Orbiting carbon observatory (OCO-2) tracks 2-3 Giga tons of carbon release to the atmosphere during the El Nino (Oct 2014 – Feb 2016)

P. K. Patra[1], D. Crisp[2], J. W. Kaiser[3], D. Wunch[4], T. Saeki[1], K. Ichii[1], T. Sekiya[1], P. Wennberg[5], D. G. Feist[6], D. Pollard[7], D. Griffith[8], M. De Maziere[9], M. K. Sha[9], C. Roehl[10]

1. Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama, 236-0001, Japan
2. NASA Jet Propulsion Laboratory, Pasadena, CA, USA
3. Max Planck Institute for Chemistry, Mainz, Germany
4. Department of Physics, University of Toronto, Toronto, Canada
5. California Institute of Technology, Pasadena, CA, USA
6. Max Planck Institute for Biogeochemistry, Jena, Germany
7. NIWA Taihoro Nukurangi, Lauder, Central Otago, New Zealand
8. School of Chemistry, University of Wollongong, NSW, 2522, Australia
9. Royal Belgian Institute for Space Aeronomy, Brussels, Belgium

Presented at the
12th International Workshop on Greenhouse Gas Measurements from Space (IWGGMS)
Kyoto University, Kyoto, Japan
7-9 June 2016

Introduction

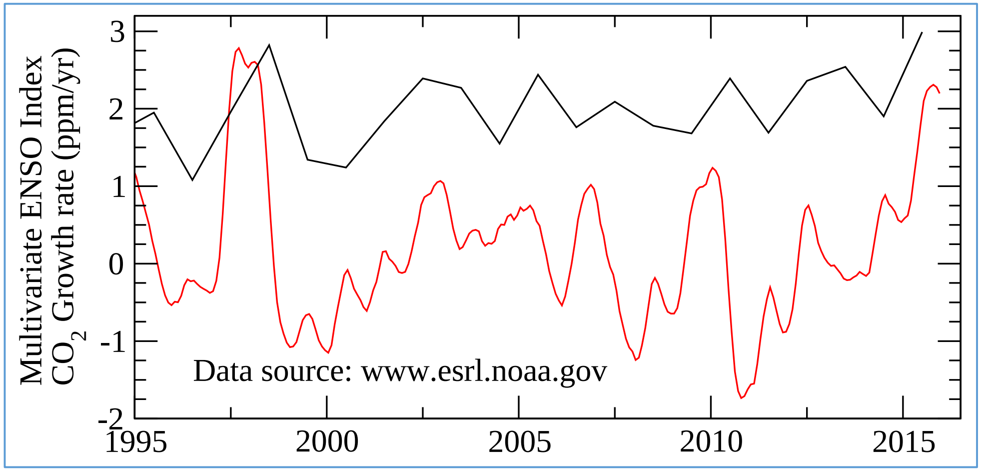
- 2014-2016 has been special time in terms of climate
  - Hot summer in most part of Asia (2016 January set the record high SAT)
  - Large El Nino induced fire occurrence over Southeast Asia in Sep-Oct'15

- CO_2 concentration is known to be affected by anthropogenic and land biospheric activities at interannual timescales

- The present measurements and modelling capabilities do not allow us (accurately enough) to track CO_2 concentration and fluxes regionally

- Here we make an attempt to analyse XCO_2 observations from OCO-2 and estimate global total CO_2 flux anomaly since Oct 2014

- Climate-carbon nexus is important for the projection of future climate scenario due to atmospheric CO_2 change



OCO-2 data processing and screening (e.g., AMF)

ACTM is sampled within 0.5 hr of OCO-2 overpass, and convolved with the OCO-2 a priori and averaging kernel

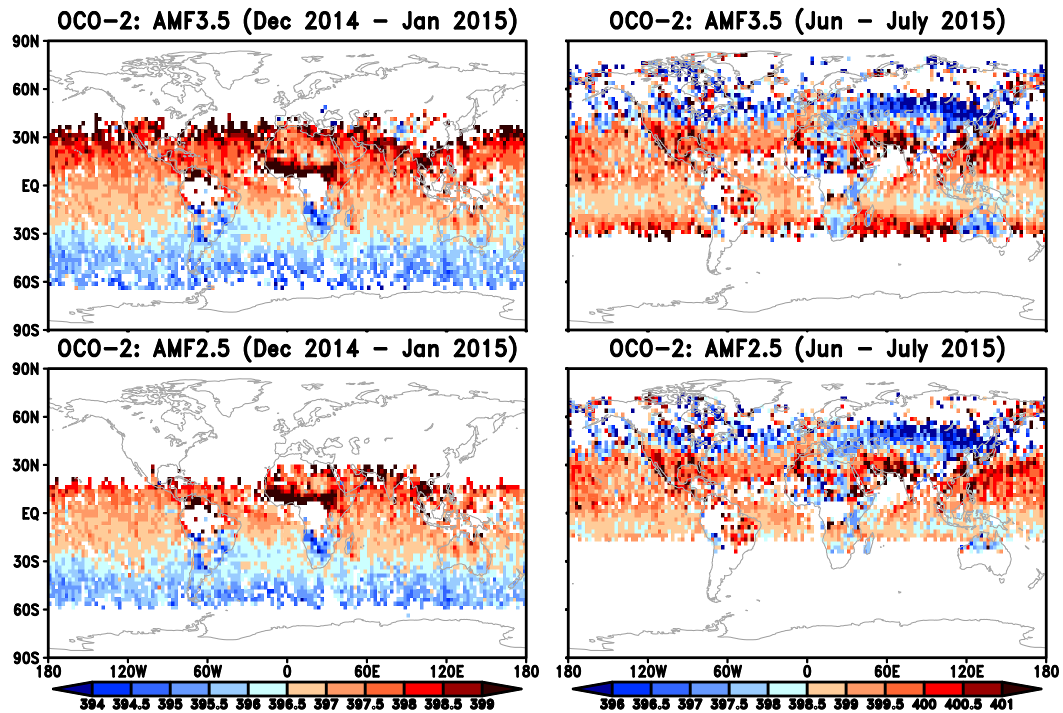
In the control case, we screen OCO-2 data as:

1. Warn level (WL) < 10
2. Air mass factor (AMF) < 3.5

All data are gridded in to 2.5ºx2.5º grid at monthly intervals

Grids with less than 3 data points are assigned missing value

In sensitivity cases, we have checked the results for WL<5 and AMF < 2.5



ACTM model transport (Patra et al., 2008-2016)

- *Based on CCSR/NIES/FRCGC Atmospheric General Circulation model developed in JAMSTEC*

- *Model Transport is nudged to Japan Meteorological Agency Reanalysis (JRA-55): horizontal winds and temperature*

- *Fossil fuel and cement production (FFC)* : Based in EDGAR4.2FT2012 spatial distribution and CDIAC top-20 country and global totals, the global total emission increased by 0.2 Pg/yr for 2015 and 2016

- *Oceanic Exchange (OCN)*: Based on air-sea pCO_2 measurements and extrapolation to global ocean [Takahashi et al., 2009]

- *Terrestrial Biosphere Flux (CASA)*: Based on Carnegie-Ames-Stanford Approach (CASA) model by Randerson et al. [1997], with a 3-hourly diurnal cycle introduced using JRA (Y. Niwa, pers. comm.)

- *Flux Inversion (CYC64 for 2008, IAV84 for 2011)*
  - *(CYC64; Patra et al., 2011)*: From the 64-region inverse model using the smoothed surface CO_2 data [GLOBALVIEW-CO_2, 2013] and additional CARIBIC measurements in 2008 [Schuck et al., 2010]. Inversion fluxes validated using the CONTRAIL observations [Machida et al., 2008].
  - *(IAV84; Saeki et al., in prep.)*: From a newly developed 84-region inverse model for the period 1992-2011 [GLOBALVIEW-CO_2, 2013]. The CO_2 fluxes have been used in a recent Asian flux assessment study, and validated using CONTRAIL CO_2 observations [Thompson et al., 2016].

- *Emissions from Fires (GFAS):* The fire-related daily CO_2 emissions from the Global Fire Assimilation System (GFAS) are taken from Kaiser et al. [2012; http://macc.icg.kfa-juelich.de:50080/access?catalogue=MACC_daily_wildfire_emissions], from October 2014 onwards.

3-simulations:

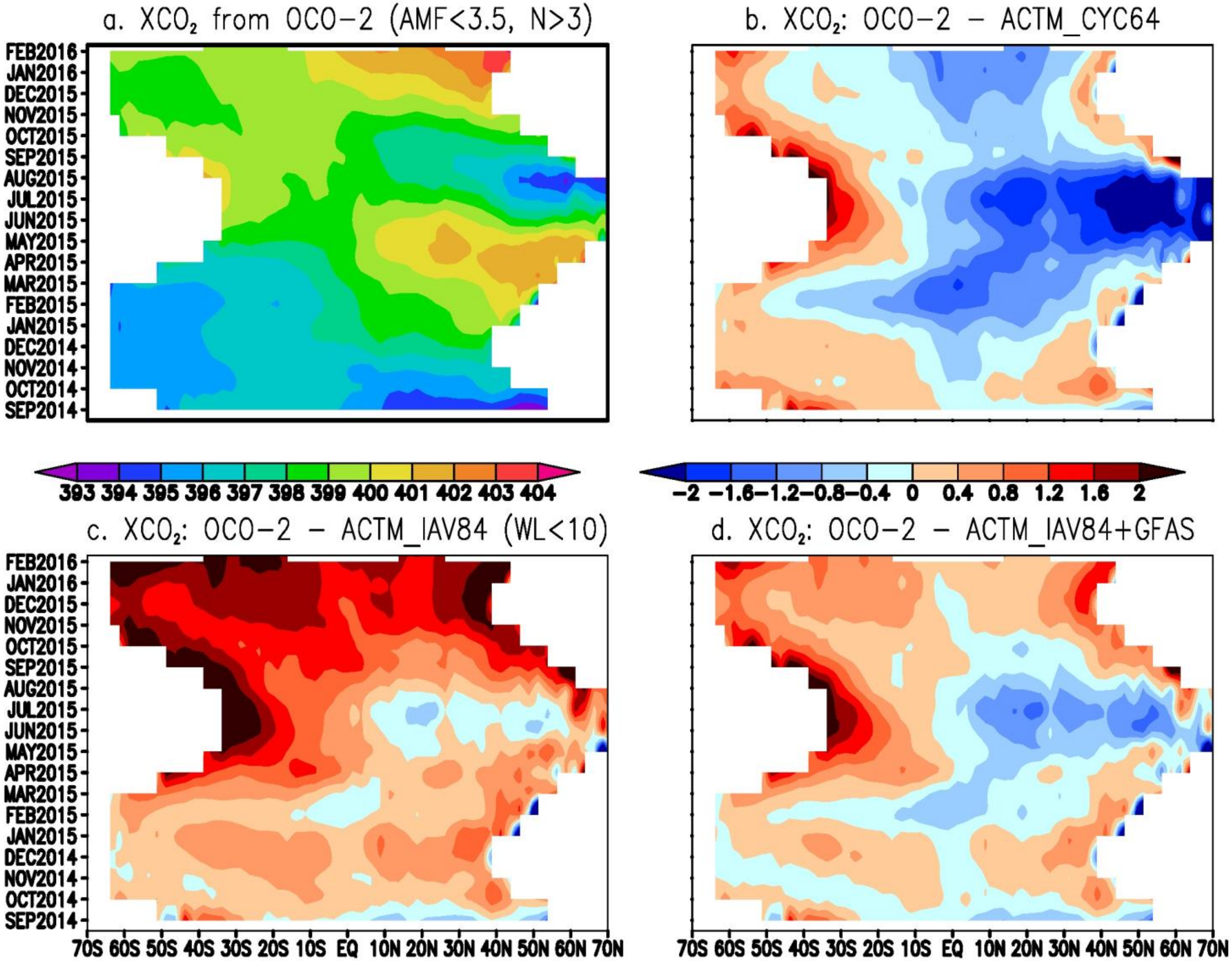
Case 1.
FFC + CYC64 (Lnd + Ocn)
(highest CO_2 growth rate)

Case 2.
FFC + IAV84 (Lnd + Ocn)
(slowest CO_2 growth rate)

Case3.
FFC + IAV84 + GFAS (fire)
(moderate CO_2 growth rate)

FFC: Fossil fuel and cement
CYC64 and IAV84: two cases of inversion fluxes

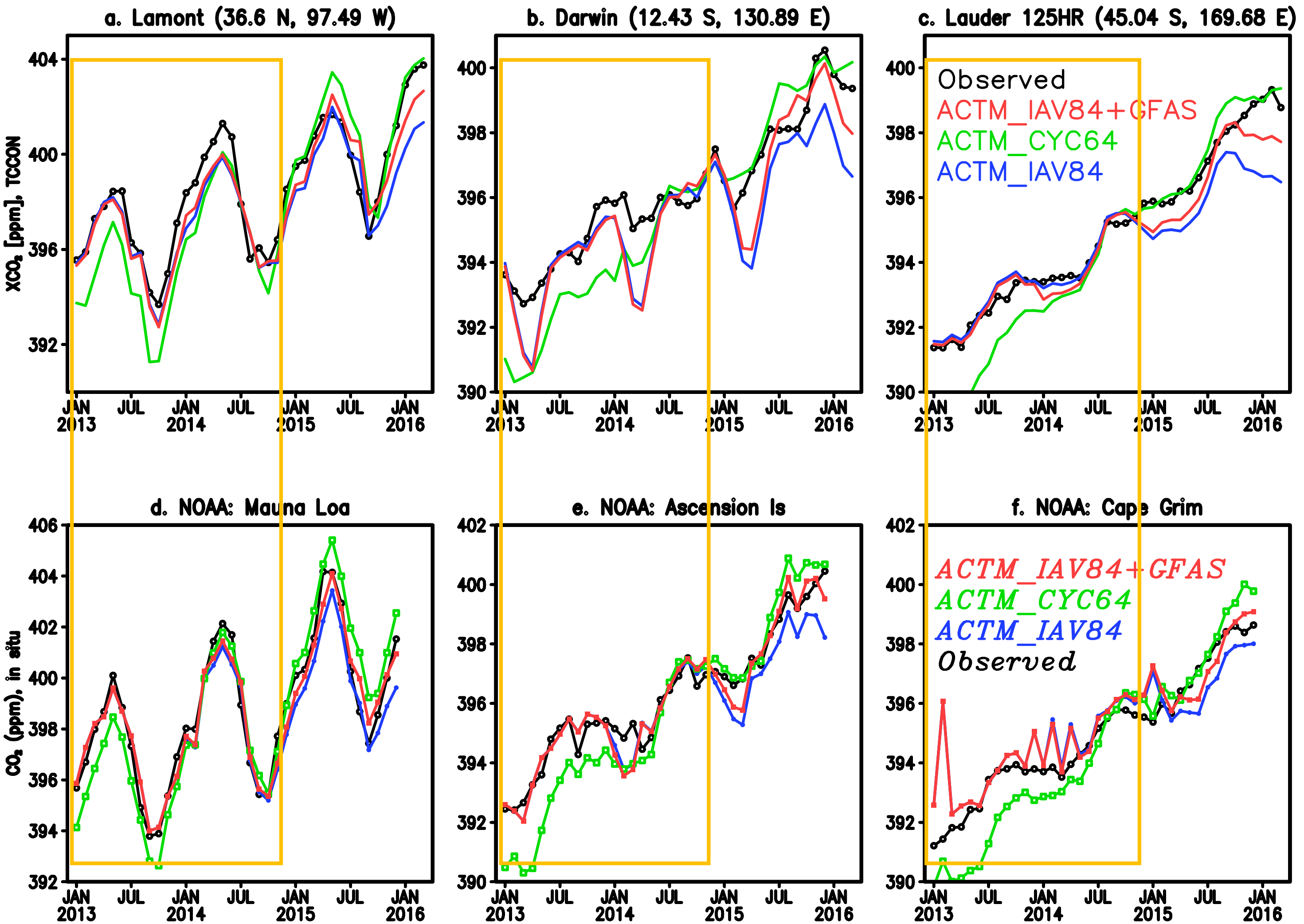
Latitude-time distributions of zonal-mean XCO_2



This analysis began with a forward modelling activity to check XCO_2 from OCO-2

Led by:
Andy Jacobson, NOAA

Reference year using ground based observation

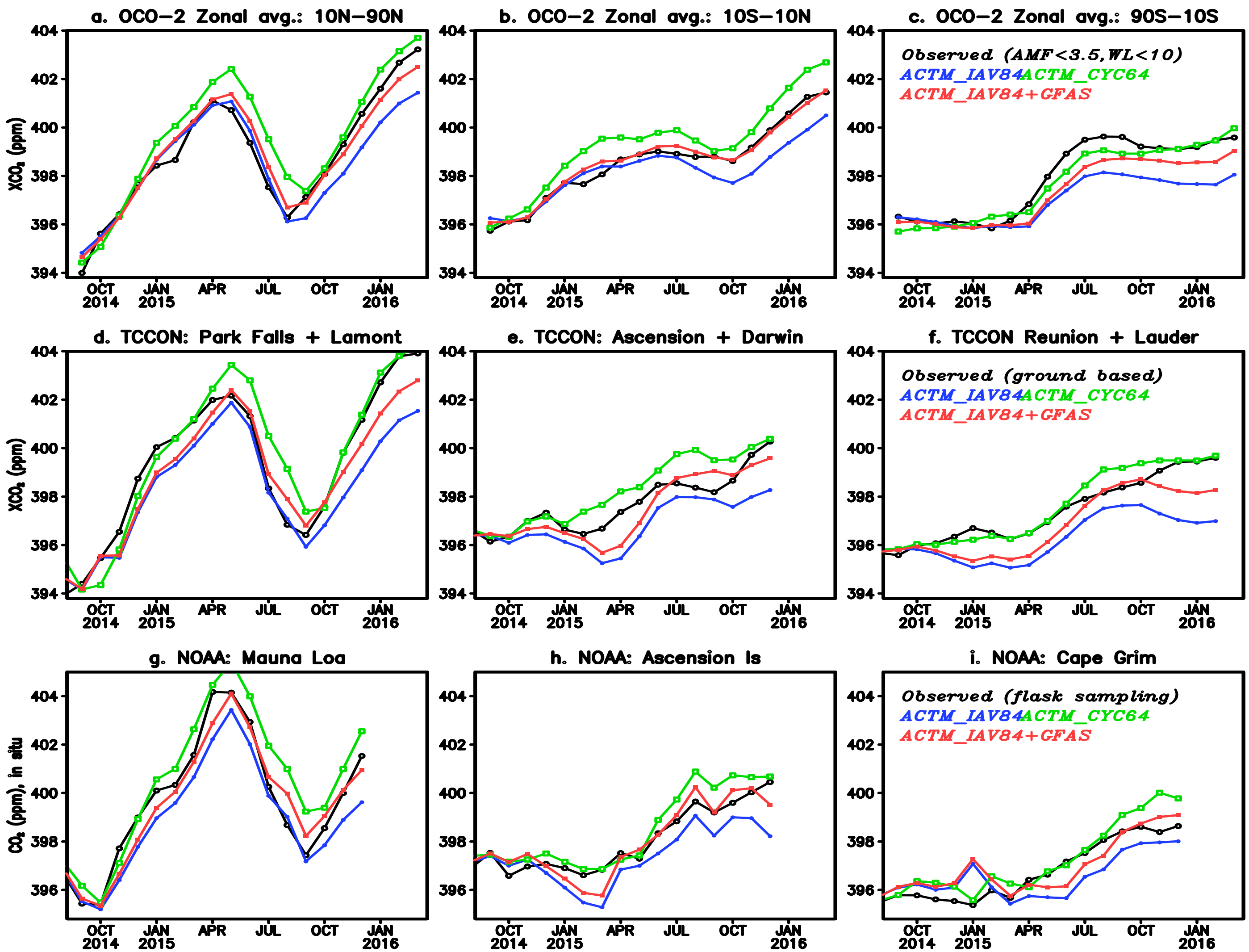


Since the ACTM_IAV84 run simulated the CO_2 growth for 1/2013 - 9/2014 and also for 2012 (not shown), we assume 2011-2013 as the reference year for the CO_2 flux anomaly calculation

NOAA data are taken from : www.esrl.noaa.gov/gmd/ccgg/

Mean XCO_2 timeseries over 3 latitude belts

Northern (left) Tropical (middle) Southern (right)



OCO-2

TCCON

Surface (NOAA)

NOAA data are taken from : www.esrl.noaa.gov/gmd/ccgg/

Calculation of CO_2 flux correction

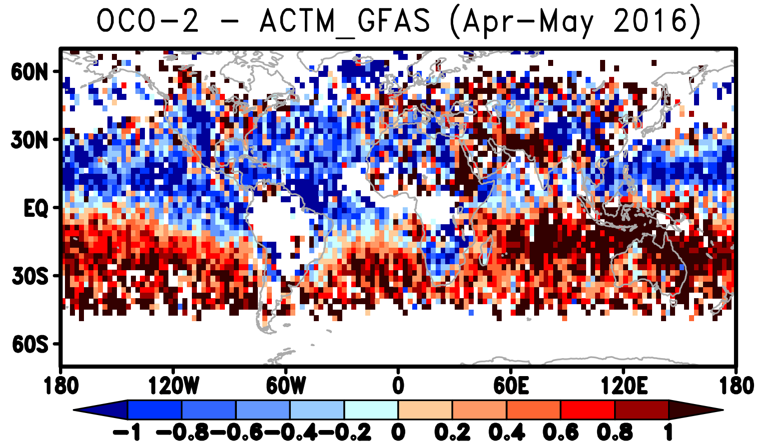
CO_2 flux corrections from sub-hemispheric atmospheric CO_2 burden change at monthly time interval.

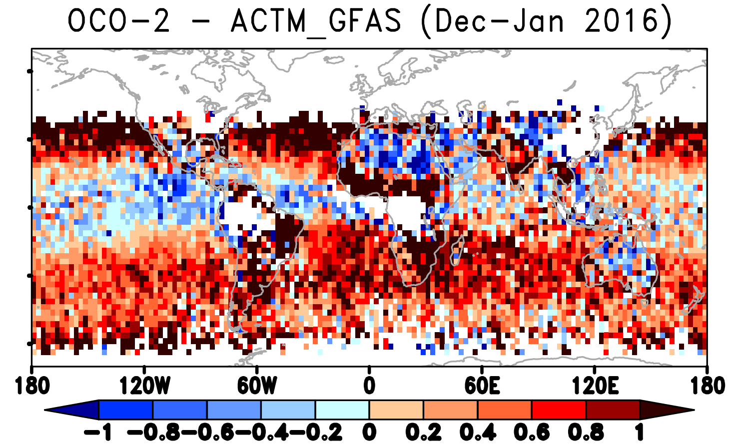
Burden difference $(= \Sigma_i \Sigma_j$ *(*XCO_2 *difference* $\times$ *area of the grid* $\times$ *air density)*

where, i *= lon grid (144),* j *= lat grid (72)*

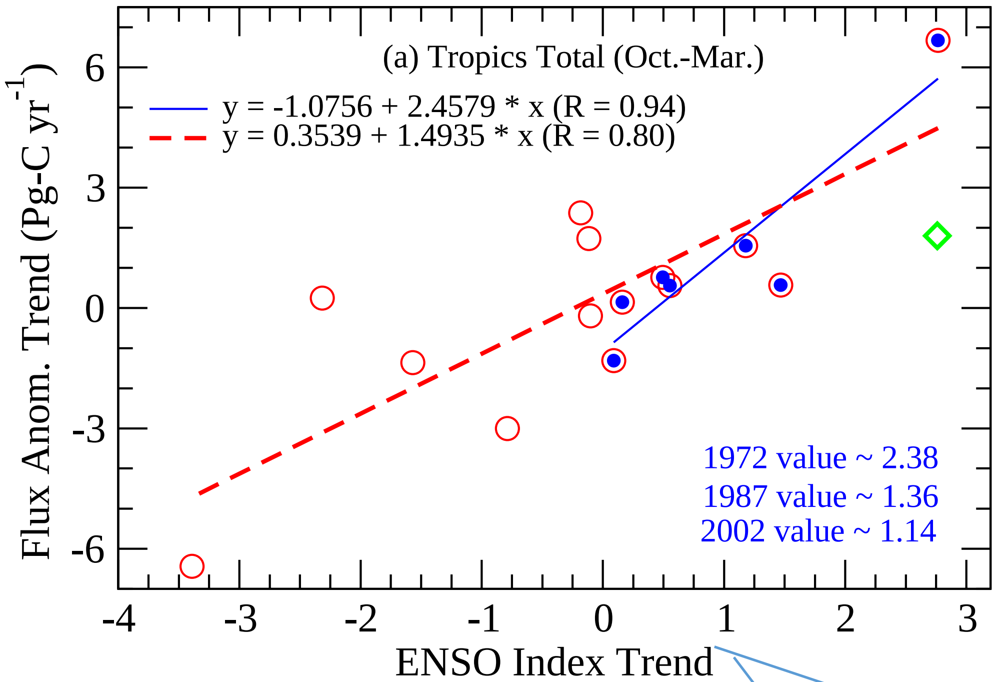
CO_2 *flux correction = d(Burden difference)/dt*

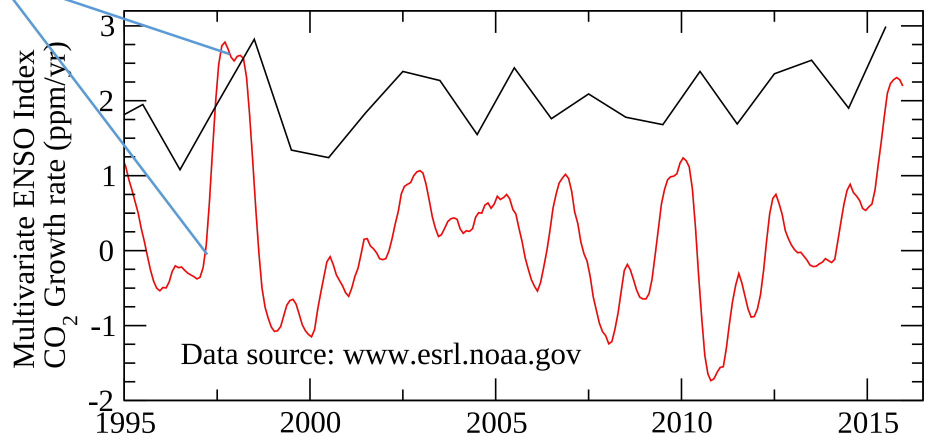
The difference in the burdens between October and September 2014 is assigned to the flux correction for October 2014.





Estimation of CO_2 flux anomaly from empirical relationship with ENSO Index trends





Patra et al., 2005c

Global total CO_2 fluxes: a priori and a poste corrections

Time window	A priori CO_2 fluxes used for ACTM simulations					Patra et al. # (2005b)	CO_2 flux corrections from OCO-2 – ACTM differences$		
	FFC	CYC64	IAV84	IAV84 +GFAS	GFAS		CYC64	IAV84	IAV84 +GFAS
Oct-Dec 2014	2.44	3.36	0.80	1.17	0.37		–0.14 - –0.42	0.35 - 0.42	0.25 - 0.30
Jan-Dec 2015	9.98	-2.86	-6.29	-4.29	2.00	2.67	–0.28 - –0.48	0.95 - 1.59	0.21 - 0.32
Jan-Feb 2016	1.70	0.64	0.10	0.36	0.26	- 2.73	–0.17 - –0.31	0.15 - 0.23	0.05 - 0.06
Oct14 -Feb16	14.12	1.14	-5.36	-2.72	2.64		–0.59 - –1.21	1.45 - 2.24	0.51 - 0.68

2015 net fluxes for the 3 simulations are: -3.34 (CYC64), -3.70 (IAV84), and -3.97 (IAV84+GFAS)

for ACTM_IAV84 sensitivity cases: -3.91 (AMF<2.5), -3.90 (WL<5)

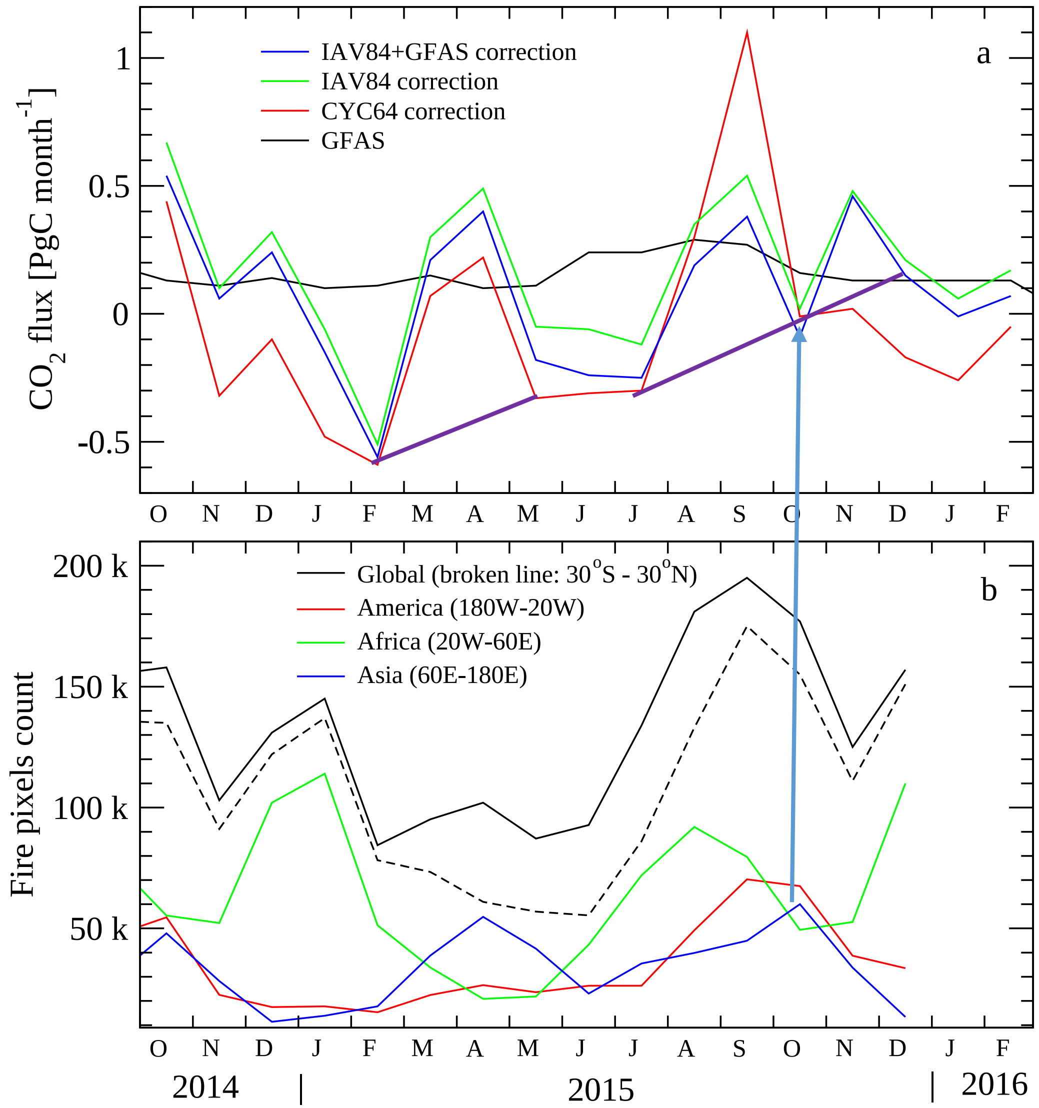
(these global total sinks are residuals – depends entirely on assumed FFC)

Range estimated from two different fits, with (= 0.3539 + 1.4935 × MEI amplitude change) or without (=-1.0756 + 2.4579 × MEI amplitude change) the La Niña years

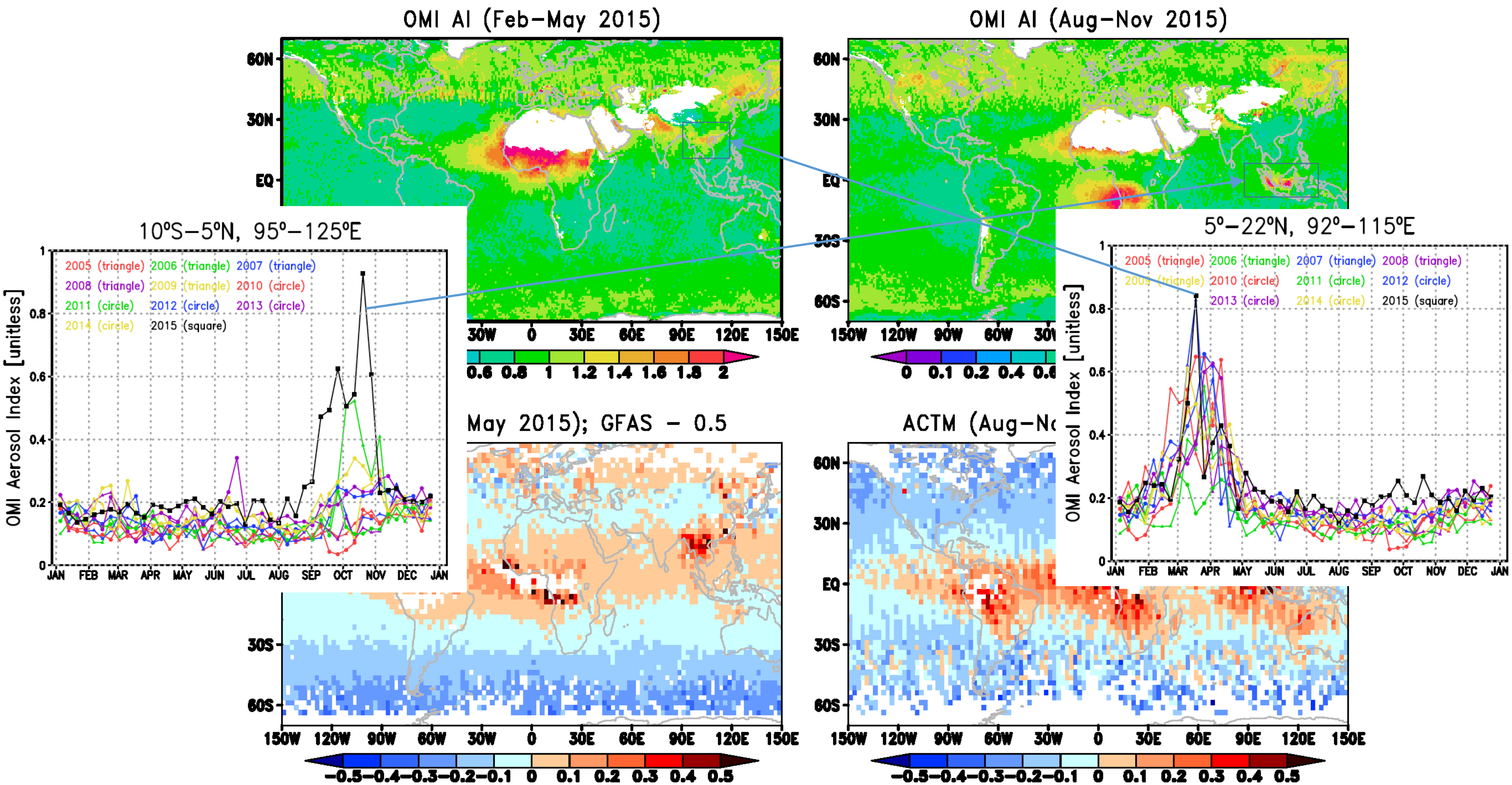
$ Range estimation using two different approximations on area coverage, lower range is for data just over the OCO-2 measurement area, higher values with data coverage extrapolated to the poles

Flux correction time series

- The flux corrections suggest pulsed emissions of ~1-month, in agreement with fire counts variability
- Pulsed emission, likely from fires, accounts for 0.7 PgC in 2015, which is 30-44% total CO_2 flux anomaly
- GFAS emissions vary surprisingly slowly throughout the year
- CO_2 emissions from Oct 2015 fire peak goes undetected due to aerosol screening



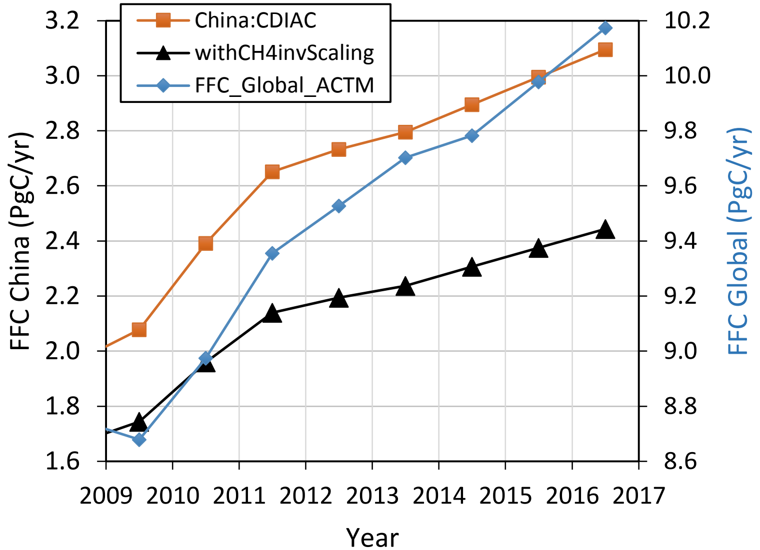
In support of strong biomass burning emissions in 2015

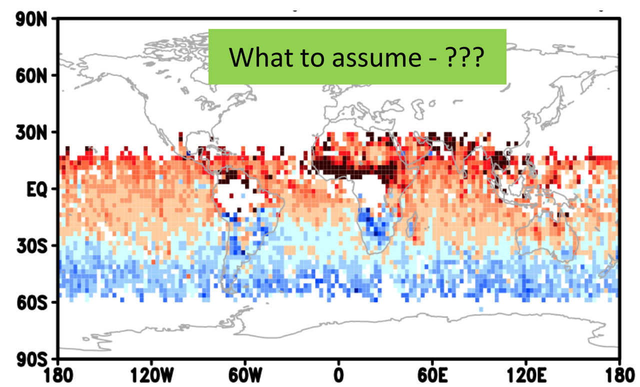


Sources of uncertainty

More discussion on this in the TransCom-style side meeting in the evenning

- **Emissions from fossil fuel and cement (FFC)**
  - FFC CO_2 emission increase is assumed to be 0.2 PgC/yr; for no increase in FFC emission, the CO_2 flux anomaly would increase by ~0.3 PgC for the OCO-2 period
  - Constant bias in total FFC emission strength wouldn't change the CO_2 flux anomaly, but affect the regional sources/sinks budgets
- **Data coverage**
  - Data screening using AMF and WL affect the estimation of CO_2 flux anomaly marginally
  - Extension of observation-model differences to the data void regions affect the flux anomaly calculation and likely misallocate the sources/sinks regionally





Summary and outlook

- We analyzed the XCO_2 from NASA's OCO-2 and JAMSTEC's ACTM during September 2014 and February 2016
- The 2014-2016 El Niño event led to an excess CO_2 release to the atmosphere in the range of 2.24-3.32 PgC yr^{-1}
- A few of the major issues to be dealt with for using XCO_2 data in inversion:
  - Handling of the data gaps in OCO-2 or other passive sensors for long-lived gases is a cause for concern (not serious for the short-lived species as their emission and chemical loss cycle is confined to a particular latitude band)
  - Accounting for chemical production of CO_2 from reduced carbon compounds, CH_4, CO, BVOCs etc. (not serious for in situ surface data, which are influenced most by surface fluxes)
  - Large-scale transport bias in the models should be tracked as the column integrated values are less sensitive to small-scale mixing
  - Low uncertainty in fossil fuel amount are needed for reduction of bias in regional source/sink estimation

Thank you and questions?

Need a smaller mesh to catch CO_2 emissions

Courtesy of Indonesia's Fire Crisis 2015 - The Biggest Environmental Crime of the 21st Century by Erik Meijaard http://jakartaglobe.beritasatu.com

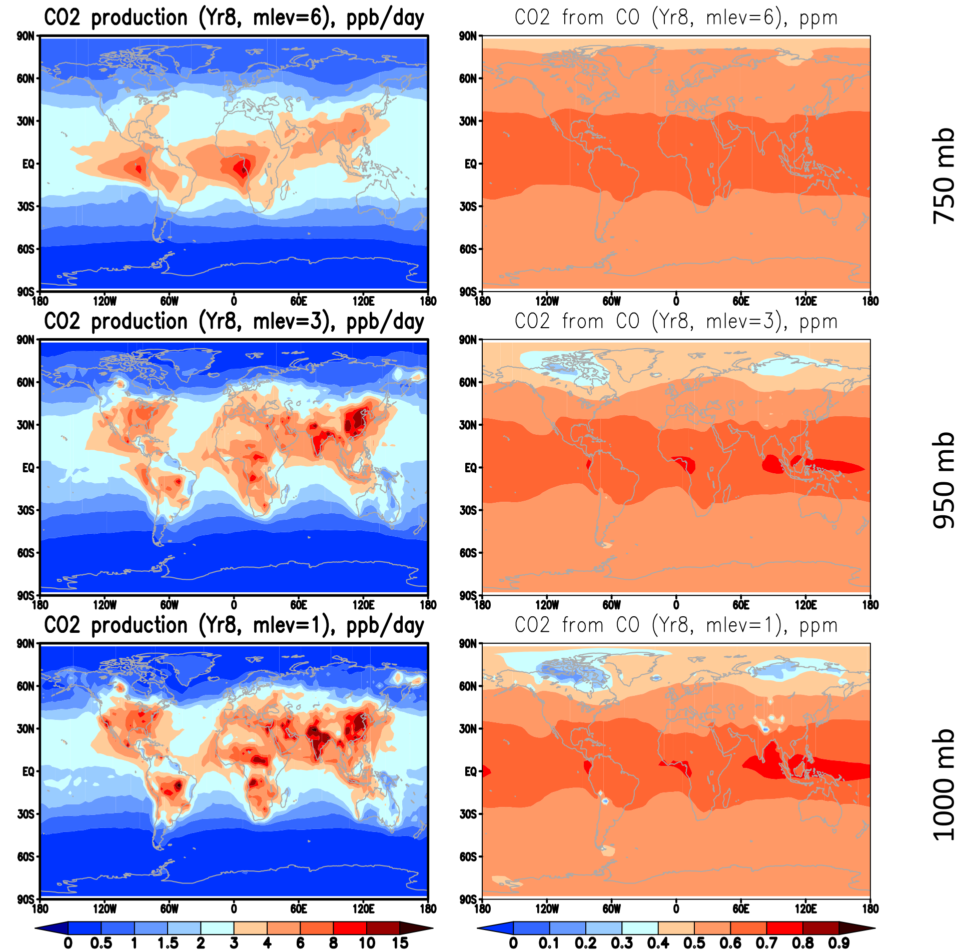
- This work is partly supported by Ministry of Environ. Res. and Tech. Development Fund (grant # 2-1401; PI. N. Saigusa)

- CO_2 measurements are available for scientific use at
  - http://ds.data.jma.go.jp/gmd/wdcgg and
  - http://www.esrl.noaa.gov/gmd/dv/ftpdata.html
  - http://tccon.ornl.gov

- All the model results and analysis tools are available unconditionally from the ACTM group; PKP thanks Kentaro Ishijima for pre-processing of JRA-55 meteorological fields

Suggested model improvements

- ACTM is well tested for large-scale transport in troposphere, but issues remain with fast Brewer-Dobson circulation in the stratosphere
- Accounting for CO_2 production from reduced carbon compounds (CO, CH_4, VOCs etc.)
    - As shown here CO_2 is produced in the tropical troposphere and over the source region
    - Chemically CO_2 source are then transported to the higher latitude with a time delay
    - This situation leads to greater CO_2 emission in tropics and greater sink in the extratropical lands by inverse modeling



CO_2 from CO model:
Courtesy of Takashi Sekiya, JAMSTEC

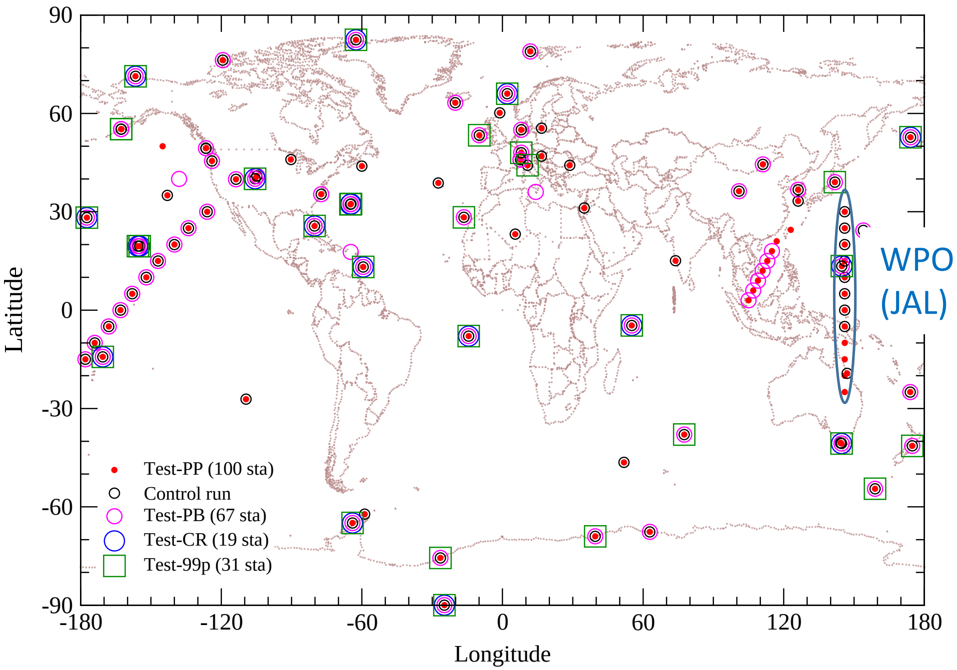
Why (NASA) satellites are important ?

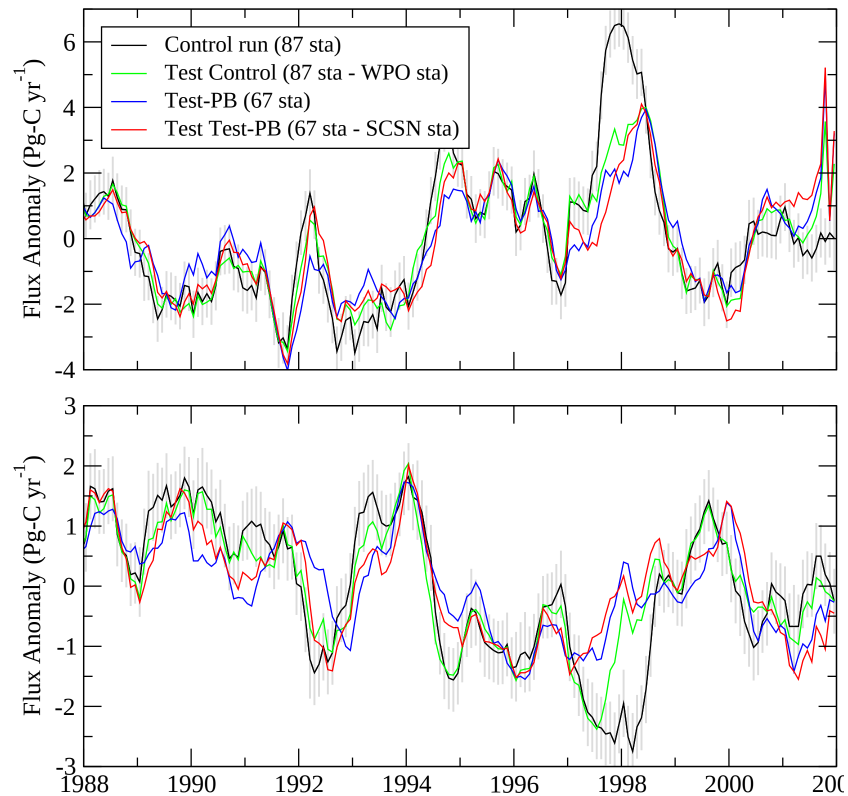
Lack of globally uniform observations leave the biologically active land areas unconstrained by inverse modelling

Without measurements at the source region, fluxes are misallocated to other regions

NASA makes everyone's life easier (NetCDF, averaging kernels, a priori profiles, near-real time data, inviting to modellers etc.)

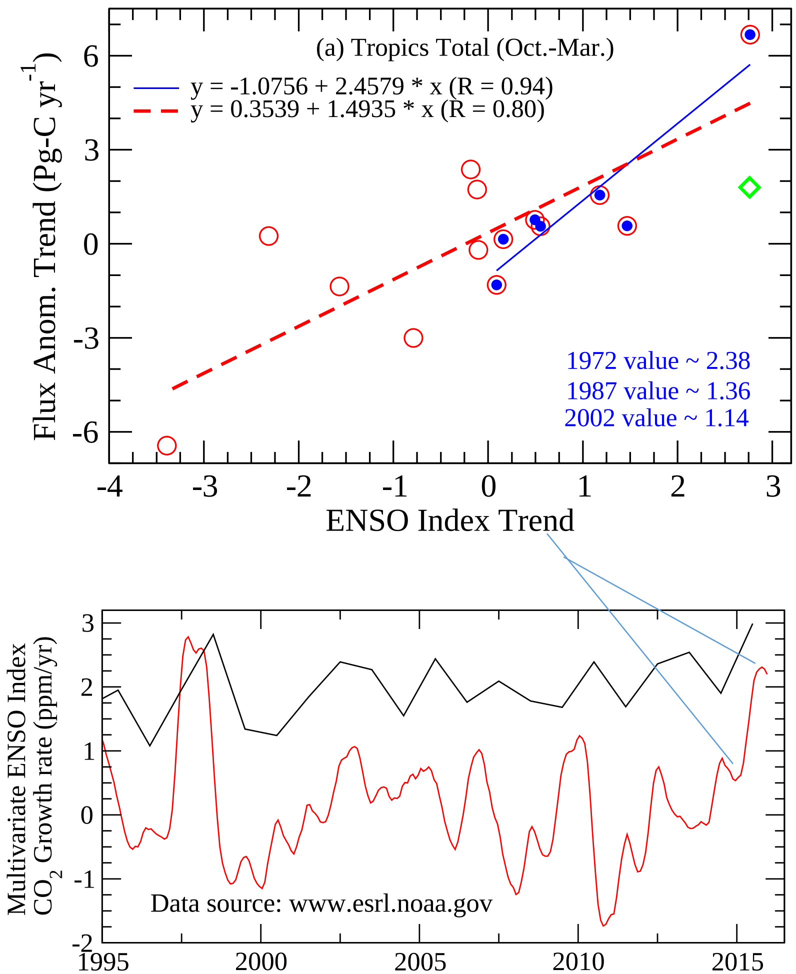
Patra et al., 2005a



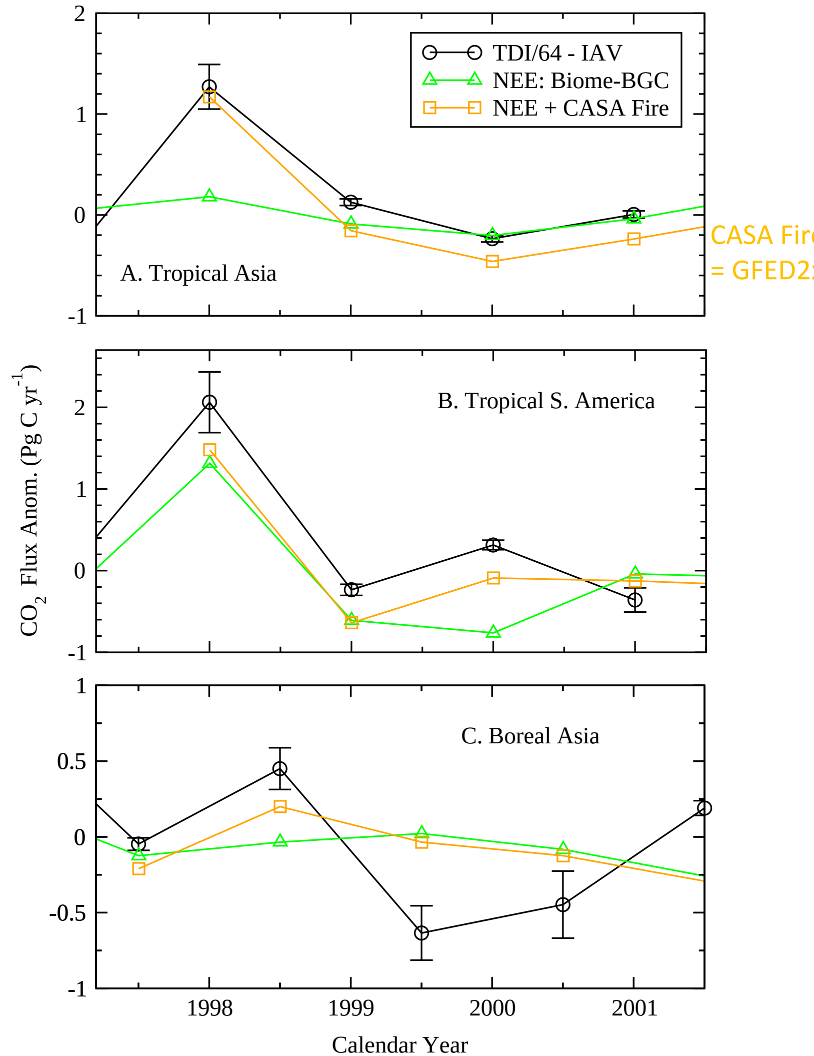


We no more have access to "full record" of JAL WPO data

Estimation of CO_2 flux anomaly from empirical relationship with ENSO Index trends

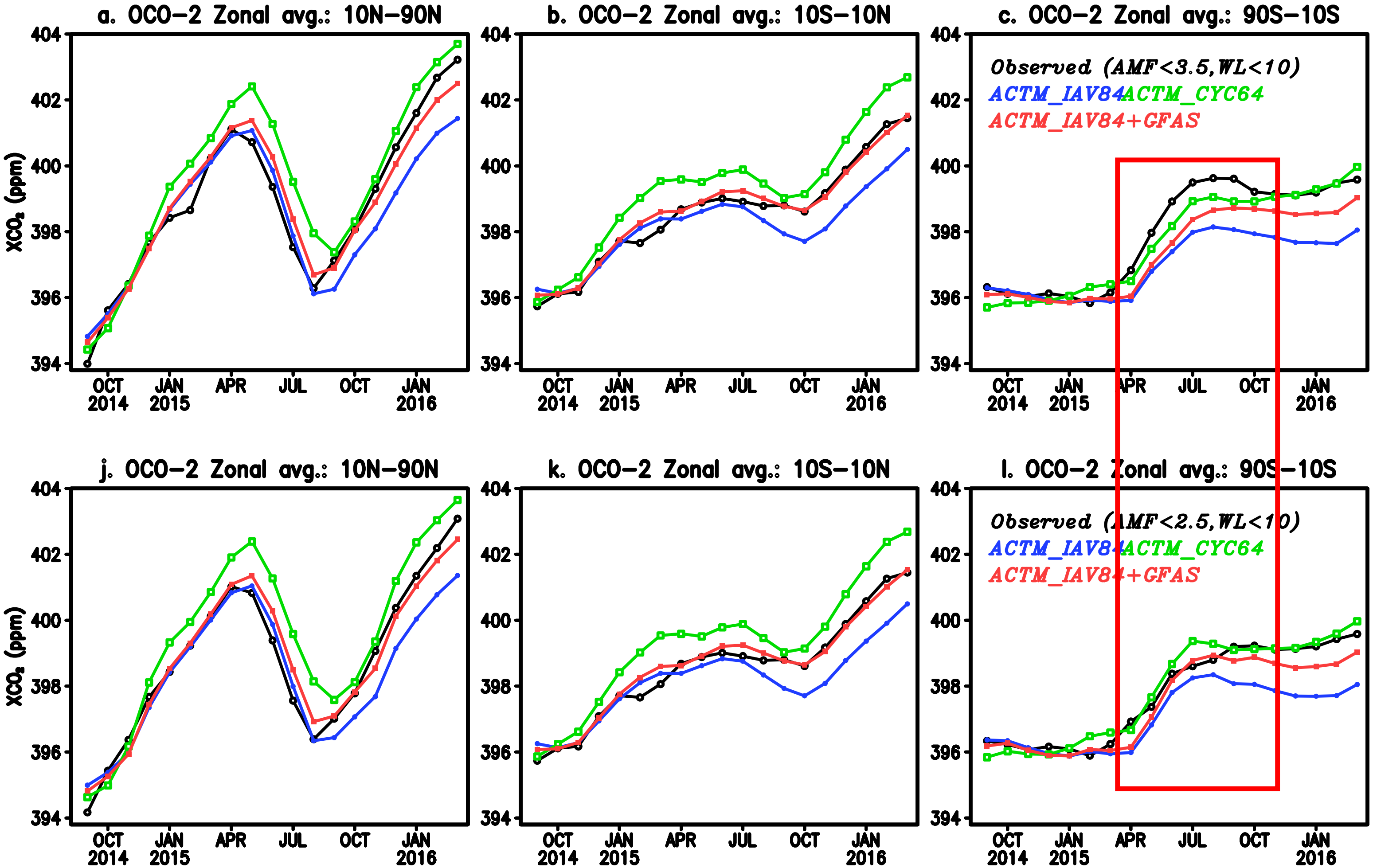


Patra et al., 2005c



Patra et al., 2005a,b; Maksyutov et al., 2007

OCO-2 sensitivity to the AMF

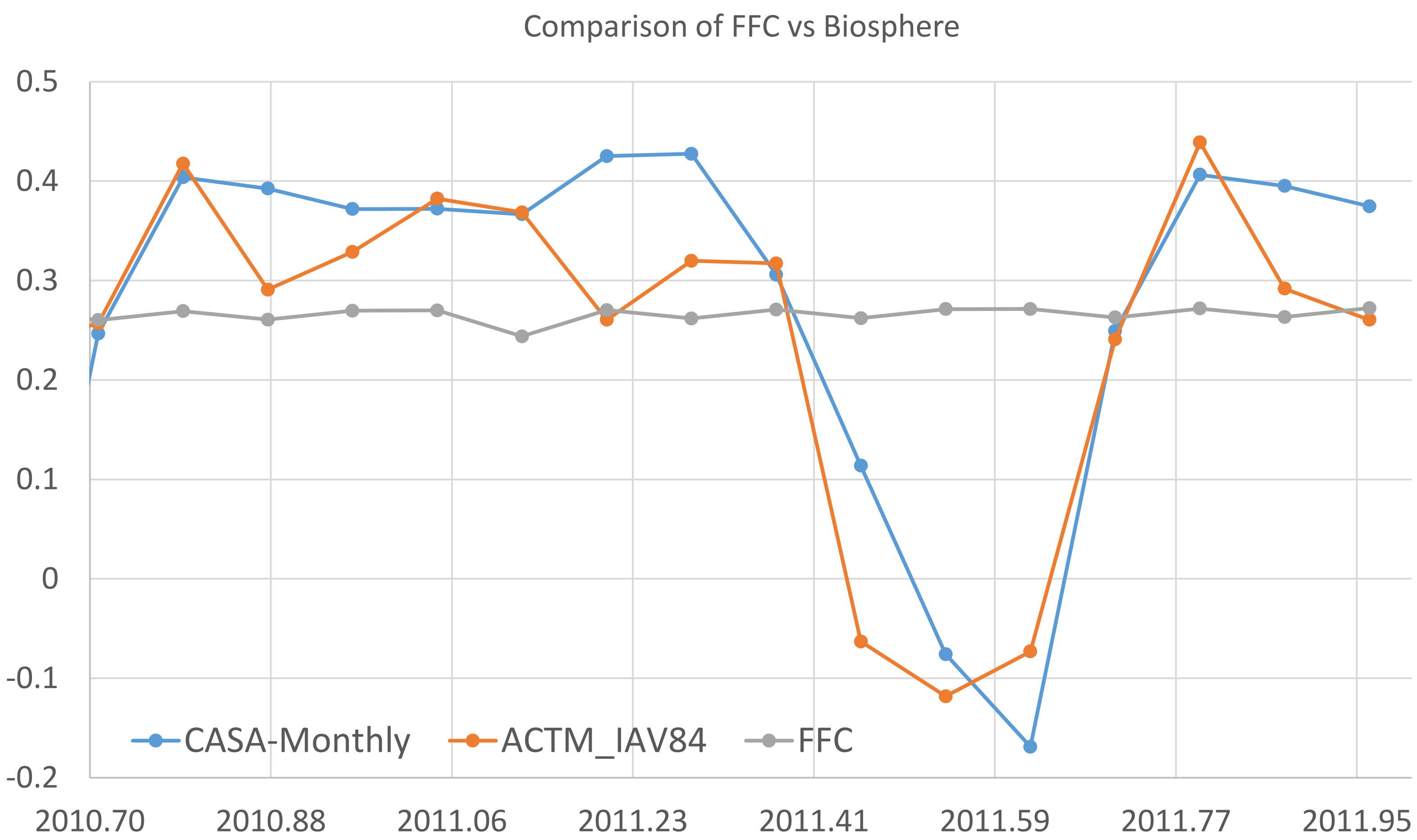


Large difference in the timing of underestimation by IAV84 and IAV+GFAS simulation cases:

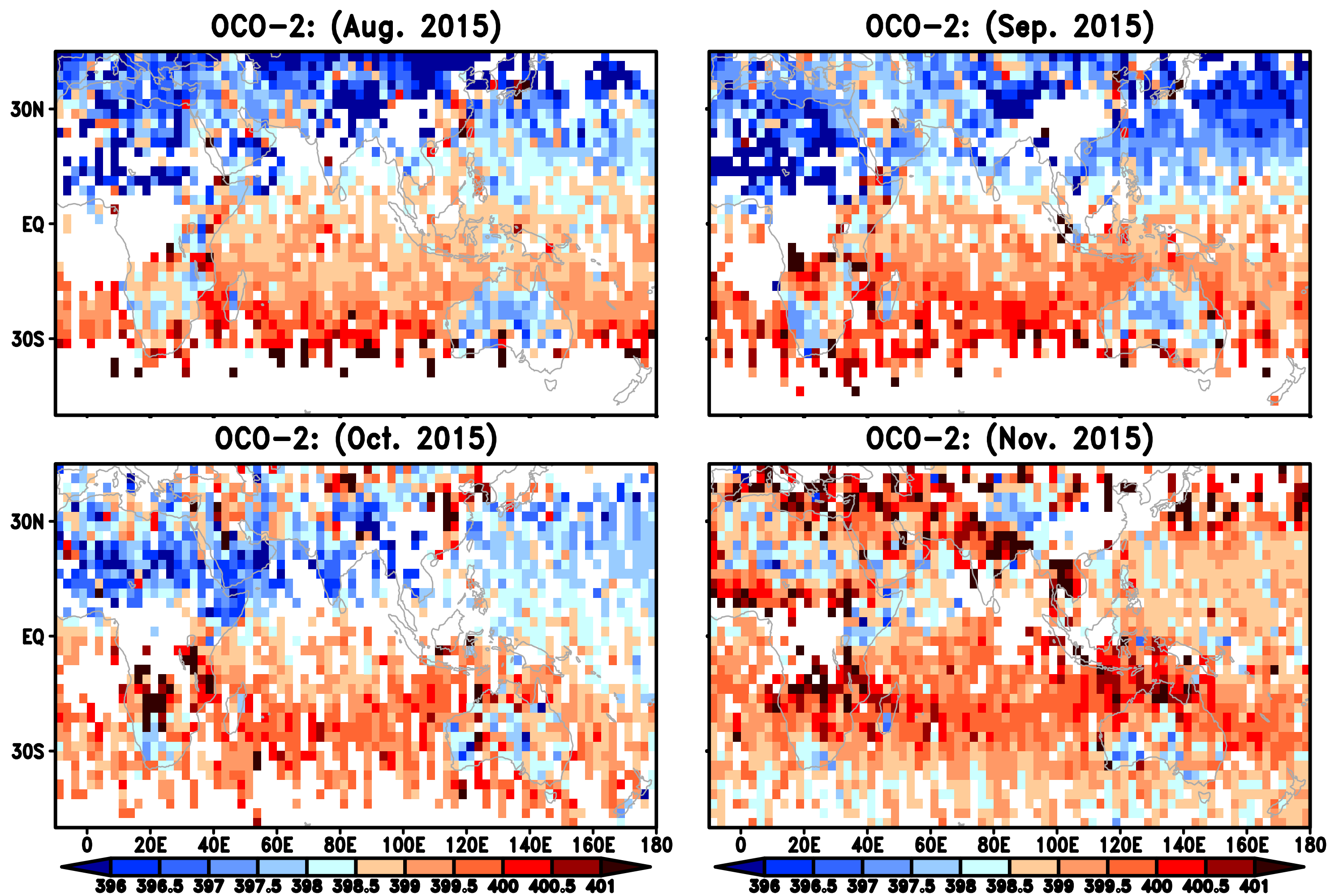
April 2015 for AMF<3.5 (top row)

July 2015 for AMF<2.5 (bottom row)

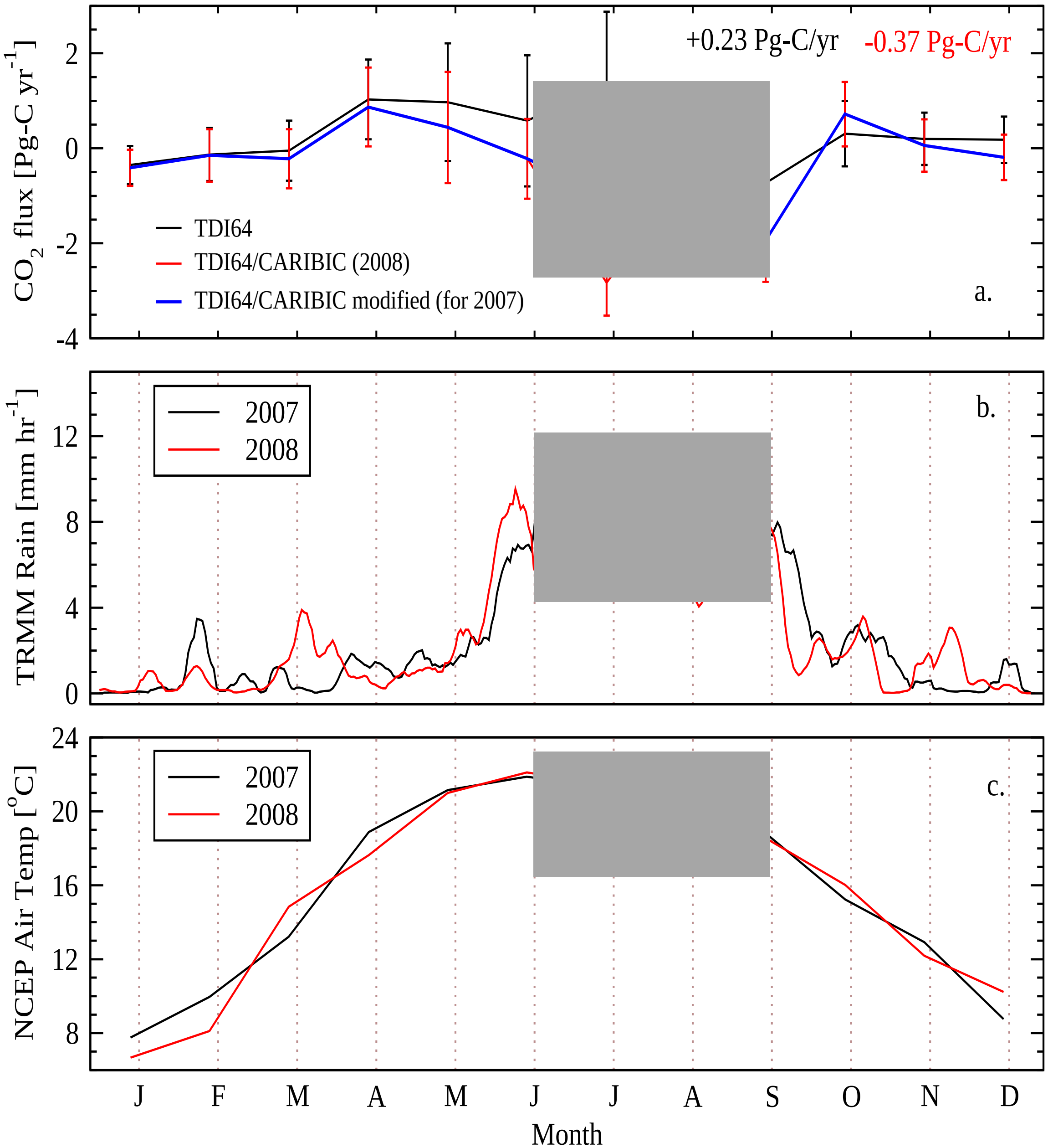
Why it is difficult to track uncertainty in FFC?



Why no emission peak in October 2015?



Handling of data gaps – seasonal sun & clouds



Patra et al., ACP, 2011; BG, 2013