Integrated Global GHG Information System (IG^{3}IS): Evidence Based Policy Support and Evaluation: Paris Agreement on Climate Change

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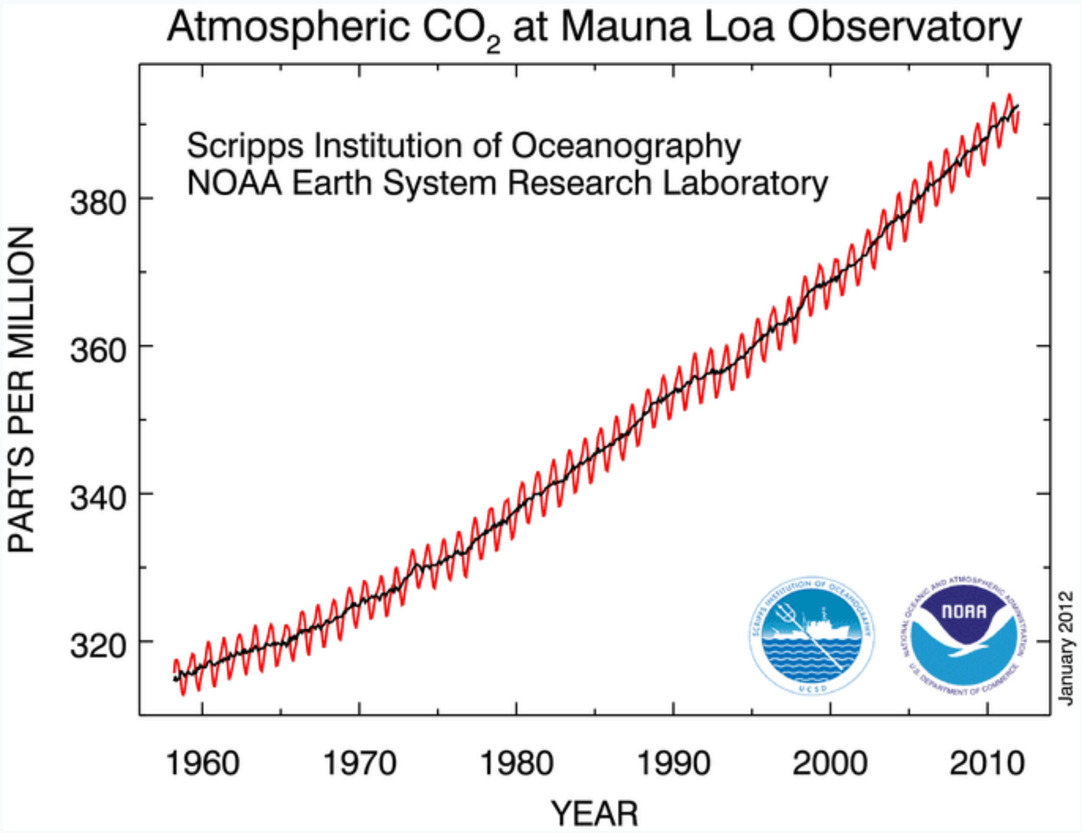
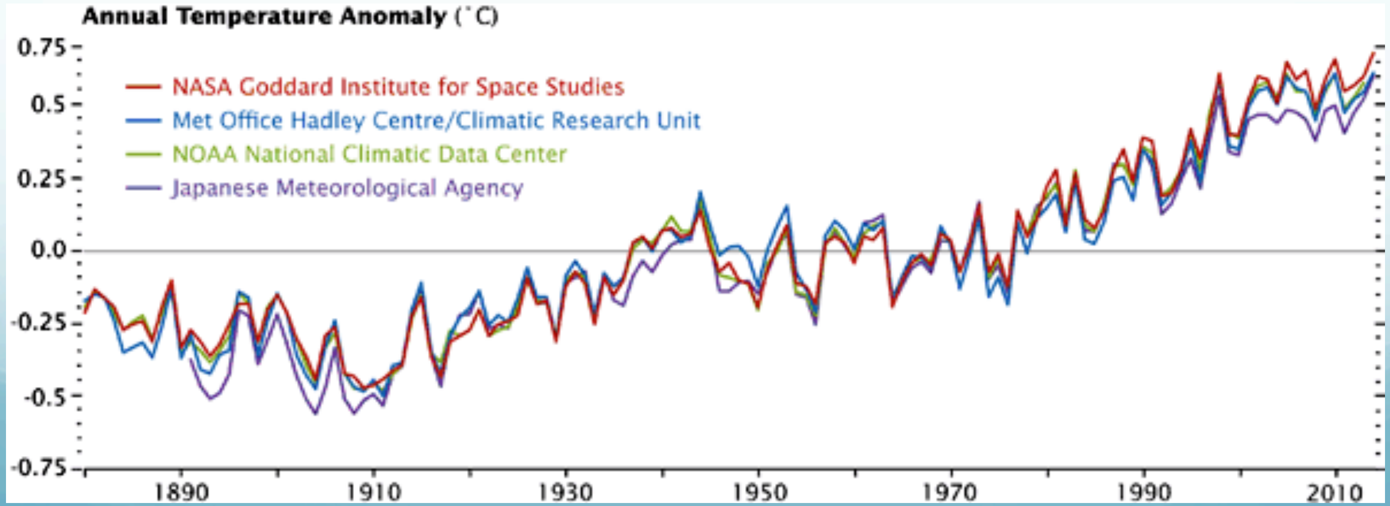
Jae Edmonds, John Miller, Riley Duren, Prabir Patra,
Shuangxi Fang, Luciana Gatti, Tim Arnold, Luisa Molina,
Toshinobu Machida, Ed Dlugokencky, Diane Stanitski,
Deon Terblanche, James Whetstone, Jack Kaye,
Hratch Semerjian, Steven Hamburg, Stephan Reimann,
Daniel Zavala-Araiza, Dominik Brunner and others

Why do we have a UNFCCC?

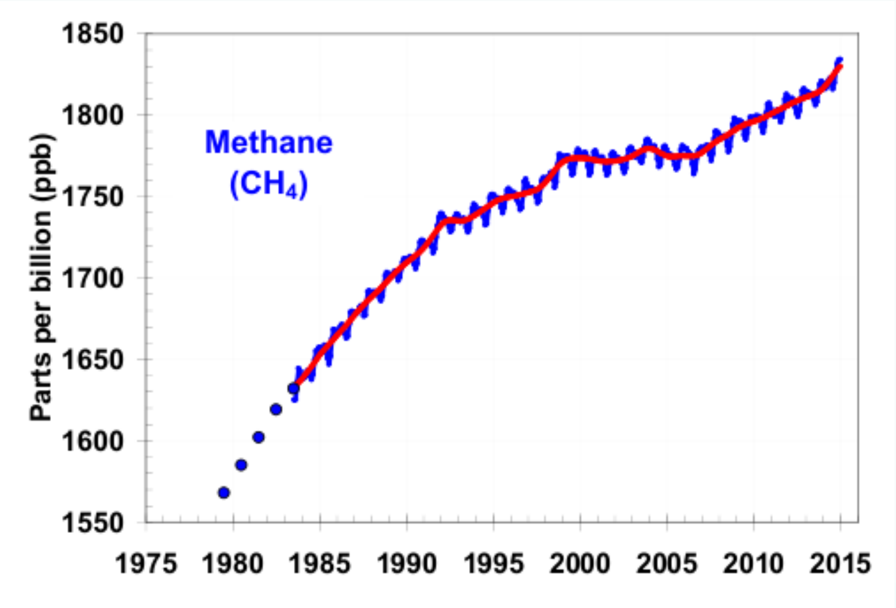


Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
January 2012

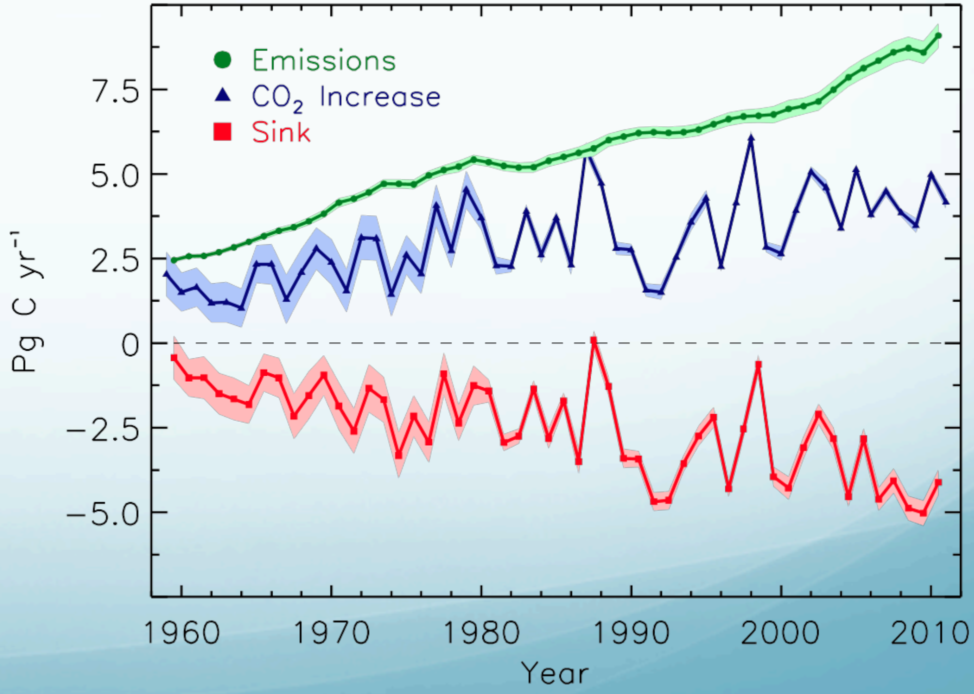


Annual Temperature Anomaly (°C)
NASA Goddard Institute for Space Studies
Met Office Hadley Centre/Climatic Research Unit
NOAA National Climatic Data Center
Japanese Meteorological Agency
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.75
1890
1910
1930
1950
1970
1990
2010

Atmospheric GHGs – Primary Driver of Climate Change – But questions remain

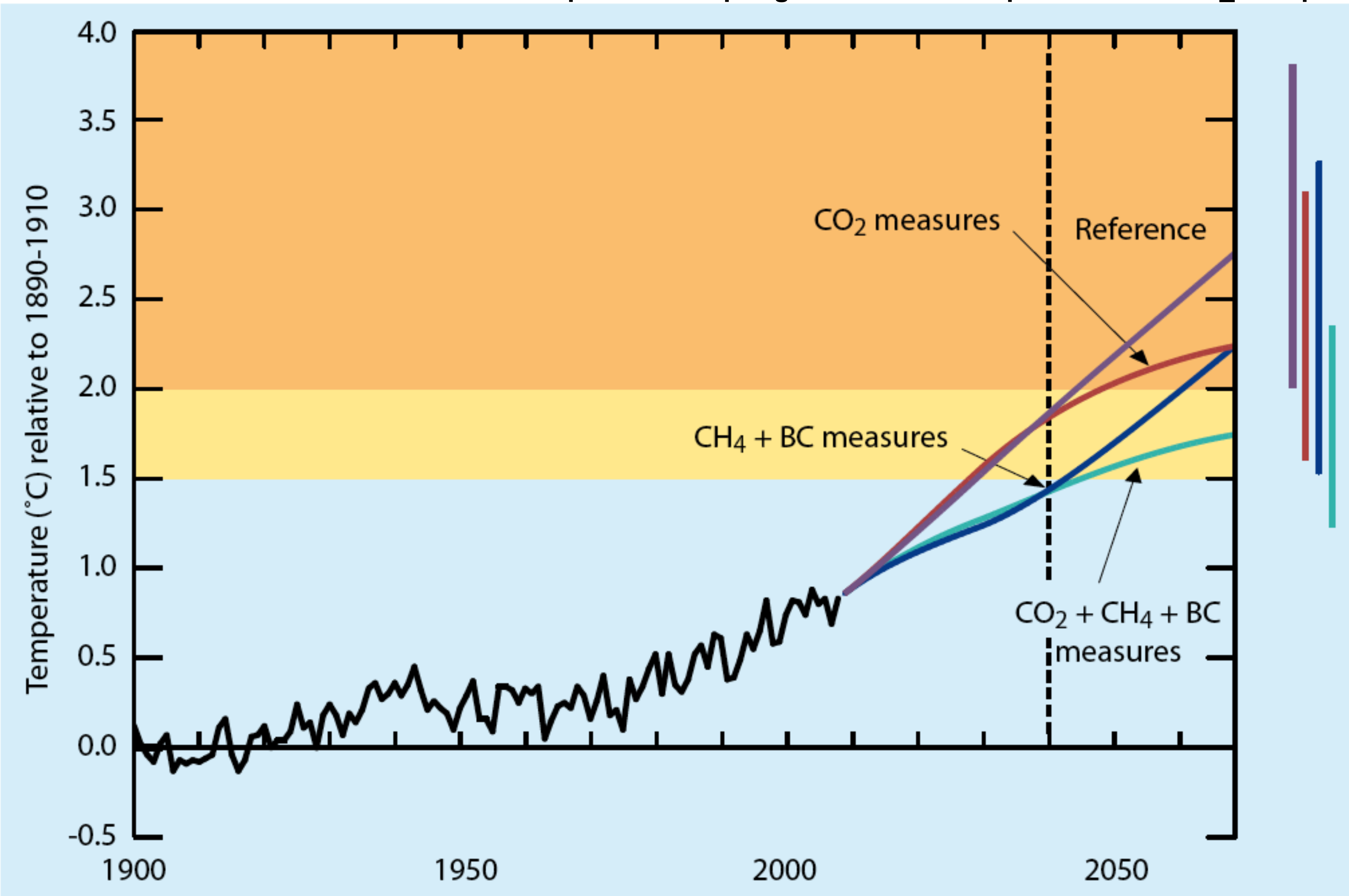


- Atmospheric CO_2 continues to increase every year
  - The trend is largely driven by fossil fuel emissions
- Methane growth rate also significant but unknown variability
  - 80 times more forcing than CO_2
- The Earth System continues to capture 50% of emissions
  - Despite the increase in emissions
  - How long can we depend on this "benefit" and how will it change with time?

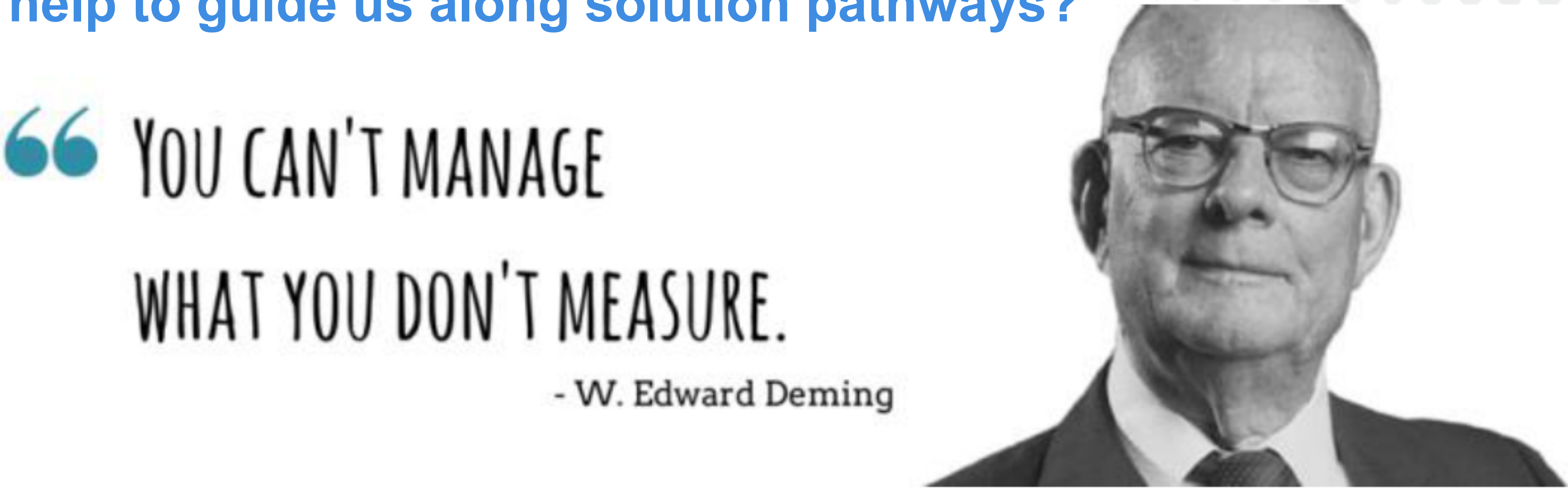


UNEP and WMO 2011 – Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers.

http://www.unep.org/dewa/Portals/67/pdf/BlackCarbon_SDM.pdf



Can science-based, evidence-based information help to guide us along solution pathways?



Paris Agreement and GHG Monitoring: Evolving from Top-Down versus Bottom-Up Paradigm

Then (2009)

Binding Multi-national Treaty Commitments

"we will verify your reported emissions"

A grand top-down GHG Information System

Advocates: Science Community!!!

Now (2016)

Nationally Determined Contributions

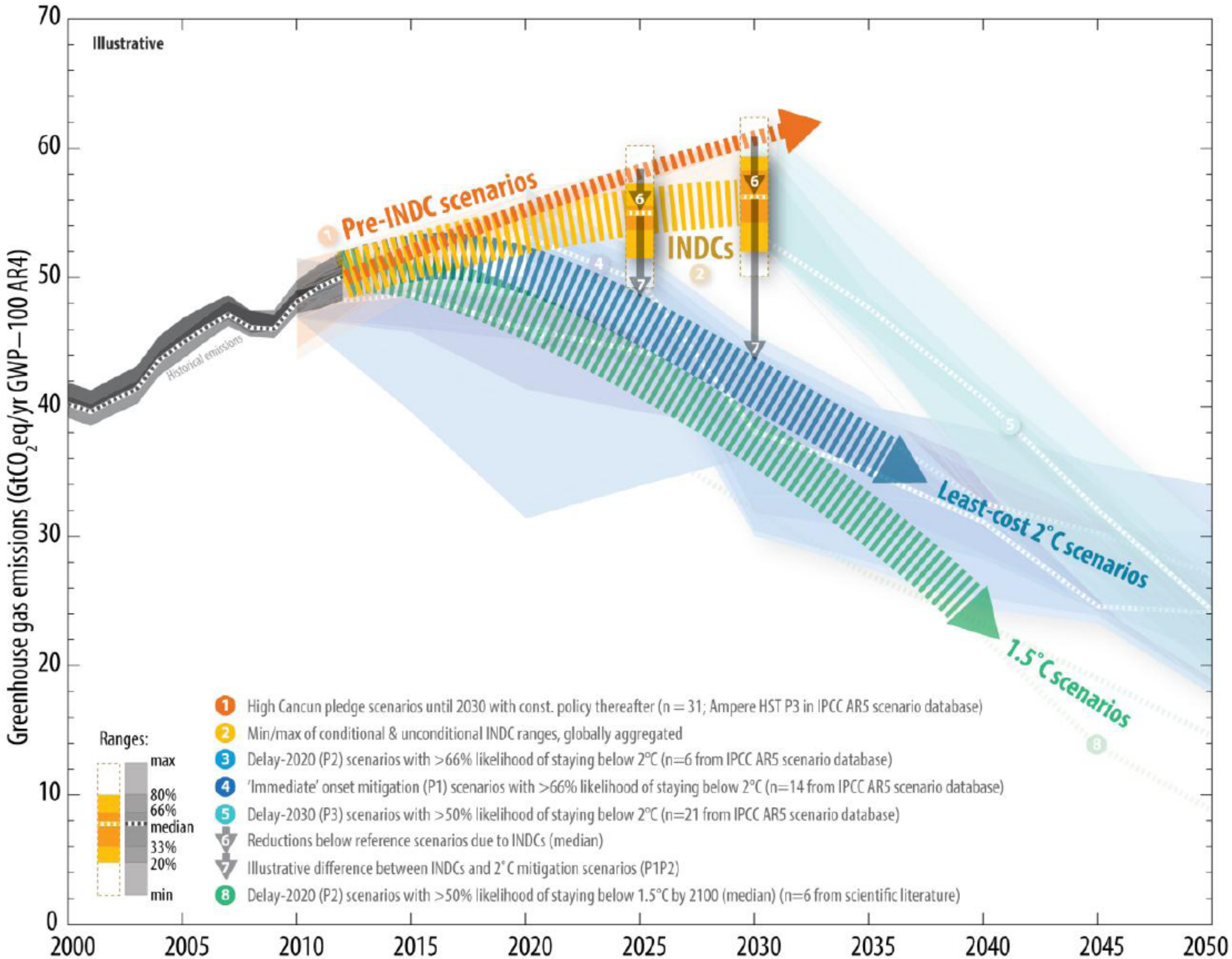
"we will help you improve your data"

Federation of focused monitoring systems

Advocates: WMO (191 countries),UNEP, Cities (eg, C40), NGOs, Industry (eg, Oil Companies)

Figure 2

Comparison of global emission levels in 2025 and 2030 resulting from the implementation of the intended nationally determined contributions and under other scenarios



Sources: Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report scenario database, 1.5 °C scenarios from scientific literature (see footnote 19), IPCC historical emission database and intended nationally determined contribution quantification.

Abbreviations: AR4 = Fourth Assessment Report of the Intergovernmental Panel on Climate Change, GWP = global warming potential, INDC = intended nationally determined contribution, IPCC AR5 = Fifth Assessment Report of the Intergovernmental Panel on Climate Change, n = number of scenarios, yr = year.

United Nations

FCCC/CP/2016/2

Framework Convention on Climate Change

Distr.: General
2 May 2016

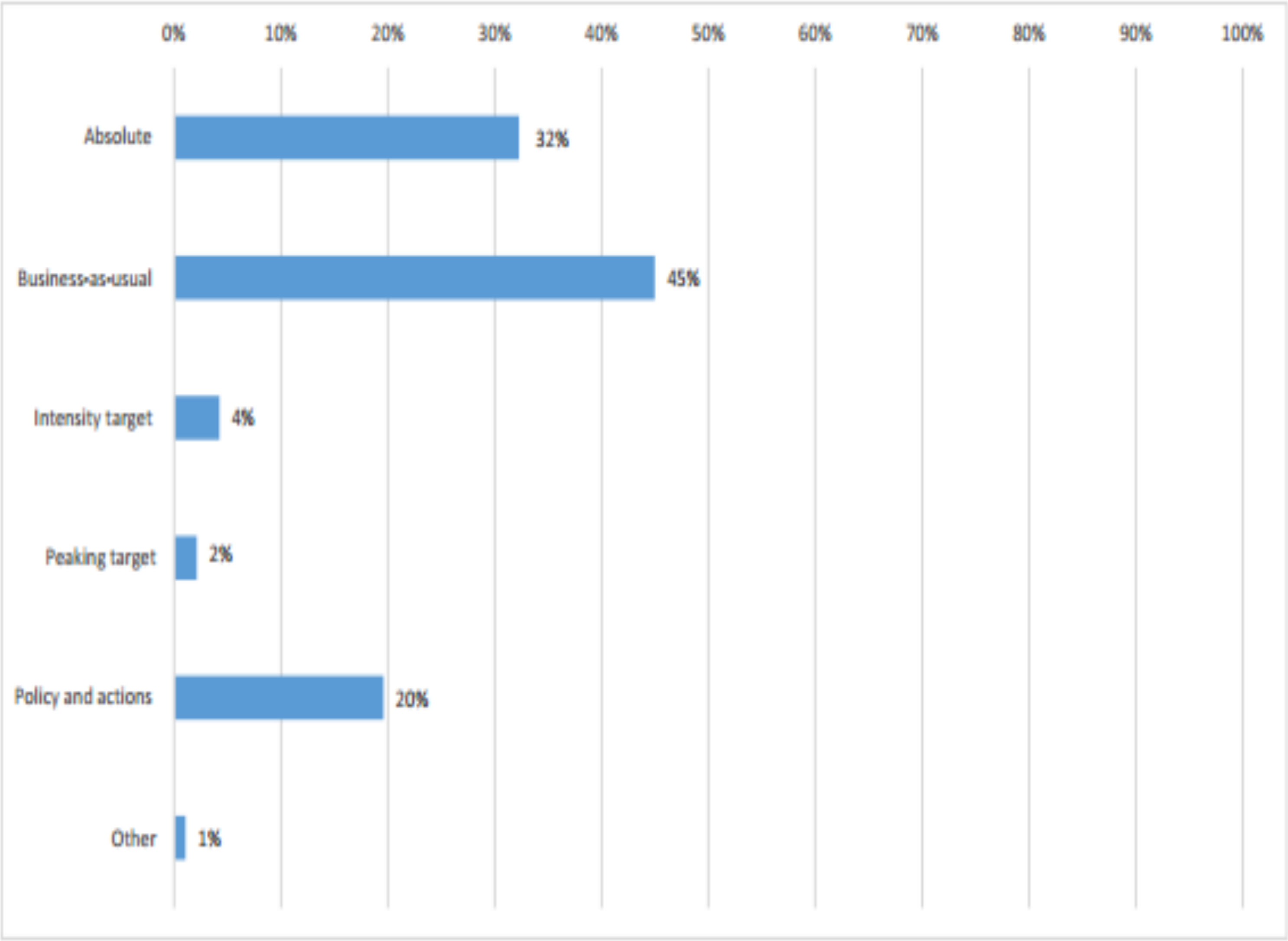
Original: English

Conference of the Parties
Twenty-second session
Marrakech, 7–18 November 2016
Item X of the provisional agenda

Aggregate effect of the intended nationally determined contributions: an update

Figure 1

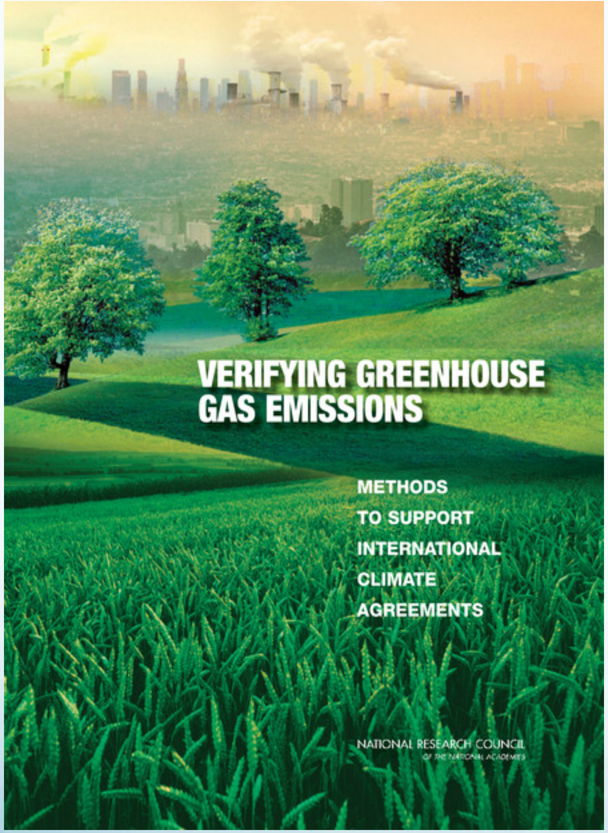
Types of mitigation target communicated in the intended nationally determined contributions

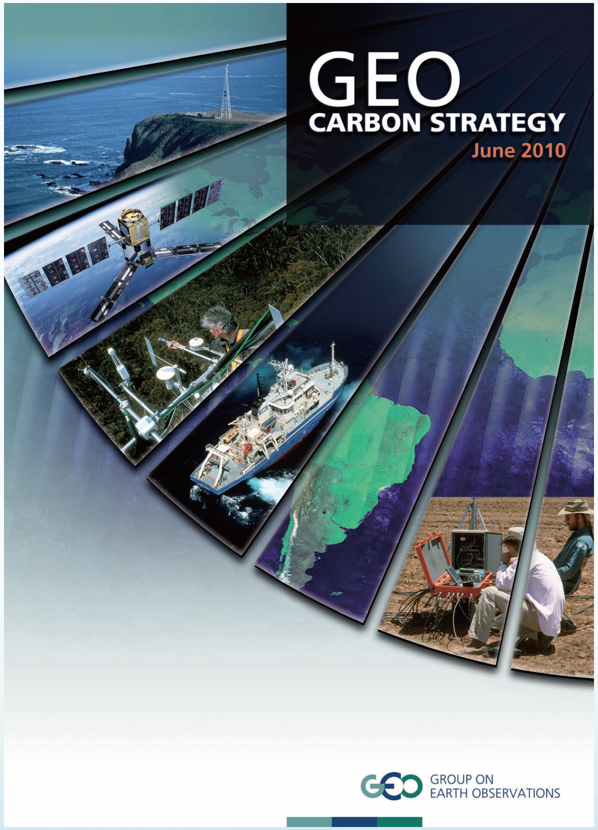


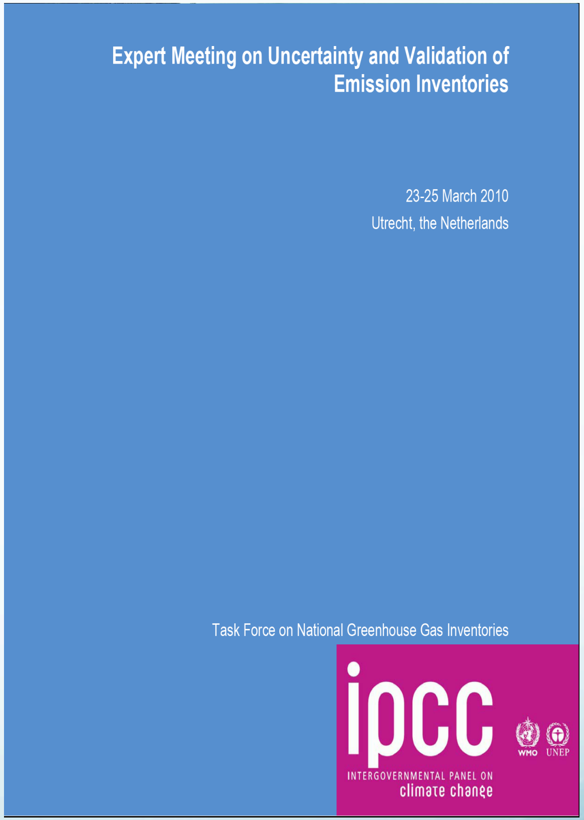
Note: The percentages shown are percentages of the Parties that submitted an INDC by 4 April 2016.

GHG monitoring and reporting in 2010: atmospheric "top-down" and inventory "bottom-up"

Can atmospheric measurements and models "verify" inventories?







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CLIMATE

Carbon trackers could help bolster climate vows

Projects lay groundwork for a global greenhouse monitoring system

By Warren Cornwall

In May, China's statistical agency quietly raised estimates of how much coal the nation has burned since 2000. That little bit of bookkeeping had big implications. It amounted to as much as 900 million metric tons of additional carbon dioxide (CO_2) emitted annually in recent years, more than the total yearly emissions of Germany. It also underscored the challenge of knowing what many countries are really pumping into the atmosphere.

After negotiators left Paris last week with vows to curb the world's climate pollution (see box, p. 1451), officials will want to know whether countries are living up to their promises. The Paris meeting addressed part of the puzzle: greenhouse gas accounting, including mechanisms for auditing emissions reports. But scientists are also in the early stages of deploying systems they hope could buttress international agreements by closely tracking greenhouse gas emissions in the air, rather than on paper.

Space-borne sensors are watching the ebb and flow of carbon around the globe, and a few experimental, city-scale monitoring systems are up and running. Ultimately, a network of instruments on satellites, commercial jets, smokestacks, and communications towers could deliver a detailed, nearly instantaneous picture of emissions in a country, city, or even a neighborhood: a global weather system for greenhouse gases.

"A carbon weather service is probably the best example of where we probably ought to get in the future," says Riley Duren, an engineer at NASA's Jet Propulsion Laboratory in Pasadena, California. He heads the Megacities Carbon Project, which is building a first-generation system in Los Angeles, California. The idea got a boost earlier this year when the United Nations World Meteorological Organization (WMO) endorsed the creation of the Integrated Global Greenhouse Gas Information System, to promote networks for tracking greenhouse gases.

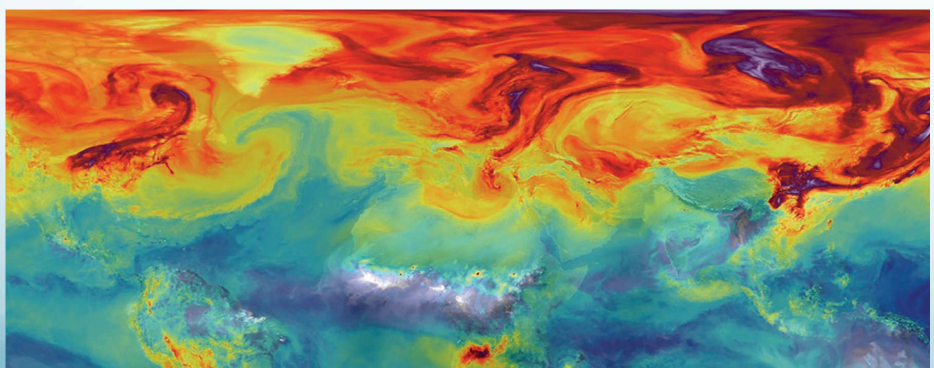
Today, the clearest data on CO_2 are the atmospheric concentrations measured at more than 40 stations around the world. Emissions for countries or cities are estimated by adding up reams of statistics about fuel consumption, deforestation, electricity generation, and other activities.

Many developed countries have honed these inventories over years of practice under the Kyoto, Japan, climate treaty. But much less is known about emissions in the developing world, which today account for an estimated 60% of climate pollution. In October, the European Union's earth observation agency, Copernicus, warned that such uncertainties "could undermine the credibility and the stability of future climate agreements."

The projects now underway in the skies and on the ground could eventually help officials determine whether their neighbors are meeting their promises and whether their own strategies are producing results. "Our goal is to say: 'Your emission reduction policies seem to be consistent with what we see in the atmosphere, although it looks like your efforts in transportation are having a bigger impact than the energy sector,'" says James Butler, director of the global monitoring division at the National Oceanic and Atmospheric Administration's Earth System Research Laboratory in Boulder, Colorado.

Cities, where a majority of human-caused greenhouse gases originate, are serving as testing grounds. Over the last 5 years, Indianapolis, Boston, Los Angeles, and Paris have been outfitted with equipment to track their carbon emissions. A similar network is being built around Washington, D.C., and it may eventually be extended up the East Coast to Boston, says James Whetstone, a scientist and manager at the National Institute of Standards and Technology in Gaithersburg, Maryland, which is helping fund several of the U.S. projects.

Los Angeles illustrates both the potential and the challenges. Today, 13 devices mounted high on tall buildings and cellphone and radio towers constantly measure CO_2 across an area of 17,000 square kilometers. Some also track methane, a potent heat-trapping gas. Atop nearby Mount Wilson, a device scans the basin every 90 minutes, detecting the gases' infrared signature. Airplanes zero in on hot spots identified by the stationary instruments. NASA's Orbiting Carbon Observatory-2 (OCO-2) satellite periodically surveys the city for a big-picture snapshot. The data



A simulation shows high CO_2 levels over Northern Hemisphere continents. New monitoring efforts aim to keep tabs on regional emissions.

Published by AAAS

Carbon trackers could help bolster climate vows, however:

"...don't want....another grand research strategy for the circular file of posterity,"

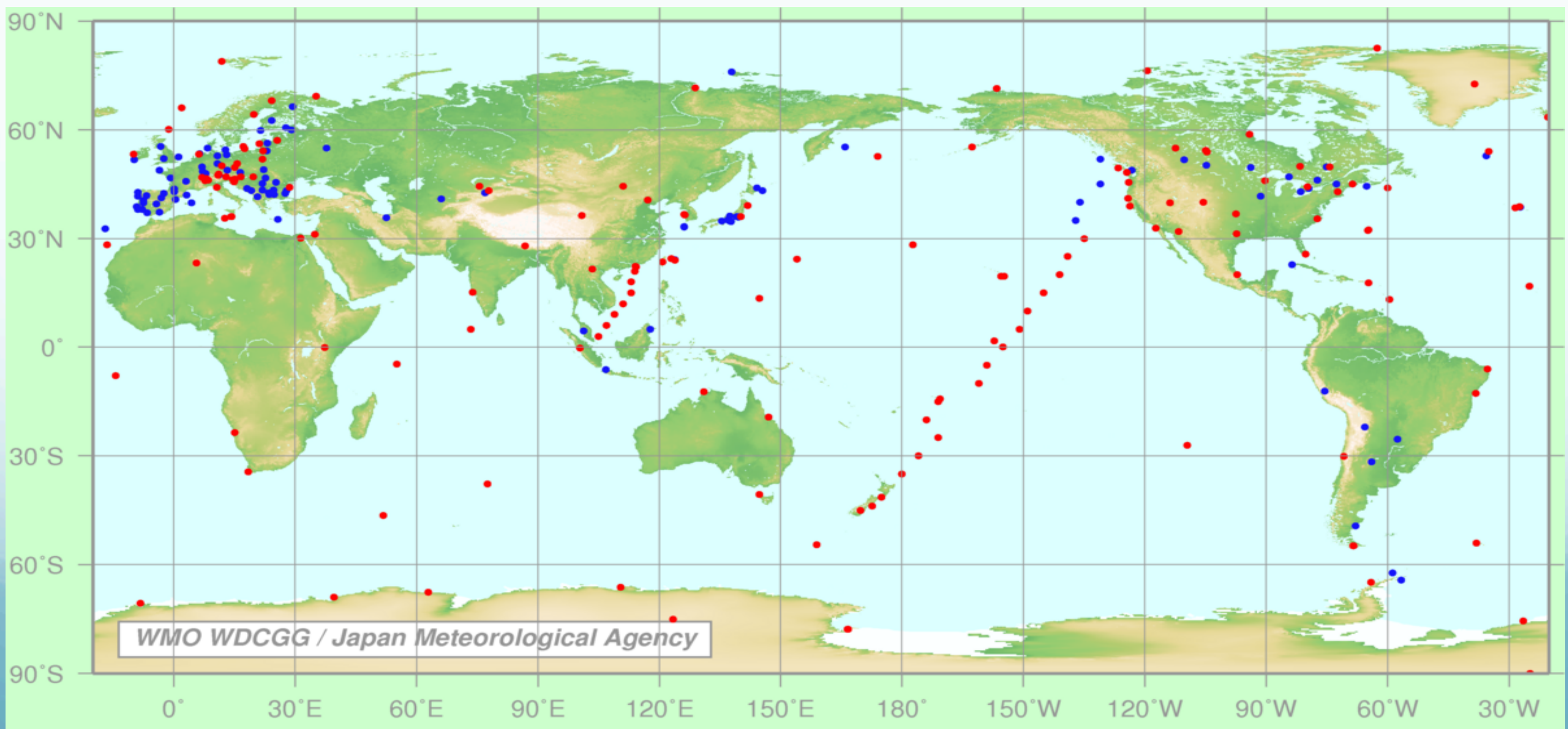
PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

Science 18 Dec 2015:
W Cornwall, Vol. 350, Issue 6267, pp. 1450-1451
DOI: 10.1126/science.350.6267.1450

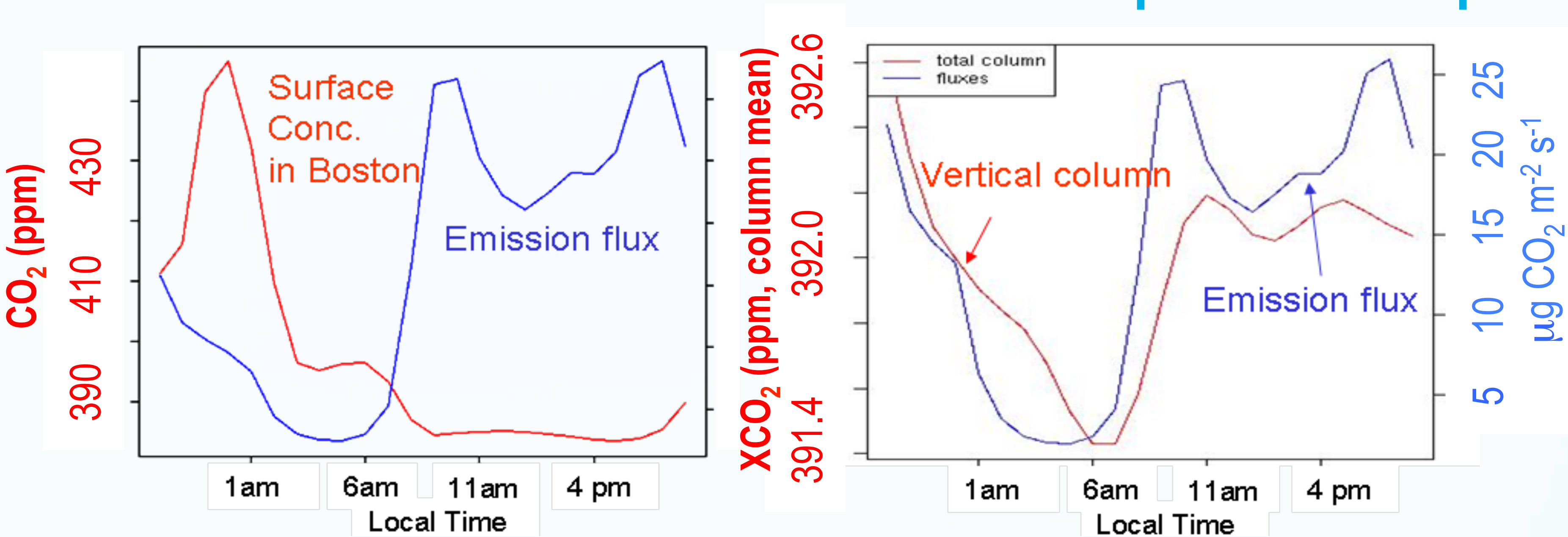
WMO Role in GHG Information and IG³IS: Methods and standards for GHG Observations

The Role of the World Meteorological Organization (WMO)

- Ensure high quality, consistent, continuous GHG and other observations of atmospheric composition
- Develop high quality atmospheric transport and data inversion models
- Coordinate global atmospheric measurements; improve models and analysis
- Leverage capabilities across programs and nations
- Build capacity in developing nations



WMO Role in GHG Information: Atmospheric Transport



The patterns in observed surface concentrations are distinctly opposite to the daily variations of emissions fluxes from human activity.

Surface concentrations of CO_2 maximize at nighttime when the nocturnal PBL is shallow, but PBL height and rush hour emissions are increasing in the morning.

Must understand atmospheric transport and dynamics to quantify emissions fluxes from atmospheric concentration measurements

The IG³IS Goals and Principles

Goal: Support the success of post-COP21 actions of nations, sub-national governments, and the private sector to reduce climate-disrupting GHG emissions through a sound-scientific, measurement-based approach that:

- **reduces uncertainty of national emission inventory reporting**,
- **identifies large and additional emission reduction opportunities**, and
- **provides nations with timely and quantified guidance on progress towards their emission reduction strategies and pledges (e.g., NDCs)**

Principles

- IG³IS will serve as an international coordinating mechanism and establish and propagate consistent methods and standards.
- Diverse measurement and analysis approaches will fit within a common framework.
- Stakeholders are entrained from the beginning to ensure that information products meet user priorities and deliver on the foreseen value proposition.
- Success-criteria are that the information guides additional and valuable emission-reduction actions.
- IG³IS must mature in concert with evolution of technology and user-needs / policy.

Near-term IG^3IS Objectives (3-5 year horizon)

Support of Paris Agreement:

- Timely and quantified trend assessment of NDCs in support of "Global Stocktaking"
- Improved national inventory reporting by making use of atmospheric measurements for all countries

Key sub-national efforts and new mitigation opportunities:

- GHG monitoring in large urban source areas (megacities)
- Detection and quantifying large unknown CH_4 emissions

An integrated multi-tool approach for national inventories - Updates to the IPCC TFI 2006 IPCC guidelines

- IPCC guidelines/guidance provide broad international calculation methods:
  - Assists development of inventories that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and quality assurance, and efficient in the use of resources
- Country-driven multi-tool approach includes:
  - National QA/QC plans
  - Internal QC checks
  - Independent QA & review
  - Reporting, documentation & archiving
  - Verification through comparison with independent data sets & atmospheric measurements
- Planned 2019 Methodological Update to improve guidance for countries on a portfolio QA/QC & verification procedures
  - Establish link with WMO/IG^{3}IS effort to make it easier for countries to use measurement & modeling information to improve inventory estimates

LOCATON Chapter 6. QA/QC and verification. Section 6.10

ISSUE Verification guidance is outdated (especially the guidance on comparisons with atmospheric measurements and new datasets are available)

Guidance to Authors

1) There is a need to discuss various ways to verify emission estimates in the context of the latest science with case examples:

i) atmospheric concentration data;

ii) independent monitoring of carbon stocks and fluxes: remote-sensing of activity data.

The refinement work should not be focused on developing detailed methods, but reference more detailed examples that have been published elsewhere. Also, other uses of these data should be discussed, for example, direct emission measurements to prepare better emission factors where other information is limited, describe circumstances where this is possible and the limitations (link to data collection chapter)

2). Guidance on the reporting of the use of such data. It was noted that there might be a need for some follow-up in the sectoral guidance about the use of atmospheric data and other data. Outline how this can be used to improve inventories. Examples. This will be advisory not mandatory. (Use IPCC workshop report on use of concentration data).

INTERGOVERNMENTAL PANEL ON climate change

Our ref.: 5207-16/IPCC/P-44

To the Executive Heads
of International and other Organizations

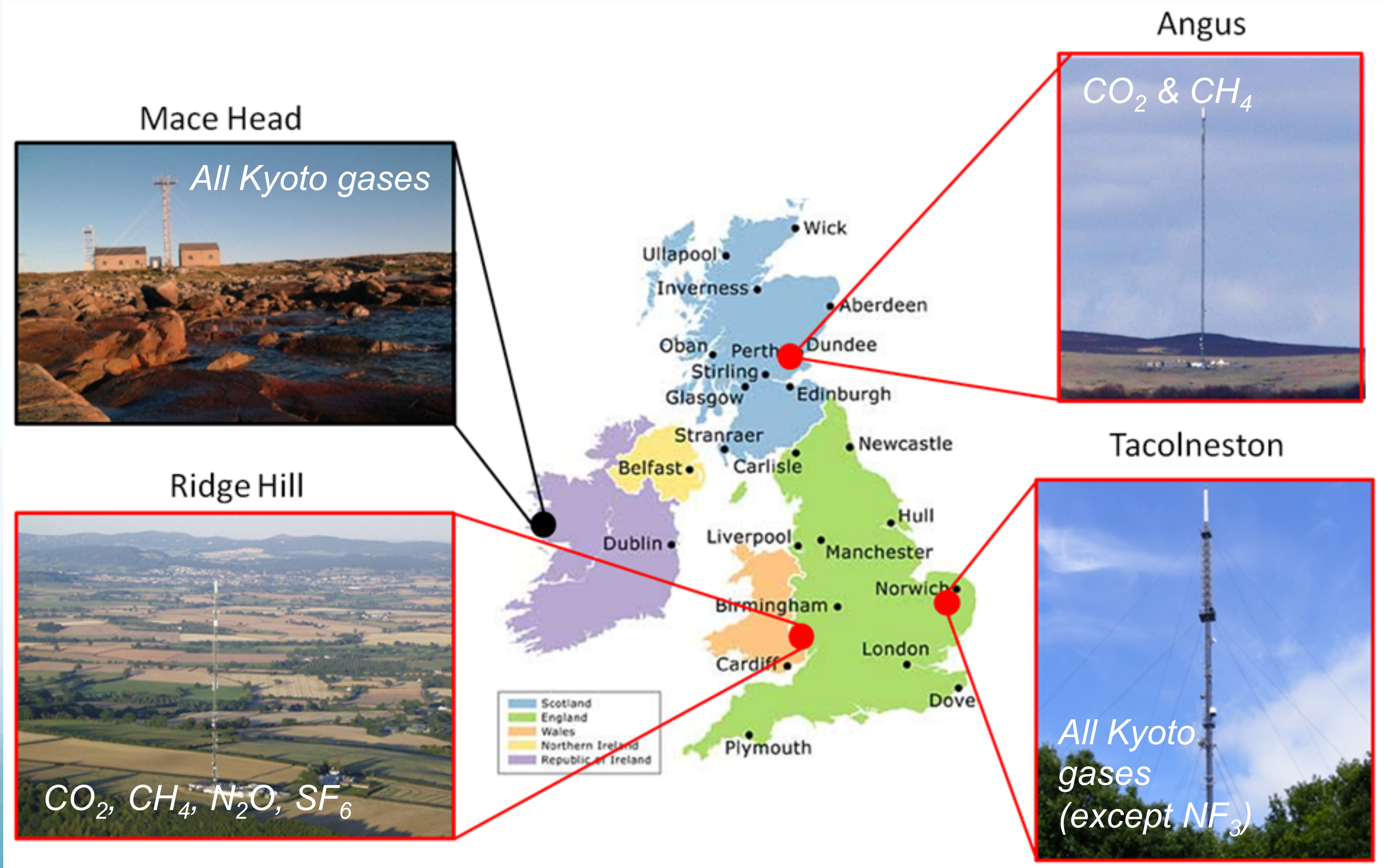
Geneva, 16 August 2016

Sir/Madam,

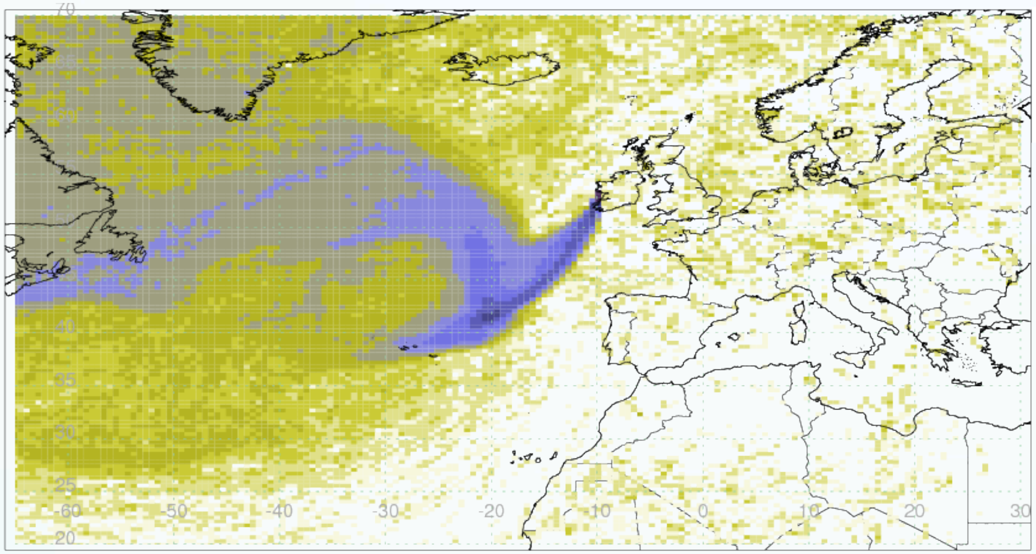
I am writing on behalf of the Chair of the Intergovernmental Panel on Climate Change (IPCC) on the subject of the Forty-Fourth Session of the IPCC (IPCC-44) scheduled to take place at the United Nations Conference Centre, United Nations ESCAP, Rajdamnern Nok Avenue, Bangkok 10200, Thailand, from 17 to 20 October 2016…...............

The **main agenda items** of the Forty-Fourth Session of the IPCC will be to consider the outline for the IPCC **Special Report** on the impacts of **global warming of 1.5 ºC above pre-industrial levels** and related global greenhouse gas emission pathways, and **to consider the outline of the Methodology Report(s) to refine the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.** The Panel will also address other items that require consideration and decision by the Panel.

UK DECC Measurement Network



UK Met Office Modelling and Analysis



Met Office

00-02z
01/08/2012

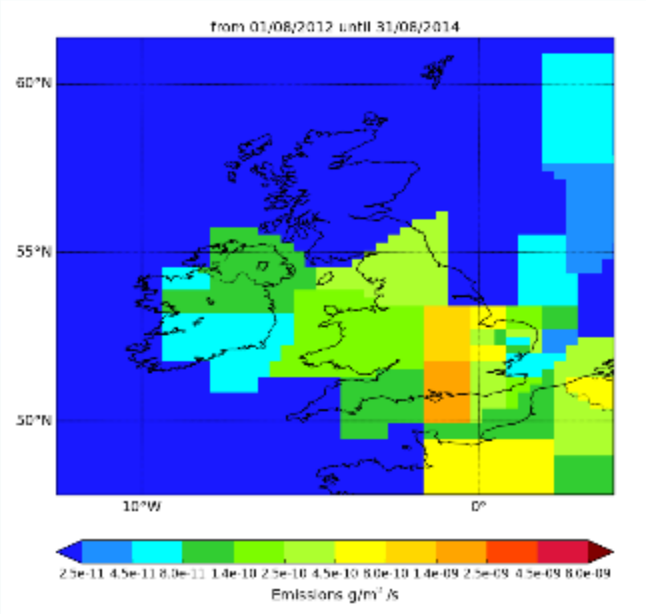
Mace Head air history maps are generated for each 2-hour period between 1989 and 2015

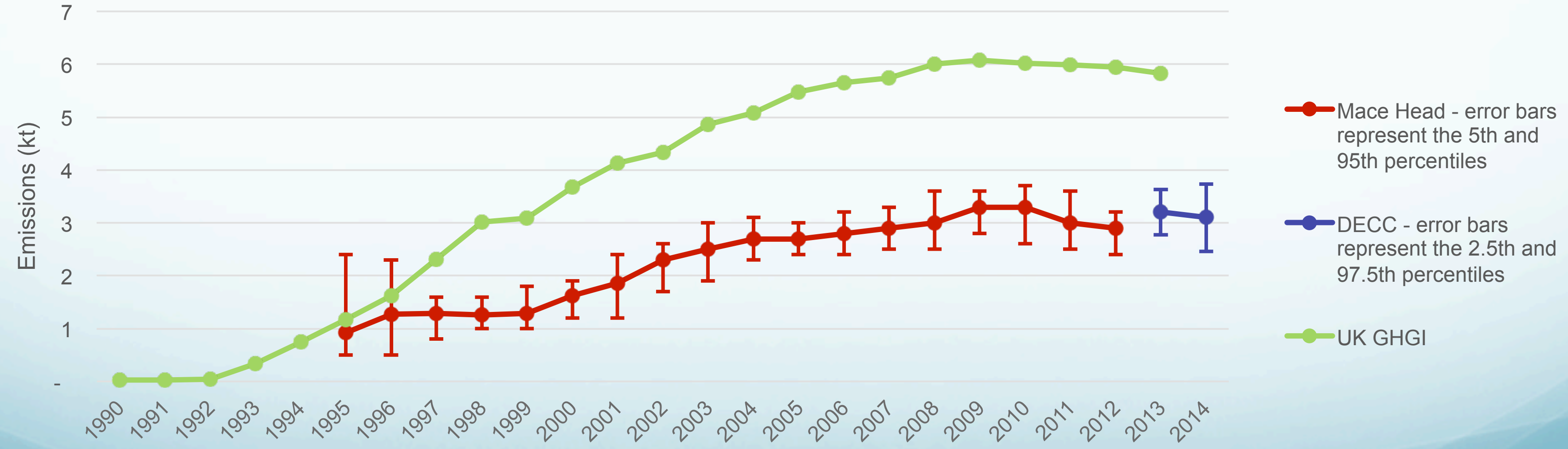
- **Use the NAME transport model driven by 3-D meteorology to understand the recent (3-4 weeks) history of the air arriving at measurement stations**
- **Two stage process:**
  - **Estimate long-term Northern Hemisphere baseline concentrations using Mace Head observations.**
  - **Estimate regional emissions through inversion modelling (InTEM).**

Example from UK report to UNFCCC: HFC-134a

- **Significant mismatch throughout the entire time-series of emissions, approximately inversion is 50% lower than inventory.**

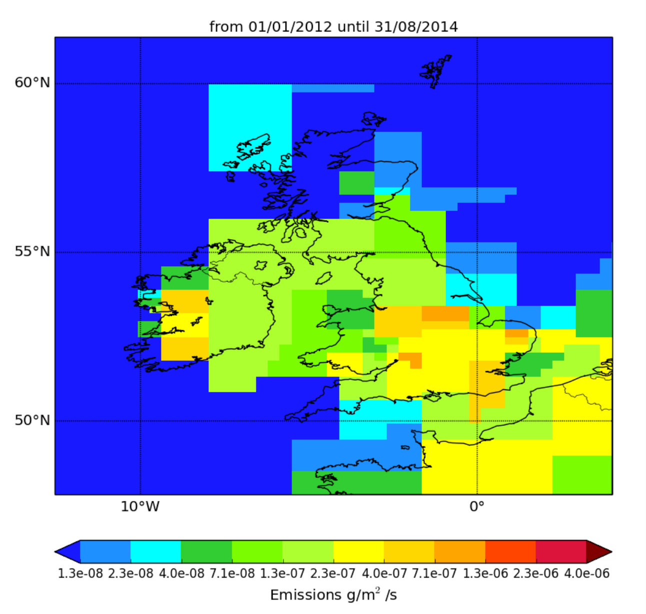
- **Investigated the refrigeration model used by inventory compilers, key variables to be re-considered by DECC:**
    - **Refill rate**
    - **Uptake rate**

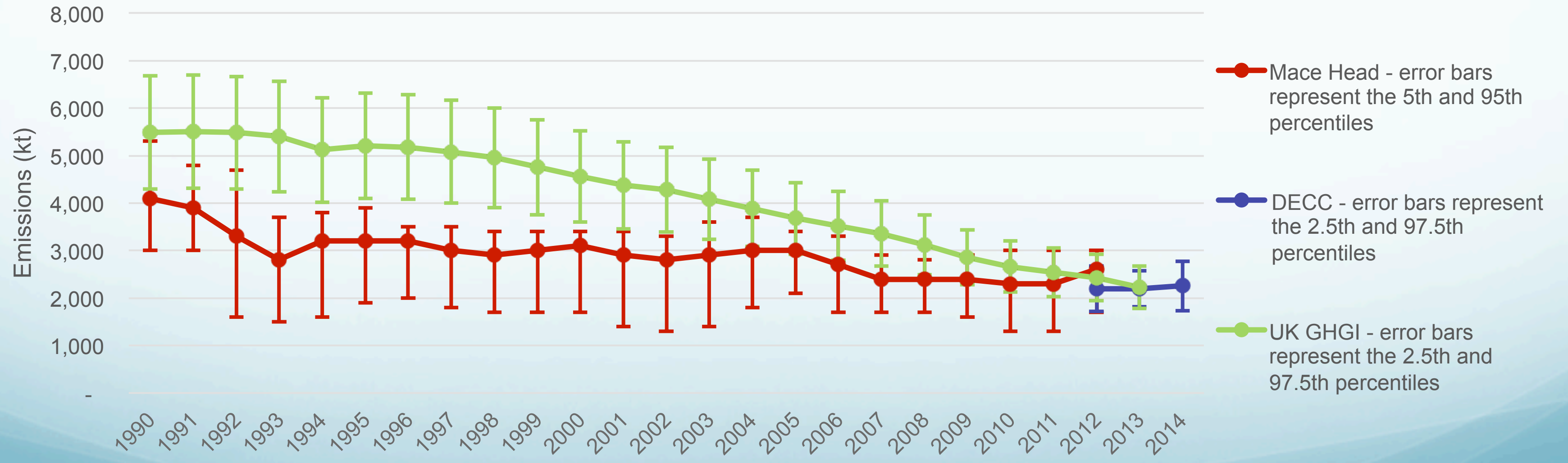




Example from UK report to UNFCCC: Methane

- Early (1990s) mismatch with the inventory.
- Difficult to understand, most likely cause is landfill emissions but retrospectively challenging to investigate.
- Inspired DECC to expand the network from 1 to 4 stations.

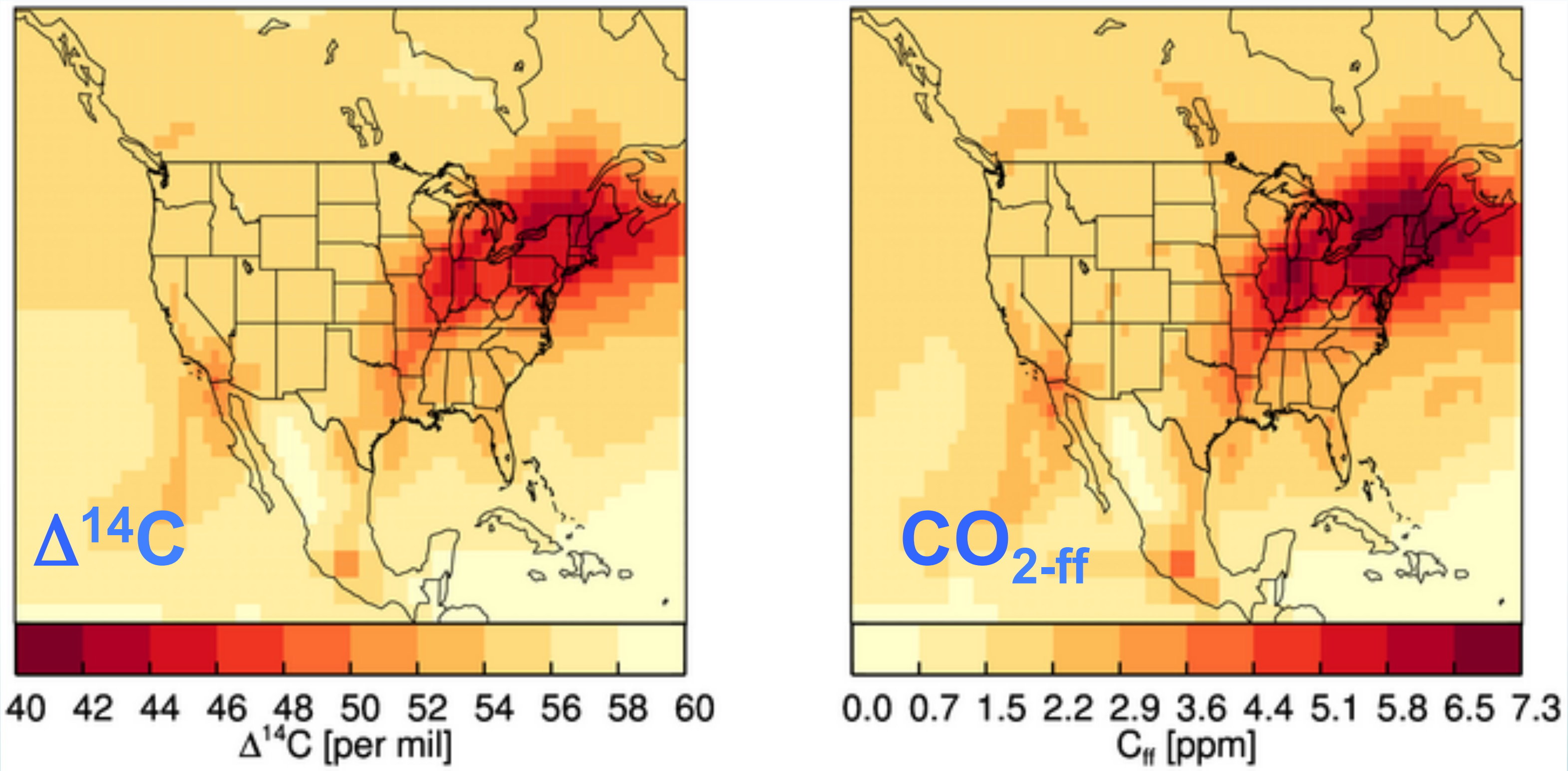




$^{14}CO_2$:$^{12}CO_2$ ($\Delta^{14}C$) is a robust tracer for fossil fuel fluxes: atmospheric $\Delta^{14}C$ looks just like fossil CO_2.

$\Delta^{14}C_{ff}$ = -1000 per mil (i.e. zero ^{14}C)

Scaling: -2.7 per mil $\Delta^{14}C$ = 1 ppm CO_2-fossil



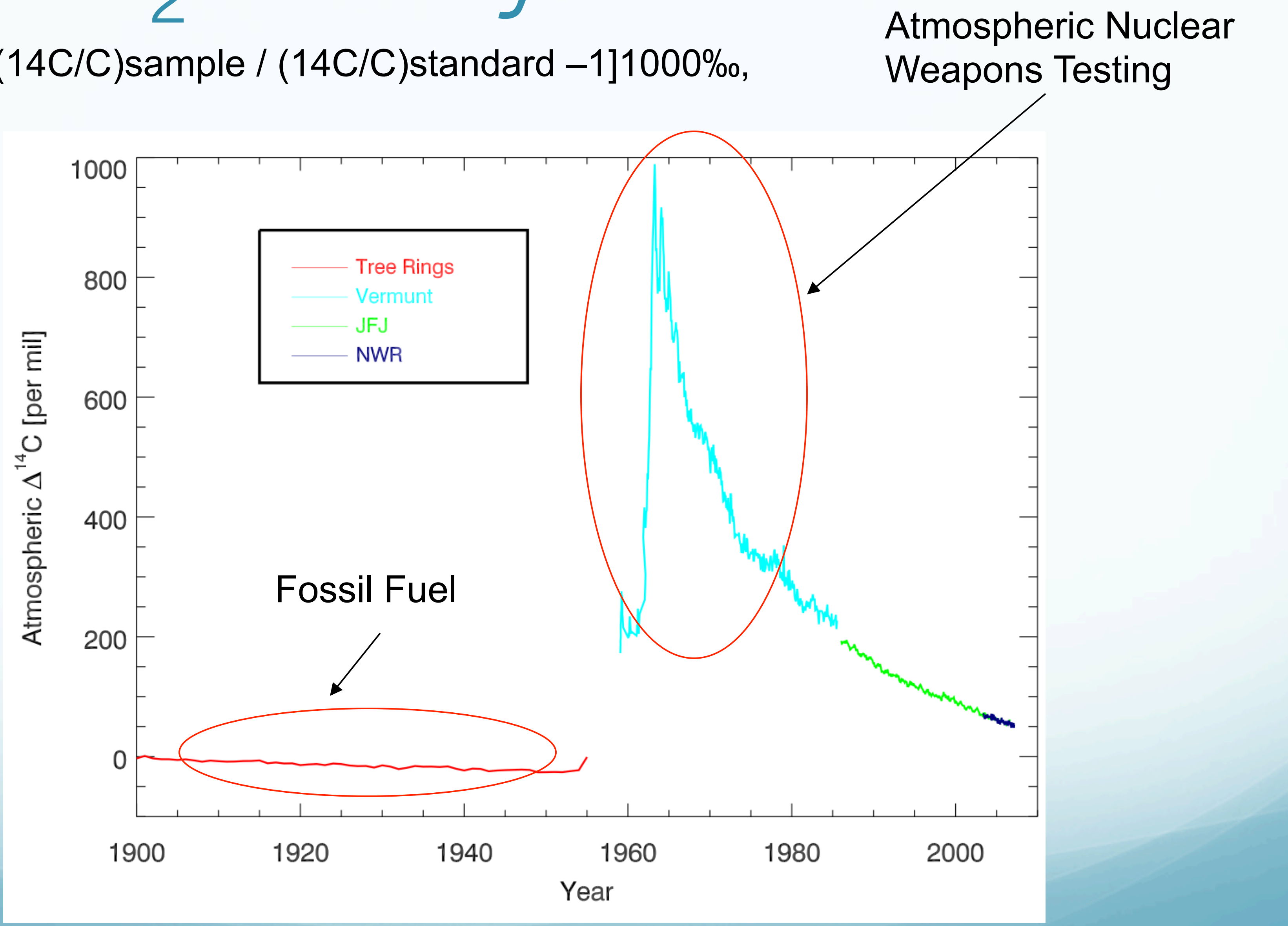
predominantly fossil fuel, but Includes small effects from ecosystems, oceans, nuclear power, cosmic rays

Includes only fossil fuel

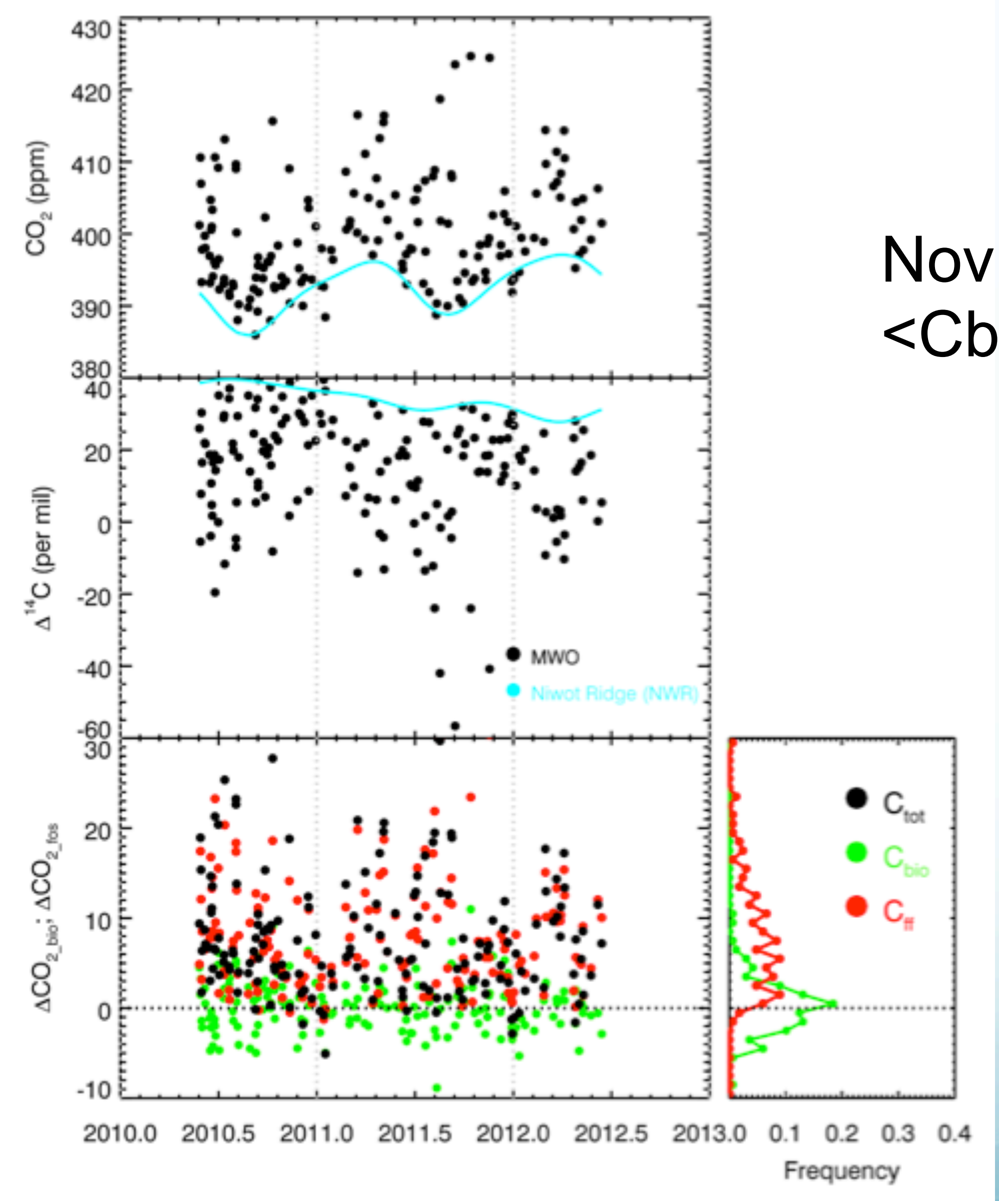
Miller et al, 2012

$^{14}CO_2$ History

$\Delta 14C = [(14C/C)_{sample} / (14C/C)_{standard} - 1]1000‰$,



Mount Wilson Observations of 14C and CO2



Nov – Feb (2011, 2012)

<Cbio/Ctot> = 15% (median)

ANALYTICAL CHEMISTRY

Ultrasensitive radiocarbon detection

Radiocarbon is rare, forming no more than one part per trillion of the total carbon content of the atmosphere. An optical method allows radiocarbon to be detected at roughly 25-fold lower levels than this, opening up fresh avenues of research.

RICHARD N. ZARE

Most isotope-ratio measurements are carried

of carbon dioxide containing ^{12}C and ^{13}C, but the low concentration of ^{14}C has made its measurement in carbon dioxide extremely difficult. Using an ultrasensitive technique called saturated-absorption cavity ring-down spectroscopy[5], Galli *et al.*[1] have now succeeded in measuring the ratio of ^{14}C to total carbon at values well below radiocarbon's natural abundance in carbon dioxide.

In their technique, the authors placed a gas sample between two or more highly reflecting mirrors that form an optical cavity. Infrared light that is incident on the cavity continually circulates within it, so that it takes many round trips. This effectively increases the optical path

PRL **107,** 270802 (2011) PHYSICAL REVIEW LETTERS week ending 30 DECEMBER 2011

Molecular Gas Sensing Below Parts Per Trillion: Radiocarbon-Dioxide Optical Detection

I. Galli, S. Bartalini, S. Borri, P. Cancio,* D. Mazzotti, P. De Natale, and G. Giusfredi

Istituto Nazionale di Ottica-CNR (INO-CNR)† *and European Laboratory for Non-Linear Spectroscopy (LENS)*‡ *Via N. Carrara 1, I-50019 Sesto Fiorentino, Italy*

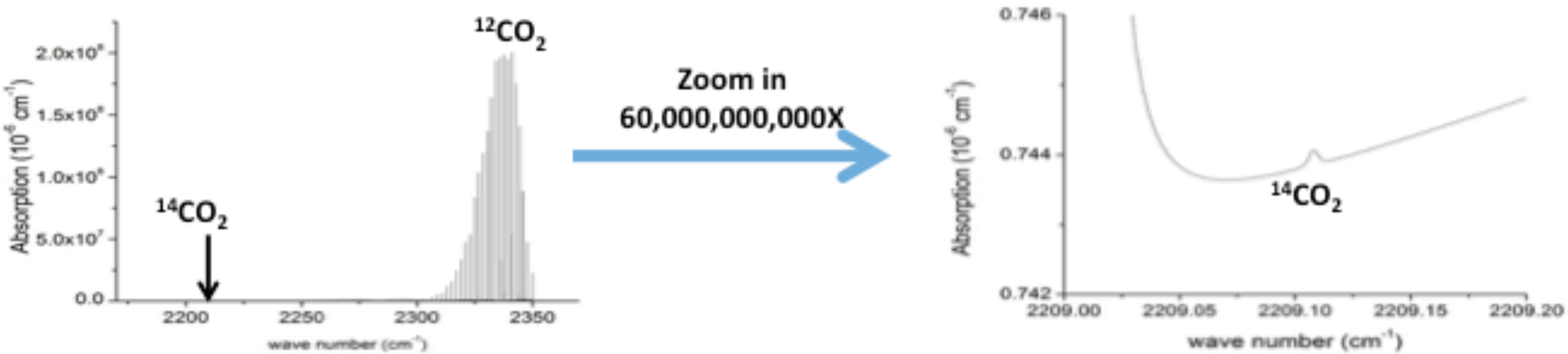
(Received 17 May 2011; published 30 December 2011)

Radiocarbon (^{14}C) concentrations at a 43 parts-per-quadrillion level are measured by using saturated-absorption cavity ringdown spectroscopy by exciting radiocarbon-dioxide ($^{14}C^{16}O_2$) molecules at the 4.5 μm wavelength. The ultimate sensitivity limits of molecular trace gas sensing are pushed down to attobar pressures using a comb-assisted absorption spectroscopy setup. Such a result represents the lowest pressure ever detected for a gas of simple molecules. The unique sensitivity, the wide dynamic range, the compactness, and the relatively low cost of this table-top setup open new perspectives for ^{14}C-tracing applications, such as radiocarbon dating, biomedicine, or environmental and earth sciences. The detection of other very rare molecules can be pursued as well thanks to the wide and continuous mid-IR spectral coverage of the described setup.

DOI: 10.1103/PhysRevLett.107.270802 PACS numbers: 07.07.Df, 33.20.Ea, 42.62.Eh, 87.64.km

Optical Measurements of $^{14}CO_2$

- $^{14}CO_2$ transitions are shifted relative to $^{12}CO_2$
  - Allows for spectroscopic measurements of $^{14}CO_2$ in the mid-infrared
  - Natural abundance – 1.2 ppt of the total CO_2 (~400 ppm) in atmospheric samples

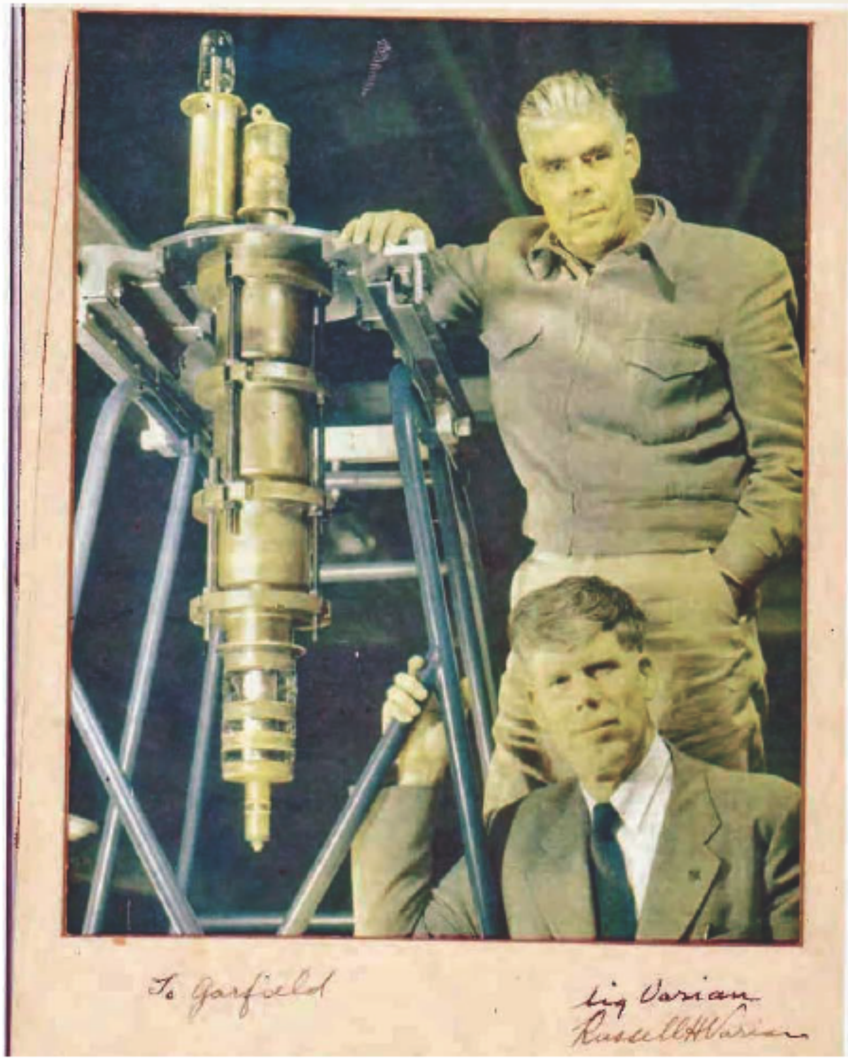


- Due to the ultralow abundance of $^{14}CO_2$ in atmospheric samples, optical detection at ambient levels has only been demonstrated by an Italian research group
- NIST has demonstrated preliminary optical detection of biogenic samples containing $^{14}CO_2$ using a significantly less complex benchtop optical method*
- Future efforts will investigate methods to reduce the detection limits of the ultra-sensitive CRDS system used in these measurements.

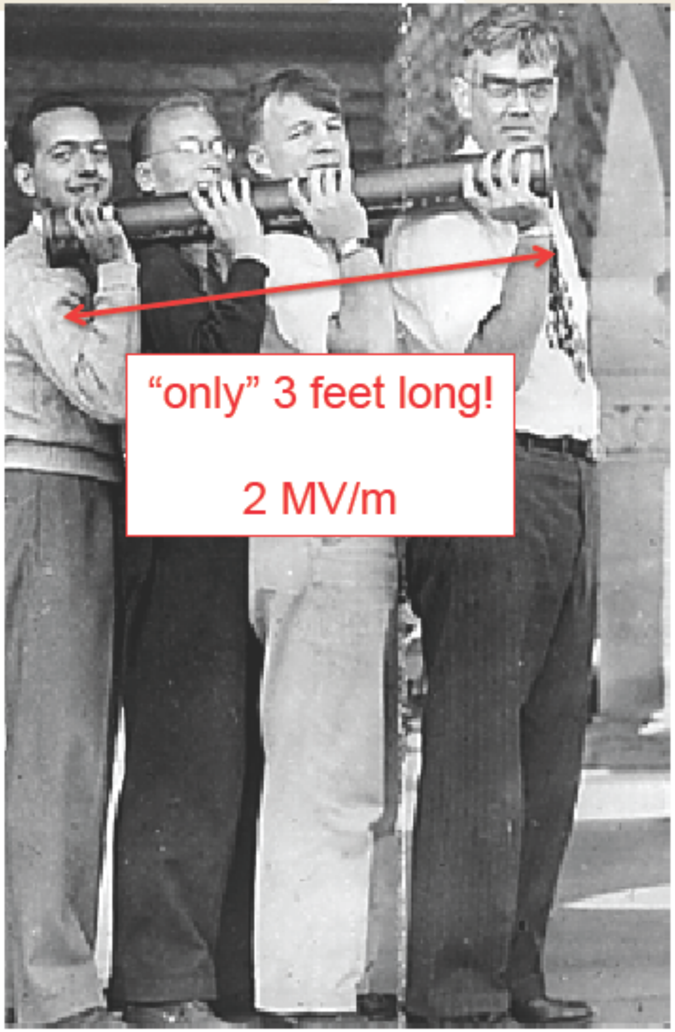
NIST

*AGU Annual Mtg. Presentation, 2015, D. A. Long

When the SLAC linac and microwave klystron were invented they were revolutionary developments



Klystron invented 1937



Microwave linac invented 1948

Shortly after lasers were invented it was suggested to use them to accelerate particles.

SLAC

Koichi Shimoda, Applied Optics 1 (1), 33 (1961)

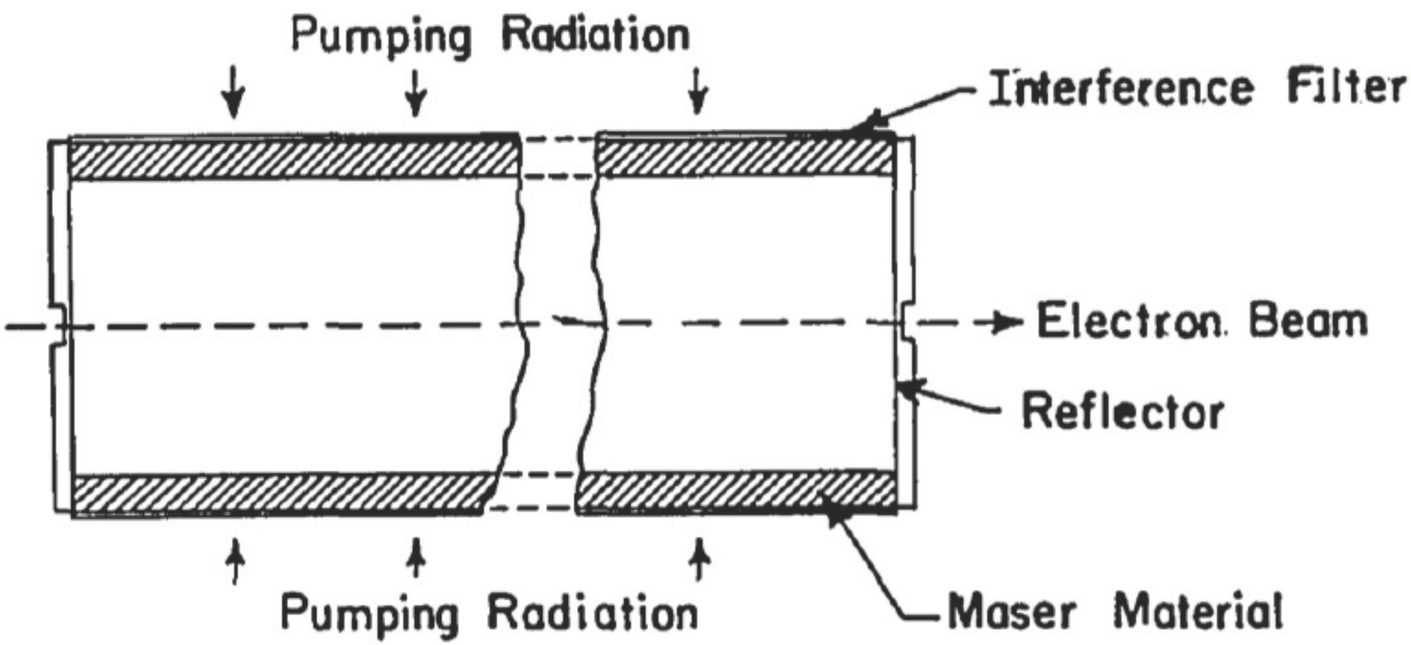
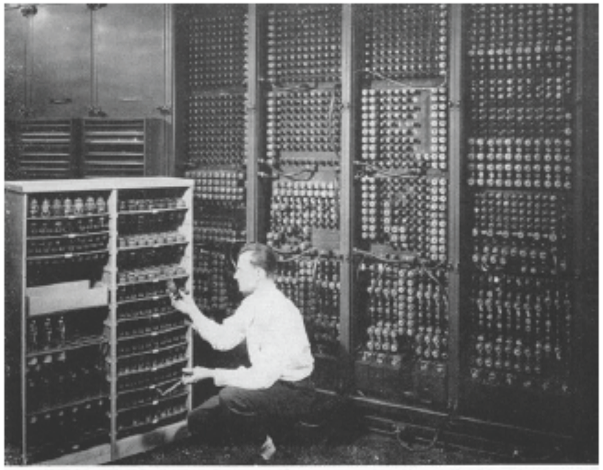


Fig. 1. Schematic diagram of an electron linear accelerator by optical maser.

Can we do for particle accelerators what the microchip industry did for computers?

ENIAC, early computer



Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

NLCTA accelerator at SLAC

smaller, affordable, faster, better

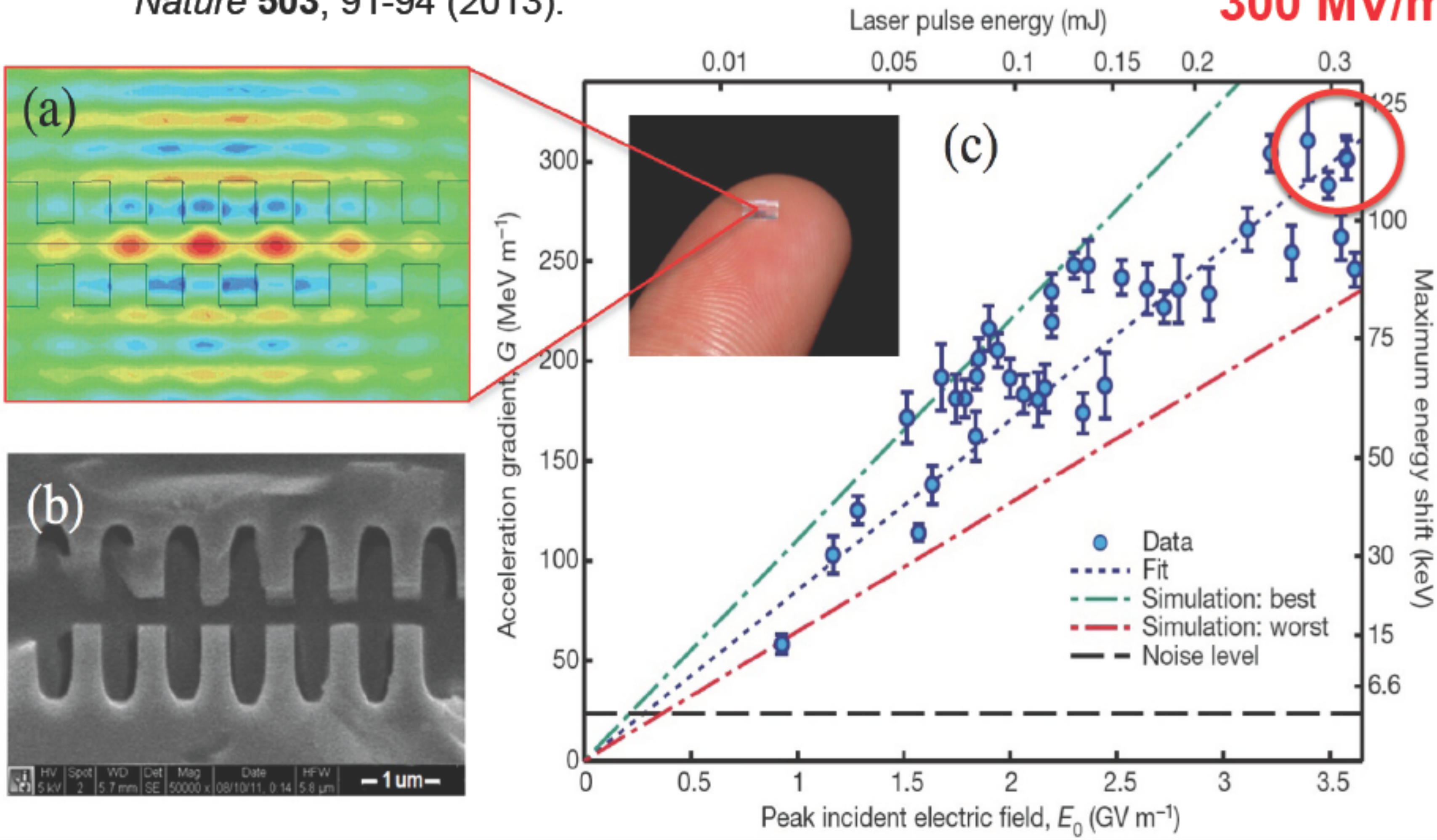
integrated circuit CPU

Micro-accelerator fabricated at Stanford

First gradients observed were 10 times higher than the main SLAC linac…

Nature **503**, 91-94 (2013).

300 MV/m



IG^{3}IS Objectives – Develop for each objective

Near-term end-to-end demonstrations (3-5 year) and,

Methodology standards (long-term implementation plans)

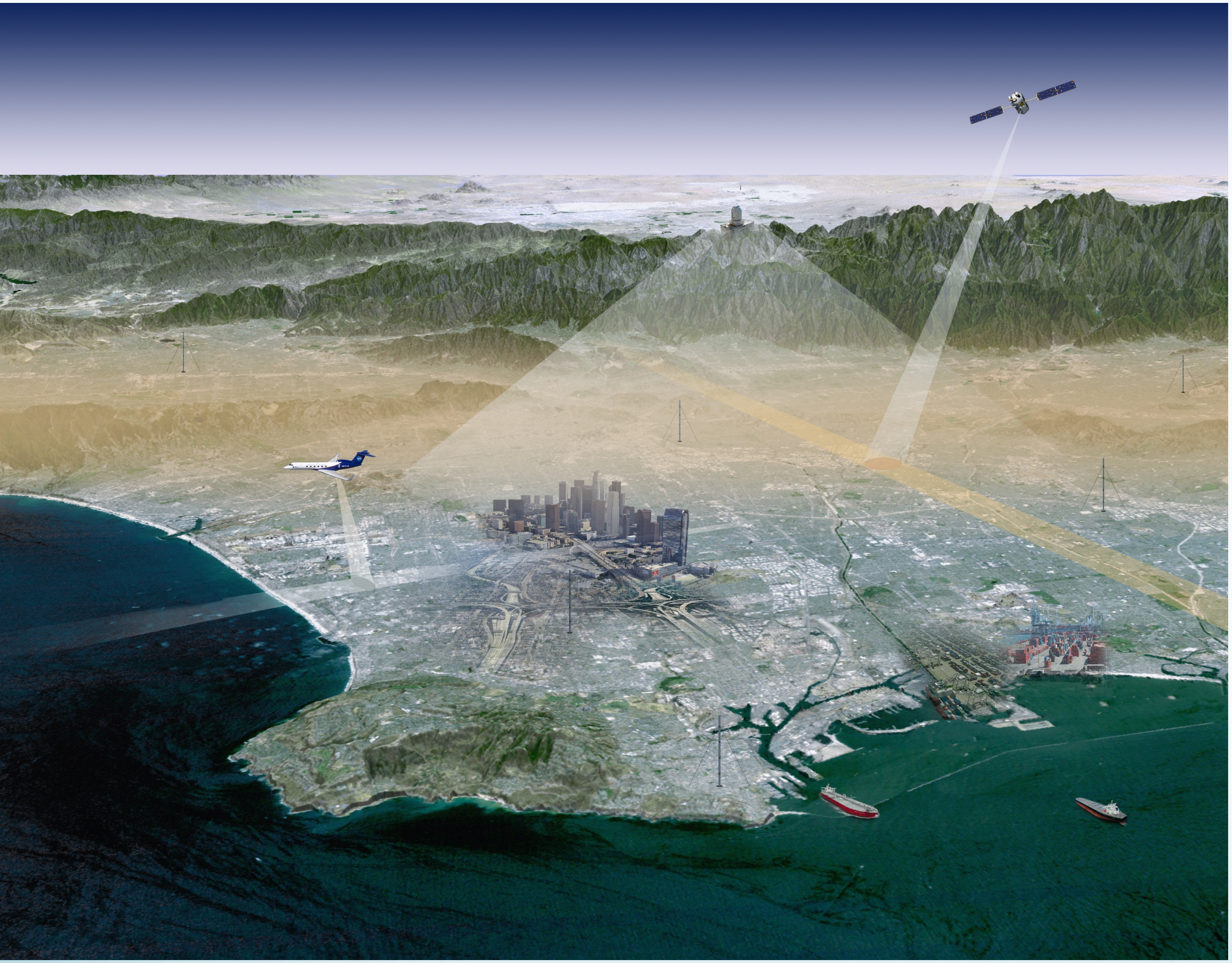
Support of Paris Agreement:

- Timely and quantified trend assessment of NDCs in support of "Global Stocktaking"
- Improved national inventory reporting by making use of atmospheric measurements for all countries

Key sub-national efforts and new mitigation opportunities:

- GHG monitoring in large urban source areas (megacities)
- Detection and quantifying large unknown CH_4 emissions

Megacity Project: Paris and Los Angeles



Carbon emissions from cities and their support systems represent the single largest human contribution to climate change.

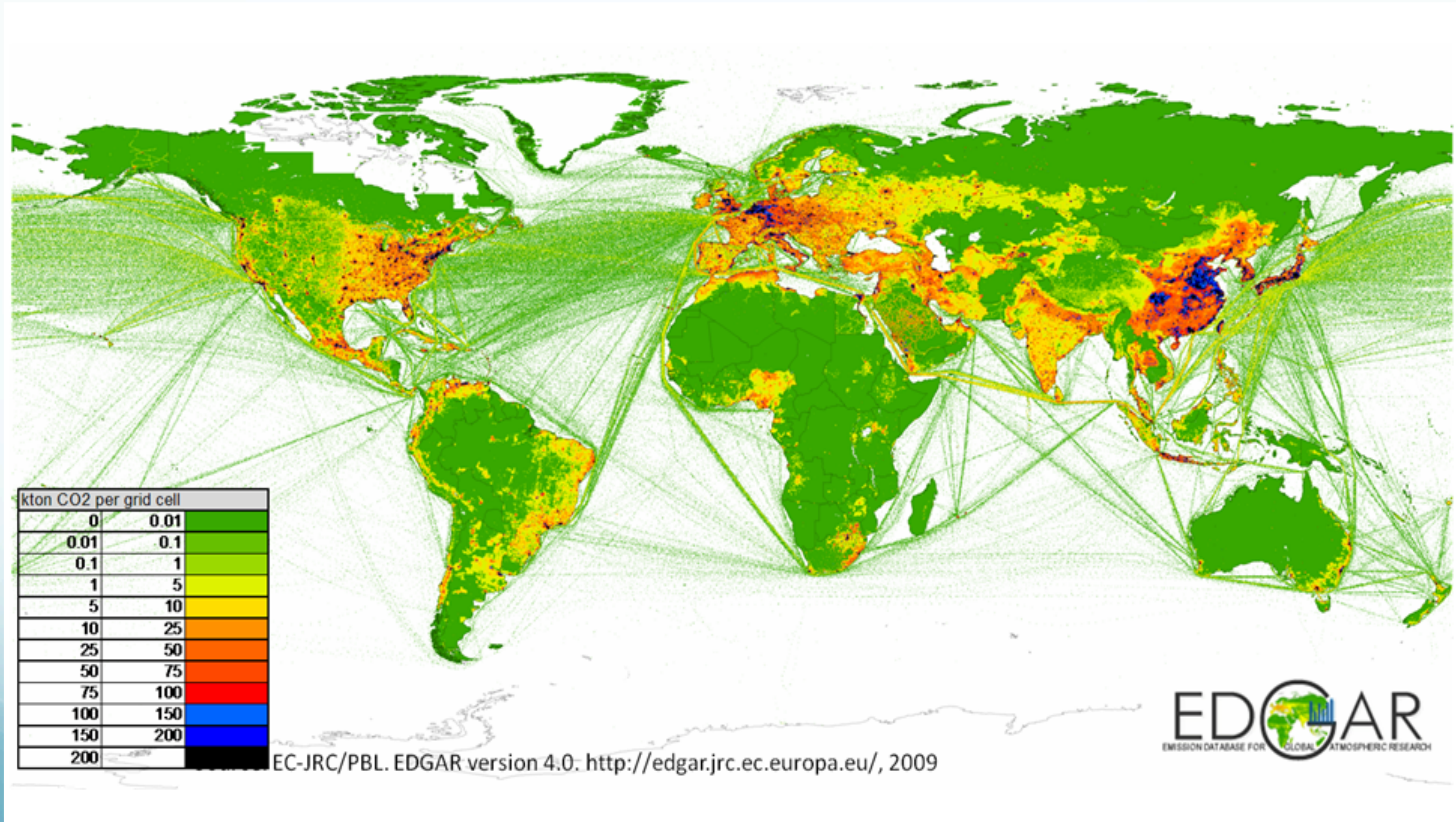
The Megacity Project provides a strategy, methodology and roadmap for an international framework to assess directly the carbon emission trends of the world's megacities.

http://megacities.jpl.nasa.gov

California Institute of Technology · City of Los Angeles · California Air Resources Board · LSCE · Scripps Institution of Oceanography UC San Diego · Earth Networks Taking the Pulse of the Planet · SigmaSpace · Berkeley Lab · Resources for the Future · Harvard · Arizona State University

Relevance: cities matter

> 70% of global fossil-fuel CO_2 (about half of that from megacities)



Source: *Cities and Climate Change: an urgent agenda*, World Bank, 2010

Cities are demonstrating the political will for climate action and increasingly possess the needed economic strength

Urgency: cities are changing rapidly

http://*www.c40cities.org*

- Both with **Stabilization**
  - Green LA Plan (2007)
    - 35% (vs 1990) by 2030
  - Paris Climate Plan (2007)
    - 25% (vs 2004) by 2020

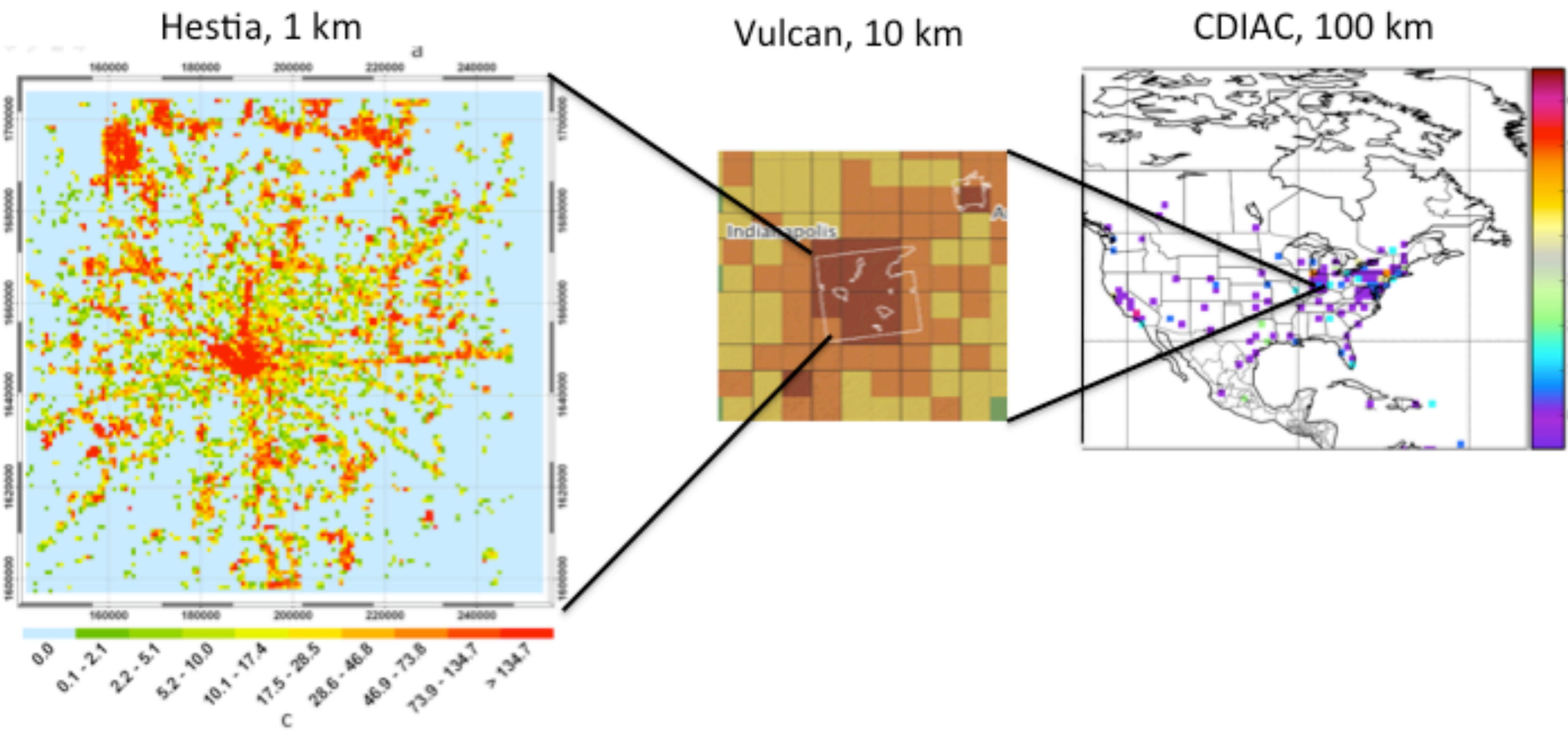
and **Growth**

- Global urbanization will ***double*** by 2050
- Explosive growth in developing megacities

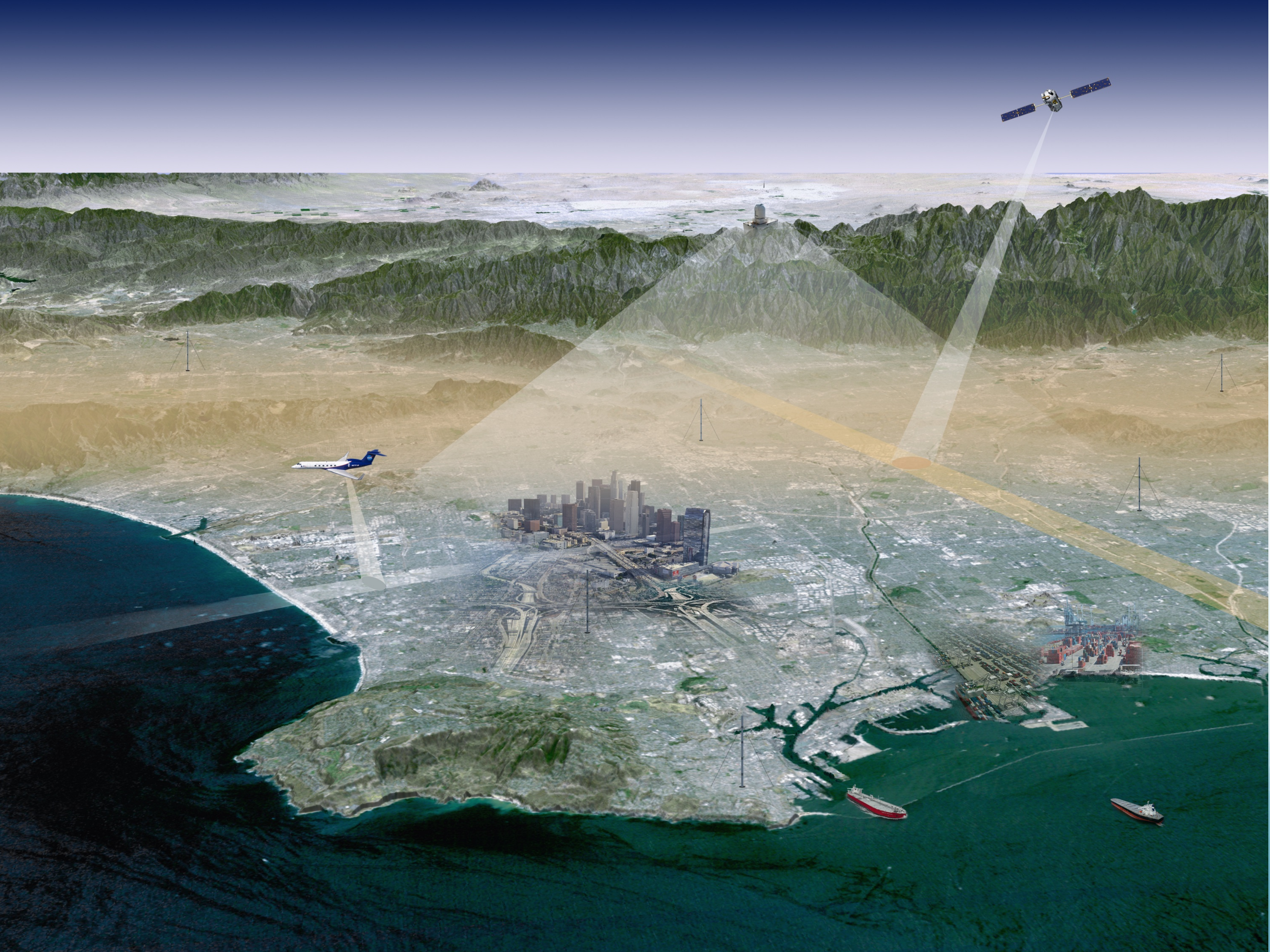
population >4%/year
emissions >10%/year

Pragmatic: monitoring cities is a tractable problem

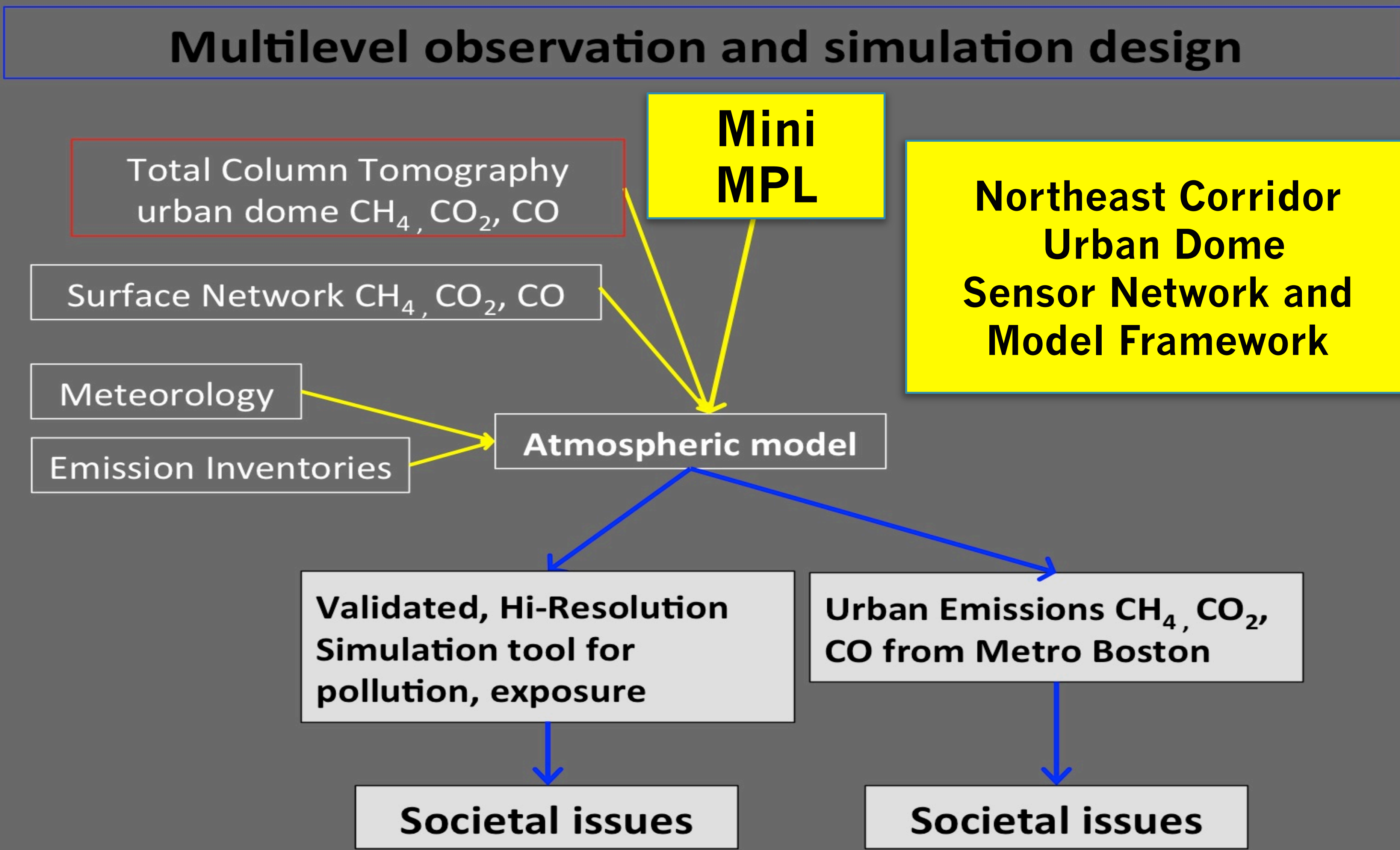
CO_2 at local (human) scales is more intense than at larger scales



Right: Gridded annual fossil fuel CO2 emissions from a medium-size city (Indianapolis) show distinct gradients at different spatial scales. Right: CDIAC 2006 emissions for the CONUS plotted on a 1° (~100 km) show avg flux 200-600 gC/m2/yr. Middle: Vulcan 2002 emissions for the ~10,000 km2 area centered on Indianapolis on a 10 km grid. Left: Hestia 2002 emissions for the urban core on a 1 km grid. The Vulcan and Hestia plots use log-normal scales (typically >20,000 gC/m2/yr).

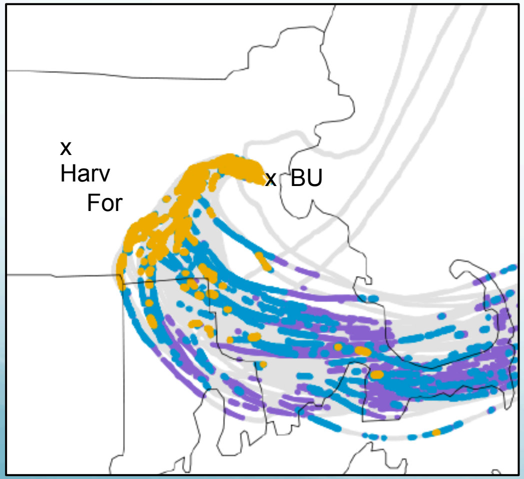


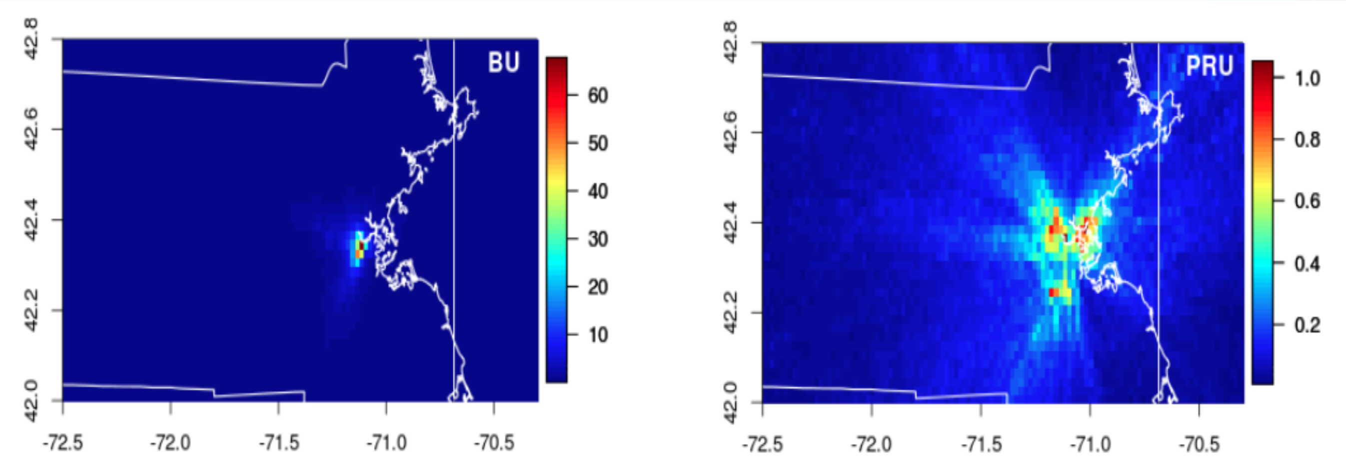
Research to Support of Emission Management: Megacity Carbon Monitoring System

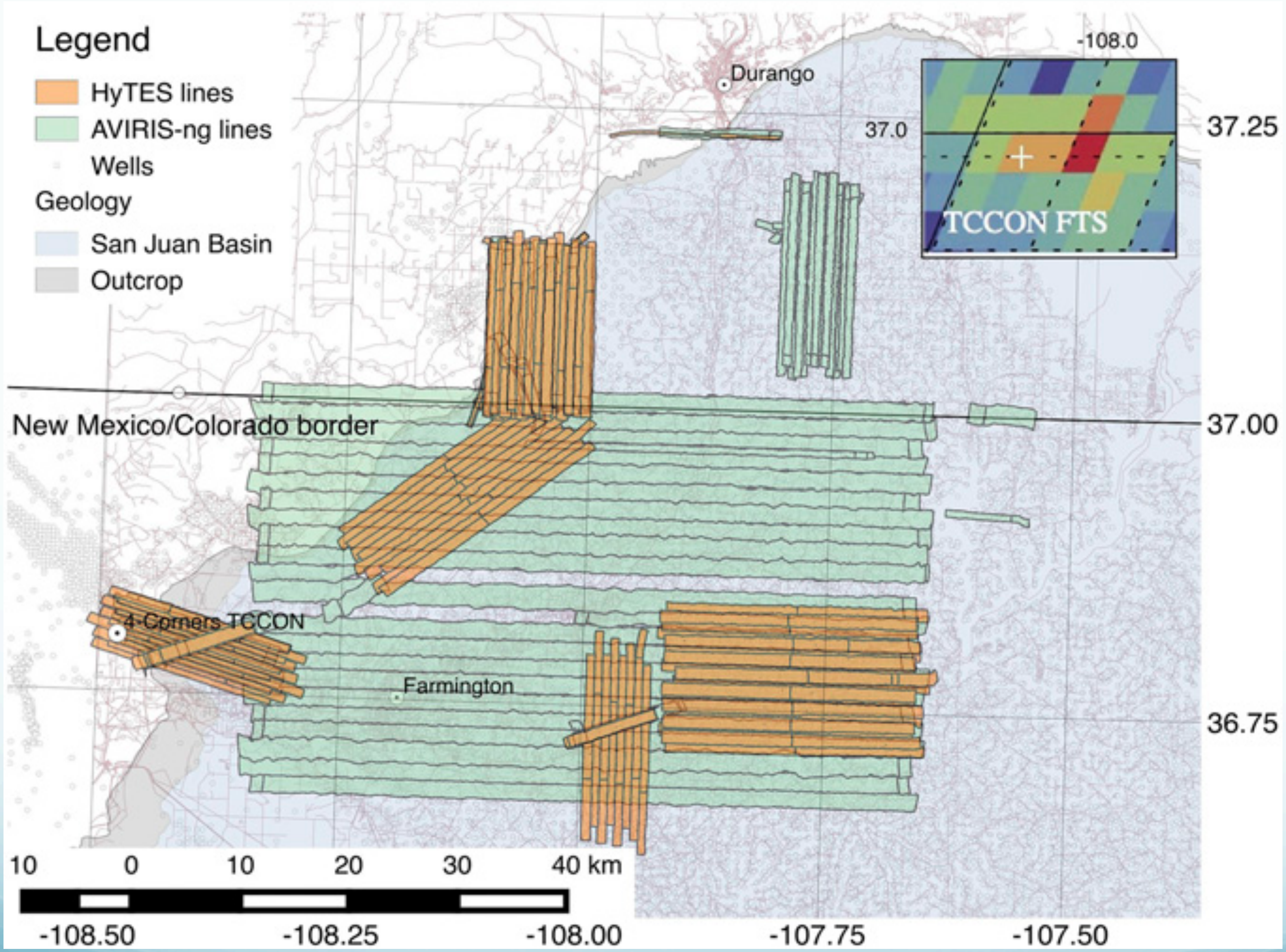


WRF-STILT Urban GHG Modeling Approach

- STILT modeling: Lagrangian Particle Dispersion Model (LPDM)
  - Compute backward trajectories and influence regions ("footprints") for measurement sites (in units of ppb/(μmoles m^{-2} s^{-1}))
  - Couple with background concentration and surface flux estimates for comparison with observations
- Weather Research and Forecasting Model (WRF) - nested domains down to 1.33 km grids
  - Intialize LPDM with winds, temperature moisture, surface pressure, and geopotential height





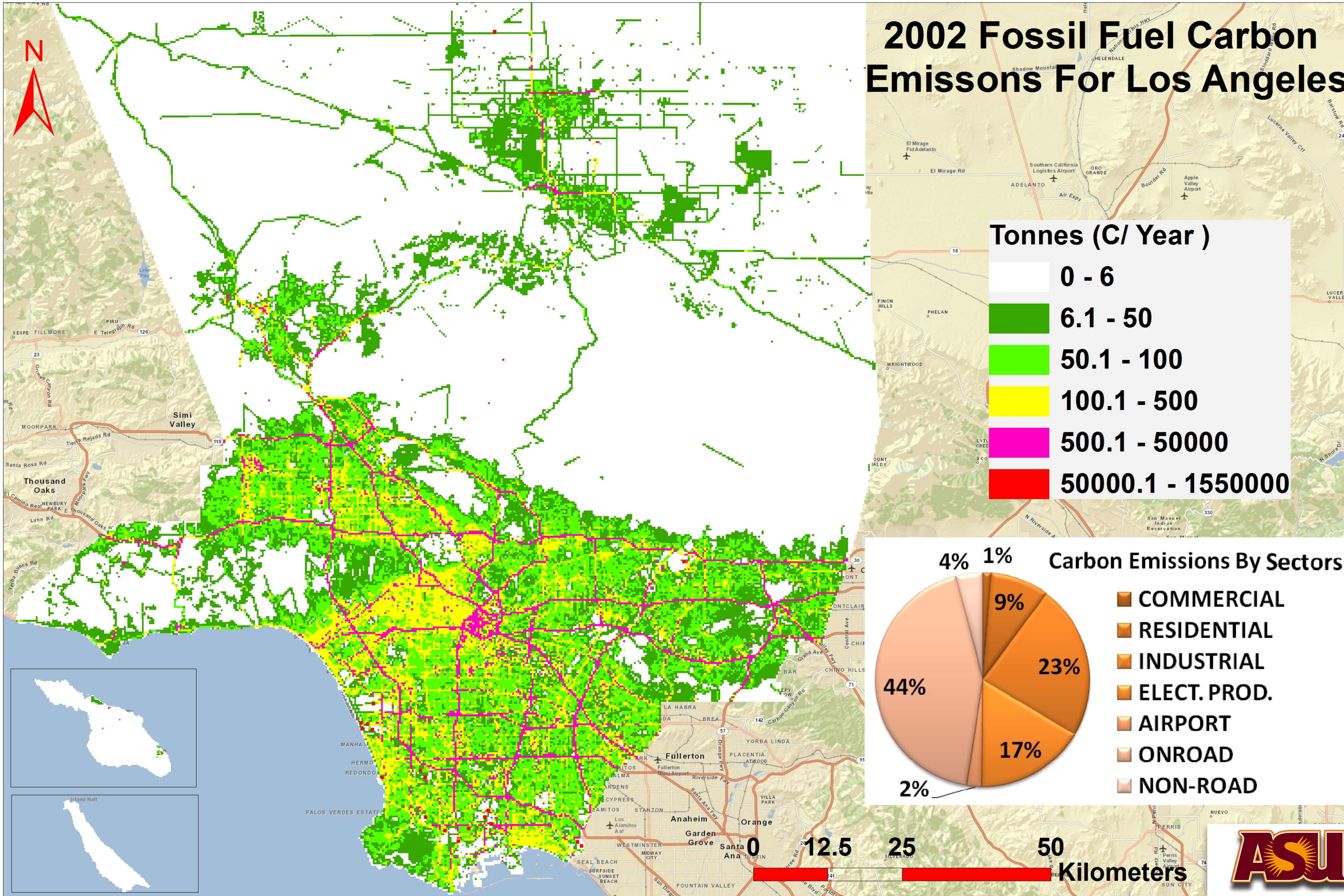


Airborne methane remote measurements reveal heavytail flux distribution in Four Corners region,

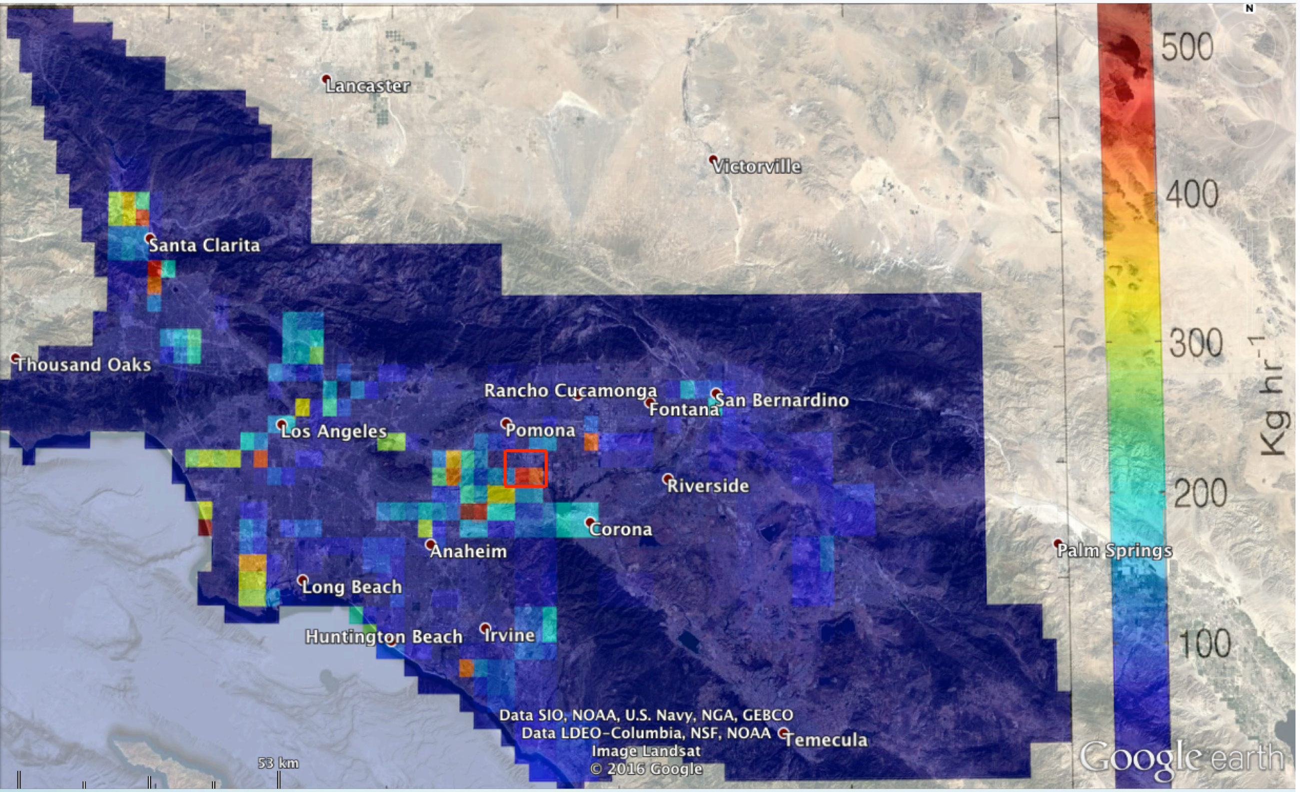
Christian Frankenberg et al, www.pnas.org/cgi/doi/10.1073/pnas.1605617113

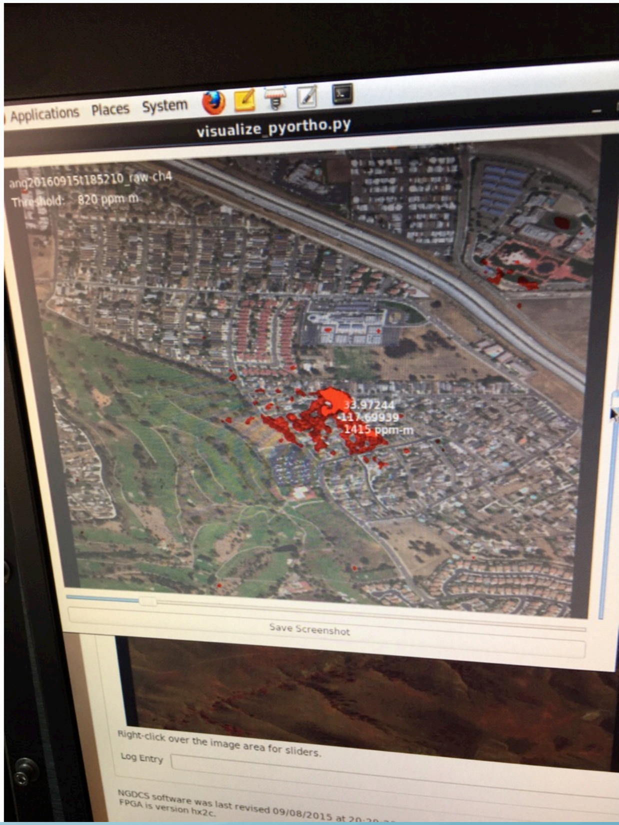
The Hestia Project:

Quantifies all fossil fuel CO_2 emissions at building and street



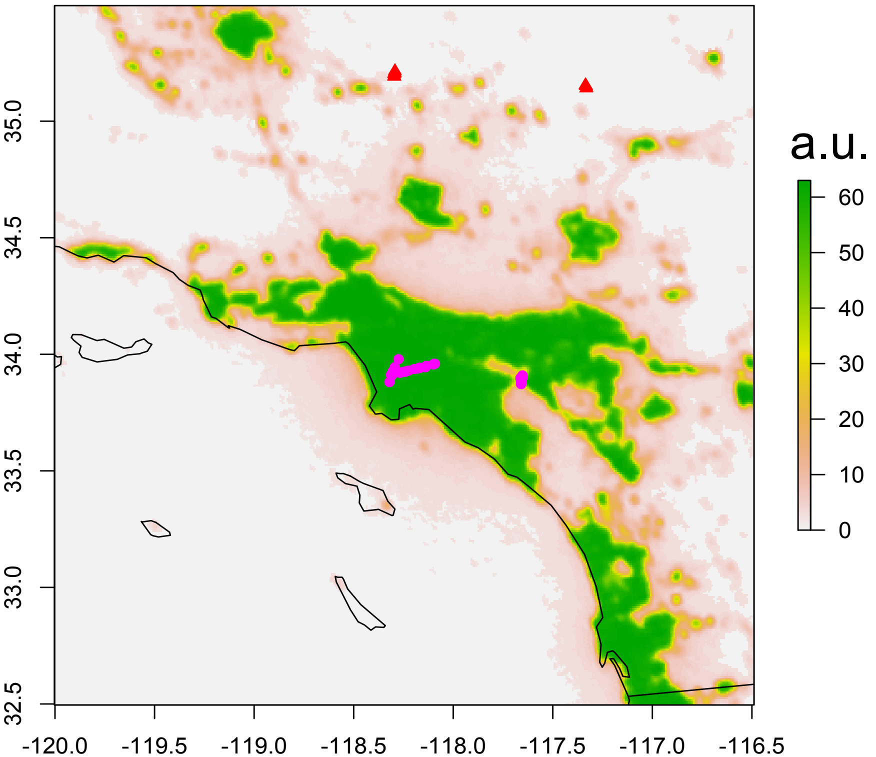
Hot off of the presses: Last week campaign in Los Angeles



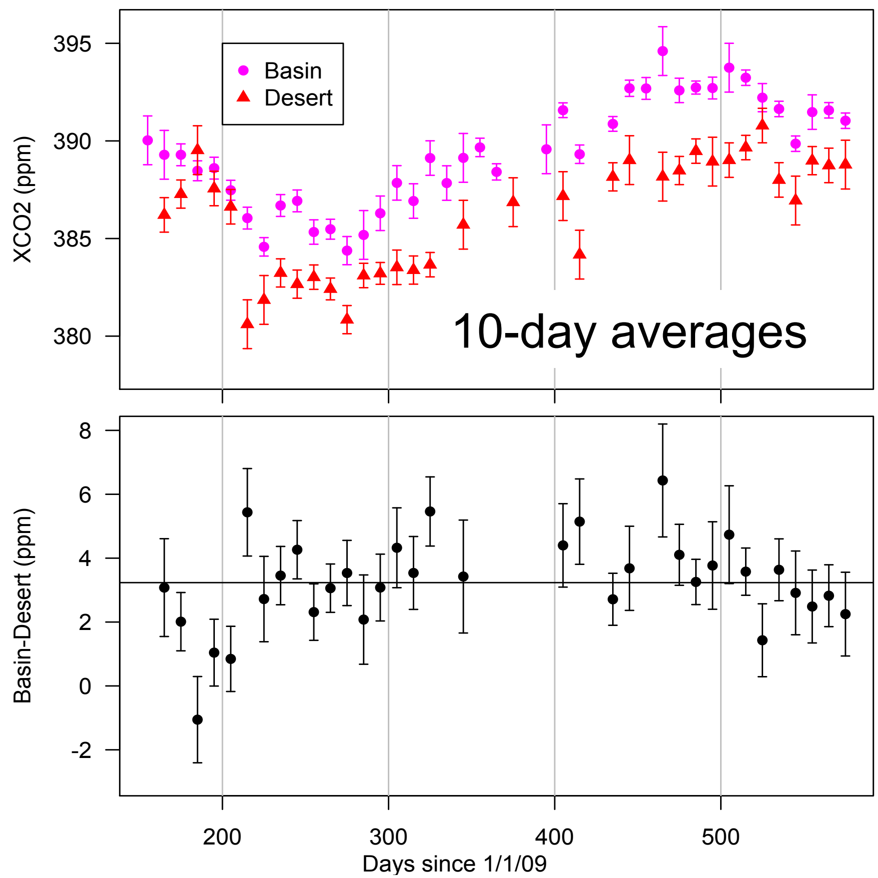


GOSAT Observations Demonstrate Space-based Detection of Megacity XCO2

Selecting observations over LA & 'Background' Location



Selected GOSAT footprint locations over LA nightlights



Kort et al., GRL (2012)

Persistent, robust enhancement = 3.2 ± 1.5 ppm

Near-term IG^3IS Objectives (3-5 year horizon)

Support of Paris Agreement:

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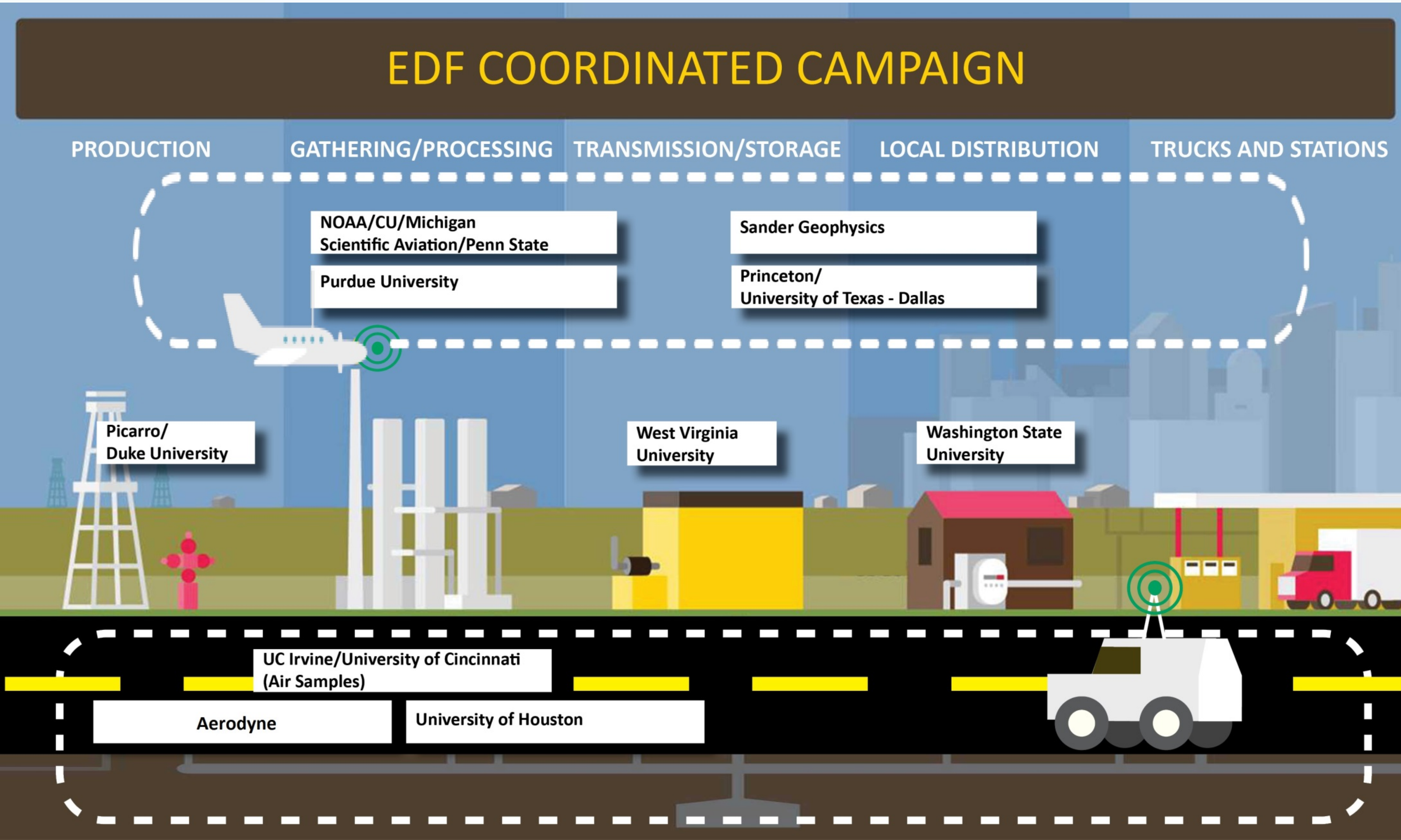
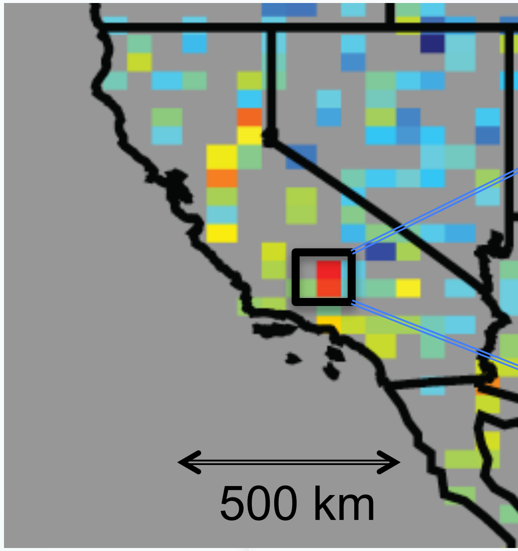
Methane from Oil and Gas Supply Chain
USA Texas (Barnett Shale) Example

Atmospheric composition plus enhanced bottom-up activity data

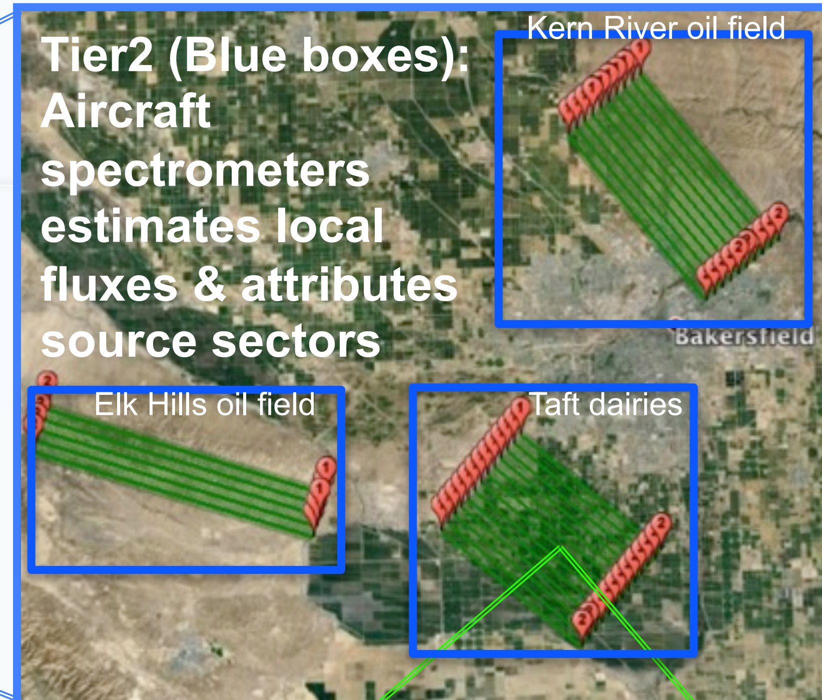


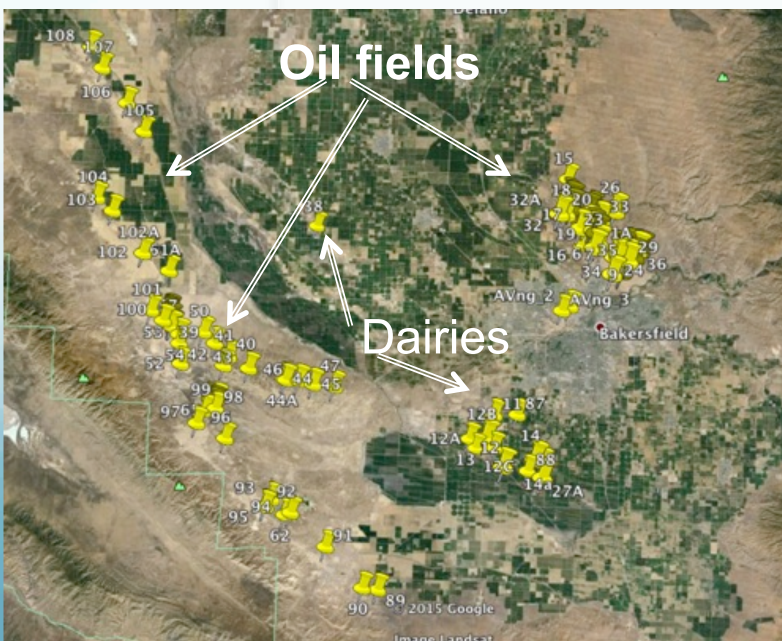
A tiered strategy for monitoring methane leaks in the US

Tier 1: Satelite detects hotspot region

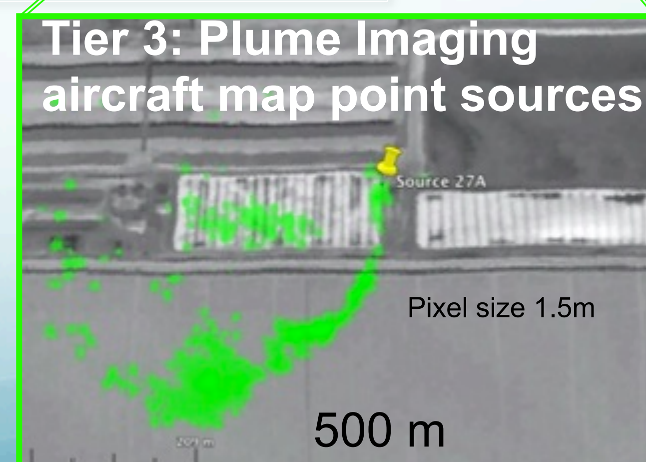


Turner et al 2015





Enhanced Activity Data



Tier 4 (not shown): Surface observations

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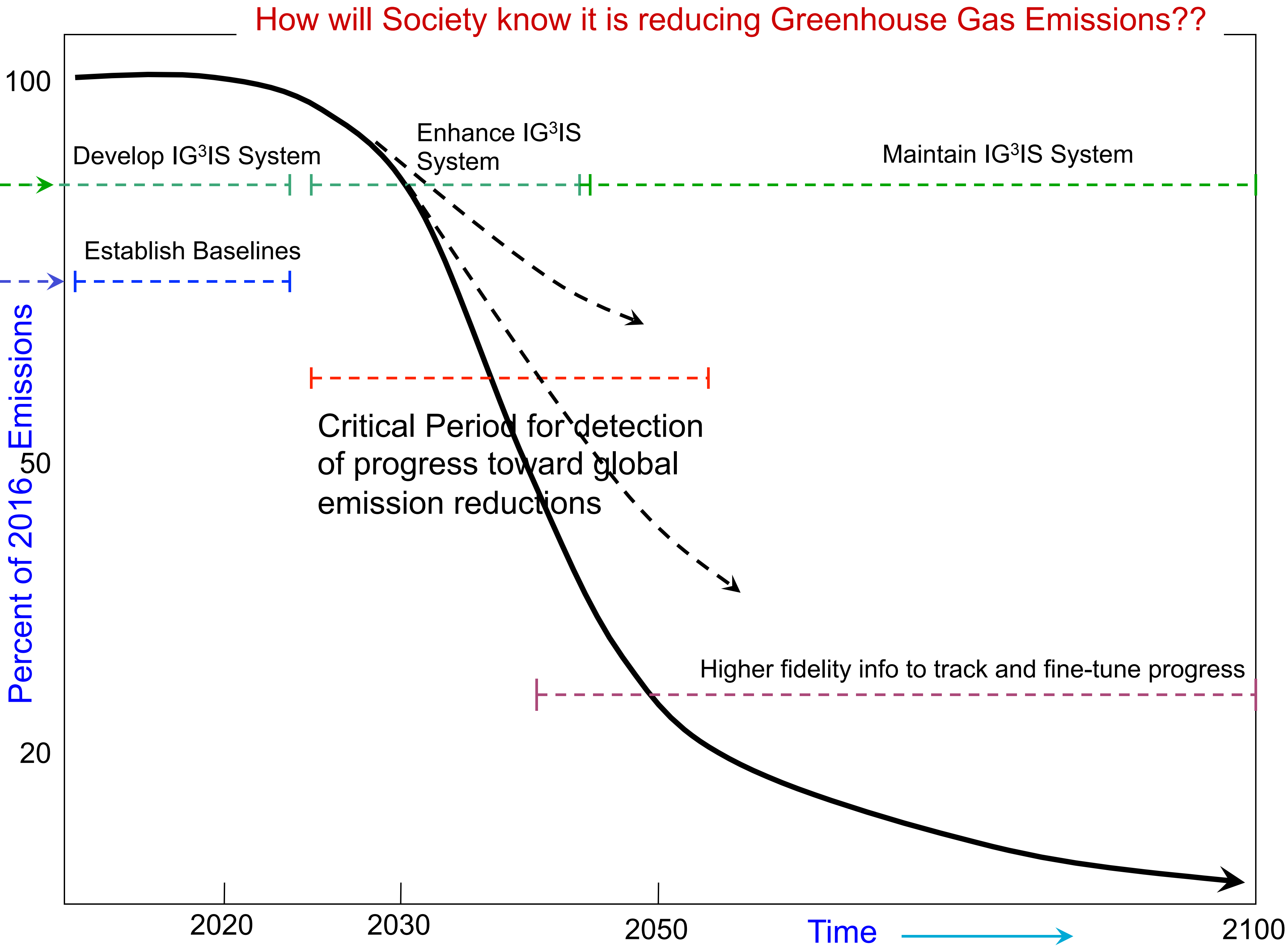
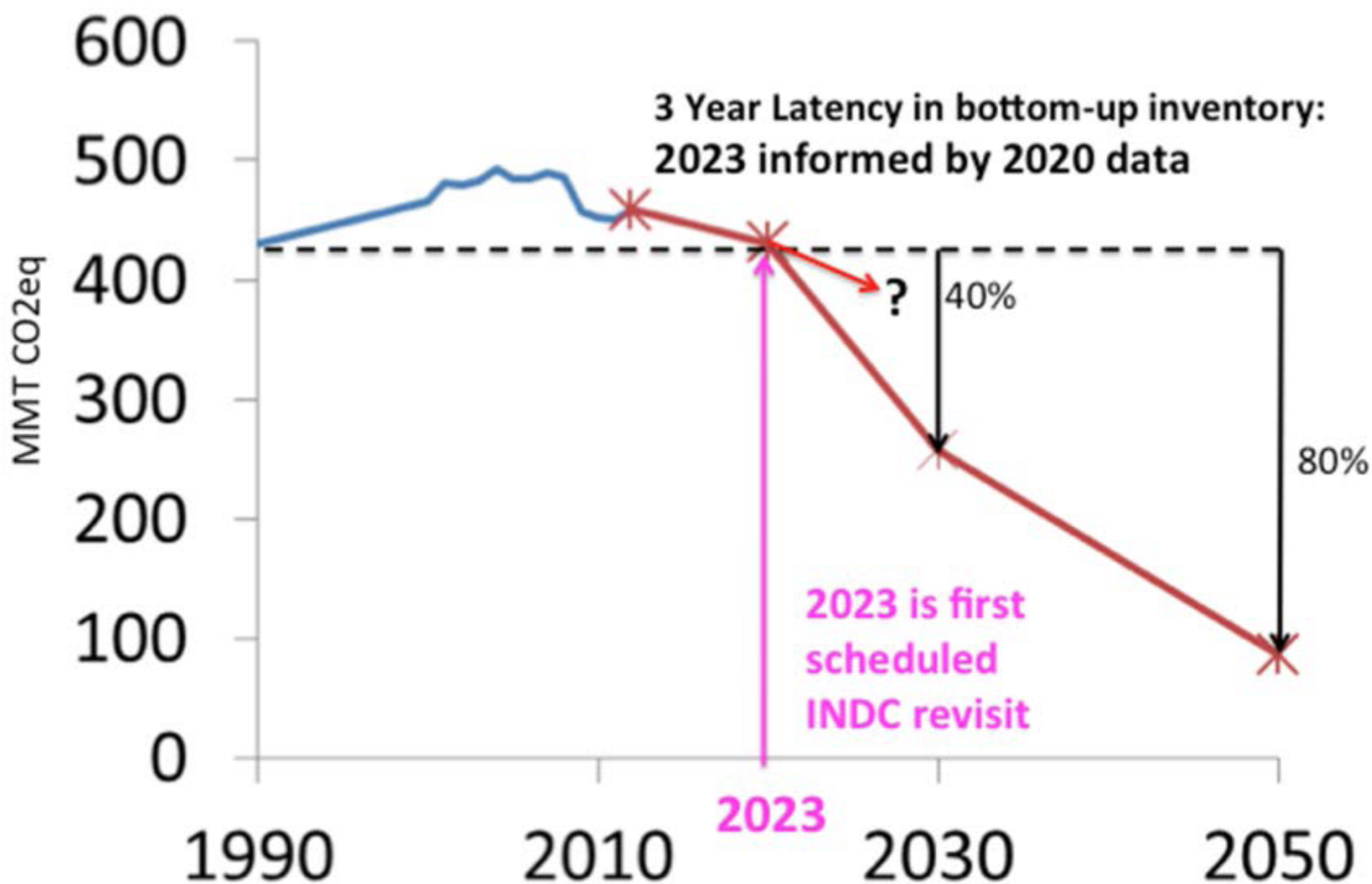


How will Society know it is reducing Greenhouse Gas Emissions??
100
50
20
Percent of 2016 Emissions
Develop IG³IS System
Enhance IG³IS System
Maintain IG³IS System
Establish Baselines
Critical Period for detection of progress toward global emission reductions
Higher fidelity info to track and fine-tune progress
2020
2030
2050
2100
Time

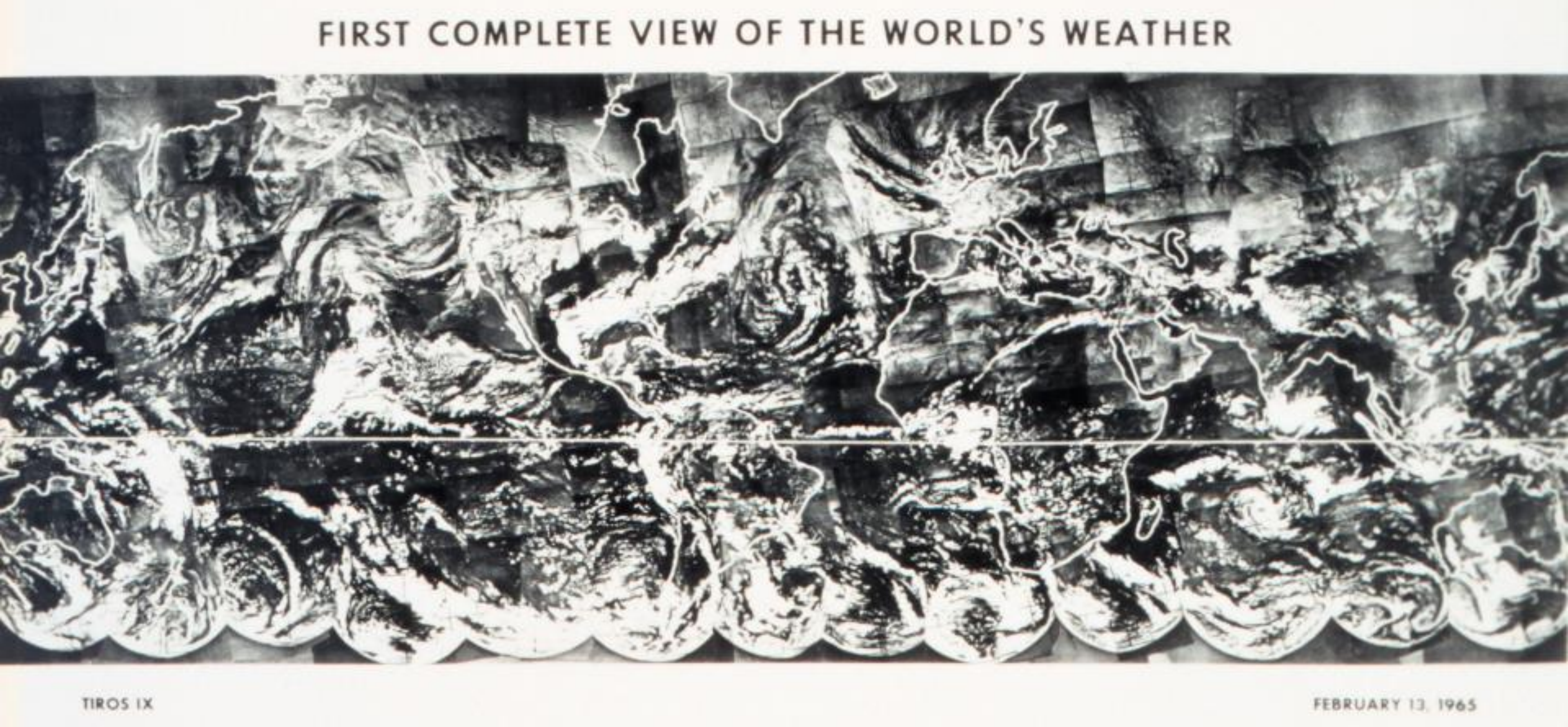
Paris Agreement "Global Stocktaking":

A combination of top-down and bottom-up methods can deliver higher-frequency, lower-latency assessments of national emission trends and with rigorously quantified uncertainties

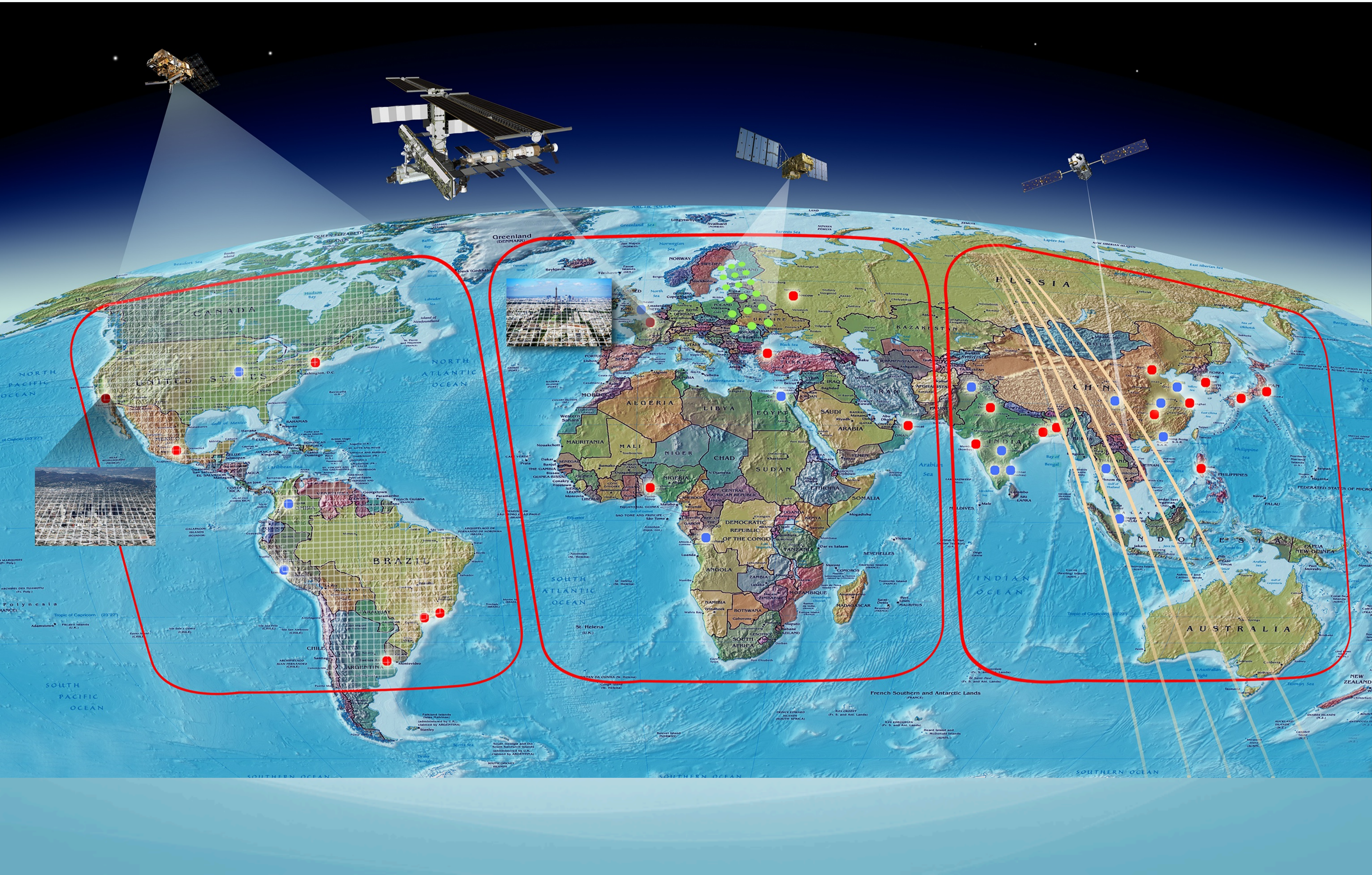


Analogous to the development of numerical weather prediction and its architecture of observations and models, IG³IS has along-term vision for “GHG weather” analyses and forecasts

The system incorporates multiple coordinated satellites in low Earth orbit (LEO) and geostationary orbit (GEO), aircraft, balloon, and ground observing systems in a true system of systems.



Future with geostationary sounders, low-Earth orbiting mapping systems and data assimilation



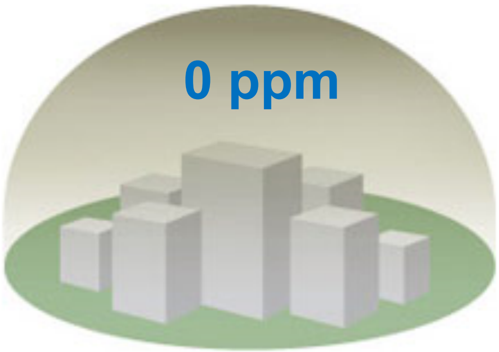
Conclusion

Build systems for future services that will meet society's evolving needs to reduce GHG emissions:

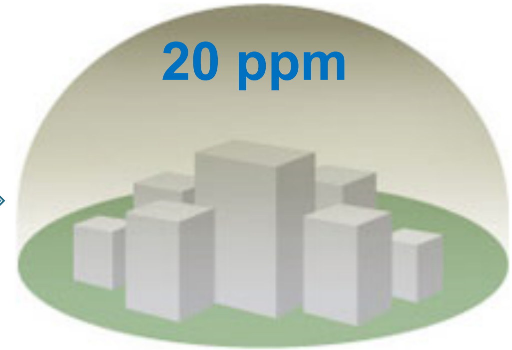
- Define the detailed implementation plan
- Prepare statement of work and budgets
- Actively entrain partners, users, and sponsors through all stages of development
- Coordinate with UNFCCC, IPCC, GCOS, GFCS, GEO Carbon Flagship, WCRP and others.

BACK UP SLIDES

GHG Concentrations and Fluxes

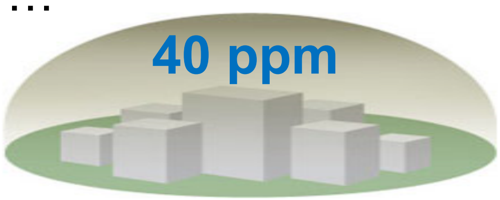


What if we start with no CO_2 difference and add a "typical" anthropogenic source …

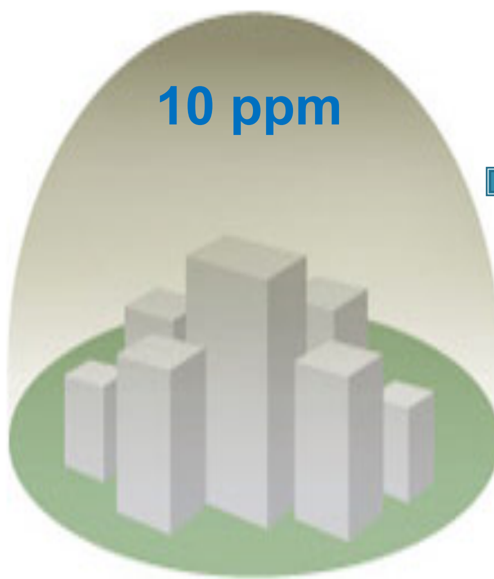


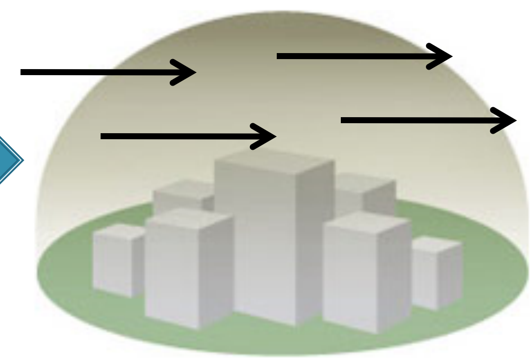
In one hour (if no advection), the CO_2 difference is up to 20 ppm.

If, instead, the boundary layer depth is half …



Or, double …



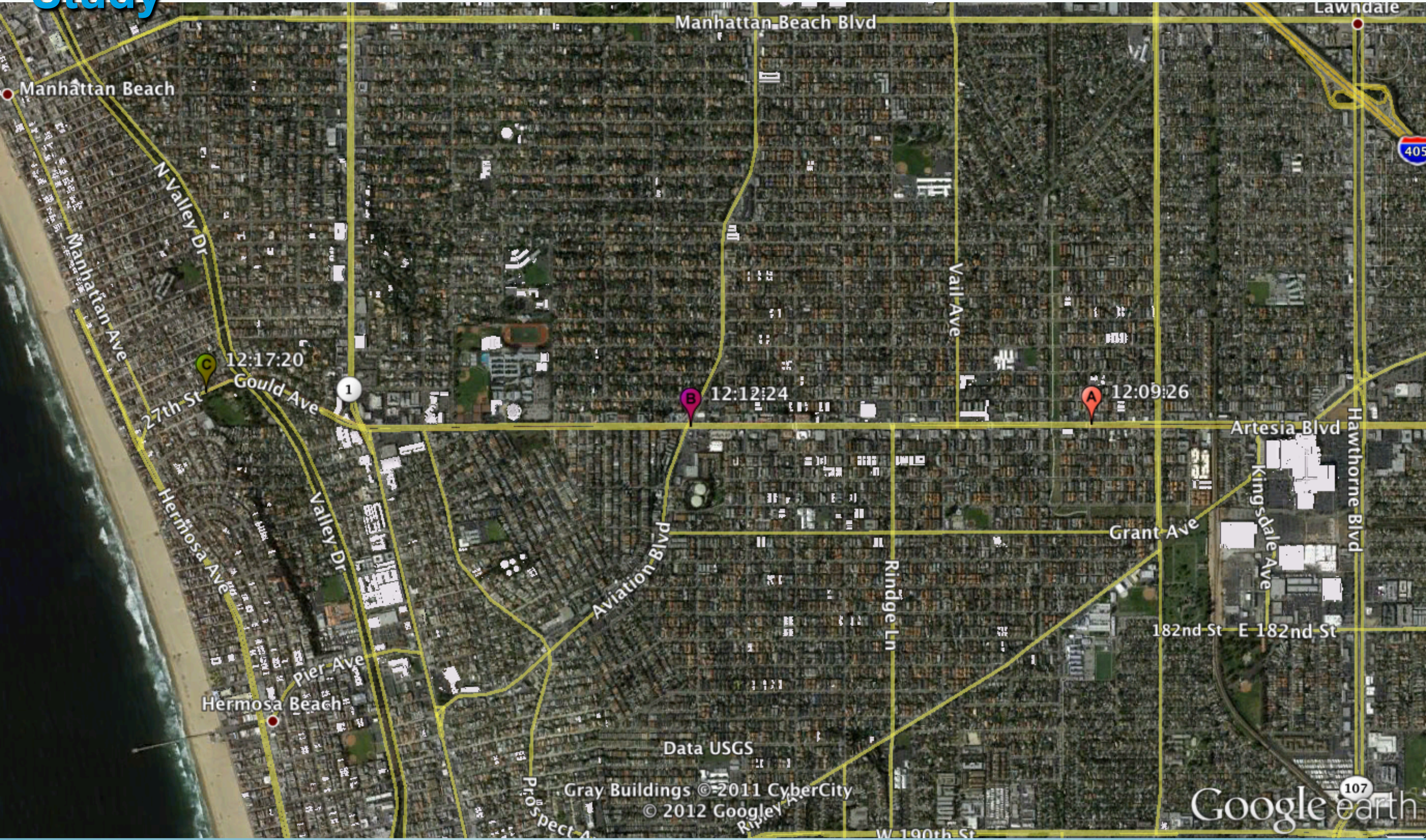


Consider advection also

170,000 mol km^{-2} hours^{-1}
PBL Depth of 400 meters

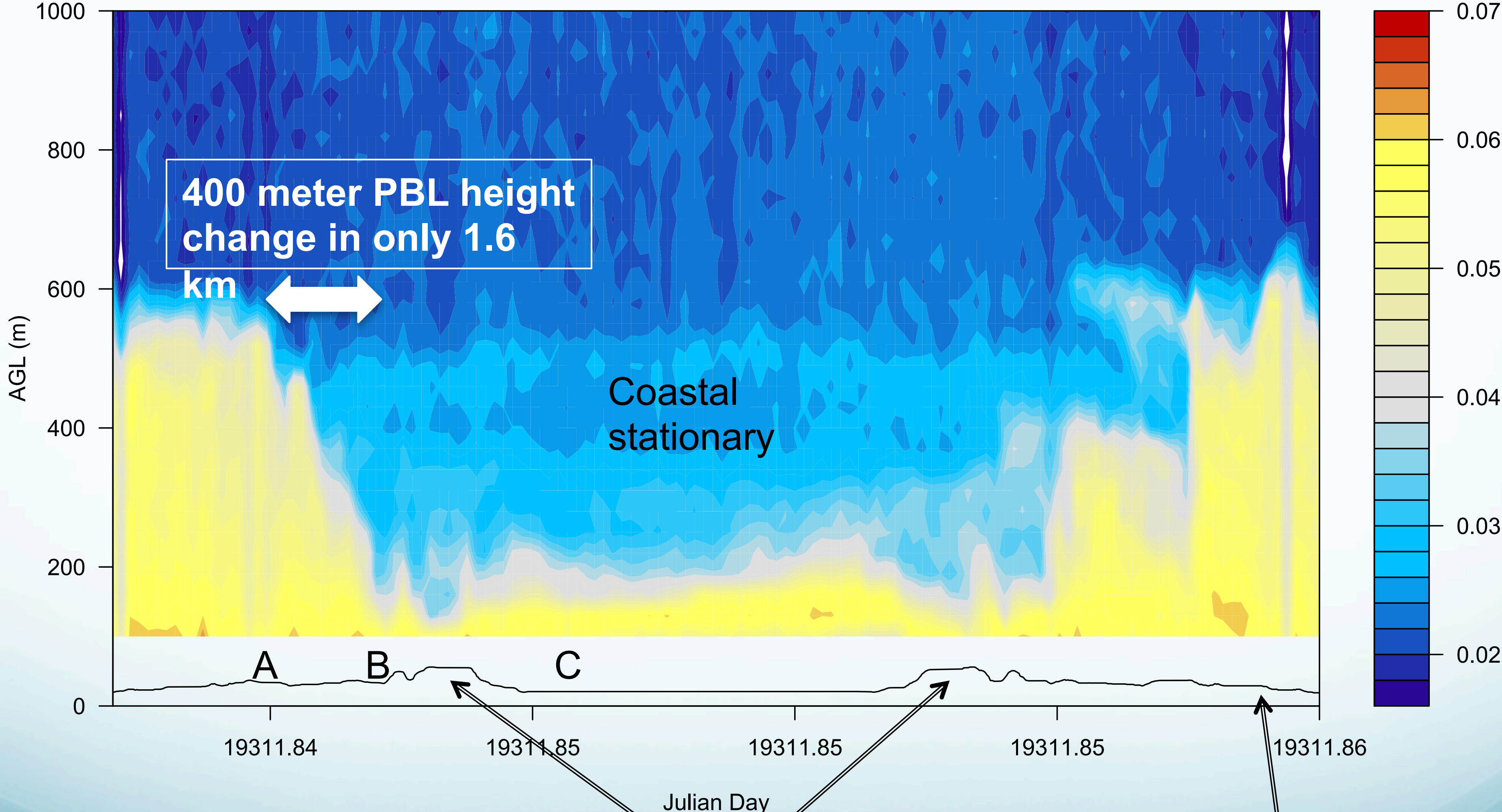

POWER
OFF
DATA
ON
USB
CAUTION
SigmaSpace

Los Angeles Megacity Monitoring: Mini MPL Mobile Study



1.63km from point A to point B

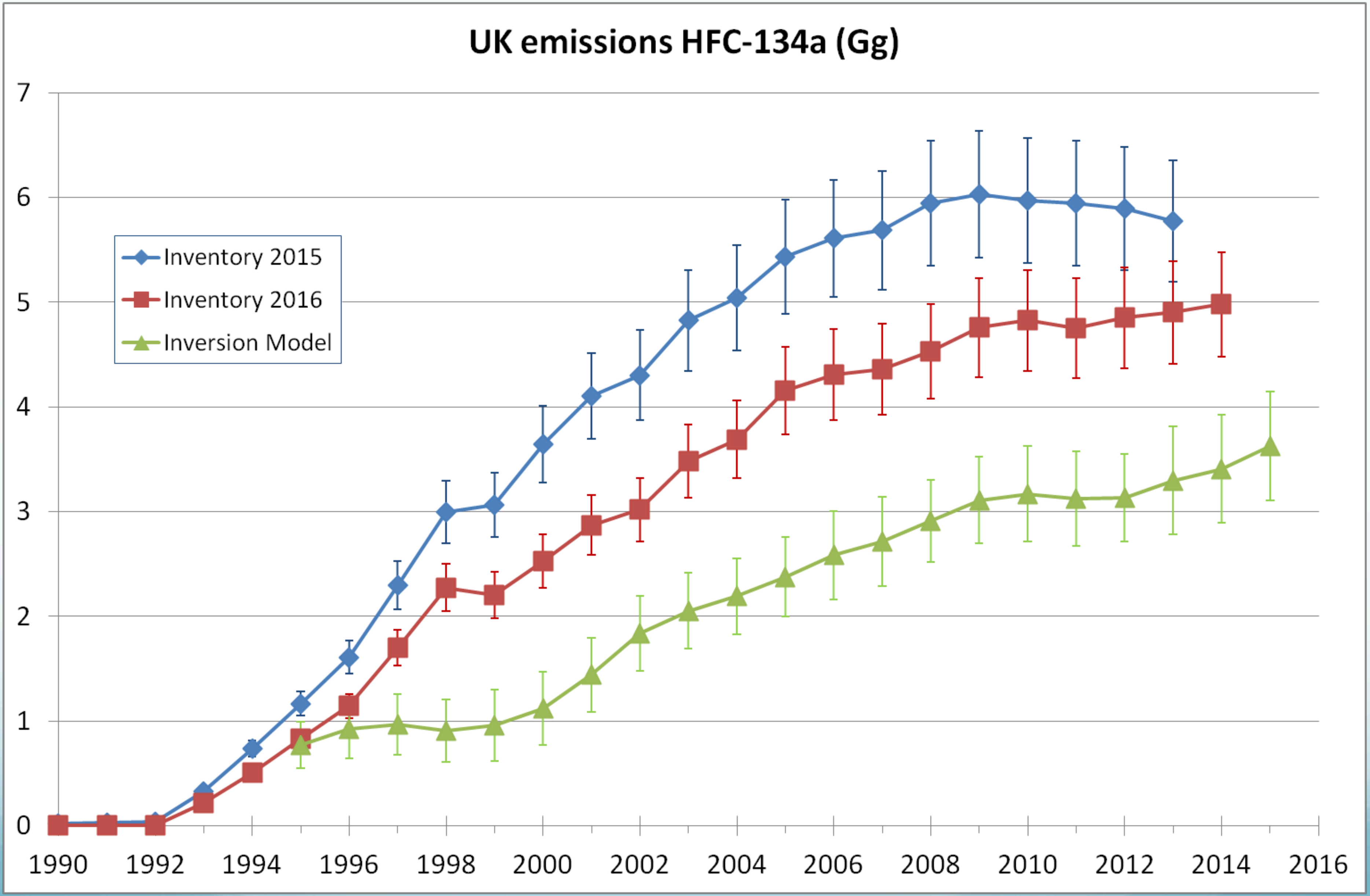
Los Angeles Megacity Monitoring: Mini MPL Mobile Study



400 meter PBL height change over a distance of 1.6 km

Small Hill- Pacific Coast Highway

Topography



UK emissions HFC-134a (Gg)
Inventory 2015
Inventory 2016
Inversion Model
0
1
2
3
4
5
6
7
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016

The IG^{3}IS Overarching Goals

Goal: Support the success of post-COP21 actions of nations, sub-national governments, and the private sector to reduce climate-disrupting GHG emissions through a sound-scientific, measurement-based approach that:

- **reduces uncertainty of national emission inventory reporting**,
- **identifies large and additional emission reduction opportunities**, and
- **provides nations with timely and quantified guidance on progress towards their emission reduction strategies and pledges (e.g., NDCs)**

Importance of Versatility: Remote-Sensing

http://www.aps.org/publications/apsnews/201601/profiles.cfm

"Nonlinear Optical Investigations of Vibrational Relaxation in Molecular Crystals"

REVIEWS OF

MODERN PHYSICS

VOLUME 31, NUMBER 3 JULY, 1959

Structure of Spectral Lines from Plasmas*

HENRY MARGENAU AND MARVIN LEWIS

Yale University, New Haven, Connecticut

CONTENTS

I. INTRODUCTION

RESEARCH on line broadening, though often regarded as pedestrian and unlikely to lead to new fundamental insights, is nonetheless inspired by a vision. One dreams that in a distant star or in some other inaccessible region filled with matter a few atoms, perhaps hydrogen atoms, emit lines whose structure can be analyzed in terrestrial laboratories. These lines carry in many cases information we have already learned to understand: red shifts revealing masses, Doppler shifts revealing motions, and sometimes Doppler widths revealing temperatures. It is clear that in principle all physical properties of the medium containing the radiating atoms are somehow reflected in the line structure, since they affect the forces between the radiating atom and its neighbors, the distances over which these forces are exerted, and the times during which they act. One hopes, therefore, that when the language of the spectral lines has been fully learned, a radiating atom in a distant material environment can serve as a noninterfering probe conveying significant data regarding pressure, temperature, or, more generally, the distribution of molecular speeds, and states of ionization in the surrounding medium. Such hope is now far from fulfillment, and this article attempts but a modest contribution to its realization.

* Work supported by the Air Force Office of Scientific Research.

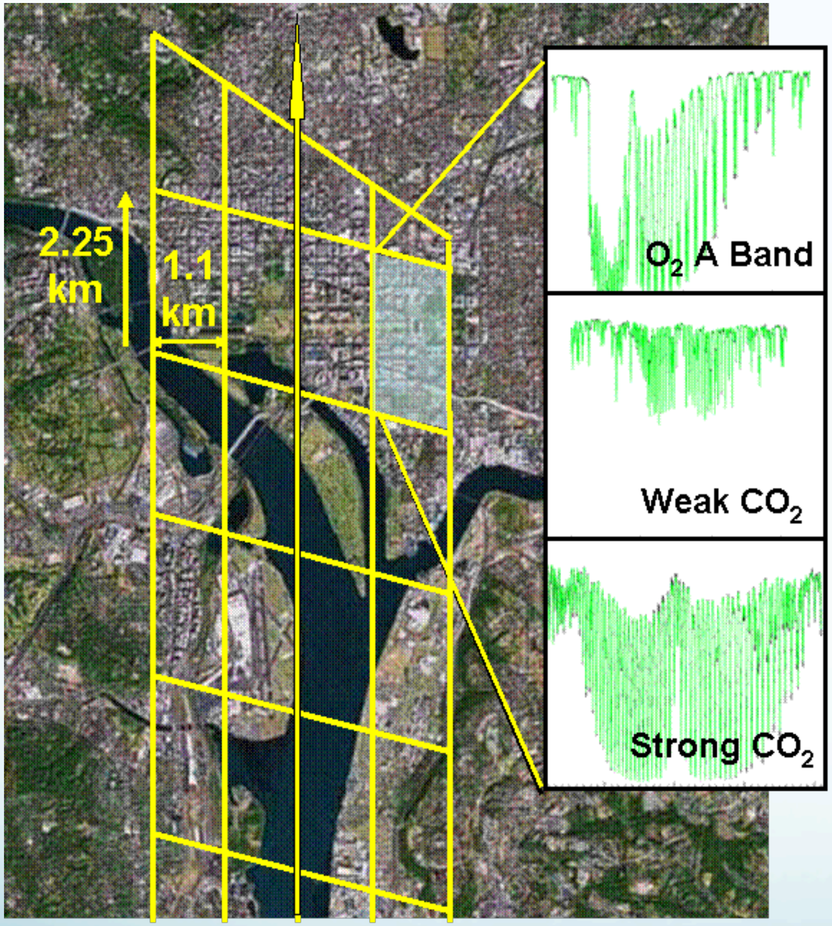
I. INTRODUCTION

RESEARCH on line broadening, though often regarded as pedestrian and unlikely to lead to new fundamental insights, is nonetheless inspired by a vision. One dreams that in a distant star or in some other inaccessible region filled with matter a few atoms, perhaps hydrogen atoms, emit lines whose structure can be analyzed in terrestrial laboratories. These lines carry in many cases information we have already learned to understand: red shifts revealing masses, Doppler shifts revealing motions, and sometimes Doppler widths revealing temperatures. It is clear that in principle all physical properties of the medium containing the radiating atoms are somehow reflected in the line structure, since they affect the forces between the radiating atom and its neighbors, the distances over which these forces are exerted, and the times during which they act. One hopes, therefore, that when the language of the spectral lines has been fully learned, a radiating atom in a distant material environment can serve as a noninterfering probe conveying significant data regarding pressure, temperature, or, more generally, the distribution of molecular speeds, and states of ionization in the surrounding medium. Such hope is now far from fulfillment, and this article attempts but a modest contribution to its realization.

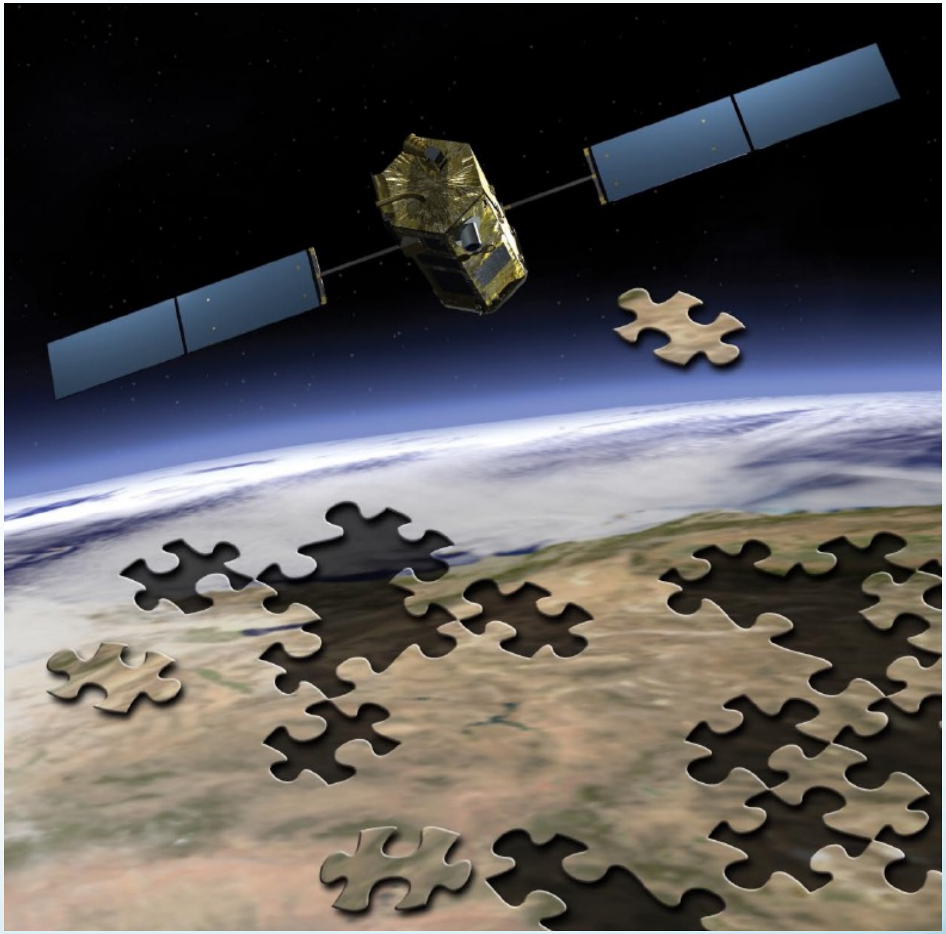
ACS Symposium: Vibrational Spectroscopy as a Probe of Biomolecular Structure and Dynamics

2007 ACS Symposium to honor the career of my Ph.D. Advisor
Prof. Robin Main Hochstrasser http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3677431/

Orbiting Carbon Observatory (OCO-2) Observations of Reflected NIR Sunlight



Mission strategy optimized to deliver accurate, global XCO2

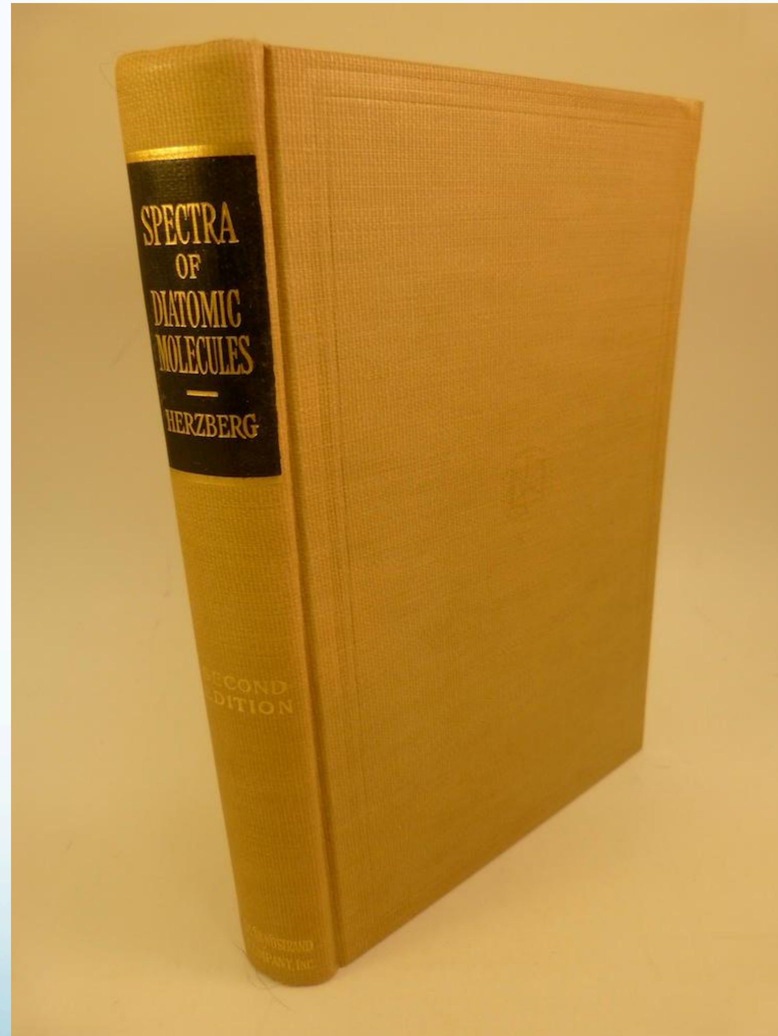


Deliver data to characterize and quantify the "missing" terrestrial carbon sink

Quantum mechanical details of the spectral lineshapes for CO_2 and O_2
to understand the macroscopic details of Earth's carbon cycle

Gerhard Herzberg

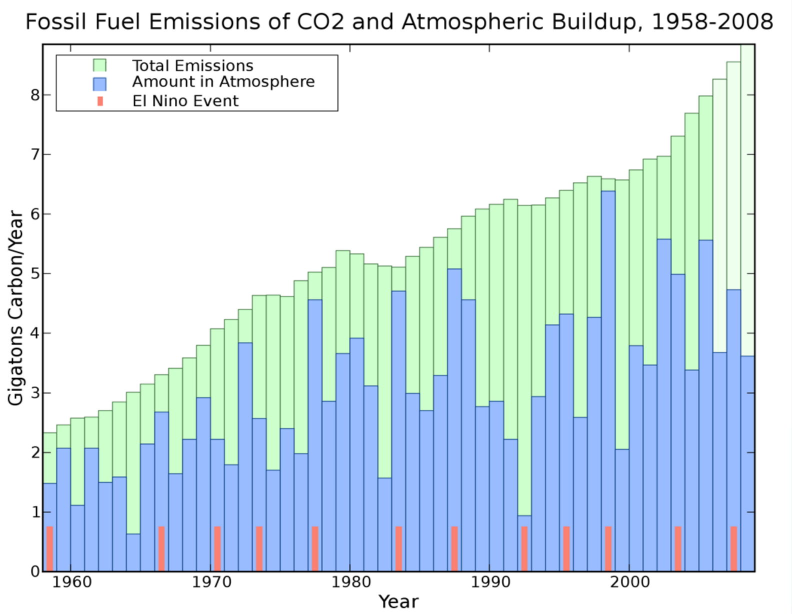
Spectra of Diatomic Molecules



Physical chemists thought we knew everything about the spectra of diatomic molecules

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.