Global Monitoring Division

GMD Overview (Butler) and

Theme1-3 PPT Presentations

2013-2017 Review

May 21-24, 2018

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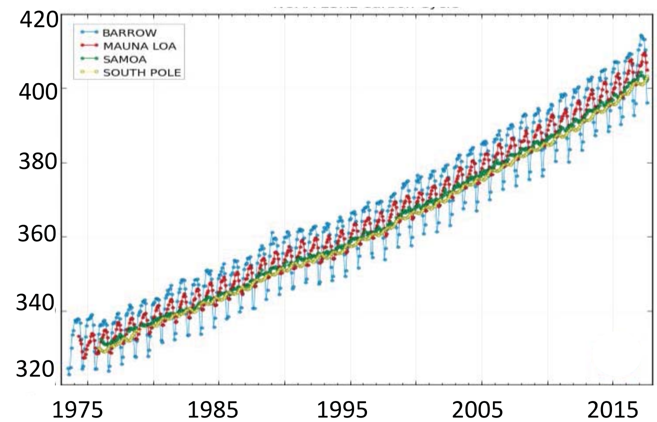
Laboratory Review NOAA/ESRL Global Monitoring Division

James Butler
Director
21-24 May 2018

Carbon Dioxide at Observatories



Outline

- Summary of Previous (2013) Panel Report
- Mission of NOAA's Global Monitoring Division
- Organization and Management
- How We Plan, Ensure, and Measure Success
- Transformative Opportunities
- Upcoming Sessions

2009-2013 Review Panel Summary

- **Relevance:**
  - "Environmental Security of the nation"
  - "Essential to the NOAA mission"
- **Quality:**
  - "GMD has become a NOAA/ESRL star"
  - "pushing the frontiers in Climate, Greenhouse Gases, Ozone Depletion, and Air Quality"
  - "will be used by the international community for decades to come"
- **Performance:**
  - "The investments into GMD have been well optimized in an underfunded environment"
  - "The work … is of the highest caliber"
  - "The scientific community, nation, and beyond are reaping the benefits, and are heavily dependent on GMD. Now is the time to strengthen the capacity of GMD even further to maintain its global lead in these activities"

2013-2018 Panel Recommendations

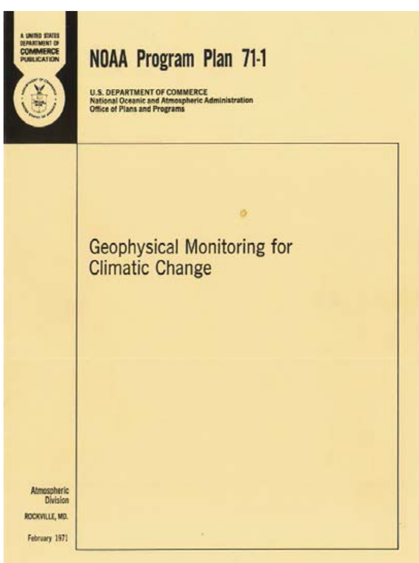
Recommendations:

- Expand the science that GMD does to support other science and regulatory agencies (state, national, and international)
- Sustain operations, scientific analysis, and technological development required for its mission.
- Add additional resources into all aspects of GMD operations, scientific analysis, and innovation.
- Recruit new talent and reinvigorate the both CIRES and NOAA positions
- Ensure continuity in observing network

GMD Mission

NOAA Program Plan 71-1

"Geophysical Monitoring for Climatic Change"


A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

NOAA Program Plan 71-1

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Plans and Programs

Geophysical Monitoring for Climatic Change

Atmospheric Division
ROCKVILLE, MD.
February 1971

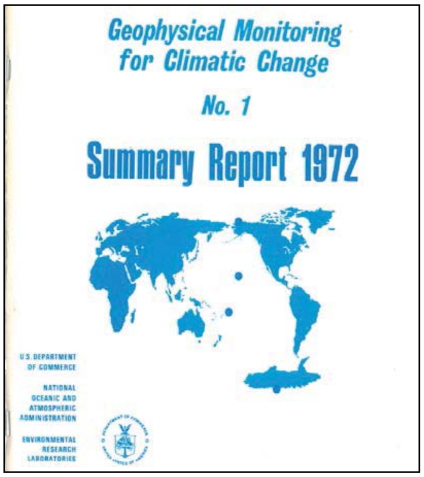
- "This plan, *Geophysical Monitoring for Climatic Change,* is NOAA's program for global monitoring of man's inadvertent modification of weather and climate."
  - *Robert White, Acting Administrator, NOAA*

- "Determination of the trends of the climatically important burden of atmospheric contaminants and resolution into natural vs. man-induced sources is essential to the preservation of environmental quality."

GMD Origins

". . . We must achieve a new awareness of our dependence on our surroundings and on natural systems which support all life, but awareness must be coupled with a full realization of our enormous capability to alter these surroundings."

Richard M. Nixon, 1970



"It is the objective of the GMCC program to respond to the need for this new awareness by providing a portion of the quantitative description and analysis needed. Specifically, it is our objective to measure the necessary parameters for establishing trends of trace constituents important to climate change and of those elements that can assist in apportioning the source of changes to natural or anthropogenic sources, or both."

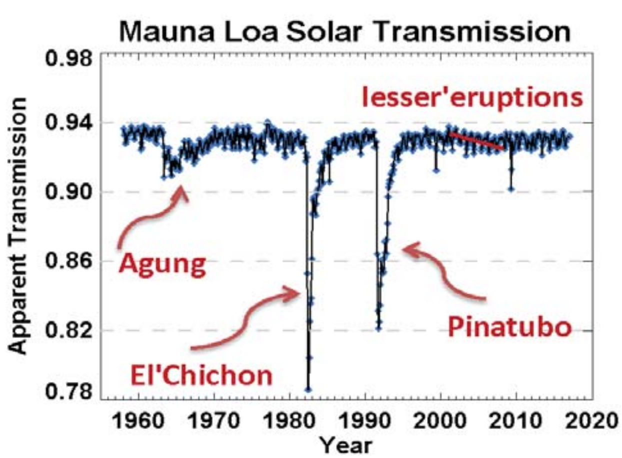
"This program has its special focus in establishing a long-term time series from ground-based information."

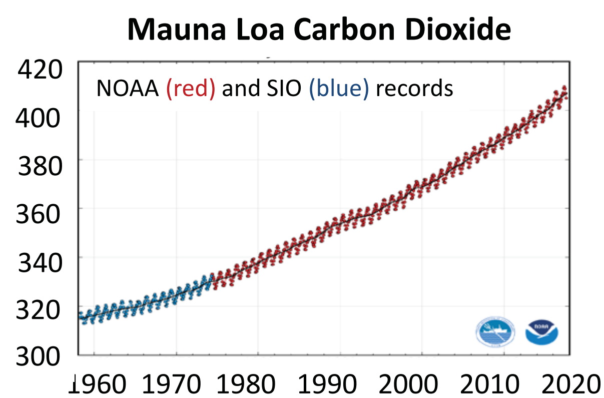
Geophysical Monitoring for Climate Change
First Summary Report, 1972

GMD Vision and Mission

Vision

GMD providing and society using the best possible information to inform climate change, weather variability, carbon cycle feedbacks, and ozone depletion





Mission

To acquire, evaluate, and make available accurate, long-term records of atmospheric gases, aerosol particles, clouds, and surface radiation in a manner that allows the causes and consequences of change to be understood

How GMD sets priorities

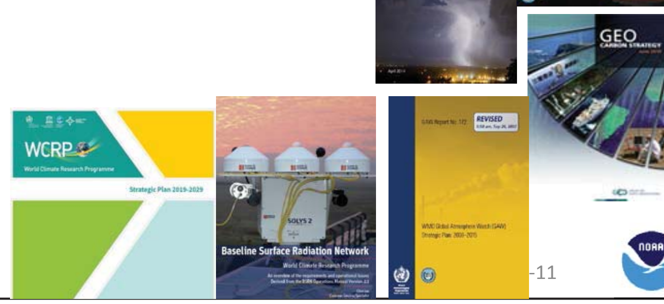
- Legislative mandates
- Consistency with NOAA's and OAR's strategic plans and priorities
- Relevance to interagency and international plans
- Relevance to national and international assessments
- Within the framework of GMD's mission:
  - Align research along Grand Challenges
  - Identify key scientific questions
  - Determine role of long-term observations to answer those questions
  - Sustain quality and continuity of observations
  - Understand the observed distributions and trends
    - Expand networks as needed
    - Conduct periodic regional-scale studies

Key Legislative Drivers of GMD's Research

- GMD's research contributes to fulfilling requirements for over 25 laws
- Four pieces of US legislation stand out
  - National Climate Protection Act (1978)
  - Global Climate Change Program Act (1990)
  - Global Change Research Act (1990)
  - Clean Air Act (1990)

Plans and Agreements

- **United States**
  - National Global Change Research Program Research Plan
  - US Carbon Cycle Science Plan
  - NOAA Next Generation Strategic Plan
  - NOAA Research Plan & OAR Priorities
  - NOAA/ESRL GMD Research Plan
- **International**
  - WMO Global Atmosphere Watch Strategic Plan
  - GCOS Implementation Plan
  - GEOSS Strategic Plan
  - GEO Carbon Strategy
  - WCRP Strategic Plan



NOAA Plans

NOAA Next Generation Strategic Plan

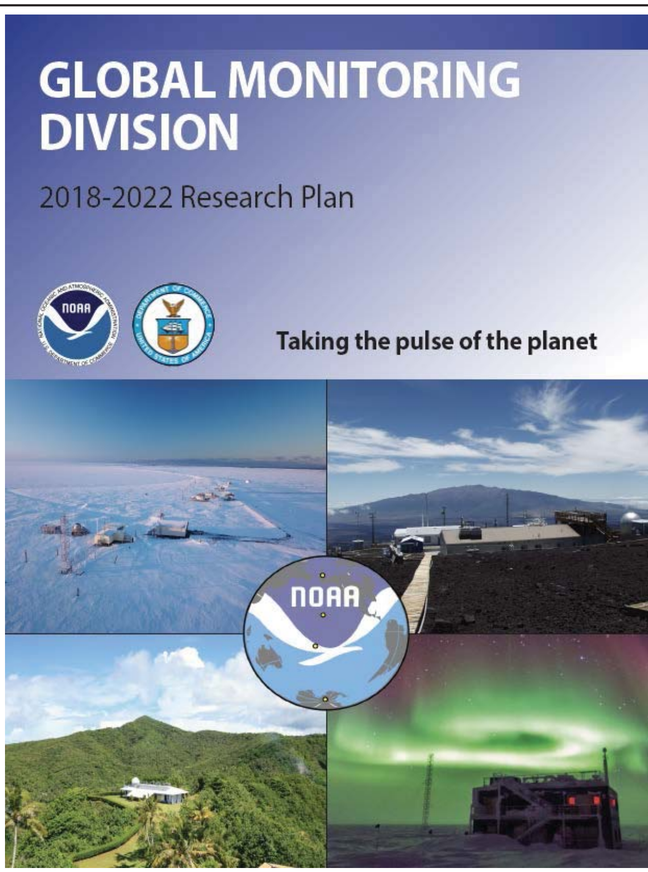
- **Goal:** Climate Adaptation and Mitigation
  - **Primary Objective:** Improved Understanding of Climate Change and its Impacts
  - **Other Objectives:** Assessments, Mitigation and Adaptation, Climate-Literate Public, Partnerships
- **Goal:** Weather Ready Nation
  - **Objectives:** Reduced loss from high impact events, improved water management and air quality, healthy people and economy, and improved transportation

OAR Strategic Plan

- **Aim:** Climate Adaptation and Mitigation
  - What is the state of the climate system and how is it evolving?
  - What causes climate variability and change on global to regional scales?
  - What improvements in global and regional climate predictions are possible?
- **Aim:** Weather Ready Nation
  - How does climate affect seasonal weather and extreme weather events?
  - How can we improve forecasts for freshwater resource management?
  - How are atmospheric chemistry and composition related to each other and ecosystems, climate, and weather?

OAR Priorities

- Sustain the long-term observations of the Earth System
- Improve the accuracy of weather forecasting and climate predictions
- Provide the environmental information needed by decision makers
- Sustain and enhance ocean exploration and research infrastructure
- Provide the essential scientific understanding of ecosystem processes and change
- Enhance marine resources management
- Detect, and provide early warning information for ocean, weather and climate events



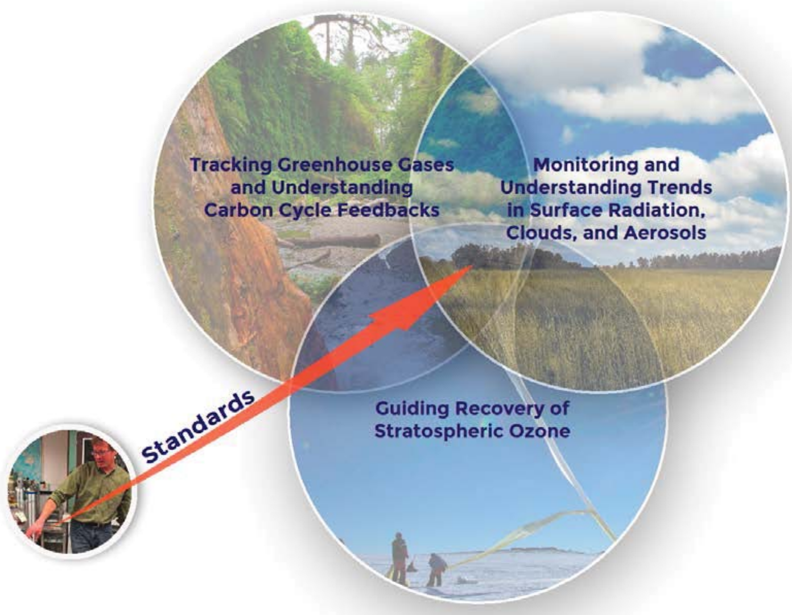
GMD Research Plan

- Documents GMD's purpose
- Built around recognized Grand Challenges*
- Identifies key scientific questions
- Shows how GMD activities help answer those questions
- Provides a path forward
- Includes milestones as measures of performance

*Weatherhead et al 2017, Earth's Future, Nov 2: WCRP https://www.wcrp-climate.org/grand-challenges/grand-challenges-overview

GMD Research Themes and Applications

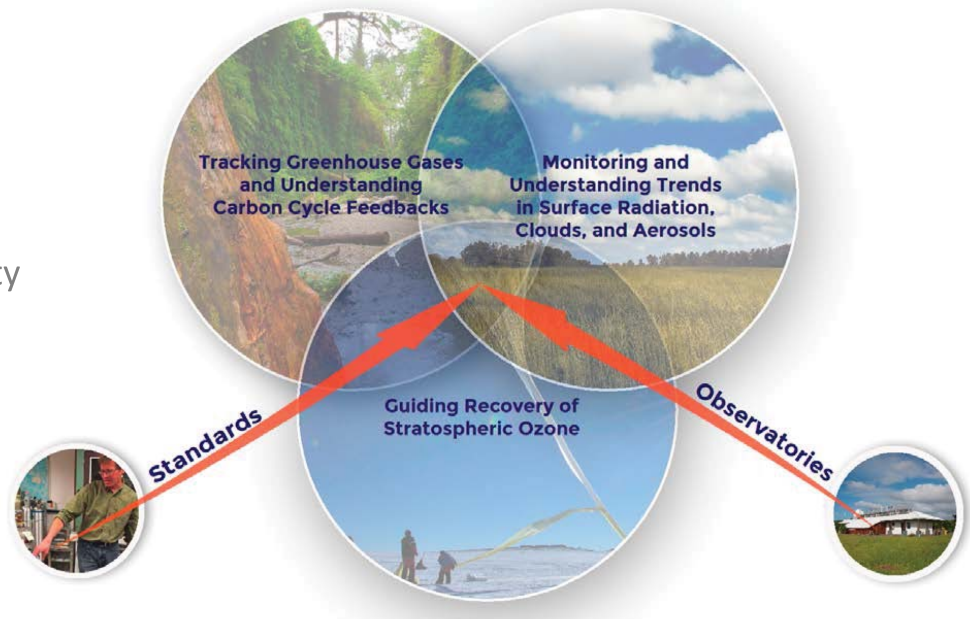
GMD Research Themes and Applications



Radiative Forcing

Renewable Energy Support

GMD Research Themes and Applications



Climate Sensitivity

Climate Intervention

Air Quality

Arctic Processes

Scientific Questions

(Details in Research Plan)

Greenhouse Gases and Carbon Cycle Feedbacks

- ✓ How do oceanic and terrestrial carbon fluxes vary in a changing climate?
- ✓ How spatially and temporally variable are anthropogenic inputs of greenhouse gases?
- ✓ How is upper tropospheric and lower stratospheric water vapor interacting with climate change?

Recovery of Stratospheric Ozone

- ✓ How well is the Montreal Protocol working to reduce ozone depletion?
- ✓ Is stratospheric ozone recovering as expected?
- ✓ How is climate influencing Brewer-Dobson circulation and its feedbacks?
- ✓ How sensitive is the oxidative capacity of the atmosphere and how is it changing over time?

Surface Radiation, Clouds, and Aerosols

- ✓ How does surface radiation vary in space and time?
- ✓ How do climate change and variability work to redistribute clouds ?
- ✓ How do aerosol optical properties vary as a function of location, time, and atmospheric conditions?
- ✓ How does black carbon influence lower atmospheric heating and cloud prevalence?
- ✓ How do changing sky conditions affect ultraviolet radiation at the Earth's surface?
- ✓ How can information on surface radiation improve renewable energy predictions?

How We Plan, Ensure, and Measure Success

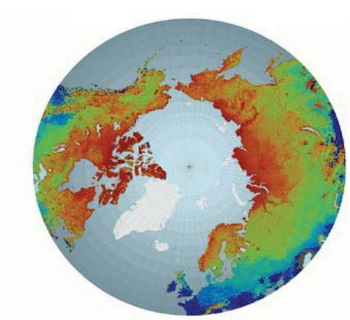
Path To Success

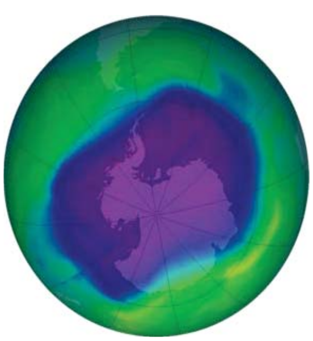
- **Rigor** – role as a world leader in measurements that we do
- **Excellence** – in the science that comes from the measurements
- **Pathfinder** – for new technology to enhance and sustain measurements
- **Transparency** – making measurements, methods, scientific findings accessible to the public
- **Leadership** – providing guidance to the rest of the scientific community to ensure compatibility of global measurements

How We Measure Success

- Sustained high-quality long-term records of atmospheric composition
- Preeminence of our science as documented through the peer-review process
- External recognition of staff
- Ability to update products regularly
- Use of products by external partners
- Leadership on councils, advisory groups, and committees
- Contributions to assessments

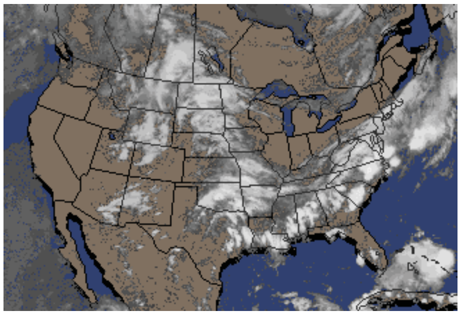
Some Substantive Accomplishments of GMD

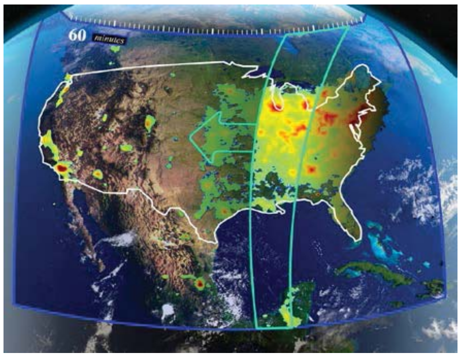




- Magnitude of the terrestrial, northern hemispheric sink for atmospheric carbon dioxide
  - Continuing to provide on-going, solid evidence that half of the CO_2 emitted to the atmosphere is taken up by land and oceans
  - Continuing to investigate the reliability of sinks
- Turnover of ozone-depleting gases and the onset of ozone recovery
  - Annually quantifying the contributions of Montreal Protocol and other gases to potential ozone recovery
- Stability of oxidizing capacity of the troposphere largely derived from these ozone-depleting gases and their replacements
  - Affects lifetimes of many gases in the atmosphere

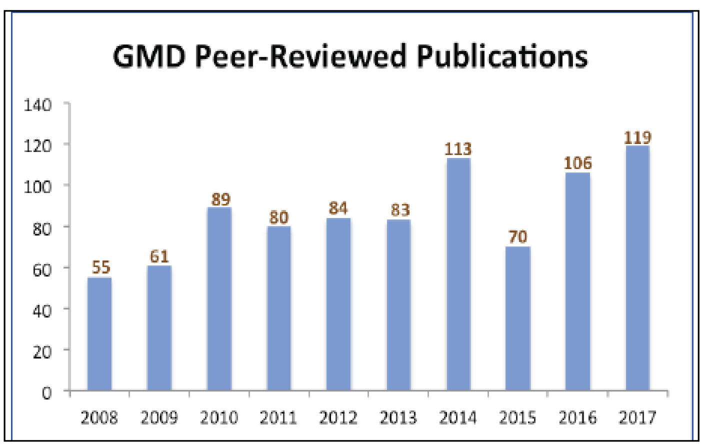
Some Substantive Accomplishments of GMD



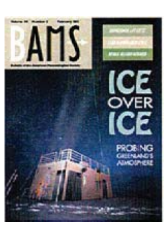


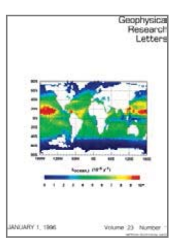
- Large increase in radiative energy at the surface across the United States over the past 15 years (equivalent to twice the forcing from a doubling of CO_2)
  - This, while noting a decrease in aerosol radiative forcing
  - Caused by variability of clouds on decadal scales
- Improving satellite retrievals through continuous evaluation of retrievals for O_3, UV, surface radiation, water vapor, and GHGs
- Primary source for information and data on hundreds of variables in the atmosphere
  - Virtually all of these are identified as GCOS Essential Climate Variables

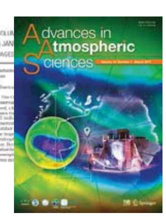
Publications Keep Increasing

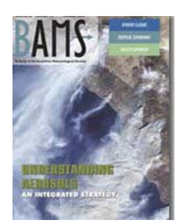


- These are publications with GMD authorships.
- The number has increased at ~7 per year since 2013, our last review.
- That's the same rate of increase since 2008.

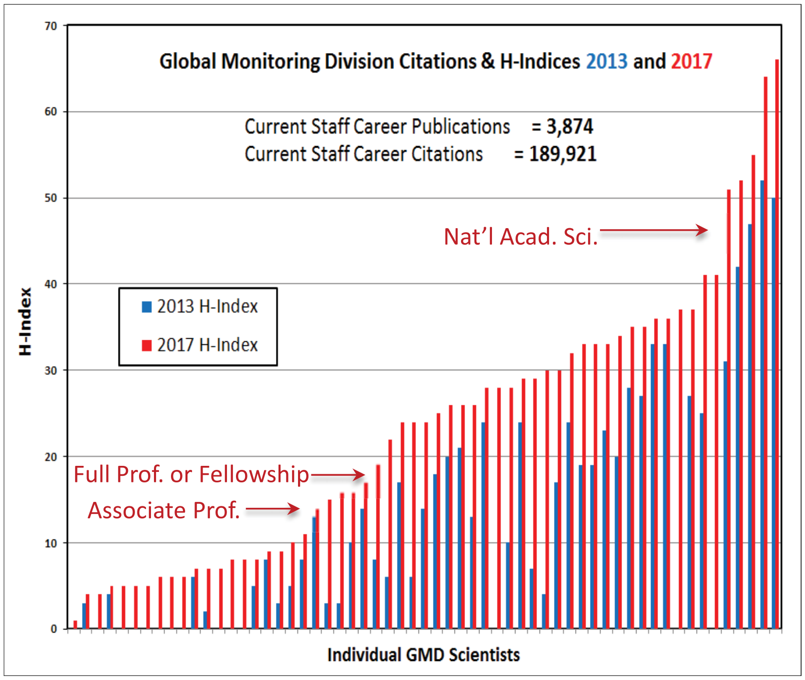








Staff Performance – Hirsch Index

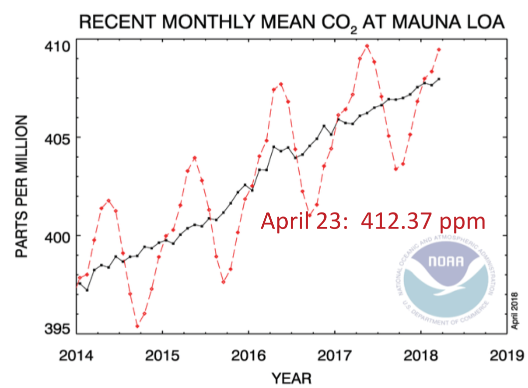


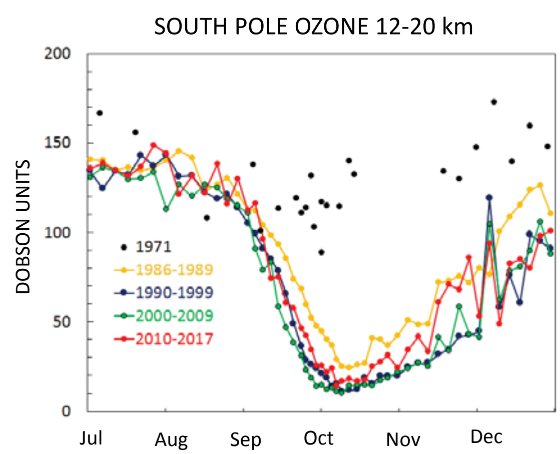
	H-Index*	# Pubs.	# Citations
Tans	66	227	17,195
Oltmans	64	234	13,015
Elkins	55	175	8,799
Ogren	52	159	8,264
Dlugokencky	51	144	8,282
Johnson	41	107	5,008
Sweeney	41	144	7,270
Long	37	94	6,574
Novelli	37	74	4,356
Hintsa	36	76	3,784
Montzka	36	147	7,812
Butler	35	59	3,804
Schnell	35	110	4,028
Bruhwiler	34	59	5,412
Andrews, A.	33	93	3,410
Conway	33	65	7,162
Miller, J.	33	89	4,257
Jefferson	32	65	3,307
Masarie	30	46	6,324
Miller, B.	30	70	4,140
Hurst	29	71	2,708
Moore	29	68	3,513
Michalsky	28	89	2,699
McComiskey	28	118	4111
Sheridan	28	63	3,502

*As of Dec 2017

On-line Products

- Interactive Data Visualization
- Annual Greenhouse Gas Index
- Ozone-Depleting Gas Index
- South Pole Ozone
- GLOBALVIEW and ObsPak
- Mauna Loa and Global Trends
- GMD 3 Dimensional Maps of Composition
- Solar Calculator





Awards Summary 2013-2017












- DOC Bronze Medal Award (1)
- NOAA/CIRES Silver Medal Award (1)
- Yoram J. Kaufman Award (1)
- OAR Outstanding Paper (2)
- CIRES Outstanding Service Awards(6)
- Governor's Award for High Impact Research (2)
- AGU Excellence in Refereeing (3)
- Vaisala Award (1)
- Total of 28 External Awards honoring 61 individuals in GMD over past 5 years

Partners

- GMD operates instruments or collects samples at 78 locations in 35 states in the US
- Nearly all of the 13 US agencies participating in the USGCRP make use of GMD's data and products
- GMD operates similarly at 161 locations in 67 countries
- Over 100 partnering scientists worldwide, many in association with WMO Global Atmospheric Watch

- NOAA/ESRL Global Monitoring Annual Conference
  - Essentially GMD's annual meeting to engage with partners contributing to, sharing, or using GMD's data and data products routinely.

2018 GMAC

National and Global Leadership

- WMO Commission for Atmospheric Science
  - US Lead Delegate
  - WMO Global Atmosphere Watch (Four members of Scientific Advisory Groups (2 chairs)
  - Many members of GHG Measurement Techniques Group
- European Research Infrastructures
  - Advisory Boards for 3 EU Infrastructures

- Global Climate Observing System (GCOS)
  - Atmospheric Observation Panel for Climate
- US Global Change Research Program
  - Carbon Cycle Interagency Working Group
  - Carbon Cycle Scientific Steering Group
  - North American Carbon Program Scientific Steering Group
  - SOCCR Co authors (3 co-leads)
- Group on Earth Observations
  - GEO Carbon
- WCRP Baseline Surface Radiation Network

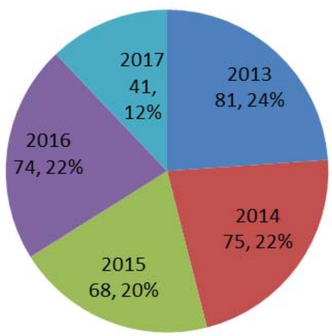
Assessments

- Our contributions to Assessments are the highest level product and ultimate transition for our research:
  - Provide evaluations and syntheses of the most recent research
  - Operate at the interface of science and policy, providing policy-relevant information
- IPCC Assessments
  - Inform nations through UNFCCC on climate and climate change mitigation
    - Significant vehicles for educating global society on climate change
- Ozone Assessments
  - Inform nations through the Vienna Convention on the Ozone layer
    - Resulted in significant amendments to the Montreal Protocol
    - Led to acceleration of production phaseouts, most recently HCFCs
- National Assessments
  - Provide US policy-makers with climate-relevant information

U.S. Global Change Research Program
National Climate Assessment

ESRL Student Program 2013-2017

- CIRES/CIRA
- Educational Partnership Program
- High Schools
- Hollings Scholars
- Research Experience for Undergraduates
- Science and Technology, Corp.
- Significant Opportunities in Atmospheric Research
- Tribal College Collaboration



339 Students served in 2013 – 2017

GMD Outreach

Building Global Capacity

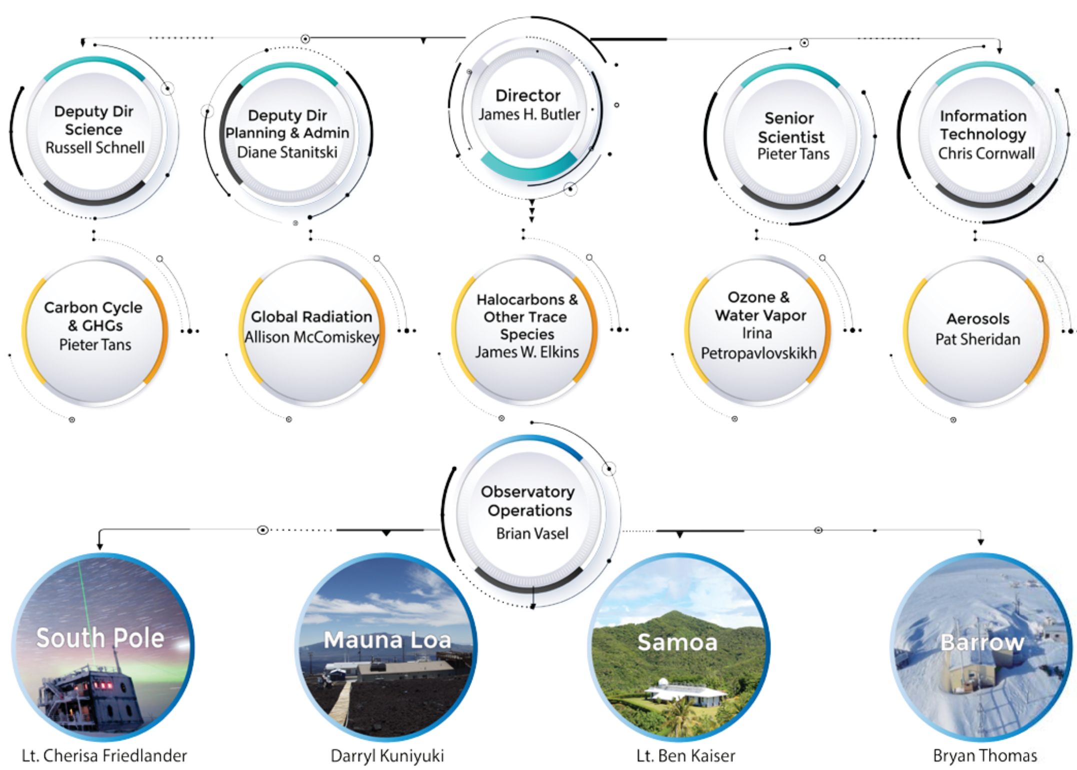
- Coordinates with scientists, universities, agencies around world to add sites to measurement networks
- Trains emerging scientists abroad and WMO partners

Public Outreach

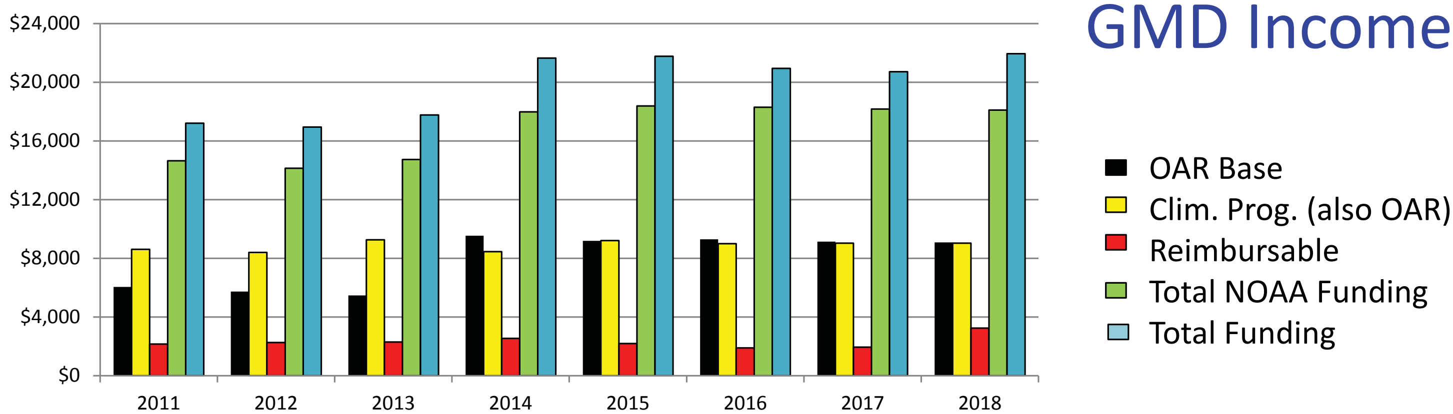
- GMD Observatories provide tours, community presentations, student field work
- 29,485 visitors to our facility in 2013-2017 were shown SOS, the GMD "Wall", and other activities
- Organized NOAA activities for Native American students and minority groups (e.g., AISES, Howard)
- Served as panelists and presenters in local high school science classes
- Presented GMD science at TEDx Boulder Salon
- Hosted anniversary events with Boulder media

Organization and Management

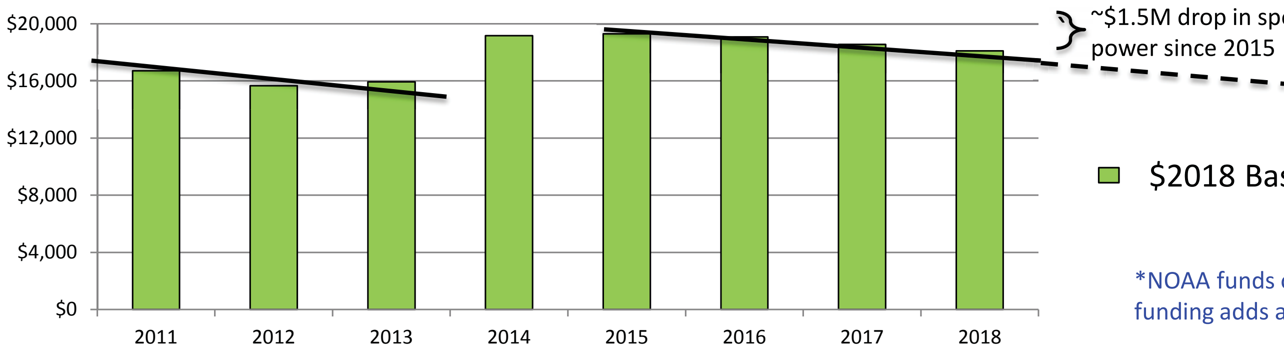
GMD Organization



GMD Income



$2018 Basis

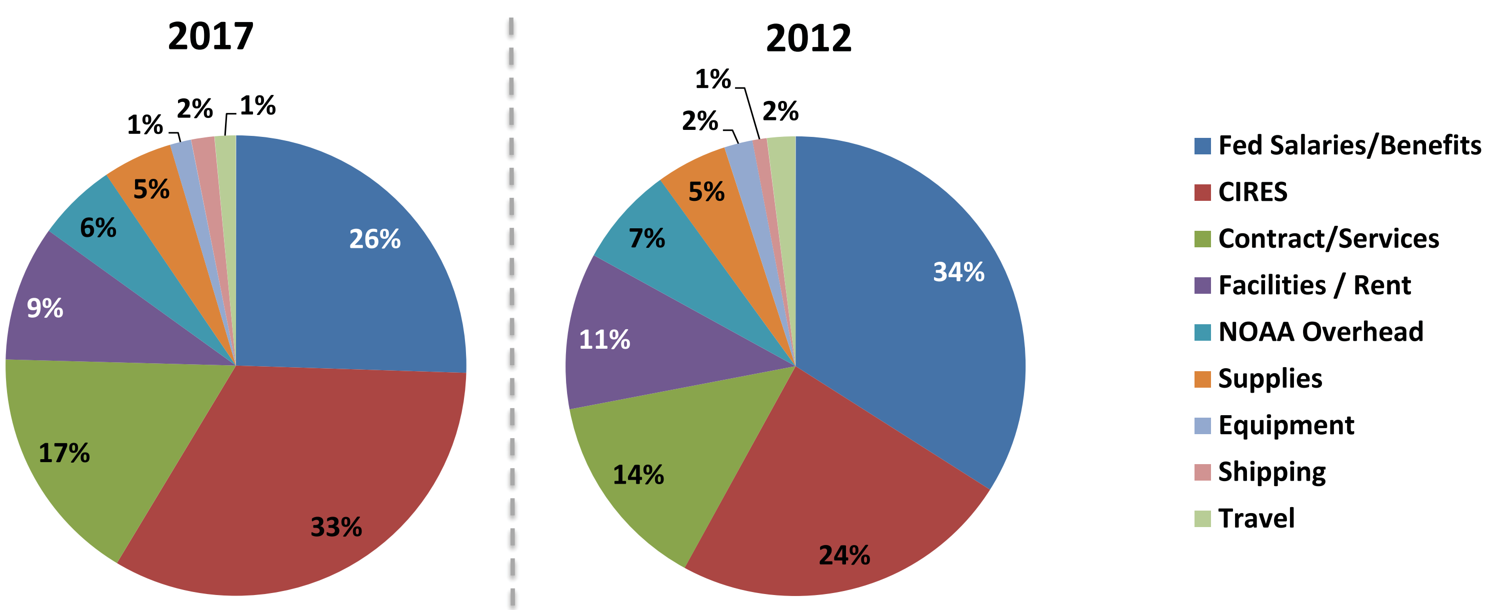


~$1.5M drop in spending power since 2015

$2018 Basis (NOAA)

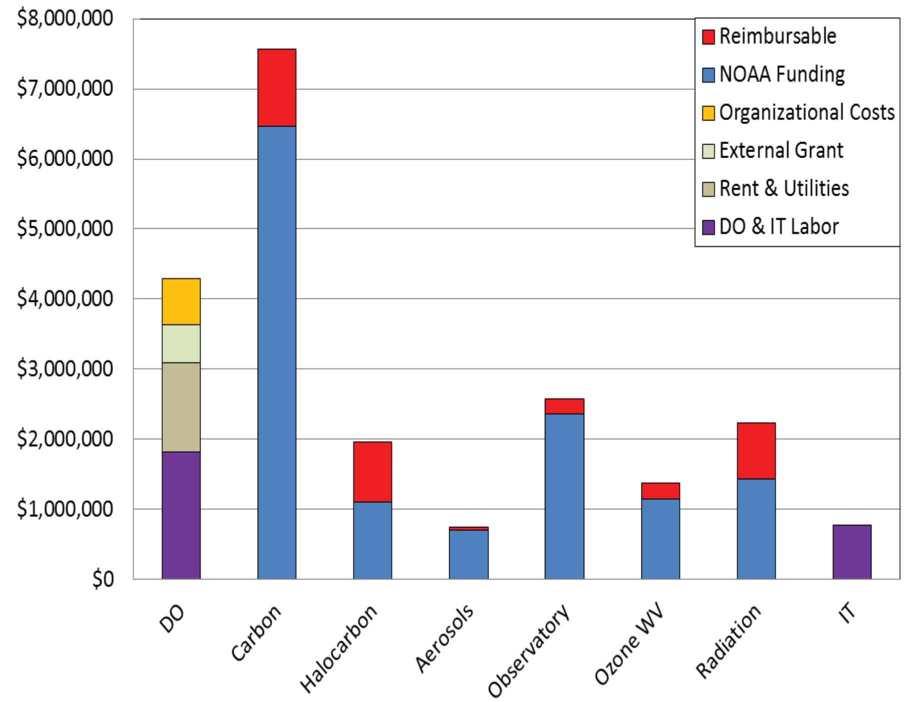
*NOAA funds only. External funding adds another 15-20 %

Expenditures by Function



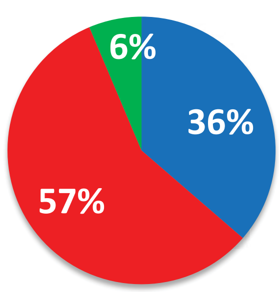
Budget distribution in GMD (2018)

- 5 Research Groups
- Observatory Operations
- Director's Office and IT
  - Includes Admin & Budget
  - Largely non-scalable



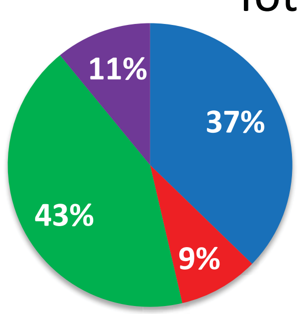
Workforce Profile

2017



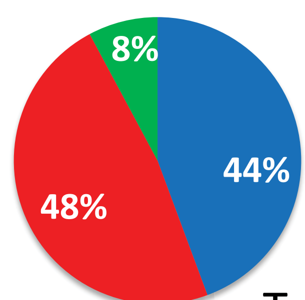
- Federal (with NOAA Corps x2)
- CI (CIRES & JIMAR)
- Contractor (STC)

Total "FTE" = 107



- PhD
- Masters
- Bachelors
- Other

2012



- Federal (with NOAA Corps x2)
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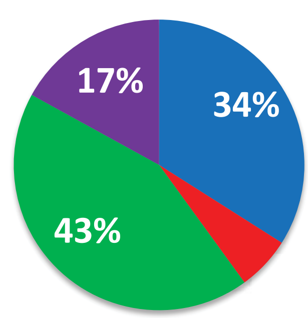
- Contractor (STC)

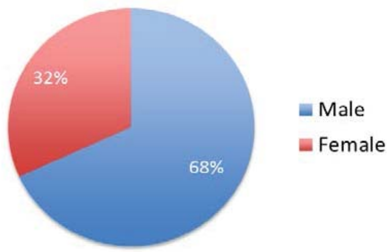
Total "FTE" = 115

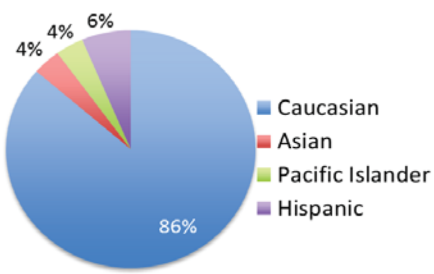


- PhD
- Masters
- Bachelors
- Other

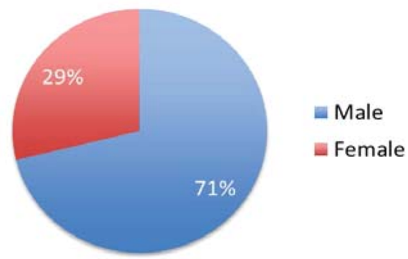
Workforce Demographics

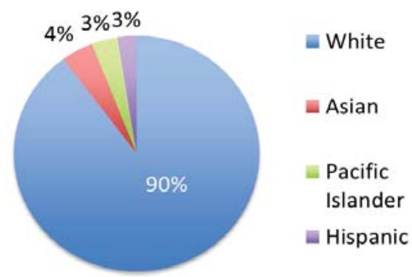
2017





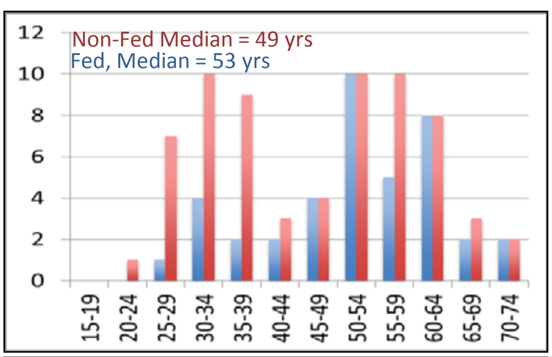
2012

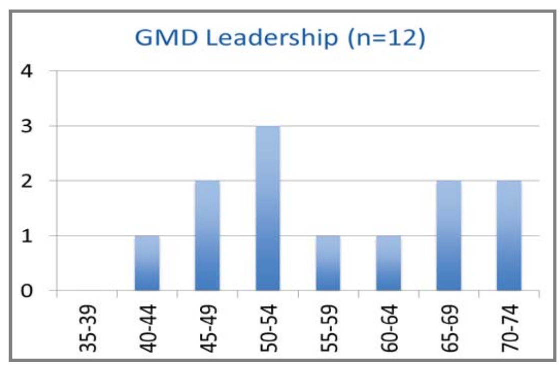




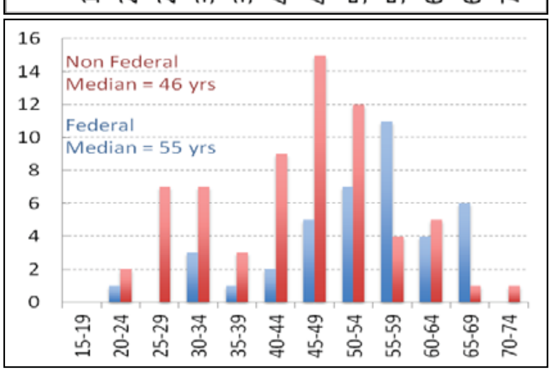
Workforce Age Distribution

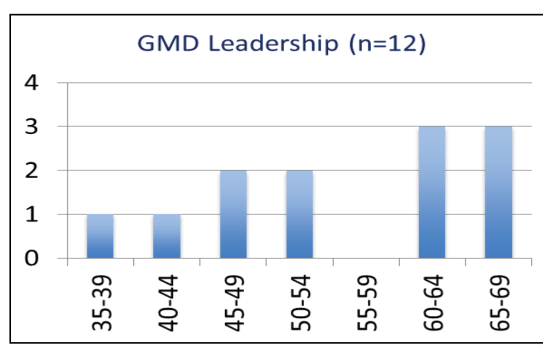
2017





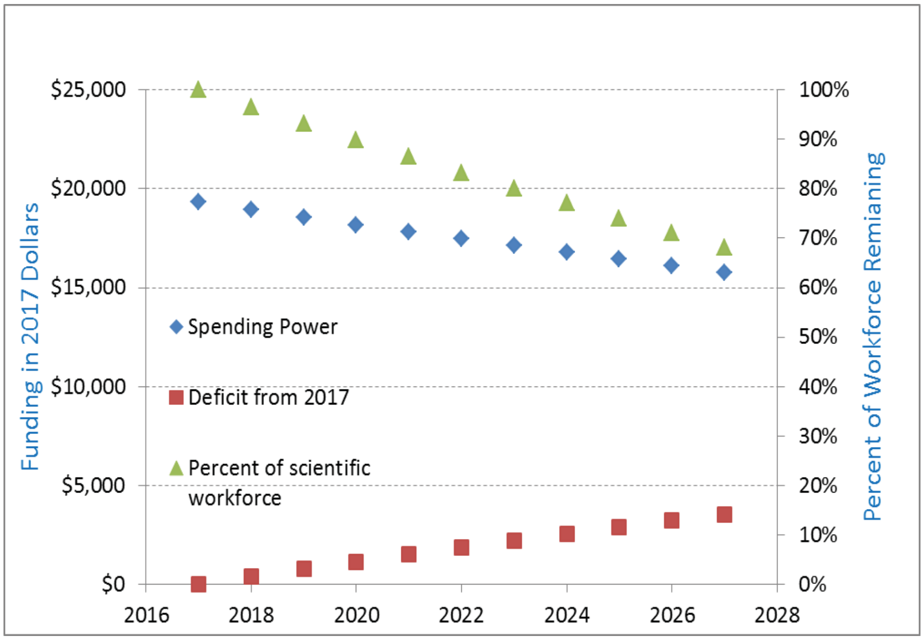
2012



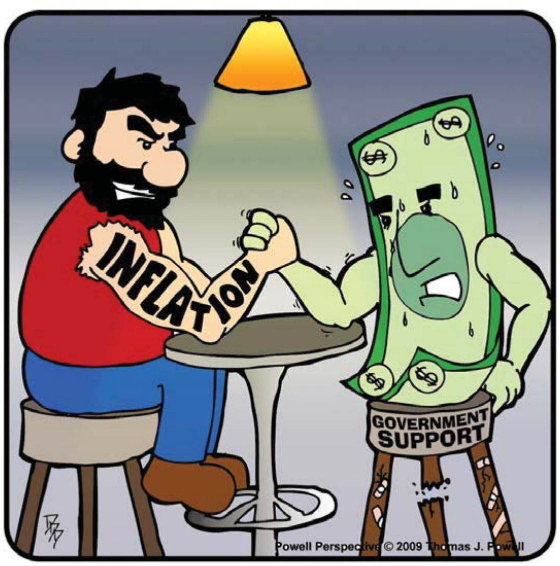


Our Challenge Ahead

- Inflationary erosion (2%/yr) impinges heavily on GMD
  - Extent of observations
  - Quality of observations
  - Number of personnel
- Steady funding means $2M loss in 5 years, $4M in 10 years.
- Steady funding puts GMD on a path to lose 1/3 of current scientific personnel in 10 years

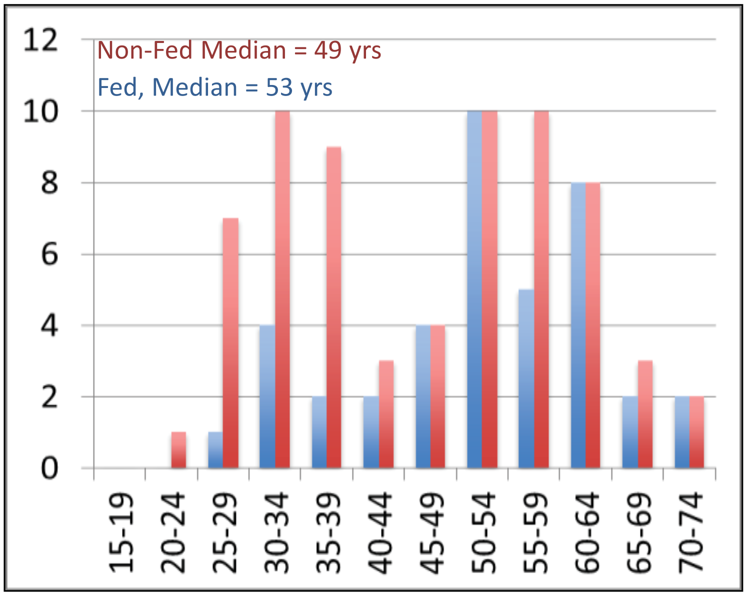


How are we addressing decreasing resources?



- Reimbursable projects
- Increasing efficiency
- Reducing redundancy
- Collaborating with other labs
- Cutting back on sites
- Renewing aging workforce?

Renewing the workforce



- Why
  - New ideas
  - New technology
  - New energy
  - Training leaders for future
  - Protecting a 50 year investment that NOAA has made
- How
  - Postdoc programs
  - Outside grants
  - Collaborations with universities

The Future

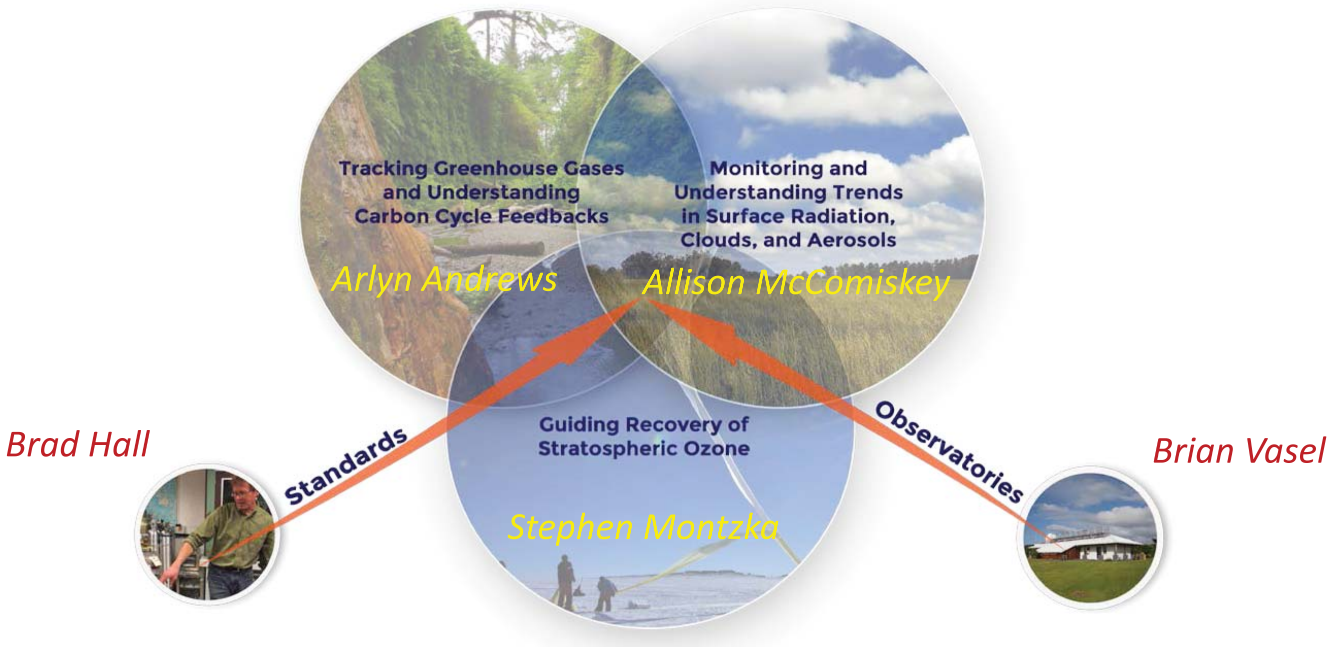
Operational Challenges

- Sustaining long-term observations in global networks
- Ensuring a world-class research workforce
- Addressing succession

Transformative Opportunities

- Build commercial aircraft capability
- Expand C-14 efforts
- Augment Surface Radiation Network to improve predictions
- Enhance upper atmospheric research
- Support renewable energy evaluation
- Advance US tall tower network for boundary layer composition studies

Upcoming Presentations



NOAA/ESRL Global Monitoring Division
Laboratory Review, 21-24 May 2018

NOAA Global Monitoring Division

- *. . . providing the best possible information to inform climate change, weather variability, carbon cycle feedbacks, and ozone depletion.*

GMD Mission

- *To acquire, evaluate, and make available accurate, long-term records of atmospheric gases, aerosol particles, clouds, and solar radiation in a manner that allows the causes and consequences of change to be understood.*

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.
- NOAA anchors the global and US atmospheric carbon observing network. We established multiple comparisons with Environment Canada, Earth Networks and university researchers. 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.

NOAA/ESRL Global Monitoring Division
Laboratory Review, May 21-24, 2018
Carbon Cycle Greenhouse Gases

Outline

- Tracking Greenhouse Gases at Regional to Global Scales
- Understanding Carbon Cycle Feedbacks
- Monitoring Greenhouse Gases in the Upper Atmosphere
- Looking Forward

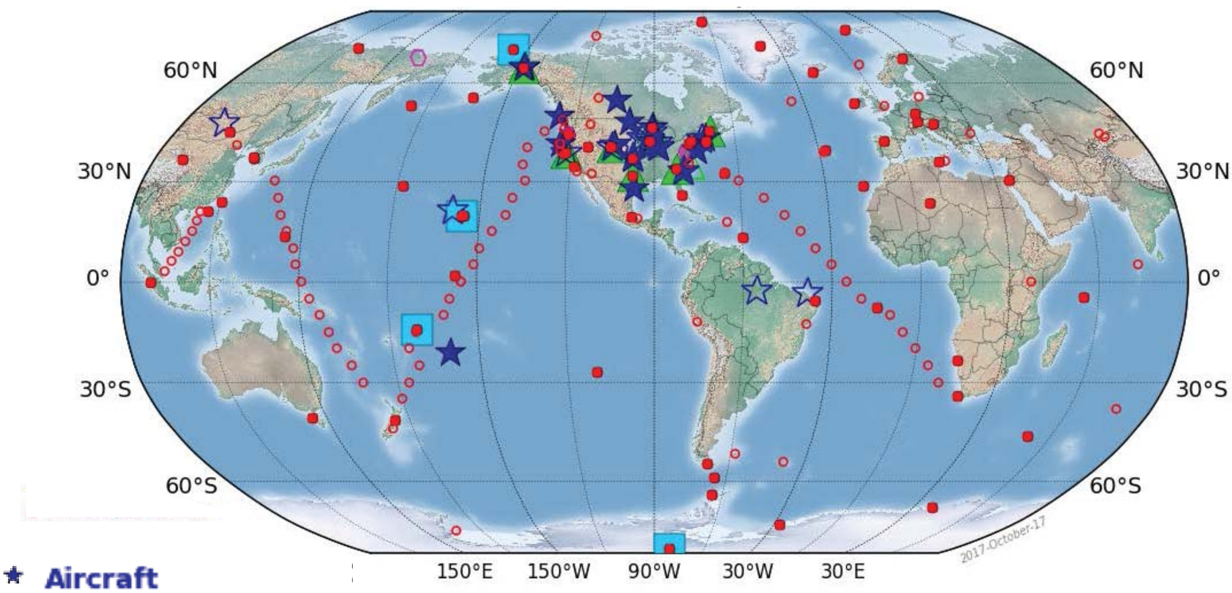
Quality, Transparency, Availability, Capacity Building

Tracking Greenhouse Gases at the Global Scale

Mauna Loa Observatory: Photograph by Forrest Mims III

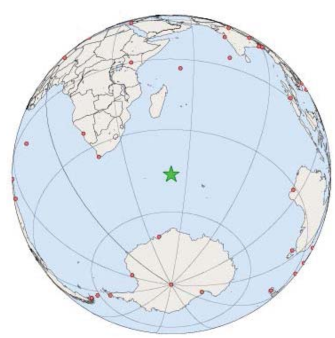
"Science-driven monitoring of the atmosphere, responding to societal needs"

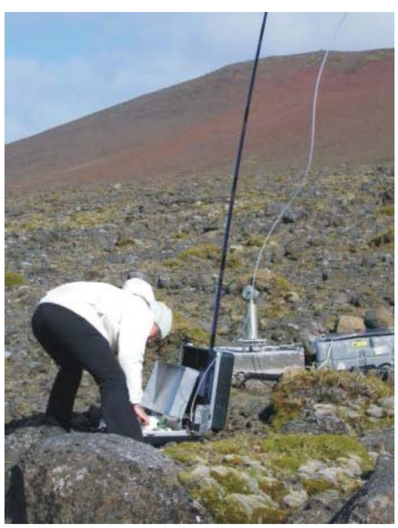
NOAA Global Greenhouse Gas Reference Network

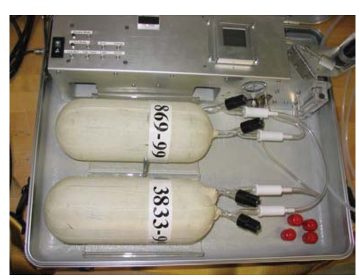


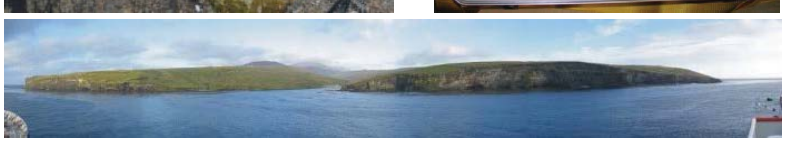
- Data are carefully calibrated relative to WMO scales
- Intra-laboratory and cross laboratory comparisons with other labs ensure data compatability
- Whole air samples are analyzed for many species

Air sampling at Crozet Island



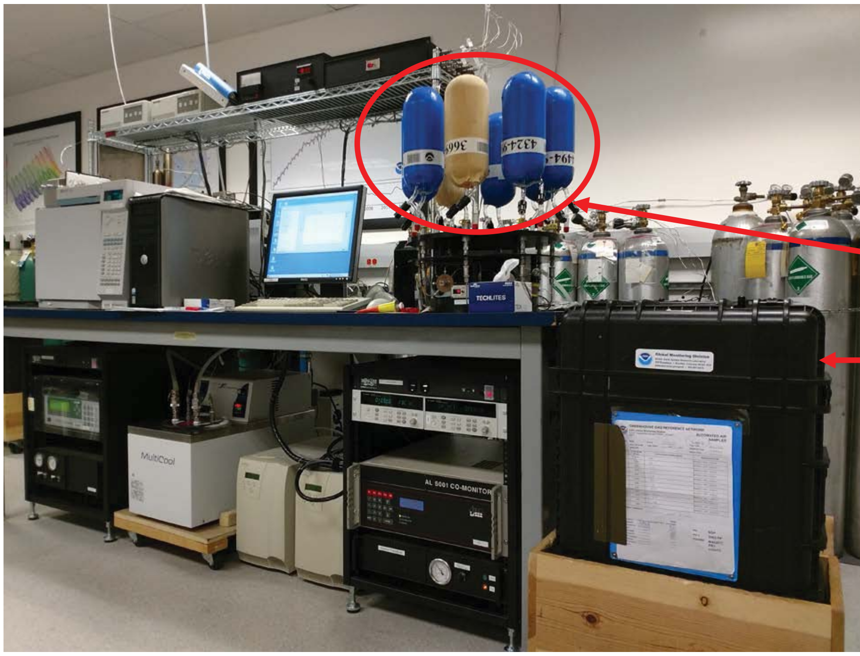






- Weekly whole air samples capture the variability at remote sites.
- Local sources and sinks are avoided.

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

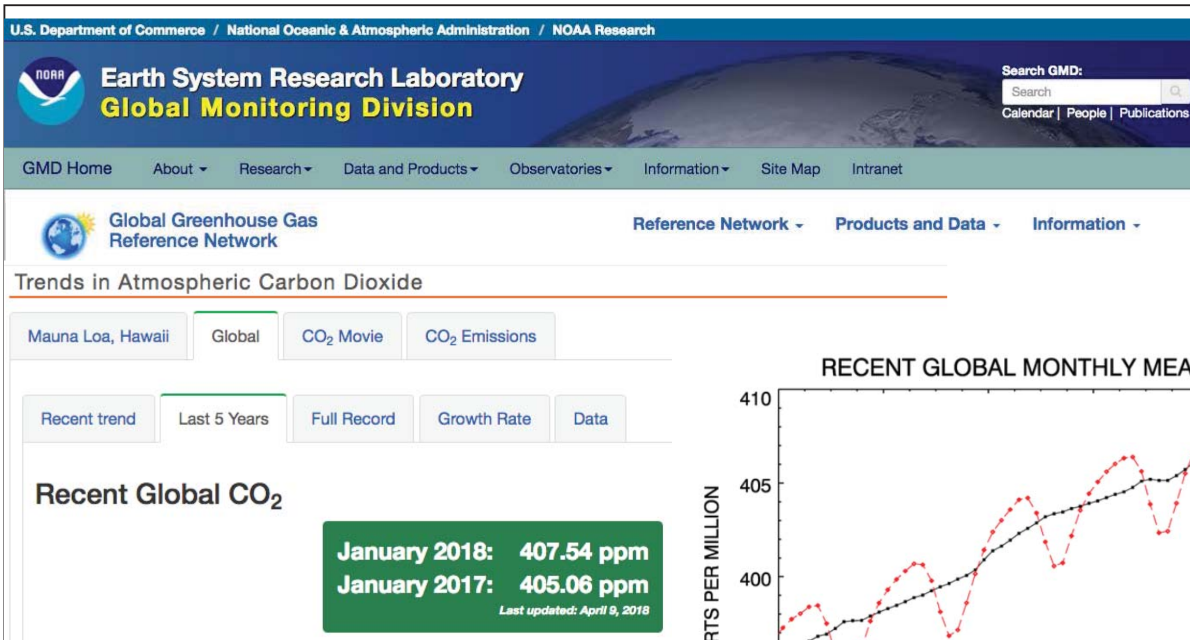


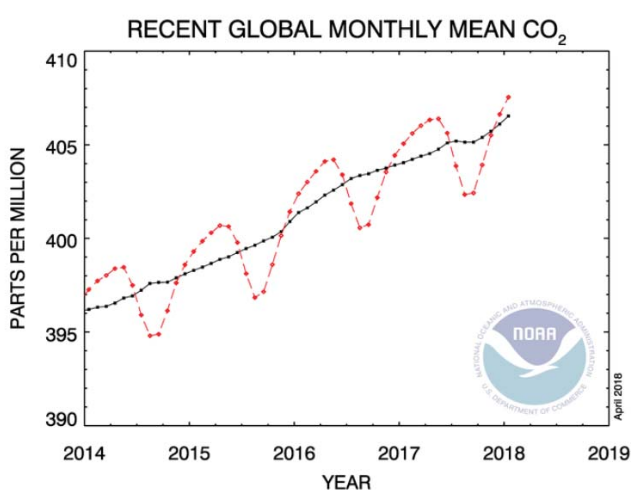
WMO compatibility goals for remote sites:

CO_2: ±0.10 ppm Northern Hemisphere, ±0.05 ppm Southern Hemisphere

CH_4: ±2 ppb

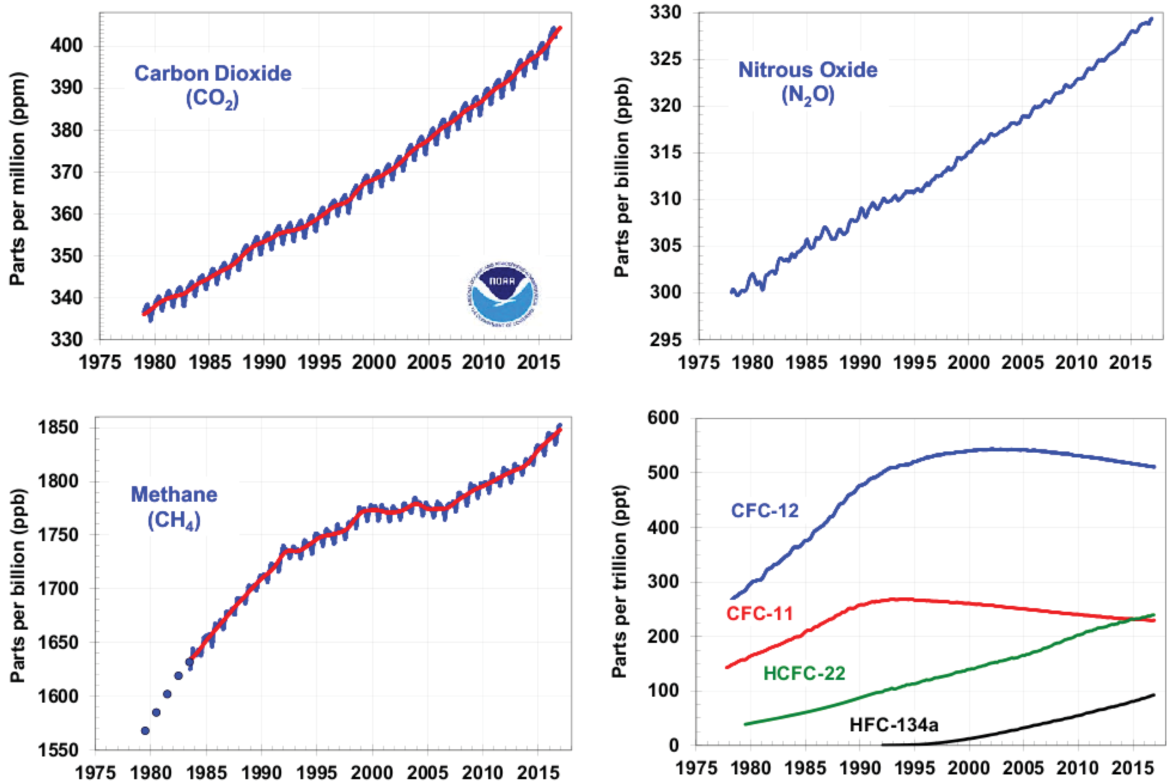
N_2O: ±0.10 ppb



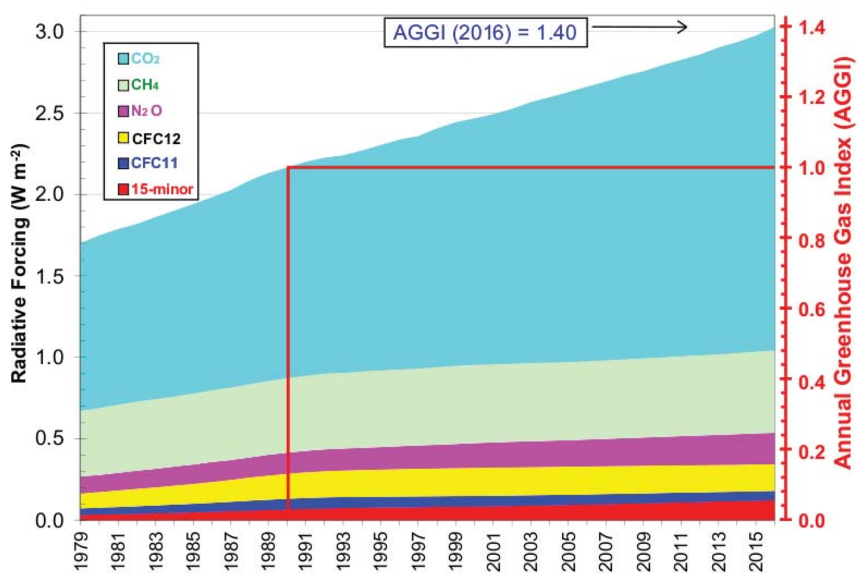


Global Means computed from the MBL reference surface are made readily available with minimal delay.

Global Mean Values for the Major Long-Lived Greenhouse Gases



NOAA Annual Greenhouse Gas Index

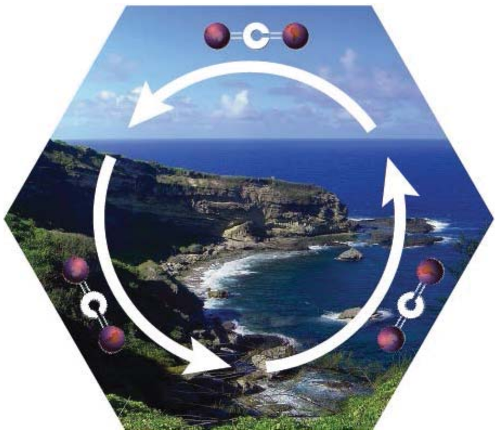


As of 2016, radiative forcing from anthropogenic greenhouse gases is up by 40% over 1990 levels.

Earth's Surface: 510.1 trillion m^2

Understanding Carbon Cycle Feedbacks

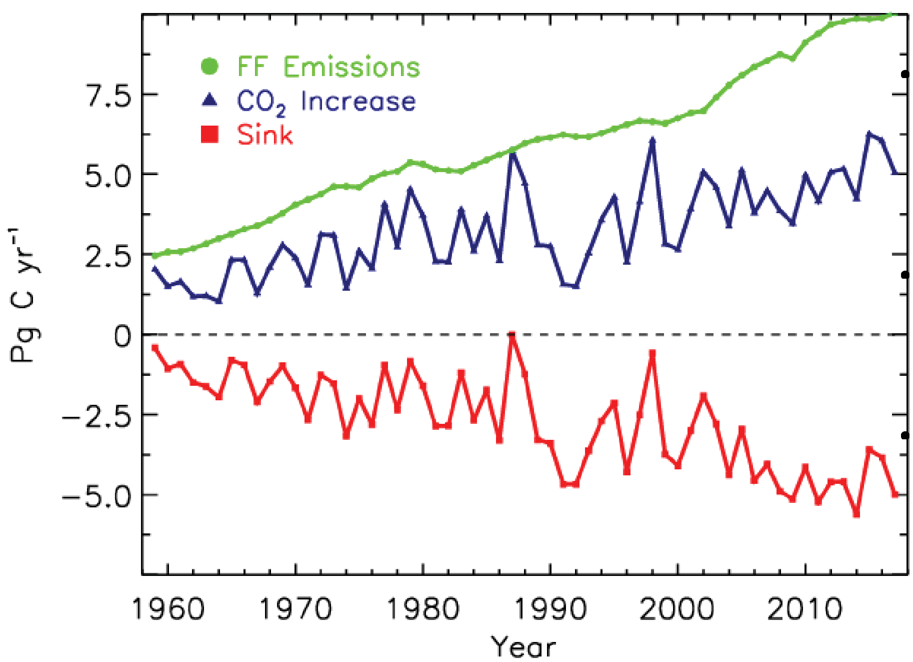
WCRP World Climate Research Programme



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

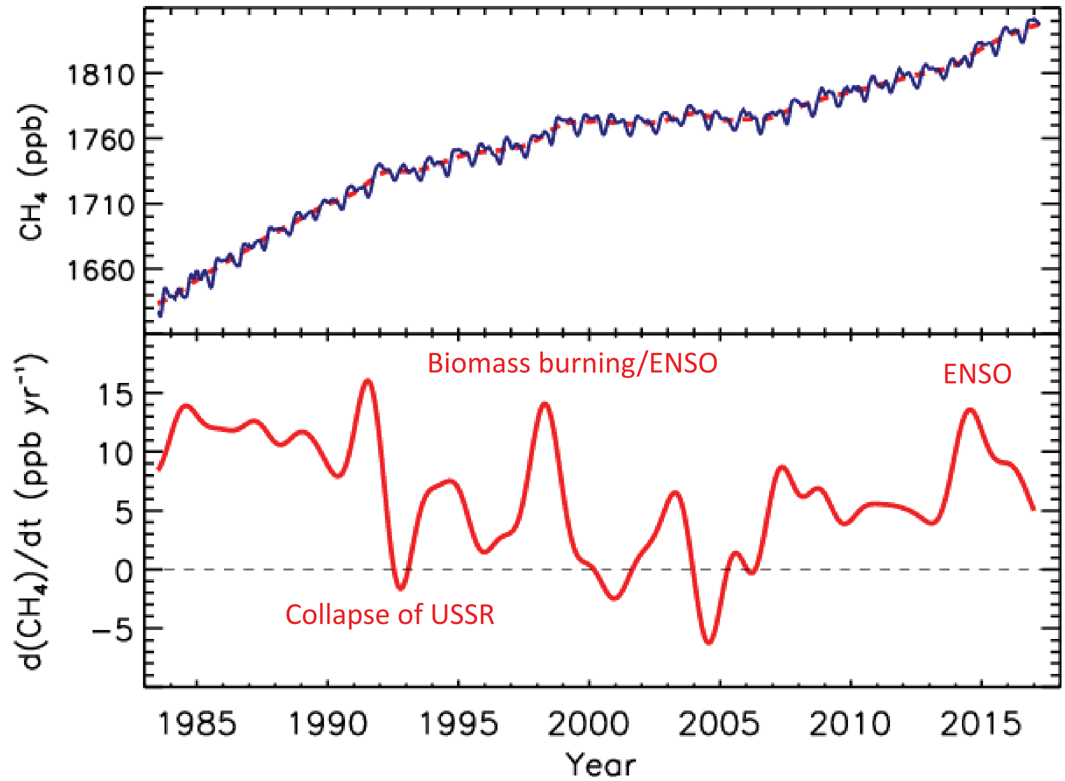


- Carbon sinks keep increasing as fossil fuels keep rising. Global C uptake now ~4 PgC/yr.
- ~50% of fossil fuel emissions are still taken up by sinks.
- Year-to-year variability driven by land uptake. We cannot yet attribute land uptake to specific processes.

Ballantyne et al., Nature, 2012, updated

GMAC presentation by Ed Dlugokencky

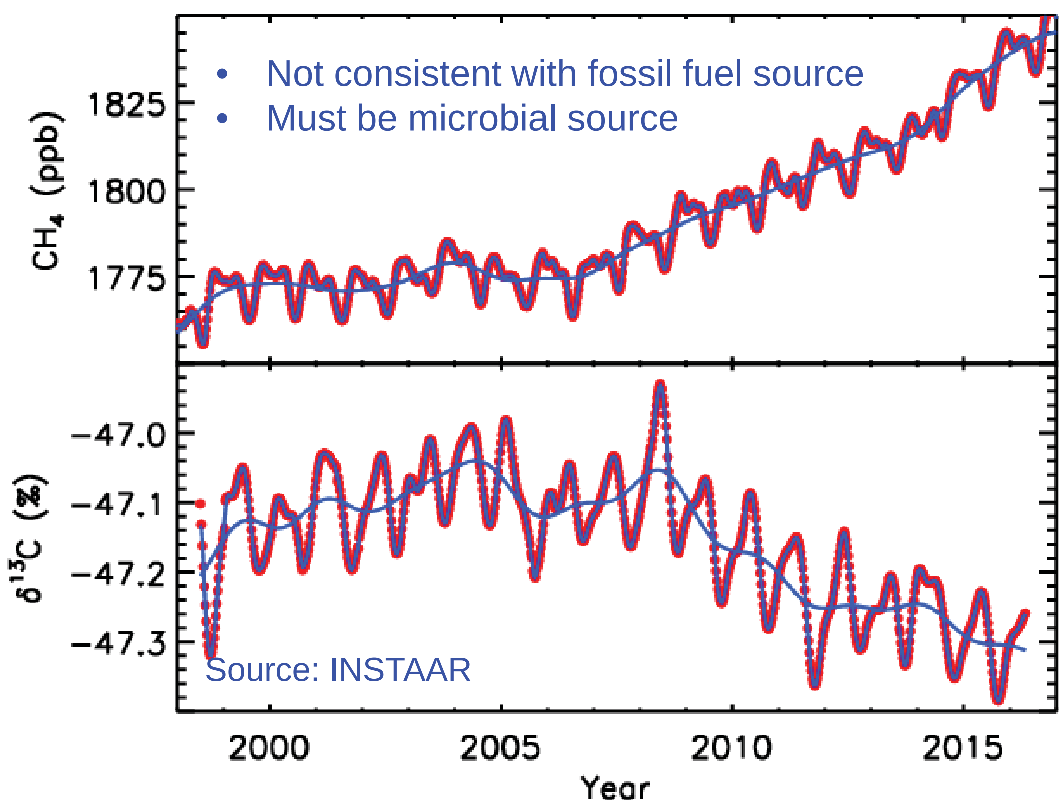
Globally averaged CH_4 and its growth rate



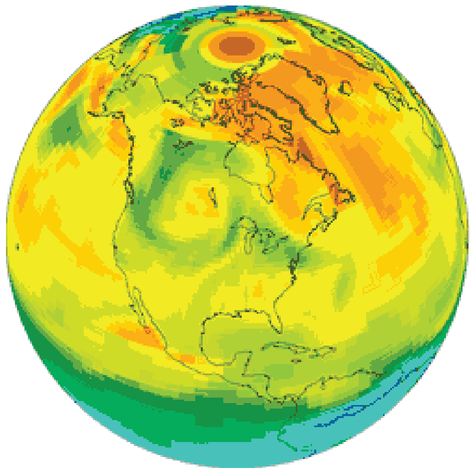
CH_4 data from Ed Dlugokencky

GMAC Presentation by Lori Bruhwiler

CH_4 from Fossil Fuels?

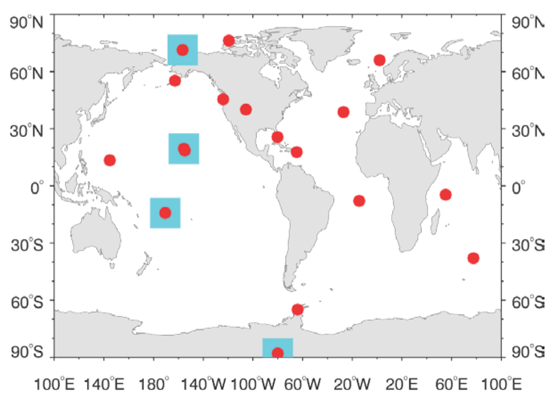


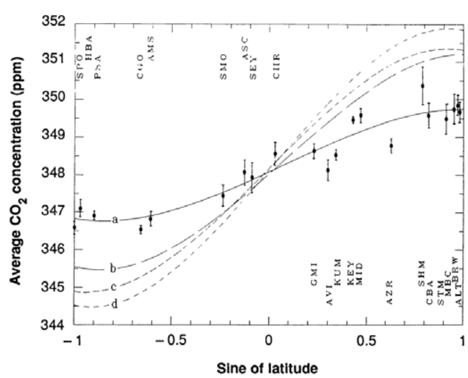
Estimating Emissions and Removals



Observational Constraints on the Global Atmospheric CO_2 Budget

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



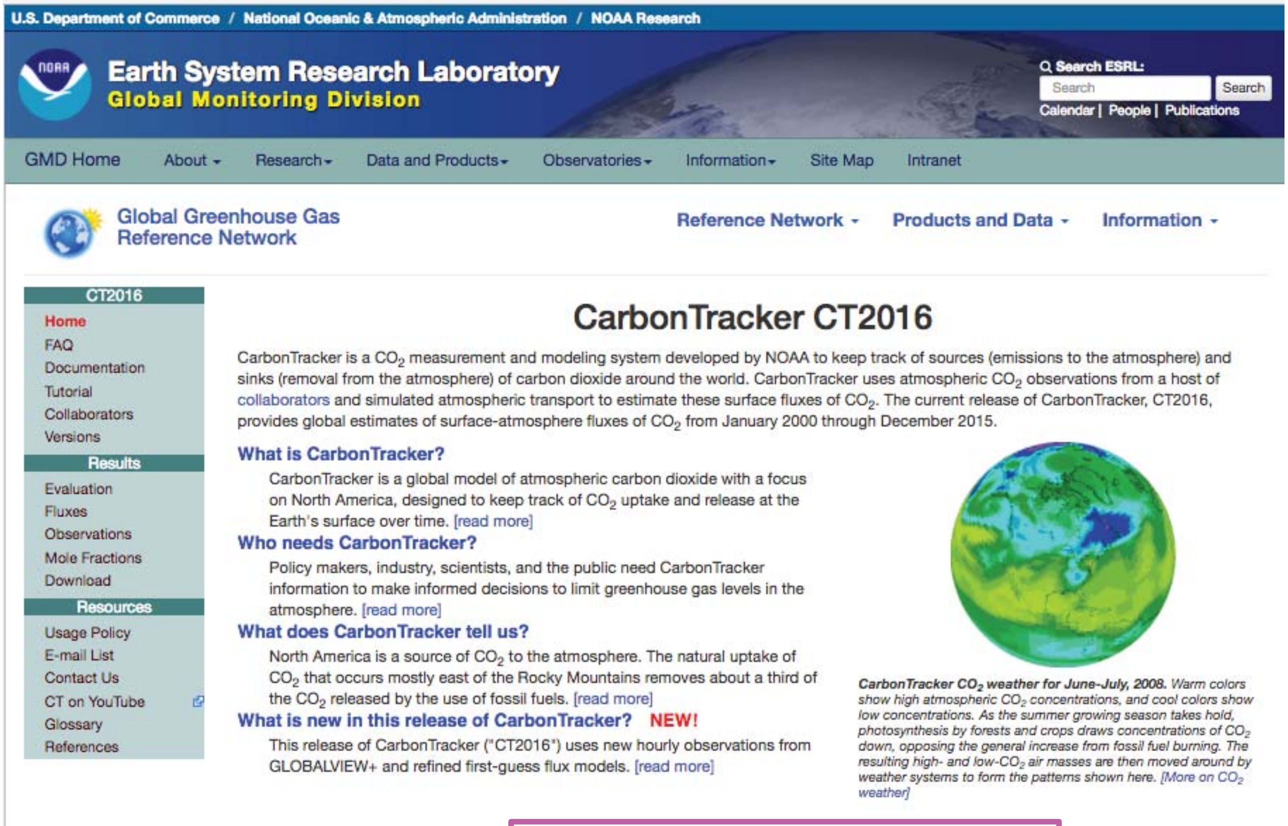


- flask sampling site (weekly)
- observatory (continuous)

Science, Mar. 23, 1990

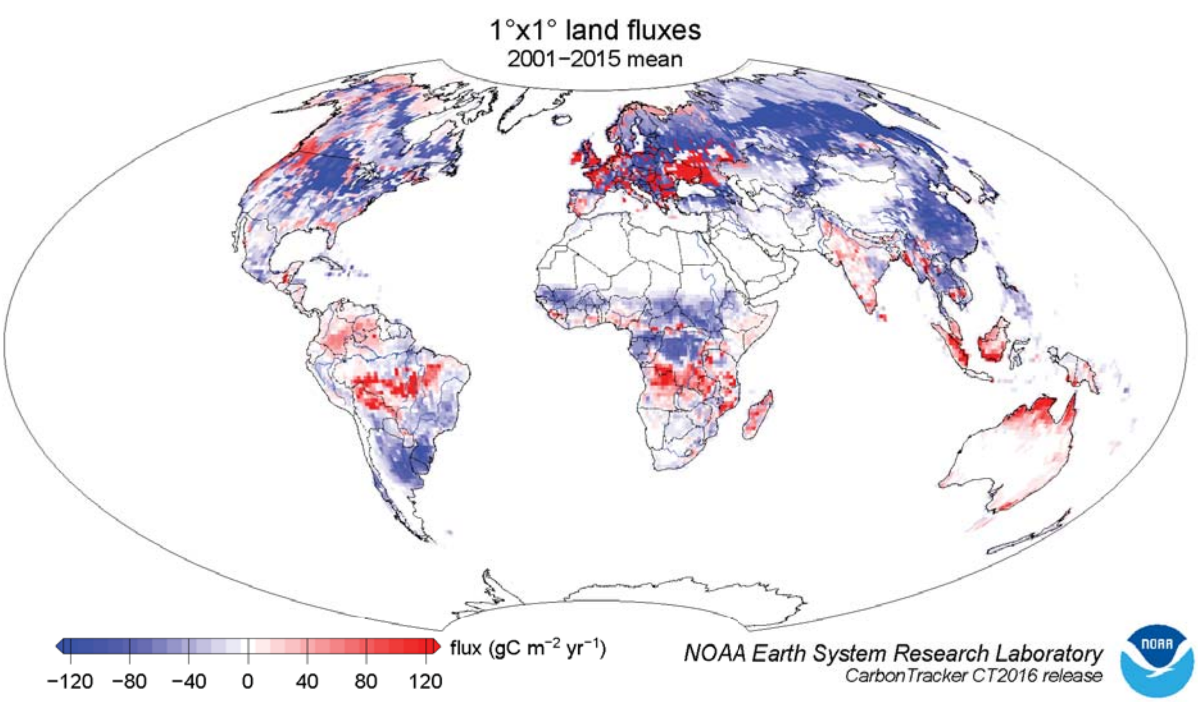
"…a large amount of the CO_2 is apparently absorbed on the continents by terrestrial ecosystems."

1439 citations!

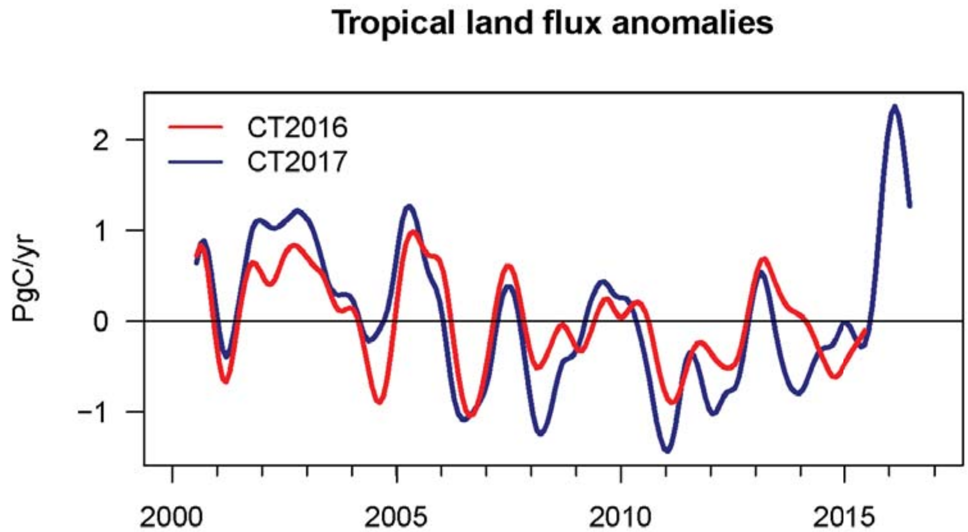


GMAC Presentation by Andy Jacobson

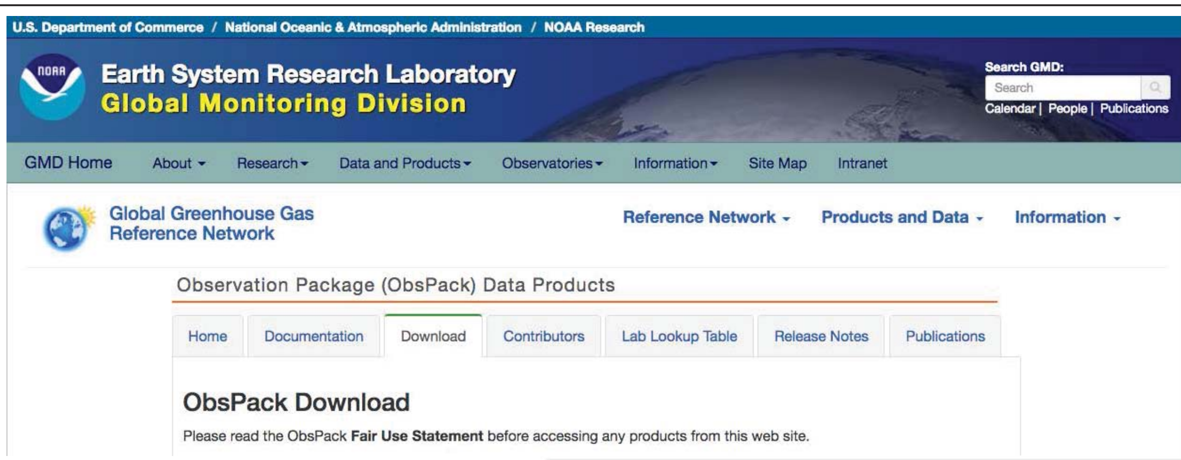
NOAA's CarbonTracker provides up to date estimates of regional carbon fluxes:



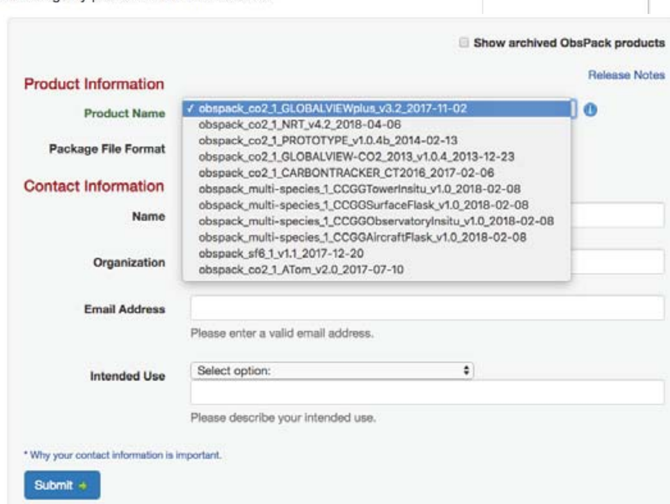
CarbonTracker



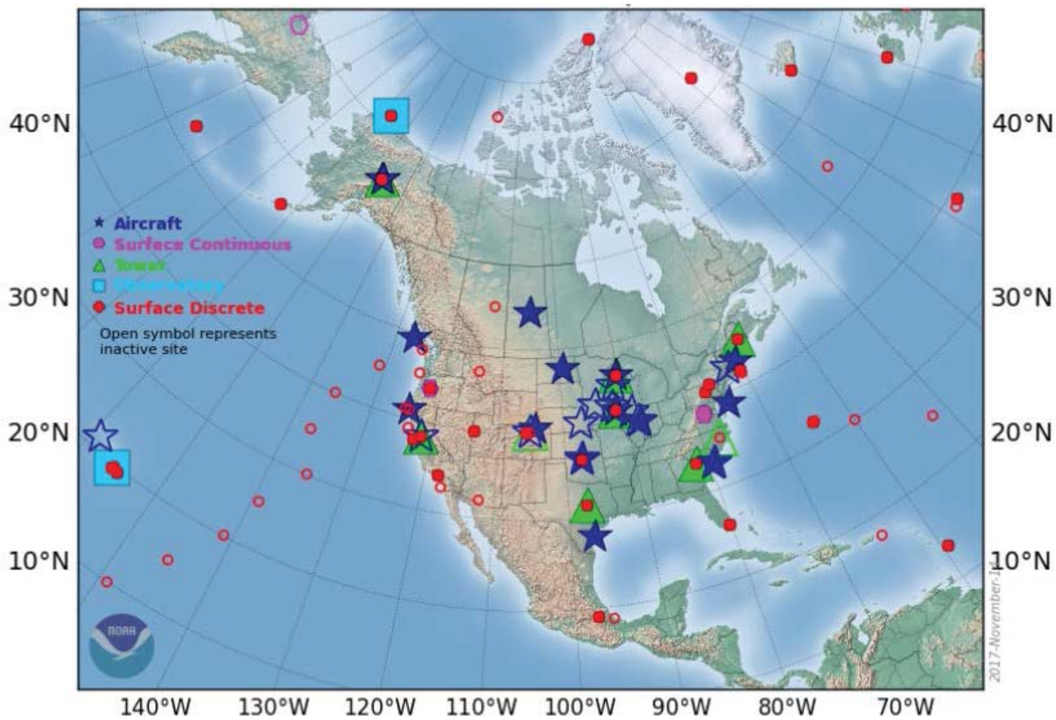
CT2017 is the first CarbonTracker release to simulate impacts of a large El Niño. In 2015 and 2016, we find about 1.2 PgC/yr extra CO_2 in the atmosphere due to this event.



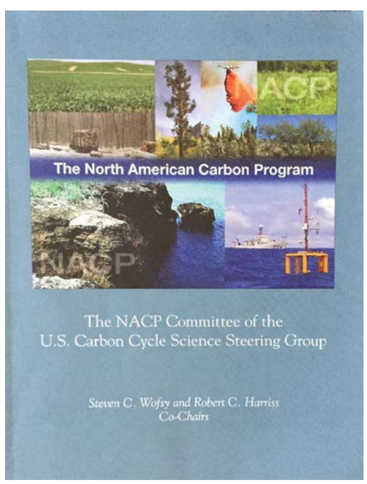
- All of the GGRN CO_2, CH_4, N_2O, SF_6 data are archived and available in ObsPack format
- Near-real time products support OCO-2 retrieval evaluation and data analysis
- GLOBALVIEWplus products are a multi-laboratory community product
- Campaign ObsPacks are available, e.g. ATom, ACT-America

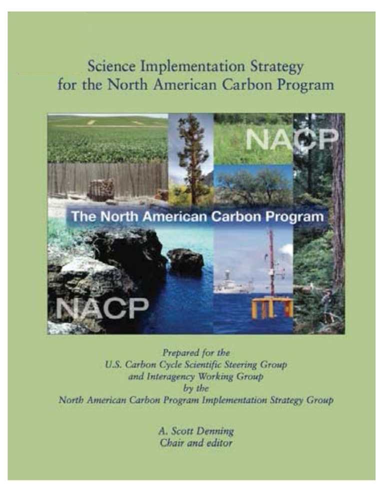


Moving from Global to Regional Scales



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!

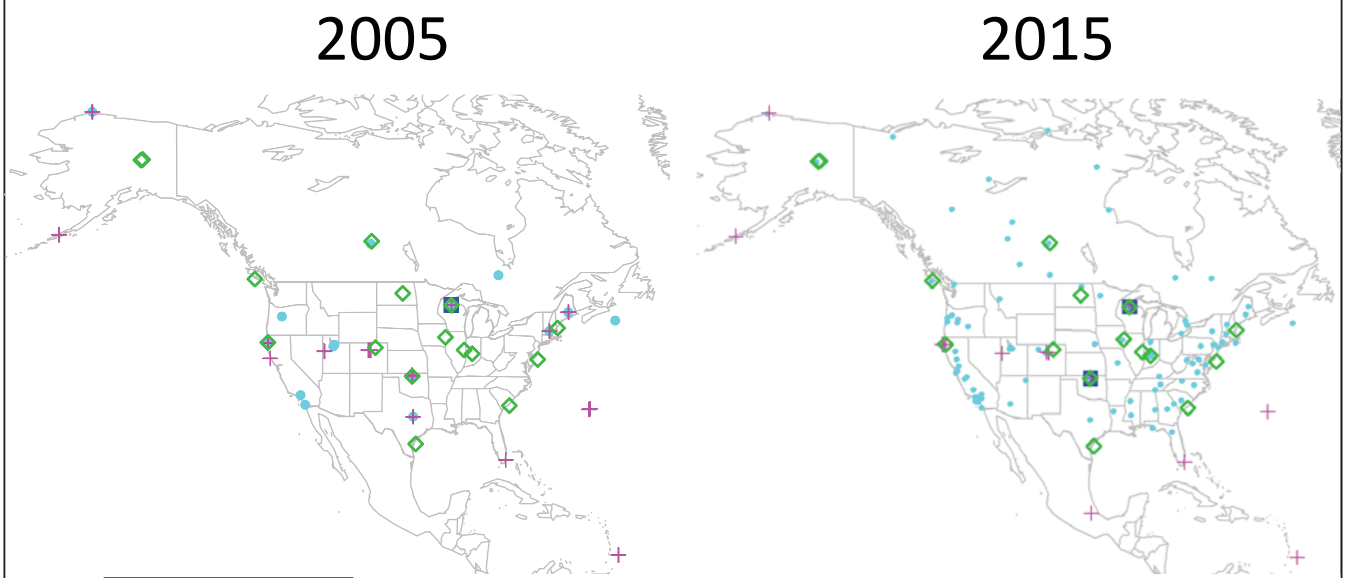
Tall tower program PI: Arlyn Andrews

Aircraft sampling with "Programmable Flask Packages"

- 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 (recently added ethane!), halocarbons

Aircraft program PI: Colm Sweeney

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



- weekly flask
- aircraft flask
- surface in situ
- TCCON

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

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

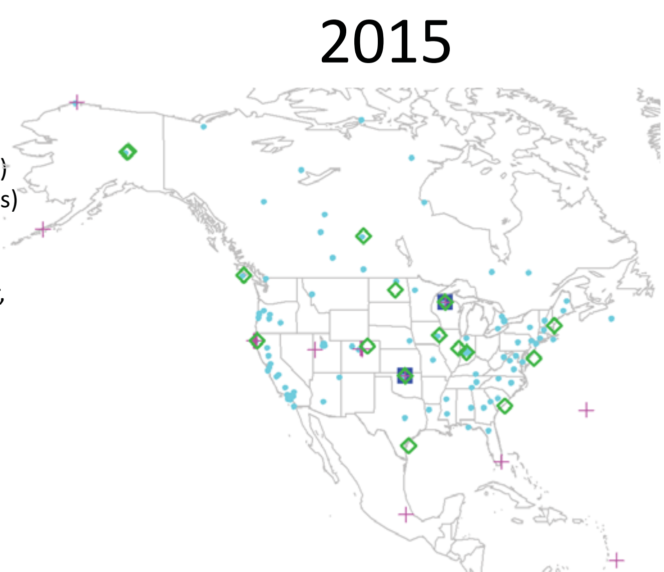
Data Providers

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

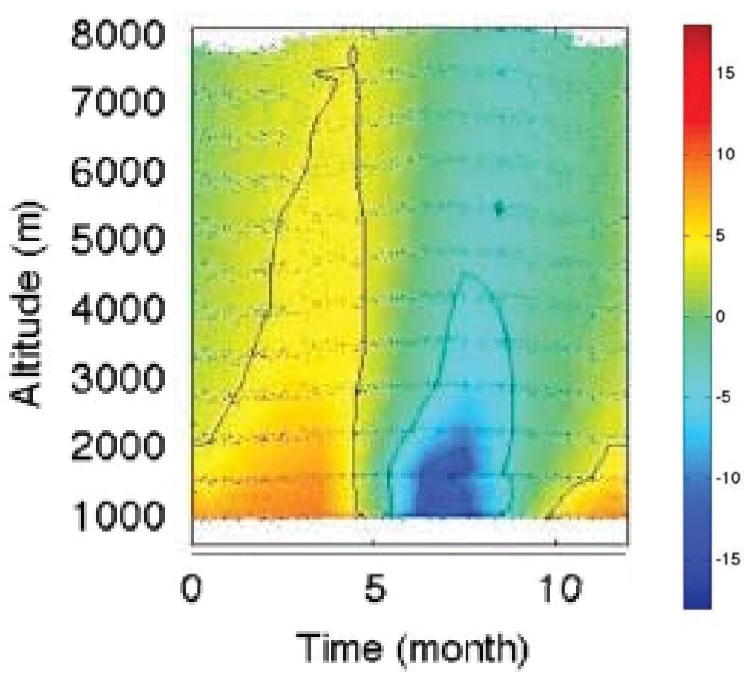


Comparability among datasets is crucial for flux estimation and trend detection.

- weekly flask
- aircraft flask
- surface in situ
- TCCON

What do the data tell us?

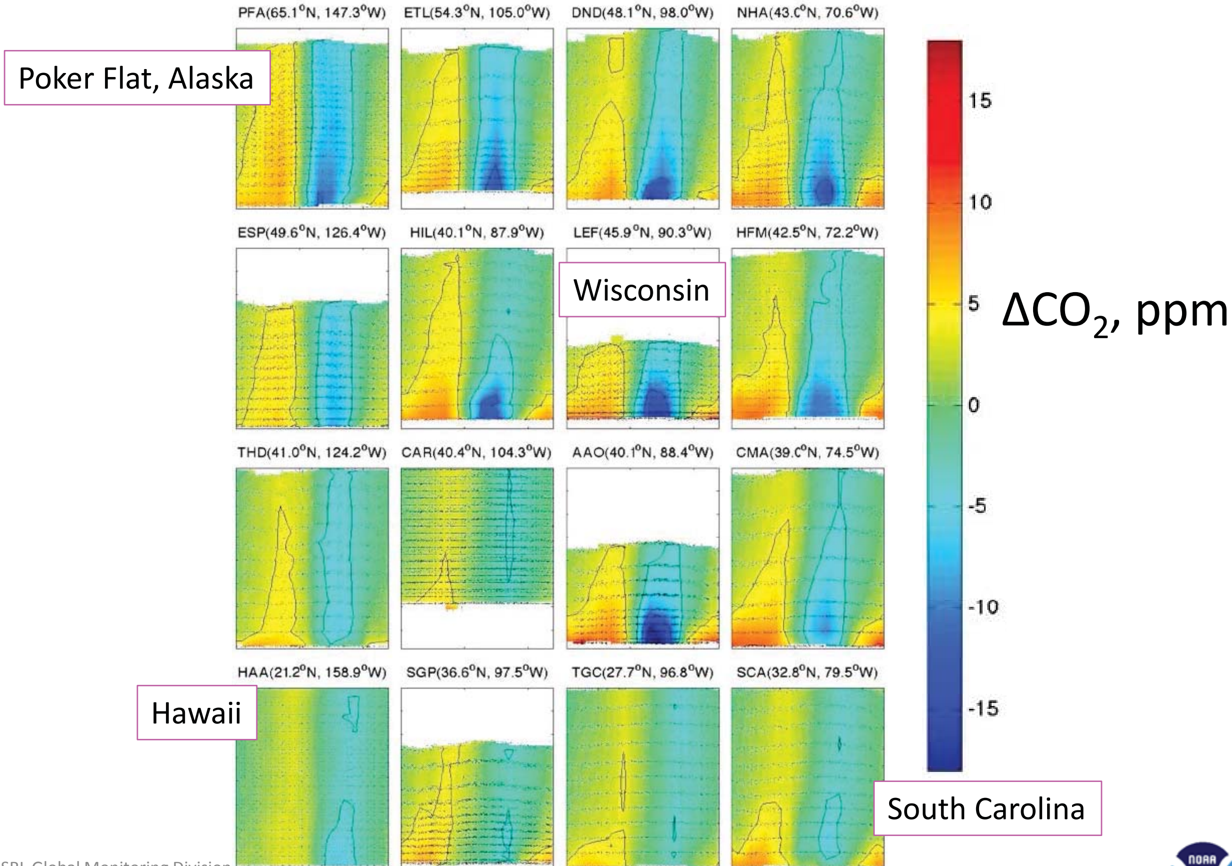
Average Seasonal Cycle of CO_2 above Homer, Illinois:



ΔCO_2, ppm

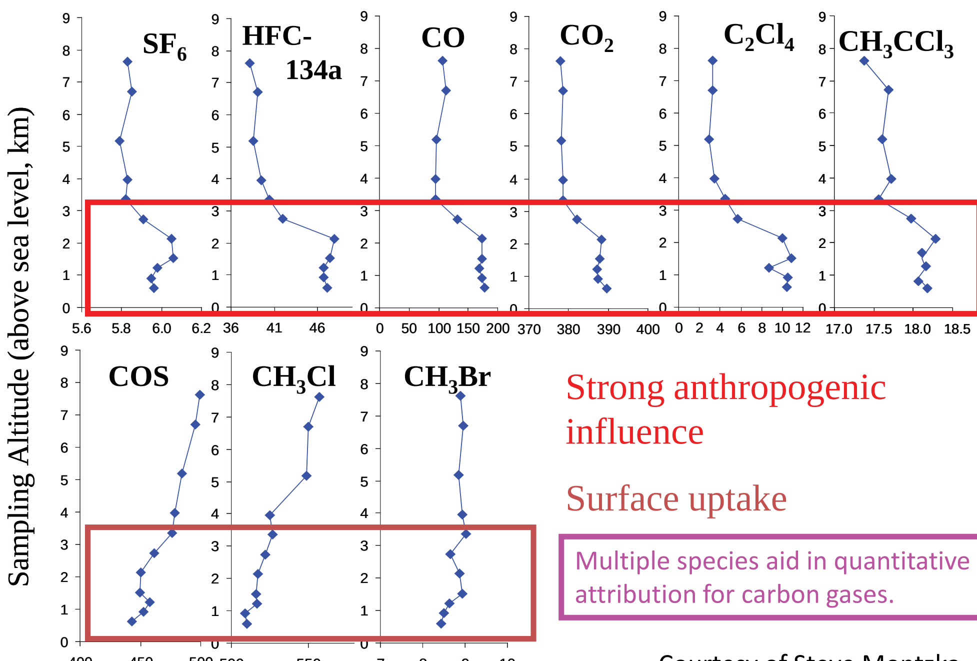
Sweeney et al., JGR, 2015

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



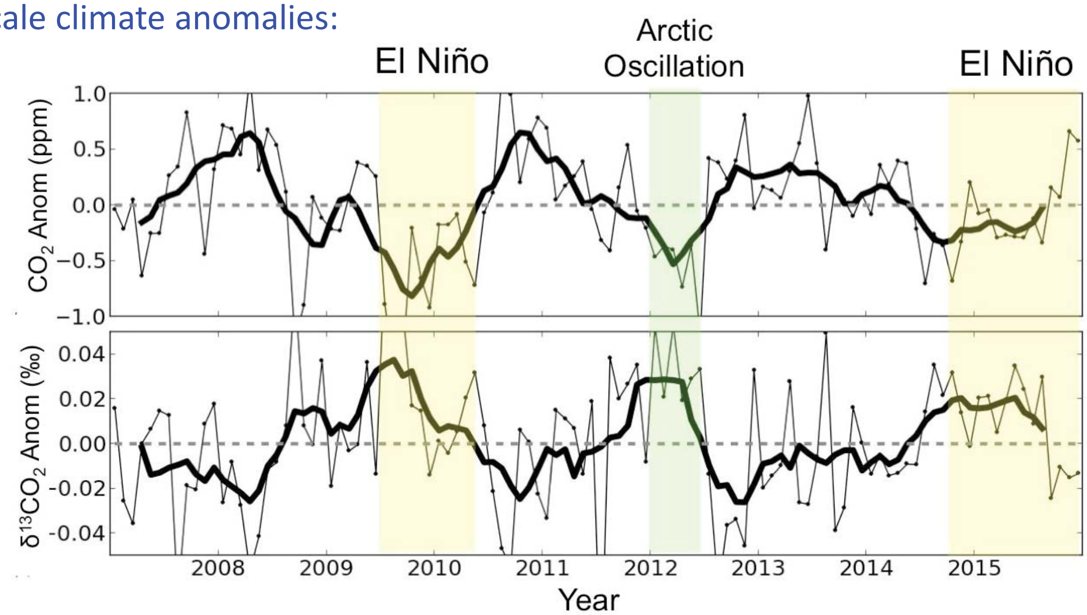
Strong anthropogenic influence

Surface uptake

Multiple species aid in quantitative source attribution for carbon gases.

Courtesy of Steve Montzka

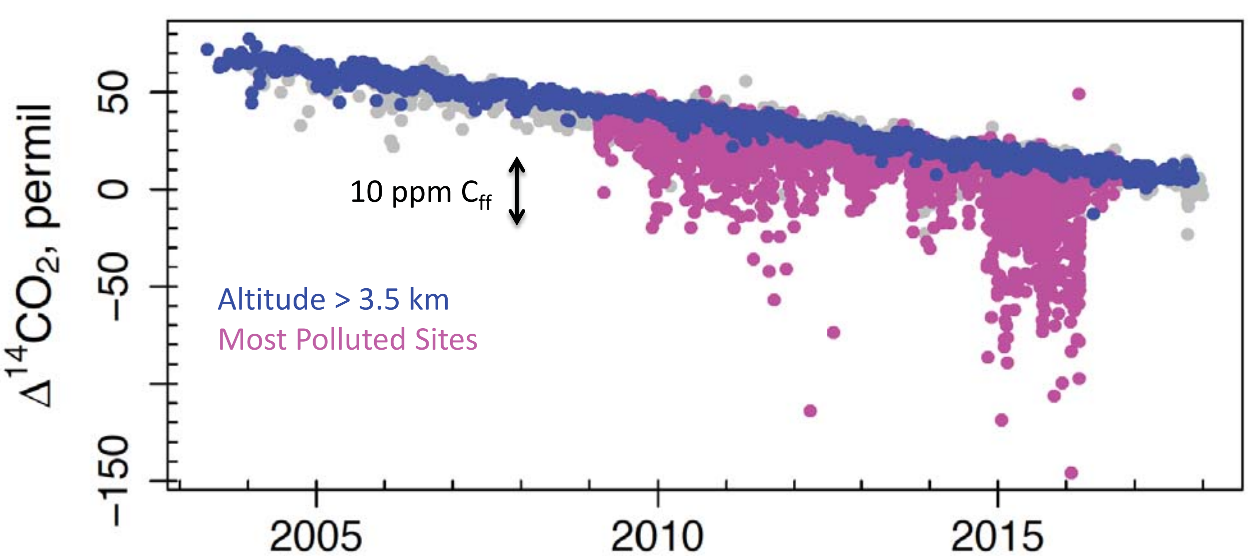
CO_2 and $^{13}CO_2$ anomalies over North America are correlated with large-scale climate anomalies:



- 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.

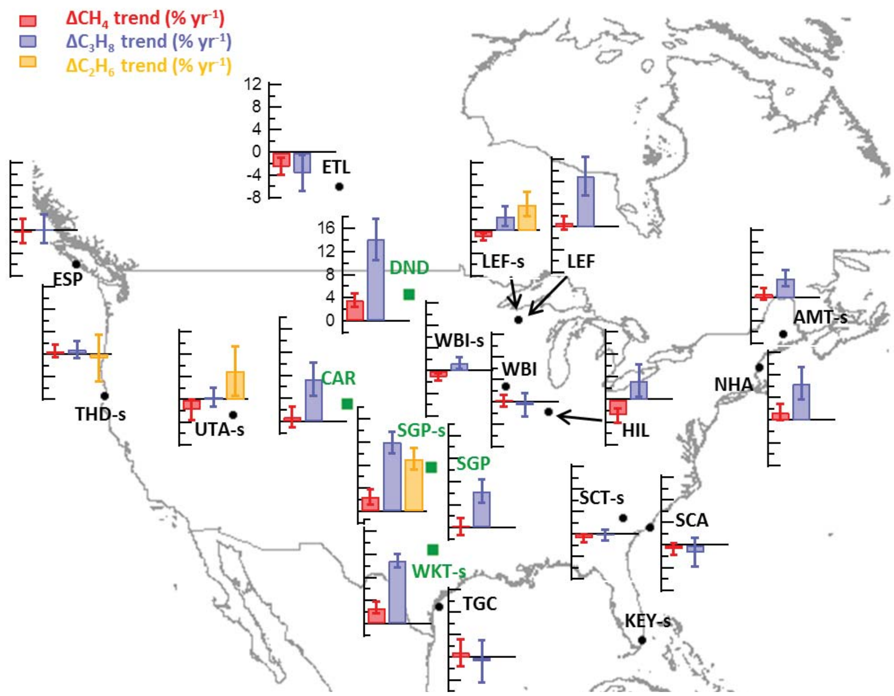
GMAC Talk by Lei Hu
Poster by Ivar van der Velde

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



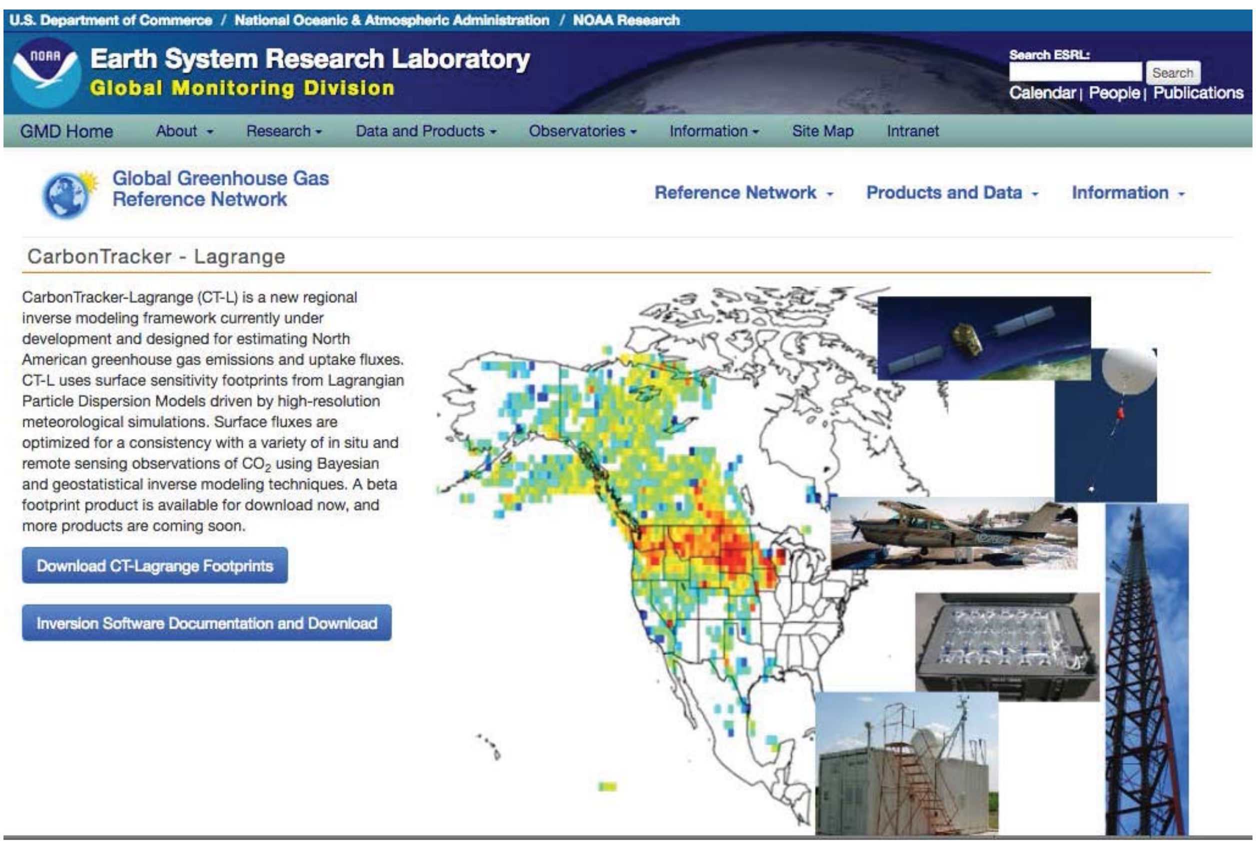
GMAC Presentations by John Miller and Sourish Basu

Methane and Hydrocarbon trends over North America:



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

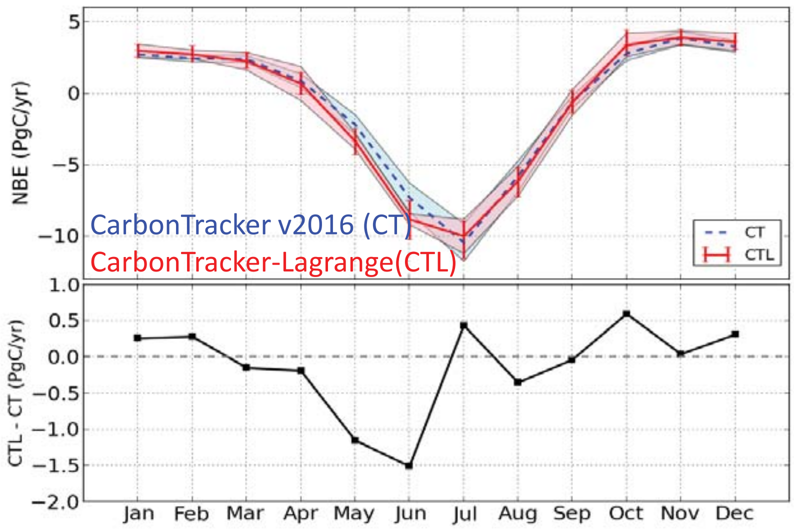
GMAC Presentation by Xin Lan



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

CT Lagrange versus CT2016 Fluxes: Long-term mean

Multi-Year Monthly Averages (2007 – 2015)

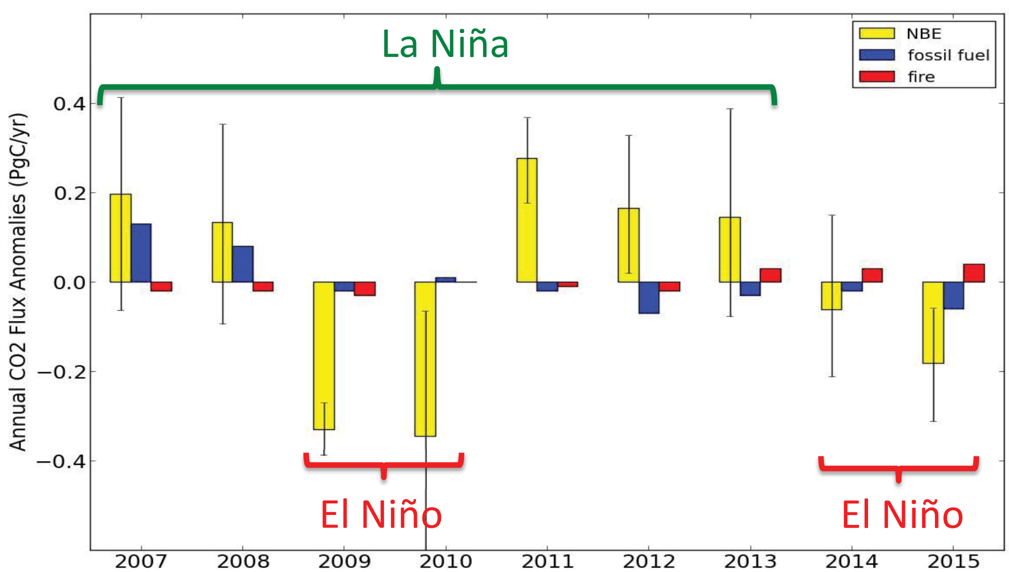


- Net biospheric uptake is similar despite very different atmospheric transport models

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

GMAC Presentation by Lei Hu

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

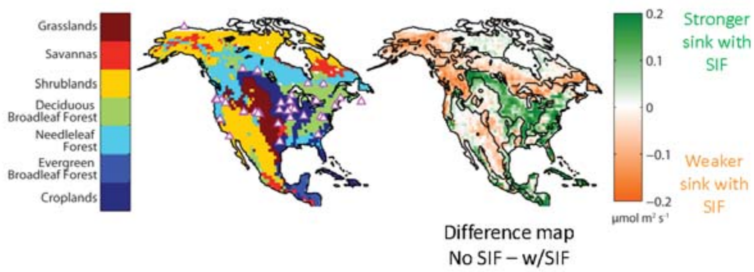
Accepted manuscript online: 1 March 2018 Full publication history

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

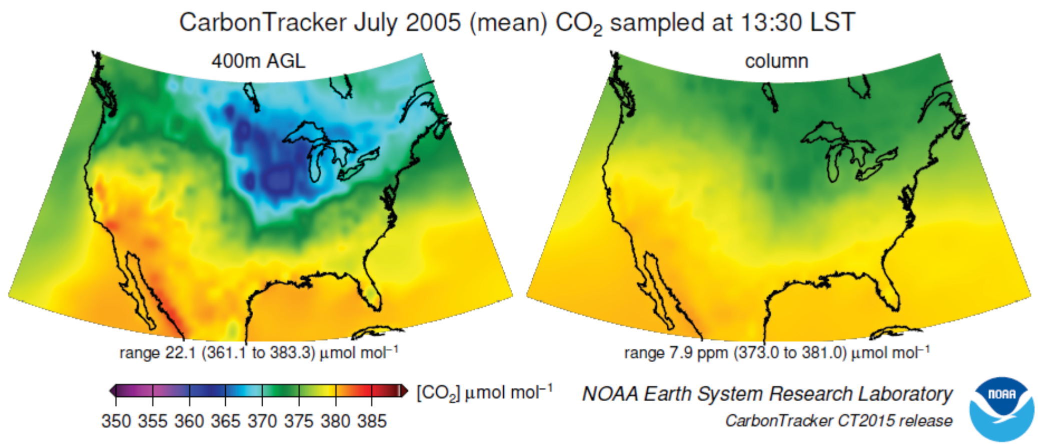
Lei Hu, Stephen A. Montzka, Ben R. Miller, Arlyn E. Andrews, John B. Miller, Scott J. Lehman, Colm Sweeney, Scot M. Miller, Kirk Thoning, Carolina Siso, Elliot L. Atlas, Donald R. Blake, Joost de Gouw, Jessica B. Gilman, Geoff Dutton, James W. Elkins, Bradley Hall, Huilin Chen, Marc L. Fischer, Marikate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

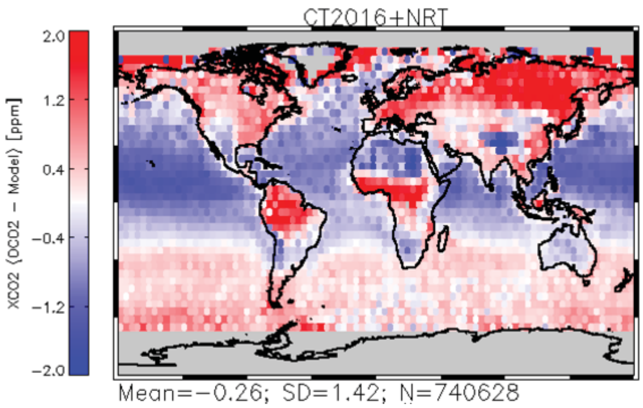
Satellite Retrieval and Model Evaluation

The challenge for satellite column CO_2 sensors:

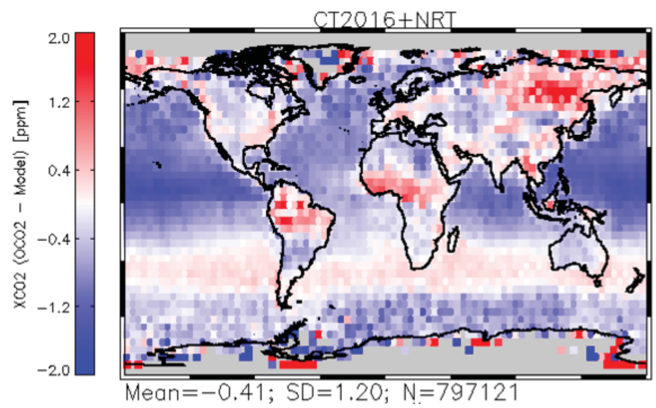


- Mass balance: on average, the total column enhancement of CO_2 downwind of the U.S. is ~0.7 ppm for 1.4 Gton C/yr of emissions.
- For a 20% reduction in emissions, column would change by ~ 0.14 ppm.

OCO-2 Retrieval Evaluation



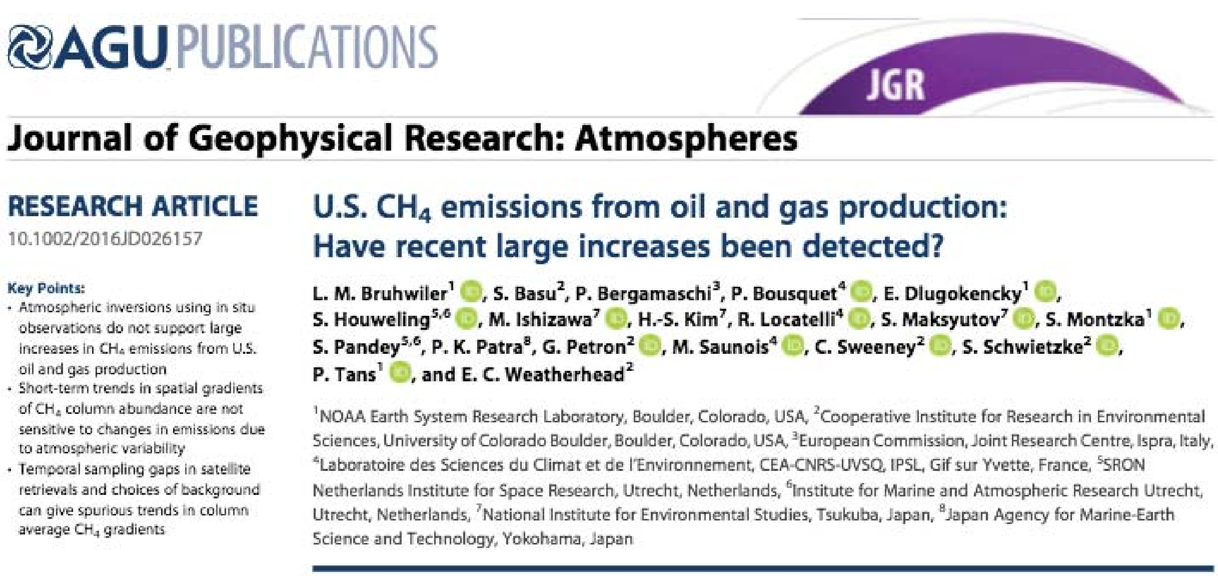
OCO-2 V7



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

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

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]

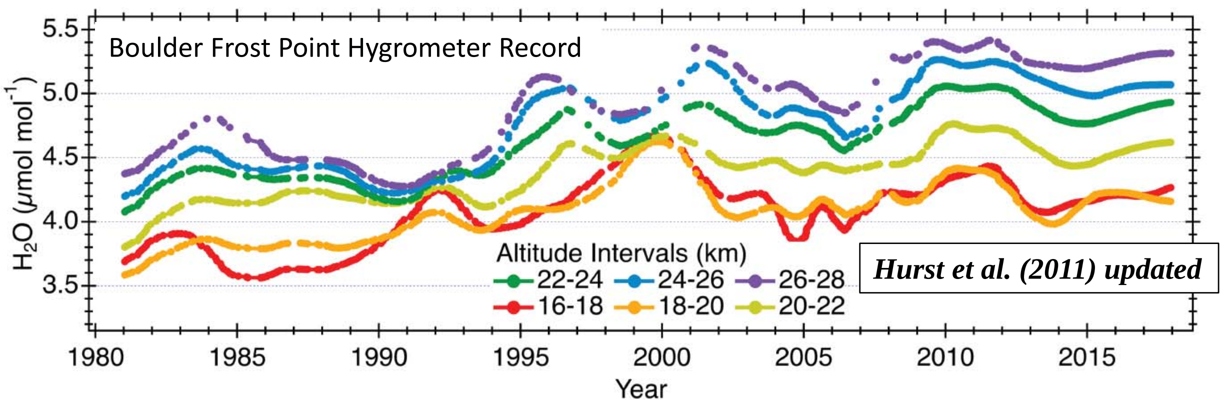
[1]NOAA Earth System Research Laboratory, Boulder, Colorado, USA, [2]Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [3]European Commission, Joint Research Centre, Ispra, Italy, [4]Laboratoire des Sciences du Climat et de l'Environnement, 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

- Temporal sampling biases cause apparent relative trends.
- Choice of inappropriate background contributes to spurious trend

Monitoring 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)***

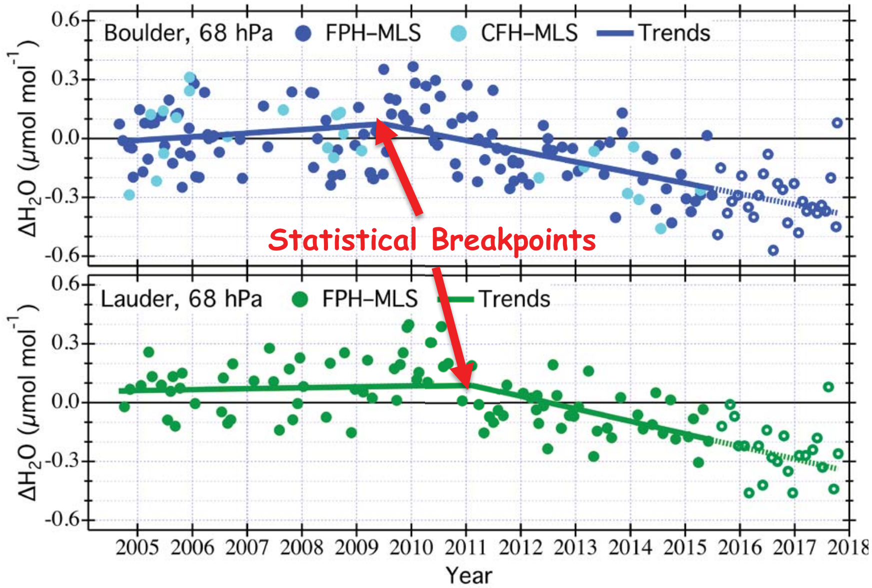
GMAC Presentation by Dale Hurst

Long-Term Monitoring of UTLS Water Vapor

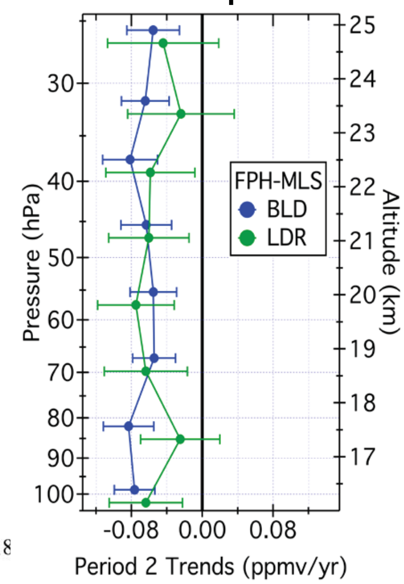
Validation of Satellite-Based Measurements

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

Differences in Coincident Measurements: FPH-MLS

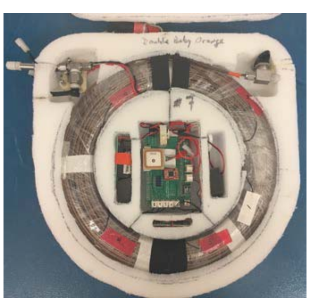


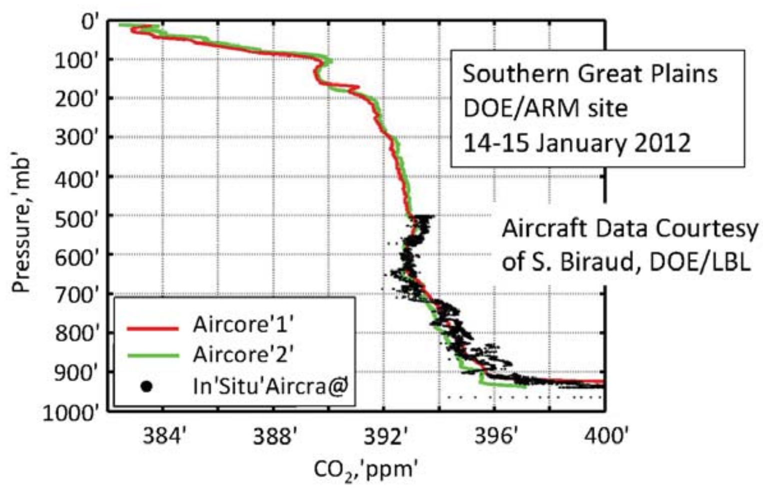
Post-breakpoint Trends



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

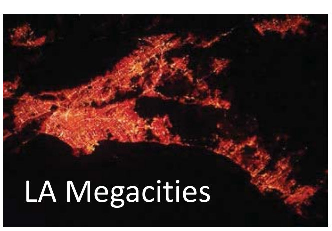
Intensive Field Campaigns & Capacity Building

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

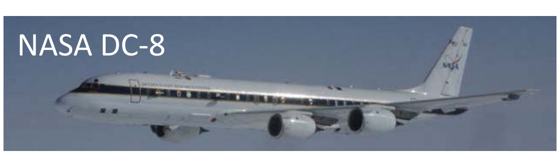
CARVE
CARBON IN ARCTIC RESERVOIRS VULNERABILITY EXPERIMENT

NASA ATOM
ATMOSPHERIC TOMOGRAPHY MISSION
EVS-2

ECO
East Coast Outflow


LA Megacities

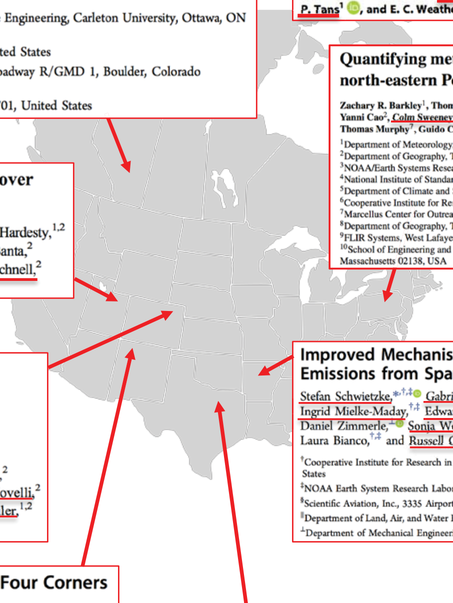
ORCAS
O_2/N_2 Ratio and CO_2 Airborne Southern Ocean Study 2016


NASA DC-8


NSF HIAPER GV


NOAA Twin Otter

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]

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]

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

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,[∥,△] 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)

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

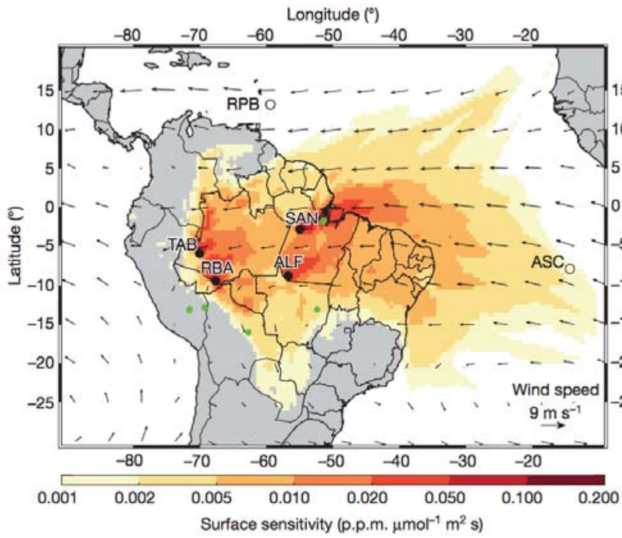
LETTER

doi:10.1038/nature12957

Drought sensitivity of Amazonian carbon balance revealed by atmospheric measurements

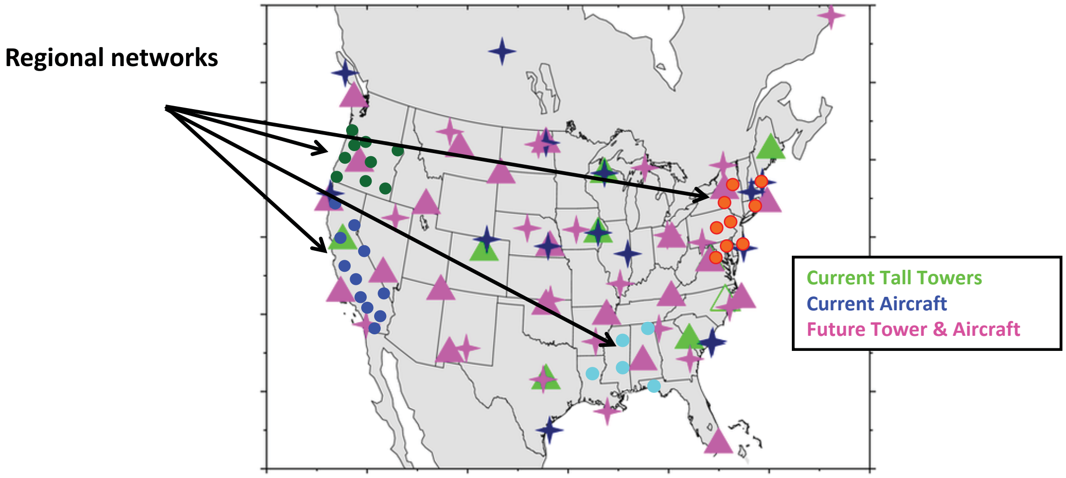
L. V. Gatti[1]*, M. Gloor[2]*, J. B. Miller[3,4]*, C. E. Doughty[5], Y. Malhi[5], L. G. Domingues[1], L. S. Basso[1], A. Martinewski[1], C. S. C. Correia[1], V. F. Borges[1], S. Freitas[6], R. Braz[6], L. O. Anderson[5,7], H. Rocha[8],

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

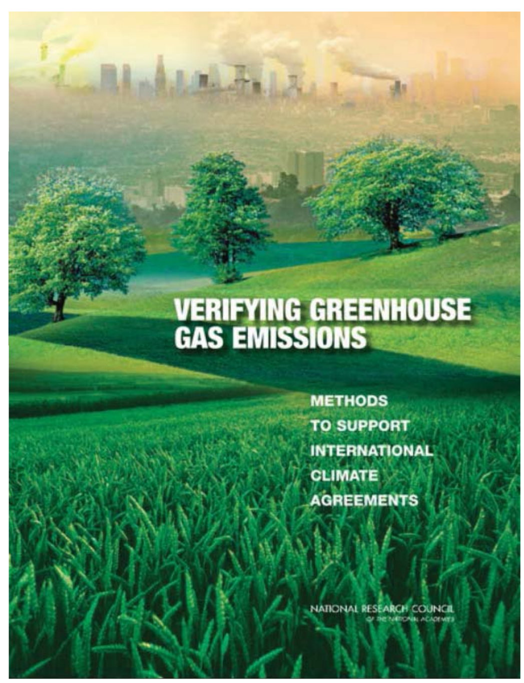
2) Increase radiocarbon sampling to constrain estimates of fossil fuel CO_2 emissions

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

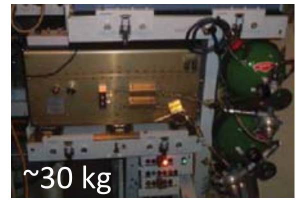
GMAC Presentations by Sourish Basu



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.

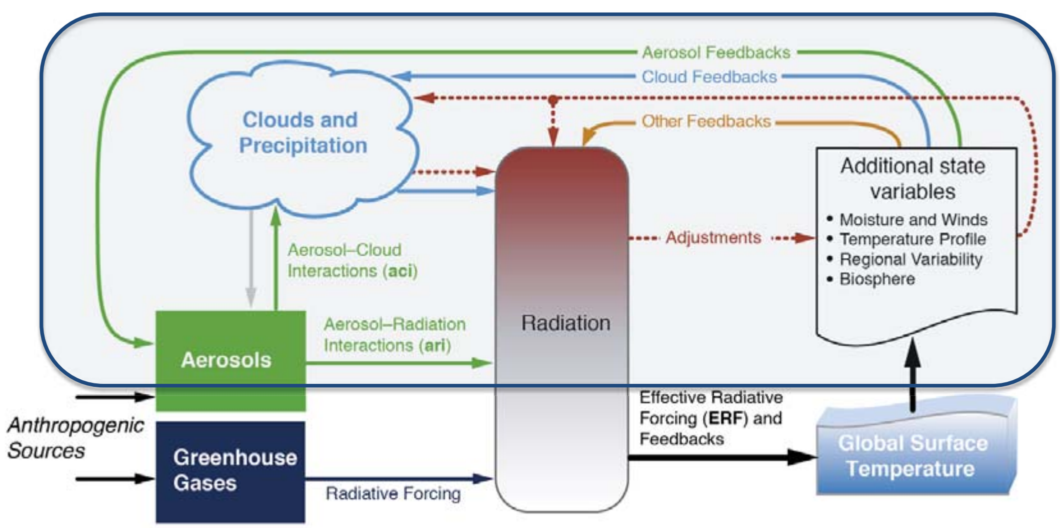
GMD's Role in an Integrated Multi-platform Greenhouse Gas Observing System

Take Home Messages

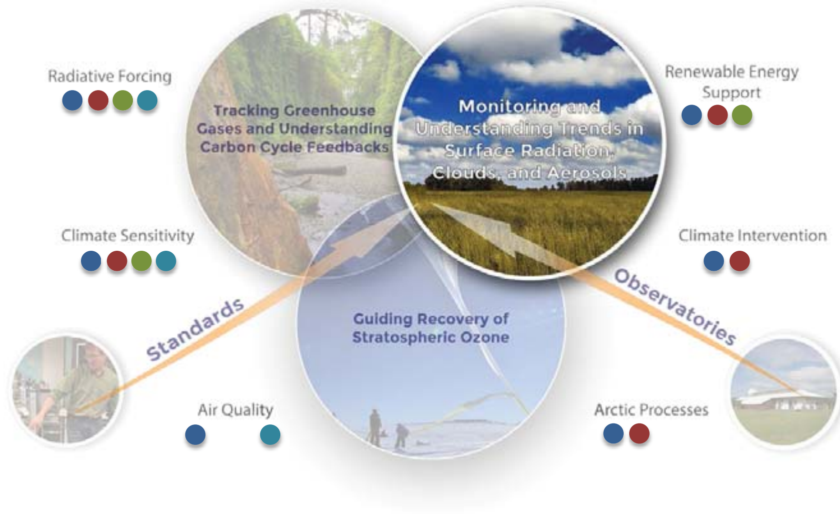
- We are creating an unassailable and well-documented record of greenhouse gases.
- We try to help society deal with the climate problem:
  - *Create a quantitative record of climate forcing.*
  - *Quantify and diagnose the response of the natural carbon cycle and greenhouse gas budgets to climate change.*
  - *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.
- NOAA anchors the global and US atmospheric carbon observing network. We established multiple comparisons with Environment Canada, Earth Networks and university researchers. 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.

Monitoring and Understanding Trends in Surface Radiation, Clouds, and Aerosols

Monitoring and Understanding Trends in Surface Radiation, Clouds, and Aerosols



Monitoring and Understanding Trends in Surface Radiation, Clouds, and Aerosols



monitoring changes | process understanding | model development | satellite evaluation

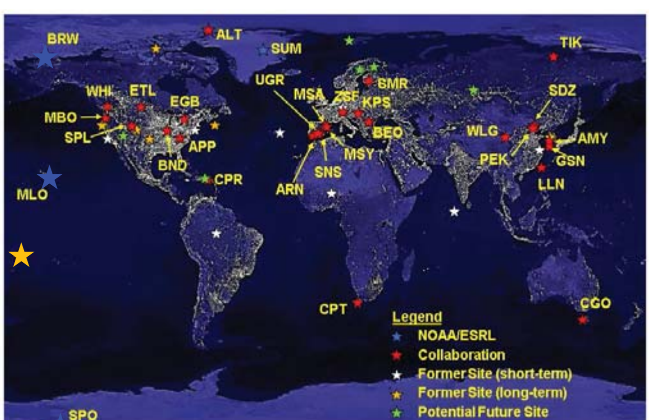
GMD Measurement Networks for Radiation, Clouds, and Aerosols

Sheridan – P-53

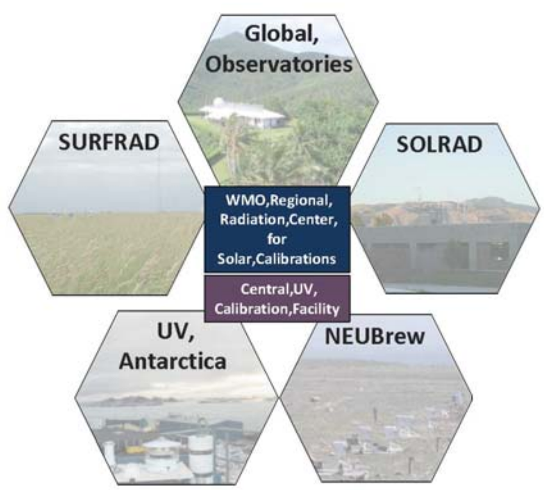
Hall, B. – overview
Hall, E. – P-40

The NOAA Federated Aerosol Network

'A collaborative effort that benefits all parties'



Global Surface Radiation Networks



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GMD Measurement Networks for Radiation, Clouds, and Aerosols

Broadband Shortwave and Longwave Radiation Networks

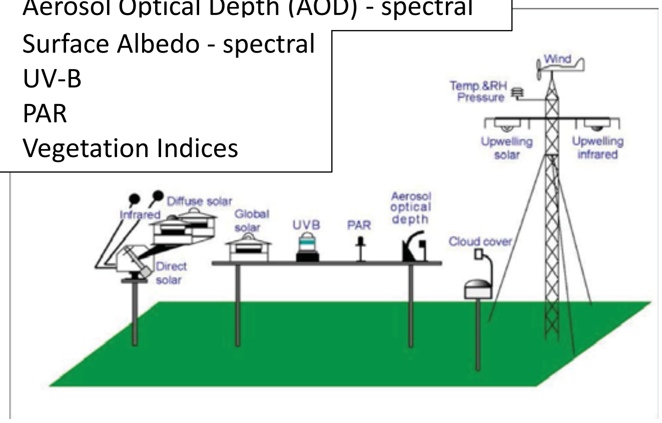
Global, regionally representative

Continental U.S., regionally representative

Continental U.S., urban environment

Properties – Measured and Derived:

- Surface Radiation Budget - components
- Sky Cover/Cloud Fraction
- Cloud Optical Depth (overcast)
- Cloud Radiative Effect
- Aerosol Optical Depth (AOD) - spectral
- Surface Albedo - spectral
- UV-B
- PAR
- Vegetation Indices



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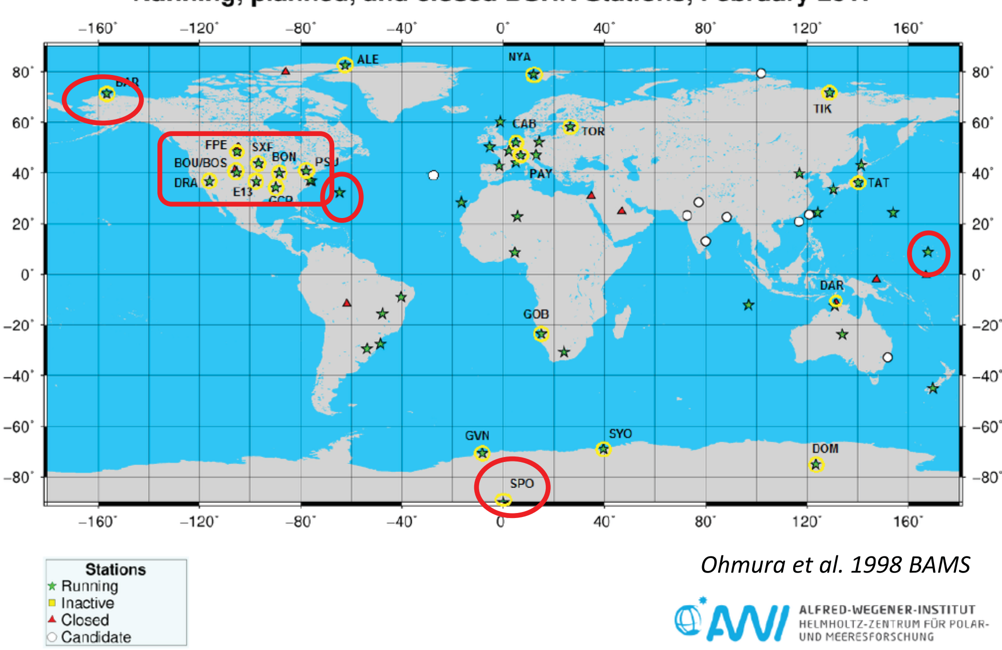
WCRP Baseline Surface Radiation Network (BSRN)

Running, planned, and closed BSRN Stations, February 2017



12 stations of 59 directly operated by NOAA ESRL GMD, the largest single contributing organization

Support measurements at an additional 9 sites

GMD is associated with 21 of the 59 sites that have contributed to the BSRN Archive (35%)

Ohmura et al. 1998 BAMS

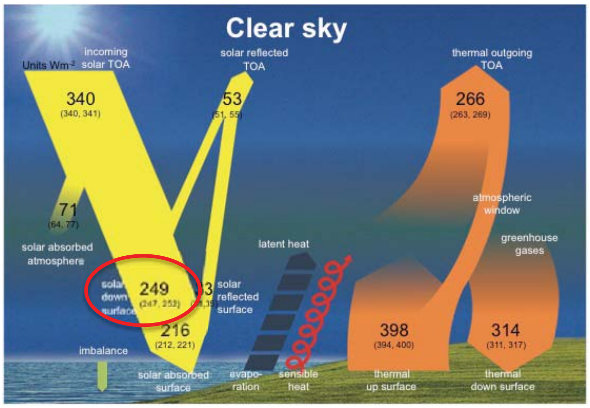
ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

monitoring changes | process understanding | model development | satellite evaluation

Long – Session 3

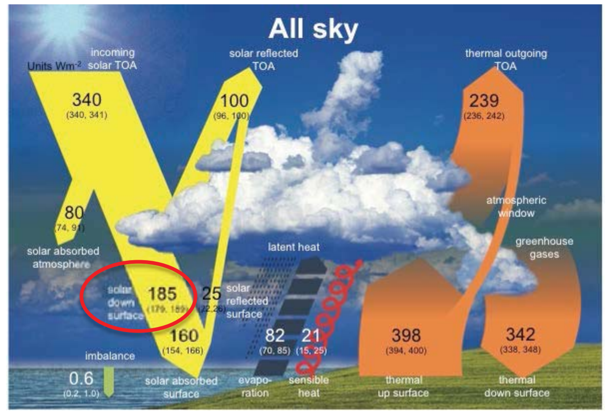
WCRP Baseline Surface Radiation Network (BSRN)

Global All- and Clear-sky Estimates using Observations and Models



New estimates for global mean radiation budget without cloud effects

Wild et al. submitted



Combined with all sky budgets provides **estimation of global mean surface, atmosphere, and TOA cloud radiative effects**

Wild et al. 2015 Clim. Dyn.

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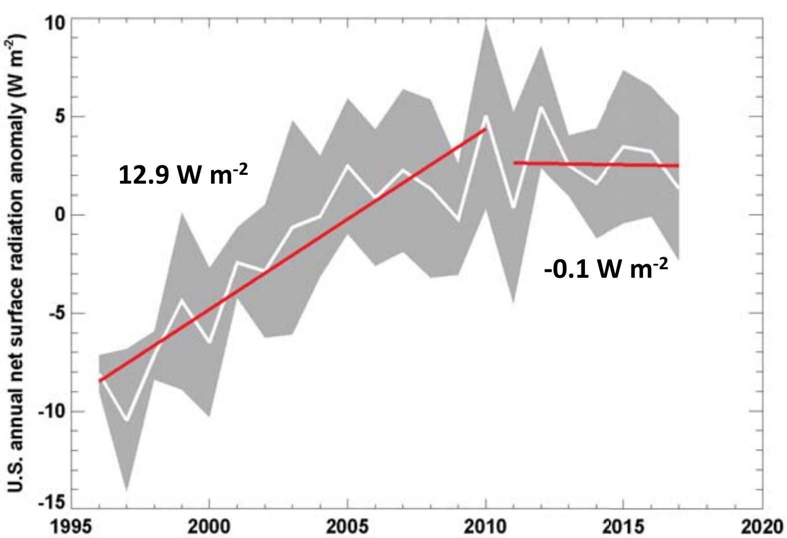
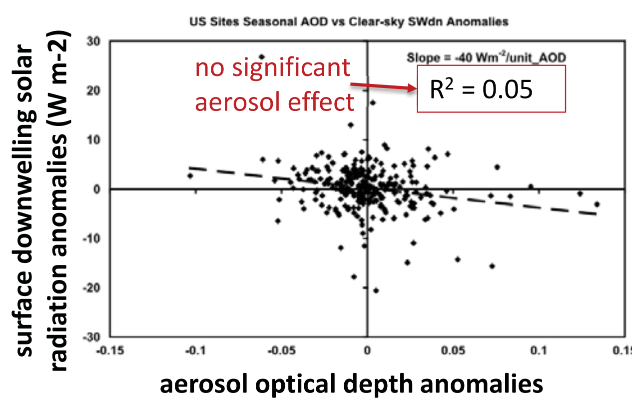
Augustine – Session 3

Surface Radiation Variability over the U.S.



updated from Augustine and Dutton 2013 JGR



Long et al 2009 JGR

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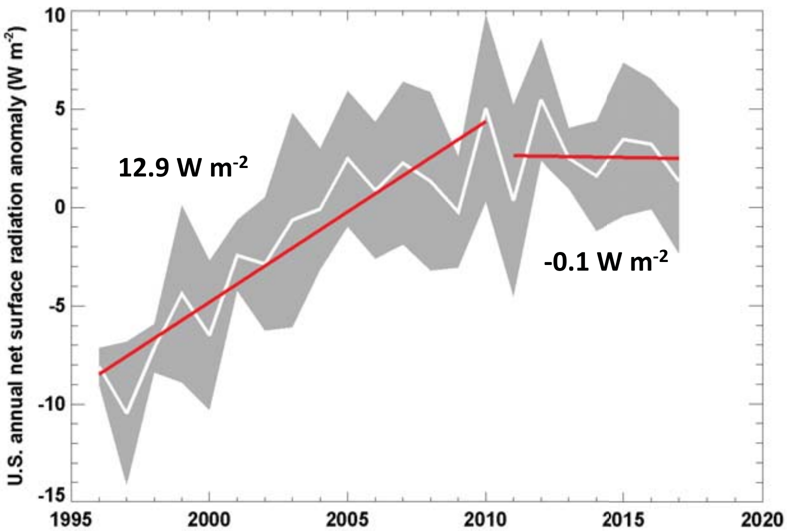
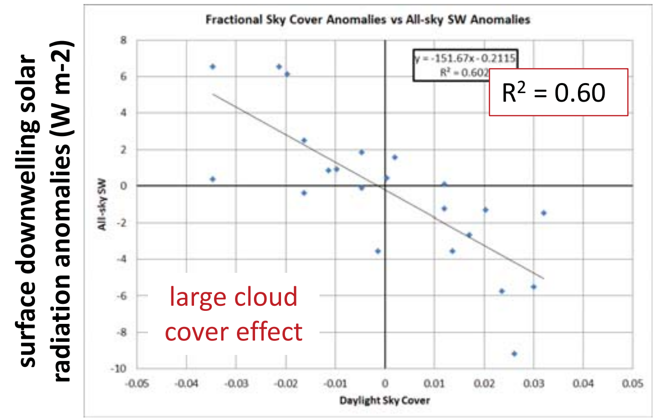
Augustine – Session 3

Surface Radiation Variability over the U.S.



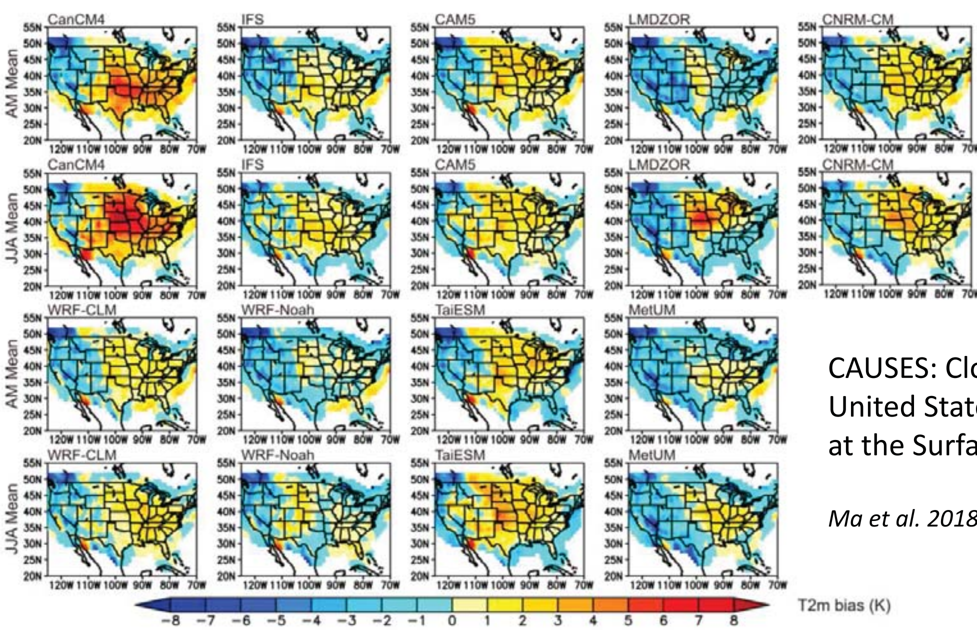
updated from Augustine and Dutton 2013 JGR



cloud cover anomalies

monitoring changes | **process understanding** | model development | satellite evaluation

Persistent Model Biases – Relationships to Surface Radiation Budget

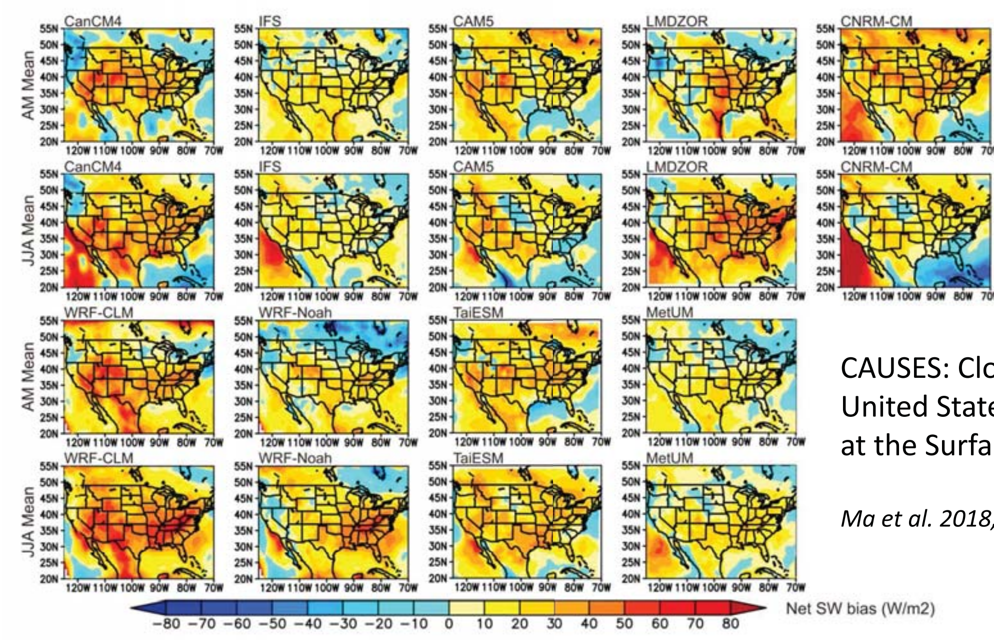


CAUSES: Cloud Above the United States and Errors at the Surface

Ma et al. 2018, JGR

monitoring changes | process understanding | **model development** | satellite evaluation

Persistent Model Biases – Relationships to Surface Radiation Budget



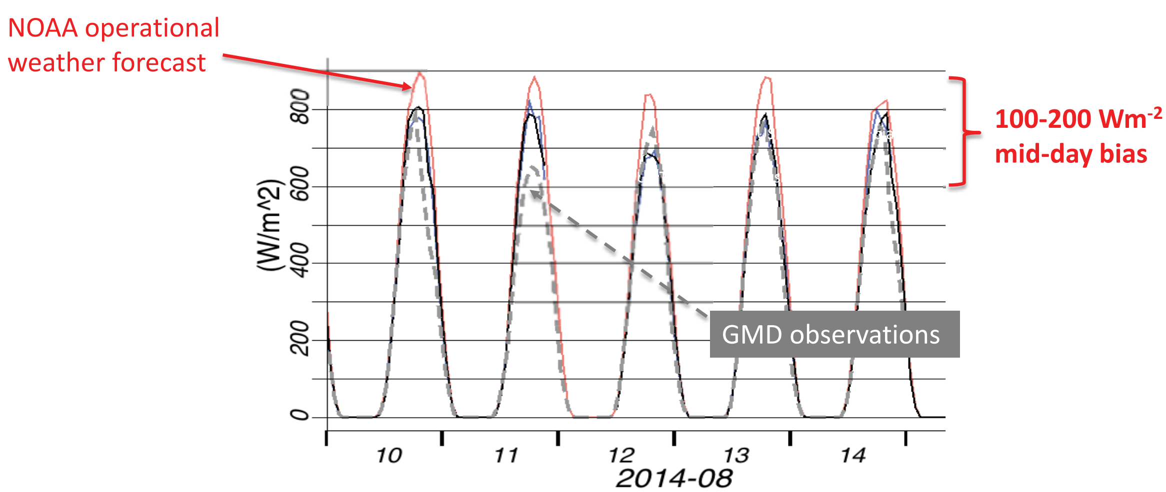
CAUSES: Cloud Above the United States and Errors at the Surface

Ma et al. 2018, JGR

monitoring changes | process understanding | **model development** | satellite evaluation

SURFRAD Observations in Numerical Weather Prediction Model Development

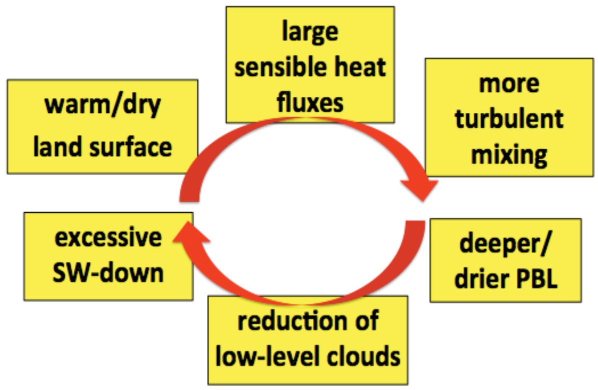
NOAA NWP Rapid Refresh Model (RAP) – SURFRAD comparisons



monitoring changes | process understanding | **model development** | satellite evaluation

SURFRAD Observations in Numerical Weather Prediction Model Development

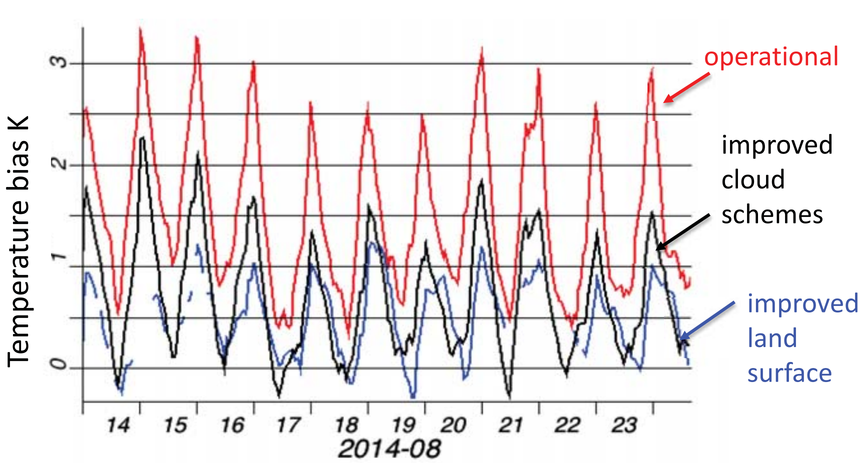
NOAA NWP Rapid Refresh Model (RAP) – SURFRAD comparisons

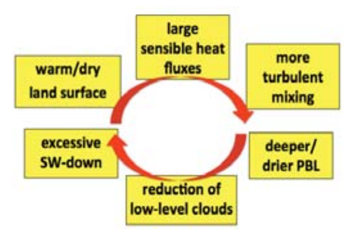


SURFRAD Observations in Numerical Weather Prediction Model Development

Benjamin – Session 7

NOAA NWP Rapid Refresh Model (RAP) – SURFRAD comparisons





~70% reduction in bias

monitoring changes | process understanding | **model development** | satellite evaluation

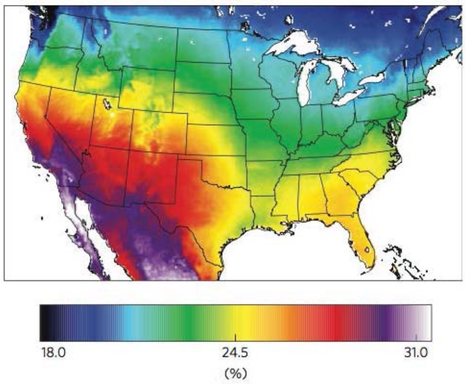
Atmospheric Science for Renewable Energy

Lantz – Session 7

ARTICLES
PUBLISHED ONLINE: 25 JANUARY 2016 | DOI: 10.1038/NCLIMATE2921
nature climate change

Future cost-competitive electricity systems and their impact on US CO_2 emissions

Alexander E. MacDonald[1*†], Christopher T. M. Clack[1,2*†], Anneliese Alexander[1,2], Adam Dunbar[1], James Wilczak[1] and Yuanfu Xie[1]

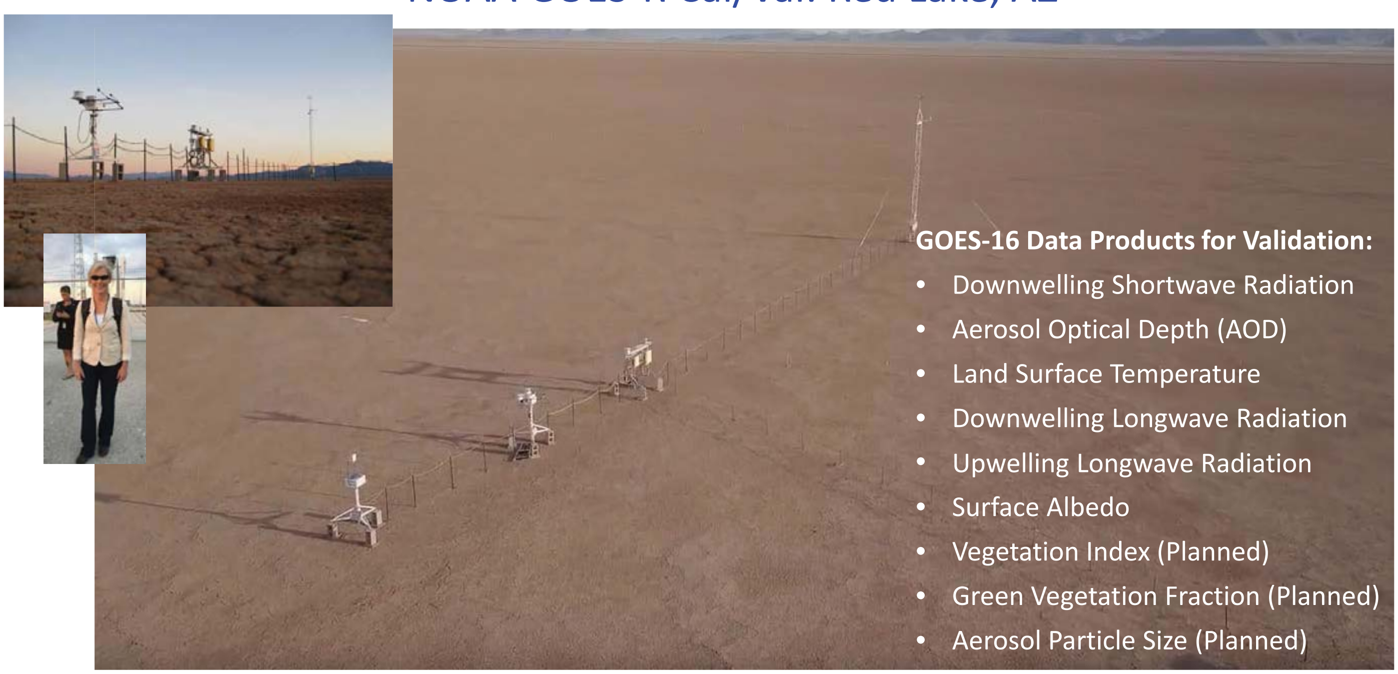


Model treatments and parameterizations addressed:

- Cloud cover – amount, nature, timing
- Land surface cover – albedo
- Aerosol – burden, transport, physical and optical properties
- Radiative transfer – link to cloud and aerosol properties, cloud overlap assumptions
- Diurnal cycles – shortwave and longwave fluxes and relationship to boundary layer growth and decay
- Meteorological regimes – e.g., cold pools

monitoring changes | process understanding | **model development** | satellite evaluation

NOAA GOES-R Cal/Val: Red Lake, AZ



GOES-16 Data Products for Validation:

- Downwelling Shortwave Radiation
- Aerosol Optical Depth (AOD)
- Land Surface Temperature
- Downwelling Longwave Radiation
- Upwelling Longwave Radiation
- Surface Albedo
- Vegetation Index (Planned)
- Green Vegetation Fraction (Planned)
- Aerosol Particle Size (Planned)

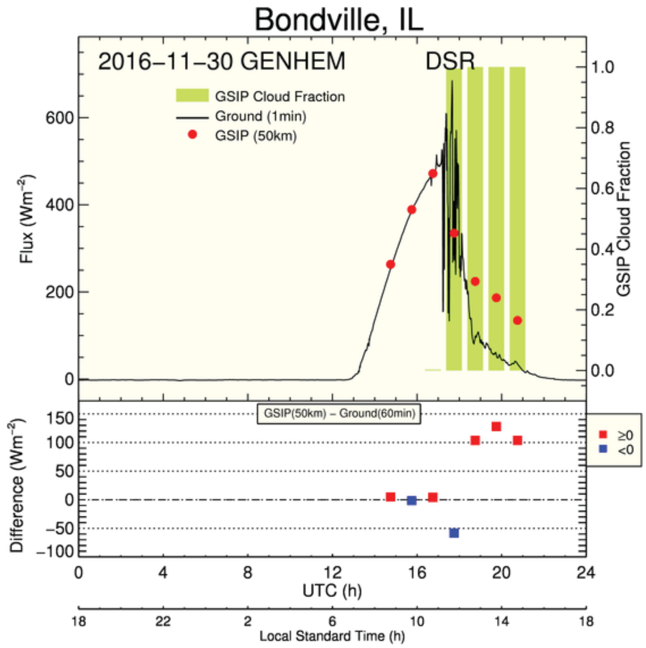
monitoring changes | process understanding | model development | **satellite evaluation**

Operational Satellite Product Evaluation

Long – Session 3

Global Operational Satellite Products:

- GEWEX Surface Radiation Budget (SRB) Product
- Geostationary Surface and Insolation Product (GSIP)



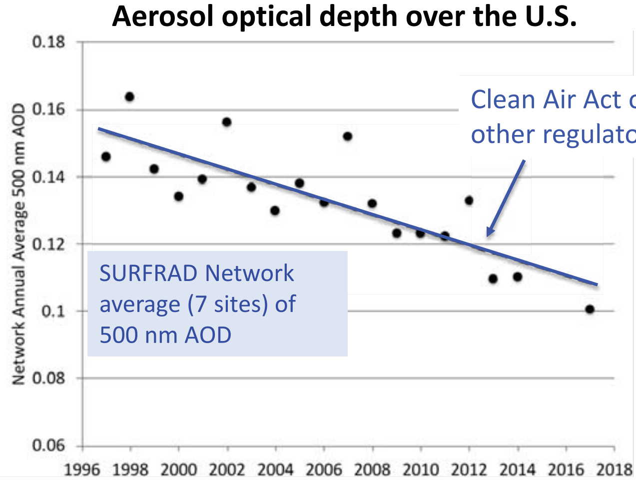
monitoring changes | process understanding | model development | **satellite evaluation**

Trends in Aerosol over the U.S.

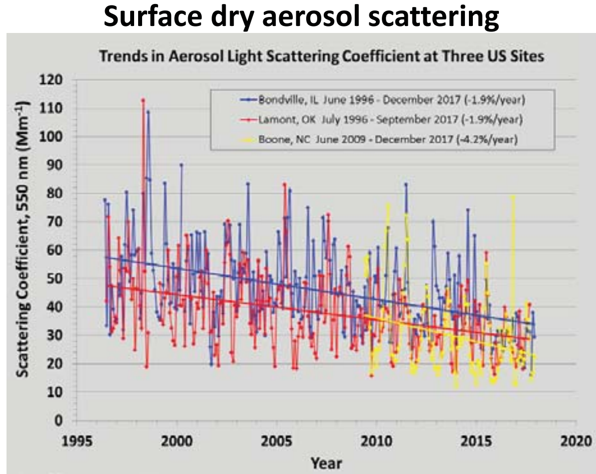
Augustine – Session 3
Pagowski – P-7

Haller – Session 3
Sherman – Session 7

Aerosol optical depth over the U.S.



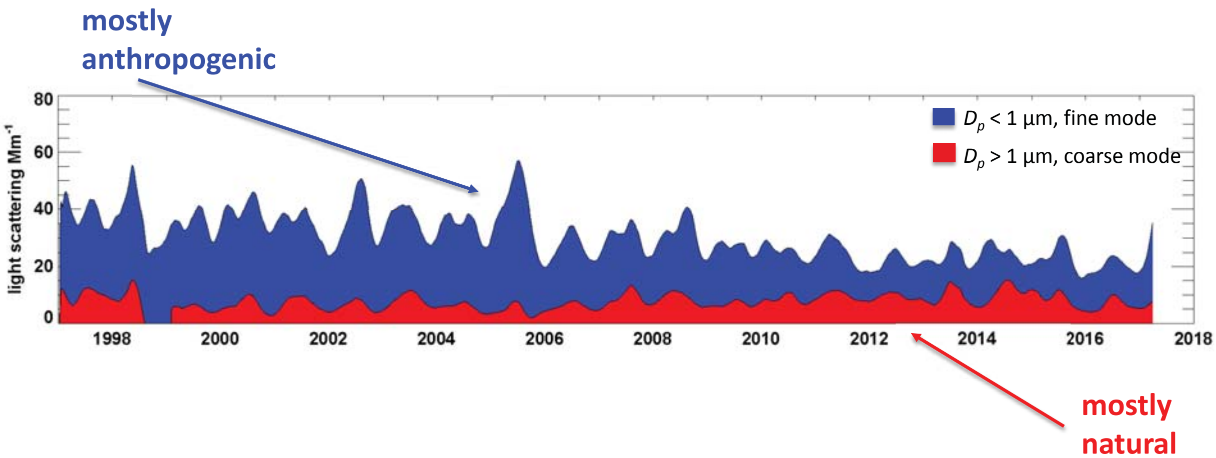
Surface dry aerosol scattering



monitoring changes | process understanding | model development | satellite evaluation

Telg – Session 7

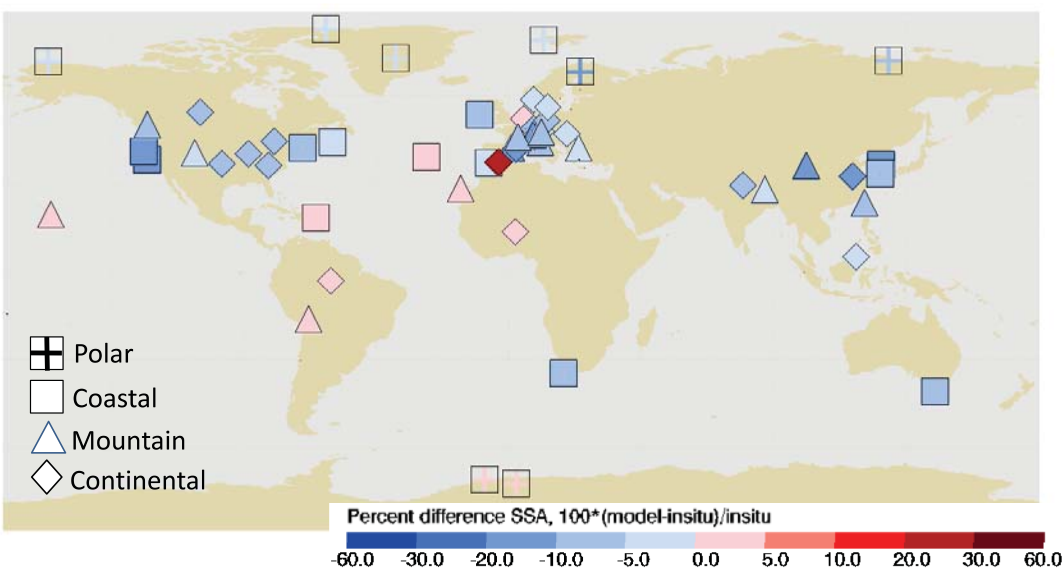
Trends in Aerosol over the U.S.



monitoring changes | process understanding | model development | satellite evaluation

NOAA Federated Aerosol Network Observations in AEROCOM Experiments

Andrews – Session 7
Pagowski – P-7

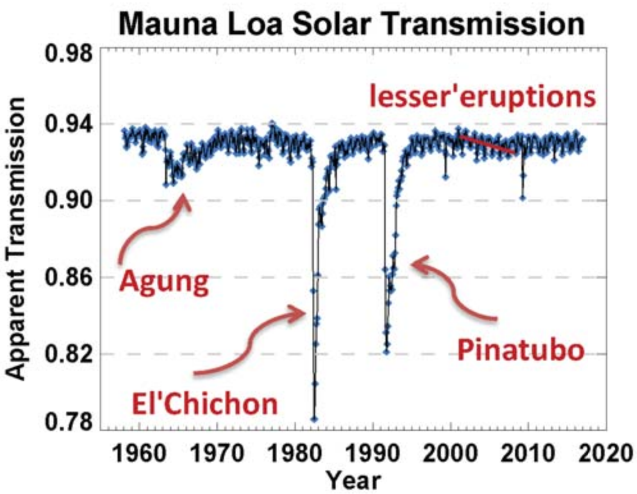


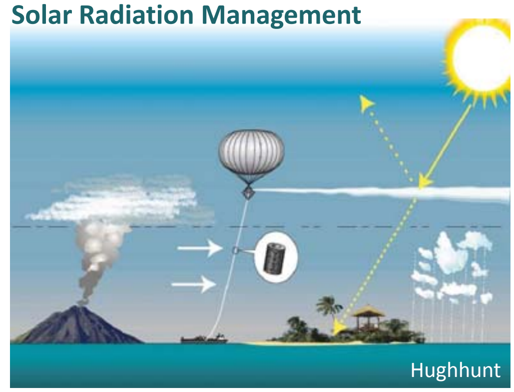
14 global climate models – in situ observations at surface:

- **model median values**
- **models underestimate observed SSA**
- **models simulate darker aerosol than observed**

monitoring changes | process understanding | model development | satellite evaluation

Mauna Loa Transmission and the Stratospheric Aerosol Record



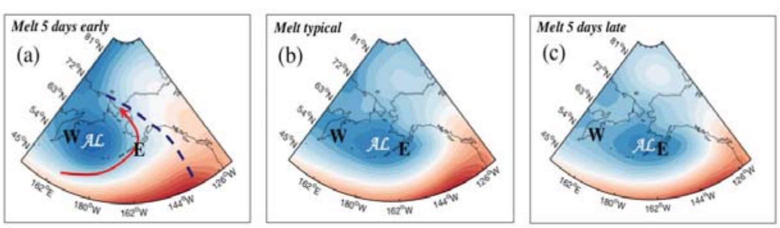


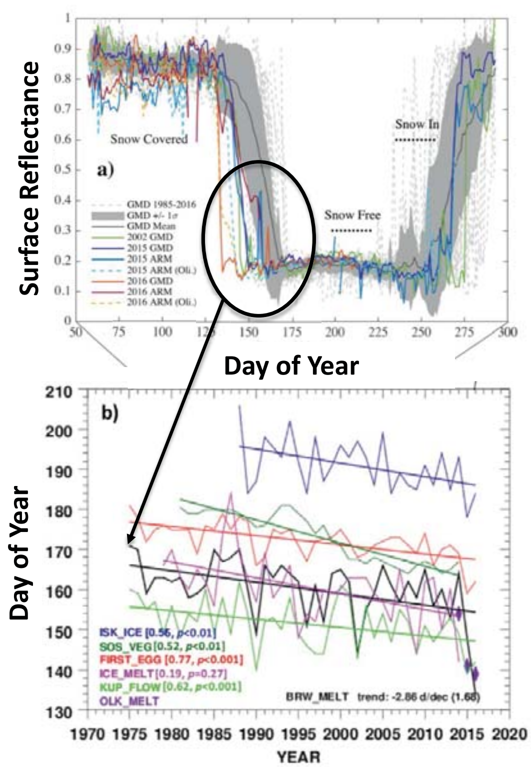
Barnes – P-43
Keen – P-41

monitoring changes | process understanding | model development | satellite evaluation

DRIVERS AND ENVIRONMENTAL RESPONSES TO THE CHANGING ANNUAL SNOW CYCLE OF NORTHERN ALASKA

CHRISTOPHER J. COX, ROBERT S. STONE, DAVID C. DOUGLAS, DIANE M. STANITSKI, GEORGE J. DIVOKY, GEOFF S. DUTTON, COLM SWEENEY, J. CRAIG GEORGE, AND DAVID U. LONGENECKER



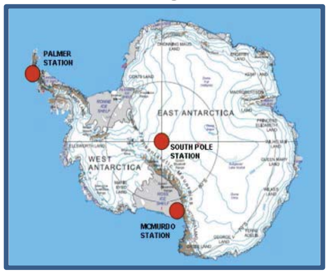


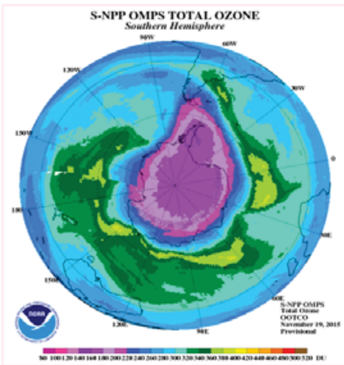
Cox – Session 3
Morris – Session 3

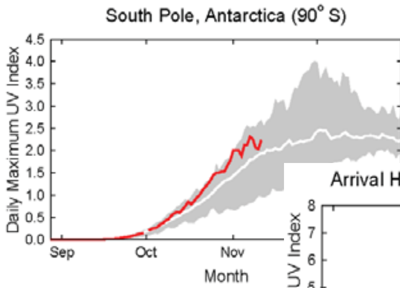
monitoring changes | process understanding | model development | satellite evaluation

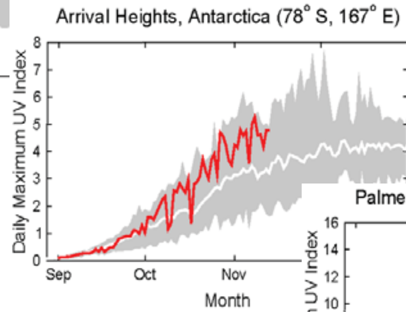
Spectral Ultra-violet (UV) Networks

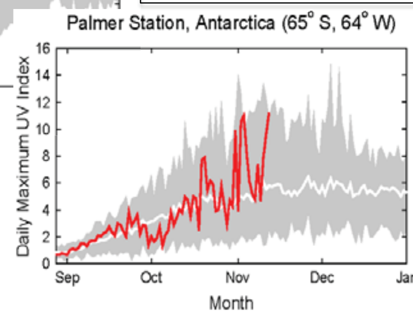
NOAA Antarctic UV Monitoring Network











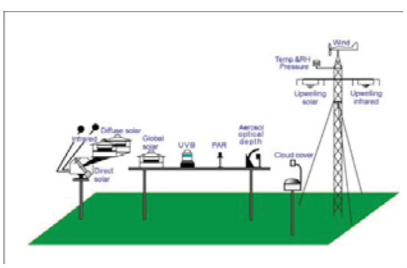
McKenzie – P-48
Shiobara – P-44

NEUBrew
NOAA Environmental Ultraviolet-ozone Brewer Network

Disterhoft – P-49
Montzka – Theme 3

monitoring changes | process understanding | model development | satellite evaluation

Looking Forward
New Instrumentation for Cloud Properties at SURFRAD Sites

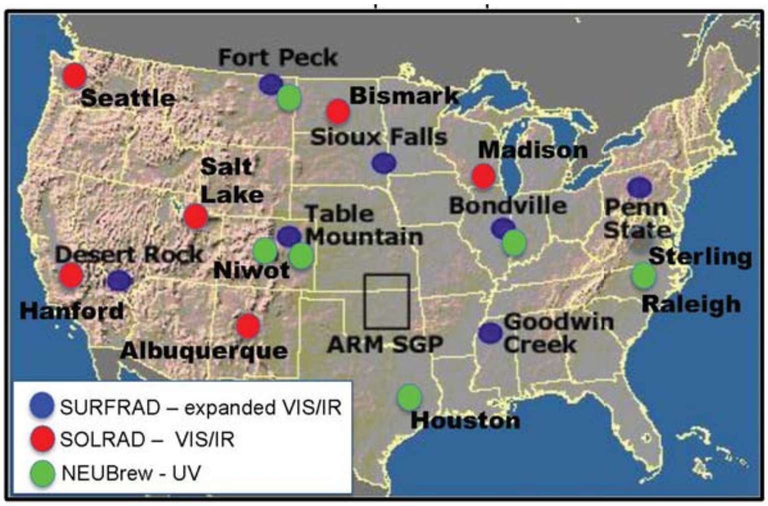


Measurements and Data Products

- Surface Radiation Budget – all components
- Sky cover/cloud fraction
- Cloud optical depth (overcast)
- Aerosol Optical Depth (AOD)
- Surface in situ aerosol optical properties
- Spectral Surface Albedo
- UV-B
- PAR
- Vegetation Indices (NDVI, GVF)
- Spectral UV irradiance, Ozone, UV Index
- Cloud Height, Cloud Layers (overlap)
- Boundary (mixing) Layer Height
- Cloud optical depth (broken cloud)
- Cloud microphysics – effective radius, drop size, phase
- Cloud liquid water path (derived)
- Ambient Column Aerosol Size Distribution, Single scattering Albedo, Asymmetry Parameter
- Spectral AOD – UV to NIR (aerosol type/composition)

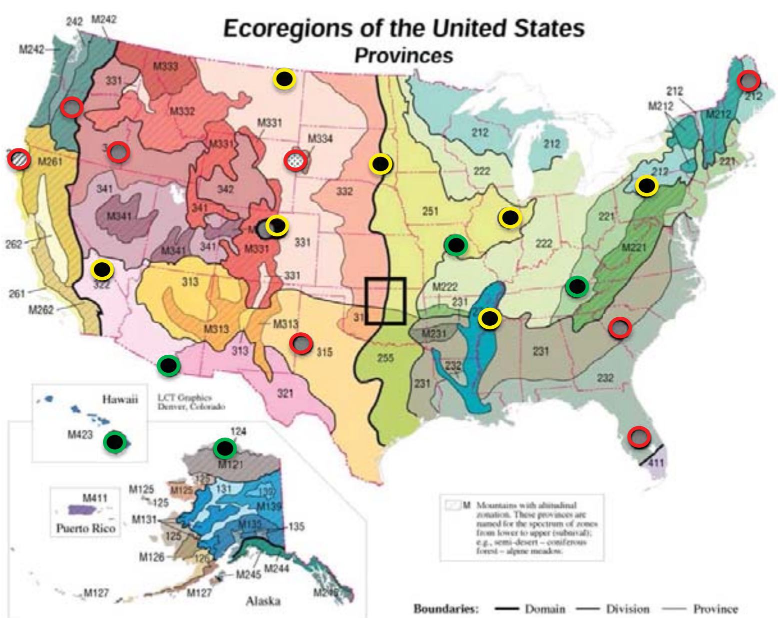
Looking Forward
An Expanded Aerosol Optical Depth Monitoring Network

Instrument upgrades, new deployments, and development of aerosol optical property retrieval algorithms will results in an expanded network.



- use of newly expanded spectral measurements at **SURFRAD** and DOE ARM sites for routine retrievals of improved aerosol microphysical and optical properties
- addition of refurbished instruments to **SOLRAD** sites for expanded spatial coverage of aerosol optical depth
- development of a spectral ultraviolet aerosol optical depth product from Brewer spectrophotometers in the **NEUBrew Network** for information on aerosol composition and its radiative impacts

Looking Forward
A NOAA Surface Energy Budget Network
for Improving Weather and Climate Predictability



- **existing radiation measurements**
- **existing heat flux measurements**
- **proposed new sites**

Monitoring and Understanding Trends in Surface Radiation, Clouds, and Aerosols

WCRP Grand Challenge: Clouds, Circulation, and Climate Sensitivity

How the interaction between clouds, greenhouse gases, and aerosols affect temperature and precipitation in a changing climate

WCRP Initiatives:	GMD Research:
Climate and hydrological sensitivity	
Coupling clouds to circulation →	Small- and large-scale atmospheric dynamical effects on cloud properties
Changing patterns →	Regionality of cloud and aerosol responses to local and large-scale forcing
Leveraging the past record →	Decadal to multi-decadal observations to constrain cloud processes and feedbacks
Towards more reliable models →	Persistent model biases evaluation and improving physical understanding

https://www.wcrp-climate.org/gc-clouds

Guiding Recovery of Stratospheric Ozone

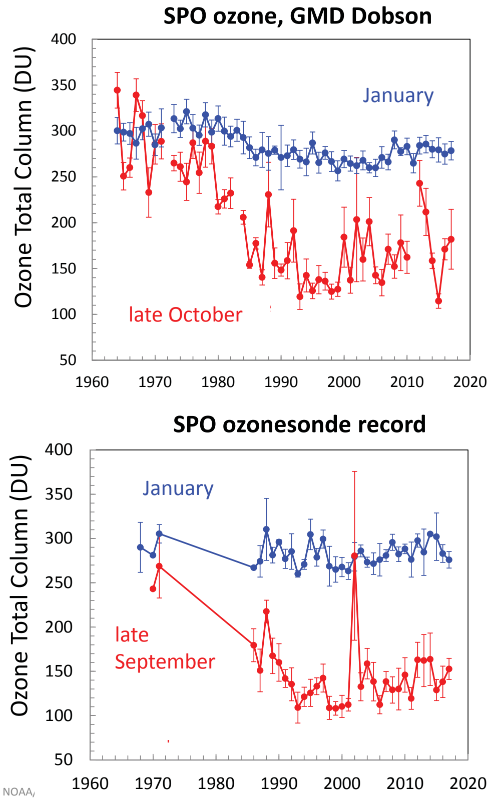
Guiding Recovery of Stratospheric Ozone at GMD

GMD plays a central role in the global effort to monitor stratospheric ozone, ozone-depleting gases, and other processes affecting stratospheric ozone

Our focus:

– ***global-to-regional scale observations*** to assess global changes *and* influences from specific processes and regions (*e.g.*, U.S.)
– ***Diagnosing observed changes*** to clarify the relative influence of policy decisions, other human behaviors, and natural processes
– ***To provide the highest-quality, policy-relevant science***

→ Guiding the recovery of the ozone layer by informing Parties to the Montreal Protocol on the progress of recovery



Stratospheric ozone depletion

→ a threat to life on Earth.

1950s: - **NOAA** begins measuring total column ozone

1970s: - Theory suggesting CFCs will deplete ozone
- **NOAA** and NASA begin measuring CFCs

1980s: - Severe ozone depletion reported in Antarctica
- Montreal Protocol controls CFC production
- Antarctic ozone hole attributed to CFCs and other chemicals

1990s: - US Clean Air Act Amended:
***NOAA** and NASA*
to monitor:
tropospheric chlorine & bromine, & stratospheric ozone depletion
to project:
peak chlorine
the rate of chlorine decline after 2000
the date when chlorine returns to two ppb

** 1996: tropospheric chlorine peaks (NOAA-GMD publication)*
** 2003: tropospheric bromine peaks (NOAA-GMD publication)*

Guiding Recovery of Stratospheric Ozone at GMD

A) Measuring chemicals that cause stratospheric ozone depletion

→ One of two global networks tracking long-term changes in ozone-depleting gases

B) Measuring long-term changes in stratospheric ozone

→ Providing reference-quality long-term measurements of stratospheric ozone

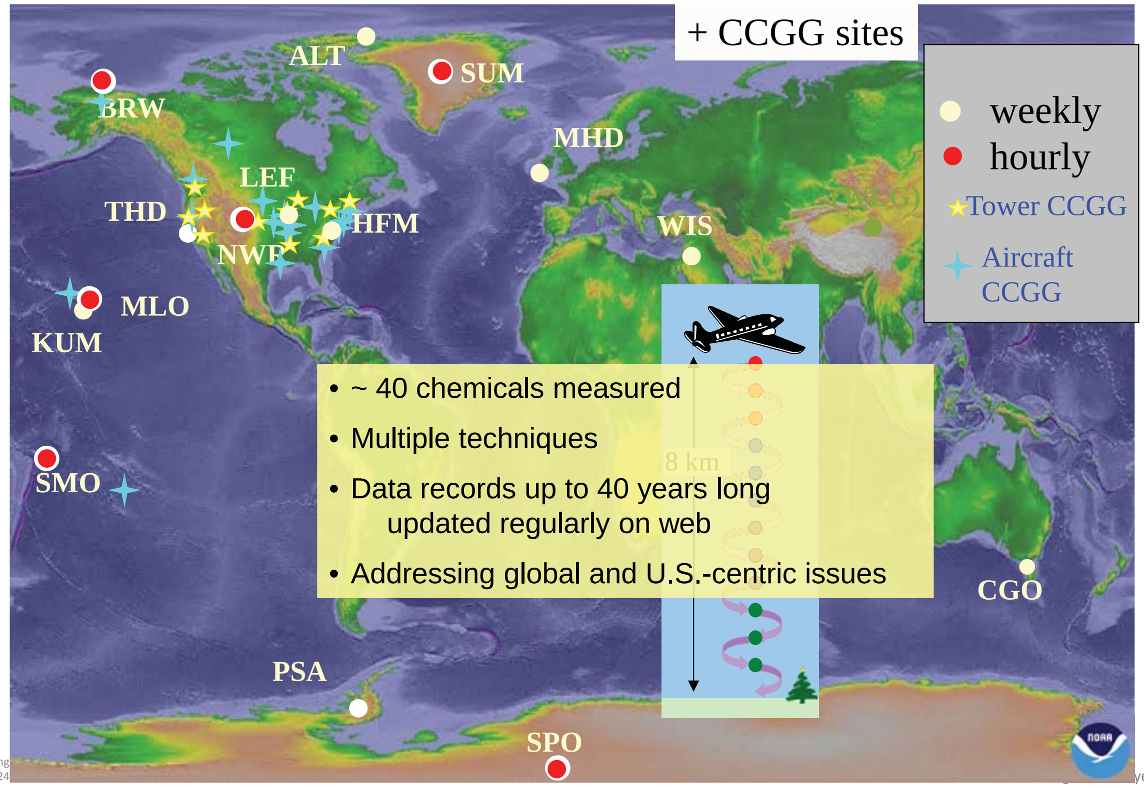
C) Advancing scientific understanding

→ Understanding causes of atmospheric composition change
and improving our understanding of atmospheric processes

D) Communicating results to a broader audience ***(stakeholders)***

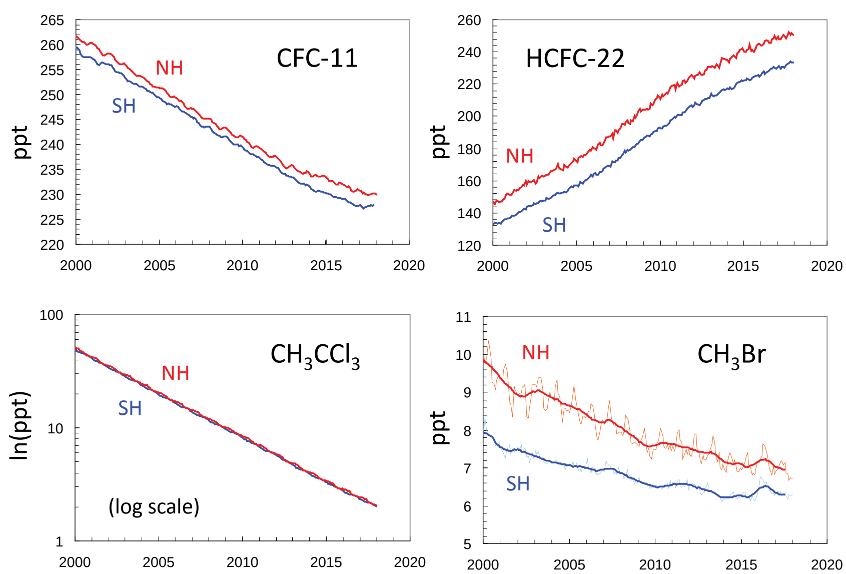
→ through simple indices, web presence, open data policies, publications,
and by contributing to national and international Scientific Assessments

A) Measuring chemicals that cause stratospheric ozone depletion



A) Measuring chemicals that deplete stratospheric ozone

– Concentrations of ozone-depleting chemicals for which **PRODUCTION IS CONTROLLED** by the Montreal Protocol



All major ozone-depleting gases are measured at NOAA/GMD.

Emphasis is on high precision and accuracy.

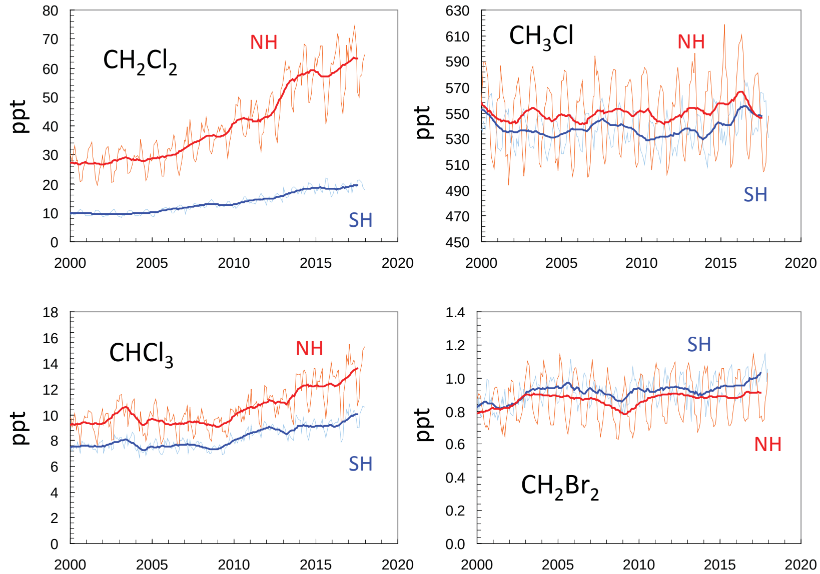
→the better the measurement, the more one can learn…

See talks by S. Montzka, and by P. Yu

Recent related pubs: Montzka *et al.*, 2015; 2018; Rigby *et al.*, 2017

A) Measuring chemicals that deplete stratospheric ozone

– Concentrations of halogenated chemicals **NOT CONTROLLED** by the Montreal Protocol, but that can influence stratospheric ozone:



Shorter-lived gases also add chlorine and bromine to the atmosphere.

→ having human and natural sources.

→ changing over time?

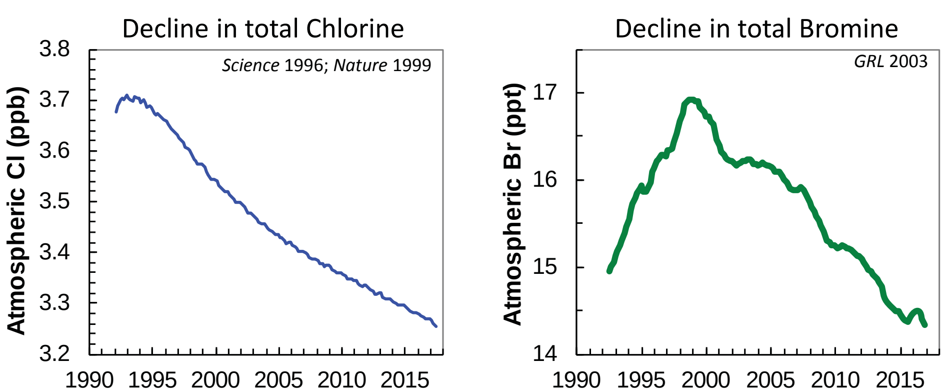
Also: N_2O, COS

See poster by G. Dutton

Recent related pubs: Hossaini *et al*., 2016; 2017

A) Measuring chemicals that deplete stratospheric ozone

– Changes in “controlled” tropospheric chlorine and bromine:



→ Sum of all controlled gases measured at GMD

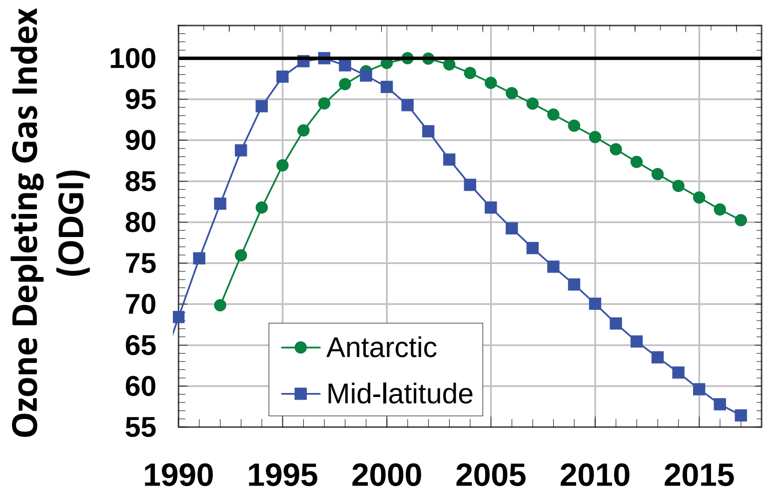
→ directly addressing Congressional mandate

→ updated annually on NOAA web page:
ftp://ftp.cmdl.noaa.gov/hats/

A) Measuring chemicals that deplete stratospheric ozone

– Distilling GMD measurements of controlled gases into a single index:

The Ozone Depleting Gas Index



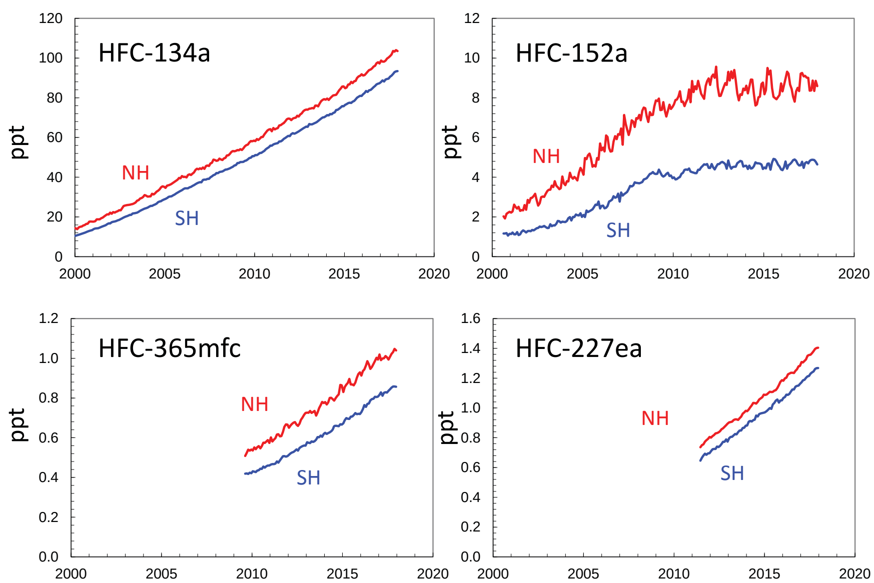
Measuring progress in the decline of ozone-depleting halogen back to 1980 concentrations (pre-ozone hole)

In 2017:
- Antarctic ODGI was 80
- Mid-latitude ODGI was 56

Annually updated at http://www.esrl.noaa.gov/gmd/aggi/

A) Measuring substitute Hydrofluorocarbons

– Concentrations of chemicals for which **PRODUCTION IS CONTROLLED** by the Montreal Protocol, ***but that do NOT deplete ozone***



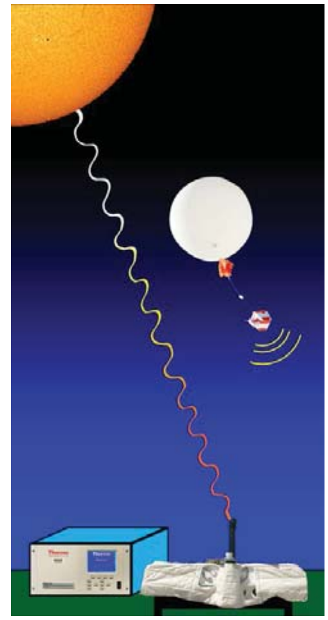
Recently added to the Montreal Protocol list of controlled substances.

These results enable a tracking of radiative forcing from ODS substitution.

Most substitute HFCs are measured at NOAA/GMD.

B) Measuring long-term changes in stratospheric ozone

→ Providing reference-quality long-term measurements of stratospheric ozone



Using a range of techniques to obtain:

Ozone total column density:
- Dobson
- Brewer

Ozone concentration vertical profile :
- Ozone Sondes (highest vertical resolution)
- Umkehr

Ozone concentrations near Earths surface

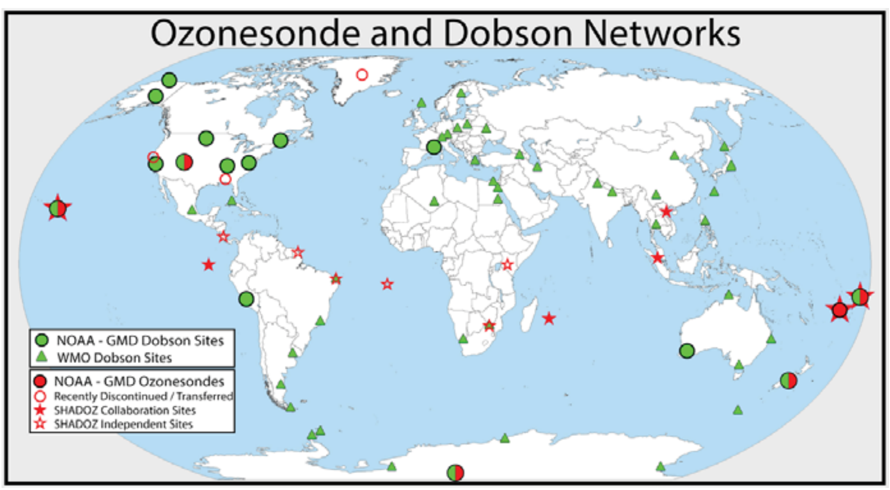
To allow an understanding of ozone concentration changes:

over time
- developing and applying statistical models to provide trend estimates

as a function of altitude
- stratospheric changes (upper vs lower stratosphere)
- tropospheric changes (pollution-related or transported from stratosphere)

as a function of latitude
- future ozone changes are expected to be latitude-dependent
  - aerosol, GHGs, circulation...

B) Measuring long-term changes in stratospheric ozone



NOAA-GMD Dobson ozone program:

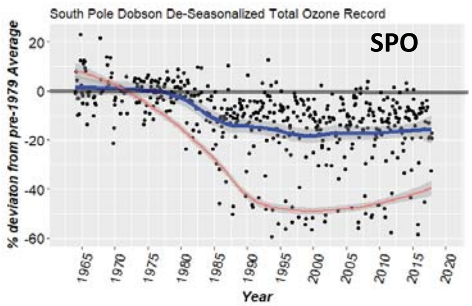
- Forms a global backbone of robust, calibrated total column ozone data
- Provides an essential reference for other ozone measurements (satellites, other Dobsons, etc.) through calibration transfers
- Maintains the WMO reference Dobson instrument (#D083)

NOAA-GMD ozone sonde program:
- adds high vertical resolution (data were recently homogenized)
- Strengthens and augments the SHADOZ program for tropical ozone data

Recent Dobson- and sonde-related pubs: Petropavlovskikh et al. (2015), Nair et al., 2015; Evans et al., 2016, Thompson et al., 2017, Sterling et al, (2018)

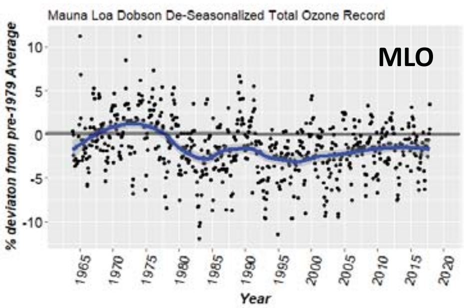
B) Measuring long-term changes in stratospheric ozone

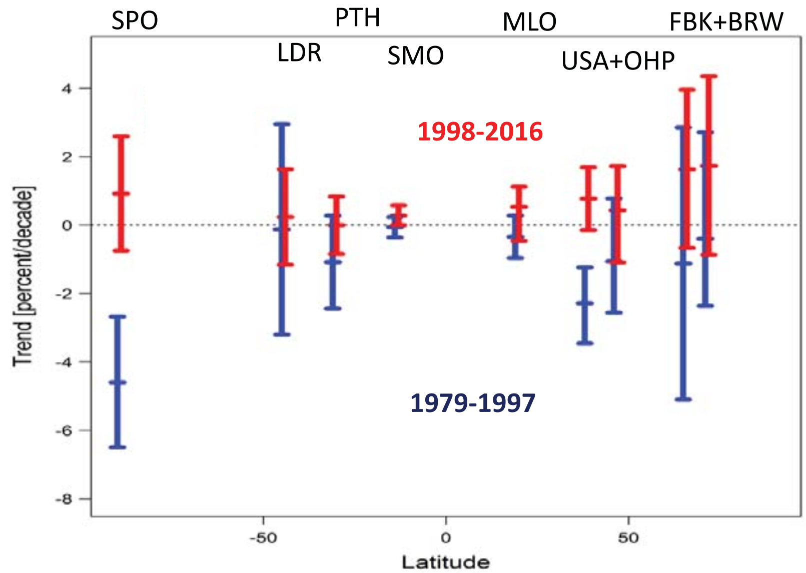
– To allow an understanding of ozone column changes by latitude (ODS+GHG+transport)



All data

Sept-Oct only

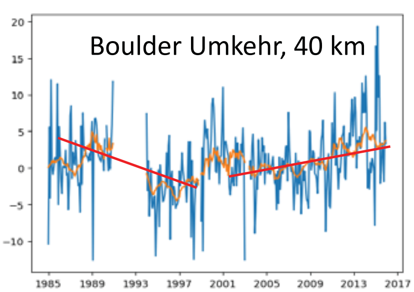


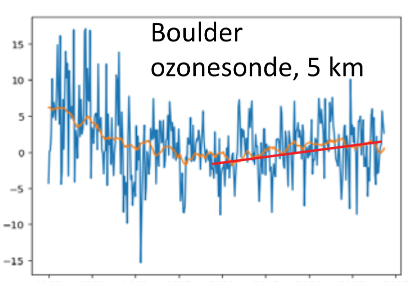


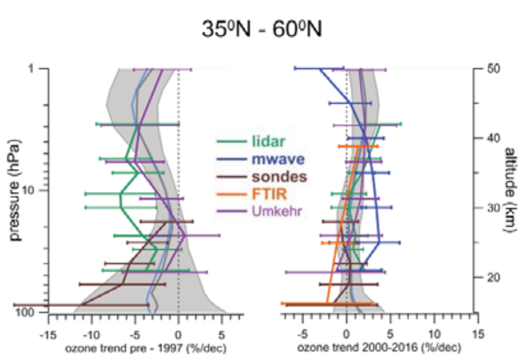
See posters by G. McConville, K. Miyagawa

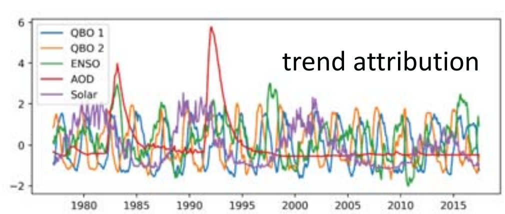
B) Measuring long-term changes in stratospheric ozone

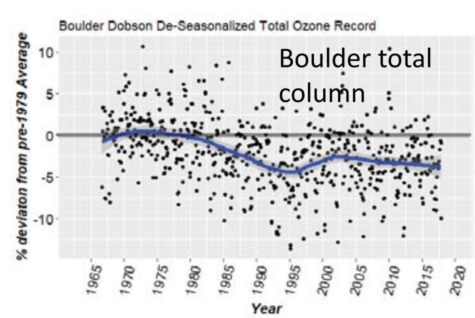
- To allow an understanding of ozone column changes by altitude (ODS+GHG+transport)









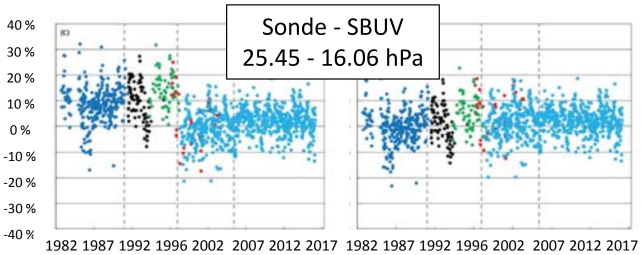


LOTUS 2018 and Ozone Assessment 2018 used GMD data and developed statistical models to derive trends in ozone profiles and total column.

B) Measuring long-term changes in stratospheric ozone

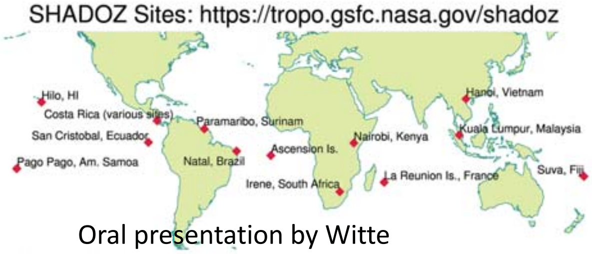
– *To allow an understanding of ozone column changes by altitude (ODS+GHG+transport)*

Is ozone in lower stratosphere still decreasing? Ball et al (2018) analyses are based on satellite records

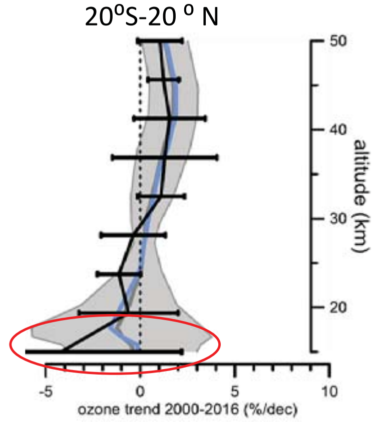


Homogenization for GMD (Sterling et al, 2018) and SHADOZ (Witte et al, 2017) ozonesonde data - improved records for future trend analyses

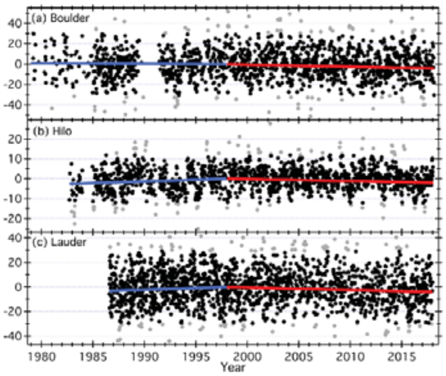
SHADOZ Sites: https://tropo.gsfc.nasa.gov/shadoz



Oral presentation by Witte



Satellite and **CCMI** model averaged trends (LOTUS, 2018, Ozone Assessment) - disagreement between models and observations?

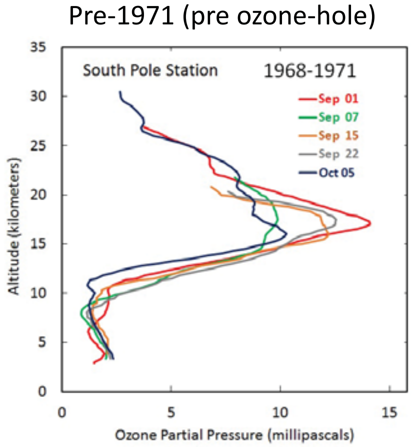


Trends in the low stratosphere will be soon assessed from homogenized ozone-sonde data in tropics and middle latitudes.

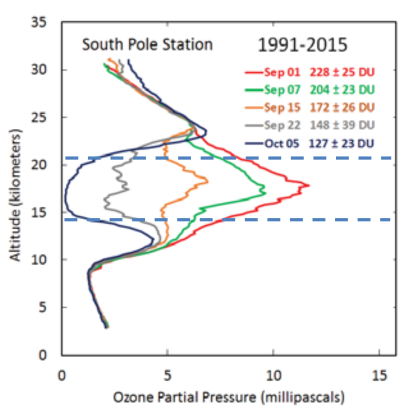
B) Measuring long-term changes in stratospheric ozone

– Ozone, **vertical profiles from ozone sondes** on balloons

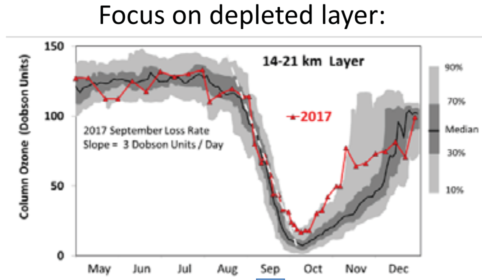
Pre-1971 (pre ozone-hole)

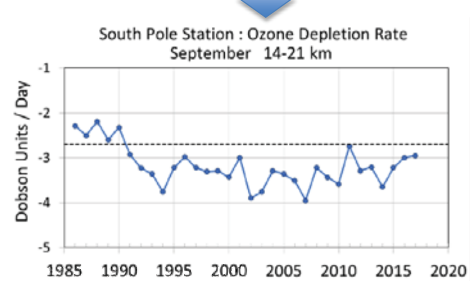


Ozone-hole conditions



Focus on depleted layer:





See talk by B. Johnson, poster by P. Cullis

Recent related pubs: Solomon et al. 2016 – ozone-sonde detected recovery, observed in Septembe
Hofmann(2010)? Recovery after the September depletion rate is less than 2.7 DU/day

C) Advancing scientific understanding (Q3 & Q4 in New Research Plan)

→Understanding the cause of atmospheric composition changes

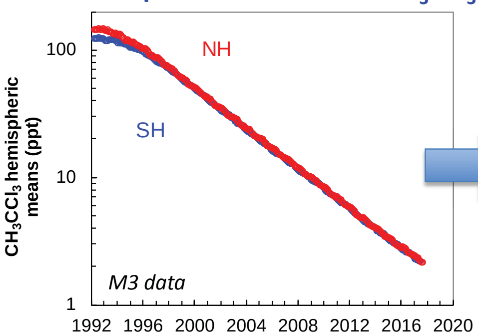
→sources, sinks, and transport

Improving our understanding of trace-gas sources and sinks

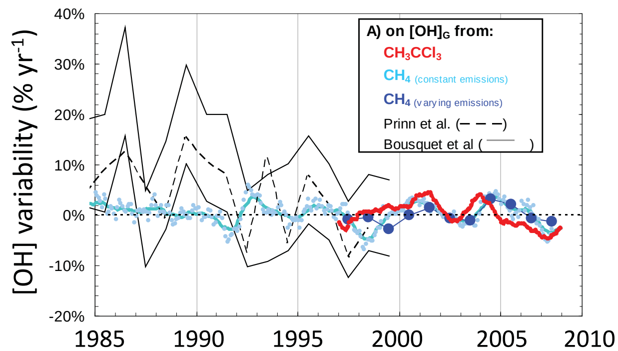
Sinks: Measuring the atmospheric oxidation capacity over time

→ budget analyses of long-lived gases

The exponential decline in CH_3CCl_3



Inferred [OH] inter-annual changes



Science 2000; Science 2011; PNAS 2017

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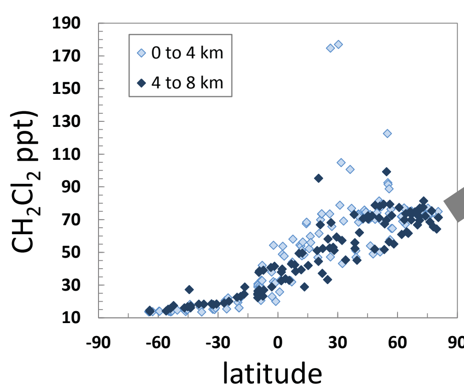
Alternative approaches to CH_3CCl_3:

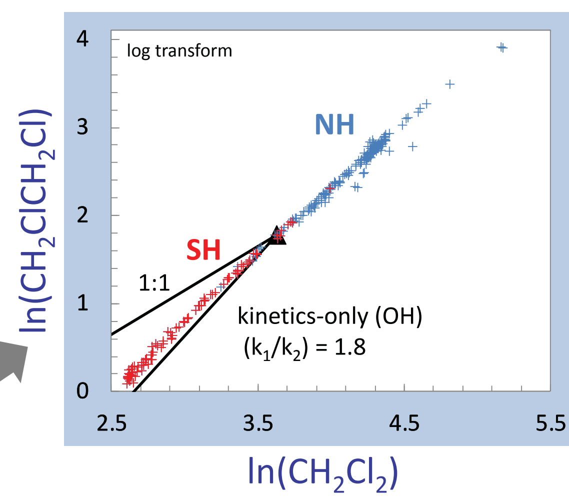
* Deriving OH loss from consideration of hemispheric mole-fraction differences

Long-lived gases (Liang *et al.*, 2017)

Short-lived gases

From network and special projects (e.g., Atom)





C) Advancing scientific understanding (Q3 & Q4 in New Research Plan)

→Understanding the cause of atmospheric composition changes

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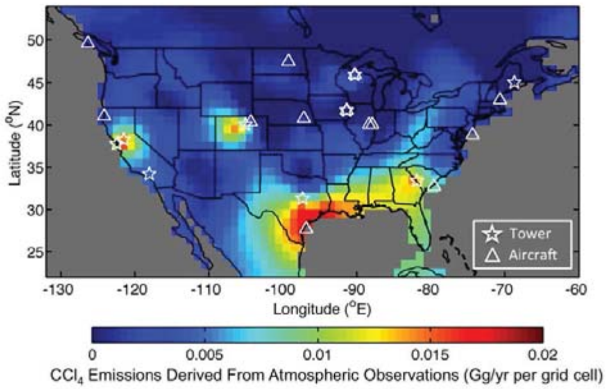
Improving our understanding of trace-gas sources and sinks

Sources, particularly U.S. contributions, but also on a global scale

Why are CCl_4 emissions continuing now that CFC production is negligible?



SPARC Report focus in 2016

What we found:

US emissions are 10% of global total

* associated with chemical industry
* this process likely accounts for much of the remaining global emissions

(Hu et al., 2016)

Other similar findings related to CFC-11 will be discussed in meeting

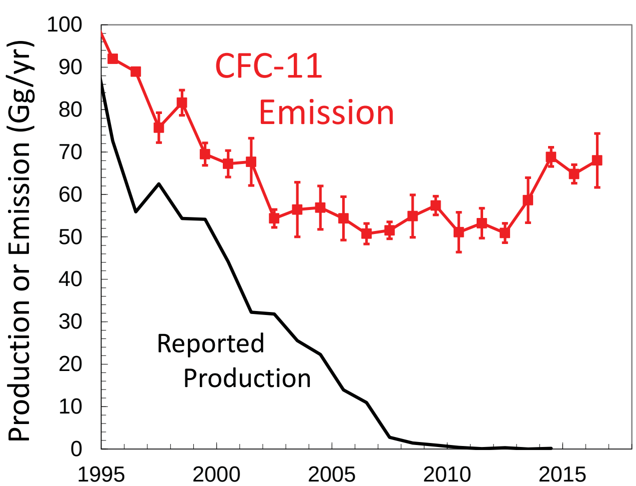
C) Advancing scientific understanding (Q3 & Q4 in Research Plan)

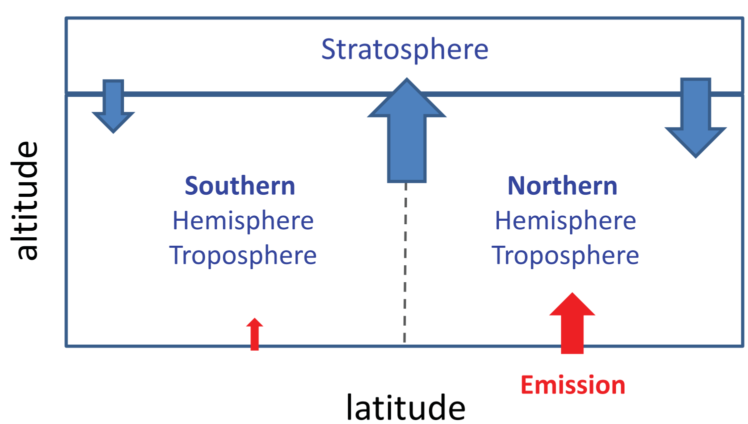
→Understanding the cause of atmospheric composition changes

→sources, sinks, and transport

Improving our understanding of trace-gas sources and sinks

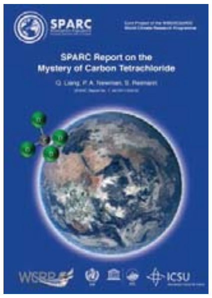
Surface measurements are influenced by variations in sources *and* sinks:





D) Communicating results

- ***Providing expertise*** to national and international Assessments on Ozone and Climate:
  - ***GMD scientists*** have been lead authors, co-authors, contributing authors, and contributors to these Assessments
  - ***GMD data*** are prominent in these Assessments



2016

2014

2013

2014

Also:
•UNEP/WMO, 2018 Scientific Assessment of Ozone Depletion—lead authors
•UNEP/WMO, Twenty questions and answers about the ozone layer, 2015

Guiding ozone layer recovery in the future at GMD:

- **Continue ongoing programs to:**
  - Monitor effectiveness of the Montreal Protocol for diminishing ozone-depleting gases
  - Accurately measure the response of stratospheric ozone to decreasing halogen and increasing greenhouse gas concentrations
- **Especially to address newly emerging issues:**
  - increases in CFC-11, CH_2Cl_2, & CH_3Br; and in future for VSLS-bromine?
  - HFCs and Kigali Amendment – locking in climate gains from the Montreal Protocol
  - lower stratospheric ozone declines (Ball et al. 2018)? Assess better-positioned GMD measurements (Unkehr; ozone-sonde)
- **Add capabilities where possible:**
  - increased sampling frequency in tropics
  - validation of new instruments (*i.e.* Pandora)
  - validation of new operational NOAA satellite products (*i.e.*, IPSS)
- **Participate in periodic field campaigns to:**
  - extend an understanding of surface-based results vertically
  - improve process-based understanding of the atmosphere
  - gauge the atmospheric response to increasing greenhouse gas concentrations

Guiding Recovery of Stratospheric Ozone at GMD

GMD plays a central role in the global effort to monitor stratospheric ozone, ozone-depleting gases, and other processes affecting stratospheric ozone

Our focus:

- ***global-to-regional scale observations*** to assess global changes *and* influences from specific processes and regions (*e.g*., U.S.)
- ***Diagnosing observed changes*** to clarify the relative influence of policy decisions, other human behaviors, and natural processes
- ***To provide the highest-quality, policy-relevant science***

→ *Guiding the recovery of the ozone layer by informing Parties to the Montreal Protocol on the progress of recovery*