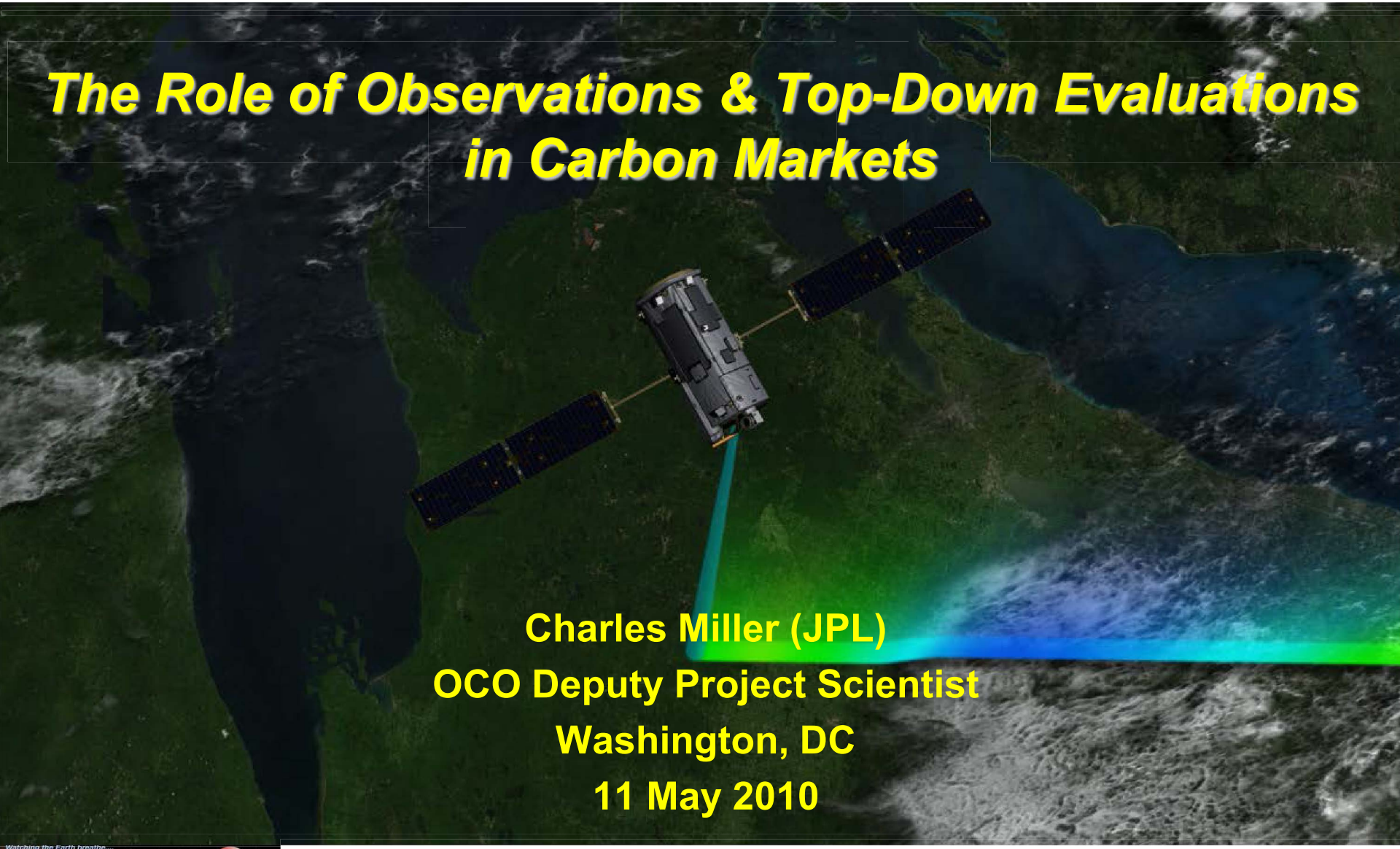
The Role of Observations & Top-Down Evaluations in Carbon Markets



Charles Miller (JPL)

OCO Deputy Project Scientist

Washington, DC

11 May 2010

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Overview

What role(s) can/should observations play in carbon markets?

- Informing C-market development
- Use during market implementation
- Evaluating efficacy

Reconciling bottom-up and top-down estimates of carbon emissions

The capabilities of current and future observing systems to attribute and quantify carbon emissions and uncertainties

The Role of Observations in Carbon Markets Depends on What Question Is Posed

Example use-case scenarios:

Are the actual emissions from individual point sources in Country-X exceeding their reported emissions?

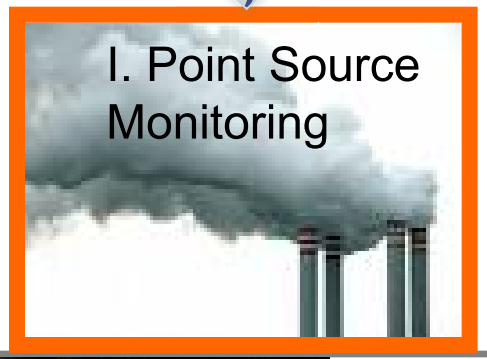
How are individual point source emitters being operated (dynamic behavior)?

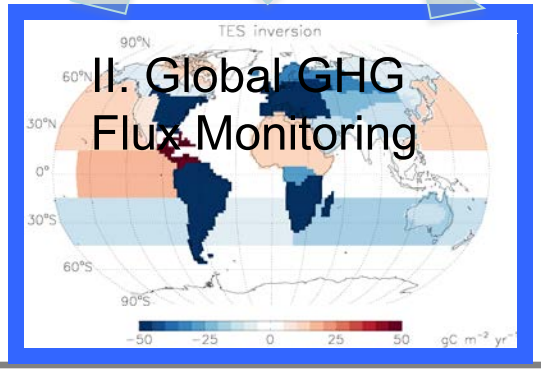
Are Country-X's actual emissions exceeding their-reported (national inventory) emissions?

Are policies meeting the desired objective (limiting GHG concentrations)?

Does the actual carbon stock match the reported baseline for a forest carbon offset credit by Country-X or Project-Y?

Are disturbances occurring in Country-X or Project-Y that impact the claimed carbon credit (is the offset permanent)?





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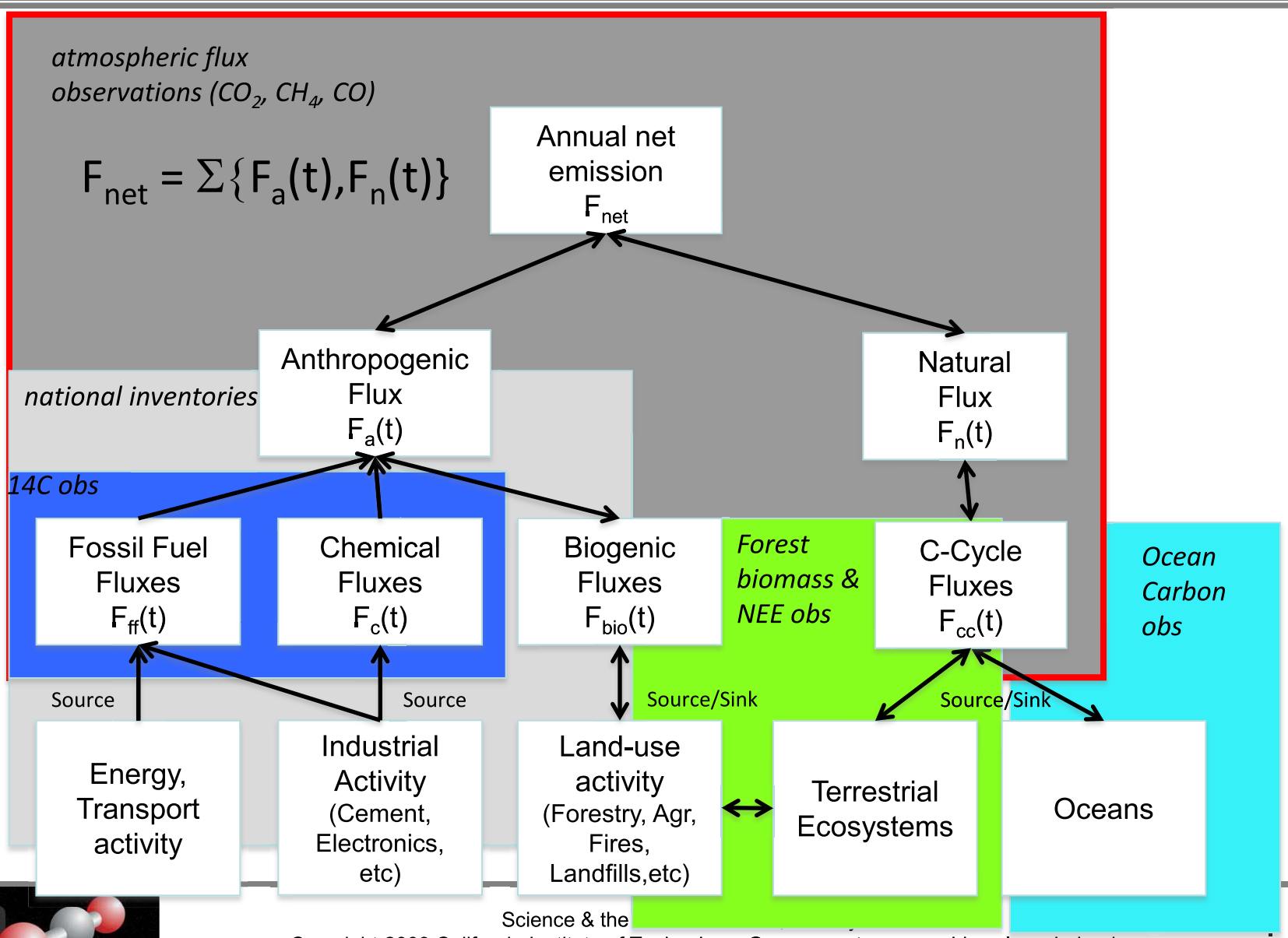
The Key Challenge: Disentangling Natural & Anthropogenic CO2 Emissions



Watching the Earth breathe.... mapping CO2 from space.
Orbiting Carbon Observatory

Science & the

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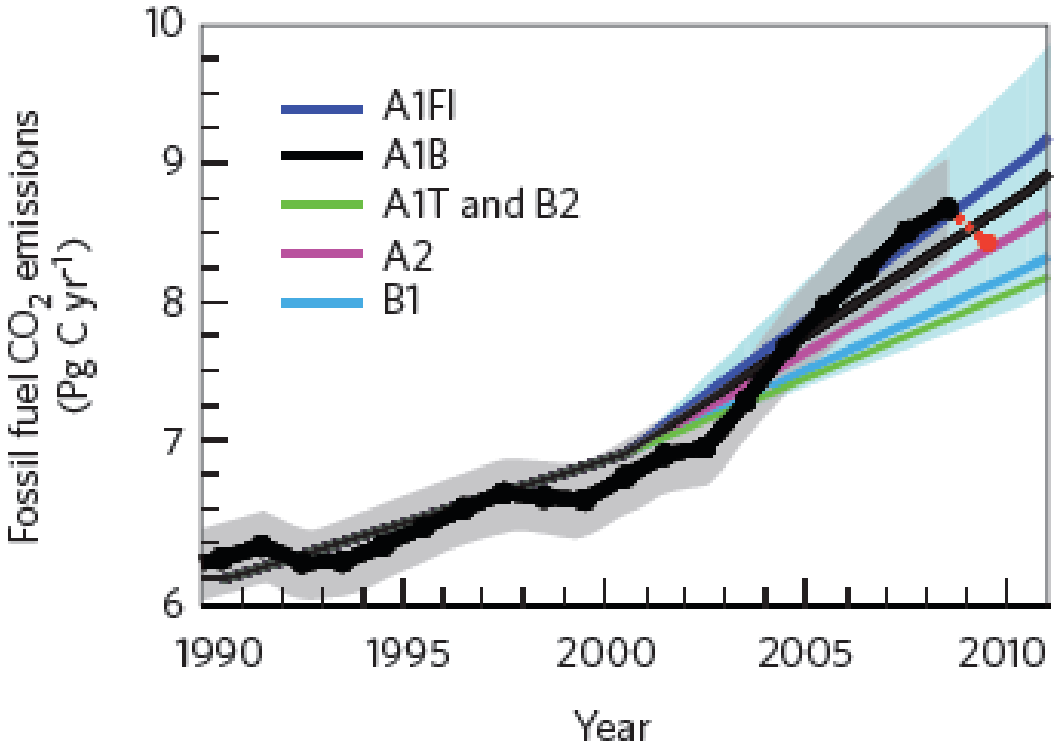
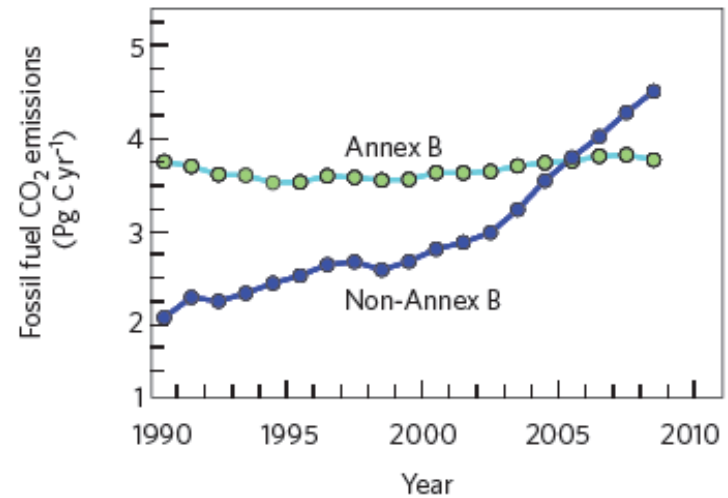
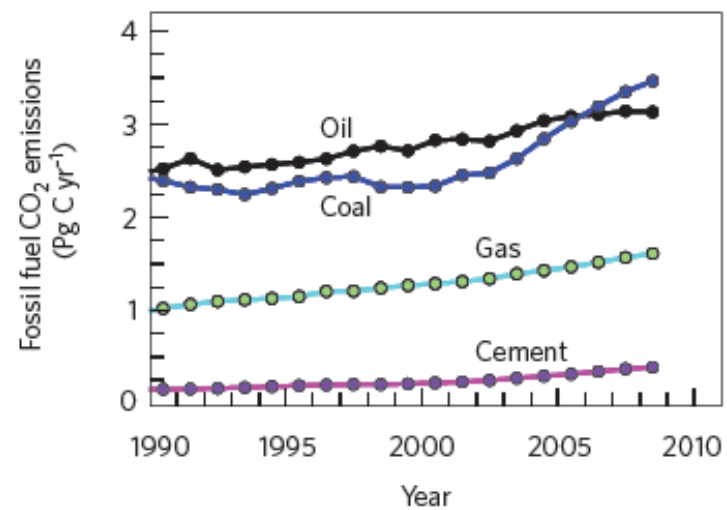
Current Understanding (2008): Global Trends in CO2 Emissions







- Actual emissions exceed A1-FI since 2005
- Annex B emissions exceed Annex A emissions
- Emissions from coal exceed emissions from oil

LeQuere et al., Nature Geosci 2009

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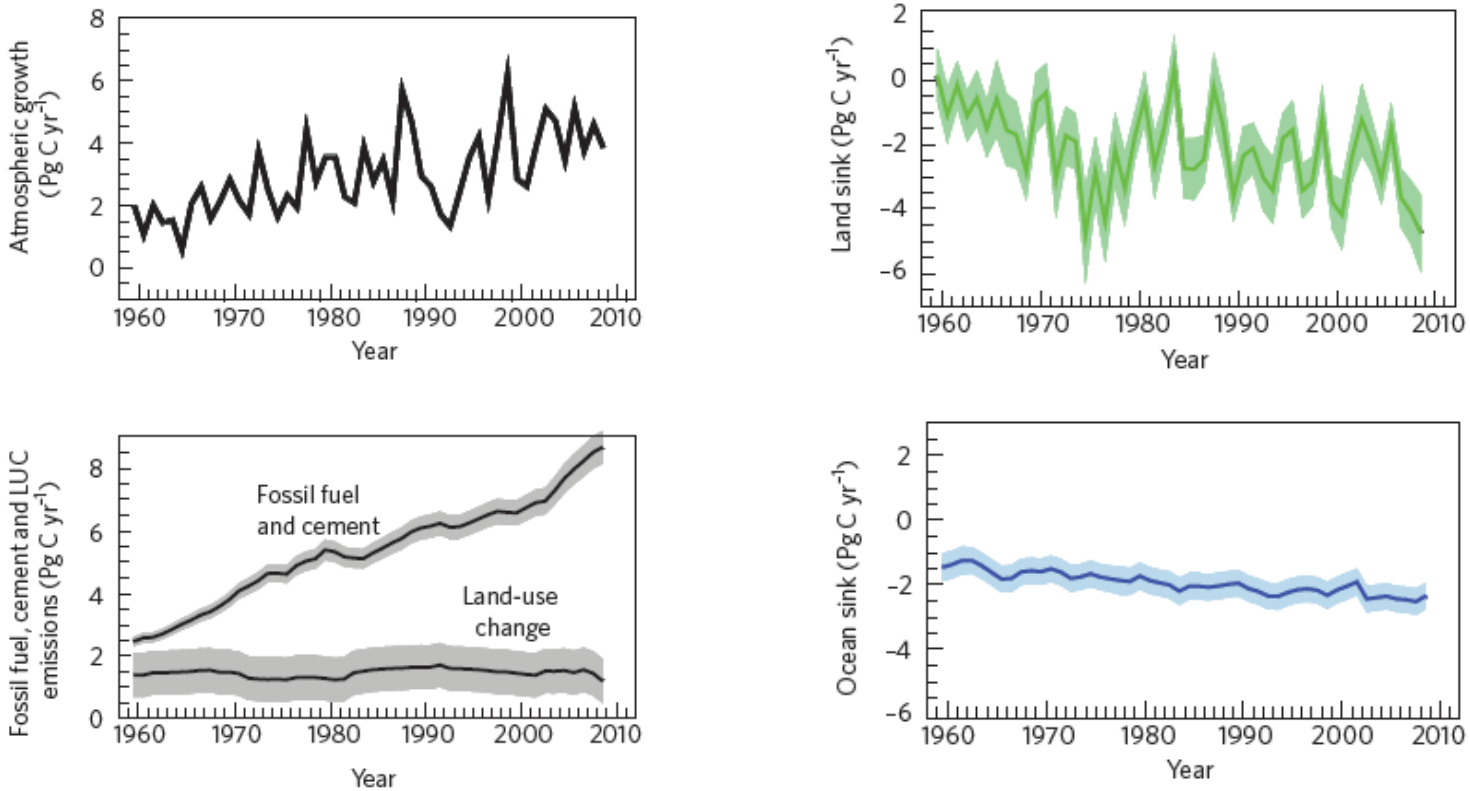
Bottom-Up vs Top-Down Estimates of Global CO2 Sources and Sinks (2008)

- FF + LUC – Land – Ocean = Atmosphere
- **Bottom-up**: (8.7 ± 0.5) + (1.2 ± 0.7) – (4.7 ± 1.2) – (2.3 ± 0.4) = **2.9 ± 1.6**
- **Top-Down**: Actual measured atmospheric growth = **3.9 ± 0.1**
- All values in PgC/yr



LeQuere et al., Nature Geosci 2009

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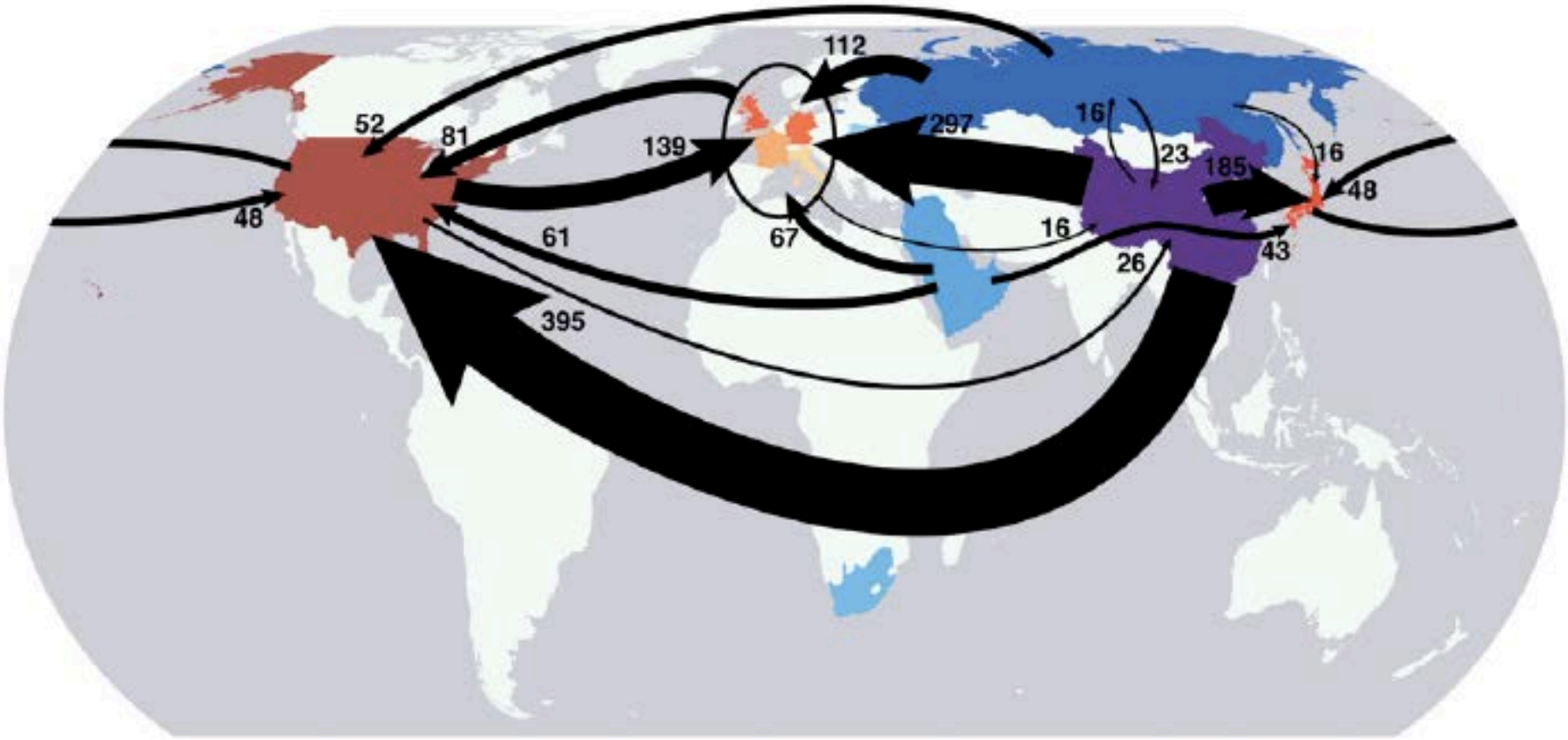
Full Carbon Accounting Requires Geospatially Resolved Emissions Inventories



- Inter-regional fluxes of CO2 emissions due to trade (MtCO2 yr^{-1})

Davis & Caldeira, PNAS (2010)

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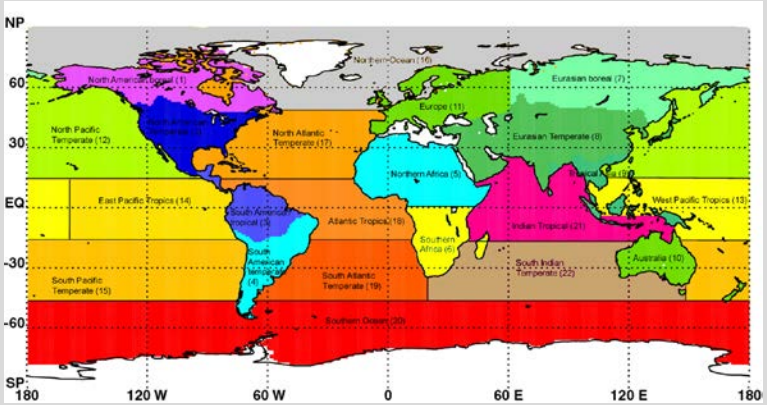
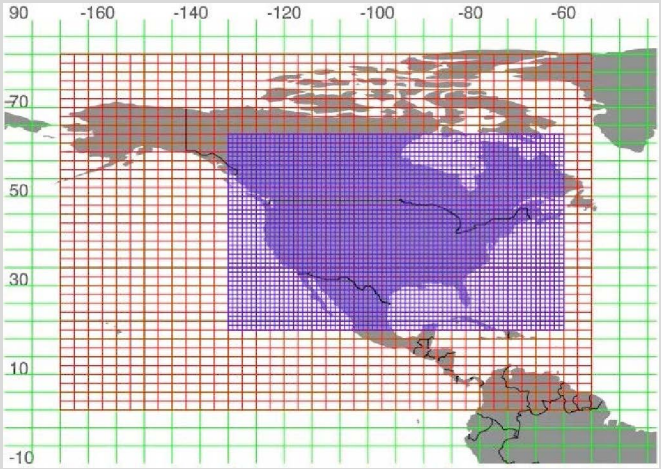
Evolution of CO2 Flux Inversions from Research to Policy-relevant Spatial Scales

Jet Propulsion Laboratory
California Institute of Technology

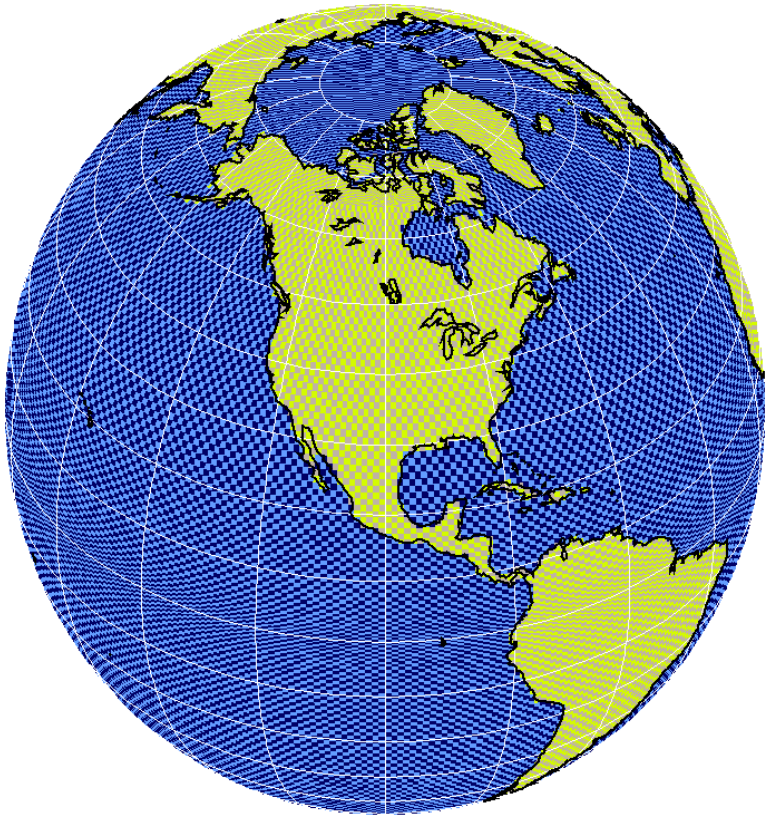
TRANSCOM
22 continental scale cells



NOAA CarbonTracker
6x4 deg global grid (3000 cells)
(1x1 US-only) *based on 100 spatially unique observations/day*



GHGIS
CO2 Flux Map
1 deg x 1 deg grid (64,800 cells)
based on 1,000,000 spatially unique observations/day



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Geospatially-resolved Observations are Needed to Identify Inventory Discrepancies

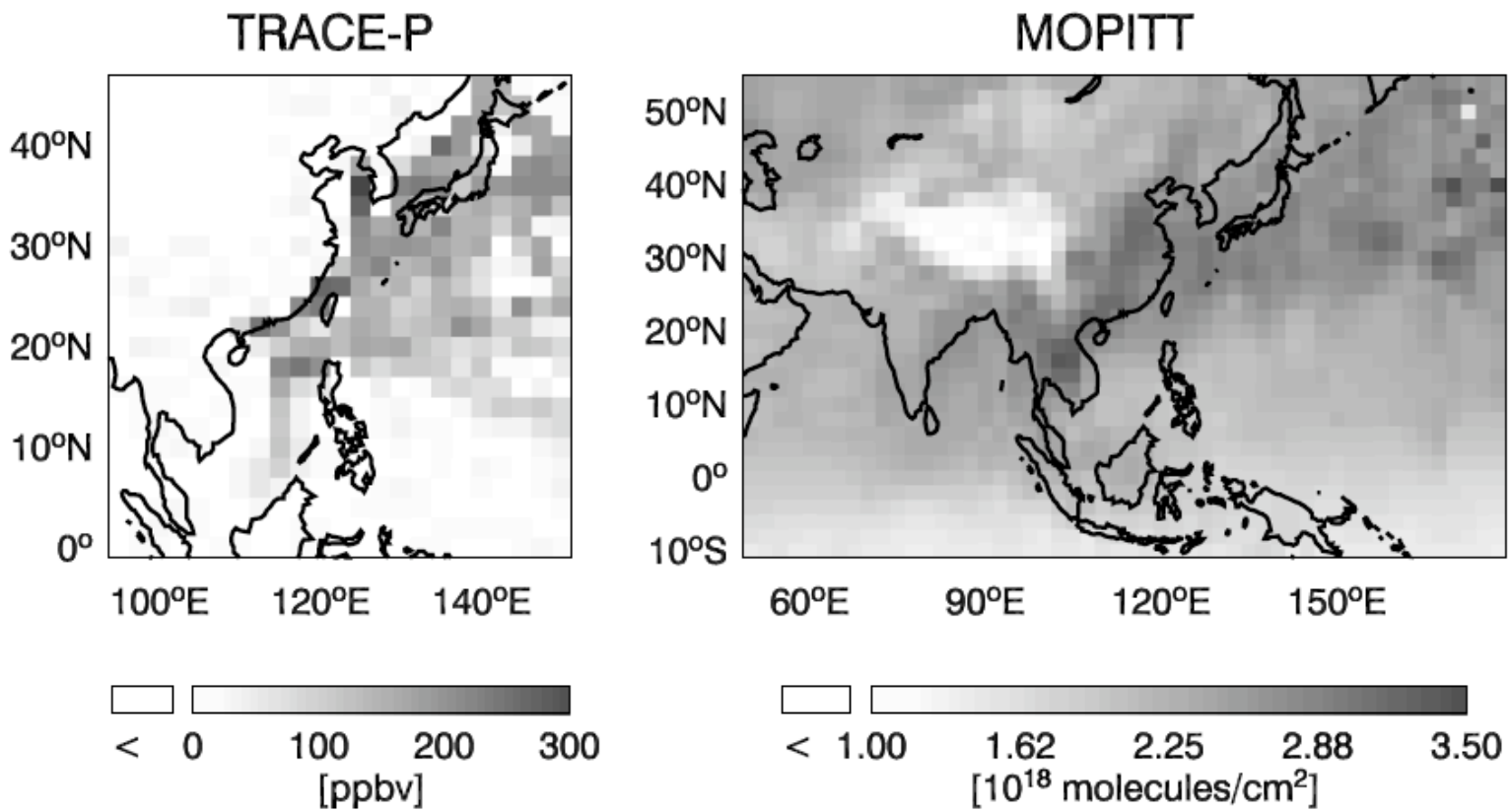

Figure 2. Mean CO observations during the TRACE-P mission (26 February to 9 April 2001) averaged over the 2° × 2.5° grid of the GEOS-CHEM CTM. TRACE-P aircraft concentrations averaged over all altitudes are shown on the left. The MOPITT CO columns (morning overpasses only) are shown on the right. See color version of this figure at back of this issue.

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Chinese CO Emissions Inventory Revised +40% After Trace-P Field Campaign

Table 1. Estimates of China's and Asian Annual CO Emissions[a]

Study	Year of Estimate	China FF + BF	China BB	China FF + BF + BB
Emission inventory methods				
EDGAR V2.0	1990	70[c]	20[c]	90[c]
EDGAR V3.2	1990	84	1	85
EDGAR V3.2	1995	88	0	88
EDGAR V3.2	2000			89
Streets and Waldhoff [2000]	1990	94	6[d]	100[d]
Streets and Waldhoff [2000]	1995	109	6[d]	115[d]
Tonooka et al. [2001]	mid-1990s			87
Nakicenovic et al. [2000]	1990			
Nakicenovic et al. [2000]	2000			
Streets et al. [2003a]: TRACE-P	2000	100	16	116
Heald et al. [2003a]	2001		19	
This study	2001	142	16	158
Inverse modeling				
Palmer et al. [2003]	2001	168	12	180
Pétron et al. [2002]	1990–1996			
Kasibhatla et al. [2002]	1994			
Arellano et al. [2004]	2000			
Heald et al. [2004]	2001			
Wang et al. [2004c]	2001			166
Pétron et al. [2004]	2000–2001			
Forward modeling				
Heald et al. [2003b]	2001			181
Tan et al. [2004]	2001			174
Allen et al. [2004]	2001	145		
Carmichael et al. [2003]	2001			163–210

[a]Units are in Tg/yr. FF, fossil fuel; BF, biofuel combustion; and BB, open biomass burning.
[b]Definition of region varies slightly across studies, but China dominates in all cases.
[c]Estimated by scaling the EDGAR value for China+ region to just China using TRACE-P national values.
[d]Agricultural waste burning only; no forest or savanna burning included.

Pre-Trace-P CO emissions inventories for China

Revised (post-Trace-P) Chinese CO emissions inventory

Chinese CO emissions from a synthesis of inventories, atmospheric modeling & observations

Streets et al., JGR, 2006

Orbiting Carbon Observatory
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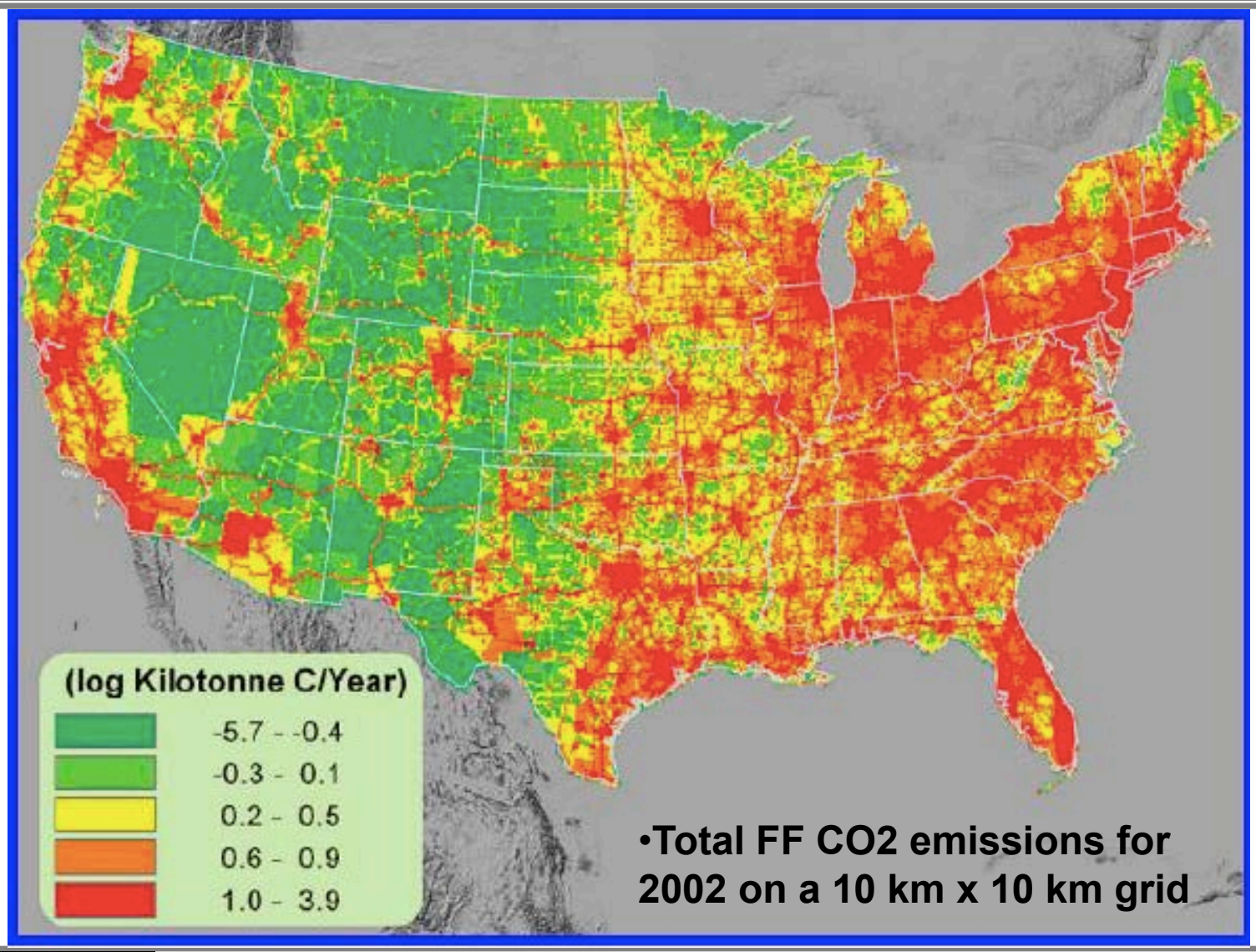
High Resolution Emissions Inventories Are Being Developed



Gurney et al., Env Sci Tech (2009)

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Night Lights in North America: The Fingerprint of Anthropogenic CO2 Emissions

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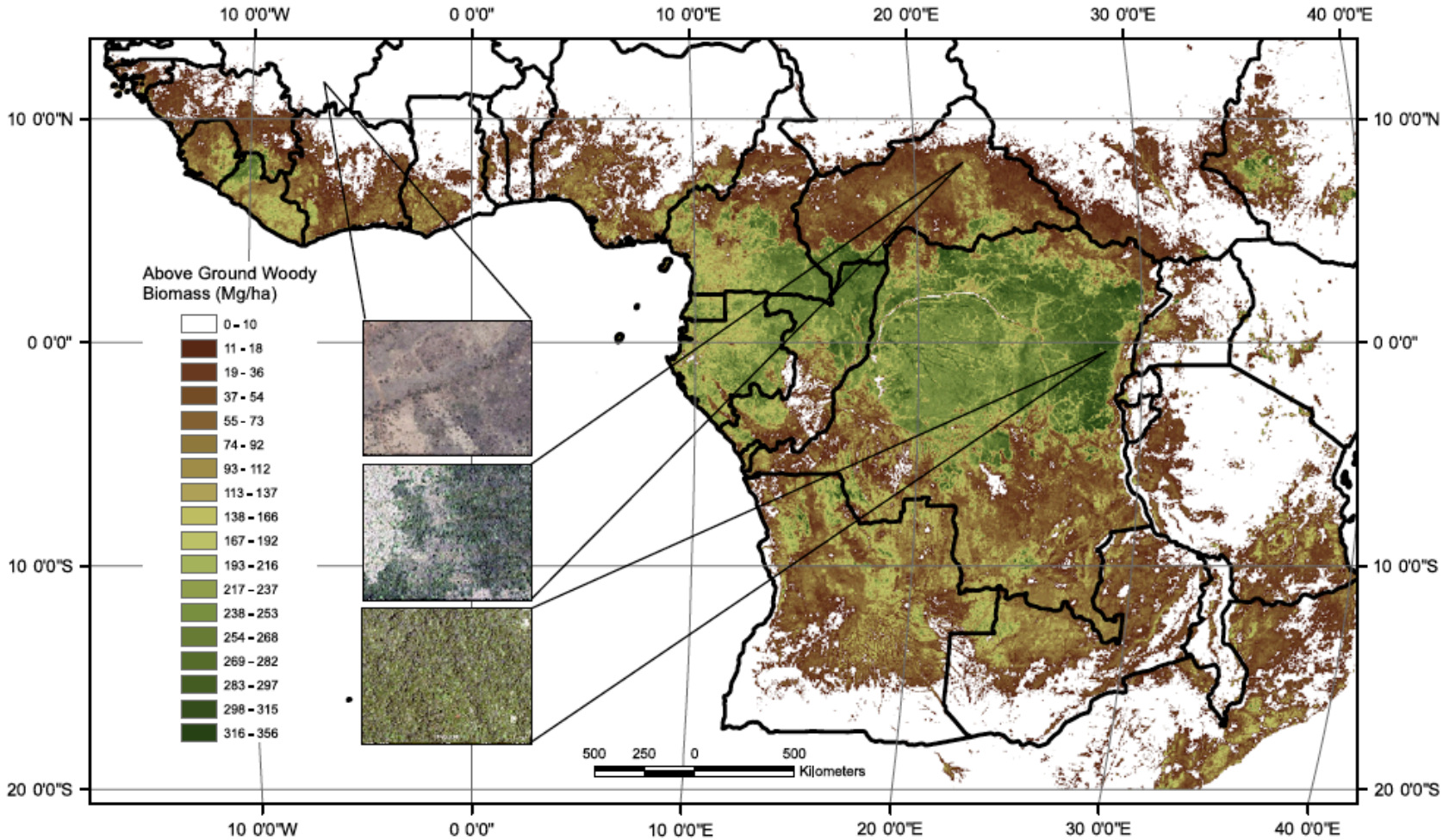
High-Resolution Satellite Derived Biomass Maps Will be Critical for Assessing Offsets



Baccini et al., Env Res Lett (2008)

•MODIS-derived above ground biomass map for tropical Africa; 1 km resolution for 2002-2003

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Existing remote-sensing (space & air) assets

GHG atmospheric concentrations:

- Satellite: AIRS*, TES*, SCIAMACHY, IASI, GOSAT
- Aircraft: MAMAP

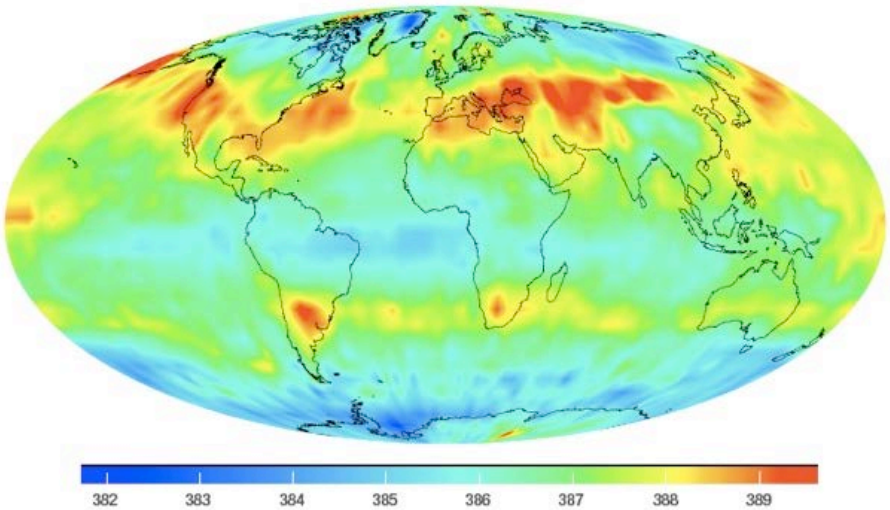
Vegetation greenness, health and productivity: Landsat*, MODIS*, AVHRR*, EO-1*

Ecosystem Structure/biomass:

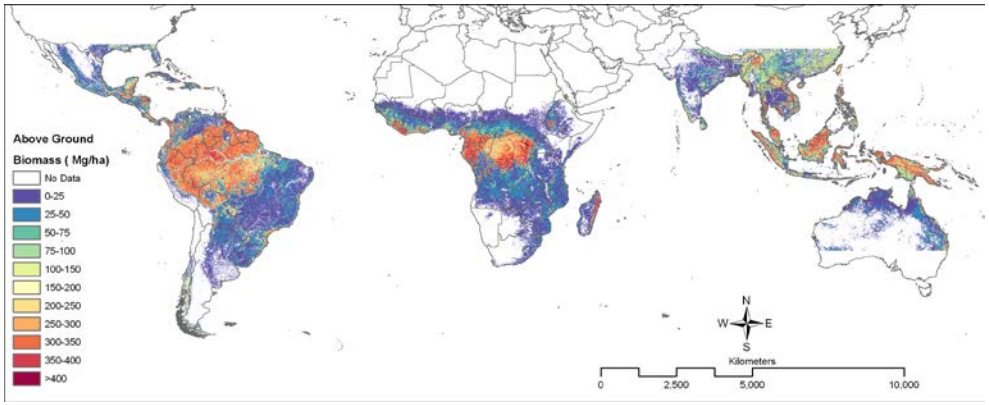
- Satellite: ICESAT-1 (GLAS Lidar)*, ALOS PALSAR
- Aircraft: UAVSAR*, LVIS*, GEOSAR*

Ocean color/photosynthetic activity: MODIS*, SeaWIFS

*US assets



AIRS mid-troposphere CO2 monthly average



Pantropical biomass (Saatchi, et al) - using MODIS, SRTM, ICESAT GLAS, QSCAT & ground

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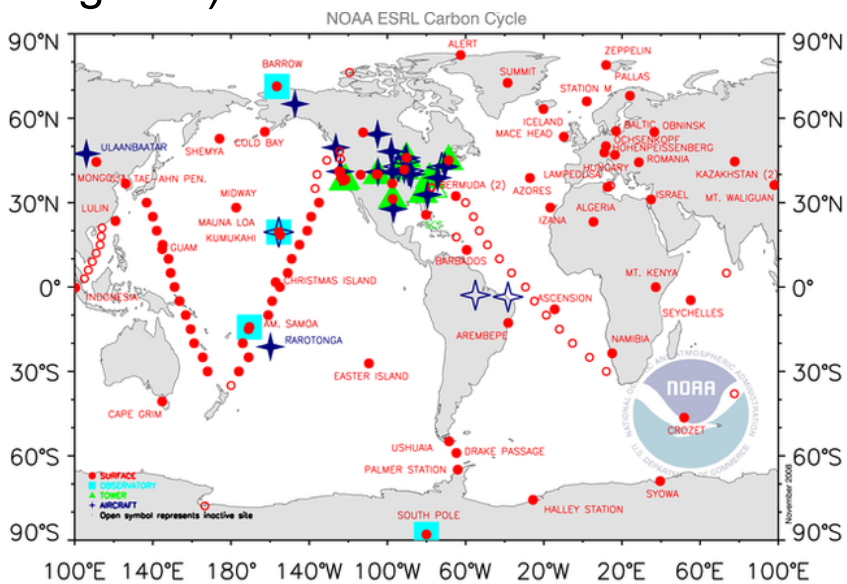
Complementary Benefits of Satellite and Surface Observations of Atmospheric GHGs

SURFACE

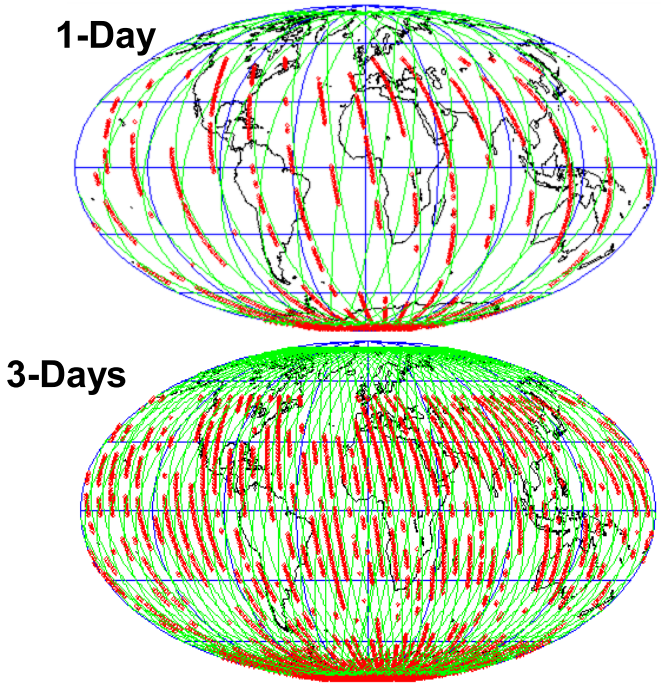
- high accuracy ("gold standard")
- cal/val of space data
- access to data only available with in-situ samples ($^{14}C/C$ ratios, other gases)



NOAA surface network
(~100 samples/wk globally, 7/hr for CONUS)

SATELLITES

- sustained global sampling with moderate/high spatio-temporal resolution
- high measurement densities reduce sensitivities to transport model errors



OCO-2 CO2 sounding coverage
(~1E6 samples per day globally)

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The Orbiting Carbon Observatory (OCO-2)

NASA's Orbiting Carbon Observatory (OCO) was designed to return space based measurements of atmospheric carbon dioxide (CO_2) with the sensitivity, accuracy and sampling density needed to quantify the large scale carbon sources and sinks and characterize their variability.

- Collects up to 1,000,000 (100) soundings over the sunlit hemisphere each day
- 0.1% (0.3% of precision, 1.7 ppm (0.3% of 389 ppm background) for both oceans and continents over the sunlit hemisphere
- 3 sq km footprint at nadir, enhances sensitivity to point sources and probability of collecting cloud free soundings

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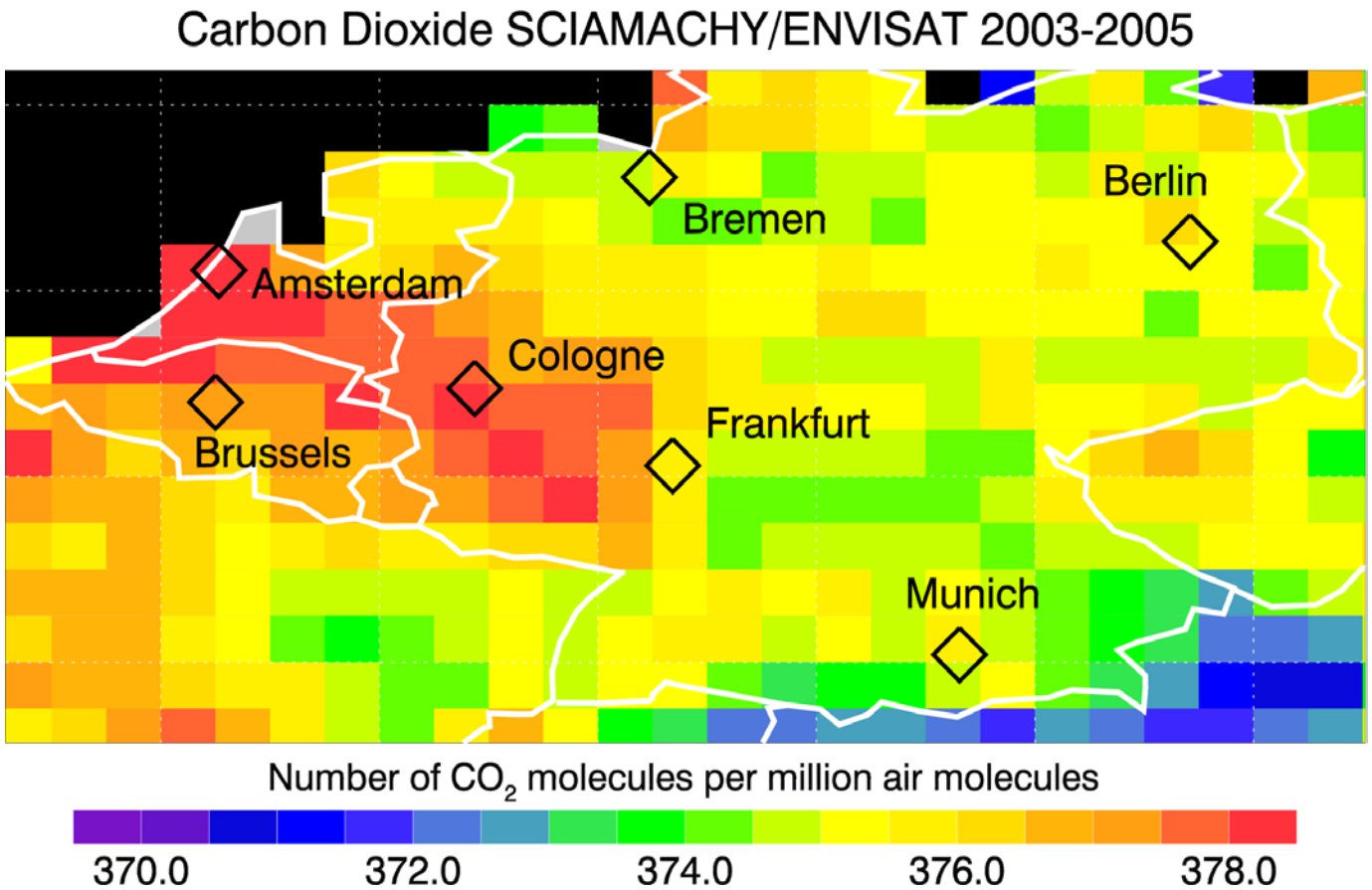
Regional CO2 Distributions from SCIAMACHY Satellite Observations



Observations quantify the expected correlation between urban centers and high XCO2

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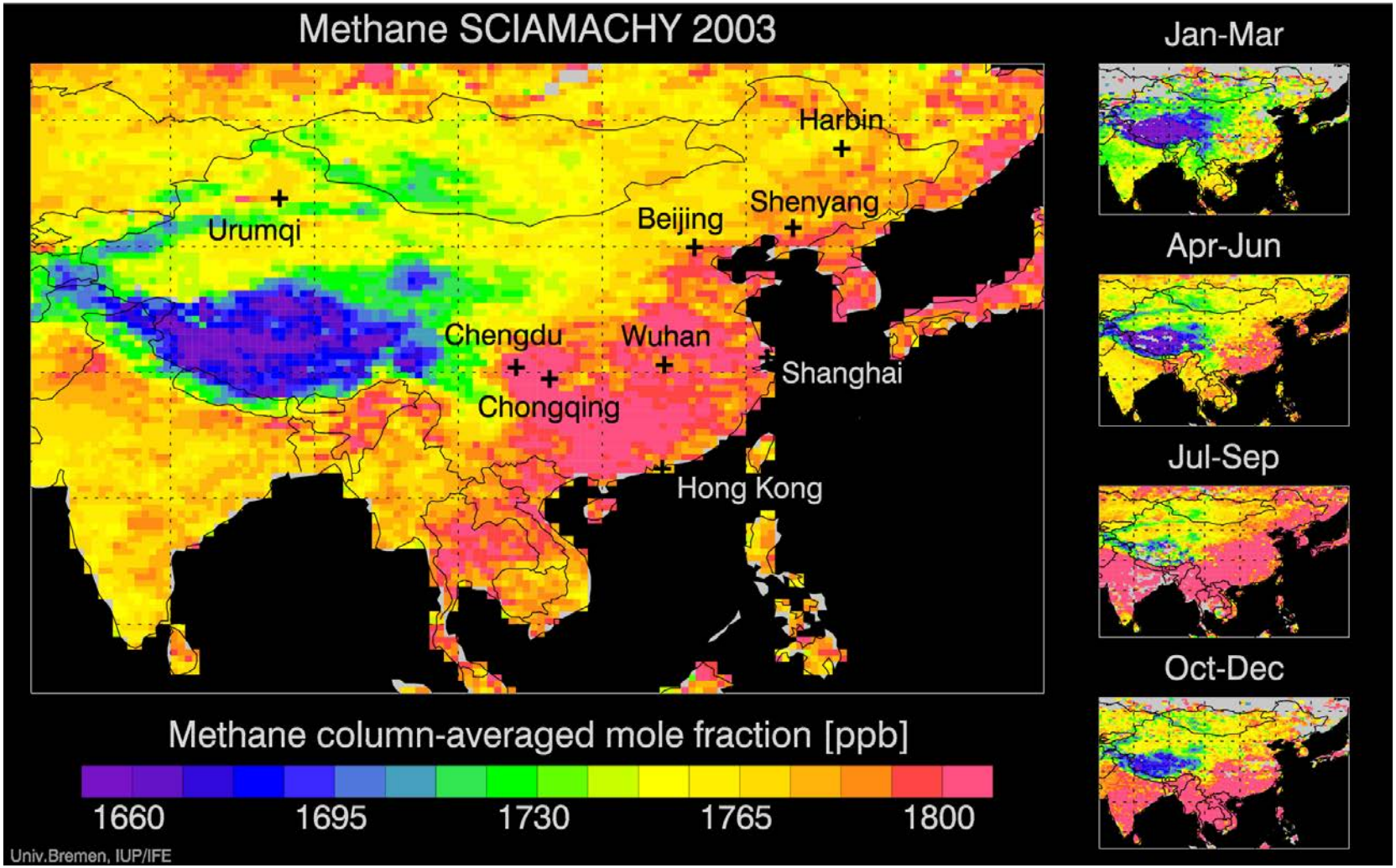
Regional CH4 Distributions from SCIMACHY Satellite Observations



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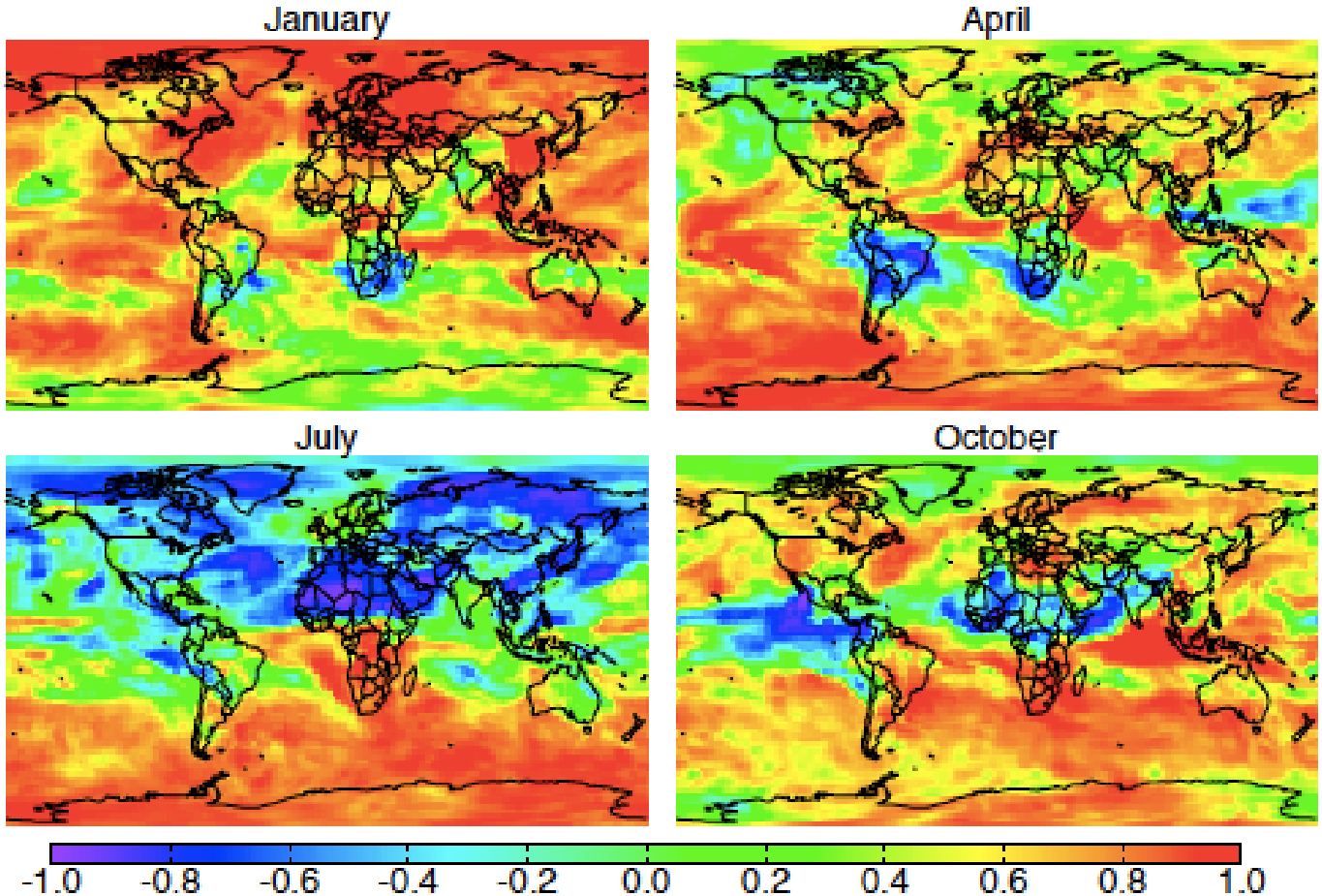
Tracer-Tracer Correlations Provide Powerful Constraints on Source Attribution

CO2/CO Correlation Coefficients



Wang et al., ACPD (2010)

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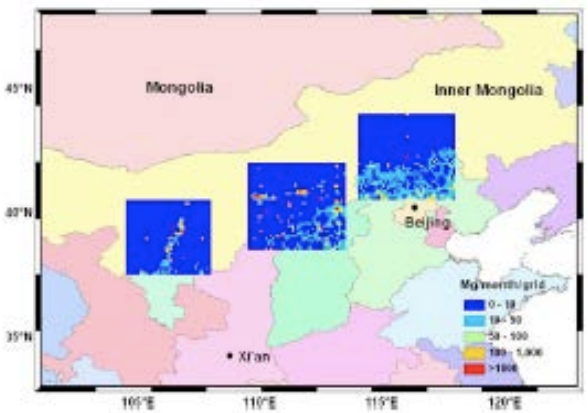
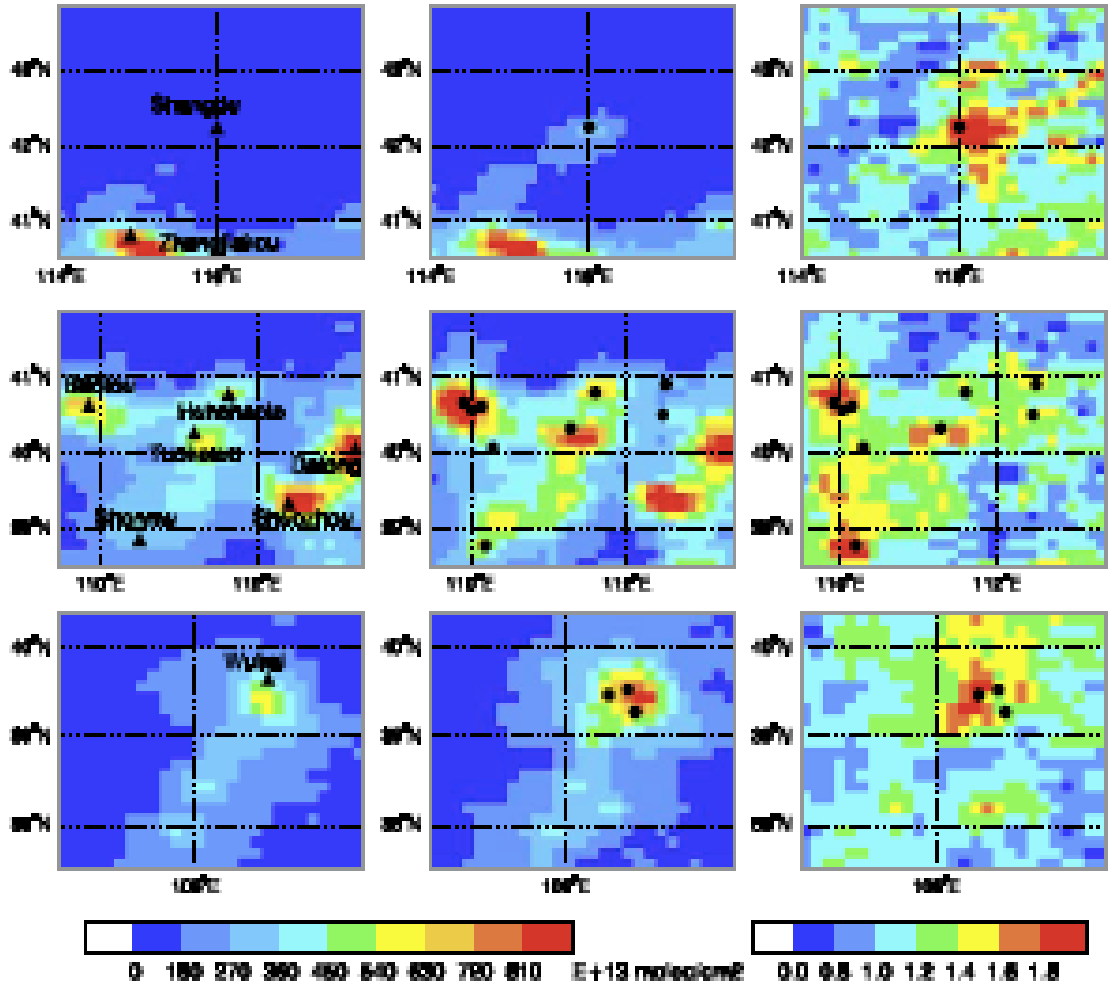
Constraints on Source Attribution from non-CO2 Proxy Observations





OMI NO2 retrievals reveal power plant emissions in Inner Mongolia

OMI = Refelcted UV

Zhang et al., GRL (2009)

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Future satellite assets critical to providing global coverage for key C-cycle parameters

Surface CO2 Fluxes: Orbiting Carbon Observatory replacement mission (OCO-2)*

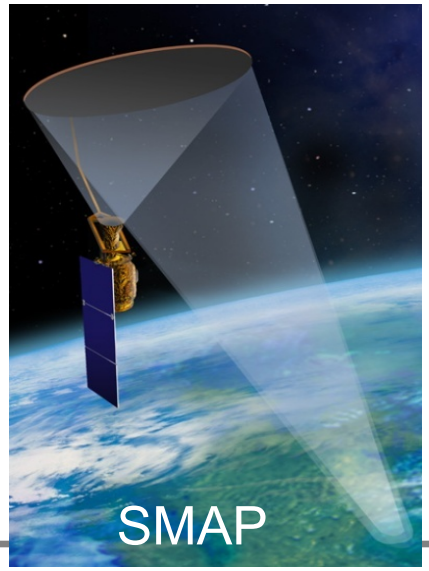
Vegetation greenness, health and productivity: HyspIRI*, LDCM*, NPOESS (VIIRS)*, Sentinel-2

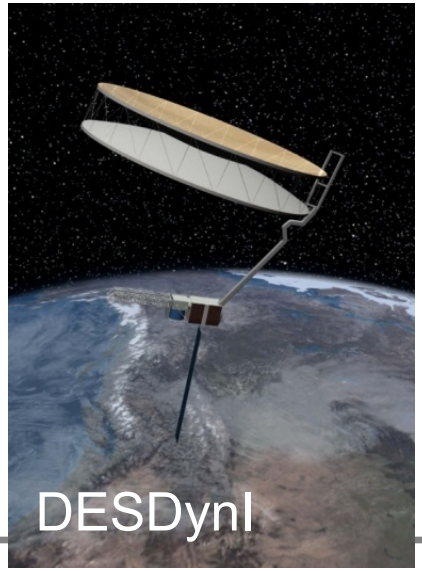
Ecosystem Structure & Biomass: DESDynI*, ICESAT-II*, Sentinel-1

Ocean color/photosynthetic activity: GEOCAPE*

Freeze-Thaw/Land Photosynthetic activity : SMAP*

*US assets





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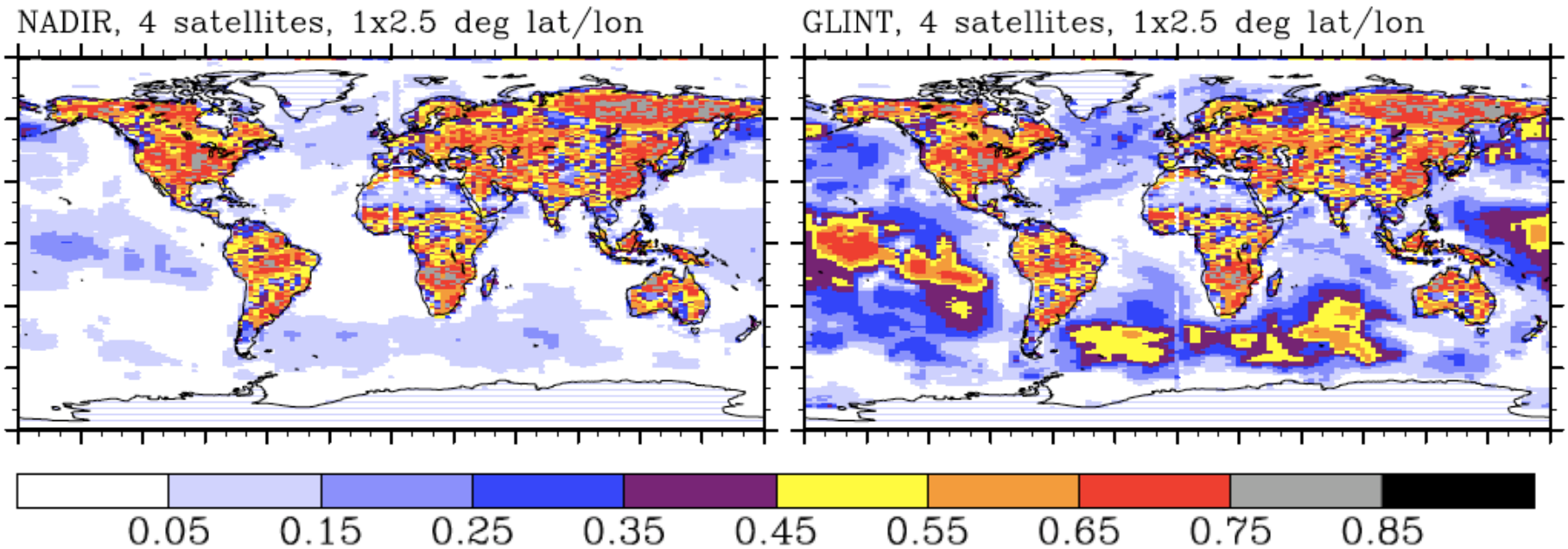
Constellations of Multiple OCOs Reduce Flux Uncertainties on Market-relevant Spatial Scales



Fractional Error Reduction

- Flux error reductions scale with the number of satellites involved in the constellation
- More clear sky scenes obtained by avoiding clouds with 4-day revisit

Miller and Baker, unpublished

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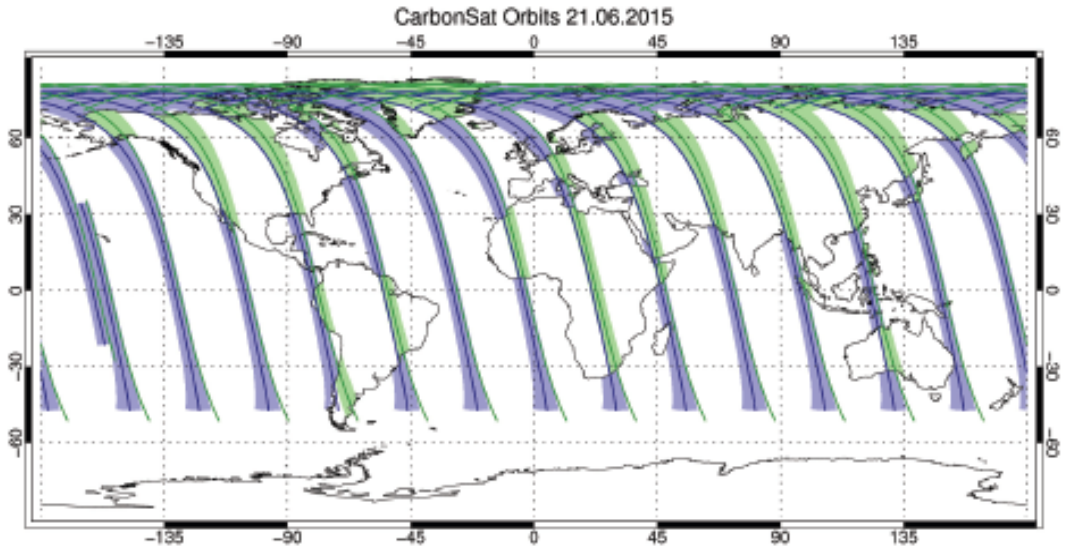
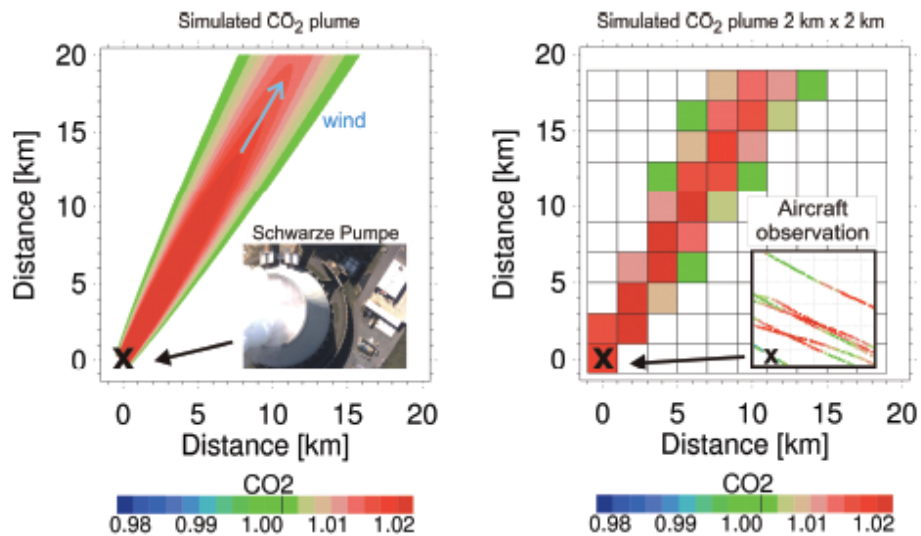
CarbonSat – A Wide-swath Mapper to Detect CO2 Point Sources

CarbonSat 1-day coverage:
- 500 km swath
- 2 km resolution



CarbonSat feasibility demonstration with MAMAP – detecting emissions from a single smokestack plume



Bovensmann et al., AMTD (2010)

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Summary

Observation-based evaluations provide independent top-down estimates of CO2 emissions to compare with inventory-based bottom-up estimates

NASA has a long history of space-based remote sensing of atmospheric CO2 and Greenhouse Gases, surface imagery, and other parameters that can support carbon markets

Current and future capabilities will extend this global, long-term measurement record

Questions for Discussion

What level of CO2 emissions uncertainty is acceptable?

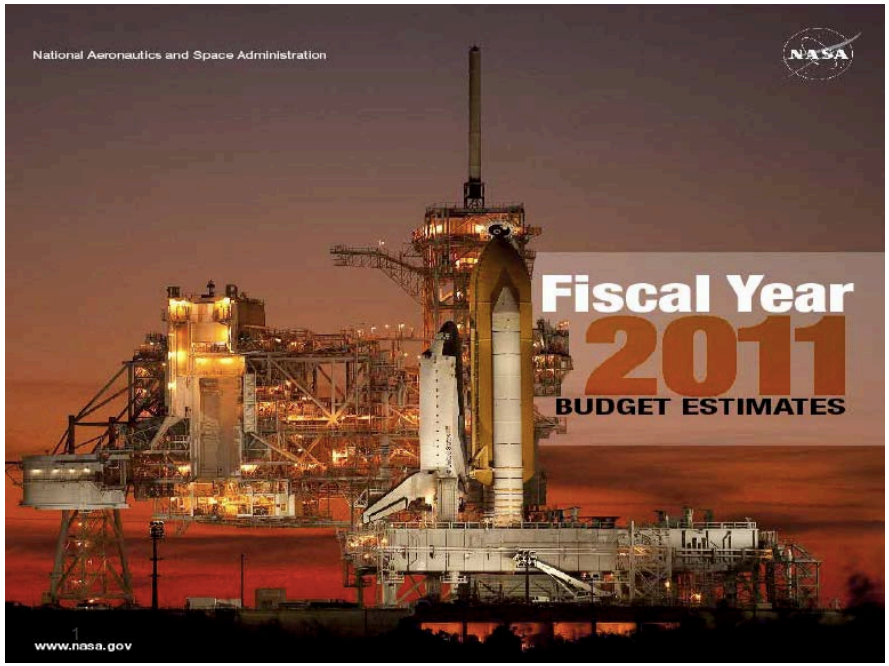
What actions or behaviors are desired as a result of implementing a carbon market?

What is the cost of permanently removing 1 tonne of CO2 from the atmosphere?

OCO Reflight Highlighted in President's 2011 Budget Proposal

- **"The Budget provides funds for NASA to develop and fly a replacement for the Orbiting Carbon Observatory, a mission designed to identify global carbon sources and sinks that was lost when its launch vehicle failed in 2009."**

- **"Enhances the Nation's global climate change research and monitoring system, including reflight of a satellite that will help identify global carbon sources and sinks"**



http://www.nasa.gov/news/budget/fy11_oco.html

The funding profile

- Supports the fastest possible OCO-2 launch
- Includes funding for a complete set of parts for a 2nd instrument (OCO-3)

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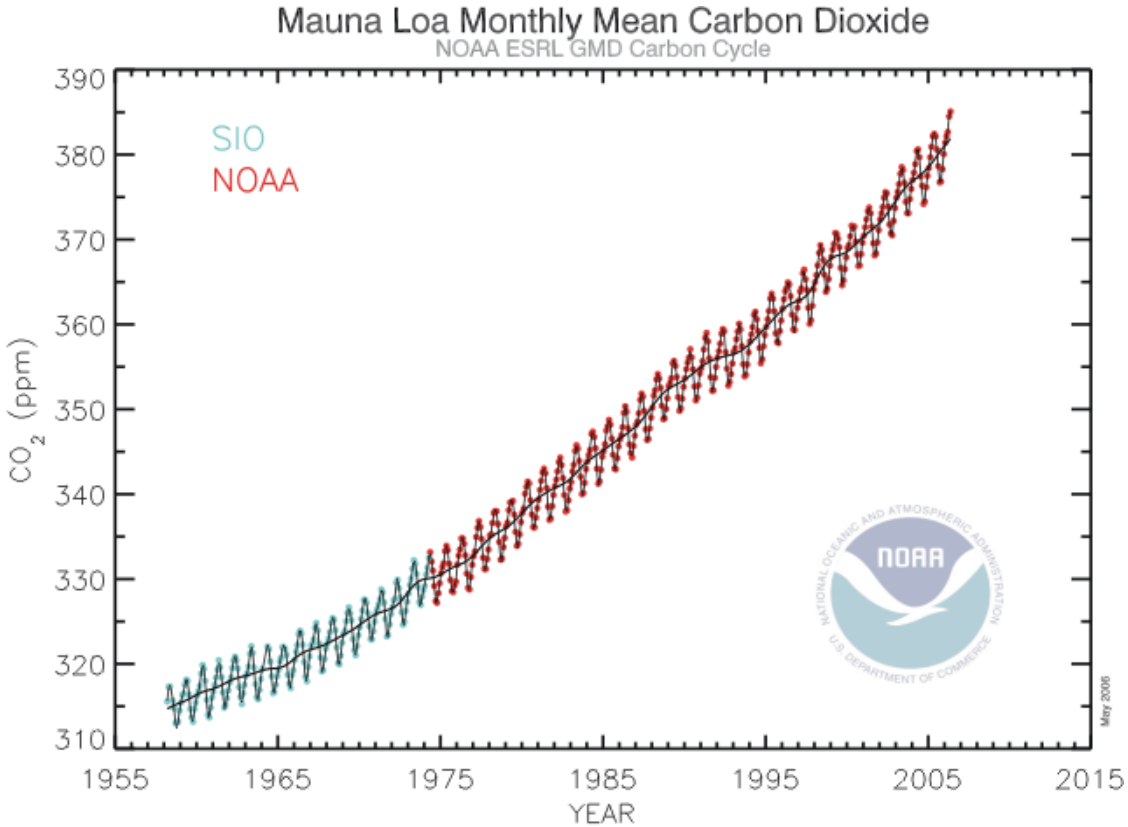
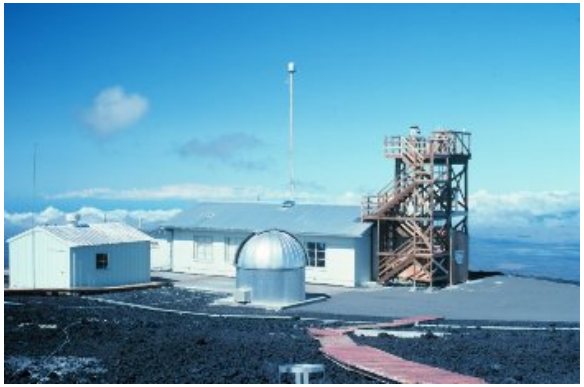
The Modern Atmospheric CO2 Record



Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (SIO, blue), data since May 1974 are from the National Oceanic and Atmospheric Administration (NOAA, red). A long-term trend curve is fitted to the monthly mean values. Contact: Dr. Pieter Tans, NOAA ESRL GMD Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, and Dr. Ralph Keeling, SIO GRD, La Jolla, California, (858) 534-7582, rkeeling@ucsd.edu.

Charles David Keeling



Mauna Loa Observatory

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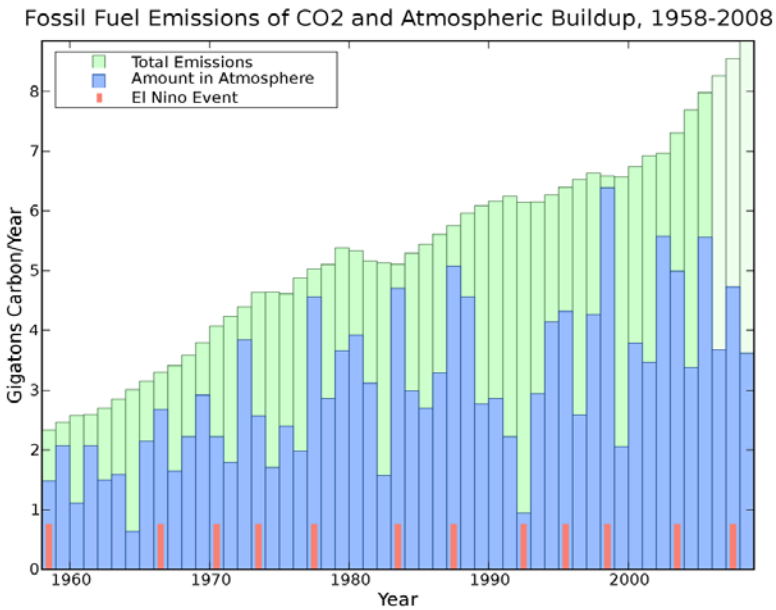
Carbon Dioxide and the Global Carbon Cycle Science

- **Human activities currently add ~10 Gt of carbon to the atmosphere each year**
- **Less than half of this CO_2 stays in the atmosphere. The rest is absorbed by natural "sinks" at the Earth's surface**
- **Current measurement networks**
  - **Can quantify the atmospheric CO_2 buildup on global scales**
  - **Provide insufficient coverage and resolution to accurately quantify sources and sinks of CO_2**
- **Fundamental questions:**
  - Where is the missing sink? land / ocean
  - Why does the sink strength vary dramatically from year to year?
  - Will the nature, location and strength of CO_2 sinks change in the future?



Annual fossil fuel emissions, the major anthropogenic CO_2 source, increase smoothly over time.

The accumulation rate of atmospheric CO_2 varies dramatically from year to year due to variation in the fundamental processes responsible for land and ocean sinks.

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