Theme 1

Tracking Greenhouse Gases and Understanding Carbon Cycle Feedbacks

Outline

Overview of GML's Capabilities and Context — Arlyn Andrews

Diagnosing the Carbon Cycle and Understanding Carbon: Climate Feedback Mechanisms — Lei Hu

Quantifying Anthropogenic Emissions — John Miller

The Future of Observing and Analyzing GHGs at GML— Colm Sweeney

Q&A with Panel

Theme 1: Overview

Overview of GML’s Greenhouse Gas Capabilities and Context

Arlyn Andrews

Question 1 - Diagnosing Earth's climate system, reducing uncertainties & addressing societal challenges

Question 2 - GML’s three pillars: Sustained Observations, Standards, Technological Innovation

Question 4 - Supporting the US GHG Measurement Monitoring and Information System (GHGMMIS)

GML is a world leader in GHG measurements and their interpretation

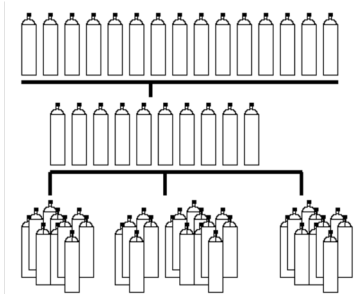
Measurements

- Global Greenhouse Gas Reference Network
- WMO Central Calibration Laboratory

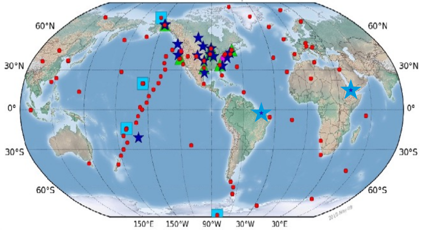
Greenhouse gas data analysis and assimilation

- Tracking greenhouse gas trends
- CarbonTracker - CO_2 and CH_4
- National estimates of GHG emissions

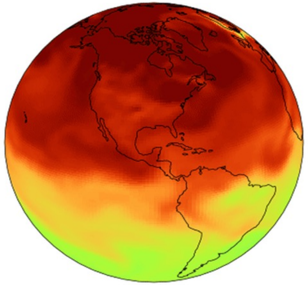
WMO CCL



GGGRN



CarbonTracker



GML occupies a key position in the research → operations continuum

- Transitioning existing research systems toward operations
  → **reliably deliver state-of-the-science data, products and services**
- Ongoing improvement of process models via research partnerships
  → **improved climate projections**

NOAA GML's GHG activities support US federal and international climate mitigation and adaptation efforts

NATIONAL STRATEGY TO ADVANCE AN INTEGRATED U.S. GREENHOUSE GAS MEASUREMENT, MONITORING, AND INFORMATION SYSTEM

U.S. Greenhouse Gas Center

Uniting Data and Technology to Empower Tomorrow's Climate Solutions

GlobalChange.gov

U.S. Global Change Research Program

Climate.gov

SCIENCE & INFORMATION FOR A CLIMATE-SMART NATION

United Nations Framework Convention on Climate Change

ipcc INTERGOVERNMENTAL PANEL ON climate change

30 MONTREAL PROTOCOL

PARIS2015

WORLD METEOROLOGICAL ORGANIZATION

IG3IS Integrated Global Greenhouse Gas Information System

GLOBAL GREENHOUSE GAS WATCH (G3W)

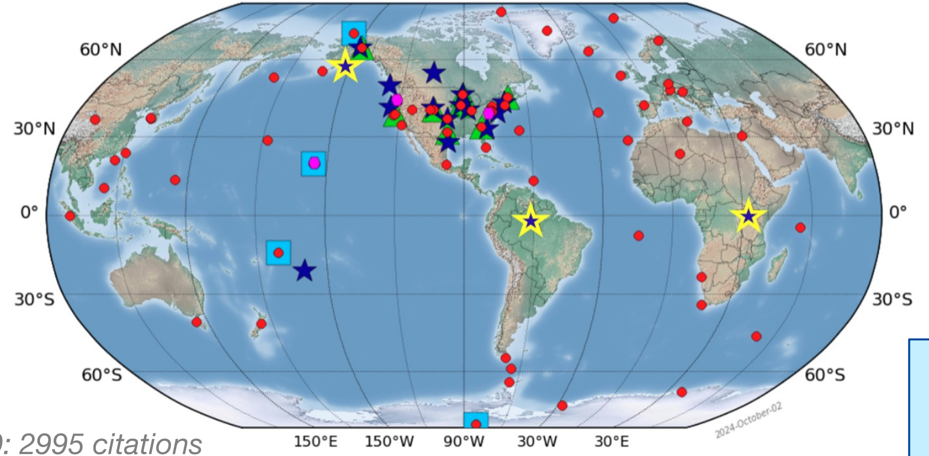
Vision: NOAA Greenhouse Gas Monitoring and Information Services to Build a Climate Ready Nation

New NOAA GHG Technical Team

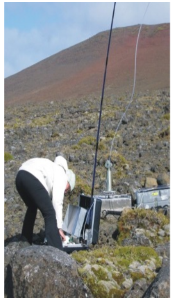
NOAA’s Global Greenhouse Gas Reference Network

- **Comprehensive, long-term, well-calibrated** atmospheric measurements of GHG mole fractions
- **Site/variability-dependent** measurement strategy
- GGGRN measurements **anchor and complement** satellite GHG products

Aircraft Flask (15)
Surface In Situ (3)
Surface Flask (70)
Observatory (4)
Tower (8)
Aircraft In Situ (3)

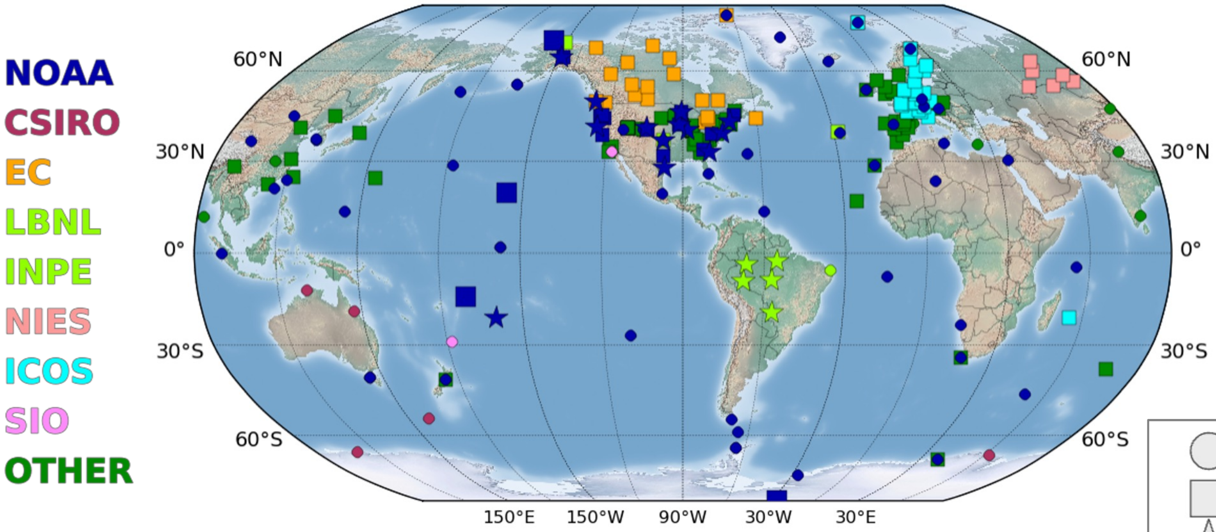


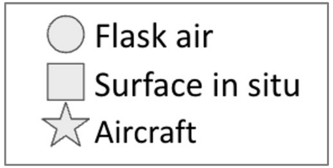
Tans et al 1990, Science, 1990: 2995 citations
P Tans: 20,873 citing articles
E Dlugokencky: 13,303 citing articles



Unique measurements per year: 145K (flask air) + 270K (hourly ABOs/towers/mountains) +600K (30 second aircraft in situ) ≈1 million

Towards an International GHG Reference Network





GML provides community data products:

Current ObsPack Data Products

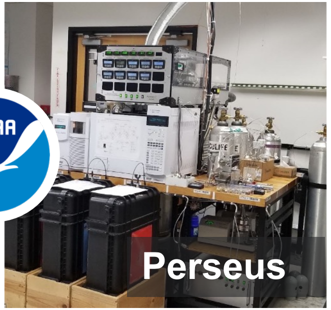
GLOBALVIEWplus CO_2

2968 Downloads FY2018-2024
1848 Unique emails

- Regional programs are loosely coordinated under WMO Global Atmosphere Watch (GAW).
- New WMO Global Greenhouse Gas Watch aims to improve standardization, latency, address coverage gaps.

GGGRN elements: Multi-species analysis of air samples

- Common suite of rigorously calibrated laboratory analyzers → global consistency over decades
- Comprehensive suite of GHGs and related species → process understanding and source sector attribution



NOAA Global Monitoring Laboratory

- Major GHGs: CO_2 , CH_4, N_2O
- Minor GHGs: CFCs, HCFCs, HFCs, SF_6 (“F-gases”)
- Process tracers: Carbonyl Sulfide, CO, H_2, Hydrocarbons

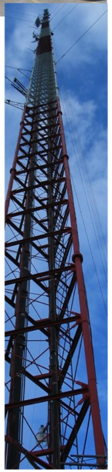
Institute of Arctic and Alpine Research, University of Colorado

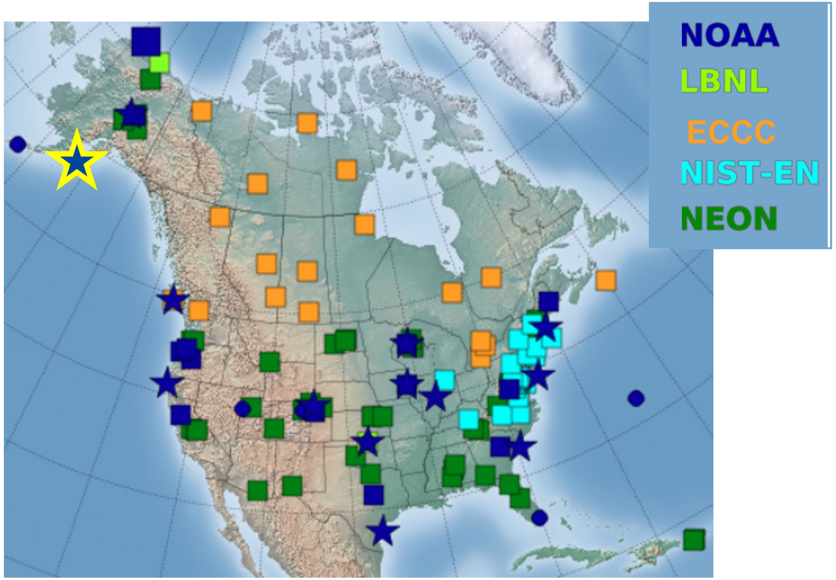
- Stable isotopes: $\delta\,^{13}C\text{-}CO_2$, $\delta^{18}O\text{-}CO_2$, $\delta\,^{13}C\text{-}CH_4$, $\delta D\text{-}CH_4$
- Radiocarbon: $\Delta^{14}CO_2$, $\Delta^{14}CH_4$

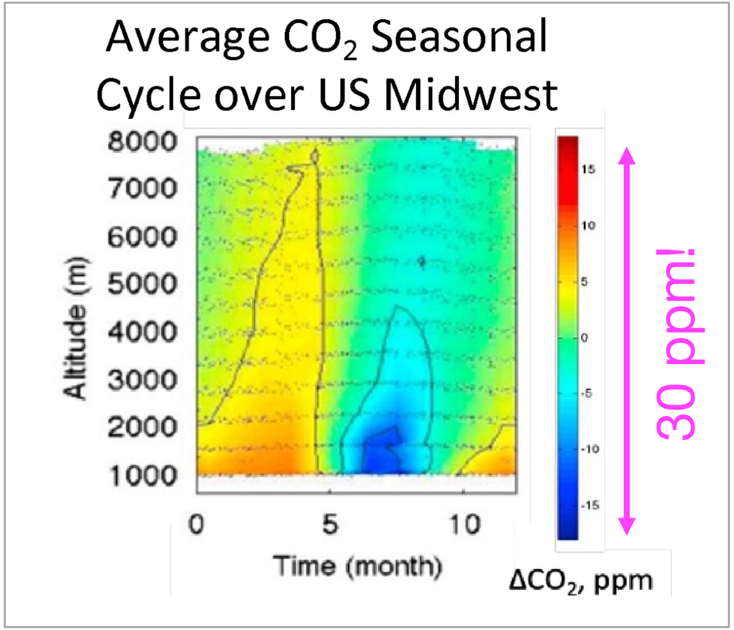
Scripps Institution of Oceanography

- Long-term ocean uptake: O_2/N_2 & Ar/N_2

GGGRN elements: Enhanced resolution over the US







- Continuous monitoring from tall towers and high elevation sites.
- Multi-species vertical profile measurements (~300 profiles/yr).

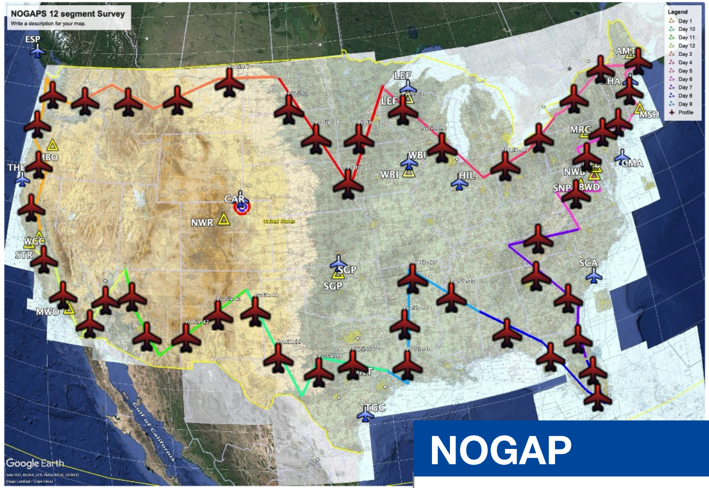
Sweeney et al., 2015: 145 citations
Andrews et al., 2013: 181 citations, 5100 downloads

- NOAA Sustained Atmospheric Observations (SAO) funding supports modernizing, maintenance.
- Opportunities exist for expanded partnerships with other US agency programs.

GGGRN elements: Regional aircraft in situ sampling

Addressing global coverage gaps over climate-sensitive regions

Repeat US intensive sampling

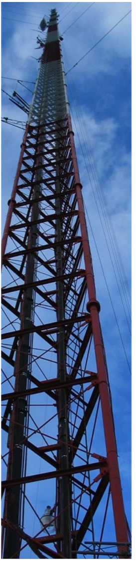


NOGAP

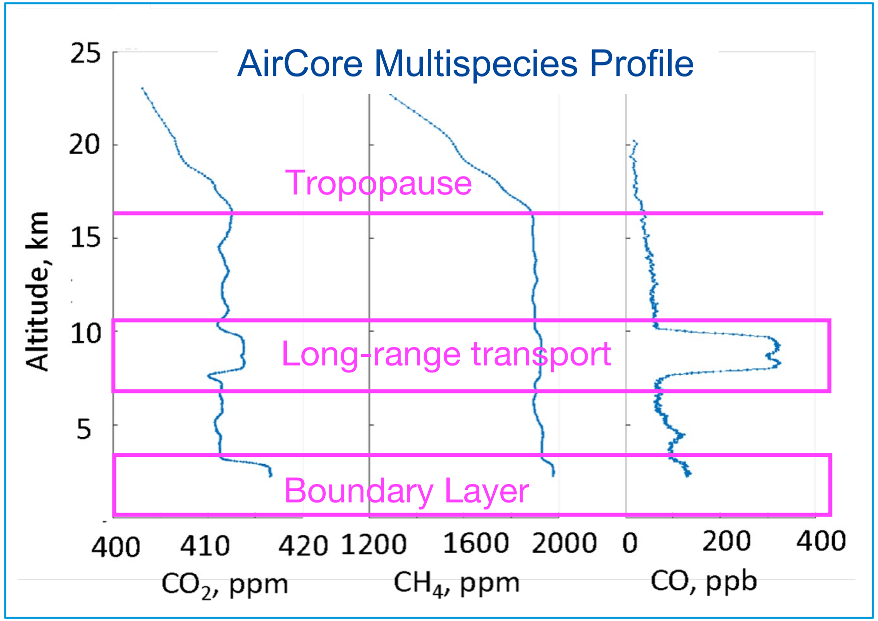
- ~100 profiles per circuit
  - $CO_2/CH_4/CO/H_2O$
  - Winds
  - Flasks
- 6 circuits per year

Supported by NOAA SAO funding

GGGRN elements: Colorado surface-to-stratosphere supersite

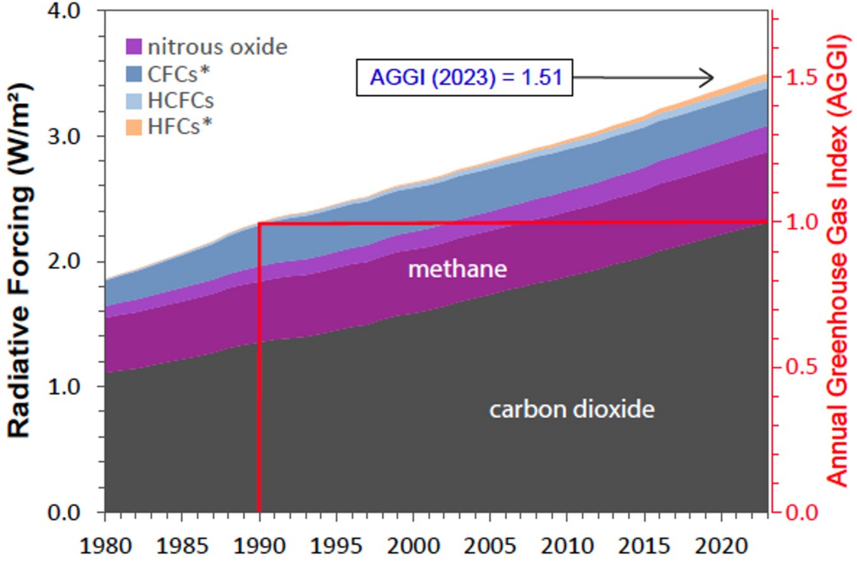


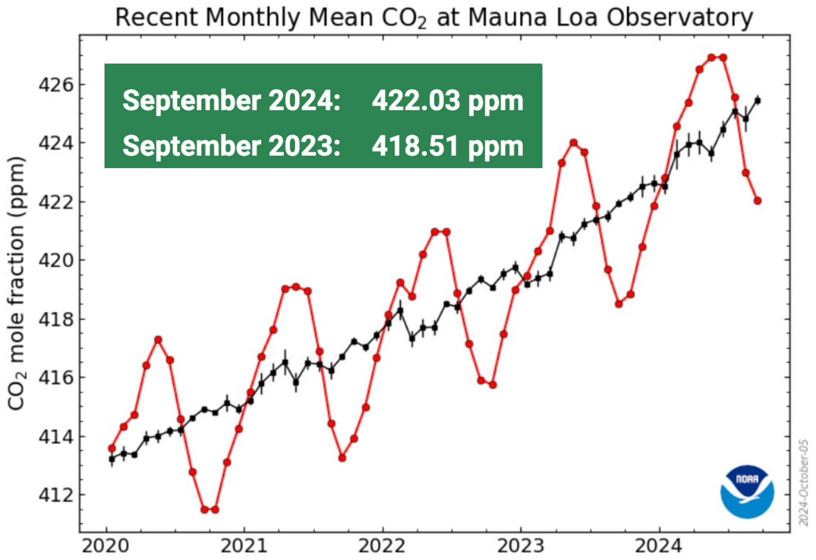
AirCore: Karion et al, 2010, 142 Citations



- Direct evaluation of satellite retrievals
- High-definition profiles → strong constraints on transport and process models
- Supported by NOAA SAO & Earth Radiation Budget with help from NESDIS, NASA
- Opportunity: add boundary layer sensors, ceilometer, ozone, additional species

GGGRN products: Tracking global distributions and trends





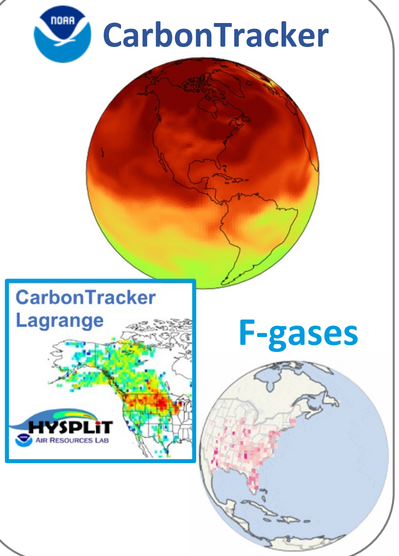
https://gml.noaa.gov/ccgg/trends/global.html

- Effective radiative forcing from anthropogenic GHGs now 1.5 times 1990 level.
- CO_2 dominates and accounts for majority of the trend.

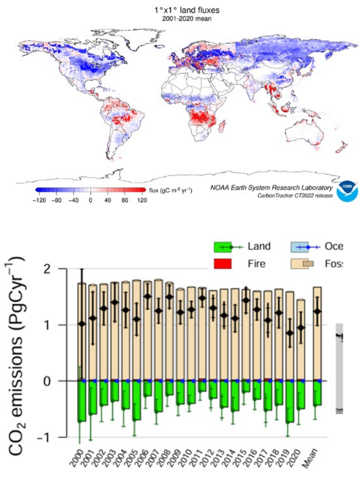
Tracking regional GHG emissions and removals

Atmospheric observations

Data assimilation



Optimized estimates of emissions & removals

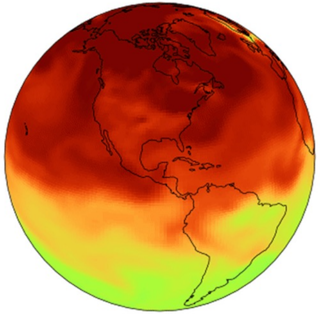


Observing system improvements

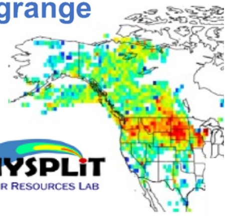
Process model & assimilation strategy improvements

Overview of NOAA CarbonTracker capabilities and context

CarbonTracker

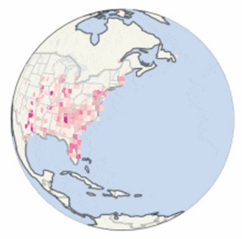


CarbonTracker Lagrange



HYSPLIT
AIR RESOURCES LAB

F-gases



Quasi-operational products

Global

- CO_2, CH_4
- (N_2O - aspirational)

National/North America

- Fluorinated (F) gases
- (CO_2, CH_4, N_2O - demonstrated)

Target: Annual updates/quarterly interim **(SAO $)**

- CarbonTracker is a candidate core contribution to US GHGMMIS and WMO G3W
- **Opportunities** to strengthen X-NOAA connections
  - Ocean and satellite products — AOML/PMEL, NESDIS
  - Improve underlying process/transport models and emissions estimates — NWS, GFDL/ARL/CSL/GSL/PSL
  - Leverage operational capabilities — NWS, NESDIS

Current CarbonTracker and F-gas products developed with support from NOAA CPO & SAO, NASA.

Theme 1

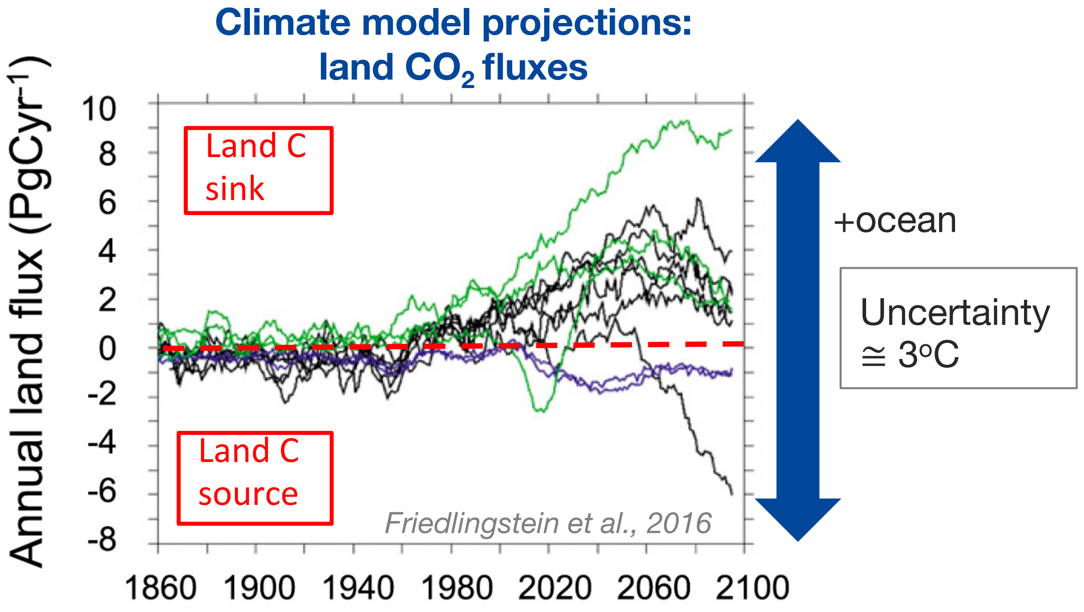
Diagnosing the Natural Carbon Cycle and Understanding Carbon:Climate Feedback Mechanisms

Lei Hu

Question 1 - Diagnosing Earth's climate system, reducing uncertainties & addressing societal challenges

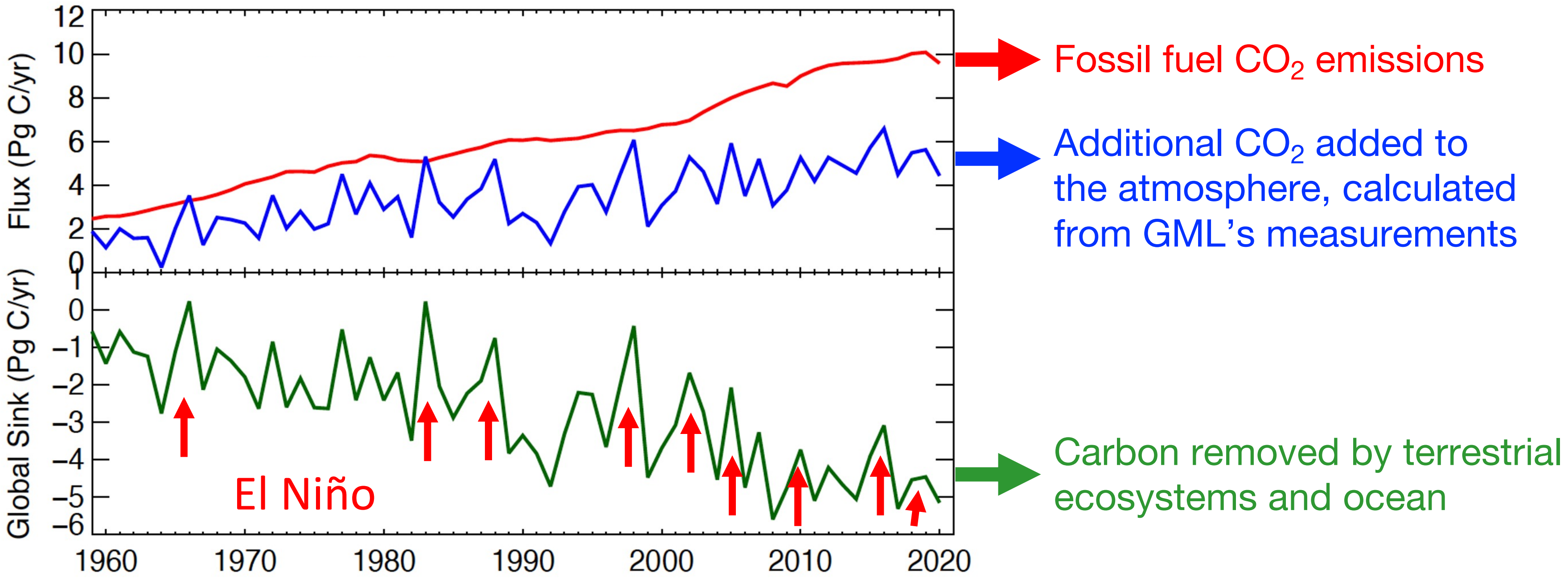
Question 4 - Supporting the US GHG Measurement Monitoring and Information System (GHGMMIS)

Inadequate understanding of carbon cycle feedbacks — a substantial challenge for climate mitigation



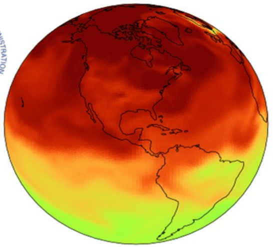
How can Carbon Dioxide Removal and other mitigation efforts succeed when fundamental understanding of “natural” carbon fluxes is lacking?

Long-term global observations: natural systems have reduced the climate impact of fossil fuel CO_2 by ~50%

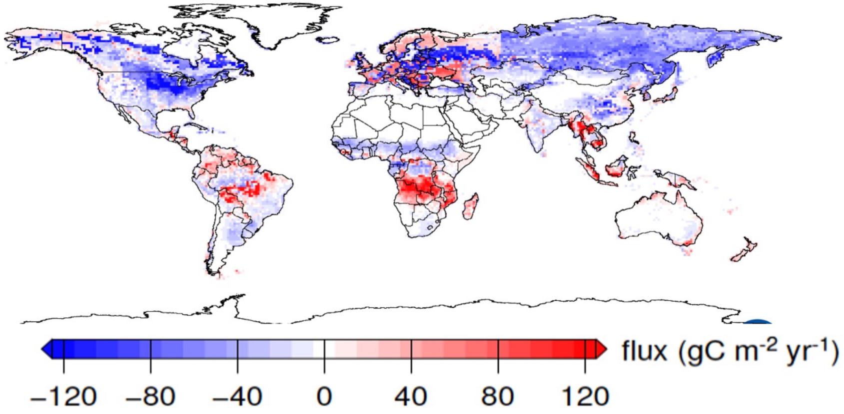


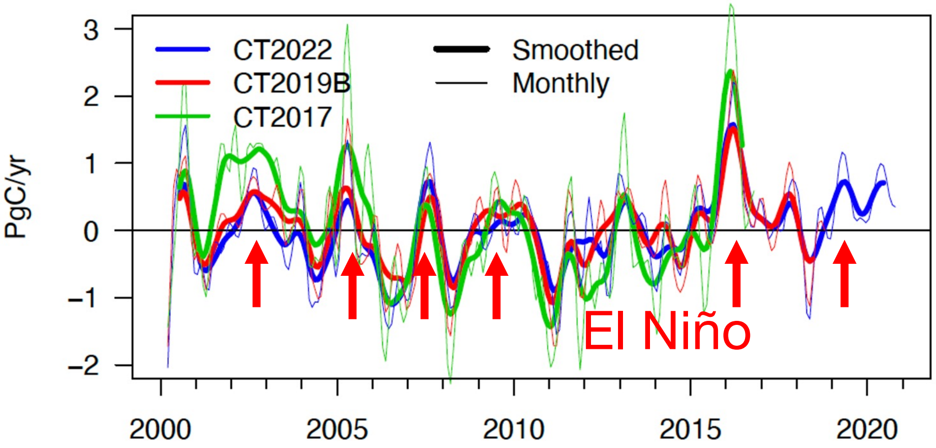
Ballantyne et al., Nature, 2012, updated: 512 Citations

CarbonTracker provides optimized estimates of regional emissions and removals



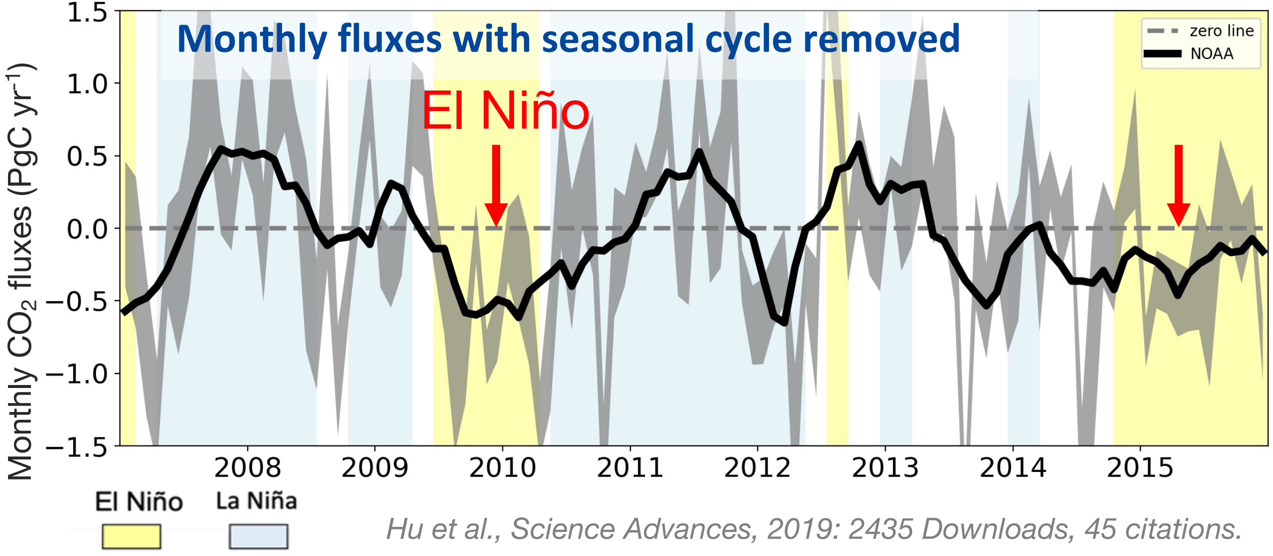
1° x 1 ° land flux: 2001-2020 mean



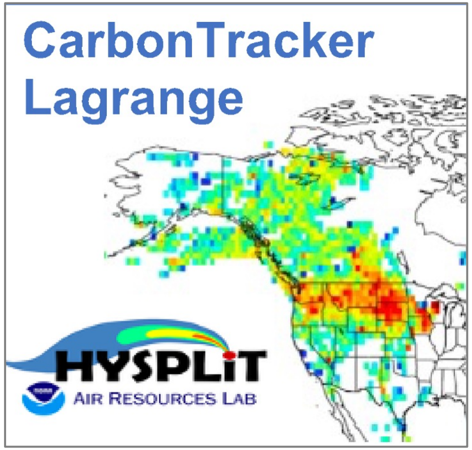


- 22 releases since 2007
- 1059 citations!
- Used in >821 individual research studies
- Supports NASA OCO-2 MIP, Global Carbon Budget, US GHG Center

CarbonTracker-Lagrange: US ecosystem uptake is strongly enhanced during El Niño



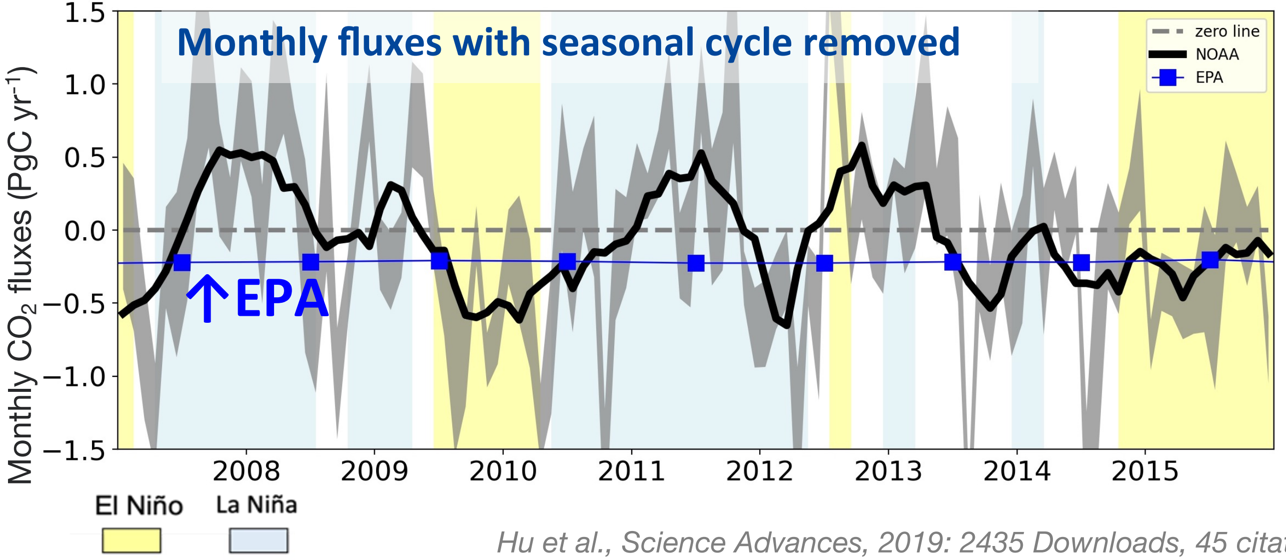
Hu et al., Science Advances, 2019: 2435 Downloads, 45 citations.

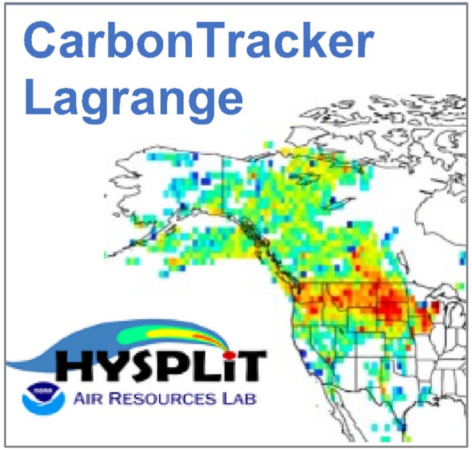


- Extratropical ecosystems (such as in the U.S.) have opposite ENSO response versus global/tropical
- Behavior is lacking in current ecosystem models → missing/underestimated mechanisms

CarbonTracker-Lagrange developed with support from NOAA CPO & NASA.

CarbonTracker-Lagrange: US ecosystem uptake is strongly enhanced during El Niño



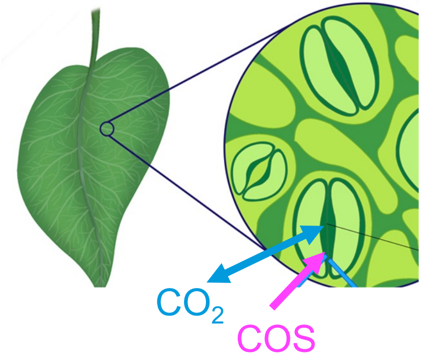


Hu et al., Science Advances, 2019: 2435 Downloads, 45 citations.

Mitigation impacts:

- Need to track US emissions reductions superimposed on highly variable ecosystem fluxes.
- US ecosystem uptake likely to change as climate continues to warm.

Multi-species measurements provide a powerful constraint on ecosystem processes: COS enables quantification of photosynthesis

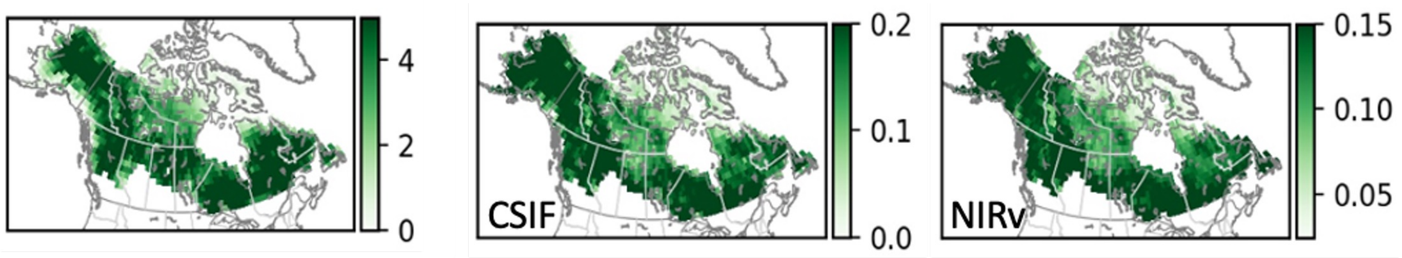


Montzka et al., 2007, JGR

First atmospheric evidence of COS constraining photosynthesis

NOAA COS-based photosynthesis

Satellite remote-sensing based photosynthesis proxies



Hu et al., 2021, PNAS: 31 Citations

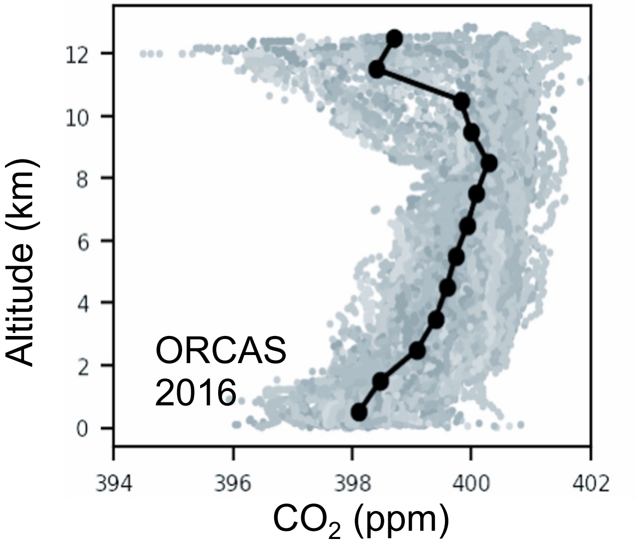
Opportunities:

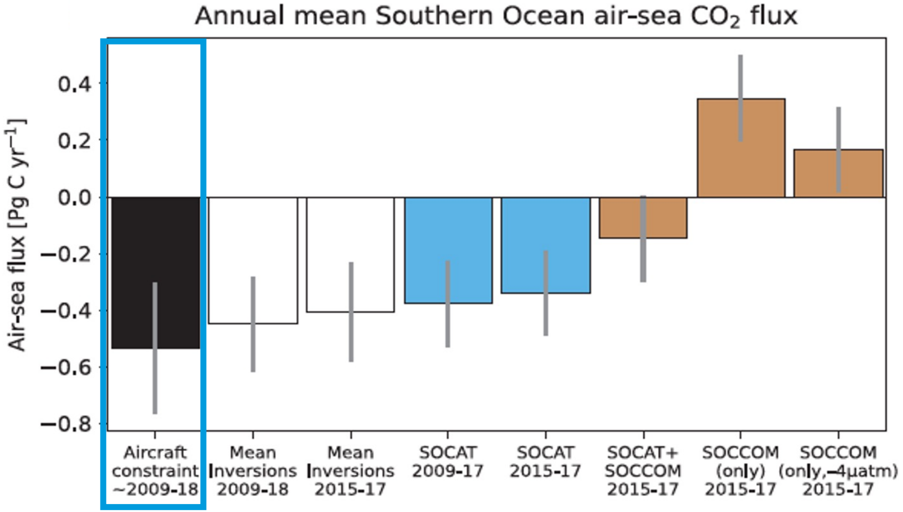
- Use COS measurements to estimate photosynthesis for additional ecosystems
- Partner with NESDIS to develop new NIRv products

Methods developed with support from NOAA CPO & NASA ABoVE

Aircraft profiles strongly constrain estimates of Southern Ocean uptake

Observed consistent 2 ppm draw-down over the Southern Ocean





New atmospheric observation-based

Long et al., Science , 2021: 57 citations

Opportunity: Work with NOAA OAR and Scripps partners to further develop observational constraints on ocean flux estimates.

GML's unique observations and modeling capabilities provide:

- **the foundation for quantifying natural carbon fluxes and their changes** on global, national and regional scales (long-term, global, 4D)
- **key insights into underlying processes** driving changes in natural carbon cycle (multi-species)

Science AAAS — Observational Constraints on the Global Atmospheric CO_2 Budget — Pieter P. Tans, Inez Y. Fung, Taro Takahashi

nature LETTER doi:10.1038/nature11299 — Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years — A. P. Ballantyne, C. B. Alden, J. B. Miller, P. P. Tans & J. W. C. White

nature LETTER doi:10.1038/nature12957 — Drought sensitivity of Amazonian carbon balance revealed by atmospheric measurements — L. V. Gatti, M. Gloor, J. B. Miller, C. E. Doughty, Y. Malhi, L. G. Domingues, L. S. Basso, A. Martinewski, C. S. C. Correia, V. F. Borges, S. Freitas, R. Braz, L. O. Anderson, H. Rocha, J. Grace, O. L. Phillips & J. Lloyd

Science RESEARCH — CARBON CYCLE — Strong Southern Ocean ca[rbon uptake evident in] airborne observations — Matthew C. Long, Britton B. Stephens, Kathryn [...], Eric A. Kort, Eric J. Morgan, Jonathan D. Bent, Róisín Commane, Bruce C. Daube, Paul B. Krumm[...], Prabir Patra, Wouter Peters, Michel Ramonet, Pieter Tans, Steven C. Wofsy

... and light help explain high-latitude atmospheric CO_2 seasonal cycle amplification — Lei Hu, Stephen A. Montzka, Aleya Kaushik, Arlyn E. Andrews, Colm Sweeney, John Miller, Ian T. Baker, Scott Denning, Elliott Campbell, Yoichi P. Shiga, Pieter Tans, M. Carolina Siso, Molly Crotwell, Kathryn McKain, Kirk Thoning, Bradley Hall, Isaac Vimont, James W. Elkins, Mary E. Whelan, and Parvadha Suntharalingam

... CO_2 uptake by plants during droughts at a continental scale — Wouter Peters, Ivar R. van der Velde, Erik van Schaik, John B. Miller, Philippe Ciais, Henrique F. Duarte, Ingrid T. van der Laan-Luijkx, Michiel K. van der Molen, Marko Scholze, Kevin Schaefer, Pier Luigi Vidale, Anne Verhoef, David Wårlind, Dan Zhu, Pieter P. Tans, Bruce Vaughn and James W. C. White

Geoscientific Model Development — The CarbonTracker Data Assimilation System for CO_2 and $\delta^{13}C$ (CTDAS-C13 v1.0): retrieving information on land–atmosphere exchange processes — Ivar R. van der Velde, John B. Miller, Michiel K. van der Molen, Pieter P. Tans, Bruce H. Vaughn, James W. C. White, Kevin Schaefer, and Wouter Peters

PNAS Proceedings of the National Academy of Sciences of the United States of America — RESEARCH ARTICLE — Large and seasonally varying biospheric CO_2 fluxes in the Los Angeles megacity revealed by atmospheric radiocarbon — John B. Miller, Sc[...], Vineet Yadav, Sally [...]

Arctic Climate Change (J Melton, Section Editor) | Open Access | Published: 02 February 2021 — The Arctic Carbon Cycle and Its Response to Changing Climate — Lori Bruhwiler, Frans-Jan W. Parmentier, Patrick Crill, Mark Leonard & Paul I. Palmer — Current Climate Change Reports 7, 14–34 (2021)

Atmos. Chem. Phys., 22, 15351–15377, 2022 — Estimating emissions of methane consistent with atmospheric measurements of methane and $\delta^{13}C$ of methane — Sourish Basu, Xin Lan, Edward Dlugokencky, Sylvia Michel, Stefan Schwietzke, John B. Miller, Lori Bruhwiler, Youmi Oh, Pieter P. Tans, Francesco Apadula, Luciana V. Gatti, Armin Jordan, Jaroslaw Necki, Motoki Sasakawa, Shinji Morimoto, Tatiana Di Iorio, Haeyoung Lee, Jgor Arduini, and Giovanni Manca

nature climate change LETTERS https://doi.org/10.1038/s41558-020-0734-z — Reduced net methane emissions due to microbial methane oxidation in a warmer Arctic — Youmi Oh, Qianlai Zhuang, Licheng Liu, Lisa R. Welp, Maggie C. Y. Lau, Tullis C. Onstott, David Medvigy, Lori Bruhwiler, Edward J. Dlugokencky, Gustaf Hugelius, Ludovica D'Imperio and Bo Elberling

NOAA RESEARCH

Theme 1

Quantifying Anthropogenic Emissions

John Miller

Question 1 - Diagnosing Earth's climate system, reducing uncertainties & addressing societal challenges

Question 4 - Supporting the US GHG Measurement Monitoring and Information System (GHGMMIS)

GML's measurements enhance understanding of GHG emissions and removals, providing information needed to:

- Track progress toward US Paris Accord Nationally Determined Contribution (NDC)
- Support US efforts to create a GHG Measurement, Monitoring and Information System to assess mitigation

GML provides societally-relevant emissions calculations:

- High-warming-potential industrial ("F-gas") emissions – **already used by EPA/UNFCCC – Questions 1 and 4**
- CO_2 emissions and removals – **advanced prototypes – Questions 1 and 4**
- Understanding global CH_4 trends – **advanced prototypes – Questions 1 and 4**

Atmospheric measurements complement traditional inventory methods

- **Independent "top-down" constraints** on national and regional emissions
  → Resolution depends on the density of observations
- **"Trust but verify"** — improve confidence in Nationally Determined Contributions
- Potential for **low latency**
  → More rapidly assess mitigation efforts (WMO G3W target is 1 month)

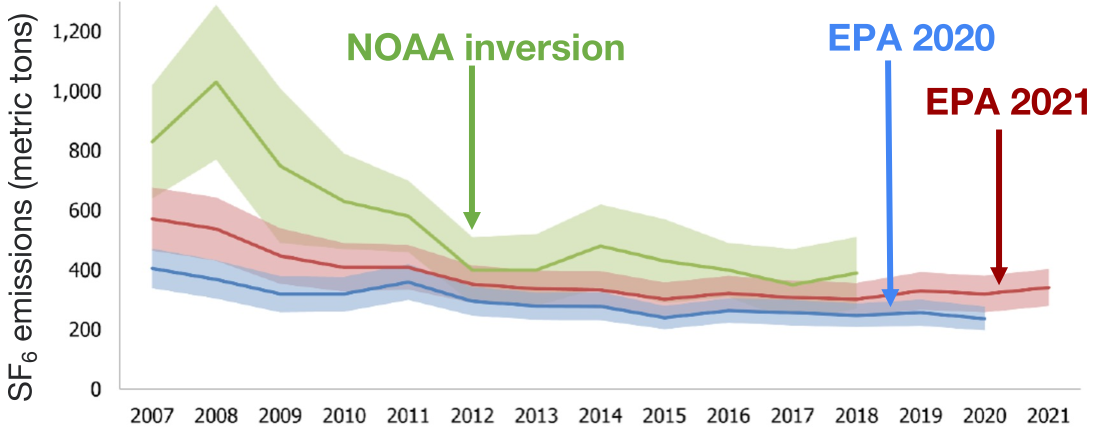


Fig. 4-3 of 2023 US National Inventory Report

→ EPA improves US national GHG inventory using GML top-down emissions estimates.

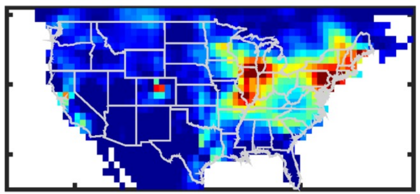
→ GML benefits from greater understanding of mechanisms by working with inventory community.

Tracking high-warming fluorinated (F) gas emissions

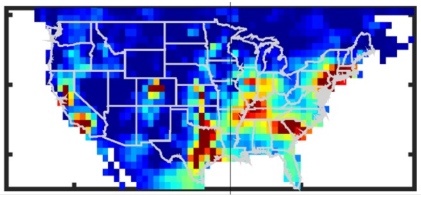
- F-gases comprise about 5% of US GHG emissions as CO_2-equivalents
- F-gases are regulated by the EPA under the “AIM” act; phase-downs are underway

Global Monitoring Laboratory
Earth System Research Laboratories

US Emission Tracker for Potent GHGs



HCFC-142b – building insulation



HFC-32 – air conditioning

Select a Gas

- HFC-134a
- HFC-125
- HFC-143a
- HFC-32
- HFC-227ea
- HFC-365mfc
- HCFC-22
- HCFC-142b
- CFC-11
- CFC-12
- CFC-113
- SF6
- Totals (8 gases)

New in 2024:
Continental U.S. Emissions updated to 2021 for SF_6 and HFCs: HFC-32, HFC-125, HFC-134a, and HFC-143a.

Support from NOAA CPO and the Grantham and High Tide Foundations

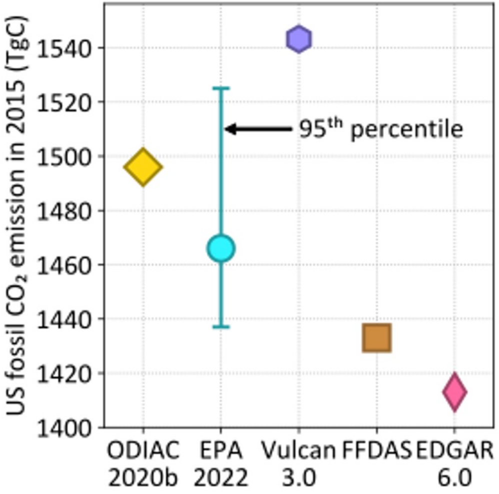
Top-down tracking of fossil fuel CO_2 emissions using radiocarbon (^{14}C)

- Fossil fuel emissions contain no radiocarbon (half life ~6000 years)

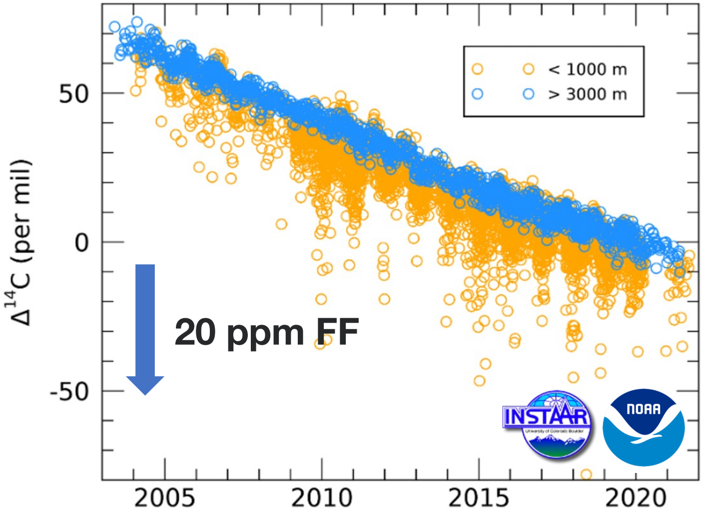
  → direct constraint on estimates of fossil fuel emissions

- Currently 1100 ^{14}C measurements per year; SAO funding → 1500 per year

Why? ~8% spread

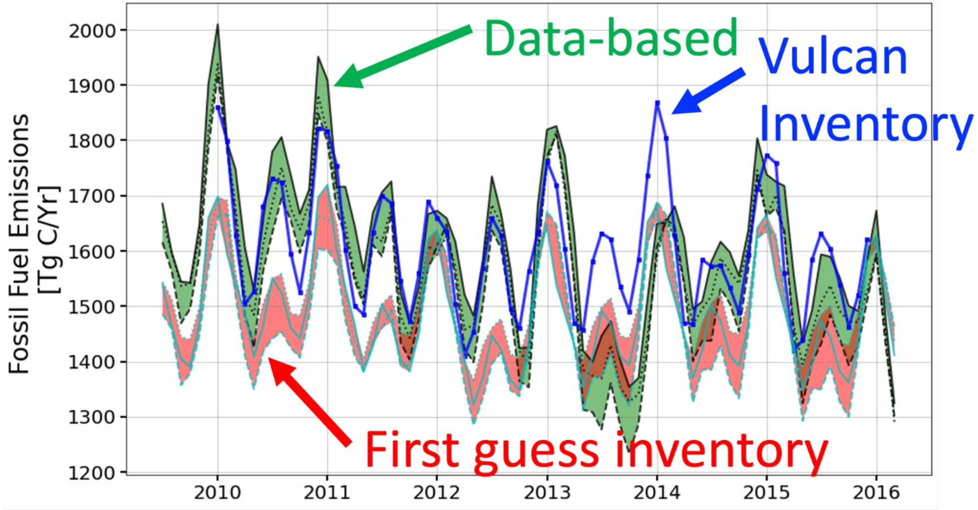


How? US ^{14}C observations



Methods developed with support from NOAA/CPO

Demonstrated capability for US fossil fuel CO_2 emissions tracking via $\Delta^{14}CO_2$ assimilation



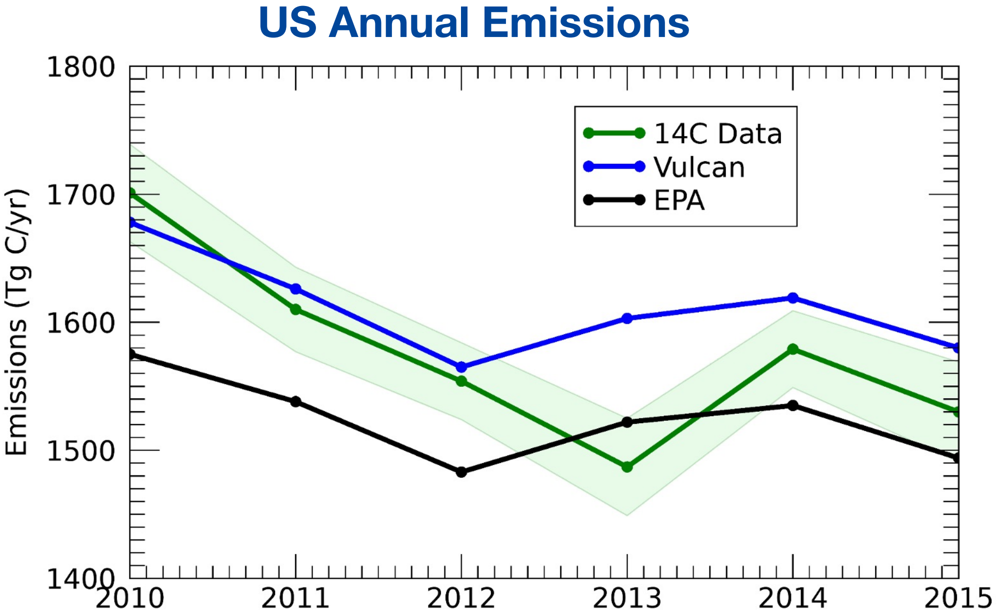
- Radiocarbon shifts first guess higher, especially summer air conditioning peak
- Strong consistency with Vulcan except 2013 (lower data density)

N. Islam et al., in prep
Vulcan Inventory: Gurney et al., in prep

Methods developed with support from NOAA/CPO

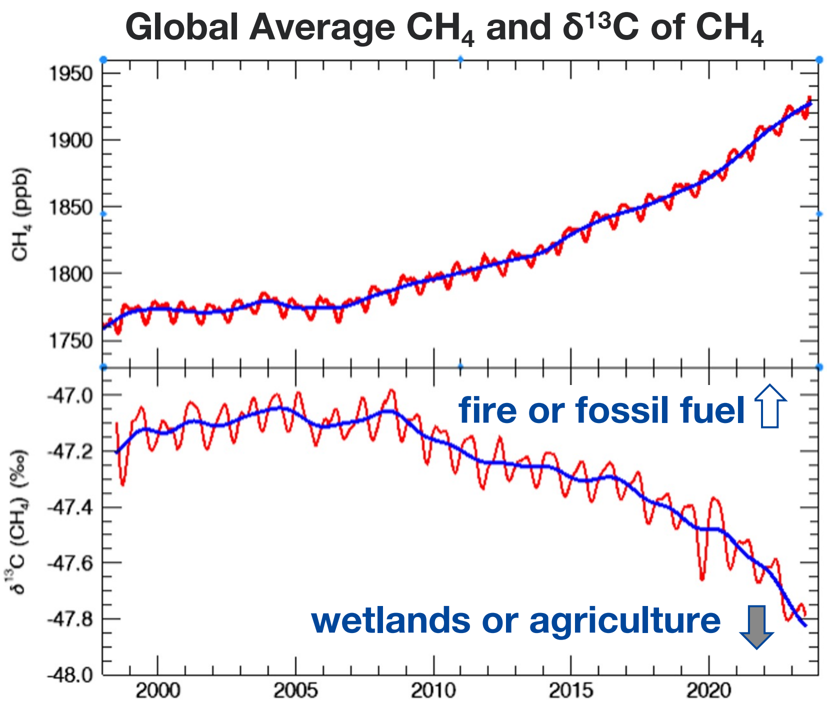
Demonstrated capability for US fossil fuel CO_2 emissions tracking via $\Delta^{14}CO_2$ assimilation

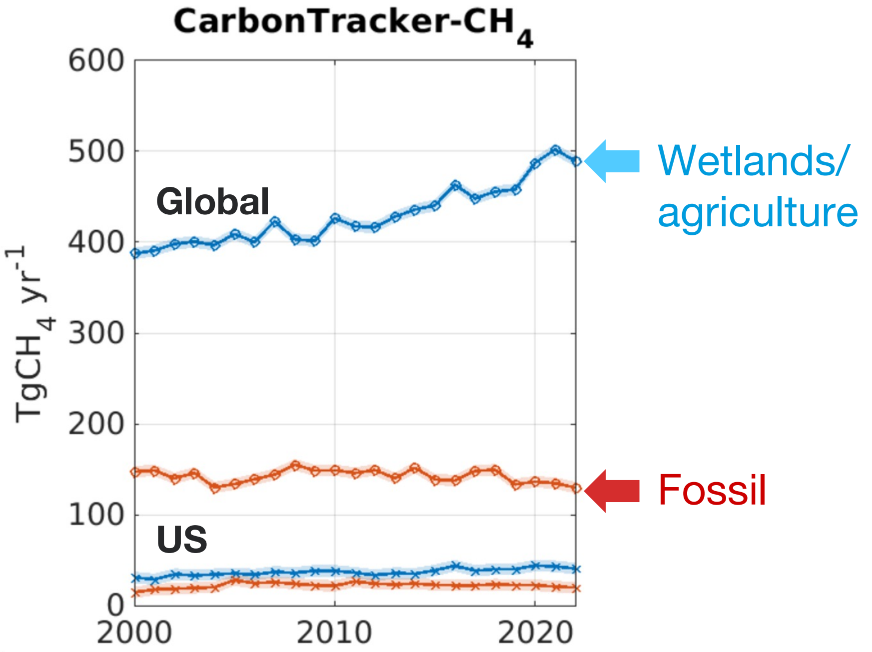
- Trend is similar to EPA: coal to gas transition
- Our estimate is ~10% higher
- More measurements → lower uncertainty and subnational resolution
- Opportunity to partner with University of Colorado for atmospheric radiocarbon facility



Islam et al., in prep

CH_4 isotope measurements show that the recent increase of global atmospheric CH_4 is not driven by fossil emissions





Lan et al., 2021, GBC: 33 citations; Basu et al., 2022, ACP: 50 citations; Michel et al., 2024, PNAS (in press)

Key question: Wetland vs. agricultural partitioning?

Quantifying anthropogenic GHG emissions

Existing

- F-gases —Routine delivery of global, national, and regional emissions at annual and monthly scales; helping to inform EPA inventory

Future

Routine atmosphere-based estimates of:

- CO_2
  - Land sector sinks
  - Fossil CO_2 emissions
- CH_4 —Global-scale and national-scale methane fossil fluxes
- N_2O —National-scale N_2O emissions

Consistent Facility ↔ Regional emissions estimates (NOAA CSL/ARL/NESDIS, NIST)

Theme 1

The Future of Observing & Analyzing GHGs at GML

Colm Sweeney

Question 2 - Sustained observations, technology innovation

Question 4 - Supporting the US GHG Measurement Monitoring and Information System (GHGMMIS)

Challenges

- **The global observing system is insufficient** to reliably quantify uncertainties and biases in reported GHG emissions and removals.
- We still **lack fundamental understanding of how natural uptake/emissions** of greenhouse gases will respond to climate change.

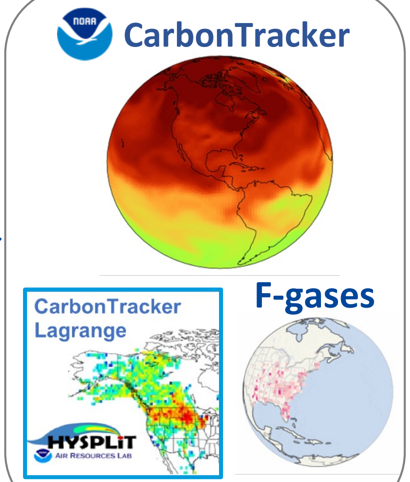
Solutions

- **Enhance observing capabilities over all scales** leveraging new platforms and instrumentation.
- **Further develop data analysis systems** to take advantage of diverse datasets spanning multiple scales and advance process understanding.
- **Utilize what we learn from observations** to inform climate projections.

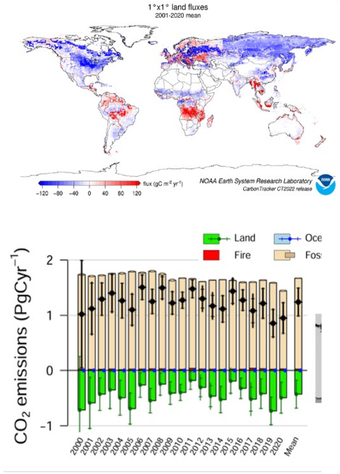
Tracking GHG emissions and removals

Atmospheric observations

Data assimilation



Optimized estimates of emissions & removals



- Measurement system upgrades
- Addressing coverage gaps
- New platforms
- Collaborations

Leveraging new platforms

NOAA and United Airlines partner to measure greenhouse gases, pollutants with high-tech flight instruments

Share:

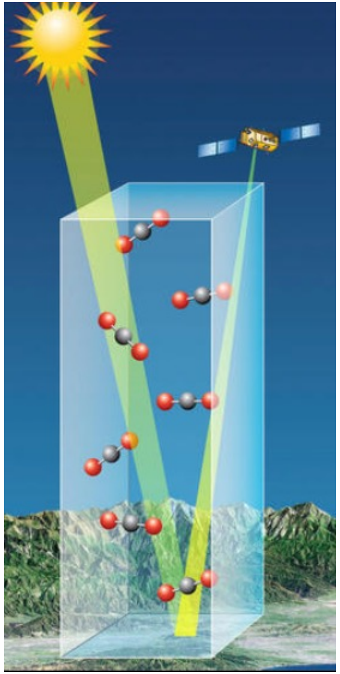
July 23, 2024

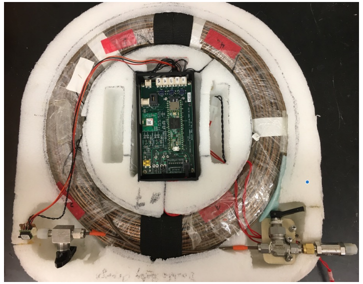
Airport legend
- > 30 direct destinations
- > 7 direct destinations
- < 7 direct destinations

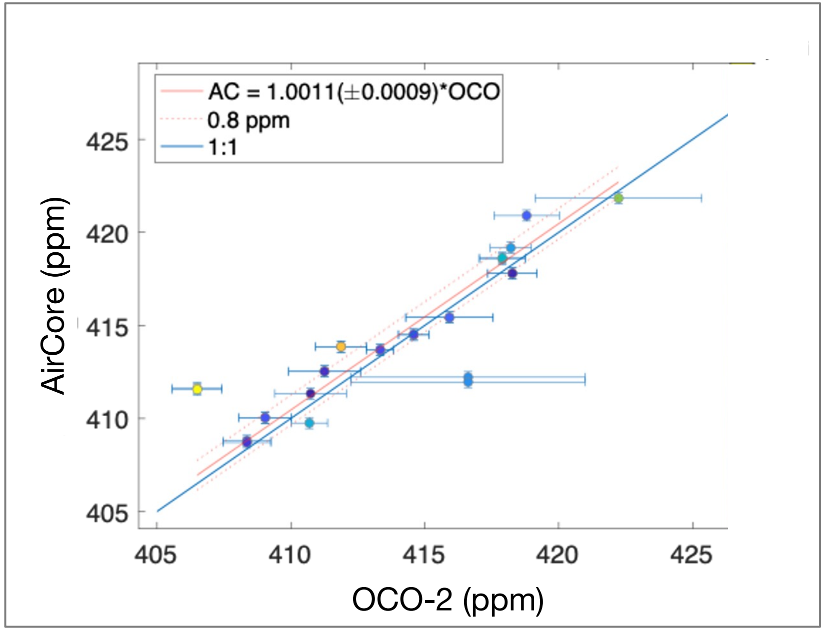
Commercial aircraft

- Mid-range aircraft
- Up to 5 cities a day
- 8 profiles a day→ ~2000/yr
- CO_2, CO, CH_4, H_2O
- Sampling large metro areas where emissions are highest

AirCore – Direct evaluation of satellite retrievals





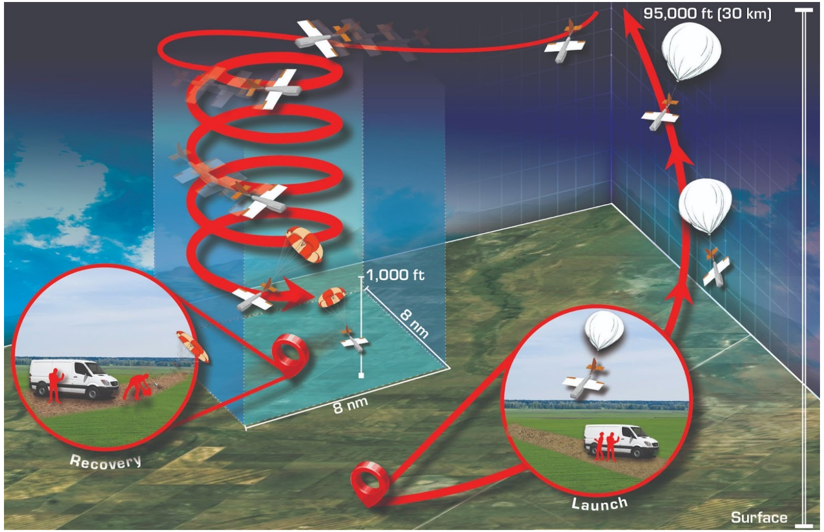


Baier et al. in prep

- AirCore profiles are uniquely valuable for retrieval evaluation.
- Timing flights coincident with overpasses extremely challenging.
- Opportunity: ground based remote sensing to link in situ and satellite

Support from NESDIS and NASA

AirCore – High-altitude Operational Return Uncrewed System (HORUS)



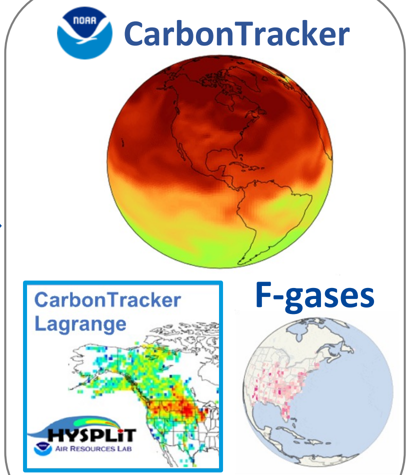
- Low cost platform
- Calibrated profiles
- High-volume payload capacity (AirCore + …)
- Enables surface-to-stratosphere sampling in data-poor regions (e.g. islands, remote areas)

Support from NOAA/UAS

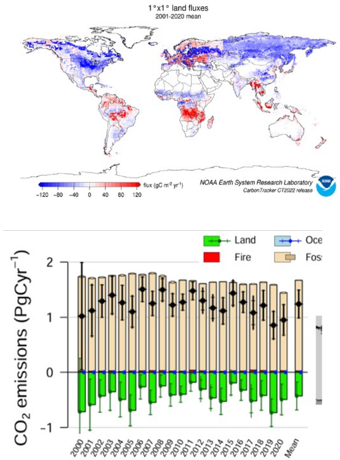
Tracking GHG emissions and removals

Atmospheric observations

Data assimilation



Optimized estimates of emissions & removals



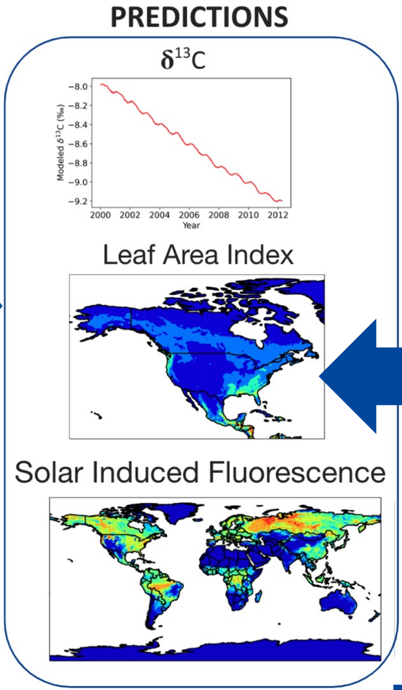
- Uncertainty
- Atmospheric Transport
- Data diversity/volume
- Process understanding

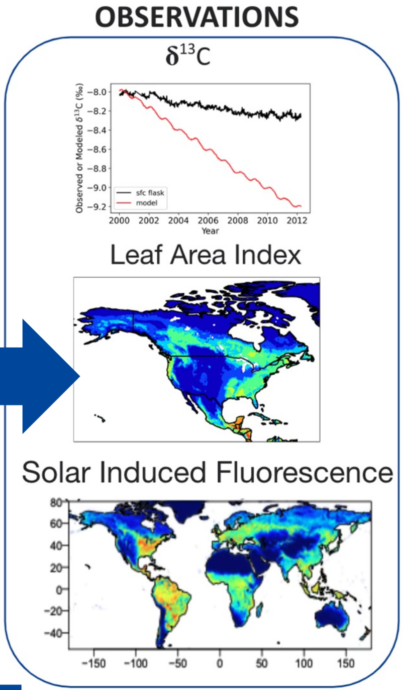
Improving process models — an example

Improved process representation
→ better climate projections

Terrestrial Biosphere Model
parameters for photosynthesis, respiration

Optimized parameters





Regional

National

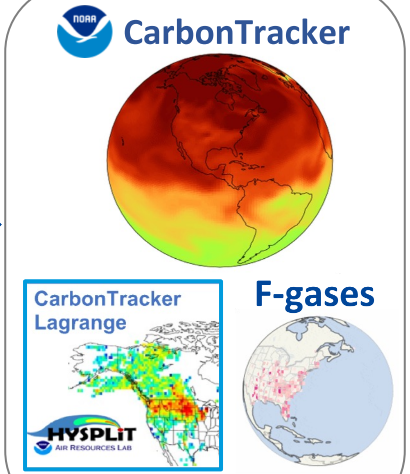
Global

Support from NOAA CPO, NOAA Information Technology Incubator, NASA

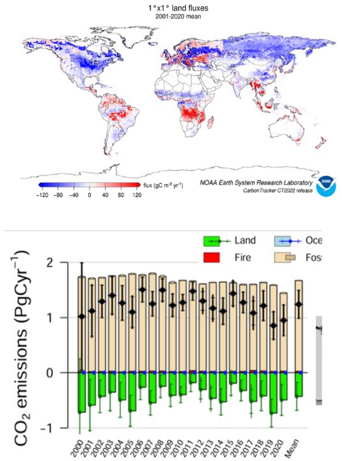
Tracking GHG emissions and removals

Atmospheric observations

Data assimilation



Optimized estimates of emissions & removals



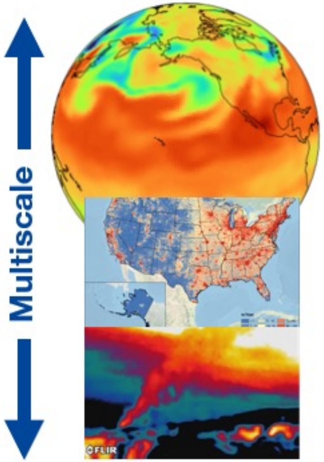
- Operationalize/Low-latency
- Consensus Estimates
- Improved Projections

CarbonTracker — Transition to sustained operations

5-year objectives

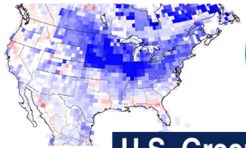
- **Low-latency GHG tracking**
  - → Robust workflow
  - → Annual releases/quarterly interim
- **Harmonized products**
  - → Regional ↔ global interoperability
  - → Links to facility/urban scale activities
- **Consensus flux estimates**
  - → Model Intercomparison
  - → Reconcile discrepancies
  - → Model improvements
  - → Reduced uncertainty

NOAA
Harmonized CarbonTracker



CO_2, CH_4, N_2O, F-gases

Low-latency operational GHG tracking



United States Environmental Protection Agency

U.S. Greenhouse Gas Center
Uniting Data and Technology to Empower Tomorrow's Climate Solutions
NASA NIST NOAA

U.S. Global Change Research Program
National Climate Assessment

30 MONTREAL PROTOCOL

G3W

PARIS2015

ipcc INTERGOVERNMENTAL PANEL ON climate change

United Nations Framework Convention on Climate Change

NOAA SAO funding key deliverable

Summary:

- GML is a world leader in GHG measurements and their interpretation
- GML aims to advance the state of GHG science and support US and international climate mitigation efforts:
  - Innovative approaches to addressing observation coverage gaps
  - Creative analysis of data to advance process understanding
  - Interoperable, low-latency, state-of-the-science CarbonTracker products
  - X-NOAA and Interagency partnerships to implement a US GHG Measurement Monitoring and Information System

Supplementary Slides

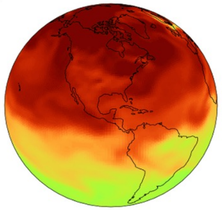
CarbonTracker — Advancing the state of the science

- **Characterizing and reducing uncertainty**
  - → Implement CarbonTracker Testbed
  - → Improve metrics for performance benchmarking
  - → Optimize assimilation strategy (satellite, in situ, multispecies)
  - → Inform observing system design

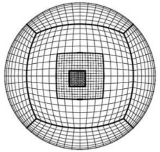
- **Reducing sensitivity to atmospheric transport errors**
  - → Multiple state-of-the-science atmospheric models
  - → Engage with model developers
  - → Evaluate against meteorological and trace gas measurements

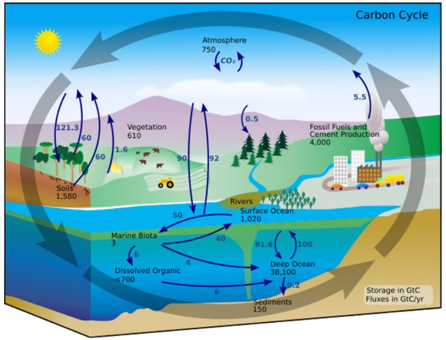
- **Diagnosis → Process Understanding → Improved Projections**
  - → Process model parameter optimization
  - → Multispecies and multiscale observations for flux attribution

CarbonTracker Testbed



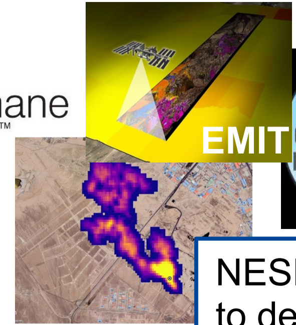
UFS
UNIFIED FORECAST SYSTEM





Towards consistent facility↔regional emissions estimates via partnerships

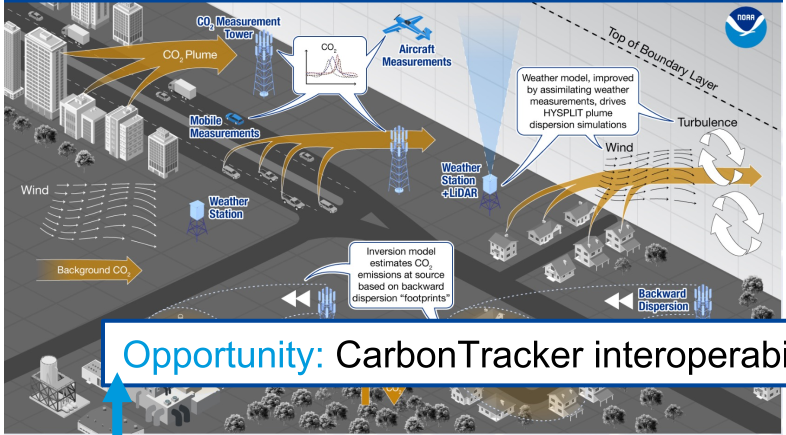
Methane SAT™



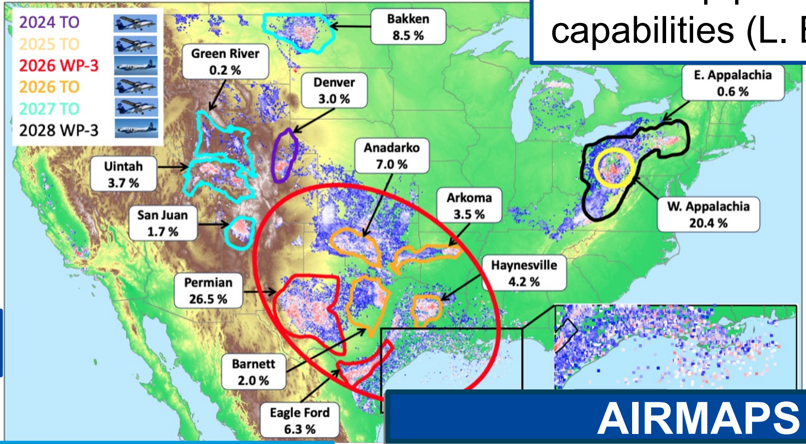
CARBON MAPPER

NESDIS/GML joint project to develop plume detection capabilities (L. Bruhwiler)

Urban-GEMMS: Prototype urban GHGMMIS NOAA/ARL and NIST



Opportunity: CarbonTracker interoperability



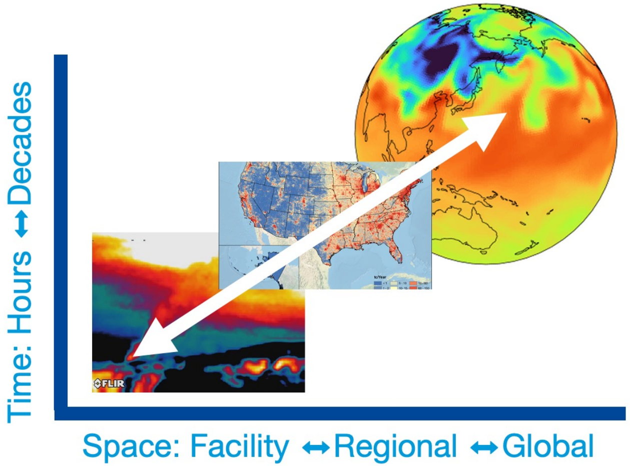
GReenhouse Gas And Air Pollutants Emissions System (GRA²PES): NIST/NOAA CSL Low Latency GHG Inventories

AIRMAPS

- NOAA CSL lead/GML support
- Targeting oil and gas basins and urban centers

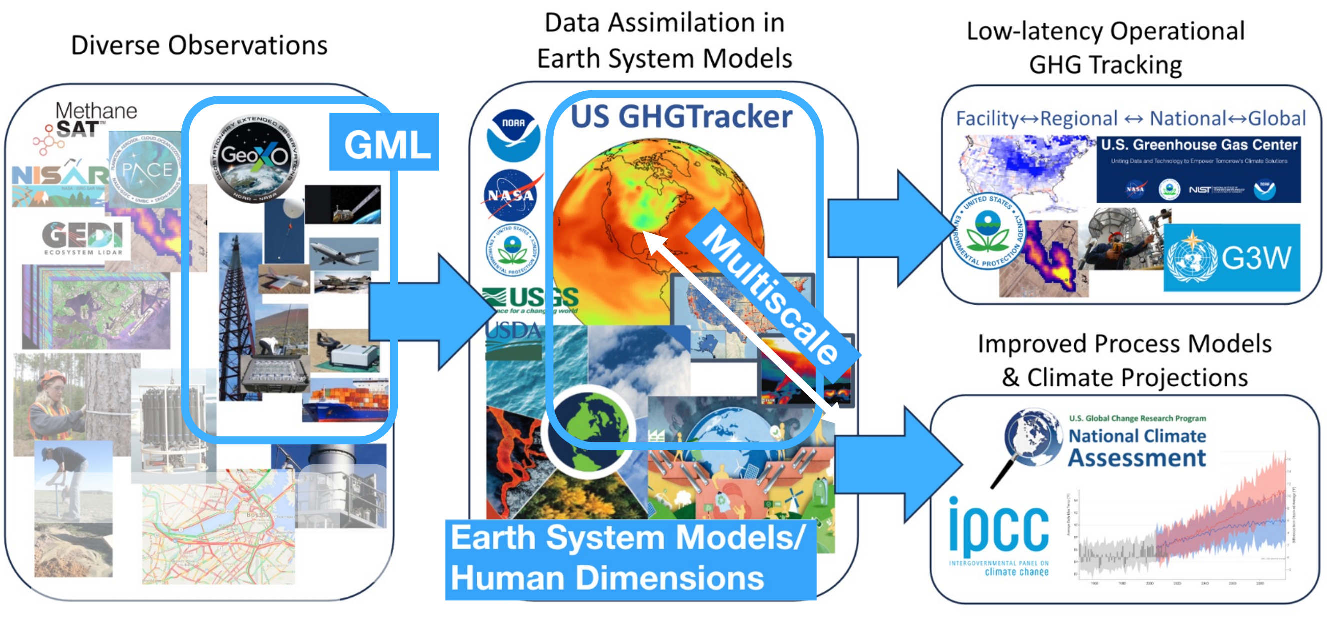
Leveraging diverse observations

Earth System Models
Human Dimensions



- Leverage diverse observations to address stakeholder needs across facility:regional:global scales
- Move beyond GHG accounting (diagnosis) to improve and directly constrain processes models (prognosis)

Next Generation GHG Information Services



- Leverage diverse observations to address stakeholder needs across facility:regional:global scales
- Incorporate coupled earth system models to represent biogeochemical processes hours:decades:centuries
- Move beyond GHG accounting (diagnosis) to improving processes understanding (prognosis)