Observational constraints on the global carbon budget and preliminary analysis of the 2015 anomaly

Philippe Ciais
Laboratoire des Sciences du Climat et de l'Environnement

Teams

The work presented here has been possible thanks to the voluntary contributions and observational and modeling efforts of the institutions and networks below

Atmospheric CO_2 datasets
NOAA/ESRL (Dlugokencky et al. 2015)
Scripps (Keeling et al. 1976)

Fossil Fuels and Industry
CDIAC (Boden et al. 2015)
USGS, 2015
UNFCCC, 2015
BP, 2015

Consumption Emission
Peters et al. 2011

Land-Use Change
Houghton et al. 2012
van der Werf et al. 2010

Atmospheric inversions
CarbonTracker (Peters et al. 2010)
Jena CarboScope (Rödenbeck et al. 2003)
MACC (Chevallier et al. 2005)

Land models
CLM4-5BGC | ISAM | JSBACH | JULES | LPJ-GUESS | LPJ | LPJmL | OCNv1.r240 | ORCHIDEE | VEGAS | VISIT

Ocean models
NEMO-PlankTOM5 | NEMO-PISCES (IPSL) | CCSM-BEC | MICOM-HAMMOC | MPIOM-HAMMOC | NEMO-PISCES (CNRM) | CSIRO | MITgem-REcoM2

SOCAT
SOCATv3 (Bakker et al. 2014, 2015)

Ocean Data products
Jena CarboScope (Rödenbeck et al. 2014)
Landschützer et al. 2015

Full references provided in Le Quéré et al 2015

Contributors 106 people | 68 organisations | 15 countries

C Le Quéré UK | **R Moriarty** UK | **RM Andrew** Norway | **JG Canadell** Australia | **S Sitch** UK | **JI Korsbakken** Norway | **P Friedlingstein** UK | **GP Peters** Norway | **RJ Andres** USA | **TA Boden** USA | **RA Houghton** USA | **JI House** UK | **RF Keeling** USA | **P Tans** USA | **A Arneth** Germany | **DCE Bakker** UK | **L Barbero** USA | **L Bopp** France | **J Chang** France | **F Chevallier** France | **LP Chini** USA | **P Ciais** France | **M Fader** France | **RA Feely** USA | **T Gkritzalis** Belgium | **I Harris** UK | **J Hauck** Germany | **T Ilyina** Germany | **AK Jain** USA | **E Kato** Japan | **V Kitidis** UK | **K Klein** Netherlands | **C Koven** USA | **P Landschützer** Switzerland | **SK Lauvset** Norway | **N Lefèvre** France | **A Lenton** Australia | **ID Lima** USA | **N Metzl** France | **F Millero** USA | **DR Munro** USA | **A Murata** Japan | **JEMS Nabel** Germany | **S Nakaoka** Japan | **Y Nojiri** Japan| **K O'Brien** USA | **A Olsen** Norway | **T Ono** Japan | **FF Pérez** Spain | **B Pfeil** Norway | **D Pierrot** USA | **B Poulter** USA | **G Rehder** Germany | **C Rödenbeck** Germany | **S Saito** Japan | **U Schuster** UK | **J Schwinger** Norway | **R Séférian** France | **T Steinhoff** Germany | **BD Stocker** Switzerland | **AJ Sutton** USA | **T Takahashi** USA | **B Tilbrook** Australia | **IT van der Laan-Luijkx** Netherlands | **GR van der Werf** Netherlands | **S van Heuven** Netherlands | **D Vandemark** USA | **N Viovy** France | **A Wiltshire** UK | **S Zaehle** Germany | **N Zeng** USA | **R Jackson** USA | **P Smith** UK | **SJ Davis** USA | **F Creutzig** Germany | **S Fuss** Germany | **J Minx** Germany | **B Gabrielle** France | **A Cowie** Australia | **E Kriegler** Germany | **DP van Vuuren** Netherlands | **J Rogelj** Switzerland & Austria | **J Milne** USA | **D McCollum** Austria | **V Krey** Austria | **G Shrestha** USA | **T Gasser** France | **A Grübler** Austria | **WK Heidug** Saudi Arabia | **M Jonas** Austria| **CD Jones** UK | **F Kraxner** Austria | **E Littleton** UK | **J Lowe** UK | **JR Moreira** Brazil | **N Nakicenovic** Austria | **M Obersteiner** Austria | **A Patwardhan** USA | **M Rogner** Austria | **E Rubin** USA | **A Sharifi** Japan | **A Torvanger** Norway | **Y Yamagata** Japan | **J Edmonds** USA | **C Yongsung** Seoul | **S Soloman** USA

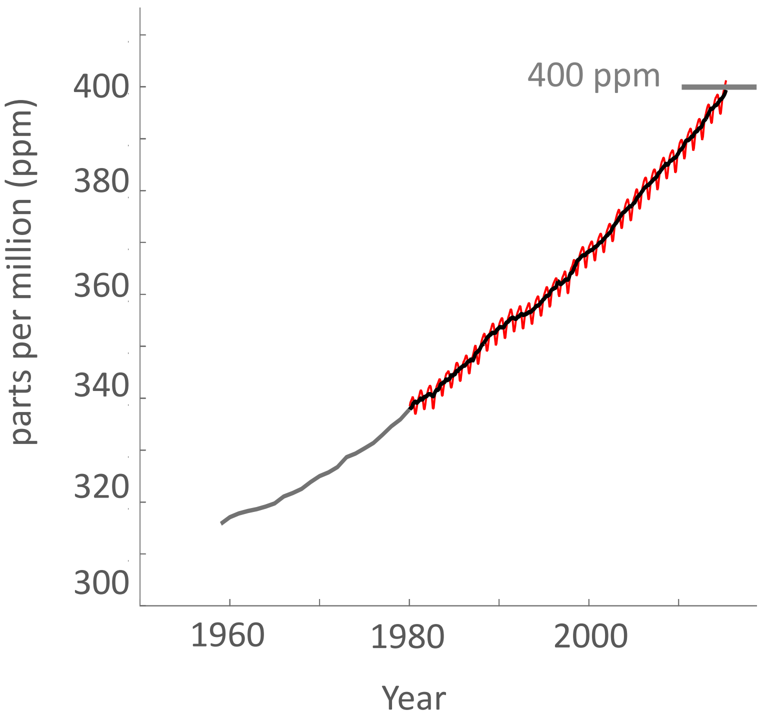
Science Committee | Atlas Engineers at LSCE, France (not already mentioned above), France
P Peylin | A Peregon | P Brockmann | V Maigné | P Evano

Atlas Designers WeDoData, France | Infographic designers UK, France & Sweden
K Bastien | Brice Terdjman | V Le Jeune | A Vessière | Nigel Hawtin | BNPParibas Design Team | azote

Communications Team
A Minns | O Gaffney | L Sayer | L Horton

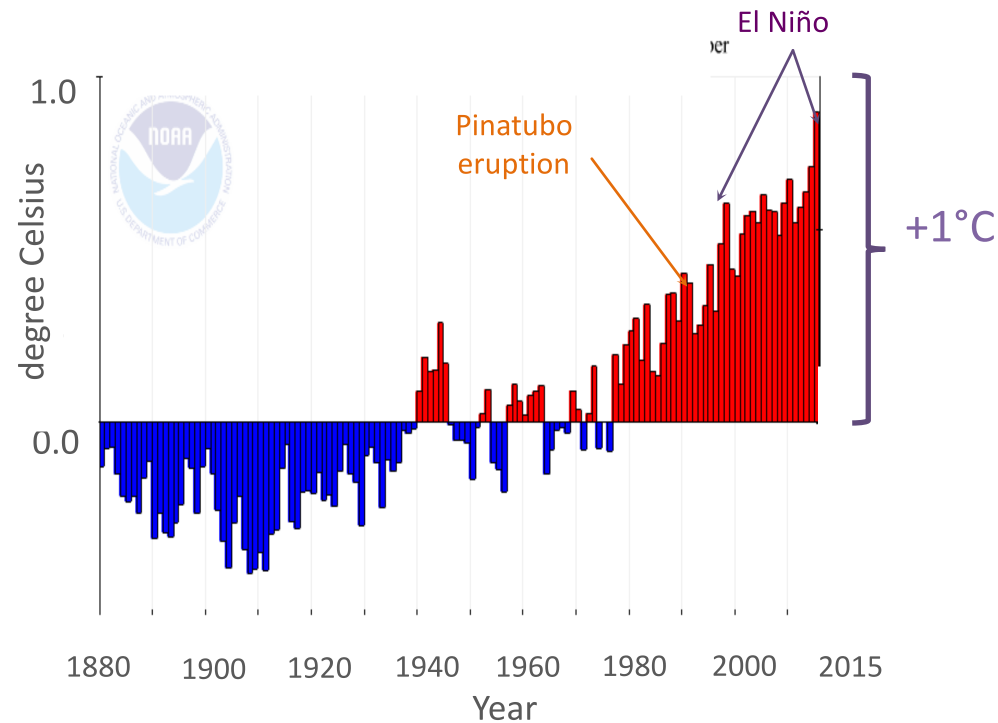
Latest trends on atmospheric CO_2 and temperature

atmospheric CO_2 concentration



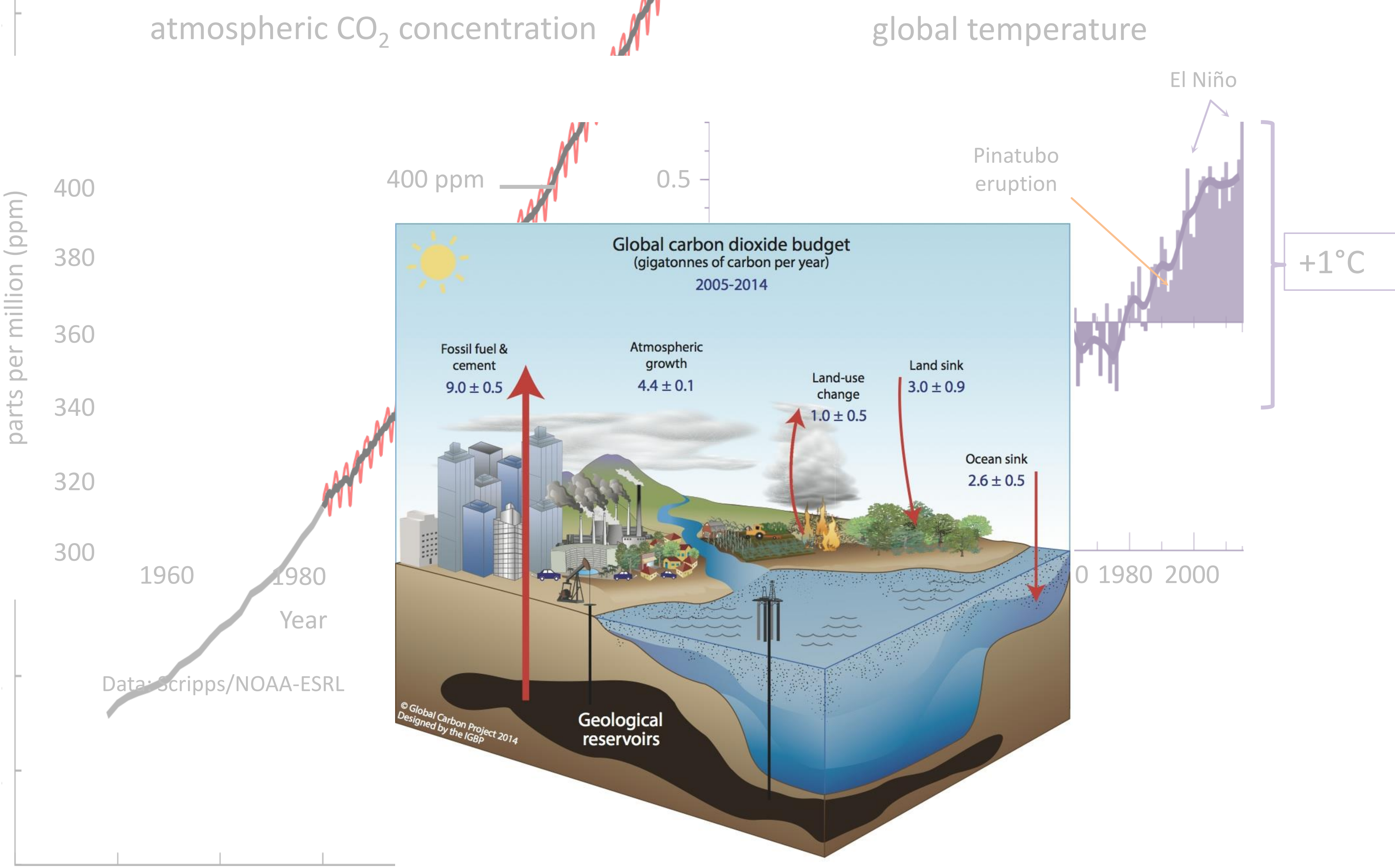
Data: Scripps/NOAA-ESRL

global temperature

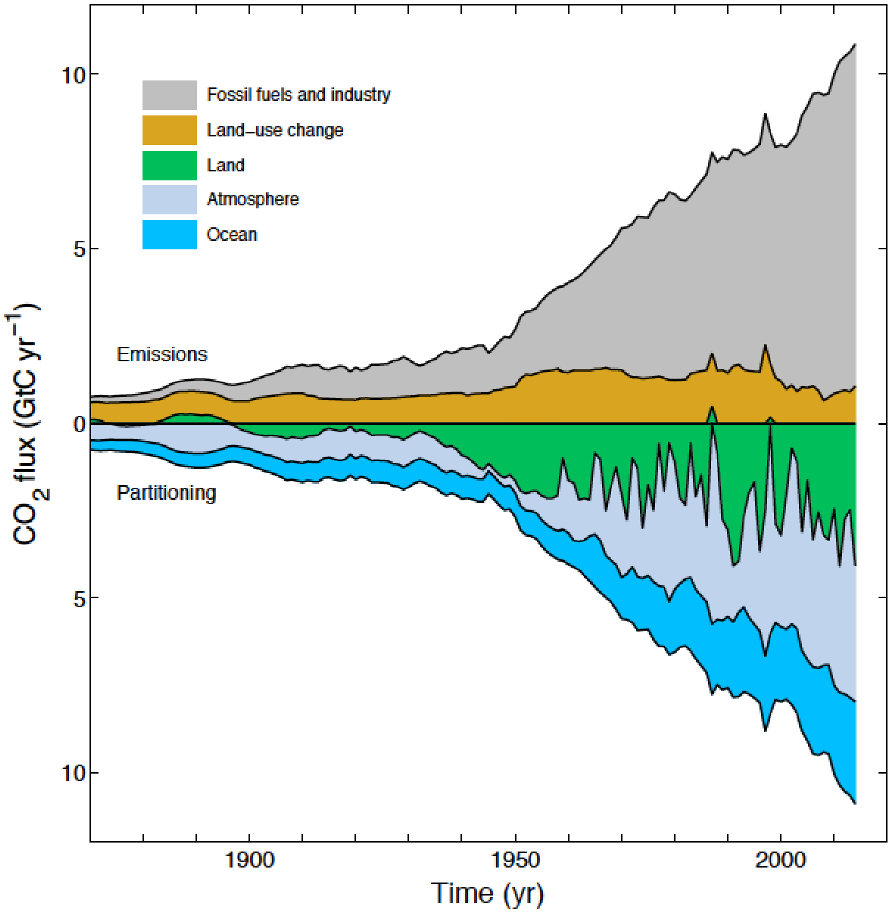


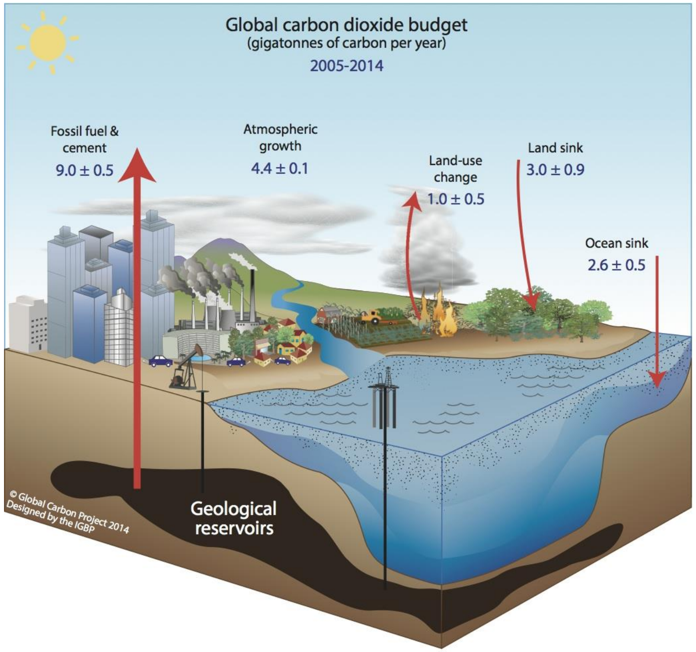
Data: NOAA National Center for Environmental information

Latest trends on atmospheric CO_2 and temperature



the concept of global carbon budgets



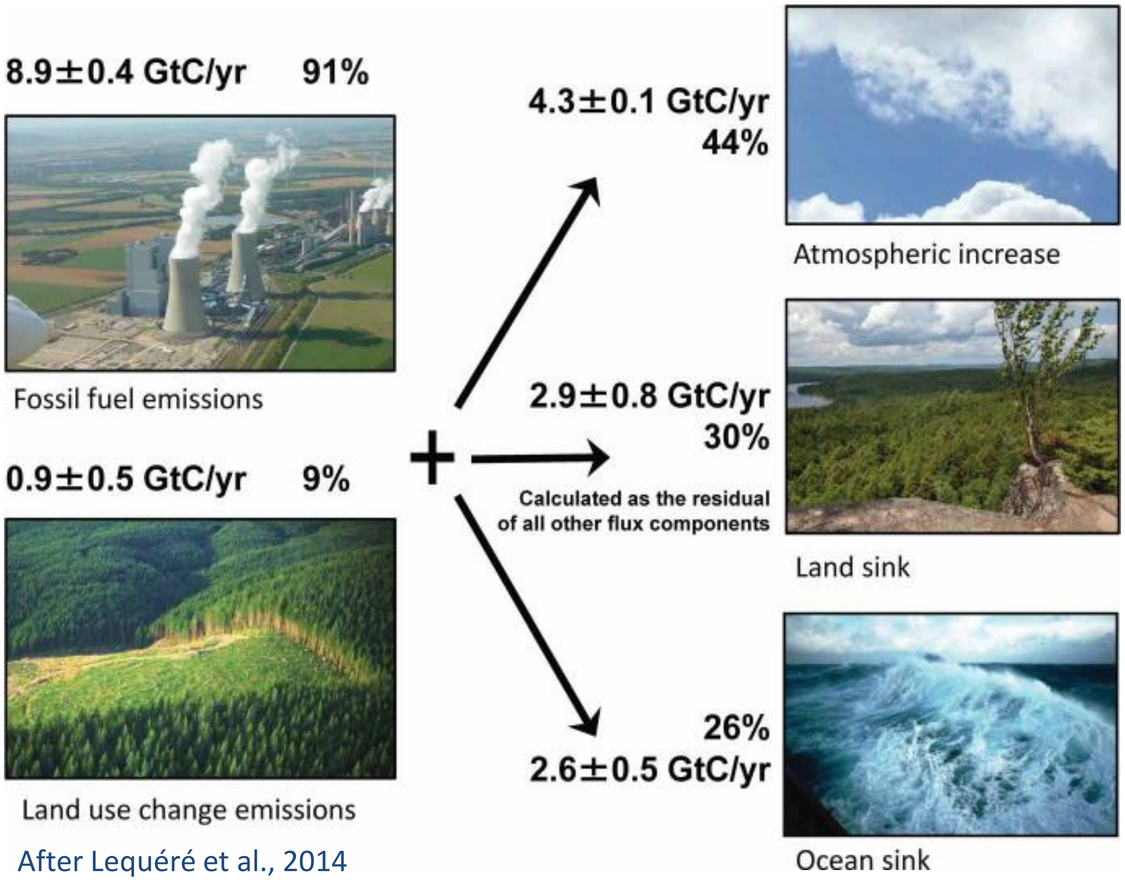


Source: Le Quéré et al ESSD 2015; Global Carbon Project 2015

GLOBAL CARBON PROJECT

The global carbon budget

- Emissions of fossil fuels are estimated from energy use statistics



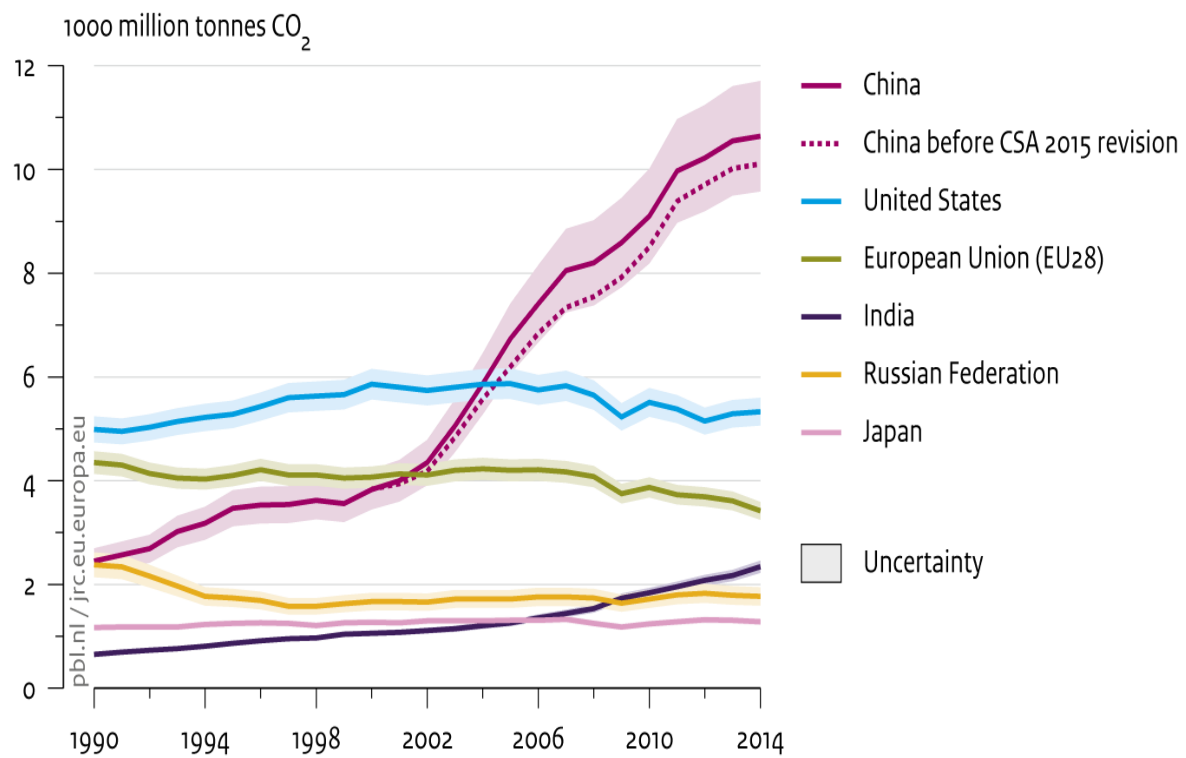
After Lequéré et al., 2014

- The global ocean sink is constrained by ocean interior & ocean surface measurements
- But the global land sink cannot be quantified by land observations

Increasing uncertainty of fossil CO_2 emissions

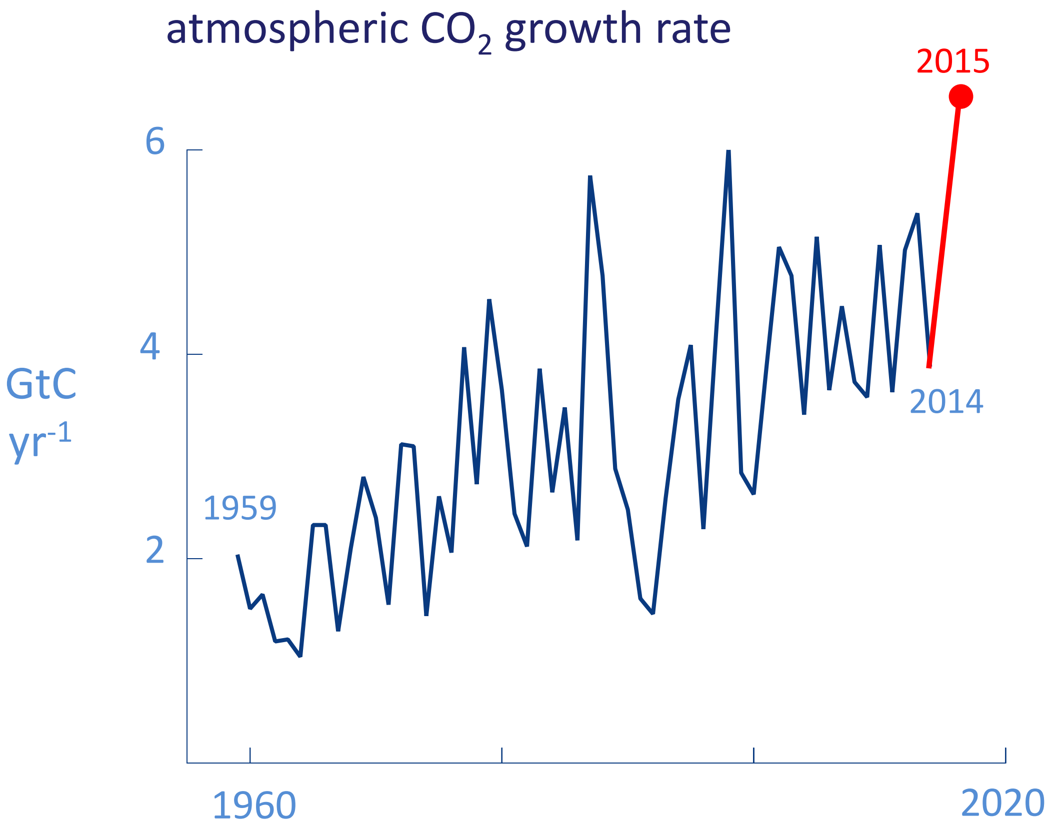
Are CO_2 emissions still rising? YES, but the trend is stalling.

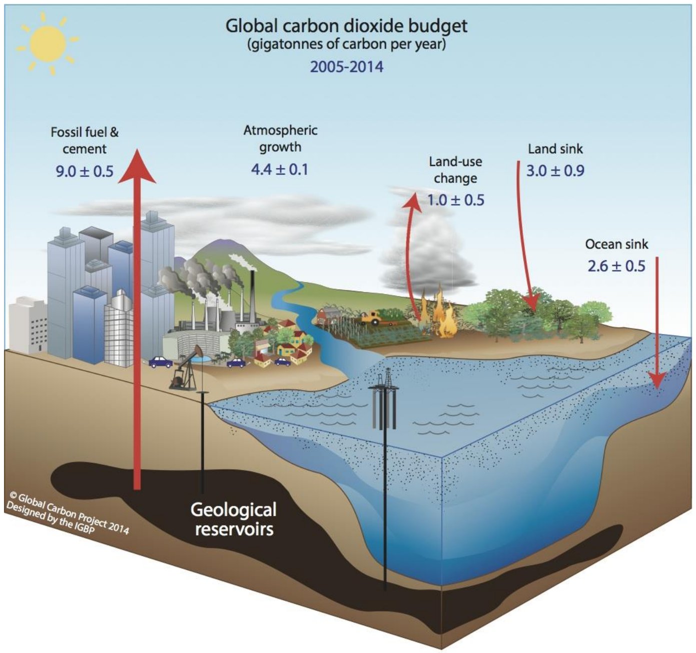
CO_2 emissions from fossil-fuel use and cement production in the top 5 emitting countries and the EU



Source: EDGAR 4.3 (JRC/PBL, 2015) (1970-2012; notably IEA 2014 and NBS 2015); FT2014 (2013-2014): BP 2015; GGFR 2015; USGS 2015; WSA 2015

information in the atmospheric CO_2 growth

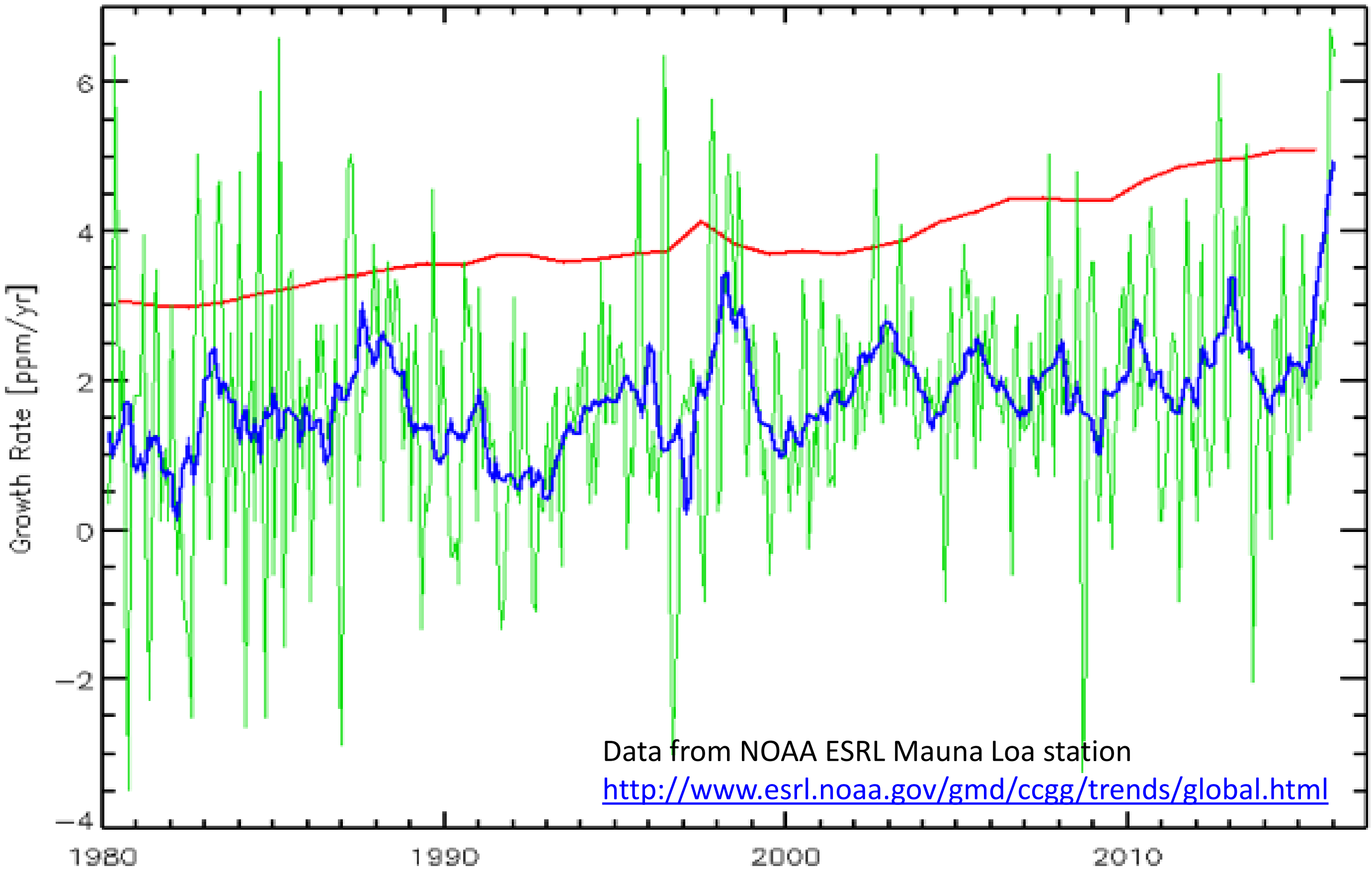




2015 is the highest atmospheric CO_2 growth rate ever observed of 3.15 ppm
Extreme El Niño year : MEI ENSO index of 2.31 vs. 2.69 in 1997/98
Probably, land ecosystems are a net source in 2015

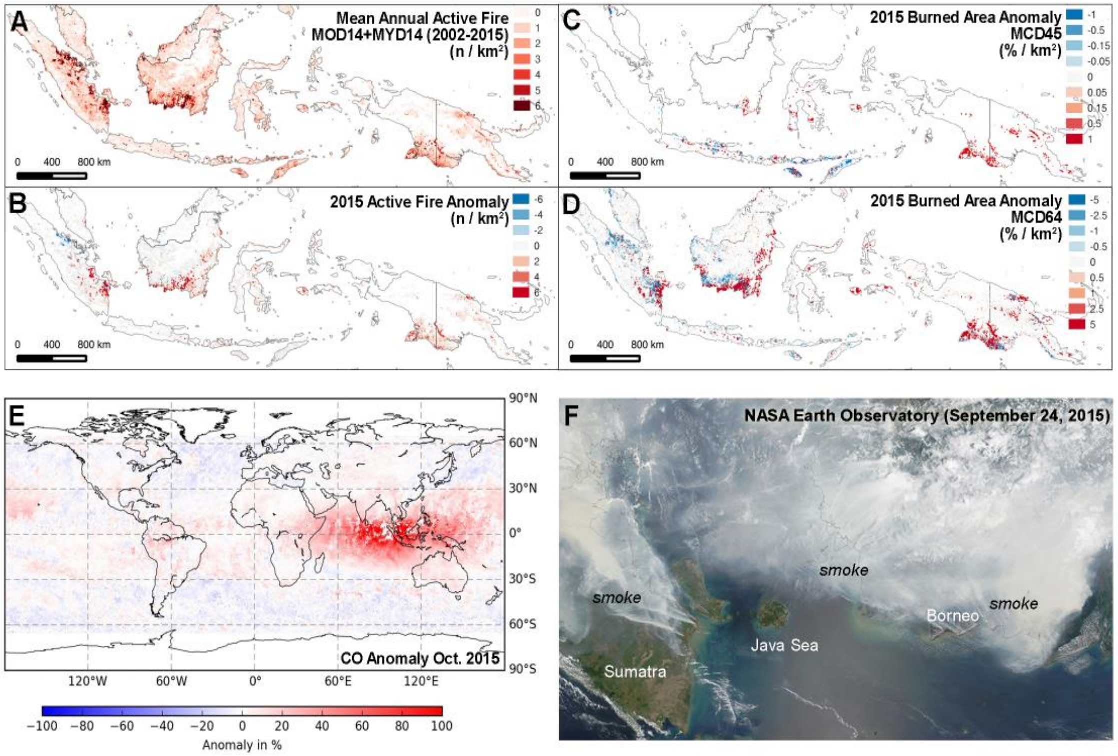
Source: NOAA/ESRL Data; Le Quéré et al ESSD 2015; Global Carbon Project 2015

CO_2 increased faster than ever in 2015



In red : CO_2 growth rate expected from anthropogenic emissions
In blue : 12-months smoothed CO_2 observed growth rate
In green : Monthly CO_2 growth rate

CO_2 increased faster than ever in 2015



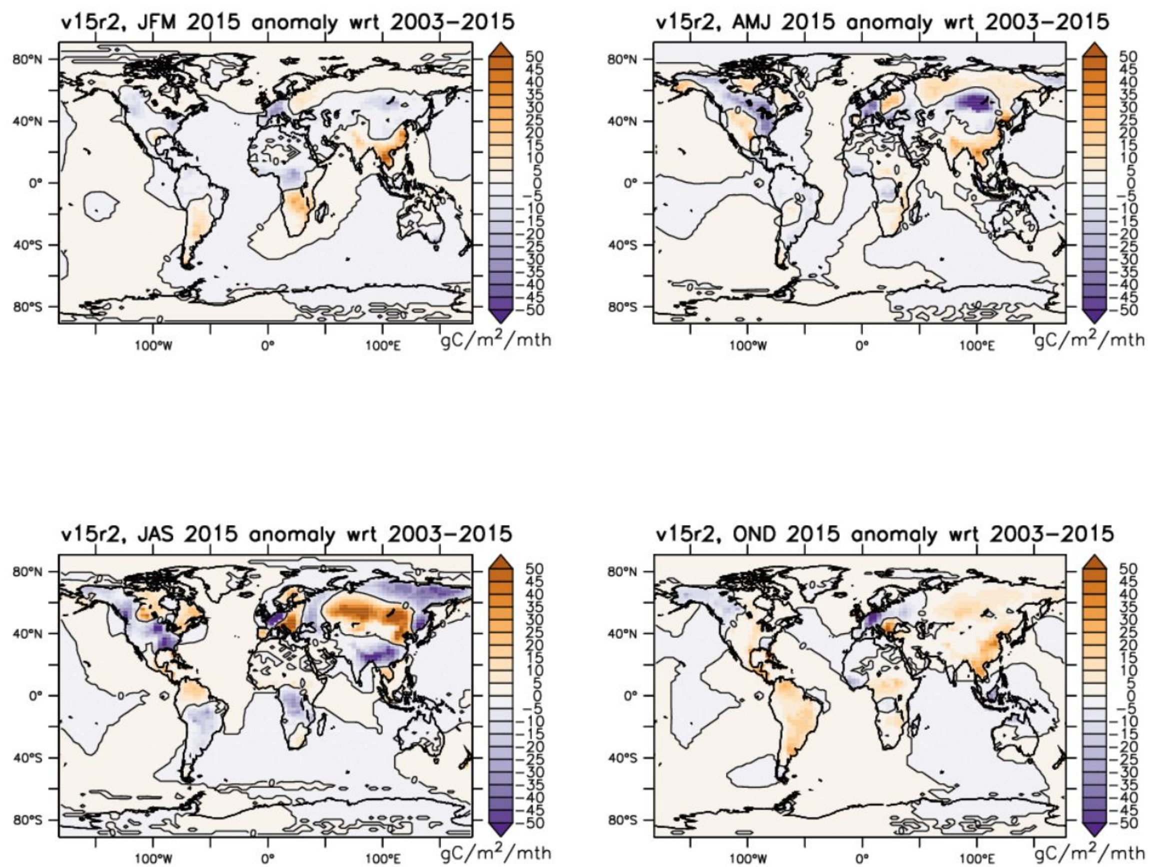
Yin et al. submitted

Abnormal fire emissions in South East Asia estimated from the inversion of carbon monoxide (CO) observed by MOPITT satellite

2015 fire emission = 0.5 ± 0.14 Pg C y^{-1}

1997 fire emission = 1.2 ± 0.3 Pg C y^{-1}

CO_2 increased faster than ever in 2015



Copernicus Core service MACC3 inversion of CO_2 fluxes

Regional attribution of CO_2 natural fluxes based on measurements of ≈ 150 in situ stations
- Droughts in Europe and Central Asia
- Source of CO_2 over tropical regions during the development of the 2015 El Niño

data access and reproducibility

Earth Syst. Sci. Data, 5, 165–185, 2013
www.earth-syst-sci-data.net/5/165/2013/
doi:10.5194/essd-5-165-2013

Open Access Earth System Science Data

The global carbon budget 1959–2011

C. Le Quéré[1], R. J. Andres[2], T. Boden[2], T. Conway[3], R. A. Houghton[4], J. I. House[5], G. Marland[6], G. P. Peters[7], G. R. van der Werf[8], A. Ahlström[9], R. M. Andrew[7], L. Bopp[10], J. G. Canadell[11], P. Ciais[10], S. C. Doney[12], C. Enright[1], P. Friedlingstein[13], C. Huntingford[14], A. K. Jain[15], C. Jourdain[1,*], E. Kato[16], R. F. Keeling[17], K. Klein Goldewijk[18,19,20], S. Levis[21], P. Levy[14], M. Lomas[22], B. Poulter[10], M. R. Raupach[11], J. Schwinger[23,24], S. Sitch[25], B. D. Stocker[26,27], N. Viovy[10], S. Zaehle[28], and N. Zeng[29]

Earth Syst. Sci. Data, 6, 235–263, 2014
www.earth-syst-sci-data.net/6/235/2014/
doi:10.5194/essd-6-235-2014

Open Access Earth System Science Data

Global carbon budget 2013

C. Le Quéré[1], G. P. Peters[2], R. J. Andres[3], R. M. Andrew[2], T. A. Boden[3], P. Ciais[4], P. Friedlingstein[5], R. A. Houghton[6], G. Marland[7], R. Moriarty[1], S. Sitch[8], P. Tans[9], A. Arneth[10], A. Arvanitis[10], D. C. E. Bakker[11], L. Bopp[4], J. G. Canadell[12], L. P. Chini[13], S. C. Doney[14], A. Harper[15], I. Harris[16], J. I. House[17], A. K. Jain[18], S. D. Jones[1], E. Kato[19], R. F. Keeling[20], K. Klein Goldewijk[21], A. Körtzinger[22], C. Koven[23], N. Lefèvre[24], F. Maignan[4], A. Omar[25,26], T. Ono[27], G.-H. Park[28], B. Pfeil[26,29], B. Poulter[30], M. R. Raupach[12,*], P. Regnier[31], C. Rödenbeck[32], S. Saito[33], J. Schwinger[26,29], J. Segschneider[34], B. D. Stocker[35], T. Takahashi[36], B. Tilbrook[37], S. van Heuven[38], N. Viovy[4], R. Wanninkhof[40], A. Wiltshire[39], and S. Zaehle[32]

Earth Syst. Sci. Data, 7, 47–85, 2015
www.earth-syst-sci-data.net/7/47/2015/
doi:10.5194/essd-7-47-2015

Open Access Earth System Science Data

Global carbon budget 2014

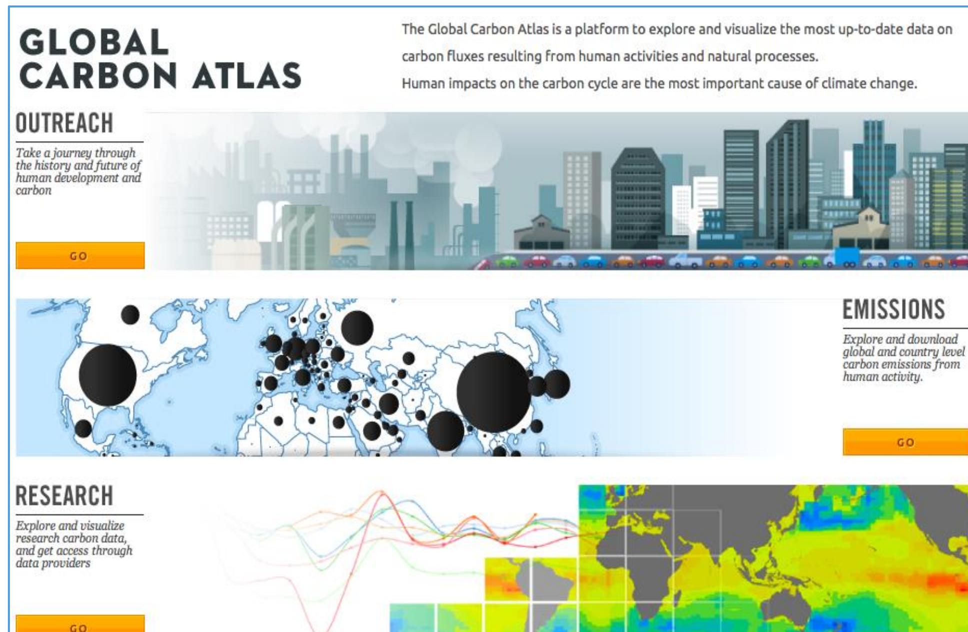
C. Le Quéré[1], R. Moriarty[1], R. M. Andrew[2], G. P. Peters[2], P. Ciais[3], P. Friedlingstein[4], S. D. Jones[1], S. Sitch[5], P. Tans[6], A. Arneth[7], T. A. Boden[8], L. Bopp[3], Y. Bozec[9,10], J. G. Canadell[11], L. P. Chini[12], F. Chevallier[3], C. E. Cosca[13], I. Harris[14], M. Hoppema[15], R. A. Houghton[16], J. I. House[17], A. K. Jain[18], T. Johannessen[19,20], E. Kato[21,22], R. F. Keeling[23], V. Kitidis[24], K. Klein Goldewijk[25], C. Koven[26], C. S. Landa[19,20], P. Landschützer[27], A. Lenton[28], I. D. Lima[29], G. Marland[30], J. T. Mathis[13], N. Metzl[31], Y. Nojiri[21], A. Olsen[19,20], T. Ono[32], S. Peng[3], W. Peters[33], B. Pfeil[19,20], B. Poulter[34], M. R. Raupach[35,†], P. Regnier[36], C. Rödenbeck[37], S. Saito[38], J. E. Salisbury[39], U. Schuster[5], J. Schwinger[19,20], R. Séférian[40], J. Segschneider[41], T. Steinhoff[42], B. D. Stocker[43,44], A. J. Sutton[45,13], T. Takahashi[46], B. Tilbrook[47], G. R. van der Werf[48], N. Viovy[3], Y.-P. Wang[49], R. Wanninkhof[50], A. Wiltshire[51], and N. Zeng[52]

Earth Syst. Sci. Data, 7,
www.earth-syst-sci-data.net
doi:10.5194/essd-7

Open Access Earth System Science Data

Global Carbon Budget 2015

C. Le Quéré[1], R. Moriarty[1], R. M. Andrew[2], J. G. Canadell[3], S. Sitch[4], J. I. Korsbakken[2], P. Friedlingstein[5], G. P. Peters[2], R. J. Andres[6], T. A. Boden[6], R. A. Houghton[7], J. I. House[8], R. F. Keeling[9], P. Tans[10], A. Arneth[11], D. C. E. Bakker[12], L. Barbero[13,14], L. Bopp[15], J. Chang[15], F. Chevallier[15], L. P. Chini[16], P. Ciais[15], M. Fader[17], R. A. Feely[18], T. Gkritzalis[19], I. Harris[20], J. Hauck[21], T. Ilyina[22], A. K. Jain[23], E. Kato[24], V. Kitidis[25], K. Klein Goldewijk[26], C. Koven[27], P. Landschützer[28], S. K. Lauvset[29], N. Lefèvre[30], A. Lenton[31], I. D. Lima[32], N. Metzl[30], F. Millero[33], D. R. Munro[34], A. Murata[35], J. E. M. S. Nabel[22], S. Nakaoka[36], Y. Nojiri[36], K. O'Brien[37], A. Olsen[38,39], T. Ono[40], F. F. Pérez[41], B. Pfeil[38,39], D. Pierrot[13,14], B. Poulter[42], G. Rehder[43], C. Rödenbeck[44], S. Saito[45], U. Schuster[4], J. Schwinger[29], R. Séférian[46], T. Steinhoff[47], B. D. Stocker[48,49], A. J. Sutton[37,18], T. Takahashi[50], B. Tilbrook[51], I. T. van der Laan-Luijkx[52,53], G. R. van der Werf[54], S. van Heuven[55], D. Vandemark[56], N. Viovy[15], A. Wiltshire[57], S. Zaehle[44], and N. Zeng[58]



GLOBAL CARBON PROJECT

Operationalization of GHG budgets

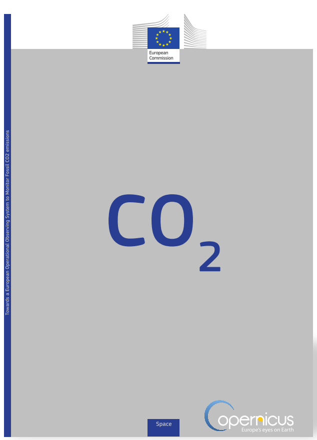
Secure support for the annual update of the global CO_2 budget

Take stock of national communications update in addition to CDIAC annual emission update

New CH_4 budget synthesis activity using bottom-up and top-down data

Towards regional yearly budgets consistent with the global CO_2 budget
- Atmospheric inversions based on in-situ data and satellites (GOSAT, OCO-2)
- Ocean data driven models
- Land models

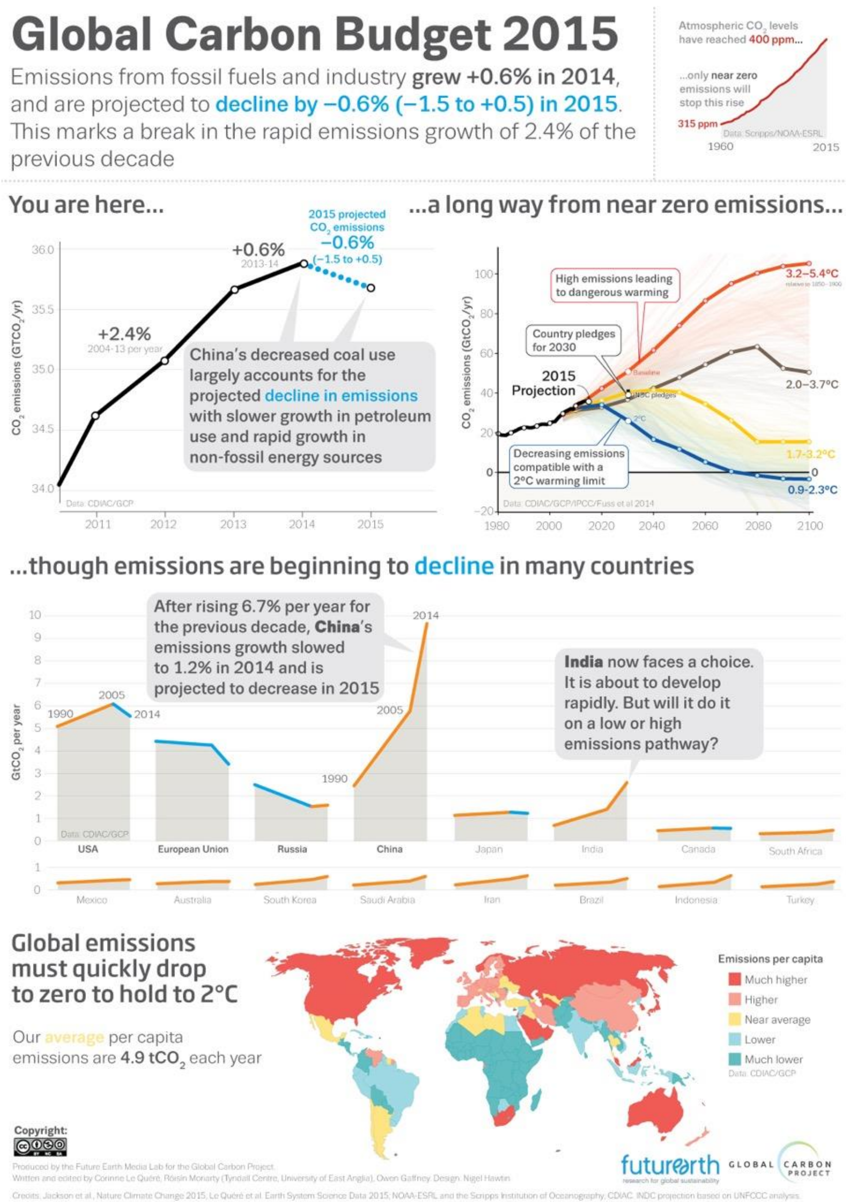
EU Copernicus initiative to monitor fossil CO2 emissions – satellite imagery + in-situ tracers



"CO_2 report" : Towards a European Operational Observing System to Monitor Fossil CO_2 Emissions

http://www.copernicus.eu/main/towards-european-operational-observing-system-monitor-fossil-co2-emissions

contributions to the public understanding of science



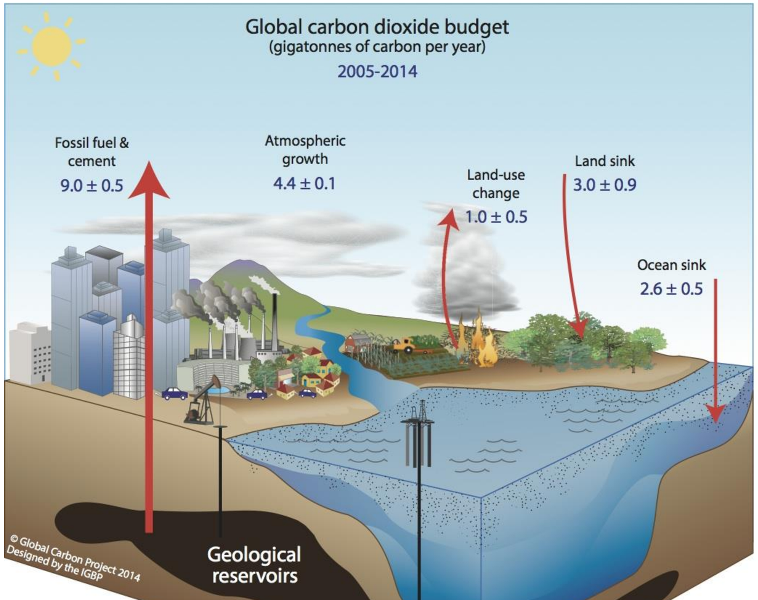
summary of climate variables used

Atmospheric CO_2 datasets
distributed network

Fossil Fuels and Industry
energy statistics
conversion factors

Consumption Emission
trade statistics

Land-Use Change
land-cover change
satellite products of biomass density & fires



Atmospheric inversions
atmospheric CO_2 distribution

Land models
observed precipitations, temperature, radiation
atmospheric CO_2 concentration

Ocean models
winds and buoyancy fluxes
atmospheric CO_2 concentration

Ocean Data products
surface pCO_2 data (SOCAT)
satellite products for SST, Chla, SSS, MLD (modelled)

Reduction of uncertainties and increased confidence in processes will need expansion of multiple key variables