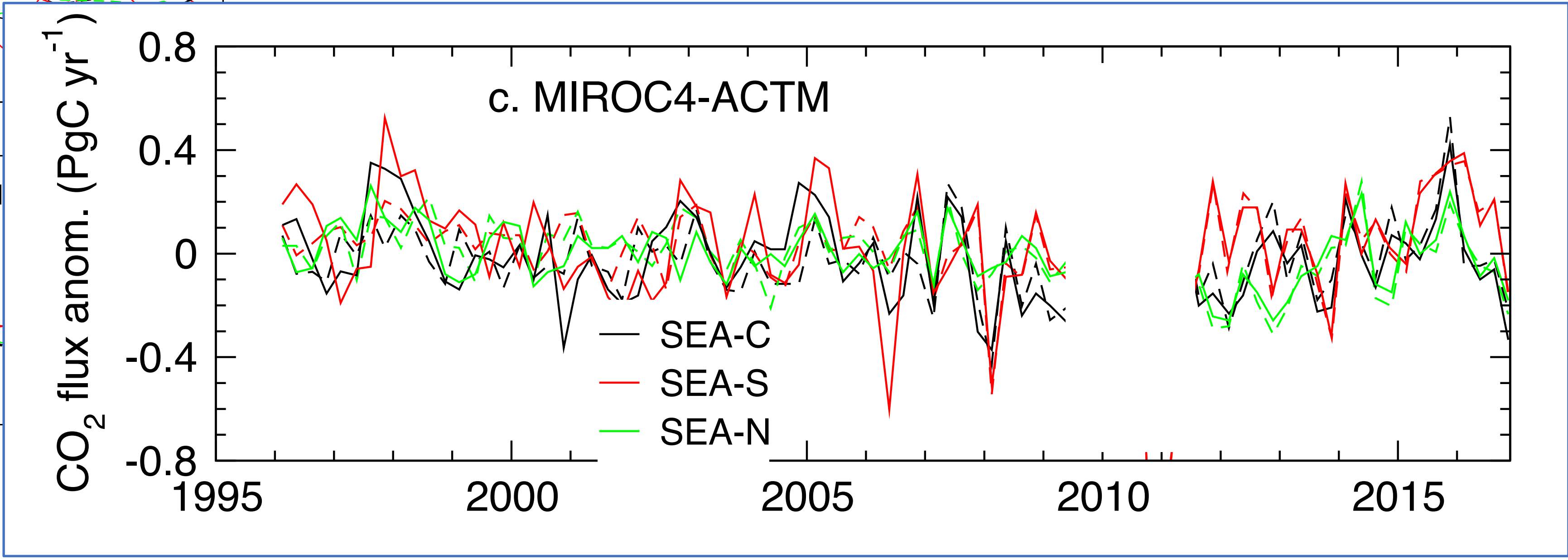
Evolution of JAMSTEC's inversion (2003-2018) : the cases of El Ninos





Broken line (surface only)
Solid line (Surface+CONTRAIL)

SEA-N : #45 (Continental)
SEA-C : #43 (Polynesian)
SEA-S : #44 (Papua New Guinea)

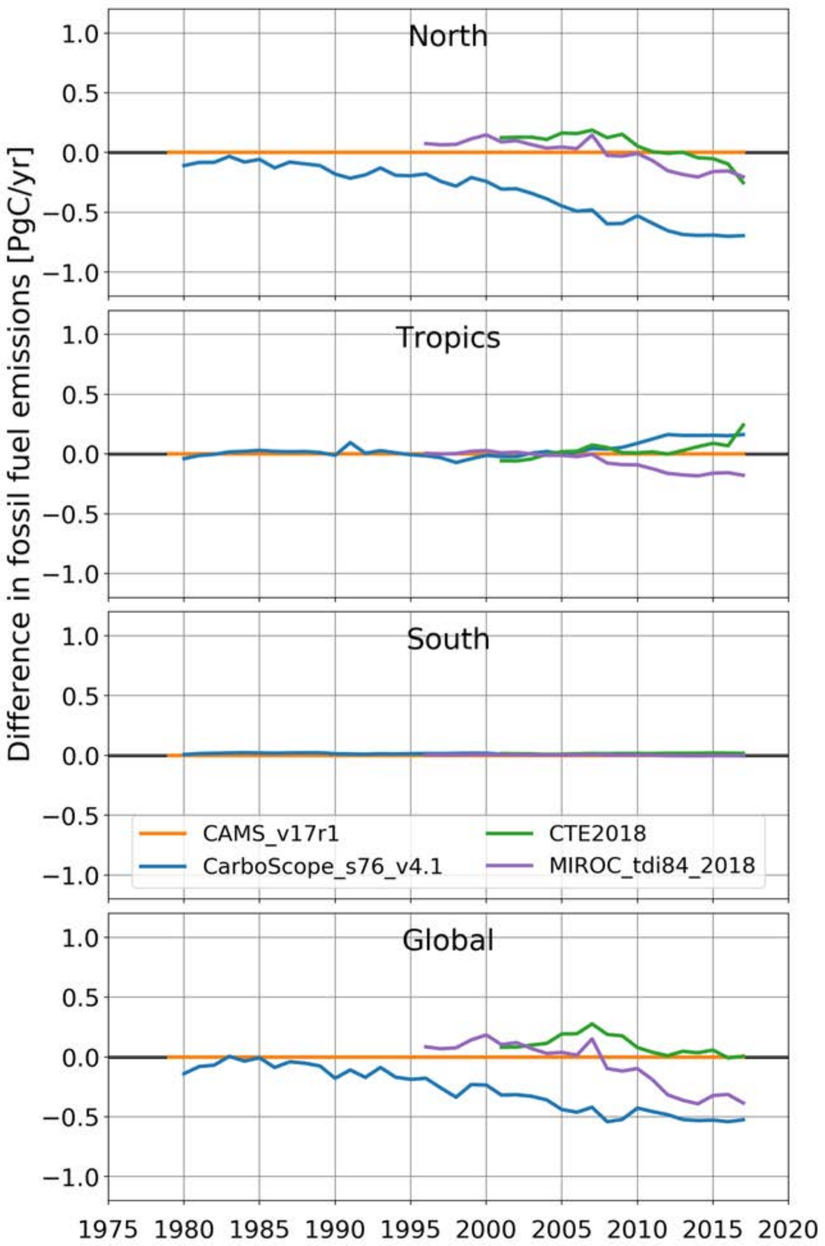


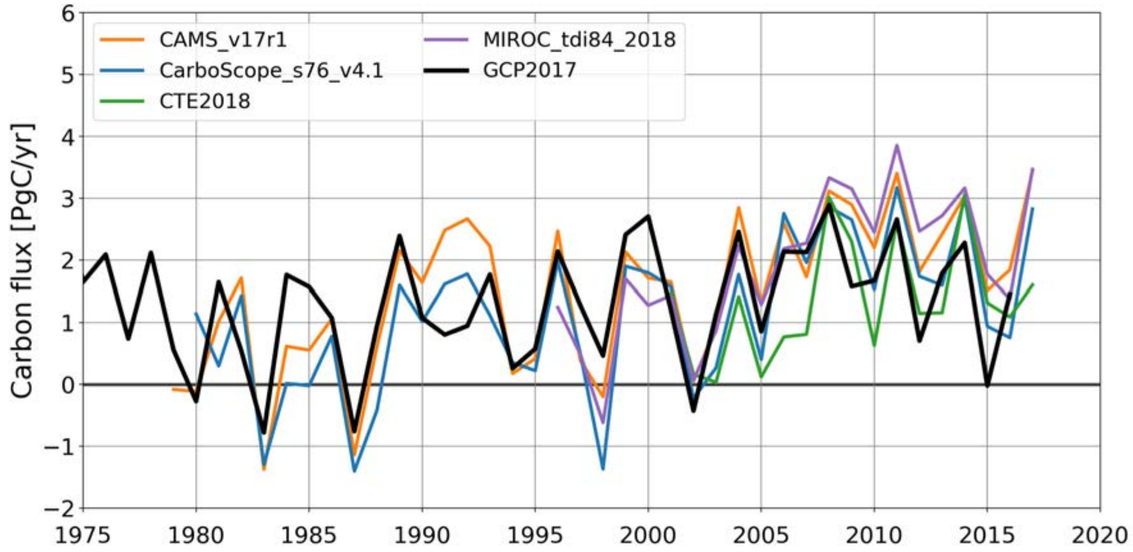
Global carbon budget 2018: inversions

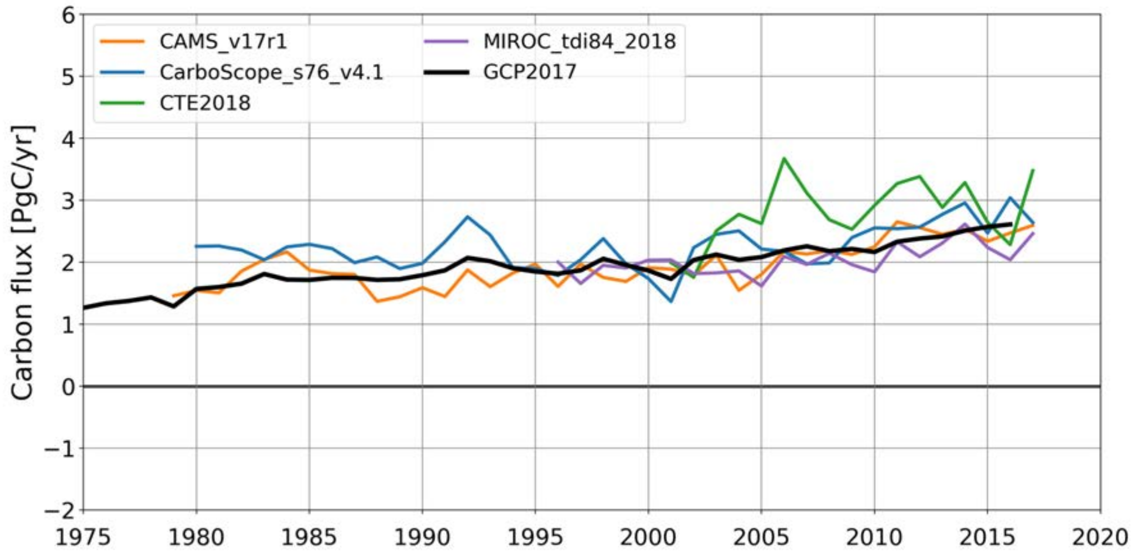
	CAMS	CarboScope	CTE	MIROC
Time period	1979-2017	1980-2017	2001-2017	1996-2017
Transport	LMDZ v5A	TM3	TM5	MIROC4-ACTM
Meteorology	ECMWF	NCEP	ECMWF	JRA55
Resolution (degrees)	Glb3.75x1.875	Glb4x5	Glb3x2, eur1x1, nam1x1	Glb2.8x2.8
Fossil fuels	EDGAR scaled to CDIAC	CDIAC	EDGAR+IER, scaled to CDIAC	EDGARv432
Biosphere and fires	ORCHIDEE (clim)+GFEDv4+GFAS	Zero	SiBCASA-GFED4	CASA (climatological)
Ocean	Landschützer et al. (2015)	pCO_2 based product oc_v1.6 (Rödenbeck et al. 2014)	Jacobson et al. (2007) Ocean Inversion Fluxes (OIF)	Takahashi et al. (2009)
Observations	Daily averages well-mixed cond. GVP3.2, NRT4.2, WDGCC, RAMCES, ICOS	Flask and hourly	Hourly resolution well-mixed cond. GVP3.2, NRT4.2.	Flask and continuous, GVP3.2, GVP4.0
Optimization	Variational	Conjugate Gradient (re-ortho-normalization)	Ensemble Kalman Filter	Matrix method, 84 regions

Global carbon budget 2018: inversions

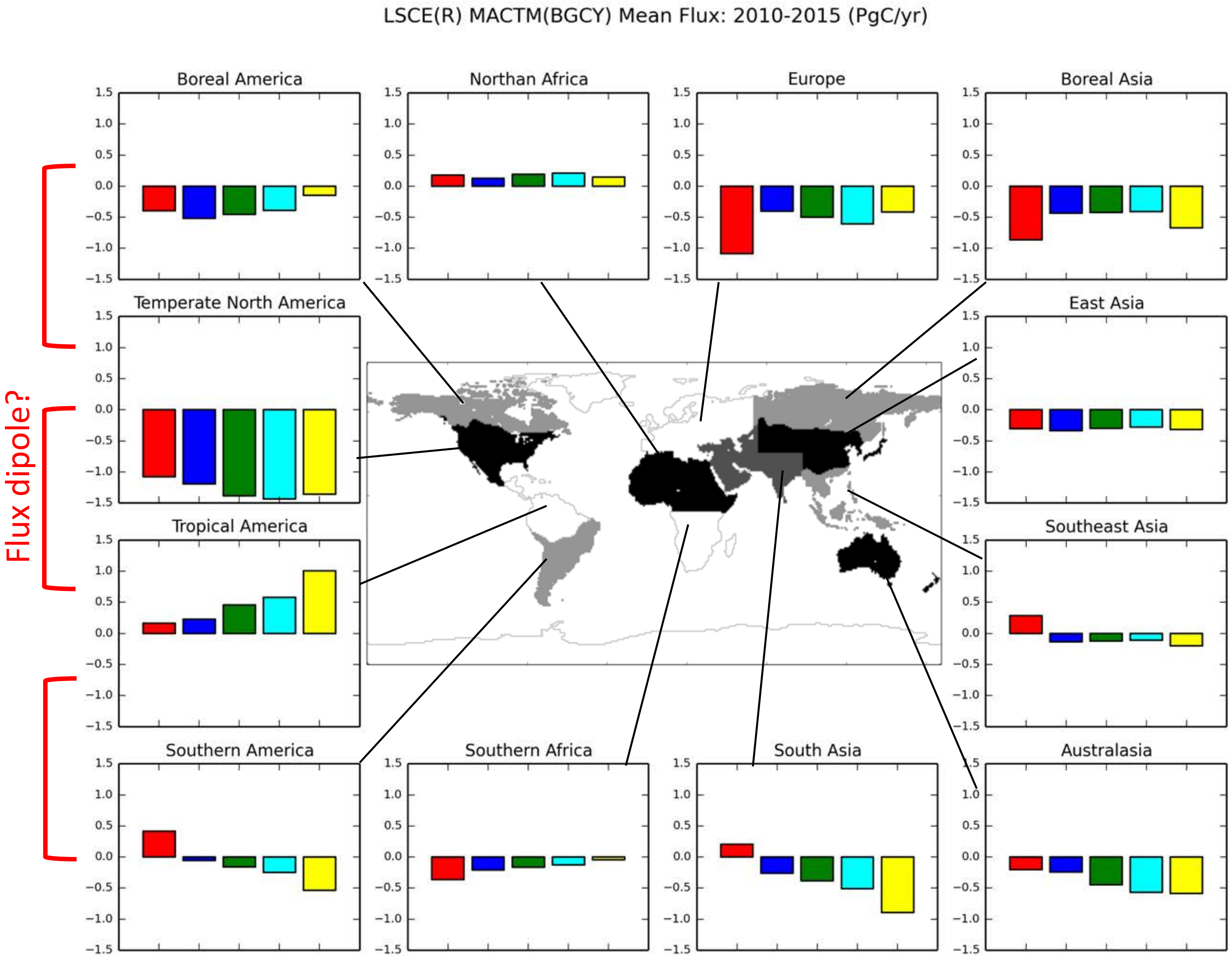
van der Laan-Luijkx et al.







Land regions:
MIROC4-ACTM sensitivity runs (for varying a priori uncertainty) compared with LSCE inversion



Control (L=1.0, O=0.5 PgC)
HiLnd (L=2.0, O=0.5 PgC)
HiOcn (L=2.0, O=1.0 PgC)
CONTRAIL (L=1.0Pg, O=0.5)

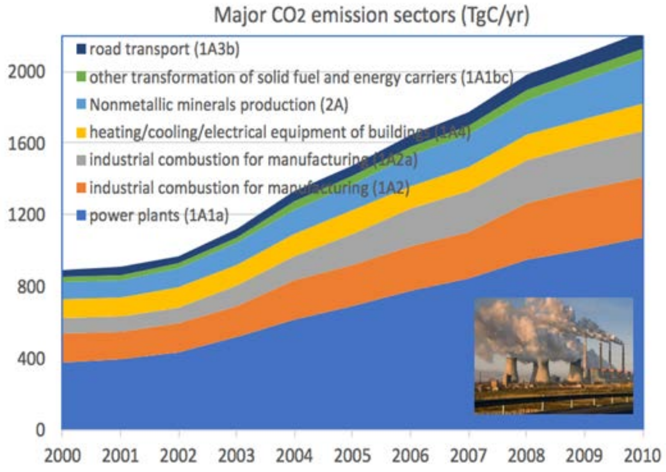
Analysis by:
Kenji Ono

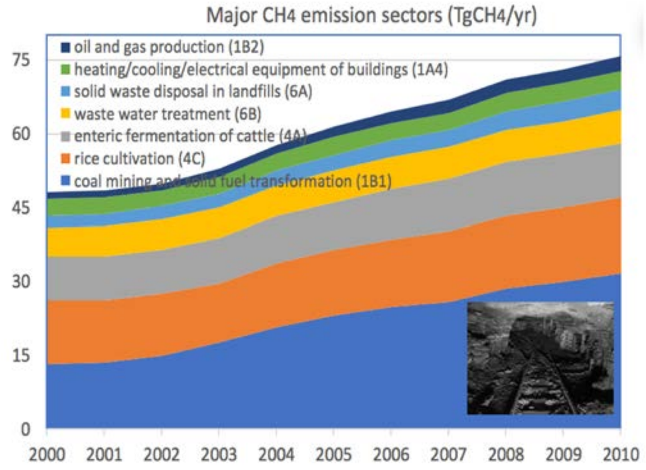
CO_2 and CH_4 emission (covariation)

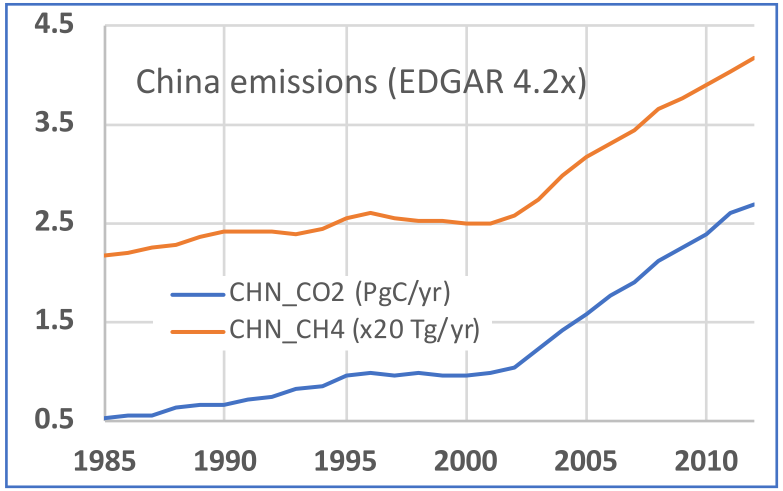
- A good linearity between anthropogenic emission inventories of CO_2 and CH_4 over the period of 1970s - 2012 (EDGAR4.x)

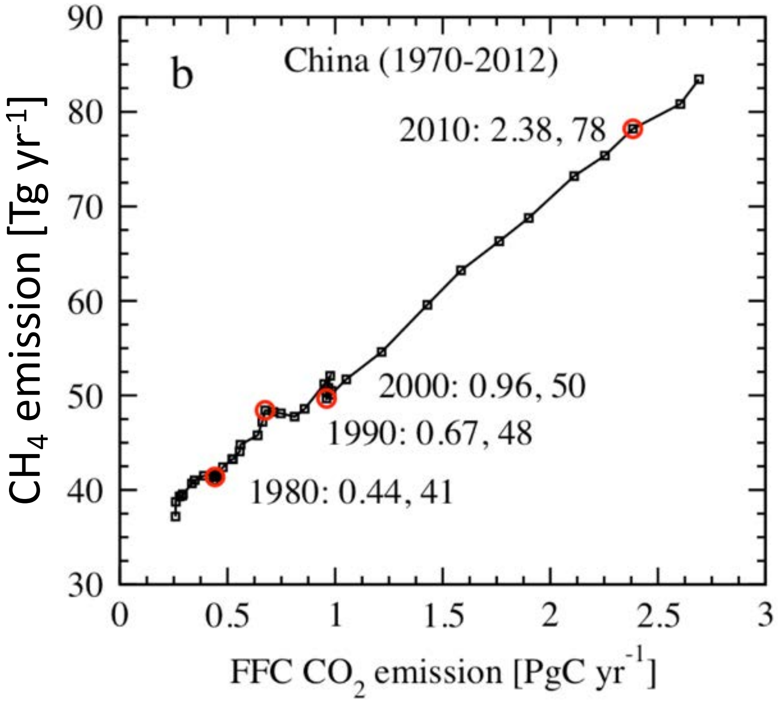
- The main driver for CO_2 and CH_4 emission increases is the coal mining and burning in China

- Linearity arises from the constant emission factors used for each of the emission processes ??









Notes

- Ms. Naoko Okamura, MEXT
- Mr. Takashi Matsuo, ADB – established in 1966, 20 b$
- Special session 1: Cross over issues of Data sharing, AO-DataCube (TG10 & TG11), User engagement and communication (TG12)
  - Qinhuo Liu (RADI, CAS)