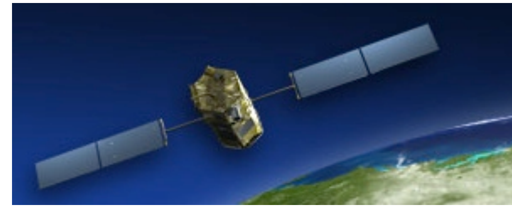


A Surface-to-Space Atmospheric Carbon Observing System for Decision Support

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NOAA Earth System Research Laboratory



STAR JPSS 2016 Annual Science Team Meeting
8-12 August 2016

Outline

- Current and planned surface, aircraft, and satellite measurements of atmospheric CO_2 and CH_4
- Magnitude of important carbon emissions and sink signatures
- A vision for a future observing system to provide decision support services

Focus here is on CO_2, but story for CH_4 is similar.

There is broad and growing consensus that rising atmospheric CO_2 is a planetary emergency:

- The Paris Agreement at the 21st Conference of the Parties of the UNFCCC was negotiated by representatives of 195 countries.

- The agreement opens for signature on Earth Day, 22 April 2016. Some 120 countries, including the US and China, are expected to sign.

PARIS2015
CONFÉRENCE DES NATIONS UNIES
SUR LES CHANGEMENTS CLIMATIQUES
COP21·CMP11

United Nations
Framework Convention on
Climate Change

Data Transparency: New Dynamic at COP-21 in Paris

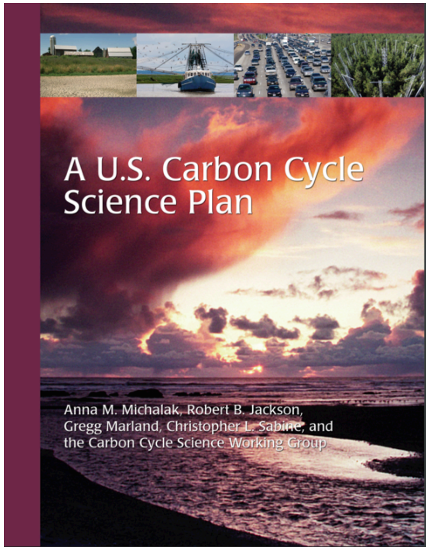
Posted by Angel Hsu, Andrew Moffat and Kaiyang Xu on Dec 22, 2015

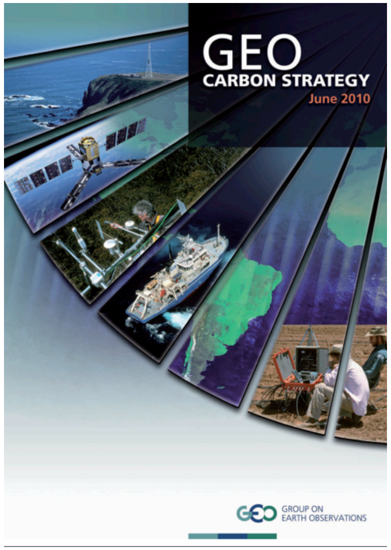
From the Paris Climate Negotiations

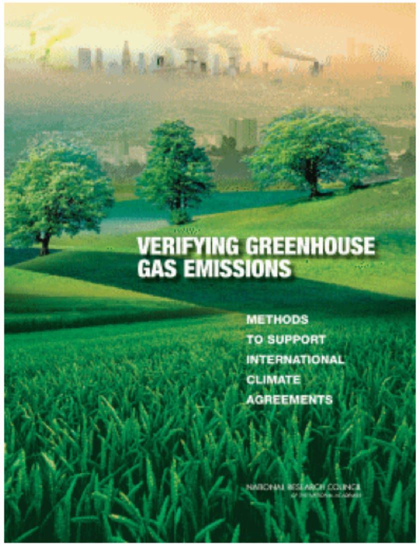
The **Paris Agreement and decision** together mention "transparency" 30 times. Language is often open to interpretation, yet **the Agreement's mandate is clear**: each country is to regularly provide standardized national GHG emissions inventories and "information necessary to track progress made in implementing and achieving its nationally determined contribution" (Article 13). This provision, part of an agreement signed by all Parties including the U.S. and China, marks a step forward toward gaining clarity on what the world is doing to address climate change.

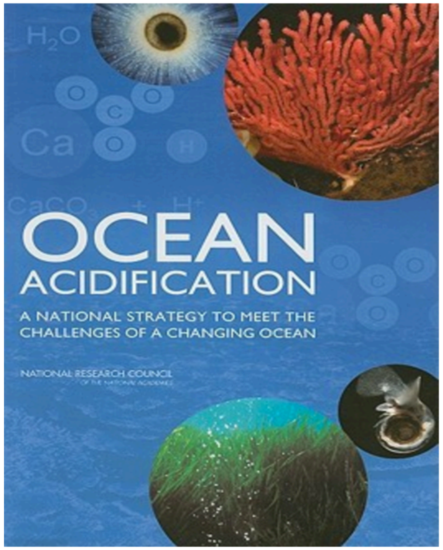
There is an urgent need to transition carbon research efforts into a state-of-the science greenhouse gas information system for decision support. Long-term monitoring of atmospheric CO_2 and CH_4 will be an essential component of this system.

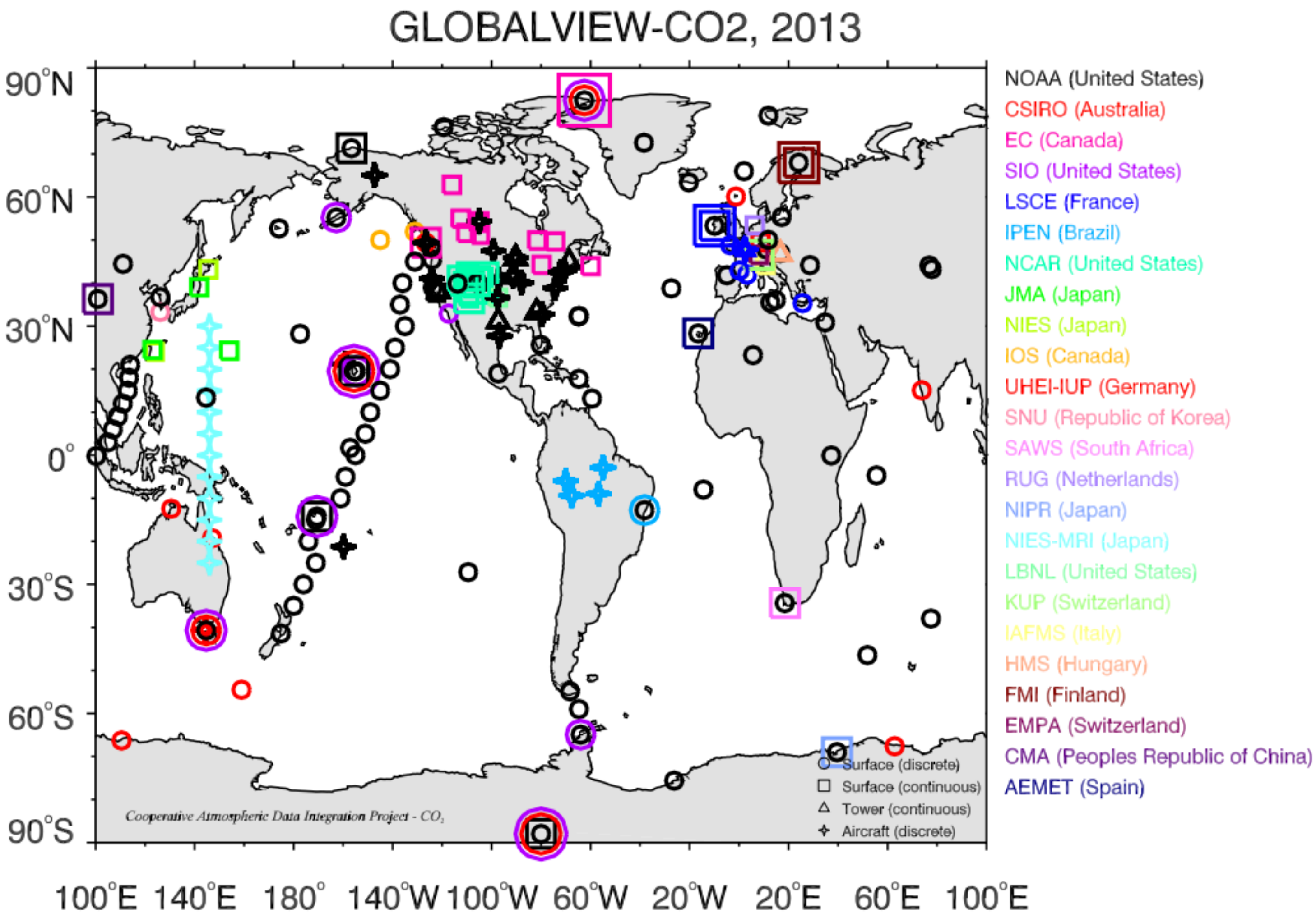
Several recent reports describe measurement requirements for carbon observations to advance science and to support policy:











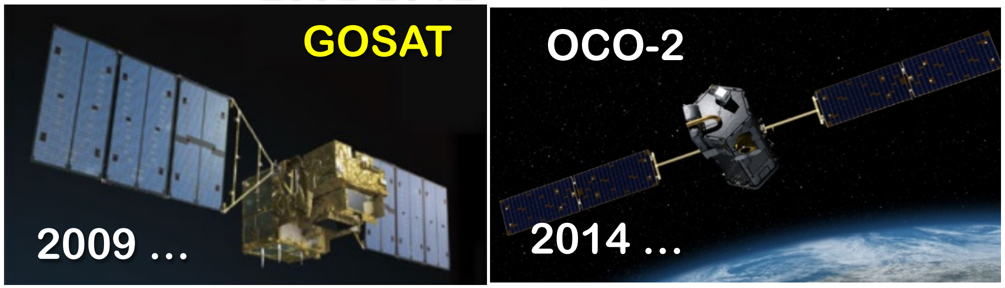
- Current knowledge of global CO_2 and CH_4 budgets is based primarily on in situ measurements, with satellite data products becoming available during the past decade.

The Evolving Near-Infrared Atmospheric Carbon Measurement Capabilities

PAST

If carefully coordinated, these missions can be integrated into an ad hoc constellation and their measurements can be combined to produce a continuous data record.

PRESENT



However, none of these missions provides the capabilities needed to identify carbon/climate tipping points

NEAR FUTURE

LATER

Slide courtesy of Dave Crisp, NASA JPL

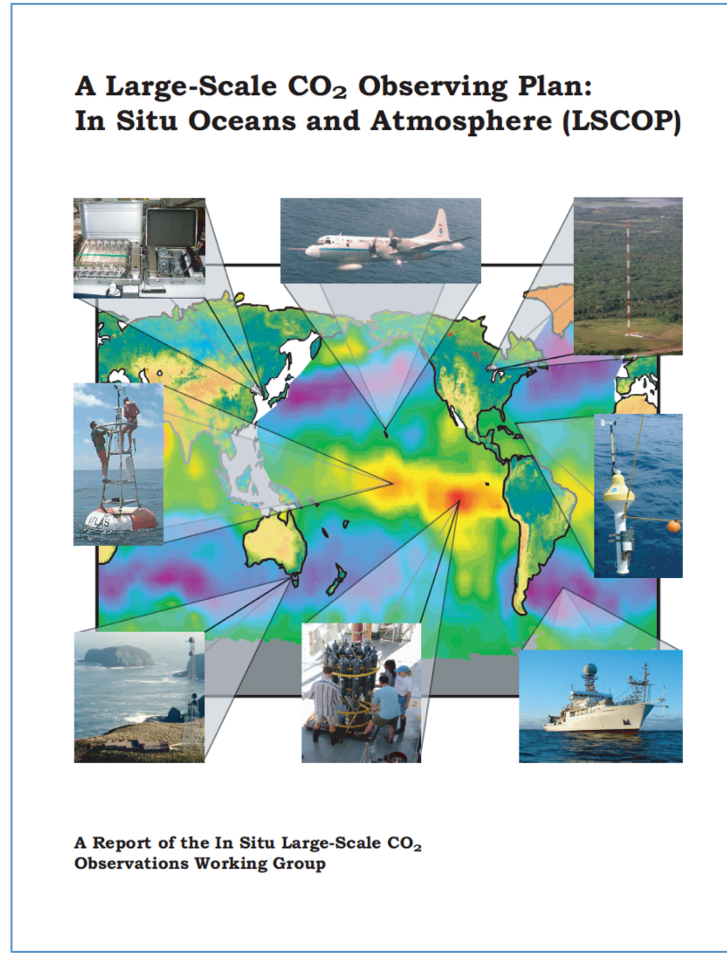
Tracking emissions and sink changes with atmospheric data: A very hard problem

Tracking emissions and sink changes with atmospheric data: A very hard problem

In Situ Large-Scale CO_2 Observations Working Group:

Bender, M., S. Doney, R.A. Feely, I. Fung, N. Gruber, D.E. Harrison, R. Keeling, J.K. Moore, J. Sarmiento, E. Sarachik, B. Stephens, T. Takahashi, P. Tans, and R. Wanninkhof

Note: the report covers oceanic and atmospheric observations, but for this talk focus is on atmospheric measurements.



A contribution to the implementation of the U.S. Carbon Cycle Science Plan, April 2002

Our future observing system should have the following characteristics:

- Regional spatial resolution, down to 10^6 km^2 on the continents and 10^7 km^2 over the oceans, with an accuracy of 0.1 Gt C/yr. This resolution will enable meaningful quantification of processes regulating surface carbon exchange. An ability to see the effects on atmospheric CO_2 of specific processes and mechanisms on these spatial scales will allow a marked increase of confidence in our understanding and predictive capability.

- Integration of satellite observations. The in situ measurements should be able to stand on their own, but will be merged with satellite CO_2 data if and when these become available, providing crucial accuracy to the latter. Space-based observations of the CO_2 mole fraction in the atmospheric column are expected to have nearly complete spatial coverage, but lower chemical resolution and accuracy.

- Assimilation of all available data. Data assimilation models must be an integral part of the observing system. The models should assimilate weather and CO_2 observations, and remotely sensed indicators of primary productivity. They should be high resolution in time and space, dynamically consistent, and include carbon processes.

Large Scale CO_2 Observing Plan, April 2002

Magnitude of atmospheric signature of various carbon fluxes:

Table 2-1: Rate of change in integrated vertical column abundance for specific CO_2 sources and sinks.

Source	Assumptions	ppm/day
Los Angeles Basin	12×10^6 people, 4,000 km^2, 1100 mol C/person/day	+10
Netherlands	16×10^6 people, 40,000 km^2, 500 mol C/person/day	+0.6
Germany	83×10^6 people, 350,000 km^2, 580 mol C/person/day	+0.4
Photosynthetic Uptake	Harvard Forest, July	–1.2
U.S. Carbon Sink	1 Gt C/yr, constant in time, uniform over the lower 48 states	–0.08
Southern Oceans	$\Delta pCO_2 = -30\ \mu$atm, wind 15 m/s	–0.06
Eastern Equatorial Pacific	$\Delta pCO_2 = 100\ \mu$atm, wind 7 m/s	+0.04

If residence time of air over Los Angeles Basin is ~3 hours, then column signal downwind would be 1.25ppm.

Signal comparisons and measurement requirements for continental-scale fluxes

Source or Sink	Emission Rate (GT C / year)	Column CO_2 signal downwind of continent (ppm)
US fossil fuel emissions	1.4	0.7
20% emissions reduction	0.28	0.14
Biological Uptake during July	5.8	2.9
Climate Induced terrestrial anomalies	0.2	0.1

Detection of subtle signals resulting from changes in emissions and from climate-induced biological flux anomalies will require sensitivity of ~0.1 ppm in X_{CO2} maintained over many years.

Space-based observations of megacity carbon dioxide

Eric A. Kort,[1,2] Christian Frankenberg,[2] Charles E. Miller,[2] and Tom Oda[3,4]

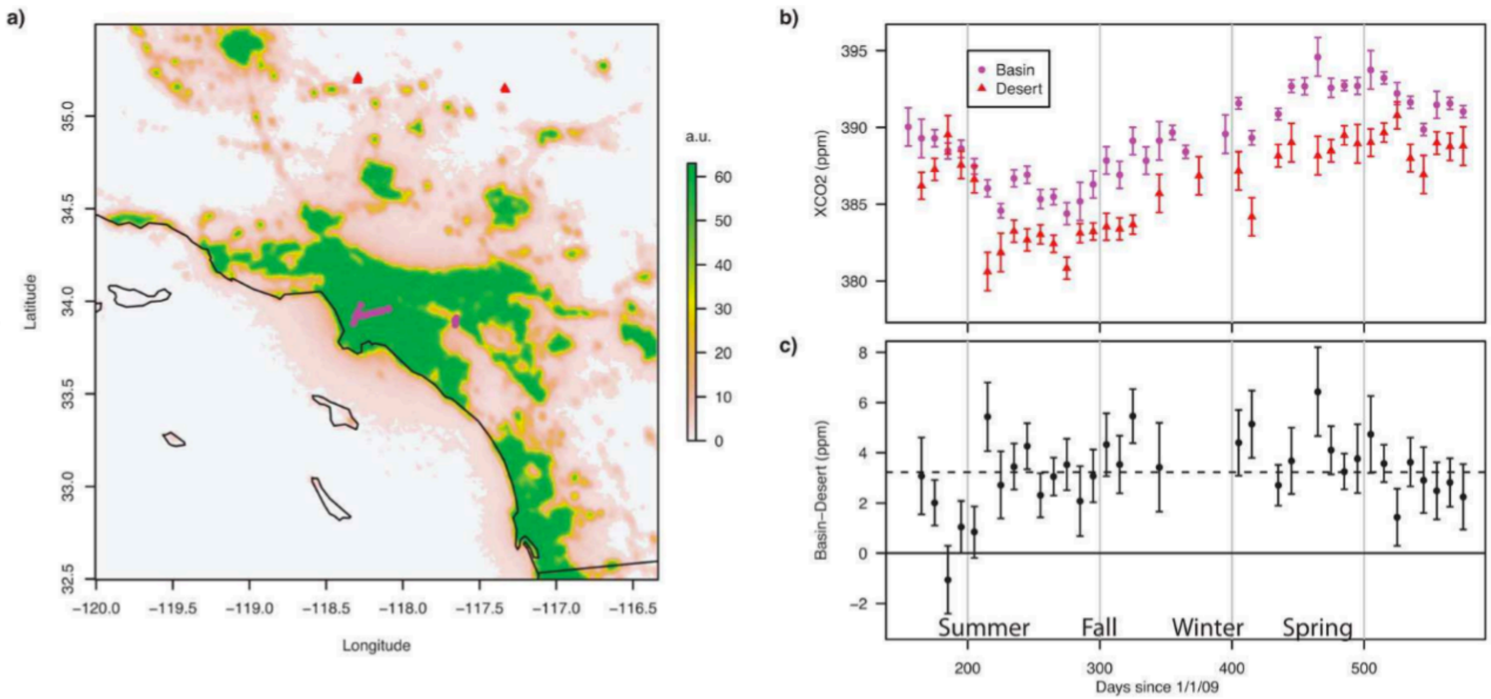
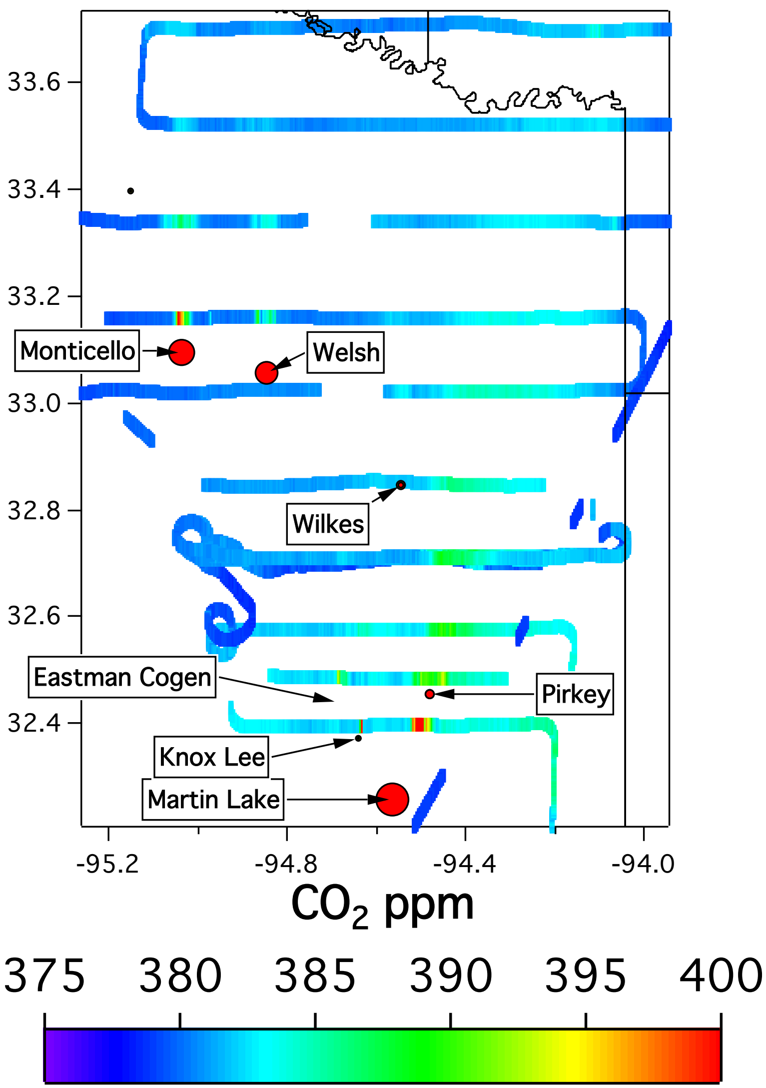


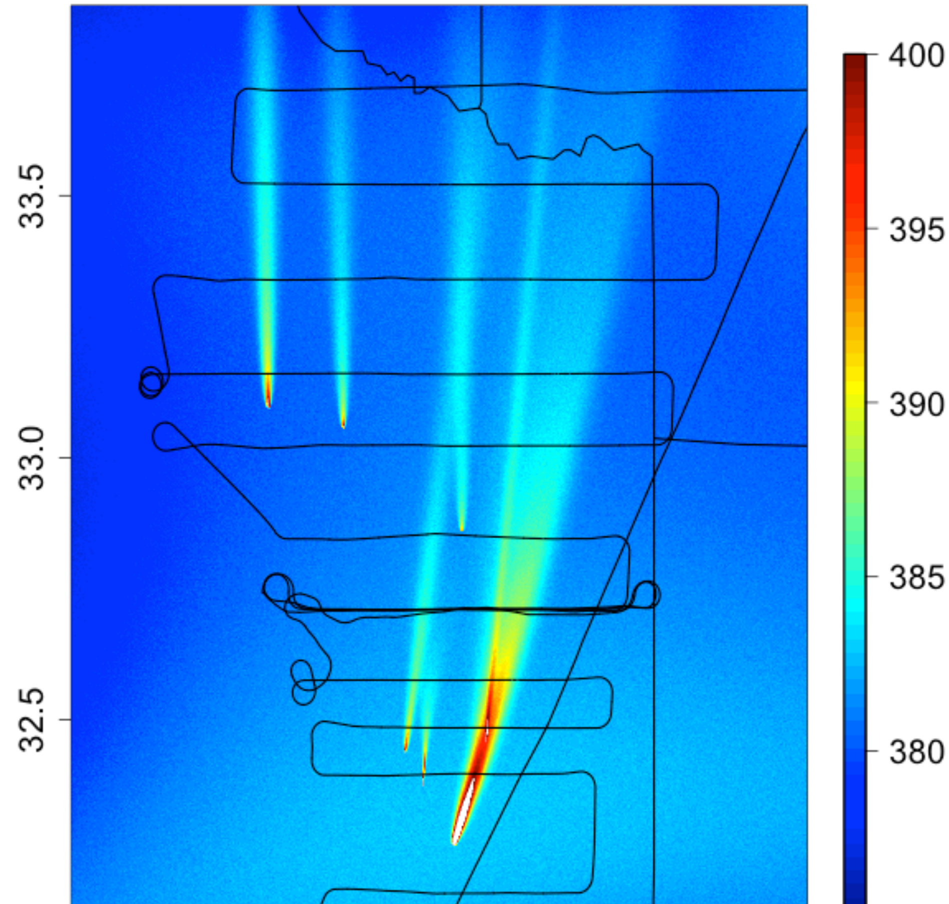
Figure 1. Observed X_{CO2} urban dome of Los Angeles from June 2009 to August 2010. (a) Nightlights map of the Los Angeles megacity and surroundings. Selected GOSAT observations within the basin (pink circles near 34°N, 118°W) and in the desert (red triangles near 35°N, 117–118°W). (b) Time-series for basin and desert observations averaged in 10-day bins. (c) The difference between 10-day block averages of basin and desert observations. The dashed black line shows the average difference (3.2 ± 1.5 ppm). All error bars plotted are one-sigma. Note Bakersfield is located near 35.4°N, 119.0°W.

GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L17806, doi:10.1029/2012GL052738, 2012

Power Plant Plume Sampling by the NOAA WP-3D Aircraft

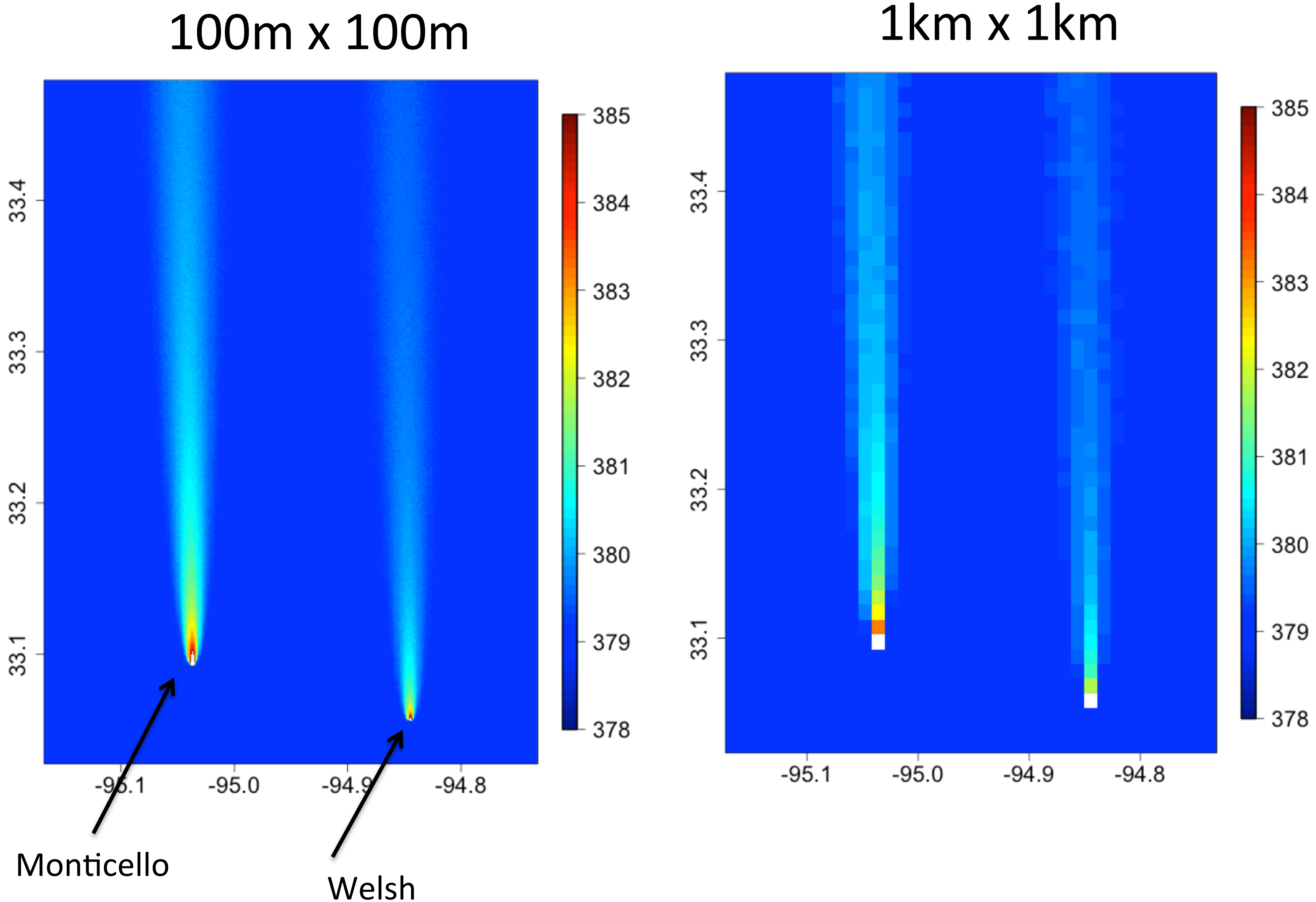
Texas: 16 Sept 2006



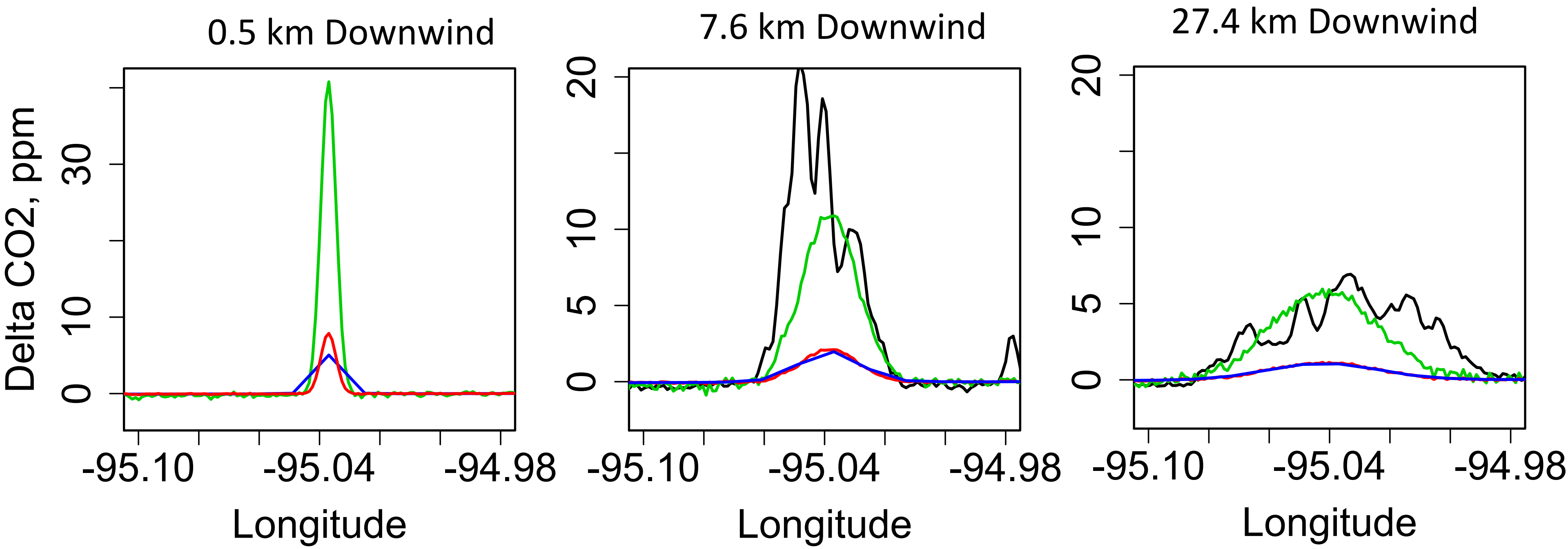


Use a simple plume model to create a 2D field representing the PBL integrated CO_2.

Total Column: XCO_2



Monticello (18.3 MTon CO_2/yr, 1.98 GW)



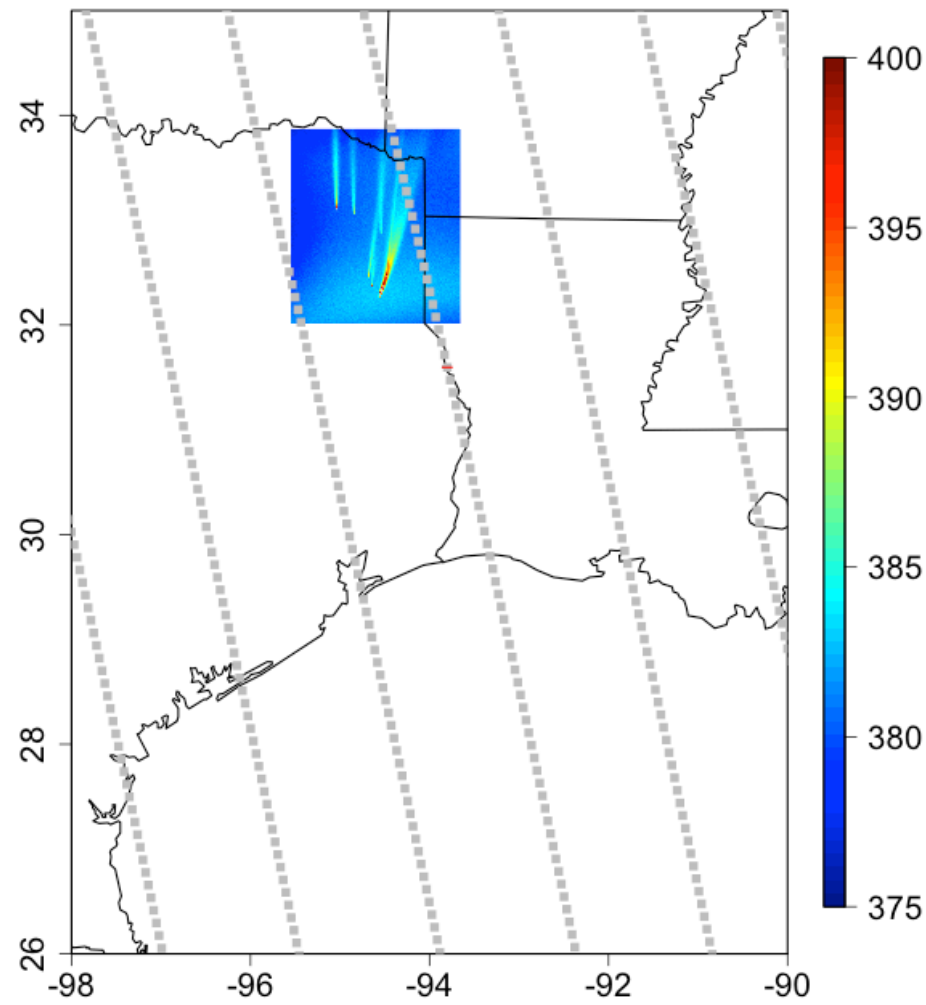
PBL: 40.8 ppm
XCO_2 100m: 7.9 ppm
XCO_2 1km: 5.0 ppm
No Obs

PBL: 10.9 ppm
XCO_2 100m: 2.1 ppm
XCO_2 1km: 1.97ppm
Obs: 600 magl

PBL: 6.0 ppm
XCO_2 100m: 1.1 ppm
XCO_2 1km: 1.0ppm
Obs: 600 magl

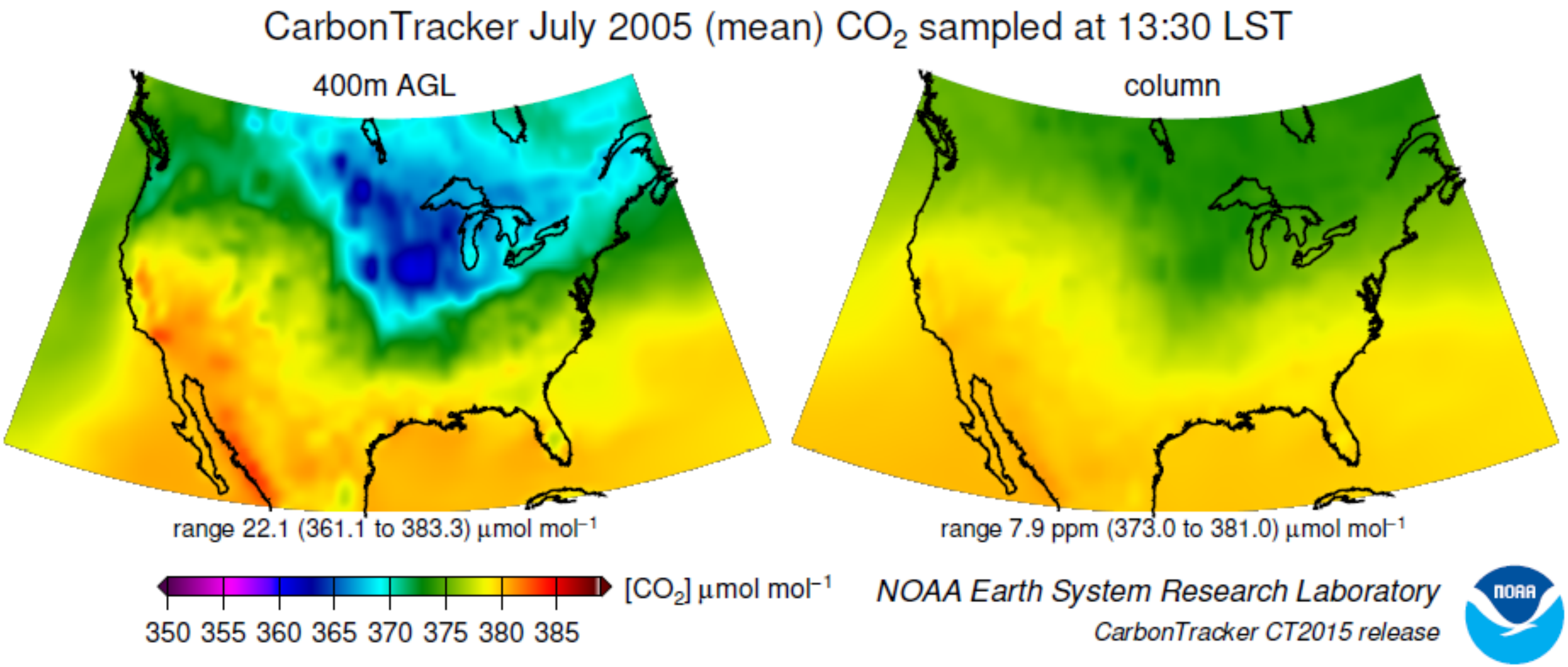
- Current and planned satellite CO_2 sensors do not have large enough field of view for emissions monitoring.

- Geostationary or Low Earth Orbiting mapping satellites have been proposed to monitor emissions from large point sources and urban areas.



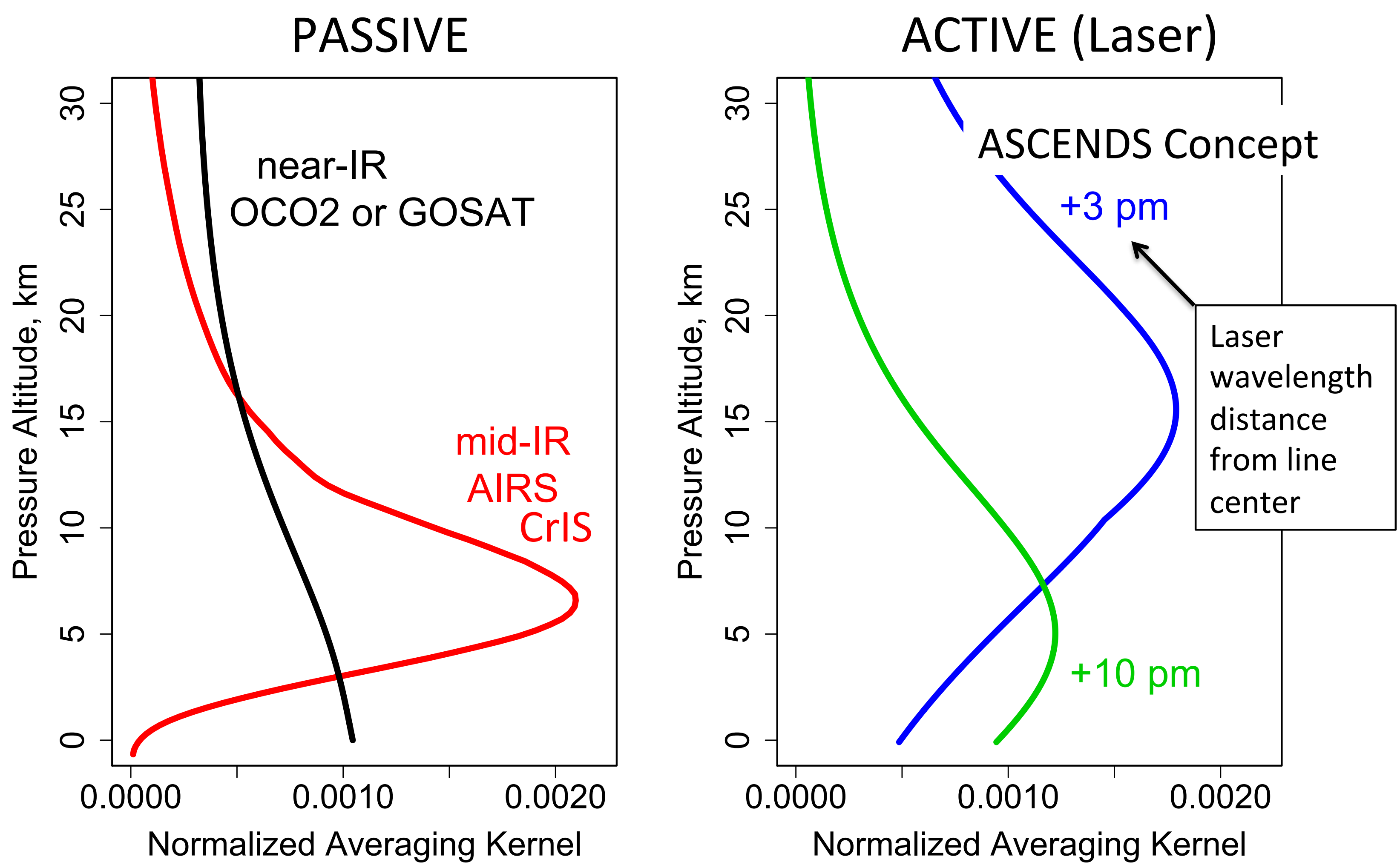
OCO-2 swath width is ~10km. Figure shows A-train afternoon orbit with 10x10 km pixel size.

Boundary Layer versus Column CO_2:



- Relevant signatures of CO_2 and CH_4 emissions are very small in the column -- detection with satellites will be extremely challenging.
- In situ measurements can be made very precisely, but measurements are sparse and variability in proximity to sources is large.

Satellite Sensor Averaging Kernels

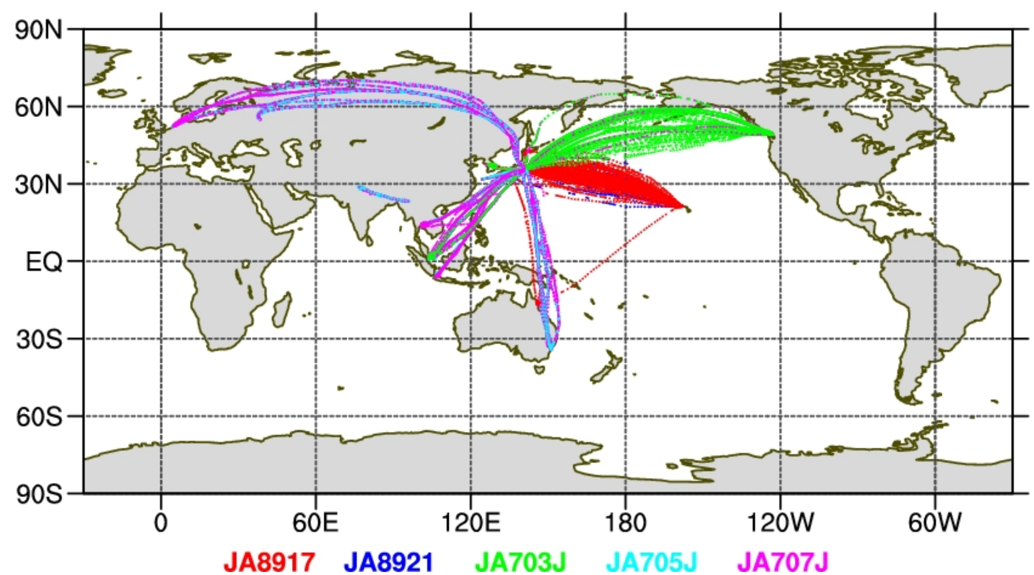


Combination of thermal-IR and near-IR satellite measurements should enable separation of boundary layer versus free-troposphere signals with rigorous data assimilation techniques.

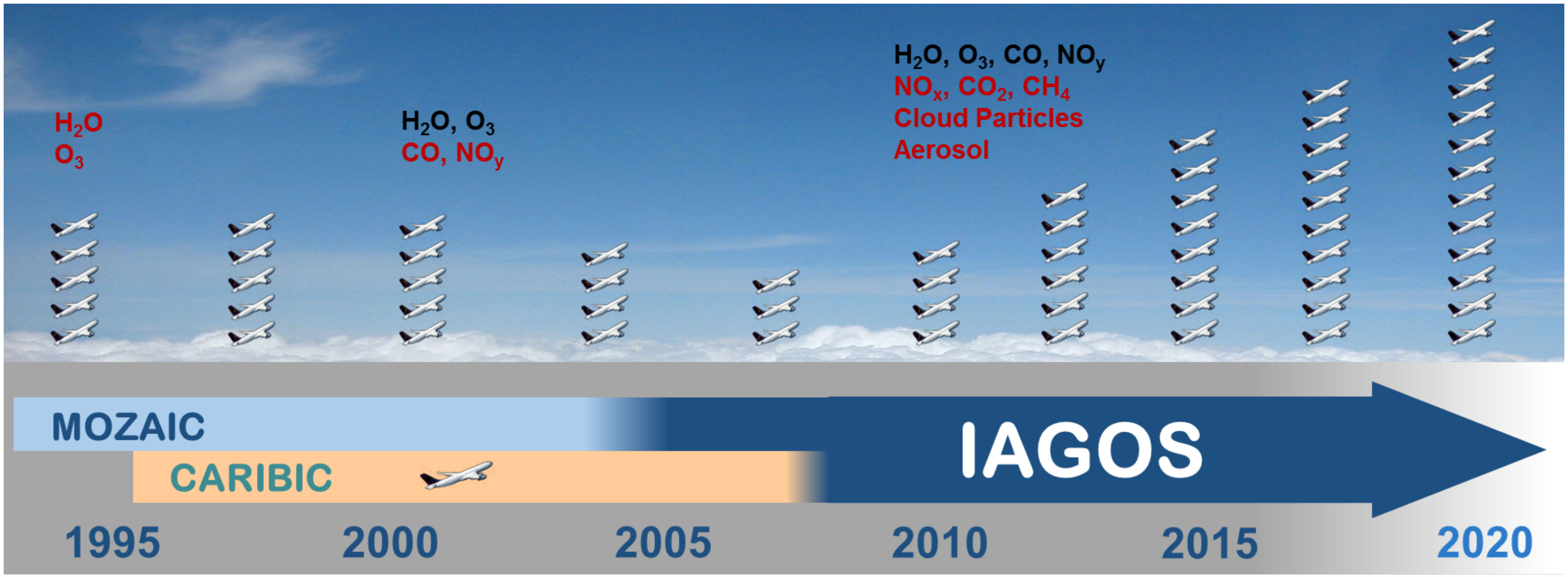
Commercial aircraft are an underutilized platform for atmospheric sampling and could provide critical data for evaluating satellite retrievals and for flux estimation:

Japanese CONTRAIL program has been making continuous CO2 measurements on Japan Airlines flights since 2005:

- Five aircraft
- 20 Airports
- >2000 vertical profiles



European In-service Aircraft for a Global Observing System (IAGOS)

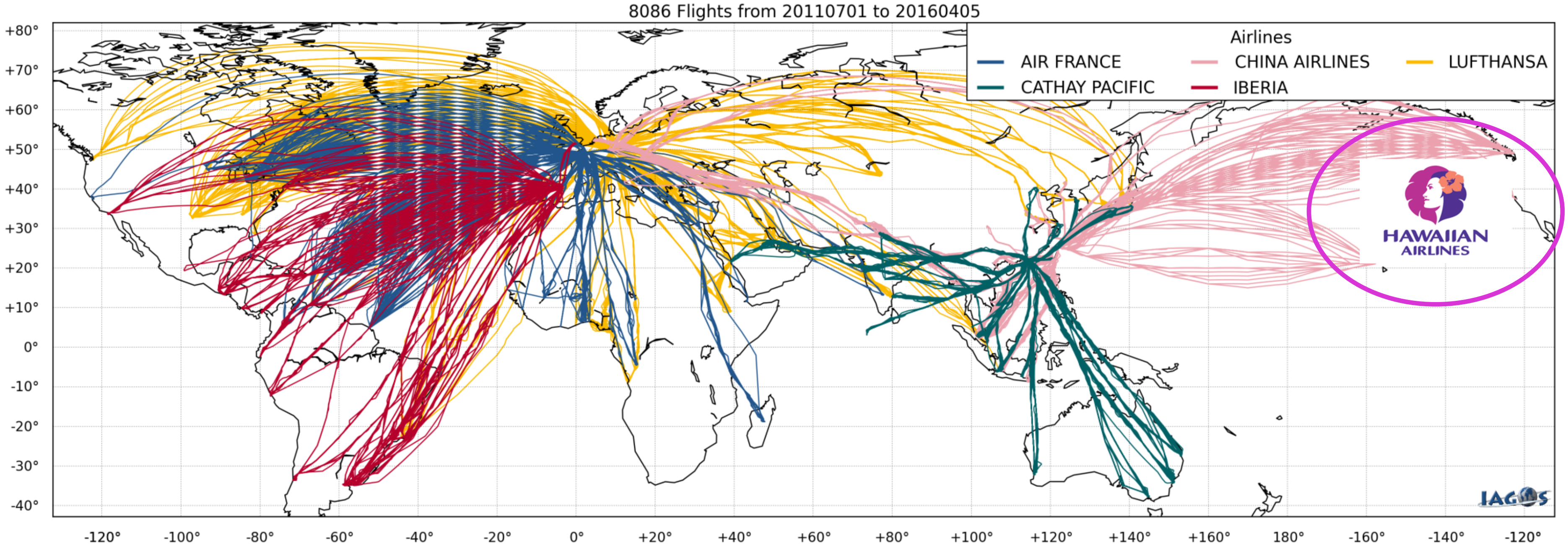


Plans to add CO_2 and CH_4 as soon as certification is finalized.

Figure courtesy of Andreas Volz-Thomas

IAGOS-CORE Flight Routes

> 8300 flights July 2011 - May 2016



Slide courtesy of Andreas Volz-Thomas

NOAA already has the WVSS-2 commercial aircraft program for measuring water vapor from more than 100 commercial aircraft:

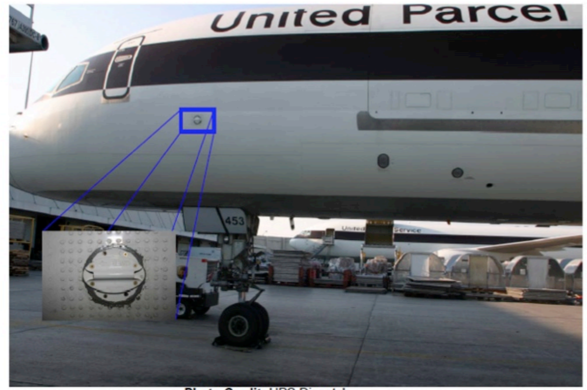
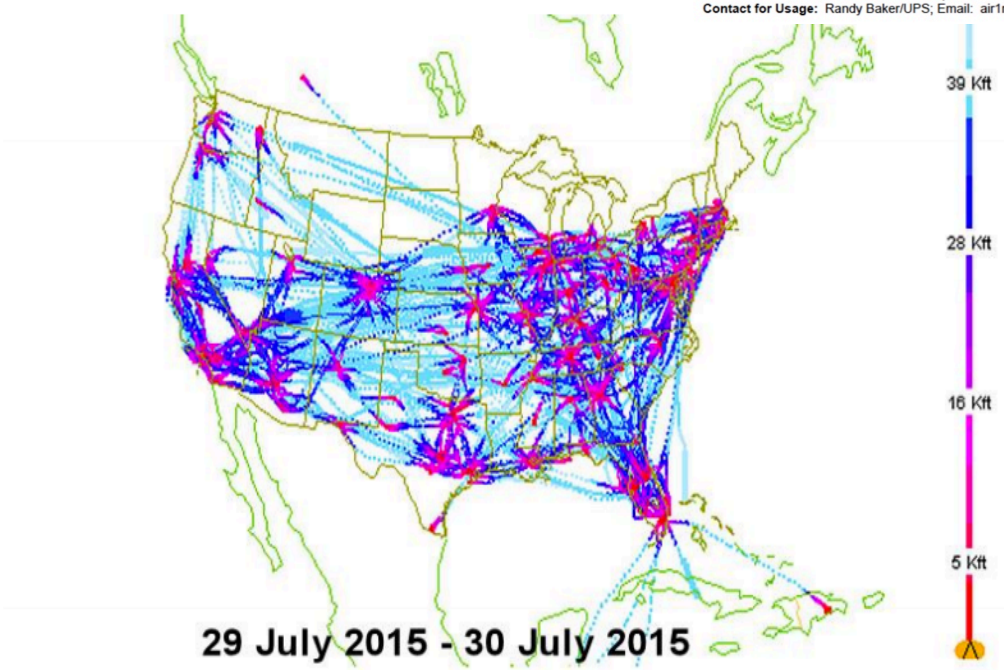


Photo Credit: UPS Dispatch
Contact for Usage: Randy Baker/UPS; Email: air1rtb@ups.com



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Final Points

New investment and coordination of existing resources will be required to realize a global greenhouse gas information system for decision support.

- Sophisticated data assimilation systems are needed that can utilize in situ, near-IR and thermal-IR measurements.
- A thorough and coordinated approach is needed to evaluate retrievals from current and future greenhouse gas missions and to establish continuity across missions.
- Careful observing system design experiments are needed to evaluate cost, risk, and information content of proposed new measurements.