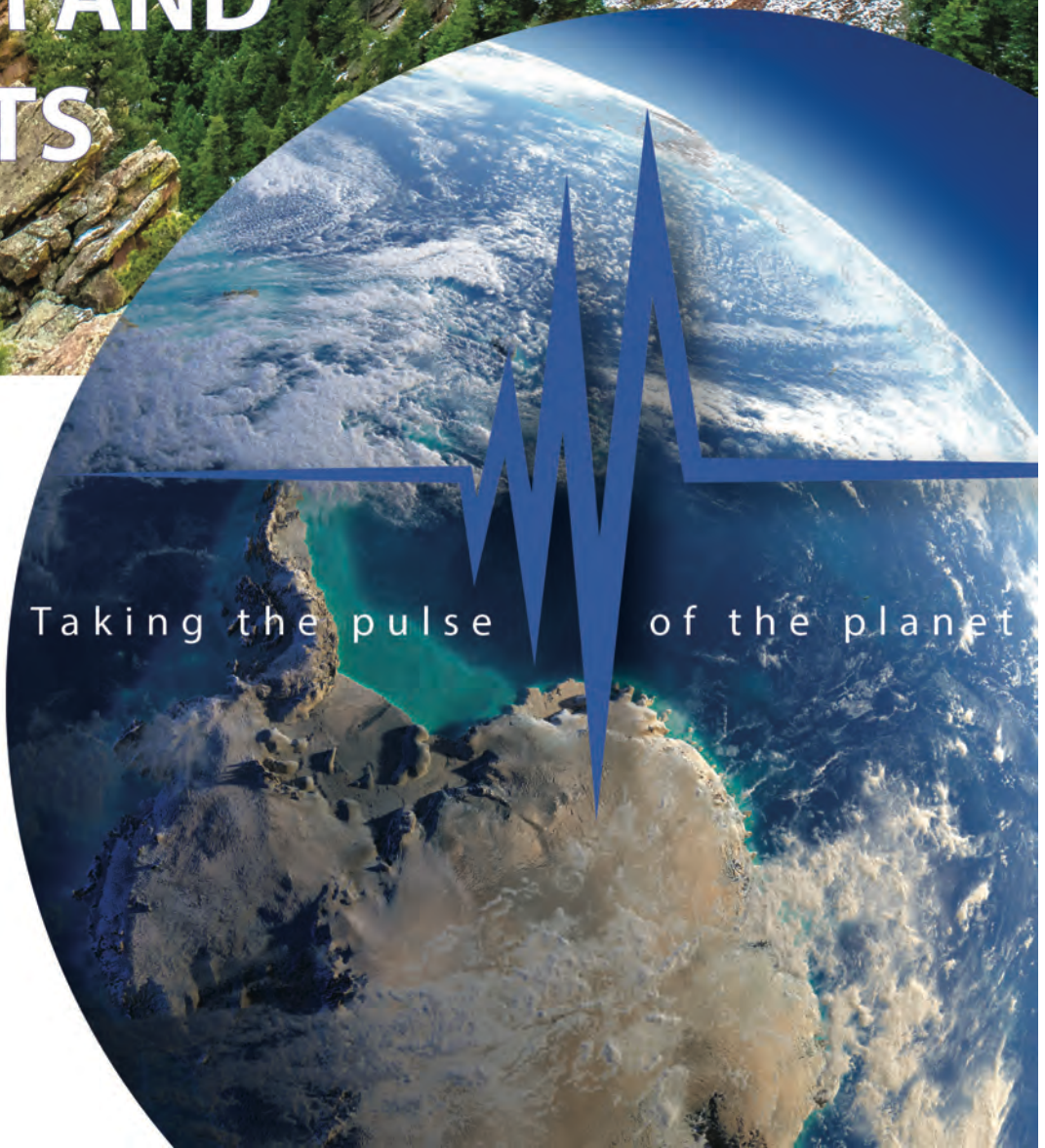
GLOBAL MONITORING ANNUAL CONFERENCE

PROGRAM AND ABSTRACTS



Boulder, Colorado
May 21–22, 2019

Hosted by:
NOAA Earth System Research Laboratory
Global Monitoring Division

Mission of the Global Monitoring Division:

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.

Conference Website:

http://www.esrl.noaa.gov/gmd/annualconference/

Purpose of the Global Monitoring Annual Conference:

To bring together preeminent scientists to discuss the latest findings in climate research and how to integrate science, observations and services to better serve society.

Terms of use:

This report may be cited as:

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National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
Earth System Research Laboratory
325 Broadway – David Skaggs Research Center
Boulder, Colorado 80305-3337

MAY 2 1 2019

Dear Friends and Colleagues,

Welcome to our 47th Global Monitoring Annual Conference (GMAC)! This meeting is once again an opportunity to reconnect with old colleagues and meet new ones in an on-going effort to advance our global observing networks and the science they support. This year, we anticipate nearly 200 attendees and, as before, we are streaming the meeting on-line for those who cannot attend in person. Abstracts are made available for each poster and presentation on the 2019 GMAC agenda so you can be aware of what's coming up next at https://www.esrl.noaa.gov/gmd/annualconference/agenda.php. After the conference, we request permission of the presenters to post the actual presentations on the meeting website for future reference. You can see many of the presentations from former GMACs at https://www.esrl.noaa.gov/gmd/publications/annual_meetings/.

In the spirit of, "You heard it here first", we have several presentations highlighting new ways of making measurements, including new observations from commercial aircraft, light aircraft, public transportation systems, and novel approaches from satellites. As our long-term records age yet another year, we see their increasing value in estimates of emissions, verification of model results, and validation of satellite retrievals – all discussed in a number of presentations at this year's meeting. GMD's longest records go back to the International Geophysical Year (1957-58) and leave in their wake a legacy of observing sites around the world that continue to inform on the changing and emerging state of Planet Earth. Global partnerships are essential in this effort and we look forward to continued engagement with our national and international partners at this and other meetings in the coming year.

Thank you for coming! It is you who make this conference what it is and who develop the opportunities that emerge every year from this conference. Thank you all for your participation and engagement!

Sincerely,

James H. Butler, Director
Global Monitoring Division

LIST OF ACRONYMS

Organizations and Networks

AERONET – NASA
AGAGE – Advanced Global Atmospheric Gases Experiment network
ARM – Atmospheric Radiation Measurement
BSRN – Baseline Surface Radiation Network
EPA – Environmental Protection Agengy
GAW – Global Atmosphere Watch
GGGRN – Global Greenhouse Gas Reference Network
HIPPO – HIAPER Pole-to-Pole Observations
IPCC – Intergovernmental Panel on Climate Change
NASA - National Aeronautics and Space Administration
NDAAC – Network for the Detection of Atmospheric Composition Change
NSF – National Science Foundation
USGS – United States Geological Survey
WMO – World Meteorological Organization

Chemical compounds

Ar - Argon
Br – Bromine
CCl_4 – Carbon tetrachloride
CFC – Chlorofluorocarbon
CH_4 – Methane
Cl – Chlorine
CO – Carbon monoxide
^{12}C – Carbon-12
^{13}C – Carbon-13
$\delta^{13}C$ – 'delta C thirteen'
^{14}C – Carbon-14, or radiocarbon
$^{14}CO_2$ – Carbon-14 CO_2
CO_2 – Carbon dioxide
H_2 – Hydrogen
H_2O – Water
HCFC – Hydrochlorofluorocarbon
HFC – Hydrofluorocarbon
N_2 - Nitrogen
O_2 - Oxygen
O_3 – Ozone
OH – Hydroxyl (radical)
N_2O – Nitrous oxide
$PM_{2.5}$ – Particulate Matter (≤ 2.5 microns width)
SF_6 – Sulfur hexafluoride

Satellites and Satellite Sensors

CERES – Clouds and the Earth's Radiant Energy System satellite
GOSAT – Greenhouse gases Observing SATellite
ISS – International Space Station
JPSS – Joint Polar Satellite System
MLS – Microwave Limb Sounder
MODIS – MODerate resolution Imaging Spectroradiometer satellite
OCO-2 – Orbiting Carbon Observatory-2
OMI – Ozone Monitoring Instrument

Other Acronyms and Terms

AAOD – Aerosol Absorption Optical Depth
AOD – Aerosol Optical Depth
CRDS - Cavity Ring Down Spectroscopy
FID - Flame Ionizing Detector
GC - Gas Chromatograph/chromatography
GCMS - Gas Chromatograph Mass Spec
GCECD - Gas Chromatograph Electron Capture Detector
GHG – Greenhouse Gas
HRRR – High-Resolution Rapid Refresh
HYSPLIT - Hybrid Single Particle Lagrangian Integrated Trajectory Model
IR – Infrared
MFRSR – Multi-Filter Rotating Shadow-band Radiometers
NWP – Numerical Weather Prediction
ODS – Ozone-depleting substance
ONG - Oil and Natural Gas
OSSEs – Observing System Simulation Experiments
$PgCyr^{-1}$ – Petagrams of Carbon per year, or Billion Tonnes of Carbon per year
ppb – parts per billion; ppm – parts per million
RAP - Rapid Refresh model
UAS – Unmanned Aerial Systems
UTC - Universal Time Coordinated (also Zulu, Greenwich Mean Time)
UTLS - Upper Troposphere Lower Stratosphere
UV – Ultraviolet; UVR – Ultraviolet Radiation
VOC – Volatile Organic Compound
Wm^{-2} – Watts per meter squared, unit of radiative forcing

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2019

David Skaggs Research Center, Room GC-402
325 Broadway, Boulder, Colorado 80305 USA

Tuesday Morning, May 21, 2019 Agenda

(Only presenter's name is given; please refer to abstract for complete author listing.)

07:30 ***Registration Opens in GC-402 - lunch orders and posters collected at registration table***

07:45 - 08:30 ***Morning Snacks - coffee, tea, fruit, bagels and donuts served***

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08:45 - 09:15	*Keynote Address:* Global Change Research: A Historical Perspective and Future Challenges *Guy Brasseur (National Center for Atmospheric Research (NCAR), Distinguished Scholar)*	1
09:15 - 09:30	On the Unexpected Increase in CFC-11 Emissions, Are They Still on the Rise? *Stephen A. Montzka (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))*	2
09:30 - 09:45	Spatial/Temporal Patterns in the Atmosphere: The Carbon Cycle Revealed *Pieter Tans (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))*	3
09:45 - 10:00	Geoengineering for Climate Change: Nature Has Already Demonstrated the Process and Effects *Russ Schnell (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))*	4
10:00 - 10:30	***Morning Break & Group Photo on the Stage***	
Session 2	***Global Carbon Cycle Observations and Monitoring*** — *Chaired by Arlyn Andrews*	
10:30 - 10:45	First IAGOS-CORE and IAGOS-CARIBIC Greenhouse Gas Observations from Commercial Airliners *Christoph Gerbig (Max Planck Institute for Biogeochemistry (MPI-BGC), Jena, Germany)*	5
10:45 - 11:00	The SIO O_2 Program: Constraints on Long-term Carbon Cycle Changes Through Measurements of Atmospheric Oxygen *Eric Morgan (Scripps Institution of Oceanography, University of California at San Diego)*	6
11:00 - 11:15	Regional Attribution of CO_2 Seasonal Amplification in Northern Hemisphere using a Tagged Tracer Transport Model *Xin Lin (University of Michigan)*	7
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11:30 - 11:45	Patterns and Controls on Trace Gas Fluxes of CO_2 and/or CH_4 in Marine and Terrestrial Habitats from Barrow, Alaska to Pago Pago, American Samoa *Walter Oechel (San Diego State University, Global Change Research Group)*	9
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12:00 - 13:00 ***Catered Lunch - Outreach Classroom GB-124 (pre-payment of $12.00 at registration)***

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2019

David Skaggs Research Center, Room GC-402
325 Broadway, Boulder, Colorado 80305 USA

Tuesday Afternoon, May 21, 2019 Agenda

(Only presenter's name is given; please refer to abstract for complete author listing.)

Keynote Address: **Global Change Research: A Historical Perspective and Future Challenges**

G. Brasseur[1,2]

[1]National Center for Atmospheric Research (NCAR), Distinguished Scholar, Boulder, CO 80307; 303-497-1632, E-mail: giu.brasseur@mpimet.mpg.de
[2]Max Planck Institute (MPI) for Meteorology, Hamburg, Germany

Since the International Geophysical Year of 1957–58, systematic observations initiated by C. D. Keeling have shown a continuous increase in the atmospheric abundance of carbon dioxide. In the early 1960's, S. Manabe and his colleagues at NOAA Geophysical Fluid Dynamics Laboratory (GFDL) showed that future CO_2 emissions will lead to temperature increase in the troposphere and a temperature decrease in the stratosphere. They also show that the high-latitude surface warming will be magnified by the recession of the ice sheet. Since the 1960's, the community has made enormous progress to identify the forcing mechanisms of the climate system, to study the complex interactions inside the Earth system, and to project climate change, and to assess how the planet will respond to human activities.

International research has shown that climate change is accelerating and that humans are to a large extent responsible for these changes. These conclusions, based on systematic investigations, have led to the recognition that climate change will have substantial impacts for our society and that decisive actions are urgently needed. The Paris Agreement would not have been concluded without the input of the science.

Today, environmental security and human welfare require complementary actions as highlighted by the 2030 UN Agenda for Sustainable Development. To implement this agenda, decision-makers will increasingly need relevant and objective information to ensure for humankind a more resilient present and a sustainable future. A priority for the research community is therefore to develop the knowledge needed for the stewardship of our planet.

Fundamental research with a focus on Earth System science remains a necessity, and should be strongly encouraged. The paper will review some of the grand scientific challenges addressed by international programs and will highlight their efforts to provide actionable information of direct benefit to society.

Figure 1. The U.N.'s sustainable development goals.

On the Unexpected Increase in CFC-11 Emissions, Are They Still on the Rise?

S.A. Montzka[1], G.S. Dutton[2,1], P. Yu[2,3], E.A. Ray[2,3], R.W. Portmann[3], J.S. daniel[3], L. Kuijpers[4], B.D. Hall[1], D. Mondeel[2,1], C. Siso[2,1], J.D. Nance[2,1], M. Rigby[5], A. Manning[6], L. Hu[2,1], F.L. Moore[2,1], B.R. Miller[2,1], and J.W. Elkins[1]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-6657, E-mail: Stephen.A.Montzka@noaa.gov
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[3]NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO 80305
[4]Eindhoven Centre for Sustainability, Technical University Eindhoven, Eindhoven, Netherlands
[5]University of Bristol, School of Chemistry, Bristol, United Kingdom
[6]UK Meteorological Office, Exeter, United Kingdom

In May 2018, we published results showing that emissions of CFC-11 have increased since 2012 despite production of this controlled ozone-depleting substance (ODS) being reportedly phased out in 2010. The results are not likely explained by increases in releases of CFC-11 from old insulating foams and chillers, suggesting production after the reported phaseout and a contravention of the Montreal Protocol on Substances that Deplete the Ozone Layer. While we determined that some of the emission increase arises from eastern Asia, emissions trends in many regions of the globe are poorly determined. In separate work by us and others, it appears that emissions have not increased from the U.S., Europe, and Australia. Since publication of our paper, the Parties to the Montreal Protocol have formally asked scientists and industry for further information so that they might consider an effective and informed response and even amendments to the Protocol itself. Ultimately, they are hoping to rapidly identify the underlying causes of the renewed production and increased emission so that they can be stopped before substantial damage to the ozone layer ensues. Meetings in China and Vienna were recently convened to assess the available information and provide feedback to the Parties working to resolve the issue. In this talk, I will discuss this issue and its implications for the ozone layer. In particular, I will explore updated measurements, which preliminarily suggest that that global and eastern Asian emissions may have declined slightly during the latter half of 2018. While these hints are encouraging, delay in ozone-layer recovery will likely be determined by the cumulative amount of post-2010 production, which is a quantity that is poorly constrained.

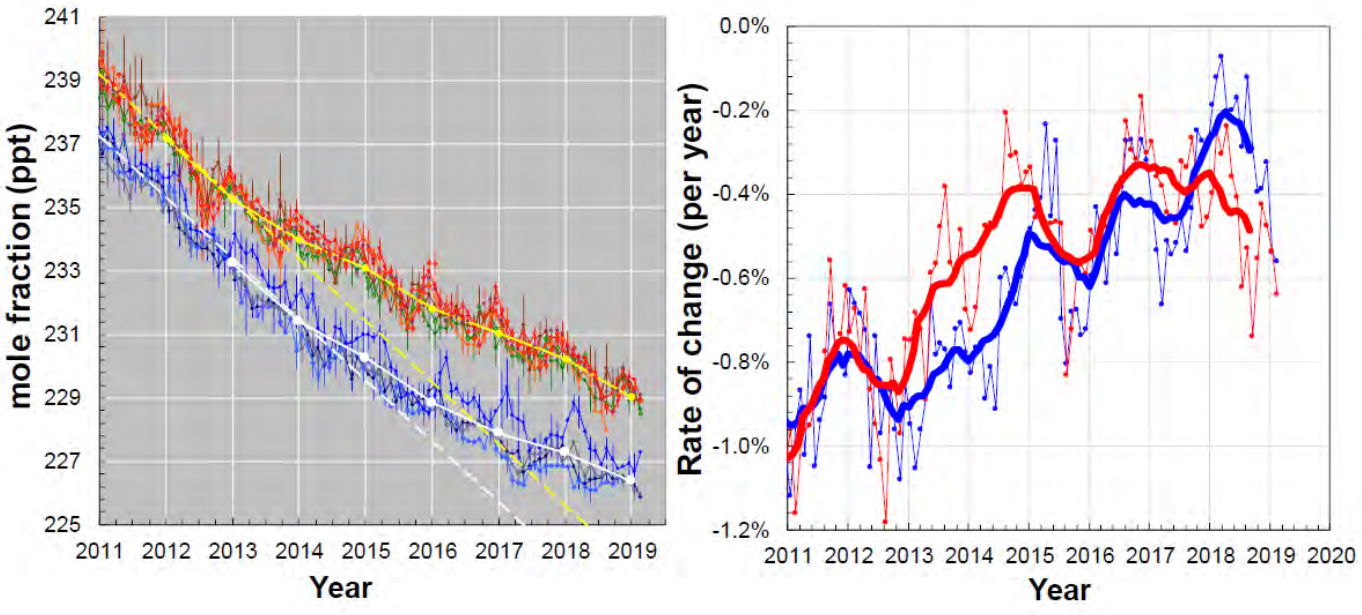


Figure 1. Left: CFC-11 atmospheric mole fraction over time measured at Northern Hemisphere sites (red and green points) and Southern Hemisphere sites (blue points). Fits to hemispheric mean data during 2002 to 2012 are extrapolated to 2018 (yellow- and white-dashed lines). Right: Hemispheric rates of change determined from the observations for the Northern Hemisphere (red) and Southern Hemisphere (blue). Rates are from monthly mean mole fraction differences [e.g., ln(jan2018/jan2017)] and are also shown as annually smoothed quantities (bold lines).

Spatial/Temporal Patterns in the Atmosphere: The Carbon Cycle Revealed

P. Tans

NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-6678, E-mail: Pieter.Tans@noaa.gov

Since 1980, we have constructed north-south pattterns of CO_2 and later also of other gases, based on air samples collected at marine boundary layer sites (MBL). At these sites, we have access to "background" air that is well mixed and minimally influenced by nearby large emissions or removals of the trace gases. The measurements are representative of large areas. CO_2 is increasing everywhere at almost the same rate, but the approximate latitude and changing magnitude of sources/sinks is evident in changes of north-south gradients. A new way to highlight these patterns will be presented. Deseasonalized CO_2 gradients are dominated by two factors: fossil fuel burning and interannual variability of terrestrial ecosystems. We can use the observed patterns of sulfur hexafluoride (SF_6) to subtract the fossil fuel component from the observed total CO_2 patterns. It leaves the influence of terrestrial ecosystem variability on the carbon cycle, which stands out very clearly.

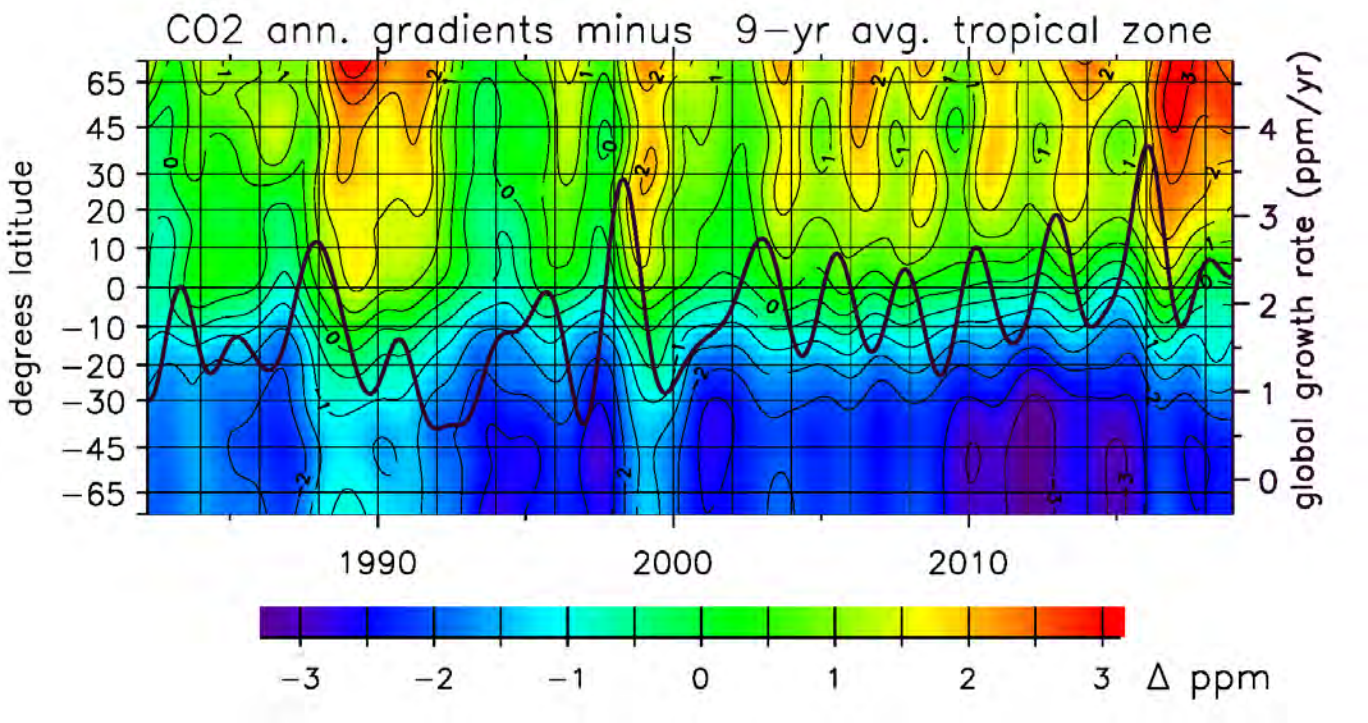


Figure 1. Deseasonalized, north-south gradients of CO_2 relative to the average of the tropical zone, defined here as -17.5 S to 17.5 N, which has been smoothed in time with a low pass filter with a width of nine years. This leaves interannual variability, incl. El Nino, in the tropics and elsewhere.

Geoengineering for Climate Change: Nature Has Already Demonstrated the Process and Effects

R. Schnell

NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-6733, E-mail: russell.c.schnell@noaa.gov

Geoengineering to reduce atmospheric air temperature is becoming a hot topic with recent articles in *Science*, *Nature*, and the *Bulletin of the American Meteorological Society* discussing the pros, cons, and methods of "solar engineering." The proposed method of choice is to inject millions of tons of sulphur or calcium carbonate aerosols (two of the proposed) into the stratosphere to reflect solar radiation back to space.

Through volcanic eruptions that spewed mineral particles and sulfur dioxide into the stratosphere, nature has provided excellent examples of geoengineering: El Chichón, Mexico (29 March, 1982, ~7 MT) and Mount Pinatubo, Philippines (14 June, 1991,~ 20 MT).

Reductions in solar radiation measured at the Mauna Loa Atmospheric Baseline Observatory (MLO), Hawaii from these eruptions (Figure 1) showed a 14% reduction from El Chichón and 11% reduction from Pinatubo at the peak of the respective stratospheric aerosol loadings. Lidar measurements of the eruption aerosols showed they were concentrated between 15 and 30 km altitude and took 4–5 years to return to background levels (Figure 2). These aerosols reduced the global and Northern Hemisphere temperatures by ~0.5ºC and ~0.7ºC respectively.

NOAA WP-3 aircraft measurements in the Arctic stratosphere off Greenland, one year after the El Chichón eruption, collected crustal debris in the 10^{0} to 10^{1} micron diameter range in concentrations of 10^{-3} to 10^{-2} cm^{-3} and sulfuric acid (H_2SO_4) droplets in the 10^{0} to 10^{-1} micron diameter range in concentrations of 10^{-1} to 10^{2} cm^{-3}.

Peak aerosol optical depth anomalies measured at the surface at MLO were 0.2 for both El Chichón and Pinatubo eruptions and 0.17 and 0.21 respectively at the Barrow Atmospheric Baseline Observatory (BRW) in Utqiaġvik, Alaska. From NOAA WP-3 measurements in the stratosphere over BRW on April 22, 1992 (Pinatubo, 10 months post eruption), the stratospheric aerosol depth was in the 0.19 to 0.2 range.

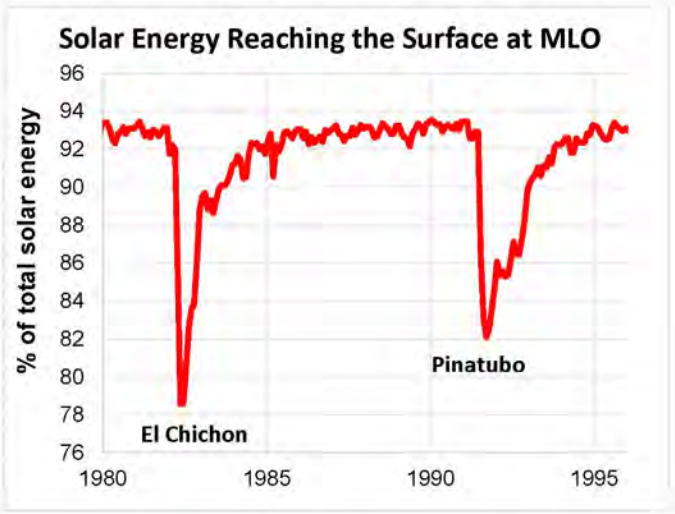


Figure 1. Solar energy reaching the surface at MLO following the El Chichón and Pinatubo eruptions.

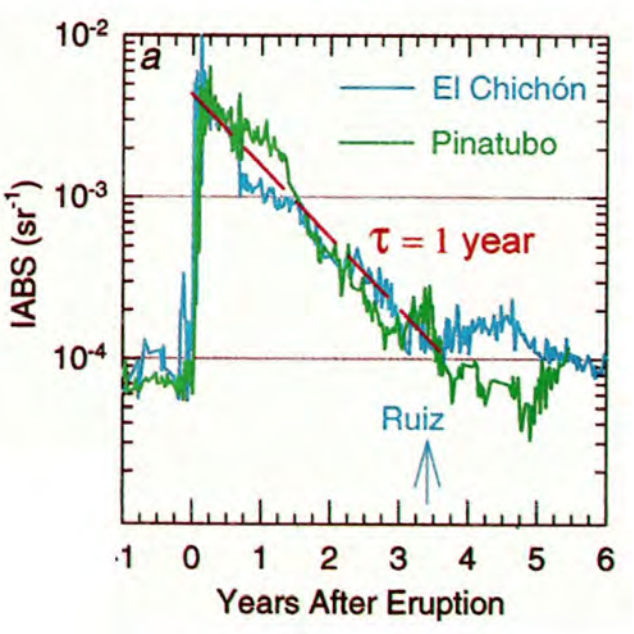


Figure 2. MLO lidar aerosol backscatter (16–33 km) above MLO after the El Chichón and Pinatubo eruptions. Nevado del Ruiz (located in Colombia) erupted November 1985.

First IAGOS-CORE and IAGOS-CARIBIC Greenhouse Gas Observations from Commercial Airliners

C. Gerbig[1], S. Baum[1], H. Franke[2], R. Stosius[2], F. Obersteiner[3], T. Gehrlein[3], and A. Zahn[3]

[1]Max Planck Institute for Biogeochemistry (MPI-BGC), Jena, Germany; +49-36-41-57-6373, E-mail: cgerbig@bgc-jena.mpg.de
[2]enviscope GmbH, Frankfurt am Main, Germany
[3]Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology, Campus Alpin, Karlsruhe, Germany

Within the framework of IAGOS-ERI (In-service Aircraft for a Global Observing System - European Research Infrastructure), a cavity ring-down spectroscopy (CRDS)-based measurement system for the autonomous measurement of the greenhouse gases (GHGs) CO_2 and CH_4, as well as CO and water vapor was deployed on a Lufthansa Airbus A330 for the first time starting September 2018 with the aim to provide regular en-route measurements. A similar system has also been deployed in the IAGOS-CARIBIC (Civil Aircraft for the Regular Invetiation of the atmosphere Based on an Instrument Container) onboard a Lufthansa Airbus A340 starting in 2018.

The IAGOS-CORE rack integrated in the avionics bay of several Airbus A330 and A340 contains all necessary provisions for installing fully-automated instruments for the measurement of ozone, and carbon monoxide (Package 1), humidity (ICH) and cloud particles (BCP). Package2d (P2d) for greenhouse gas measurements is one of four additional Package 2 options, of which only one can be installed at a time in a given aircraft, provided that Package 1 is installed which is necessary for data transmission. The P2d system uses components of a commercially-available CRDS instrument (G2401-m, Picarro Inc.). To enable robust and autonomous operation of the IAGOS-CORE GHG package over six-month deployment periods, numerous technical issues had to be addressed. This includes an inlet system providing ram-pressure to allow for operation to ceiling altitude without a sample compression pump, and the use of a two-standard, in-flight calibration system to allow for trace gas measurements to be fully traceable to WMO calibration scales.

The first deployments on a Lufthansa A330 showed minor problems related to accurate temperature control, a prerequisite for accurate measurements. These initial problems were addressed by modifications of the power management in order to improve temperature control and were included in a minor change of the supplemental type certification (STC) of Package 2 for Airbus A330 and A340 aircraft.

First IAGOS GHG data will be presented, and the availability of GHG data to the research community will be discussed. Future deployments on aircraft from further airlines providing regular, long-term GHG observations covering major parts of the globe will also be explained.

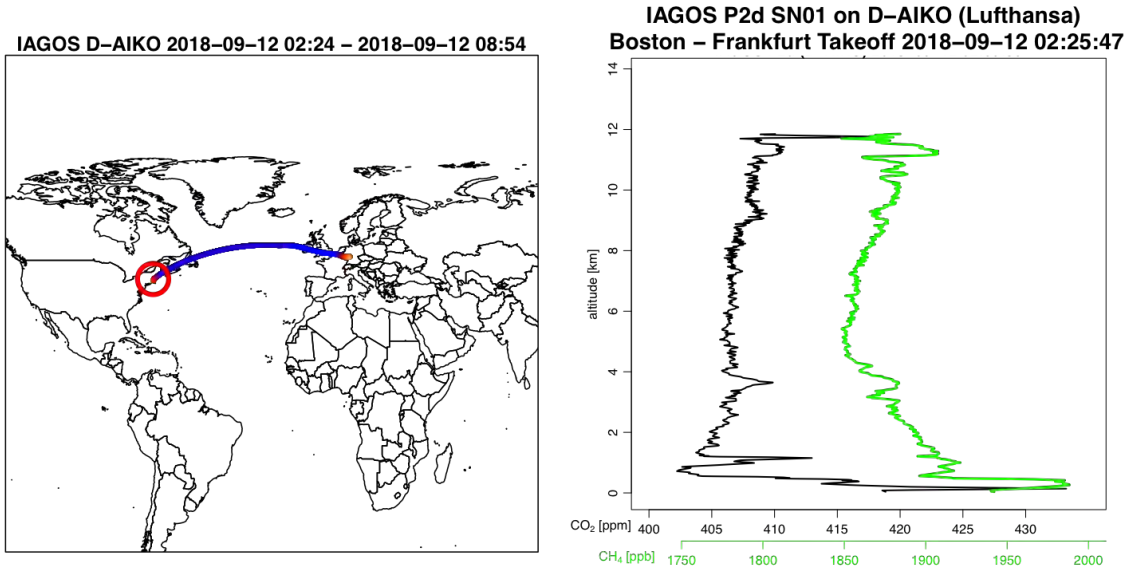


Figure 1. First data provided by P2d-SN01 during the ascent out of Boston Logan airport on September 12, 2018. A clear enhancement of the greenhouse gases CO_2 and CH_4 can be seen near the surface, also around 11.5 km altitude.

The SIO O_2 Program: Constraints on Long-term Carbon Cycle Changes Through Measurements of Atmospheric Oxygen

E. Morgan[1], C. Nevison[2], M. Manizza[1], and R. Keeling[1]

[1]Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92037; 858-822-1642, E-mail: ejmorgan@ucsd.edu
[2]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309

The Scripps O_2 Program maintains long-term time series measurements of atmospheric CO_2, O_2/N_2 ratio, and Ar/N_2 ratio, through a global network of flask sampling sites. Measurements have been made regularly since the 1990s at nine locations [with a tenth site at Utqiaġvik, Alaska (BRW) added to the network in 2011]. This ~30-year record can be leveraged to estimate the global terrestrial and oceanic CO_2 sinks (Keeling and Shertz, 1992; Keeling and Manning, 2014). We present an update of these sink estimates and discuss sources of uncertainty. For the period 2010–2016, we find a net land sink of 1.09 ± 0.97 Pg C yr^{-1} and an ocean sink of 3.62 ± 0.66 Pg C yr^{-1}. In context of land-use emissions of around 2 Pg C yr^{-1}, the net land sink of 1.1 Pg C yr^{-1} requires a residual sink of ~ 3 Pg C yr^{-1}. The ocean sink is on the high end of recent estimates and subject to several important caveats, which will be discussed.

We also highlight some recent work on the seasonality of $\delta(O_2/N_2)$ in the Southern Hemisphere. Since much of the seasonality of O_2 change is driven by the terrestrial biosphere, we focus on the tracer atmospheric potential oxygen (APO), $APO \simeq O_2 + 1.1CO_2$, which combines CO_2 and $\delta(O_2/N_2)$ variations to produce a quantity that is insensitive to the land biosphere fluxes. We find a significant correlation between wintertime APO seasonal anomalies and the Southern Annular Mode (SAM) at select sites in the Southern Hemisphere (see figure). Negative anomalies of APO occur in years of greater wind stress, and hence ventilation of subsurface waters, at higher latitudes.

References:

Keeling and Shertz, 1992. *Nature*, 358:723–727.

Keeling and Manning, 2014. *Treatise on Geochemistry*, Vol 5, 385–404.

Marshall, 2003. *J of Clim*, **16:** 4134−4143.

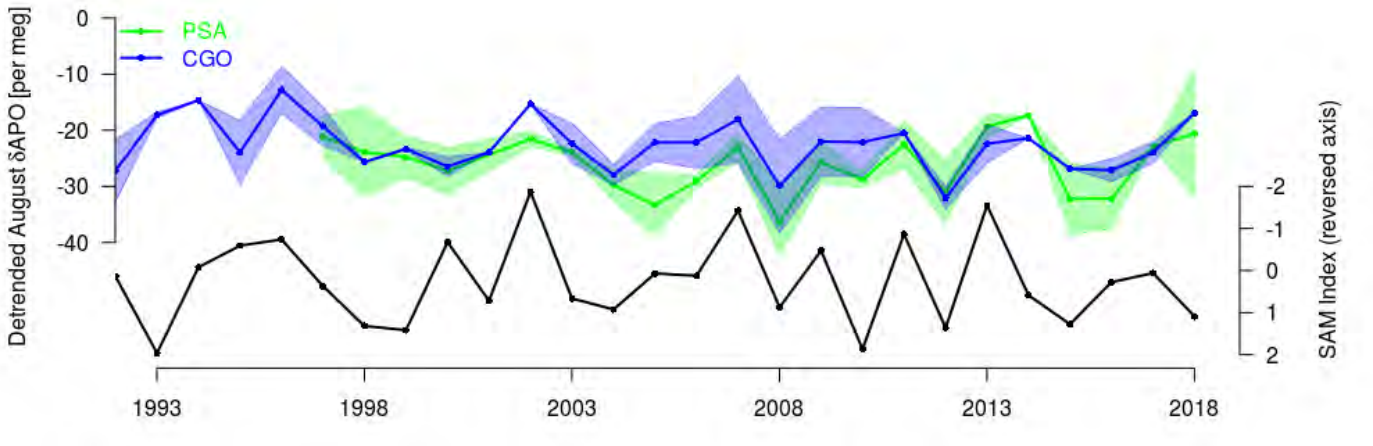


Figure 1. In the top panel, detrended APO in August for two flask sampling sites, Palmer Station, Antarctica (PSA) and Cape Grim Observatory (CGO). Bottom panel: SAM index shown in black with y-axis reversed; data from Marshall, 2003.

Regional Attribution of CO_2 Seasonal Amplification in Northern Hemisphere using a Tagged Tracer Transport Model

X. Lin[1], G. Keppel-Aleks[1], and B.M. Rogers[2]

[1]University of Michigan, Ann Arbor, MI 48109; 734-800-6393, E-mail: xinlinn@umich.edu
[2]Woods Hole Research Center, Falmouth, MA 02540

The atmospheric CO_2 observations from surface monitoring stations and aircraft campaigns have shown an increasing trend in CO_2 seasonal cycle amplitude (SCA) in the Northern Hemisphere (NH), especially at high latitudes, over the past decades. Despite the large signal, we have limited knowledge of the geographic regions and underlying processes that have contributed to the amplification. Here, we present a quantitative regional attribution of CO_2 seasonal amplification for the period 1980–2017, using the GEOS-Chem CO_2 tracer transport model with prescribed fluxes from two CO_2 inversion systems (CAMS and CarbonTracker). We separately tag regional CO_2 fluxes so that we can differentiate the contribution of arctic and boreal regions over North America, Europe, and Siberia, as well as temperate regions, on the spatial patterns of CO_2 amplification. The increasing amplitude of ecosystem exchange in Siberia is the dominant contributor to large-scale CO_2 amplification at the surface over northern high latitudes, while the contribution from North American tundra and boreal forests is more spatially limited. Over midlatitudes and at midtroposphere in high latitudes, the dominant contributor shifts to temperate ecosystems, but the contribution from Siberia is still significant. Our study suggests that Siberian and temperate ecosystems together shape the overall CO_2 seasonal amplification in the atmosphere over the past decades, highlighting the need for further investigation of underlying processes in these regions.

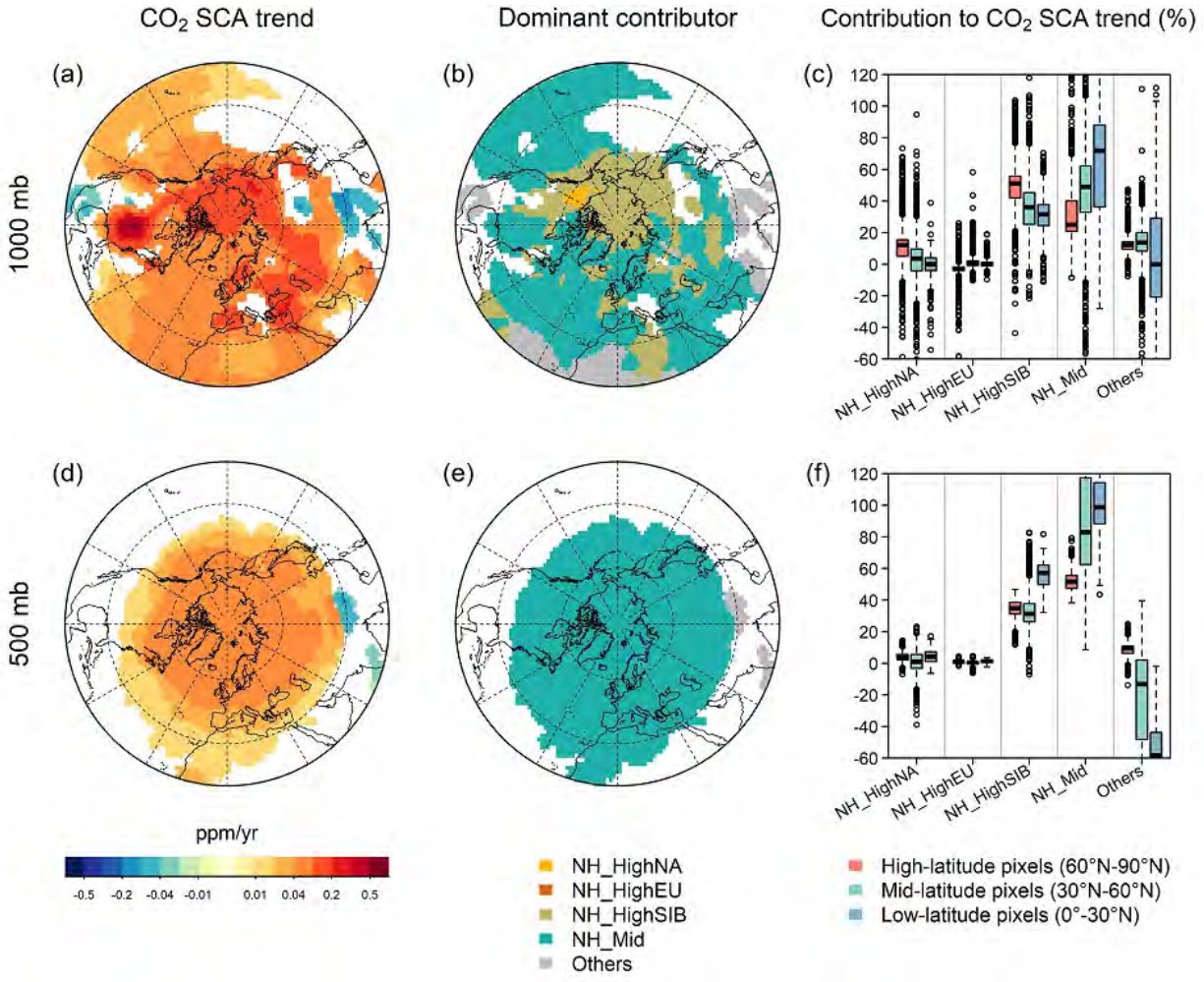


Figure 1. Spatial patterns of CO_2 seasonal cycle amplitude (SCA) trends at 1000 mb and 500 mb (a, d) and the region that imparts the largest trend (b,d). Zonal contributions are summarized in (c) and (f).

The Prospects for Top-down Atmospheric Flux Inventories for CO_2 and CH_4

D. Crisp[1], and for the OCO-2, OCO-3 and GeoCarb Teams[2]

[1]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; 818-687-9939, E-mail: David.Crisp@jpl.nasa.gov
[2]NASA Integrated Project Teams, Washington, DC 20546

Atmospheric CO_2 and CH_4 measurements complement bottom-up greenhouse gas (GHG) inventories by providing an integrated constraint on the exchanges of these gases between land and ocean surfaces and the atmosphere (including anthropogenic emissions) and their trends over time. While CO_2 and CH_4 fluxes inferred from atmospheric measurements are not as source-specific as the data sources typically used in inventories, they include contributions from sources that are often omitted or poorly characterized by bottom-up inventory methods. At global scales, atmospheric concentrations of CO_2, CH_4 and other well-mixed GHGs are well characterized by precise, ground-based, *in situ* measurements from surface and airborne systems. Recent advances in space-based remote sensing methods are providing new opportunities to augment the resolution and coverage of the ground and airborne measurements with estimates of the column-averaged CO_2 and CH_4 dry-air mole fractions (XCO_2 and XCH_4). These XCO_2 and XCH_4 estimates are less precise and accurate than the *in situ* measurements, but can provide near-global coverage at spatial scales as fine as a few km. These ground-based, airborne, and space-based atmospheric CO_2 and CH_4 estimates are now being assimilated into atmospheric transport models to estimate CO_2 and CH_4 fluxes on scales spanning individual large power plants to nations. The long-term objective of these efforts is to develop top-down global inventories that (i) reduce uncertainty of national emission inventory reporting, (ii) identify additional emission reduction opportunities and provide nations with timely and quantified guidance on progress towards their emission reduction targets, and (iii) track changes in the natural carbon cycle caused by human activities and climate change. This presentation will summarize ongoing efforts by the OCO-2 Science Team and its partners in the measurement and modeling community to create a prototype atmospheric inventory by 2021 that can support the 2023 global stocktake mandated by the Paris Agreement.

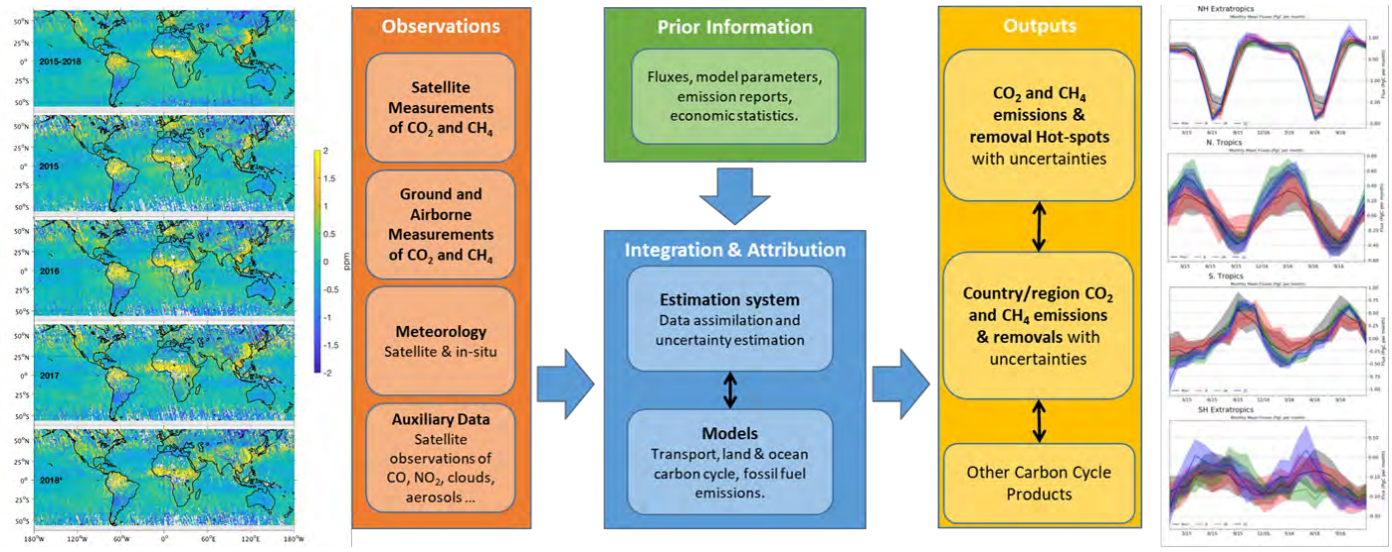


Figure 1. A system-level approach for generating a top-down atmospheric CO_2/CH_4 inventory.

Patterns and Controls on Trace Gas Fluxes of CO_2 and/or CH_4 in Marine and Terrestrial Habitats from Barrow, Alaska to Pago Pago, American Samoa

W. Oechel, M.J. Trunkhill, C. Algata, A. Carsh, M. Ward, A. Fenner, B. Gillespie, J. Montes, K. Adnt, J. Hashimi, A. Kalhori, and D. Zona

San Diego State University, Global Change Research Group, San Diego, CA 92182; 619-594-4818, E-mail: woechel@sdsu.edu

San Diego State University (SDSU) has been conducting research on the patterns and controls of trace gas flux from terrestrial and marine ecosystems for over five decades. Recently, SDSU joined with the NOAA Educational Partnership Program to involve students, particularly from under-represented minorities, by joining the NOAA Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies (NOAA-CESSRST) also known as "CREST". CREST conducts research, educates, and trains a diverse group of students, early career scientists, and engineers, in NOAA-related science missions. The goal is to help create a diverse STEM workforce for NOAA and its contractors, Academia, Industry, and the Private Sector. CREST supports NOAA's mission *"to understand and predict changes in Earth's environment and to conserve and manage coastal and marine resources to meet the nation's economic, social, and environmental needs"* by training a diverse group of successful students in disciplines that will augment NOAA's future workforce and by leading successful research and development collaborations that will contribute to the improvement of NOAA's products and services. NOAA-CREST students are involved in terrestrial and marine research from Barrow, Alaska to Pago Pago, American Samoa, working to better understand the patterns and controls on CO_2 and/or CH_4 flux from Alaska to American Samoa.

Recent research results have helped elucidate the temporal and spatial patterns and controls on CO_2 and CH_4 fluxes and energy balance. Of particular relevance is the importance of fall and winter periods and upland sites to net CH_4 emissions. Current research includes variations in and control on energy balance. Research in chaparral is exploring the effect of fire, drought, and temperature on net CO_2 balance and carbon sequestration in the chaparral of Southern California. Special emphasis is on developing management strategies to maximize carbon sequestration in the chaparral while maximizing wildlife habitat value and minimizing fire risk. Long-term eddy covariance research is documenting the pattern and controls of sea surface-atmosphere CO_2 exchange and partial pressure of CO_2 (pCO_2) and boat-based eddy covariance are being used to document the seasonal, anthropogenic, and biotic controls and sea surface-atmosphere exchange of CO_2 flux. These data will be used to improve models of surface-atmosphere CO_2 exchange and to inform management policies to help reduce atmospheric CO_2 levels.

This study is supported and monitored by NOAA-CREST under NOAA CA Grant #: NA16SEC4810008, and grants from NSF and NASA in the U.S., National Environmental Research Council (NERC) in the United Kingdom, and Horizon 2020 (Integrated Arctic Observation System, INTAROS) in the European Union.

Figure 1. Chaparral "Old Stand" at San Diego State University Sky Oaks Field Station in San Diego, CA.

Simulating International Drought Experiment Field Observations Using The Community Land Model

T.W. Hilton[1], M.E. Loik[2], and J.E. Campbell[2]

[1]University of California at Merced, Merced, CA 95343; 415-314-7478, E-mail: twhilton@ucsc.edu
[2]University of California at Santa Cruz, Santa Cruz, CA 95064

Anthropogenic climate change will alter regional hydrologic cycles around the world, in part by increasing the frequency or duration of droughts in some areas. The International Drought Experiment (IDE) is investigating the impact of severe drought on terrestrial vegetation by experimentally reducing precipitation at dozens of sites. Here we implement the IDE precipitation reduction protocol using the Community Land Model (CLM). Though many model results suggest that carbon fertilization will outpace drought-caused reduction of terrestrial carbon uptake, uncertainty is large. We therefore configure CLM to consider carbon cycling impacts of reduced moisture availability without intertwining the effects of carbon fertilization or phenological changes. California hosts a number of IDE sites and a wide range of topography, climate, and biomes. CMIP5 predictions suggest 21st century California will experience droughts in excess of the 1000-year climatological record for both frequency and magnitude. CLM suggests that some regions, including much of northern California, may experience a steeper decline in gross primary productivity (GPP) during 21st century severe droughts than during 20th century severe droughts. Vegetation in northern California experiences virtually all of this GPP reduction during the dry season, with little wet season GPP reduction even during severe drought. Southern California vegetation experiences soil moisture GPP limitation at virtually all times, increasing substantially with drought severity. Southern California should experience a more pronounced shift in GPP seasonality and decline in magnitude relative to northern California during droughts. Some parts of every vegetated continent see changes to drought response and seasonality similar to southern California. Our CLM results provide drought impacts that forthcoming IDE field observations may test, can help to spatially upscale site-based IDE observations of drought impact, and provide CLM's prediction of reduced precipitation impacts per unit leaf area index.

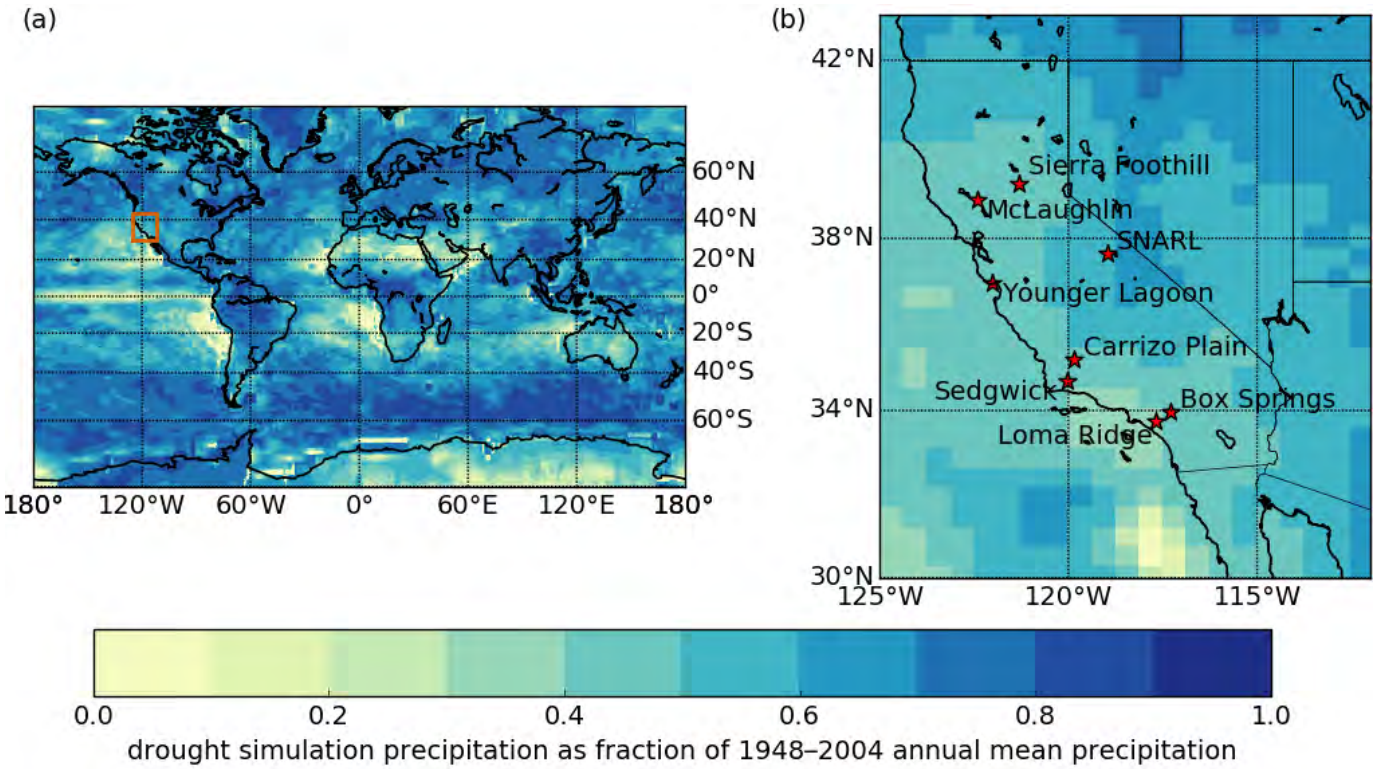


Figure 1. International Drought Experiment (IDE) per-gridcell precipitation reduction. Panel (a): global precipitation reduction as a fraction of the 1948–2004 annual mean total precipitation. Panel (b): same as panel (a), but zoomed to the California, U.S. analysis area [shown in the orange box in panel (a)]. Precipitation reduction fractions are calculated as [(1st percentile)/(50th percentile)] of the 1948–2004 (Qian et al., 2006) annual total precipitation. Red stars on panel (b) denote California analysis sites.

Recent Increases in the Burden of Atmospheric CH_4: Implications for the Paris Agreement

E. Dlugokencky[1], M. Manning[2], E. Nisbet[3], and S.E. Michel[4]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-6228, E-mail: ed.dlugokencky@noaa.gov
[2]Victoria University of Wellington, Wellington, New Zealand
[3]Royal Holloway, University of London, Egham, United Kingdom
[4]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309

More than three decades of observations of the global distribution of atmospheric CH_4 reveal a dynamic budget of emissions and sinks. From 1983 to 2006, CH_4's global burden approached steady state with near-zero growth from 1999 to 2006, but then abruptly began increasing again in 2007. Annual increases in globally-averaged CH_4 at Earth's surface in 2014 and 2015 exceeded 10 ppb. These recent increases in the burden of atmospheric CH_4 jeopardize the goals of the United Nations Framework Convention on Climate Change's Paris Agreement to limit globally-averaged temperature increase this century to 2° C above pre-industrial temperature, and to pursue policies to limit it to 1.5° C. Observations of $\delta^{13}C(CH_4)$ can be used to constrain changes to atmospheric CH_4 emissions by source-sector and sinks, and they show something remarkable: after increasing for about two centuries (based on measurements from air extracted from ice cores), $\delta^{13}C(CH_4)$ began decreasing nearly simultaneously with the increase in CH_4 burden.

A variety of explanations have been proposed to explain changes in atmospheric CH_4 burden, many of them inconsistent with one another. In Nisbet et al. (2019), an observation-driven analysis of the data with a four-box mass-balance model, the scenario most consistent with the long-and short-term changes in globally-averaged atmospheric CH_4 and $\delta^{13}C(CH_4)$ and changes in their spatial patterns is an increase in emissions from microbial sources in the tropics. The observations further show that recent increases in radiative forcing from CH_4 exceed those in the only IPCC scenario that keeps radiative forcing to ≤2.6 W m^{-2} by 2100 (RCP2.6), which is the only one of four considered in AR5 that could limit global average temperature increase to 1.5° C. Despite the extensive long-term observations presented here, the global CH_4 budget remains poorly constrained by observations, especially in the tropics, and this limits our ability to determine if the recent changes are anthropogenic or driven by climate change. If the former, it creates an opportunity to significantly reduce radiative forcing from CH_4. But if these recent increases in CH_4 burden result from feedbacks from climate change, the potential for reductions become much more uncertain.

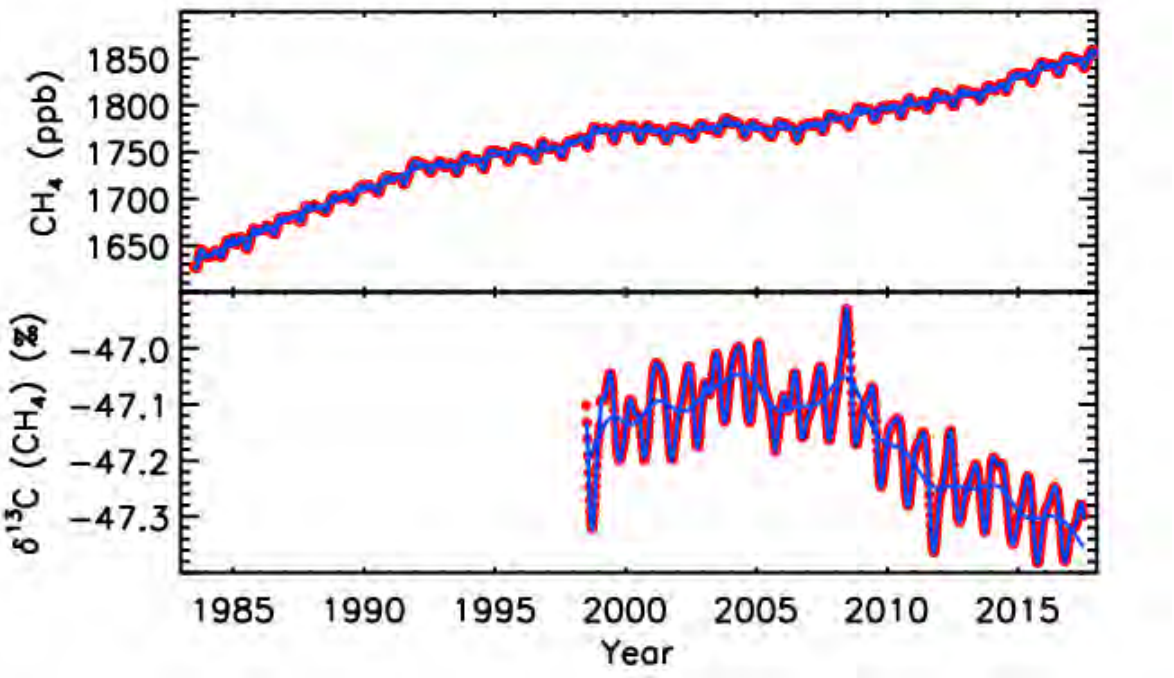


Figure 1. Globally-averaged CH_4 (top) and $\delta^{13}C(CH_4)$ (bottom) from GMD's cooperative global air sampling network (red symbols). The global averages have been fitted with a smooth curve and deseasonalized trend (blue lines).

Quantification of Methane Emissions and the Role of Satellites Moving from Global to Local Scales

S. Houweling[1,2], S. Pandey[2], P. Sadavarte[2], J.V. Peet[1], J. Landgraf[2], and I. Aben[2,1]

[1]Vrije Universiteit Amsterdam, Department of Earth Sciences, Amsterdam, The Netherlands; +31-20-598-3687, E-mail: s.houweling@vu.nl
[2]Space Research Organization Netherlands (SRON), Netherlands Institute for Space Research, Utrecht, The Netherlands

Since the early 2000s satellites contribute significantly to the pool of atmospheric data that are available for quantifying global and regional methane emissions using inverse modelling. Despite important progress in the quality of satellite sensors and retrieval methods, our understanding of the processes that drive the global growth rate of methane is still largely based on ground-based networks, albeit supported increasingly by space-borne data. Measuring long-lived greenhouse gases at sufficient accuracy remains a challenge. Nevertheless, satellites are becoming an increasingly valuable complement to ground-based data already now, in ways that we have only started to explore.

With the launch of TROPOspheric Monitoring Instrument (TROPOMI) about a year and a half ago, the scientific landscape is changing quickly in the direction of higher resolution applications. Using SCanning Imaging Absorption SpectroMeter for Atmospheric CHartography (SCIAMACHY), some strong local sources could be detected, but only after averaging several years of data. With TROPOMI, evidence of local emissions is abundant, and detectable in single satellite overpasses. This major step forward has important implications not only for the kind of information that can be extracted from satellite data, but also for the inverse modelling methods that are used. TROPOMI offers a unique playground to develop and compare methods. Limitations in data availability and quality, as well as the performance of high-resolution transport models prompt for the development hybrid methods, combining pieces of information from the data and models that are useful. To this end, the instrument offers measurements of other compounds, such as NO_2 and CO, which are much easier to observe with regard, e.g., to signal over noise and can facilitate the methodological development.

This presentation discusses the methodological transition as well as its future prospects, illustrated with examples from the data collected so far.

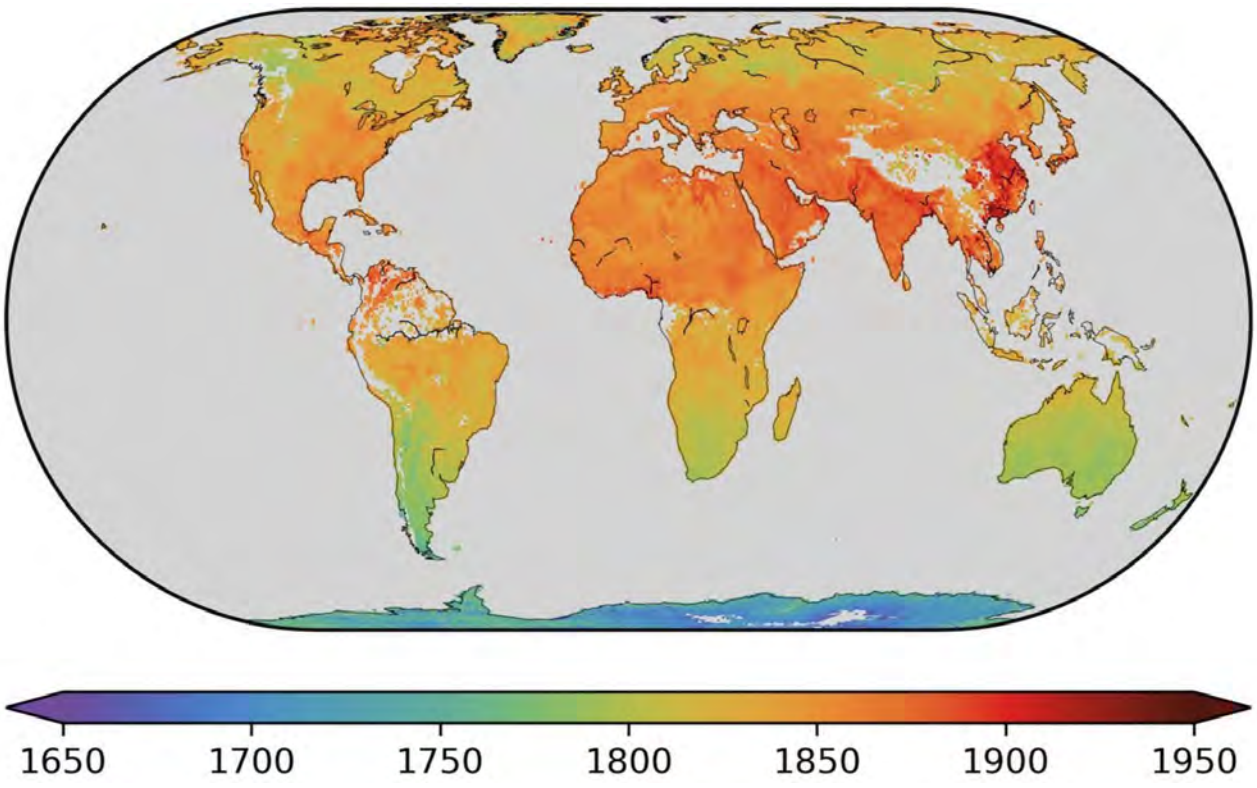


Figure 1. Total column methane from TROPOMI averaged over the second half of 2018.

Recent Acceleration of Methane Growth Rate: Leading Contributions from Tropical Wetlands and China

Y. Yin[1], F. Chevallier[2], C. Frankenberg[3], P. Ciais[2], P. Bousquet[2], M. Saunois[2], A. Bloom[3], and J. Worden[3]

[1]California Institute of Technology, Pasadena, CA 91125; 949-345-9733, E-mail: yiyin@caltech.edu
[2]Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Institut Pierre-Simon Laplace, Orme des Merisiers, France
[3]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

An acceleration of the methane (CH_4) growth rate has been observed at background marine surface stations since 2014, from 5.7±1.1 ppb a^{-1} during the post-stagnation period (2007–2013) to about 9.2±2.7 ppb a^{-1} (2014–2017). While causes for the early 2000s stagnation and the re-growth since 2007 are still not well determined, the recent increase occurred in a period with better observational coverage from both surface stations and satellites. Using atmospheric inversions that map observed changes in CH_4 concentrations to fluxes while accounting for the dynamics of atmospheric transport and changes in chemically related tracers, we find consistent interannual variations in the global CH_4 emissions based on surface or satellite observations during the 2010–2017 period, whereas very small changes are noted in the OH sink. The global CH_4 emissions increased by more than 15 Tg CH_4 a^{-1} between 2010–2013 and 2014–2017, yielding an average trend of ~4 Tg CH_4 a^{-2} during the eight study years. Based on the spatial distribution of different emission sectors in the prior, the largest contributions come from tropical wetlands (~30%) and anthropogenic emissions in China (~25%). The unexpectedly rapid increases in both the natural CH_4 emissions and the continued growth in anthropogenic emissions push the climate towards warmer temperatures.

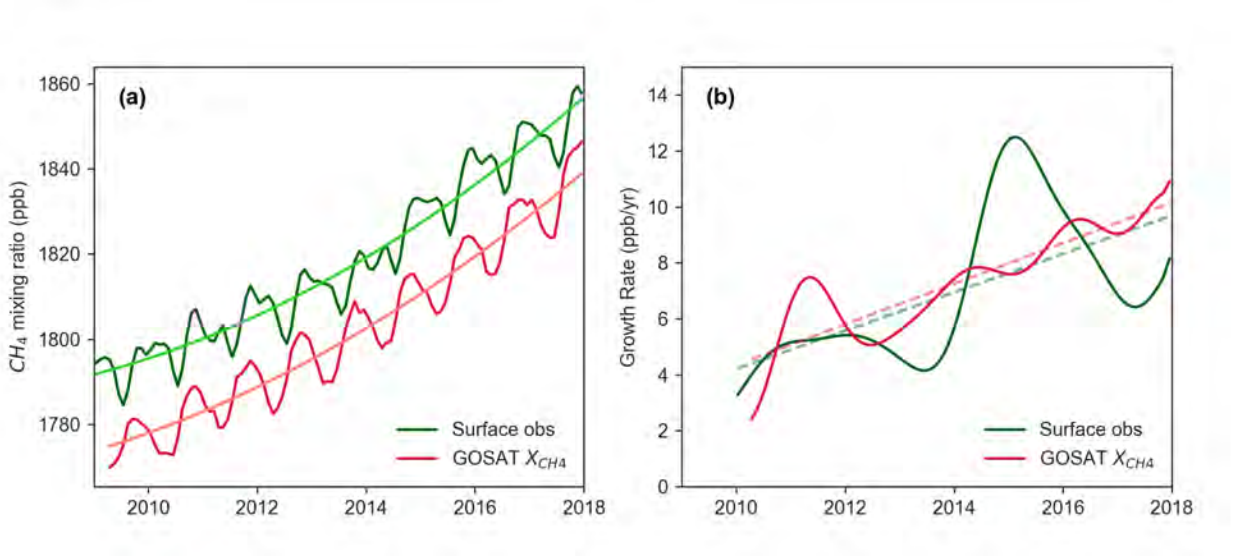


Figure 1. Global mean atmospheric methane mixing ratios and growth rates. (a) Monthly methane mixing ratios measured from background surface stations and from the GOSAT total column retrievals X_{CH4} over land. (b) Methane growth rate.

High Affinity Methanotrophs Are an Important Overlooked Methane Sink in Arctic and Global Methane Budget

Y. Oh[1], Q. Zhuang[1], L. Liu[1], L.R. Welp[1], M. Lau[2], T.C. Onstott[2], D. Medvigy[3], G. Hugelius[4], L. D'imperio[5], B. Elberlinig[5], S. Schwietzke[6,7], X. Lan[6,7], S. Basu[6,7], L. Bruhwiler[7], and E. Dlugokencky[7]

[1]Purdue University, West Lafayette, IN 47907; 765-418-3537, E-mail: oh145@purdue.edu
[2]Princeton University, Princeton, NJ 08540
[3]Notre Dame University, Notre Dame, IN 46556
[4]Stockholm University, Stockholm, Sweden
[5]University of Copenhagen, Copenhagen, Denmark
[6]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[7]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

Methane oxidation by microbes in soils is the second largest sink in the global methane budget, but its importance has been widely underestimated. Especially in the Arctic, recent field studies have documented a strong and consistent methane sink in mineral soils, thought to be due to High Affinity Methanotroph (HAM) activity. To represent the distinctive physiology of HAM in the Arctic, we simulated regional methane productions and consumptions by implementing explicit microbial dynamics of HAM and permafrost dynamics into a biogeochemistry model. The simulation of a contemporary period showed that our model estimates smaller net annual methane emissions (23 Tg $CH_4\,yr^{-1}$) when compared with a default model without HAM (48 Tg $CH_4\,yr^{-1}$) (Fig. 1). This reduces the gap in estimates of Arctic CH_4 emissions between biogeochemical models and atmospheric inversions. Moreover, without HAM, the model simulated large net emissions (85 Tg $CH_4\,yr^{-1}$) from the Arctic by 2100 under the RCP 8.5 scenario, but with HAM, 30–40 Tg $CH_4\,yr^{-1}$ (Fig. 2). Lastly, our model with temperature-sensitive microbial dynamics showed that net Arctic CH_4 emissions could potentially decrease in the future as HAM adapted better in a warmer Arctic than methanogens. Our results emphasize the importance of microbial dynamics to accurately predict the future pan-Arctic methane budget.

Extending our research focus from the Arctic to a global scale, we hypothesize that the additional global methane soil sink by HAM will improve estimates of global methane emissions in process models. Preliminary results show that the global methane soil sink can be up to 90 Tg $CH_4\,yr^{-1}$, when assuming HAM to be dominant in all uplands, which is ~60 Tg $CH_4\,yr^{-1}$ larger than previous estimates. We conducted sensitivity tests to change the HAM-dominant regions based on different soil properties and found that the global methane soil sink could be in the range of 35 to 90 Tg $CH_4\,yr^{-1}$. We are running forward and inversion simulations of the global methane budget that consider different soil sink estimates and are constrained by observations from NOAA flask-air measurements and NASA satellite and field campaigns.

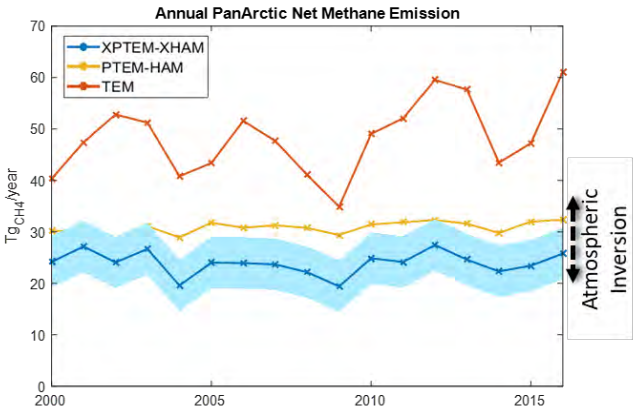


Figure 1. Annual pan-Arctic net methane emissions from 2000–2016 (XPTEM-XHAM: model with microbial and permafrost dynamics, TEM: default model).

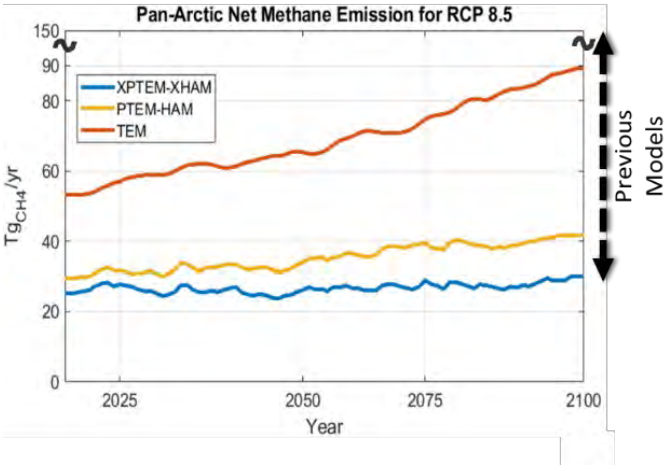


Figure 2. Annual pan-Arctic net methane emission from 2016–2100 under the RCP 8.5 scenario (XPTEM-XHAM: model with microbial and permafrost dynamics, TEM: default model).

Investigation of the Global Methane Budget Based on Improved Measurement Datasets and Prior Emission Information

X. Lan[1,2], S. Schwietzke[1,2], S. Basu[1,2], L. Bruhwiler[2], E. Dlugokencky[2], S.E. Michel[3], O.A. Sherwood[3], G. Etiope[4], Q. Zhuang[5], L. Liu[5], Y. Oh[5], J.B. Miller[2], G. Petron[1,2], B.H. Vaughn[3], and P.P. Tans[2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-3615, E-mail: xin.lan@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309
[4]Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome 605 00143, Italy
[5]Purdue University, West Lafayette, IN 47907

The global atmospheric CH_4 abundance was stable during 1999 to 2007, but has significantly increased ever since. The reasons behind the post-2007 increase in global CH_4 remain uncertain. Current debates include changes in major sources and sinks. Another uncertainty in the CH_4 budget concerns the quantification of emission magnitudes from individual CH_4 source categories. The emission magnitudes are not well understood considering that bottom-up estimates of all CH_4 sources surpass top-down estimates by more than 30%. These uncertainties are partially caused by the sparsity of global atmospheric measurements and the difficulty in accurately quantifying CH_4 sources at policy-relevant spatial scales. Analyses using spatially representative isotopic ($\delta^{13}CH_4$) source signatures to partition source contributions are still limited.

Understanding emission magnitudes from individual sources and their contributions to temporal changes in CH_4 abundance is important to predict the response of CH_4 sources to future climate and design mitigation policies. This study attempts to improve our understanding of the CH_4 budget by using forward and inverse modeling with the following features: (a) an extensive atmospheric CH_4 and $\delta^{13}C$-CH_4 measurement dataset with contributions from 32 laboratories worldwide complemented by remote sensing products, (b) newly developed gridded CH_4 and $\delta^{13}C$-CH_4 maps of geologic seeps and (c) improved spatially resolved $\delta^{13}CH_4$ signatures from wetland emissions. In addition to illustrating these features, this presentation will highlight our new model results to evaluate different source and sink scenarios by comparing observed and simulated long-term trends and spatial gradients of CH_4 and $\delta^{13}CH_4$.

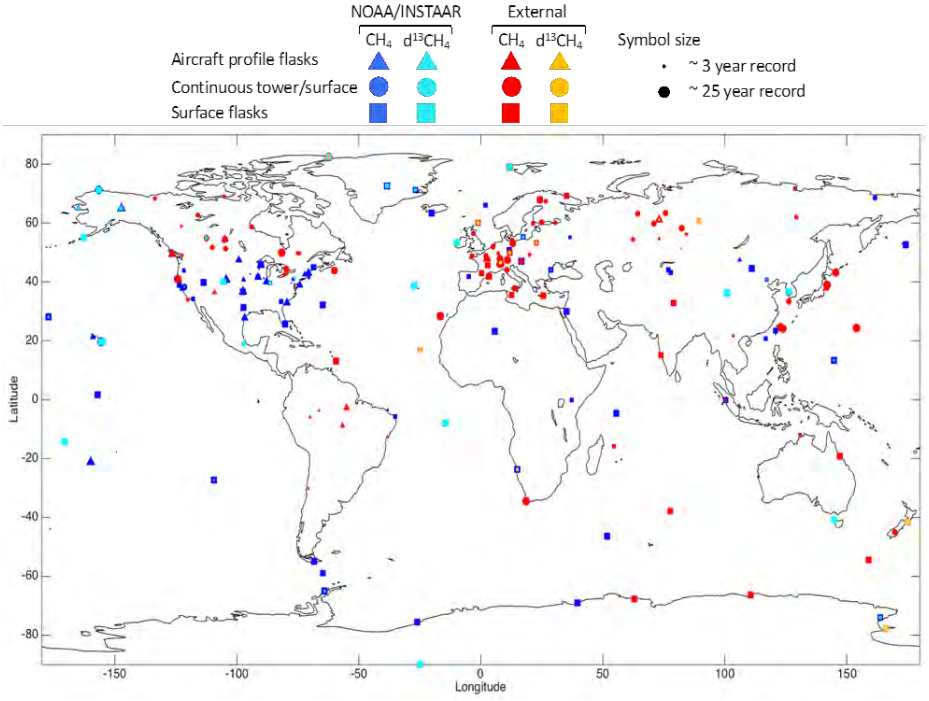


Figure 1. Overview of combined NOAA/INSTAAR (blue/cyan) and external (red/yellow) atmospheric CH_4 and $\delta^{13}C$-CH_4 dataset compiled for this study. Only "fixed" sites are shown, and additional data include measurements from container ships and aircraft routes.

Ground-truth Validation of VIIRS Nightfire for Gas Flaring Estimates

M. Zhizhin[1,2], C. Elvidge[2], and Z. Kodesh[3]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6385, E-mail: Mikhail.Zhizhin@noaa.gov
[2]NOAA National Environmental Satellite, Data, and Information Service (NESDIS), National Centers for Environmental Information (NCEI), Boulder, CO 80305
[3]John Zink LLC, Tusla, OK 74116

A series of 24 nighttime gas flares were run at the John Zink LLC test facility in Tulsa, Oklahoma, in January and February 2018. The flares were lit at the time of the VIIRS overpass, so they could be detected by VIIRS with clear sky and wind speed < 20 mph local weather. The test plan included three sizes of low pressure natural gas flares with flowrates of 750, 7500 and 75000 lb/hour, and double-stack flares with small and medium flowrate combinations. The flares were observed by Suomi NPP and NOAA-20 satellites from nadir, medium angle and side views. During the calibration experiment the flares were filmed by 2 ground-based video cameras and a hyperspectrometer. This is the first ground truth validation for the relation between the flared volume (BCM) and the Planck curve fitted to the flare infrared signature detected at nighttime by VIIRS (Nightfire algorithm). The experiment has confirmed the correlation between flow rate and satellite-derived radiative heat with 0.99 R^2. This calibration can be used in the satellite-based estimates of the natural gas flaring at the oil field or national level.

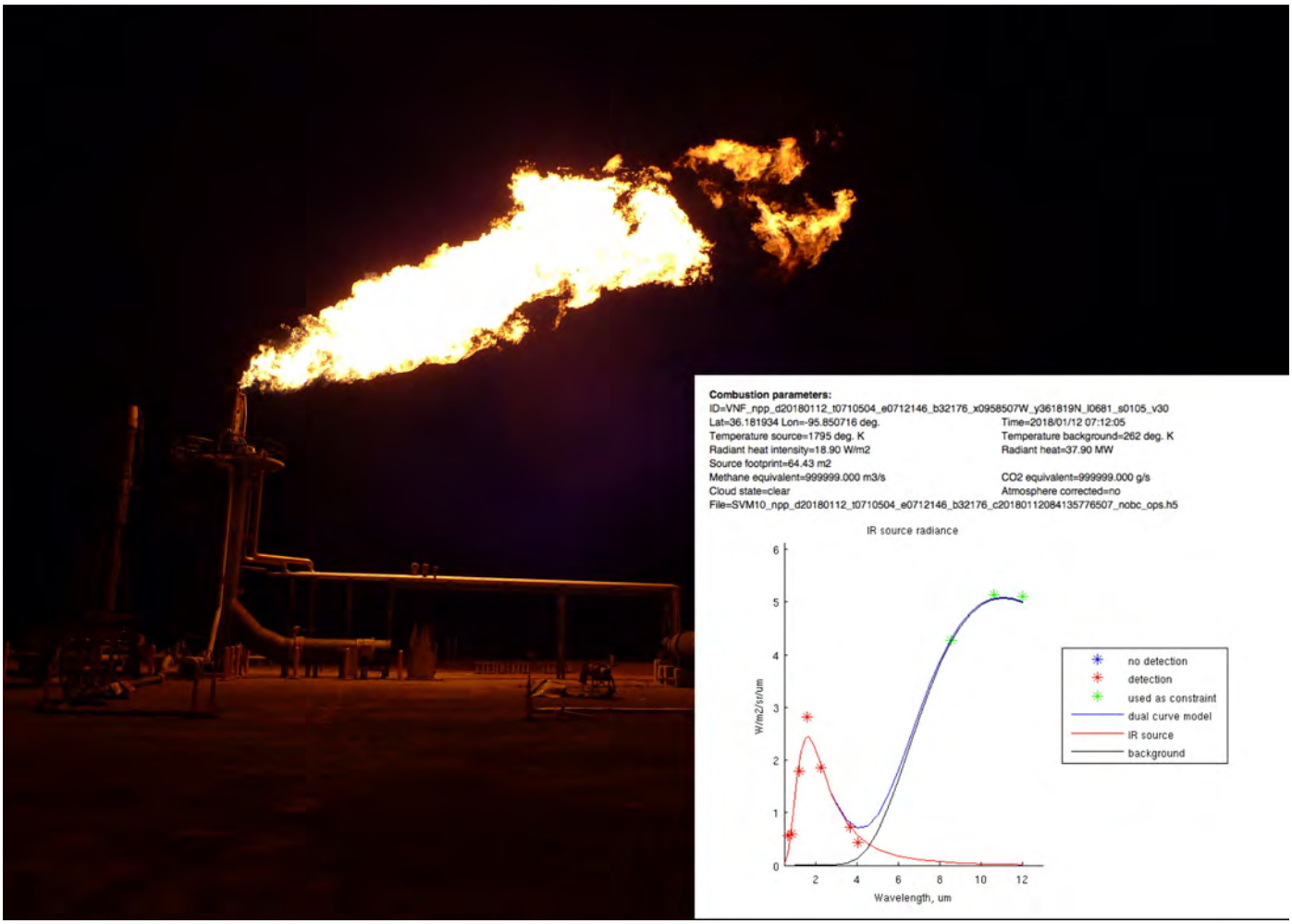


Figure 1. Test flare with 75000 lb/hour flowrate and its Nightfire signature.

NOAA Ozonesonde Sites from the Tropics to Midlatitudes: Ozone Variability, Links to Meteorological Conditions, and Validation of NASA Chemical Models

R.M. Stauffer[1,2], A.M. Thompson[2], J.C. Witte[3,2], B.J. Johnson[4], P. Cullis[5,4], and A. Jordan[5,4]

[1]Universities Space Research Association (USRA) - NASA Postdoctoral Program (NPP), Columbia, MD 21046; 301-614-5552, E-mail: ryan.m.stauffer@nasa.gov
[2]NASA Goddard Space Flight Center (GSFC), Atmospheric Chemistry and Dynamics Laboratory, Greenbelt, MD 20771
[3]Science Systems and Applications, Inc. (SSAI), Lanham, MD 20706
[4]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[5]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309

NOAA oversees the regular launching of balloon-borne ozonesondes at sites all over the globe, including the Boulder, CO, and Hilo, HI; sites, which are operationally about 40 years old. NOAA also participates in the Southern Hemisphere Additional Ozonesondes (SHADOZ) network, the gold standard for tropical ozone profile data for over 20 years. In this work, we use a statistical clustering technique (self-organizing maps; Stauffer et al., 2018, JGR), NASA MERRA-2 meteorological reanalyses, and state-of-the-art NASA chemical simulations (Stauffer et al., 2019, JGR) to compare and contrast the ozone profile data sets at NOAA sites. We examine the differences in ozone/meteorological relationships and chemical model performance at midlatitude (Boulder), subtropical (Hilo), and tropical (Fiji) sites. The clustering technique identifies major patterns in ozone profile shape and assists the linkage of meteorological and chemical conditions to the ozone profile (See Figure for ozone/convection example at Fiji). Our comparisons with ozone output from NASA models highlight the poor representation of tropical tropospheric ozone, and the need for continued monitoring, particularly at low latitudes.

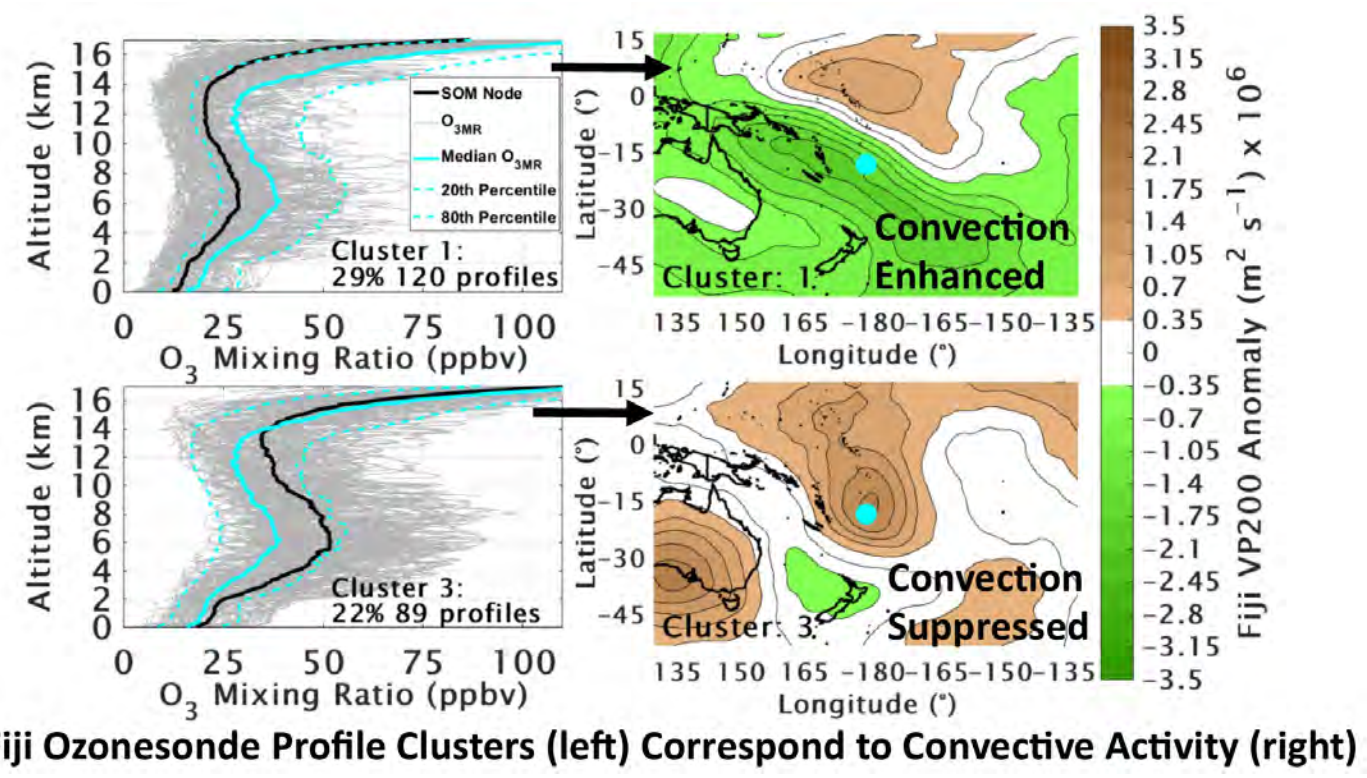


Figure 1. Figure: (L) Ozone mixing ratio profile clusters from the Fiji SHADOZ site. Individual profiles are shown in grey, with the cluster mean in black. For reference, the median and 20th and 80th percentile O_3 for the entire site data set is shown in cyan. (R) Contoured maps of average MERRA-2 calculated 200 hPa velocity potential anomalies from climatology (colors) corresponding to the ozone profile clusters shown on the left. Fiji's location is marked by the cyan dot in the center of the panels. In general, low tropospheric ozone amounts at Fiji are linked to enhanced convective activity, and high ozone amounts are linked to suppressed, or a lack of, convective activity.

OCTAV-UTLS (Observed Composition Trends and Variability in the UTLS) SPARC Activity - Jet-relevant Data Analyses of NOAA Ozonesonde Records

I. Petropavlovskikh[1,2], A. Jordan[1,2], P. Hoor[3], L.F.M. Valle[4], D. Kunkel[3], T. Leblanc[4], G. Manney[5,6], B.J. Johnson[2], and P. Cullis[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6279, E-mail: irina.petro@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Institute for Atmospheric Physics, Johannes Gutenberg University, Mainz, Germany
[4]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
[5]NorthWest Research Associates, Boulder, CO 80301
[6]New Mexico Institute of Mining and Technology, Socorro, NM 87801

The variability of the tracer distribution at the tropopause introduces a large uncertainty to estimates of future surface temperatures (e.g., Riese et al., 2012). Further, recent work shows that ozone trends in the upper troposphere / lower stratosphere (UTLS) are poorly understood and are strongly affected by dynamical processes (Chipperfield et. al, 2018; and references therein). It is therefore essential to account for the variability of the jets and tropopause location and their effects, particularly for assessing long-term composition changes. The Stratosphere-Troposphere Process and their Role in Climate (SPARC) and WMO-sponsored activity OCTAV-UTLS (Observed Composition Trends and Variability in the UTLS) aims to reduce the uncertainties in trend estimates by accounting for dynamically-induced sources of variability. As a central task for OCTAV-UTLS, we are developing and applying common metrics to compare UTLS data using geophysically-based coordinate systems including tropopause and upper tropospheric jet relative coordinates. The central tool to achieve these goals is the JETPAC-tool (Jet and Tropopause Products for Analysis and Characterization; Manney et al., 2011, 2014, 2017; Manney & Hegglin, 2018), which provides this information based on modern reanalysis datasets consistently across numerous measurement platforms with different sampling, resolution, and measurement uncertainties. Our presentation will provide an overview of the OCTAV-UTLS activity and examples of analyses of ozone variability measured by NOAA GMD and NASA SHADOZ ozonesondes over the same time period and over different geophysical regions. We will specifically assess the effect of different geophysically-based coordinates on the variability of ozone distributions.

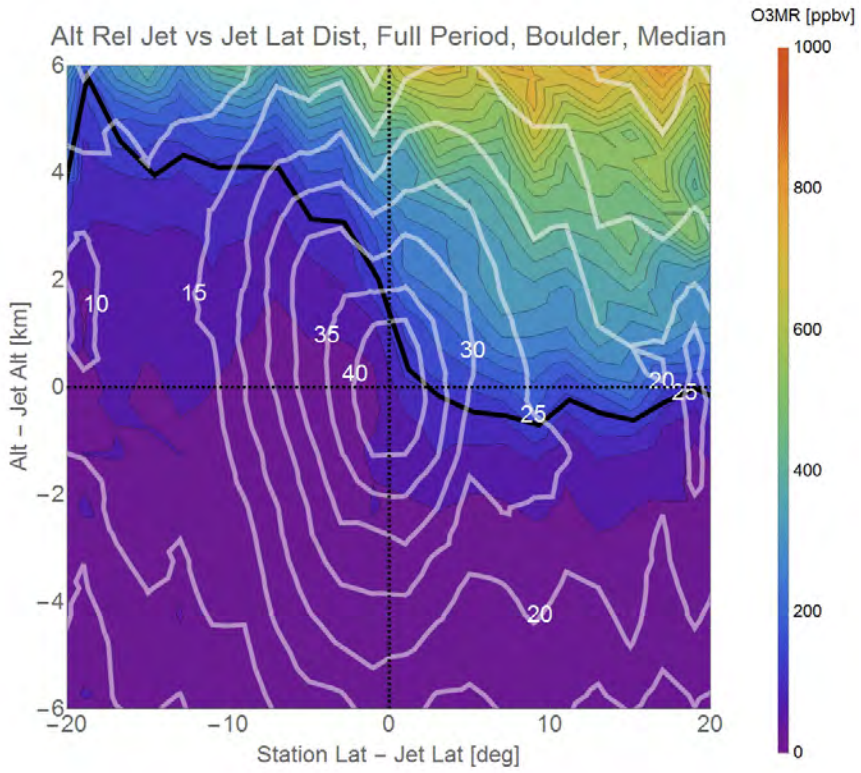


Figure 1. Mean ozone mixing ratio distribution derived from Boulder, CO 1979–2013 observations and binned in coordinates relative to the latitude and altitude of the subtropical jet. Ozone mixing ratio is depicted in color, the legend is shown on the right side of the plot. An ozone anomaly is seen in the right half of the plot, where high ozone values wrap around the jet location (the origin on the plot), suggesting stratosphere to troposphere transport in that region. White contours are wind speeds (m/sec) averaged over a distance from the jet, where highest wind speeds are centered on the origin of the plot. The black solid line is the median of the 4.5 PV tropopause height binned relative to the Subtropical jet location.

Drivers of Variations in the Vertical Profile of Ozone in the Greenland Sector of the Arctic

S.B. Shams[1], V.P. Walden[1], I. Petropavlovskikh[2,3], D.W. Tarasick[4], R. Kivi[5], S.J. Oltmans[6], B.J. Johnson[3], P. Cullis[2,3], C.W. Sterling[7], L. Thölix[8], and Q. Errera[9]

[1]Laboratory of Atmospheric Research, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA 99164; 509-592-8374, E-mail: s.bahramvashshams@wsu.edu
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[4]Environment and Climate Change Canada, Toronto, Ontario, Canada
[5]Space and Earth Observation Centre, Finnish Meteorological Institute, Sodankylä, Finland
[6]Retired from NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[7]Formerly at Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[8]Climate Research, Finnish Meteorological Institute (FMI), Helsinki, Finland
[9]Belgian Institute for Space Aeronomy, Uccle, Belgium

Various chemical and dynamical processes affect Arctic ozone. The effective contributions of these processes to changes in ozone depend on location and altitude. We aim to understand the effect of various parameters on the ozone at different levels of the atmosphere over Arctic stations near Greenland: Alert and Eureka, Nunavut; Ny Alesund, Svalbard; and Summit Station, Greenland. We also investigate the similarities and differences between the different Arctic sites. We first construct vertical profiles of ozone using a combination of *in situ* measurements, balloon-borne ozonesondes from surface to low/middle stratosphere, and satellite retrievals from the Microwave Limb Sounder (MLS) for upper ozone. We focus on the time period between 2005 and 2017 because during this time ozonesondes were launched at all four sites, plus MLS data are available. We then apply stepwise multiple linear regression (MLR) on deseasonalized ozone time series to define the contribution of different parameters at different atmospheric layers: solar flux (SF), the Quasi-Biennial Oscillation (QBO), the El Niño-Southern Oscillation index (ENSO), the Arctic Oscillation (AO), eddy heat flux (EHF), the volume of polar stratospheric clouds (VPSC), equivalent latitude (EL), and the tropopause pressure (TP). The MLR is applied separately to total column ozone (TCO) as well as partial ozone column (PCO) in the troposphere and the lower, middle, and upper stratosphere. We define the most important dynamical drivers of Arctic ozone at each level. These drivers are defined based on mutual selected proxies of stepwise multiple regression analysis using various dynamical parameters on deseasonalized data over these four sites. The final regression model is able to explain more than 80% of the TCO and more than 70% of the PCO in almost all of the layers. The regression model provides the greatest explanatory value in the middle stratosphere.

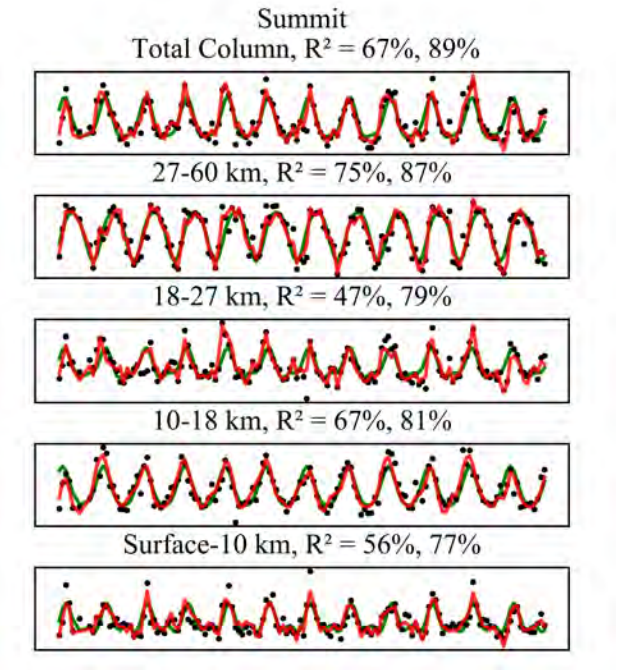


Figure 1. The results of the final model of ozone variations (red curve) for time series of the total column ozone and the partial column ozone (black dots) in four atmospheric layers from Summit. The fitted seasonal cycle is shown as the green curve. The coefficient of determintation (R^2) for each seasonal fit and for the final model are shown in the title.

Twenty Years of Observed Tropospheric Ozone Increases Across the Northern Hemisphere

A. Gaudel[1,2], O.R. Cooper[1,2], K. Chang[3,2], V. Thouret[4], J. Ziemke[5], S. Strode[6,7], P. Nédélec[4], and R. Blot[4]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6563, E-mail: audrey.gaudel@noaa.gov
[2]NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO 80305
[3]National Research Council Post-Doc, Boulder, CO 80305
[4]Laboratoire dAérologie, The National Center for Scientific Research (CNRS), and Universite Paul Sabatier Toulouse III, Toulouse, France
[5]University of Maryland, College Park, MD 20742
[6]Universities Space Research Association (USRA), Colombia, MD 21046
[7]NASA Goddard Space Flight Center (GSFC), Greenbelt, MD 20771

Tropospheric ozone is the third most important greenhouse gas, is detrimental to human health and crop and ecosystem productivity, and controls the oxidizing capacity of the troposphere. Due to tropospheric ozone's high spatial and temporal variability, the current *in situ* monitoring network has been insufficient for quantifying ozone's net global change on time scales less than two decades. The In-service Aircraft for a Global Observing System (IAGOS) has used commercial aircraft to monitor ozone worldwide since 1994. Here we show IAGOS observations that demonstrate 20 years of ozone increases above seven polluted regions distributed across the northern tropics and midlatitudes. Annual median ozone increased in nearly all levels of the troposphere, above all regions, including the eastern U.S. and western Europe, where ozone precursor emissions have decreased. Ozone reductions were limited to extreme ozone pollution events in the lower troposphere of the eastern U.S. and western Europe.

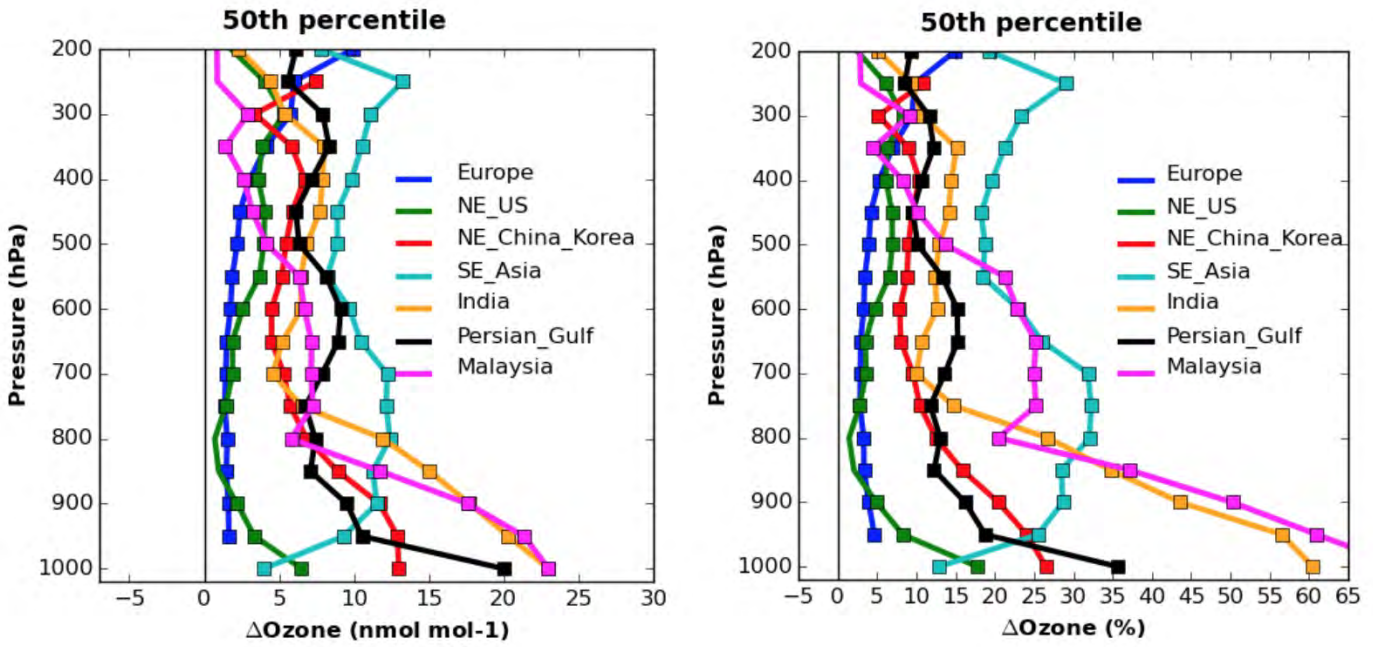


Figure 1. Annual differences in the 50th percentile of ozone (nmol mol^{-1}). The differences are calculated at each vertical pressure level between 1994–2004 and 2011–2016 above Europe (blue), Northeast U.S. (green), Northeast China / Korea (red), Southeast Asia (cyan), India (orange), and between 1998–2005 and 2011–2016 above Persian Gulf (black). The statistically significant differences between both periods at each pressure level are indicated with a square.

The Alpha Jet Atmospheric EXperiment (AJAX): Past, Present, and Future Airborne Measurements

E.L. Yates[1,2], L.T. Iraci[1], C. Parworth[1,3], and J. Ryoo[1,4]

[1]NASA Ames Research Center, Atmospheric Science Branch, Moffett Field, CA 94043; 650-604-2237, E-mail: emma.l.yates@nasa.gov
[2]Bay Area Environmental Research Institute, Sonoma, CA 95476
[3]Universities Space Research Association (USRA) - NASA Postdoctoral Program (NPP), Columbia, MD 21046
[4]Science and Technology Corporation, Boulder, CO 80305

The Alpha Jet Atmospheric eXperiment (AJAX) has been flying a scientific payload since January 2011 measuring ozone, carbon dioxide, methane, formaldehyde and meteorological parameters up to nine km. AJAX is located and operated from the San Francisco Bay Area and has flown a total of 229 flights, on a regular basis (approx. three per month) over all seasons cataloguing a long-term record of trace gas concentrations over California and Nevada. The AJAX project focuses on science questions which benefit from routine, frequent observations with flexible scheduling including:

- Long-range transport (LRT) and Stratosphere-to-Troposphere Transport (STT). Regular sampling by AJAX has aided identification of LRT and evidence of STT, which during spring and summer months are visible as elevated ozone laminae within airborne profiles. Some laminae have the ability to impact surface-level air quality.

- Satellite validation. Regular AJAX missions include flights to Railroad Valley, NV in coordination with GOSAT and OCO-2 observations, and more recently to provide coincident measurements under the TROPOspheric Monitoring Instrument (TROPOMI).

- Wildfires. The AJAX project is uniquely flexible to incorporate specialized flights with limited planning notice, such as sampling emissions from California wildfires. Twelve wildfires have been sampled, some more than once, allowing observation of emission changes as the fire progresses.

After a year of aircraft down time, we are planning for the future with AJAX 2.0, including a new aircraft and additional measurement capabilities.

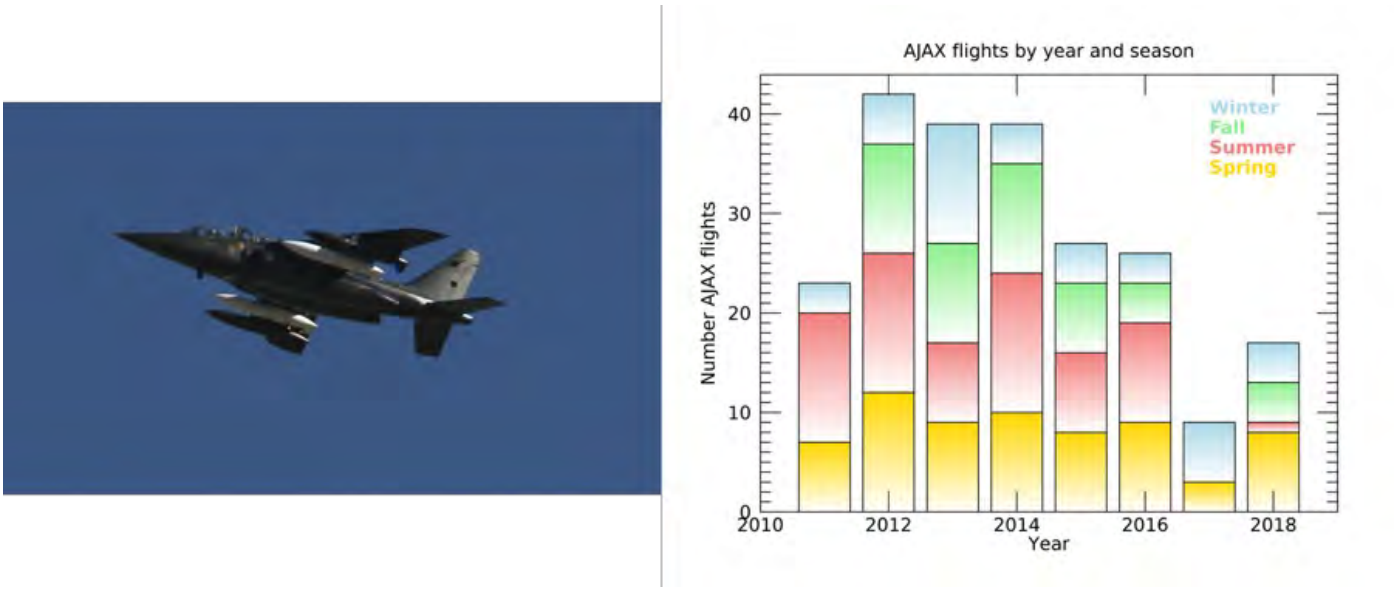


Figure 1. AJAX in-flight (left) and the number of AJAX flights by year and season (right).

Observational-based Assessment of Contributions to Southwest U.S. Maximum Ozone Concentrations

D.D. Parrish[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-517-2963, E-mail: david.d.parrish@noaa.gov
[2]NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO 80305

The 2015 U.S. National Ambient Air Quality Standard (NAAQS) requires that the Ozone Design Value (ODV) not exceed 70 ppb. The ODV is defined as the three-year average of the annual fourth-highest daily maximum eight-hour average (MDA8) ozone concentration, which represents ~98th percentile of MDA8 values observed in the warm half of the year. A time series of ODVs is thus a smoothed measure of the temporal evolution of the maximum ozone concentrations that impact a site. At any urban or rural location, ozone concentrations arise from natural sources (stratospheric input, production from natural precursors) and photochemical production from anthropogenic precursor emissions (local, that transported on regional and intercontinental scales). We focus solely on ODV time series observed in the southwest U.S., and approximately assess the time evolution of the separate contributions to ODVs from local production, regional transport and U.S. background (which includes intercontinental transport of anthropogenic ozone, plus all natural contributions). The U.S. background dominates the ODVs throughout the southwest U.S., even in the Phoenix and Las Vegas urban areas. In these two urban areas, local production enhances the ODVs by a smaller amount. Regional transport makes a major contribution only at locations immediately downwind of the Los Angeles urban area. To the east of the Sierra Nevada Mountains, no impact of regional transport of California ozone can be discerned. For example, in 2015 in Phoenix, the U.S. background ODV contribution was ~69 ppb, with an enhancement of maximum ODVs from local photochemical production of ~12 ppb. Unless the U.S. background concentration continues to decrease as it has during the past decade, it will be very difficult for Phoenix to reduce its maximum ODV to the NAAQS.

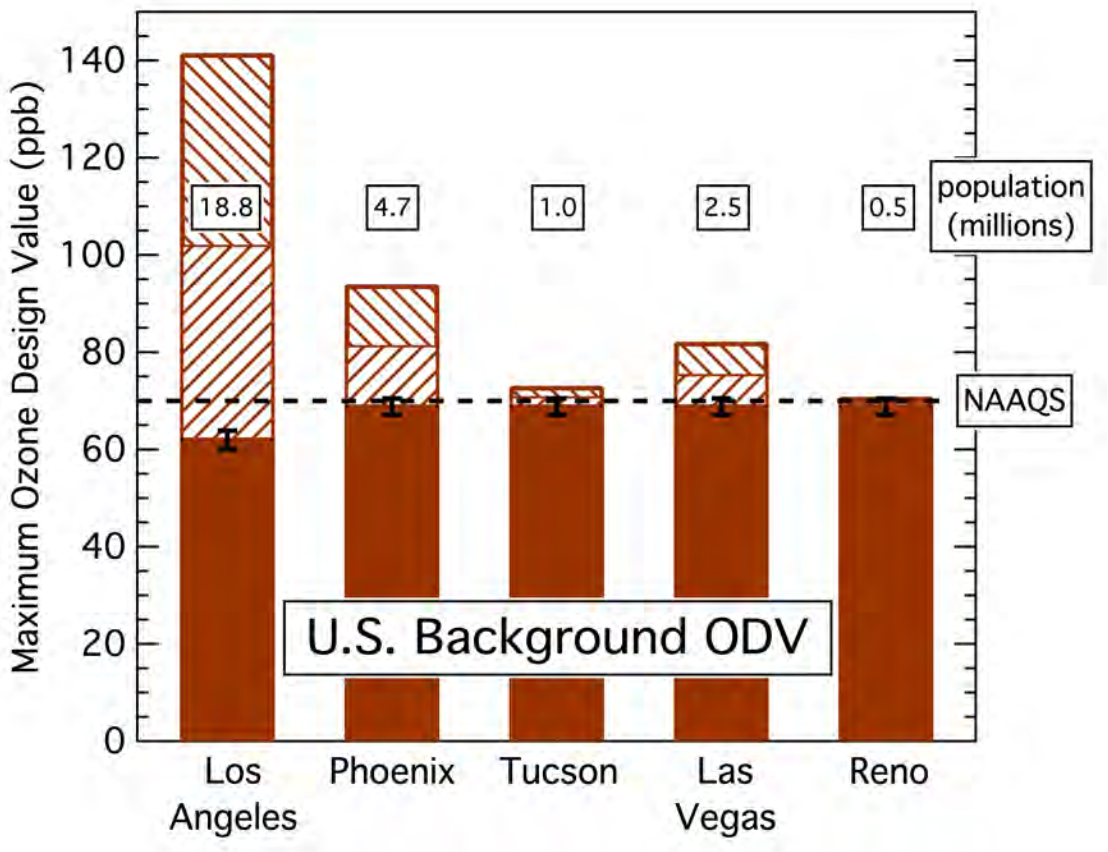


Figure 1. Comparison of maximum ODVs observed in five southwestern U.S. urban areas (populations annotated). Solid bars indicate the ODV contribution from U.S. background ozone, and the lower and upper dashed bars indicate the estimated enhancement from U.S. anthropogenic emissions in 2015 and 2000, respectively. Dashed line indicates the 2015 ozone NAAQS.

***HOLOSCENES / Little Boxes* Presented on Science On a Sphere®**

M. Kirn[1], and S. Gupta[2,3]

[1]EcoArts Connections, Boulder, CO 80302; 303-449-2128, E-mail: info.ecoarts@gmail.com
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[3]NOAA Earth System Research Laboratory, Global Systems Division (GSD), Boulder, CO 80305

Getting science data out to the general public in ways that are accessible and that help people understand its importance can sometimes be challenging. For the complex and connected relationships between our actions and our environment in the Anthropocene,

"How can we feel climate change in our gut?"
"Can we socially evolve as quickly as we have transformed our Earth?" *

These and other questions are explored by internationally-acclaimed artist Lars Jan/Early Morning Opera, immersive media artist/technologist Pablo N. Molina, and a team of scientists, engineers, and artists in the original live performance work *HOLOSCENES*, which has been performed all over the world, including Times Square as part of the World Science Festival.

Come experience *HOLOSCENES / Little Boxes*, a new six-minute art/science film based on the original *HOLOSCENES* and specially adapted for Science On a Sphere® (SOS) thanks to Jan, Molina, and NightLight Labs, with advisors from across the country including NOAA climate scientists, educators, SOS docents, a film producer, and youth advisors aged 9 to 21. *HOLOSCENES / Little Boxes* fuses together the cognitive tools of science (facts, analysis, charts, and graphs) with the affective tools of art (images, metaphors, and storytelling). The film invites viewers to connect in new ways to global data - including sea level rise, CO_2, and our changing climate - making the data personal and visceral.
https://sos.noaa.gov/datasets/holoscenes-little-boxes/

HOLOSCENES / Little Boxes was made possible thanks to a collaboration between EcoArts Connections and SOS with funding from the National Endowment for the Arts, 3P Biotechnologies, Inc., and the Boulder Arts Commission.

**HOLOSCENES* / Printed Matter Newsprint

Figure 1. Film still from *HOLOSCENES.*

Notes:

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2019

David Skaggs Research Center, Room GC-402
325 Broadway, Boulder, Colorado 80305 USA

Wednesday Morning, May 22, 2019 Agenda

(Only presenter's name is given; please refer to abstract for complete author listing.)

07:30 ***Registration Opens in GC-402 - lunch orders collected at registration table***

07:45 - 08:30 ***Morning Snacks - coffee, tea, fruit, bagels and donuts served***

12:00 - 13:00 ***Catered Lunch - Outreach Classroom GB-124 (pre-payment of $12.00 at registration)***

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2019

David Skaggs Research Center, Room GC-402
325 Broadway, Boulder, Colorado 80305 USA

Wednesday Afternoon, May 22, 2019 Agenda

(Only presenter's name is given; please refer to abstract for complete author listing.)

Western European Emissions of CFC-11 and CFC-12 Inferred from Atmospheric Observations and Inverse Modelling

M. Maione[1,2], A. Manning[3], S. Henne[4], F. Graziosi[1], S. Reimann[4], M.K. Vollmer[4], J. Arduini[1], S. O'Doherty[5], D. Young[5], K. Stanley[5], and C. Harth[6]

[1]University of Urbino, Department of Basic Sciences and Foundations, Urbino, Italy; 340-415-7897, E-mail: michela.maione@uniurb.it
[2]Institute of Atmospheric Sciences and Climate, National Research Council of Italy, Bologna, Italy
[3]UK Meteorological Office, Exeter, United Kingdom
[4]Swiss Federal Laboratories for Materials Science and Technology, Empa, Dübendorf, Switzerland
[5]University of Bristol, School of Chemistry, Bristol, United Kingdom
[6]Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92037

The slowdown in CFC-11 emission decrease rates observed since 2013 on a global scale suggest that unreported emissions of this chemical, whose production is banned under the Montreal Protocol, are occurring. Studies aimed at evaluating emissions at the regional scale are important in order to close the CFC-11 global budget and identify/rule out possible source regions. Here we present the results of a study focused on western Europe, based on a combination of long-term, high-frequency, high-precision observations of CFC-11 and CFC-12 at four European sites embedded in the AGAGE network (Mace Head, IE; Tacolneston, UK; Jungfraujoch, CH and Monte Cimone, IT) and three independent inverse modelling systems.

Analysis of the Mace Head observational record from 1990 shows that the magnitude of the pollution events have dramatically declined from their peak in the very early 1990s. Western European emissions of CFC-11 and CFC-12 have been quantified for the period 2008–2017 and 2012–2017, respectively. CFC-11 emissions showed a decrease rate that is consistent with the bank decay rate, suggesting that no unreported emissions are occurring. As shown in Figure 1, an area in north western Europe, corresponding to Benelux, has been identified by the three models as the strongest source region.

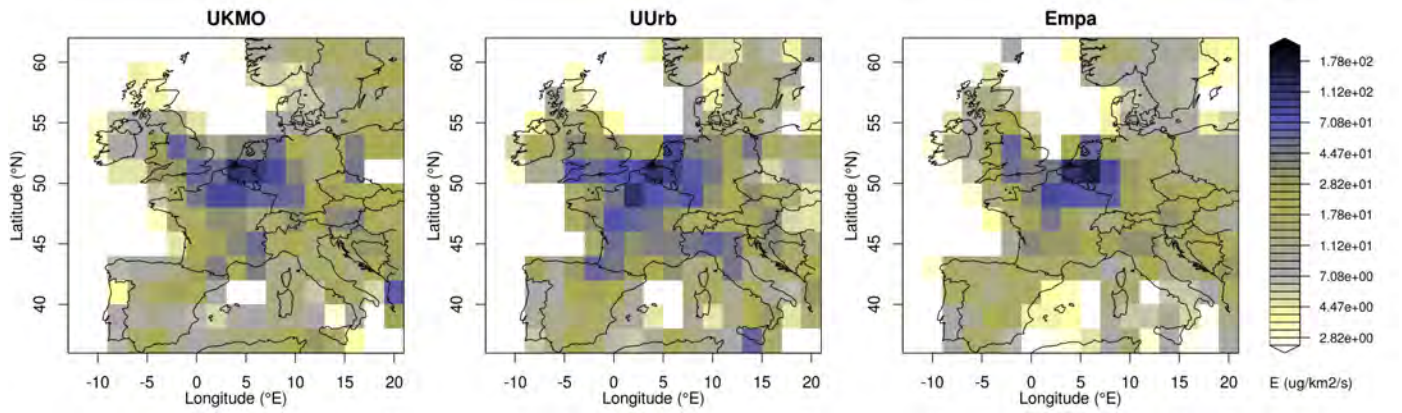


Figure 1. A-posteriori CFC-11 emissions from western Europe estimated through three different inverse modelling systems; UKMO (UK Met Office, Name-InTEM), UUrb (University of Urbino, Flexpart-Bayesian Inversions), Empa (Empa, Flexpart-Bayersian Inversion).

What Science Have We Learned from Our Combined Airborne and Ground-based Measurements of Halocarbons and other Trace Atmospheric Species?

J.W. Elkins[1], F.L. Moore[2,1], E. Hintsa[2], S.A. Montzka[1], C. Sweeney[1], E.A. Ray[2,3], J.D. Nance[2,1], G.S. Dutton[2,1], B.D. Hall[1], D. Hurst[2,1], B.R. Miller[2,1], D. Mondeel[2,1], and C. Siso[2,1]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-530-9017, E-mail: james.w.elkins@noaa.gov
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[3]NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO 80305

The Halocarbons and other Atmospheric Trace Species (HATS) Group ground-based and airborne measurements have complimented each other in scientific discoveries. Ground-based measurements began in 1977 with just 3 molecules (CFC-11 and -12, & N_2O) and has expanded to a total of 64 molecules currently. NOAA and CIRES scientists in the HATS Group started measuring vertical profiles and cruise-altitude levels of atmospheric trace species in 1991, first on high-altitude aircraft (NASA ER-2, 1991–2000; NASA WB-57F, 1999–2016) and balloons (1996–2003), then civilian aviation altitude aircraft [NASA DC-8, 2001–2018; UND Citation, 2003; NCAR GV (2008–2011)], and Unmanned Aircraft Systems (UAS: NASA Altair, 2005–2006, and Global Hawk, 2010–2014). The scope of our observations included many different regional missions and global campaigns, many over or near our baseline stations (Figure 1a). Earlier airborne studies (1990s through early 2000s) had a stratospheric ozone depletion and long-lived greenhouse gases (GHGs) focus, whereas later work included more tropospheric measurements of GHGs and short-lived gases [O_3, H_2O, peroxyacetyl nitrate (PAN), & short-lived halocarbons]. Scientific results include the rate of destruction of ozone in the polar stratosphere during airborne missions [Second Airborned Arctic Stratospheric Expedition (AASE-II), Airborne Southern Hemispheric Ozone Experiment - Measurements for Assessing the Effects of Stratospheric Aircraft (ASHOE-MAESA), Photochemistry of Ozone Loss in the Arctic Region in Summer (POLARIS), & SAGE III Ozone Loss and Validation Experiment (SOLVE)], atmospheric lifetimes of many trace gases including a substantially shorter lifetime for SF_6, due to a mesospheric sink (Figure 1b) observed in 2000 from balloons, stratospheric and tropospheric mean age of the air mass, large-scale transport, and satellite validation. This presentation will focus on the long-term trends of select trace gases over time (Figure 1b), and results from the recent airborne missions National Science Foundation HIPPO and NASA ATom where NOAA flasks [Programmable Flask Packages (PFPs)] were included for the first time.

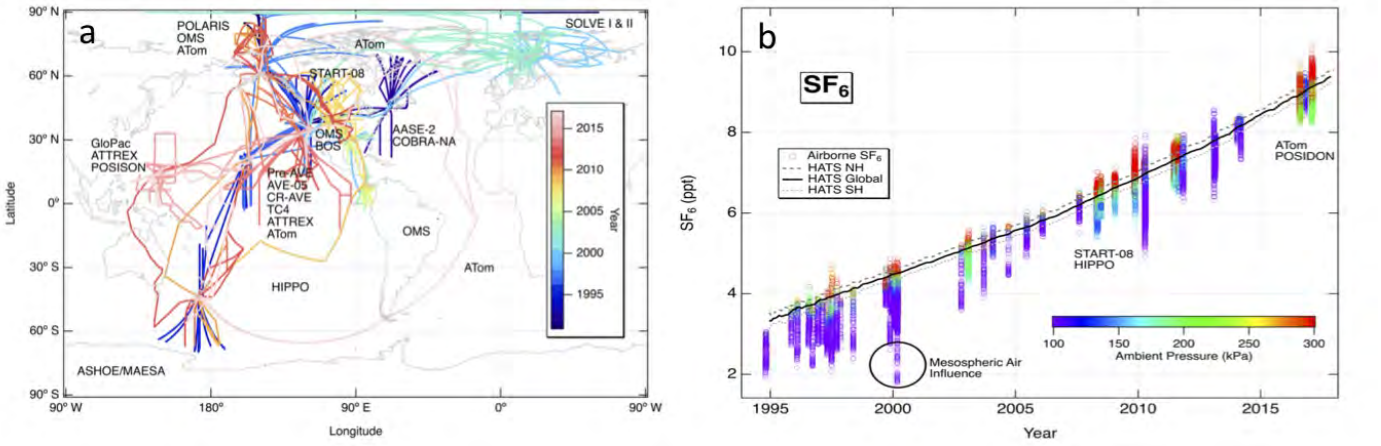


Figure 1. (a) Flight paths from airborne missions (color coded by year, 1991–2018), (b) airborne measurements of atmospheric SF_6 (color coded by ambient pressure), a potent GHG tied to electrical distribution with strong almost constant growth rate of 0.24 ppt per year (2018: ~3% per year) together with our ground-based remote global and hemispheric atmospheric trends.

The Stratospheric Quasi-Biennial Oscillation Influence on Trace Gases at the Earth's Surface

E.A. Ray[1,2], R.W. Portmann[2], P. Yu[1,2], J. Daniel[2], S.A. Montzka[3], G.S. Dutton[1,3], B.D. Hall[3], and F.L. Moore[1,3]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-7628, E-mail: eric.ray@noaa.gov
[2]NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO 80305
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The quasi-biennial oscillation (QBO) of tropical zonal wind is one of the most important modes of interannual variability in the stratosphere. It is well known that the QBO induces a secondary mean meridional circulation that extends from the tropics into the extratropics and influences the distribution of trace gases throughout the global stratosphere. In this work we show that the QBO variability of stratospheric transport and trace gas distributions extend down into the troposphere, influencing the interannual variability of long-lived trace gas mole fractions through the stratosphere to troposphere mass flux. The QBO variability is seen in surface measurements as well as throughout the stratosphere and troposphere in chemistry-climate model (CCM) simulations of CFC-11, CFC-12 and N_2O. We show that the interannual variability in surface annual growth rates, after long-term changes are removed, is mostly driven by the QBO. Correlations between QBO zonal winds and interannual variability in surface trace gas mole fractions are highly significant in both the measurements and model output. We also show how the emission estimates of the trace gases considered here can be affected by not accounting for QBO-driven variability.

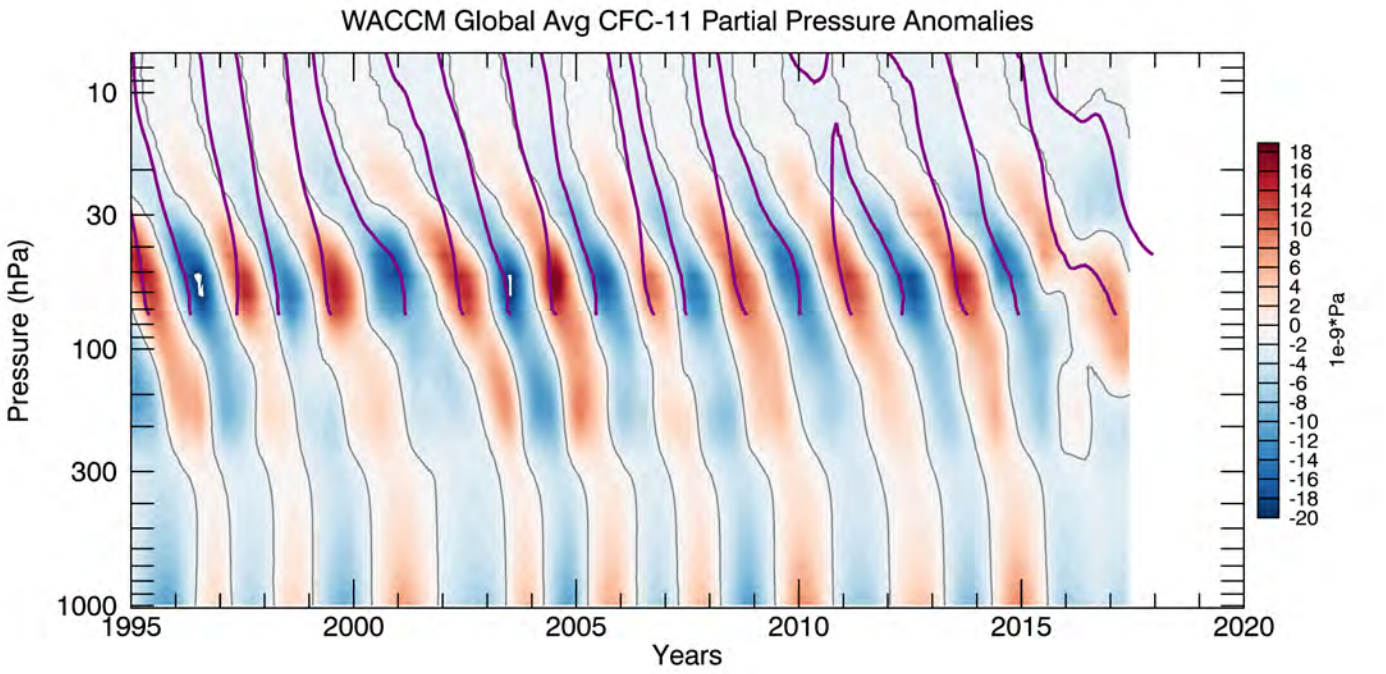


Figure 1. Time series of Whole Atmosphere Community Climate Model (WACCM) global average CFC-11 partial pressure anomalies (orange positive, blue negative) as a function of pressure. The tropical average zonal wind 0 m/s contours are shown in the purple lines for pressures less than 80 hPa. This shows a clear propagation of modeled CFC-11 partial pressure anomalies from the middle stratosphere to the surface.

Iodine Detection in the Lower Stratosphere

R. Volkamer[1,2], T. Koenig[2], A.S. Lopez[3], P. Campuzano-Jost[1,2], B.A. Nault[1,2], and J.L. Jimenez[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-492-1843, E-mail: rainer.volkamer@colorado.edu
[2]University of Colorado, Department of Chemistry, Boulder, CO 80309
[3]Consejo Superior de Investigaciones Científicas (CSIC), Atmospheric Chemistry and Climate Group, Madrid, Spain

Iodine is emitted into the atmosphere mostly from marine sources, and in inorganic form. In the atmosphere, iodine participates in catalytic reaction cycles that destroy ozone and can form new particles. The impact on stratospheric ozone is currently not well established, in part due to the lack of quantitative measurements in the daytime lower stratosphere (LS). Previous stratospheric measurements detected iodine qualitatively in particles, establish low upper limits of iodine oxide (IO) radicals under twilight conditions, and small amounts of methyl iodide (CH_3I). Based on these observations, the WMO currently estimates an upper limit of <0.15 pptv I_y [total inorganic gas-phase iodine: sum of iodide atoms (I), IO, hypoiodous acid (HOI), higher iodine oxides (I_xO_y), iodine nitrate/nitrite (INO_x), CH_3I] are injected into the LS.

However, recent IO observations in the daytime tropical tropopause layer (TTL) challenge this view: 0.13±0.04 pptv IO in the Northern Hemisphere TTL; and 0.15±0.04 pptv IO in the Southern Hemisphere (Dix et al., 2013, 2016; Volkamer et al., 2015; Wang et al., 2015) suggest that between 0.25 to 0.70 pptv I_y are injected into the LS. This is 1.6 to 3.5 times the currently-established WMO upper limit (Saiz-Lopez et al., 2015). At these levels, gas-phase I_y is responsible for 30% of ozone destruction in the LS, which is comparable or larger to the effect of short-lived brominated species [i.e., bromoform ($CHBr_3$), dibromomethane (CH_2Br_2)]. A better understanding of iodine is needed.

Here, we present the first daytime IO detection from aircraft in the LS and TTL over the Western Pacific Ocean, also deemed the gateway to the stratosphere. These measurements were obtained using the University of Colorado Airborne MultiAxis Differential Optical Absorption Spectroscopy (CU AMAX-DOAS) instrument during the Convection Transport of Active Species in the Tropics (CONTRAST, Jan/Feb 2014) campaign (Pan et al., 2017). We also present the first quantification of iodine in LS submicron aerosol by the High Resolution Aerosol Mass Spectrometer (HR-AMS) from the Atmospheric Tomography Mission (ATom1, Jul/Aug 2016, ATom2, Jan/Feb 2017). Figure 1 shows the locations where iodine has been detected in the upper troposphere/lower stratosphere. We use these new data in conjunction with a global model to re-assess the I_y burden in the LS. The implications for lower stratospheric ozone destruction are also discussed.

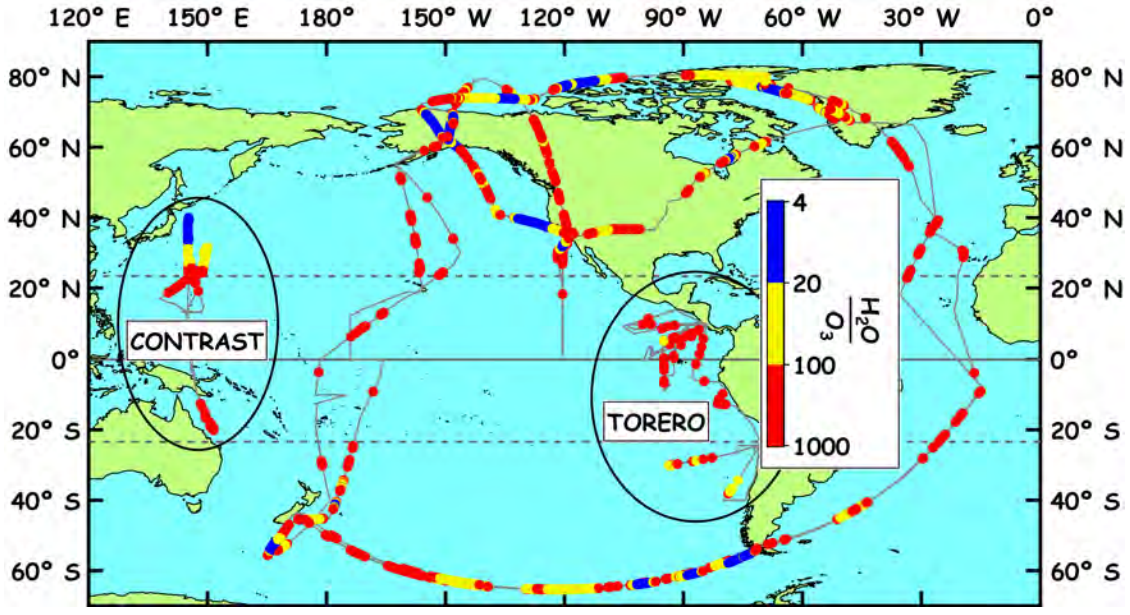


Figure 1. Selected flight tracks from the Tropical Ocean tRoposphere Exchange of Reactive halogen species and Oxygenated VOC (TORERO), CONTRAST, ATom1 and ATom2 field campaigns, and locations where iodine was detected in the upper troposphere and lower stratosphere.

Atmospheric History of Carbonyl Sulfide During the 20th century from Antarctic and Greenland Firn Air Measurements

M. Aydin[1], S.A. Montzka[2], C. Buizert[3], and E.S. Saltzman[1]

[1]University of California at Irvine, Department of Earth System Science, Irvine, CA 92697; 949-824-1726, E-mail: maydin@uci.edu
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Oregon State University, College of Earth, Ocean and Atmospheric Sciences, Corvallis, OR 97331

Carbonyl sulfide (COS) was measured in firn air from multiple field campaigns carried out in Greenland (at Summit in 2006 and 2013) and in Antarctica (at Mega Dunes in 2003 and at South Pole in 2001, 2008, and 2015). Firn air samples were collected in glass flasks and measured at NOAA GMD and UC Irvine laboratories 2 to 6 months after collection. A Monte Carlo-based Bayesian inversion algorithm is used to recover a Northern Hemisphere and a Southern Hemisphere atmospheric history consistent with data from Summit, Greenland and Antarctica, respectively. The Antarctic record constrains atmospheric COS variability during the entire 20th century, while the Greenland record is highly uncertain prior to 1950. The records show that atmospheric COS levels generally increased through the first 70–80 years of 20th century, peaked in the 1970s and 1980s, then declined to near present-day levels. During the rise period, COS levels in the Northern Hemisphere were higher than the Southern Hemisphere except early on, suggesting the source of the increase was in the Northern Hemisphere and likely anthropogenic. There are differences in both the timing and the intensity of the COS peaks in the two hemispheres, with the Southern Hemisphere lagging the north by about ten years and leveling off at lower mixing ratios. The COS peak over Greenland was 550–600 ppt, which is about 20% higher than the atmospheric levels at Summit today. The COS peak over Antarctica was 530–550 ppt, which is about 10–15% higher than the present-day levels. A six-box coupled ocean-atmosphere model is used to explore the implications of the firn air-based COS records on the atmospheric COS budget. Results suggest changes in anthropogenic emissions alone do not explain the atmospheric variability of COS during the 20th century.

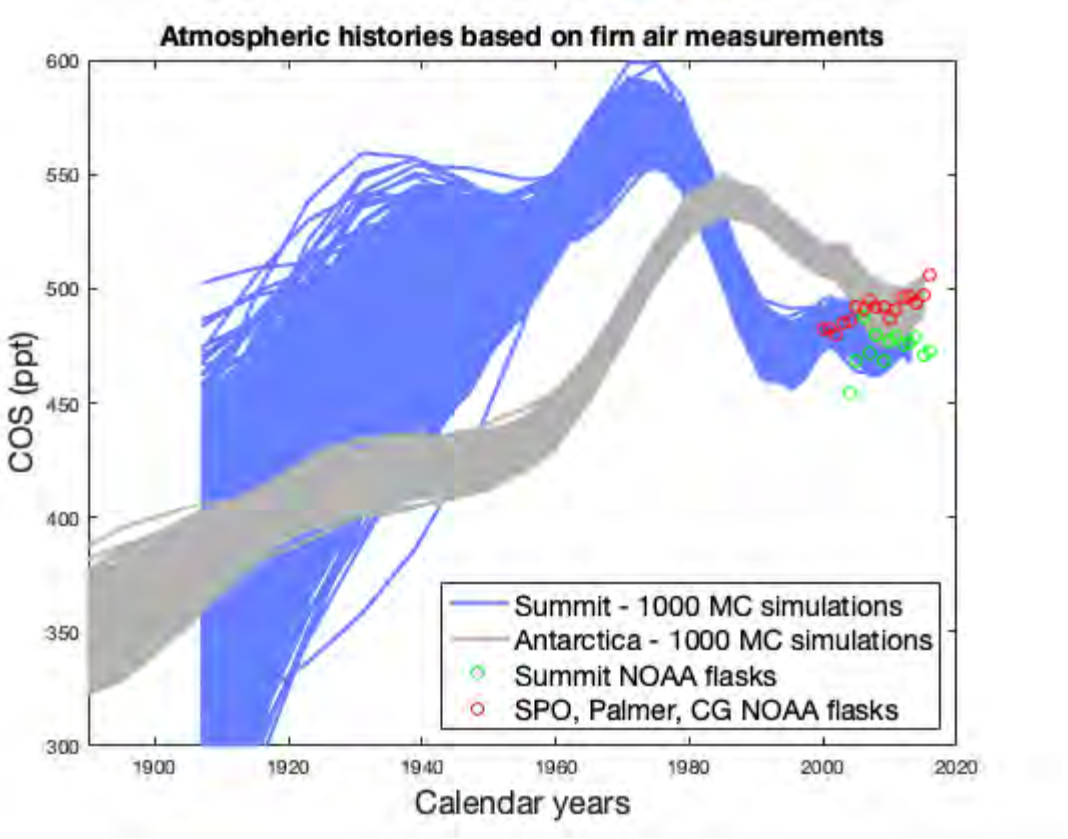


Figure 1. COS atmospheric histories based on firn air measurements from Greenland and Antarctica.

Constraints on Ocean Heat Uptake from the Atmospheric Argon to Nitrogen Ratio

B. Birner, and R. Keeling

Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92037; 858-291-2269, E-mail: bbirner@ucsd.edu

Over 90% of all additional heat trapped on Earth by atmospheric greenhouse gases will eventually accumulate in the ocean. However, due to temporally and spatially sparse sampling of the oceans, our best estimates of ongoing ocean warming vary considerably. Here, we present a recently developed, globally integrated approach to quantifying ocean heat uptake through observations of the atmospheric argon to nitrogen ratio (Ar/N_2).

Water temperature determines the solubility of the chemically inert noble gas Ar and N_2 in the oceans. A warming ocean releases proportionally more Ar than N_2 to the atmosphere (Ar is twice as soluble as N_2), where the gases are rapidly mixed on a time-scale of about one year. Atmospheric mixing thus intrinsically integrates the ocean warming signal globally and makes discrete local observations a powerful measure of global ocean heat uptake.

Ultra-high precision Ar/N_2 data collected continuously at five stations in the Scripps CO_2 flask network, consistently suggest stronger ocean warming over the last 15 years than other observational estimates based on *in situ* temperature readings. Moreover, previously published observations of stratospheric trace gases ratios including Ar/N_2 show a significant gravitational fractionation well below the mesosphere. Therefore, variability in stratospheric circulation can modulate tropospheric Ar/N_2. This is supported by a correlation of our tropospheric Ar/N_2 observations with variability in the quasi-biennial oscillation of stratospheric wind direction over the equator. These results will be discussed in the context of measurement uncertainties and complexities in the geochemistry of N_2 and Ar.

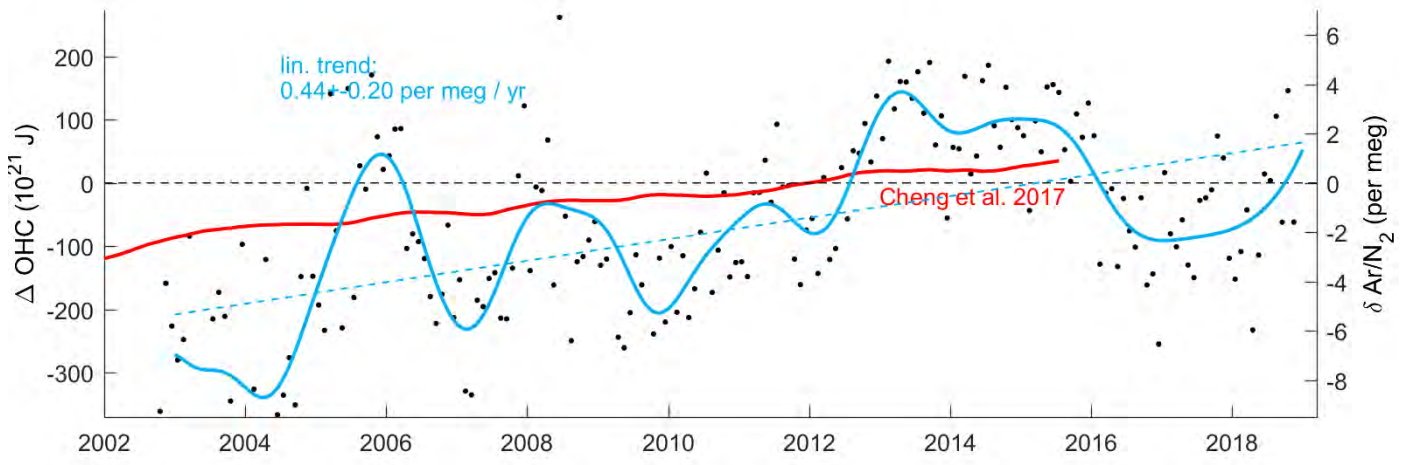


Figure 1. Evolution of the global tropospheric Ar/N_2 record compared to the Quasi-Biennial Oscillation (QBO) Index (i.e., NOAA ESRL PSD 30-mb average zonal wind at the equator), and the total ocean heat content anomaly (Cheng et al., 2017). Monthly mean Ar/N_2 data (black dots, right axis) are calculated from seasonally detrended observations at five different observing stations. Ar/N_2 is translated to ocean heat content anomalies (left axis) using a sensitivity of 2.57 per meg per 100 ZJ (Keeling et al., 2004).

Optical Properties of Black Carbon and Brown Carbon and Their Contribution to Aerosol Light Absorption

S. Kim[1], C. Cho[1], M. Lee[2], S. Lim[2], W. Fang[3], O. Gustafsson[4], A. Andersson[4], and P. Sheridan[5]

[1]Seoul National University, South Korea; +82-10-5110-7866, E-mail: sangwookim@snu.ac.kr
[2]Korea University, Seoul, South Korea
[3]East China Normal University, Shanghai, China
[4]Stockholm University, Stockholm, Sweden
[5]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

We estimated the contribution of black carbon (BC) and brown carbon (BrC) to aerosol light absorption from surface *in situ* and column aerosol robotic network (AERONET) observations. The mass absorption cross section (MAC) of BC (MAC_{BC}) was estimated to be 6.4±1.5 m^2 g^{-1} at 565 nm from *in situ* aerosol measurements at Gosan, Korea, in January 2014, which was lower than those observed in polluted urban areas (Figure 1). A BrC MAC of 0.88±0.05 m^2 g^{-1} (565 nm) in our estimate is approximately seven times lower than MAC_{BC} at 565 nm. The contribution of BC and BrC to the carbonaceous aerosol absorption coefficient at 565 nm was estimated at 88.1±7.4% and 11.9±7.4%, respectively. Similarly, the contribution of BC and BrC to the absorption aerosol optical depth (AAOD) for carbonaceous aerosol (CA AOD), constrained by AERONET observations at 14 sites over East Asia by using different spectral dependences of the absorption (i.e., absorption Ångström exponent) of BC and BrC, was 84.9±2.8% and 15.1±2.8% at 565 nm, respectively. The contribution of BC to CA AAOD was greater in urban sites than in the background areas, whereas the contribution of BrC to CA AAOD was higher in background sites (Figure 2). The overall contribution of BC to CA AAOD decreased by 73%–87% at 365 nm, and increased to 93%–97% at 860 nm. The contribution of BrC to CA AAOD decreased significantly with increasing wavelength from approximately 17% at 365 nm to 4% at 860 nm.

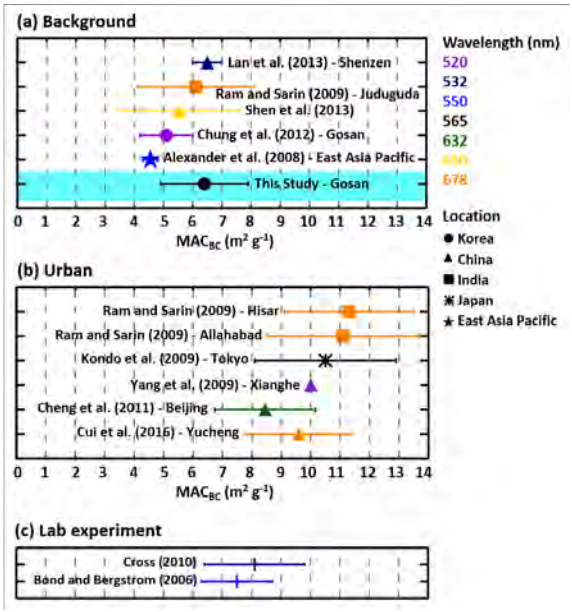


Figure 1. Comparison of MAC_{BC} measured at the (a) background and at (b) urban sites, and from (c) laboratory experiment. The symbols and colors represent observed locations and wavelengths, respectively (see right of figure).

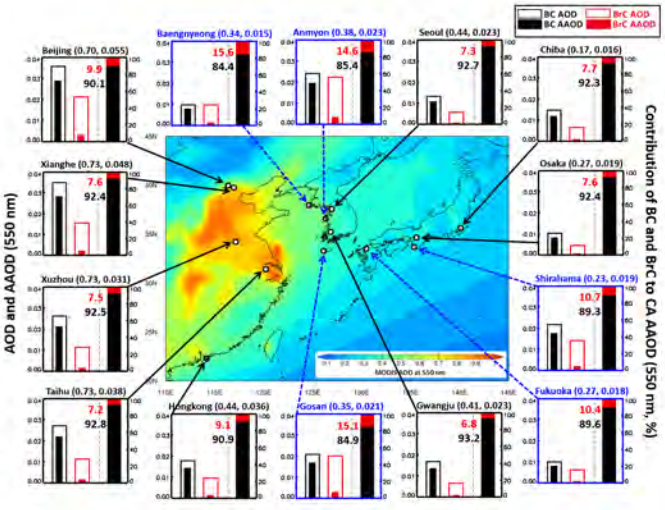


Figure 2. AOD (open bar) and AAOD (filled bar) of BC (black bar; left Y-axis) and BrC (red bar; left Y-axis), and their contribution to AAOD (percentage; right Y-axis) at 14 AERONET sites (9 urban: black arrow, 5 rural: blue dashed arrow). Mean AOD and AAOD (in parentheses) at each site are given with site name at the top of the figure. The contribution of BC (black) and BrC (red) to CA AAOD in percentage (%) are given inside each figure. The background color map denotes 14-year average MODIS AOD (Level 3 Collection 6) at 550 nm over East Asia.

The Role of Ground-based Aerosol Networks in Evaluating Satellite-retrieved Aerosol Radiative Properties over Mountainous Regions

J.P. Sherman[1], I. Krintz[1], A.G. Hallar[2,3], and W.P. Arnott[4]

[1]Appalachian State University, Department of Physics and Astronomy, Boone, NC 28608; 828-262-2438, E-mail: shermanjp@appstate.edu
[2]University of Utah, Salt Lake City, UT 84112
[3]Storm Peak Laboratory, Desert Research Institute, Steamboat Springs, CO 80488
[4]University of Nevada, Reno, NV 89557

Satellite-based retrievals of aerosol radiative properties are being used increasingly for climate and air quality studies, due to their near-global spatial coverage and recent improvements in the aerosol retrieval algorithms. However, these retrievals often suffer (or are not even attempted) over complex mountainous terrain. Satellite validation studies match 'ground-truth' AOD measured by sunphotometers within a time window centered at the satellite overpass with satellite-measured AOD within a fixed radius of the sunphotometer site. However, the agreement between the satellite and ground-truth AOD is affected by the choice of this spatio-temporal window, which becomes even more critical over mountainous terrain. Even when the spatio-temporal collocation window is optimized for a given ground site, agreement between satellite and ground-truth AOD is affected by the assumed surface reflectance and aerosol intensive radiative properties (single-scattering albedo, size distribution) used by the satellite AOD retrieval algorithm. Ground sites with co-located sunphotometers (as part of NASA AERONET or NOAA SURFRAD) and NOAA ESRL aerosol measurements are uniquely positioned to evaluate satellite-retrieved AOD accuracy and the influence of aerosol intensive property assumptions on the AOD accuracy. The current study evaluates AOD retrieved by MODIS and Multi-angle Imageing SpectroRadiometer (MISR) over four mountainous U.S. sites: (1) Appalachian State University (APP; Boone, NC); (2) Walker Branch TN (WB); (3) Storm Peak Laboratory (SPL; Steamboat Springs, CO); and (4) University of Nevada-Reno (Reno). Each site is home to a NASA AERONET site and/or has a multi-filter rotating shadowband radiometer (MFRSR). In addition, the APP and SPL sites are also part of the NOAA ESRL aerosol monitoring network. The four sites collectively represent aerosol and terrain types present in mountainous U.S. regions. In this presentation, we first illustrate a simple method for optimizing the spatio-temporal collocation window over mountainous sites. The method can be easily extended to more spatially-homogeneous regions. We than evaluate the performance of AOD retrieved by MODIS dark target and deep blue algorithms and MISR over the mountainous sites, including the influence of surface reflectance and (for APP and SPL) aerosol-intensive radiative properties. Overall, the satellite-based AOD retrievals agree well with ground-truth measurements over the eastern U.S. mountain sites (APP and WB) and the choice of spatio-temporal collocation window does not strongly influence the AOD agreement. Greater sensitivity to the satellite sensor and spatio-temporal collocation window is demonstrated at the western U.S. mountain sites (SPL and Reno). Aerosol and surface properties influencing this agreement (or lack thereof) are also presented.

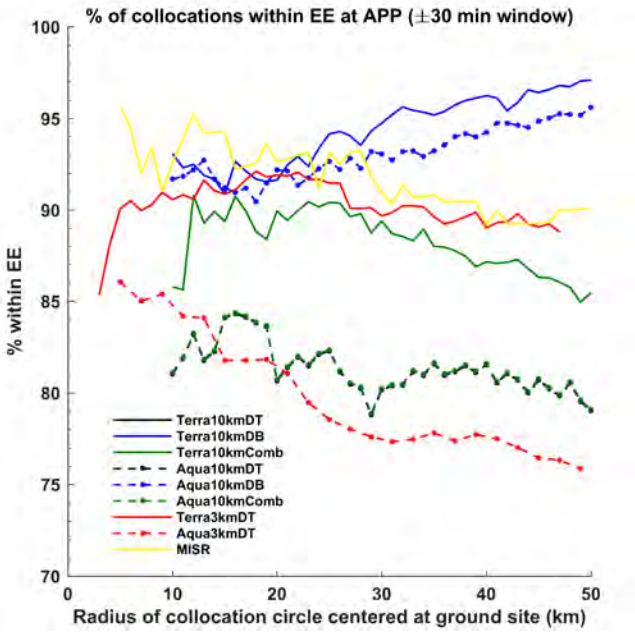


Figure 1. Percent of satellite AOD retrievals lying within the expected error envelope for that sensor, as a function of the radius of spatio-temporal collocation circle centered at the APP site. Traces are shown for MISR and for the various MODIS products onboard the Aqua and Terra satellites. MODIS products are the 10-km dark target (DT) product, the 3-km DT product, the 10-km deep blue (DB) product, and the combined product.

Evaluation of Novel NASA Aerosol Fire Products Over Extreme Fire Events in the Semi-arid Western U.S.

S.M. Loria-Salazar[1], J. Lee[2], A.M. Sayer[2], A. Lyapustin[2], N.C. Hsu[2], N. Lareau[3], J. Redemann[4], and H.A. Holmes[3]

[1]University of Oklahoma, Norman, OK 73019; 775-300-8346, E-mail: marce.marcelaloria@gmail.com
[2]NASA Goddard Space Flight Center (GSFC), Greenbelt, MD 20771
[3]University of Nevada, Reno, NV 89557
[4]NASA Ames Research Center, Moffett Field, CA 94035

Climate change has increased the frequency of droughts in recent decades and consequently, the occurrence and severity of wildfires have amplified. Smoke emissions are a public health problem that is continuously impacting vulnerable populations worldwide. Near extreme fire events, satellite characterization of aerosol pollution is desired because it can capture the horizontal extent of the fires at a reasonable spatial resolution. Previous studies have shown that former algorithms related to the retrieval of aerosol properties from satellite remote sensing have limitations in characterizing aerosol loading during fire events. However, the horizontal transport and the aerosol vertical mixing within the atmosphere are relevant phenomena to understand health effects due to wildfire smoke exposure and the impact in climate change. New versions of aerosol products from NASA MODIS instruments promise a better characterization of aerosol pollution from wildfires. This study will present a review of the new NASA MODIS collection 6.1 Deep-Blue, Multiangle Implementation of Atmospheric Correction (MAIAC), and Aerosol Single scattering albedo and height estimation (ASHE) satellite algorithms near an extreme fire event to evaluate aerosol loading and plume injection height (PIH) products using ground-based sunphotometry and aerosol lidar techniques. Preliminary results show an improvement in fire detection and aerosol concentrations from the new algorithms. A high spatial-temporal correlation (r~0.9) between satellite-derived aerosol optical depth and ground-based sunphotometry was found. In addition, MAIAC and ASHE PIHs agreed with ground-based lidar observations. Finally, a first-order approximation air quality ratio (AQR) was developed to distinguish between aerosol pollution within the planetary boundary layer and the free troposphere using information of aerosol vertical profiles from satellite-derived PIH products and weather forecast model outputs. This AQR has the potential to improve air quality forecasting due to smoke from wildfires through quantifying the percentage of the smoke at near-ground level.

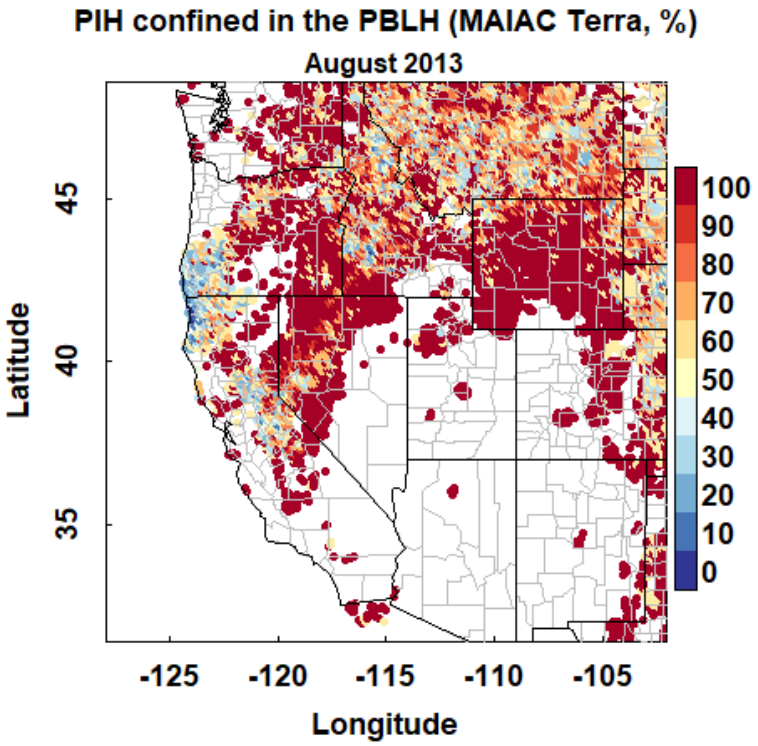


Figure 1. Percentage of occasions when the fire plumes were found within the PBLH.

Application of Solar Aureole for Atmospheric Monitoring

P. Wang, and A. Deepak

Taksha Institute, Hampton, VA 23666; 757-272-3066, E-mail: pnvera@yahoo.com

A study of the application of solar aureole for atmospheric monitoring is carried out with the main focus on determinating atmospheric aerosols size distribution (ASD). The application primarily includes aerosol scattering involved in atmospheric Almucantar and limb scattering processes related to solar aureole phenomena. The details of the study are documented in a book entitled "SOLAR AUREOLE METHOD: Atmospheric Almucantar and Limb Scattering Remote Sensing", briefly referred to as SAM, to be published in 2019. The study treats the spherical Earth-atmosphere system, and analyzes the atmospheric radiative transfer in it, to include carrying out the interaction between incoming solar radiation and atmospheric constituents for all possible sun-zenith angles. In addition, detailed formulation is developed for studying the atmospheric constant-altitude multiangle, limb-scattering radiance during sunrise and sunset events. An example of Almucantar scanning radiance at six large sun-zenith angles between 89 and 94 degrees for a sensor at 25-km altitude is presented (see Figure 1). An example of a set of simulated vertical profiles of constant-altitude, multiangle, limb-scattering radiance is provided in Figure 2. In this SAM study, the investigation of ASD retrievals from a simulated set of scattering radiance data is also described. Finally, the development of the constant-altitude, multiangle atmospheric, limb-scattering methodology, in combination with the solar occultation technique, facilitates monitoring of the tropospheric and stratospheric aerosols by fully utilizing the atmospheric limb-sounding opportunity during sunrises and sunsets.

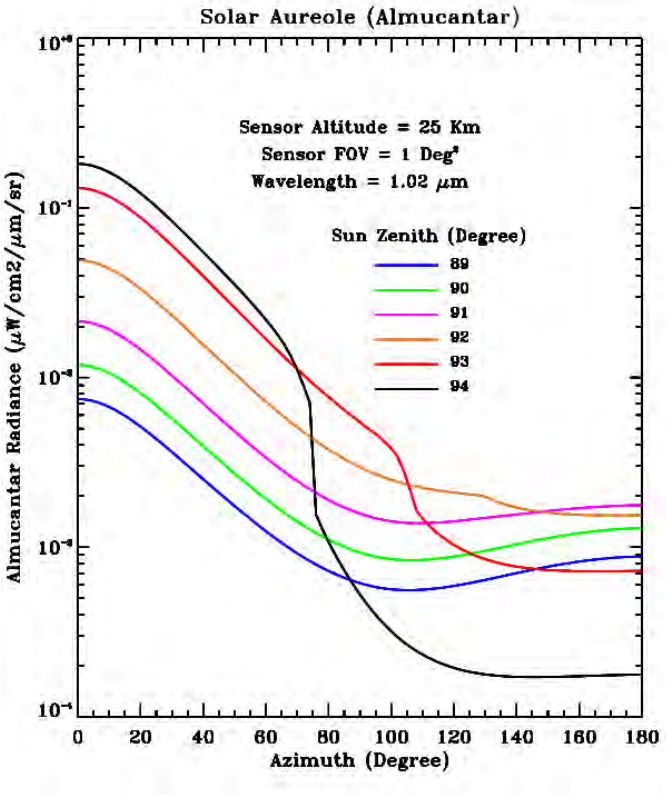


Figure 1. Almucantar radiance vs. azimuth at 6 sun zeniths between 89 and 94 degrees.

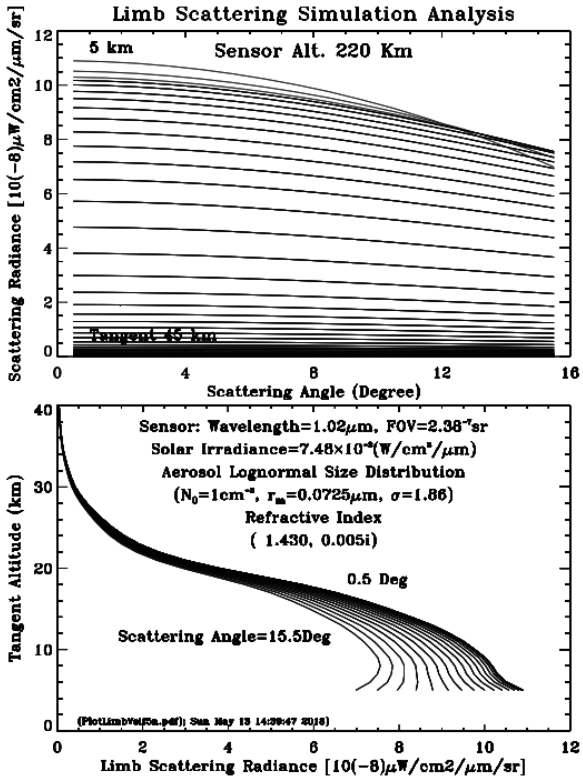


Figure 2. Limb-scattering radiance for sensor at 220 km.

Developing Solar Forecasting Model Diagnostics of Cloud Impacts on Solar Variability

L. Riihimaki[1,2], J. Sedlar[1,2], K. Lantz[1,2], and L. Berg[3]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-5244, E-mail: laura.riihimaki@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Pacific Northwest National Laboratory, Richland, WA 99352

Solar forecasting can help manage the inclusion of solar energy with its inherent variability into the electrical grid. Because traditional weather models were designed to predict temperature and precipitation, they have not been optimized for solar forecasting. To improve intraday and day-ahead forecasts of the solar resource in weather forecasting models, we need observational tools to quantify the impacts of clouds on surface solar irradiance at short and long time scales, allowing testing and development of new parameterizations and model configurations to better simulate surface irradiance. To produce these observational tools, we examine surface irradiance amounts and variability by cloud type and cloud fraction. Initial testing and development is done at the Atmospheric Radiation Measurement (ARM) Southern Great Plains site using cloud type determined from cloud layer height measurements from vertically pointing cloud radar and lidar. The combination of cloud radar and lidar can give a relatively comprehensive picture of the vertical structure of multilayered clouds. We test and show that using a ceilometer alone, which measures lowest cloud base, can still give a reliable cloud type classification for the purposes of estimating surface irradiance variability and amount. The Surface Radiation (SURFRAD) network is now installing ceilometers at all sites. This allows us to expand the cloud type analysis to the SURFRAD network throughout the continental U.S., giving a much wider observational data set for testing models in different climatic regimes and weather conditions.

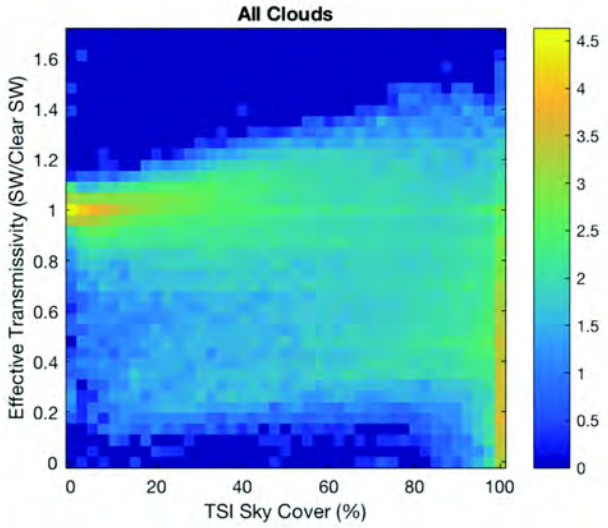


Figure 1. Density plot of cloud fraction (measured by a Total Sky Imager) versus Effective Transmissivity (calculated from irradiance measurements using the Radiative Flux Analysis method) for data at SGP from 2016. Color bar shows a log scale of the number of 1-minute measurements in a given bin.

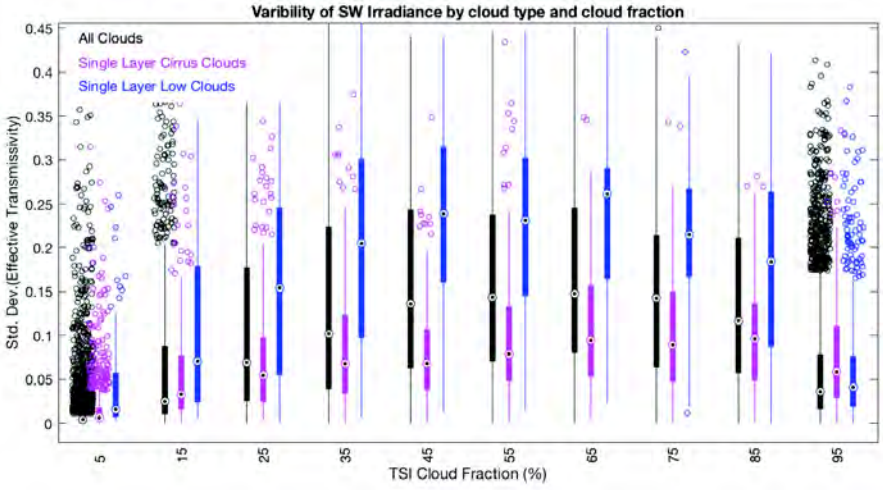


Figure 2. Distributions of the 15-min standard deviation of effective transmissivity in 10% cloud fraction bins. Median values are shown in the circles, solid bars show 25/75 percentiles, full range in thin lines. Colors show different cloud types.

The Aleutian Low – Beaufort Sea Anticyclone: A Climate Index for Predicting the Timing of Springtime Melt in the Pacific Arctic Cryosphere

C.J. Cox[1,2], R.S. Stone[3,4], D.C. Douglas[5], D.M. Stanitski[4], and M.R. Gallagher[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-4518, E-mail: christopher.j.cox@noaa.gov
[2]NOAA Earth System Research Laboratory, Physical Sciences Division (PSD), Boulder, CO 80305
[3]Science and Technology Corporation, Boulder, CO 80305
[4]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[5]USGS Alaska Science Center, Juneau, AK 99801

Early and late extremes in the timing of snowmelt have recently been observed in the Pacific Arctic. Subseasonal-to-seasonal forecasts of this timing are important for industry, environmental management and Arctic communities. In northern Alaska, the timing is influenced by the advection of marine air from the north Pacific by the Aleutian Low, modulated by high pressure centered in the Beaufort Sea. A new climate index that integrates their interaction could advance melt predictions. We define this index based on 850 hPa geopotential height at four fixed locations referred to as the Aleutian Low – Beaufort Sea Anticyclone (ALBSA). During positive ALBSA in May, advection of +0.5–1.5 K/day is observed through the Bering Strait. ALBSA is correlated with both snowmelt in northern Alaska and the onset of sea ice melt over the adjacent seas. ALBSA, therefore, may be suitable for monitoring the relevant circulation patterns and for developing predictive tools.

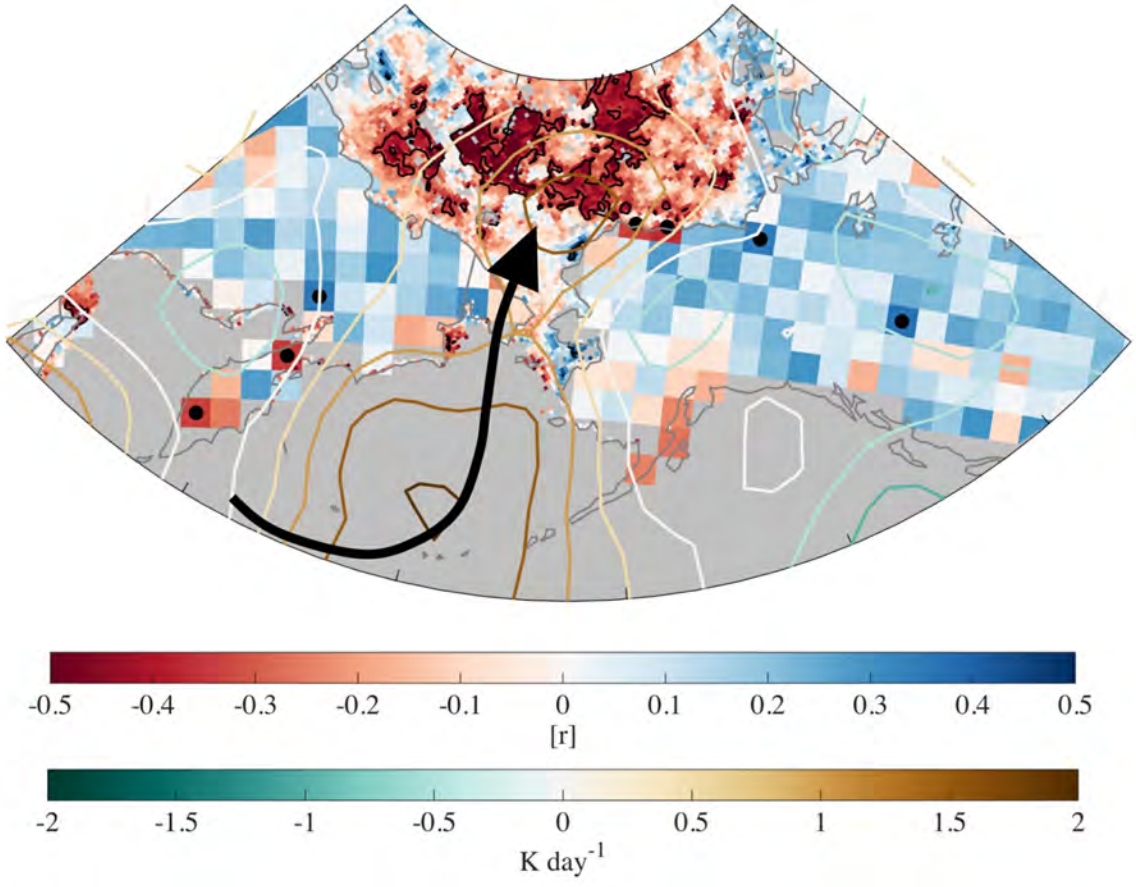


Figure 1. Correlation (r) between average May ALBSA and the timing of melt onset over sea ice (ocean pixels, 1979–2017) and the date of snowmelt over land (land pixels, 1979–2018). Dots over land and contours over ocean mark pixels with statistically significant correlations nominally for $p < 0.05$, but adjusted to a stricter threshold of ~0.04 to account for false discovery rates for tested pixels inside the domain. Black arrow is the approximate path of advection in early melt years. Advection (u + v) is shown for days with ALBSA > +1σ based on all days in May, 1979–2018.

Airborne *in situ* Measurement of CO_2 and CH_4 in South Korea

S. Li, S.T. Kenea, L. Labzovskii, Y. Oh, T. Goo, and Y. Byun

National Institute of Meteorological Sciences, Seogwipo-si, Jeju-do, South Korea; +82-64-780-6675, E-mail: sunranlee@korea.kr

A new Korean Meteorological Administration (KMA) airborne measurement platform has been established for regular observations with scientific purpose over South Korea since 2018. The Beechcraft King Air 350HW was used to measure *in situ* CO_2, CH_4, CO, and H_2O with the cavity ring-down spectrometer G-2401m analyzer. The overall uncertainty of airborne measurements is estimated to be 0.16 ppm for CO_2, 2.1 ppb for CH_4, and 5.0 ppb for CO by combination of NOAA whole-air accuracy, cavity pressure sensitivity and water vapor correction uncertainty. The airborne vertical profile measurements were performed at a regional GAW Anmyeon-do (AMY) station that belongs to the Total Carbon Column Observing Network (TCCON) and provides concurrent observations to the Greenhouse Gases Observing Satellite (GOSAT) overpasses [Fig. 1(a)]. The vertical profile of CO_2 shows clear altitude gradient [Fig. 1(b)], while the CH_4 shows a non-homogenous pattern in the free troposphere [Fig. 1(c)]. The 1.5–9.0 km vertically averaged CO_2 mixing ratios are comparable with background surface values at AMY and Ryori station but CH_4 mixing ratios show lower levels than those from ground GWA stations, comparable with flask airborne data taken in the Western Pacific region [Fig.2 (a, b)]. Furthermore, this study shows that the combination of CH_4 distribution in free troposphere and trajectory analysis, taking convective mixing into account, is a useful tool in investigating CH_4 transport processes.

This work was funded by the KMA Research and Development Program "Research and Development for KMA Weather, Climate, and Earth System Services - Support to Use of Meteorological Information and Value Creation" under Grant (KMA2018-00321).

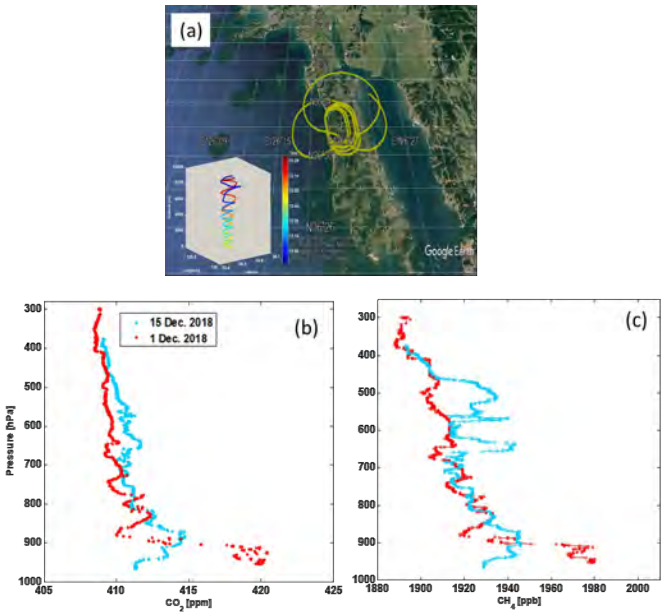


Figure 1. Typical spiral flight track (a) and vertical descending profiles of CO_2 (b), CH_4 (c) on 1, 15 December in 2018 at AMY station in South Korea.

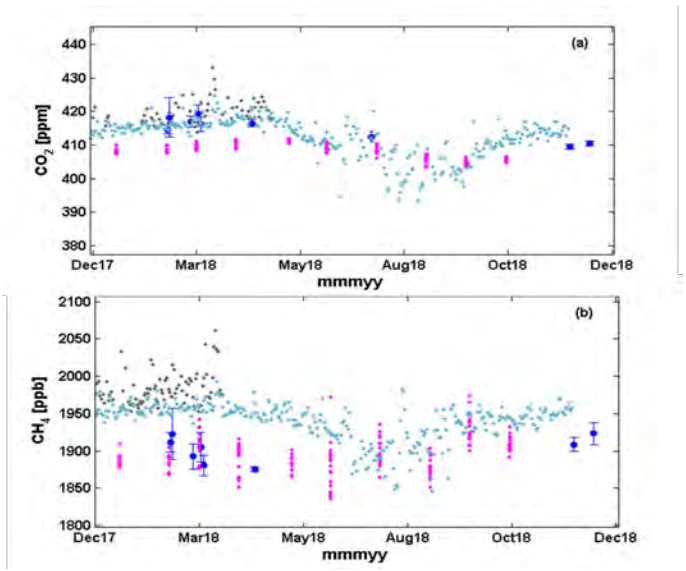


Figure 2. Time series of daily mean surface CO_2 (a) and CH_4 (b) mixing ratio measured at AMY (36.53°N, 126.33°E) in South Korea (gray circle) and Ryori (39.03°N, 141.82°E) in Japan (sky blue circle) and flask aircraft measurement (above 5 km) from Tokyo to Minamitorishima (pink circle). The blue circles with vertical bars are the 1.5–8 km average CO_2, CH_4 with one standard deviation from KMA Kingair 350 measurements during 2018, respectively.

Trace Gas Observations from Small Research Aircraft over the Mid Atlantic States and Hebei, China

R.R. Dickerson[1], R. Salawitch[2], X. Ren[1,3], H. He[1], and S. Benish[1]

[1]University of Maryland, Department of Oceanic and Atmospheric Science, College Park, MD 20742; 301-405-5364, E-mail: rrd@umd.edu
[2]University of Maryland, College Park, MD 20742
[3]NOAA Air Resources Laboratory (ARL), Silver Spring, MD 20910

The University of Maryland has been making airborne measurements of aerosols and trace gases including CO_2, CH_4, and CO, both over the Mid Atlantic States and over China during the NASA-sponsored Korea-United States Air Quality Study (KORUS-AQ) campaign. These programs, supported by the National Institute of Standards and Technology (NIST), National Science Foundation (NSF), and other agencies, aim to advance our understanding of chemistry and fluxes of greenhouse gases, short-lived pollutants, and chlorofluorocarbons. Results will be compared to emissions inventories and in context of global budgets as well as the Montreal Protocol.

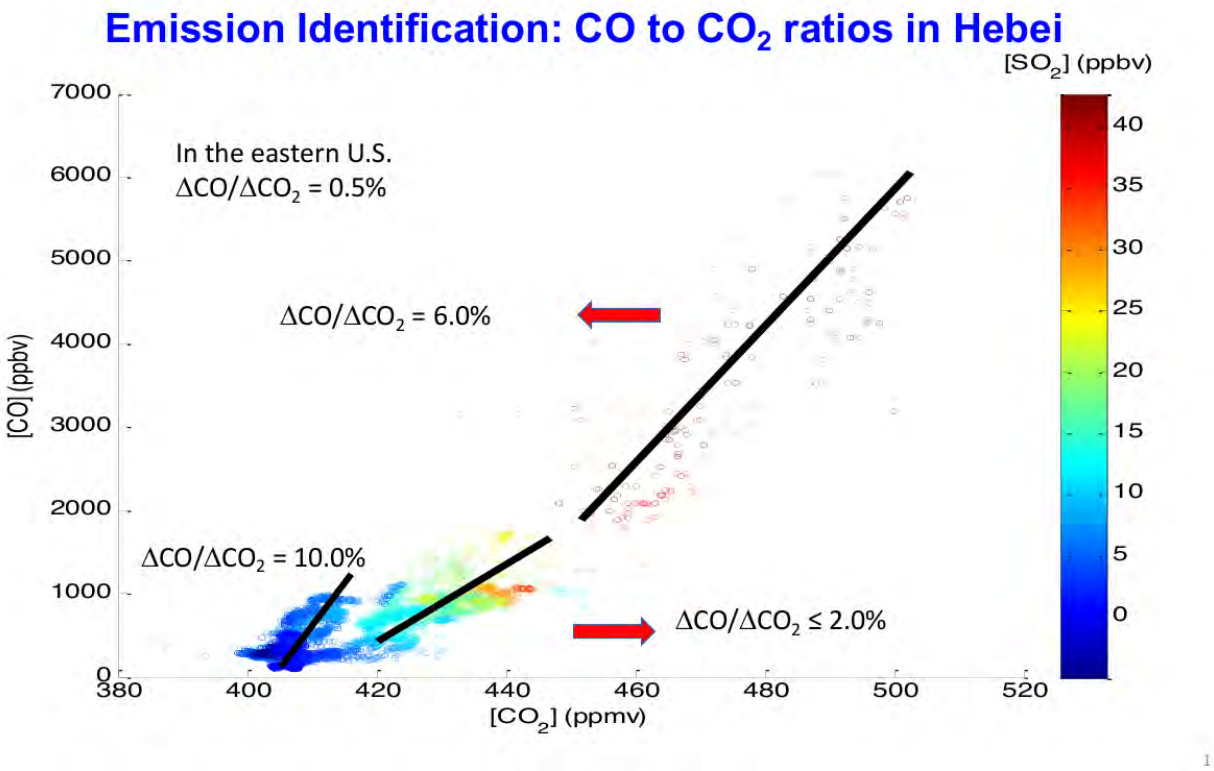


Figure 1. Trace gases observed over Hebei Province, China demonstrating the wide variety of sources present locally, including biomass burning, high-tech coal combustion, low-tech coal combustion, and vehicles.

Characteristics and Mechanisms of Atmospheric CO_2 Variations during Summer Frontal Passages

S. Feng[1], A. Samaddar[1], S. Pal[1], L. Campbell[1], T. Lauvaux[1], A. Schuh[2], and K.J. Davis[1,3]

[1]The Pennsylvania State University, Department of Meteorology and Atmospheric Science, University Park, PA 16802; 814-863-8320, E-mail: sfeng@psu.edu
[2]Colorado State University, Fort Collins, CO 80523
[3]Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, PA 16802

Mid-latitude cyclones and the associated frontal passages mix long-distance transport of atmospheric CO_2 with local sources and sinks via horizontal advection, convergent lifting, and cumulus convection. These synoptic scale weather phenomena create sharp gradients in atmospheric CO_2 mole fractions along frontal boundaries. The quantitative studies of the net transport of CO_2 by these weather systems have been limited. The Atmospheric Carbon and Transport (ACT) – America aircraft campaigns were designed to sample the horizontal and vertical distributions of greenhouse gas across frontal boundaries and within midlatitude cyclones in three regions of the eastern United States. These data are enabling a careful observational and numerical study of the atmospheric CO_2 transport associated with frontal passages.

Here we use aircraft data and atmospheric transport models to examine CO_2 transport along frontal boundaries observed during the summer of 2016. The airborne *in situ* measurements show 5–30 ppm difference in the atmospheric boundary layer and up to 5 ppm in the free troposphere across the frontal boundaries. Using a high-resolution regional model, we further investigate the mechanisms of the CO_2 transport during these summer cold fronts. The sign of the large-scale mole fraction gradients is simulated reliably, and appears to be caused by a combination of advection of the seasonal latitudinal gradient in CO_2, and regional fluxes, mainly biological but with fossil contributions, that reinforce this gradient. Biogenic fluxes appear to play a major role in the high CO_2 band found in advance of the front, suggesting that observations of this phenomenon could provide a strong constraint on regional biological CO_2 fluxes. The majority of CO_2 transport is attributed to horizontal advection, but cumulus-permitting simulations show an increased contribution to vertical advection. Additional future analyses will explore the ability of airborne lidar and polar-orbiting satellites to capture these frontal CO_2 structures.

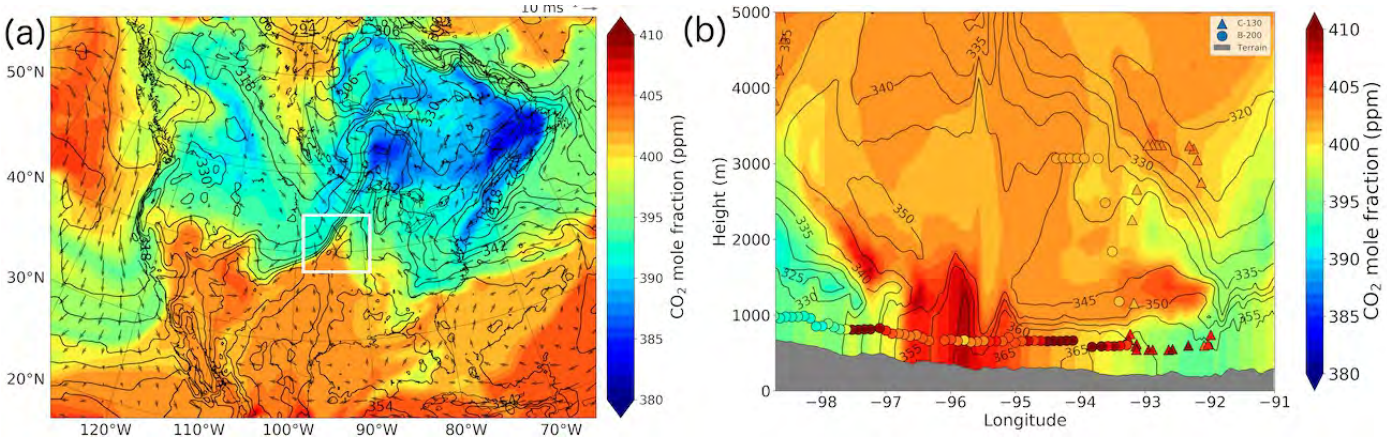


Figure 1. CO_2 distributions along a summer cold front over the Midwest region. (a) Synoptic view of the atmospheric boundary layer CO_2 mole fractions (shaded), winds (vectors), and equivalent potential temperature (contours) generated by a 27-km resolution WRF-Chem simulation. (b) Cross-section of the CO_2 mole fractions (shaded) and equivalent potential temperature (contours) generated by a three-km resolution WRF-Chem simulations nested within (white box) the 27-km resolution simulation. Aircraft observations are overlaid on the vertical cross-section.

The Potential for Public-transit Based Atmospheric Monitoring to Advance Air Quality and Atmospheric Chemistry Research and to Engage Urban Stakeholders

L.E. Mitchell, E. Crosman, B. Fasoli, A. Jacques, D. Mendoza, D. Mallia, J. Horel, and J.C. Lin

University of Utah, Salt Lake City, UT 84112; 541-207-7204, E-mail: logan.mitchell@utah.edu

Urban environments are characterized by both spatial complexity and temporal variability, each of which present challenges for measurement strategies aimed at understanding greenhouse gas emissions and air quality. To address these challenges, we initiated a project in December 2014 to measure greenhouse gases and air pollutants (CO_2, CH_4, O_3, $PM_{2.5}$, and NO_2) by way of a Utah Transit Authority (UTA) light rail train car whose route traverses the Salt Lake Valley in Utah, retracing the same route through commercial, residential, suburban, and rural typologies. Public transit light rail vehicles present advantages as a measurement platform, including the absence of *in situ* fossil fuel emissions, repeated transects across an urban region that provides both spatial and temporal information, and relatively low operating and maintenance costs. We will discuss this ongoing project and how the observations are being used to advance our understanding of atmospheric chemistry, identify emission sources, evaluate emission inventories, and improve air pollution exposure models. We will also discuss the public, stakeholder, and policymaker engagement opportunities that arise from this approach to monitoring. Lastly, we will discuss how public transit platforms can complement existing and emerging monitoring networks, and the many future applications.

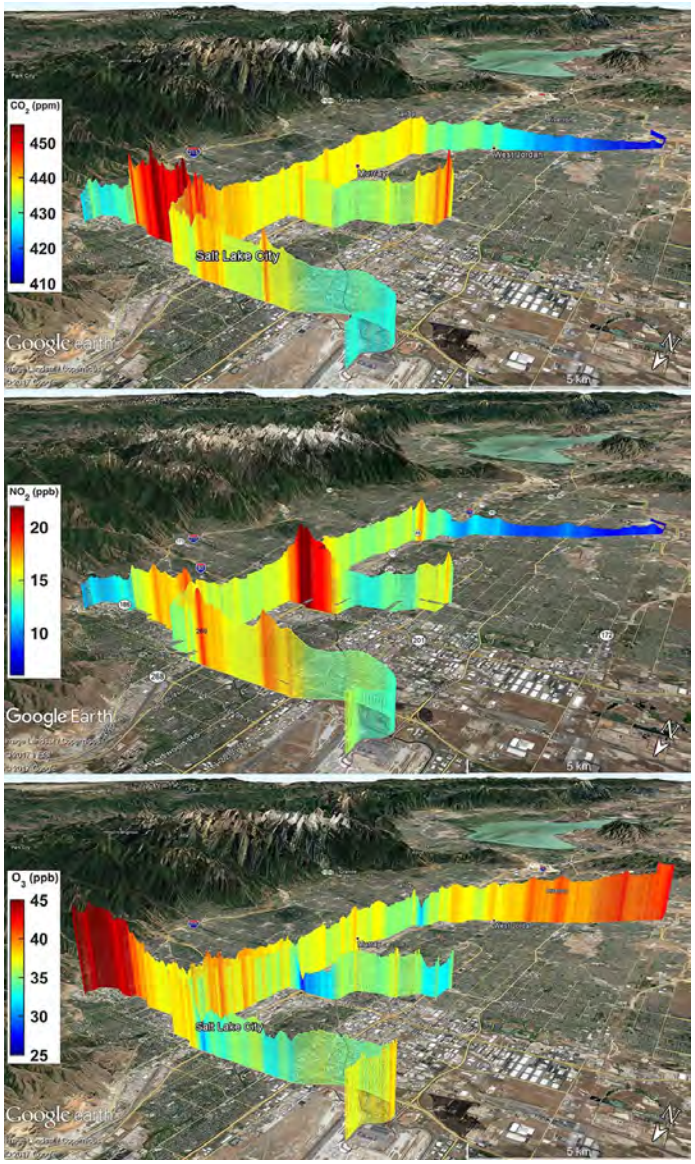


Figure 1. Spatial patterns of CO_2, NO_2, and O_3 in Salt Lake City averaged over time.

Fire Emissions in California: Analysis of Airborne Measurements of Trace Gases from Thirteen Fires

C. Parworth[1,2], J.E. Marrero[3], E.L. Yates[1,4], J. Ryoo[1,5], and L.T. Iraci[1]

[1]NASA Ames Research Center, Atmospheric Science Branch, Moffett Field, CA 94043; 650-604-0713, E-mail: carolineparworth@gmail.com
[2]Universities Space Research Association (USRA) - NASA Postdoctoral Program (NPP), Columbia, MD 21046
[3]Sonoma Technology Inc., Petaluma, CA 94954
[4]Bay Area Environmental Research Institute, Sonoma, CA 95476
[5]Science and Technology Corporation, Boulder, CO 80305

Biomass burning, which includes wildfires, prescribed, and agricultural fires, is an important source of trace gases and particles, and can influence air quality on a local, regional, and global scale. With the threat of fire events increasing due to changes in land use, increasing population, and climate change, the importance of characterizing fire emissions is vital. In this work we characterize trace gas emissions from 12 wildfires and 1 prescribed fire event in California between 2013–2018, in some cases with multiple measurements performed during different burn periods of a single fire. Airborne measurements of carbon dioxide (CO_2), methane (CH_4), water vapor (H_2O), ozone (O_3), and formaldehyde (HCHO) were made by the Alpha Jet Atmospheric eXperiment (AJAX). The majority of these measurements were made as close as possible to each fire and represent fresh emissions from known fire sources. The dependence of trace gas emissions on meteorology, vegetation, and fire conditions is explored. Results presented include emission ratios (ER) of O_3, HCHO, and CH_4 for individual fires, which differ in vegetation type, burning intensity, duration, and location. Occurrences of trace gas heterogeneity observed in the plumes of several fires are investigated. Evidence of mixed urban and fire emissions sampled is also discussed.

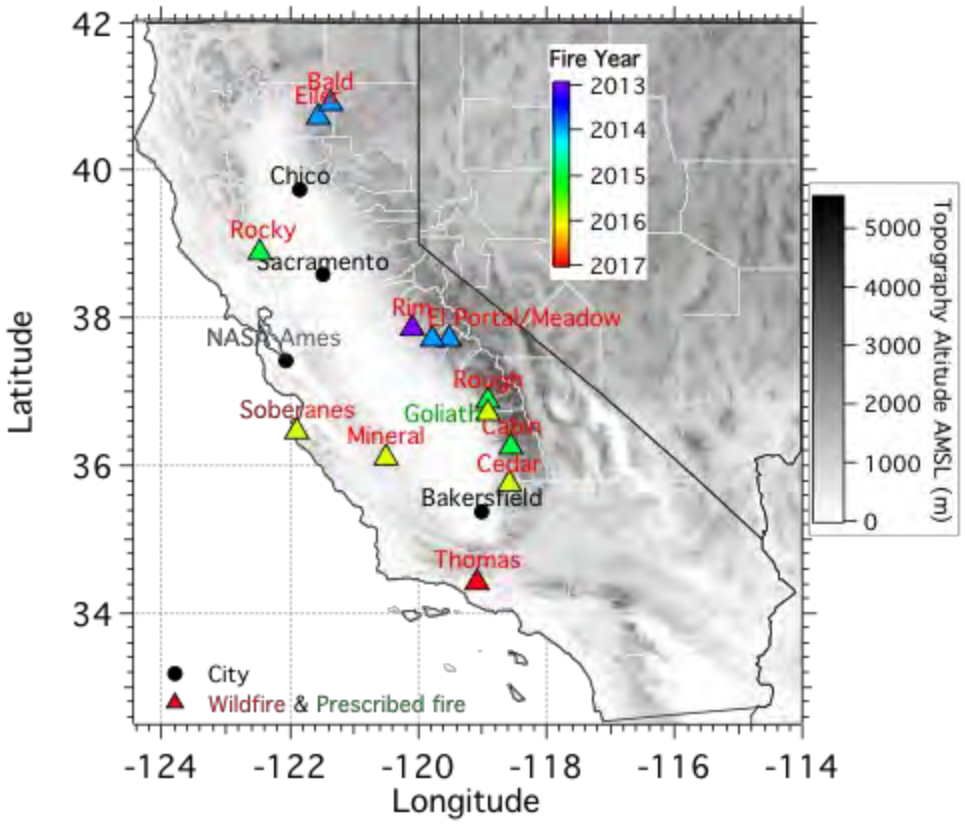


Figure 1. A topographic map of California (gray color scale) with the location of fires (triangles), measured by AJAX. The fire locations are colored by year (rainbow color scale).

Commissioning of High Precision *in situ* Measurements of N_2O and CO at Cape Grim

Z. Loh, P.B. Krummel, E. Guerette, D.A. Spencer, and R.L. Langenfelds

Commonwealth Scientific and Industrial Research Organisation (CSIRO), Oceans and Atmosphere, Aspendale, Australia; +61-3-9239-4518, E-mail: zoe.loh@csiro.au

To date, *in situ* measurements of atmospheric nitrous oxide (N_2O) and carbon monoxide (CO) at the Cape Grim Baseline Air Pollution Station have been made under the auspices of the Advanced Global Atmospheric Gases Experiment (AGAGE) utilizing a gas chromatography multidetector (GC-MD) system [electron capture (ECD) for N_2O and reduction gas (RGA) for CO], which measures a single ambient air aliquot once every 40 minutes.

In March 2019, CSIRO installed a new CO and N_2O analyser based on mid-IR cavity ring-down spectroscopy (CRDS) (Picarro Inc., model G5310) at Cape Grim to provide higher precision, higher frequency measurements of these two important atmospheric trace gases at this key global monitoring site.

Here we present results from tests performed in our Aspendale laboratories before deployment of the instrument, including characterisation of the instrument response to water vapour content in the sample. We also present the initial CRDS time series from Cape Grim, including comparison to GC-MD N_2O and CO measurements as shown in Figure 1. Importantly, the two techniques provide time series that are largely faithful to each other for both species. The N_2O precision from the CRDS instrument is notably superior to the GC-MD system. Data from the two instruments are on different scales (AGAGE GCMD data are on the SIO-16 N_2O scale while the CRDS data are on the NOAA-06A scale). Occasional divergence in the CO measurements reflect differences in intake height [70m for the CRDS and currently 10m for the GC-MD (normally 70m)] and known issues with the GC-MD. Data from both instruments are on the CSIRO94 CO scale.

Finally, we explore two challenges posed by the commissioning of this new instrument. Firstly, what is the best strategy to handle the propensity of CO to drift in the Luxfer aluminium cylinders we commonly use in the preparation of working standard and calibration cylinders for our continuous *in situ* analysers? And secondly, unlike the GC systems we use for cascading our calibrations, the CRDS instrument is sensitive to only the major isotopologue ($^{12}C^{16}O$ and $^{14}N^{14}N^{16}O$). This potentially introduces error in the CRDS measurements at high mole fractions when high mole fraction standards have been prepared by 'spiking' clean air cylinder fills with CO of a different isotopic composition than is likely to be present in the well-mixed atmosphere.

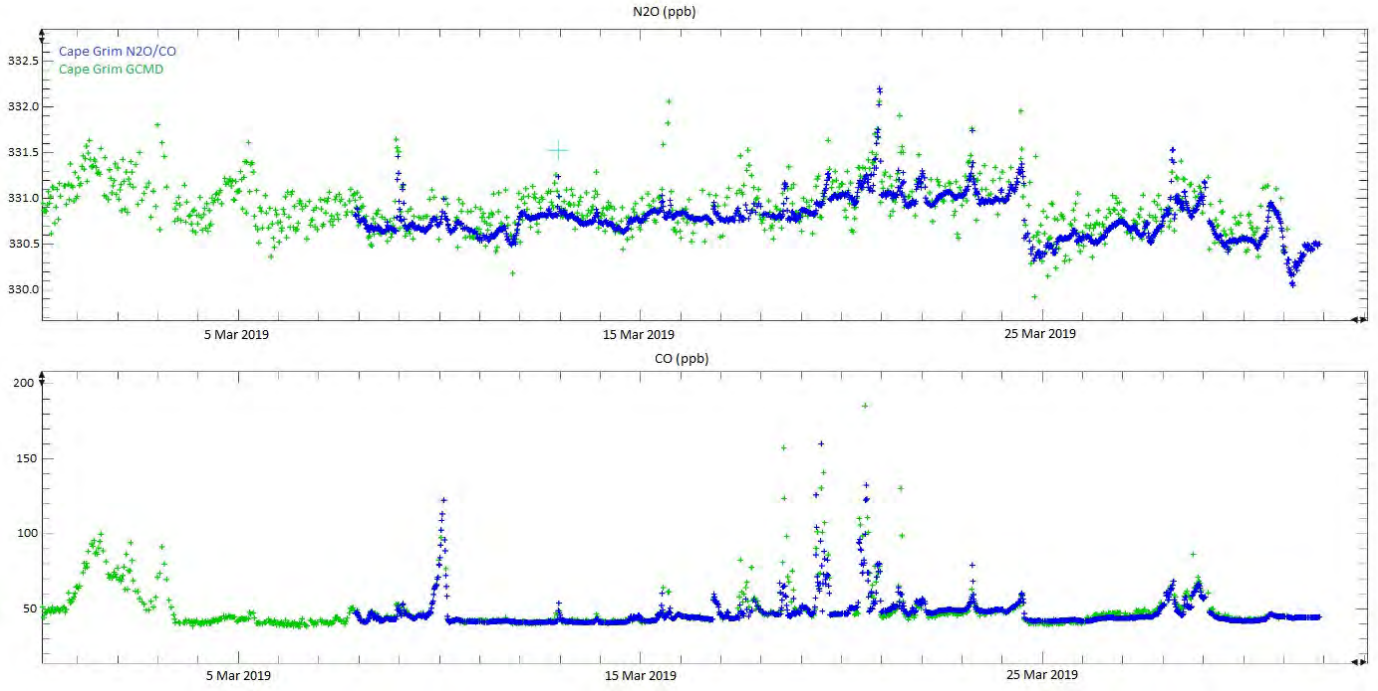


Figure 1. Time series of N_2O (upper panel) and CO (lower panel) at Cape Grim. Green data points are from the AGAGE GC-MD system, blue data points are from the Picarro G5310 system.

Large Fugitive Methane Emissions from Urban Centers Along the U.S. East Coast

G. Plant[1], C. Sweeney[2], E.A. Kort[1], C. Floerchinger[3], I. Vimont[4,2], and A. Gvakharia[1]

[1]University of Michigan, Ann Arbor, MI 48109; 303-443-9173, E-mail: geplant@umich.edu
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Harvard University, Department of Earth and Planetary Sciences, Cambridge, MA 02138
[4]National Research Council Post-Doc, Boulder, CO 80305

Urban emissions remain an underexamined part of the methane budget. Here we present and interpret aircraft observations of six major urban centers along the East Coast of the United States. We use direct observations of methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO), ethane (C_2H_6), and their correlations to quantify CH_4 emissions and attribute to natural gas. We find the five largest cities emit 0.84 (0.61,1.12) Tg $CH_4 \cdot y^{-1}$, of which 0.79 (0.51,1.14) Tg $CH_4 \cdot y^{-1}$ can be attributed to natural gas. These urban centers in combination emit more CH_4 than major energy production regions such as the Four Corners area or the Bakken shale. Our estimates are more than twice that reported in the most recent gridded EPA inventory. The estimated fugitive natural gas emissions from these five cities alone exceed current nation-wide estimates of natural gas emissions due to local distribution.

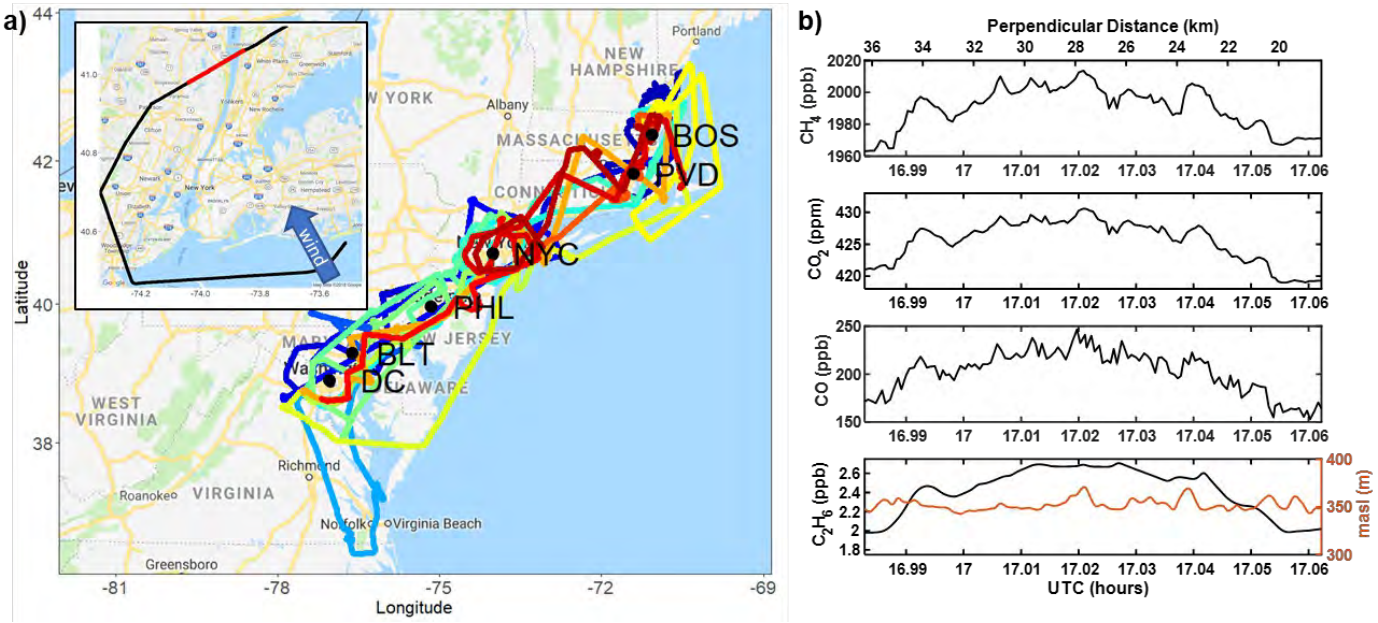


Figure 1. (a) Flight coverage by the East Coast Outflow (ECO) campaign around the major urban regions of Washington, DC (DC); Baltimore, MD (BLT); Philadelphia, PA (PHL); New York, NY (NYC); Providence, RI (PVD); and Boston, MA (BOS). Each flight is represented by a different color. The inset shows the flight path (black) and the region representing the downwind plume (red) for NYC on May 9th, 2018. Map source: *Google Maps*, Accessed 9/18/2018 (b) The tracer concentration time series of the NYC plume corresponding to the inset of (a).

A Multiplatform Inversion Estimation of Statewide and Regional Methane Emissions in California during 2014–2016

Y.Y. Cui[1], A. Vijayan[1], M. Falk[1], Y.K. Hsu[1], D. Yin[1], Z. Zhao[1], J. Avise[2,1], X.M. Chen[1], Y. Chen[1], K.R. Verhulst[3], R. Duren[3], C. Miller[3], R.F. Weiss[4], R. Keeling[4], J. Kim[4], L.T. Iraci[5], T. Tanaka[6,7], M.S. Johnson[6], M. Fischer[8], K. Stroud[1], J. Herner[1], and B. Croes[1]

[1]California Air Resources Board, Sacramento, CA 95812; 916-323-2999, E-mail: Yuyan.Cui@arb.ca.gov
[2]Washington State University, Department of Civil and Environmental Engineering, Pullman, WA 99164
[3]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
[4]Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92037
[5]NASA Ames Research Center, Atmospheric Science Branch, Moffett Field, CA 94043
[6]NASA Ames Research Center, Earth Science Division, Moffet Field, CA 94035
[7]Japan Weather Association, Tokyo, Japan
[8]Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA 94720

California adopted the landmark Global Warming Solutions Act of 2006 to reduce Greenhouse Gas (GHG) emissions to the 1990 levels by 2020, and has also enacted several ambitious climate regulations to mitigate the global warming impacts of methane (CH_4), such as Senate Bill No. 1383 which requires a 40% reduction in CH_4 emissions below 2013 levels by 2030. To achieve the ambitious emission reduction goals and implement real and efficient reduction policies, a thorough understanding of CH_4 emissions is important. In this study, we conducted a multiplatform inversion analysis for a multiyear evaluation of bottom-up CH_4 emissions inventories of California, based on atmospheric measurements from two tower networks and one aircraft campaign during the period. The tower networks were California Air Resources Board's Statewide GHG Monitoring Network, and a regional-scale urban network in Los Angeles built by the Megacities Carbon Project. The aircraft measurements were conducted by NASA Ames in northern California. It is the first time that such an analysis has been conducted by using multiple measurement platforms and different prior inventories for multiple years to constrain CH_4 emissions in California. The rigorous inversion analysis has important policy implications for regulatory programs. It provides a multiyear evaluation of the emissions inventory using independent atmospheric measurements, investigates the utility of a complementary multiplatform approach in understanding spatial and temporal patterns of CH_4 emissions in the state, and identifies opportunities for the expansion and applications of the monitoring network.

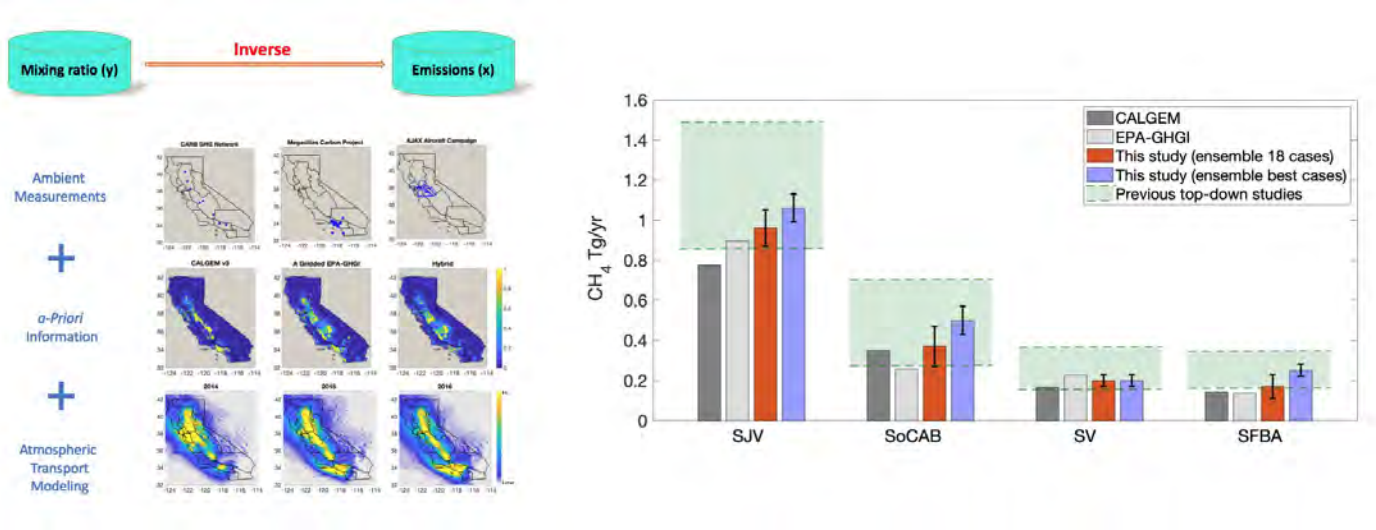


Figure 1. Major components for the inversion analysis are shown in the left panel; inversion results by subregion are shown in the right panel.

Optimization of Methane Emissions in the United States Gulf Region Using Aircraft-based Measurements Across Frontal Boundaries

Z. Barkley[1], K. Davis[1], N. Balashov[1], S. Feng[1], A. Fried[2], and J. DiGangi[3]

[1]The Pennsylvania State University, Department of Meteorology and Atmospheric Science, University Park, PA 16802; 570-905-7621, E-mail: zrb5027@gmail.com
[2]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309
[3]NASA Langley Research Center, Hampton, VA 23681

The United States Gulf and lower Midwest region are a hotspot for anthropogenic methane (CH_4) emissions, with the largest contributions coming from the oil/gas and animal agriculture sectors. During frontal weather events, airflow is directed across the region in a manner that combines CH_4 enhancements from these various sources into a large, easily observable enhanced plume greater than 100 ppb in magnitude. In this study, we take CH_4 and ethane (C_2H_6) observations from the Atmospheric Carbon Transport-America campaign for seven flights that cross frontal systems in the Midwest and Gulf and adjust emissions from the oil/gas and animal agriculture sectors such that modelled CH_4 and C_2H_6 enhancements produced by WRF-Chem simulations match the observed plume. From the CH_4 optimization we find that there is more CH_4 than projected by the EPA Gridded CH_4 Inventory by about a factor of 1.5. Results from the joint CH_4-C_2H_6 optimization indicate that this increase is due to an underestimation of emissions from the oil/gas sector (1.4–2.8 times larger than inventory estimates), whereas deviations from expected animal agriculture emissions are not necessary to explain the observed signals. Our results for the oil and gas sector match synthesis work from recent literature, and reject the possibility that this increase compared to inventories is due to a potential bias in daytime-only measurements of gas facilities. Modelled CH_4 from this study is able to produce a near-perfect match with observations across the 7 flights ($r > 0.9$), providing confidence in the results and raising the possibility of using trace gas measurements along frontal crossings to solve for emissions in other regions of the U.S.

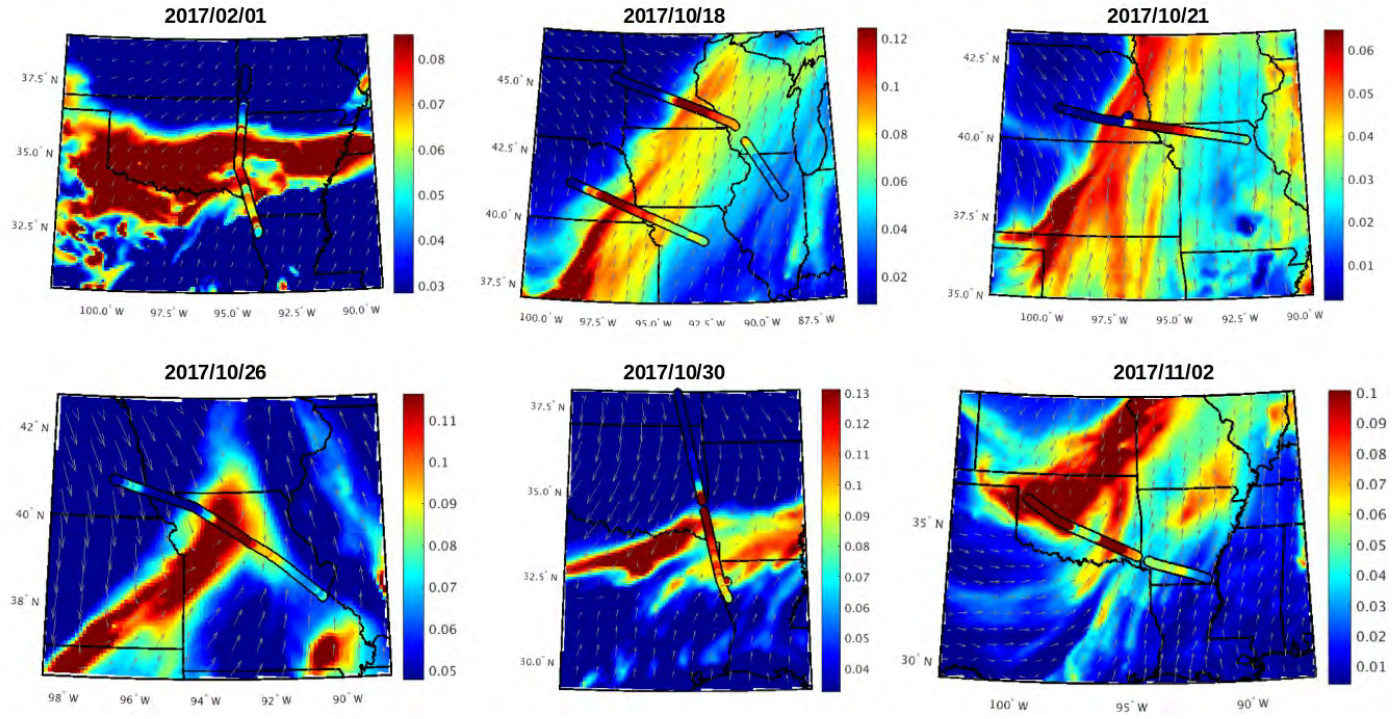


Figure 1. Modelled vs. observed CH_4 enhancements (in ppm) for the seven flights used in this study. Model results shown in each image were created using WRF-Chem and are a snapshot of projected enhancements at 18Z at a height of 300 m above ground level using unadjusted emissions from the EPA Gridded Methane Inventory.

Importance of Super-emitter Natural Gas Well Pads in the Marcellus Shale

D. Caulton

University of Wyoming, Laramie, WY 82071; 307-766-5363, E-mail: dcaulton@uwyo.edu

A large-scale study of methane emissions from well pads was conducted in the Marcellus shale (PA), the largest producing natural gas shale play in the U.S., to better identify the prevalence and characteristics of super-emitters. Roughly 2100 measurements were taken from 673 unique unconventional well pads corresponding to ~18% of the total population of active sites and ~32% of the total statewide unconventional natural gas production. A lognormal distribution with a geometric mean of 2.0 kg hr^{-1} and arithmetic mean of 5.5 kg hr^{-1} was observed, which agrees with other independent observations in this region. The geometric standard deviation (4.4 kg hr^{-1}) compared well to other studies in the region, but the top 10% of emitters observed in this study contributed 77% of the total emissions, indicating an extremely skewed distribution. The distribution of emissions is shown in Figure 1. The integrated proportional loss of this representative sample is equal to 0.53% with a 95% confidence interval of 0.45–0.64% of the total production of the sites, which is greater than the EPA inventory estimate (0.29%), but in the lower range of other mobile observations (0.09–3.3%). These results emphasize the need for a sufficiently large sample size when characterizing emissions distributions that contain super-emitters.

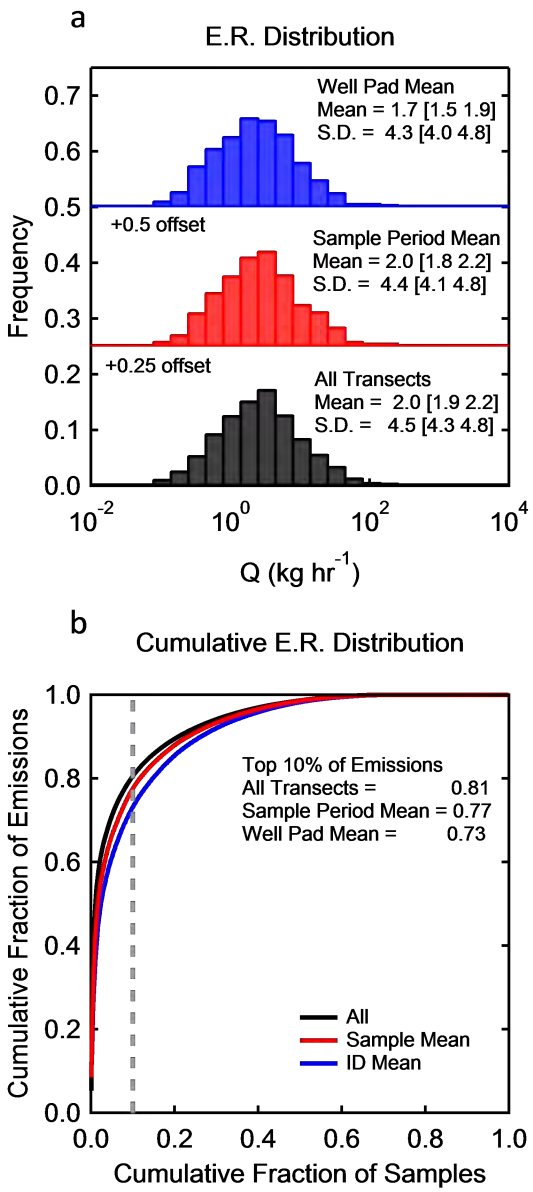


Figure 1. Figure 1. (a) Distribution of emissions for three scenarios: all transects, transects averaged to unique sample periods and transects averaged to unique well pads, excluding sites with no emissions. (b) Cumulative emissions for the same three scenarios, including sites with no emissions.

Characterization of Methane Emissions in Los Angeles with Airborne Hyperspectral Imaging

K.M. Saad, Y. Landa, E.R. Keim, J.L. Hall, K.N. Buckland, P.D. Johnson, and D.M. Tratt

The Aerospace Corporation, El Segundo, CA 90245; 310-336-1350, E-mail: katherine.m.saad@aero.org

As urban areas develop regulations to limit atmospheric methane (CH_4), accurate quantification of anthropogenic emissions will be critical for program development and evaluation. However, relating emissions derived from process-level metadata to those determined from assimilating atmospheric observations of CH_4 concentrations into models is particularly difficult. Nonmethane hydrocarbons (NMHCs) can help differentiate between thermogenic and biogenic CH_4 emissions, as they are primarily co-emitted with the former; however, these trace gases are subject to the same limitations as CH_4. Remotely-sensed hyperspectral imaging bridges these approaches by measuring emissions plumes directly with spatial coverage on the order of 10 km^2 min^{-1}. We identify the sources of and evaluate emissions plumes measured by airborne infrared hyperspectral imagers flown over the Los Angeles (LA) metropolitan area, which encompasses various CH_4 sources, including petroleum and natural gas wells and facilities. We quantify total CH_4 and NMHC emissions, as well as their relative column densities, at the point-source level to create fingerprints of source types. We aggregate these analyses to estimate the range of variability in chemical composition across source types.

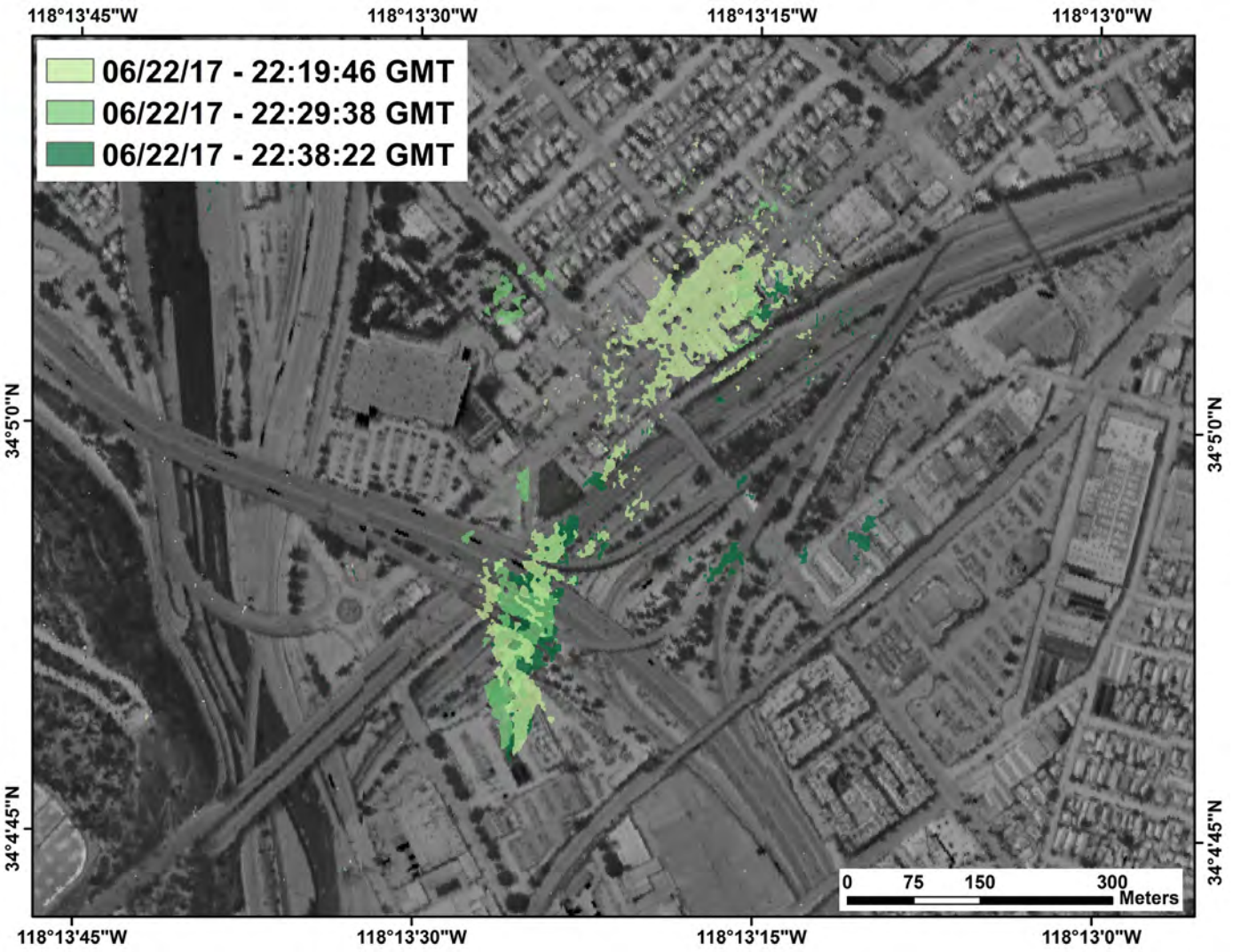


Figure 1. Methane plume from a liquefied-compressed natural gas fueling station in Los Angeles, imaged three times 10 minutes apart, by the Mako hyperspectral sensor.

Could O&G Wastewater Be a Significant Source of Air Toxics in the Northern Colorado Front Range?

R. Edie[1], A.M. Robertson[1], S. Murphy[1], G. Petron[2,3], M. Madronich[2,3], and B.H. Vaughn[4]

[1]University of Wyoming, Laramie, WY 82071; 719-244-6364, E-mail: redie@uwyo.edu
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[4]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309

Upstream oil and natural gas (O&G) operations in the Northern Colorado Front Range (NCFR) ozone non-attainment area have come under scrutiny as sources of ozone precursor emissions and hazardous air pollutants such as benzene, toluene, ethylbenzene, and xylenes (BTEX). Additionally, drilling operations in close proximity to residential areas have increased the public's concern about possible health impacts. An often-overlooked byproduct of oil and gas extraction—produced water—is another area of concern for potential air quality and health impacts in the region.

Emission plumes from produced water disposal facilities were investigated with the University of Wyoming mobile laboratory, which houses an Ionicon Proton Transfer Reaction Time of Flight Mass Spectrometer (measuring BTEX), Picarro $CH_4/CO_2/CO$ analyzer, meteorological instrumentation, and GPS. BTEX enhancements observed at these facilities were three to four orders of magnitude above background in some instances. These real-time measurements of BTEX mixing ratios downwind of disposal wells reveal seasonal and day-to-day variations in emission composition profiles. Additionally, the relative abundance of BTEX species is not reflected in the inventory (Figure 1). Most striking is the complete absence of benzene in the State inventory for some facilities.

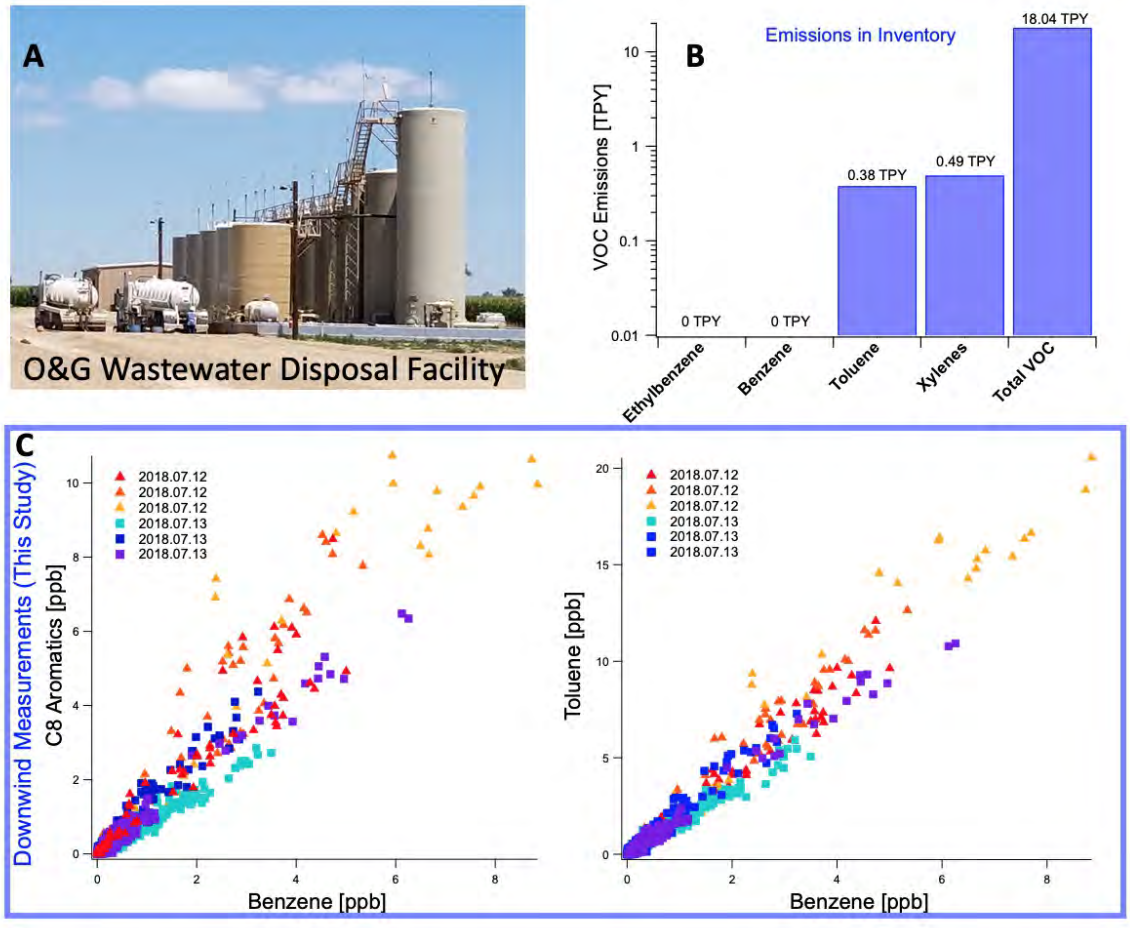
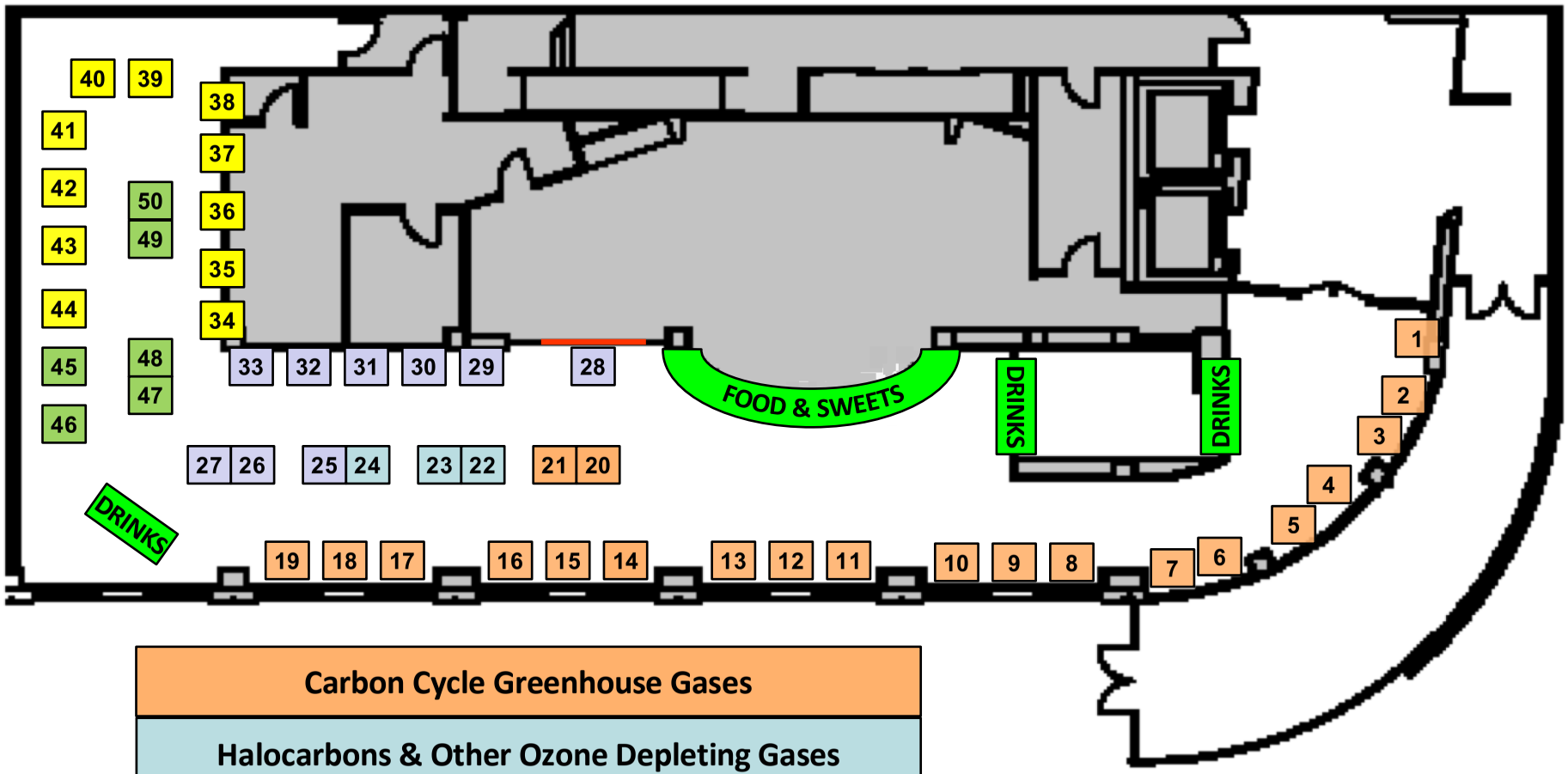


Figure 1. Oil and gas wastewater disposal facility (A) with associated emissions from the State inventory (B). Emissions measured in this study (C) indicate benzene is missing from the inventory.

Notes:

2019 GMAC Poster Session



Carbon Cycle Greenhouse Gases
Halocarbons & Other Ozone Depleting Gases
Ozone & Water Vapor
Surface Radiation, Clouds, & Aerosol Distributions
Interdisciplinary Connections & Partnerships
Food & Drinks

Link to full Poster Session agenda & map

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2019

David Skaggs Research Center, Cafeteria
325 Broadway, Boulder, Colorado 80305 USA

Tuesday, May 21, 2019 Poster Session Agenda

(Only presenter's name is given; please refer to abstract for complete author listing.)

2019 GMAC Poster Session - Carbon Cycle Greenhouse Gases

P-1 One-step Preparation of Gravimetric CO_2-in-air Standards

Brad Hall (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))

P-2 Development of a New Flask-air Analysis System for the Global Greenhouse Gas Reference Network

Andrew Crotwell (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-3 Laboratory Identification and Testing of Sources of Bias in Carbon Dioxide Measurements of Atmospheric Air Collected and Stored in Glass Flasks

Don Neff (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-4 Tower *in situ* and Flask CO_2 Comparisons

Jonathan Kofler (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-5 High Humidity-induced Bias in Aircraft Network CO_2 Data Due to Water Condensation in Flasks

Kathryn McKain (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-6 Stable Carbon Isotope Analysis of Airborne Particulate Matter Using a Carbon Aerosol Analyzer and a Cavity Ringdown Spectrometer

Jonathan Bent (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-7 Standoff Measurements of CO_2 and H_2O in Boulder using DIAL And IPDA Techniques

David Plusquellic (National Institute of Standards and Technology (NIST), Physical Measurement Laboratory, Quantum Electromagnetics Division)

P-8 Combining *in situ* and Satellite Observations of CO_2 in a Synthesis Inversion Framework for the U.S. Corn Belt

Bharat Rastogi (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-9 Partitioning Sources of CO_2 Atmospheric Signal in an Urban Site Using Carbon Monoxide as a Tracer

Wilson K. Gichuhi (Department of Chemistry, Tennessee Technological University)

P-10 Utilization of CH_4:CO_2 and CO:CO_2 Correlations in Deciphering Temporal Changes in Urban CH_4 and CO Emissions

Lahiru P. Gamage (School of Environmental Studies, Tennessee Technological University)

P-11 Utilizing Public Transit for Urban Atmospheric Monitoring in Denver, CO

Isaac Vimont (National Research Council Post-Doc)

P-12 Creating an Emissions Map for Benzene Based on Fossil Fuel CO_2 emissions: "HESTIA Benzene"

Isaac Vimont (National Research Council Post-Doc)

P-13 Characterization and Quantification of Benzene Emissions from a New Multiwell Pad in a Colorado Front Range Residential Community

Ingrid Mielke-Maday (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-14 Measuring BTEX with a Commercial GC-PID System in an Oil and Gas Field

Monica Madronich (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-15 Open-path, Mid-infrared, Dual Comb Spectroscopy for Measurement of Ambient Ethane and Propane

Kevin Cossel (National Institute of Standards and Technology (NIST))

P-16 Continuous Methane Leak Detection in Oil and Gas: Recent Progress Toward a Regional Approach with Dual Frequency Comb Spectroscopy and Inversions

Caroline Alden (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-17 Measurement Capabilities of the CU SOF Instrument: Separation of Methane Emissions from Agricultural and Natural Gas Sources & Developing Techniques to Quantify Wildfire Emissions

Rainer Volkamer (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-18 Modeling Ground- and Aircraft-based Methane Monitoring Systems for Natural Gas Storage Facilities using LPDM-LES

Alex Rybchuk (University of Colorado, Department of Mechanical Engineering)

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2019

David Skaggs Research Center, Cafeteria
325 Broadway, Boulder, Colorado 80305 USA

Tuesday, May 21, 2019 Poster Session Agenda

(Only presenter's name is given; please refer to abstract for complete author listing.)

2019 GMAC Poster Session - Carbon Cycle Greenhouse Gases (continued)

P-19 How Useful Are Carbon Stable Isotopes of Methane? Improvements in Analysis and Quality Controls at the INSTAAR Stable Isotope Lab
Sylvia Englund Michel (Institute of Arctic and Alpine Research (INSTAAR), University of Colorado)

P-20 Sensitivity of the Isotopic Composition of Atmospheric Methane to Oxidant Fields in the GEOS Model
Sarah Strode (Universities Space Research Association (USRA))

P-21 Quantification of Transport Error Using a Coupled Meteorological and Constituent Transport Model Within an Ensemble Kalman Filter (EnKF)
Vikram Khade (University of Toronto, Department of Physics, Toronto, Canada)

2019 GMAC Poster Session - Halocarbons and Other Ozone Depleting Substances

P-22 Two Years of MAX-DOAS Data from Remote Tropical Marine Mountaintops
Theodore K. Koenig (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-23 Improving the Sampling and Analysis of Atmospheric Carbonyl Sulfide (OCS) in the GMD Networks
Benjamin R. Miller (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-24 SO_2 Profiles during the Kilauea Eruption
Paul J. Walter (St. Edward's University)

2019 GMAC Poster Session - Ozone and Water Vapor

P-25 Optimizing Umkehr Ozone Profile Retrievals during the Mt. Pinatubo Volcanic Eruption
Koji Miyagawa (Guest Scientist at NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))

P-26 South American Dobson Intercomparison Campaign for RA-III
Glen McConville (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-27 New Volumetric Flow Rate Tests of Ozonesonde Pumps at Reduced Pressures
Bryan Johnson (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))

P-28 Ozonesonde Observations at South Pole Station During the 2018 Ozone Hole
Patrick Cullis (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-29 The Role of Convection in Tropical Ozone Variability Inferred from Profiles at NOAA's SHADOZ Stations (1998–2017)
Anne M. Thompson (NASA Goddard Space Flight Center (GSFC), Atmospheric Chemistry and Dynamics Laboratory)

P-30 Measured and Modeled Ozone Distributions over the Atlantic and Pacific Oceans from the ATom Mission
Eric Hintsa (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-31 Comparison of Vertical Distribution of Ozone Profiles between Ozonesondes and the GMI Merra II Model
Emrys Hall (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-32 Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE III/ISS) Science Data Products: Preliminary Validation Results
Susan Kizer (Science Systems and Applications, Inc. (SSAI))

P-33 Seasonal Trends in Observed Surface Ozone Conditions in the Arctic
Audra McClure-Begley (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2019

David Skaggs Research Center, Cafeteria
325 Broadway, Boulder, Colorado 80305 USA

Tuesday, May 21, 2019 Poster Session Agenda

(Only presenter's name is given; please refer to abstract for complete author listing.)

2019 GMAC Poster Session - Surface Radiation, Clouds, and Aerosol Distributions

P-34 Overview and Selected Results from the NOAA Federated Aerosol Network
Patrick Sheridan (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))

P-35 An Overview of the Effect of Water Uptake on Aerosol Particle Light Scattering: Observations, Evaluation of Proxies, and Comparison with Global Models
Elisabeth Andrews (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-36 Seasonal Dependence of Column-averaged and Near-surface Aerosol Optical Properties Measured at Appalachian State University (APP)
Taylor Foote (Appalachian State University, Department of Physics and Astronomy)

P-37 Variability of Aerosol Optical Properties at Mauna Loa and its Characteristics According to Source Regions
Jong-Uk Park (Seoul National University, South Korea)

P-38 Case Study of Air Quality during Winter Season over Northeastern Pakistan during 2007 to 2015
Muhammad Zeeshaan Shahid (College of Earth & Environmental Sciences University of the Punjab, Lahore, Pakistan)

P-39 34-year Trends in Aerosol Chemistry in Relation to Aerosol Acidity at Alert, NU, Canada
Sangeeta Sharma (Environment and Climate Change Canada, Toronto, Canada)

P-40 Variation of Carbonaceous Aerosols on Foggy Days in and Around Special Episodic Events
Pallavi Saxena (University of Delhi, Hindu College, Department of Environmental Sciences, Delhi, India)

P-41 Two Centuries of Volcanic Aerosols Derived from Lunar Eclipse Records, 1805–2019
Richard A. Keen (University of Colorado, Emeritus, Department of Atmospheric and Oceanic Sciences)

P-42 Holographic Cloud Particle Imager (HCPI) for Unmanned Aircraft Systems (UASs)
Andrew M. Harrington (Radiation Monitoring Devices, Inc.)

P-43 The De-Icing Comparison Experiment (D-ICE): A Study of Broadband Radiometric Measurements Under Icing Conditions in the Arctic
Christopher J. Cox (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado)

P-44 The Need for a Surface Energy Budget Network and Increased Surface Radiation Measurements to Improve Weather and Climate Forecasting
John A. Augustine (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))

2019 GMAC Poster Session - Interdisciplinary Connections and Partnerships

P-45 Curating a Multiagency Set of Federal Climate Indicators
Laura Stevens (North Carolina State University (NCSU))

P-46 The New Barrow Atmospheric Baseline Observatory
Brian Vasel (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD))

P-47 Opportunity to Plan and Develop a Comprehensive U.S. Arctic Research Infrastructure Network Hub at Oliktok Point, Alaska
Jasper Hardesty (Sandia National Laboratories)

P-48 Soil Respiration Response To *Adenostoma Sparsifolium* Microsites Among Seasons in Semiarid Shrubland
Jessica Montes (San Diego State University, Global Change Research Group)

P-49 The Acquisition of Fog in Montane California Chaparral: Ecosystem Inputs and Use by Plants
Breahna Gillespie (San Diego State University, Global Change Research Group)

P-50 A Bibliometric Analysis of GMD Publications, 2010–2018
Sue Visser (FedWriters)

Notes:

One-step Preparation of Gravimetric CO_2-in-air Standards

B. Hall[1], A. Crotwell[2,1], B.R. Miller[2,1], and J.W. Elkins[1]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-7011, E-mail: Bradley.Hall@noaa.gov
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309

The NOAA Global Monitoring Division maintains the mole fraction scale for CO_2 used by the WMO Global Atmosphere Watch program. That scale is defined by 15 primary standards (modified natural air) value-assigned using the NOAA CO_2 manometer. We have recently identified a potential bias in the manometric measurement (X2007 scale ~0.04% too low). In order to better understand this bias and move towards a scale revision, we have prepared CO_2 standards using an independent method. Recent advances in our understanding of the behaviour of CO_2 in aluminum cylinders (drift) and experiments to characterize the adsorption of pure CO_2 to stainless steel surfaces enable the preparation of gravimetric CO_2-in-air standards with relatively low uncertainty. Five gravimetric standards, of nominal range 350–500 ppm, were prepared in 29.5-L aluminum cylinders. The gravimetric standards compare well with a proposed revision of the WMO X2007 CO_2 scale, confirming a ~0.04% bias. This work supports our efforts to maintain the WMO CO_2 scale.

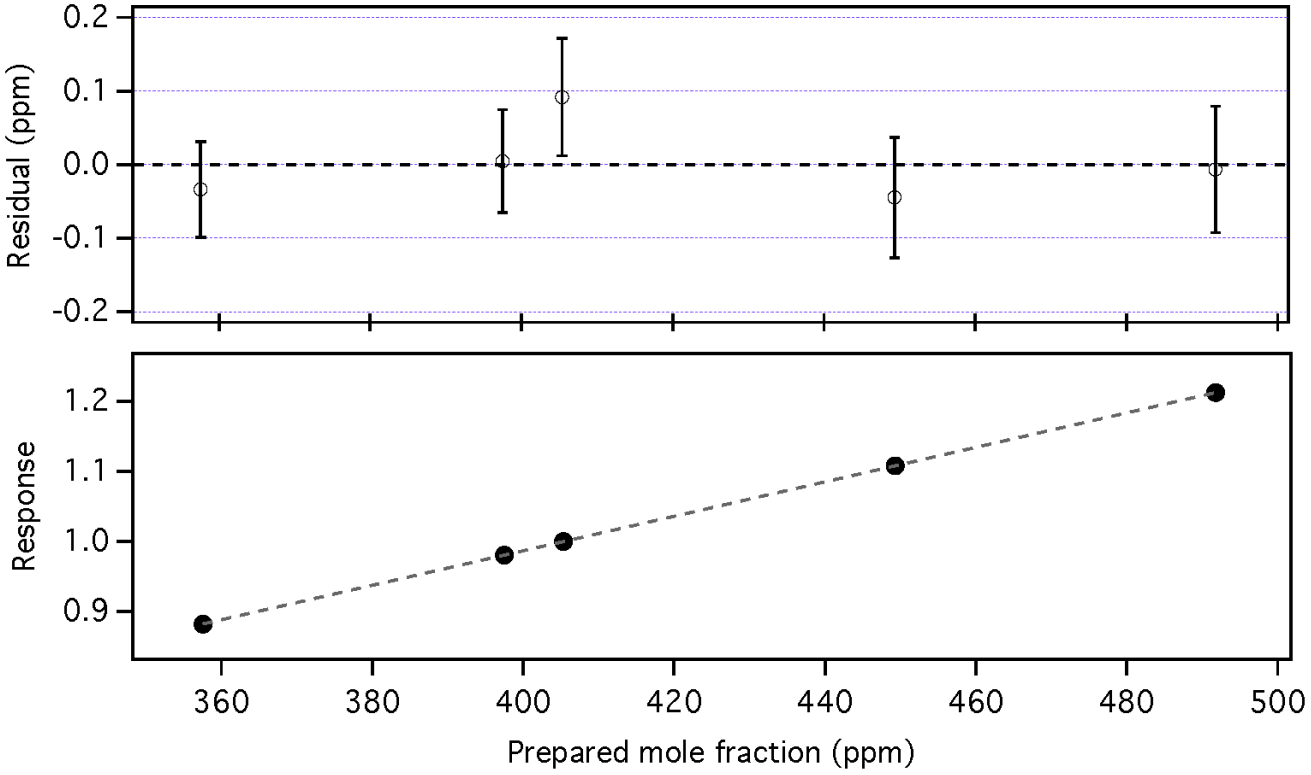


Figure 1. Comparison of five gravimetric CO_2 standards, analyzed by laser spectroscopy.

Development of a New Flask-air Analysis System for the Global Greenhouse Gas Reference Network

A. Crotwell[1,2], E. Dlugokencky[2], P. Lang[3], M. Madronich[1,2], E. Moglia[1,2], G. Petron[1,2], and K. Thoning[2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6494, E-mail: andrew.crotwell@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Retired from NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The Carbon Cycle Greenhouse Gases group (CCGG) of NOAA GMD monitors the major long-lived greenhouse gases CO_2, CH_4, N_2O, and SF_6 (along with CO and H_2) by collecting discrete air samples (flask samples) from a global network of surface sites through its Global Greenhouse Gas Reference Network (GGGRN). In addition to the surface sites, the CCGG aircraft project collects flask-air samples by light aircraft to provide vertical profiles through the free troposphere. Air samples are returned to Boulder for analysis on a single analytical system to provide high internal consistency of the measurements. The current flask-air analysis system, which measures all six species simultaneously, has been in use since 1997 and has measured more than 300,000 discrete air samples.

New analytical techniques based on laser spectroscopy have become commercially available that may lead to improvements in measurement uncertainty. However, these instruments are often developed for *in situ* applications where sample gas is unlimited. For flask-air samples, the amount of gas available is limited by the size of the sample collected and the needs of additional measurements performed on the flasks after the CCGG analysis.

We describe here the development and testing of a new flask-air analysis system using laser spectroscopic techniques for CO_2, CH_4, N_2O, and CO (along with gas chromatographic techniques for SF_6 and H_2) that minimizes gas usage while improving the analytical repeatability for CO_2 (±0.02 μmol mol^{-1}), CH_4 (±0.1 nmol mol^{-1}), and N_2O (±0.05 nmol mol^{-1}). The analytical performance for CO (±0.2 nmol mol^{-1}), SF_6 (±0.04 pmol mol^{-1}), and H_2 (±1.0 nmol mol^{-1}) is the same as for the current system. Other improvements in consistency of sample/standard gas treatment, time of analysis, and efficiency of operation will be highlighted.

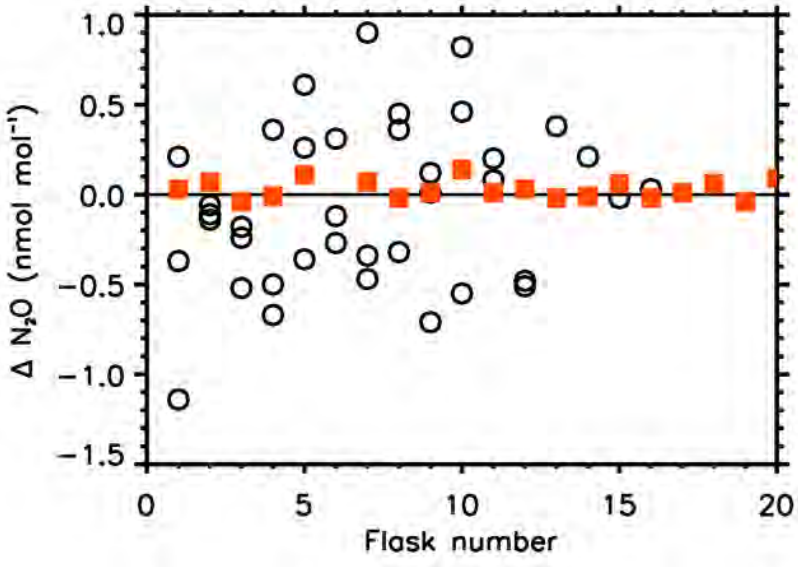


Figure 1. Flasks filled from a calibrated cylinder of air are used to compare the performance of the N_2O measurements on the new flask-air analysis system using laser spectroscopy (red squares, average difference from the assigned value of the cylinder = 0.03 ±0.05 nmol mol^{-1}) with the current flask-air analysis system which uses gas chromatography with an electron capture detector (black circles, average difference = -0.06 ±0.4 nmol mol^{-1}).

Laboratory Identification and Testing of Sources of Bias in Carbon Dioxide Measurements of Atmospheric Air Collected and Stored in Glass Flasks

D. Neff[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-4271, E-mail: don.neff@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The Global Monitoring Division's Carbon Cycle Greenhouse Gases research group carries out extensive quality control activities related to its Global Greenhouse Gas Reference Network, with the goal that the atmospheric measurements obtained meet the uncertainty guidelines outlined by the World Meteorological Organization Global Atmosphere Watch. For measurements of the dry-air mole fraction of carbon dioxide this guideline is for an interlaboratory comparability of ± 0.1 ppm.

Laboratory tests have revealed that the presence of ordinary levels of water vapor in atmospheric air samples (with or without drying) collected and stored in glass flasks, in conjunction with contaminates on the flask surface, can significantly bias measurements of carbon dioxide in these samples. This bias appears to be related to a process involving the surface adsorption characteristics of water vapor and carbon dioxide inside the flasks. This process can bias the measured dry-air mole fraction of carbon dioxide, ranging from a 0.1 ppm to more than a 1.0 ppm increase relative to the ambient air initially collected. Results of these laboratory tests and related tests are presented, including flask preparation and sampling techniques that can greatly reduce or eliminate these biases in field samples. In the laboratory, the adsorption related bias outlined above can be eliminated simply by “prefilling” the glass flask with air that includes a small amount of water vapor (e.g. ~0.6% by volume) prior to collecting the air sample to be measured. The figure below shows examples of this bias and how it is eliminated by using an appropriate “prefill”.

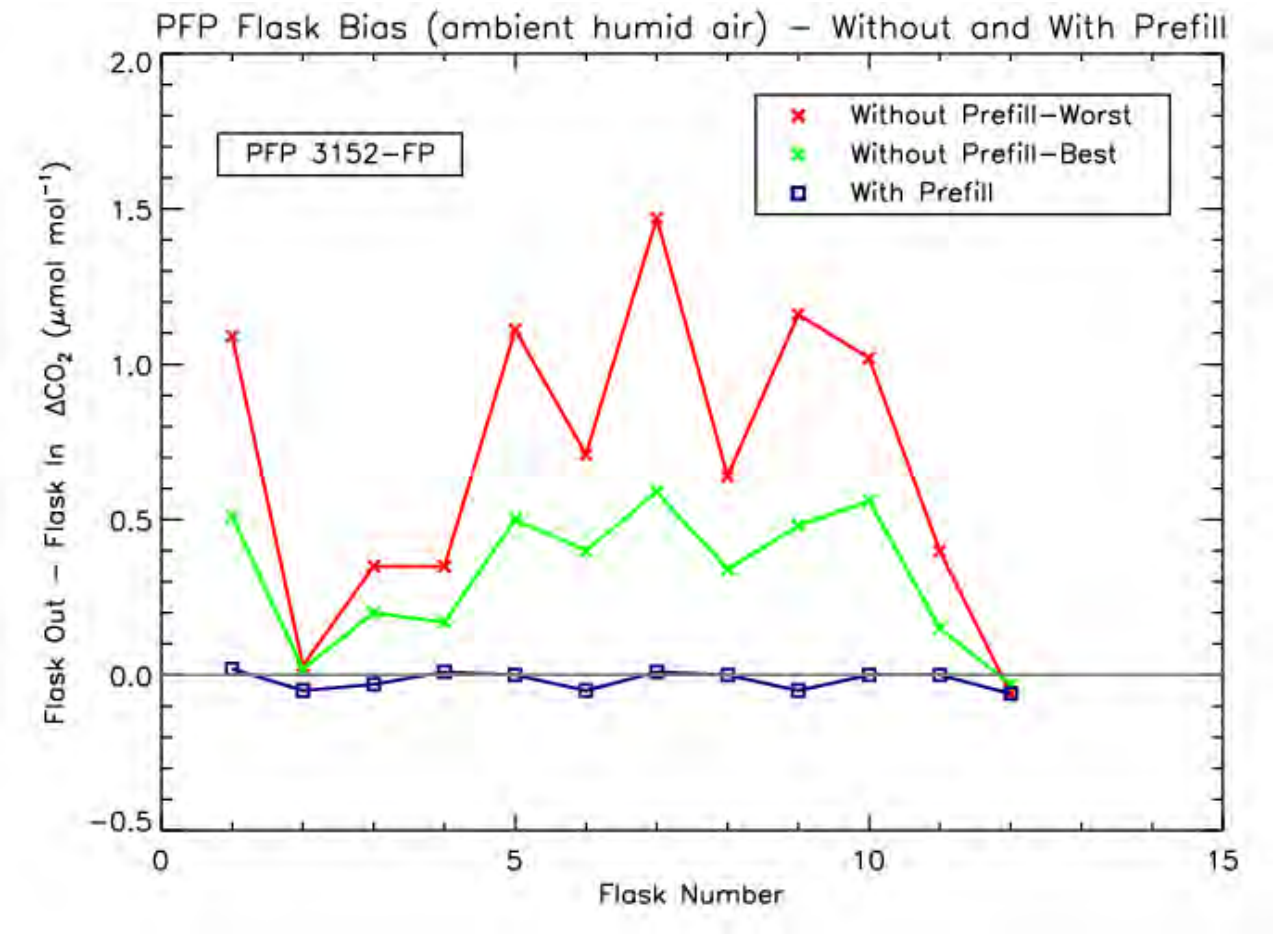


Figure 1. Example of adsorption related bias and its elimination through "prefilling".

Tower *in situ* and Flask CO_2 Comparisons

J. Kofler[1,2], D. Neff[1,2], A.E. Andrews[2], and P. Handley[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-4679, E-mail: jonathan.kofler@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

Programmable Flask Packages (PFP's) containing twelve glass flasks are used to take samples at NOAA aircraft and tall tower network sites. Measurement of flask samples taken at tower sites are compared to simultaneous *in situ* measurements. Around 2009 or 2010 we noticed that some flasks would have anomalously high CO_2 at tower sites when compared with *in situ* measurements. Lab tests to understand the high CO_2 values revealed some flasks develop offsets that are triggered by humidity. It was determined that pre-filling flasks with sample air could reduce the offsets. Statistical agreement between flask and *in situ* comparisons at tower sites improved from showing +0.1 ppm CO_2 offset to a close 0.0 when an appropriate prefill strategy was implemented. History of prefill strategy and changes to CO_2 flask - *in situ* is discussed.

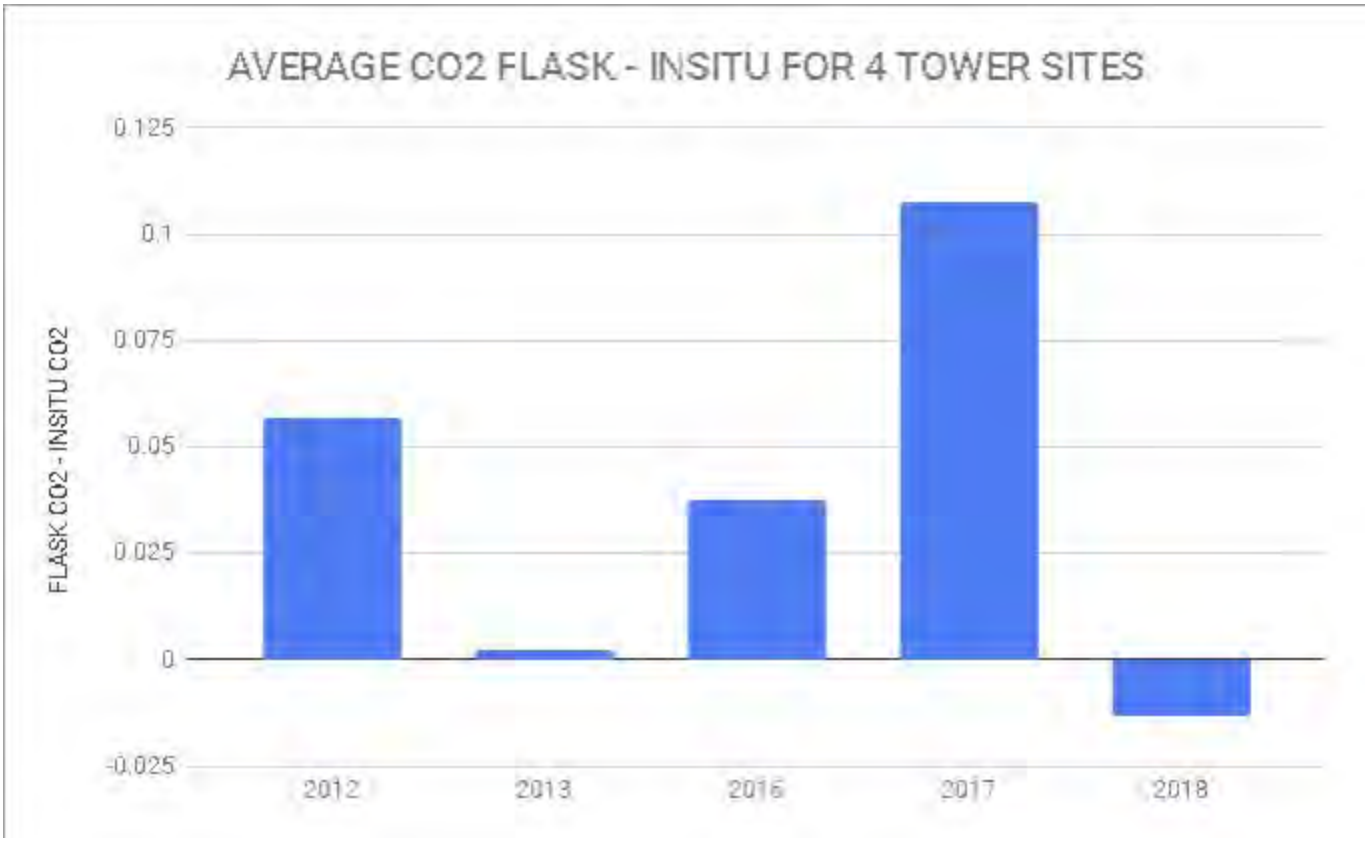


Figure 1. In years 2013 and 2016 longer prefill strategies were implemented resulting in better flask *in situ* agreemement than other years.

High Humidity-induced Bias in Aircraft Network CO_2 Data Due to Water Condensation in Flasks

K. McKain[1,2], C. Sweeney[2], A.E. Andrews[2], D. Neff[1,2], J. Mund[1,2], B. Baier[1,2], and S. Basu[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6229, E-mail: kathryn.mckain@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

In the Aircraft Program of the NOAA Greenhouse Gas Reference Network, Programmable Flask Package (PFP) samples are filled to a pressure of 40 psi and sample air is typically not dried. Recent comparisons of undried PFP CO_2 measurements with coincident CO_2 measurements made by other methods show evidence for a low CO_2 bias from PFPs related to ambient water vapor concentrations > ~1.7% v/v. We hypothesize the CO_2 has dissolved into liquid water condensed onto the sides of the flask at the time of analysis, although this may be partly compensated by other effects. We recently implemented a flagging scheme for the entire aircraft PFP dataset which resulted in the rejection of ~5% of the data. This poster presentation will show empirical evidence for the high humidity-related CO_2 bias, describe our procedure for identifying affected data, characterize patterns in rejected data, explore the potential for correcting historical data, and offer possible solutions for eliminating this problem in the future. To begin to understand the potential impact of such a bias on CO_2 flux calculations that utilize the aircraft network data, we will investigate the size of the bias relative to the terrestrial uptake signal at individual sites.

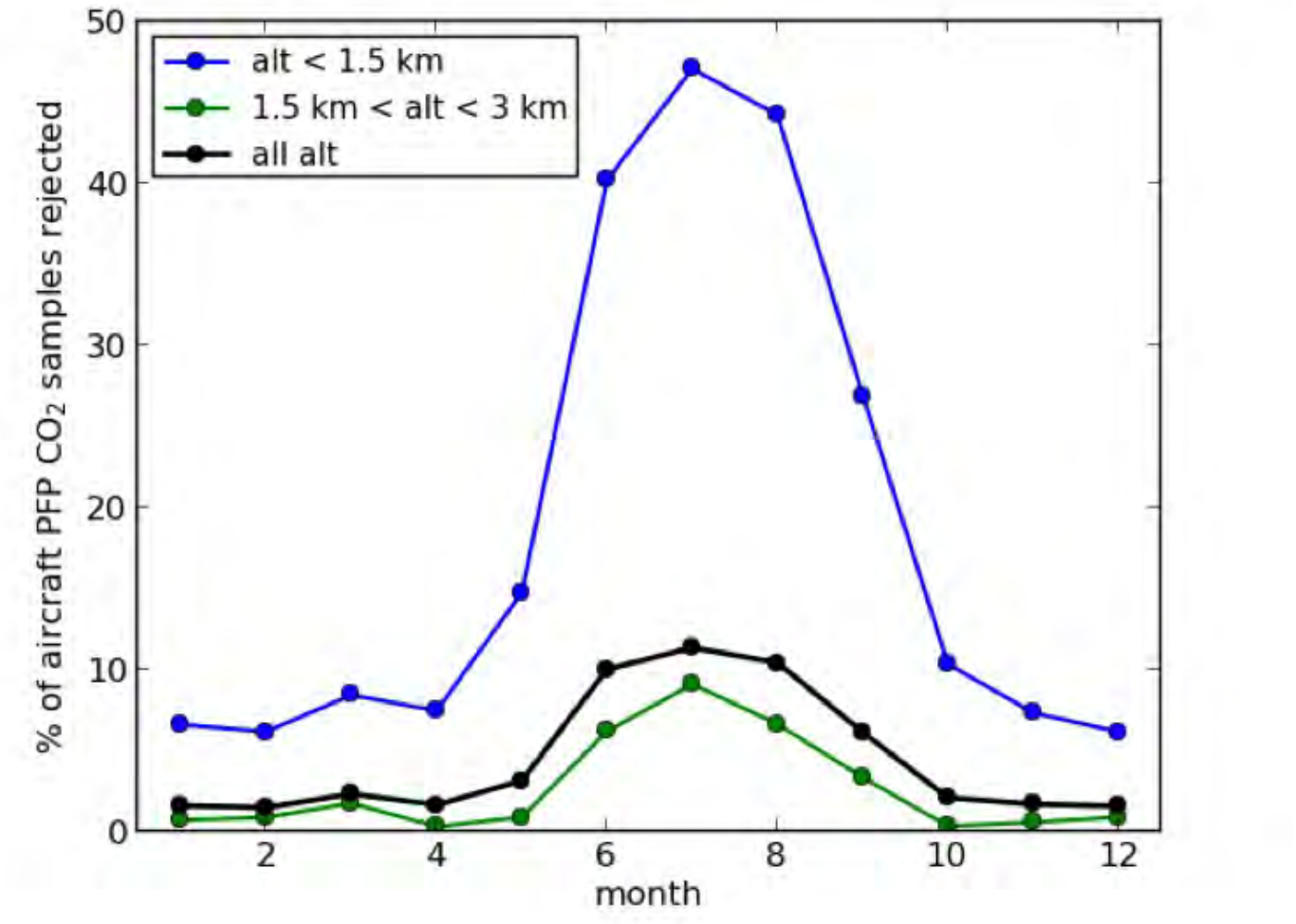


Figure 1. Fraction of CO_2 data from the aircraft PFP network that has been rejected by month and altitude bin based on having ambient humidity levels > 1.7% v/v at the point of sampling.

Stable Carbon Isotope Analysis of Airborne Particulate Matter Using a Carbon Aerosol Analyzer and a Cavity Ringdown Spectrometer

Z. Lin[1], C. Rella[1], J. Hoffnagle[1], R. Winkler[1], Y. Zhang[2], R. Cary[3], and J. Bent[4,5]

[1]Picarro Inc., Santa Clara, CA 94054; 408-962-3973, E-mail: zlin@picarro.com
[2]Yale- Nanjing University of Information Science and Technology (NUIST) Center on Atmospheric Environment, Nanjing, Jiangsu Province 210044, China
[3]Sunset Laboratory Inc., Tigard, OR 97223
[4]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-8747, E-mail: jbent@ucar.edu
[5]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

Particulate matter (PM) affects more people than any other ambient air pollutant, leading to increased risk of cardiovascular and respiratory diseases. Levels of PM_{10} and $PM_{2.5}$ in the developing world, especially southeast Asia and the Indian subcontinent, routinely exceed World Health Organization guidelines, often by a factor of 10 or more. Despite their importance to poor air quality in urban areas in the developing world, the mechanisms that lead to heavy particulate loading are not well understood. Consequently, there is great interest in developing new tools for understanding the pollution sources and mechanisms that drive the formation of harmful aerosols. Stable isotope analysis of the carbon contained in the aerosols promises to provide important information about the sources and processes that govern aerosol formation and transport. We have coupled a Sunset Laboratories organic and elemental carbon (OC/EC) analyzer to a cavity ringdown spectrometer (CRDS) to create a system that provides hourly measurements of the $d^{13}C$ content of PM in the ambient air. The OC/EC system executes a sequence of temperature and oxygenation steps to create distinct CO_2 pulses of organic carbon, carbonate carbon, and elemental carbon, which are subsequently analyzed by the CRDS instrument for $d^{13}C$-CO_2. We present laboratory measurements with this system, including calibration, precision, and drift, demonstrating that a system of this design can deliver aerosol stable isotope analysis at sub-permil accuracy and precision. This system can be operated unattended, and is thus suitable for remote field deployment.

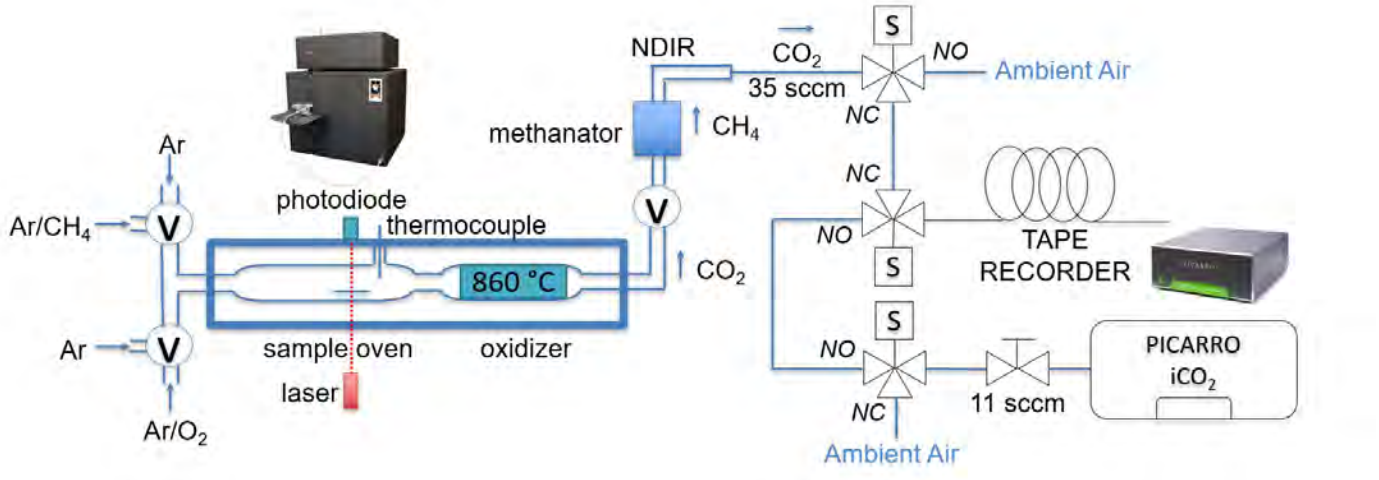


Figure 1. Experiment setup, showing Sunset OC/EC Aerosol Analyzer and Picarro CRDS.

Standoff Measurements of CO_2 and H_2O in Boulder using DIAL And IPDA Techniques

D. Plusquellic, G.A. Wagner, and K. Briggman

National Institute of Standards and Technology (NIST), Physical Measurement Laboratory, Quantum Electromagnetics Division, Boulder, CO 80305; 303-497-6089, E-mail: david.plusquellic@nist.gov

Integrated path differential absorption (IPDA), light detection and ranging, and differential absorption LIDAR (DIAL) systems have been developed to monitor and detect sources of CO_2 in the spectral region of ≈ 1602.2 nm. The strategy of both approaches is to rapidly scan through a narrow spectral window that contains both CO_2 and H_2O absorption lines and to fit the observed line shapes to obtain CO_2 dry-air mixing ratios. The IPDA system is based on an electro-optic (EO) modulated continuous-wave (CW) laser to produce >100 frequencies at a scan repetition frequency (SRF) of 10 kHz. The DIAL system consists of an optical parametric oscillator (OPO) operating at a pulse repetition frequency of 100 Hz. The OPO is sequentially injection-seeded with 10 frequencies from an EO-modulated CW laser at a SRF of 10 Hz. We compare the dry-air mixing ratio results with those of a calibrated cavity ringdown point sensor for several nighttime periods.

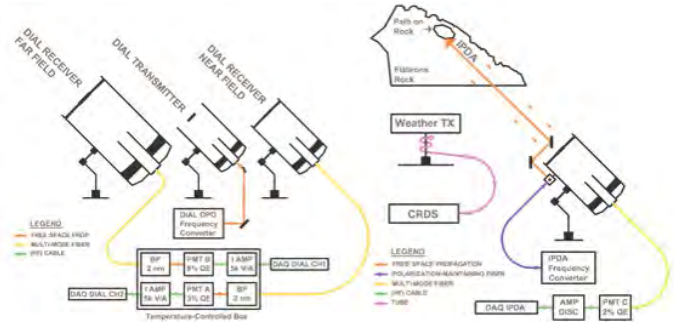


Figure 1. Multifrequency DIAL system consisting of a near- and far-field receiver and hybrid photon current/count detection system (left panel) and natural target IPDA system consisting of a coaxial transmitter and photon counting detection system (right panel).

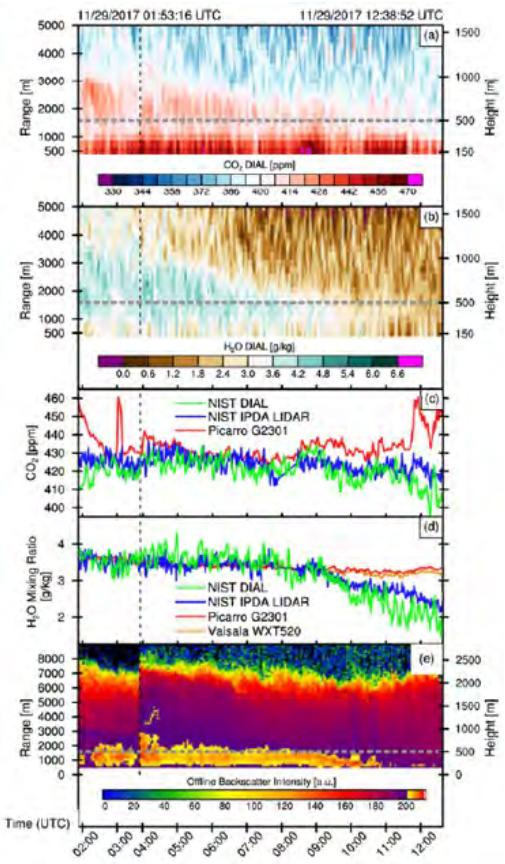


Figure 2. DIAL measurements on 11/29/2017 consisting of the (a) range resolved CO_2, (b) range resolved H_2O dry-air mixing ratios, and (e) range and background corrected offline backscatter signals. Comparisons of the IPDA LIDAR and point sensor data (Picarro G2301 and Vaisala WXT520) are made with the column-averaged DIAL data (0.5 km to 1.75 km) for (c) CO_2 and (d) H_2O, respectively. DIAL surfaces are shown for an effective time resolution of 10 min and for increasing range bin size (see text for details). Dashed vertical line indicates a small gap in data. Time on abscissa is UTC (local time −7 hrs).

Combining *in situ* and Satellite Observations of CO_2 in a Synthesis Inversion Framework for the U.S. Corn Belt

B. Rastogi[1], C. Alden[1,2], A.E. Andrews[2], J.B. Miller[2], and K. Guan[3]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 707-567-8793, E-mail: bharat.rastogi@colorado.edu
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Department of Natural Resources and Environmental Sciences, College of Agriculture, Consumer, and Environmental Sciences, University of Illinois at Urbana-Champaign, Urbana, IL 61801

Agriculture has been central to the Anthropocene, is intricately tied to recent and projected increases in global population, and is fundamentally coupled to the global carbon cycle. Farming activity contributes a substantial portion of the total anthropogenic-greenhouse gas emissions but intensification and advances in technology have also resulted in high levels of crop photosynthesis (GPP). As a result, intensively managed, high-productivity agricultural areas such as the U.S. corn belt exhibit the largest growing season fluxes globally, and result in drawdown of atmospheric CO_2. Increases in crop GPP are also due, in part, to effects of rising CO_2 concentrations, a phenomenon known as CO_2 fertilization. However, higher CO_2 levels can also reduce stomatal conductance and density, thereby suppressing carbon uptake. Stomatal conductance also decreases in response to rising atmospheric demand of moisture from the leaf surface, which is associated with rising temperatures. Taken together, these factors complicate our ability to accurately model crop yield responses to climate change and carbon-climate feedbacks. Carbon cycle models typically use biogeochemical relationships between processes and meteorological variables to infer carbon fluxes. However, processes are often simplified and sometimes remain unvalidated at large spatial and temporal scales. Top down models can be used to assimilate observed CO_2 concentrations to constrain fluxes, but prior flux models, sparsity of CO_2 observations, and errors in modelling transport can be major sources of uncertainties in these models. Recently, satellite measurements of column-integrated CO_2 have been successfully assimilated in inversion models, helping to increase measurement density, but evidence of potential biases in satellite retrievals has been found. No studies to-date have combined surface data with the satellite data in such a framework that combines the increased observation density of the satellite data with state-of-the-art, crop-specific prior flux models and highly precise surface observations. We introduce here an approach that combines these strengths in an attempt to minimize posterior flux uncertainty. Here we present preliminary results from a synthetic data study, in which pseudo-data CO_2 concentrations simulate real observational coverage (i.e., *in situ* surface data and satellite data) for the U.S.-corn belt (Fig. 1) for the 2015 growing season. We used NOAA's CT-Lagrange inversion framework coupled with WRF-STILT footprints and a novel crop-specific, spatially explicit parametrization of the CLM-APSIM model as prior flux.

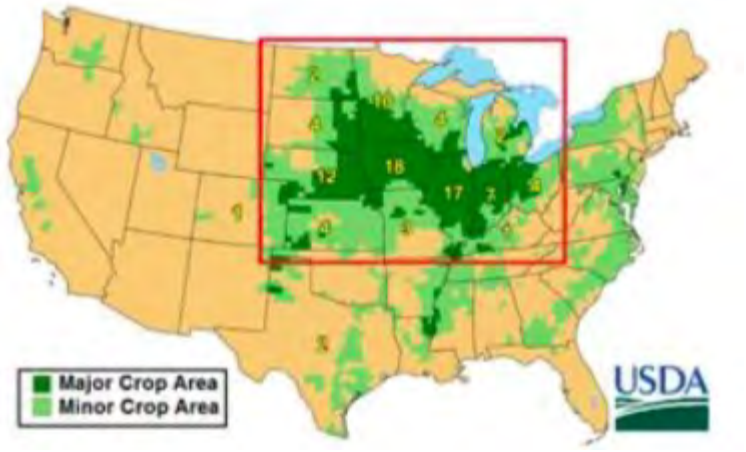


Figure 1. Study domain shown in the red box. The background shows the averaged corn production from 2007–2012, and the numbers indicate the percentage (%) of the state production to the national total corn production.

Partitioning Sources of CO_2 Atmospheric Signal in an Urban Site Using Carbon Monoxide as a Tracer

W.K. Gichuhi[1], L.P. Gamage[2], and E. Hix[3]

[1]Department of Chemistry, Tennessee Technological University, Cookeville, TN 38505; 931-372-3499, E-mail: wgichuhi@tntech.edu
[2]School of Environmental Studies, Tennessee Technological University, Cookeville, TN 38505
[3]University of Tennessee at Knoxville, Knoxville, TN 37996

The uncertainty associated with atmospheric measurements of fossil fuel CO_2 (CO_{2foss}) in an urban environment is mainly attributed to the presence of high spatiotemporal variability, atmospheric complexity, complicated underlying processes governing gas mixing and flux dynamics, and influence by local emission patterns. Despite the associated uncertainties, the partitioning of mixing ratios into anthropogenic CO_2 (CO_{2An}), background CO_2 (CO_{2bac}), and biospheric CO_2 (CO_{2bio}) in an urban CO_2 signal are essential in carbon cycle and air quality regulations. In this research, we present and evaluate a CO:CO_2 ratio technique, based on measurements obtained using a wavelength-scanned cavity ring down spectrometry technology, as a direct method of identifying the source of urban CO_2 signals in Cookeville (36.1628° N, 85.5016° W), a medium-sized city located within the Eastern Highland Rim region of the United States. The NOAA HYSPLIT model is used to construct backward trajectories of the CO_2 and CO to determine the origin of the air masses contributing to the consistent diurnal and seasonal mixing ratio cycles that are accompanied by distinct seasonal CO:CO_2 ratios (β). In contrast to the spring and summer seasons, β values for the winter season are reasonably high, which is an indication of a strong CO:CO_2 correlation that corresponds to a reduced biospheric influence. The reduced biospheric influence is suggestive of a local or regional CO_2 signal that is driven by human-induced combustion processes at a time when photosynthesis is weak. For the year 2017, β values (ppb:ppm^{-1}) of 9.7 ±0.4, 5.3 ±0.4, and 2.0 ±0.2 were obtained for the winter, spring, and summer seasons, respectively. In 2018, a similar trend in the β ratios was obtained with values of 8.9 ±0.5, 7.4 ±0.7, and 2.6 ±0.5 for winter, spring, and summer seasons, respectively.

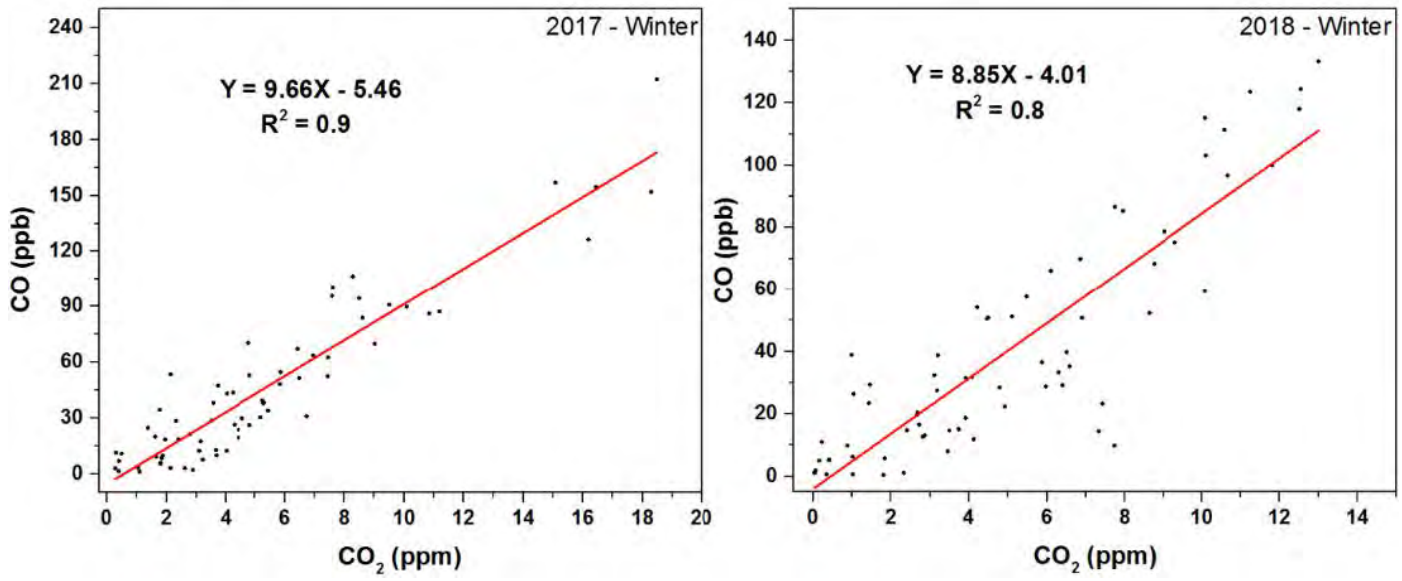


Figure 1. CO:CO_2 correlation plots obtained using CO and CO_2 mixing ratios above background levels.

Utilization of CH_4:CO_2 and CO:CO_2 Correlations in Deciphering Temporal Changes in Urban CH_4 and CO Emissions

L.P. Gamage[1], and W.K. Gichuhi[2]

[1]School of Environmental Studies, Tennessee Technological University, Cookeville, TN 38505; 931-539-2363, E-mail: lpgamage42@students.tntech.edu
[2]Department of Chemistry, Tennessee Technological University, Cookeville, TN 38505

The continued measurements of urban CH_4 and CO_2 atmospheric signals at local, regional, and global levels have continued to enhance our understanding and interpretation of carbon and methane cycles. In this study, the seasonal correlation between CH_4 and CO_2 (CH_4: CO_2) and CO and CO_2 (CO: CO_2) are evaluated within an urban setting. The linear regression analysis is used to determine seasonal correlations between the respective tracer gas and CO_2. The NOAA HYSPLIT model is utilized in determining the origin of the air masses that contribute to the observed emission ratios and the consistent diurnal mixing ratio patterns throughout the year. These mixing ratio measurements are simultaneously and continuously taken at a site near the Cookeville city (36.1628° N, 85.5016° W), which is located within the greater Eastern Highland Rim region of Tennessee. Both the correlation coefficient (R^2) and emission ratios (ppb:ppm^{-1}) of CO and CO_2 for the winter season are reasonably high compared to all the other seasons, which is indicative of elevated anthropogenic emissions during the winter that are supplemented by high winter respiratory fluxes. For the years 2017 and 2018, CO:CO_2 winter emission ratio values were about five times higher than in the summer. Even though the CH_4 mixing ratios are different for each season, the calculated CH_4:CO_2 seasonal emission ratios do not show any significant difference throughout the year, with monthly averaged seasonal values ranging between 4.85 to 4.93 ppb:ppm^{-1}.

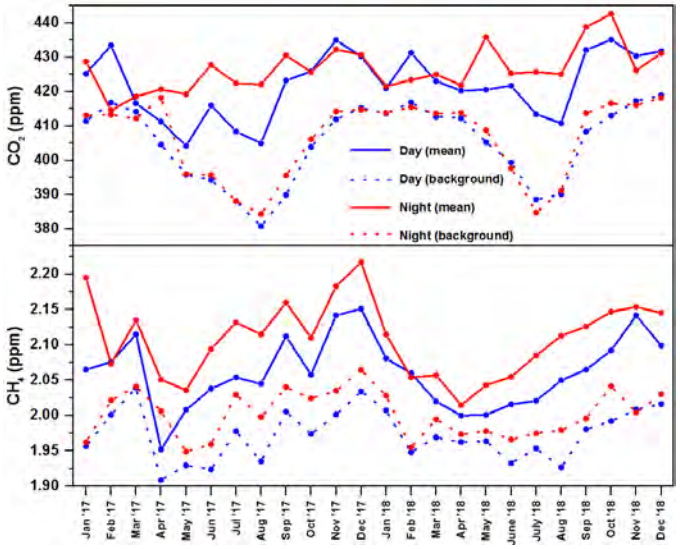


Figure 1. Day-night CO_2 and CH_4.

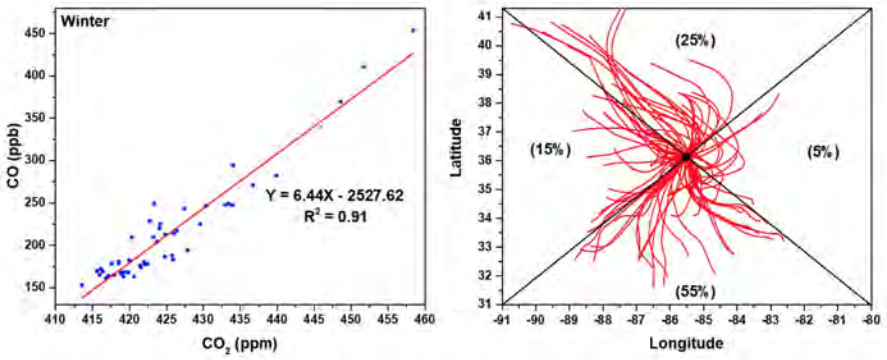


Figure 2. Correlation of CO_2 and CO in winter.

Utilizing Public Transit for Urban Atmospheric Monitoring in Denver, CO

L.E. Mitchell[1], I. Vimont[2,3], S.E. Michel[4], and B.H. Vaughn[4]

[1]University of Utah, Salt Lake City, UT 84112; 541-207-7204, E-mail: logan.mitchell@utah.edu
[2]National Research Council Post-Doc, Boulder, CO 80305; 303-497-6044, E-mail: isaac.vimont@noaa.gov
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[4]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309

Global awareness of the magnitude of emissions reduction needed to keep climate warming under 1.5°C is increasing. A recent IPCC report found that global CO_2 emissions must decline by 45% by 2030, reaching net zero around 2050 in order to meet that objective. At the same time, many cities have elevated levels of air pollution that lead to adverse health impacts in millions of people annually. To address both of these challenges, cities and states in recent years have been developing plans to reduce emissions of both greenhouse gases and air pollutants. In light of these commitments, new cost-effective measurement strategies that are able to track the spatial and temporal variability of atmospheric species within complex urban environments are needed.

Denver, CO is an excellent candidate for increased air quality monitoring and evaluation. Denver is consistently out of attainment for ozone (O_3) air quality standards and if the standards are tightened, the challenges facing Denver's pollution mitigation will increase. In order to better understand the nature of O_3 in Denver, higher spatial resolution measurements are needed than are currently employed around the greater Denver urban region. One promising new approach to urban atmospheric monitoring is deploying measurement systems on public transit vehicles. In Salt Lake City, UT (SLC) a monitoring system was deployed in December 2014 on a light rail public transit car measuring greenhouse gases and air pollutants (Mitchell et al., 2018). Analysis of the data from that project is ongoing, yet it has already yielded important policy-relevant insight about emissions from transportation and energy systems across the city.

To further utilize public transit-based monitoring we are exploring the possibility of a similar deployment on the RTD light-rail system in Denver, CO. Denver and SLC have similar air quality issues and also both have GHG reduction targets (50% reduction by 2030 in SLC; 30% reduction by 2025 in Denver). In this presentation we will discuss some of the results from the TRAX (Transit Express) project in SLC and also discuss how a similar project could be deployed in Denver.

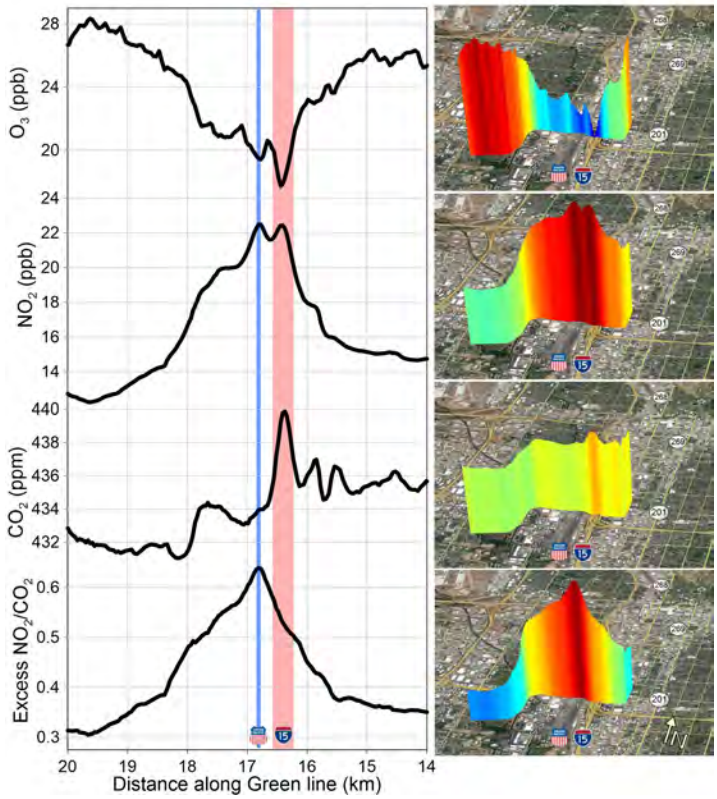


Figure 1. Relationships between species illustrating sources of NO_2 and CO_2 along a subsection of the TRAX line.

Creating an Emissions Map for Benzene Based on Fossil Fuel CO_2 emissions: "HESTIA Benzene"

I. Vimont[1,2], J. Turnbull[3,2], T. Lauvaux[4], K. Gurney[5], B.R. Miller[6,2], and S.A. Montzka[2]

[1]National Research Council Post-Doc, Boulder, CO 80305; 303-497-6044, E-mail: isaac.vimont@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]GNS Science, National Isotope Centre, Lower Hutt, New Zealand
[4]The Pennsylvania State University, Department of Meteorology and Atmospheric Science, University Park, PA 16802
[5]Arizona State University, Tempe, AZ 85287
[6]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309

Urban emissions are an important component of the global atmospheric burden of many trace gasses. These emissions are estimated through a variety of methods, each with its own set of advantages and disadvantages. In this work, we present an effort to use tracer ratios to fossil fuel CO_2 in order to estimate benzene (C_6H_6) emissions at Indianapolis, Indiana, as part of the Indianapolis Flux Experiment (INFLUX). INFLUX is a multiinstitutional experiment that combines trace gas measurements with high-resolution modeling and surface energy balance to evaluate urban emissions and provide a test bed for urban experiments.

Initially, we used the measurements of C_6H_6 and fossil fuel-derived carbon dioxide (CO_{2FF}) from INFLUX to obtain an approximate ratio of C_6H_6:CO_{2FF} based on the measurements. We then combined county-level C_6H_6 emissions from the U.S. Environmental Protection Agency's National Emissions Index 2014 (EPA NEI 2014) with CO_{2FF} estimates obtained from the Vulcan data product. We subdivided these emissions into eight sectors, Residential, Commercial, Industrial, On-Road, Non-Road, Rail, Utility, and Airport. For each sector, we calculated a unique C_6H_6:CO_{2FF} ratio. Once we obtained the estimated sectoral emission ratios, we used the Hestia data product for Indianapolis (Gurney et al., 2012) as a base, and multiplied each sector in the Hestia product by our estimated ratios. We then transported the Hestia-derived emissions for each of these sectors using footprints generated for each of the towers at Indianapolis by the Weather Research Forecast chemistry model (WRF-chem). This generated so called "receptors", or simulations of the tower measurement sites.

We compared the receptor data to the real-world tower measurements and found the predicted receptor C_6H_6 ratio to be too large. This was expected due to overestimation of On- and Non-Road C_6H_6 (mobile sector) in the EPA NEI (e.g., Borbon et al., 2013). Once we reduced the mobile sector C_6H_6 by a factor of 2 (ref), we obtained good agreement between the real-world measurements and the receptor values (Figure 1). Using these results, we present a new method for estimating benzene emissions based off of a fossil fuel CO_2 emissions model.

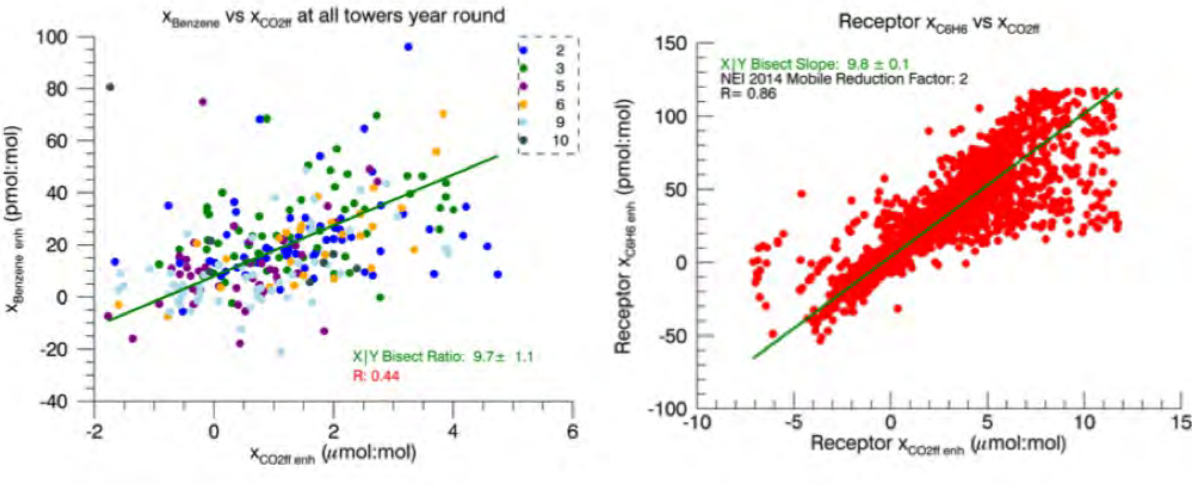


Figure 1. Plot benzene vs CO_{2FF} from INFLUX towers 2, 3, 5, 6–9, and 10 (left) and our receptor predicted benzene and CO_{2FF} (right). The receptor plot includes all days from 11/2012–10/2013, while data on right is all data from INX towers for 2011–2016. Slopes indicate C_6H_6:CO_{2FF} ratios. Receptor data has had mobile sector ratios reduced by a factor of 2.

Characterization and Quantification of Benzene Emissions from a New Multiwell Pad in a Colorado Front Range Residential Community

I. Mielke-Maday[1,2], M. Madronich[1,2], P. Handley[1,2], J. Kofler[1,2], B.D. Hall[2], B.R. Miller[1,2], J. Mund[1,2], D. Kitzis[1,2], P. Lang[3], A. Crotwell[1,2], M.J. Crotwell[1,2], E. Moglia[1,2], T.K. Mefford[1,2], B.H. Vaughn[4], R.C. Schnell[2], and G. Petron[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6296, E-mail: ingrid.mielke-maday@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Retired from NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[4]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309

Recent population growth in the Colorado Front Range has brought oil and natural gas operations and people in closer proximity. Of particular concern to public health is benzene, a carcinogen linked to leukemia and classified as a hazardous air pollutant by the United States Environmental Protection Agency (EPA). A naturally occurring component of oil and gas, benzene can be released from equipment and during processes at oil and natural gas-producing well pads. In an effort to minimize cost and maximize productivity and efficiency, oil and natural gas operators have developed multi-well pads, production sites with 20 or more wells. If located in a residential area, these types of larger facilities with more equipment and more potential benzene sources may pose a higher health risk to nearby residents than traditional, smaller well pads.

Here we present results from five weeks of continuous, calibrated *in situ* measurements at a residence downwind of a new 22-well oil and natural gas-producing multiwell pad in Greeley, Colorado. Using ratios between hydrocarbon species measured at the residence and meteorological data collected on-site, emission sources are identified. Results of inverse modeling using the steady-state plume dispersion model AERMOD to quantify benzene emissions rates from the well pad are presented.

This work is funded by the National Science Foundation AirWaterGas Sustainability Research Network and is a collaboration with the Colorado School of Public Health.

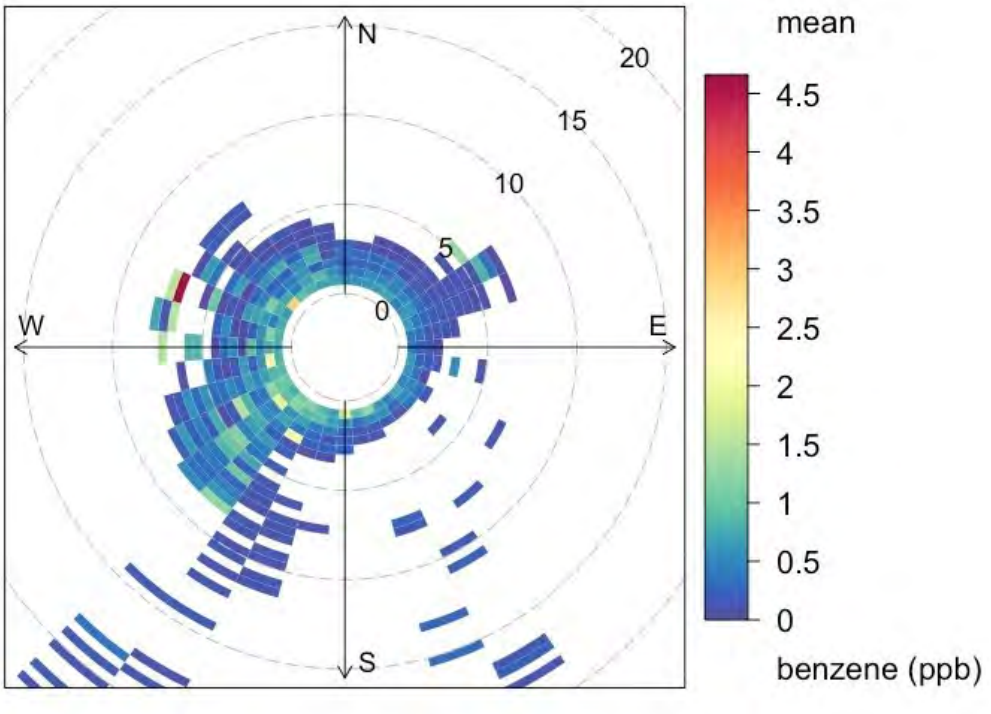


Figure 1. Mean observed ambient benzene mixing ratios binned by wind direction for the five-week field campaign. The largest enhancements in benzene tend to originate from the southwest, where the multi-well pad is located.

Measuring BTEX with a Commercial GC-PID System in an Oil and Gas Field

M. Madronich[1,2], A. Crotwell[1,2], E. Dlugokencky[2], A. Gniewek[3], B.D. Hall[2], P. Handley[1,2], J. Kofler[1,2], B. Kahn[3], I. Mielke-Maday[1,2], B.R. Miller[1,2], J. Mund[1,2], G. Petron[1,2], and K. Thoning[2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-3264, E-mail: monica.madronich@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Baseline Gas Analyzers & Sensors, AMETEK MOCON, Lyons, CO 80540

The air quality in several oil- and natural gas- (O&NG) producing regions in the U.S. has been under scrutiny. Some O&NG processes can emit compounds to the atmosphere that are detrimental to human health. Among those compounds are benzene, toluene, ethylbenzene, and xylenes (BTEX), which are classified as Hazardous Air Pollutants by the Environmental Protection Agency. This work shows *in situ* BTEX measurements conducted near Greeley, CO during the summer of 2018. We used a commercial gas chromatograph with a photo-ionization detector (GC-PID Series 9100 GC-PID, MOCON, Lyons, Colorado, U.S.A.), which analyzes an air sample every six minutes.

The equipment was operated inside an instrumented van that provided semicontrolled environmental conditions. The instrument showed consistent results through the measurement period with the exception of certain events when ambient temperature changed dramatically. In those instances, the retention time of the compounds in the chromatograms shifted. The GC-PID software did not recognize the peaks and we used a different software (gcplot, NOAA-CCG) to reprocess all chromatograms.

This work presents the results of different instrument tests, including response curves and detection limits. We also show the data acquired during the summer of 2018. This is one of the first datasets that show continuous measurements of BTEX in a multiday field study.

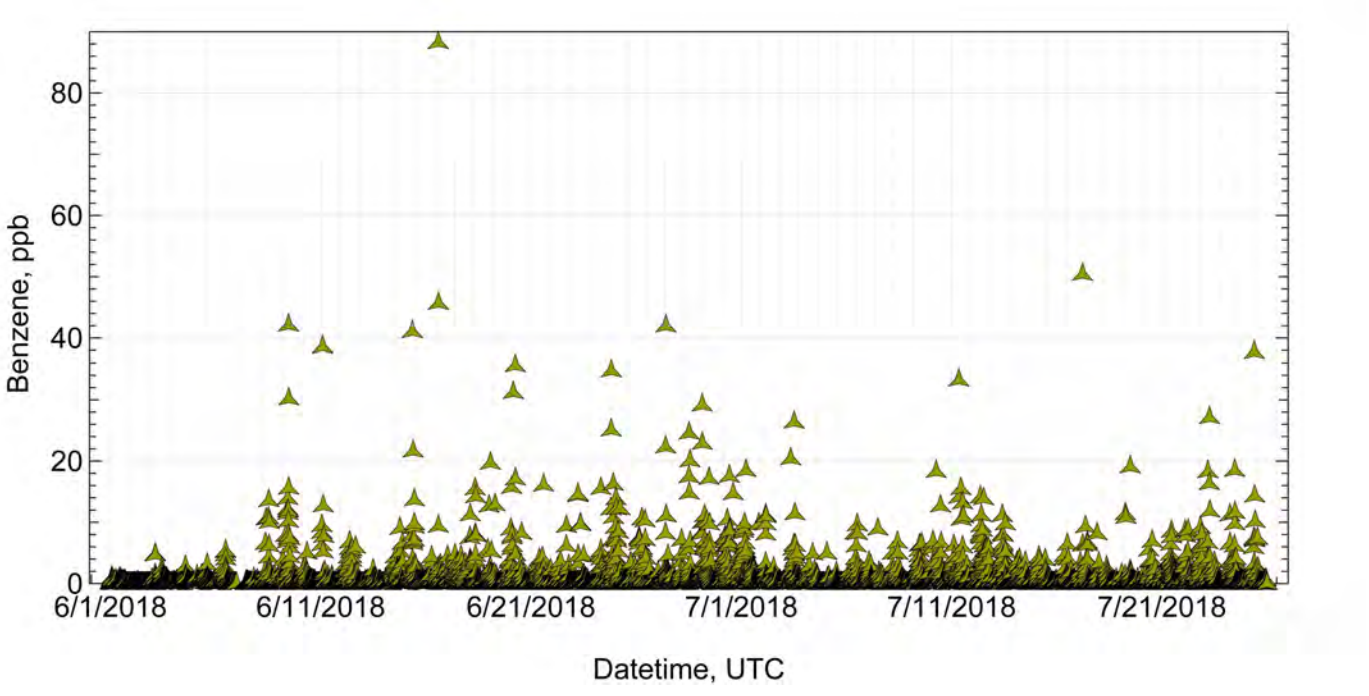


Figure 1. Time series of benzene during the summer of 2018.

Open-path, Mid-infrared, Dual Comb Spectroscopy for Measurement of Ambient Ethane and Propane

K. Cossel, G. Ycas, F. Giorgetta, E. Baumann, J. Friedlein, D. Herman, E. Waxman, I. Coddington, and N. Newbury

National Institute of Standards and Technology (NIST), Boulder, CO 80305; 303-497-4115, E-mail: kevin.cossel@nist.gov

Open-path measurements of atmospheric gas species over km-scale path lengths are well suited to quantify emissions from sources like oil and gas, forest fires, and industry. Dual frequency comb spectroscopy (DCS) is a relatively new technique that combines high-resolution and broad spectral coverage with no instrument lineshape and near perfect frequency calibration. These features make DCS well suited for accurate measurements of multiple species simultaneously. Because the frequency comb lasers can be well collimated, such a system can be used for long open-path measurements with pathlengths ranging from hundreds of meters to several kilometers.

Previous demonstrations of open-path DCS have primarily been in the 1–2 μm spectral region; however, in order to reach the sensitivity necessary to detect many atmospheric trace constituents, including volatile organic compounds, operation in the mid-infrared (or UV/Vis) is required. Here, we show a mid-infrared, open-path, dual comb spectrometer operating in the 3–5 μm spectral region. We have used this spectrometer to measure methane, ethane, and propane (arising primarily from oil and gas activity) across a 1–km-long path in Boulder, CO for one week with an ethane sensitivity of ~0.1 ppb for a two-minute time resolution. In addition, we show quantitative measurements of intentionally released acetone and isopropanol with a 1-σ sensitivity of 5.7 ppm·m and 2.4 ppm·m, respectively. Finally, we discuss the outlook for detection of additional species such as N_2O, CO, and O_3 as well as a second-generation instrument that is more compact and has improved stability.

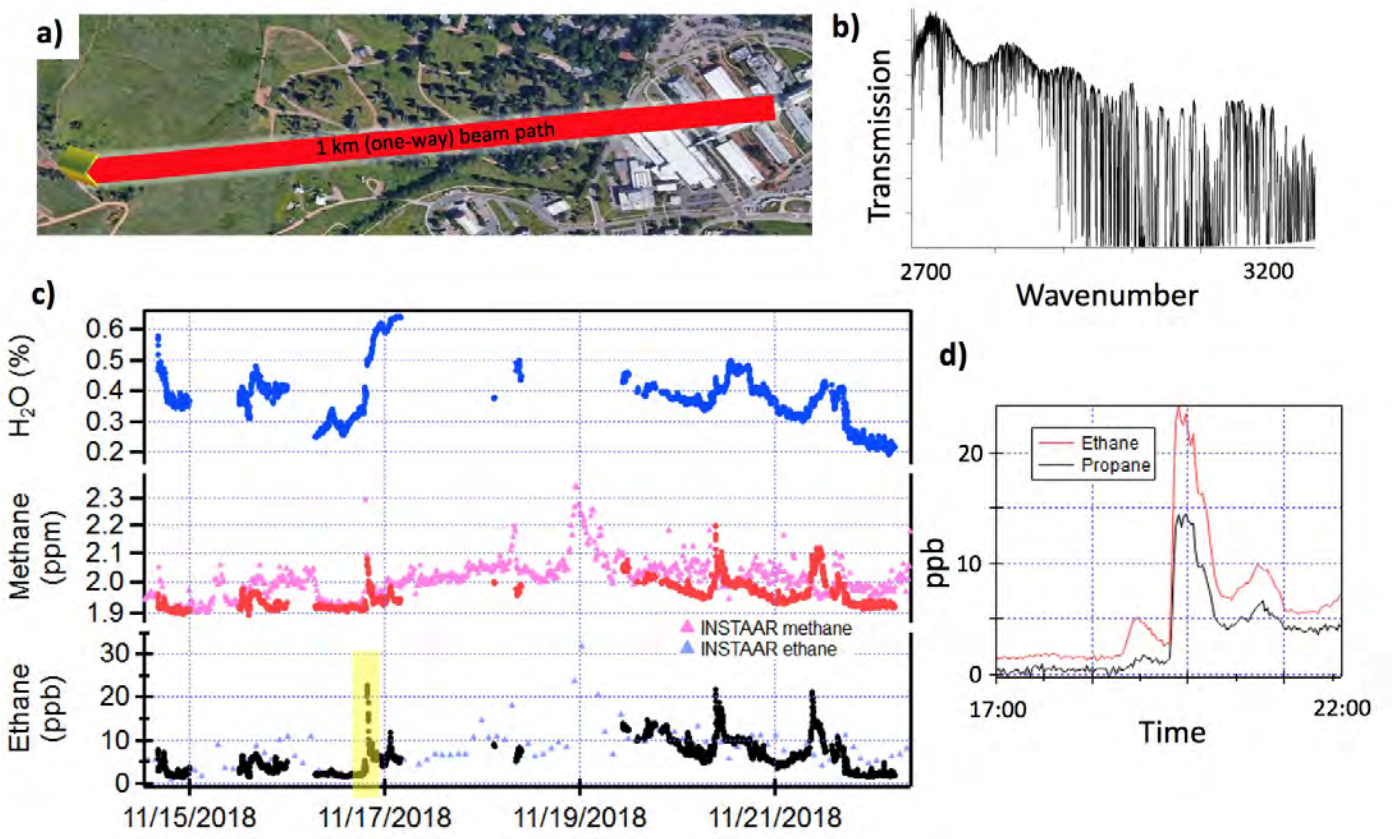


Figure 1. Open-path, mid-infrared, dual comb spectroscopy. (a) 1–km measurement path from NIST to Kohler Mesa. (b) Transmission spectrum showing strong water and methane absorption. (c) Retrieved path-averaged concentrations of H_2O, methane, and ethane over a one-week measurement series. The gaps are primarily due to poor weather. (d) Shorter time series showing retrieved propane.

Continuous Methane Leak Detection in Oil and Gas: Recent Progress Toward a Regional Approach with Dual Frequency Comb Spectroscopy and Inversions

C. Alden[1,2], S. Coburn[3], R. Wright[3], A. Rybchuk[3,4], I. Coddington[5], and G.B. Rieker[3]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 719-930-5281, E-mail: caroline.alden@colorado.edu
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]University of Colorado, Department of Mechanical Engineering, Boulder, CO 80309
[4]Precision Laser Diagnostics Laboratory, University of Colorado, Boulder, CO 80309
[5]National Institute of Standards and Technology (NIST), Boulder, CO 80305

A current major area of focus for science, industry, and regulators is methane emissions from the oil and gas supply chain in the United States. Recently, substantial advances have been made in 1) scientific understanding of the magnitude and distribution of emissions across this sector, and 2) new technologies and programs for leak detection and repair, with complementary efforts toward frameworks for comparison of their efficacies and suitability for industrial use. Here we provide an update on recent progress of one such new technology and leak detection method. We use dual frequency comb spectroscopy to detect very small changes in the dry air mole fraction of methane (and other trace gases) along open-path transects of the atmosphere (up to 2 km in length). The trace gas measurements are coupled with atmospheric inversions to yield rapid leak detection, attribution, and quantification. The technology and leak detection methods have been validated in two separate rounds of single-blind testing at the Methane Emissions Test and Evaluation Center test site in Fort Collins, CO. The observing system includes a series of retroreflectors placed in the field to direct light back to a detector. A gimbaling system rotates the laser light to sample the atmospheric path to each individual retroreflector in a sequential pattern, so that a 360º view of surrounding pads and facilities is allowed. The laser light spans 1620–1680 nm with 0.002 nm resolution, simultaneously measuring hundreds of individual absorption features from multiple species, and resulting in high-stability trace gas (here CH_4, CO_2, and H_2O) measurements over the long, open paths through the atmosphere. The system is operated continuously and autonomously, allowing for continuous observations; known intermittency in fugitive methane emissions means that continuous measurements are critical for effective emissions quantification and mitigation. By contrast, "snapshot" observation programs may miss important emission signals or overestimate total emissions if the measurement occurs during daytime operations or, for example, a liquid unloading event. Extreme variability in our long-term, continuous time series of emissions from a production site and a natural gas storage facility confirm the literature-stated needs for continuous observational coverage. Here, we present a summary of recent field testing and observations of both natural gas production and underground natural gas storage sites.

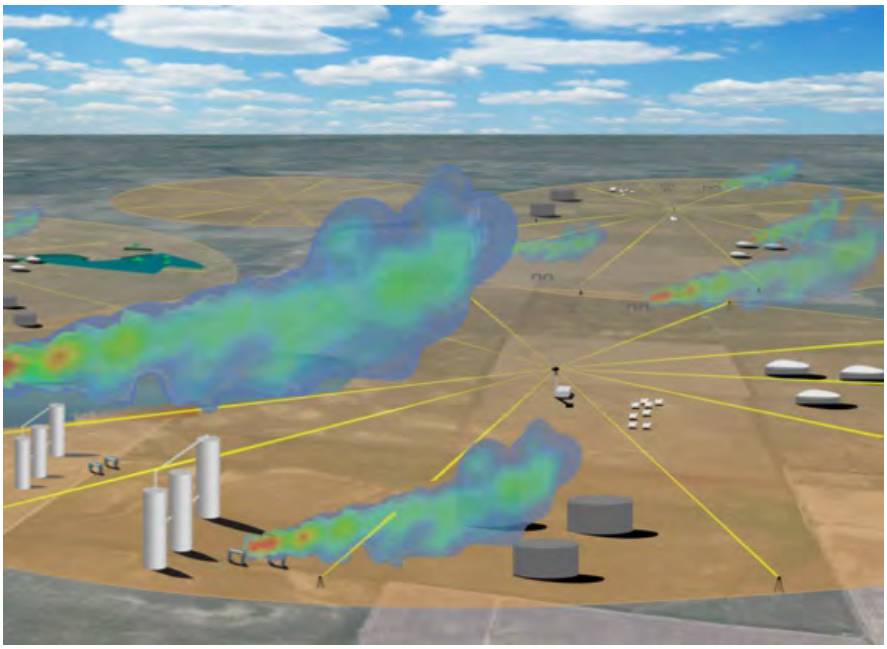


Figure 1. Schematic showing dual frequency comb spectrometer in the center of an observed area of potential methane sources; yellow lines show the paths of laser light beams measuring integrated open-atmosphere trace gas concentrations.

Measurement Capabilities of the CU SOF Instrument: Separation of Methane Emissions from Agricultural and Natural Gas Sources & Developing Techniques to Quantify Wildfire Emissions

N. Kille[1], R. Chiu[1], M. Frey[2], F. Hase[2], M.K. Sha[3,2], T. Blumenstock[2], J.W. Hannigan[4], J. Orphal[2], D. Bon[5], and R. Volkamer[1,6]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-735-2235, E-mail: natalie.kille@colorado.edu
[2]Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology, Campus Alpin, Karlsruhe, Germany
[3]Royal Belgian Institute for Space Aeronomy, Brussels, Belgium
[4]National Center for Atmospheric Research (NCAR), Atmospheric Chemistry Observations and Modeling Laboratory, Boulder, CO 80307
[5]Colorado Department of Public Health and Environment (CDPHE), Denver, CO 80246
[6]University of Colorado, Department of Chemistry, Boulder, CO 80309

This proof-of-concept study demonstrates that methane (CH_4) emissions from natural gas (NG) and agriculture can be disentangled using the concept of excess column observations. The University of Colorado Solar Occultation Flux (CU SOF) instrument and three Collaborative Carbon Column Observing Network (COCCON) instruments were set up across Colorado's Front Range. This network of cost-effective sensors measured excess column-averaged, dry-air mole fractions for CH_4 (ΔXCH_4; measured by COCCON), ethane (ΔXC_2H_6 as NG tracer; measured by CU SOF), and ammonia (ΔXNH_3 from agriculture; measured by CU SOF) in the Denver-Julesburg Basin during March 2015. ΔXCH_4 varied up to 17 ppb, and was > 3 times higher with winds from directions where NG is produced. The ΔXCH_4 variance is explained by variations in the C_2H_6-NH_3 tracer pair, attributing 63±17% to NG, 25±10% to agriculture, and 12 ±12% to other sources. The ratios $\Delta XC_2H_6/\Delta XCH_4$ (16 ±2%; indicates wet NG), and $\Delta XNH_3/\Delta XCH_4$ (43 ±12%) were compatible with *in situ*-measured ratios. Excess columns are independent of boundary layer height, characterize gases in the open atmosphere, are inherently calibrated, averaged over extended spatial scales, and provide a complementary perspective to quantify and attribute CH_4 emissions on regional scales.

An airborne version of the CU SOF instrument was deployed on research aircraft to quantify wildfire emissions during the 2018 wildfire season in the Pacific Northwest (BB-Flux project). We show that column measurements can be used to quantify emission fluxes from wildfires as well.

Figure 1. In Colorado, oil and gas operations sit within feet from cattle farms. Photo credit: Frank Flocke/ NCAR

Figure 2. One of the COCCON instruments measuring CH_4 at the main measurement site inside the Denver-Julesburg Basin. CU SOF, deployed in the trailer, measured the NG and agricultural tracers.

Modeling Ground- and Aircraft-based Methane Monitoring Systems for Natural Gas Storage Facilities using LPDM-LES

A. Rybchuk[1,2], C. Alden[3,4], S. Coburn[1], R. Wright[1], D.J. Caputi[5], I. Faloona[5], J.K. Lundquist[6], and G.B. Rieker[1]

[1]University of Colorado, Department of Mechanical Engineering, Boulder, CO 80309; 201-983-8084, E-mail: alex.rybchuk@colorado.edu
[2]Precision Laser Diagnostics Laboratory, University of Colorado, Boulder, CO 80309
[3]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[4]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[5]University of California at Davis, Davis, CA 95616
[6]University of Colorado, Department of Atmospheric and Oceanic Sciences, Boulder, CO 80309

Recent literature has highlighted large discrepancies in estimates of methane emissions from the U.S. oil and gas supply chain. Methane emissions at natural gas storage facilities can be challenging to accurately quantify due to complicating factors such as time-varying emissions, multiple potential sources, and complex terrain. To investigate this complexity, we are undertaking an ongoing campaign of ground- and aircraft-based measurements at a series of natural gas storage sites in the U.S. In this campaign, a dual-comb spectrometer (DCS) provides continuous, ground-based observations of methane concentrations that provide emissions estimates on fine spatio-temporal scales. Aircraft *in situ* measurements complement the DCS by providing a facility-wide snapshot of emissions using a mass-balance approach. However, it is possible that observations from these instruments could lead to conflicting estimates, given that they sample different air masses. Here, we investigate the potential for estimate discrepancies between different platforms using simulated emissions at a real natural gas storage facility. We use a Lagrangian particle dispersion model driven by large-eddy simulation (LPDM-LES) to generate synthetic DCS and aircraft *in situ* measurements of emissions under controlled conditions. These measurements are inverted with operational dispersion models (e.g. Gaussian plume, mass balance) to produce emission rate estimates. The estimates are compared to true emission rates; bias and variance of the estimates are discussed.

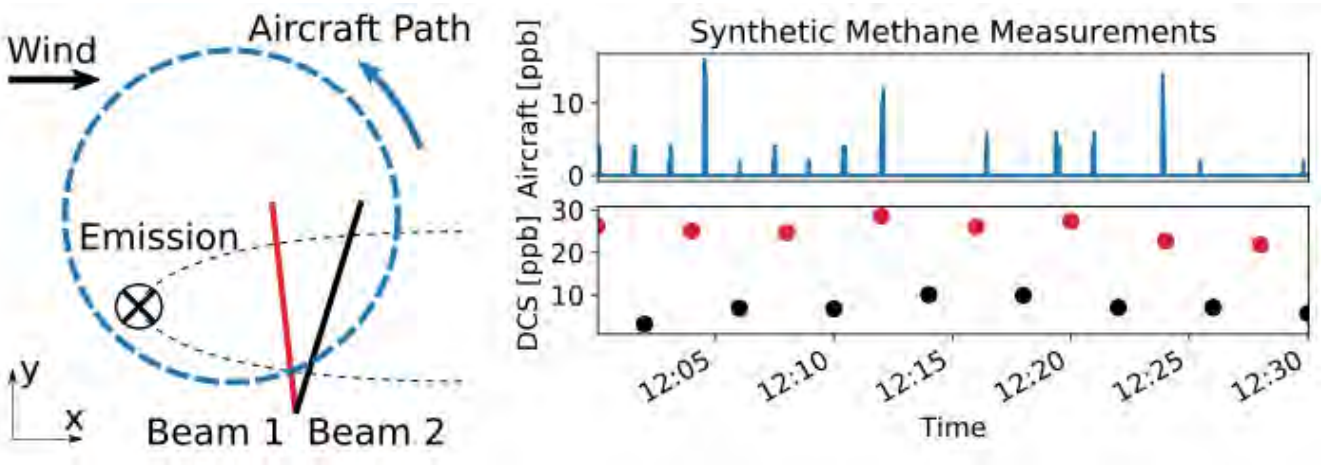


Figure 1. Synthetic aircraft and DCS measurements of a continuous point-source emission at a simulated natural gas storage facility.

How Useful Are Carbon Stable Isotopes of Methane? Improvements in Analysis and Quality Controls at the INSTAAR Stable Isotope Lab

S.E. Michel[1], K.S. Rozmiarek[1], A.K. Johnson[1], B.H. Vaughn[1], I. Vimont[2,3], J. White[1], and J.B. Miller[3]

[1]Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309; 303-817-2255, E-mail: sylvia.michel@colorado.edu
[2]National Research Council Post-Doc, Boulder, CO 80305
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The INSTAAR Stable Isotope Lab has a twenty-year record of $d^{13}C$ measurements of methane from a subset of sample flasks in NOAA's Global Greenhouse Gas Reference Network. These data have been useful for testing hypotheses about the source of the increase in the atmospheric methane burden since 2007 (Schwietzke *et al.*, 2016, Schaeffer *et al.*, 2016, Nisbet *et al.*, 2016). However, the signals interpreted in these studies, with a range of ~0.3 permil, are small relative to our quoted measurement reproducibility of 0.07 permil, which is based on surveillance cylinders. As the growth rate of the atmospheric methane burden remains above 5 ppb yr^{-1}, and more scrutiny is given to both natural and anthropogenic emission sources, it will become increasingly more important not to over- or understate uncertainties in critical $d^{13}C\text{-}CH_4$ measurements.

Here we ask what we can do to improve our data quality, both by increasing measurement precision from our analytical system, and by strengthening our post-processing quality control. For example, we address the step in which we combust CH_4 to CO_2. The oxygen for this reaction comes from a laboratory cylinder, and the isotope ratio mass spectrometer measures the $d^{18}O\text{-}CO_2$ simultaneous with $d^{13}C\text{-}CO_2$, and these data may contain useful information regarding the efficiency of the combustion. We also consider new methods for oxygenating our reaction, such as dosing the combustion furnace with O_2 between every sample.

Furthermore, the uncertainty of global averages of atmospheric $d^{13}C\text{-}CH_4$ is dominated by analytical uncertainty – unlike for methane mole fraction, where uncertainty is dominated by variability in the atmosphere or by the choice of sites in the network. Here we use test flasks, flask pair differences, and surveillance cylinders to assess the uncertainty in our data over time. We also show how different metrics of analytical uncertainty affect our calculations of zonal and global means. We show that despite the large signal to noise ratio, our measurements are useful for understanding changes in the global methane budget.

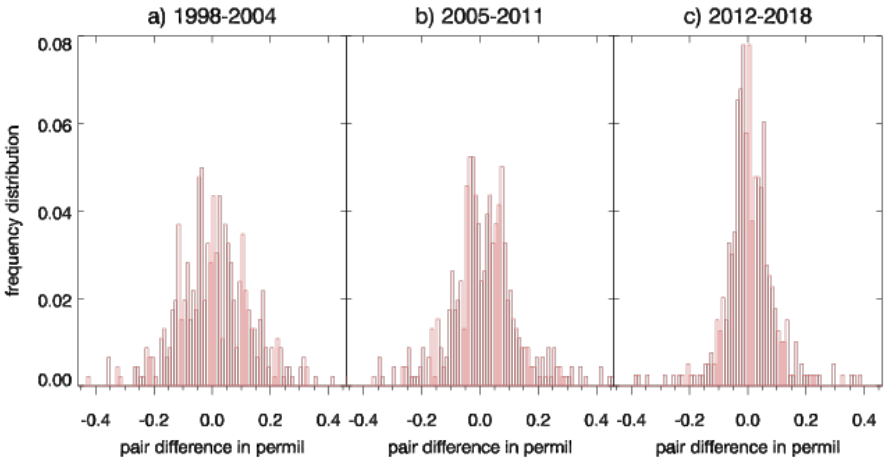


Figure 1. Flask pair agreement of $d^{13}C\text{-}CH_4$ data has improved since we began measurements in 1998. Data here are from the South Pole Station.

Sensitivity of the Isotopic Composition of Atmospheric Methane to Oxidant Fields in the GEOS Model

S. Strode[1,2], J. Wang[1,2], M. Manyin[3], B. Duncan[4], and C. Keller[1,5]

[1]Universities Space Research Association (USRA), Colombia, MD 21046; 301-614-5547, E-mail: sarah.a.strode@nasa.gov
[2]NASA Goddard Space Flight Center (GSFC), Greenbelt, MD 20771
[3]Science Systems and Applications, Inc. (SSAI), Lanham, MD 20706
[4]NASA Goddard Space Flight Center (GSFC), Atmospheric Chemistry and Dynamics Laboratory, Greenbelt, MD 20771
[5]NASA Goddard Space Flight Center (GSFC), Global Monitoring & Assimilation Office, Greenbelt, MD 20771

The isotopic composition of methane provides valuable information on methane sources and their trends, but oxidation reactions also alter the isotopic composition, complicating the interpretation of the isotopic ratios. We use the Goddard Earth Observing System (GEOS) global atmospheric model to simulate the global distribution and temporal evolution of atmospheric methane and its isotopic composition. The simulation shows reasonable agreement with the spatial distribution observed at NOAA GMD surface sites, although the interhemispheric gradient of $\delta^{13}C$ is underestimated. This underestimate is also present in comparison with aircraft observations from the Atmospheric Tomography (ATom) mission. Since $^{13}CH_4$ and $^{12}CH_4$ have different loss rates with respect to OH and chlorine, we use the model to investigate the sensitivity of the isotopic composition to OH and chlorine. We find that using a chlorine field simulated by the GEOS-Chem model, which increases tropospheric chlorine concentrations relative to our base simulation, has little effect on total methane but has a large effect on the isotopic ratio. Inclusion of spatially-varying $\delta^{13}C$ values for wetland emissions also improves the comparison to GMD observations.

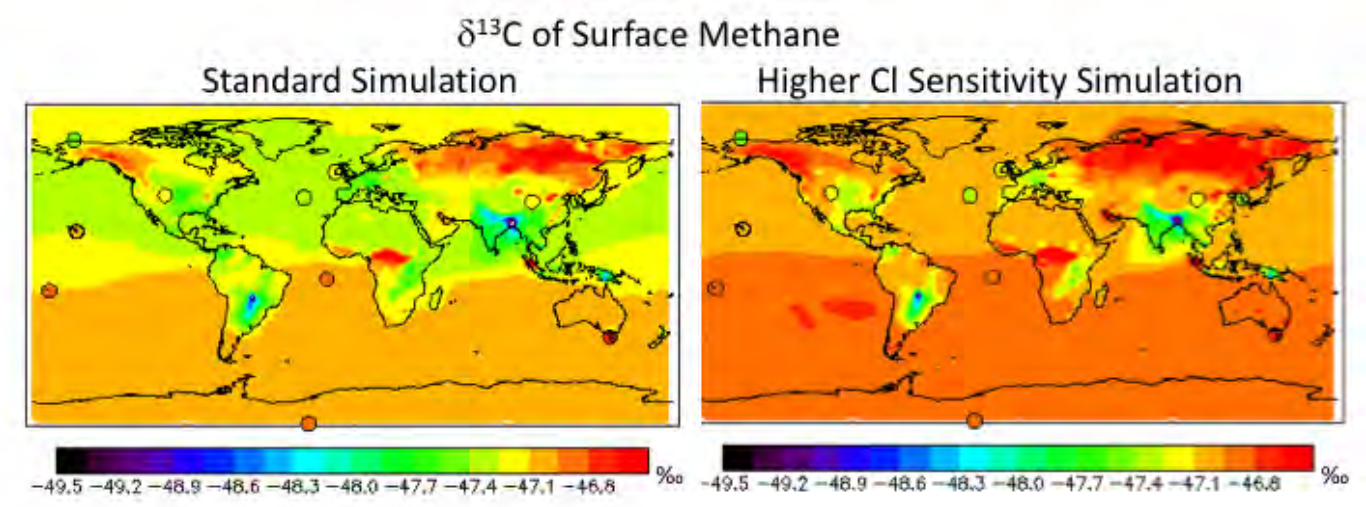


Figure 1. The January 2005 $\delta^{13}C$ of methane observed at GMD sites (circles) is overplotted on the surface $\delta^{13}C$ simulated by the GEOS model. The simulations used chlorine concentrations from the GMI (left) and GEOSChem (right) chemical mechanisms.

Quantification of Transport Error Using a Coupled Meteorological and Constituent Transport Model Within an Ensemble Kalman Filter (EnKF)

V. Khade[1], S. Polavarapu[2], M. Neish[2], P. Houtekamer[2], and D. Jones[3]

[1]University of Toronto, Department of Physics, Toronto, Ontario, Canada; 647-290-9031, E-mail: vikram.khade@canada.ca
[2]Environment and Climate Change Canada, Toronto, Ontario, Canada
[3]University of Toronto, Toronto, Ontario, Canada

The uncertainty in the forecast estimate of a constituent is due to a combination of errors arising from uncertainties in wind fields, prescribed surface fluxes, and initial states of the constituent. The errors in wind fields are due to errors in initial states of winds and model formulation errors. Here we use the Environment and Climate Change Canada's (ECCC) weather forecast model adapted for GHG simulation (Polavarapu et al. 2016, ACP) to generate an ensemble of 64 forecasts of carbon monoxide (CO). Meteorological observations are assimilated every six hours. Over a period of a month, the various sources of errors are simulated in the ensemble. Flux errors use a spatial correlation length of 2000 km. The model formulation errors are simulated by every ensemble member using a different combination of parameterization (e.g. convective transport, boundary layer parameterizations, etc.). The initial state errors in CO are parameterized using a sample of 24-h differences in CO fields. Figure 1 shows that after 30 days of cycling, errors in CO are due in equal parts to those in fluxes, meteorology, and model formulation.

While it is difficult to account for all components of transport error in the context of a standard flux inversion, with a coupled state and flux estimation system within an Ensemble Kalman Filter (EnKF), this becomes feasible. Thus, ECCC's operational EnKF was extended for the estimation of CO_2, CH_4 and CO and their fluxes. This system is called the EC-CAS. Testing of this system was begun with CO state estimation. With simulated observations, the behaviour of the system was explored using a variety of observation networks [hypothetically dense, *in situ*, and Measurement of Pollution in the Troposphere (MOPITT)]. Figure 2 shows the benefit of assimilating MOPITT observations. The error reduction (benefit) due to the assimilation of MOPITT CO data is proportional to the root mean square error (RMSE) of CO when no data are assimilated. Thus, the benefit is greatest where flux errors are largest (central Africa and east Asia) and ranges from 5 to 40 ppb. Having demonstrated that the system is working, the next stage is to assess the ability to retrieve fluxes. The goal of this system is to provide estimates of GHGs and their fluxes along with their uncertainties on seasonal to annual timescales.

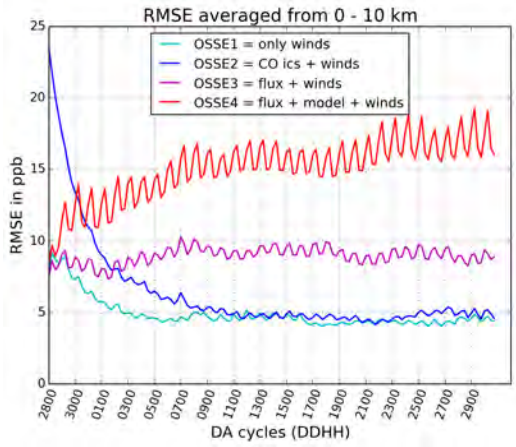


Figure 1. The RMSE is the difference between the ensemble mean and the truth in the model space. The cyan curve gives the lowest RMSE. This experiment uses only perturbed initial condition of winds. The blue curve uses perturbed CO initial conditions and perturbed winds. On a time scale of about 12 days the RMSE is similar to perturbing winds only. The red and magenta curves are for experiments using the perturbed flux field. The red curve additionally simulates model error.

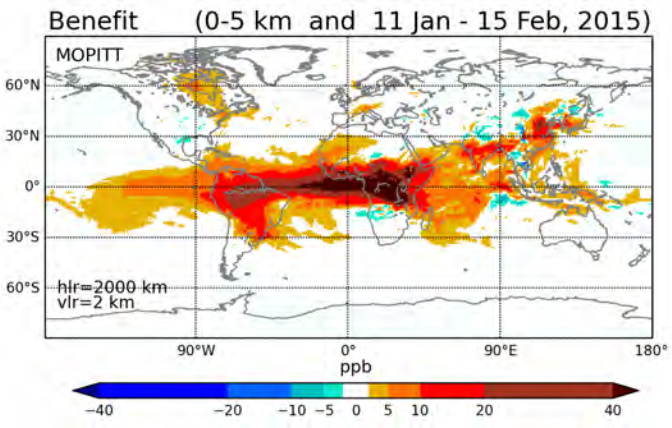


Figure 2. The benefit is the difference between the column averaged RMSE of the control and data assimilation (DA) experiment. The control experiment assimilates only meteorological observations (radiosonde, aircraft, surface, scatterometer and GPS radio occultation). The DA experiment assimilates both meteorological and MOPITT observations.

Two Years of MAX-DOAS Data from Remote Tropical Marine Mountaintops

T.K. Koenig[1,2], F. Hendrick[3], C.F. Lee[1,2], M. VanRoozendael[3], and R. Volkamer[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-735-2235, E-mail: theodore.koenig@colorado.edu
[2]University of Colorado, Department of Chemistry, Boulder, CO 80309
[3]Royal Belgian Institute for Space Aeronomy, Brussels, Belgium

The remote tropical troposphere is responsible for about 75% of the chemical removal of ozone (O_3) and methane (CH_4), two important greenhouse gases. Yet the atmospheric chemistry over remote oceans is largely unconstrained in the free troposphere (FT). Mountaintops on isolated oceanic islands provide access to FT with minimal continental and boundary layer influence. Since February 2017 we have deployed Multi-AXis Differential Optical Absorption Spectroscopy (MAX-DOAS) instruments at two sites: 1) Mauna Loa Atmospheric Baseline Observatory (MLO) at 19.5°N, 155.6°W, at 3.4-km altitude in the northern hemisphere tropics; and 2) Maïdo Observatory (Maïdo) at 21.1°S, 55.4°E, at 2.2-km altitude in the southern hemisphere tropics. We consistently measure the halogen oxide radicals bromine oxide (BrO) and iodine oxide (IO), small oxygenated volatile organic compounds [OVOC; e.g. formaldehyde (HCHO) and glyoxal (CHOCHO)]; which impact oxidative capacity and inform carbon cycling. We also measure total columns of O_3, and nitrogen dioxide (NO_2) using NDACC retrievals, and aerosol optical depth, which can be used for satellite validation.

We present an overview of the two-year time series of these measurements at both sites, highlighting chemical and dynamic changes at and above the observatories occuring on diurnal to seasonal scales. These include: 1) diurnal variations driven by orographic meteorology; 2) large-scale tropospheric systems on time scales of days to weeks; and 3) an annual cycle of the upper atmosphere between tropical conditions in hemispheric summer, and midlatitude conditions in hemispheric winter. Progress toward an efficient cloud-screening procedure for the MAX-DOAS data is demonstrated. A high degree of freedom profile retreival for BrO, leveraging O_3 and NO_2 columns, coupling photochemical change into radiative transfer, and iteratively determining reference contibutions is highlighted in case studies.

Figure 1. A view over the MLO MAX-DOAS telescope (pictured here without it's protective cover) in the primary scanning direction. Light is collected through viewing port (faceon here) and sent to two spectrometers for analysis via optical fibers. By rotating in the veritcal plane, spectra can be collected along lines of sight pointing below, at, and above instrument altitude. The instrument has collected data on a vareity of tropospheric and stratospheric trace gases since February 2017.

Improving the Sampling and Analysis of Atmospheric Carbonyl Sulfide (OCS) in the GMD Networks

B.R. Miller[1,2], B.D. Hall[2], T. Legard[1,2], B. Baier[1,2], M.J. Crotwell[1,2], D. Neff[1,2], S.A. Montzka[2], and J. Higgs[2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6624, E-mail: ben.r.miller@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

Recent experimental work in GMD has revealed a number of significant issues regarding the sampling and the GCMS analysis of ambient atmospheric samples for carbonyl sulfide (OCS). Here we detail our current understanding and tentative conclusions as part of our efforts to produce an accurate, artifact-free global OCS dataset. There are currently two GCMS instruments, "M3" and "PR1" in GMD that measure OCS in ambient air, and each instrument has used a slightly different subset of the same suite of NOAA OCS standards to create their respective (and potentially instrument-dependent) OCS calibration scales. Our goal is to reconcile all OCS data to one calibration scale.

To begin with, a recent attempt was made to replicate the NOAA 2004 OCS absolute calibration scale, this time using a new "high purity 99%" starting material from Synquest Labs. Using the same methodology as previously, gravimetrically prepared mixtures of this new OCS were diluted to ambient mole fractions (~ 500 ppt) in zero air, which is a synthetic blend of pure oxygen in nitrogen at ambient ratios. Analyses of three of these new standards on M3 and PR1 yielded an excellent agreement of 0.05% between the two instruments. However, the results of both instruments indicated a ~9% higher response relative to the 2004 scale standards, consistent with the hypothesis that the older standards were prepared from OCS starting material that was considerably lower in purity than the 99+% specified by the manufacturer.

Second, we observed a site-weighted average ~2.1% discrepancy between the M3 and PR1 OCS measurements, with PR1 higher, of the same air samples over the past ~5 years in GMD Halocarbons & oher Trace Species (HATS) steel and glass flasks taken at remote global sites. This discrepancy, when considered with the excellent agreement noted above for the very 'simple' gravimetric mixtures, suggests that one or both instruments suffer an artifact in analyses of the 'complex' mixtures of real air from field sites.

Third, we have recently discovered that Essex Cryogenics, Inc. cylinders purchased in the last few years, and that have been used to prepare OCS standards, can exhibit significant apparent "growth" in OCS mole fraction during storage. While the mechanism for this growth is still under investigation, such drift is carefully monitored and accounted in the ambient OCS datasets.

Fourth and finally, we discovered in 2018 that a suite of Programmable Flask Packages (PFPs) used to sample aboard some aircraft campaigns, such as during portions of the Atmospheric Carbon and Transport (ACT) campaign, were contaminating the sample stream, with some PFPs as much as doubling the ambient OCS mole fraction. Exhaustive searching revealed that the fourteen Viton o-rings used to create the glass-to-metal seals within these PFPs were outgassing OCS. Replacement of those o-rings with non-contaminating Viton o-rings has reduced this issue to less than a 9 ppt (95% C.I.) positive bias.

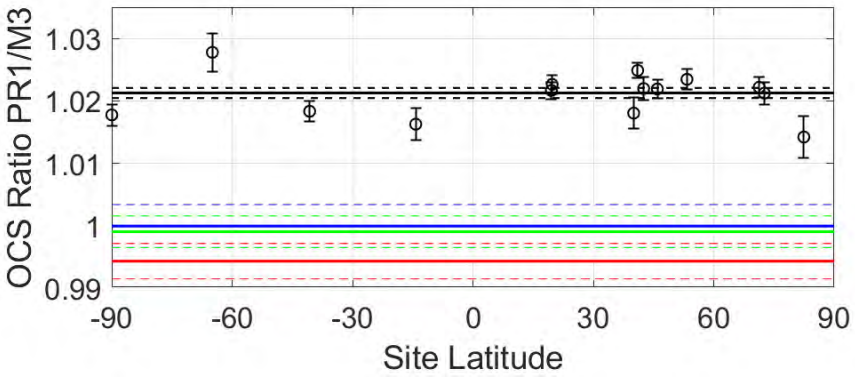


Figure 1. Measured OCS ratios PR1/M3 from two distinctly different sample types. Black circles with 1-σ standard deviation bars represent the remote field site means (weighted by number of samples) for these complex, real air samples. In contrast, the green, blue and red solid lines, with dashed lines of 1-σ standard deviation, represent the much better agreement for PR1/M3 ratios in the relatively simple mixtures of gravimetric OCS standards (tanks SX-3503, SX-3506B and SX-3594, respectively).

SO_2 Profiles during the Kilauea Eruption

P.J. Walter[1], J.H. Flynn[2], S.L. Alvarez[2], E. Klovenski[2], A.E. Kotsakis[3,2], G.A. Morris[1], and M.D. Spychala[4,1]

[1]St. Edward's University, Austin, TX 78704; 512-637-5636, E-mail: pauljw@stedwards.edu
[2]University of Houston, Houston, TX 77004
[3]NASA Goddard Space Flight Center (GSFC), Greenbelt, MD 20771
[4]New Mexico State University, Las Cruces, NM 88003

We report on vertical sulfur dioxide (SO_2) profiles of nine flights that used a single-pump SO_2 sonde and took place from 21–30 June 2018 on the Big Island of Hawaii during the then ongoing Kilauea lower East Rift Zone eruption. The launch site for all flights was downwind of the eruption on the southern portion of the island. The single-pump SO_2 sonde has an increased upper detection limit beyond what was available using a dual-sonde approach, where the latter was limited to SO_2 concentrations that were less than the ozone concentration.

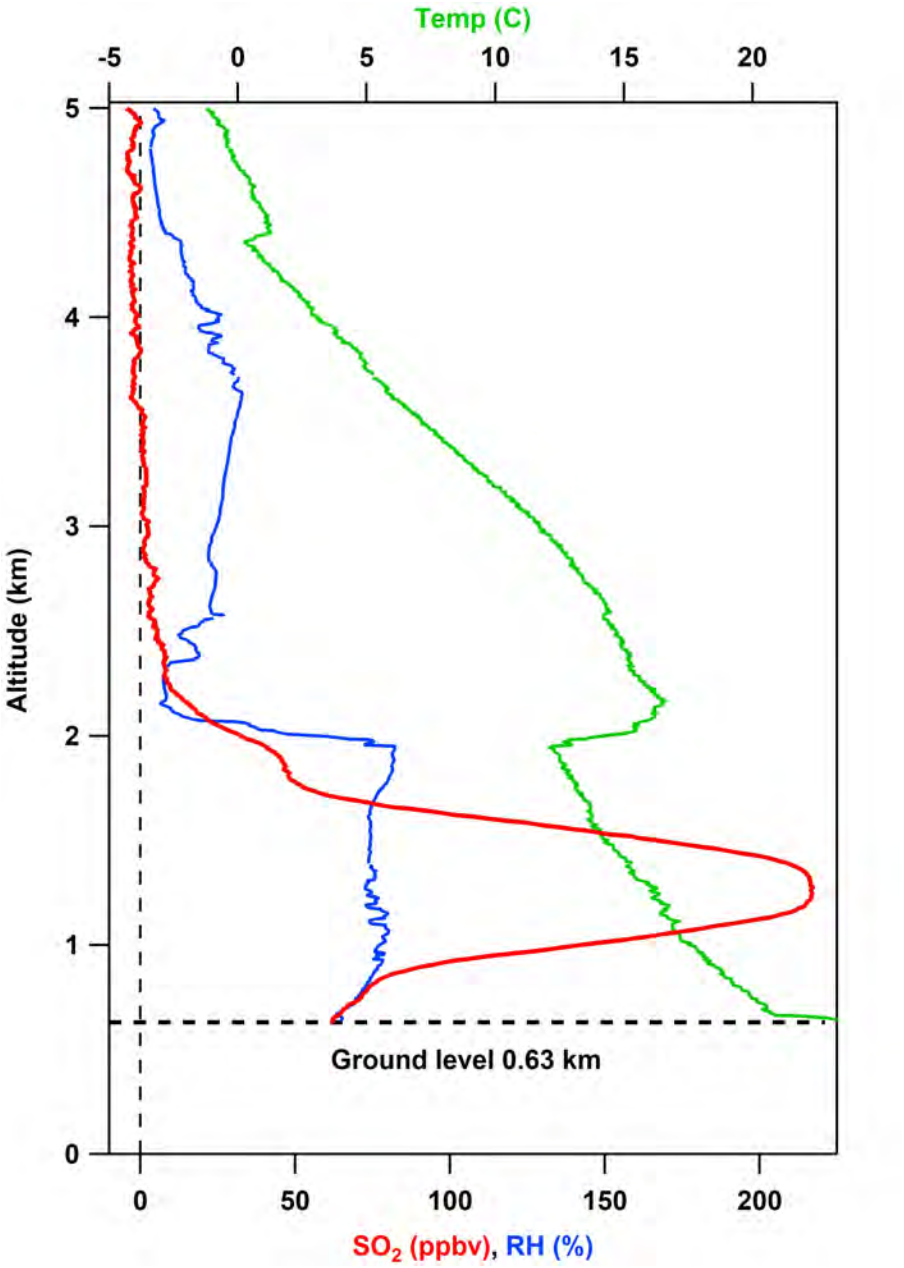


Figure 1. Vertical profile of SO_2 for flight taking place on 26 June 2018 near Kahuku Ranch on the southern part of the Island of Hawaii downwind of the then ongoing Kilauea lower East Rift Zone eruption.

Optimizing Umkehr Ozone Profile Retrievals during the Mt. Pinatubo Volcanic Eruption

K. Miyagawa[1], I. Petropavlovskikh[2,3], G. McConville[2,3], and A. McClure-Begley[2,3]

[1]Guest Scientist at NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 720-939-5313, E-mail: miyagawa.koji@noaa.gov
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The Umkehr method is based on a sequence of zenith sky observations during sunrise/sunset. NOAA Umkehr ozone profile records have been collected since the 1970s. Umkehr ozone profiles are used to monitor and guide stratospheric ozone recovery predicted by the 2050s. Current operational Umkehr profile algorithms produce data that have uncertainty on the order of ~ 5% in the stratosphere. However, when large volcanic eruptions inject aerosols into the stratosphere, the errors can be as large as 70%. In order to evaluate Umkehr records for aerosol-related and instrumental errors, we compare observations with a Hindcast simulation of the NASA Global Modeling Initiative (GMI) chemistry transport model (CTM, PI S. Strahan) that provides hourly-sampled vertical profiles of ozone and temperatures matched to the location of the Umkehr station. In addition, GMI ozone and temperature profiles are used for simulations of Umkehr observations. The biases found between the model and observations are summarized for each Dobson calibration period, thus providing a reference for homogenization of the Umkehr time series and successful removal of aerosol errors. Figure 1 demonstrates the ability of the optimized Umkehr ozone retrieval method to post-correct errors encountered by Umkehr operational retrieval during the volcanic eruption of Mt. Pinatubo (1991). The record is shown for Mauna Loa Observatory (MLO).

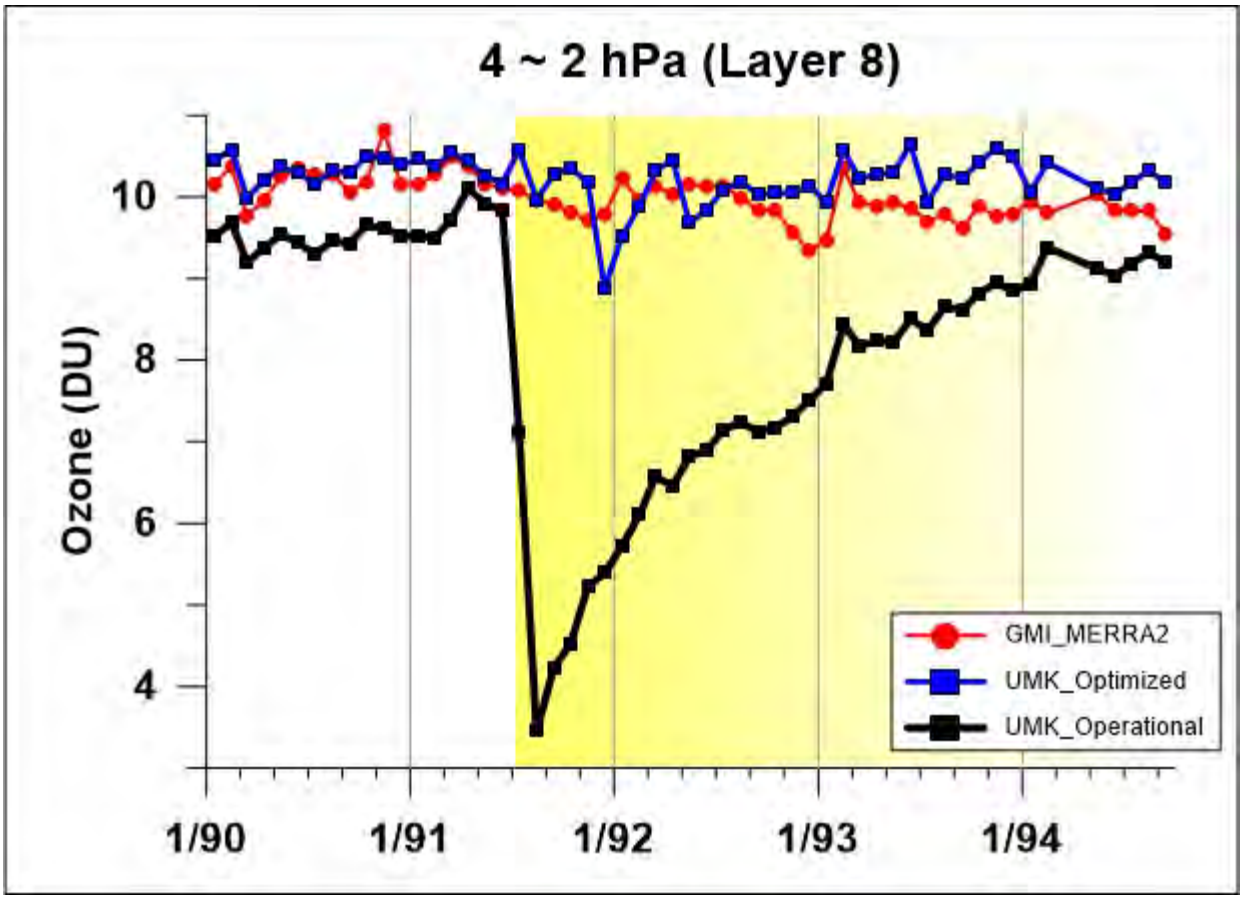


Figure 1. MLO ozone monthly-mean time series at 2–4 hPa (Umkehr layer 8) are shown for the Umkehr operational (Black), Umkehr optimized (Blue) algorithms and the station matched GMI (Red) data (NDACC Theory and Modeling group project, PI S. Strahan). The plot is focused on the period of 1991 eruption of Mt. Pinatubo volcano. A yellow grading shows a time period of enhanced aerosols that introduced large errors in the Umkehr operational ozone retrievals.

South American Dobson Intercomparison Campaign for RA-III

G. McConville[1,2], and K. Miyagawa[3]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-3989, E-mail: glen.mcconville@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Guest Scientist at NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The WMO GAW Regional Association III (RA-III) international comparison of Dobson spectrophotometers was held between March 4–22, 2019 in Buenos Aires, Argentina. This activity is performed as a quality control requisite condition for monitoring atmospheric total ozone. Previous Region III intercomparisons were carried out in 1999, 2003, 2006, and 2010. The individual participants performed a WMO GAW-required calibration procedure under the scientific staff's supervision. The event also provided instructions on standard operating procedures for making observations with a Dobson spectrophotometer, conducting routine maintenance checks, and data management. The final intercomparison showed a maximum difference of 0.2% in total ozone values from the standard for ADDSGQP observations in the mu range 1.5 to 2.5. The participant countries and Dobson instrument numbers are below (Figure 1).

Dobson #	Organization	Country	WOUDC/others
65	NOAA	USA	World Secondary
67	La Habana, Instituto de Meteorologia de Cuba	CUBA	311
70	Buenos Aires Observatory	Argentina	091/RA III Std.
87	Servicio Nacional de Meteorológico e Hidrografía de Perú – SENHAMI Marcapomacocha	PERÚ	429
93	Sao Paulo Instituto Nacional de Investigaciones Espaciales (INPE)	BRASIL	219
97	La Quiaca Observatory, Jujuy Servicio Meteorológico Nacional	Argentina	513
98	MÉXICO: Cd. De México	MÉXICO	192
99	Estación Antártica Marambio	Argentina	233
114	Instituto Nacional de Investigaciones Espaciales (INPE)	BRASIL	200
131	Ushuaia – GAW Station, Provincia de Tierra del Fuego, Antártida e Islas del Atlántico Sur. Servicio Meteorológico Nacional	Argentina	339
133	Comodoro Rivadavia Station, Chubut Servicio Meteorológico Nacional	Argentina	342
134	El Salto Instituto Uruguayo de Meteorologia	URUGUAY	343

Figure 1. Table of participants.

Figure 2. The final intercomparison of all the participating Dobson instruments and the U.S.A. world Secondary Dobson (D065) on March 18, 2019.

New Volumetric Flow Rate Tests of Ozonesonde Pumps at Reduced Pressures

B. Johnson[1], A. Jordan[2,1], and P. Cullis[2,1]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-475-5816, E-mail: bryan.johnson@noaa.gov
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309

New ozonesonde pump flow rate measurements at reduced pressures will be presented here. Balloon-borne, electrochemical concentration cell (ECC) ozonesondes measure high-resolution profiles of ozone concentration from the surface to 35 km (5 hPa) altitude. Regular evaluation of ECC ozonesonde performance are evaluated at the world calibration center in Jülich, Germany. However, measuring the ozonesonde pump efficiency at low pressures is not a part of the calibration experiments. The ozonesonde volumetric flow rate is constant at surface pressure and remains nearly 100% efficient to 300 hPa pressure then steadily decreases with altitude (lower pressure) due to the greater effect of resistance from pumping against the cathode solution fluid head, dead space in the cylinder of the piston pump, and pump leakage. The ozone equation accounts for the decrease in flow rate by multiplying by a pump correction factor (PCF) which is a function of pressure. The PCF value is simply the inverse of the pump efficiency. The most widely used PCF curves are based on experimental measurements by Komhyr (1986, 1995). Several other methods have been used to measure PCF curves. However, the only two methods in use at this time are the bag deflation method (automated version of the University of Wyoming method) by the Japanese Meteorological Agency (JMA) and the oil bubble flow meter by NOAA GMD. Figure 1 shows the 3 PCF curves. The NOAA GMD method has recently been modified and these new results will be presented.

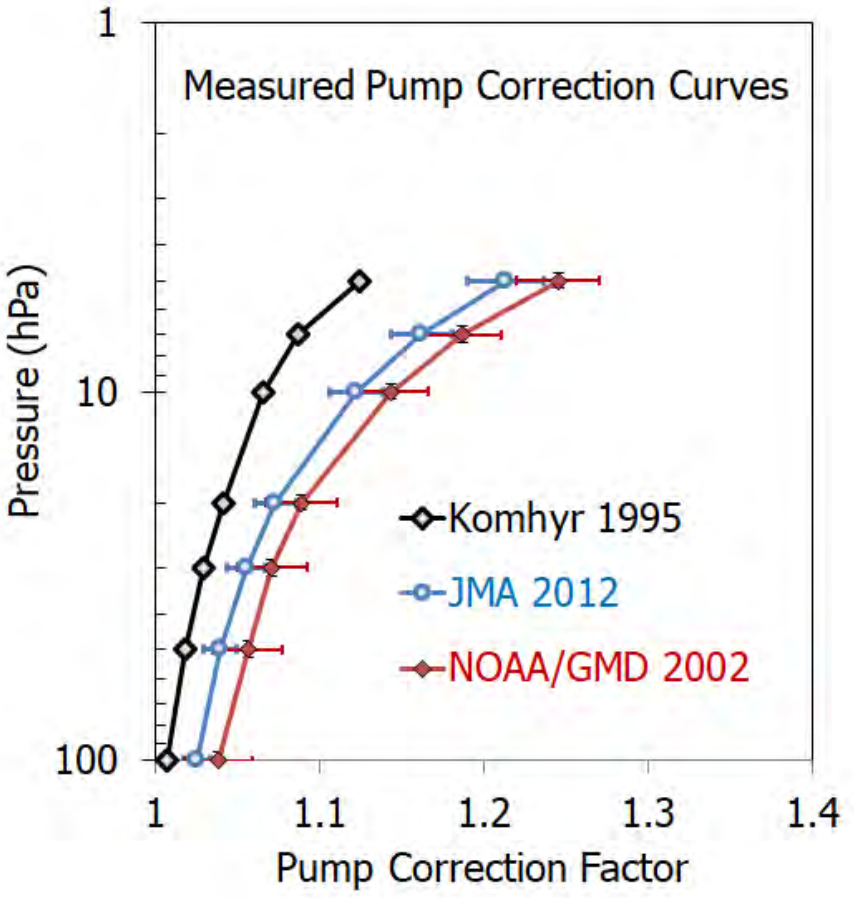


Figure 1. The standard PCF curve from Komhyr (1995) and the average values (±1 standard deviation) of the other two methods by the JMA and the NOAA ozonesonde groups.

Ozonesonde Observations at South Pole Station During the 2018 Ozone Hole

B. Johnson[1], P. Cullis[2,1], G. McConville[2,1], A. Mcclure[2,1], I. Petropavlovskikh[2,1], K. Miyagawa[3], and R.C. Schnell[1]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-475-5816, E-mail: bryan.johnson@noaa.gov
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6674, E-mail: Patrick.Cullis@noaa.gov
[3]Guest Scientist at NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

Balloon-borne, electrochemical-concentration cell (ECC) ozonesondes launched at South Pole station have tracked the development of the yearly Antarctic ozone hole since 1986. The severity of ozone depletion depends on active chlorine concentrations in the stratosphere, wintertime stratospheric temperatures, and the stability of the polar vortex. In 2018, satellite and sonde observations showed very cold Antarctic lower stratosphere temperatures (Kramarova et al., 2019, BAMS 2018 State of the Climate Report) resulting in severe depletion. The South Pole ozonesonde minimum profile of 104 Dobson Units recorded on October 12, 2018 was the 12th lowest in the 33-year record.

Figure 1 shows the smoothed 8-year medians of ozone and temperature in the 16–18 km layer, where the maximum ozone loss occurs. There are signs of improvement in the 2009–2016 period trending above the 1990–2014 median, but remains well below the higher ozone observed during the 1986–1992 period, when stratospheric chlorine levels were lower. Year-to-year variability in ozone depletion, driven by dynamical activity over Antarctica, is shown by comparing the warm (2017) and cold (2018) stratospheric vortex conditions. Trends in the 2-km column ozone layers from 10 to 24 km will be presented.

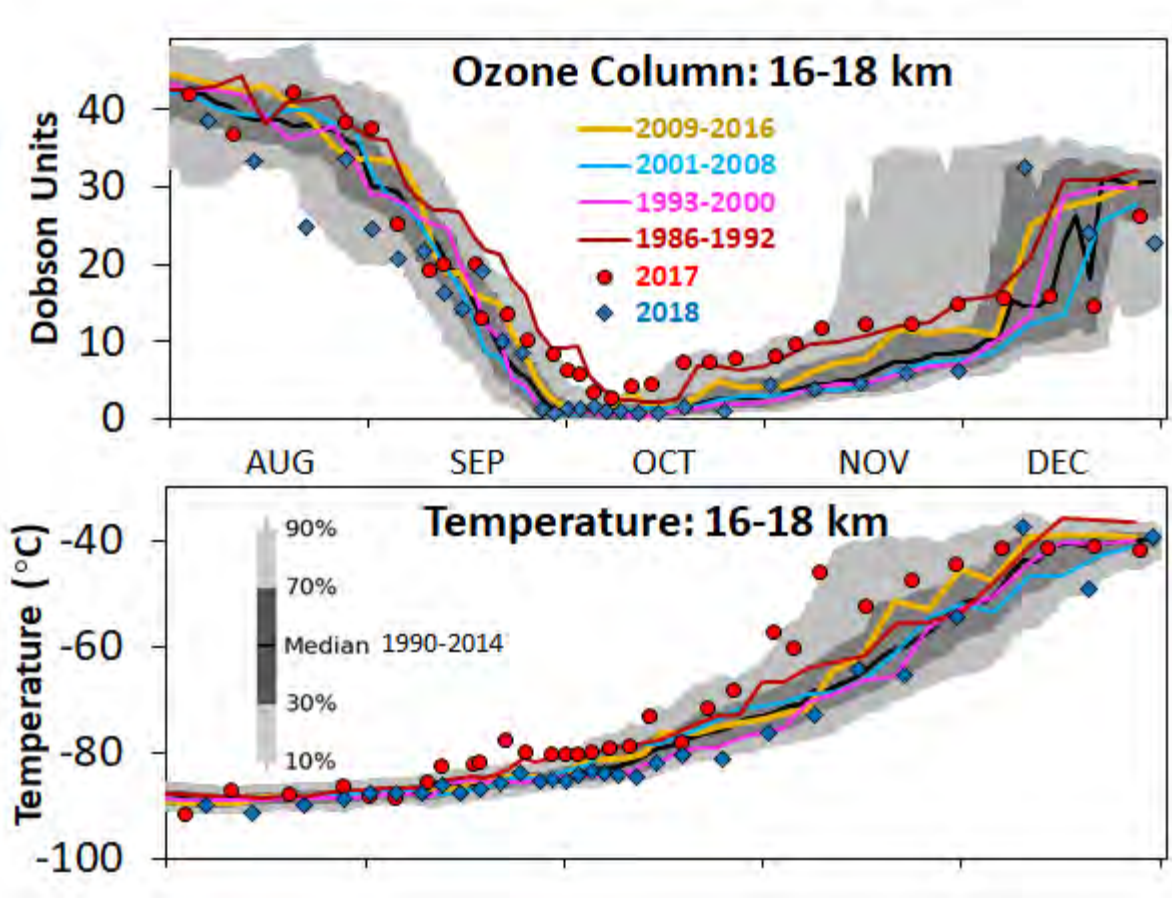


Figure 1. 8-year medians of ozone partial column and temperature within the 16–18 km layer compared to the 1990–2014 median climatology at South Pole Station. The cold, stable vortex in 2018 correlates with 100% ozone depletion by late September, while 2017 showed much higher ozone during warm stratospheric conditions.

The Role of Convection in Tropical Ozone Variability Inferred from Profiles at NOAA's SHADOZ Stations (1998–2017)

A.M. Thompson[1], J.C. Witte[2,1], R.M. Stauffer[3,1], B.J. Johnson[4], P. Cullis[5,4], H.B. Selkirk[6], H. Vömel[7], and A. Jordan[5,4]

[1]NASA Goddard Space Flight Center (GSFC), Atmospheric Chemistry and Dynamics Laboratory, Greenbelt, MD 20771; 301-614-5905, E-mail: anne.m.thompson@nasa.gov
[2]Science Systems and Applications, Inc. (SSAI), Lanham, MD 20706
[3]Universities Space Research Association (USRA) - NASA Postdoctoral Program (NPP), Columbia, MD 21046
[4]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[5]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[6]Universities Space Research Association (USRA), Colombia, MD 21046
[7]National Center for Atmospheric Research (NCAR), Boulder, CO 80307

The tropical free troposphere (FT) and tropopause transition layer (TTL) are critical regions in changing atmospheric composition because of feedbacks among temperature (i.e., radiative forcing), dynamics, and key species like water vapor and ozone. Because of these sensitivities, quantifying ozone variability and trends in the FT and TTL over the past several decades remains an on-going subject of interest. Here we use the reprocessed SHADOZ (Southern Hemisphere Additional Ozonesondes; *Thompson et al.,* 2017; *Sterling et al.,* 2018; *Witte et al.,* 2017; 2018) ozonesonde dataset to analyze variability in FT and TTL ozone at ten tropical stations with an emphasis on those that NOAA has overseen since 1998: Am. Samoa; Fiji; San Cristóbal, Galapagos; San Pedro, Costa Rica. Ozone vertical structure in the FT and TTL suggests convective influence (CI) with clear transitions in frequency 3–4 times/yr as shown in the two examples below. Standard metrics (e.g., seasonal mean mixing ratio), augmented by laminar wave-identification of wave impact (Gravity Wave Index [GWI], *Thompson et al.,* 2011) and SOM (Self-Organizing Maps; *Stauffer et al.*, 2018), are used to quantify the role of CI in seasonal, intraseasonal and interannual variability in FT and TTL ozone. We find an inverse relationship between CI, quantified by the GWI, in the TTL and FT ozone column amount. A standard Multi-variate Linear Regression Model (MLR) that includes convectively-related oscillations, e.g. El Niño Southern Oscillation (ENSO), Indian Ocean Dipole, Madden-Julian Oscillation, is applied to monthly mean ozone. Of these, the most significant is the ENSO impact. CI needs to be taken into account when computing trends. Statistics for the NOAA (Pacific) stations are compared to those for Atlantic SHADOZ stations.

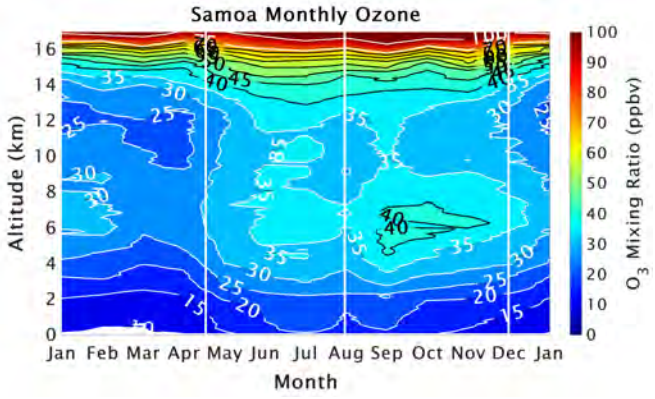


Figure 1. Mean monthly ozone mixing ratios (in ppbv) from the surface to 17 km at the American Samoa SHADOZ station. White lines indicate transition periods in the seasonal cycle of tropospheric and upper tropospheric/lower stratospheric ozone.

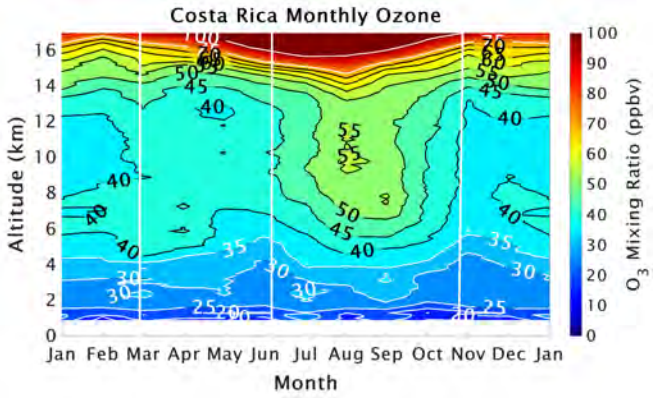


Figure 2. Mean monthly ozone mixing ratios (in ppbv) from the surface to 17 km at the Costa Rica SHADOZ station. White lines indicate transition periods in the seasonal cycle of tropospheric and upper tropospheric/lower stratospheric ozone.

Measured and Modeled Ozone Distributions over the Atlantic and Pacific Oceans from the ATom Mission

E. Hintsa[1], F.L. Moore[1,2], G.S. Dutton[1,2], B.D. Hall[2], A. McClure-Begley[1,2], J.D. Nance[1,2], J. Elkins[2], C. Thompson[1,3], J. Peischl[1,3], T. Ryerson[3], J. Liu[4], S. Strode[5,4], A. Fiore[6], L. Murray[7], and C. Flynn[8]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303 497-4888, E-mail: Eric.J.Hintsa@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO 80305
[4]NASA Goddard Space Flight Center (GSFC), Greenbelt, MD 20771
[5]Universities Space Research Association (USRA), Colombia, MD 21046
[6]Columbia University, Lamont-Doherty Earth Observatory, Palisades, NY 10964
[7]University Of Rochester, Rochester, NY 14627
[8]University of California at Irvine, Irvine, CA 92697

Field deployments of the NASA Atmospheric Tomography (ATom) Mission in 2016–2018 have provided a large set of chemical and other data over the Atlantic, Pacific, Southern, and Arctic Oceans from near the surface to about 12 km in each season. The mission was designed to study ozone and methane chemistry, atmospheric oxidation, and other chemical cycles on large scales, and to challenge chemical transport models. I will present data and intercomparisons from ATom deployments, focusing on analysis of tropospheric ozone, related gas phase species, and model results (some from arbitrary years and some using meteorology from the ATom time periods, with results interpolated onto ATom flight tracks). The goals are to 1) map out the distributions of ozone along North-South transects across the Atlantic and Pacific Oceans and the polar regions as a function of altitude, latitude, and season, 2) compare with model results both along flight tracks and as probability distributions, and 3) improve our understanding of model-measurement agreement or differences resulting from chemistry and transport. All the models examined do a reasonable job of predicting large-scale features in ozone. The NASA Global Modeling Initiative (GMI) chemical transport model performed well in hindcasting ozone distributions in ATom-1, 2, and 3 using actual meteorology. Some discrepancies exist between model and measured data over the tropical Atlantic, where ozone observed during ATom was much higher compared to the tropical Pacific throughout the troposphere. Further work includes exploring the origin of air masses with high (and low) ozone in ATom, comparing to model runs from the same date and year as the ATom deployments, and exploring the chemical relationships between ozone and other species in models and measurements.

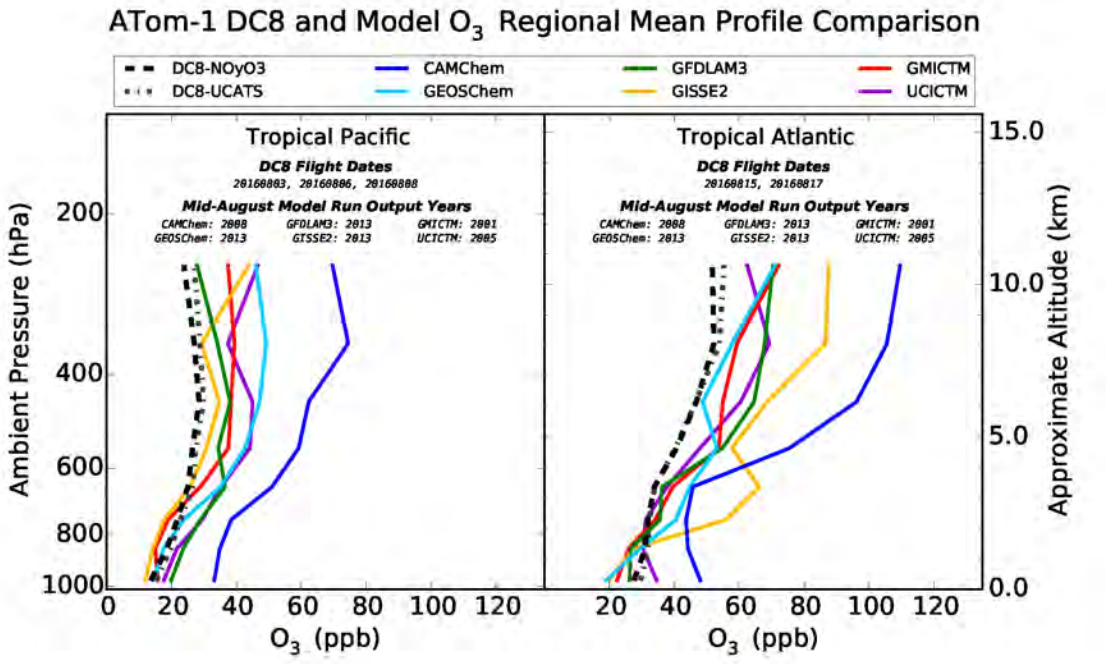


Figure 1. Average vertical profiles of ozone from the DC-8 and six global models, interpolated onto the ATom-1 flight tracks for the tropical Pacific (left) and tropical Atlantic (right). The modeled ozone results are often higher than the *in situ* data, though the model and DC-8 flight data are from different years.

Comparison of Vertical Distribution of Ozone Profiles between Ozonesondes and the GMI Merra II Model

E. Hall[1,2], K. Miyagawa[3], B.J. Johnson[2], P. Cullis[1,2], A. Jordan[1,2], and I. Petropavlovskikh[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-4288, E-mail: emrys.hall@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Guest Scientist at NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

NOAA has recently completed a homogenization using consistent reprocessing of the long-term vertical ozonesonde profile record which now includes ozonesonde uncertainty (Sterling et al., 2018). In this work we will use an hourly Hindcast simulation of the NASA Global Modeling Initiative (GMI) chemistry transport model (CTM, PI S. Strahan) to show the relative bias with the vertical distribution of the homogenized ozonesonde profiles. The vertical resolution for ozonesondes and the GMI model are 0.1 and 0.75 km, respectively. In this study we will use pressure interpolation with roughly a 1.0-km vertical resolution for all comparisons. As an example, we summarized the bias of the ozone mixing ratio with the GMI model since 1985 over Boulder. The bias is approximately 30% around the tropopause (~100 hPa) where ozone values have quick transitions from low to high concentrations in a short vertical range. The model shows good agreement above and below the area surrounding the tropopause. Different models of ozonesondes have been used throughout the record and we will show these transitions along with the biases that still remain even after homogenization. Additionally, we will show differences between the sondes and model for temperature and altitude from the stations at Boulder, Colorado and Hilo, Hawaii.

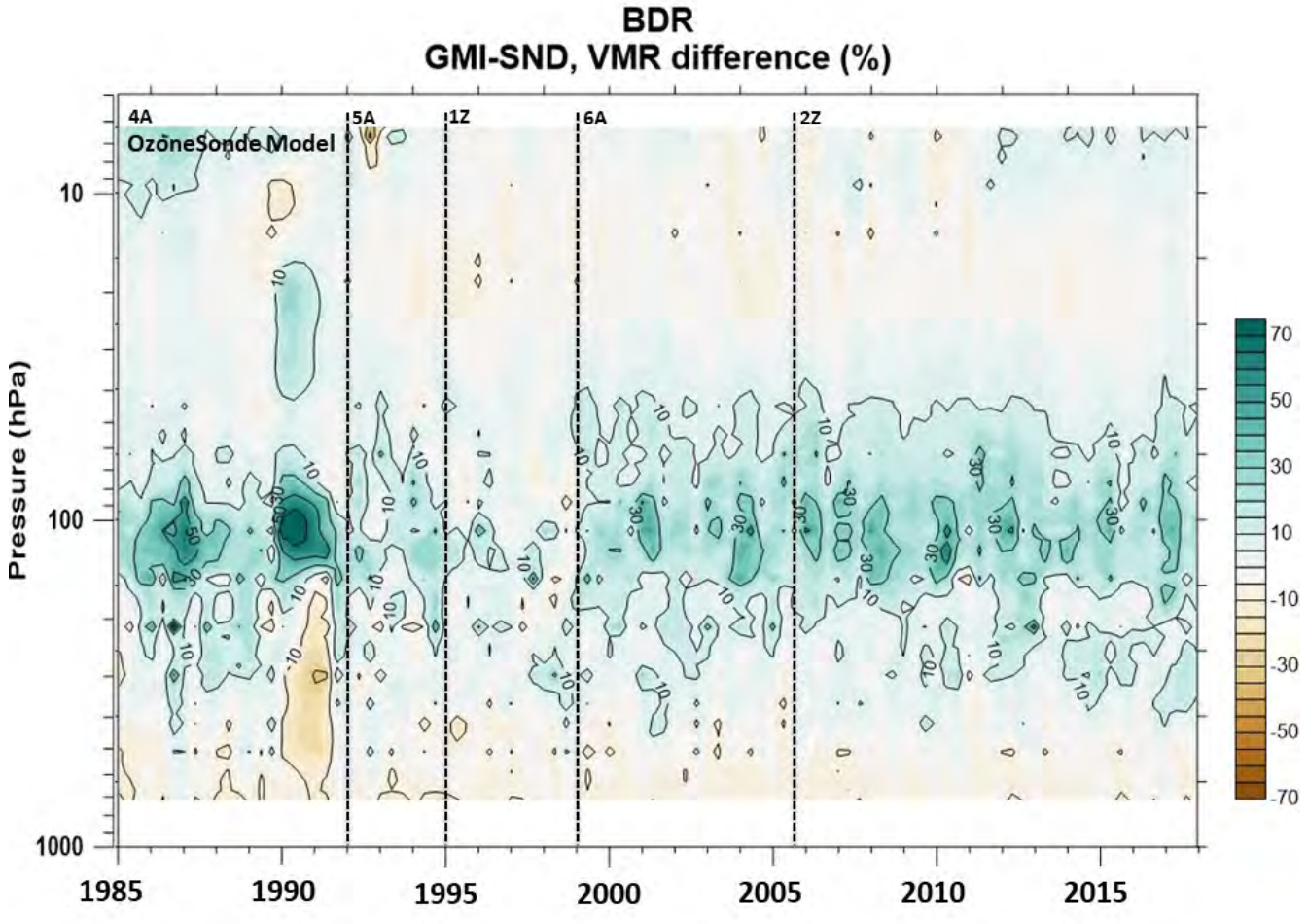


Figure 1. Shown above are the differences in the ozone monthly mean time series between the GMI model and ozonesonde observations. The vertical bars denote an ozonesonde model change.

Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE III/ISS) Science Data Products: Preliminary Validation Results

S. Kizer[1,2], M. Roell[2], D. Flittner[2], R. Damadeo[2], L. Thomason[2], T. Knepp[1,2], J.R. Moore[1,2], K. Leavor[1,2], D. Hurst[3,4], E. Hall[3,4], A. Jordan[3,4], P. Cullis[3,4], B.J. Johnson[4], and R. Querel[5]

[1]Science Systems and Applications, Inc. (SSAI), Lanham, MD 20706; 757-864-8358, E-mail: susan.h.kizer@nasa.gov
[2]NASA Langley Research Center, Hampton, VA 23681
[3]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[4]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[5]National Institute of Water and Atmospheric Research (NIWA), Wellington, New Zealand

The Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument, installed on the International Space Station (ISS), has completed over a year of data collection and production of science data products. The SAGE III/ISS is a solar and lunar occultation instrument, scanning the light from the sun and moon, through the limb of the Earth's atmosphere. It was launched in February 2017 and provides data from June 2017 to the present. It continues SAGE's legacy of ozone, aerosol and water vapor profile measurements and extends the lengthy records for monitoring constituents important for understanding stratospheric ozone trends. This presentation shows the preliminary validation results of comparing SAGE III/ISS ozone and water vapor vertical profiles with those of NOAA ESRL GMD and NIWA mission-funded ozonesondes and frost point hygrometers (FPH), and comparisons with other correlative data.

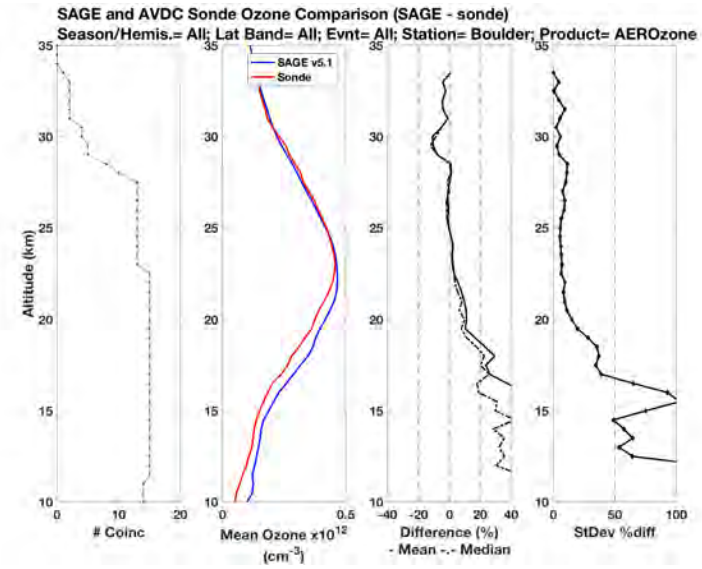


Figure 1. SAGE III/ISS and NOAA ESRL Boulder Ozone Comparison.

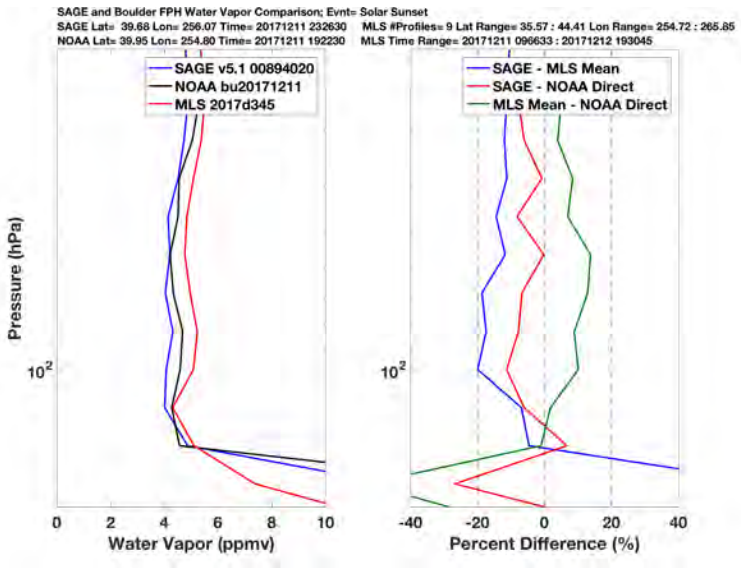


Figure 2. SAGE III/ISS, NOAA ESRL Boulder FPH, Microwave Limb Sounder (MLS) Water Vapor Comparison.

Seasonal Trends in Observed Surface Ozone Conditions in the Arctic

A. McClure-Begley[1,2], S.M. Morris[1,2], I. Petropavlovskikh[1,2], T. Uttal[3], O.R. Cooper[1,4], D.W. Tarasick[5], H. Skov[6], and S.J. Oltmans[7]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-6823, E-mail: audra.mcclure@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]NOAA Earth System Research Laboratory, Physical Sciences Division (PSD), Boulder, CO 80305
[4]NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO 80305
[5]Environment and Climate Change Canada, Toronto, Ontario, Canada
[6]Aarhus University, Aarhus, Denmark
[7]Retired from NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The Arctic is a region that is currently experiencing dramatic variations in environmental and atmospheric conditions, and is likely to continue to be influenced by a changing climate. In order to understand the implications of drastic changes to the Arctic climate system, it is imperative to understand the expected behavior and associated impacts of different atmospheric constituents. Tropospheric ozone is an important greenhouse gas that contributes to Arctic surface temperatures and is the primary component of photochemical smog. Both formed and destroyed by photochemical reactions with other compounds, ozone concentrations influence the chemical composition and photochemical oxidation properties of the atmosphere. In addition, understanding ground-level ozone is imperative as high levels of ozone can have negative impacts on ecosystem functioning and public health.

Measurements of tropospheric ozone have been made in the Arctic since 1973, which provides a unique opportunity to investigate the long-term trends and changes in observed ozone conditions. Ozonesonde profiles can provide additional information about the observed trends by providing information regarding the surface up to the tropopause from vertically distributed measurements. Currently, eight Arctic sites monitor ground-level ozone and are used for this investigation (Alert, Canada; Barrow, Alaska; Eureka, Canada; Ny-Ålesund, Svalbard; Pallas, Finland; Summit, Greenland; Tiksi, Russia; and Villum Research Station, Greenland). Ozonesondes are launched at seven sites: Churchill, Alert, Eureka, Ny-Ålesund, Sodankyla, Summit, and Scoresbysund.

Trends in ozone conditions vary between stations as well as seasons. Some measurement location records, such as Barrow, show a statistically significant increase in observed mixing ratios over the 45-year measurement period. Further evaluation of the trend reveals that the dominant increases occur during the spring months, but a slight decrease occurs during the winter months. Other Arctic measurement stations do not observe the same spring trend, but have similar trends during the winter months. Complex interactions of meteorological conditions, long-range transport patterns, sea ice conditions, pollutant sources, and photochemical processes drive spatial and temporal variations of ozone in the troposphere observed across the Arctic. Co-located measurements, climate models, back-trajectory analysis, and satellite imagery are used to interpret the trends in surface ozone conditions.

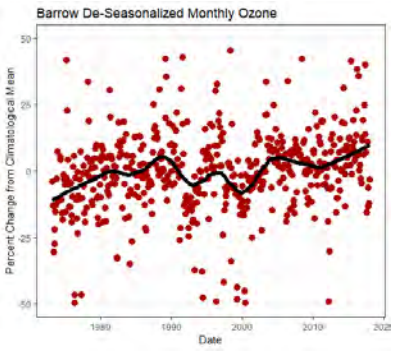


Figure 1. Percent change in monthly ozone mixing ratio across time that reveals a recent increase in observed surface ozone conditions from the Barrow Observatory.

Figure 2. Trends calculated for each month of the year show the seasonality of trends which are drivng the overall patterns in observed surface ozone from Barrow, Alaska.

Overview and Selected Results from the NOAA Federated Aerosol Network

P. Sheridan[1], D. Hageman[2,1], J. Wendell[1], and B. Andrews[2,1]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-6672, E-mail: patrick.sheridan@noaa.gov
[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309

The NOAA Earth System Research Laboratory (ESRL) maintains Atmospheric Baseline Observatories to monitor the atmospheric background levels of trace gases and aerosols. Measurements at these remote sites permit us to determine to what extent the global backgrounds are changing over time. Since aerosols are perturbed near the sources, these Observatories are in prime locations to assess baseline changes to the atmospheric aerosol. In order to better understand anthropogenic aerosol radiative forcing and its effects on climate, and to reduce the uncertainties associated with extrapolating relatively few discrete observations up to regional or global scales, many more stations in different climatological regions were needed. To accomplish this ESRL has over the past two decades significantly expanded its network of stations to include locations that are at times influenced by anthropogenic emissions. This long-term strategy permits estimates of how much of the aerosol radiative forcing at these locations is caused by human activities and sheds light on whether changes in policy can influence the effects of these aerosols. It is not realistic for NOAA to fund the operation of monitoring stations all over the world. The primary way we have been able to expand the network to include another major anthropogenic aerosol source region (Southeast Asia), the region considered the bellwether of global climate change (the Arctic), and other perturbed areas is to foster collaborations with interested science organizations and universities in the U.S. and around the world. The collaborations we have developed present advantages for all parties and the aerosol data collected are directly comparable with those from other stations in the network. This presentation describes the growth of this collaborative global surface aerosol-monitoring network (the NOAA Federated Aerosol Network) and shows some recent results from these collaborations.

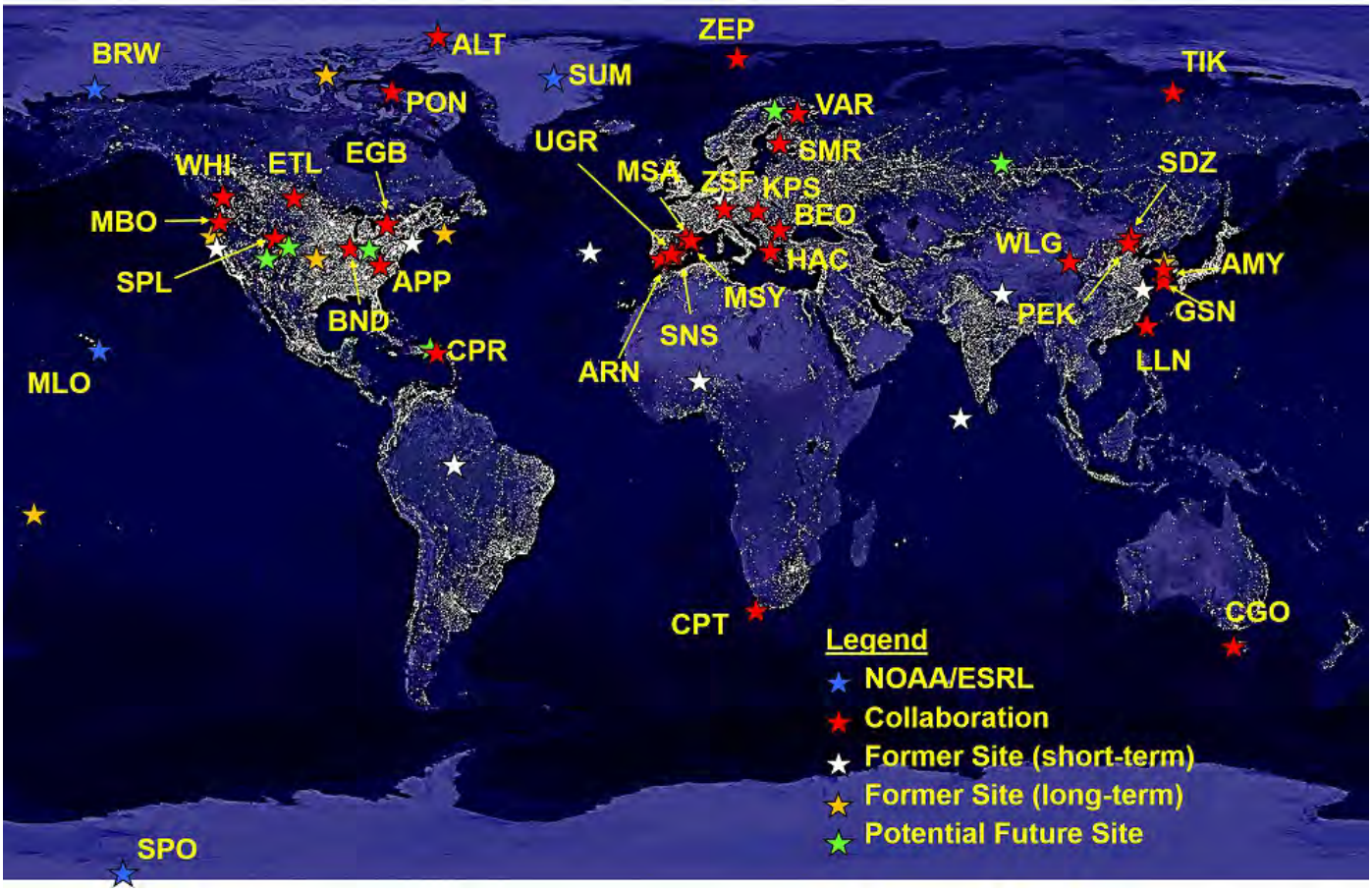


Figure 1. The NOAA Federated Aerosol Network in April 2019.

An Overview of the Effect of Water Uptake on Aerosol Particle Light Scattering: Observations, Evaluation of Proxies, and Comparison with Global Models

E. Andrews[1,2], G. Titos[3], M. Burgos[4], and P. Zieger[4]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-5171, E-mail: betsy.andrews@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]University of Granada, Department of Applied Physic, Granada, Spain
[4]Stockholm University, Stockholm, Sweden

Ambient aerosol particles can take up water and thus change their optical properties depending on their hygroscopicity, their size, and the relative humidity (RH) of the surrounding air. Knowledge of the hygroscopicity effect is of importance for radiative forcing calculations but is also needed for the evaluation of remote sensing and model results with *in situ* measurements. The dependence of particle light scattering on RH can be described by the scattering enhancement factor f(RH), which is defined as the particle light scattering coefficient at a given RH divided by the scattering coefficient at dry conditions.

Here we present an analysis of the scattering enhancement factor from tandem nephelometer measurements at 26 sites across the globe. The raw measurement data sets from multiple research groups were analyzed identically in order to ensure the best comparability of the results. The lowest f(RH) was observed at a desert site, while the highest values were found at arctic and marine sites (Figure 1). Scattering enhancement values for rural and urban sites fell between these two extremes.

Most measurements of aerosol light scattering are made at low humidity (RH<40%) to comply with international protocols. The data set described here may be useful in developing proxies for estimating f(RH) for sites where tandem nephelometer data are not available. Such proxies would simplify relating dry measurements to ambient data (e.g., aerosol optical depth). We present preliminary results evaluating the use of other aerosol optical properties (e.g., scattering Angstrom exponent and single scattering albedo) to estimate aerosol hygroscopicity.

Finally, a major goal of this project is to use the observations of aerosol hygroscopic growth to evaluate and constrain simulations of the effect of water uptake on aerosol optical properties in global climate models (GCMs). Some initial results comparing the observational data set to GCM simulations demonstrate that some models better capture observed measurement diversity while other models exhibit a narrow range of f(RH) regardless of aerosol type.

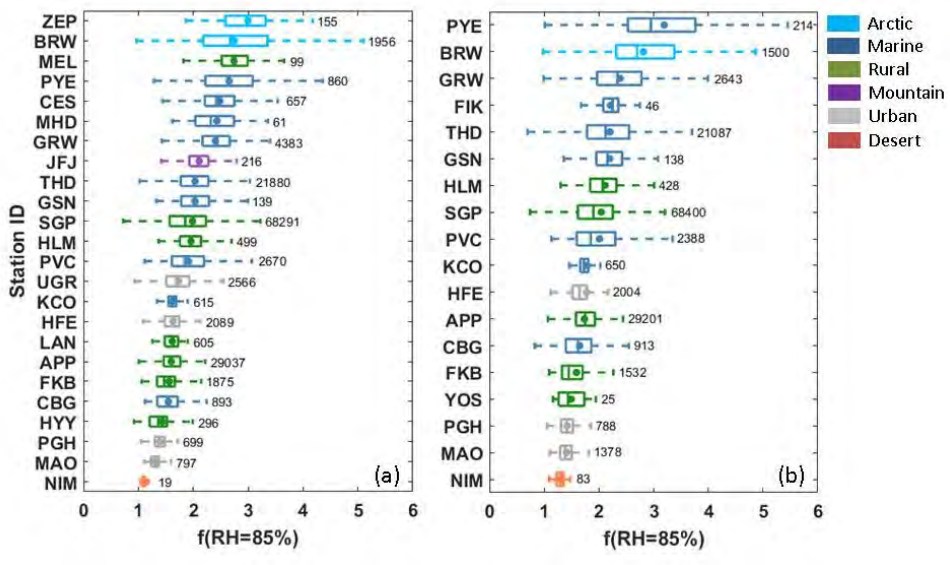


Figure 1. Observed scattering enhancement factor at 26 sites for (a) PM_{10} and (b) PM_1 aerosol.

Seasonal Dependence of Column-averaged and Near-surface Aerosol Optical Properties Measured at Appalachian State University (APP)

T. Foote

Appalachian State University, Department of Physics and Astronomy, Boone, NC 28608; 919-692-5639, E-mail: footetm@appstate.edu

Appalachian State University (APP) is home to the only co-located NOAA ESRL, NASA AERONET, and NASA MPLNET aerosol monitoring sites in the U.S., with all but the MPLNET datasets extending back to at least 2010. Measurements of surface-level aerosol mass concentrations for dried particles smaller than 10μm (PM_{10}) and smaller than 2.5μm ($PM_{2.5}$) were added in November 2016. The vast datasets have led to studies of aerosol variability (Sherman et al., 2015), aerosol direct radiative effect and its uncertainties (Sherman and McComisky, 2018), and evaluations satellite-based aerosol measurements (Sherman, et al., 2016; Krintz and Sherman, manuscript in progress). Satellite-measured aerosol optical depth (AOD) is gaining more applications in climate and air quality studies. One application is to estimate surface-level aerosol mass concentrations. However, some studies (Goldstein, 2009; Heald and Ford) have hypothesized that a significant upper-level summer aerosol layer can explain the lack of seasonal dependence of surface-level $PM_{2.5}$ in the SE U.S., relative to the seasonal dependence of AOD. Other studies have instead hypothesized that summer venting of the planetary boundary layer (PBL) heights or increase in relative humidity with height may instead be the source of these seasonal discrepancies.

Three years of lidar-measured vertical aerosol profiles at APP (as part of MPLNET) indicate that most of the aerosols reside in the PBL, even in summer. AOD at APP is much higher in summer than in winter (by factors of ~5-6) and $PM_{2.5}$ mass concentrations demonstrate small seasonal dependence, both of which are consistent with the above-mentioned (and other) studies. However, near-surface aerosol light scattering coefficient (σ_{sp}) for PM_{10} and PM_{10} aerosols measured at low relative humidity does show a summer enhancement (factor of ~2-3), relative to winter. While the seasonal variations in the AOD and σ_{sp} have decreased in recent years, it is still key to understand why there is a difference in observed seasonal dependency between AOD, $PM_{2.5}$, and σ_{sp} in order to assess the feasibility of space-based estimates of surface-level air quality. In this presentation, seasonal relationships between AOD, $PM_{2.5}$, and σ_{sp} measured at APP will be presented, along with select column-averaged and near-surface aerosol optical properties that could shed light on the relationships amongst them.

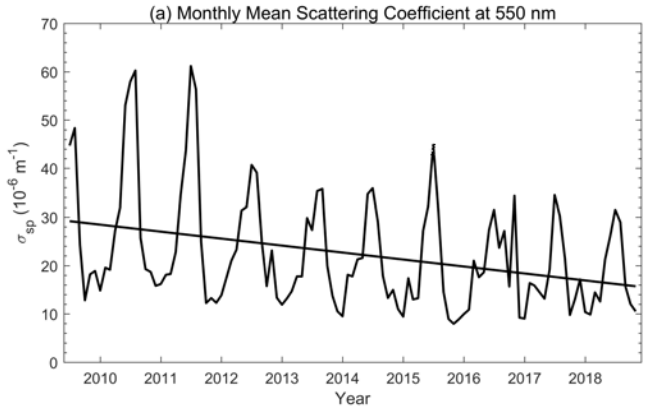


Figure 1. The scattering coefficient at 550 nm is shown over an eight-year period using the mean for each month.

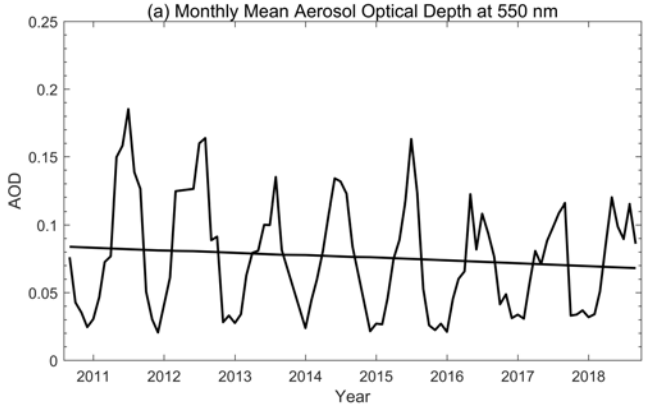


Figure 2. The aerosol optical depth at 550 nm is shown over an eight-year period using the mean for each month.

Variability of Aerosol Optical Properties at Mauna Loa and its Characteristics According to Source Regions

J. Park[1], S. Kim[1], P. Sheridan[2], A.G. Williams[3], and S.D. Chambers[3]

[1]Seoul National University, South Korea; +82 10-3037-9115, E-mail: jonguk7628@snu.ac.kr
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, Australia

Mauna Loa Observatory (MLO) is one of the NOAA Atmospheric Baseline Observatories, located far from major anthropogenic sources and at very high altitude (3397 m asl). These geographical conditions enable observations at MLO to be representative of Free-Tropospheric (F.T.) background conditions over the Pacific Ocean. However, MLO is suspected to be influenced by aerosols originating from remote continents and local sources. Global scale meteorological patterns and distinct diurnal radiation wind fields are known to be the reason, respectively, estranging MLO from obtaining free-tropospheric background aerosol optical properties (AOPs) (Bodhaine et al., 1981; Perry et al., 1999; Sheridan et al., 2017).

In this study, we investigated diurnal and seasonal variability of AOPs using long-term data (1974–2015). The aerosol scattering coefficient (σ_{sp}) showed distinct diurnal variation with peaks in the afternoon and minimum in the morning throughout the year. On the other hand, the aerosol absorption coefficient (σ_{ap}) didn't show a significant diurnal pattern. Based on a diurnal minimum of Radon-222 concentration in the morning, we defined the time period with the least local influence (LLI time period of 8:00–11:00 LST) to separate local influence and F.T. conditions (Chambers et al., 2013). Single scattering albedo (ω_0) was relatively high in the afternoon and in summer, which is when local radiation wind develops the most, showing that aerosols from local sources are scattering dominant. σ_{sp} and σ_{ap} under F.T. conditions showed a noticeable springtime peak, inferring that the free troposphere over the Pacific Basin shows higher aerosol concentrations during boreal spring than any other times of the year.

The HYSPLIT model was used to calculate backward trajectories to identify F.T. aerosol source regions. The most popular source regions were East Asia and South East Asia, which accounted for 25% and 13% in frequency, respectively. The frequency of Asian influence was greatest during the winter, but its normalized contribution with respect to measured σ_{sp} and σ_{ap} was greatest in spring. The systematic relationship between AOPs was analyzed to examine characteristics of aerosols according to respective source regions. Moreover, a significant increasing trend was found with σ_{sp} (1.85 %/yr), and a probable trend with σ_{ap} (6.59 %/yr). The positive trend on σ_{sp} and σ_{ap} was distinct in spring. East Asian influence is the most likely cause since its contribution increases as its average σ_{sp} increases.

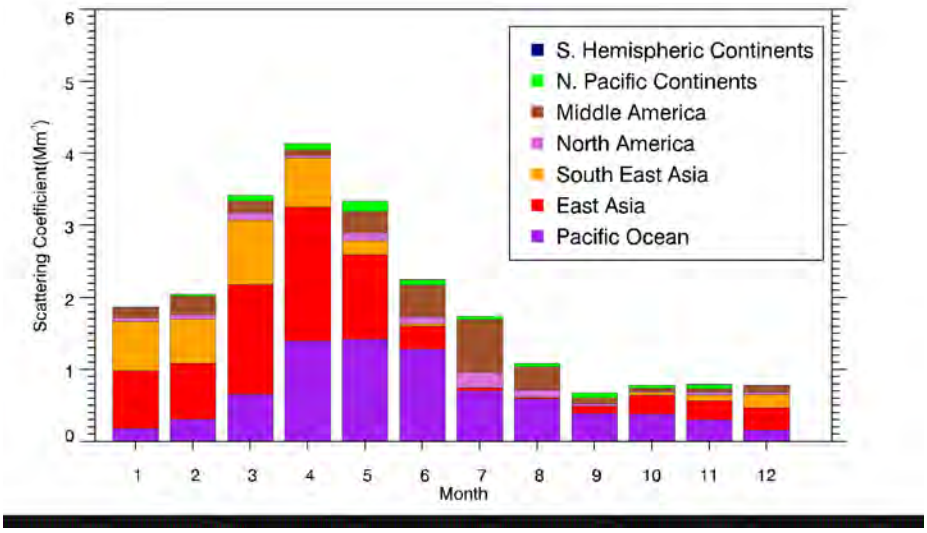


Figure 1. Monthly variation of contribution on aerosol scattering coefficient by each source region. Contribution was calculated using frequency and a measured aerosol scattering coefficient at collocated time.

Case Study of Air Quality during Winter Season over Northeastern Pakistan during 2007 to 2015

M.Z. Shahid

College of Earth & Environmental Sciences University of the Punjab, Lahore, Pakistan; +92-334-6589835, E-mail: mzeeshanshahid@gmail.com

Air pollution during winters over northeastern (NE) Pakistan (28–34 °N, 71–74.5 °E) is a serious challenge that affects human health, climate, and daily life. We use the Modern-Era Retrospective analysis for Research and Applications, V. 2 (MERRA-2) and satellite observations to quantify the last decade trend and interannual variation of aerosol during wintertime over NE Pakistan. Aerosols [sulfate, black carbon (BC), and organic carbon (OC)] are retrieved from MERRA-2 during 2007 to 2015. This study provided a unique opportunity to reveal temporal and spatial air pollution levels in mega cities in NE Pakistan. This study analysed the air pollution characteristics during winter, 2007 to 2015 in four mega cities including national and provincial capital cities in NE Pakistan. Averaged over winters from 2007 to 2015, over the four mega cities, Islamabad, Lahore, Faisalabad and Multan, the concentrations of sulfate were 5.06, 14.09, 14.29, 16.22 μg m^{-3}; BC were 1.5, 4.69, 4.46 4.52 μg m^{-3}; and OC were, 5.85, 17.32, 16.99 μg m^{-3} and 17.29, respectively. Aerosol concentrations during wintertime over NE Pakistan showed an increasing trend of aerosol optical depth and increased up to 0.5–0.8 over the past decade.

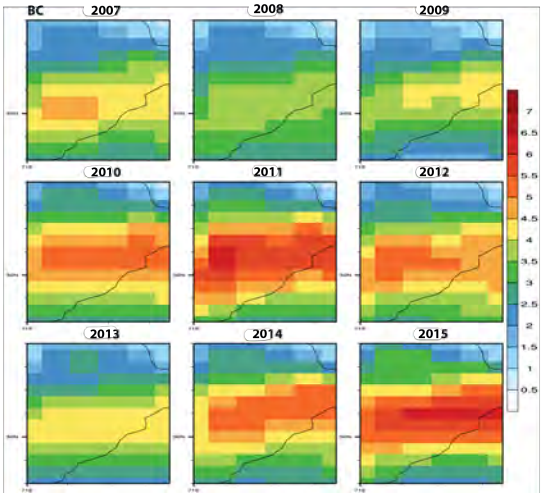


Figure 1. Concentration of BC (μg m^{-3}) over northeastern Pakistan (28–34 °N, 71–74 °E) during winter (average over December, January, February), 2007 to 2015.

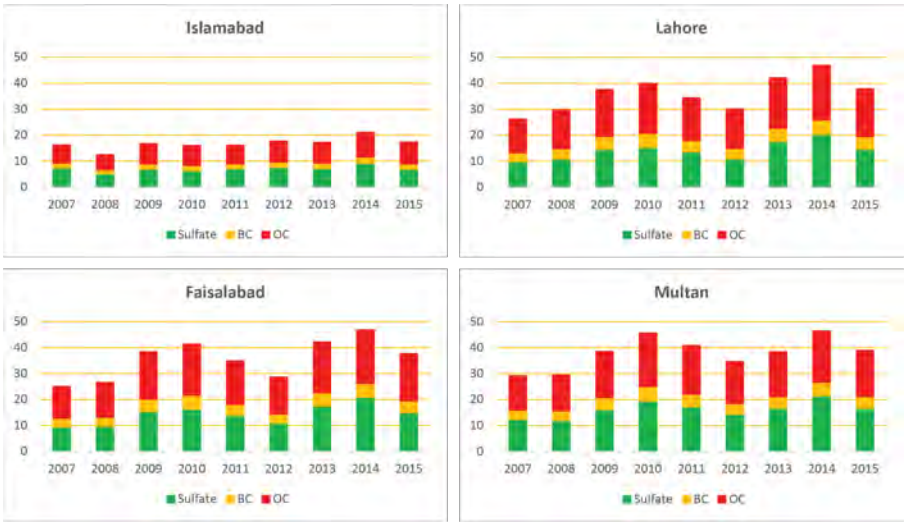


Figure 2. Aerosol conc. (average over December, January, February) over Islamabad, Lahore, Faisalabad and Multan during 2007 to 2015.

34-year Trends in Aerosol Chemistry in Relation to Aerosol Acidity at Alert, NU, Canada

S. Sharma[1], L. Barrie[2,3], E. Magnusson[3], and G. Brattssrom[3]

[1]Environment and Climate Change Canada, Toronto, Ontario, Canada; 416-739-5820, E-mail: sangeeta.sharma@canada.ca
[2]McGill University, Montreal, Canada
[3]Stockholm University, Stockholm, Sweden

Trends in aerosol chemistry, including 20 aerosol components and equivalent black carbon (EBC) over 34 years at Alert, Canada, shed some light on the changing chemical nature of the Arctic haze, due to changes in source influence on the Arctic troposphere (Sharma et al., 2019 submitted). Here we focus only on the changes in aerosol acidity due to changes in concentrations of sulfate, ammonium, and neutralization potential to form ammonium sulphate. Figure 1 shows that trends in concentrations of sulfate, nitrate, and aerosol acidity (H^+) have decreased over 34 years at a surface measurement site Alert, Canada. A decrease in anthropogenic Eurasian emissions in the early 1990's resulted in decreasing trends in (a) sulfate, (b) ammonium, and (c) H^+, but an increase in trends in (d) nitrate have been related to a decrease in acidity, and partitioning more nitrate onto aerosol. Arctic aerosol is becoming less acidic. The increasing neutralization potential Figure 1(e) shows that sulfur oxide (SO_x) emissions are decreasing faster than ammonia (NH_3) emissions in the Eurasian region. The similar results measured at Alert also indicate that the presence of ammonium improves the neutralization process. This change in atmospheric neutralization and an increase in the formation of ammonium sulfate hydrate might have climate implications.

Sharma, S., L. Barrie, E. Magnusson, G. Brattstrom, R. Leaitch, A. Steffen and S. Landsberger (2019), Multi-Decadal trends in lower tropospheric Arctic Aerosol chemistry, Equivalent Black Carbon, Ozone and Mercury at Alert, Canada. Submitted to J. Geophysical Res.

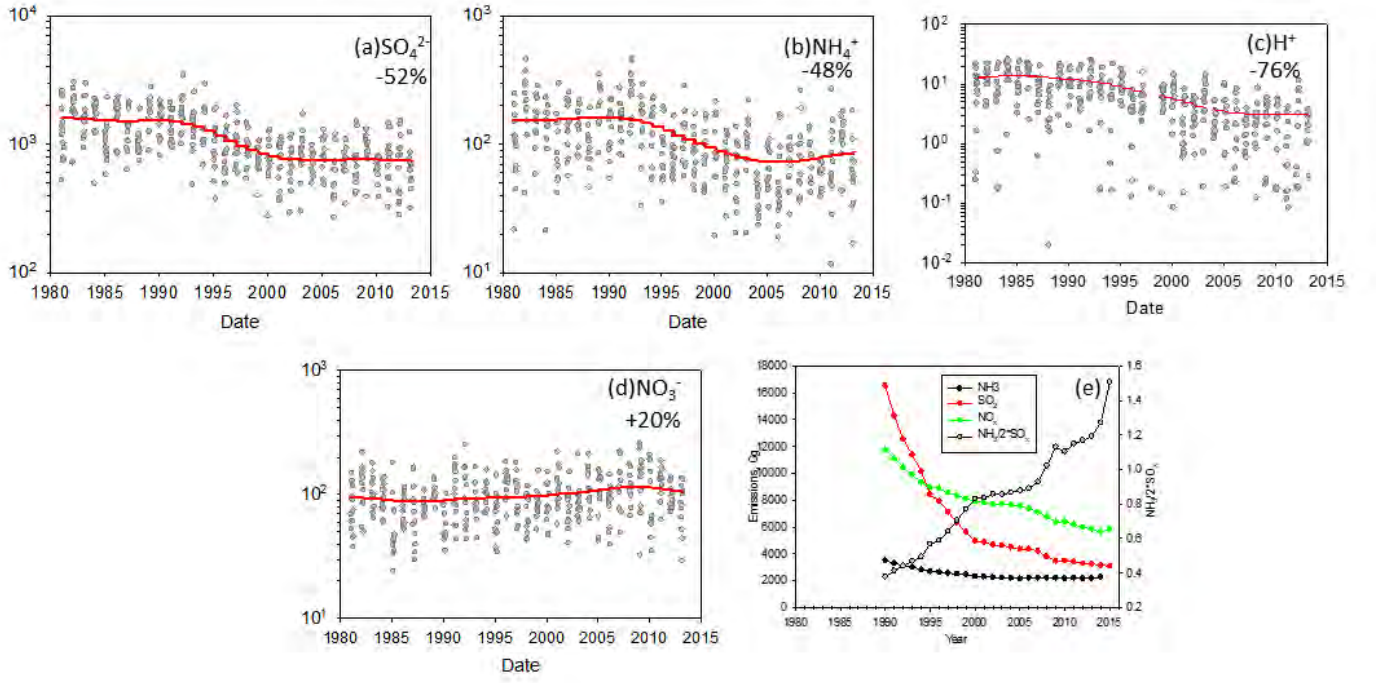


Figure 1. Trends in aerosol concentrations of (a) sulfate, (b) ammonium (NH_4^+), (c) H^+, (d) nitrate (NO_3^-) and emissions of NH_3, SO_x, nitrogen oxide (NO_x), and equivalence ratios of NH_3 and SO_x emissions.

Variation of Carbonaceous Aerosols on Foggy Days in and Around Special Episodic Events

P. Saxena[1], and S. Sonwani[2]

[1]University of Delhi, Hindu College, Department of Environmental Sciences, Delhi, India; +91-98732-45631, E-mail: pallavienvironment@gmail.com
[2]Jawaharlal Nehru University, School of Environmental Sciences, Delhi, India

The present study deals with the impact of special episodic events like firework activities on the variation of carbonaceous aerosols on foggy days during, in, and around Diwali at three different sites. The data were segregated on the basis of land use pattern viz. JNU (dense vegetative), VN (residential) and AN (industrial) in Delhi, India. The average organic carbon [OC (99.24 μg/m^3)] and elemental carbon [EC (24.31 μg/m^3)] concentrations, found to be highest at VN, depicts high influence of firework activities during Diwali including other significant sources like vehicular and commercial activities. The MOZART model-simulated vertical profile of EC and OC over Delhi also suggests that EC and OC concentrations increase drastically in the lower atmosphere during the Diwali period, and then a gradual decline is reported during the post-Diwali period. During post-Diwali, OC and EC concentrations showed a drastic decline during the day as compared to night, due to scavenging of aged particles from firework emissions during the morning hours. This study is the first of its kind to identify the nature of carbonaceous aerosols during foggy days which can be studied with respect to firework activity. In addition to a detailed illustration about the impact of firework activities, this study also helps to comprehend the role of fog in scavenging of aged particles.

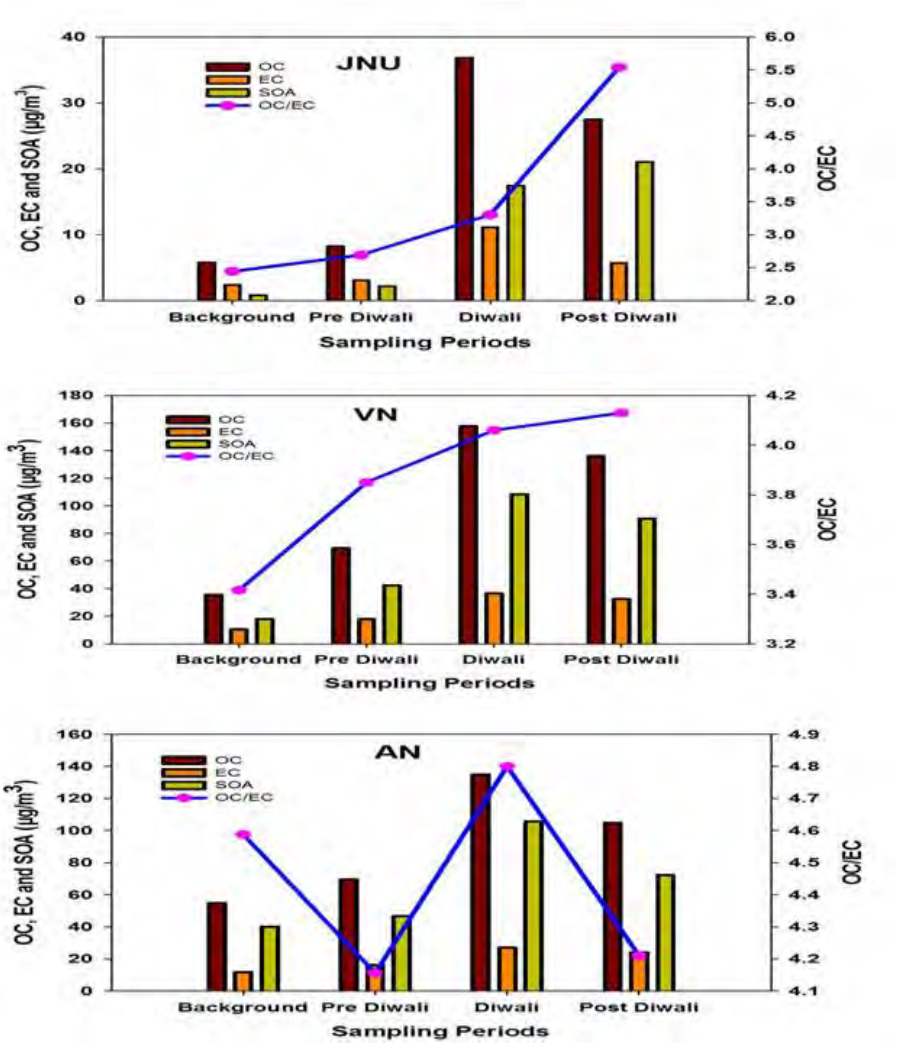


Figure 1. Comparative variation of OC, EC, OC/EC ratios and secondary organic aerosol concentrations on foggy days at different sites during Diwali.

Two Centuries of Volcanic Aerosols Derived from Lunar Eclipse Records, 1805–2019

R.A. Keen

University of Colorado, Emeritus, Department of Atmospheric and Oceanic Sciences, Boulder, CO 80309; 303-642-7721, E-mail: richard.keen@colorado.edu

About once per year, on average, the moon is totally eclipsed; the moon is then illuminated by sunlight refracted into the umbra, primarily by the stratosphere. Stratospheric aerosols can affect the brightness of the eclipsed moon, and climatically significant, visible-band, global aerosol optical depth (AOD) can be directly measured from the difference between observed and predicted brightness.

In 2004, Hofmann et al. summarized five decades of stratospheric aerosol observations, "Surface-Based Observations of Volcanic Emissions to the Stratosphere", in Volcanism and the Earth's Atmosphere, Geophysical Monograph 139, American Geophysical Union. Among the records were lunar eclipse AOD, updated at the 2018 and earlier NOAA Global Monitoring Annual Conferences (GMAC):

https://www.esrl.noaa.gov/gmd/publications/annual_meetings/2018/abstracts/22-180320-A.pdf and

https://www.esrl.noaa.gov/gmd/publications/annual_meetings/2018/posters/P-40.pdf

Hofmann concluded that a 200-year record of eclipse-based AOD was a "goal worth pursuing".

Using records of 147 lunar eclipses published in the recent and historic literature, observations communicated directly from observers around the globe, and 31 eclipses observed by the author, the AOD time series now extends from 1805 to 2019. Some climatically-significant implications of the AOD record:

1. There was more volcanic effect on the climate during 1915–1962, and less from 1820–1882, than previously determined by Dust Veil and Volcanic Explosivity Indices and other estimates. The largest DVI event, Cosigüina in 1835, is demoted to a minor event in the eclipse AOD record.
2. There have been no climatically significant volcanic eruptions since Pinatubo, 27 years ago. This is the longest period without a major climatically significant volcano in the past two centuries.
3. A continuum of smaller volcanic eruptions since Pinatubo has maintained a steady activity level, with no detectable trend in stratospheric AOD. The most recent, Ambae in 2018, produced an AOD of just 0.01.
4. The average volcanic AOD for 1996–2018 is 0.002, compared to 0.041 for the previous 14 years. According to Hansen et al. (2002), this corresponds to an increase of forcing of +0.82 W/m. For comparison, forcing increase due to CO_2 and other GHG during the same interval is less, at +0.62 W/m^2.

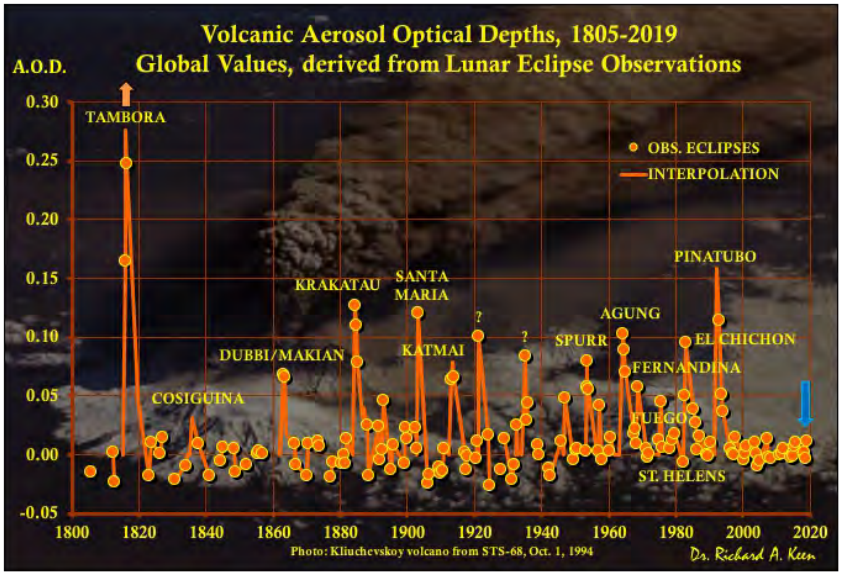


Figure 1. Global volcanic aerosol optical depth from lunar eclipse observations, 1805–2019.

Holographic Cloud Particle Imager (HCPI) for Unmanned Aircraft Systems (UASs)

D.R. McAdams[1], A.M. Harrington[1], G.J. Stoddard[1], K. Miller[2], M. Snow[2], B. Boiko[2], E.M. Wilcox[3], L. Gao[3], M. Giordano[3], and J.F. Christian[1]

[1]Radiation Monitoring Devices, Inc., Watertown, MA 02472; 617-668-6887, E-mail: dmcadams@rmdinc.com
[2]High Precision Devices, Inc., Boulder, CO 80301
[3]Desert Research Institute, Reno, NV 89512

Many current climate models assume a homogeneous and uncorrelated spatial distribution of the particles within clouds. *In situ* measurements point toward small-scale (mm to cm) correlations between particles due to droplet inertia and turbulence, and adjusting climate models to account for the inhomogeneity of clouds would increase the accuracy of climate predictions. The spatial distribution of droplets in a cloud influences radiative transfer, collision and coalescence, and droplet growth by condensation. This work presents results from two test flights of a prototype holographic cloud particle imager (HCPI) and the design and fabrication of a lighter UAS-compatible version. The HCPI measures both the 3-D spatial distribution *and* size distribution of cloud particles in the 14 mm to several millimeter size range. The 3-D spatial distribution of particles can also help identify artifacts such as particle shattering by the probe. The instrument was developed as part of a Department of Energy Small Business Innovation Research program and is meant to fly on a Group 3 UAS like the TigerShark.

The instrument uses in-line holography, a common technique due to its simplicity and the resolution constraints of currently available imagers, to generate cloud particle holograms. Diffraction theory enables a numerical reconstruction of the particle positions and sizes within the sample volume (about 20 cm^3). With this information, the "patchiness" of the particles relative to a Poisson distribution can be quantified with the pair correlation function. This patchiness affects the optical transport and energy balance, and other important parameters in climate models that include clouds.

A synopsis of test flight results from Grand Junction, CO in August 2018 and Fargo, ND in February 2019 will be presented. The resulting cloud particle holograms and spatial distributions will be presented, along with a discussion of the meaning of the results with respect to the particular clouds that were sampled. The radiative impact of droplet clustering in observed clouds will be estimated with a Monte-Carlo radiative transfer code. There will also be a discussion of changes that have been made for the lighter UAS-compatible prototype.

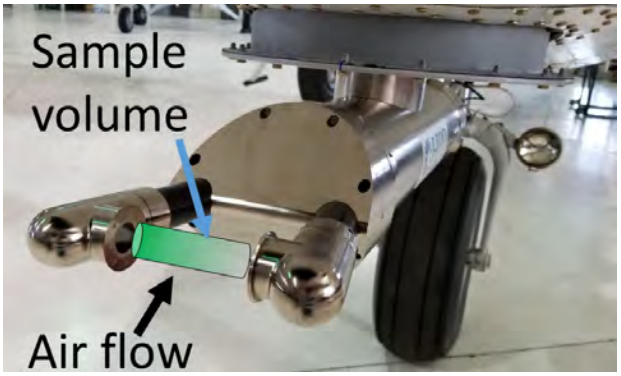


Figure 1. Manned aircraft version of HCPI mounted under the nose of a Twin Otter aircraft.

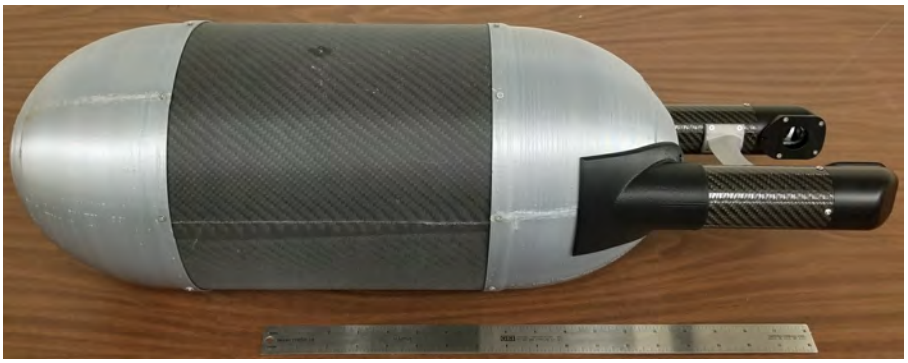


Figure 2. UAS-compatible HCPI prototype with 18-inch ruler for size reference.

The De-Icing Comparison Experiment (D-ICE): A Study of Broadband Radiometric Measurements Under Icing Conditions in the Arctic

C.J. Cox[1,2], S.M. Morris[1,3], T. Uttal[2], and C.N. Long[4]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-4518, E-mail: christopher.j.cox@noaa.gov
[2]NOAA Earth System Research Laboratory, Physical Sciences Division (PSD), Boulder, CO 80305
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[4]Retired from NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

The De-Icing Comparison Experiment (D-ICE) was a campaign carried out at the NOAA Barrow Atmospheric Baseline Observatory in Utqiaġvik, Alaska, from August 2017 to July 2018. The purpose of D-ICE was to evaluate ventilation and heating technologies developed to mitigate radiometer icing. D-ICE consisted of 20 pyranometers and 5 pyrgeometers operating in various ventilator housings alongside operational stations run by NOAA and the Department of Energy - Atmopsheric Raditation Measurement (DOE-ARM) North Slope of Alaska (NSA) and Oliktok Point (AMF3) observatories. All radiometers were monitored continuously using cameras, and a total of more than one million images of sensor domes were archived. The data are used to calculate both the effectiveness of the ventilators in mitigating ice formation and biases associated with icing that does occur. Results are used to formulate recommendations for the operational and end-user communities.

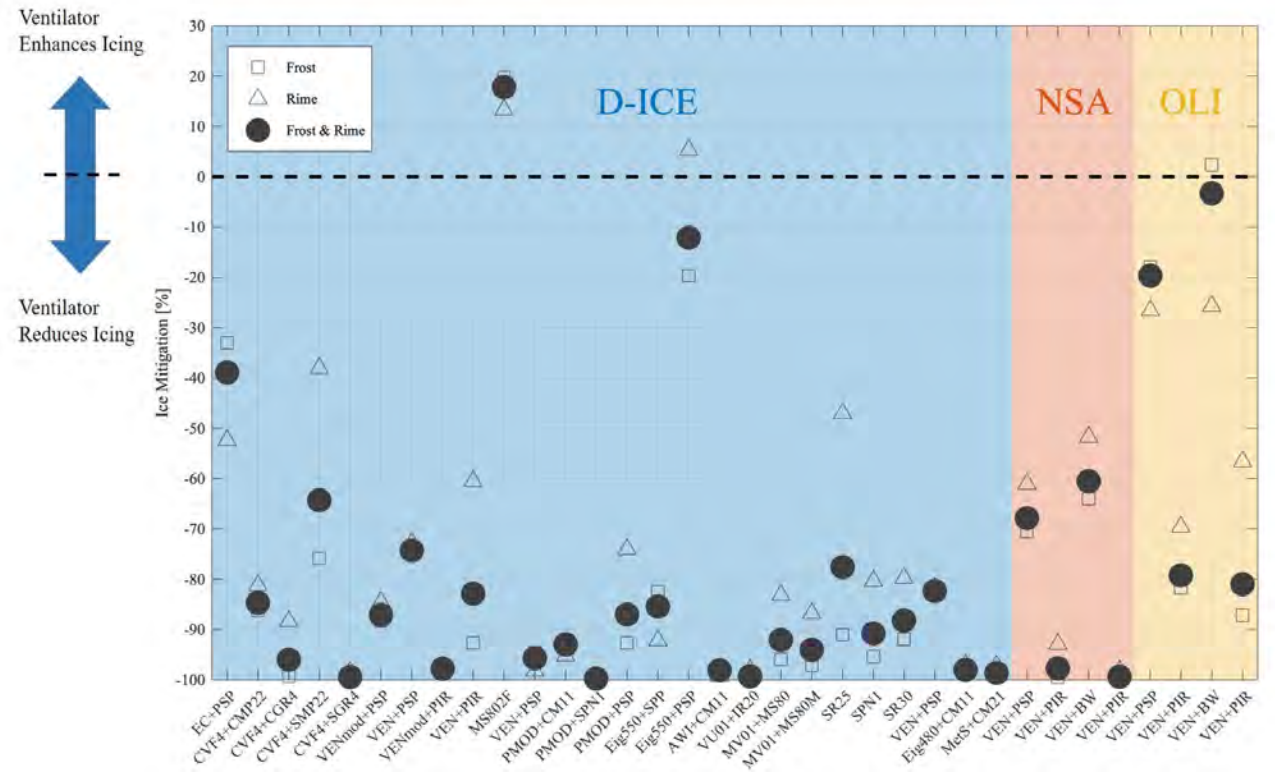


Figure 1. Effectiveness of tested systems in mitigating ice formation derived from qualitative analysis of images collected during the campaign. Effectiveness is relative to the icing conditions that occurred in the vicinity of the systems such that a value of 0 indicates that the radiometer was iced equally as often as the surrounding environment and negative values are the percent reduction in icing observed on the radiometer dome; -100% indicates mitigation of all icing. Values > 0 inidicate that a radiometer was observed to be iced more frequently than the surrounding environment.

The Need for a Surface Energy Budget Network and Increased Surface Radiation Measurements to Improve Weather and Climate Forecasting

J.A. Augustine[1], D.M. Stanitski[1], T.P. Meyers[2], S. Benjamin[3], and A.C. McComiskey[4]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-6415, E-mail: john.a.augustine@noaa.gov
[2]NOAA Air Resources Laboratory Air Turbulence and Diffusion Division, College Park, MD 20740
[3]NOAA Earth System Research Laboratory, Global Systems Division (GSD), Boulder, CO 80305
[4]Department of Energy's Brookhaven National Laboratory, Upton, NY 11973

The surface energy budget (SEB) represents the surface net radiation, or available energy at the surface, and its partitioning between atmospheric heating and evaporation—the basic fuel for weather. Enhanced observation of the SEB is one of the most fundamental needs to improve understanding and predictability of weather and climate. At this point, a systematic strategy for observing this fundamental energy source to best serve the needs of the climate and weather prediction and environmental satellite data communities is lacking. Without an adequate observation network, validation of model surface energetics will continue to be tied to just a few disjointed locations deficient in climatological diversity.

Surface net radiation, atmospheric heating and evaporation drive atmospheric boundary layer processes. At the very least, components of the SEB must be simulated accurately in models to achieve success in synoptic, sub-seasonal and seasonal forecasts. Recent work with foundational NWP models developed and used operationally by NOAA has shown that existing surface radiation budget measurements from the Surface Radiation Budget (SURFRAD) network can be used to detect, diagnose, and improve model biases. At least for some applications, to address the SEB gap this existing system of NOAA's surface radiation budget measurements across the conterminous U.S. should be enhanced with latent and sensible heat flux measurements. Co-locating heat flux and radiation budget measurements at the current seven sites would greatly improve their value. Further, expanding the number of the sites will provide the geographical and climate regime representativeness and more downward radiation measurements that weather forecast model developers desire most. This enhanced network would integrate downwelling direct, diffuse, and reflected solar irradiance, downwelling and upward directed thermal infrared, surface latent, sensible, and soil heat fluxes, and spectral direct and diffuse irradiance measurements for aerosol and cloud properties. The forecasting and predictability community would benefit from modest upgrades to instrumentation and long-term network management. A national Surface Energy Budget Network (SEBN) will provide the foundation to improve reanalyses, NOAA satellite products, NOAA climate models, weather forecasts, and climate assessments, significantly aiding the NOAA National Environmental Satellite, Data, and Information Service, the National Weather Service, and the general atmospheric science research community.

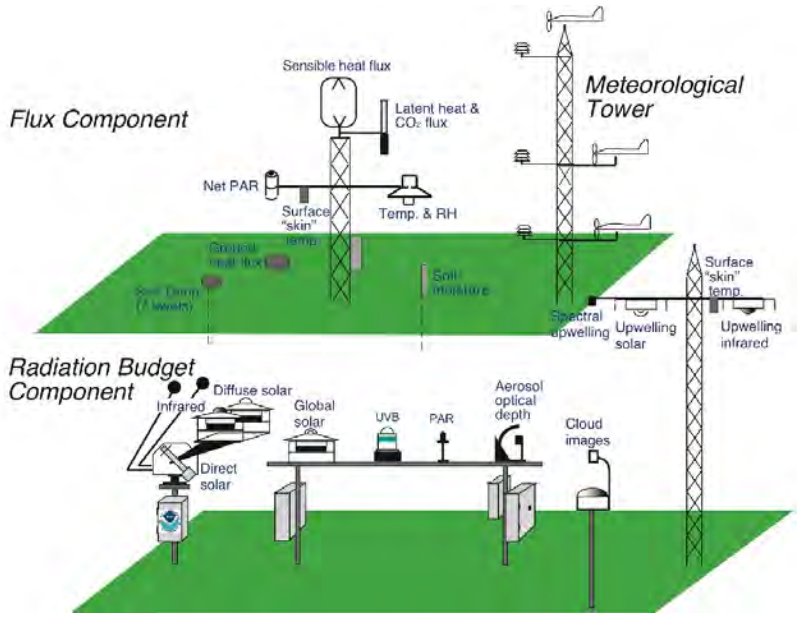


Figure 1. Details of a Prototype SEBN Station.

Curating a Multiagency Set of Federal Climate Indicators

L. Stevens[1,2], J. Blunden[3], and D. Arndt[3]

[1]North Carolina State University (NCSU), Raleigh, NC 27695; 828-257-3006, E-mail: laura.stevens@noaa.gov
[2]Cooperative Institute for Climate and Satellites - North Carolina (CICS-NC), Asheville, NC 28801
[3]National Centers for Environmental Information (NCEI), Asheville, NC 28801

The U.S. Global Change Research Program (USGCRP) commissioned the curation of a set of climate-relevant indicators, which are "observations or calculations that can be used to track conditions and trends". These are considered to be "an important part of the vision for the sustained National Climate Assessment (NCA)." To this end, an interagency workgroup is managing a set of curated indicators, and working toward highlighting various efforts across the federal government related to climate indicators and how they can be leveraged for communicating key aspects of climate change. Much of this work draws on data, tools, and expertise already in place at NOAA's National Centers for Environmental Information and the Cooperative Institute for Climate and Satellites - North Carolina, both located in Asheville, NC. This poster will briefly describe the background, goals, and structure of the USGCRP Indicators effort, and plans for growing - and using! - this set of "Assessment-grade" quality indicators, and insights into the indicator "platform" that spans deeper efforts by several USGCRP agencies. Interaction with, and guidance from, global monitoring professionals is highly anticipated!

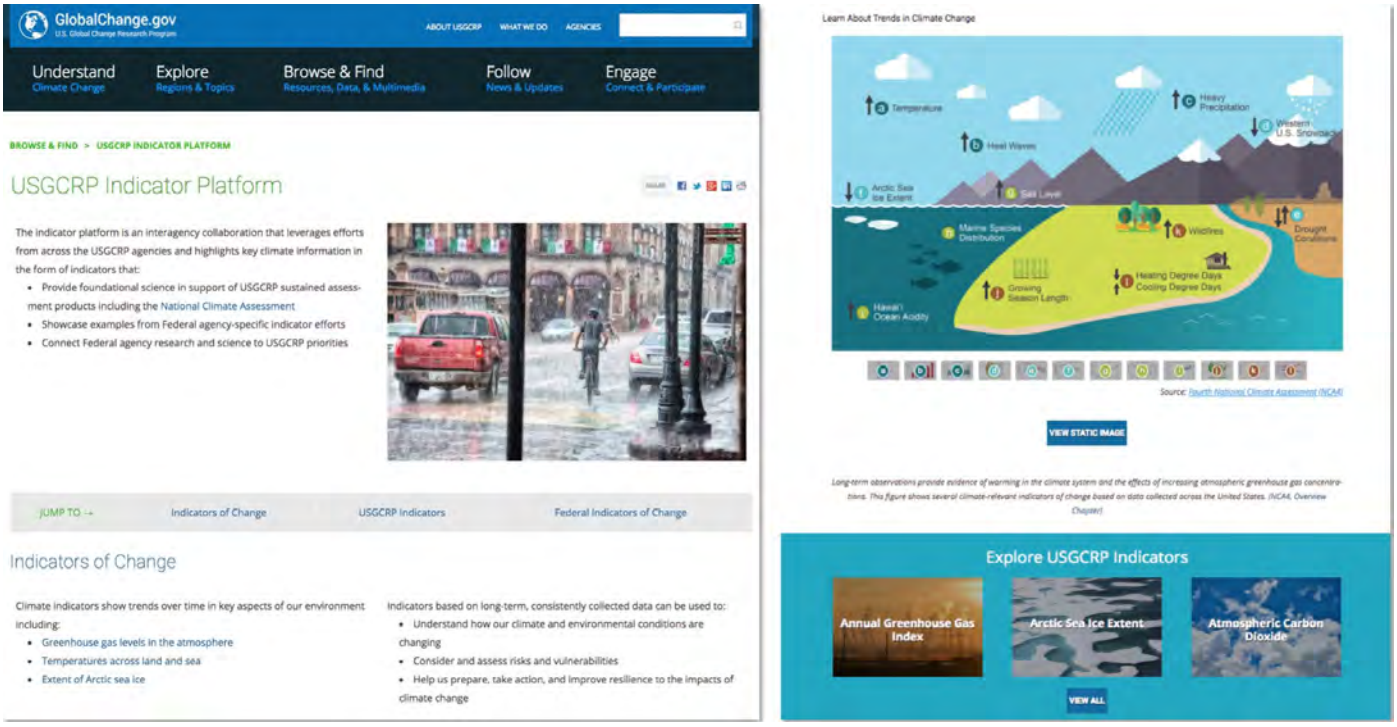


Figure 1. The USGCRP Indicators Platform at https://www.globalchange.gov/browse/indicators. This newly redesigned website includes a suite of 16 climate change indicators, as well as links to related federal resources.

The New Barrow Atmospheric Baseline Observatory

B. Vasel[1], C. Schultz[1], B. Thomas[2], A. Clarke[3,1], S. Ingalls[4], B. Blau[5], and R. Edwards[5]

[1]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305; 303-497-6655, E-mail: brian.vasel@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Barrow Observatory, Utqiaġvik, AK 99723
[3]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[4]NOAA Office of the Chief Administrative Officer (OCAO), Project Planning and Management Division (PPMD), Seattle, WA 98115
[5]NOAA Acquisition and Grants Office (AGO), Western Acquisition Division (WAD), Boulder, CO 80305

The Barrow Atmospheric Baseline Observatory (BRW) is located in the Arctic on the northernmost point of the United States, approximately 8 km northeast of the village of Utqiaġvik.

NOAA's long-term BRW facility is undergoing a major upgrade (2019–2020) that will significantly increase the site's scientific capabilities and opportunity for collaboration:

- New state-of-the-art observatory with flexible laboratory space
  - ~1,000 sqft of NOAA laboratory space
  - ~275 sqft of collaborative project laboratory space
- Garage expansion
- New 30-meter instrument tower
- Campaign science deck sized to hold 20-ft sea containers

Figure 1. BRW observatory and garage exapansion footprint, overlaid on current facility for comparison. From 50% architectural design, April 2019.

Opportunity to Plan and Develop a Comprehensive U.S. Arctic Research Infrastructure Network Hub at Oliktok Point, Alaska

J. Hardesty[1], M. Ivey[1], F. Helsel[1], D. Dexheimer[1], C.F. Cahill[2], H. Eicken[2], L. Brigham[2], and E.L. Roesier[2]

[1]Sandia National Laboratories, Albuquerque, NM 87185; 505-844-8388, E-mail: joharde@sandia.gov
[2]University of Alaska, Fairbanks, Fairbanks, AK 99775

The U.S. does not have a comprehensive U.S. research facility in the High Arctic… but it could. The Arctic is changing rapidly, with impacts on environment, ecology, communities, industry, and security. These impacts are also felt globally via changes in weather patterns, ocean currents, and sea level. Human activity for resource extraction, shipping, tourism, and defense purposes is increasing. Infrastructure for search and rescue and emergency response is substandard; while coastal erosion, less sea ice, more storms, and thawing permafrost compromise infrastructure. All activity in the Arctic will benefit from improved understanding to forecast and predict operational conditions and future changes. As Arctic waters open, increased international activities will place greater demands for domain awareness to inform services and security. There is a compelling need for comprehensive U.S. Arctic research infrastructure to address pressing needs.

We identify the opportunity for a comprehensive, multi-agency U.S. High Arctic Research Center (HARC) and network as a national asset to address opportunities and challenges of Arctic change and impacts on energy, food and water security, economic and environmental health, and national security. HARC will contribute to a network to serve Federal and State government, industry, Arctic communities, and researchers in addressing infrastructure, emergency response, search and rescue, domain awareness, environmental change, and Arctic technology challenges. A facility at Oliktok Point, Alaska can serve as a hub for coordinated research in the U.S. Arctic between Toolik Lake, Utqiagvik (Barrow), and Prudhoe Bay; and can take advantage of unique assets. These include: access via land, sea and air; coastal, marine and terrestrial ecologies; controlled airspace across land and ocean; medical and logistic support; atmospheric observations; connections to Utqiagvik and Toolik research sites; broadband fiber-optic link; University of Alaska Fairbanks Unmanned Aircraft Systems (UAS) Test Facility partnership; and an airstrip and hangar for UAS. Combined with the Toolik Field Station and Barrow Environmental Observatory, they would provide complimentary research opportunities via an integrated network of U.S. Arctic Stations.

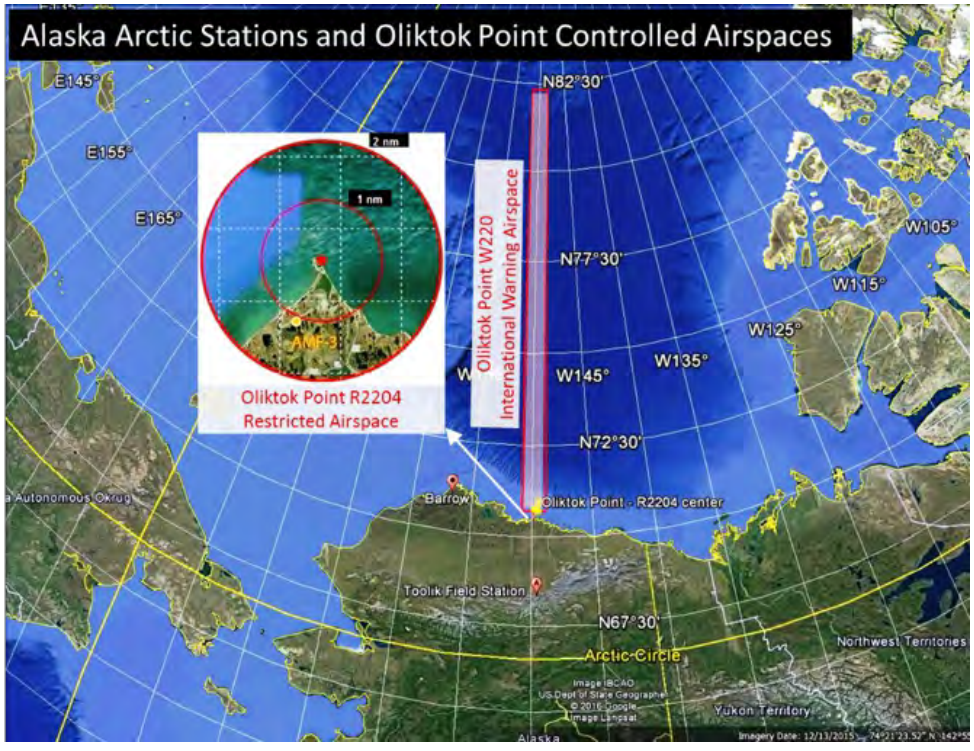


Figure 1. Locations of Alaska Arctic Stations and Controlled Airspaces.

Soil Respiration Response To *Adenostoma Sparsifolium* Microsites Among Seasons in Semiarid Shrubland

J. Montes

San Diego State University, Global Change Research Group, San Diego, CA 92182; 619-870-6679, E-mail: jamontes@sdsu.edu

Arid and semiarid ecosystems have an essential role in terrestrial carbon cycling and should be considered in models that attempt to predict the effects of global warming. In the last decade, studies have shown that semiarid shrublands are significant carbon sinks. Hence, downward carbon dioxide (CO_2) fluxes into soils in arid and semiarid ecosystems is a growing topic of research. Moreover, quantifying temporal and spatial variability in soil respiration can be challenging to achieve. Soil is highly heterogeneous due to the variant nutrients, minerals, organic compounds, and microorganisms it contains. These soil segments can react differently to meteorological conditions and are specifically paired with biological mechanisms, resulting in an immense variability of soil CO_2 effluxes. Additionally, patchiness in vegetation can create microsites that have different responses to increased temperatures, influencing their soil respiration rates. Soil carbon cycling activity beneath shrub canopies has been found to be higher than in bare soil gaps because of higher soil organic matter, higher litter biomass, and reduced solar radiation reaching the ground, creating cooler, wetter microclimates. Therefore, it is important to study the impacts of shrub canopies on soil respiration, especially in semiarid ecosystems where these effects have been scarcely researched. Among the semiarid chaparral vegetation communities, *Adenostoma sparsifolium* (redshank) shrubs create significant amounts of litter below canopies, which may increase soil respiration rates. However, redshank communities have not been thoroughly studied and there is no knowledge of how these shrub's microsites can affect soil CO_2 fluxes in semiarid shrublands. Here we introduce a project with three research objectives: (1) examine temporal patterns in soil respiration among beneath redshank shrub and bare ground microsites, (2) examine spatial variation of soil respiration by analyzing the effects of microsite characteristics, and (3) evaluate the impact of microsites on temperature sensitivity. To achieve this, we will conduct a randomized 12-month experiment with different microsites created by redshank shrub communities. We will collect continuous 24-hour CO_2 flux measurements with automated dynamic chambers at six 5 m x 5 m plots and each plot will include two microsite types: beneath redshank shrub (50 cm from trunk or main roots) and bare ground (150 cm away from trunk or main roots). We will determine if soil respiration differs among seasons (growing, dry, and wet), and establish if microsites characteristics including soil temperature, soil moisture, litter biomass, and shrub size influence soil CO_2 fluxes. We will also examine the effects of microhabitats on temperature sensitivity by analyzing the relationships between soil respiration and soil temperature. We hypothesize higher variability of soil CO_2 effluxes during the dry season, due to the soil respiration pulses that will be created by precipitation events. Also, we foresee microsites beneath larger shrubs, with greater litter depth and dry biomass to have higher soil respiration than smaller shrub's microsites and bare ground. And we also expect microhabitats with higher moisture to be more sensitive to temperature in this chaparral ecosystem.

Figure 1. Sky Oaks Field Station located northeast of San Diego, CA and 75 km east of Pacific Ocean.

Figure 2. LI-8100 long-term chamber placed 150 cm from redshank trunk at Sky Oaks Field Station.

The Acquisition of Fog in Montane California Chaparral: Ecosystem Inputs and Use by Plants

B. Gillespie

San Diego State University, Global Change Research Group, San Diego, CA 92182; 760-458-1942, E-mail: bgillespie@ucsdavis.edu

Semi-arid ecosystems of the Southwest U.S. are very sensitive to variation in precipitation and soil moisture (Xu et al. 2004, Austin et al. 2004). Soil moisture is one of, if not, the most limiting resource for primary productivity and net ecosystem carbon exchange in semi-arid ecosystems such as the chaparral (Huxman et al. 2004, Potts et al. 2006). And, chaparral ecosystems are expected to be especially impacted by reduction in available soil moisture and increases in extreme precipitation events associated with global warming in coming decades (Thomey et al. 2011, Bell et al. 2012, Biederman et al. 2016, Miranda et al. 2009). In most ecosystems, it is assumed that precipitation occurring as either snow or rain are the dominant sources that contribute to water balance and, consequently, productivity. For systems that are severely limited by water, other sources of water might be more important for the water balance than previously thought. Fog, which is usually considered minimal in inland areas, might demonstrate ameliorating effects for drought-characterized systems.

Figure 1. The thickness in the layers of fog is readily apparent at the Sky Oaks Biological Field Station in San Diego, CA.

A Bibliometric Analysis of GMD Publications, 2010–2018

S. Visser[1,2]

[1]FedWriters, Fairfax, VA 22030; 303-497-5750, E-mail: sue.visser@noaa.gov
[2]NOAA Earth System Research Laboratory (ESRL), Boulder, CO 80305

Bibliometrics – the quantitative analysis of publication and citation data – is an evolving field that is gaining attention among administrators and stakeholders as a tool for measuring scientific value and impact. Traditionally, peer review has been the gold standard for assessment, but because peer review is time-consuming and may be subject to bias, bibliometrics is increasingly seen as an alternative, or companion, method of evaluation.

The study of bibliometrics assumes that citation counts represent a reasonable proxy for research quality. While quality is a complex notion that cannot be easily quantified, a substantial body of research into the validity of bibliometric indicators has shown a weak to strong correlation between citation data and peer review.

The Boulder Labs Library conducted bibliometrics analyses to measure the performance of 712 GMD peer-reviewed publications from 2010–2018. This set of publications has been cited over 25,600 times, by authors in 148 countries. Citations to GMD's work are found in subject areas as wide ranging as law, public health, and the hospitality industry, as well as the expected scientific categories. Furthermore, the results of the analyses indicate that GMD consistently ranks above all baseline bibliometric indicators. These results demonstrate that GMD's research has a significant global impact both in the science of global monitoring and the many aspects of human life that depend on this science.

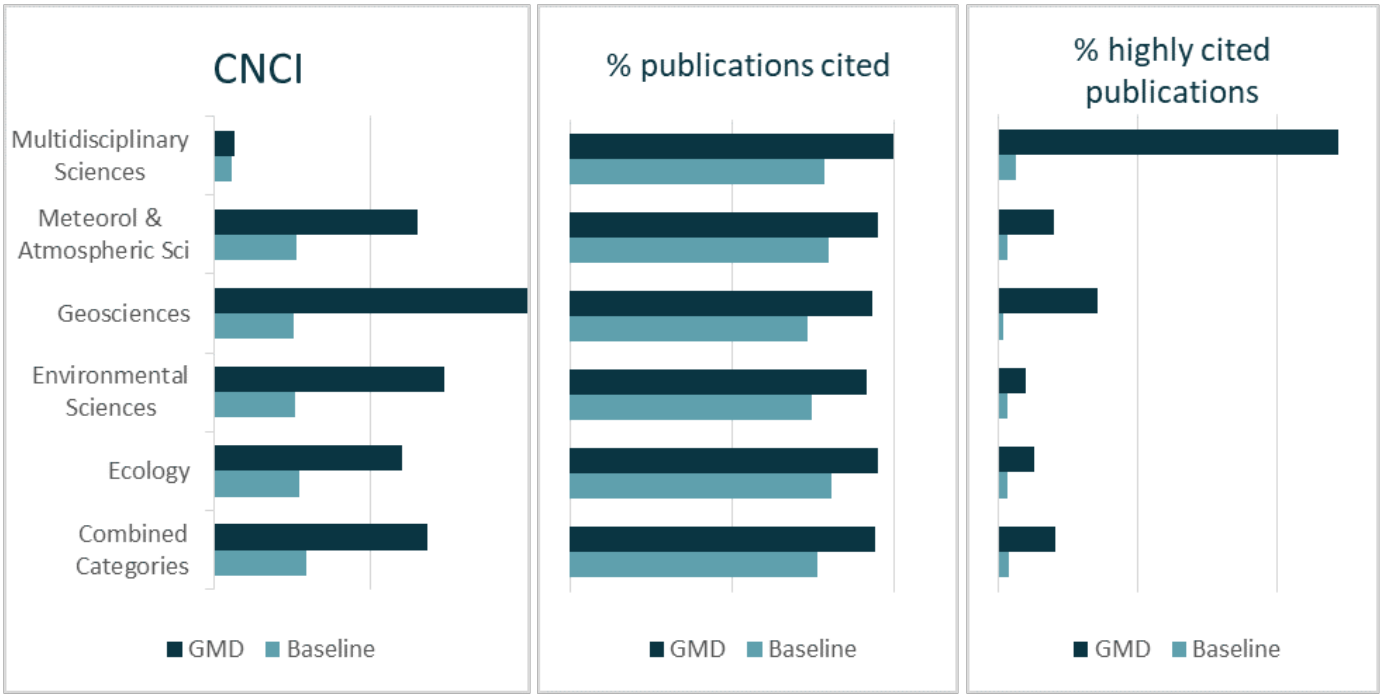
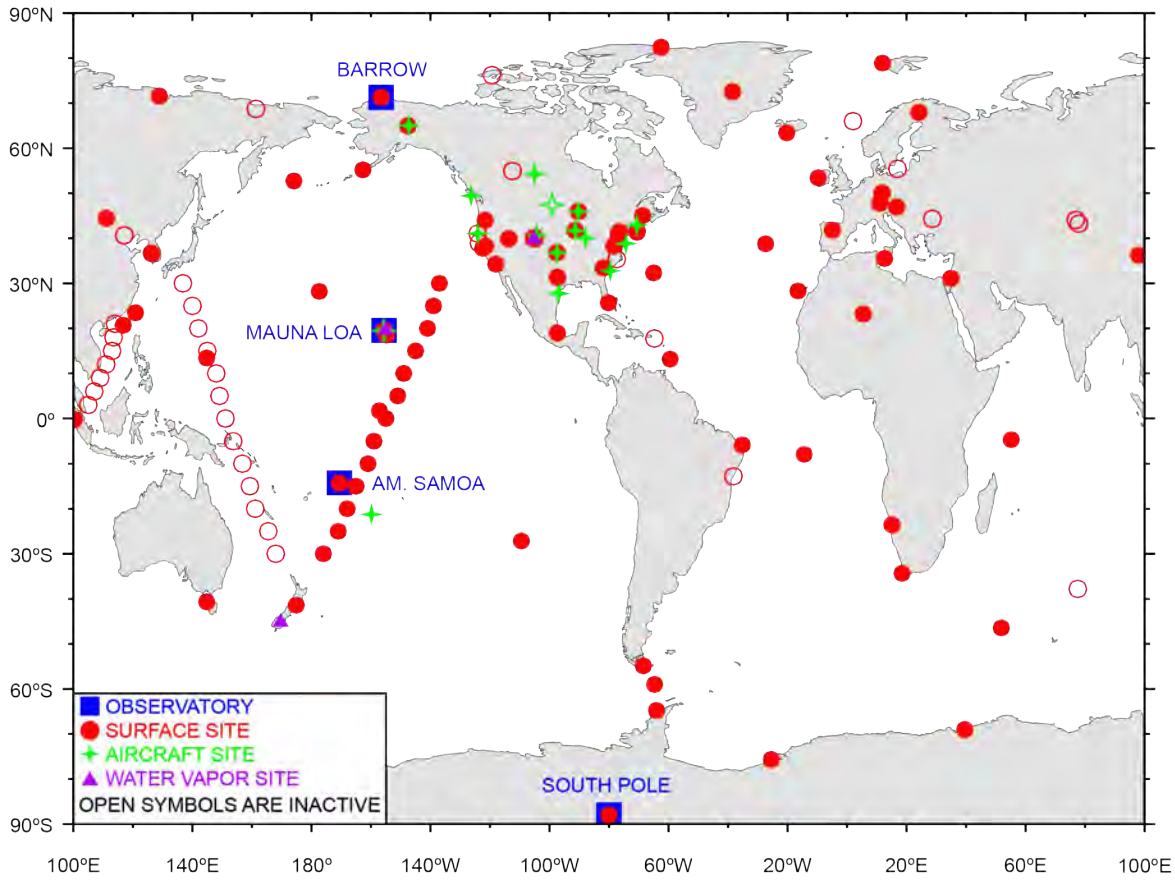


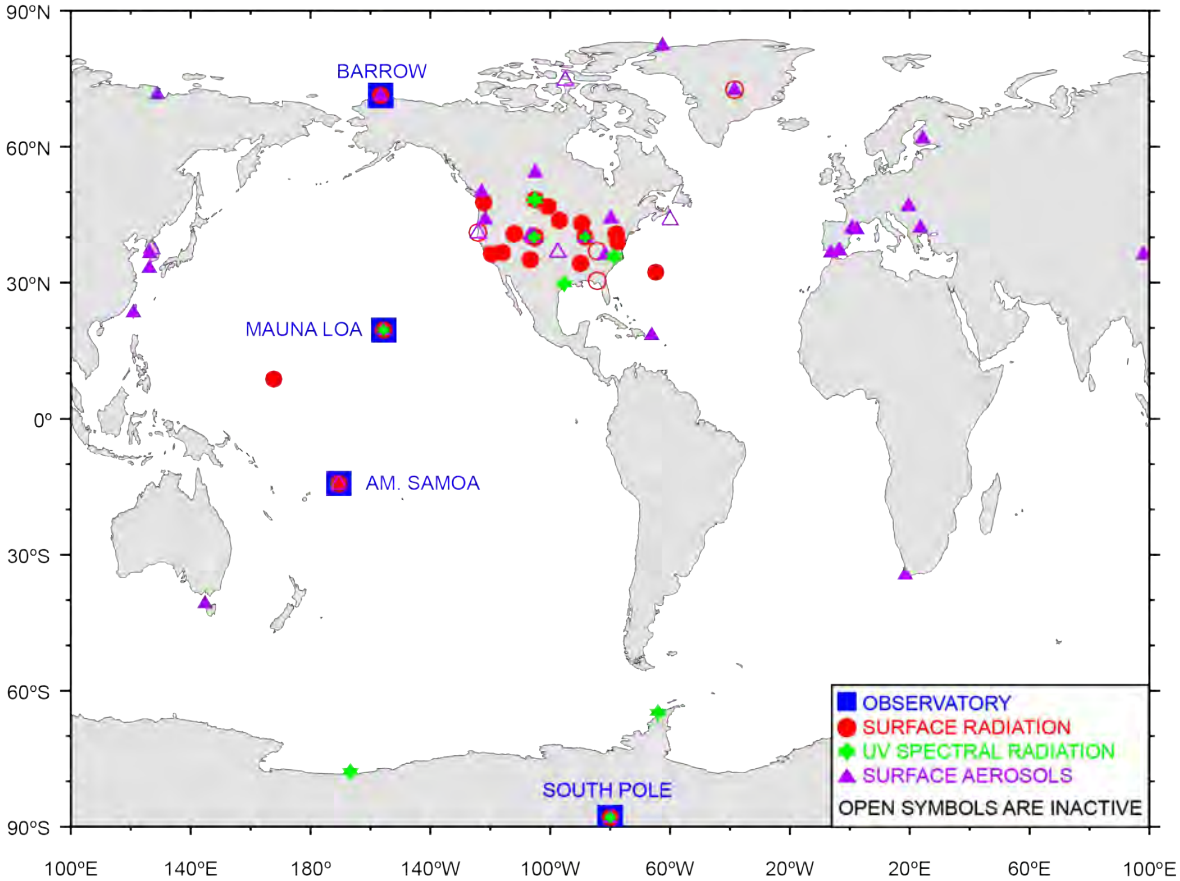
Figure 1. GMD metrics compared to baseline. Baseline metrics are derived from the average citation performance of all papers in the same research category, for the same time period. CNCI (Category Normalized Citation Index) is a normalized indicator where an average performance equals 1; a value above 1 indicates performance above average. In nearly all categories and metrics, GMD's performance significantly exceeds the baseline.

Notes:

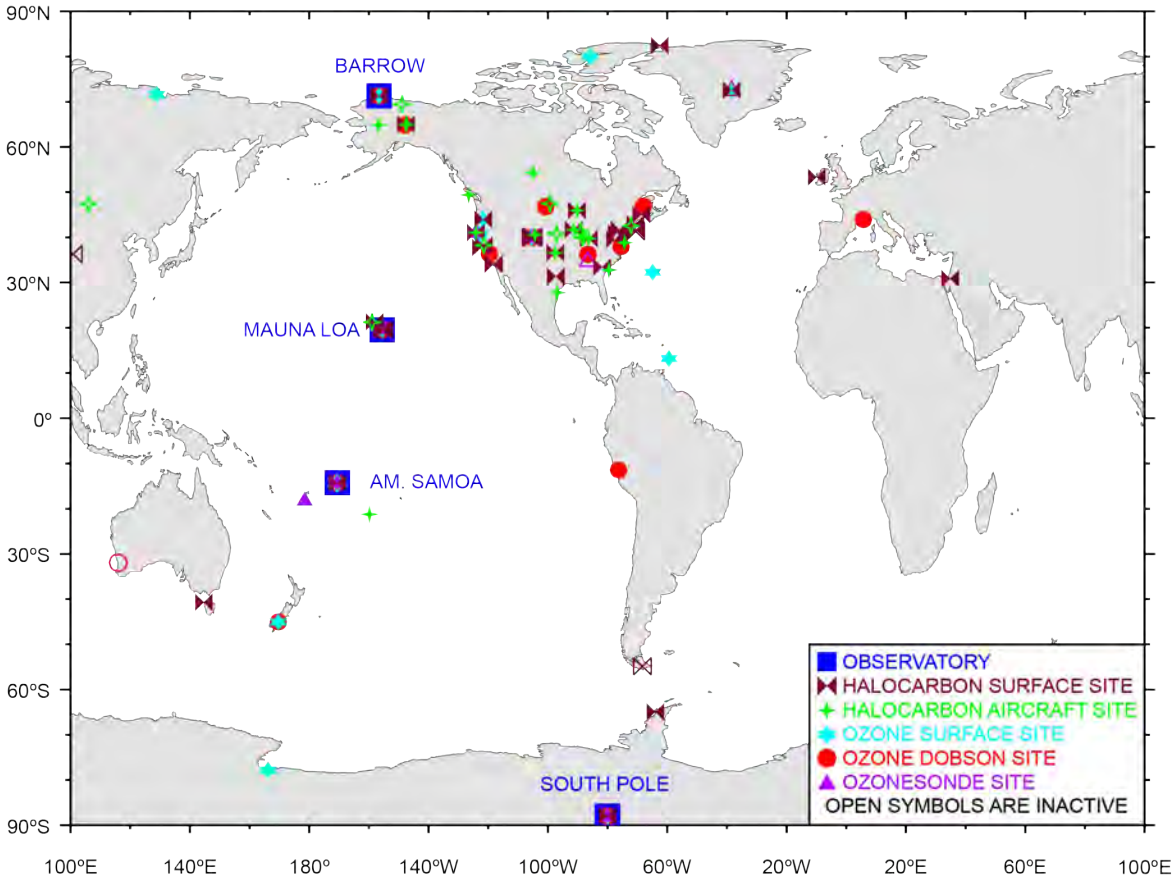
Tracking Greenhouse Gases and Understanding Carbon Cycle Feedbacks



Monitoring and Understanding Changes in Surface Radiation, Clouds, and Aerosol Distributions



Guiding Recovery of Stratospheric Ozone



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