The 9TH GEOSS Asia-Pacific Symposium

Earth Observations Supporting the Implementation of the SDGs in the Asia Pacific Region
Tokyo, Japan, 11 – 13 January 2017

WG3: THE GEO CARBON AND GHG INITIATIVE

Global Carbon Project (GCP) - Regional Carbon Cycle Assessment and Processes (RECCAP) in Asia

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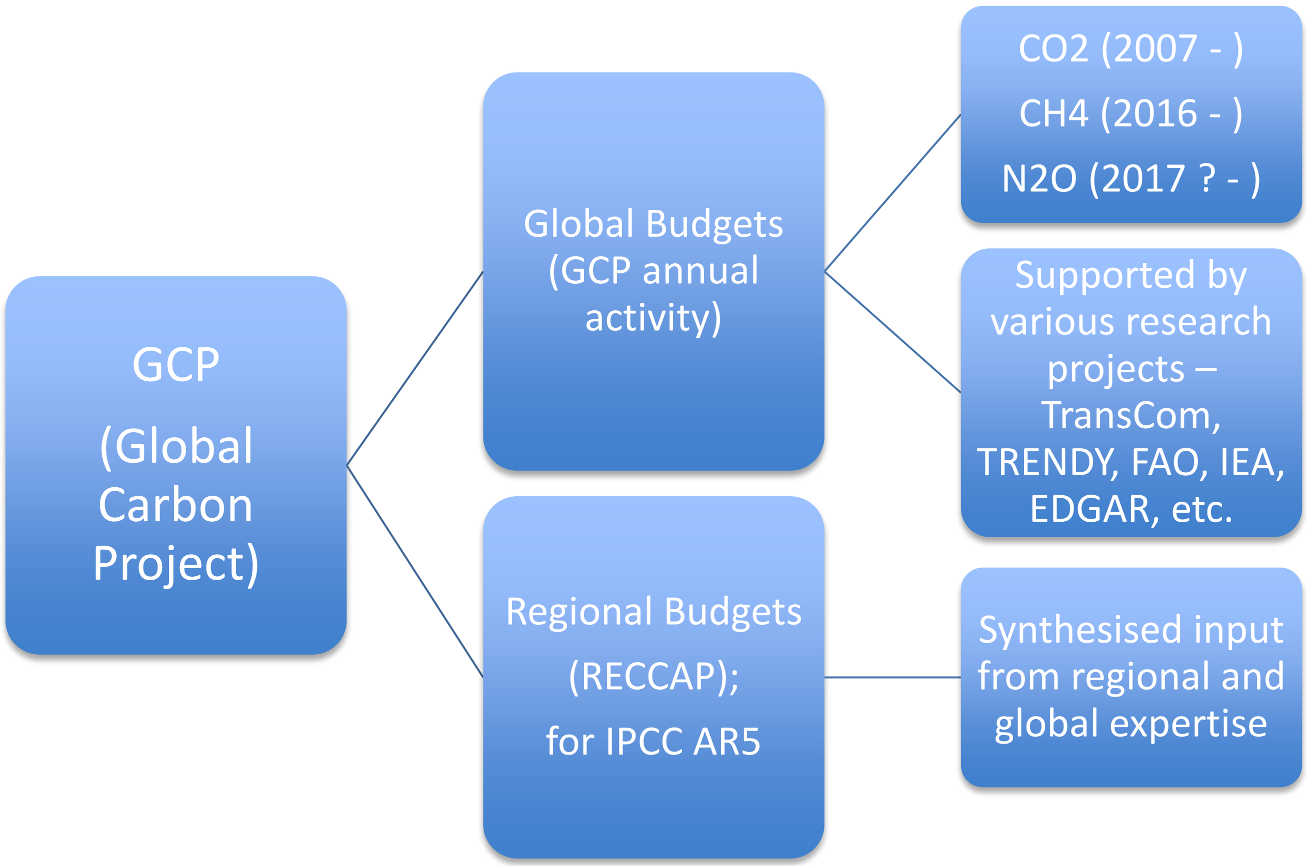
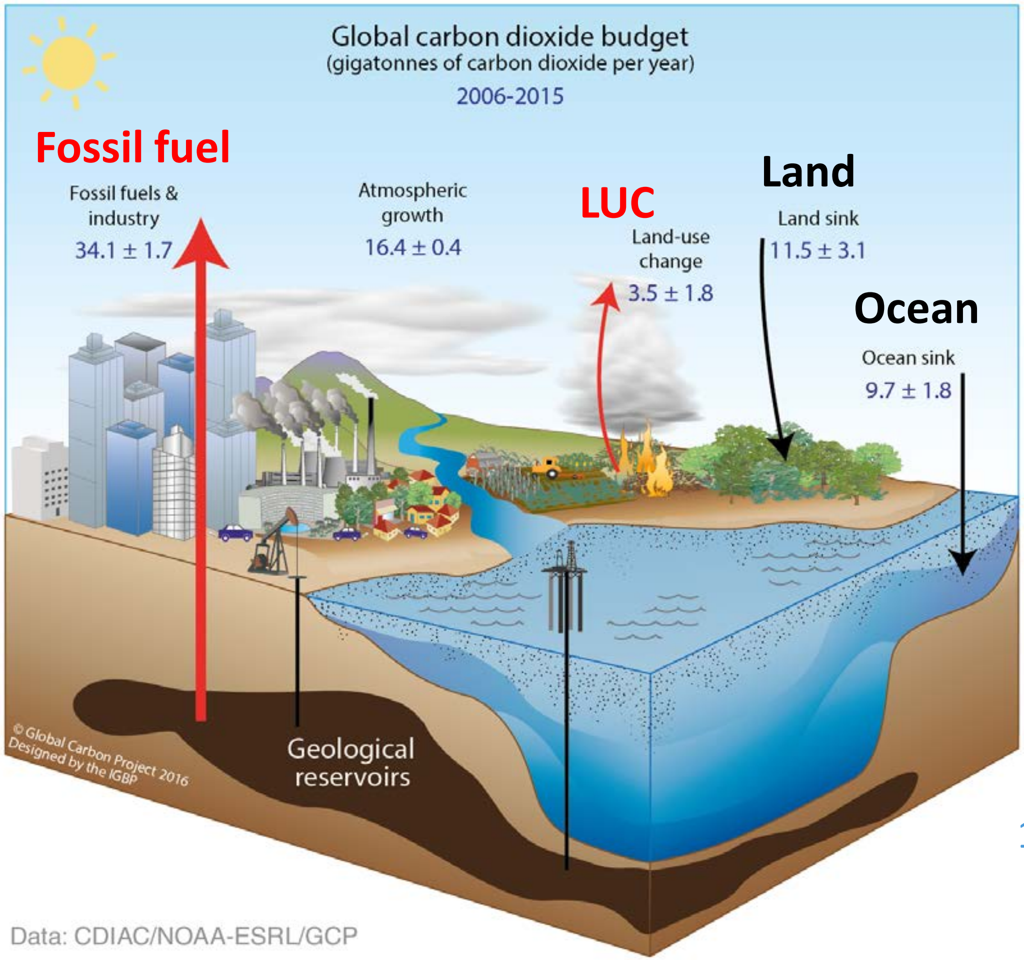
MEXT

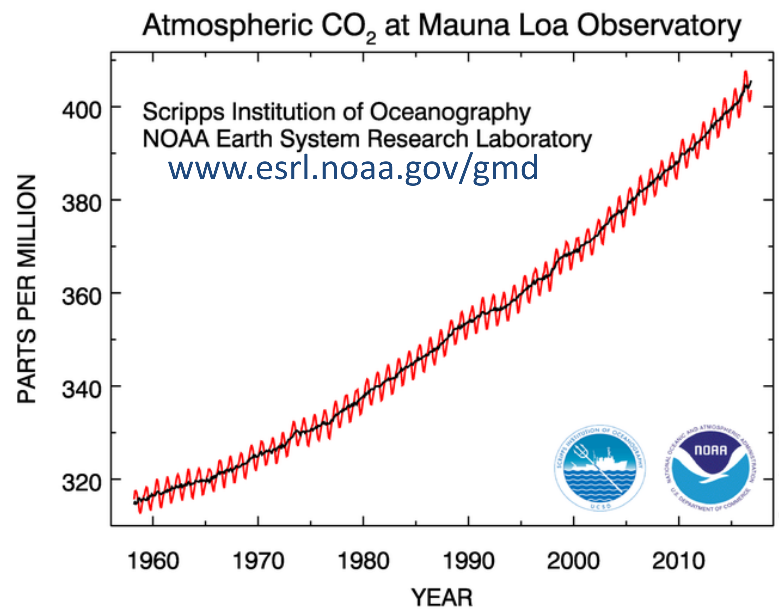
環境省 MoE Suishin-hi

Talk outline



Global CO_2 cycle





Global Carbon Project: www.globalcarbonproject.org
Le Quéré et al., 2016

1 Gigatonne (Gt) = 1 billion tonnes = 1×10^{15}g = 1 Petagram (Pg)

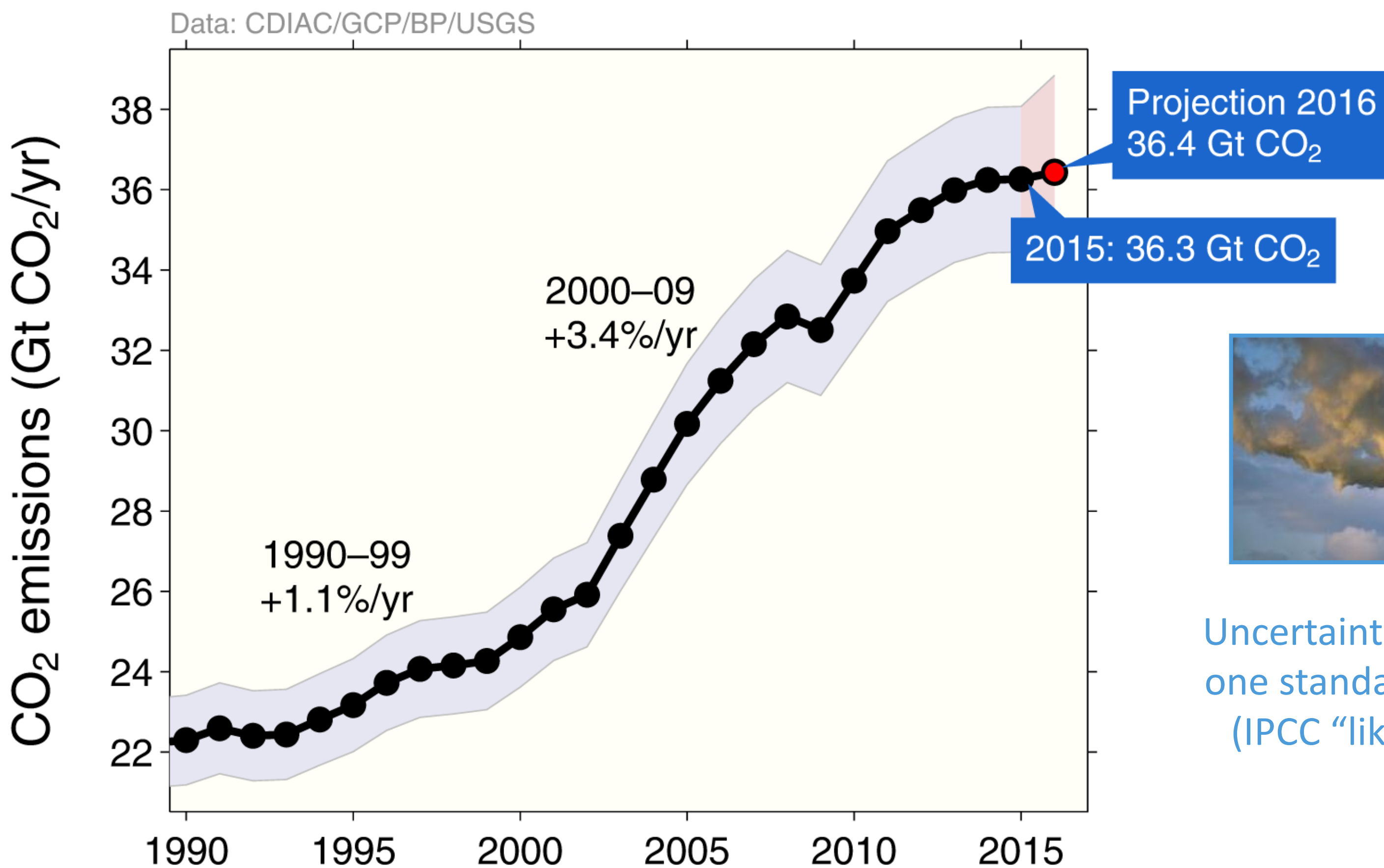
1 kg carbon (C) = 3.664 kg carbon dioxide (CO_2)

1 GtC = 3.664 billion tonnes CO_2 = 3.664 $GtCO_2$

Emissions from fossil fuel use and industry

Global emissions from fossil fuel and industry: 36.3 ± 1.8 GtCO_2 in 2015, 63% over 1990

● Projection for 2016: 36.4 ± 2.3 GtCO_2, 0.2% higher than 2015

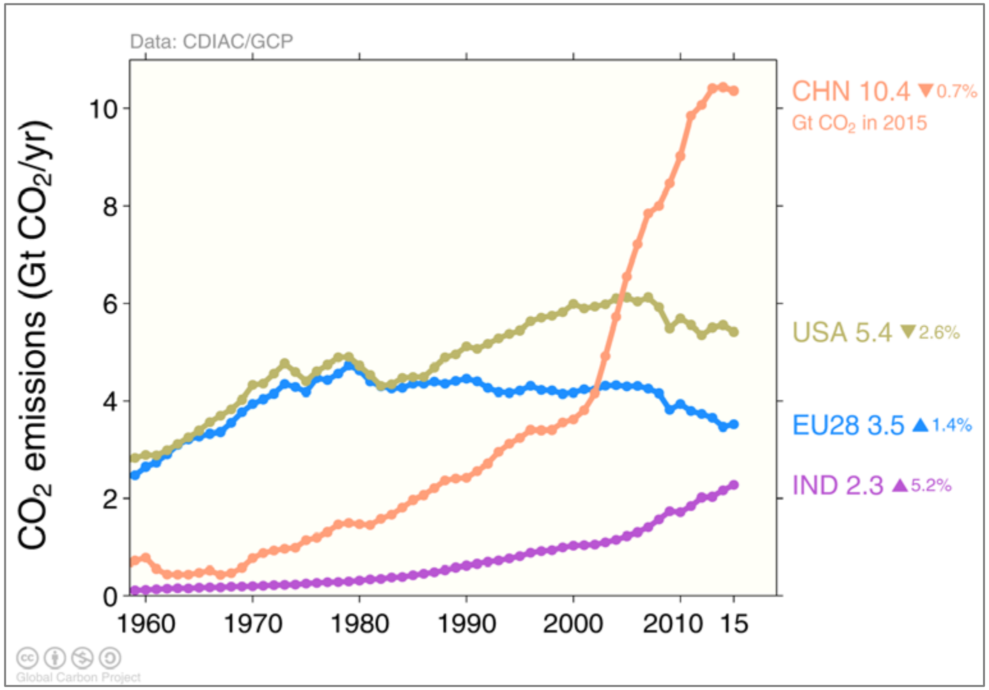


Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

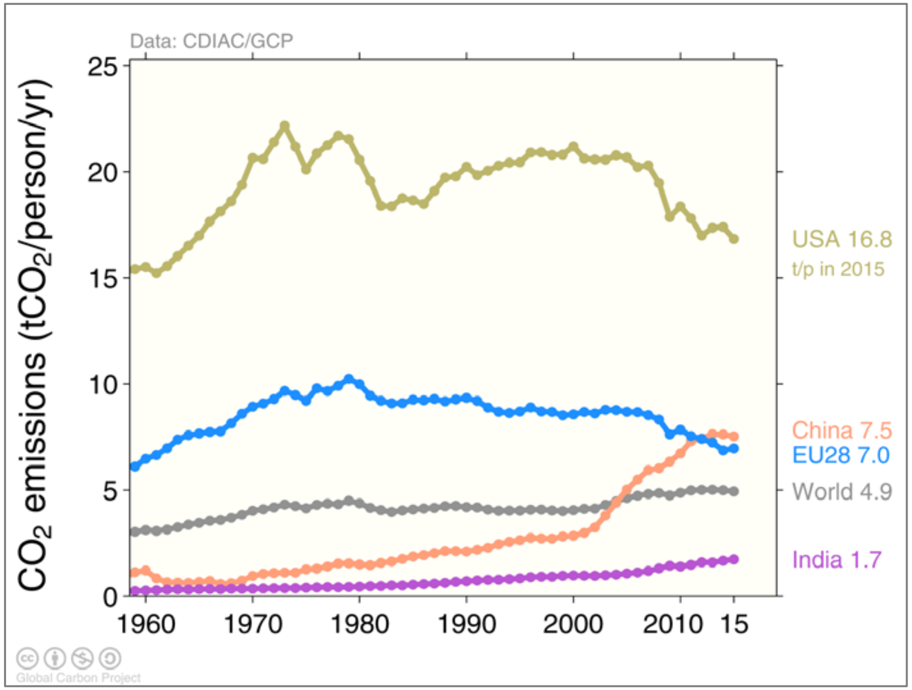
Estimates for 2014 and 2015 are preliminary. Growth rate is adjusted for the leap year in 2016.
Source: CDIAC; Le Quéré et al 2016; Global Carbon Budget 2016

Top emitters: fossil fuels and industry (absolute)

The top four emitters in 2015 covered 59% of global emissions
China (29%), United States (15%), EU28 (10%), India (6%)



Countries have a broad range of per capita emissions reflecting their national circumstances



Statistical differences between the global estimates and sum of national totals are 1.2% of global emissions.
Source: CDIAC; Le Quéré et al 2016; Global Carbon Budget 2016

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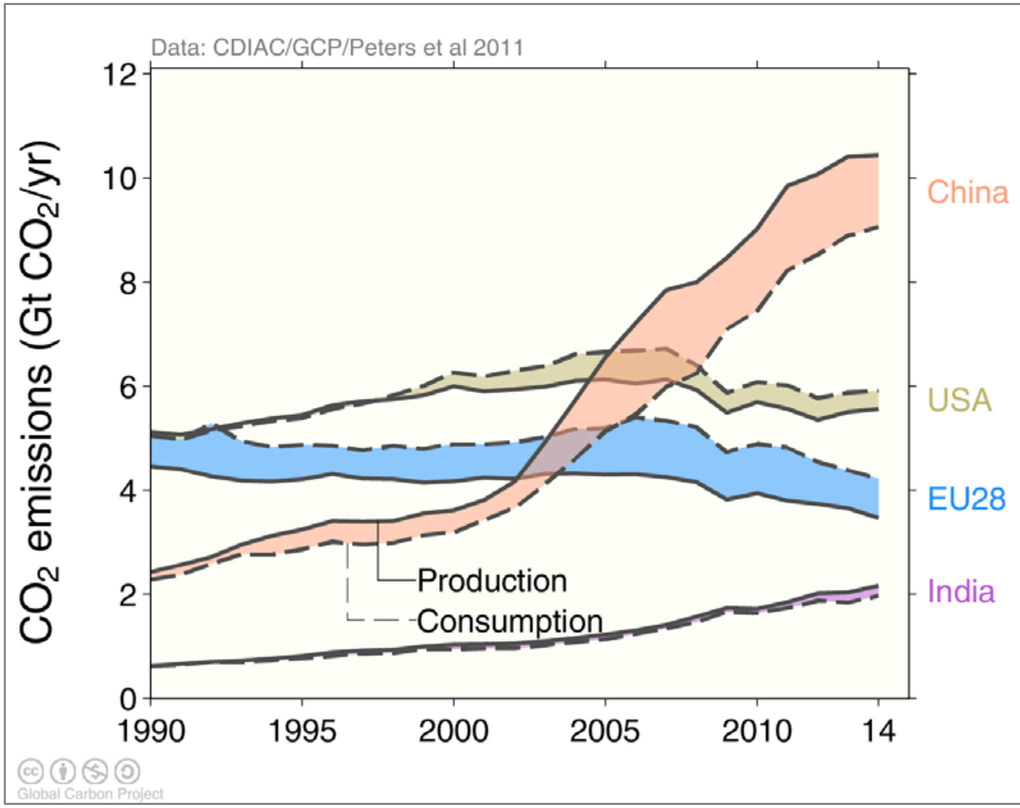
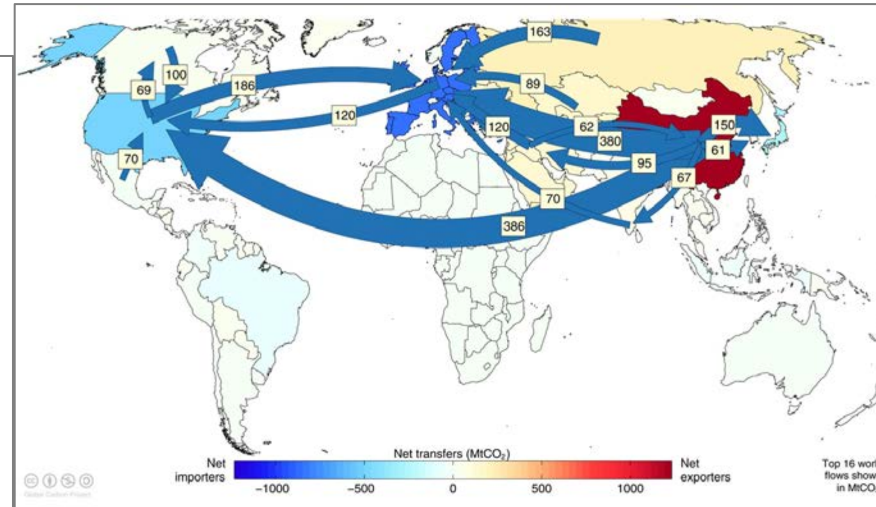
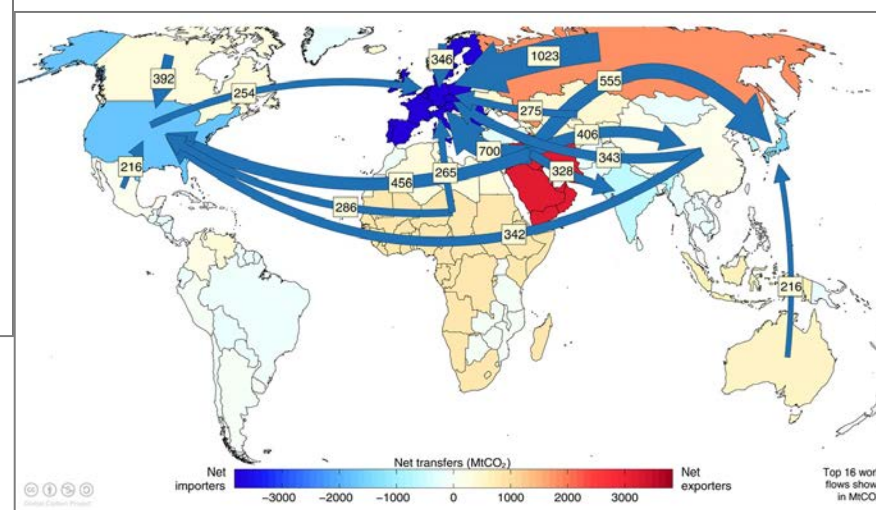
Consumption-based emissions (carbon footprint)

Allocating emissions to the consumption of products provides an alternative perspective
USA and EU28 are net importers of embodied emissions, China and India are net exporters





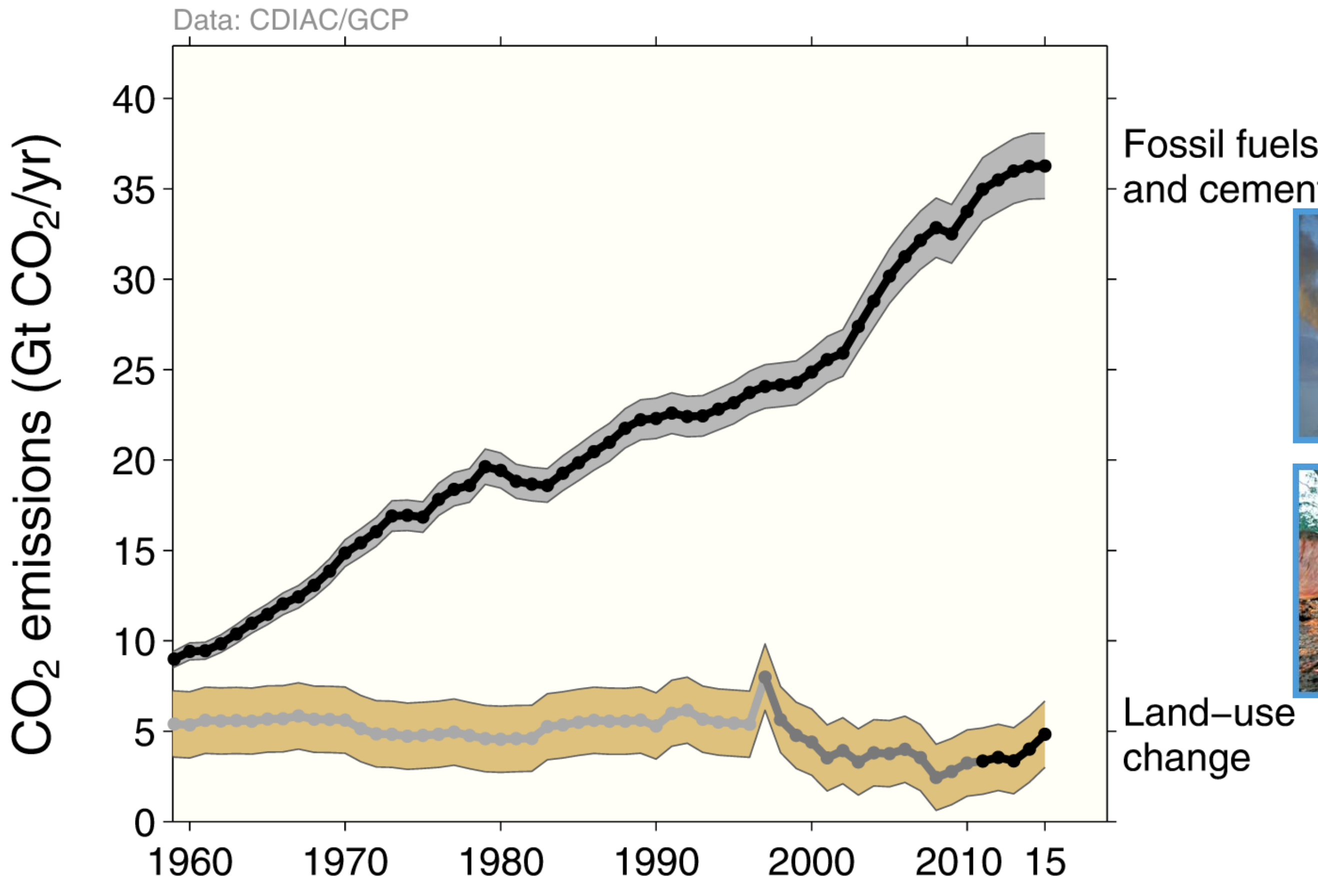


Consumption-based emissions are calculated by adjusting the standard production-based emissions to account for international trade

Source: Peters et al 2011; Le Quéré et al 2016; Global Carbon Project 2016

Total global emissions

Total global emissions: 41.9 ± 2.8 $GtCO_2$ in 2015, 49% over 1990
Percentage land-use change: 36% in 1960, 9% averaged 2006-2015



Three different methods have been used to estimate
land-use change emissions, indicated here by different shades of grey

Source: CDIAC; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2016

Fate of anthropogenic CO_2 emissions (2006-2015)

34.1 $GtCO_2$/yr

91%

9%

3.5 $GtCO_2$/yr

Sources = Sinks

16.4 $GtCO_2$/yr

44%

31%

11.6 $GtCO_2$/yr

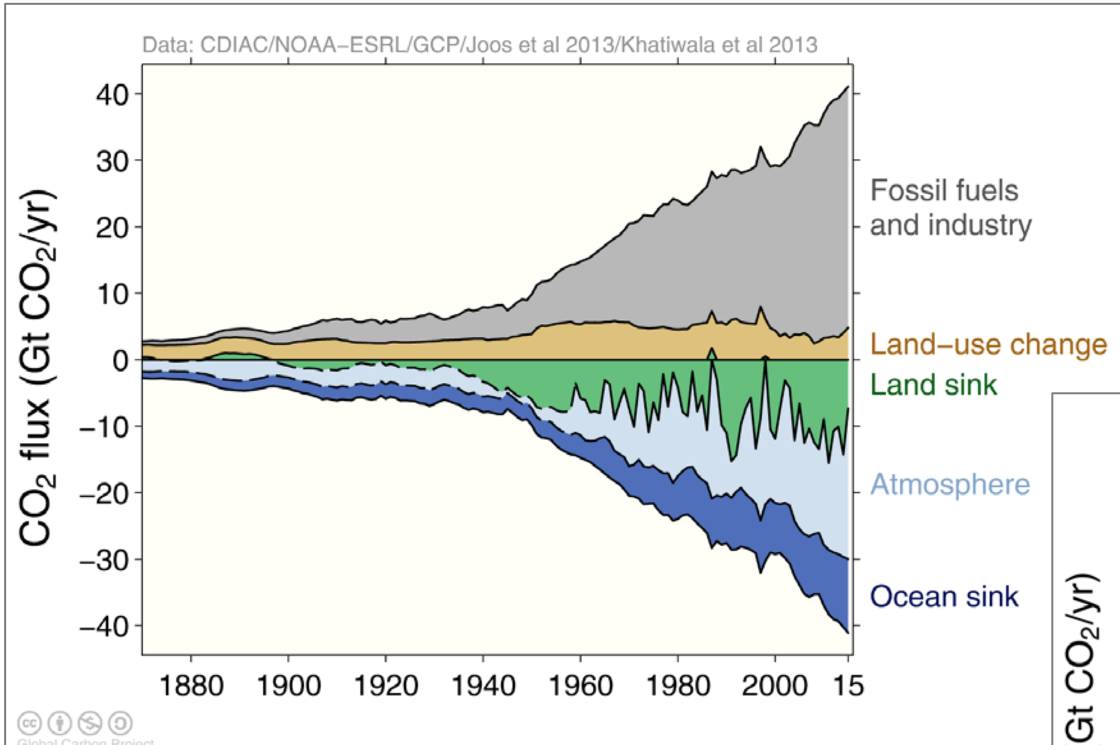
26%

9.7 $GtCO_2$/yr

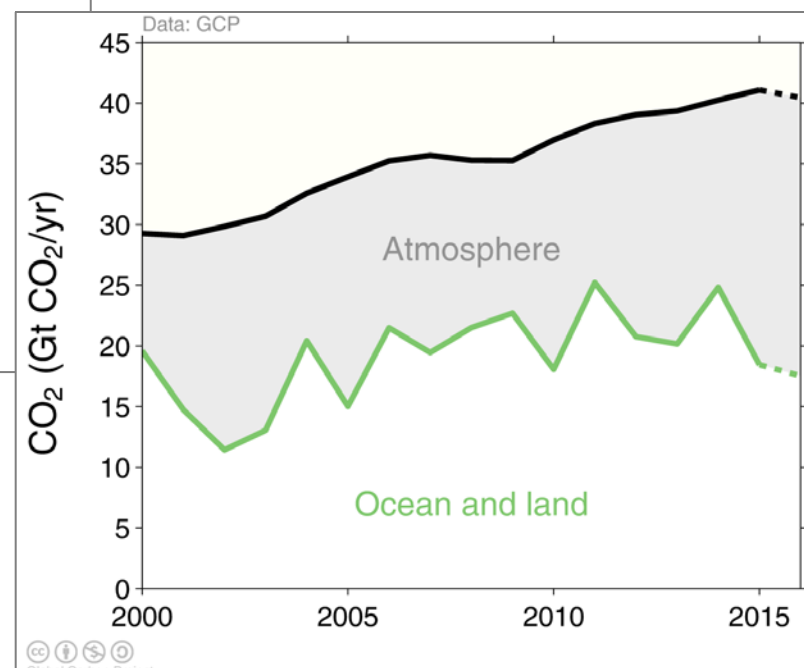
Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2016

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



Partitioning of total CO_2 emissions

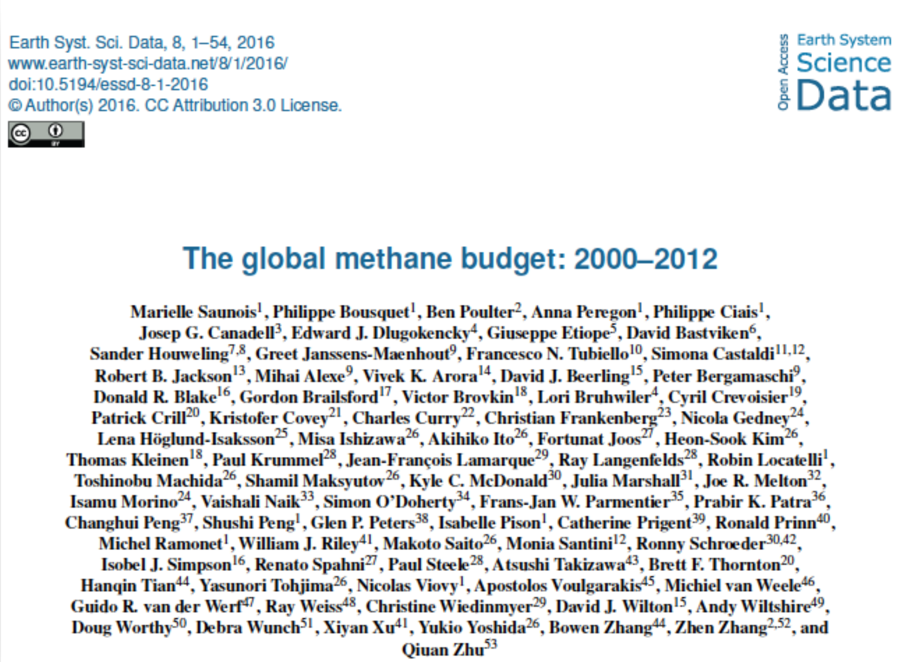


How much flux is to Land and Ocean??
uncertainty grows quickly for regional breakdowns

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

The methane (CH_4) context – new to GCP

- After carbon dioxide (CO_2), methane (CH_4) is the second most important greenhouse gas contributing to human-induced climate change.
- For a time horizon of 100 years, CH_4 has a Global Warming Potential 28 times larger than CO_2.
- Methane is responsible for 20% of the global warming produced by all greenhouse gases so far.
- The concentration of CH_4 in the atmosphere is 150% above pre-industrial levels (cf. 1750).
- The atmospheric life time of CH_4 is 9±2 years, making it a good target for climate change mitigation



Earth Syst. Sci. Data, 8, 1–54, 2016
www.earth-syst-sci-data.net/8/1/2016/
doi:10.5194/essd-8-1-2016

Open Access Earth System Science Data

The global methane budget: 2000–2012

Marielle Saunois[1], Philippe Bousquet[1], Ben Poulter[2], Anna Peregon[1], Philippe Ciais[1], Josep G. Canadell[3], Edward J. Dlugokencky[4], Giuseppe Etiope[5], David Bastviken[6], Sander Houweling[7,8], Greet Janssens-Maenhout[9], Francesco N. Tubiello[10], Simona Castaldi[11,12], Robert B. Jackson[13], Mihai Alexe[9], Vivek K. Arora[14], David J. Beerling[15], Peter Bergamaschi[9], Donald R. Blake[16], Gordon Brailsford[17], Victor Brovkin[18], Lori Bruhwiler[4], Cyril Crevoisier[19], Patrick Crill[20], Kristofer Covey[21], Charles Curry[22], Christian Frankenberg[23], Nicola Gedney[24], Lena Höglund-Isaksson[25], Misa Ishizawa[26], Akihiko Ito[26], Fortunat Joos[27], Heon-Sook Kim[26], Thomas Kleinen[18], Paul Krummel[28], Jean-François Lamarque[29], Ray Langenfelds[28], Robin Locatelli[1], Toshinobu Machida[26], Shamil Maksyutov[26], Kyle C. McDonald[30], Julia Marshall[31], Joe R. Melton[32], Isamu Morino[24], Vaishali Naik[33], Simon O'Doherty[34], Frans-Jan W. Parmentier[35], Prabir K. Patra[36], Changhui Peng[37], Shushi Peng[1], Glen P. Peters[38], Isabelle Pison[1], Catherine Prigent[39], Ronald Prinn[40], Michel Ramonet[1], William J. Riley[41], Makoto Saito[26], Monia Santini[12], Ronny Schroeder[30,42], Isobel J. Simpson[16], Renato Spahni[27], Paul Steele[28], Atsushi Takizawa[43], Brett F. Thornton[20], Hanqin Tian[44], Yasunori Tohjima[26], Nicolas Viovy[1], Apostolos Voulgarakis[45], Michiel van Weele[46], Guido R. van der Werf[47], Ray Weiss[48], Christine Wiedinmyer[29], David J. Wilton[15], Andy Wiltshire[49], Doug Worthy[50], Debra Wunch[51], Xiyan Xu[41], Yukio Yoshida[26], Bowen Zhang[44], Zhen Zhang[2,52], and Qiuan Zhu[53]

- Methane also contributes to tropospheric production of ozone, a pollutant that harms human health and ecosystems.
- Methane also leads to production of water vapor in the stratosphere by chemical reactions, enhancing global warming.

1 teragram (Tg) = 1 million tonnes = 1×10^{12}g; 2.78 Tg CH4 per ppb

Sources : Saunois et al. 2016, ESDD; Kirschke et al. 2013, NatureGeo.; IPCC 2013 5AR; Voulgarakis et al., 2013

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An ensemble of tools and data to estimate the global methane budget

Bottom-up budget ← Emission inventories, Biogeochemistry models & data-driven methods, Methane sinks

Top-down budget ← Atmospheric observations, Emission inventories, Biogeochemistry models & data-driven methods, Methane sinks, Inverse models

Atmospheric observations

Ground-based data from observation networks (AGAGE, CSIRO, NOAA, UCI, LSCE, others).

Satellite data (SCIAMACHY, GOSAT)

Emission inventories

Agriculture and waste related emissions, fossil fuel emissions (EDGARv4.2, USEPA, GAINS, FAO).

Fire emissions (GFED3 & 4s, FINN, GFAS, FAO).

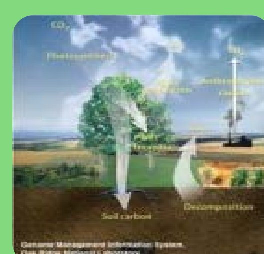
Biofuel estimates

Biogeochemistry models & data-driven methods

Ensemble of 11 wetland models, following the WETCHIMP intercomparison

Model for Termites emissions

Other sources from literature

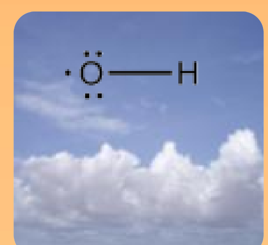


Methane sinks

From Kirschke et al., (2013) Long-term trends and decadal variability of the OH sink.

ACCMIP CTMs intercomparison.

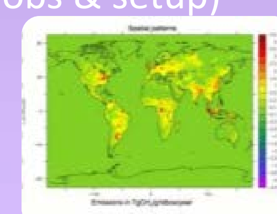
Soil uptake & chlorine sink taken from the literature



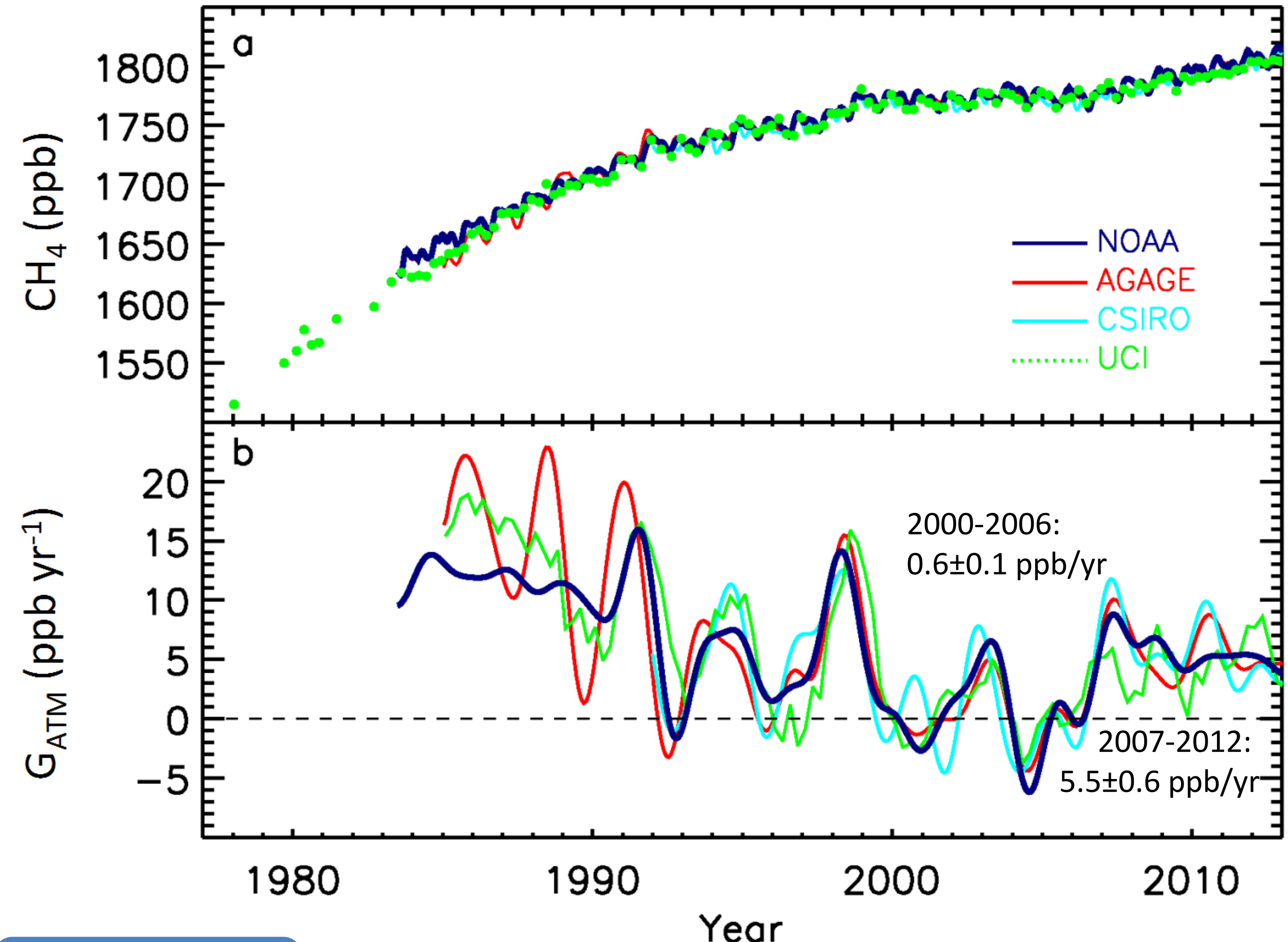
Inverse models

Suite of eight atmospheric inversion models (TM5-4DVAR (JRC & SRON), LMDZ-MIOP, PYVAR-LMDz, C-Tracker-CH_4, GELCA, ACTM, TM3, NIESTM).

Ensemble of 30 inversions (diff. obs & setup)



CH_4 Atmospheric Growth Rate, 1983-2012



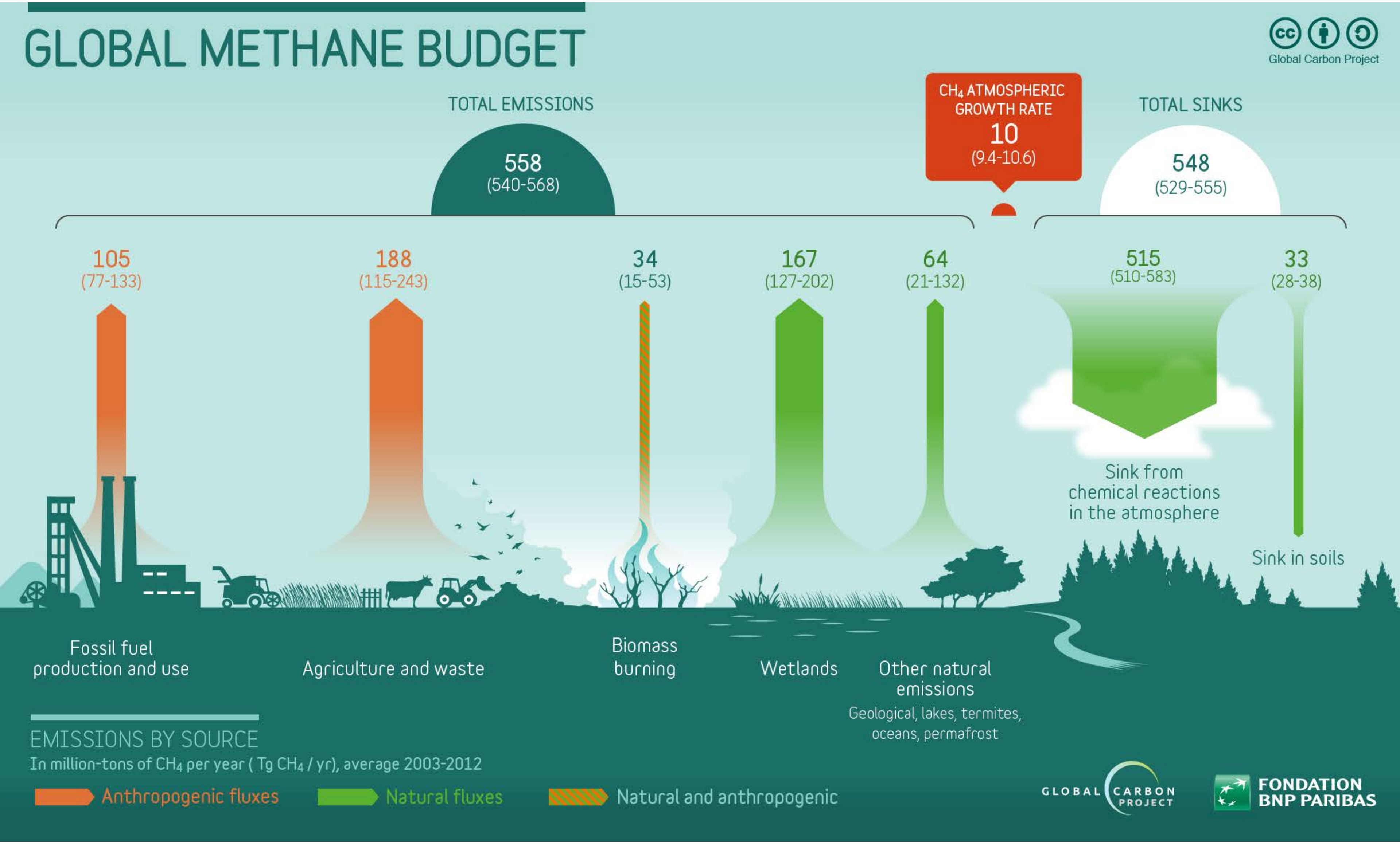
- Slowdown of atmospheric growth rate before 2006
- Resumed increase after 2006

Figure compiled by: Saunois et al. 2016

Atmospheric observations

Data Source: Prinn et al., Dluegokencky et al., Blake et al., Steele et al. and others (Nakazawa et al., Tohjima et al. , Tsuboi et al.)

Global Methane Budget 2003-2012



http://www.globalcarbonatlas.org

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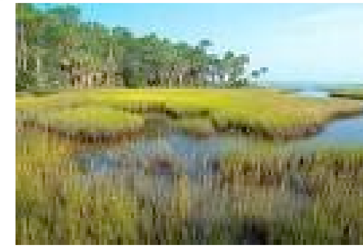
Global methane emissions 2003-2012

Bottom-up budget	($TgCH_4$/yr)	Top-down budget
185 [40%]	← Natural wetlands →	167 [80%]
195 [15%]	← Agriculture & waste →	188 [65%]
Rice 30 [10%]		
Enteric ferm & manure 106 [20%]		
Landfills & waste 59 [20%]		
121 [20%]	← Fossil fuel use →	105 [50%]
Coal 42 [80%]		
Gas & oil 79 [10%]		
30 [30%]	←Biomass/biofuel burning→	34 [55%]
199 [90%]	←Other natural emissions→	64 [150%]
Fresh waters 122 [100%]		
Wild animals 10 [100%]		
Wild fires 3 [100%]		
Termites 9 [120%]		
Geological 40 [50%]		
Oceans 3 [100%]		
Permafrost 1 [100%]		



Mean [uncertainty= min-max range %]

Mean [uncertainty= min-max range %]

Bottom-up budget
Process models, inventories, data driven methods
734 $TgCH_4$/yr [596-884]

Mean [min-max range %]

Top-down budget
Atmospheric inversions
559 $TgCH_4$/yr [540-568]

Source : Saunois et al. 2016, ESSD

REgional Carbon Cycle Assessment and Processes

>130 collaborators

Land

L1 Africa
L2 Arctic tundra
L3 Australia
L4 Europe
L5 North America
L6 Russia
L7 South America
L8 East Asia
L9 Southeast Asia
L10 South Asia

Oceans

O1 Pacific
O2 Atlantic and Arctic
O3 Southern Ocean
O4 Indian

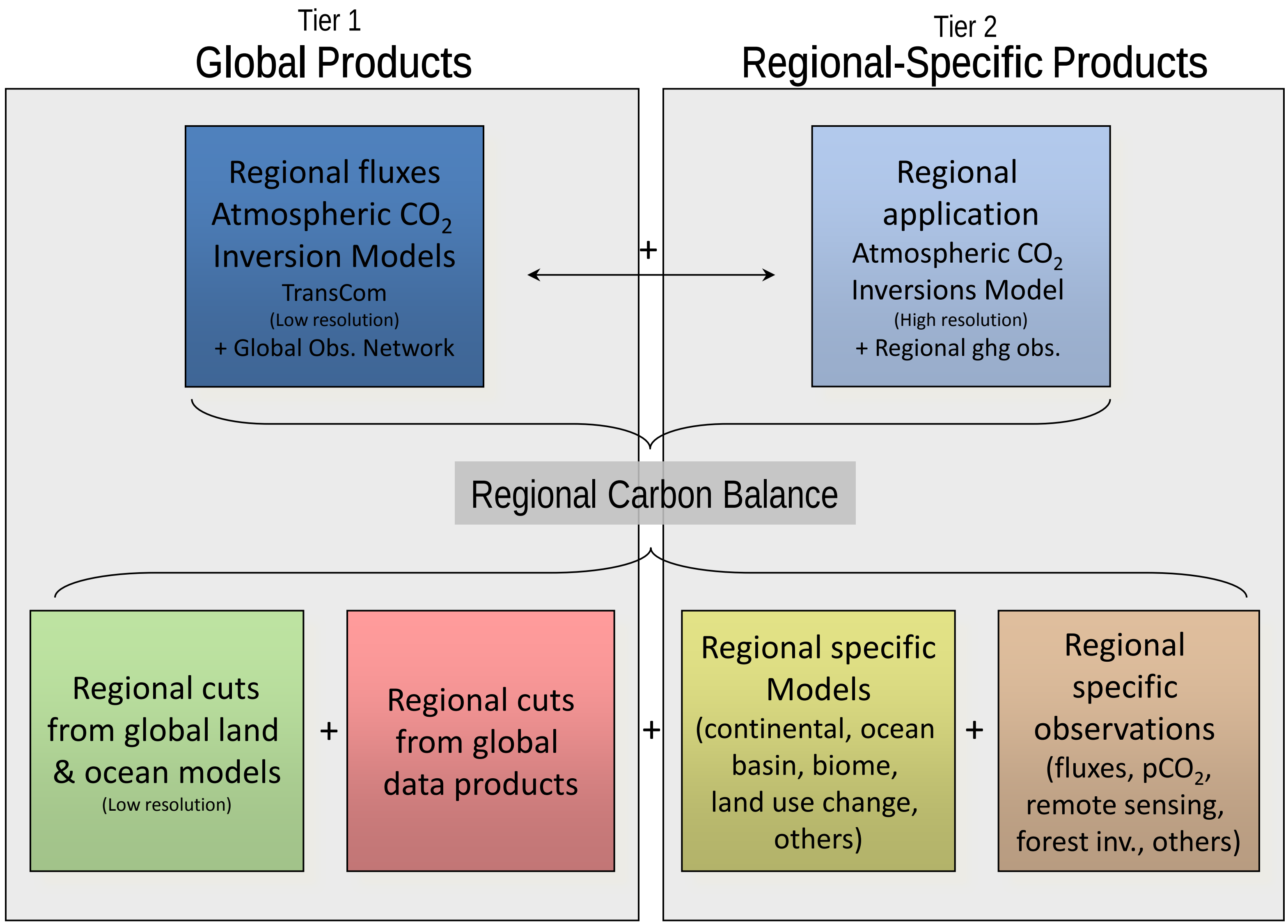
RECCAP (2007-2013)

Global

- Fossil Fuel Emissions
- Land Use Change emissions
- Riverine transport
- Atmospheric inversions
- Marginal seas
- Interior ocean
- Air-sea flux
- Coastal zones

Canadell et al., EOS, 2011

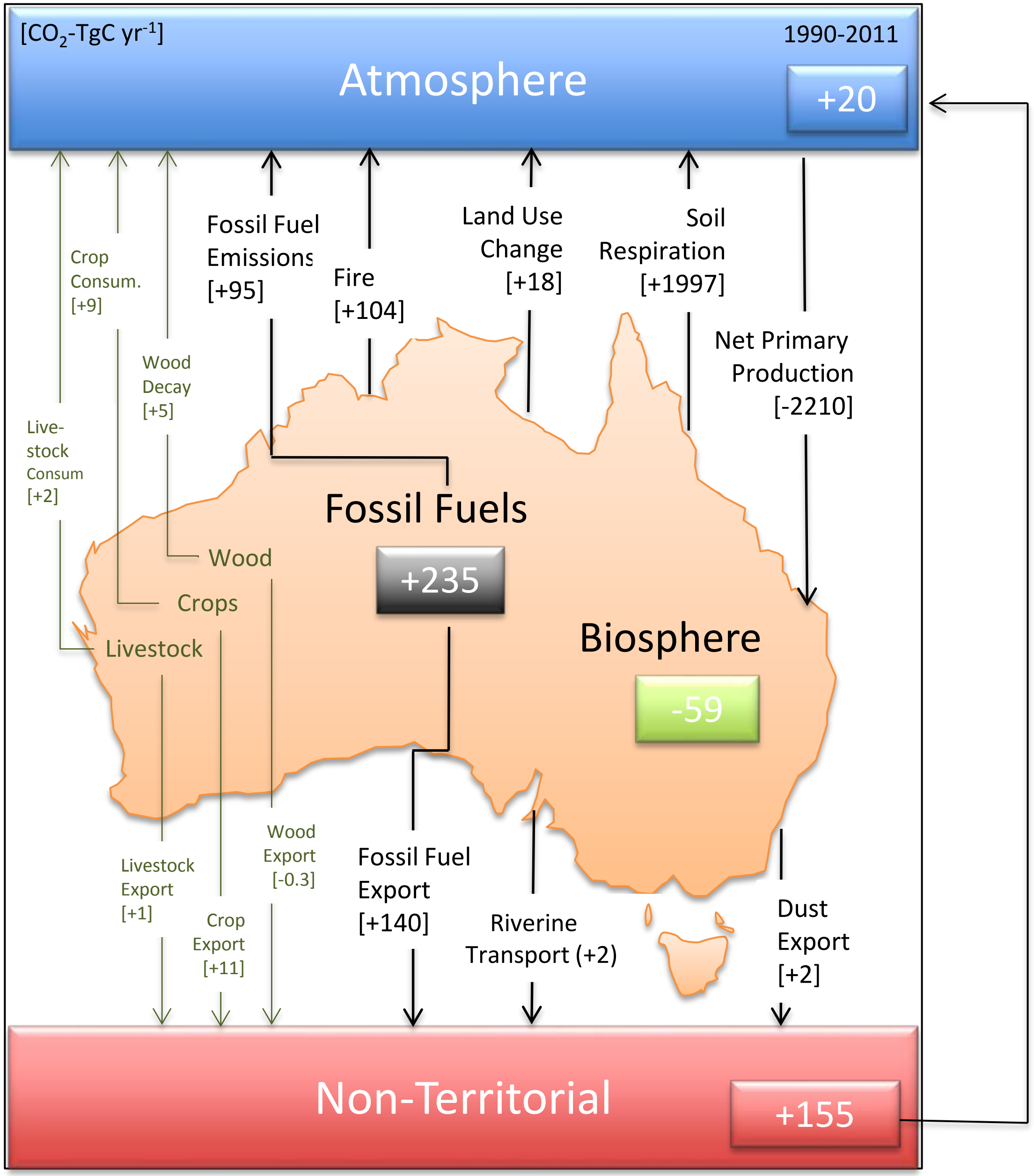
Components of Regional Syntheses



Tier 1 model outputs are coordinated by RECCAP

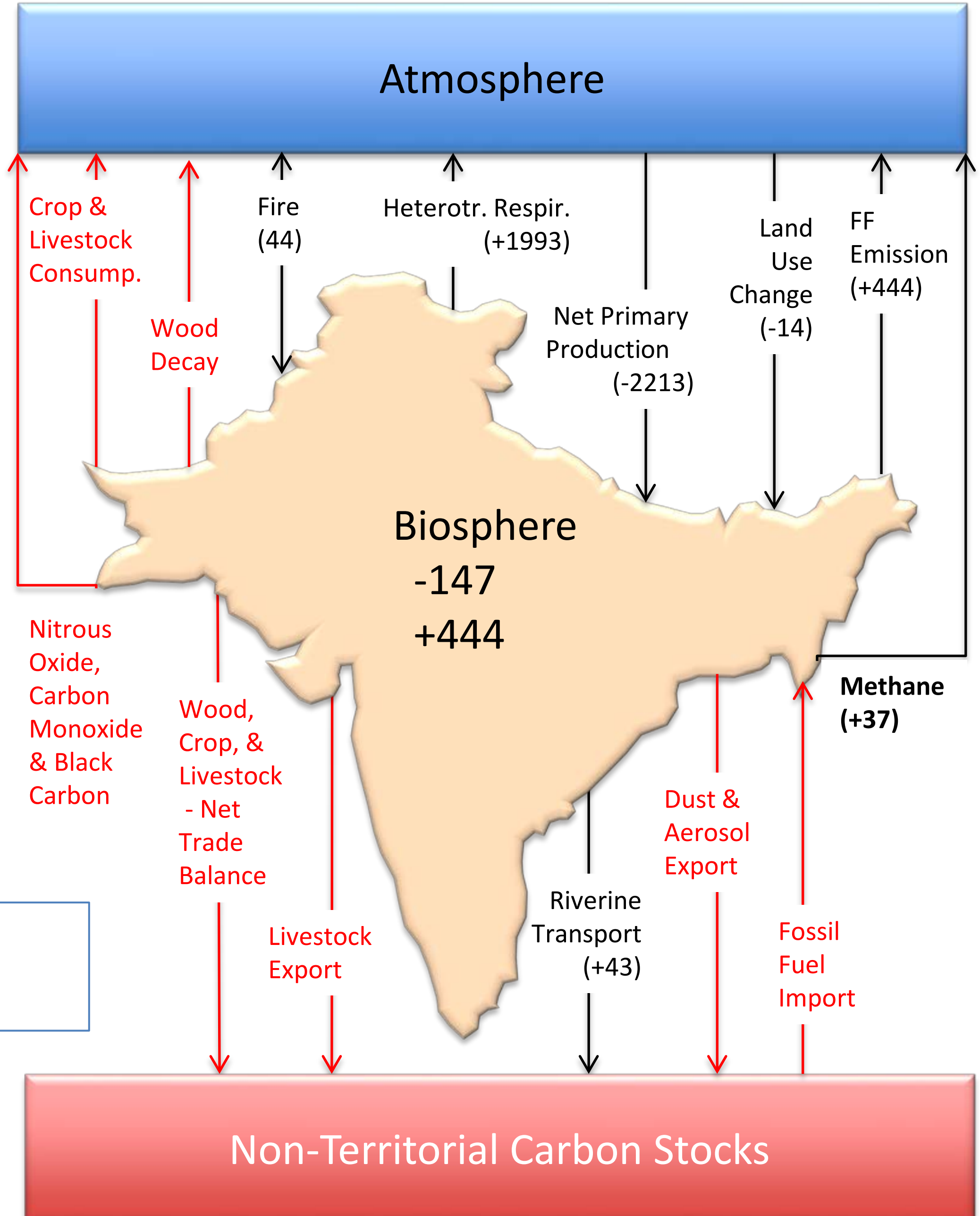
Australia CO_2 Budget (1990-2011)

Bottom-up estimations only



Haverd et al. 2013 a, b. Biogeosciences

The South Asian Carbon Budget

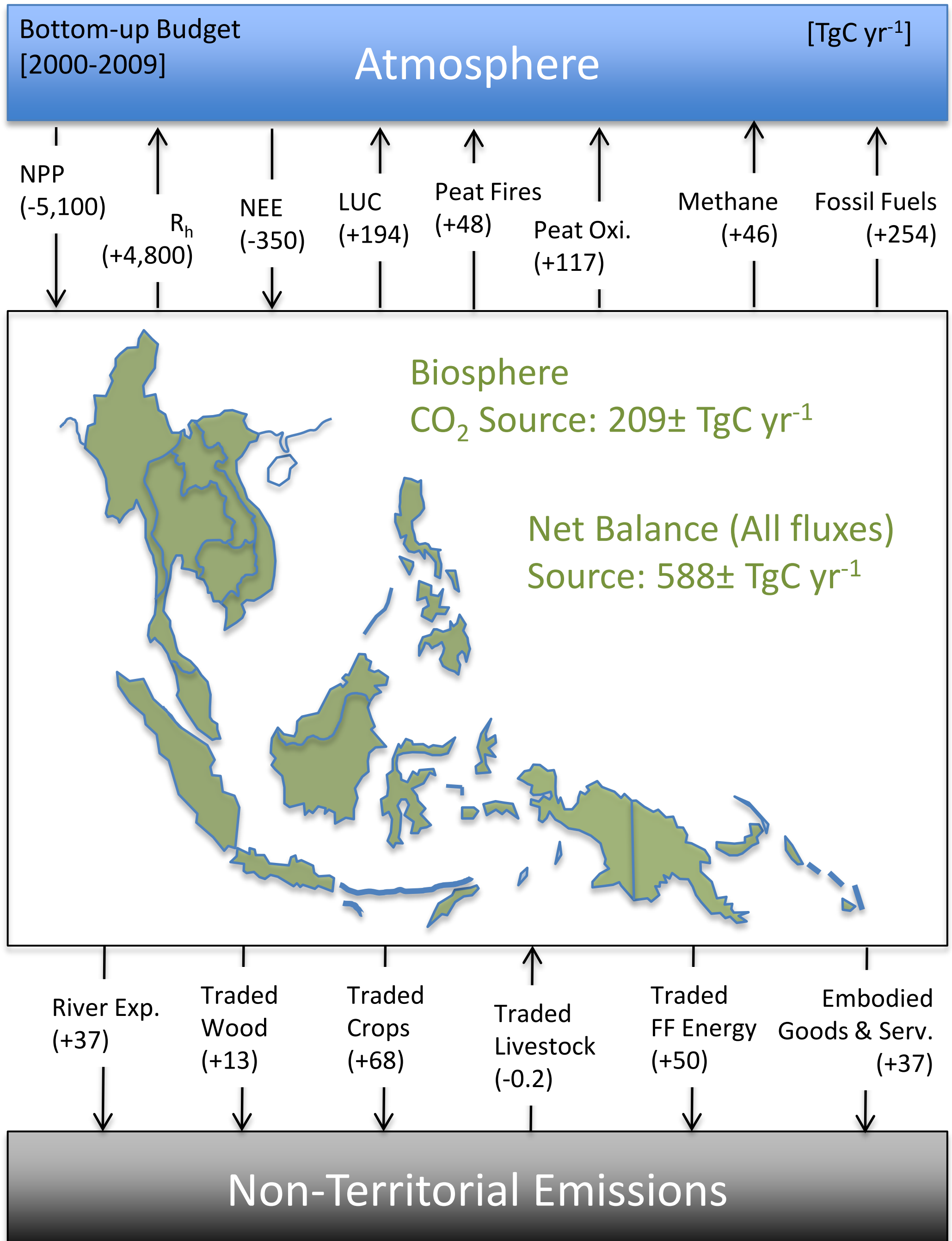


Bottom-up estimations and top-down estimations

Asia Pacific Network (APN) for Global Change Research **(ARCP2013-01CMY-Patra/Canadell)**

Patra et al. 2013, Biogeosciences

The Southeast Asian Carbon budget



Asia Pacific Network (APN)
for Global Change Research
(ARCP2013-01CMY-Patra/Canadell)

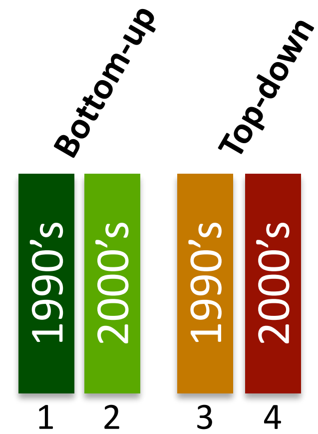
Canadell, Patra et al, in preparation

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**)



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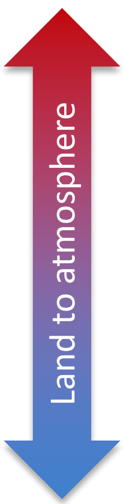
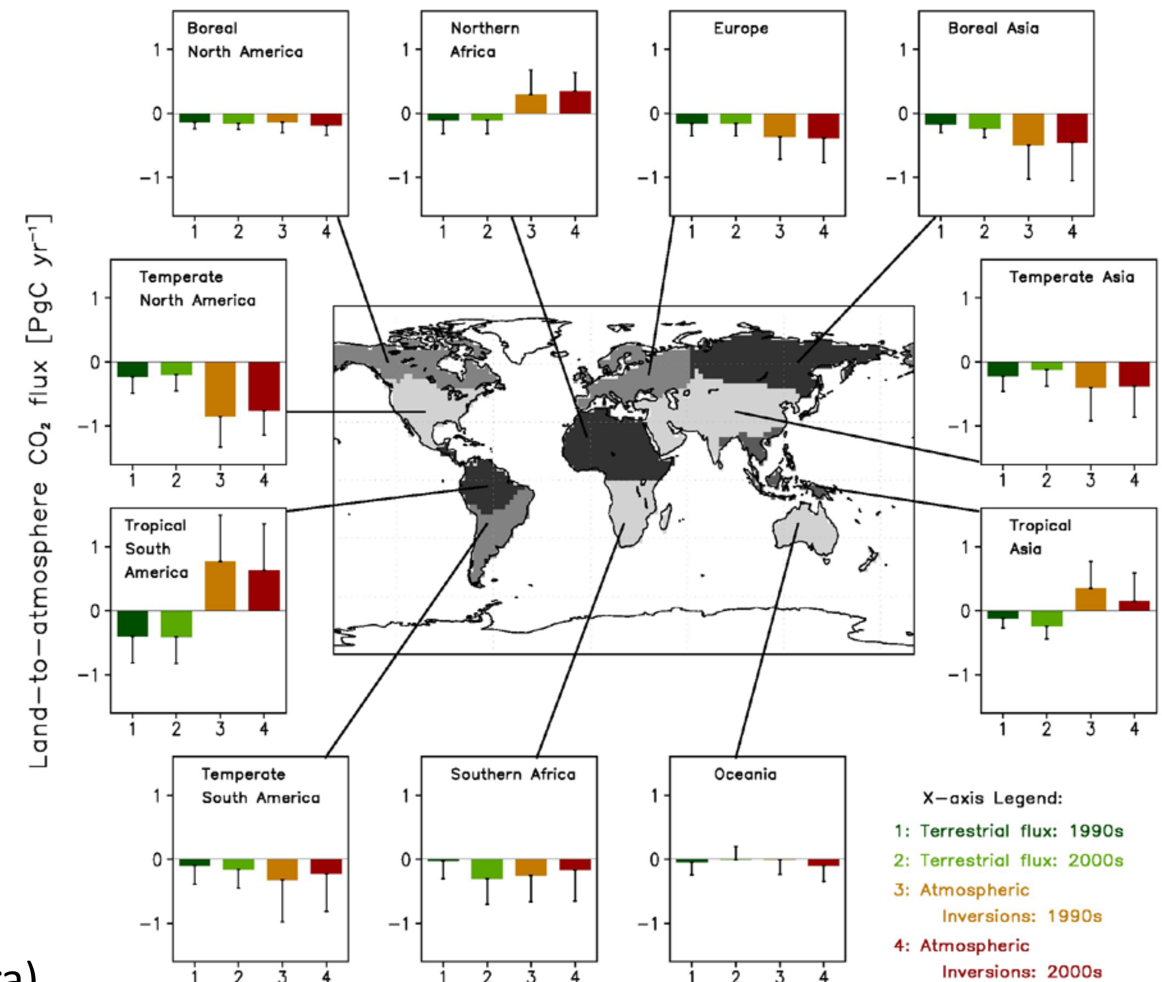


-: sink



IPCC AR5, 2013

Fig. 6.15 (by P. Patra)

Data access

More information, data sources and data files:
www.globalcarbonatlas.org
(funded in part by BNP Paribas Foundation)
Contact: philippe.ciais@lsce.ipsl.fr

How the Earth observations can help us further?

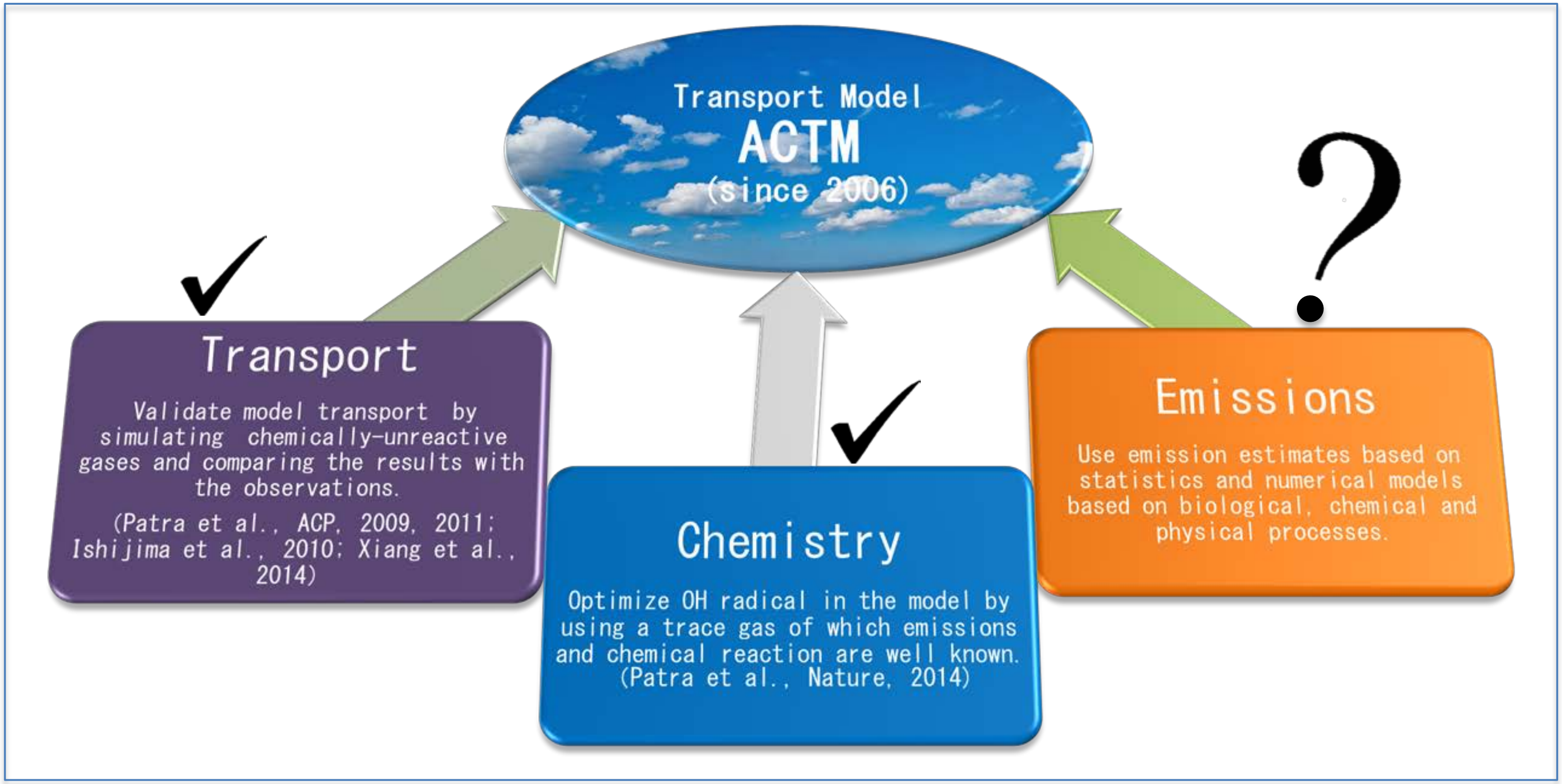
Our Evolved Philosophy for inverse modelling:

going multi-species and more accurate transport

$$\frac{dCH_4(x,y,z,t)}{dt} = S_{CH4}(x,y,t) - L_{CH4}(x,y,z,t) - \nabla \bullet \Phi_{CH4}(x,y,z,t)$$

Concentration — Emission/Sinks — Chemistry/Loss — Transport

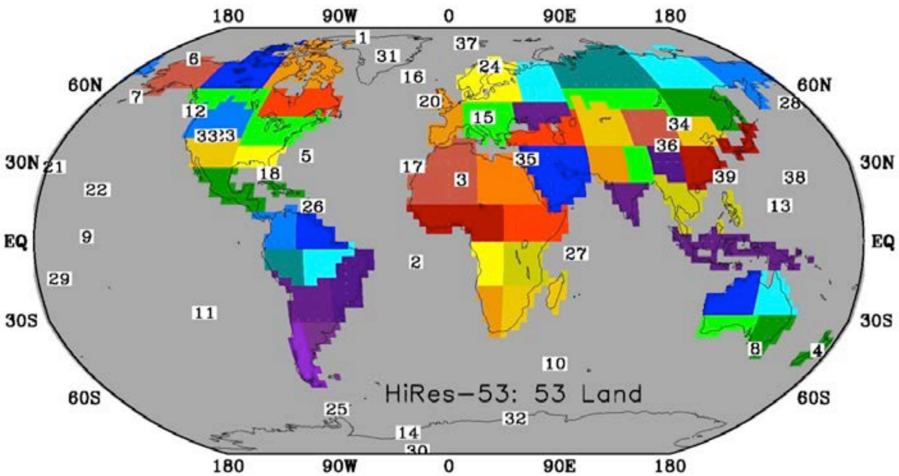
CH_4+OH/O[1]D/Cl →



CCSR/NIES/FRCGC AGCM5.7b-based Chemistry-Transport Model (**ACTM**) is developed in JAMSTEC

(AGCM by Numaguti et al.; CTM by **Takigawa et al.**; GHGs/ODSs by Patra/Ishijima et al.; EnKF by Miyazaki et al.)

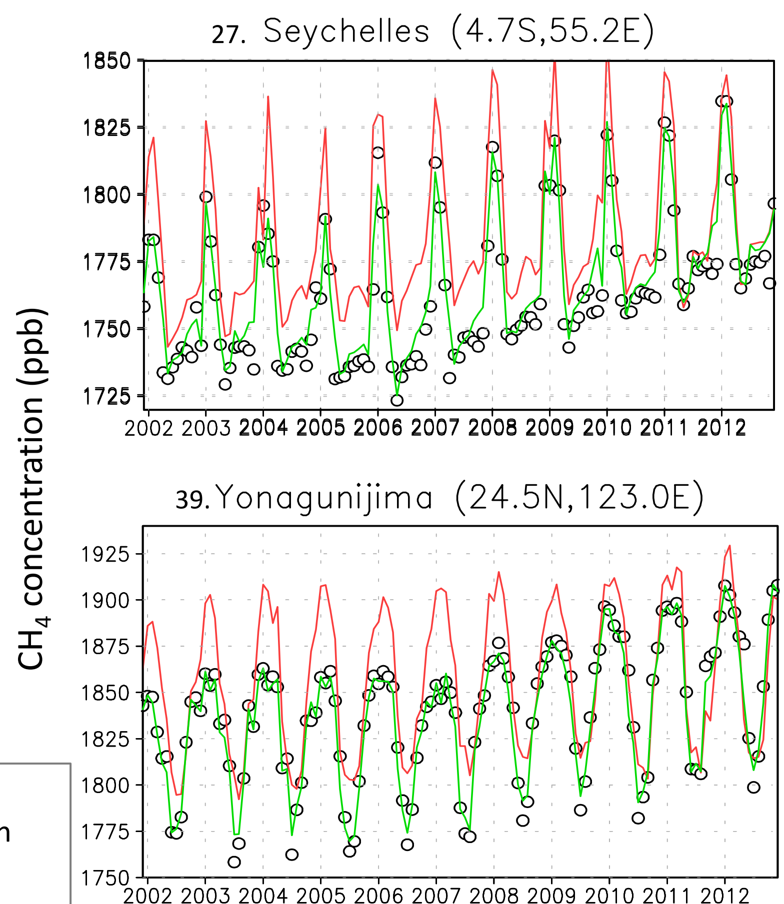
53-Regions (land only) Inverse Model for CH_4



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

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

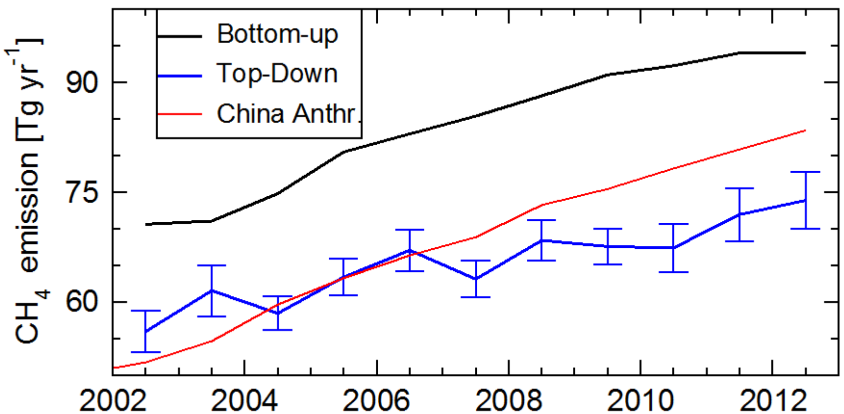
S_0 = regional prior sources
C_{S0} = Prior source covariance = 50% of region-total emission for each month
D = atmospheric concentration data
C_D = **D**ata covariance = 10 ppb; 5 ppb for measurements + 5 ppb for model
D_{ACTM} = ACTM simulation using S_0
G = Green's functions for regional source-receptor relationships



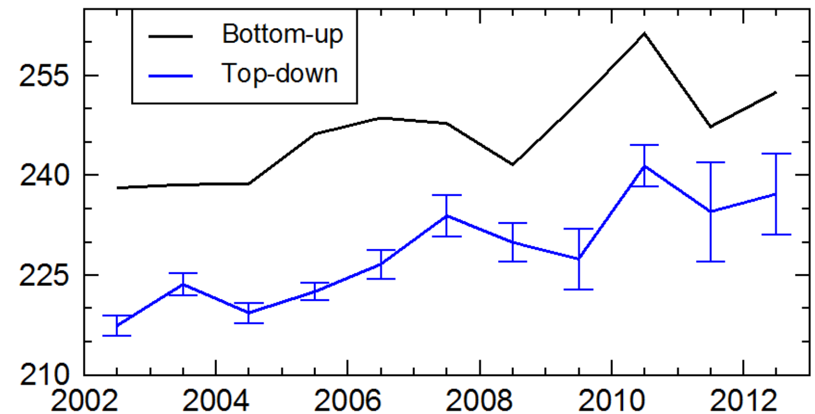
Patra et al., J. Meteorol. Soc. Jpn., 2016

CH_4 emission trends and variability –
Validation using Tohoku University observations over Sendai

East Asia (China, Japan, Korea)

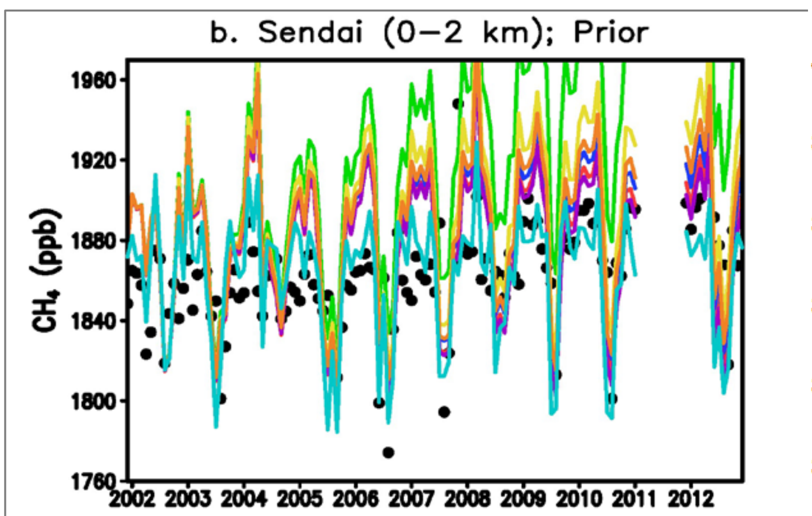


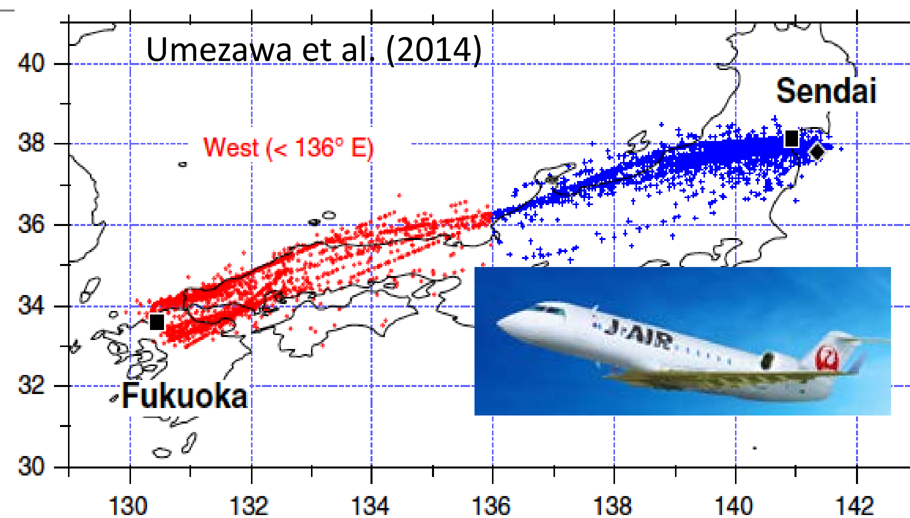
Tropical Land (Africa, America, Asia)



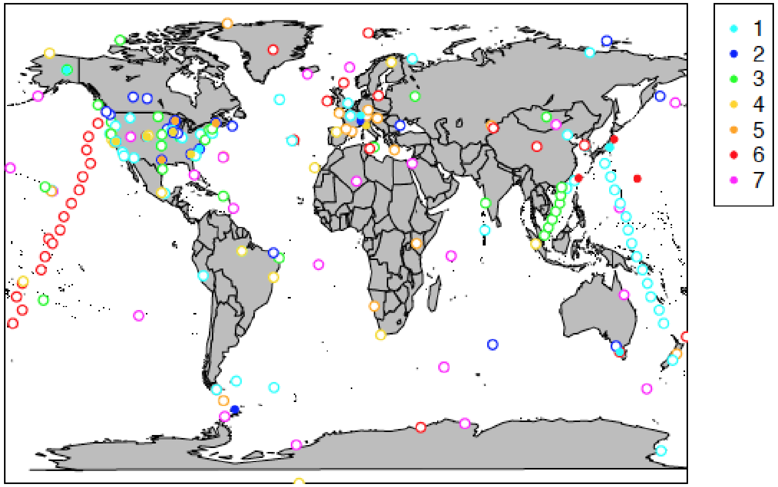
3-5%/yr increase in CH_4 emission of East Asian emission; about half of the prior

Validation of emissions using Tohoku Univ. aircraft data



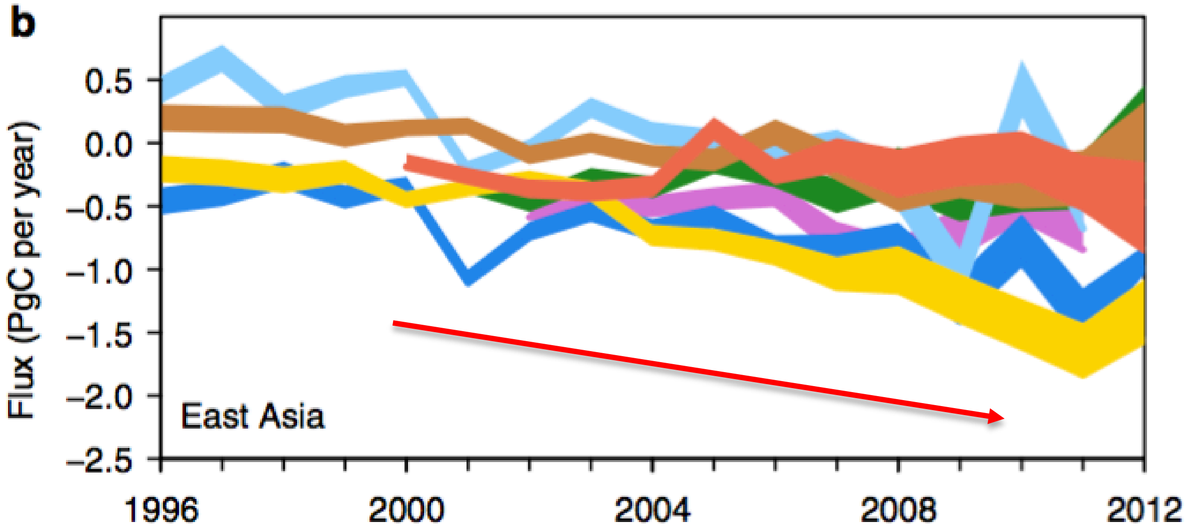


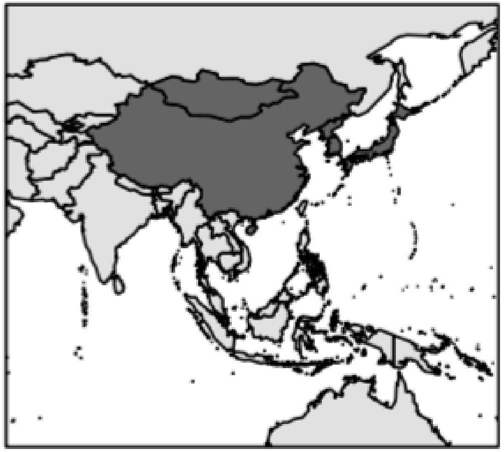
APN Asian GHG project: results from CO_2 inversion



In East Asia, the annual CO2 **sink increased** between 1996–2001 and 2008– 2012 by 0.56 (0.30–0.81) PgC,

East Asia (China, Japan, Korea, Mongolia)



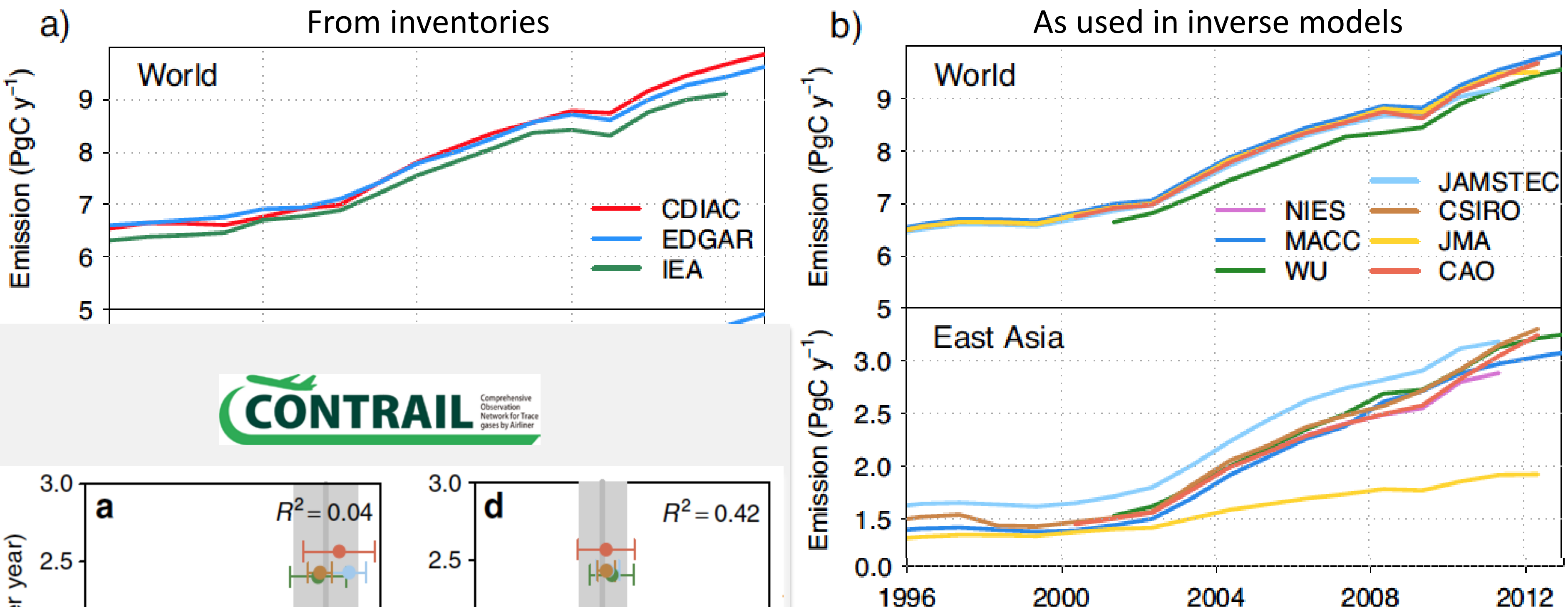


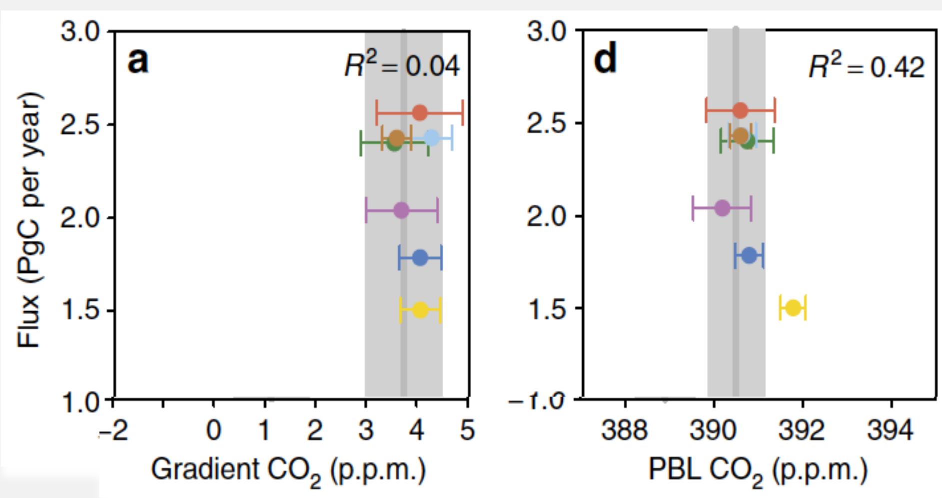
Ensemble of 7 inverse models (incl. JAMSTEC's ACTM)

Thompson et al., Nature Comm., 2016

- Afforestation・reforestation and revegetation・CO_2 fertilization ??
- Error in anthropogenic emission ??

Do uncertainties in fossil fuel emission affect East Asian CO_2 inversion?





Validation of inversion fluxes using JAL-CONTRAIL CO_2 data over the East Asia region remained inconclusive

Thompson et al., Nature Comm., 2016

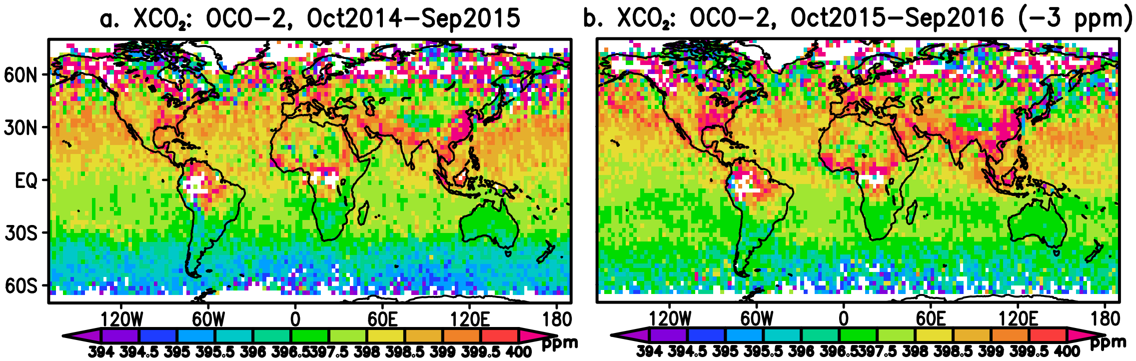
Summary

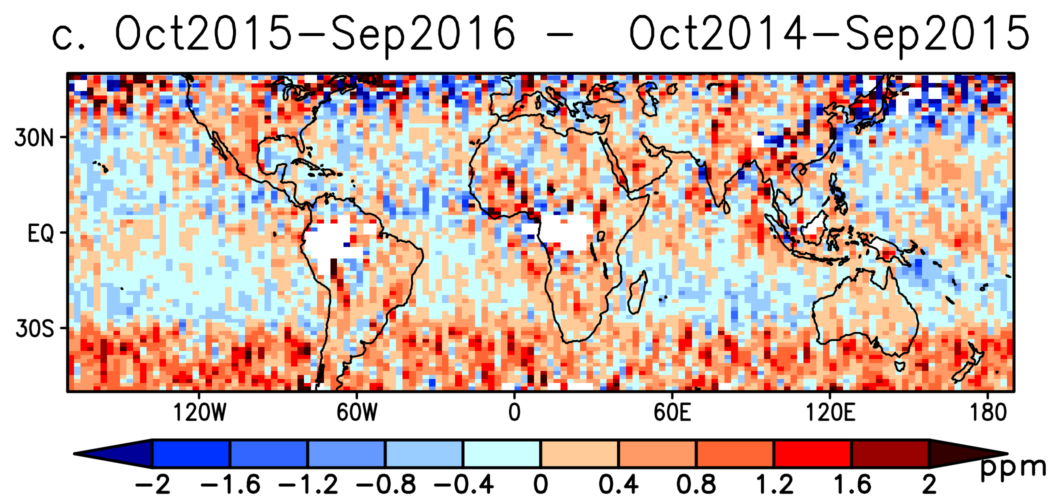
- Global budgets of major greenhouse gases are being produced by synthesizing a large amount of data sources, involving hundreds of scientists:
  - GCP-CO_2 (2007-) : Annual updates on global CO2 budgets and sectorial breakdown of (1) emissions from fossil fuel and land-use change, (2) sinks in to the terrestrial and oceanic surfaces
  - GCP-CH_4 (2016-) : One of the complex exercise producing numerous sectorial emissions using a variety of methods, and chemical loss budgets in the troposphere and stratosphere
  - GCP-N_2O (2017-) : in planning, which will prepare global sources and sinks due to agricultural activities, natural processes, stratospheric loss etc.

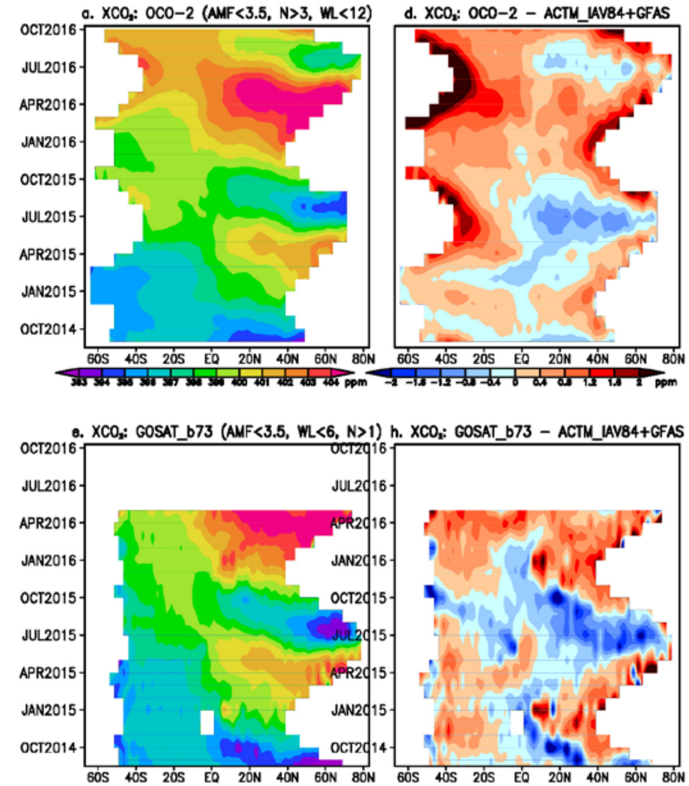
- Future needs are proposed toward better assessments of regional GHGs budgets and their trends
  - For monitoring, reporting and verification (MRV) of national reporting
  - For understanding the role of human activity and natural variability on the climate change and their feedbacks
  - Most, if not all, regional GHG budgets are severely under-constrained by observations – coverage and data types (molecular and isotopes) should be increased
  - Uncertainties in global atmospheric and vegetation dynamics models – supplemental measurements of chemical and transport tracers, and carbon-nitrogen pools

The future – is bright

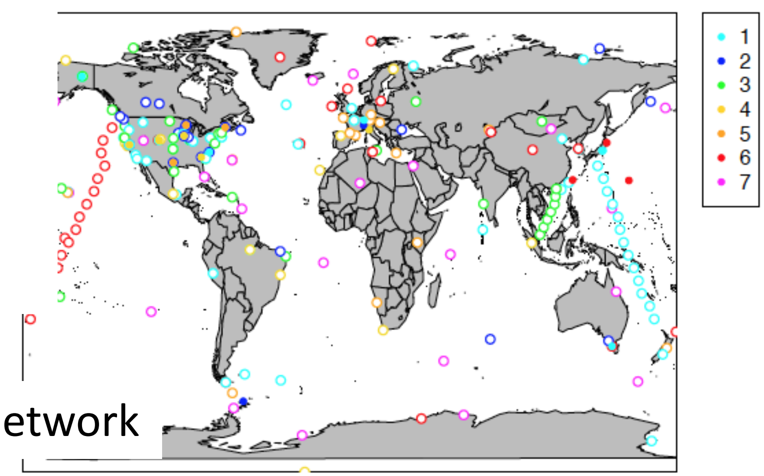
Satellite & Model







Satellite: OCO-2 & GOSAT



in situ network

Notes – day 1

- AO-GEOSS : Asia-Oceanic GEOSS (Osamu Ochai), there is also AmeriGEOSS, AfrGEOSS
- Reduction of food waste – a low hanging fruit (Sanjaasuren Oyun)

- AOGEOSS:
  - TG3 : Carbon cycle and response to climate change
  - TG9 : Himalayan task group, led by ICMOD
- TWO QUESTIONS:
  - 1. what are the data needs for transforming observations to information for decision making? Koike: How to convince, to work together, have a protocol?; GEO-BOB: gather quality data and combine them, GEO-Carb: something useful to the users, data scattered in different repository, BluePlanet: need both in situ and satellite data, top-down and bottom-up perspective for data – what the users need & how data can be used, GEOGLAM: data are needed for timely crop monitoring, challenge is to transform big amount of data in to information
  - 2. What should be discussed tomorrow? GEOGLOWS: each country should protect themselves, but for effectiveness international communities should work together, GEO-BON: , GHG: needs of the region, data gaps, how can be …, BluePlanet: main ocean acidification (7.9 or 8.2?), and its effect on biosphere, data availability, GLAM: multi-platfom observations, SDG20130:
  - Audience: Nakajima: dialogue between the govt and GEO

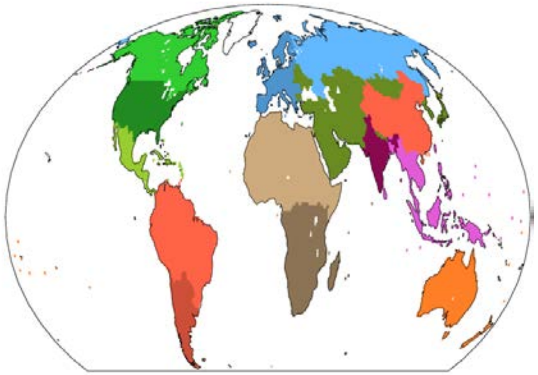
Notes – day 2

- Antonio:
  - #2 Have a common platform for MRV
  - GEO-C: towards policy-relevant global carbon cycle observations
  - Lack of communication: inter- and intra- groups (obs, mod, user)
  - Tasks: Optimal observation network, GHG budgets
  - Deliverables : annual budgets – PKP: why not work towards improving the budgets – valid point?
  - Q. Nakajima – what about including SLCFs? – Antonio: we focus on carbon, PKP: we actually include Methane
- Hiroyuki: GEO2017-2019 & SDGs
- Liu : TanSat is launched on 22 December 2016 (video shown)
  - Showed my Land IPCC figure, Jiang's CT-China budget
- CS Jha: Reddy et al., Env. Monit. Assess. 2015
  - Most carbon sinks in Biospheric reserves in India – invasive species are the biggebst problem
  - Vegetation carbon pools: many 10, 000 forest AGB obs plots, plus a lot of works (Chave et al, Phil. Trans. Roy. Soc., 2004)
  - Reddy et al., Global Planetary Change, accepted. (carbon mapping for all south asian countries)
- Toshinobu: CONTRAIL
  - GEO should produce data summary from all data providers, with QA/QC statements

Regional Methane Sources (2003-2012)

Source: Saunois et al. 2016 ESSD (Fig 7)

- Largest emissions in Tropical South America, South-East Asia and China (50% of global emissions)
- Dominance of wetland emissions in the tropics and boreal regions
- Dominance of agriculture & waste in India and China
- Balance between agriculture & waste and fossil fuels at mid-latitudes



erica

Temperate
South America

- Uncertain magnitude of wetland emissions in boreal regions between TD and BU
- Chinese emissions lower in TD than in BU, African emissions larger in TD than in BU

Emission inventories

Biogeochemistry models & data-driven methods

Inverse models