Theme 1: Tracking Greenhouse Gases and Understanding Carbon Cycle Feedbacks

Take Home Messages

- We are creating an unassailable and well-documented record of greenhouse gases.
- We try to help society deal with the climate problem:
  - *Create a quantitative record of climate forcing.*
  - *Quantify and diagnose the response of the natural carbon cycle and greenhouse gas budgets to climate change.*
  - *Evaluate potential "surprises" and give early warning if warranted.*
  - *Support mitigation by providing objective and transparent verification of emissions.*
- Close relationships between measurers and modelers have kept us at the forefront of carbon science and are crucial to continued success.
- GMD anchors the global and US atmospheric carbon observing network. We have established ongoing comparisons with all of the major laboratories. We rely on partnerships with other labs and institutions.
- We have just begun to reap the scientific rewards of our investment in North American monitoring – multiple-species analysis will provide critical process constraints and enable improved source attribution.

"Science-driven monitoring of the atmosphere, responding to societal needs"

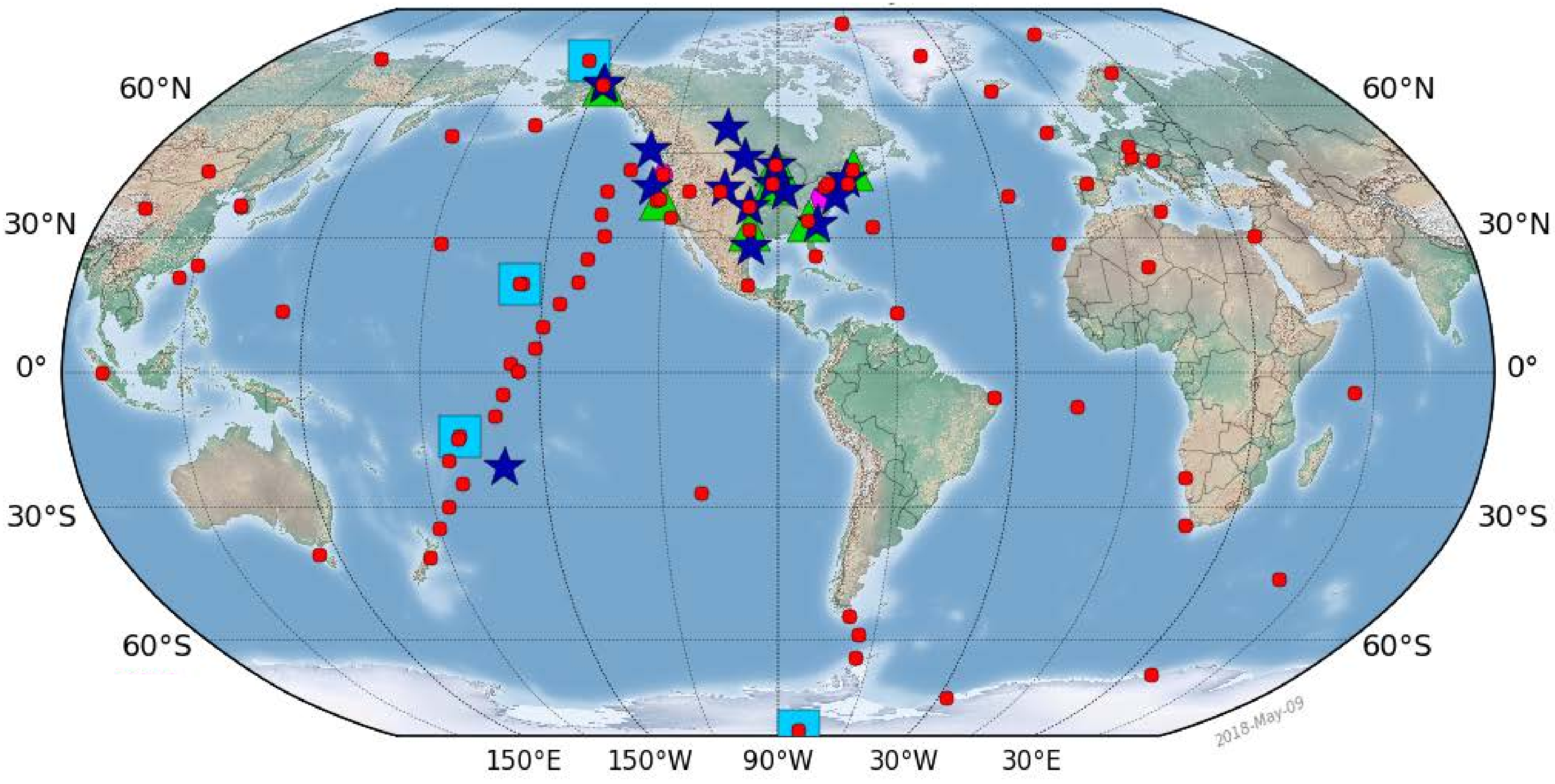
Outline

- Tracking Greenhouse Gases at the Global Scale
- Understanding Carbon Cycle Feedbacks
- Satellite Retrieval and Model Evaluation
- Monitoring Greenhouse Gases in the Upper Atmosphere
- Intensive Field Campaigns and Capacity Building
- Looking Forward

Tracking Greenhouse Gases at the Global Scale

Mauna Loa Observatory: Photograph by Forrest Mims III

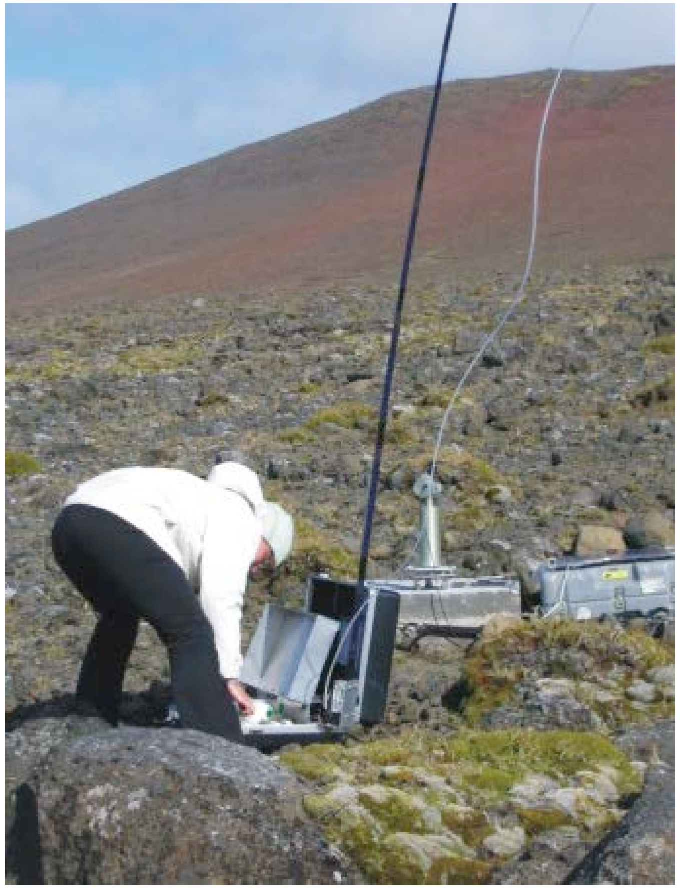
NOAA Global Greenhouse Gas Reference Network

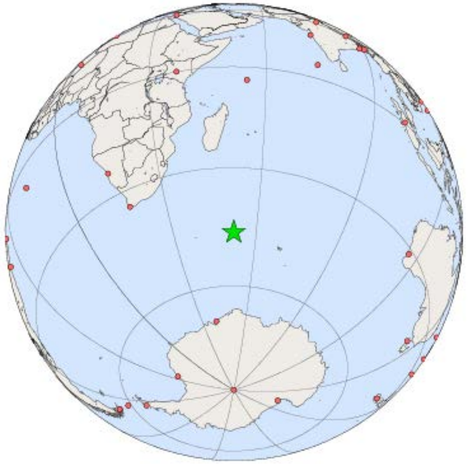


- ★ Aircraft
- ● Surface Continuous
- ▲ Tower
- ■ Observatory
- ● Surface Discrete

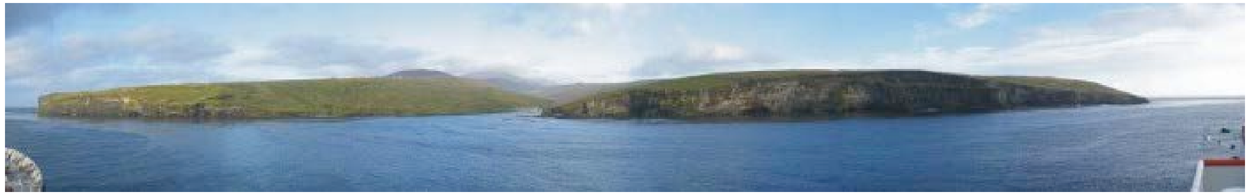
- Data are carefully calibrated relative to WMO scales
- Intra-laboratory and cross laboratory comparisons with other labs ensure data compatibility
- Whole air samples are analyzed for many species
- Many partners!

Air sampling at Crozet Island

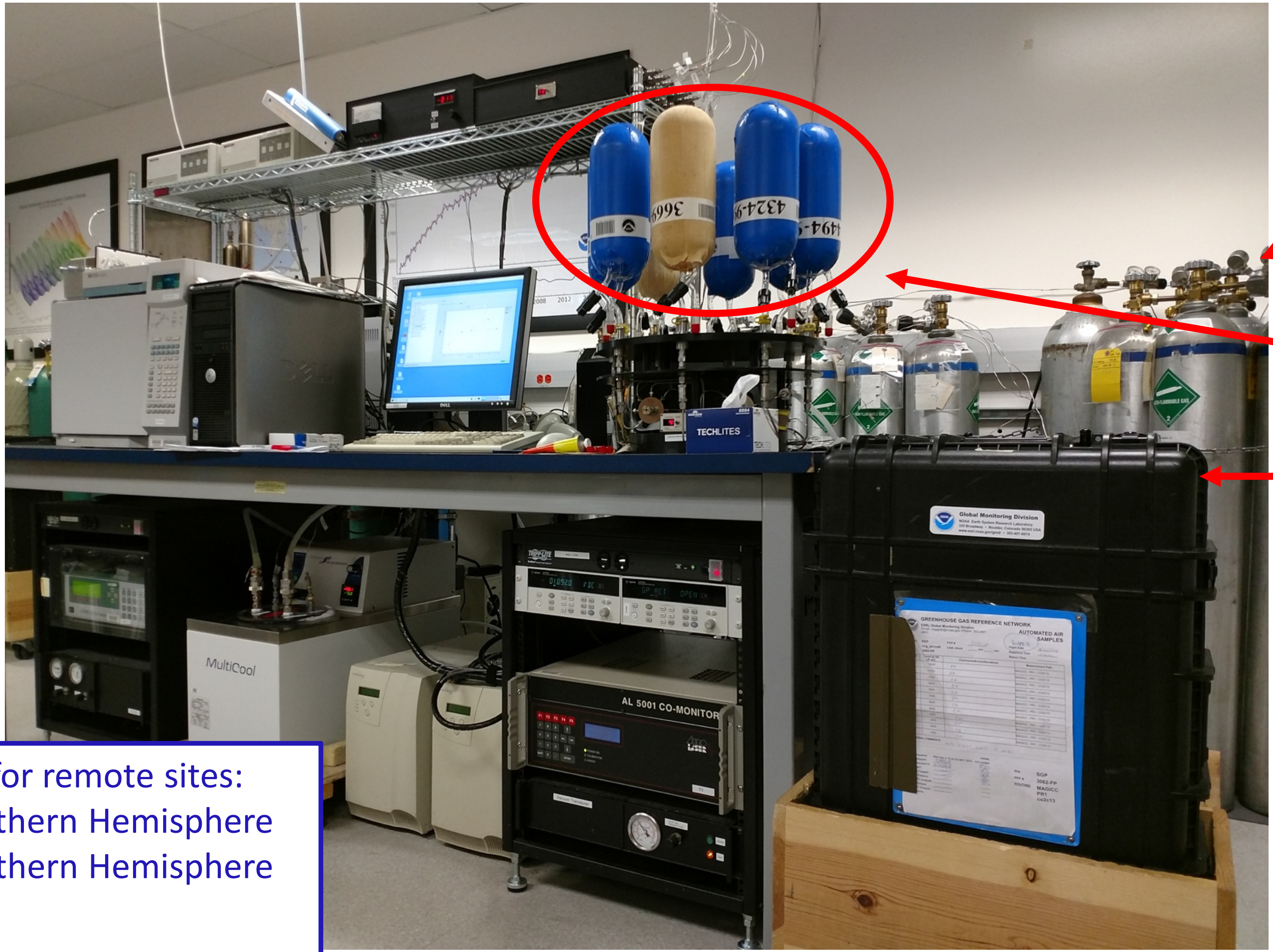




- Weekly whole air samples capture the variability at remote sites.
- Local sources and sinks are avoided.



Measurement of Atmospheric Gases that Influence Climate Change (MAGICC) Whole Air Sample Analysis System



Calibration Gases

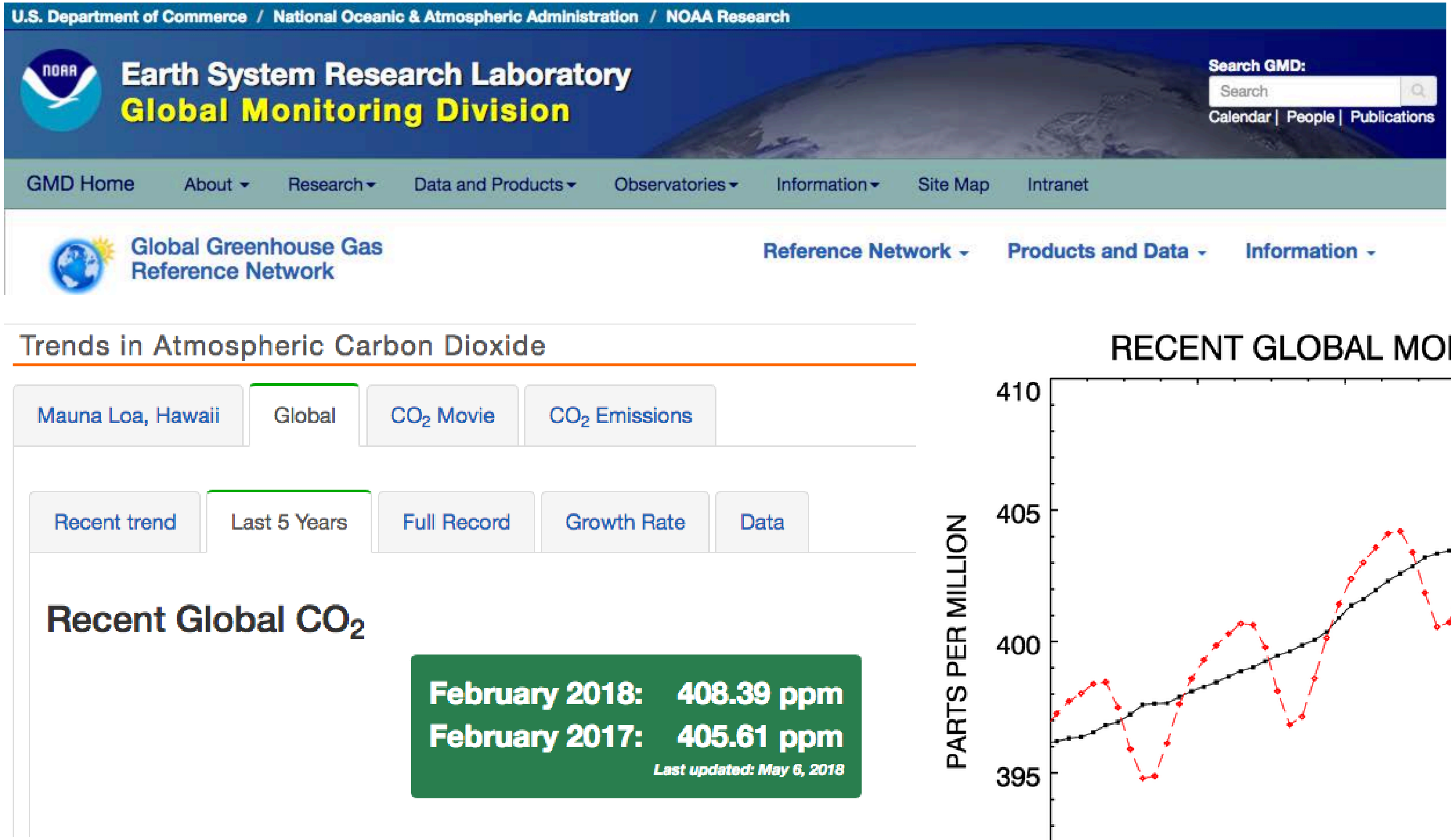
Presentation by Brad Hall

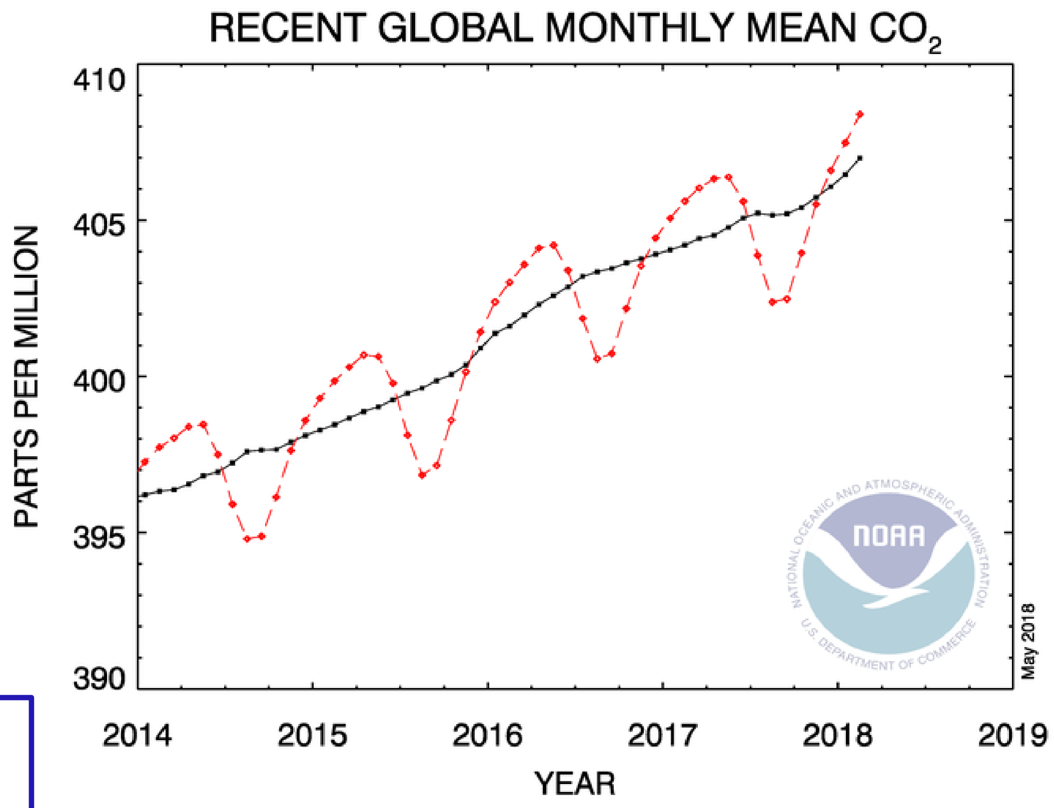
Manually Sampled Flasks

Programmable Flask Packages

WMO compatibility goals for remote sites:

- CO_2: ±0.10 ppm Northern Hemisphere
- ±0.05 ppm Southern Hemisphere
- CH_4: ±2 ppb
- N_2O: ±0.10 ppb

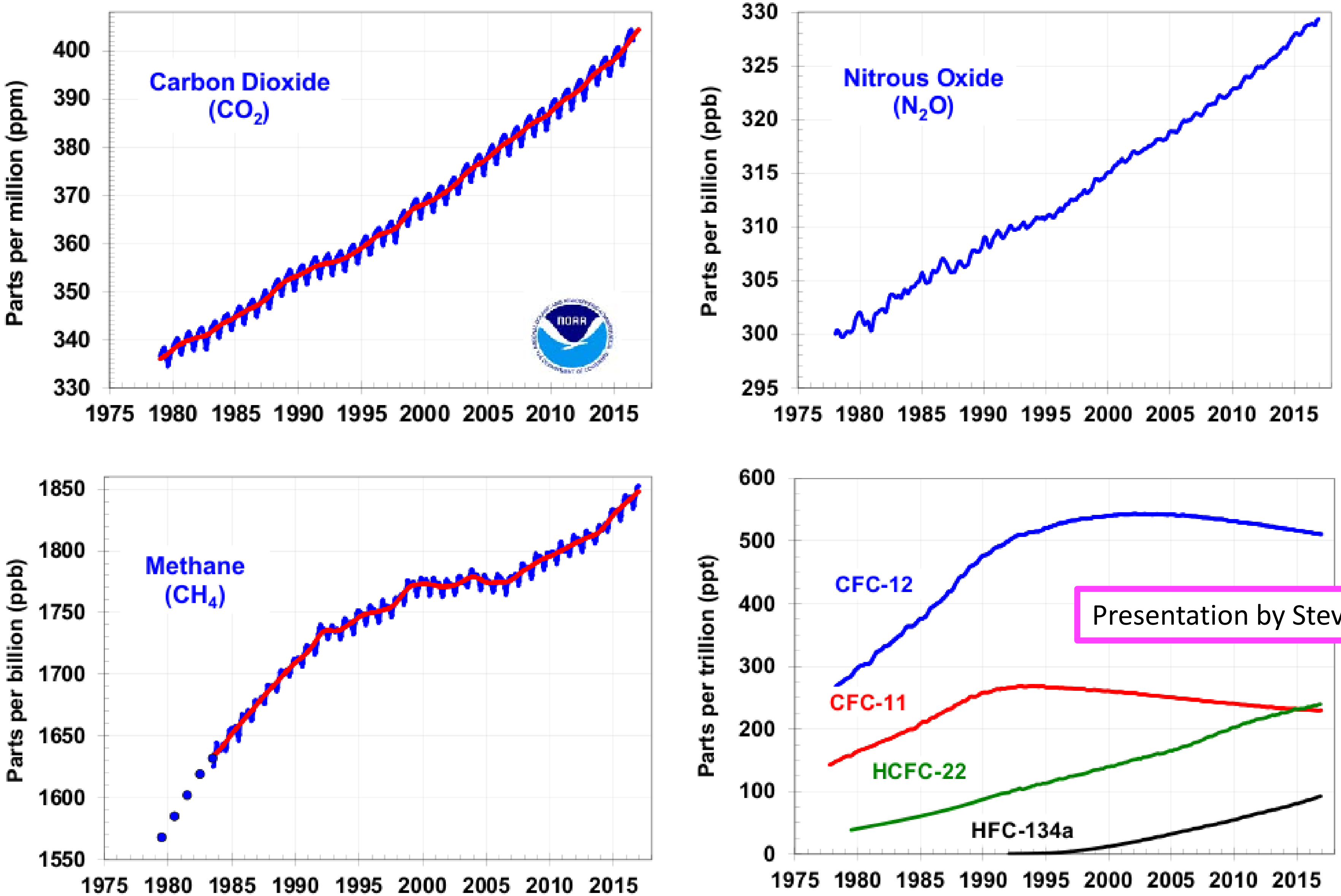




Global Means computed from the Marine Boundary Layer data are publically posted with minimal delay.

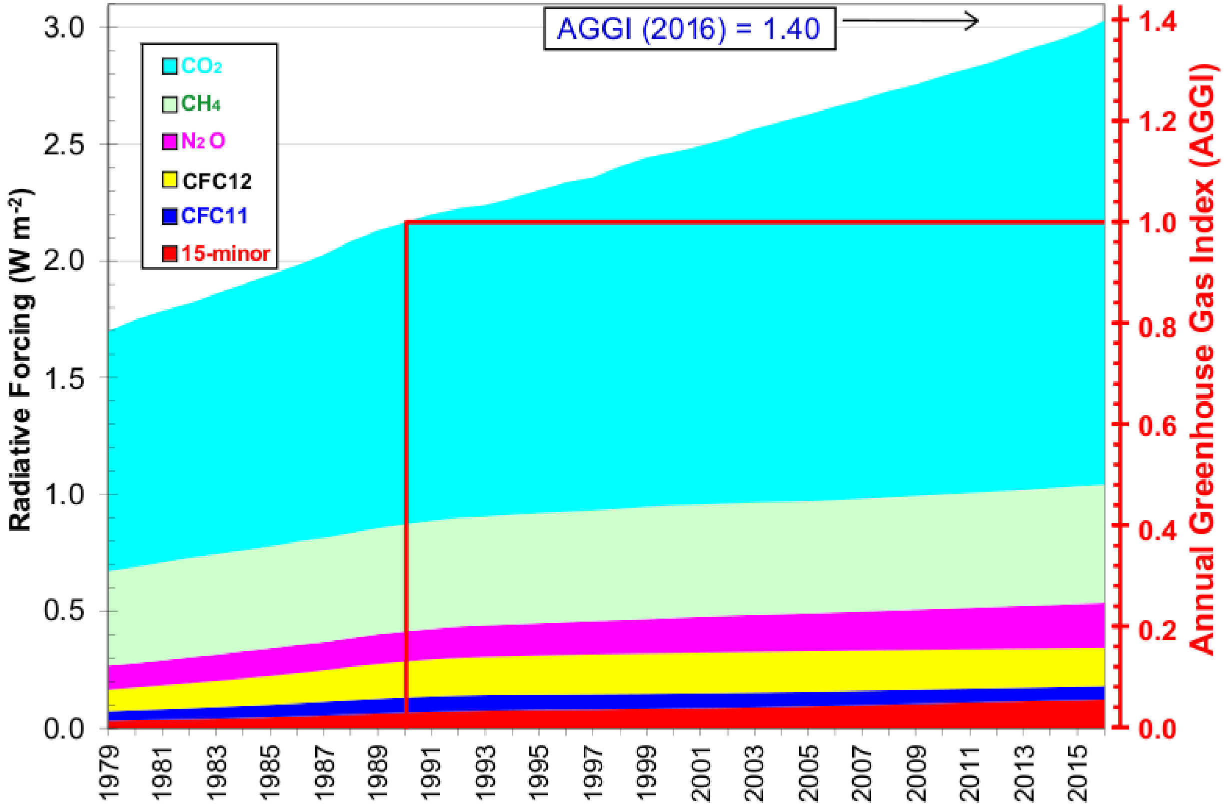
GMAC presentation by Ed Dlugokencky

Global Mean Values for the Major Long-Lived Greenhouse Gases



Presentation by Steve Montzka

NOAA Annual Greenhouse Gas Index



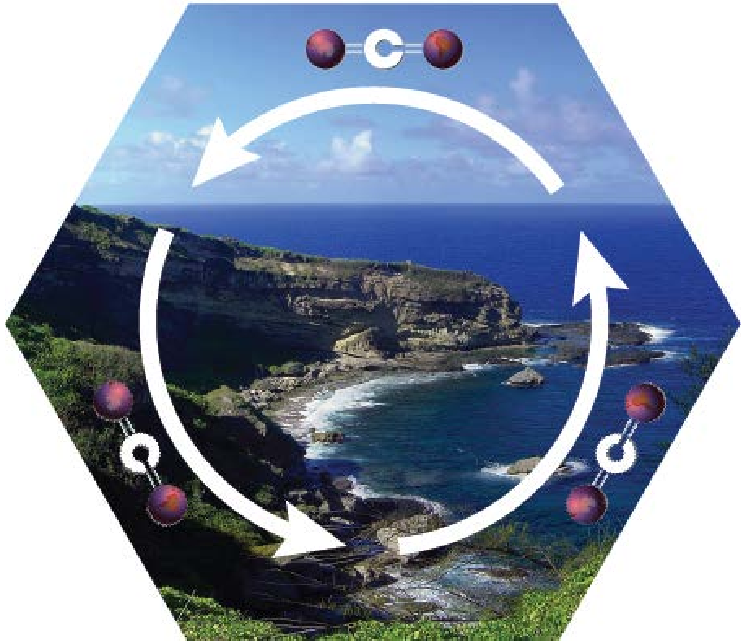
As of 2016, radiative forcing from anthropogenic greenhouse gases is up by 40% over 1990 levels.

Earth's Surface: 510.1 trillion m²

3 W/m² over Earth's Surface ≈ 4.8×10^{22} Joules of Energy per year
⇒ enough to melt 60% of Greenland's ice in one year
⇒ enough to heat 100m of ocean 0.32°C in one year

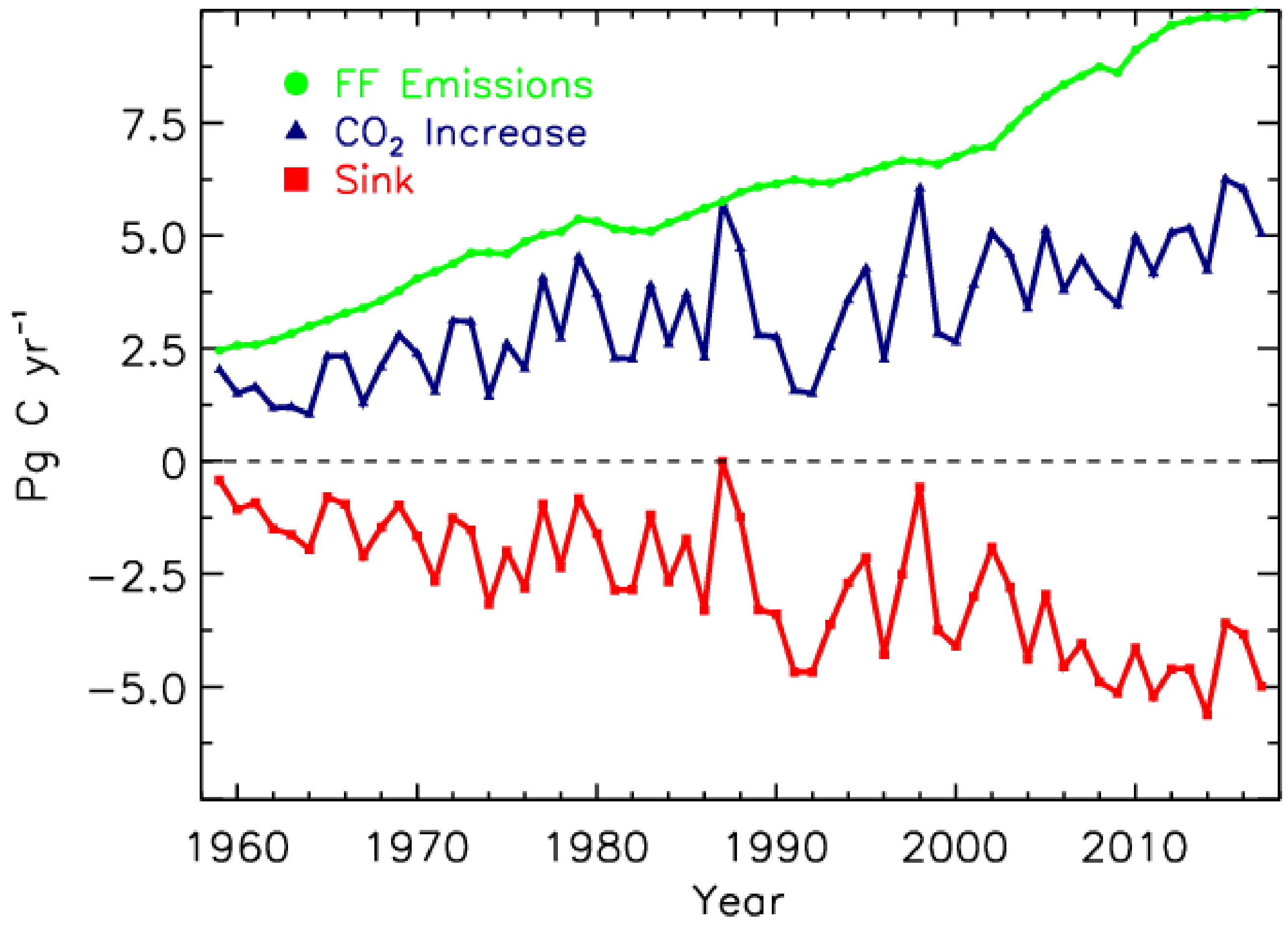
Understanding Carbon Cycle Feedbacks

Grand Challenge: Carbon Feedbacks in the Climate System



- ***What biological and abiological processes drive and control land and ocean carbon sinks?***
- ***Can and will climate-carbon feedbacks amplify climate changes over the 21st century?***
- ***How will highly-vulnerable land and ocean carbon reservoirs respond to a warming climate, to climate extremes, and to abrupt changes?***

Global carbon sinks are increasing

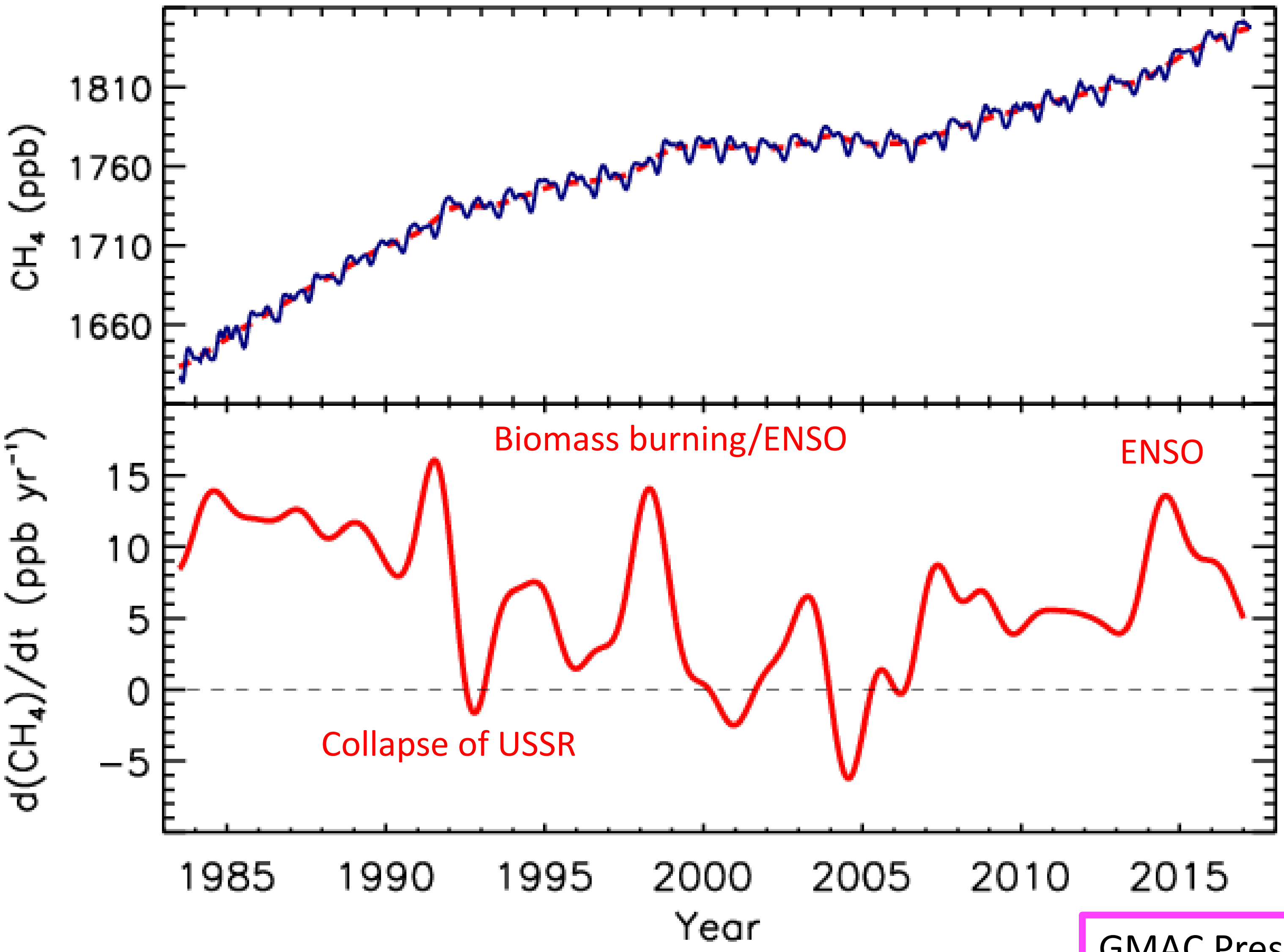


Ballantyne et al., Nature, 2012, updated

- Carbon sinks keep increasing as fossil fuels keep rising. Global C uptake now ~4 PgC/yr.
- ~45% of fossil fuel emissions are still taken up by sinks.
- Year-to-year variability driven by land uptake. We cannot yet attribute land uptake to specific processes.

GMAC presentation by Ed Dlugokencky

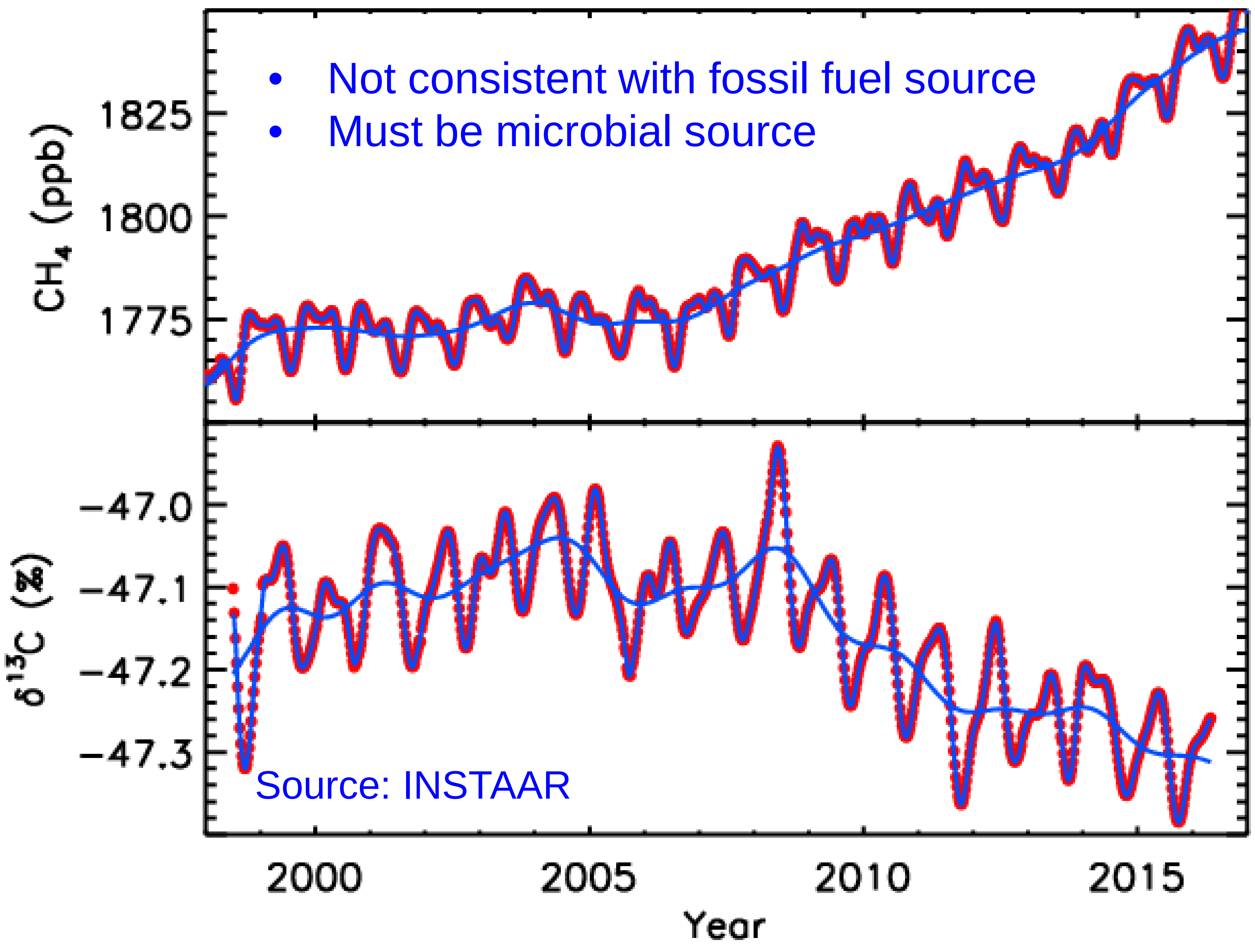
Globally averaged CH_4 and its growth rate



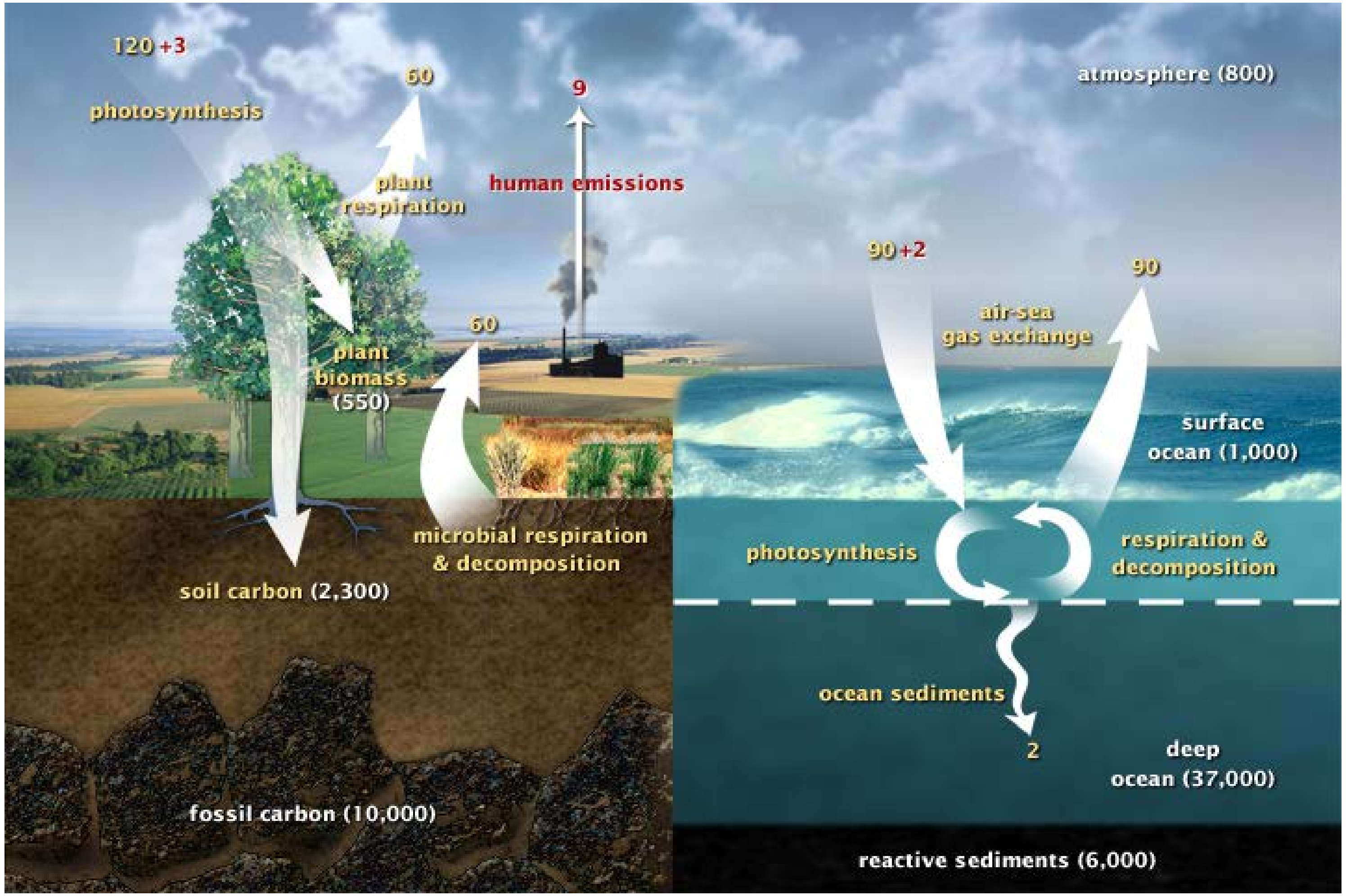
GMAC Presentation by Lori Bruhwiler

CH_4 data from Ed Dlugokencky

CH_4 from Fossil Fuels?



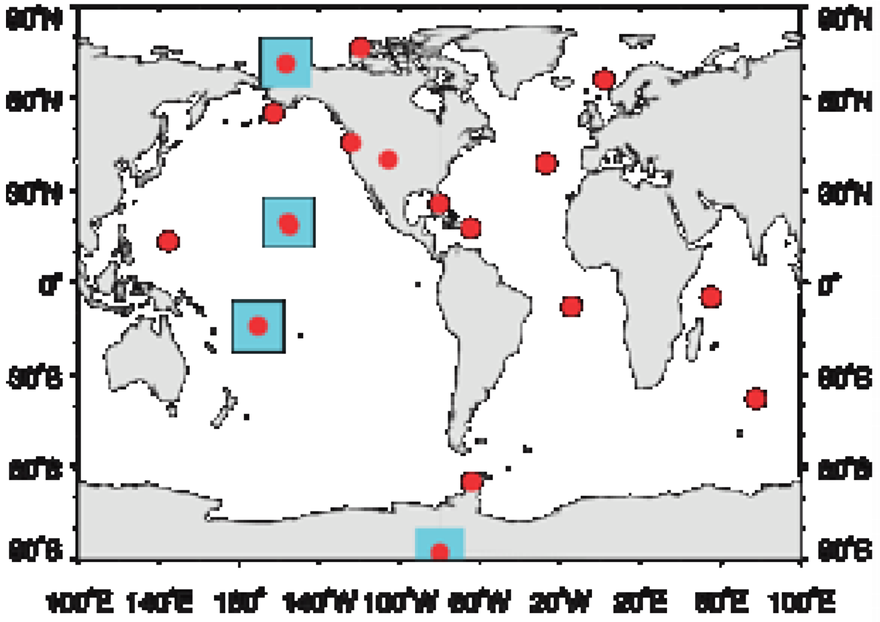
Estimating Emissions and Removals

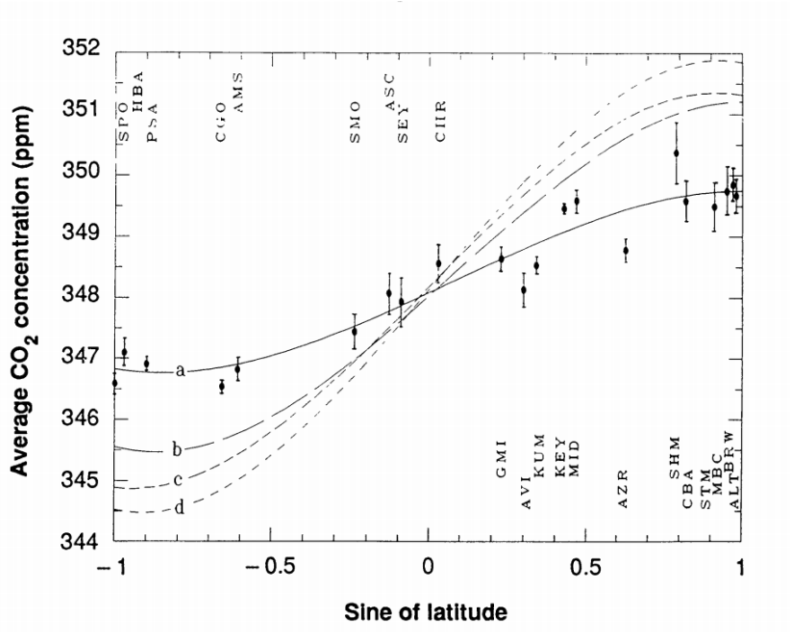


https://earthobservatory.nasa.gov/Features/CarbonCycle/

Observational Constraints on the Global Atmospheric CO_2 Budget

PIETER P. TANS, INEZ Y. FUNG, TARO TAKAHASHI





● flask sampling site (weekly)
■ observatory (continuous)

Science, Mar. 23, 1990

"…a large amount of the CO_2 is apparently absorbed on the continents by terrestrial ecosystems."

1439 citations!

U.S. Department of Commerce / National Oceanic & Atmospheric Administration / NOAA Research

Earth System Research Laboratory
Global Monitoring Division

Search ESRL: Search
Calendar | People | Publications

GMD Home | About | Research | Data and Products | Observatories | Information | Site Map | Intranet

Global Greenhouse Gas Reference Network

Reference Network | Products and Data | Information

CT2016
- Home
- FAQ
- Documentation
- Tutorial
- Collaborators
- Versions

Results
- Evaluation
- Fluxes
- Observations
- Mole Fractions
- Download

Resources
- Usage Policy
- E-mail List
- Contact Us
- CT on YouTube
- Glossary
- References

CarbonTracker CT2016

CarbonTracker is a CO_2 measurement and modeling system developed by NOAA to keep track of sources (emissions to the atmosphere) and sinks (removal from the atmosphere) of carbon dioxide around the world. CarbonTracker uses atmospheric CO_2 observations from a host of collaborators and simulated atmospheric transport to estimate these surface fluxes of CO_2. The current release of CarbonTracker, CT2016, provides global estimates of surface-atmosphere fluxes of CO_2 from January 2000 through December 2015.

What is CarbonTracker?

CarbonTracker is a global model of atmospheric carbon dioxide with a focus on North America, designed to keep track of CO_2 uptake and release at the Earth's surface over time. [read more]

Who needs CarbonTracker?

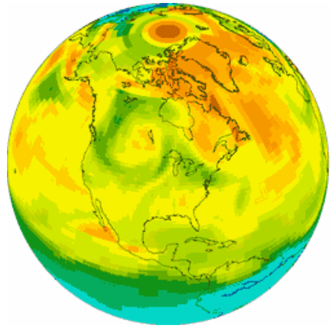
Policy makers, industry, scientists, and the public need CarbonTracker information to make informed decisions to limit greenhouse gas levels in the atmosphere. [read more]

What does CarbonTracker tell us?

North America is a source of CO_2 to the atmosphere. The natural uptake of CO_2 that occurs mostly east of the Rocky Mountains removes about a third of the CO_2 released by the use of fossil fuels. [read more]

What is new in this release of CarbonTracker? NEW!

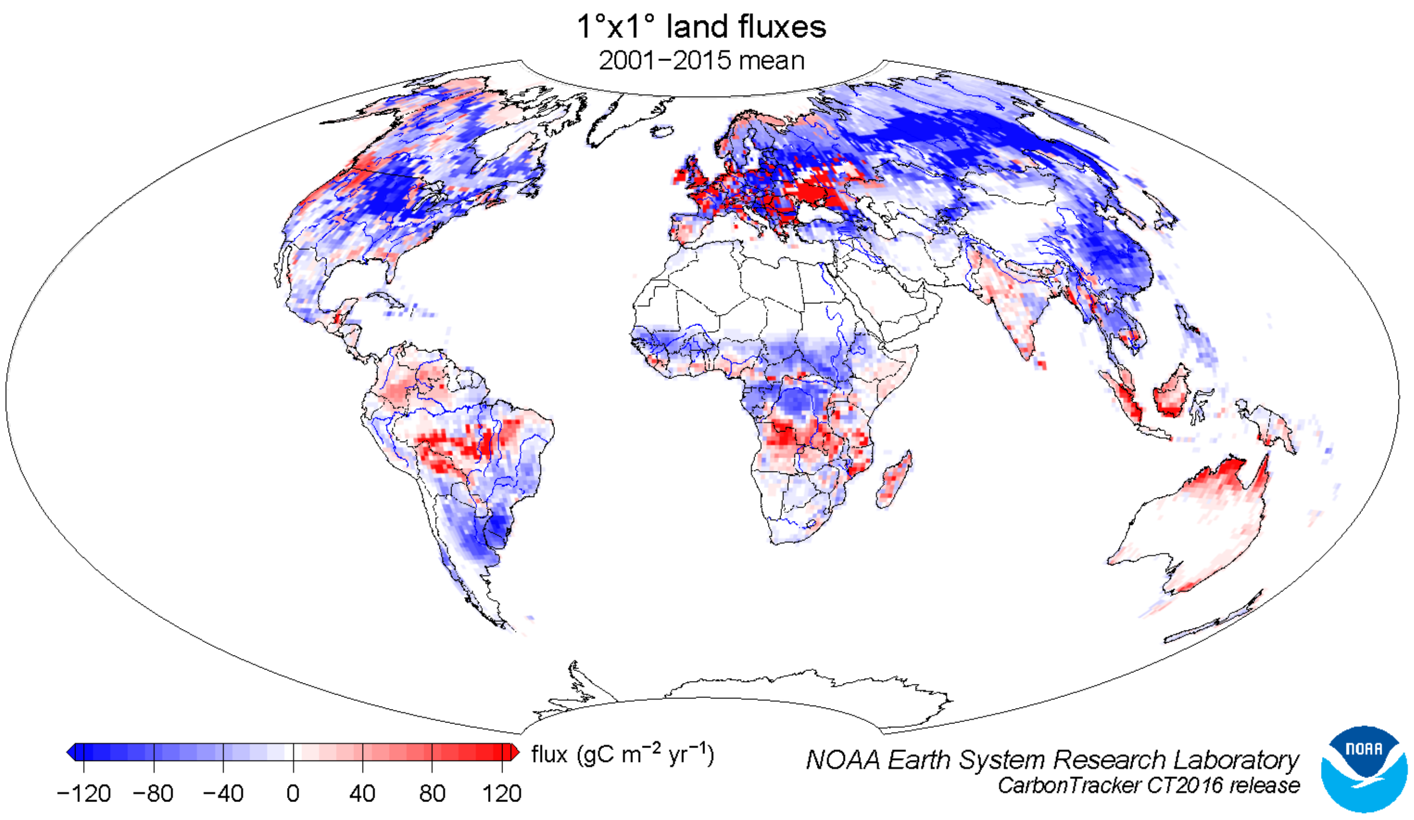
This release of CarbonTracker ("CT2016") uses new hourly observations from GLOBALVIEW+ and refined first-guess flux models. [read more]

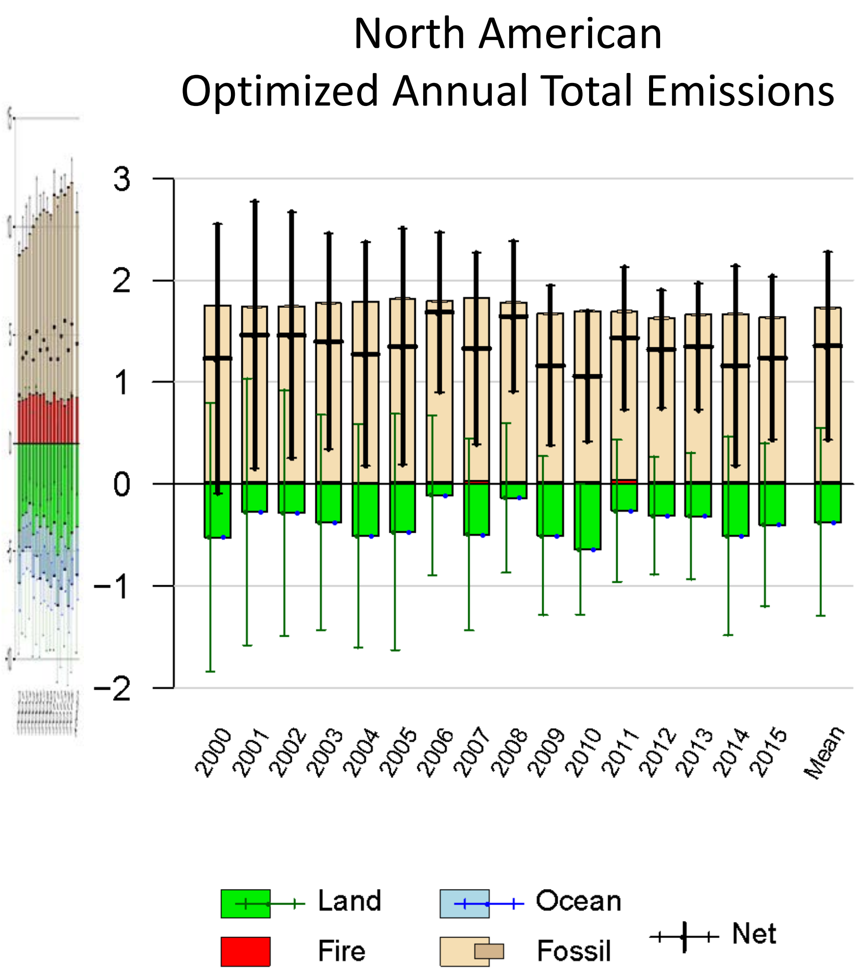


CarbonTracker CO_2 weather for June-July, 2008. *Warm colors show high atmospheric CO_2 concentrations, and cool colors show low concentrations. As the summer growing season takes hold, photosynthesis by forests and crops draws concentrations of CO_2 down, opposing the general increase from fossil fuel burning. The resulting high- and low-CO_2 air masses are then moved around by weather systems to form the patterns shown here. [More on CO_2 weather]*

GMAC Presentation by Andy Jacobson

NOAA's CarbonTracker provides up to date estimates of regional carbon fluxes

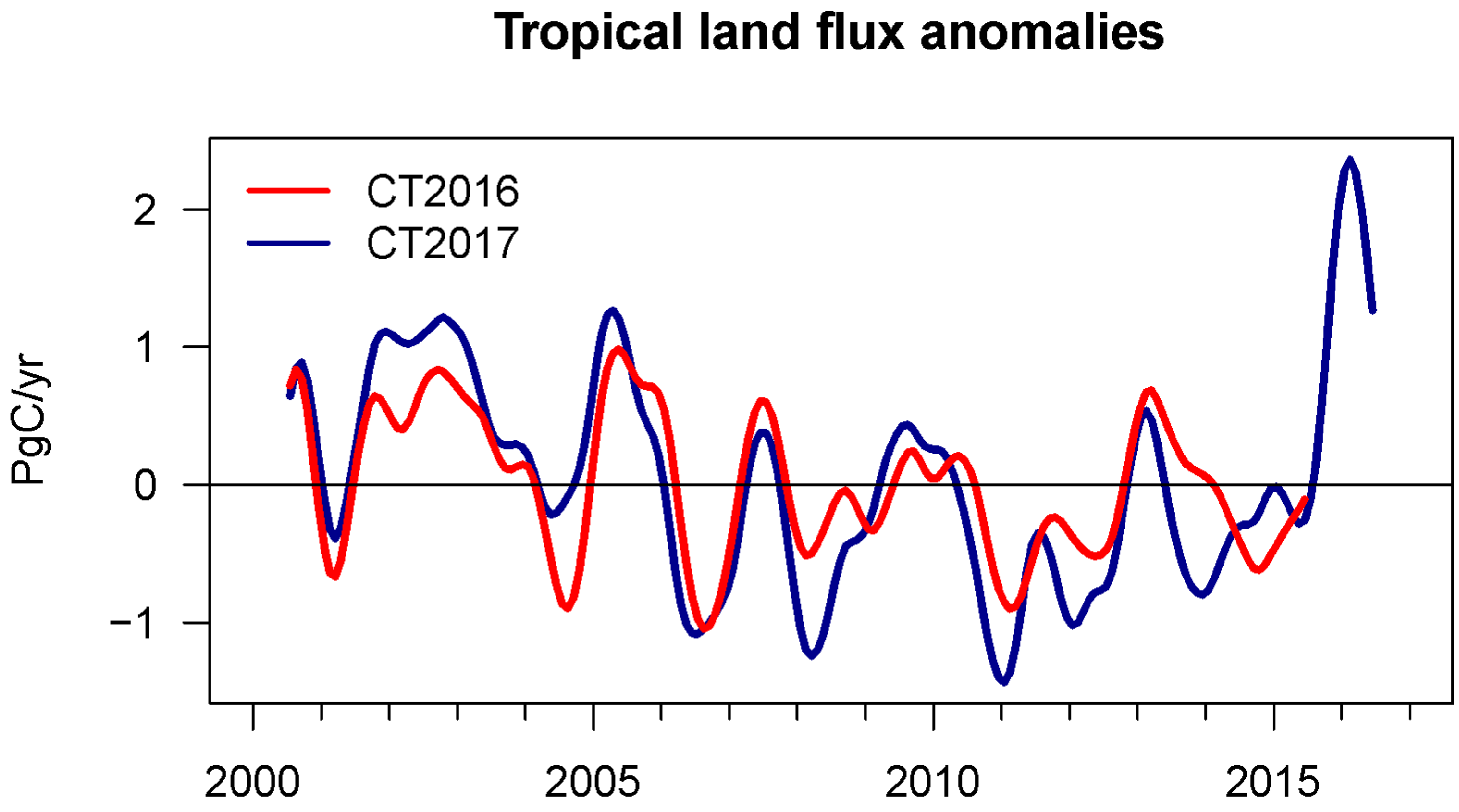




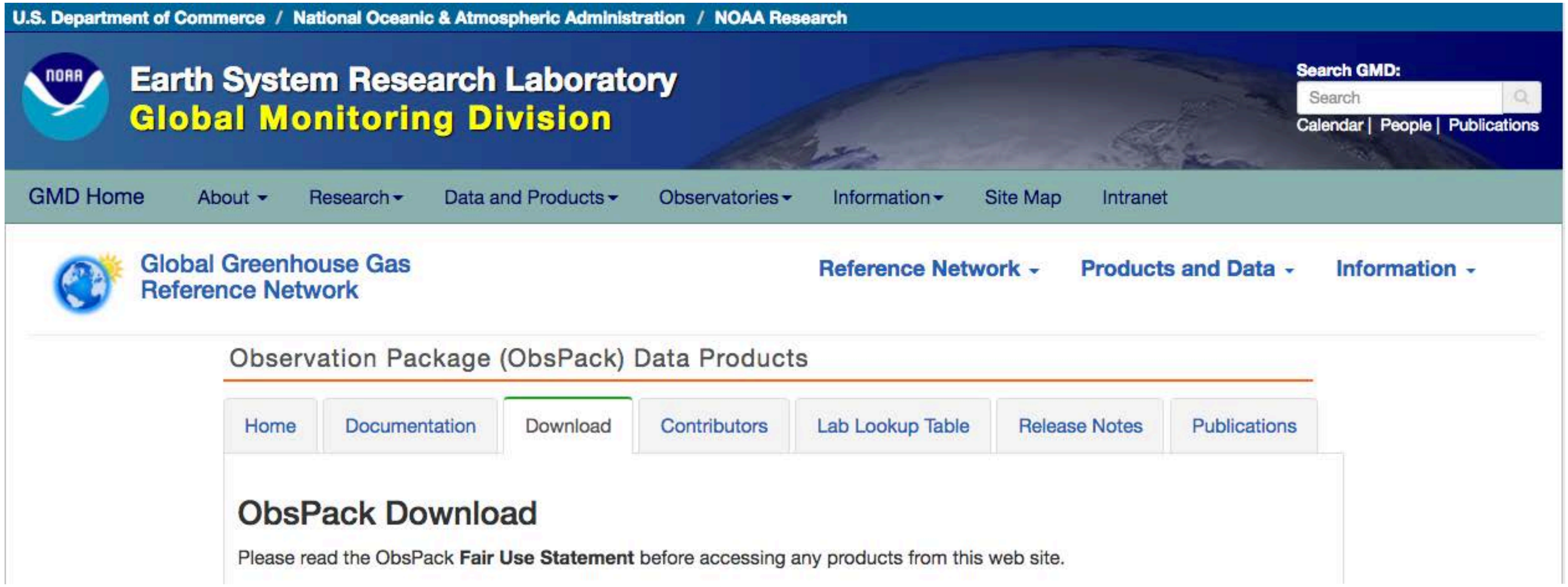
- Globally land and ocean absorb 46.6% of fossil fuel emissions for the period 2000-2015.

Total Uptake: 0.56±1.29
Fossil Fuel: 1.74±0.02

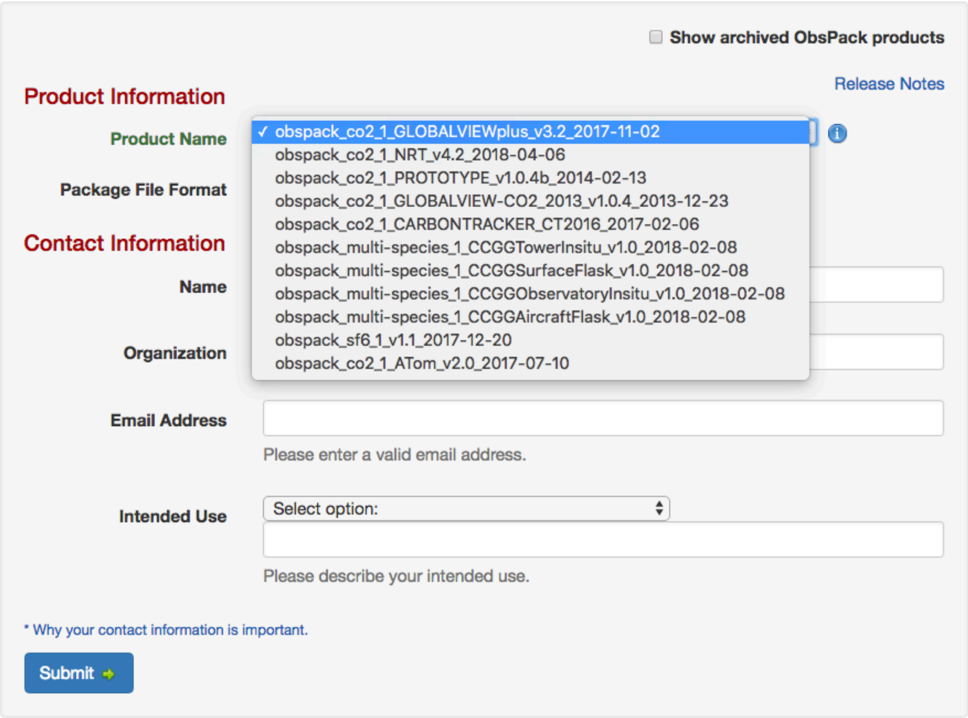
CarbonTracker – Impact of 2015/2016 El Niño



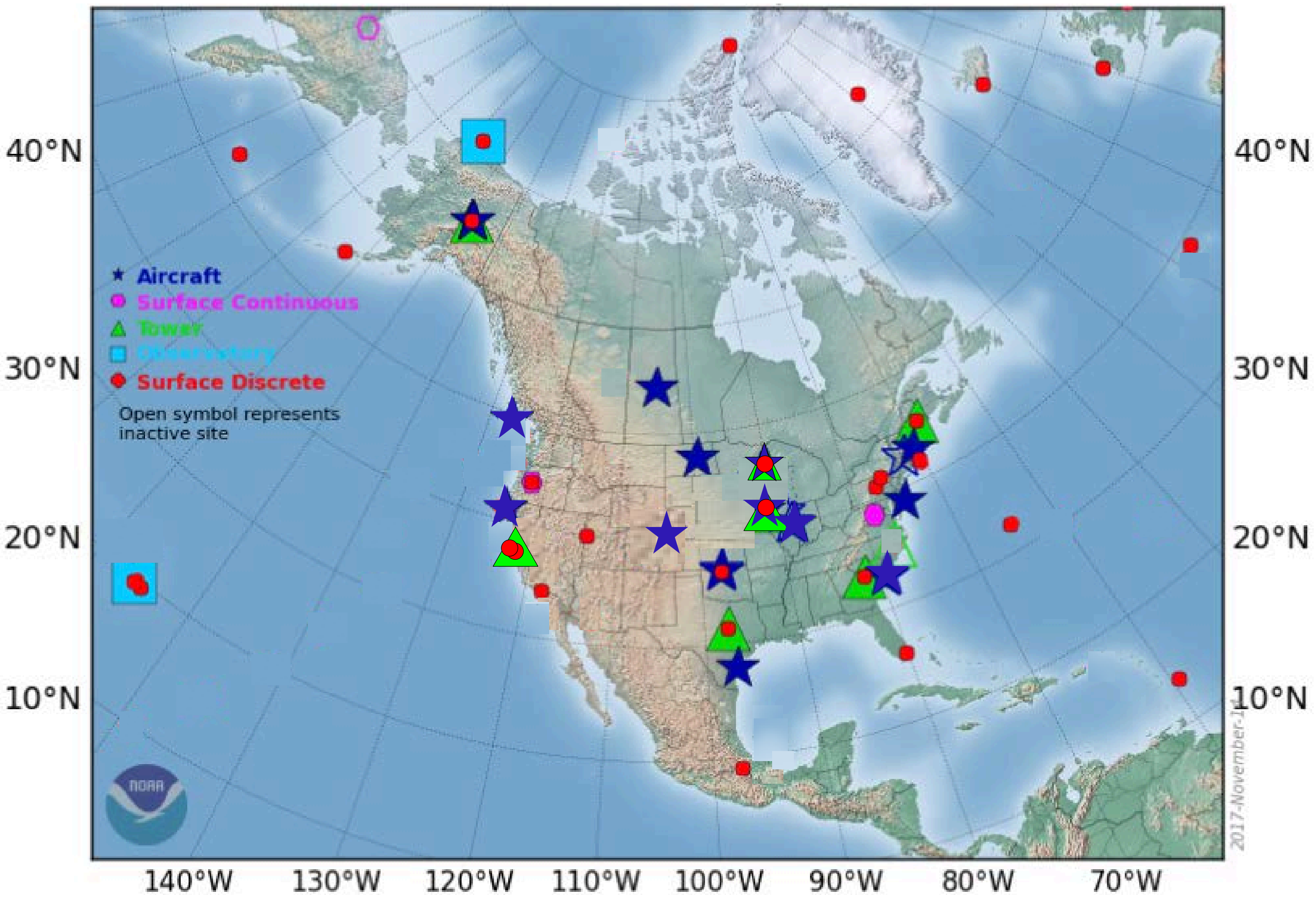
- CT2017 is the first CarbonTracker release to simulate impacts of a large El Niño.
- In 2015 and 2016, we find about 1.2 PgC/yr extra CO_2 in the atmosphere due to this event.



- All of the GGGRN CO_2, CH_4, N_2O, SF_6 data are archived and available in ObsPack format
- Near-real time products support OCO-2 retrieval evaluation and data analysis
- GLOBALVIEWplus products are a multi-laboratory community product
- Campaign ObsPacks are available, e.g. ATom, ACT-America

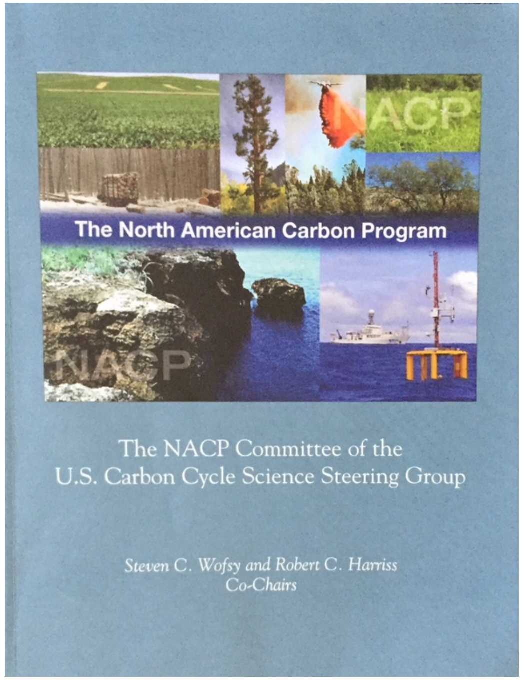


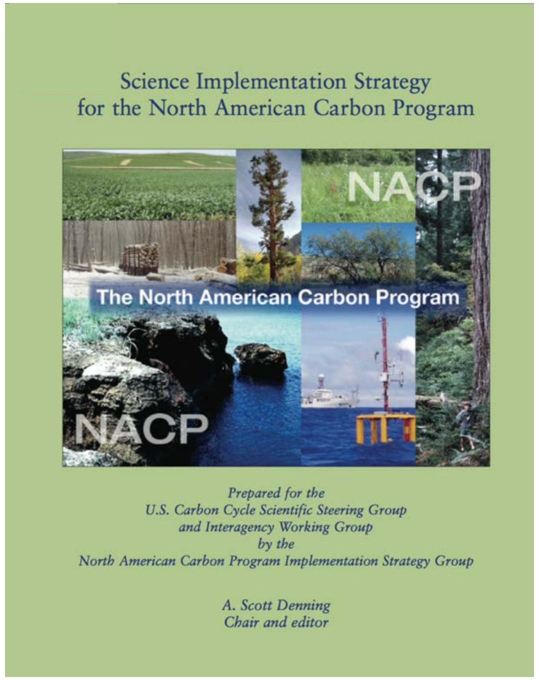
Moving from Global to Regional Scales



★ Aircraft
● Surface Continuous
▲ Tower
■ Observatory
● Surface Discrete

North American Carbon Program: A US Inter-Agency Effort





*"Consider uptake of CO_2 due to woody encroachment… 0.12 GtC/yr… spread out over an area the size of Texas, the annual mean decrease of CO_2 in the column would be 0.11 ppm/day…The associated depletion in atmospheric CO_2 over 1000 km could be 0.6 ppm in the lowest 3 km, comparable to the CO_2 from fossil fuels…**A total of 30 sites for North America are anticipated...Vertical profiles should be obtained at frequency of every other day…**"*

- 0.1 ppm measurement comparability to resolve the signal of important processes

Tall tower in situ and flask sampling:

- All NOAA tall tower sites have continuous CO_2 and CO and flask measurements (every other day sampling, $\Delta^{14}CO_2$ 3x per week)
- Three sites also have continuous CH_4
- Additional mountaintop sites have continuous CO_2 and/or flask
- Many partners!

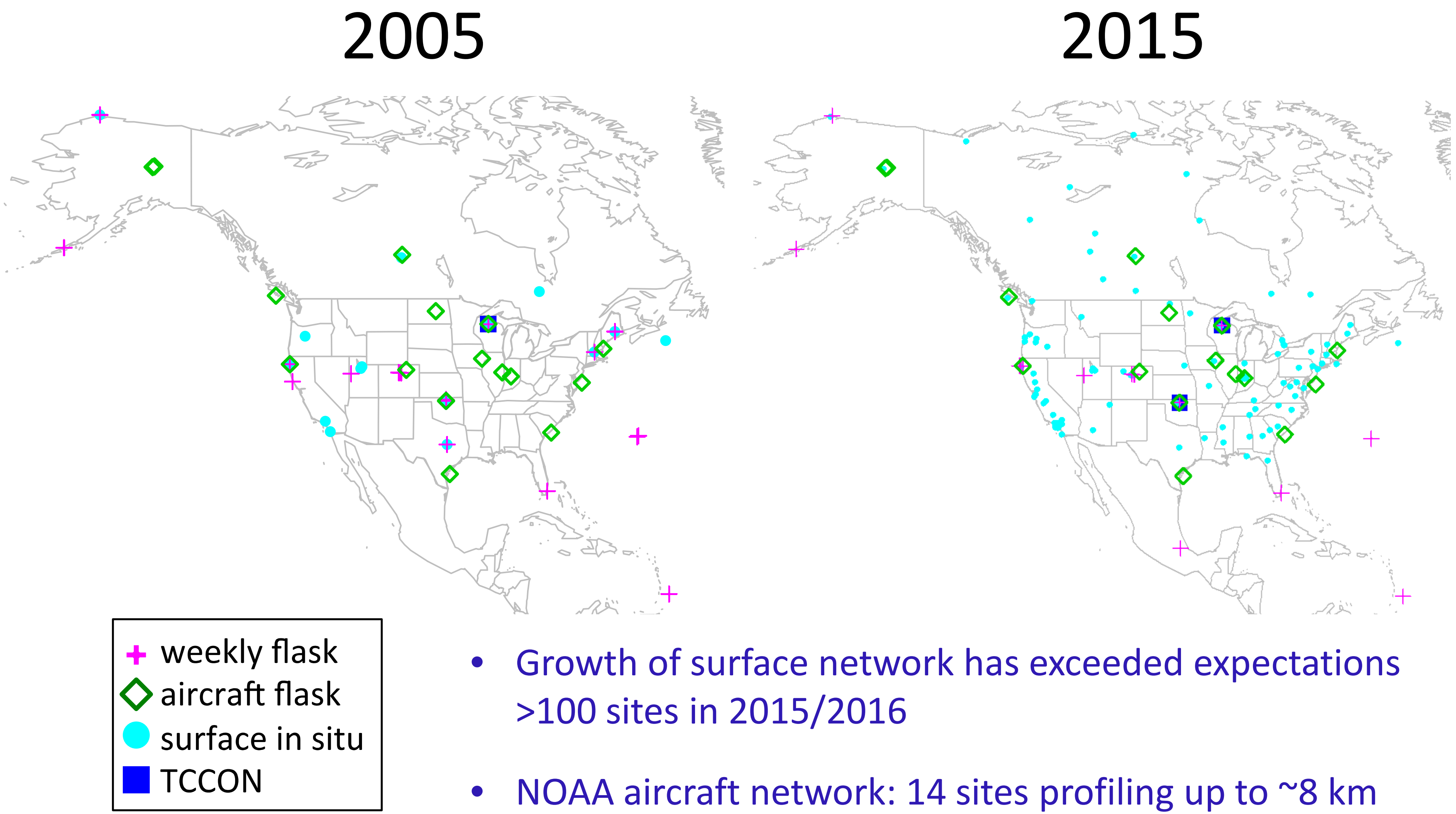
Tall tower program PI: Arlyn Andrews

Aircraft sampling with "Programmable Flask Packages"

Aircraft program PI: Colm Sweeney

- Nominal schedule 2 flights per month
- Most aircraft max altitude 6000 to 8000 masl
- Twelve flasks per package
- Flasks measured for CO_2, CH_4, CO, N_2O, SF_6, H_2, stable isotopes of CO_2 and sometimes CH_4, $\Delta^{14}CO_2$ (subset of samples), hydrocarbons ethane (starting in 2015), halocarbons

The past decade has seen major expansion of the North American atmospheric carbon observing system:



- Growth of surface network has exceeded expectations >100 sites in 2015/2016
- NOAA aircraft network: 14 sites profiling up to ~8 km once or twice per month

Many different laboratories are providing data, with different levels of quality assurance and stability of funding:

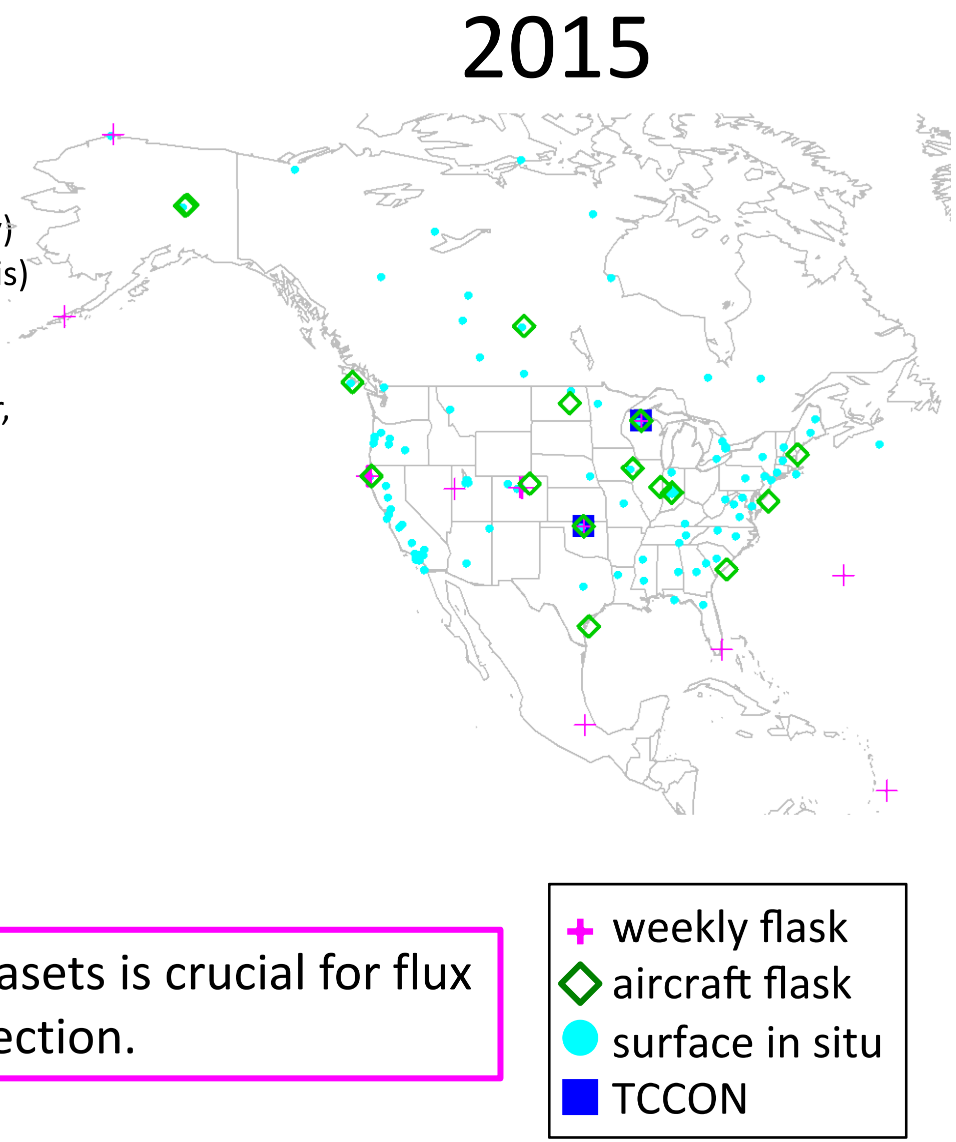
Data Providers

In Situ:

- NOAA Earth System Research Laboratory Global Monitoring Division (A. Andrews, E. Dlugokencky, K. Thoning, C. Sweeney, P. Tans)
- Environment and Climate Change Canada (D. Worthy)
- Penn State University (N. Miles, S. Richardson, K. Davis)
- NCAR (B. Stephens)
- Oregon State University (B. Law, A. Schmidt)
- Lawrence Berkeley National Lab (S. Biraud, M. Fischer, M. Torn)
- Earth Networks (C. Sloop)
- California Air Resources Board (Y. Hsu)
- Harvard University (J. W. Munger, S. Wofsy)
- U of Minnesota (T. Griffis)
- Scripps (J. Kim, R. Keeling, R. Weiss)
- NASA JPL (C. Miller, K Verlhulst)

Remote Sensing:

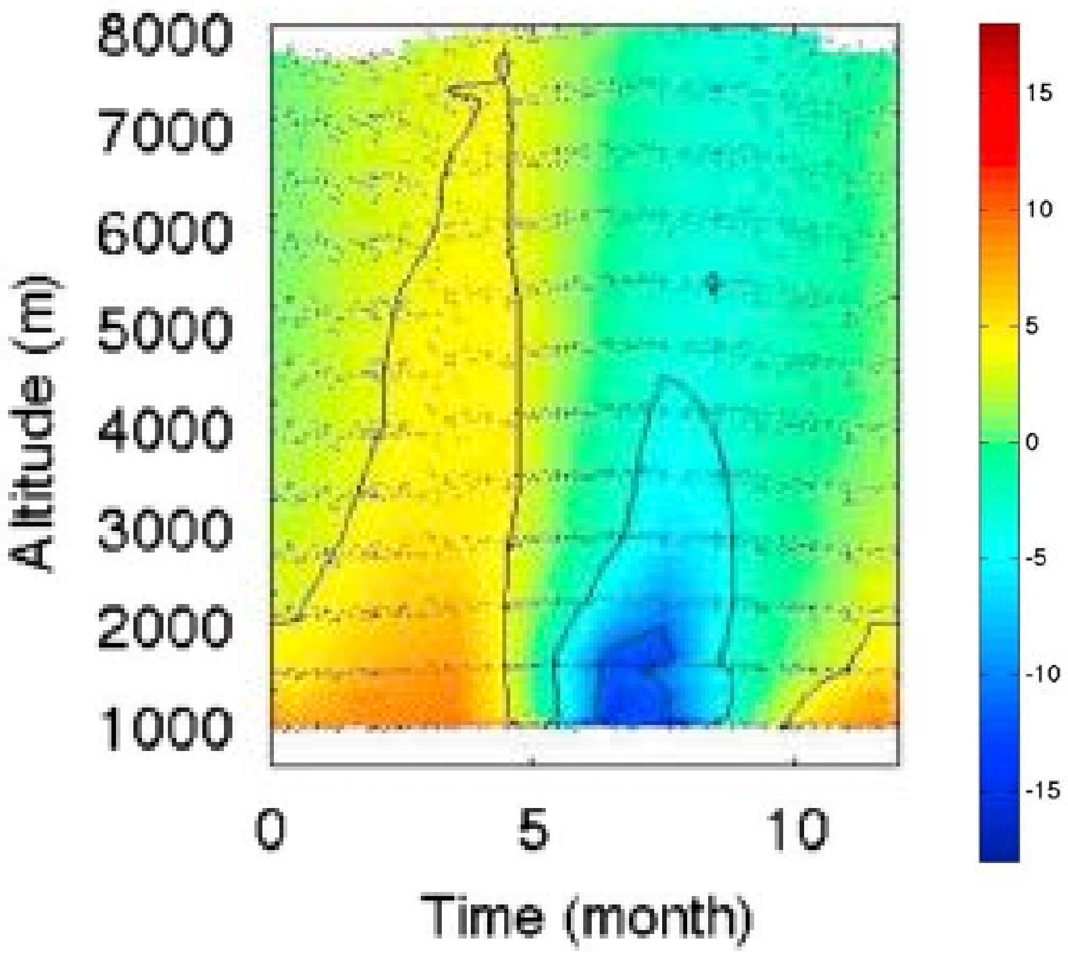
- TCCON (D. Wunch, P. Wennberg, G. Toon)
- GOSAT-ACOS (C. O'Dell)
- OCO-2 team



Comparability among datasets is crucial for flux estimation and trend detection.

What do the data tell us?

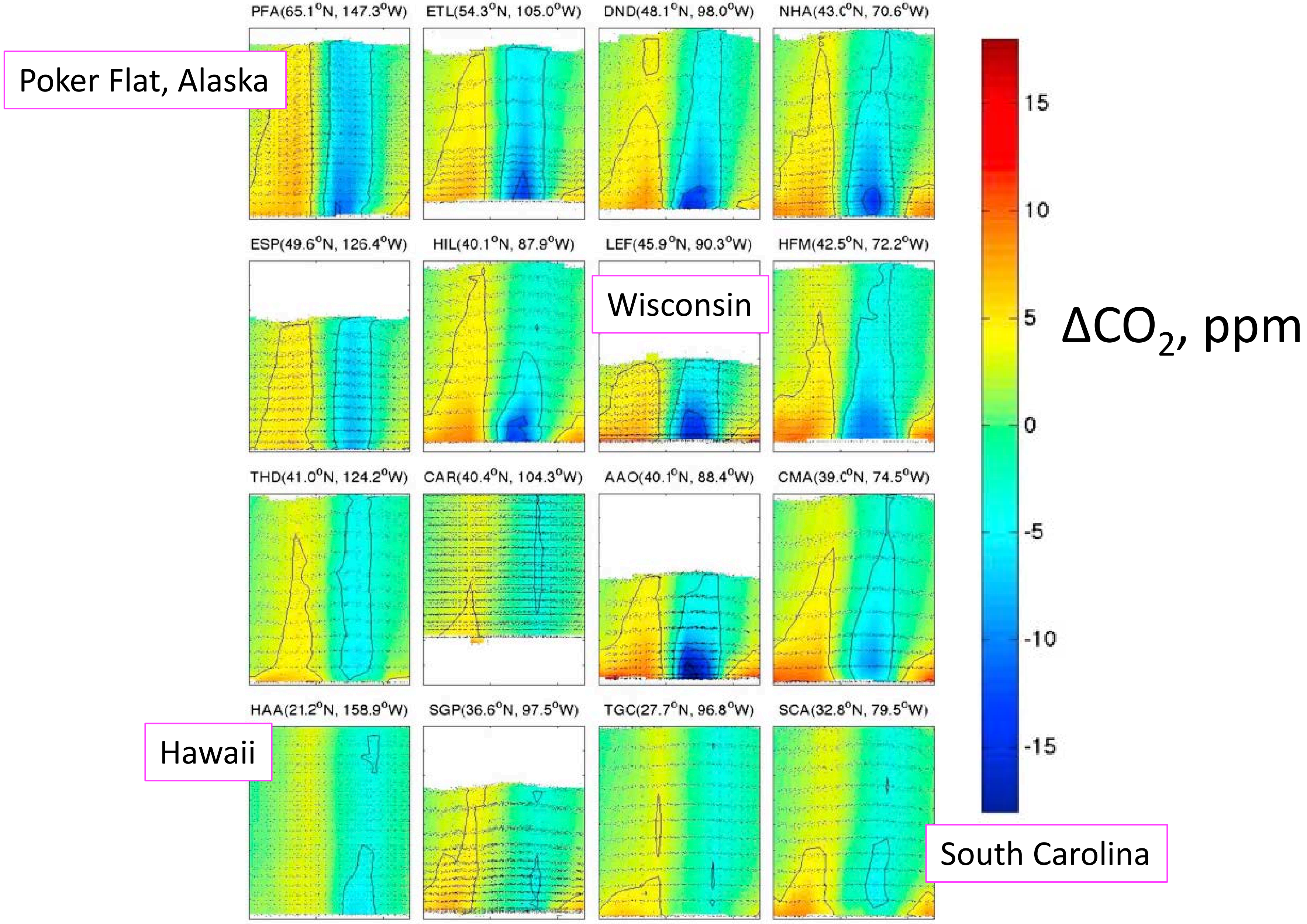
Average Seasonal Cycle of CO_2 above Homer, Illinois:



ΔCO_2, ppm

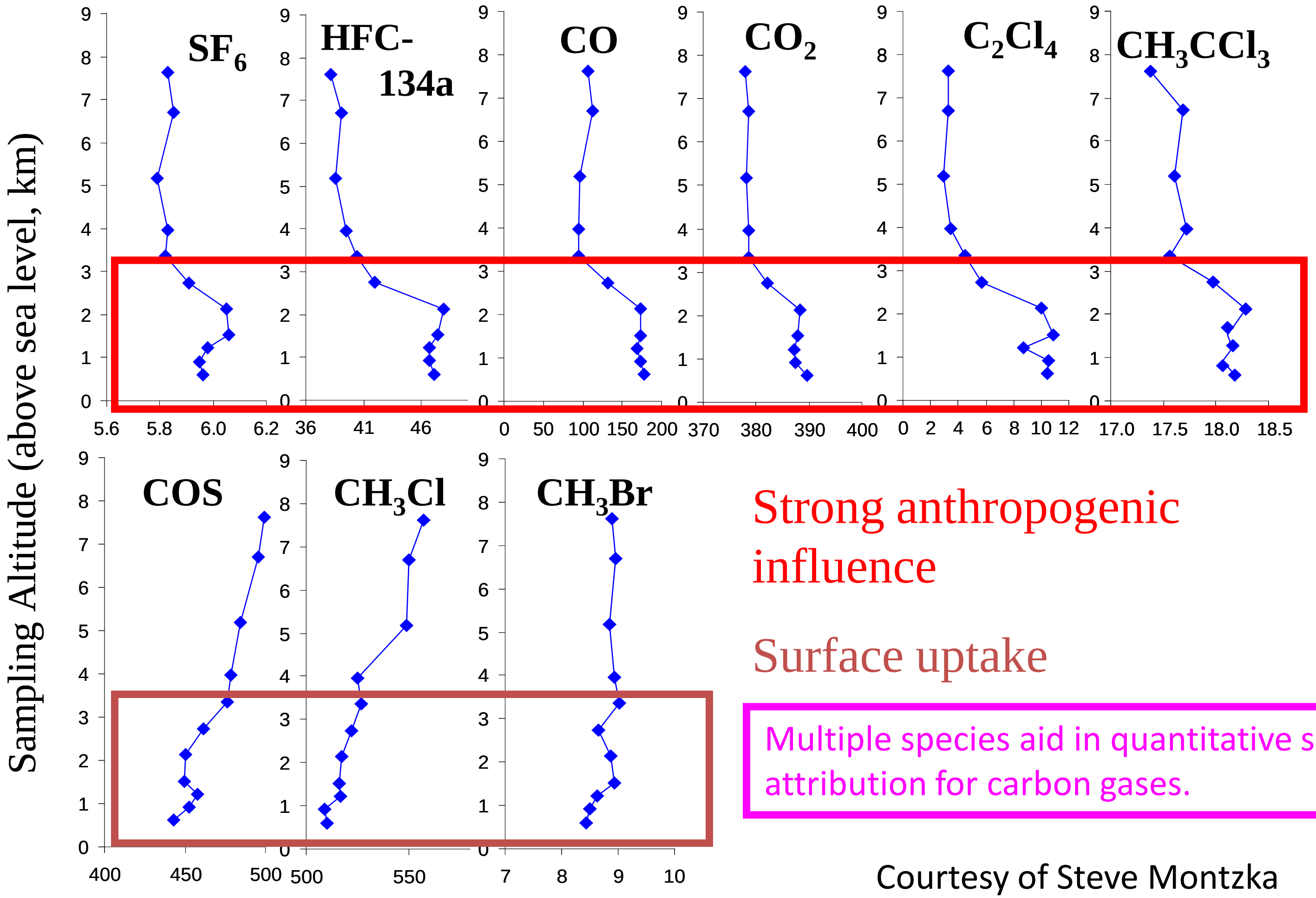
Sweeney et al., JGR, 2015

Annual CO_2 Climatology above North America, from Sweeney et al., JGR, 2015:



Multi-species profiles provide powerful constraints on flux estimates:

Eastern USA (NHA)
Nov 2005



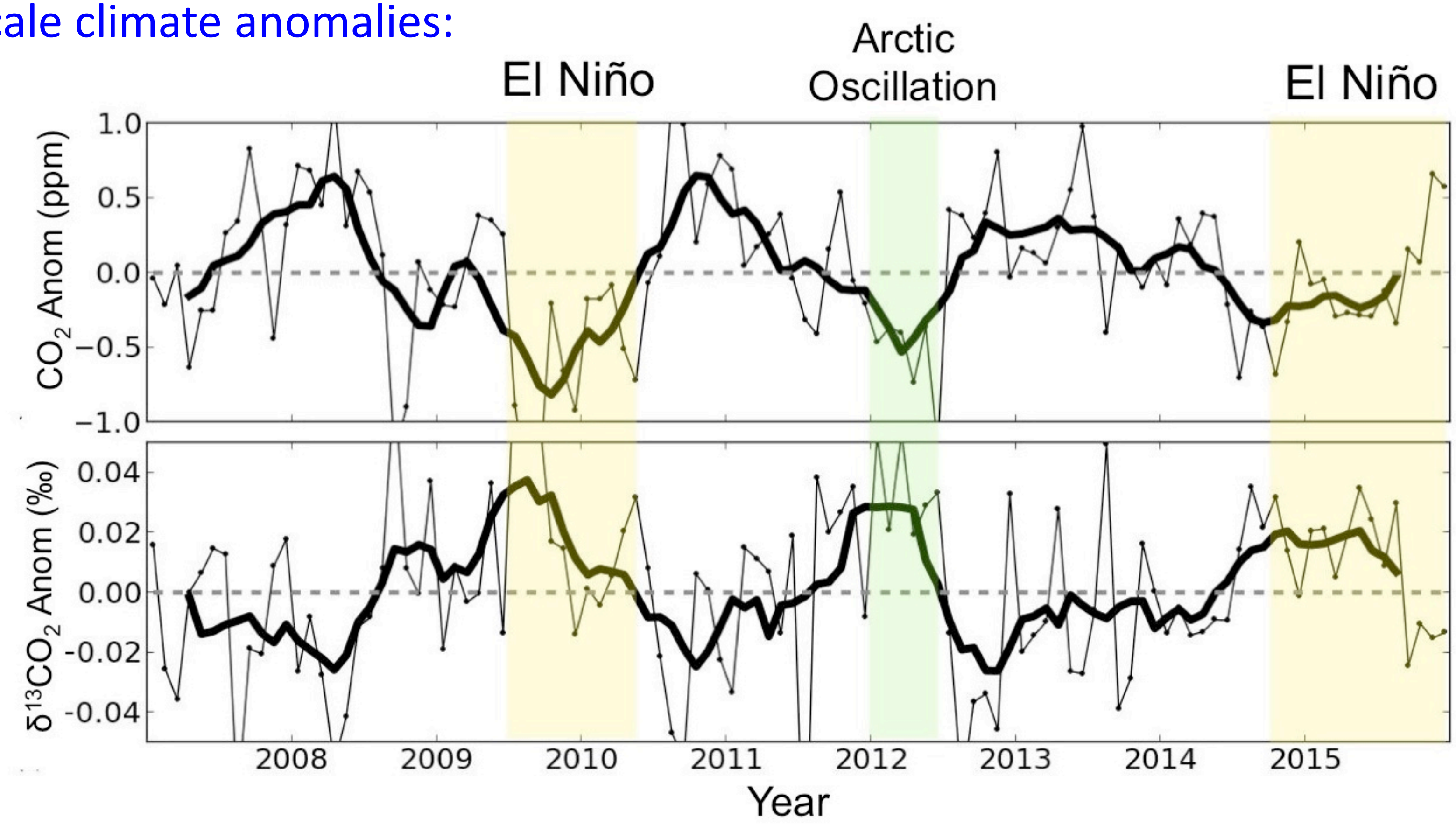
Strong anthropogenic influence

Surface uptake

Multiple species aid in quantitative source attribution for carbon gases.

Courtesy of Steve Montzka

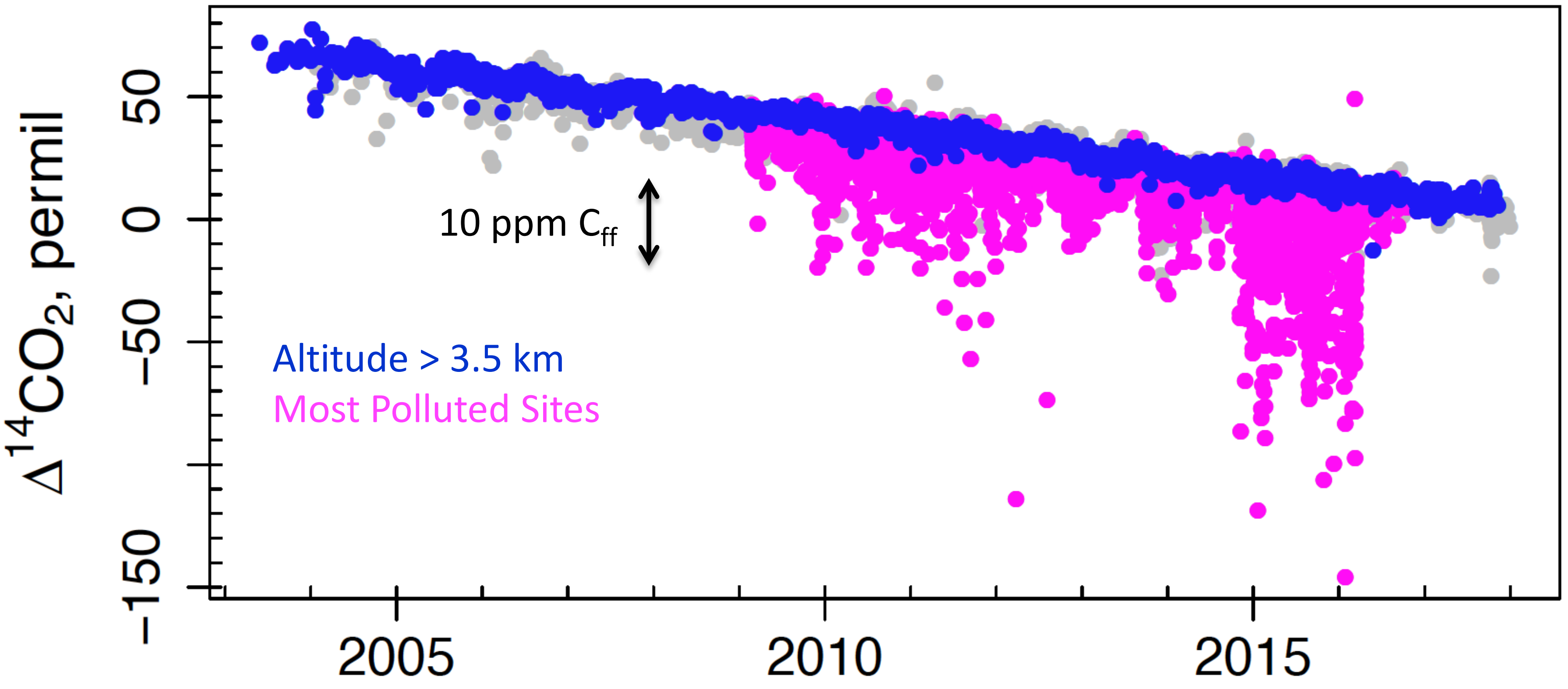
CO_2 and $^{13}CO_2$ anomalies over North America are correlated with large-scale climate anomalies:



- Monthly anomalies (thin lines) of atmospheric CO_2 and $\delta^{13}CO_2$ averaged across North American sampling sites.
- $\delta^{13}CO_2$ provides information about how plants respond to drought stress.

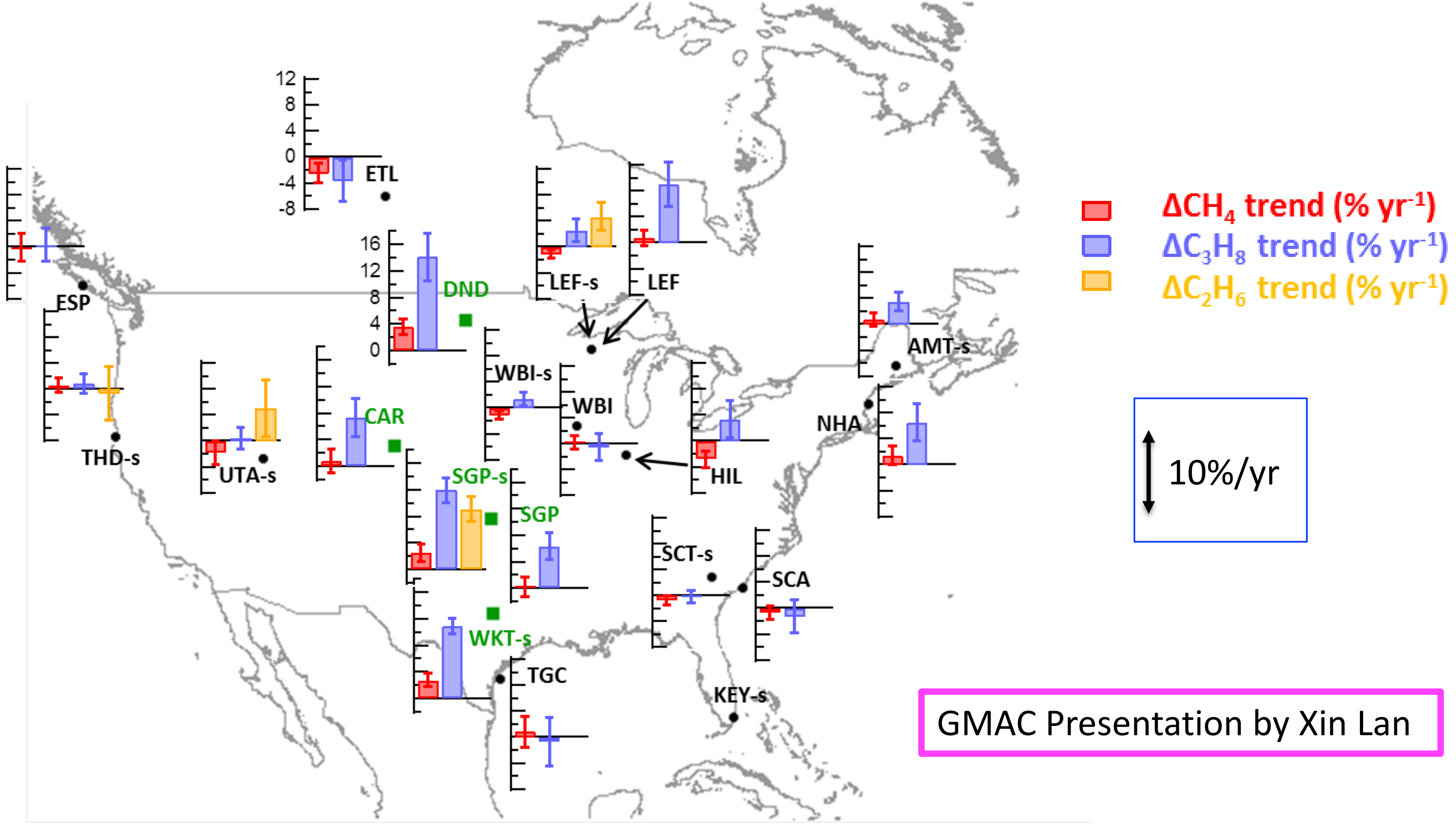
GMAC Talk by Lei Hu
Poster by Ivar van der Velde

Radiocarbon over North America shows decreasing trend due to global fossil fuel emissions and local depletion due to local fossil fuel sources:



GMAC Presentations by John Miller and Sourish Basu

Methane and Hydrocarbon trends over North America:



GMAC Presentation by Xin Lan

- Methane trends are only observed at a few sites near oil and gas development
- Increasing propane and ethane trends are observed at many sites

U.S. Department of Commerce / National Oceanic & Atmospheric Administration / NOAA Research

Earth System Research Laboratory
Global Monitoring Division

Search ESRL: Search
Calendar | People | Publications

GMD Home | About | Research | Data and Products | Observatories | Information | Site Map | Intranet

Global Greenhouse Gas Reference Network

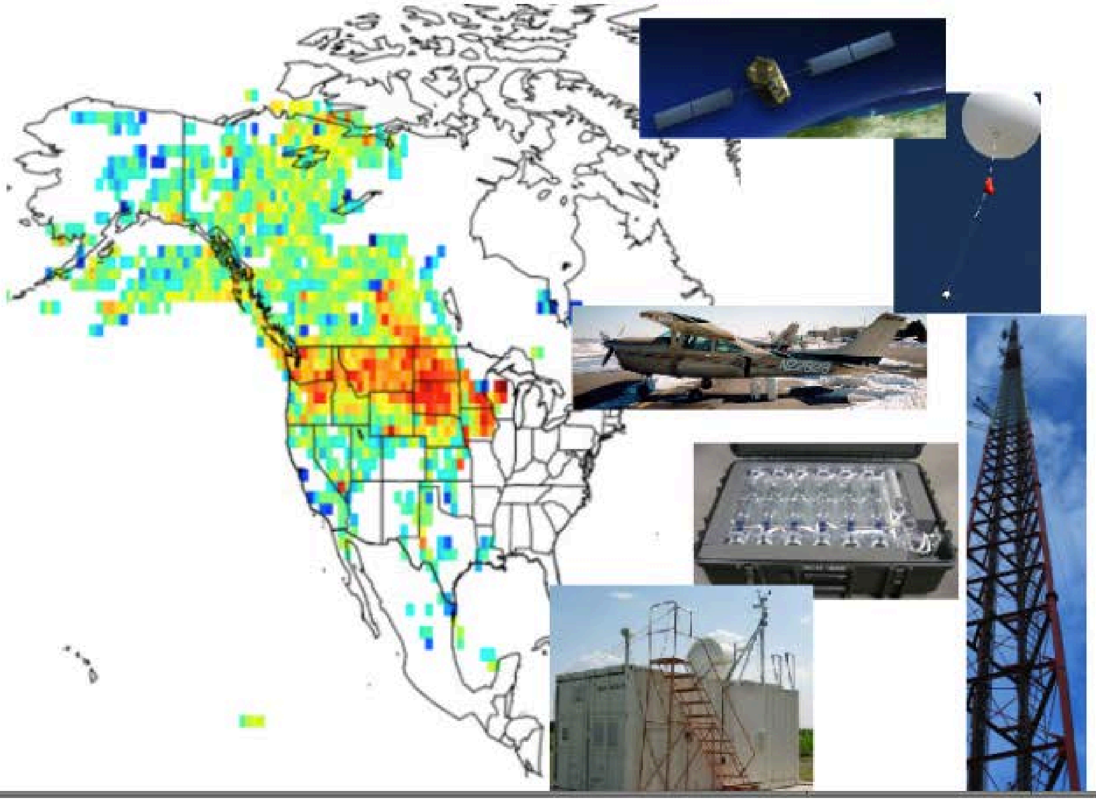
Reference Network | Products and Data | Information

CarbonTracker - Lagrange

CarbonTracker-Lagrange (CT-L) is a new regional inverse modeling framework currently under development and designed for estimating North American greenhouse gas emissions and uptake fluxes. CT-L uses surface sensitivity footprints from Lagrangian Particle Dispersion Models driven by high-resolution meteorological simulations. Surface fluxes are optimized for a consistency with a variety of in situ and remote sensing observations of CO_2 using Bayesian and geostatistical inverse modeling techniques. A beta footprint product is available for download now, and more products are coming soon.

Download CT-Lagrange Footprints

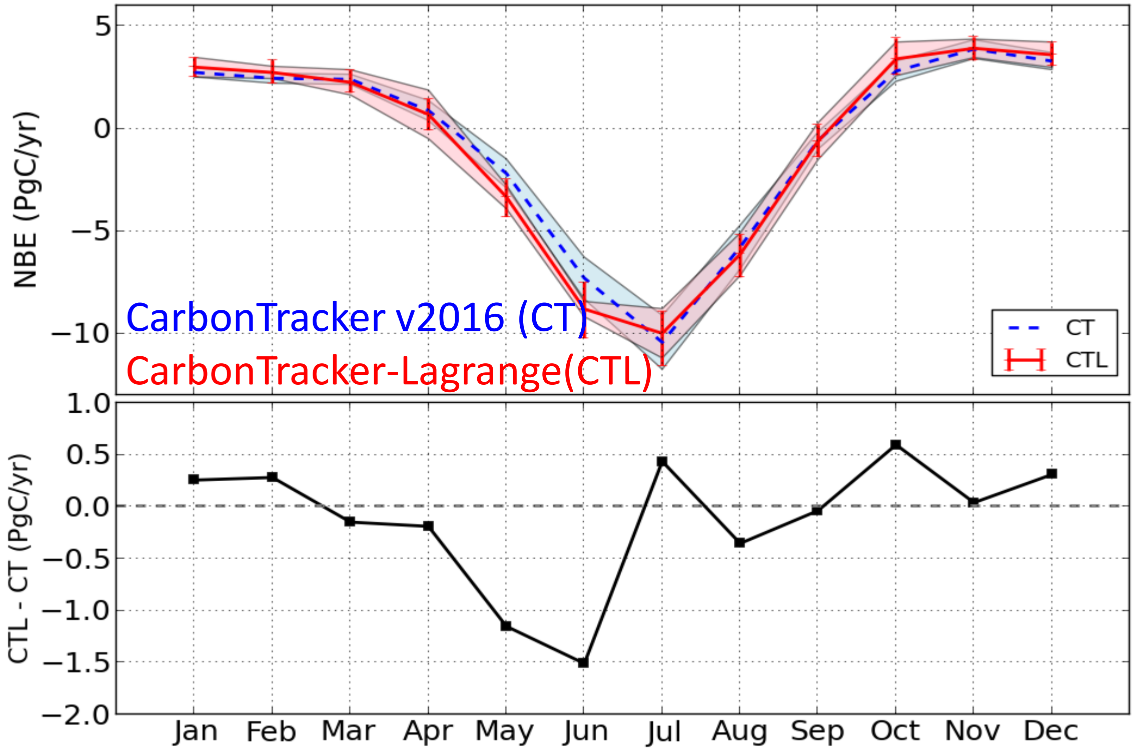
Inversion Software Documentation and Download



http://www.esrl.noaa.gov/gmd/ccgg/carbontracker-lagrange/

CT Lagrange versus CT2016 Fluxes: Long-term Mean

Multi-Year Monthly Averages (2007 – 2015)

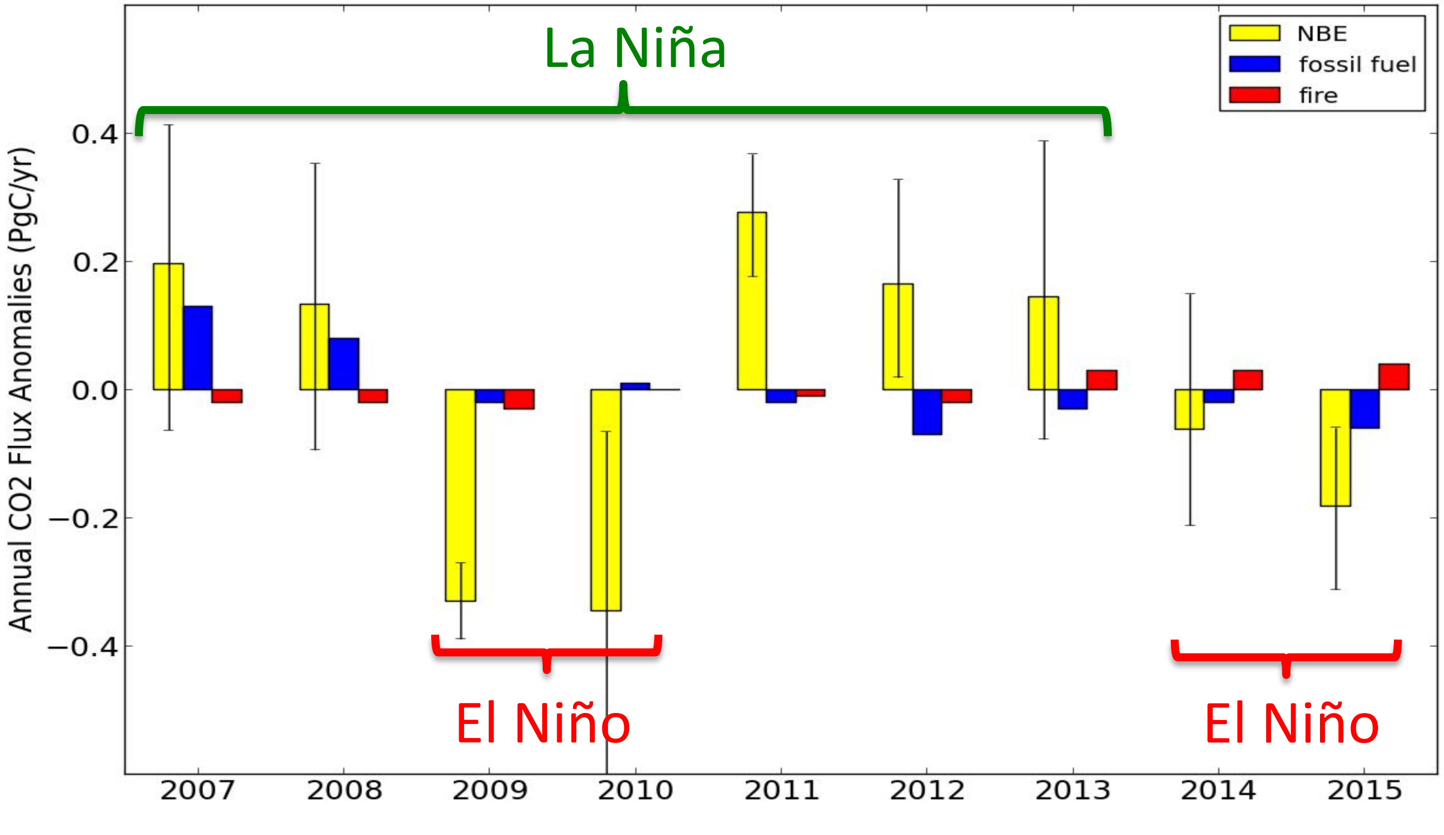


GMAC Presentation by Lei Hu

- Net biospheric uptake is similar despite very different atmospheric transport models

CT2016: -0.56±1.29 PgCyr^{-1}
CT-L: -0.70±0.92 PgCyr^{-1}

CT-L terrestrial CO_2 fluxes show emergent and persistent response to ENSO



GMAC Presentation by Lei Hu

Research Article

Nitrous oxide emissions estimated with the CarbonTracker-Lagrange North American regional inversion framework

Cynthia Nevison, Arlyn Andrews, Kirk Thoning, Ed Dlugokencky, Colm Sweeney, Scot Miller, Eri Saikawa, Joshua Benmergui, Marc Fischer, Marikate Mountain, Thomas Nehrkorn

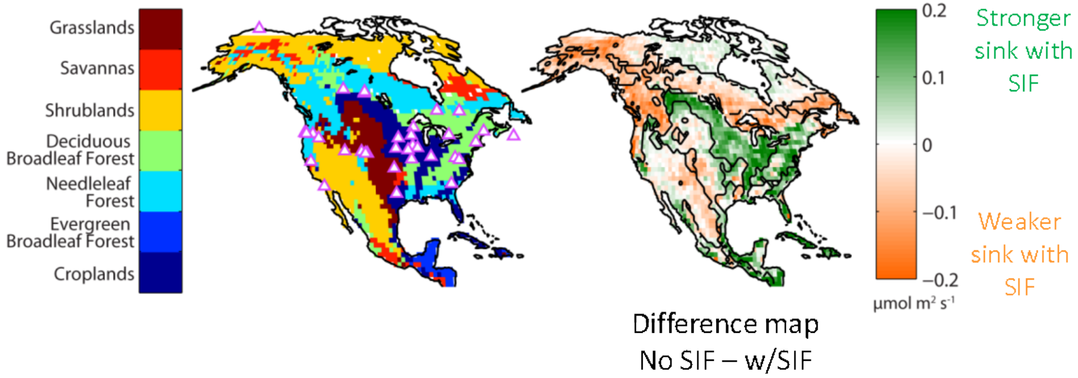
Accepted manuscript online: 1 March 2018 Full publication history

DOI: 10.1002/2017GB005759

Recent papers using the CarbonTracker-Lagrange Framework highlight our close and mutually beneficial relationships with academic researchers.

Atmospheric CO_2 observations reveal strong correlation between regional net biospheric carbon uptake and solar induced chlorophyll fluorescence

Shiga, Y. P., Tadić, J. M., Qiu, X., Yadav, V., Andrews, A. E., Berry, J. A. & Michalak, A. M. (2017) Geophysical Research Letters, 44. https://doi.org/10.1002/2017GL076630



JGR

RESEARCH ARTICLE

10.1002/2014JD022617

Journal of Geophysical Research: Atmospheres

U.S. emissions of HFC-134a derived for 2008–2012 from an extensive flask-air sampling network

Lei Hu[1,2], Stephen A. Montzka[2], John B. Miller[1,2], Aryln E. Andrews[2], Scott J. Lehman[3], Benjamin R. Miller[1,2], Kirk Thoning[2], Colm Sweeney[1,2], Huilin Chen[4], David S. Godwin[5], Kenneth Masarie[2], Lori Bruhwiler[2], Marc L. Fischer[6], Sebastien C. Biraud[7], Margaret S. Torn[7], Marikate Mountain[8], Th
Janusz Eluszkiewicz[8], Scot Miller[9], Roland R. Draxler[10], Ariel F. Stein[10], Bradley D
James W. Elkins[2], and Pieter P. Tans[2]

PNAS Proceedings of the National Academy of Sciences of the United States of America

Continued emissions of carbon tetrachloride from the United States nearly two decades after its phaseout for dispersive uses

Lei Hu, Stephen A. Montzka, Ben R. Miller, Arlyn E. Andrews, John B. Miller, Scott J. Lehman, Colm Sweeney, Scot M. Miller, Kirk Thoning, Carolina Siso, Elliot L. Atlas, Donald R. Blake, Joost de Gouw, Jessica B. Gilman, Geoff Dutton, James W. Elkins, Bradley Hall, Huilin Chen, Marc L. Fischer, Marikate E. Mountain, Thomas Nehrkorn, Sebastien C. Biraud, Fred L. Moore and Pieter Tans

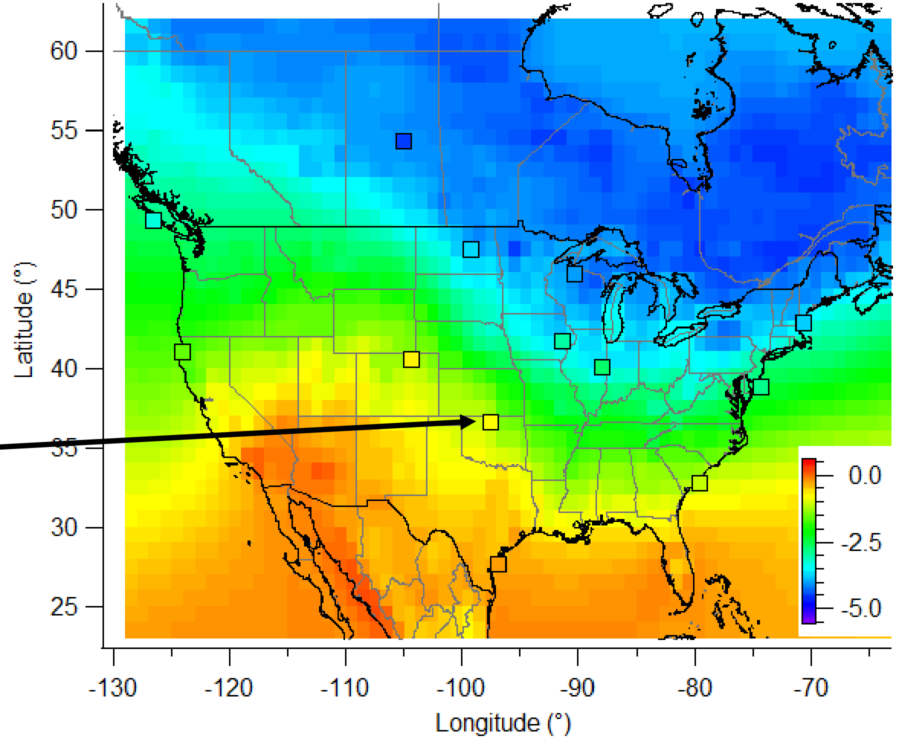
PNAS March 15, 2016. 113 (11) 2880-2885; published ahead of print February 29, 2016.
https://doi.org/10.1073/pnas.1522284113

We plan to collect top-down emissions estimates from all of these studies and make them available for download.

Satellite Retrieval and Model Evaluation

Long-term mean summer total column ΔXCO_2 from CT2015

Column ΔXCO_2 constructed from aircraft & tower data

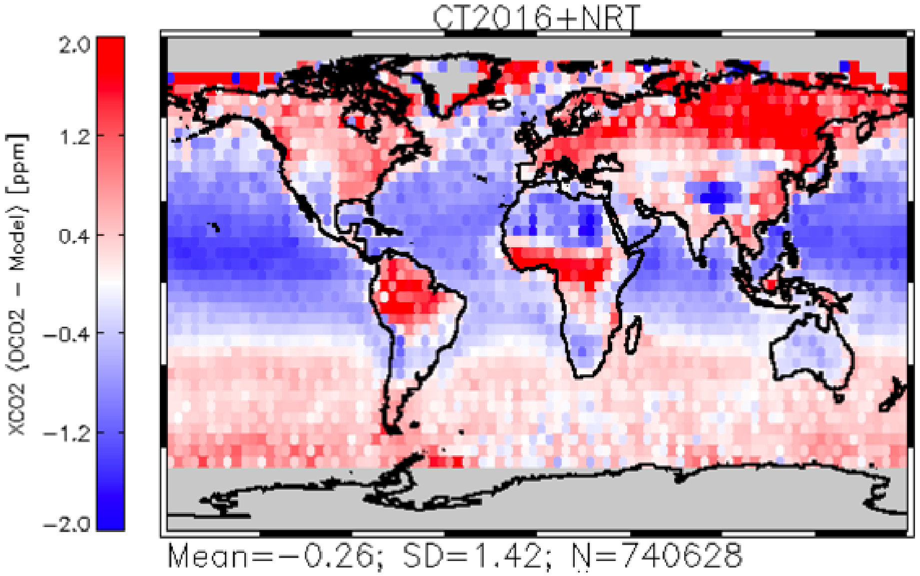


Xin Lan et al., *ACP*, 2017

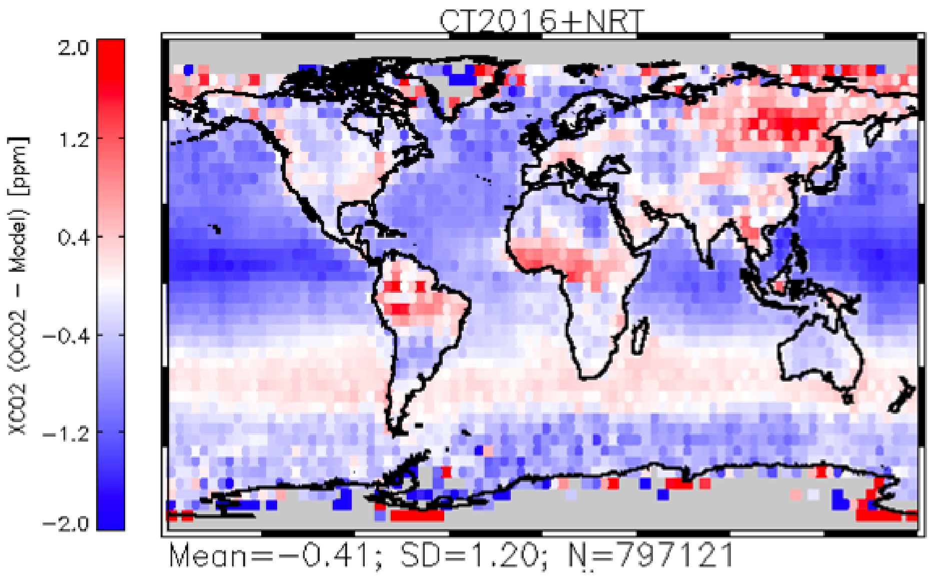
The challenge for satellite column CO_2 sensors:

- Mass balance: on average, the total column enhancement of CO_2 downwind of the U.S. is ~0.7 ppm for 1.4 Gton C/yr of emissions.
- For a 20% reduction in emissions, column would change by ~0.14 ppm.

OCO-2 Retrieval Evaluation



OCO-2 V7



OCO-2 V8

- CarbonTracker-NearRealTime is one of a suite of models used to evaluate and bias-correct OCO-2 retrievals
- CarbonTracker-NRT work is funded by NASA OCO-2 project and enables quick evaluation of retrievals and assessment of information content
- The CarbonTracker Team prepares observations and provides to all the other modeling teams along with information about CarbonTracker data selection and weighting

GMAC Presentation by Andy Jacobson

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2016JD026157

U.S. CH_4 emissions from oil and gas production: Have recent large increases been detected?

L. M. Bruhwiler[1], S. Basu[2], P. Bergamaschi[3], P. Bousquet[4], E. Dlugokencky[1], S. Houweling[5,6], M. Ishizawa[7], H.-S. Kim[7], R. Locatelli[4], S. Maksyutov[7], S. Montzka[1], S. Pandey[5,6], P. K. Patra[8], G. Petron[2], M. Saunois[4], C. Sweeney[2], S. Schwietzke[2], P. Tans[1], and E. C. Weatherhead[2]

[1]NOAA Earth System Research Laboratory, Boulder, Colorado, USA, [2]Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [3]European Commission, Joint Research Centre, Ispra, Italy, [4]Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS-UVSQ, IPSL, Gif sur Yvette, France, [5]SRON Netherlands Institute for Space Research, Utrecht, Netherlands, [6]Institute for Marine and Atmospheric Research Utrecht, Utrecht, Netherlands, [7]National Institute for Environmental Studies, Tsukuba, Japan, [8]Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan

Key Points:

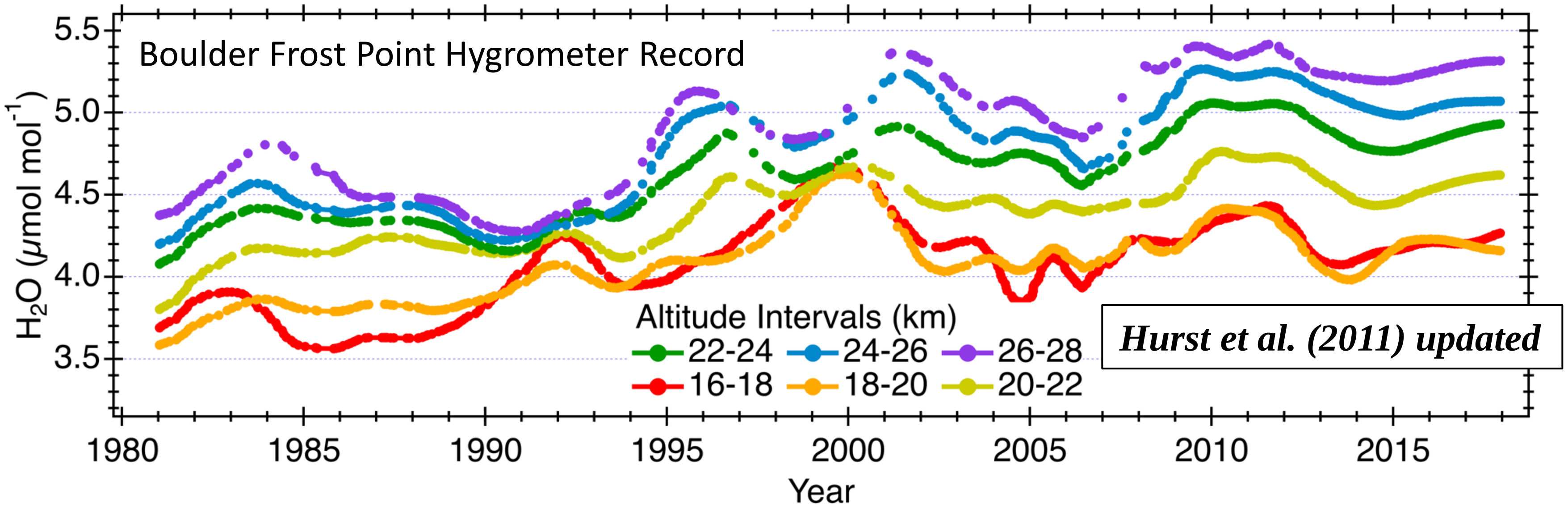
- Atmospheric inversions using in situ observations do not support large increases in CH_4 emissions from U.S. oil and gas production
- Short-term trends in spatial gradients of CH_4 column abundance are not sensitive to changes in emissions due to atmospheric variability
- Temporal sampling gaps in satellite retrievals and choices of background can give spurious trends in column average CH_4 gradients

- Temporal sampling biases cause apparent relative trends.
- Choice of inappropriate background contributes to spurious trend
- Additional aircraft profile data would enable reliable trend detection

Monitoring Greenhouse Gases in the Upper Atmosphere

photo credit: Patrick Cullis (patrick.cullis@noaa.gov)

Long-Term Monitoring of Upper Troposphere/Lower Stratosphere (UTLS) Water Vapor



Net increase in UTLS water vapor: Positive climate forcing feedback

- Strong absorber of outgoing long wave radiation, weak thermal emission to space
- Climate change warms the tropical tropopause layer, increasing UTLS water vapor
- Additional UTLS water vapor absorbs more outgoing long wave radiation

Changes in UTLS water vapor have a significant impact on surface temperatures

- The ~1 mmol mol^{-1} (~25%) increase in [UTLS water vapor] between 1980 and 2000 would have enhanced the rate of surface warming in the 1990s by ~30% ***Solomon et al. (2010)***

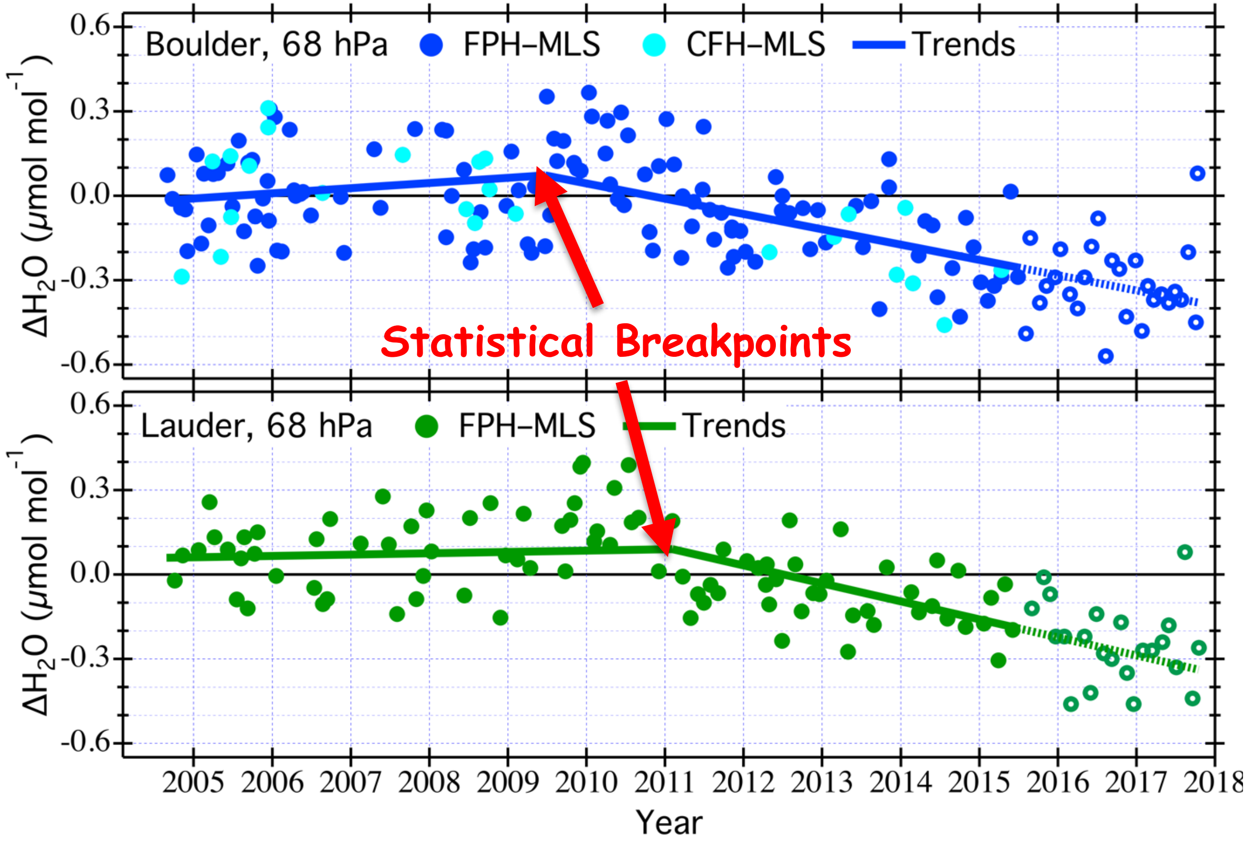
GMAC Presentation by Dale Hurst

Long-Term Monitoring of UTLS Water Vapor

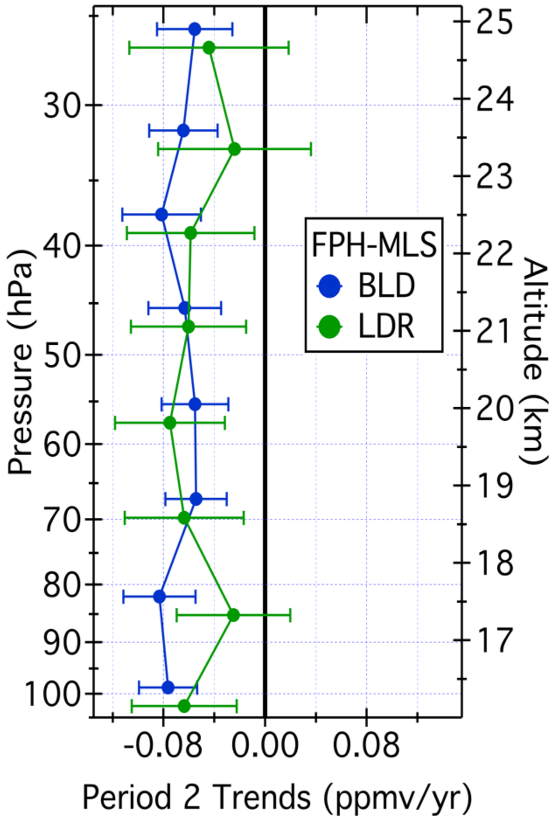
Validation of Satellite-Based Measurements

Satellite-based instruments provide near-global coverage but are susceptible to biases and/or drifts in their measurements

Differences in Coincident Measurements: FPH-MLS

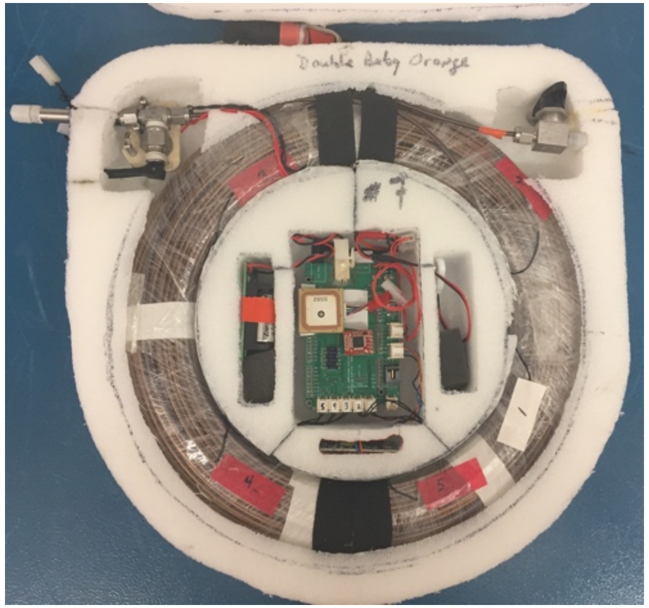


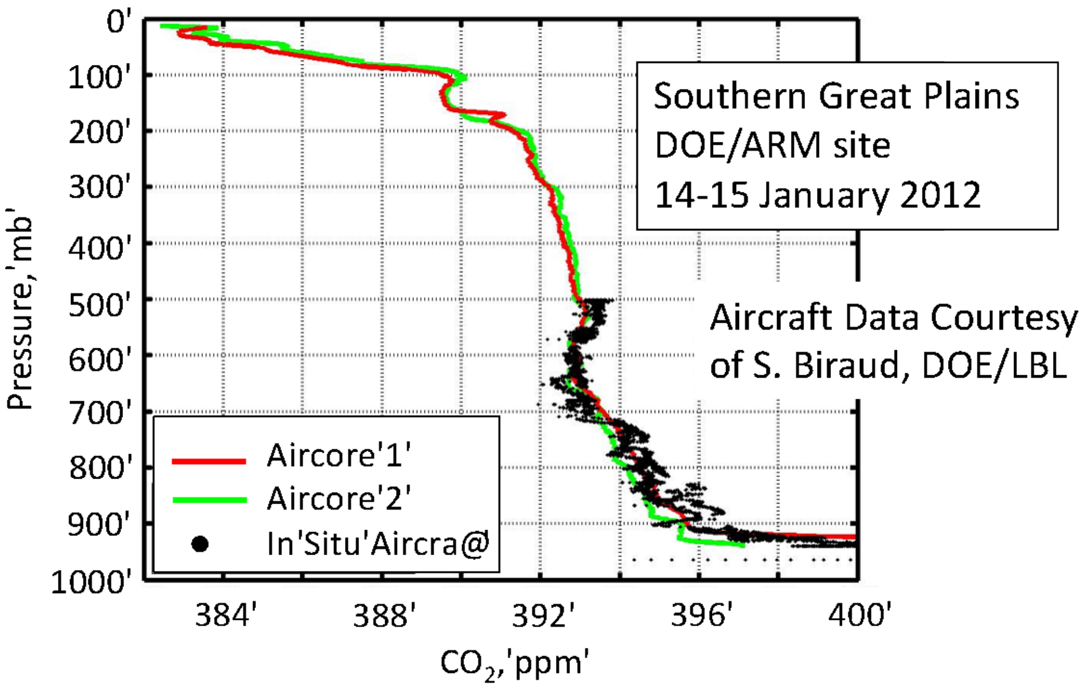
Post-breakpoint Trends



updated from Hurst et al. (2016)

AirCore for Surface to Stratosphere GHG Sampling: CO_2, CH_4, CO



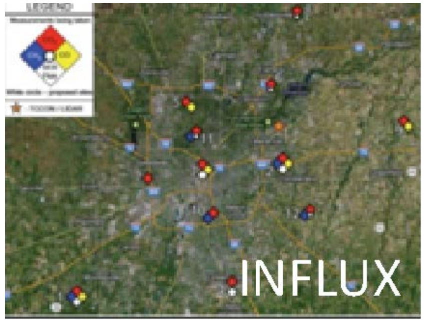


- > 70 flights starting in 2012
  - New twin AirCore provides paired sampling to ensure repeatabilty
- OCO-2 Science Team
  - Direct comparison with TCCON & OCO-2 underflights
  - Improved stratospheric prior
- Analysis of stratospheric Mean Age as a tracer of the Brewer-Dobson circulation
- Evaluation of stratospheric simulations in CarbonTracker and other models

GMAC Poster by Colm Sweeney

Intensive Field Campaigns & Capacity Building

GMD Participation in Intensive Measurement Campaigns Leverages and Complements our Monitoring Efforts

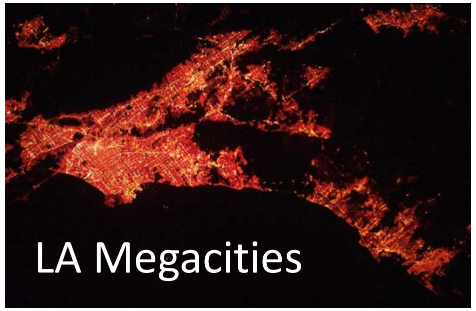


CARVE
CARBON IN ARCTIC RESERVOIRS VULNERABILITY EXPERIMENT

NASA ATom
ATMOSPHERIC TOMOGRAPHY MISSION
EVS-2

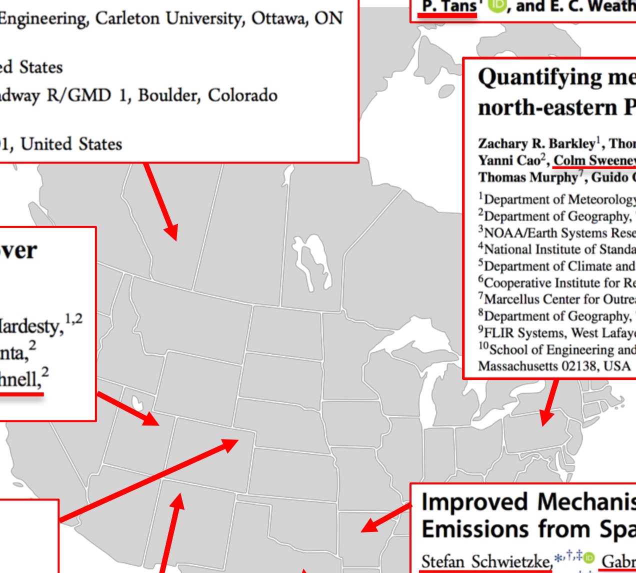
ECO

East Coast Outflow



ORCAS
O_2/N_2 Ratio and CO_2 Airborne Southern Ocean Study 2016

GMD's footprint on oil & gas methane research in N. America



Comparisons of Airborne Measurements and Inventory Estimates of Methane Emissions in the Alberta Upstream Oil and Gas Sector

Matthew R. Johnson,[*,†] David R. Tyner,[†] Stephen Conley,[‡] Stefan Schwietzke,[§] and Daniel Zavala-Araiza[∥]

[†]Energy & Emissions Research Laboratory, Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON Canada, K1S 5B6

[‡]Scientific Aviation, Inc., 3335 Airport Road Suite B, Boulder, Colorado 80301, United States

[§]CIRES/University of Colorado, NOAA ESRL Global Monitoring Division, 325 Broadway R/GMD 1, Boulder, Colorado 80305-3337, United States

[∥]Environmental Defense Fund, 301 Congress Avenue Suite 1300, Austin, Texas 78701, United States

U.S. CH_4 emissions from oil and gas production: Have recent large increases been detected?

L. M. Bruhwiler[1], S. Basu[2], P. Bergamaschi[3], P. Bousquet[4], E. Dlugokencky[1], S. Houweling[5,6], M. Ishizawa[7], H.-S. Kim[7], R. Locatelli[4], S. Maksyutov[7], S. Montzka[1], S. Pandey[5,6], P. K. Patra[8], G. Petron[2], M. Saunois[4], C. Sweeney[2], S. Schwietzke[2], P. Tans[1], and E. C. Weatherhead[2]

Quantifying methane emissions from natural gas production in north-eastern Pennsylvania

Zachary R. Barkley[1], Thomas Lauvaux[1], Kenneth J. Davis[1], Aijun Deng[1], Natasha L. Miles[1], Scott J. Richardson[1], Yanni Cao[2], Colm Sweeney[3], Anna Karion[4], MacKenzie Smith[5], Eric A. Kort[6], Stefan Schwietzke[6], Thomas Murphy[7], Guido Cervone[8], Douglas Martins[9], and Joannes D. Maasakkers[10]

[1]Department of Meteorology, The Pennsylvania State University, University Park, PA 16802, USA
[2]Department of Geography, The Pennsylvania State University, University Park, PA 16802, USA
[3]NOAA/Earth Systems Research Laboratory, University of Colorado, Boulder, CO, 80305, USA
[4]National Institute of Standards and Technology, Gaithersburg, MD 20899, USA
[5]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI, 48109, USA
[6]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado, USA
[7]Marcellus Center for Outreach and Research, The Pennsylvania State University, University Park, PA 16802, USA
[8]Department of Geography, The Pennsylvania State University, University Park, PA 16802, USA
[9]FLIR Systems, West Lafayette, IN 47906, USA
[10]School of Engineering and Applied Sciences, Harvard University, Pierce Hall, 29 Oxford Street, Cambridge, Massachusetts 02138, USA

Methane emissions estimate from airborne measurements over a western United States natural gas field

Anna Karion,[1,2] Colm Sweeney,[1,2] Gabrielle Pétron,[1,2] Gregory Frost,[1,2] R. Michael Hardesty,[1,2] Jonathan Kofler,[1,2] Ben R. Miller,[1,2] Tim Newberger,[1,2] Sonja Wolter,[1,2] Robert Banta,[2] Alan Brewer,[2] Ed Dlugokencky,[2] Patricia Lang,[2] Stephen A. Montzka,[2] Russell Schnell,[2] Pieter Tans,[2] Michael Trainer,[2] Robert Zamora,[2] and Stephen Conley[3]

Improved Mechanistic Understanding of Natural Gas Methane Emissions from Spatially Resolved Aircraft Measurements

Stefan Schwietzke,[*,†,‡] Gabrielle Pétron,[†,‡] Stephen Conley,[§,∥] Cody Pickering,[⊥] Ingrid Mielke-Maday,[†,‡] Edward J. Dlugokencky,[‡] Pieter P. Tans,[‡] Tim Vaughn,[⊥] Clay Bell,[⊥] Daniel Zimmerle,[⊥] Sonja Wolter,[†,‡] Clark W. King,[‡] Allen B. White,[‡] Timothy Coleman,[†,‡] Laura Bianco,[†,‡] and Russell C. Schnell[‡]

[†]Cooperative Institute for Research in Environmental Sciences, University of Colorado, 216 UCB, Boulder, Colorado 80309, United States

[‡]NOAA Earth System Research Laboratory, 325 Broadway, Boulder, Colorado 80305, United States

[§]Scientific Aviation, Inc., 3335 Airport Road Suite B, Boulder, Colorado 80301, United States

[∥]Department of Land, Air, and Water Resources, University of California, One Shields Avenue, Davis, California 95616, United States

[⊥]Department of Mechanical Engineering, Colorado State University, 400 Isotope Dr, Fort Collins, Colorado 80521, United States

Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study

Gabrielle Pétron,[1,2] Gregory Frost,[1,2] Benjamin R. Miller,[1,2] Adam I. Hirsch,[1,3] Stephen A. Montzka,[2] Anna Karion,[1,2] Michael Trainer,[2] Colm Sweeney,[1,2] Arlyn E. Andrews,[2] Lloyd Miller,[4] Jonathan Kofler,[1,2] Amnon Bar-Ilan,[5] Ed J. Dlugokencky,[2] Laura Patrick,[1,2] Charles T. Moore Jr.,[6] Thomas B. Ryerson,[2] Carolina Siso,[1,2] William Kolodzey,[7] Patricia M. Lang,[2] Thomas Conway,[2] Paul Novelli,[2] Kenneth Masarie,[2] Bradley Hall,[2] Douglas Guenther,[1,2] Duane Kitzis,[1,2] John Miller,[1,2] David Welsh,[2] Dan Wolfe,[2] William Neff,[2] and Pieter Tans[2]

Airborne Quantification of Methane Emissions over the Four Corners Region

Mackenzie L. Smith,[†] Alexander Gvakharia,[†] Eric A. Kort,[*,†] Colm Sweeney,[‡,§] Stephen A. Conley,[∥,⊥] Ian Faloona,[⊥] Tim Newberger,[‡,§] Russell Schnell,[§] Stefan Schwietzke,[‡,§] and Sonja Wolter[‡,§]

[†]Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, Michigan 48109, United States

[‡]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado 80309, United States

[§]NOAA Earth System Research Laboratory, Boulder, Colorado 80305, United States

[∥]Scientific Aviation, Boulder, Colorado 80301, United States

[⊥]Department of Land, Air, & Water Resources, University of California Davis, Davis, California 95616, United States

Aircraft-Based Estimate of Total Methane Emissions from the Barnett Shale Region

Anna Karion,[*,†,‡] Colm Sweeney,[†,‡] Eric A. Kort,[§] Paul B. Shepson,[∥] Alan Brewer,[‡] Maria Cambaliza,[∥,Δ] Stephen A. Conley,[⊥] Ken Davis,[#] Aijun Deng,[#] Mike Hardesty,[†,‡] Scott C. Herndon,[∇] Thomas Lauvaux,[#] Tegan Lavoie,[∥] David Lyon,[○] Tim Newberger,[†,‡] Gabrielle Pétron,[†,‡] Chris Rella,[◆] Mackenzie Smith,[§] Sonja Wolter,[†,‡] Tara I. Yacovitch,[∇] and Pieter Tans[‡]

Brazilian Replica of the NOAA Flask Analysis Lab:

Lab. de Química Atmosférica CQMA/IPEN
Réplica do Laboratório da NOAA/ESRL/GMD
(National Oceanic Atmospheric Administration / Earth System Research Laboratory / Global Monitoring Division)

INPE

Luciana V. Gatti , Andrew Crotwell, Kirk Thoning, Ed Dlugokencky, John B. Miller , and many others

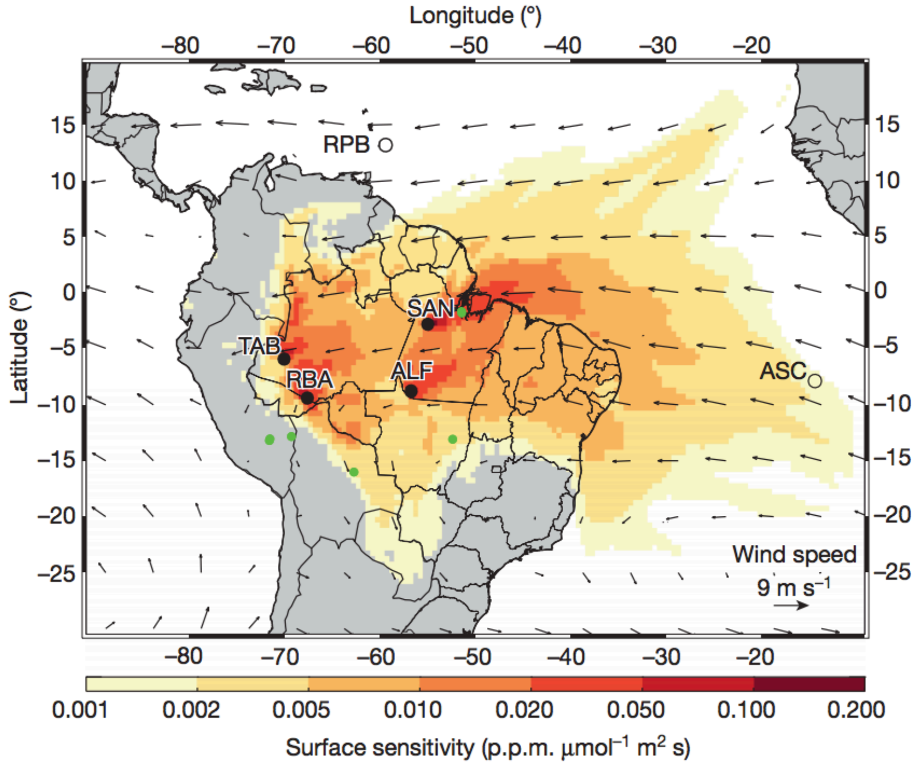
LETTER

doi:10.1038/nature12957

Drought sensitivity of Amazonian carbon balance revealed by atmospheric measurements

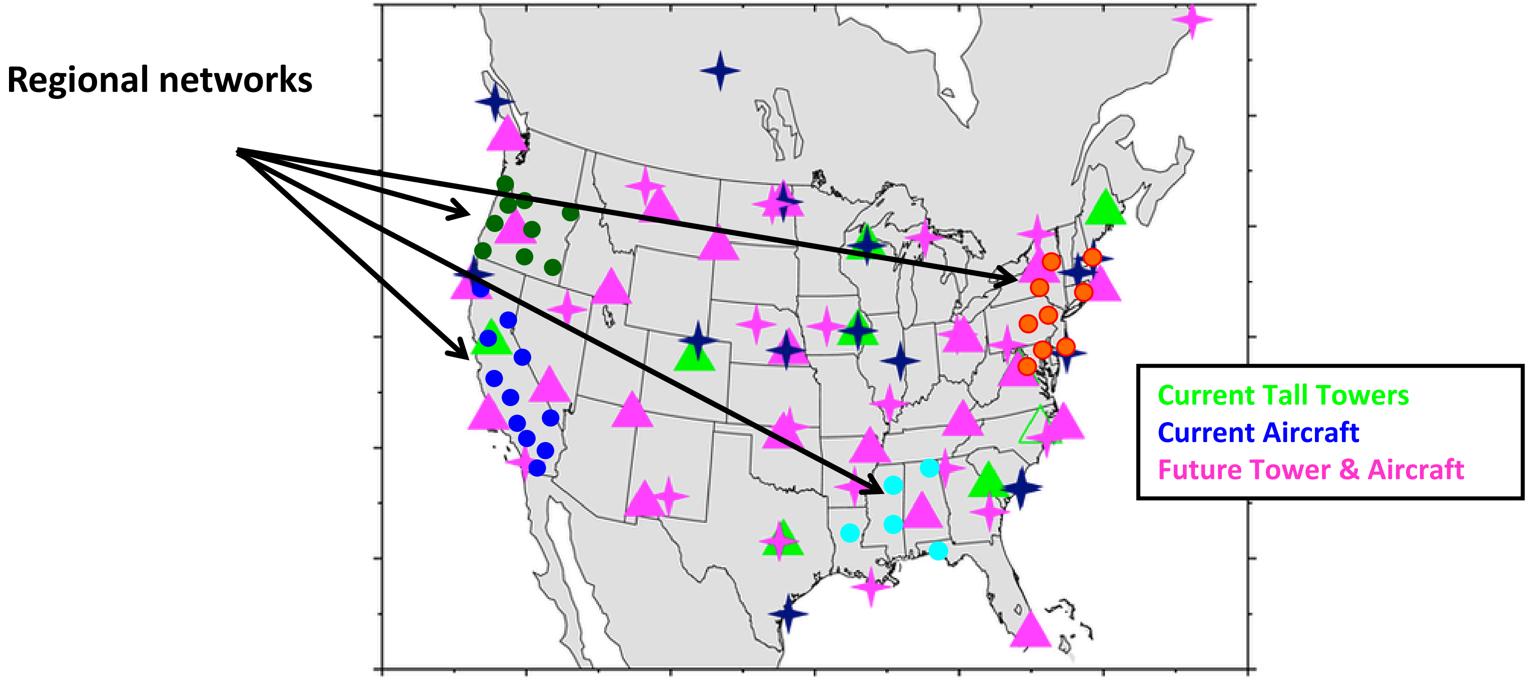
L. V. Gatti[1]*, M. Gloor[2]*, J. B. Miller[3,4]*, C. E. Doughty[5], Y. Malhi[5], L. G. Domingues[1], L. S. Basso[1], A. Martinewski[1], C. S. C. Correia[1], V. F. Borges[1], S. Freitas[6], R. Braz[6], L. O. Anderson[5,7], H. Rocha[8],

10+ year collaboration has enabled creation of aircraft network and new insights into Amazonian fluxes.



Looking forward

1) Develop Partnerships and Links with Regional Networks



- Obtaining tower leases through the federal government is cost prohibitive and slow. Better to work with partners whenever possible.
- Opportunities exist to strengthen ties with regional monitoring efforts already underway: California Air Resources Board, Earth Networks, Baltimore/DC, Oregon State University, Penn State University

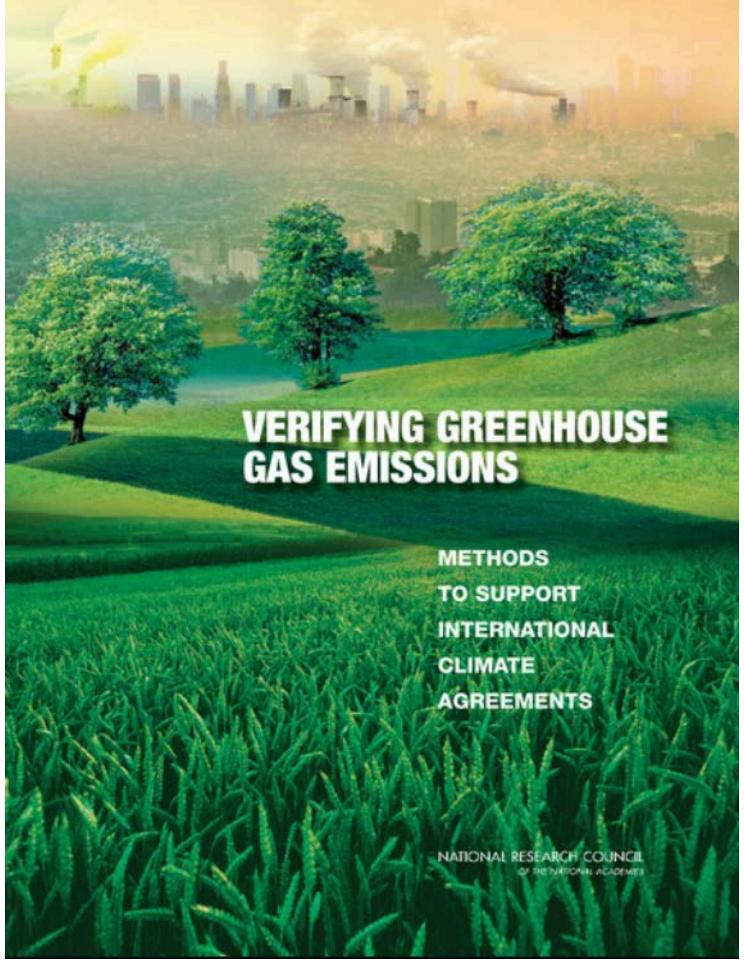
2) Increase radiocarbon sampling to constrain estimates of fossil fuel CO_2 emissions

Separation of biospheric and fossil fuel fluxes of CO_2 by atmospheric inversion of CO_2 and $^{14}CO_2$ measurements: Observation System Simulations

Sourish Basu[1,2], John Bharat Miller[1,2], and Scott Lehman[3]

[1]Global Monitoring Division, NOAA Earth System Research Laboratory, Boulder CO, USA
[2]Cooperative Institute for Research in Environmental Science, University of Colorado, Boulder CO, USA
[3]Institute for Arctic and Alpine Research, University of Colorado Boulder, Boulder CO, USA

Atmos. Chem. Phys., 16, 5665–5683, 2016
www.atmos-chem-phys.net/16/5665/2016/
doi:10.5194/acp-16-5665-2016



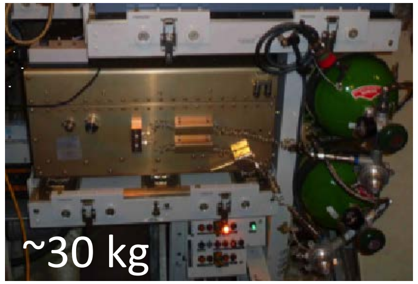
- 5000 $\Delta^{14}CO_2$ measurements per year will allow us to determine fossil fuel CO_2 emissions using atmospheric data and improve estimates of biological emissions and removals.
- The new U of CO/INSTAAR building was designed with laboratory infrastructure to host a dedicated accelerator mass spectrometer facility.

GMAC Presentation by Sourish Basu

3) Commercial Aircraft Measurements of CO_2, CH_4 and H_2O

Japanese and European programs already exist for a limited number of long-haul aircraft (5 CONTRAIL and 10 IAGOS aircraft):

IAGOS
CO_2/CH_4/H_2O Analyzer:

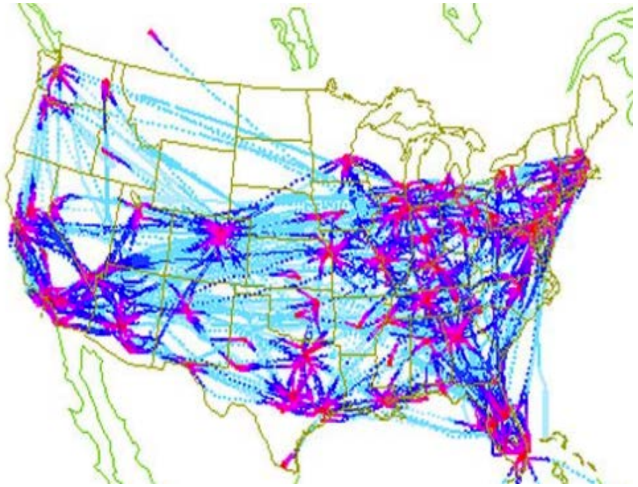


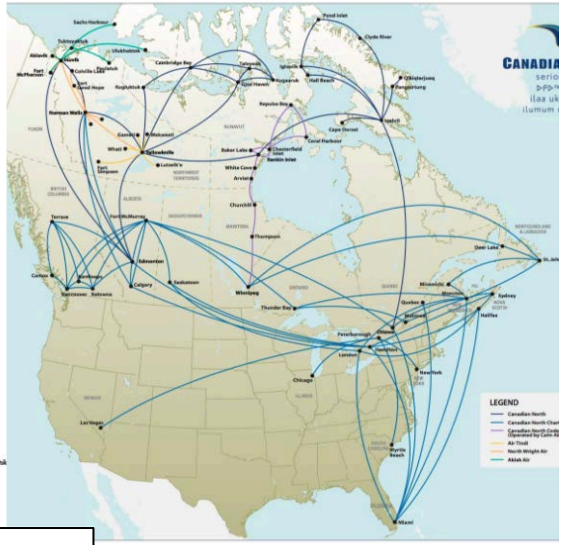
The US National Weather Service has a regional commercial aircraft program to measure water vapor:

3.5 kg

137 aircraft
>1000 profiles per day

These systems use 10-20 year old technology. A next-generation commercial aircraft greenhouse gas analyzer would provide reliable measurements in a lightweight and compact package for deployment on regional jets.





*Route maps shown are examples only to illustrate what type of coverage is possible. The airlines have not been contacted with regard to this project.

Science Priorities

Vulnerable Carbon Reservoirs

- Arctic: Track Emissions from Permafrost Release
- Amazon: Monitor Uptake from Tropical Forests

Carbon Accounting for Decision Support

- CONUS

Estimated Cost: < $10M per year

5 year goal: Implementation on 10 aircraft covering CONUS and Alaska

10 year goal: Establish international partnerships to extend coverage over Arctic and Amazon.

GMD’s Role in an Integrated Greenhouse Gas Observing System

Take Home Messages

- We are creating an unassailable and well-documented record of greenhouse gases.
- We try to help society deal with the climate problem:
  - *Create a quantitative record of climate forcing.*
  - *Quantify and diagnose the response of the natural carbon cycle and greenhouse gas budgets to climate change.*
  - *Evaluate potential "surprises" and give early warning if warranted.*
  - *Support mitigation by providing objective and transparent verification of emissions.*
- Close relationships between measurers and modelers have kept us at the forefront of carbon science and are crucial to continued success.
- GMD anchors the global and US atmospheric carbon observing network. We have established ongoing comparisons with all of the major laboratories. We rely on partnerships with other labs and institutions.
- We have just begun to reap the scientific rewards of our investment in North American monitoring – multiple-species analysis will provide critical process constraints and enable improved source attribution.

"Science-driven monitoring of the atmosphere, responding to societal needs"