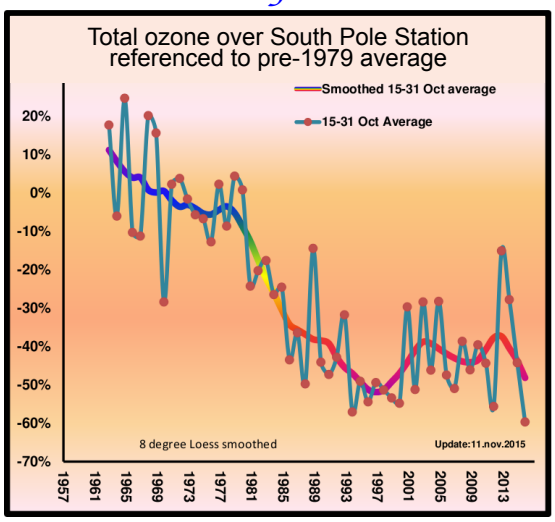
Global Monitoring Annual Conference 2016

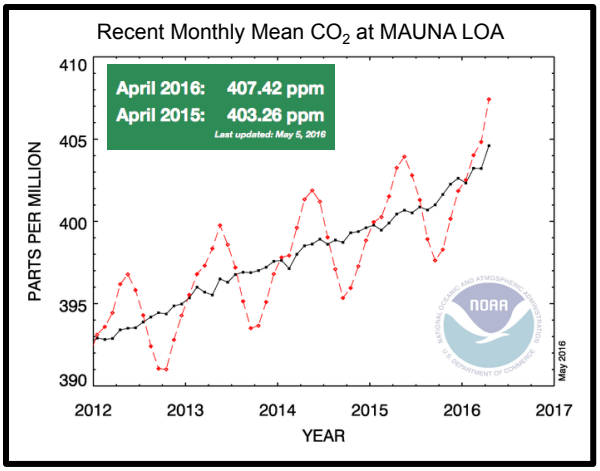
Boulder, Colorado — May 17th - 18th

Global Monitoring Highlights

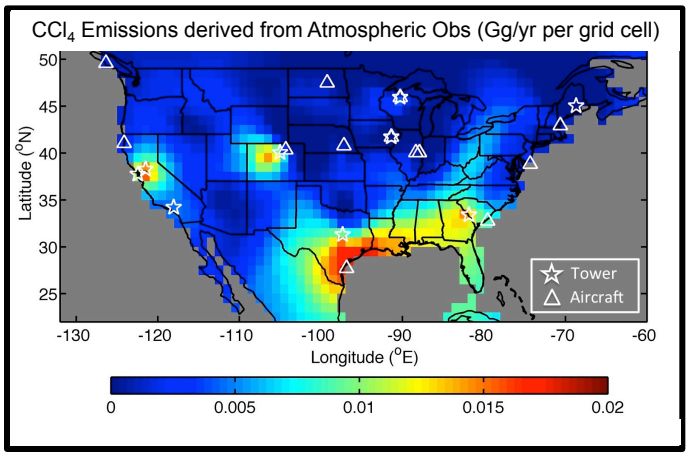
Low Stratospheric Ozone



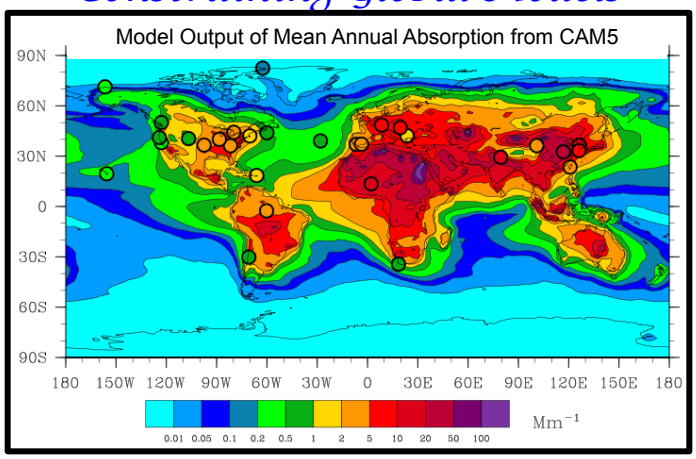
Dramatic Increases in CO_2



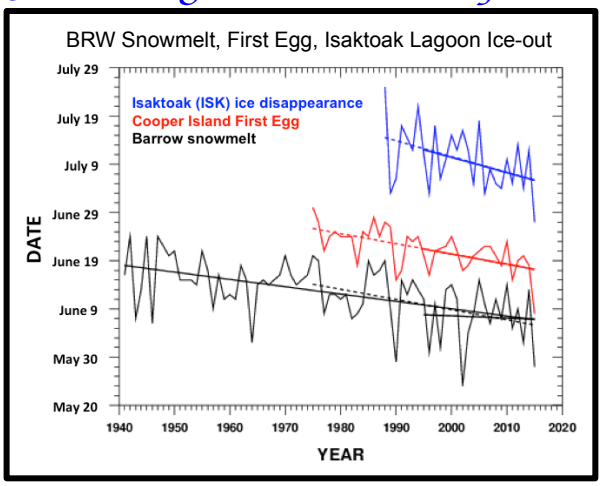
Identifying Halocarbon Sources



Constraining Global Models



Following Radiation Impacts



PROGRAM & ABSTRACTS

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, and solar radiation in a manner that allows the causes 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:

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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

NOAA Earth System Research Laboratory
44th Global Monitoring Annual Conference

May 17-18, 2016
Boulder, Colorado

It is always a privilege and a moment of pride for us in GMD to host this annual gathering of scientists from around the world. Every year this conference brings us all up to date quickly on the latest approaches to making measurements, building and maintaining networks, and interpreting data to improve our understanding of the atmosphere and the Earth System as a whole. This conference represents our long-term commitment to the global community to share and advance our collective knowledge base and practices. We seek to create a forum for thoughtful and lively discussion of results not just from our own networks, but from those of our many partners in this endeavor.

Decades ago, when GMD's predecessor (Geophysical Monitoring for Climate Change – GMCC) was in its infancy, and long before email, the web, Powerpoint, and Google existed, these meetings were small and internally focused. Were the instruments working right? Were the approaches sound? Did we have the right networks? What were the data management issues? What were the data showing? Today, these questions still resonate, but in a much bigger way. Global networks require global partners working together and that is what we in NOAA try to promote on a daily basis, especially at this meeting. Central to GMD's mission and the goals of the conference is understanding how we as a global community can learn from and leverage long-term records and observing systems. It's the only way we will advance the science needed to address 21st century issues.

So, welcome to this year's conference. We trust you will find the exchange of scientific information valuable and the partnerships and camaraderie unsurpassed. The conference agenda and abstracts from all presentations and posters at the conference are available at the GMAC conference site, http://www.esrl.noaa.gov/gmd/annual/conference/.

Thank you for your participation in the conference. We look forward to yet another exciting event.

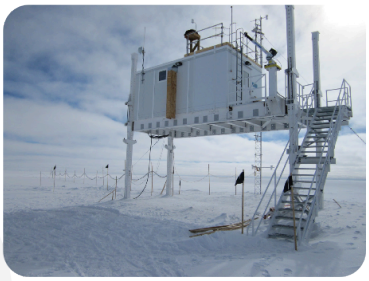
James H. Butler, Director
Global Monitoring Division

NOAA Atmospheric Baseline Observatories

Barrow, Alaska

Trinidad Head, California

Summit, Greenland



Mauna Loa, Hawaii

American Samoa

South Pole

Barrow, Alaska (est. 1973), 71.32˚ North, 156.61˚ West

Trinidad Head, California (est. 2002), 41.05˚ North, 124.15˚ West

Mauna Loa, Hawaii (est. 1957), 19.53˚ North, 155.57˚ West

Cape Matatula, American Samoa (est. 1974), 14.24˚ South, 170.56˚ West

South Pole, Antarctica (est. 1957), 90.00˚ South, 24.80˚ West

Summit, Greenland (est. 2010), 72.58˚ North, 38.48˚ West

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2016

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

Tuesday Morning, May 17, 2016 AGENDA

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

• 07:00 ***Registration Opens in GC-402 - lunch orders and posters collected at registration table***

• 07:30 - 08:15 ***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 2016

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

Tuesday Afternoon, May 17, 2016 AGENDA

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

Keynote Address - Keeping Up the Standards: Building and Maintaining a Global Atmospheric Measurement Network

R.F. Weiss

Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92037; 858-534-2598, E-mail: rfweiss@ucsd.edu

The challenges and the rewards of building and maintaining a global observational network at the highest observational standards can be considerable. The example I know best is the Advanced Global Atmospheric Gases Experiment (AGAGE), which operates a network of field stations around the globe that measures, at high frequency and over long time periods, more than 50 gases of importance to climate forcing and/or stratospheric ozone depletion research. Doing the AGAGE job properly has required designing, building and deploying custom instrumentation: a multi-detector gas chromatograph with whole air injection, and the *Medusa* gas chromatograph-mass spectrometer with cryogenic pre-concentration. And as long-term observations continue, there is also a need to adapt to new technologies and changing scientific priorities. In AGAGE the emphasis is on adapting new optical and mass-spectrometric techniques to automated field measurements of trace gas abundances and isotopic compositions, and on commercializing such applications so that scientists can spend their time doing science. Similarly, in AGAGE instrument operation and diagnostics, data acquisition, data processing, and data quality control have all required custom software for automated monitoring applications that has become commercially available to other projects. AGAGE also maintains independent primary calibration scales that are propagated to the global network. While AGAGE operates independently, it also works cooperatively with the NOAA global network of atmospheric observations and with other monitoring programs around the world, thus helping to insure the robustness of these important measurements. Following the COP-21 Paris Agreement and its "pledge and review" approach to emissions reductions there will be an increased need for the regional high frequency measurements required for "top-down" regional emissions verification by inverse modeling.

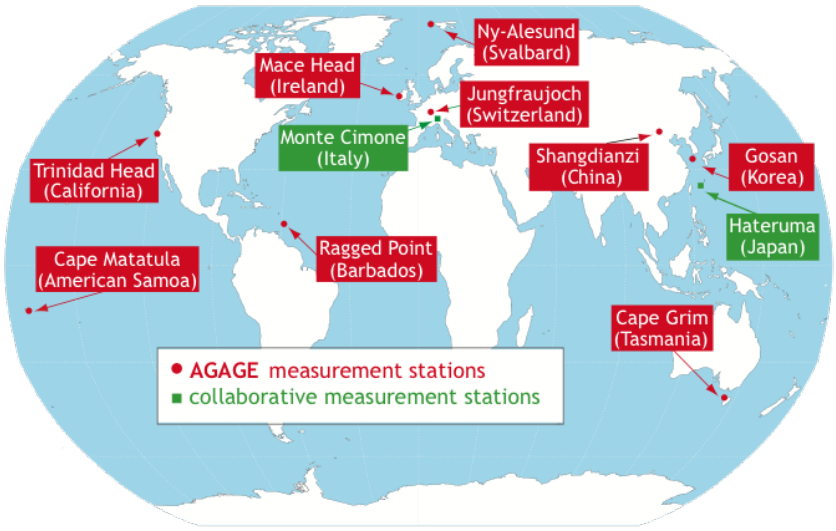


Figure 1. Locations of AGAGE and collaborating measurement stations.

In-service Aircraft for Global Monitoring: Status and Perspectives

A. Volz-Thomas

IAGOS-AISBL Forschungszentrum Jülich, Jülich 52425, Germany; +49-1607-02-8943, E-mail: a.volz-thomas@fz-juelich.de

In-Service Aircraft for a Global Observing System (IAGOS) is a European Research Infrastructure (www.iagos.org) which has been established in 2014 from the two European research projects Measurement of Ozone and Water Vapour on Airbus in-service Aircraft (MOZAIC) and Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container (CARIBIC). The goal is to establish and operate a sustainable observing system for monitoring of atmospheric trace gases, aerosol and cloud particles from commercial aircraft at a global scale, using two complementary technical approaches:

IAGOS-CORE: *In situ* instruments permanently installed aboard currently six AIRBUS A330 or A340 aircraft operated by Deutsche Lufthansa, Air France, China Airlines, Cathay Pacific, and Iberia. The long-term plan is to expand the fleet to 20 aircraft in order to improve global coverage.

IAGOS-CARIBIC: Monthly deployment of a cargo container currently equipped with 16 instruments for *in situ* measurements and remote sensing, as well as provisions for the collection of samples for subsequent analysis of many trace gases and aerosol chemical composition.

The presentation will discuss the ultimate goals of IAGOS, the current status of the technical implementation, and the planned developments, including the plans for liaising with airlines, such as Hawaiian. Selected results will be presented to highlight the value of 20 years of regular airborne data from commercial aircraft for a better understanding of atmospheric composition and its variability in a changing climate. IAGOS data are extensively used for process studies, trend analysis, as well as model and satellite validation. Near real-time data are provided for the Copernicus Atmosphere Monitoring Service (CAMS). For a recent overview of scientific achievements of the MOZAIC-IAGOS programme see http://www.tellusb.net/index.php/tellusb/pages/view/thematic.

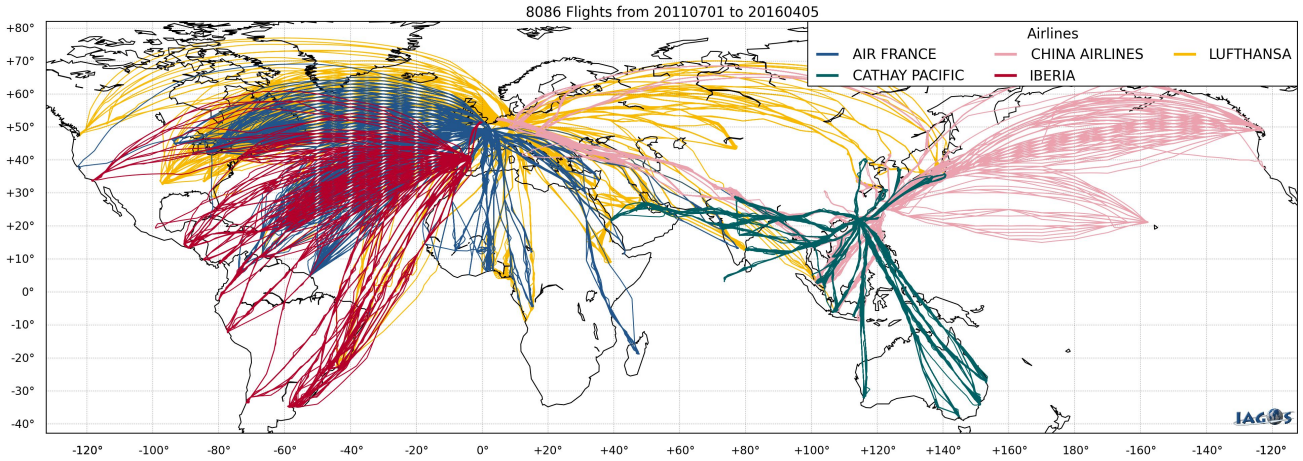


Figure 1. Map of flight routes of the aircraft equipped with IAGOS instruments.

Traceability of Measurements Within the Global Atmosphere Watch Programme: Results from the World Calibration Centre WCC-Empa

C. Zellweger, M. Steinbacher, L. Emmenegger and B. Buchmann

Swiss Federal Laboratories for Materials Science and Technology, Empa, Dübendorf CH-8600, Switzerland; +41-58-765-43-28, E-mail: christoph.zellweger@empa.ch

Empa operates the World Calibration Centre for Carbon Monoxide (CO), Methane, Carbon Dioxide and Surface Ozone (O_3) (WCC-Empa) since 1996 as a Swiss contribution to the Global Atmosphere Watch (GAW) programme and has conducted over 70 system and performance audits over the past 20 years. This activity significantly contributes to sustain and improve the data quality required for climate and environmental research. The concept of the performance audits was recently expanded by the addition of parallel measurements with a travelling instrument using an entirely independent inlet system and calibration scheme.

The presentation will focus on results of CO and O_3 comparisons with relation to the measurement technique. Our performance audit results for CO show that the World Meteorological Organization (WMO)/GAW compatibility goal of 2 nmol/mol is often not met. Further, the advantages of the new performance audit approach will be shown. Results of CO comparisons from various stations using different analytical techniques will be analyzed, and aspects such as water vapor interference, calibration frequency, data coverage, and aggregation times will be addressed. An example of a parallel measurement between the station CO analyzer of Ushuaia (Horiba APMA-360 NDIR instrument) and the WCC-Empa travelling analyzer (Picarro G2401 Cavity Ring-Down Spectrometer) is shown in Figure 1. The temporal variation was well captured by both instruments, and a mean offset of 2.8±2.7 nmol/mol was observed. Our results further indicate that the Ushuaia station can be significantly influenced by local and / or regional pollution sources, which has to be considered for data interpretation.

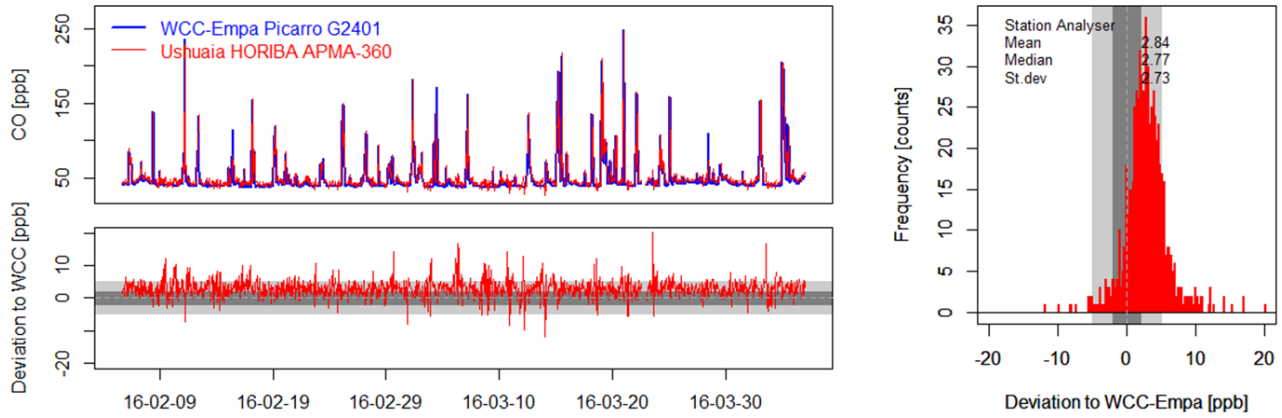


Figure 1. Left: Upper panel: Time series (1-h averages) of the Ushuaia station CO analyzer (red line) and the WCC-Empa travelling instrument (blue line). Lower panel: Difference between Ushuaia and WCC-Empa. Right: Deviation histogram. The dark and light grey areas correspond to the WMO/GAW compatibility and extended compatibility goals.

Multiple Immediate Benefits of Emissions Mitigation

P.P. Tans

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

We have known for a long time that climate forcing by carbon dioxide (CO_2) depends primarily on cumulative emissions. In addition we have observed that the rate of CO_2 increase has been at a record high during the last decade driven by emissions that are also at a record high. Projections of future climate forcing span a large range, but the main variable is cumulative emissions from fossil fuel burning. The 21st Conference Of Parties meeting in December 2015 in Paris correctly put a strong emphasis on the urgency of emissions mitigation. Fortunately, there are many socio-economic benefits to aggressive mitigation strategies. A few will be discussed. At the same time we have to figure out how to run an improved economic system that does not require never-ending growth, which destroys the ecosystems we depend on, while providing food, shelter, jobs, health care, and education for all.

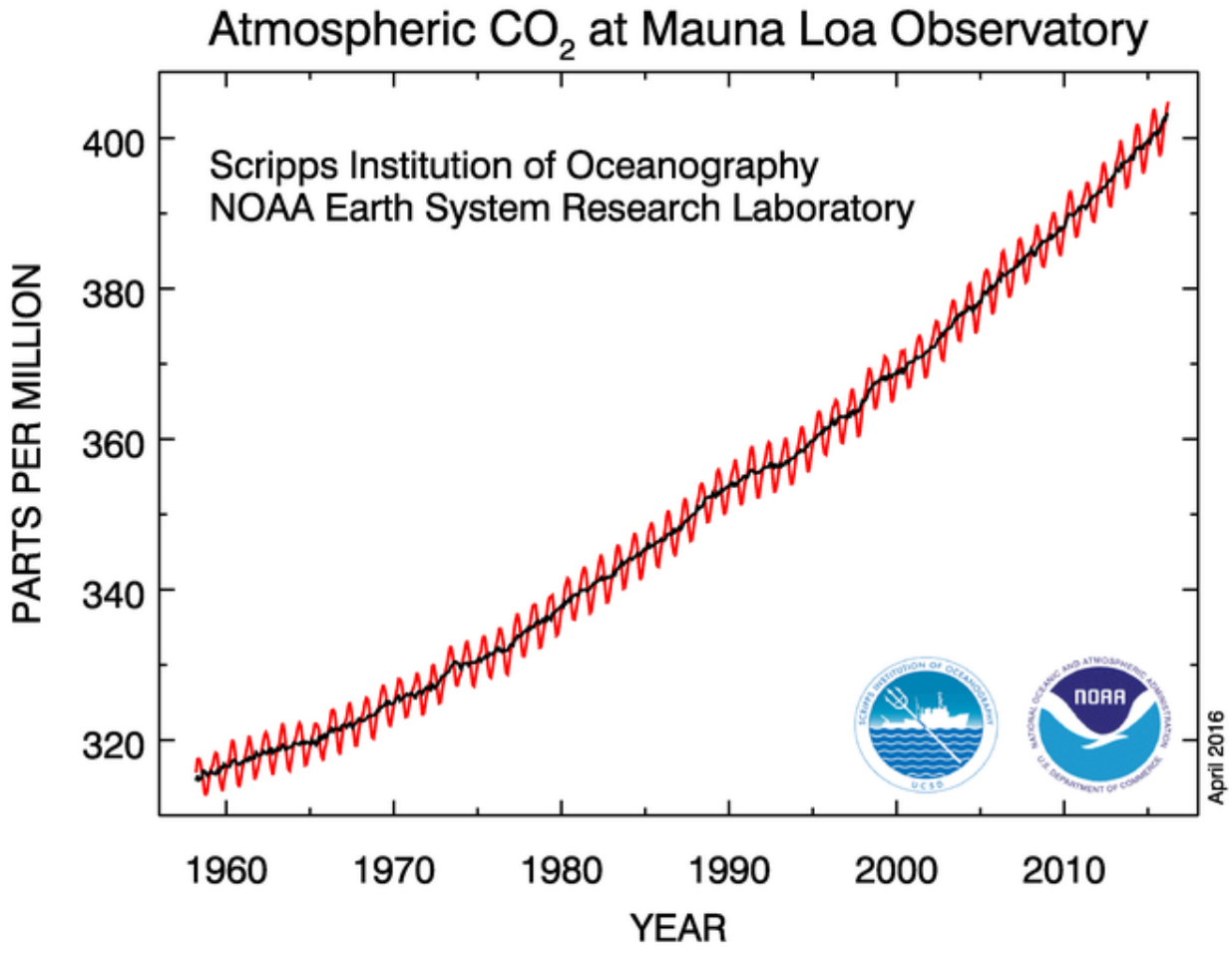


Figure 1. The continually increasing Mauna Loa CO_2 curve.

Global Reconciliation of Land, Ocean, and River Carbon Fluxes

L. Resplandy[1], R. Keeling[1], A.R. Jacobson[2,3], C. Roedenbeck[4] and S. Khatiwala[5]

[1]Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92037; 858-534-9944, E-mail: lresplandy@ucsd.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]Max Planck Institute (MPI) for Biogeochemistry, Jena, Germany
[5]Oxford University, Oxford OX1 2JD, United Kingdom

Disparities and uncertainties in the sinks for carbon on land are tied to uncertainties in the magnitude and the north-south distribution of ocean and river carbon fluxes. We use a new observational constraint based on ocean heat transport and its tight link to ocean carbon transport to evaluate existing ocean and river fluxes and propose a revised budget. Our revised ocean/river budget, combining carbon dioxide partial pressure (pCO_2) based ocean flux estimates with a global river carbon discharge of ~0.8 PgC/y, shows a stronger ocean and river carbon uptake in the northern extra-tropics than prior budgets and therefore calls for a weaker northern land sink.

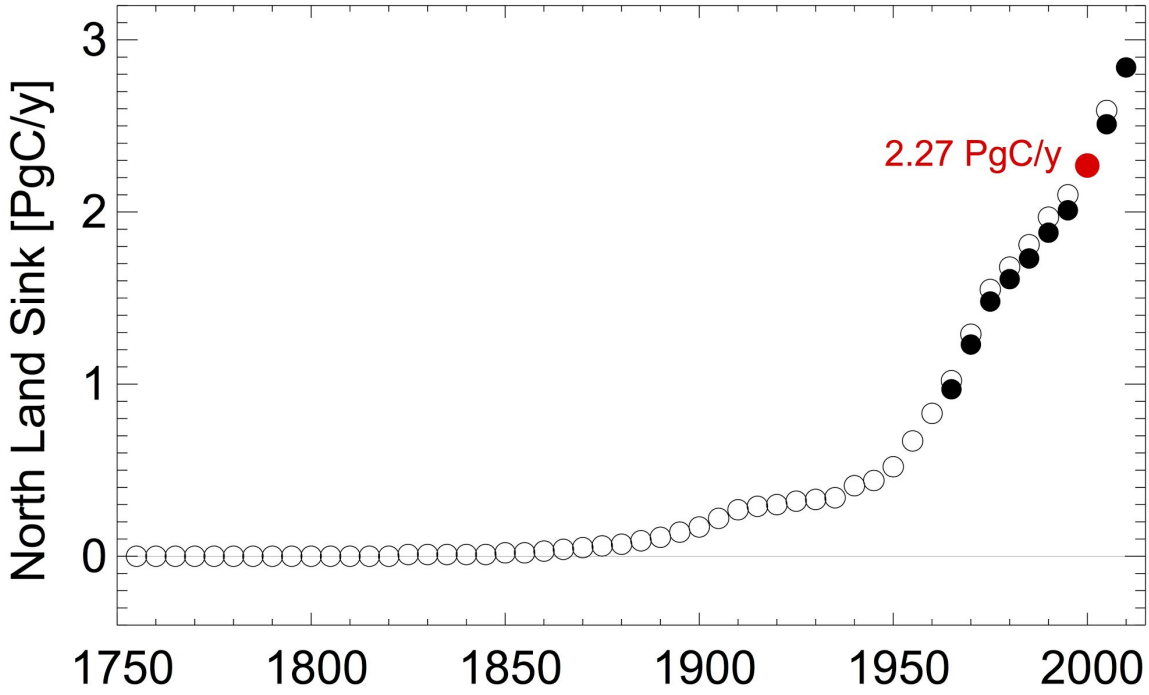


Figure 1. Temporal evolution of the Northern land sink derived from our revised carbon budget for the 1990-2010 period and extrapolated in time using a linear relationship with fossil fuel emissions from 1) Le Quéré et al. (2015) (filled circles) and 2) Boden et al. (2015) (open circles). Fossil fuel emissions were averaged over 10-year periods to smooth out interannual variability.

Boden, T.A., G. Marland, and R.J. Andres. 2015. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy. doi 10.3334/CDIAC/00001_V2015

Le Quéré, C. et al. Global Carbon Budget 2015 Earth System Science Data, 7, 349-396 doi:10.5194/essd-7-349-2015 (2015).

The Carbon Cycle Response to the 2015 El Niño

A.R. Jacobson[1,2], D.F. Baker[3], P.K. Patra[4], C. Wiedinmyer[5], R. Wanninkhof[6], E. Dlugokencky[2], K. Thoning[2], P.P. Tans[2] and M. Hoerling[7]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-497-4916, E-mail: andy.jacobson@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO 80521
[4]Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Natsushimacho, Japan
[5]National Center for Atmospheric Research (NCAR), Boulder, CO 80307
[6]NOAA Atlantic Oceanographic Meteorological Laboratory, Key Biscayne, FL 33149
[7]NOAA Earth System Research Laboratory, Physical Sciences Division (PSD), Boulder, CO 80305

The net sink of atmospheric carbon dioxide (CO_2), defined as the difference of anthropogenic emissions and the observed atmospheric growth rate, displays interannual variability linked to El Niño Southern Oscillation (ENSO) and to volcanic eruptions (see figure). During a typical El Niño, outgassing of carbon dioxide from the tropical Pacific Ocean is suppressed, increasing the net atmospheric sink of CO_2. This effect is generally overwhelmed by emissions of carbon dioxide from the tropical land biosphere, due particularly to wildfires in Southeast Asia. The overall result is generally a reduced net surface sink of carbon dioxide. The exceptionally strong El Niño in 2015 coupled with rising fossil fuel emissions resulted in an annual-mean atmospheric CO_2 growth rate at Mauna Loa of approximately 3 ppm/yr, corresponding to an atmospheric accumulation rate of about 6 PgC/yr. Since the last major El Niño in 1997-8, significant new observational programs and modeling tools have become available, and we now have a unique opportunity to observe and assess this event. In this presentation, we will discuss the physical nature of the 2015 El Niño and its impact on the global carbon cycle, as revealed by analysis of *in situ* atmospheric CO_2 observations, remote atmospheric soundings from surface- and space-based instruments, ocean pCO_2 observations and analyses, global wildfire emissions estimates, and atmospheric models.

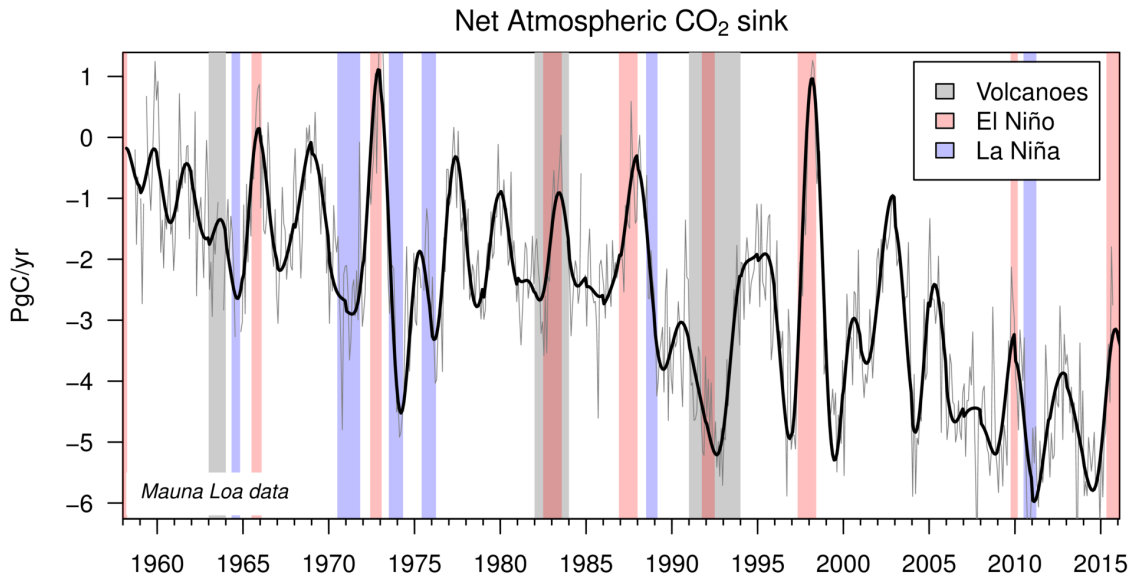


Figure 1. The net atmospheric CO_2 sink as inferred from the difference of the atmospheric growth rate and fossil fuel emissions estimates. The atmospheric CO_2 growth rate is computed in two different ways (thin and thick lines) from monthly-mean Mauna Loa observations. El Niños (shaded in red) and La Niñas (shaded in blue) are defined as deviations of ±1.0 in the Multivariate ENSO Index lasting at least 5 months. Impacts of major volcanic eruptions (shaded in gray) are computed as periods for which the weighted volcanic dust veil index exceeds 100.

Space-based Observations of CO_2 with the NASA Orbiting Carbon Observatory-2 (OCO-2)

D. Crisp[1] and The Orbiting Carbon Observatory Science Team[2]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; 818-354-2224, E-mail: David.Crisp@jpl.nasa.gov
[2]National Aeronautics & Space Administration (NASA), Greenbelt, MD 20771

The NASA Orbiting Carbon Observatory-2 (OCO-2) was launched from Vandenberg Air Force Base in California on 2 July 2014. By early September 2014, its spectrometers were routinely returning almost one million soundings over the sunlit hemisphere each day. About 10% of these soundings are sufficiently cloud free to yield full-column estimates of the column-averaged CO_2 dry air mole fraction, XCO_2. The OCO-2 team started delivering an initial data product (version 7/7r) to the Goddard Earth Sciences Data and Information Services Center (GES-DISC) in early June 2015. Preliminary, global maps of XCO_2 compiled from this product reveal some of the most robust features of the annual atmospheric carbon cycle, such as the intense northern hemisphere spring drawdown across Eurasia and then across North America, as land plants rapidly absorbed CO_2 to form new leaves, stems, and roots. They also show enhanced XCO_2 over regions with intense fossil fuel combustion, such as the east coasts of China and the U.S., and regions of intense biomass burning in the tropics. Comparisons of OCO-2 XCO_2 estimates with Total Carbon Column Observing Network (TCCON) results and other standards indicate single sounding random errors near 0.5 ppm, and absolute accuracies better than 2 ppm over most of the globe. However, there are some regions where this initial XCO_2 product appears to be anomalous, such as over the ocean at high southern latitudes during southern winter. These anomalies are currently under investigation.

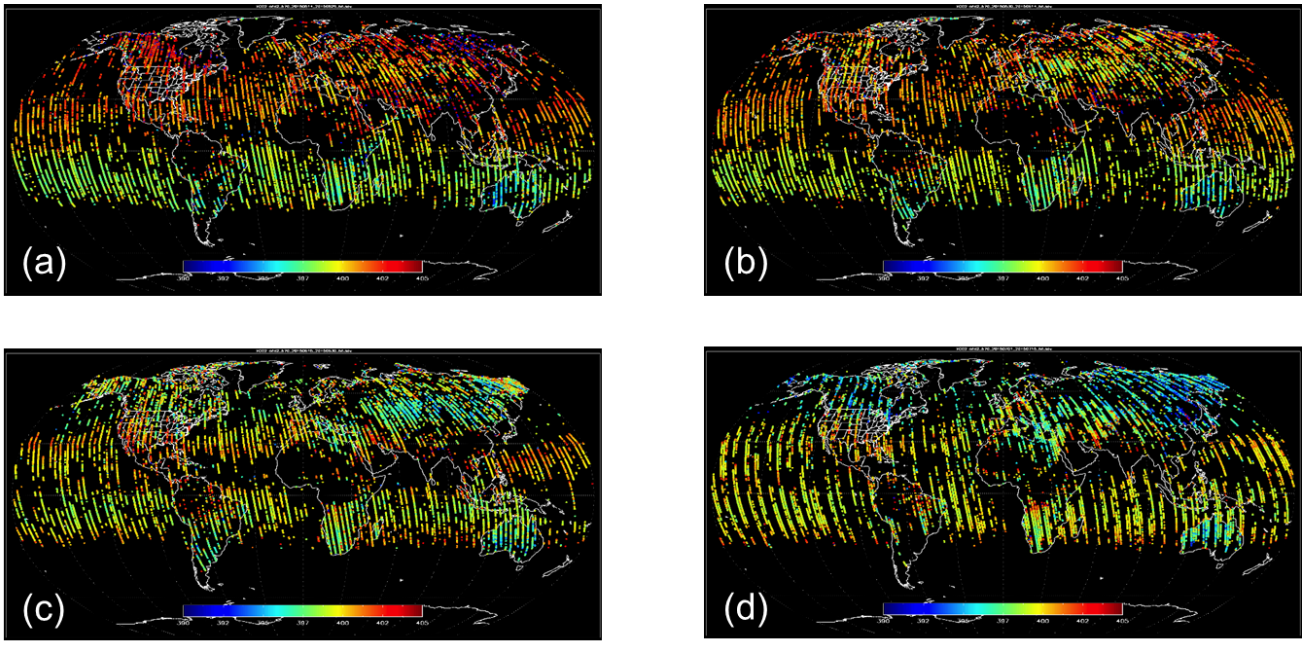


Figure 1. Global maps of XCO_2 for (a) 14-29 May, (b) 30 May to 14 June, (c) 15-30 June and (d) 1-15 July, produced from OCO-2 observations. The range of latitudes in the southern hemisphere is limited during this season because the sun is near it northernmost latitude. Large-scale reductions in XCO_2 are clearly seen in the northern hemisphere, as the land biosphere becomes active and rapidly absorbs CO_2.

Sensitivity of CO_2 Flux Inversions to the Temporal and Spatial Distribution of Observations

B. Byrne[1], D. Jones[1,2] and K. Strong[1]

[1]University of Toronto, Toronto, Ontario, Canada; 416-835-2544, E-mail: bbyrne@physics.utoronto.ca
[2]Joint Institute for Regional Earth System Science and Engineering (JIFRESSE), UCLA, Los Angeles, CA 90095

Inverse modeling of regional carbon dioxide (CO_2) sources and sinks is sensitive to the observational coverage of the observing network. Here we use the GEOS-Chem adjoint model to examine the sensitivity of observations to surface fluxes of CO_2 for data from the surface *in situ* network, the Total Carbon Column Observing Network (TCCON), the Greenhouse Gases Observing Satellite (GOSAT), and the Orbiting Carbon Observatory (OCO-2). We find that OCO-2 has the highest sensitivity to surface fluxes throughout the tropics and southern hemisphere, while surface observations have the highest sensitivity to surface fluxes in the northern extratropics (Fig. 1). We perform Observing System Simulation Experiments (OSSEs) to examine how differences in sensitivities influence the ability to recover surface fluxes. In particular, we examine the impact of the spatio-temporal coverage of the different observing systems on the ability of the inversion analyses to recover the timing and amplitude of the seasonal cycle of the surface fluxes.

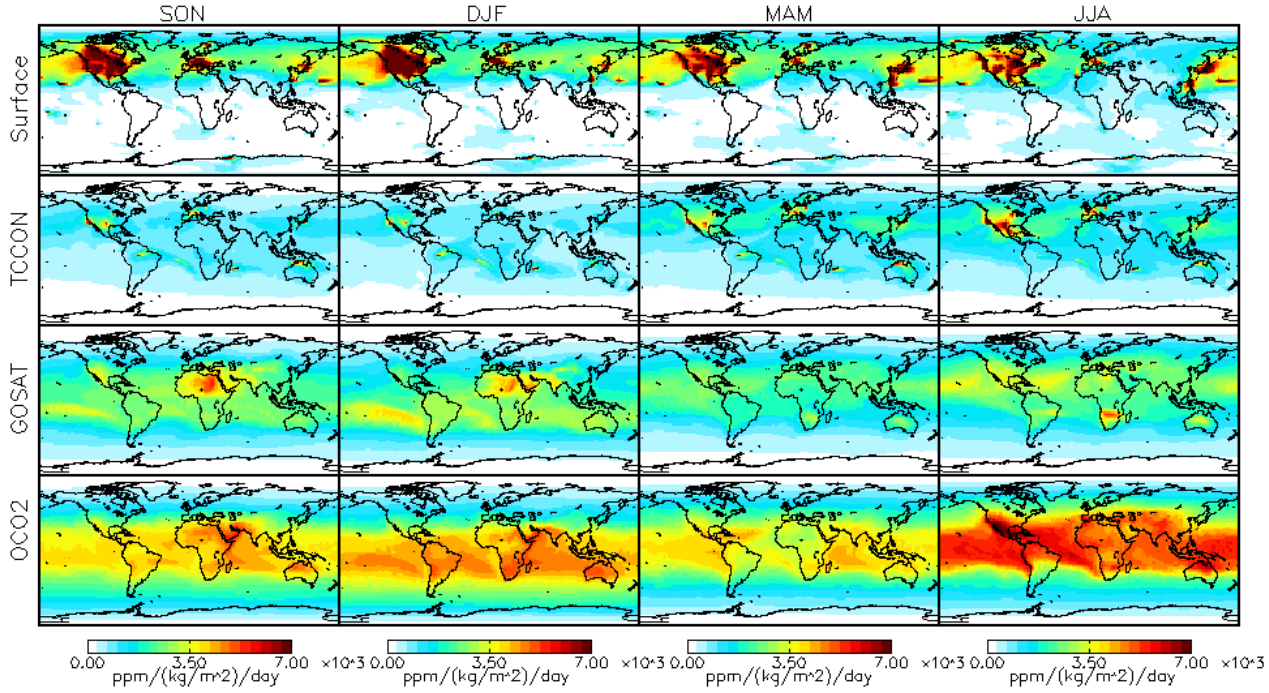


Figure 1. Seasonal sensitivities for surface *in situ*, TCCON, GOSAT, and OCO-2 observations to surface fluxes. Sensitivities are in observed quantity (ppm) per flux (kg/m^2/day), resulting in units of ppm/(kg/m^2)/day.

The Impact of Meteorological Analysis Uncertainties on the Spatial Scales Resolvable in CO_2 Model Simulations

S. Polavarapu[1], M. Neish[1], M. Tanguay[1], C. Girard[1], J. deGrandpre[1], K. Semeniuk[1], S. Gravel[1], S. Ren[1], S. Roche[2], D. Chan[1] and K. Strong[2]

[1]Environment and Climate Change Canada, Toronto, Ontario M3H 5T4, Canada; 416-739-4887, E-mail: saroja.polavarapu@canada.ca
[2]University of Toronto, Toronto, Ontario, Canada

The evolution of CO_2 is governed by the species transport equation and thus may be considered to be perfectly predictable if the advecting winds are perfectly known. However, this is never the case. In this work, we study the predictability of CO_2 in order to better understand the contribution of uncertain meteorological analyses to CO_2 transport error. Specifically, we identify the spatial scales resolvable in CO_2 simulations given that advecting winds are imperfectly known. A newly developed coupled meteorological and greenhouse gas transport model based on Environment and Climate Change Canada's operational weather and environmental prediction models are used for this purpose. With posterior fluxes from Earth Systems Research Laboratory Global Monitoring Division's (ERSL/GMD) CarbonTracker, CO_2 simulations compare well to observations assimilated by CarbonTracker (surface continuous) as well as to independent observations (TCCON and ERSL/GMD aircraft profiles). This coupled model is then used to show that the predictability of CO_2 is much shorter than that of the temperature field but is commensurate with that of the wind fields. When broken down into spatial scales, CO_2 has predictability at the very largest scales (wave numbers less than 10 near the surface) due to long time scale memory in surface CO_2 fluxes as well as in land and ocean surface forcing of meteorological fields. The predictability due to the land and ocean surface is most evident in boreal summer when biospheric uptake produces large spatial gradients in the CO_2 field. Predictability errors provide an upper limit for errors arising solely from the use of uncertain meteorological analyses. When considering meteorological analysis errors, CO_2 can be simulated well only on large scales (see Figure 1). Thus, there is a spatial scale below which information cannot be obtained simply due to the fact that meteorological analyses are imperfect.

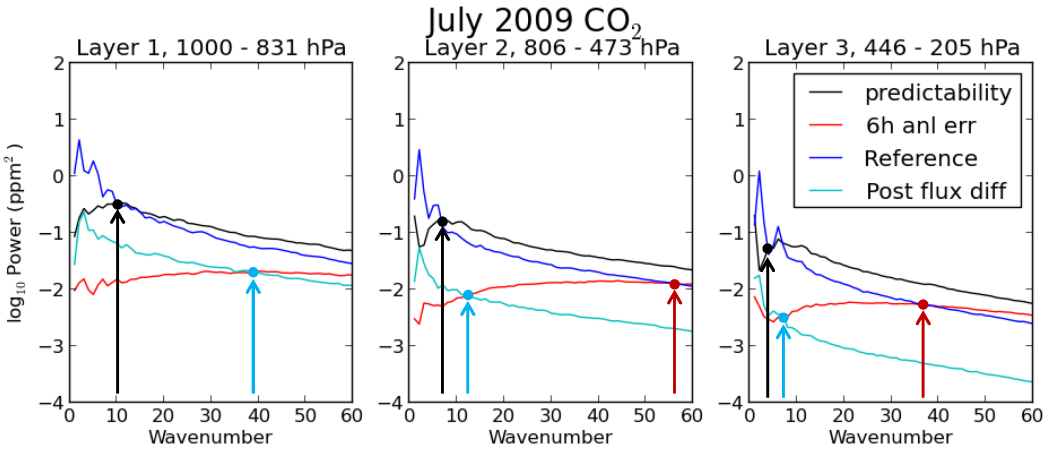


Figure 1. Spectra of various fields as a function of total wavenumber. Spectra are averaged over one month for July 2009 and over 12 model levels. The lower and upper model levels averaged are indicated above each frame in approximate pressure. The CO_2 reference state spectra (blue curves), predictability error (black curves), error due to a 6-h shift in analysis fields (red curves) and differences due to the use of different posterior fluxes (CT2010 or CT2013B) (cyan curves) are shown. Wavenumbers smaller than the black arrows are theoretically predictable. Wavenumbers smaller than the red arrow are definable in the presence of meteorological analysis errors. The scales for which the difference in CO_2 resulting from two different posterior fluxes exceed CO_2 errors due to uncertain meteorology are to the left of the cyan arrows.

Evidence That Palmer Station Antarctica Seasonal O_2 and CO_2 Cycles Understate Regional Marine Boundary Layer Means

J. Bent[1], B.B. Stephens[1], R. Keeling[2], S. Mikaloff-Fletcher[3] and P. Patra[4]

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[2]Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92037
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The Scripps O_2 Program has collected biweekly CO_2 and O_2 flasks samples from Palmer Station, Antarctica (PSA) since 1996. These data have served as an invaluable representation of regional carbon cycle signals and play an essential role in evaluating how well ocean models capture Southern Ocean dynamics and surface productivity.

Atmospheric CO_2 data reflect interfering oceanic solubility, upwelling and productivity signals, and are buffered by carbonate chemistry. Because of this, atmospheric O_2, and the related "atmospheric potential oxygen" (APO) quantity provide a much clearer representation of seasonal oceanic carbon cycle processes than CO_2 alone.

There is growing evidence in the oxygen measurement community, however, that Scripps Palmer Station APO data may not accurately represent a regional marine boundary layer (MBL) mean, possibly because of wind direction sampling selection criteria that tend to favor downslope flow from the glacier above the station, and mountains to the East. *In situ* shipboard data taken on the ASRV Laurence M. Gould between 2012 and 2016 near Palmer Station confirm this suspicion: a comparison of two-harmonic fits to station and Gould data suggests that the flasks understate the regional mean MBL seasonal cycle by at least 15%.

We present an observation- and modeling- based study of the differences in the two datasets, leveraging recent airborne data near Palmer Station from the ORCAS campaign on the NCAR Gulfstream V. We focus on addressing sampling bias, and reconciling prior measurements with current understanding so that scientists can better evaluate ocean models with representative data.

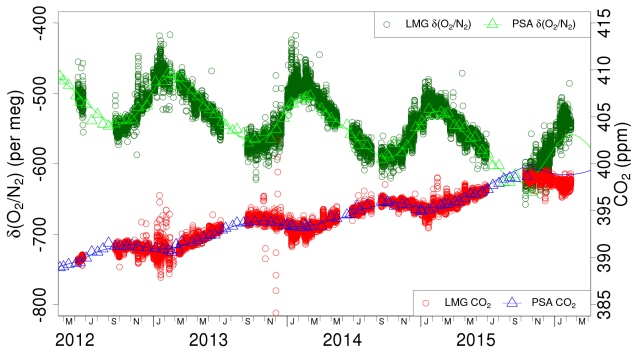

Figure 1. O_2 and CO_2 records from the ASRV Gould O2 instrument (circles) and Palmer Station flask samples (triangles) near Palmer Station. Gould records show larger seasonal cycles than equivalent Palmer samples, with largest differences around the austral summer seasonal maximum.

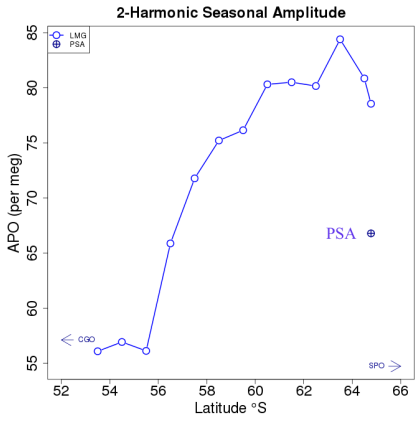

Figure 2. 2-harmonic amplitudes of atmospheric potential oxygen (APO=O_2+1.1*CO_2) between 53 and 65 South along the path of the ASRV Gould, representing seasonal air-sea O_2 exchange. Arrows denote the amplitudes for South Pole and Cape Grim, off plot.

Adventures with CO_2 at the Mt. Bachelor Observatory

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he Mt. Bachelor Observatory (MBO) is a high-elevation (2.8 km asl) research site located on the summit of Mt. Bachelor in Central Oregon. The site was started by the University of Washington in 2004, with a focus on O_3, aerosols and related trace species. The Figure below shows an aerial view of Mt Bachelor. Since 2004, we have intermittent observations of CO_2, then starting in 2012 we initiated daily flask and continuous *in situ* observations, in collaboration with the NOAA-GMD. Our goals for this work are:

1. To characterize the boundary layer and free tropospheric distribution of this important greenhouse gas;
2. Use CO_2 as tracer of atmospheric processes;
3. Use CO_2 with other tracers (such as CO) as a means to gauge combustion efficiency and source type.
4. Use the MBO data to constrain continental inflow of CO_2, CH_4 and other gases for global flux estimates.

One particular question we wanted to address with our observations is "why does CO_2 frequently not appear enhanced in biomass burning plumes? Using our CO_2 data over the past several years we have reached several conclusions:

1. In most seasons CO_2 is enhanced in free tropospheric air, compared to boundary layer air (McClure et al 2015).
2. Wildfire plumes may contain enhanced CO_2 due to biomass combustion, but if the transport pathway to MBO is long and in the boundary layer, enhanced CO_2, can be obscured by surface uptake (McClure et al 2015).
3. We have developed a new approach to calculate the modified combustion efficiency (MCE) that considers mixing with background air and the associated uncertainty in MCE (Briggs et al 2016).

In this presentation, I will give an overview of MBO gas and aerosol observations over the past 12 years, with a focus on these results using CO_2.

Figure 1. Mt. Bachelor located in central Oregon.

A Comprehensive Approach to Understanding Renewed Increase in Atmospheric CH_4

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NOAA observations of atmospheric methane (CH_4) from a globally distributed network of air sampling sites began in 1983. Much of what we know about the global CH_4 budget of emissions and sinks is based on these observations of CH_4 abundance. Since 1998, NOAA's measurements have been complemented by measurements of $\delta^{13}C$ in CH_4 in a subset of samples by our colleagues at INSTAAR, further constraining the global CH_4 budget. The combination of CH_4 abundance and stable carbon isotope ratio are particularly powerful in constraining the causes of renewed increase in atmospheric CH_4 burden that began in 2007 (see Figure). Common opinions regarding the renewed increase are "it must be fracking" or "it must be the Arctic". But observations of CH_4 abundance and isotopic composition representative of large spatial scales rule out both as significant contributors. Spatial patterns on CH_4 abundance suggest a significant contribution from the tropics, while the measurements of $\delta^{13}C$ in CH_4 clearly indicate changed emissions predominantly from microbial sources, not fossil fuels.

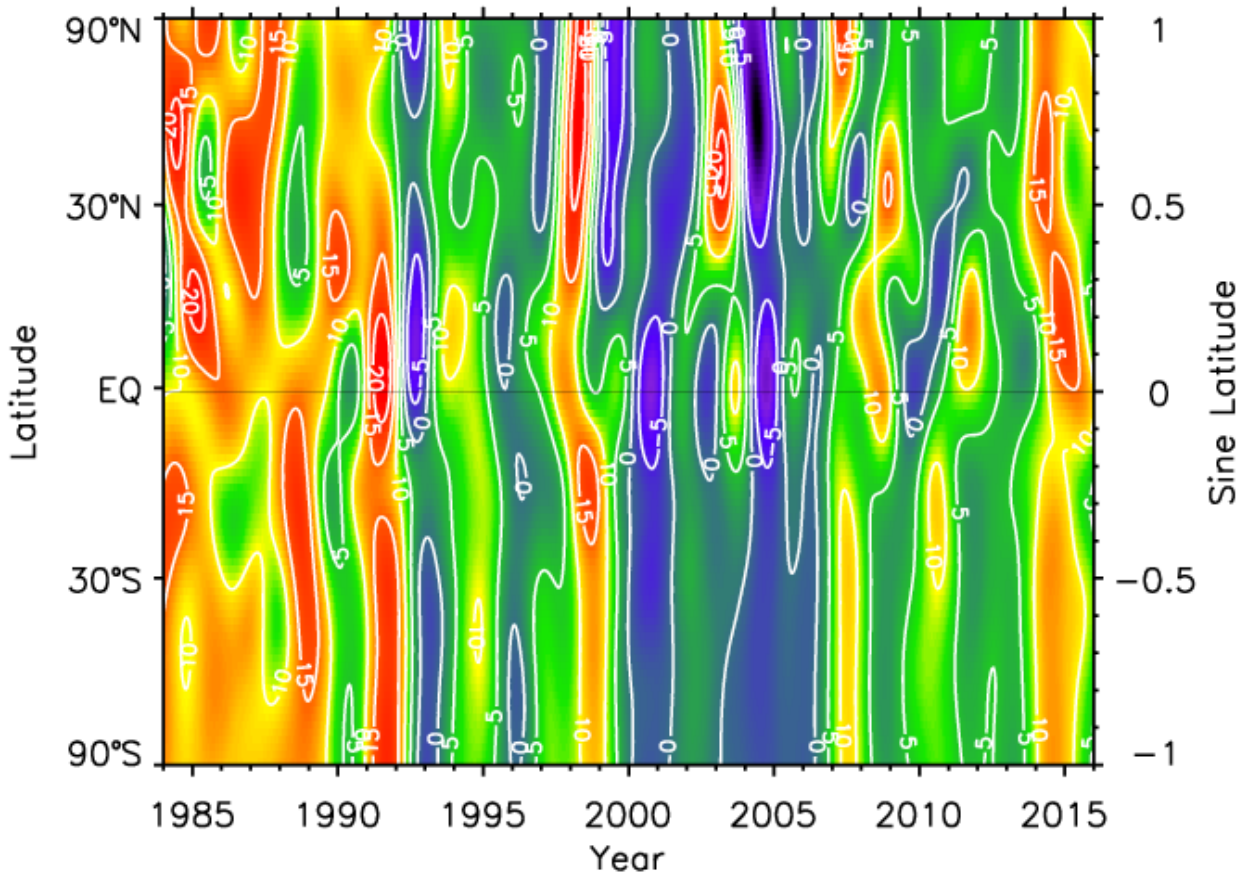

Figure 1. Contours of atmospheric CH_4 growth rate as functions of time and latitude in units of ppb yr^{-1}. Warm colors are for positive growth and cool colors for negative growth; green is near-zero growth. Contours are calculated from trends based on measurements of CH_4 in air samples collected at sites in NOAA's Cooperative Global Air Sampling Network.

Speculation on the Origin of Sub-baseline Excursions of CH_4 at Cape Grim

Z.M. Loh[1], P.B. Krummel[2], R.L. Gregory[1], L.P. Steele[2], A.R. Stavert[3,1], M.V.V.D. Schoot[1], D.A. Spencer[1], B. Mitrevski[1], D.P. Thornton[1], I.E. Galbally[1], J.Z. Ward[4], N.T. Somerville[4], S.D. Chambers[5] and A.G. Williams[5]

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The Advanced Global Atmospheric Gases Experiment (AGAGE) program has historically measured *in situ* methane (CH_4) at Cape Grim via gas chromatography with flame ionization detection (GC-FID) in 40 minutely grab samples. By adding continuous, high precision *in situ* measurements of CH_4 (Picarro cavity ring-down spectroscopy [CRDS]) at both Cape Grim, Tasmania, and Casey, Antarctica, a new feature has become apparent in the Cape Grim CH_4 record. During the austral summer (December to February), the Cape Grim CH_4 record periodically drops below baseline. For example, in Figure 1, a number of sustained episodes of depressed CH_4 concentration can be seen below the baseline selected data shown in red. Notably, these episodes are also seen in the GC-FID record.

In this presentation, we examine these sub-baseline excursions of CH_4. In conjunction with meteorology and a variety of other chemical species measured at Cape Grim, including radon, ozone, hydrogen and ethane, we speculate on a number of possible mechanisms that might be responsible for these dips in CH_4 mixing ratio.

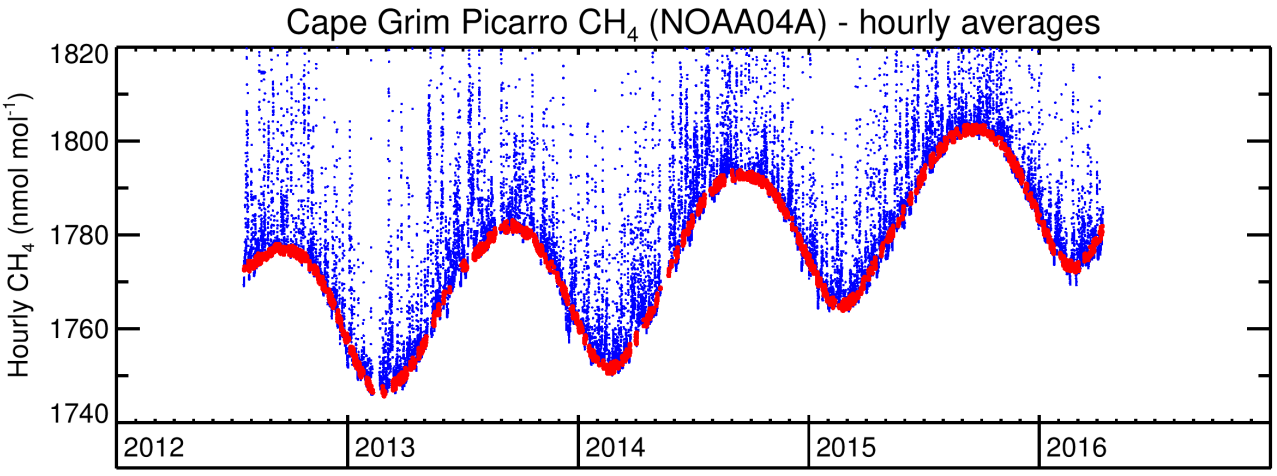

Figure 1. Hourly mean methane mixing ratios in ppb at Cape Grim, Tasmania from Picarro CRDS. Red data are baseline selected.

Cold Season Emissions Dominate the Arctic Tundra Methane Budget on the North Slope of Alaska

W. Oechel and D. Zona

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Arctic terrestrial ecosystems are major global sources of methane (CH_4); hence, it is important to understand the seasonal and climatic controls on CH_4 emissions from these systems. Here, we report year-round CH_4 emissions from Alaskan Arctic tundra eddy flux sites and regional fluxes derived from aircraft data. We find that emissions during the cold season (September to May) account for ≥50% of the annual CH_4 flux, with the highest emissions from noninundated upland tundra. A major fraction of cold season emissions occur during the "zero curtain" period, when subsurface soil temperatures are poised near 0 °C. The zero curtain may persist longer than the growing season, and CH_4 emissions are enhanced when the duration is extended by a deep thawed layer as can occur with thick snow cover. Regional scale fluxes of CH_4 derived from aircraft data demonstrate the large spatial extent of late season CH_4 emissions. Scaled to the circumpolar Arctic, cold season fluxes from tundra total 12 ± 5 (95% confidence interval) Tg CH_4 y^{-1}, ~25% of global emissions from extratropical wetlands, or ~6% of total global wetland methane emissions. The dominance of late-season emissions, sensitivity to soil environmental conditions, and importance of dry tundra are not currently simulated in most global climate models. Because Arctic warming disproportionally impacts the cold season, our results suggest that higher cold-season CH_4 emissions will result from observed and predicted increases in snow thickness, active layer depth, and soil temperature, representing important positive feedbacks on climate warming.

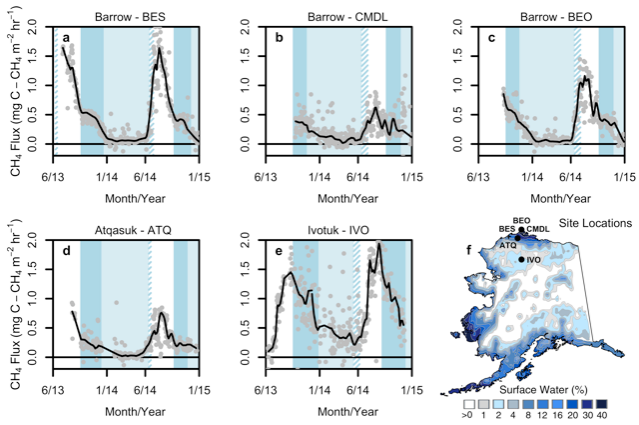

Figure 1. Methane flux (mg C-CH_4 m^{-2} h^{-1}) measured at the five EC sites on the North Slope, AK at: Barrow-BES (A), Barrow-BEO (B), Barrow-CMDL (C), ATQ (D), and IVO (E) from June 2013 to January 2015 [the gray dots are daily median for a minimum of 24 points per day, and the black line is a 35-d smoothing (lowess) applied to that daily median]. (F) Map of Alaska indicating the location of the sites and the percentage of surface inundation (*SI Materials and Methods*). The zero curtain (dark blue), spring thawing with soil temperature around 0 ± 0.75 °C (diagonal hatching) (Fig. S1 and Table S1), summer (no shading), and the balance of the cold season below –0.75 °C (light blue) periods are indicated (A–E). From Zona et al. 2016.

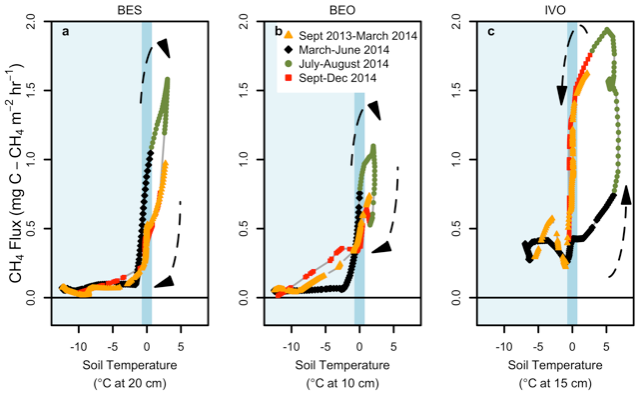

Figure 2. The methane flux variation with soil temperature on the North Slope of Alaska at: Barrow-BES (BES) (A), Barrow-BEO (BEO) (B), and IVO (C) during the indicated periods. The zero curtain period is shaded in dark blue, with soil temperatures below –0.75 °C in lighter blue. The seasonal progression of each phase is indicated by the black arrows. Winter-time data are shown as orange triangles (September 1, 2013 to March 12, 2014) and red squares (September 1, 2014 to December 31, 2014). Data collected during the spring (March 13, 2014 to June, 30, 2014) are shown as black diamonds. Data during the summer period (July 1, 2014 to August 31, 2014) are shown as green circles. From Zona et al. 2016.

No Significant Increase in Long-term CH_4 Emissions on North Slope of Alaska Despite Significant Increase in Air Temperature

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Continuous measurements of atmospheric methane (CH_4) mole fractions measured by NOAA's Global Greenhouse Gas Reference Network in Barrow, AK (BRW), show strong enhancements above background values when winds come from the land sector from July through December, indicating that emissions from arctic tundra continue through autumn and into early winter. Twenty-nine years of measurements show little change in seasonal mean land-sector CH_4 enhancements, despite an increase in annual mean temperatures of 1.2±0.8°C/decade (2s). The record does reveal small increases in CH_4 enhancements in November and December after 2010 due to increased late-season emissions. The lack of significant long-term trends suggests more complex biogeochemical processes are counteracting the observed short-term (monthly) temperature sensitivity of 5.0±3.6 ppb CH_4/°C. Our results suggest that even the observed short-term temperature sensitivity from the Arctic will have little impact on the global atmospheric CH_4 budget in the long-term if future trajectories evolve with the same temperature sensitivity.

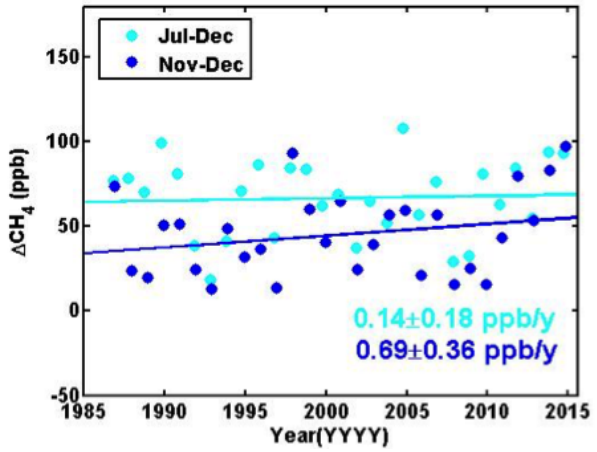

Figure 1. Trends in CH_4 enhancements and surface temperature from the North Slope 1986-2014. **Left)** Land sector CH_4 enhancements, July – December (cyan) and November - December (blue) during >3 m/s wind events coming between 150° and 210°.

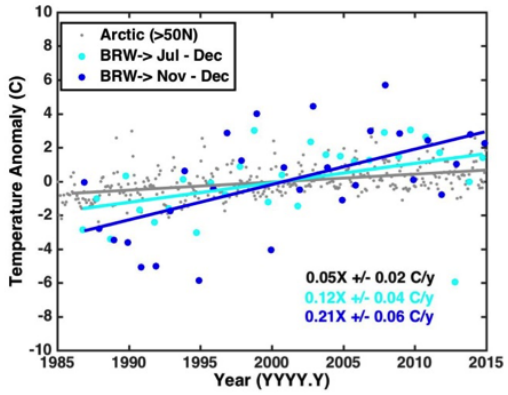

Figure 2. Air temperature anomalies, relative to the time series mean, at BRW and the entire Arctic. Grey points are monthly anomalies in Arctic (>50°N) temperature from the GISS Surface Temperature Analysis (GISTEMP, http://www.esrl.noaa.gov/psd/data/gridded/data.gistemp.html). Cyan and blue points show surface air temperature anomalies at 2-m made at the BRW tower for 1986-2014, July – December and November – December, respectively.

Studies of Carbon Isotopic Ratios ($\delta^{13}C$) of Methane in Atmospheric Air Samples from Different Locations in India

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Methane (CH_4) currently has a globally averaged mixing ratio of ~1800 parts per billion by Volume (ppbV) in the troposphere. Its concentration increased from approximately 700 ppbV during the pre-industrial period to about 1800 ppbV today. Between 30 to 40% of CH_4 emissions are from natural origin. The other emissions are related to anthropogenic activity: agriculture, fossil fuel combustion, biomass burning and waste treatment. Removal of CH_4 from the atmosphere is primarily due to oxidation by the hydroxyl radical (OH). A small fraction of the CH_4 is also removed by oxidation in soils. Recent studies indicate that a very small fraction of atmospheric CH_4 is lost in caves. The carbon isotopic composition ($\delta^{13}C$) of CH_4 is useful for constraining the global CH_4 budget and identifying CH_4 sources. This technique is widely used all over the world to identify methane sources, especially in the northern Hemisphere. Very limited work has been done from India in the last decade to measure $\delta^{13}C$ of CH_4 in atmospheric air to identify its sources. We present here a summary of the work carried out in the last decade on $\delta^{13}C$ of CH_4 in air samples collected from different environments like 1) a high-altitude station (Mt. Abu); 2) inside caves (A.P state); 3) a marine environment (Arabian Sea) and 4) an urban area (Ahmedabad) and discuss its implications. The scientific conclusions are given below.

The values of $\delta^{13}C$ of CH_4 in air samples collected from a high-altitude station are enriched compared to that of from tropospheric value (-47.1‰) which indicates that methane is consumed (less than tropospheric value in few samples) due to either biogeochemical process or more interaction with OH radicals. An interesting observation in Billasurgam cave air samples is a decrease in methane concentration from mouth to interior of the cave. As the sampling location is closed further and hence the ventilation is poor, it clearly implies that the carbon from CH_4 is being consumed by the methanotrophic bacteria in the interior of the cave and creating a concentration gradient which is seen in the results. The values of $\delta^{13}C$ of CH_4 in air samples collected from coastal area of Arabian Sea are enriched compared to the tropospheric values (-47.1‰) which indicates that the excess methane(~ 9%) is thermogenic type and probably from land. The data from an urban area (Figure 1) suggests that two dominant sources (automobile exhaust and natural gas leakage) contribute during night time. Both the sources have equal contribution from 21:00 to 6:00 where as automobile exhaust dominates after 6:00 hours.

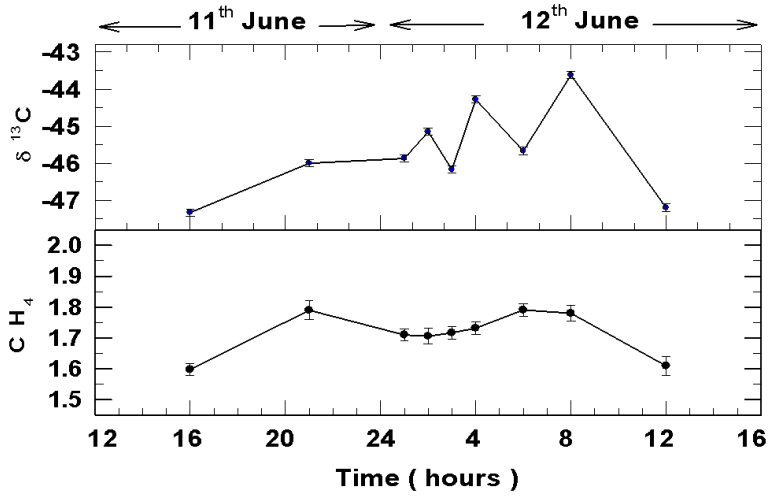

Figure 1. Diurnal cycle of CH_4 ppmV mixing ratio and $\delta^{13}C$ (‰) in Ahmedabad city during 11-12th June 2003.

Top-down Estimate of Methane Emissions in California Using Aircraft Measurements During the CalNex 2010 Field Campaign

Y. Cui[1,2], J. Brioude[1,2], W.M. Angevine[1,2], S.A. McKeen[1,2], J. Peischl[1,2], D.K. Henze[3], N. Bousserez[3], M. Fischer[4], S. Jeong[4], H.A. Michelsen[5], R.P. Bambha[5], Z. Liu[5], G.W. Santoni[6], G. Frost[2], T.B. Ryerson[2], S. Wofsy[6] and M. Trainer[2]

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Methane (CH_4) has a large global warming potential and mediates global tropospheric chemistry, but there are large uncertainties in the spatial distribution, magnitude and trends of methane emissions. In the United States, major anthropogenic sources of CH_4 include oil and natural gas (ONG) extraction, processing, and distribution, livestock management, agriculture, trash disposal, and wastewater treatment. Some of these sources have been changing rapidly in recent years. In the U.S. state of California, CH_4 emissions estimates derived from "top-down" methods based on atmospheric observations have been found to be greater than expected from "bottom-up" population-apportioned national and state inventories. Differences between bottom-up and top-down estimates suggest that the understanding of California's CH_4 sources is incomplete, leading to uncertainty in the application of regulations to mitigate regional CH_4 emissions. In this study, we use airborne measurements from the California research at the Nexus of Air Quality and Climate Change (CalNex) campaign in 2010 to estimate CH_4 emissions in the South Coast Air Basin (SoCAB), which includes California's largest metropolitan area (Los Angeles), and the Central Valley, California's main agriculture and ONG production area. Measurements of 12 daytime aircraft flights, prior information from national and regional official inventories (e.g. U.S. Environmental Protection Agency's [EPA] National Emission Inventory [NEI] and California Greenhouse Gas Emissions Measurement [CALGEM]), and the FLEXPART-WRF transport model are used in our mesoscale Bayesian inverse system. This presentation will focus on comparing our optimized posterior CH_4 emissions to prior bottom-up inventories, quantifying uncertainties in our CH_4 emissions estimates, analyzing spatial distributions of CH_4 surface fluxes in California, and discussing the significant role of local ONG industry and livestock sources in this region.

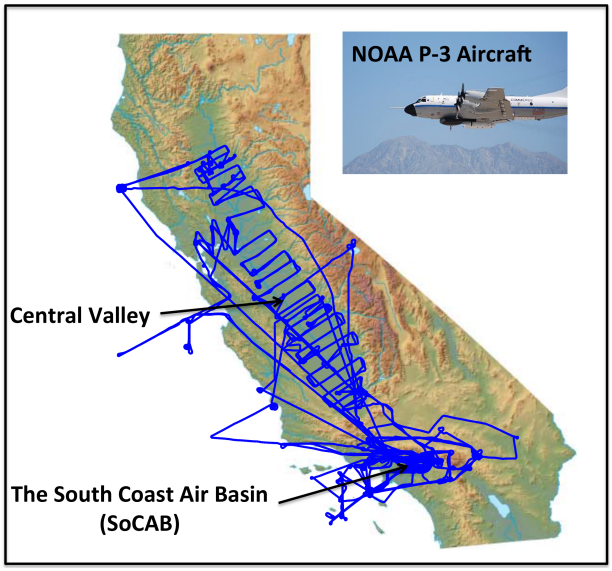

Figure 1. Blue lines are flight tracks of 12 daytime NOAA P-3 flights over California during the CalNex 2010 field campaign, including the South Coast Air Basin (SoCAB) and the Central Valley regions.

Amazonian Atmospheric CO_2 Data Suggest Missing Moisture Sensitivity in Carbon-climate Models

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It is critical to assess whether the prognostic terrestrial biosphere models included in Earth System Models (ESMs) accurately represent carbon dynamics in the tropics, because of the distinct possibility of strong positive feedbacks between tropical carbon stocks and global climate. Atmospheric observations of carbon dioxide (CO_2) can help constrain surface-to-atmosphere fluxes of CO_2, but until recently this has been difficult in the tropics due to sparse high-quality observations. New, regular sampling of vertical profiles of air above the Brazilian Amazon in four locations from 2010 to 2015 was recently analyzed in three studies: a mass balance approach, a global inversion and a regional atmospheric inversion. All three studies found that during the 2010 drought, NBE was higher (i.e. the rate of carbon loss to the atmosphere was higher) than in the year(s) following, a result that agrees with forest-plot studies in the Amazon. The regional inversion study further found strong negative correlations between wet season precipitation anomalies and NBE in the month following, and strong positive correlations between wet season temperature anomalies and NBE in the same month, in the central and eastern regions of the Amazon. We compare regional inversion results with NBE from 8 dynamic global vegetation models (DGVMs) that are part of the TRENDY model project and find that the TRENDY models agree with basin-wide NBE differences between years. The TRENDY models also correctly identify a positive correlation between temperature anomalies and NBE in the wet season in the eastern and central Amazon. The TRENDY models do not appear, however, to capture the observed negative correlation between NBE and precipitation anomalies in the Amazon that is identified by the atmospheric inversion. The lack of sensitivity of the carbon balance of the TRENDY models to moisture represents a serious shortcoming in their model structure.

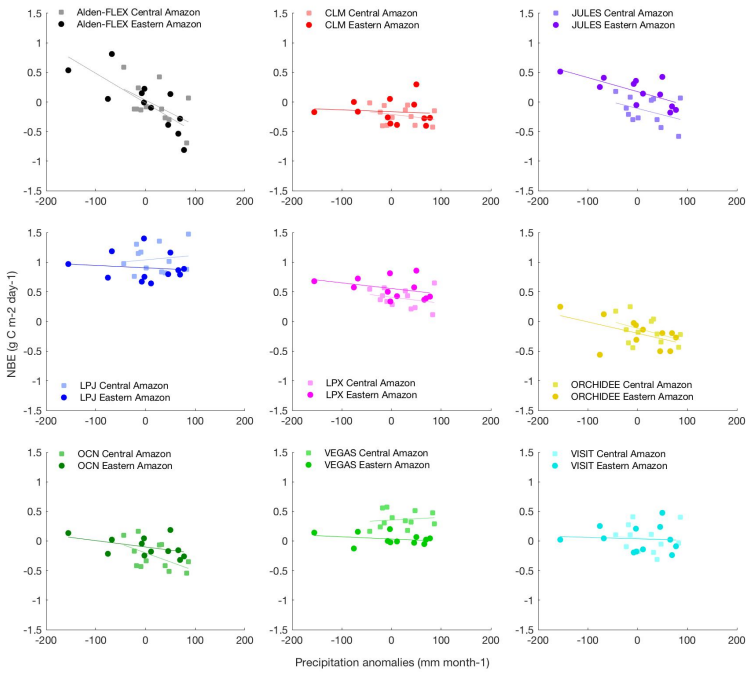

Figure 1. Wet season NBE from inversion results of Alden et al. (2016) (top left panel) and from 8 TRENDY models, plotted against precipitation anomalies. NBE is lagged 1 month behind precipitation. Linear fits shown for each. TRENDY model NBE is compared with precipitation anomalies from driver data (CRU-NCEP) and Alden-FLEX is compared with precipitation anomalies from GPCP.

A Different View of Atmospheric Carbon Monitoring

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In 2013 Harris and Atmospheric and Environmental Research (AER) were selected by the Department of Energy (DOE) National Energy Technology Laboratory (NETL), Carbon Storage group to develop a new measurement approach for continuous monitoring of CO_2 over an entire storage field for verification of ground carbon storage facilities. The result of that effort was the Greenhouse gas Laser Imaging Tomography Experiment (GreenLITE). The GreenLITE system consists of two Laser Absorption Spectroscopy (LAS) transceivers and a number of reflectors used to establish a grid of overlapping CO_2 density measurements. GreenLITE hardware and operational software leverages many years of prior work done by Harris, then ITT, on an airborne demonstrator for the NASA Decadal Survey Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission. Both systems utilize the synchronous transmission Intensity Modulated (IM) Continuous Wave (CW) LAS approach, but GreenLITE uses it in a new and unique way. The retrieval approach also leverages many years' of work by AER for multiple programs. The differential transmission is measured along each line (chord) and is then used along with locally measured temperature, pressure and relative humidity via a cloud-based processing environment to drive retrieval to dry air-mixing ratio through the comparison of a Line-By-Line Radiative Transfer Model (LBLRTM) and the observed data. The intersections of the multiple chords also serve as a means to constrain an estimate of the 2D spatial distribution of the gas over the area of regard.

In 2015 Harris designed and built an expanded version of the transceivers to work over a 5 km path length enabling coverage of ~30 km2 in the current configuration and got the system deployed over the city of Paris, France in November 2015. AER advanced the user interface, made the retrieval algorithms capable of retrieval over the long slant path by including layered weather data, and implemented a more robust cloud-based data storage and dissemination architecture. The system has been operating over the city of Paris continuously and provides real-time concentrations and maps via a web-based interface, as shown in the figure. Harris and AER have been working with Climate and Environment Sciences Laboratory (LSCE) and Laboratoire Atmospheres, Milieux, Observations Spatiales (LATMOS) on evaluation of the data using both model and *in situ* measurements to evaluate the performance and utility of the system in complex urban environments.

Figure 1. Prototype GreenLITE transceivers in side-by-side comparison (left), Example of the near-real time data for the GreenLITE system as deployed in Paris (right). Red dots are the transceivers and magenta dots are the reflectors. The red lines indicate the lines for a single 10 second measurement. The heat map shows the estimated concentration distribution.

High-accuracy, High-precision, High-resolution, Source-specific Monitoring of Urban Greenhouse Gas Emissions? Results to Date from INFLUX

J. Turnbull[1,2], C. Sweeney[3,2], K. McKain[3,2], I. Vimont[4], S. Lehman[4], K.J. Davis[5], T. Lauvaux[5], N. Miles[5], S. Richardson[5], B. Nathan[5], K. Wu[5], P.B. Shepson[6], A. Heimburger[6], K.R. Gurney[7], R. Patarasuk[7], A. Karion[8] and J. Whetstone[8]

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[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
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[8]National Institute of Standards and Technology, Gaithersburg, MD 20880

The Indianapolis Flux Experiment (INFLUX) is testing the boundaries of our ability to use atmospheric measurements to quantify urban greenhouse gas (GHG) emissions. The project brings together inventory assessments, *in situ* and flask measurements of GHGs and ancillary tracers from towers, aircraft and onroad platforms, and atmospheric modeling to provide high-accuracy, high-resolution, and source-specific monitoring of emissions of GHGs from the city. This presentation will highlight how observations from the different platforms and measurement methods can be integrated to attribute urban carbon dioxide (CO_2) emissions to specific source sectors and constrain overall emissions.

Recent research in several cities has shown that the urban biogenic CO_2 flux is poorly-known but non-negligible, even in winter, so that separation into biogenic and fossil components is essential if CO_2 emissions are to be reliably constrained. In addition to *in situ* CO_2 observations, we determine fossil fuel CO_2 (CO_{2ff}) at high resolution by combining flask $^{14}CO_2$ and carbon monoxide (CO) measurements with *in situ* CO observations. This improves both aircraft mass balance and atmospheric inversion estimates (using tower-based measurements) of urban CO_2 fluxes, relative to the use of CO_2 measurements alone. In the example of Indianapolis, this technique also allows separation and quantification of the CO_{2ff} emissions from the large Harding Street coal-fired power plant. We will also present results of our initial attempts to further resolve urban source-sector CO_{2ff} emissions using the wealth of information available from NOAA multispecies flask measurements and point to possible ways forward to resolve this challenging problem.

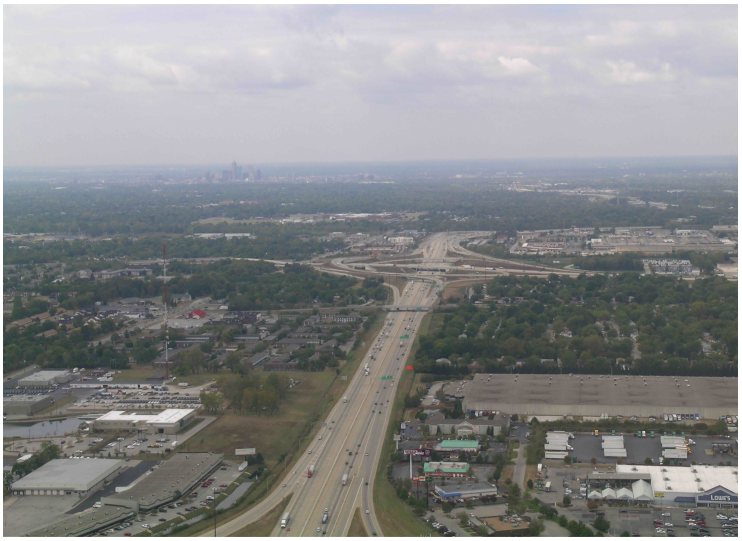

Figure 1. Looking west towards Indianapolis. INFLUX tower two is in the left foreground, photo was taken during an aircraft sampling flight.

Gradients of Column CO_2 Across North America from Aircraft and Tall Tower Measurements in the NOAA/ESRL Global Greenhouse Gas Reference Network

X. Lan[1,2], P.P. Tans[2], C. Sweeney[1,2], A.E. Andrews[2], A.R. Jacobson[1,2] and E. Dlugokencky[2]

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This study analyzes seasonal and spatial patterns of column CO_2 over the North America using *in situ* aircraft and tall tower measurements from the NOAA/ESRL Global Greenhouse Gas Reference Network over the period of 2004 to 2015. The long-term trend of background CO_2 from Mauna Loa Observatory is first subtracted from all measurements before comparisons. We found that the largest spatial gradients of CO_2 among the seven regions we defined across North America appear below 2km during summer time, while upper layer data (above 5km) show little contribution to spatial gradients. Although individual CO_2 profiles have relatively large variability across different heights, the long-term mean profiles show clear seasonal propagations of surface signals to levels above. Strong seasonality also exists on the time series of column averaged CO_2 from aircraft measurements. Large spatial gradients of long-term mean column CO_2 mainly occurred during June to August with strong summer drawdowns. Since Carbon Tracker modeled CO_2 agrees well with our aircraft measurements and AirCore measurements, modeled CO_2 from upper layer (~ 340 mbar to 0 mbar) are utilized with aircraft and tall tower data to produce the whole atmospheric column CO_2 (XCO_2). We found that the XCO_2 gradients across North America mainly reflect the large-scale circulation patterns instead of only surface source and sink. The long-term mean summer drawdowns at the northern regions are stronger by ~ 3ppm than the southern regions. This spatial gradient of XCO_2 is only half of the amount reported in a recent study in Europe (Reuter et al., 2014).

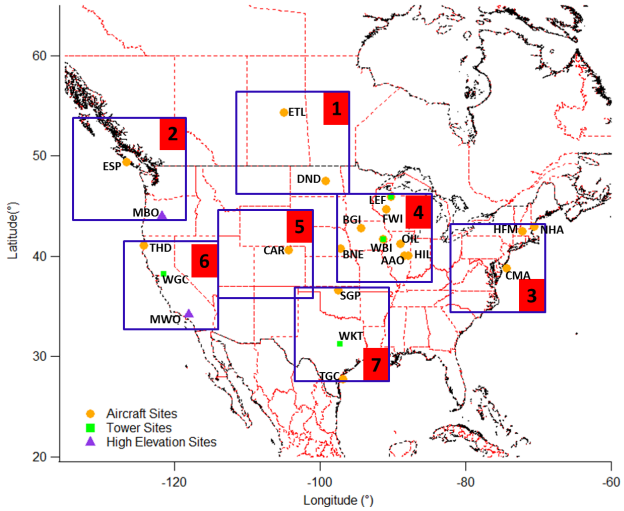

Figure 1. Aircraft and Tall Tower Sites in the NOAA/ESRL Global Greenhouse Gas Reference Network that are analyzed in this study. Seven regions are defined for spatial comparisions.

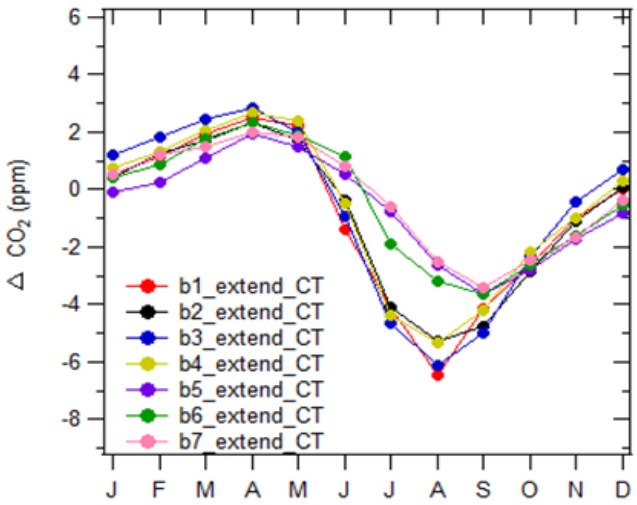

Figure 2. Long-term mean XCO_2 calculated from aircraft and tall tower measurements combined with upper levels Carbon Tracker modeled data. B1 to B7 in figure legend represent the regions in Figure 1.

Gross Uptake of Carbon in the U.S. Is Largest in the Midwest Region

T.W. Hilton[1], A. Zumkehr[1], M. Whelan[1], S. Kulkarni[2], J. Berry[3] and J.E. Campbell[1]

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Regional photosynthetic carbon dioxide fluxes (gross primary production, GPP) are a first-order uncertainty in future climate predictions, but direct observation of these fluxes is not possible because of confounding ecosystem respiration fluxes of roughly equal magnitude but opposite direction. Carbonyl sulfide (COS or OCS) may offer a new and independent constraint on regional GPP, but uncertainties in key leaf-level COS exchange parameters and concurrent non-plant terrestrial surface COS fluxes must be accounted for. Here we analyze North American airborne COS observations with a regional chemical transport model and a wide range of source and sink parameterizations. We found that GPP in the U.S. growing season is concentrated in the Midwest region. While these results are not consistent with some process-based ecosystem models and emerging data-driven models, they are supportive of recent space-based estimates from sun-induced chlorophyll fluorescence. Extension of our modeling approach with increased capabilities from remote sensing may provide information on gross carbon fluxes in other regions.

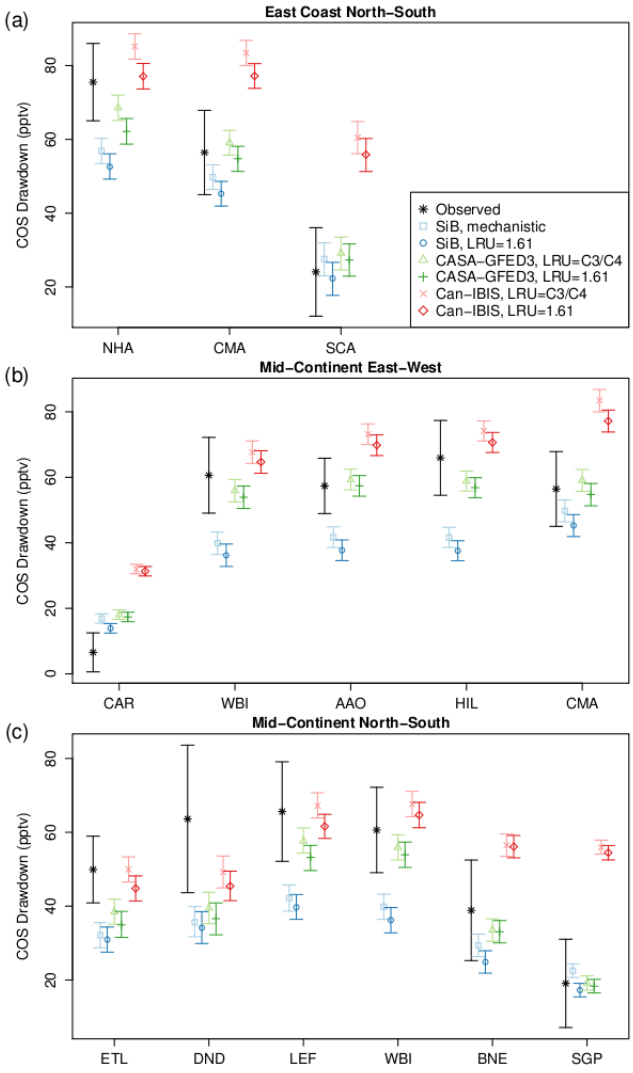

Figure 1. July and August mean COS vertical drawdown for 48 STEM simulations with bootstrapped 95% confidence intervals. Site locations (horizontal axis) refer to NOAA ESRL observation site codes. COS drawdown values shown here include all model components (COS plant flux, COS soil flux, COS anthropogenic flux, and boundary conditions) and all COS plant flux models (mechanistic, C3/C4-varying COS–CO2 leaf-scale relative uptake (LRU), and fixed LRU. We calculated drawdown to approximate the difference in COS concentration between the atmospheric boundary layer and the free troposphere.

Meteorological and Greenhouse Gas Measurements for the Characterization of Errors in Mesoscale Carbon Inversions

T. Lauvaux[1], L. Diaz-Isaac[1], M. Butler[2], S. Feng[1], A. Deng[1], J. Liu[3], K. Bowman[3], K.J. Davis[1], X. Ye[1], B. Gaudet[1], M. Hardesty[4] and A. Brewer[4]

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From urban to continental scales, networks of meteorological and atmospheric Greenhouse Gas measurements are being deployed to densify long-term infrastructures intended to constrain carbon sources and sinks. Among these observing systems, both remote sensing and *in situ* measurements offer a wide range of observational constraints potentially able to evaluate and improve components of atmospheric modeling systems, at the center of the inverse calculation. Beyond assimilation strategies targeted for specific objectives, we present here different approaches to incorporate aircraft-, surface-, and satellite-based information in regional and local inversion problems. We determine model weaknesses and redefine the objectives of each inverse problem in order to identify the most valuable contribution of atmospheric data to specific inverse problems. We discuss here the joint use of meteorological and greenhouse gas data to evaluate surface fluxes and atmospheric transport, and possibly correct for current model limitations by implementing assimilation approaches. We present multi-model evaluation strategies using aircraft and tower *in situ* data for continental-scale inversions and compare our findings to high resolution inverse applications. Finally, we discuss vertical errors and their significant impact on inverse estimates at regional scales for both satellite and tower data inversion, opposed to the source attribution problem from horizontal advection errors as a cause of systematic errors at higher resolutions.

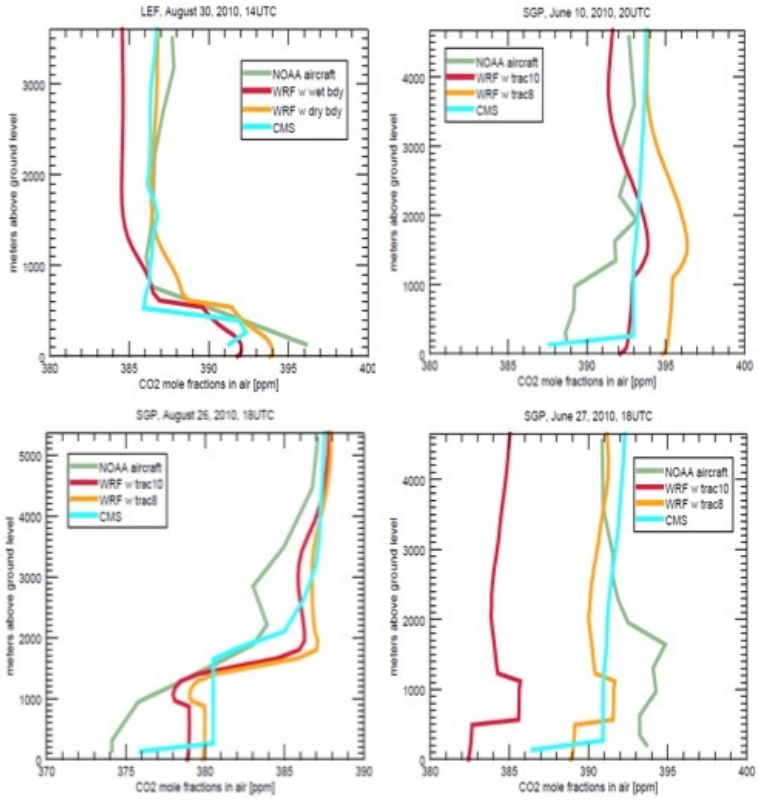

Figure 1. Comparisons of global CMS (GEOS-Chem) and regional WRF-Chem profiles to NOAA aircraft CO_2 flask data at four different sites collected over summer 2010. The model-data mismatch in vertical gradients indicate transport model errors in near-surface turbulent mixing.

Diurnal and Seasonal Variations in the Sources of Anthropogenic CO_2 Emissions Over Two Years in the Los Angeles Megacity from Atmospheric Measurements

S. Newman[1], X. Xu[2], Y.K. Hsu[3], A.E. Andrews[4] and Y.L. Yung[1]

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[2]University of California at Irvine, Department of Earth System Science, Irvine, CA 92697
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Human activities in urban regions are the largest contributors to anthropogenic greenhouse gas emissions, with carbon dioxide (CO_2) being the dominant species emitted, creating large variations that are easily observed. As governments sign treaties limiting emissions in order to curb global warming, they must understand the temporal distribution of the signals. Inventory based data (bottom-up) account for emissions at all times of day from various sectors but are based only on economic data, with no observational confirmation. Atmospheric observations (top-down) from satellites generally record variations at one time of day only a few times per month for any given location. Therefore we must use long-term *in situ* measurements to develop higher temporal resolution data sets. Attributing the observed emissions to different sources requires modeling using bottom-up emission data products and/or isotopic and tracer/tracer ratio measurements. Here we extend our 8-year analysis of CO_2 emissions due to fossil fuel combustion from flask sampling to results of two years (June 2013 – June 2015) of hourly average measurements of carbon monoxide (CO), CO_2, and delta thirteen carbon ($\delta^{13}C$) from Pasadena, CA, to examine diurnal and seasonal variations in emissions from the biosphere and from natural gas and petroleum combustion. COxs/CO_2xs (excess over background) values can be used to determine the amount of fossil fuel-derived CO_2 relative to that from the biosphere. We calibrate this with mid-afternoon data using radiocarbon data from flask samples. We then use continuous measurements of $\delta^{13}C$ to differentiate between petroleum and natural gas combustion, which are characterized by distinct isotopic compositions. The results of this study show that the relative amounts of emissions of the three sources are different at different times of day as well as different times of year. We discuss the possible causes for these variations.

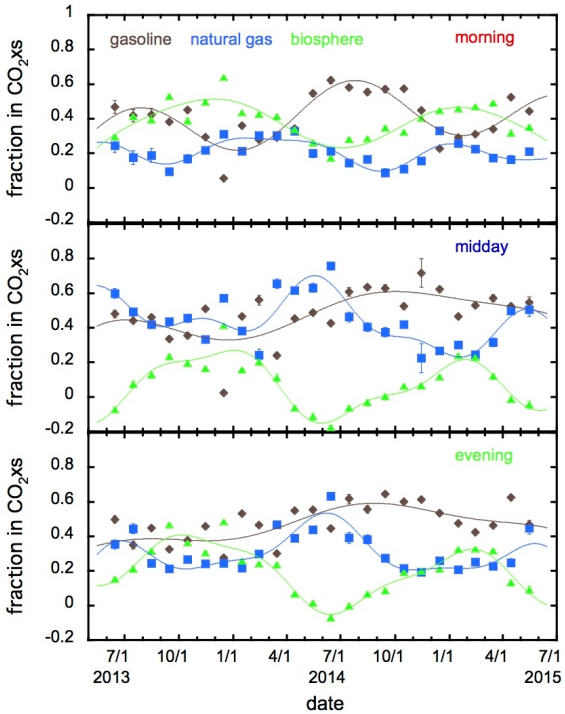

Figure 1. Source allocation of CO_2 excess over background (CO_2xs), as fraction of CO_2 from petroleum combustion, natural gas combustion, or the biosphere, in the local contribution to the atmosphere.

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2016

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

Wednesday Morning, May 18, 2016 AGENDA

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

• 07:00 ***Registration Opens in GC-402 - lunch orders collected at registration table***

• 07:30 - 08:15 ***Morning Snacks - coffee, tea, fruit, bagels and donuts served***

• 9:45 - 10:15 ***Morning Break***

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

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2016

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

Wednesday Afternoon, May 18, 2016 AGENDA

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

Relationships Amongst Lower Tropospheric and Column-averaged Aerosol Properties and Composition Measured at the Co-located Appalachian State University NOAA and NASA Monitoring Sites - What Do They Tell Us?

J.P. Sherman[1], M. Link[2] and Y. Zhou[3]

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The southeastern U.S. (SE US), home to large warm-season aerosol loading, is one of only a few regions where surface temperatures did not increase in the 20th century (Trenberth, et al., 2007). One of the high-priority tasks recommended (Kahn et al., 2009) to reduce the uncertainty in aerosol radiative effects is to "*Maintain, enhance, and expand the surface observation networks measuring aerosol optical properties for satellite retrieval validation, model evaluation, and climate change assessments"*. Established in 2009, the high-elevation Appalachian Atmospheric Interdisciplinary Research facility(AppalAIR) at Appalachian State University in Boone, NC (36.21°N, 81.69°W, 1080m) is home to the only co-located NOAA-ESRL, NASA AERONET, and NASA MPLNET aerosol monitoring sites in the SE US and is only one of two such sites in the entire U.S.. Sub-1μm aerosol chemical composition was also measured during summers 2012-2013 and winter 2013 (Link et al., 2015). However, sampling differences introduce significant challenges when trying to integrate the various aerosol datasets. Relationships amongst the aerosol properties can in some cases be used to estimate aerosol properties when only a subset of the measurements are available. In this initial study, we develop simple linear models relating lower tropospheric aerosol optical properties (AOPs), column-averaged AOPs, and aerosol chemical composition measured at AppalAIR over multiple years. We apply the model results to answer the following questions: (1) What information do these simple relationships give us about the aerosols? (2) How well do the lower tropospheric aerosol optical properties track those of the column-averaged aerosols? (3) Can any AOP measurements be used as a proxy for organic and sulfate concentrations and mass fractions and vice versa? The results have implications for sites where only a subset of the aerosol measurements are available, in addition to evaluating chemical transport models and developing satellite-based aerosol classification schemes.

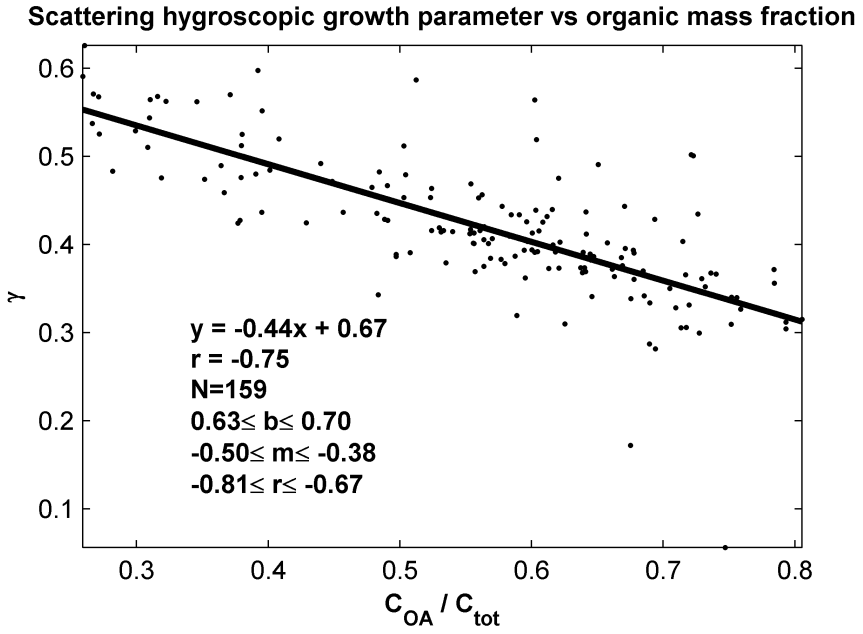

Figure 1. Linear model y=mx+b of daily-averaged sub-1μm aerosol scattering hygroscopic growth factor ϒ versus sub-1μm organic aerosol mass fraction. The ranges of linear model parameters encompass 95% confidence intervals

A Comprehensive Climatology of Arctic Aerosol Properties on the North Slope of Alaska

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[2]NOAA Earth System Research Laboratory, Physical Sciences Division (PSD), Boulder, CO 80305
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Evaluating aerosol properties has implications for the surface radiation budget and the formation of clouds in the Arctic, resulting in impacts on cloud lifetime, precipitation processes, and radiative forcing (Figure 1). There are many remaining uncertainties and large discrepancies regarding modeled and observed Arctic aerosol properties, illustrating the need for more detailed observations to improve simulations of Arctic aerosol and more generally, projections of the components of the aerosol-driven processes that impact Arctic climate. Here, we present a comprehensive, long-term record of aerosol observations from the NOAA North Slope of Alaska site at Barrow. These measurements include total mass and number concentrations, chemical composition, particle size distributions, and optical property measurements. Aerosol extinction and number concentration measurements extend back to 1976, while the remaining measurements were implemented since. Corroboration between the ground-based chemical, physical, and optical property measurements is evident during periods of overlapping observations, demonstrating the reliability of the measurements. During the Arctic Haze in the winter/spring, high concentrations of long-range transported submicron sea salt, mineral dust, industrial metals, pollution (non-sea salt sulfate, nitrate, ammonium), and biomass burning species are observed concurrent with higher concentrations of particles with sizes that span the submicron range, enhanced absorption and scattering coefficients, and largest Ångström exponents. The summer is characterized by high concentrations of small biogenic aerosols (< 100 nm) and low extinction coefficients. Fall is characterized by clean conditions, with supermicron sea salt representing the dominant aerosol type supporting the highest single scattering albedos. In addition to evaluating the aerosol properties themselves, linkages between aerosol source and cloud ice water content in single layer mixed phase clouds are investigated during the winter/spring haze season, when the large influence from transported aerosols have the greatest potential to influence cloud formation. When used in unison, this complete set of aerosol and cloud measurements can be used to improve our knowledge of the climatic impact and characteristics of aerosols found in the Arctic.

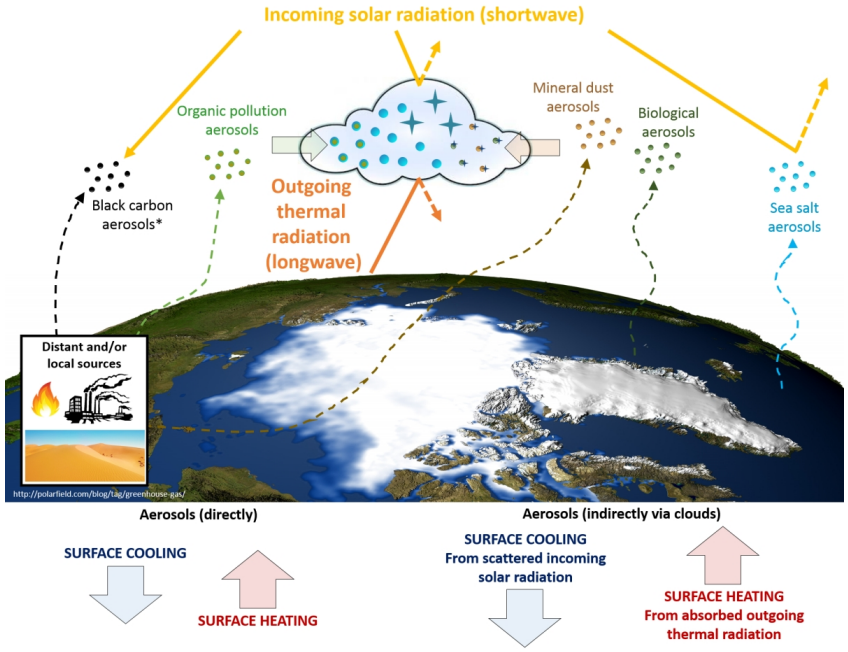

Figure 1. Conceptual schematic of potential aerosol impacts on Arctic sea ice cover. The surface heating (cooling) would enhance (inhibit) sea ice reduction. *Note that black carbon absorbs shortwave radiation, heating the air surrounding it. Depending on its proximity to the surface, the magnitude of warming it induces at the surface is likely a function of its altitude. Mineral dust and organic aerosols can both scatter and absorb shortwave radiation, depending on their particle composition.

Gaseous Elemental Mercury Measurements at GMD Barrow and the 2015 Arctic GEOTRACES Cruise to the North Pole

S. Brooks[1], R. Mason[2], C. Moore[3] and B. DiMento[2]

[1]University of Tennessee Space Institute, Tullahoma, TN 37388; 931-571-0372, E-mail: sbrooks@utsi.edu
[2]University of Connecticut, Avery Point Campus, Groton, CT 06340
[3]Gas Technology Institute, Des Plaines, IL 60018

Gaseous elemental mercury (Hg^o) in the near-surface air was monitored at the Global Monitoring Divison (GMD) Barrow Observatory and on the U.S. Coast Guard icebreaker Healy (2015 Arctic GEOTRACES cruise Dutch Harbor – North Pole – Barrow - Dutch Harbor) from August to October 2015. In addition, dissolved Hg^o in the near-surface seawater was continuously monitored on the ship. Atmospheric Hg^o concentrations at Barrow averaged 1.21 ng m^{-3} with a standard deviation of 0.08 ng m^{-3}, while shipboard values were 1.25 and 0.11 ng m^{-3}, respectively. During the 48 hours centered on the ship's closest approach to Barrow (~100 km), the averages were 1.21 (Barrow) and 1.18 (Ship) ng m^{-3}, a mere ~2.5% difference. In comparison, this difference is smaller than the average inter-annual concentration variability at Barrow (1997-2002) and Alert, Nunavut, Canada (A. Steffen, per. comm.). This lack of difference at the two locations indicates that the Barrow Observatory, for this species and time period, was highly representative of the Arctic marine environment. However, 2015 was an anomalous year for Arctic sea ice. February 2015 marked the lowest "maximum" winter ice coverage on record, while ice coverage in September was the 4th lowest on record (National Snow and Ice Data Center).

On the ship the dissolved Hg^o concentrations in the open water were very low suggesting the potential for diffusive Hg^o deposition to the ocean from the atmosphere. The marginal ice zones showed a well-mixed balance of similar Hg^o concentrations between the near surface air and water. However, under contiguous ice during mid-cruise, the results showed that dissolved Hg^o built up such that the concentrations were much higher than found in open water. This difference demonstrated that the contiguous ice was effectively a "lid" that limited gas exchange. Regional comparisons of Hg^o concentrations, to place the measurements near the sea ice into perspective, would not have been possible without the measurements at the Barrow Observatory. The instrument at Barrow was a newer Tekran model 2537x that allowed remote control and data up/down-loading.

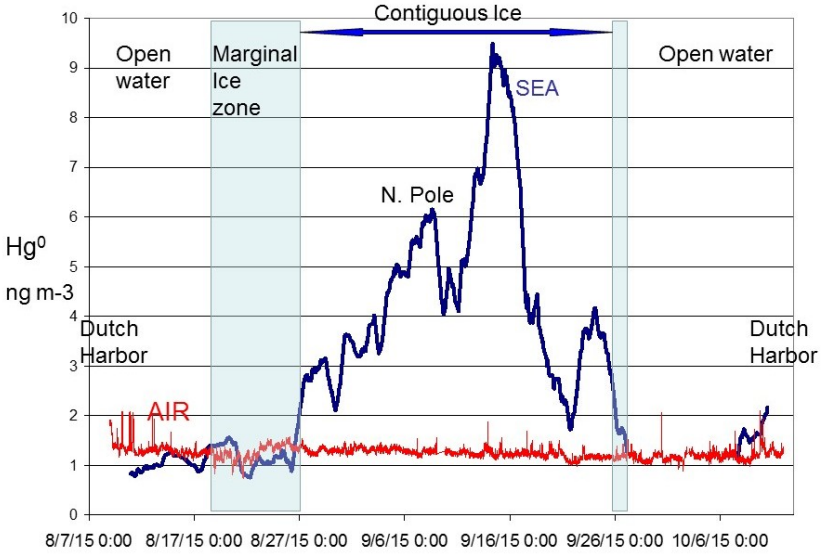

Figure 1. Ship concentrations of Hg^o in the atmosphere and surface water, indicating where the water concentrations are subsaturated or supersaturated. As can be seen, dissolved Hg^o was highest (supersaturated) under the contiguous ice surrounding the north pole.

Observations, Ray-tracing, and Data Assimilation in the Assessment of Aerosols

S. Albers[1,2], Y. Xie[2] and Z. Toth[2]

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By tracing rays from natural (Sun, Moon, and other astronomical objects) and artificial (city) light sources and assessing how they are affected by the atmosphere, aerosols, and land / ocean surface, full-color visually realistic images of the environment can be created based on 3D Numerical Weather Prediction (NWP) analyses or model forecasts. Simulated Weather IMagery (SWIM) can be compared with observed images (camera or other photometric measurements) to (1) validate existing ray tracing and NWP analyses / forecast algorithms, or (2) assimilate observed images affected by atmospheric, aerosol, and surface variables into numerical analyses (NWP Data Assimilation, DA).

As for (1), in clear daytime skies, radiance patterns depend on the aerosol optical depth (AOD, see Fig. 1) and size distributions. The appearance of the sky during twilight, on the other hand, is most sensitive to the presence of stratospheric aerosols. Other relationships and observation platforms will be discussed in the presentation.

Since aerosols affect both simulated and observed weather images, we will use DA techniques to synthesize all aerosol related observational information into analysis states expanded by aerosol related "control" variables. AOD, scale height, single scattering albedo, and other aerosol parameters that are currently manually prescribed using a subjective estimation of visibility will be variationally estimated as 2- or 3D control variables, influenced by aerosol related observations (e.g., camera, photometer, LIDAR, AERONET, aerosonde, satellite) and a "first guess" forecast from an aerosol resolving numerical model such as GSD's WRF- or FIM-Chem.

Figures below show simulated (top) and observed (camera, bottom) weather images as seen from the top of the Boulder, CO DSRC building.

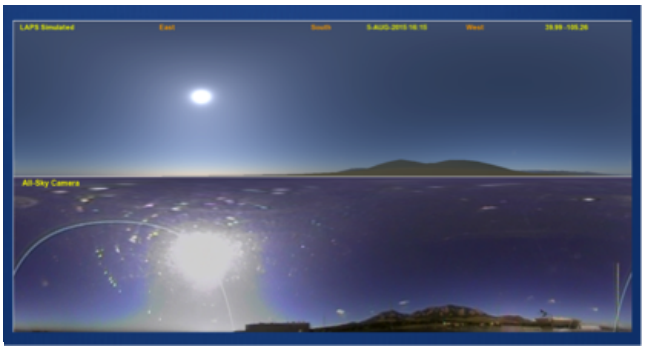

Figure 1. 16:15 UTC 5 Aug 2015 (AOD ~0.05).

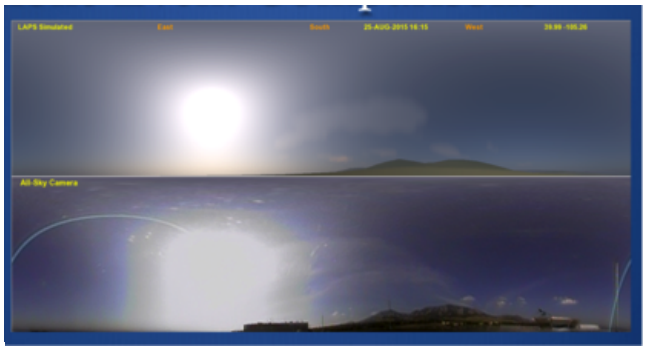

Figure 2. 25 Aug 2015 (right, AOD=0.23).

Analysis of the Diurnal Cycle of Cloud Effects on the Surface Radiation Budget of the SURFRAD Network

C.N. Long[1,2], J.A. Augustine[2] and A. McComiskey[2]

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ESRL/GMD operates a network of seven surface radiation budget sites (SURFRAD) across the continental United States. The SURFRAD network was established in 1993 with the primary objective to support climate research with accurate, continuous, long-term measurements of the surface radiation budget over the United States. The data from these sites have been used in many studies including trend analyses of surface solar brightening (Long et al, 2009; Augustine and Dutton, 2013; Gan et al., 2015). These studies have focused mostly on long term aggregate trends. We will present studies that take a closer look across the years of the cloud influence on the surface radiation components partitioned by seasonal and diurnal analyses.

Augustine, John A. and Ellsworth G Dutton, (2013), Variability of the surface radiation budget over United States from 1996 through 2011 from high-quality measurements, Journal of Geophysical Research, 118, DOI: 10.1029/2012JD018551

Gan, C.-M., Pleim, J., Mathur, R., Hogrefe, C., Long, C. N., Xing, J., Wong, D., Gilliam, R., and Wei, C.: Assessment of multi-decadal WRF-CMAQ simulations for understanding direct aerosol effects on radiation "brightening" in the United States, Atmos. Chem. Phys. Discuss., 15, 17711-17742, doi:10.5194/acpd-15-17711-2015, 2015.

Long, C. N., E. G. Dutton, J. A. Augustine, W. Wiscombe, M. Wild, S. A. McFarlane, and C. J. Flynn (2009): Significant Decadal Brightening of Downwelling Shortwave in the Continental US, JGR, 114, D00D06, doi:10.1029/2008JD011263.

Figure 1. Graphic illustration of overall relative surface downwelling all-sky shortwave brightening trends at the U.S. SURFRAD and ARM sites from 1996 through 2007 (Long et al., 2009).

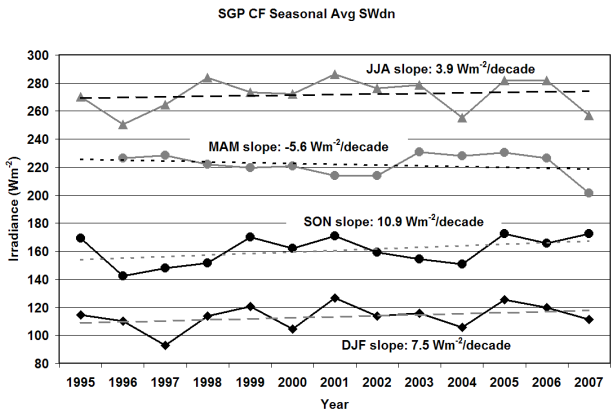

Figure 2. Seasonal trends in yearly average downwelling shortwave at the ARM U.S. site from 1996 through 2007 (Long et al, 2009).

A Long-term Study of Aerosol–cloud Interactions and Their Radiative Effect at a Mid-latitude Continental Site Using Ground-based Measurements

E.T. Sena[1], A. McComiskey[2] and G. Feingold[3]

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Empirical estimates of the microphysical response of cloud droplet size distribution to aerosol perturbations are commonly used to constrain aerosol–cloud interactions in climate models. Instead of empirical microphysical estimates, here macroscopic variables are analyzed to address the influences of aerosol particles and meteorological descriptors on instantaneous cloud albedo and radiative effect of shallow liquid water clouds. Long-term ground-based measurements from the Atmospheric Radiation Measurement Program over the Southern Great Plains are used. A broad statistical analysis was performed on 14 years of coincident measurements of low clouds, aerosol, and meteorological properties. Two cases representing conflicting results regarding the relationship between the aerosol and the cloud radiative effect were selected and studied in greater detail. Microphysical estimates are shown to be very uncertain and to depend strongly on the methodology, retrieval technique, and averaging scale. For this continental site, the results indicate that the influence of aerosol on shallow cloud radiative effect and albedo is weak and that macroscopic cloud properties and dynamics play a much larger role in determining the instantaneous cloud radiative effect compared to microphysical effects.

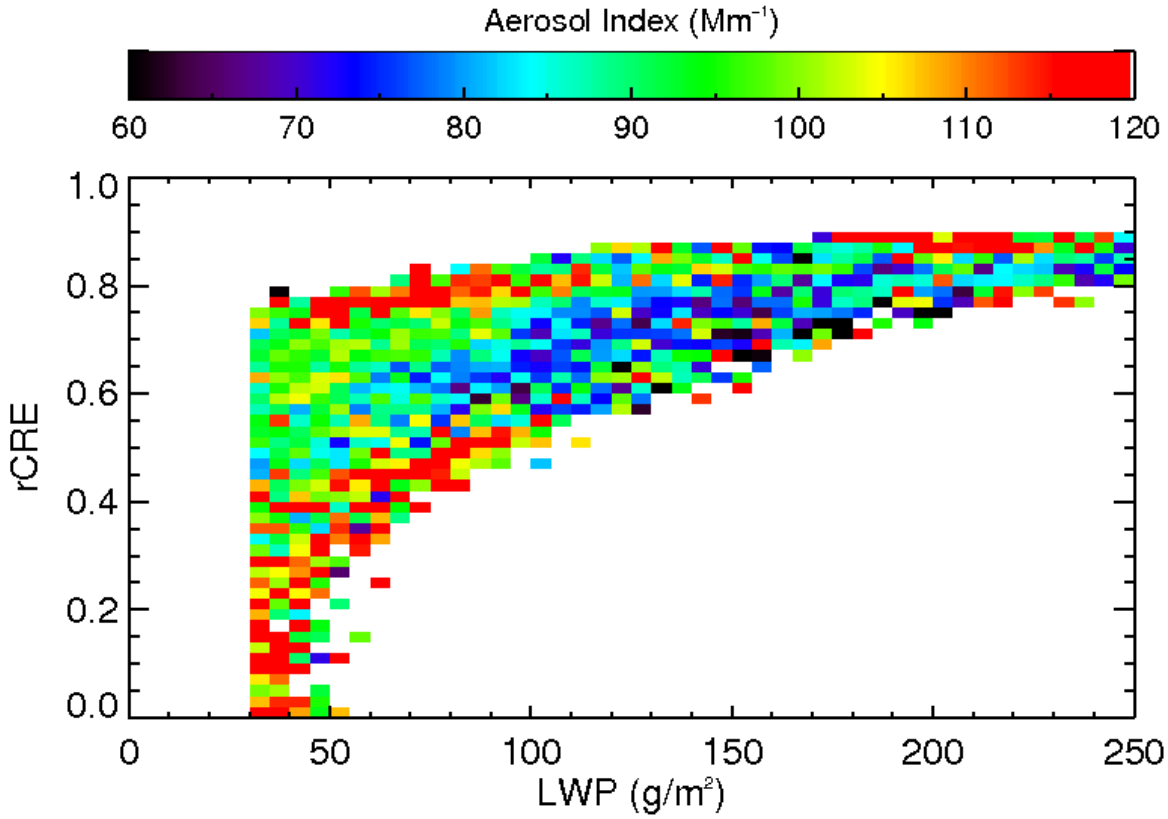

Figure 1. Relative cloud radiative effect (rCRE) as a function of liquid water path (LWP) colored by 14-year averaged aerosol index (A_i) observed for low clouds at the Southern Great Plains, Oklahoma.

On the Uneven Decline of Atmospheric CFC-11: Bumps in the Road to Ozone Recovery or Variations in Atmospheric Transport and/or Loss?

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Atmospheric mole fractions of the ozone-depleting and greenhouse gas CFC-11 have declined since 1995 owing to global controls on production associated with the fully adjusted and amended Montreal Protocol on Substances that Deplete the Ozone Layer. From 2002 to 2012, CFC-11 mole fractions decreased at a near-constant rate of 2.2 ± 0.2 ppt/yr in both the northern and southern hemisphere. Since 2012, however, a substantial slow-down in the atmospheric decline of CFC-11 has been observed by three quasi-independent techniques at NOAA/GMD (the 2013 to 2015 rate was –1.3 ± 0.1 ppt/yr), with the slow-down being most prominent in the northern hemisphere. Given that global production of CFC-11 has been essentially zero since 2007, it seems improbable that this anomaly is due to increased emissions. Here we will explore this possibility, as well as the possibility that variations in transport (or in loss rates as captured by surface observations) might explain the slower decline. Preliminary analyses with an idealized model suggest that the mass flux of CFC-11 from the stratosphere to the troposphere was anomalously low during 2014. Does this transport-related anomaly explain the anomalous rates in 2014 and does it persist through 2015? Or, do the observations provide irrefutable evidence of a significant increase in global CFC-11 emissions since 2013?

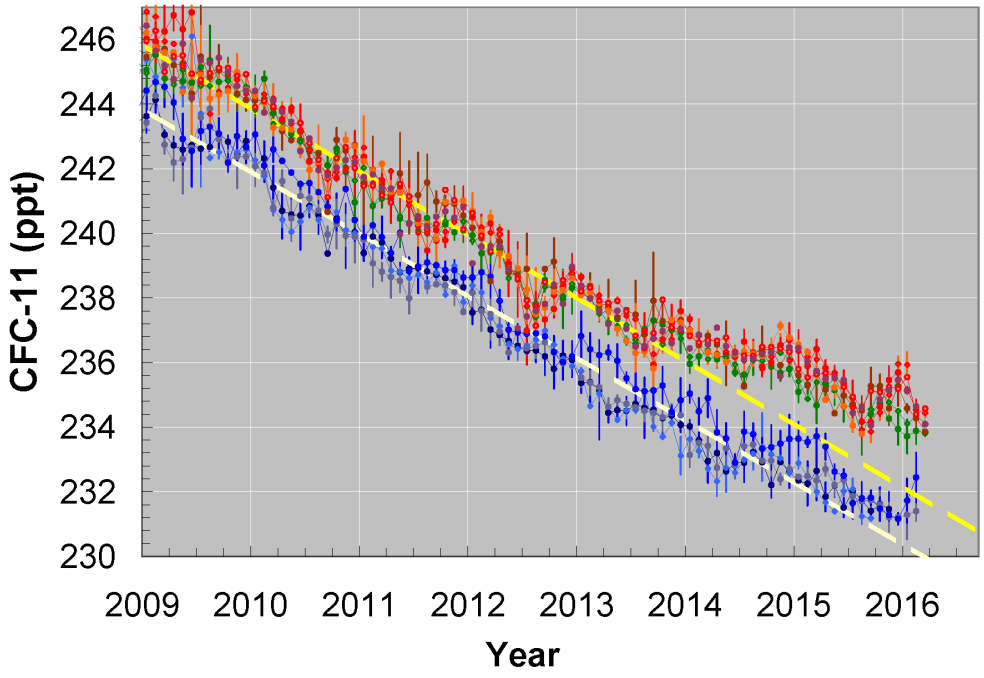

Figure 1. Monthly mean mole fractions of CFC-11 at northern hemispheric sites (red and green points) and southern hemispheric sites (blue points) since 2009 as measured from flasks by gas chromatography with mass spectrometry detection. Bold dashed lines are fits to hemispheric means from decade between 2004 and 2013 (yellow dashed line for northern and white dashed line for southern hemispheres) and are extrapolated through 2016.

Sulfur Hexafluoride Lifetime Adjustment Based on Measured Loss in the Stratospheric Polar Vortex

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The current best estimate of the atmospheric lifetime of sulfur hexafluoride (SF_6) is 3200 years (Ravishankara et al., 1993). This lifetime, as for other long-lived trace gases, is dependent on estimated transport through the region where rapid loss occurs. In this study we use *in situ* measurements in the polar vortex, where the entire mesosphere is descended each winter, to sample air with extensive SF_6 loss and calculate an SF_6 lifetime based on the observed loss. The measurements were taken in the winter of 1999-2000, during which the vortex was relatively undisturbed so that we sampled mesospheric air in the vortex from 16 to 32 km altitude. Comparison of these measurements with output from the Whole Atmosphere Community Climate Model (WACCM) show large differences with very little SF_6 loss in the modeled polar vortex. However, comparisons between other trace gases in the vortex with mesospheric production or loss, such as carbon monoxide (CO) and hydrogen gas (H_2), show very close agreement, suggesting WACCM transport into the vortex is accurate and an SF_6 loss mechanism is missing in the model. Based on the measurements and estimates of the size of the vortex, we calculate an SF_6 lifetime of 800 years with an uncertainty range from 580-1150 years. This estimate is considered an upper limit since our calculation does not include mesospheric air that left the vortex before we sampled it as well as mesospheric air that descended outside the vortex into the stratosphere. Based on this revised lifetime the global warming potential of SF_6 will decrease only slightly for short time horizons (up to 5% for < 100 years), but will decrease substantially for long time horizons (50-75% for > 2000 years).

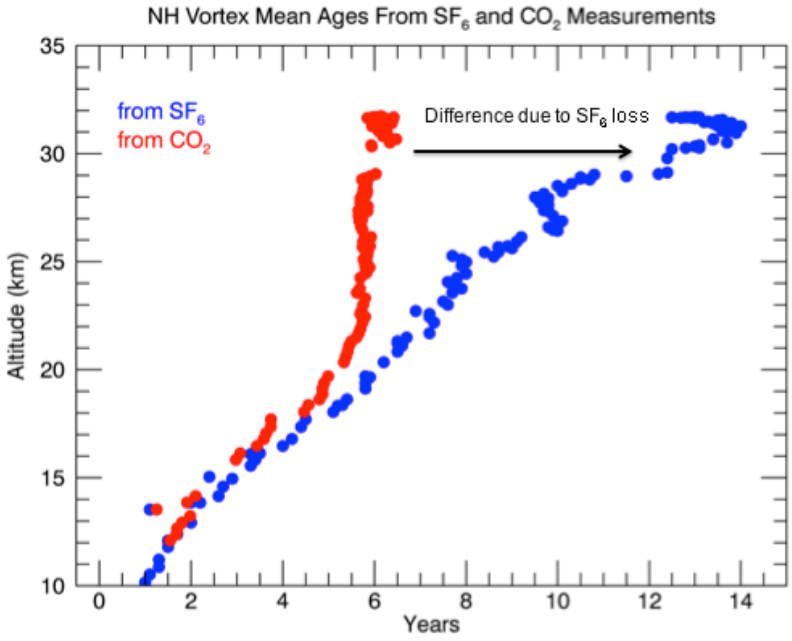

Figure 1. Profiles of mean age of air in the Northern Hemisphere polar vortex based on *in situ* measurements of SF_6 and CO_2 from a balloon flight at 67°N on March 5, 2000.

Variabilities of Atmospheric HCFCs and HFCs Over the United States and Their Implied Emissions for the Years of 2008 – 2014

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Hydrochlorofluorocarbons (HCFCs) are transitional substitutes for chlorofluorocarbons (CFCs) with relatively lower ozone depleting potentials. The consumption of HCFCs has been controlled under the Montreal Protocol since 1996. By 2014, the consumption of HCFCs within the U.S. had declined by roughly 90% relative to its peak during 1998 – 2002. Hydrofluorocarbons (HFCs) were initially considered as long-term substitutes for both CFCs and HCFCs. Although they do not deplete stratospheric ozone, they are potent greenhouse gases. In this study, we have analyzed atmospheric data of HCFCs and HFCs from more than 20 ground-based, tall towers, and aircraft sites within the U.S., for the period of 2008 – 2014 when uses of HCFCs were phasing down and applications for some HFCs underwent rapid expansion. These atmospheric observations show continued increases in background atmospheric mole fractions of HCFCs, but considerable decreases in enhanced mole fractions observed in the U.S. boundary layer relative to the remote atmosphere (Figure 1). In the meantime, significant increases have been observed over the U.S. in the enhancements of certain HFCs (HFC-125, HFC-143a, HFC-32, HFC-365mfc and HFC-227ea) that are used as replacements for HCFCs (Figure 1). The magnitudes of their relative increases in the atmospheric enhancements seem to be consistent with the relative increases of reported emissions of HFCs by the U.S. Environmental Protection Agency (EPA) Greenhouse Gas Inventory (GHGI) over a similar period. In this presentation, we will further discuss emission estimates of HCFCs and HFCs derived from inverse modeling of these atmospheric observations and compare them with emissions reported by the EPA's GHGI.

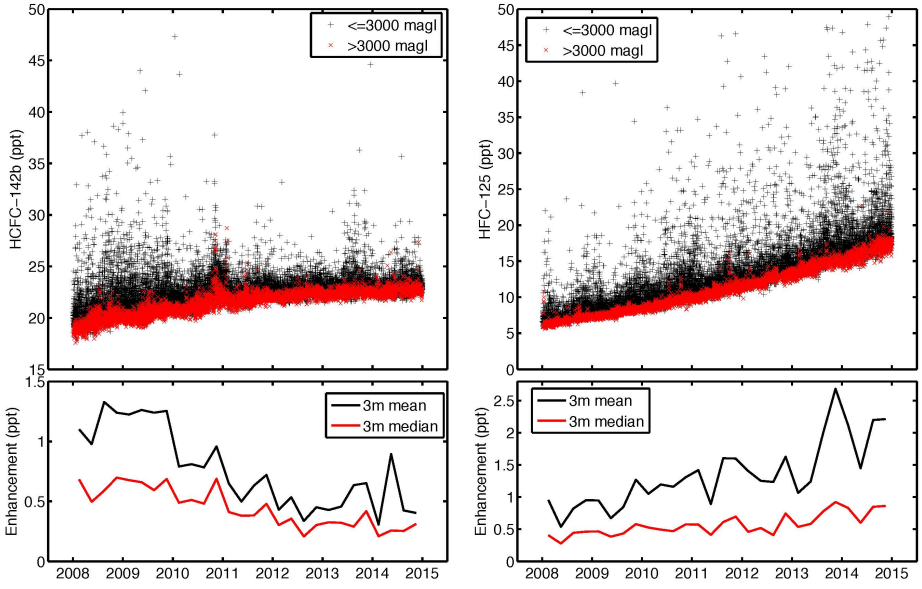

Figure 1. Observed atmospheric mole fractions of HCFC-142b (upper left) and HFC-125 (upper right) within 3000 magl (black) and above 3000 magl (red) at sites in the contiguous U.S.. The three-monthly mean (black) and median (red) enhancements for observations made within 3000 magl relative to the free troposphere (3000 – 6000 magl) are shown in the bottom panels for HCFC-142b (bottom left) and HFC-125 (bottom right).

Tropospheric Observations of CFC-114 and CFC-114a

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Chlorofluorocarbons (CFCs) are well known for their involvement in depleting stratospheric ozone and also their direct role in climate change as highly efficient greenhouse gases. Within the family of CFCs, one compound has received little attention in the literature, namely CFC-114 ($C_2Cl_2F_4$). Of particular interest here is the differentiation between CFC-114 (CF_2ClCF_2Cl) and its isomeric form CFC-114a (CF_3CFCl_2) as atmospheric measurements so far have been assumed to represent the sum of both isomers. This study has quantified CFC-114 and CFC-114a in unpolluted samples collected at Cape Grim, Australia and their changing concentrations from 1978 to 2014 have been determined. For CFC-114, the mixing ratio has doubled from 7.9 to 14.8 ppt and the mixing ratio of CFC-114a trebled from 0.35 to 1.03 ppt. Mixing ratios of both isomers were no longer increasing significantly at the end of that record, which agrees with aircraft observations of insignificant interhemispheric mixing ratio gradients. However we find that the fraction of CFC-114a mixing ratio relative to that of CFC-114 increased from 4.3% to 6.9% over the 37-year period. This is not in agreement with the current assumption that both isomers have been largely co-emitted. Complementary ground-based observations from air extracted from deep polar firn as well as from air samples collected in Taiwan support this hypothesis with the latter pointing toward a persisting source of CFC-114a in East Asia. We also present top-down global annual emission estimates of CFC-114 and CFC-114a derived from these measurements and a two-dimensional atmospheric chemistry-transport model. In general, the emissions for both compounds grew steadily during the 1980s, followed by a substantial reduction from the late 1980s onwards, which is consistent to the reduction of emission in response to the Montreal Protocol. However, we infer that emissions of both isomers remain in 2014. Moreover changes to the ratio of emissions of the two isomers since the 1990s confirm that the sources of the two gases are partly unrelated. In addition, our model-derived annual emissions were also compared with published emission inventories where available.

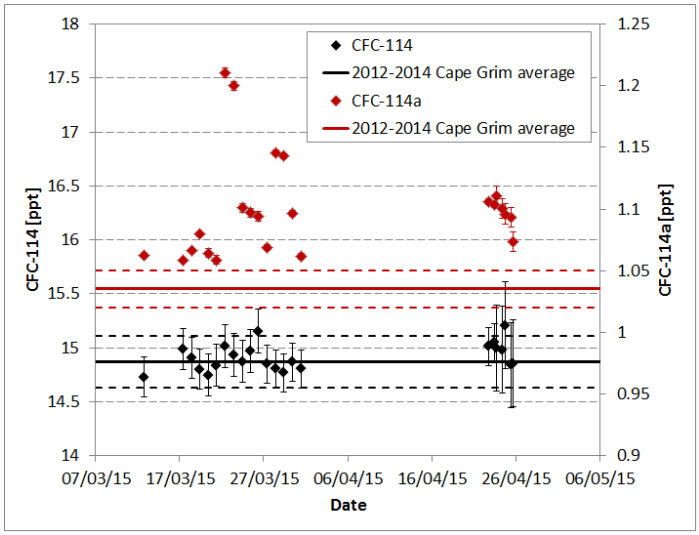

Figure 1. Mixing ratios of CFC-114 and CFC-114a from samples collected during a ground-based campaign near Hengchun, Taiwan in early 2015 (diamonds) in comparison to mixing ratios observed at Cape Grim averaged from 2012 to 2014 (lines).

Histories of Halogenated Strong Greenhouse Gases from Ice Cores, Deep Firn and Air Archive Records

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Air extracted from ice cores and from firn offer the means to study the gaseous composition of the atmosphere before the time of instrumental records or "archiving" of whole air samples. We have examined a variety of halocarbons in ice from Law Dome, Antarctica, and in firn from several polar locations. Very high sensitivity techniques are required to determine halocarbon abundances in ice cores, as typically only a few tens of cm^3 of air can be extracted from each sample. Using a magnetic field sector mass spectrometer we are able to measure selected CFCs, halons, SF_6, and perfluorocarbons (PFCs) in the ice at sub-pmol mol^{-1} abundances. A unique feature of the ice drilling location at Law Dome is the high snow accumulation rate, and therefore narrow distribution of ages in air extracted from firn and ice, enabling relatively short-term (multi-year) features to be observed. After surveying a number of species measured in ice and firn, we then report on three of the PFC species (CF_4, C_2F_6, C_3F_8) measured in glacial and also in archived air (Cape Grim, Tasmania). Using two independent firn diffusion models, and an atmospheric inversion calculation, it was possible to reconstruct continuous histories of these gases from the early 20th century to 2014. We were able to confirm that CF_4 has a natural emission flux, whereas this is undetectable for the other two gases. Emissions of CF_4 and C_2F_6 exhibited a peak during WWII, doubtless associated with wartime aluminium production, followed by sustained increases post 1960 to annual emission rates that dwarfed those observed during the war years. Emission rates for all three gases have, however, declined substantially since at least 2000 (the early 1980s for CF_4). Moreover there has been a large reduction in PFC emissions per kg of aluminium production, presumably due to better management of the production process (this can be determined up to the point when emissions from semiconductor manufacture became important). There is a substantial gap between calculated "bottom-up" emissions based on inventory estimates, and "top-down" estimates based on these reconstructed histories.

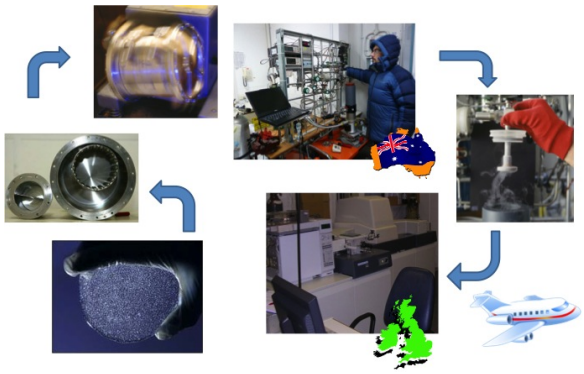

Figure 1. Air trapped in bubbles in glacial ice is extracted with a shaken "cheesegrater" device and collected in cold-fingers at ~10K at the CSIRO-CMAR laboratories in Melbourne, Australia, and subsequently analysed at UEA in Norwich, UK with a gas chromatograph/tri-sector mass spectrometer combination.

Sources and Abundance of Inorganic Bromine and Iodine in the Tropical Transition Layer: Constraints from Recent DOAS Aircraft Observations of Bromine Oxide (BrO) and Iodine Oxide (IO)

R. Volkamer[1], T. Koenig[1], B. Dix[1], E. Apel[2], E. Atlas[3], R. Salawitch[4], L. Pan[2], S. Baidar[1] and the TORERO and CONTRAST Science teams

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The tropical free troposphere is a key atmospheric environment to understand chemistry-climate interactions. About 75% of the tropospheric ozone (O_3) and methane (CH_4) loss occurs at tropical latitudes. There is a particular need to understand the emissions and chemistry of tropospheric halogens in pristine remote environments, because they influence the reactive chemical removal pathways of climate active gases, and can modify aerosols that affect Earth's radiation balance.

Recently, field measurements over the remote tropical Eastern Pacific ocean have shown that tropospheric halogen chemistry has a larger capacity to destroy O_3 and oxidize atmospheric mercury than previously recognized. Halogen chemistry is currently missing in most global and climate models, and helps explain the low O_3 levels in preindustrial times (Volkamer et al., 2015; Wang et al., 2015). These aircraft measurements help resolve a long standing conundrum in the tropospheric bromine oxide (BrO) column abundance between satellites and balloon profiles, and highlight the importance of heterogeneous bromine recycling on aerosol and ice surfaces. They also provide vertical profiles of iodine oxide (IO) to evaluate models for I_y in the troposphere (Sherwen et al., 2016), and estimate iodine injections into the stratosphere (Saiz-Lopez et al., 2015). This presentation reviews the available evidence whether inorganic sources of halogens influence the composition of the tropical free troposphere, and possibly need to be considered for modeling of the Ozone layer.

Figure 1. The University of Colorado Airborne MAX-DOAS instrument telescope mounted below the wing of the NSF/NCAR GV aircraft is being serviced by CU graduate student Sunil Baidar. The instrument measured sub-pptv concentrations of BrO and IO radicals directly in the open atmosphere, spanning altitudes from the tropical Marine Boundary Layer (MBL) into the tropical transition layer (TTL), and the sub-tropical lower stratosphere (LS) during the TORERO and CONTRAST field campaigns.

N_2O emissions Estimated with the Carbon Tracker Lagrange North American Regional Inversion Framework

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The Carbon Tracker Lagrange (CTL) regional inversion framework is used to estimate North American nitrous oxide (N_2O) emissions of ~ 1.4 ± 0.4 Tg N/yr in 2012. The CTL framework is a Bayesian method based on footprints from the Stochastic Time-Inverted Lagrangian Transport (STILT) model applied to atmospheric N_2O data from the ESRL/GMD Global Greenhouse Gas Reference Network, including surface, aircraft and tall tower platforms. Nearly half of the North American emissions (including Central America and Canada) are estimated to come from the Midwestern U.S. agricultural belt, and are strongest in spring and early summer, consistent with a synthetic nitrogen (N) fertilizer-driven source. While earlier regional atmospheric inversion studies have suggested that global inventories such as Emission Database for Global Atmospheric Research (EDGAR) may be underestimating U.S. anthropogenic N_2O emissions by a factor of 3 or more, our results, integrated over a full calendar year, are generally consistent with those inventories and with global inverse model results and budget constraints. The CTL inversion results are sensitive to the prescribed boundary condition or background value of N_2O, which is estimated based on a new Empirical Back-Ground (EBG) product derived from STILT back trajectories applied to ESRL/GMD data. Analysis of the N_2O EBG products suggests a significant, seasonally-varying influence on surface N_2O data due to the stratospheric influx of N_2O-depleted air.

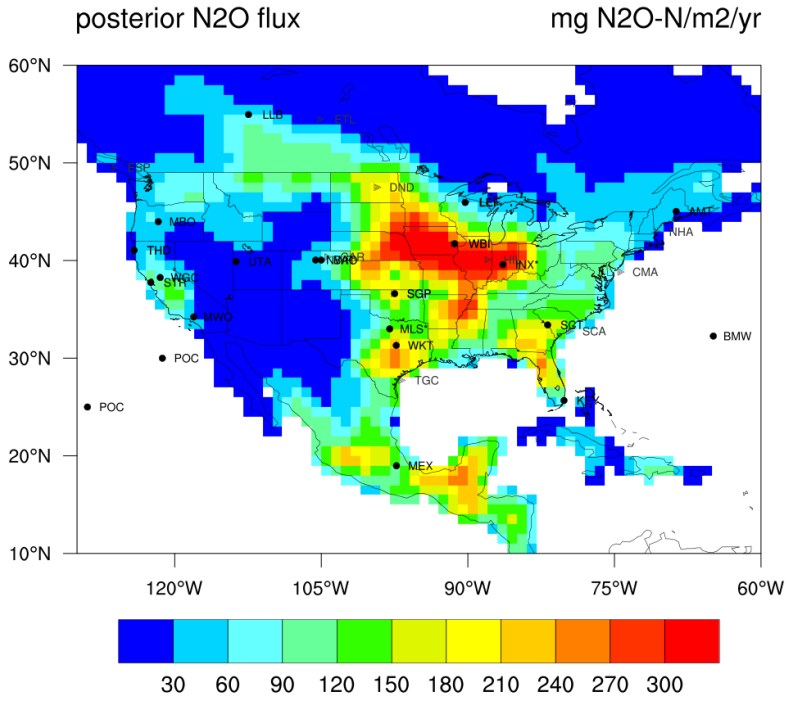

Figure 1. Posterior annual mean N_2O emissions for 2012 estimated with the CTL regional inversion framework. The locations of ESRL/GMD surface and aircraft data used in the inversion are superimposed as black circles and grey triangles, respectively. Mobile surface sites are indicated with asterisks.

SPARC Water Vapour Assessment II

K.H. Rosenlof[1], D. Hurst[2,3] and the SPARC WAVAS team

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The goals of Stratosphere-troposphere Processes And their Role in Climate Water Vapor Assessment II (SPARC WAVAS-II) are to 1) provide quality assessment of upper tropospheric to lower mesospheric satellite records since the early 1990s, 2) provide validation against ground-truth instruments, 3) assess inter-instrument biases, depending on altitude, location, and season, 4) assess representation of temporal variations on various scales, 5) include data records on isotopologues, and 6) provide recommendations for usage of available data records and for future observation systems. To achieve these goals, many intercomparisons between satellite profiles and comparisons with ground-based measurements have been undertaken. Upper tropospheric comparisons have also been done, as well as comparisons between derived quantities (such as H_2O tape recorder speed and seasonal cycles). The systematic comparisons between satellite profiles and all the available frost point balloon-borne hygrometers (with NOAA Earth System Research Laboratory [ESRL] Global Monitoring Division [GMD] frostpoint measurements providing a significant fraction of the data used) and ground-based microwave radiometers have never been done before. Goals and preliminary results from the WAVAS-II satellite assessment report will be presented.

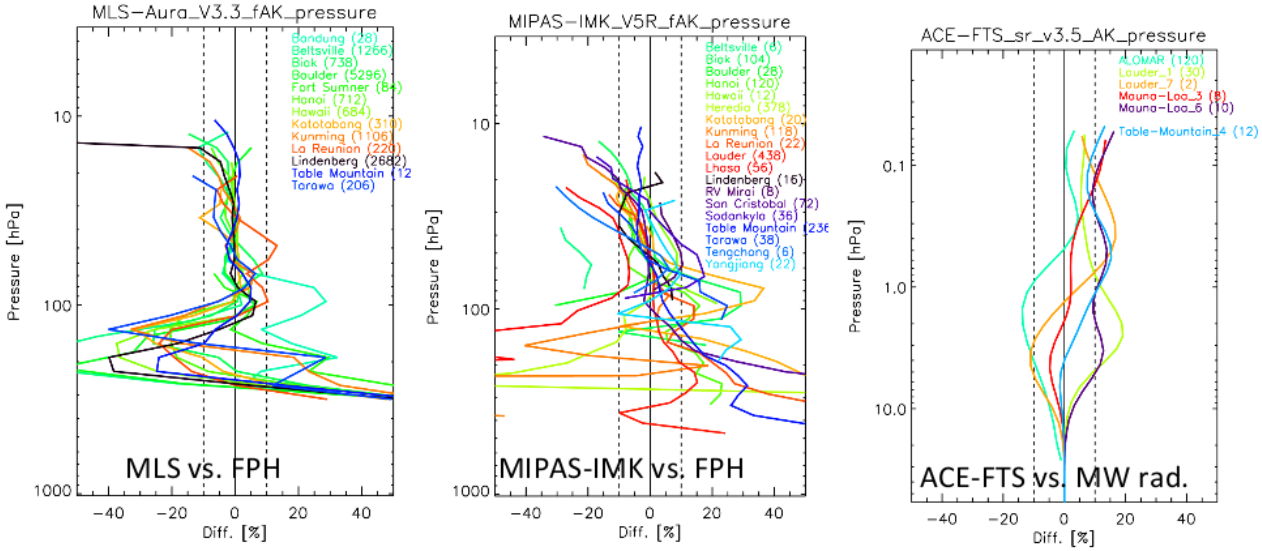

Figure 1. Example of the types of comparisons performed for the SPARC WAVAS-II satellite report. This shows the **M**icrowave **L**imb **S**ounder (MLS) compared with frost point profiles (left panel), the **M**ichaelson **I**nterferometer for **P**assive **A**tmospheric **S**ounding (MIPAS) compared with frost point profiles (center panel) and the **A**tmospheric **C**hemistry **E**xperiment-**F**ourier **T**ransform **S**pectrometer (ACE-FTS) compared with microwave radiometer profiles. The individual stations used are noted on each panel.

Recent Divergences in Stratospheric Water Vapor Measurements by Aura MLS and Frost Point Hygrometers

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Almost every day since August 2004 the Aura Microwave Limb Sounder (MLS) has provided approximately 3500 near-global vertical profile measurements of water vapor from the upper troposphere to well past the stratopause. Long-term agreement between the MLS and balloon-borne frost point hygrometers (FPs) has been excellent until recently. Now there is compelling evidence of divergences in spatiotemporally coincident stratospheric water vapor measurements by MLS and FPs. Time series of FP-MLS differences at 8 stratospheric pressure levels (100-26 hPa) over 5 different FP sites site were analyzed (Figure 1). Statistically significant changepoints were detected in many of the time series of FP-MLS differences, so trends were evaluated using piecewise continuous linear regression. The analysis reveals statistically significant (95% confidence) downward trends in FP-MLS differences during the last 4-6 years. By mid-2015 the stratospheric FP-MLS differences had changed by -0.3 to -0.4 ppm (-7 to -9%) and half of the endpoint differences exceeded the combined accuracy estimates for FPs and MLS. These recent divergences are attributed to increasing wet (high) biases in MLS retrievals, primarily because it is highly unlikely that two different types of FPs (FPH and CFH), independently manufactured and calibrated, are drifting at similar rates at several FP sounding sites.

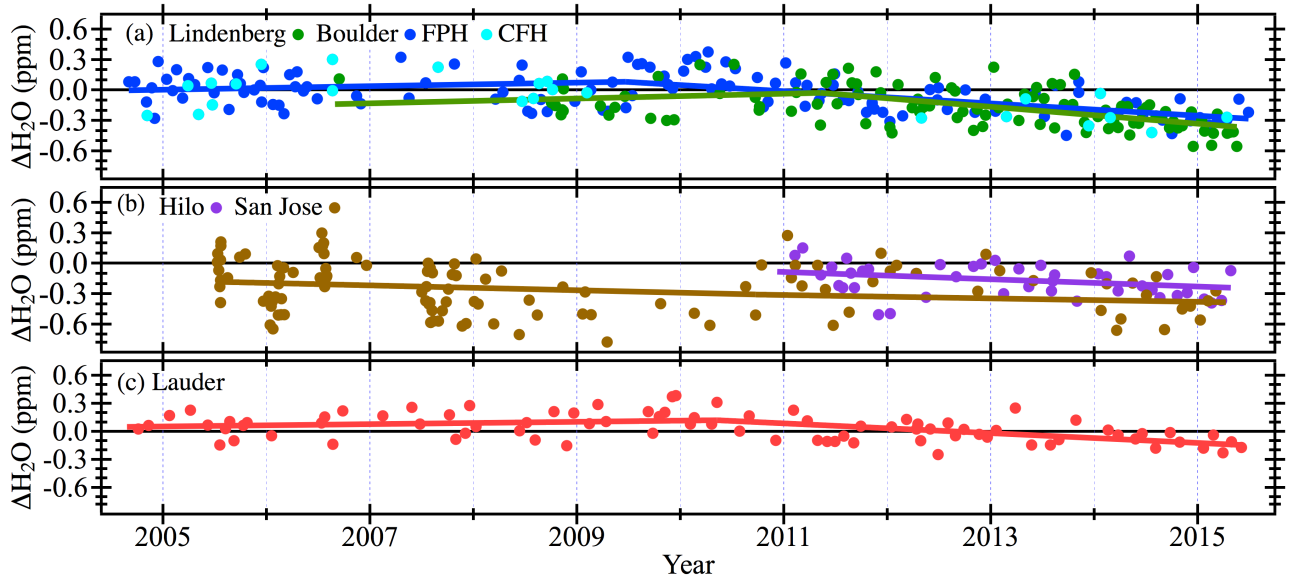

Figure 1. Differences in coincident stratospheric water vapor measurements by frost point hygrometers (FPs) and the MLS at 68 hPa over five FP sites. Trends were determined using piecewise continuous linear regression because statistically significant changepoints were detected.

Do Stratospheric Ozone Measurements Show Large Tropical Width Changes?

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The total column ozone amount varies with latitude, in part due to the difference in tropopause height between the tropics and midlatitudes. This dependency of column ozone on latitude has been exploited by several studies to identify tropical edge latitudes and to compute their trends. The tropical widening trend over the past several decades from this method is greater than 3° latitude decade^{-1}, a rate which is significantly larger than most other tropical widening estimates.

We assess the robustness of the previously used methodology by comparing it to a new objective gradient-based method of total column ozone. The total column ozone methodologies are then compared to a diagnostic based on vertically resolved satellite ozone data from the Stratospheric Water and OzOne Satellite Homogenized (SWOOSH) data set. Our results indicate a general lack of robustness of the previous estimates, and are more in line with other tropical widening estimates indicating poleward expansion rates of < 1° latitude decade^{-1}.

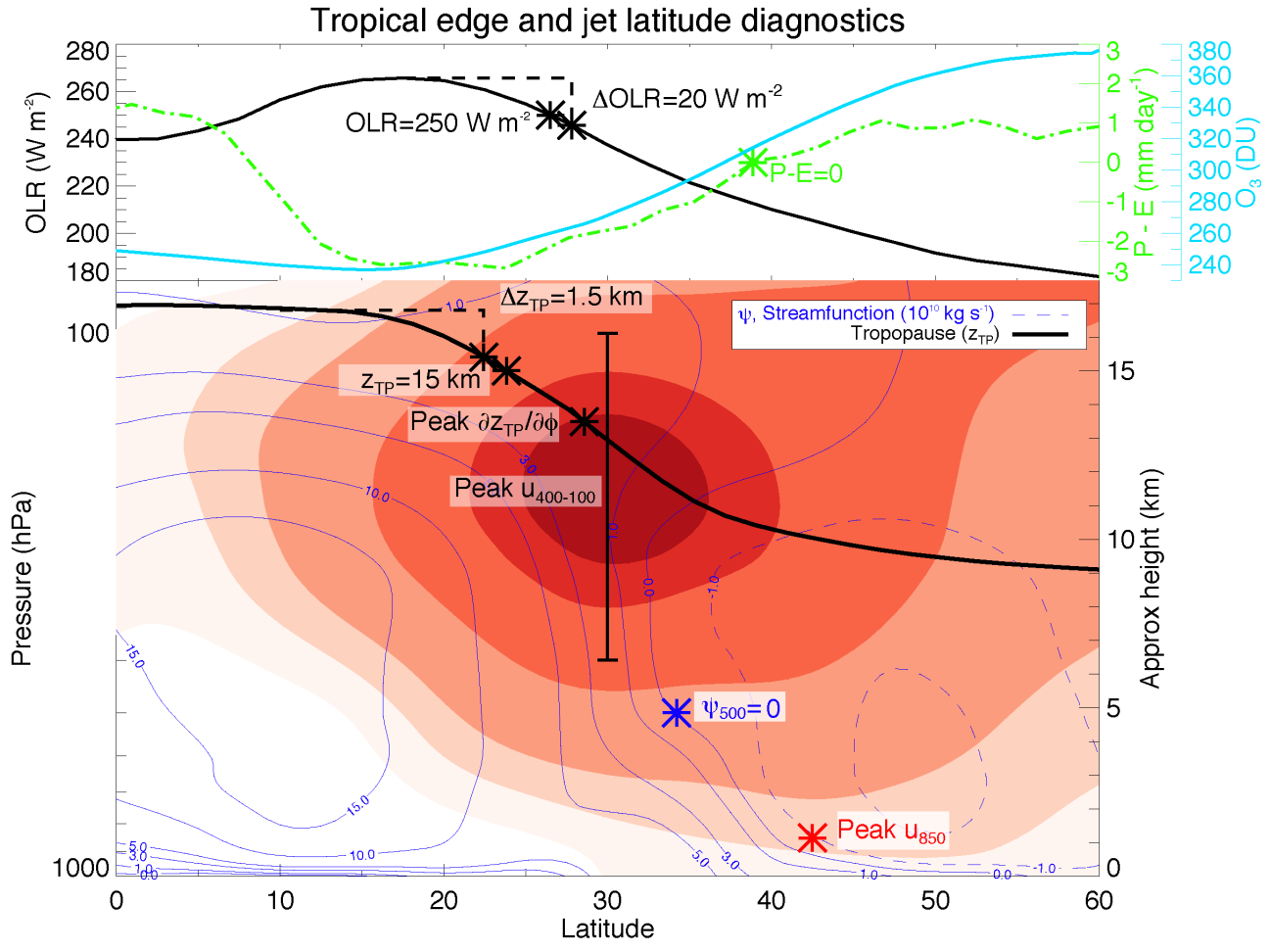

Figure 1. Some of the myriad diagnostics used for identifying the tropical edge latitude, including the total column ozone as a function of latitude used in this study (figure adapted from Davis and Rosenlof, J. Clim., 2012)

Origins of Filaments in Boulder Ozonesonde Data

I. Petropavlovskikh[1,2], B.J. Johnson[2], A. Jordan[1,2], G. Manney[3,4], K. Minschwaner[4], A. Giljum[4] and L.F.M. Valle[5]

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Ozonesonde data launched in June-July 2014 from Boulder, Colorado are analyzed to determine the origins of laminae observed in the upper troposphere/lower stratosphere (UTLS). We use NASA Global Monitoring and Assimilation Office's GEOS-5 data assimilation system products, including Modern-Era Retrospective analysis for Research and Applications (MERRA), interpolated to Boulder, Colorado (40°N, 105°W) to assess incidence of upper tropospheric jets that influence UTLS ozone distribution. Our tools include back trajectory analysis coupled with 4D satellite ozone profile data, including those from NASA's V3.3 Aura Microwave Limb Sounder (MLS) and Ozone Monitoring Instrument (OMI). Filaments causing laminae in ozone profiles observed at Boulder are tracked to origins in either stratospheric or tropospheric intrusions using reverse domain-filling trajectory methods (RDF). The RDF captures many of the filament features, but it only captures the effects of large scale differential transport. A case where RDF misses a feature in the 340-350K altitude is likely related to ozone stratification caused by the gravity waves. In addition, satellite observations indicate that air from the tropical tropopause layer (TTL) can be transported into regions with multiple tropopauses over the middle latitudes in the vicinity of the subtropical jets. Detailed studies of several ozone profiles collected over Boulder in June/July 2014 help with determining techniques for future analysis of a larger dataset that goes back to 1980s. Ozone variability in the UTLS over Boulder is of importance for studies of local climatological ozone conditions, trends and their causes/attribution to the changes in the long-range transport.

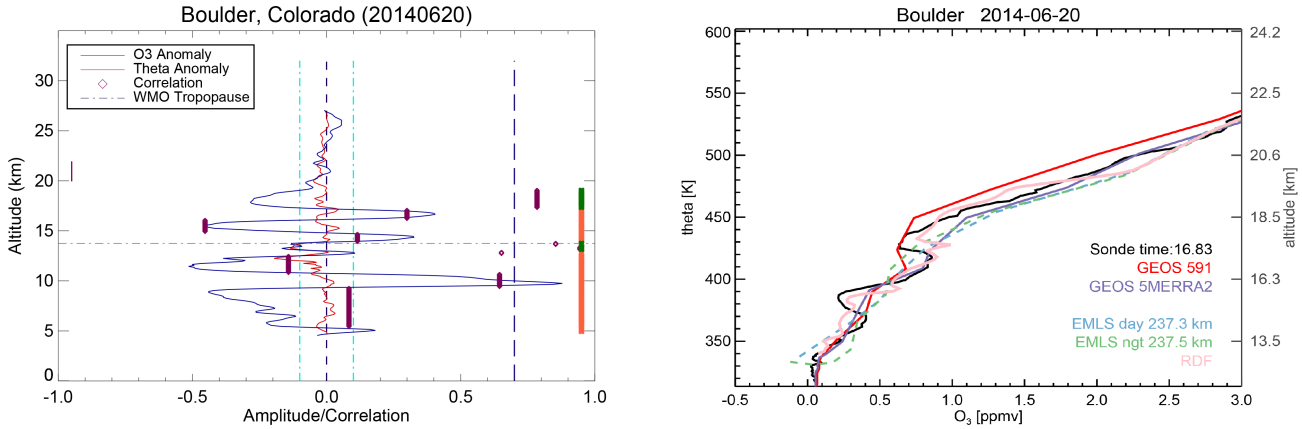

Figure 1. Left panel shows analyses of the ozone and potential temperature lamination (dark blue and red respectively) as recorded by sonde launched on June 20, 2014. Vertical solid bars indicate periods of correlation in measurements (dark red), significance (dashed lines), the impact of STE transport (orange) and gravity waves (green). Panel on the right shows ozone vertical distribution from ozone-sonde (black), GEOS-591 analysis (red), GEOS 5 MERRA2 analysis (purple), MLS ozone profile from Boulder overpass during the day (blue) and night (green), and RDF profile (pink). MERRA analysis indicates formation of a double tropopause over Boulder around 3 UTC on June 19th, which then persists for several days.

Balloon-borne Ozonesonde Profile Measurements at South Pole Station, Antarctica during the 2015 Ozone Hole

B.J. Johnson[1], P. Cullis[2,1], C.W. Sterling[2,1], J. Booth[1], I. Petropavlovskikh[2,1] and G. McConville[2,1]

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Balloon-borne ozonesondes from South Pole Station, Antarctica showed no signs of long-term stratospheric ozone hole recovery in 2015 as total column ozone dropped from 260 Dobson Units (DU) winter average to a minimum of 112 DU on October 15, 2015. This was the 15th lowest minimum in the ESRL/GMD 30-year record. The September ozone loss rate, within the main ozone altitude layer from 14-21 kilometers, also nearly averaged at 3.2 DU/day compared to the 1990-2014 average of 3.4 ± 0.3 DU/day. However, the 2015 ozone hole season was unique in the record number of days the stratospheric vortex air over South Pole remained undisturbed. The slow linear recovery rate of 0.6 DU/day within the 14-21 km layer began on October 15 and ended abruptly on December 8 when total column ozone increased by over 100 Dobson Units to 288 DU. Above 15 km, the high ozone filaments and much warmer stratosphere indicated the late arrival of midlatitude air over South Pole. The 2 km altitude layers also showed an average ozone hole and the slow break up of the 2015 ozone hole at all levels.

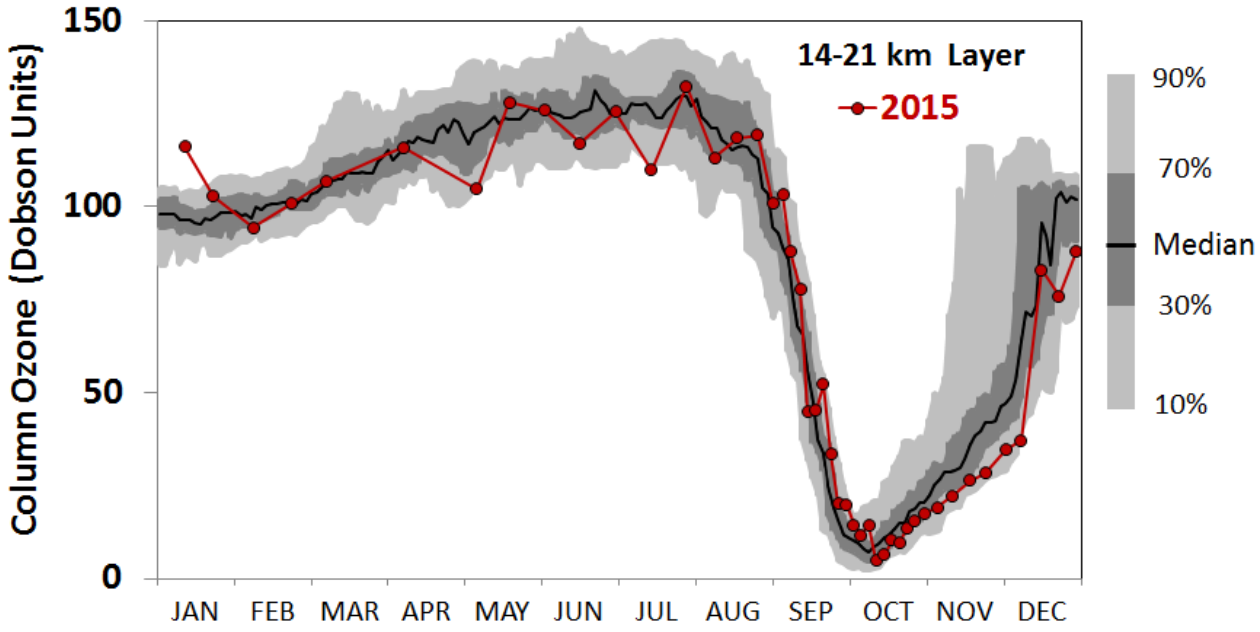

Figure 1. South Pole column ozone within the 14-21 kilometer layer during 2015 (red line) with long term median and percentile envelopes.

Long-term Trends of Tropospheric Ozone Over North America and Southeast Asia

A. Gaudel[1,2], O. Cooper[1,2], B. Hassler[1,2], H. Petetin[3], D. Tarasick[4] and V. Thouret[5]

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Tropospheric ozone is a greenhouse gas and pollutant detrimental to human health and crop and ecosystem productivity. Since 1990 a large portion of the anthropogenic emissions that react in the atmosphere to produce ozone have shifted from North America and Europe to Asia. This rapid shift, coupled with limited ozone monitoring in developing nations, has left scientists unable to answer the most basic questions: Is ozone continuing to decline in nations with strong emission controls? To what extent is ozone increasing in the developing world? In response to these questions this presentation will show results from International Global Atmospheric Chemistry's (IGAC) Tropospheric Ozone Assessment Report, focusing on long-term trends (1994-2014) of tropospheric ozone over North America and Southeast Asia measured by the In-service Aircraft for a Global Observing System (IAGOS) program and by ozonesondes. The study is aimed at evaluating OMI/MLS satellite observations as well as the chemistry-climate models participating in the Chemistry Climate Model Initiative (CCMI) and Task Force on Hemispheric Transport of Air Pollutants (TF-HTAP) experiments that indicate a steady 21st century increase of tropospheric ozone extending from India to western North America.

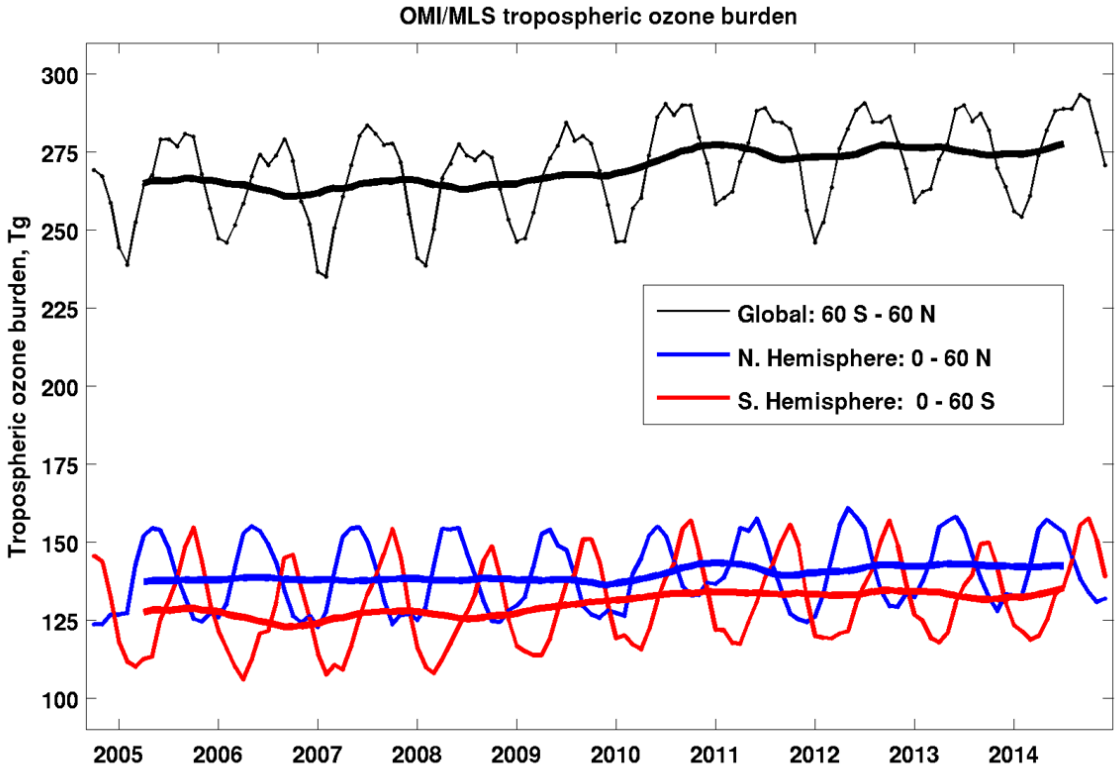

Figure 1. Time series of global tropospheric ozone burden in Tg with Ozone Monitoring Instrument Microwave Limb Sounder (OMI/MLS) dataset for the period 2004-2014.

Methane Emissions from the 2015 Aliso Canyon Blowout in Los Angeles, CA

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[2]University of California at Davis, Davis, CA 95616
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Single-point failures of the natural gas infrastructure can hamper deliberate methane emission control strategies designed to mitigate climate change. The 23 October 2015 blowout of a well connected to the Aliso Canyon underground storage facility in California resulted in a massive release of natural gas. Analysis of methane (CH_4) and ethane (C_2H_6) data from dozens of plume transects from 13 research aircraft flights between 7 Nov 2015 and 13 Feb 2016 shows atmospheric leak rates of up to 60 metric tonnes of CH_4 and 4.5 metric tonnes of C_2H_6 per hour. At its peak this blowout effectively doubled the CH_4 emission rate of the entire Los Angeles Basin, and in total released 97,100 metric tonnes of methane to the atmosphere.

Figure 1. IR camera image of leaking CH_4 plume from Aliso Canyon well SS-25. Image courtesy of Environmental Defense Fund.

Methane Emissions from the Denver-Julesburg Basin of Colorado Estimated by Bayesian Inversion with Five Datasets

W.M. Angevine[1,2], J. Brioude[1,2], S.A. McKeen[1,2], Y.Y. Cui[1,2], T. Campos[3], G. Diskin[4], E.V. Fischer[5], J. Peischl[1,2], C. Sweeney[1,6], G. Petron[1,6], T.B. Ryerson[2] and J. Zaragoza[5]

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Emissions of methane (CH_4) from the Denver-Julesburg Basin of northeastern Colorado are estimated using a Bayesian inversion method. The objectives are to use the broadest possible base of measurements, and to understand uncertainties in the process. Five measurement datasets are used: Flights by a small aircraft in May 2012, the Front Range Air Polution and Photochemistry Éxperiment (FRAPPE') and Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) aircraft campaigns in 2014, measurements from a tall tower also in 2014, and the Shale Oil and Natural Gas Nexus (SONGNEX) aircraft campaign in 2015. The 2012 flights have previously been analyzed using a mass balance method. Combining all results, we find methane emissions of 29±10 t CH_4 h-1 (2.9 ± 1.0x107 g h-1), consistent with mass balance results. The reported uncertainty is dominated by uncertainty in the meteorological fields driving the transport model. A primary reason to use inversion techniques is to allow the use of data like the tall tower and DISCOVER-AQ datasets, which sample the atmosphere in ways that do not allow mass-balance calculations. Tall tower data in particular provide the opportunity to observe long-term trends at reasonable cost. Estimation of trends in emissions will be possible if those trends exceed 40% of the total.

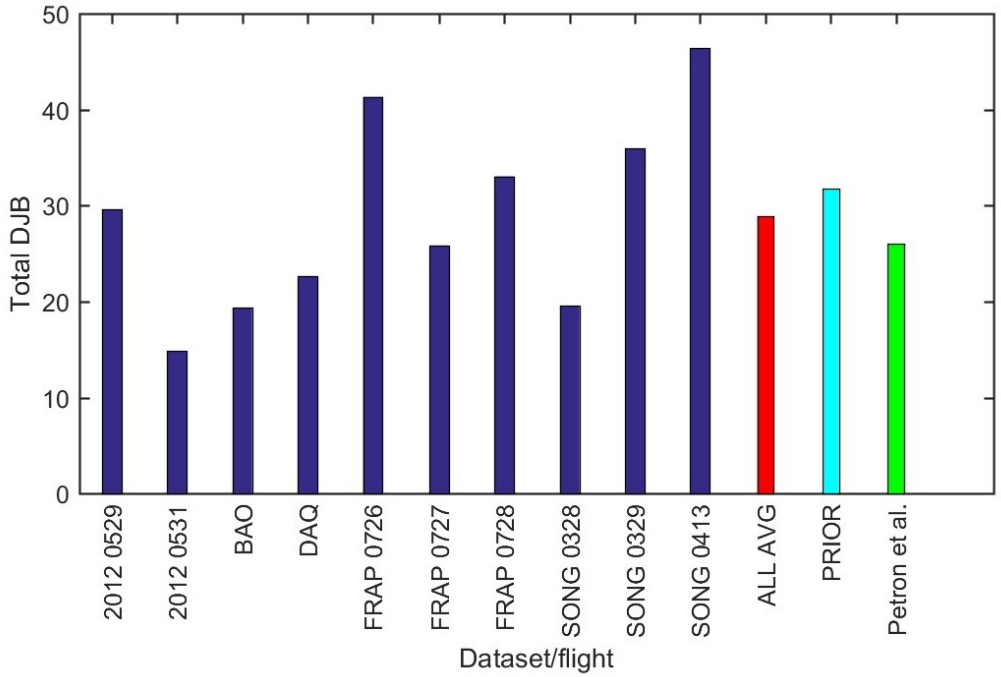

Figure 1. Total methane emissions (t/h) from the DJB derived by this study from individual flights or datasets (blue bars), overall average (red), the prior inventory (cyan), and [*Pétron et al.*, 2014] (green). Flights/datasets are sorted in rough temporal order.

Have We Detected Large Increases in U.S. Emissions of CH_4 from Oil and Gas Production?

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Recent studies have proposed significant increases in methane (CH_4) emissions from North America over the past decade, and implicated rapid growth in U.S. oil and gas production. The evidence for the increase in North American oil and gas emissions is based on (1) observed increases in co-emitted species such as ethane and propane (2) a trend derived from different atmospheric inversions (3) spatial differences across North America derived from space-based retrievals of column CH_4 abundance. We examine these claims using an ensemble of time-dependent inversions collected as part of the Global Carbon Project, and we also consider what long-term observations from the NOAA aircraft observation network tell us about U.S. emissions. We find that none of the time-dependent inversions estimate large trends in U.S. emissions, and this is true for inversions using only surface observations and for those that use retrieved column CH_4. Furthermore, we find that short term (< 5 year) trends of up to 1.5 ppb/yr can occur in spatial gradients between the Pacific "background" CH_4 values and continental locations due to transport effects, and that the trends in spatial differences are very sensitive to what is chosen as the background value. Furthermore, we show that zonal spatial differences for long-lived atmospheric species are not likely to be sensitive to even large trends due to relatively fast synoptic zonal transport. Finally, we consider the extent to which trends in co-emitted hydrocarbons can be used to estimate emissions of CH_4.

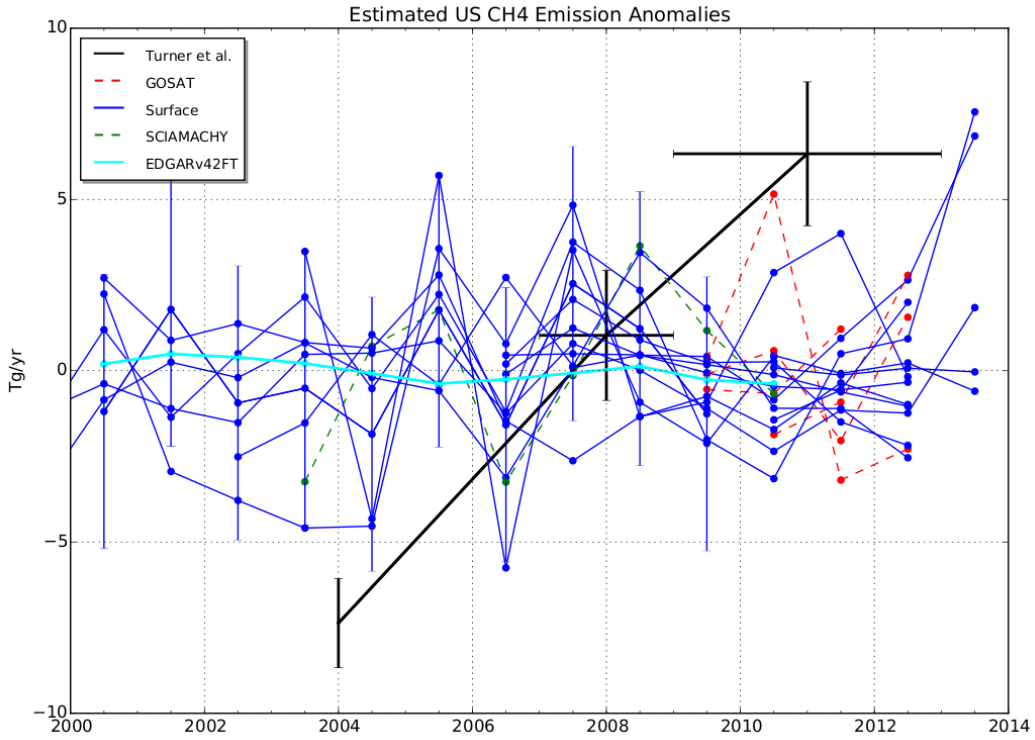

Figure 1. Annual U.S. CH_4 emission anomalies from time-dependent global inversions (blue) archived by the Global Carbon Project (GCP). Dashed lines indicate inversions using space-based retrievals of XCH_4 (red: GOSAT, green: SCIAMACHY). The black points and line shows results used by Turner et al. (2016). Note that error bars are shown for only 1 GCP inversion, since it is difficult to obtain uncertainty estimates for solution methods used by some groups.

Results from a Survey of Global Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data

C.D. Elvidge[1], M. Zhizhin[2,1], K. Baugh[2,1] and F. Hsu[2,1]

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A global survey of natural gas flaring in 2012-2014 has been completed with nighttime Visible Infrared Imaging Radiometer Suite (VIIRS) data. The survey identifies flaring site locations, annual duty cycle, and provides an estimate of the flared gas volumes in methane equivalents. VIIRS is particularly well suited for detecting and measuring the radiant emissions from gas flares through the collection of shortwave and near-infrared data at night, recording the peak radiant emissions from flares. A total of 17,314 individual flare sites were identified with that number steadilygrowing from 11,851 to 13,610 per year. The total flared gas volume is estimated at 140 +/30 billion cubic meters per year, corresponding to 3.5% of global natural gas production. While the U.S.A. has the largest number of flares, Russia leads in terms of flared gas volume. The largest individual gas flares are observed in Venezuela. Ninety percent of the flared gas volume was found in upstream production areas, 8% at refineries and 2% at liquefied natural gas terminals. The data are available at: http://www.ngdc.noaa.gov/eog/viirs/download_global_flare.html.

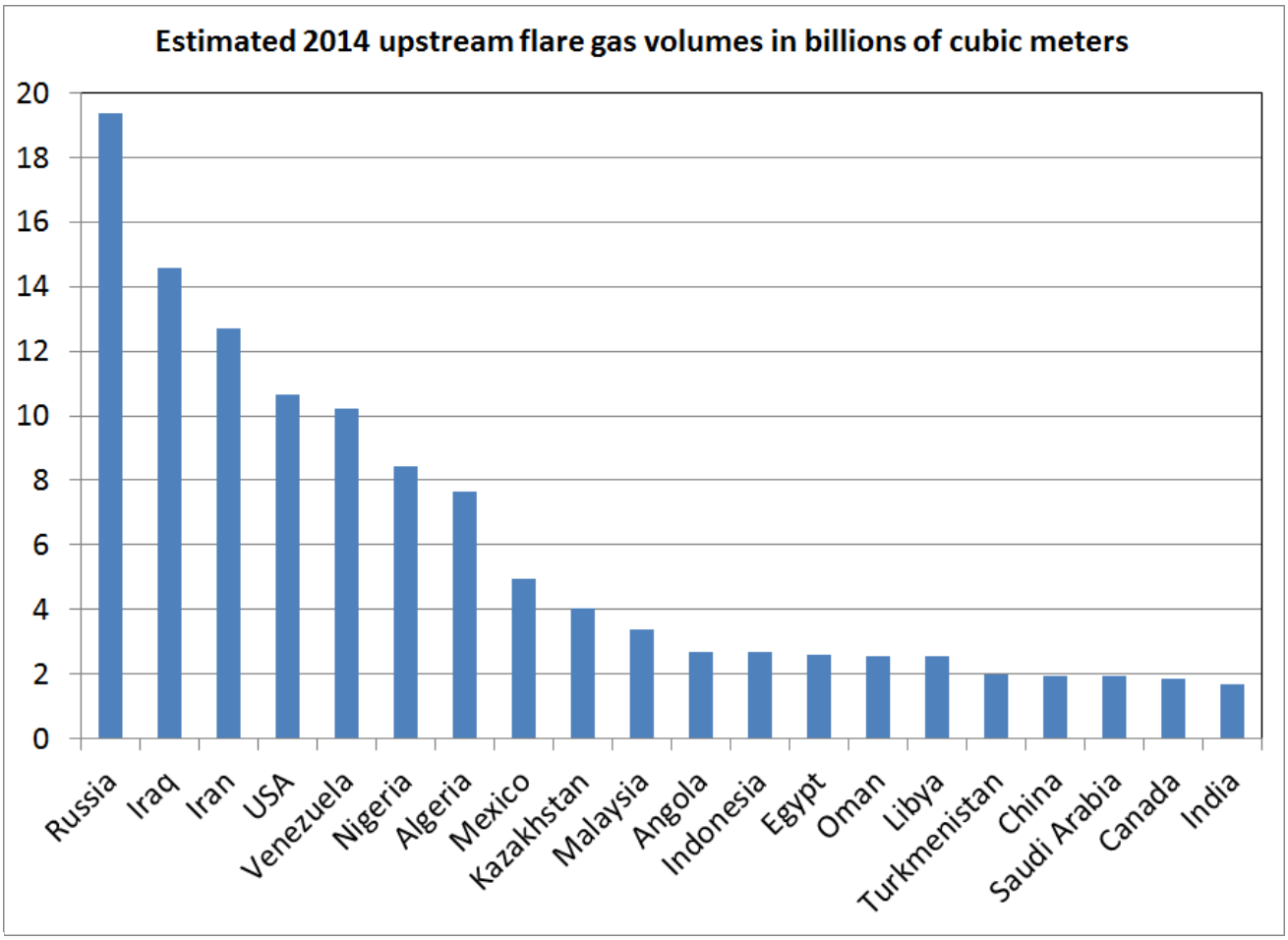

Figure 1. Top twenty countries for upstream gas flaring in 2014.

Methane Emissions from Natural Gas Production in Pennsylvania: Aircraft Model Comparison

Z. Barkley[1], K.J. Davis[1], T. Lauvaux[1], A. Deng[1], D. Martin[1], N. Miles[1], S. Richardson[1], Y. Cao[1], A. Karion[2], C. Sweeney[3,4], S. Schwietzke[3,4], K. McKain[3,4], M. Smith[5] and E. Kort[5]

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[2]National Institute of Standards and Technology, Gaithersburg, MD 20880
[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 Michigan, Ann Arbor, MI 48109

Leaks in natural gas infrastructure release methane (CH_4), a potent greenhouse gas, into the atmosphere. The estimated fugitive emission rate associated with the production and transportation of natural gas is uncertain, hindering our understanding of the energy's efficacy as a "bridge fuel". This study presents a new application of inverse methodology for estimating regional emission rates from natural gas production. An inventory of methane emissions was compiled for major sources in Pennsylvania. This inventory was coupled to the Weather Research and Forecasting model with chemistry enabled (WRF-Chem) and atmospheric CH_4 concentration fields at 3km resolution were generated. Projected atmospheric CH_4 enhancements from WRF-Chem were compared to observations obtained from a three-week flight campaign in May 2015, performed by a team from the NOAA ESRL/GMD and the University of Michigan. Emission rates from unconventional wells and compressor stations were adjusted in the model to minimize errors between aircraft observations and the model-simulated concentrations for each flight, and an optimal emission rate is solved for. Average emission rates for the region are found to be approximately half a percent of unconventional natural gas production during the period. Similar results are obtained through changes in model configurations and optimization methods, and mass balance calculations using aircraft data on days with applicable flight patterns also reach a similar conclusion, providing a sense of robustness to calculated emission rate. Despite confidence in the mean emission rate, large variations are present in emission rates across individual days of the flights in both the model optimization and mass balance results. There is still uncertainty as to whether these daily differences are associated with errors of the day or rather are temporal variability in natural gas emissions, though agreement in the daily trends between the different methodologies may be indicative of the latter.

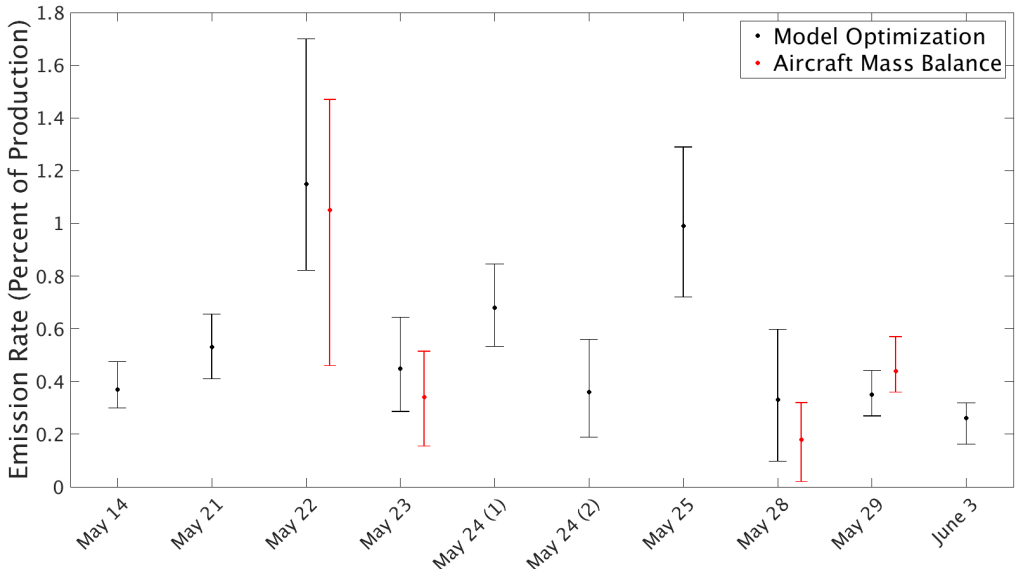

Figure 1. Natural gas emission rates in northeastern Pennsylvania as a function of production, calculated using model optimization technique (black) and mass balance technique (red) when applicable. Error bars represent a potential background value error of ±5ppb.

A Reversal of Long-term Global Trends in Atmospheric Ethane and Propane from North American Oil and Natural Gas Emissions

D. Helmig[1], S. Rossabi[1], J. Hueber[1], P.P. Tans[2], S.A. Montzka[2], K. Masarie[2], K. Thoning[2], C. Plass-Duelmer[3], A. Claude[3], A.C. Lewis[4], L.J. Carpenter[4], S. Punjabi[4], S. Reimann[5], M.K. Vollmer[5], R. Steinbrecher[6], J. Hannigan[7], L. Emmons[7], E. Mahieu[8], B. Franco[8], D. Smale[9] and A. Pozzer[10]

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[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]Deutscher Wetterdienst, Hohenpeissenberg, Germany
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[9]National Institute of Water and Atmospheric Research (NIWA), Lauder, New Zealand
[10]Max Planck Institute for Chemistry, Mainz, Germany

Ethane, the longest-lived and most abundant non-methane hydrocarbon (NMHC) peaked in the background atmosphere around 1970. This was followed by a ~20% reduction of the atmospheric burden and a resulting atmospheric downward trend for the next four decades, mostly due to reduced emissions from oil and gas industries and stricter air quality controls. Here, we show that the near 40-year trend of declining global ethane halted between 2005-2010 in most of the Northern Hemisphere (NH), and that since it has reversed. The largest increases in ethane and of the shorter-lived propane are seen in the central and eastern U.S. and immediately downwind, identifying this region as the primary source of increased NMHC emissions. The spatial distribution of observed concentration increases for ethane and propane provides convincing evidence that renewed emissions are primarily associated with the growth of oil and natural gas development in North America. Using source region relationships, emission estimates for increases of co-emitted NMHCs and methane, as well as impacts on tropospheric ozone production have been developed.

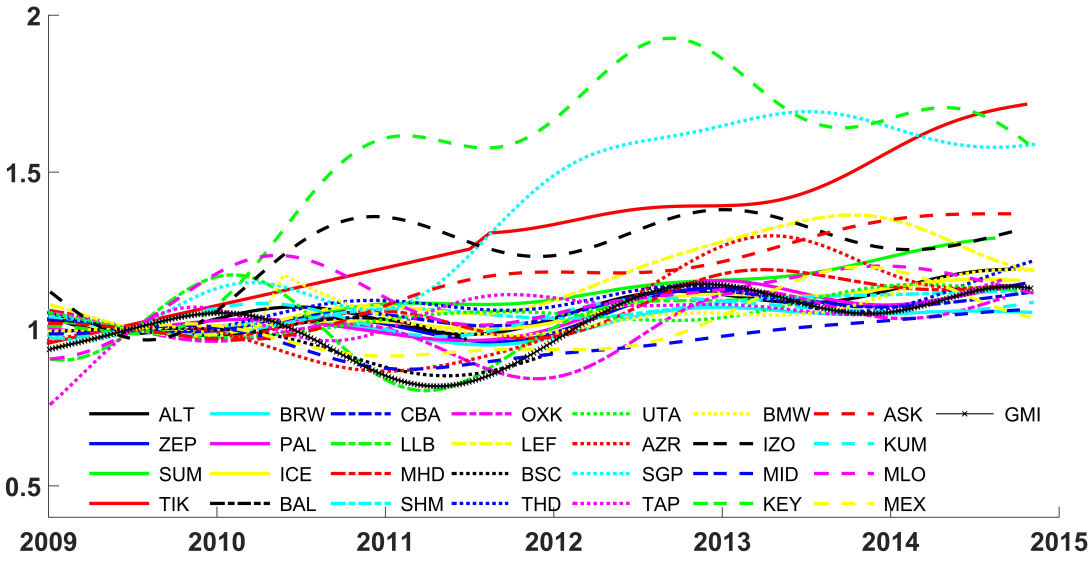

Figure 1. Ethane de-seasonalized five-year rate of change at 29 NH Global Greenhouse Gas Reference Network (GGGRN) sites normalized to 2009.5 mixing ratios.

A Quantification of Methane Emissions from Oil and Natural Gas Extraction Regions in the U.S. and a Comparison to Previous Studies

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We present airborne measurements of methane (CH_4) and ethane (C_2H_6) taken aboard a NOAA WP-3D research aircraft over five regions of oil and natural gas extraction in March and April, 2015, as part of the Shale Oil and Natural Gas Nexus (SONGNEX) field study. The five regions are the (1) Haynesville, (2) Barnett, and (3) Eagle Ford regions in Texas, (4) the Denver-Julesburg region of Colorado, and (5) the Bakken region of North Dakota. From these measurements, we derive methane emission rates from these regions using the mass balance method. We then compare these emissions to those reported from previous studies, where applicable. Finally, we compare reported methane emissions from multiple regional-scale studies with inventory estimates of methane emissions from U.S. oil and natural gas production.

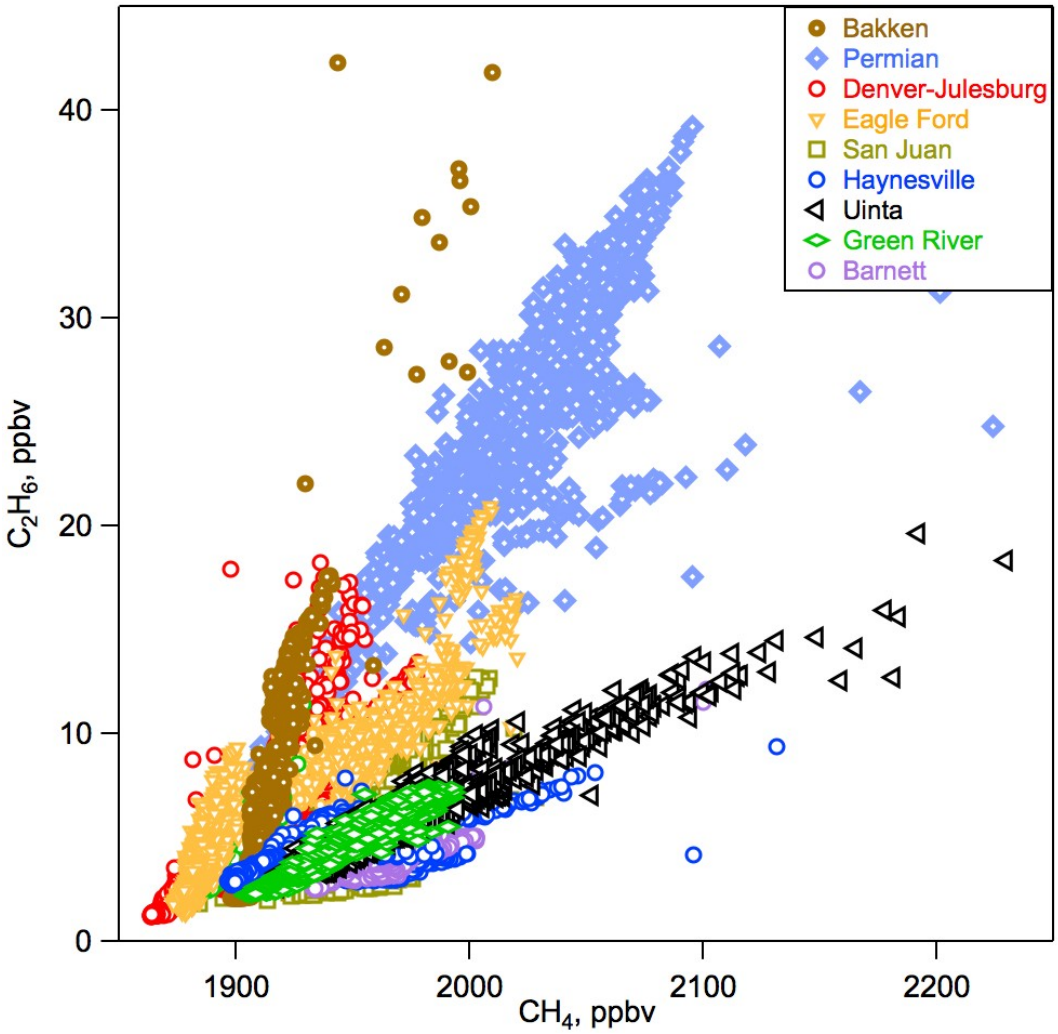

Figure 1. Measurements of ethane and methane from nine oil and natural gas extraction regions sampled during the SONGNEX field study. Note that the fields that produce "wetter" gas typically have greater atmospheric enhancements of ethane relative to methane.

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2016

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

Tuesday, May 17, 2016 17:00 - 20:00 POSTER SESSION AGENDA

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

• *Carbon Cycle & Greenhouse Gases*

P-1 Separating Methane Emissions From Biogenic Sources And Natural Gas by Vertical Column Enhancements of Ammonia, Ethane, and Methane Along the Colorado Front Range

Randall Chiu (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-2 Tower-based Measurements of CH_4 Dry Mole Fraction and Istopic Ratio ($^{13}CH_4/^{12}CH_4$) in the Northeastern Pennsylvania Marcellus Shale Gas Region

Natasha Miles (The Pennsylvania State University, University Park, PA)

P-3 Aircraft-based Quantification of Individual Oil and Gas Facilities' Methane Emissions

Stefan Schwietzke (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-4 Global Inventory of Natural Gas Molecular and Isotopic Compositions

Owen A. Sherwood (Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO)

P-5 Methane and Nonmethane Hydrocarbons in the Denver-Julesburg Basin of Colorado: from Source Signatures to Regional Impacts

Gabrielle Petron (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-6 CO_2, CO, and CH_4 Surface *In Situ* Measurement Network in Support of the Indianapolis FLUX (INFLUX) Experiment

Scott Richardson (The Pennsylvania State University, University Park, PA)

P-7 Stable Isotopic Analysis of Carbon Monoxide During Two Summers at Indianapolis, Indiana

Isaac Vimont (Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO)

P-8 Spatiotemporal Patterns of Urban Trace Gases and Pollutants Observed with a Light Rail Vehicle Platform in Salt Lake City, UT

Logan Mitchell (University of Utah, Salt Lake City, UT)

P-9 Imprint of Urban CO_2 Emissions Detected by OCO-2 Observations of Total Column CO_2

Xinxin Ye (The Pennsylvania State University, University Park, PA)

P-10 Atmospheric Carbon and Transport – America: A NASA Earth Venture Mission Dedicated to Improving the Accuracy, Precision and Resolution of Atmospheric Inverse Estimates of CO_2 and CH_4 Sources and Sinks

Scott Richardson (The Pennsylvania State University, University Park, PA)

P-11 Using *In Situ* CO_2 Measurements to Help Understand GOSAT and OCO-2 Column CO_2 Retrievals

David F. Baker (Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO)

P-12 A Multi-sensor Approach to Cloud and Aerosol Detection in Support of OCO-2 XCO_2 Retrieval Validation

Heather Q. Cronk (Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO)

P-13 Toward Continuous Monitoring of Climate Pollutant Emissions at Site- to Regional- Scales

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

P-14 Reconstructing Urban Fossil Fuel Carbon Dioxide Emissions Utilizing the Radiocarbon Composition of Tree Rings from the Wellington Region, New Zealand

Bella Ansell (GNS Science, National Isotope Centre, Lower Hutt, New Zealand)

P-15 Influence of Subgrid Terrain Variability on Simulated Planetary Boundary Layer Depths in Large-scale Transport Models

Gert-Jan Duine (University of Virginia, Charlottesville, VA)

P-16 Sensitivity and Uncertainty Analysis of Physical Parameterization and Initial Conditions on Meteorological Variables and CO_2 Mole Fractions

Liza Diaz-Isaac (The Pennsylvania State University, University Park, PA)

P-17 Assimilation of GOSAT XCO_2 Retrievals in CarbonTracker

Jinwoong Kim (Yonsei University, Department of Atmospheric Sciences, Seoul, South Korea)

P-18 A Re-examination of the WMO X2007 CO_2 Calibration Scale

Brad D. Hall (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO)

NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE 2016

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

Tuesday, May 17, 2016 17:00 - 20:00 POSTER SESSION AGENDA

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

• Carbon Cycle & Greenhouse Gases (continued)

P-19 Ensuring High-quality Data from NOAA'S Cooperative Global Air Sampling Network
Molly J. Crotwell (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-20 Comparison of CH_4 Monitoring Methods at GEOSummit
Dominique Colegrove (Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO)

P-21 Characteristics of Atmospheric CO_2 and CH_4 at the Shangdianzi Regional Background Station in China
Miao Liang (China Meteorological Administration, Centre for Atmosphere Watch and Services, Meteorological Observation Centre, Beijing, China)

P-22 A Compact Cavity Ring-down Spectroscopy Analyzer for *In Situ* Measurements of Carbon Dioxide, Methane, and Water Vapor
Milos Markovic (Picarro Inc, Santa Clara, CA)

P-23 Integrated Path Differential Absorption (IPDA) LIDAR Measurement of CO_2, CH_4, and H_2O
Gerd A. Wagner (National Institute of Standards and Technology (NIST), Physical Measurement Laboratory, Quantum Electromagnetics Division, Boulder, CO)

P-24 An Ultra-stable and High-precision N_2O/CO Analyzer for Continuous Ambient Monitoring
Graham Leggett (Picarro Inc, Santa Clara, CA)

P-25 Atmospheric Measurements of Methane, Isotopic Methane, and Ethane Using a Cavity Ring-down Spectrometer
Iain Green (Picarro Inc, Santa Clara, CA)

P-26 Adaptation of a Commercial Greenhouse Gas Analyzer for Expanded Altitude Range
Kathryn McKain (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-27 Characterization of a Quantum Cascade-Tunable Infrared Laser Differential Absorption Spectrometer (QC-TILDAS) for Atmospheric Ethane and Methane Field Measurements
Ingrid Mielke-Maday (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-28 Global Warming Is Real - Highlights of the Data
Phil Morris (Retired Molecular Biologist and High School Science Teacher, Edmond, OK)

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• Ozone & Water Vapor

P-29 Uncertainties in Total Ozone Retrievals from Dobson Zenith Sky Observations
Koji Miyagawa (Science and Technology Corporation, Boulder, CO)

P-30 Centuries of Data: the U.S. Dobson Station Network Reevaluated
Robert D. Evans (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-31 Long-lived Stratospheric Ozone Depletion Over The South Pole During Spring 2015
Glen McConville (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-32 Total Column Water Vapor from OCO-2
Robert R. Nelson (Colorado State University, Department of Atmospheric Science, Fort Collins, CO)

P-33 Introducing the EXC^{3}ITE Project: EXploring Stratospheric Composition, Chemistry and Circulation with Innovative TEchniques
Emma Leedham Elvidge (University of East Anglia, School of Environmental Sciences, Norwich, United Kingdom)

P-34 Intercomparison of Total Ozone Column Observed by Pandora and Brewer Spectrophotometers at Taipei
Kun-Wei Lin (Central Weather Bureau, Observation Division, Taipei, Taiwan)

P-35 First Look at the NOAA Aircraft-based Tropospheric Ozone Climatology in Colorado
Mark Leonard (Science and Technology Corporation, Boulder, CO)

P-36 Analysis, Determination and Reprocessing Methods Used For Homogenization of the NOAA Long-term ECC Ozonesonde Time Series
Chance W. Sterling (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-37 The First Reprocessing of SHADOZ (Southern Hemisphere ADditional OZonesondes) Data Records
Jacquelyn Witte (Science Systems and Applications, Inc. (SSAI), Lanham, MD)

P-38 Results from Balloon Launches at the MaïDo Observatory On RéUnion Island
Karen H. Rosenlof (NOAA Earth System Research Laboratory, Chemical Sciences Division (CSD), Boulder, CO)

P-39 Ozone and Other Trace Gases in the Tropical Tropopause Layer Over the Pacific Ocean
Eric Hintsa (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-40 Investigating Below-cloud Rain Evaporation and Boundary Layer Moisture Recycling by Coupling Stable Water Isotopes in Vapor and Precipitation to Raindrop Size Distributions at the Boulder Atmospheric Observatory Site
Aleya Kaushik (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-41 Geographical and Temporal Differences in NOAA Observed Surface Ozone in the Arctic
Audra McClure-Begley (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

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

• *Halocarbons*

P-42 Using Box Models to Quantify Zonal Distributions and Surface Emissions of Halocarbons in the Background Atmosphere
James W. Elkins (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO)

P-43 Halogenated Trace Gases and Volatile Organic Compounds at the Global Atmospheric Watch Observatory Schneefernerhaus/Zugspitze, Germany
Wei Wang (Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO)

P-44 GMD'S GC/MS Analytical System for Preconcentration of Environmentally Relevant Species (PERSEUS)
Benjamin R. Miller (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-45 Infrared Spectra and Radiative Efficiencies of Atmospherically Persistent Perfluoroamines
François Bernard (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

• *Radiation*

P-46 Evaluation of Environmental and Logistic Conditions at Yushan Station In Taiwan for an Outdoor Radiation Calibration Facility
Cheng-Chien Huang (Central Weather Bureau, Observation Division, Taipei, Taiwan)

P-47 The NOAA Global Monitoring Division'S UV Monitoring Networks: Update on Antarctica and NEUBrew
Scott Stierle (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-48 Synthesis of Aerosol Physical, Chemical, and Radiative Properties from Various Sources: Consistency and Closure
Hagen Telg (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-49 Pioneering Detector Technology and Architecture Used in a Next Generation Pyranometer Yielding Negligible Thermal Offsets and Sub-second Response
Will Beuttell (EKO Instruments USA Inc, San Jose, CA)

P-50 Annual Evolution of Surface Energy Flux at Summit, Greenland
Nathaniel Miller (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-51 A Method to Correct Longwave Radiation Measurements Corrupted by a Bad Thermistor
John Augustine (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO)

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• *Aerosols*

P-52 Aerosol Climatology at Mt. Lulin: AERONET and *In Situ* Measurements
Sheng-Hsiang Wang (National Central University, Department of Atmospheric Sciences, Chung-Li, Taiwan)

P-53 Multi-year Measurements of Aerosols at Jaipur, a Site in Northwestern India
Sunita Verma (Birla Institute of Technology Mesra, Ranchi, India)

P-54 Mitigation of Particulate Matter Problem Caused by Vegetation Fires in Thailand
Sirirat Yensong (Faculty of Engineering and Environment, University of Southampton, Southampton, United Kingdom)

P-55 Source Influences on the Aerosol Size Distribution and Cloud Condensation Nucleus (CCN) Activity at the Resolute Bay Ground Site in Canada
Sangeeta Sharma (Environment and Climate Change Canada, Toronto, Ontario, Canada)

P-56 A Comparison of Inlet Setups at Storm Peak Laboratory
Andrew Kumler (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-57 Design of a Novel Aircraft Open-path Cavity Ring-down Spectrometer
Gabriela Adler (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-58 A "MAGIC" Water Condensation Particle Counter
Patricia B. Keady (Aerosol Devices Inc., Fort Collins, CO)

P-59 Boundary Layer Observations at Mauna Loa Observatory, Hawaii
John E. Barnes (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-60 The Calbuco Chronicle: Volcanic Aerosols in the Post-Pinatubo Stratosphere
Richard A. Keen (University of Colorado, Emeritus, Department of Atmospheric and Oceanic Sciences, Boulder, CO)

• *Meteorology and Partner Stations*

P-61 Environmental Change in Barrow, Alaska Resulting from a 2015 Record Heat Wave
Diane Stanitski (NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO)

P-62 Seasonal and Latitudinal Variations of Surface Fluxes and Meteorological Variables at Arctic Terrestrial Sites
Andrey A. Grachev (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-63 Definition of Summer Monsoon Index for Vietnam Region
Mau Nguyen-Dang (Vietnam Institute of Meteorology, Hydrology, and Climate Change, Hanoi, Vietnam)

P-64 ARM North Slope of Alaska Research Facilities
Jasper Hardesty (Sandia National Laboratories, Albuquerque, NM)

P-65 The Pikes Peak Observatory
Mark Miesch (National Center for Atmospheric Research (NCAR), High Altitude Observatory, Boulder, CO)

P-66 Wind Sensor Comparison – Lufft Ventus-UMB Vs. RM Young 5103, Summit Station Greenland – July 2015 to April 2016
Michael O'Neill (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO)

P-67 Normalized Distribution Function: A Statistical Analysis of Surface Temperature for the Investigations for Seismic Precursor During the Large Ferndale, California Earthquake (M=6.8)
Rahul Shrivastava (Space Science Laboratory, Department of Physics and Electronics, Barkatullah University, Bhopal, India)

• *Technology*

P-68 SOS Explorer™: Interactive Visualizations for Museums and Classrooms
Eric Hackathorn (NOAA Earth System Research Laboratory, Global Systems Division (GSD), Boulder, CO)

Notes:

Separating Methane Emissions From Biogenic Sources and Natural Gas by Vertical Column Enhancements of Ammonia, Ethane, and Methane Along the Colorado Front Range

R. Chiu[1], M. Frey[2], F. Hasse[2], T. Blumenstock[2] and R. Volkamer[3]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-735-2235, E-mail: randall.chiu@colorado.edu
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[3]University of Colorado, Department of Chemistry and Biochemistry, Boulder, CO 80309

Methane sources along the Colorado Front Range include biogenic sources from cattle feedlots and natural gas operations. Although numerous studies have measured methane emissions, there remains significant uncertainty regarding the relative contributions of these various methane emission sources. Here we present data from a March 2015 field campaign that deployed two Bruker EM27 Sun Fourier Transform Spectrometers (FTS) and the University of Colorado Solar Occultation Flux (CU-SOF) FTS in Eaton, Colorado; the former were used to measure enhancements in the methane vertical column densities (VCD), while the latter was used to measure ethane and ammonia VCDs. A third EM27 FTS was deployed to a background site in Westminster, Colorado which was far removed from cattle and petroleum operations. Northerly winds make possible the determination of methane VCD column enhancement from Westminster to Eaton. All instruments were compared during several background days at the National Center for Atmospheric Research in Boulder, Colorado. This presentation explores the potential of methane source attribution using ammonia as a tracer for feedlot emissions and ethane as a tracer for petroleum emissions.

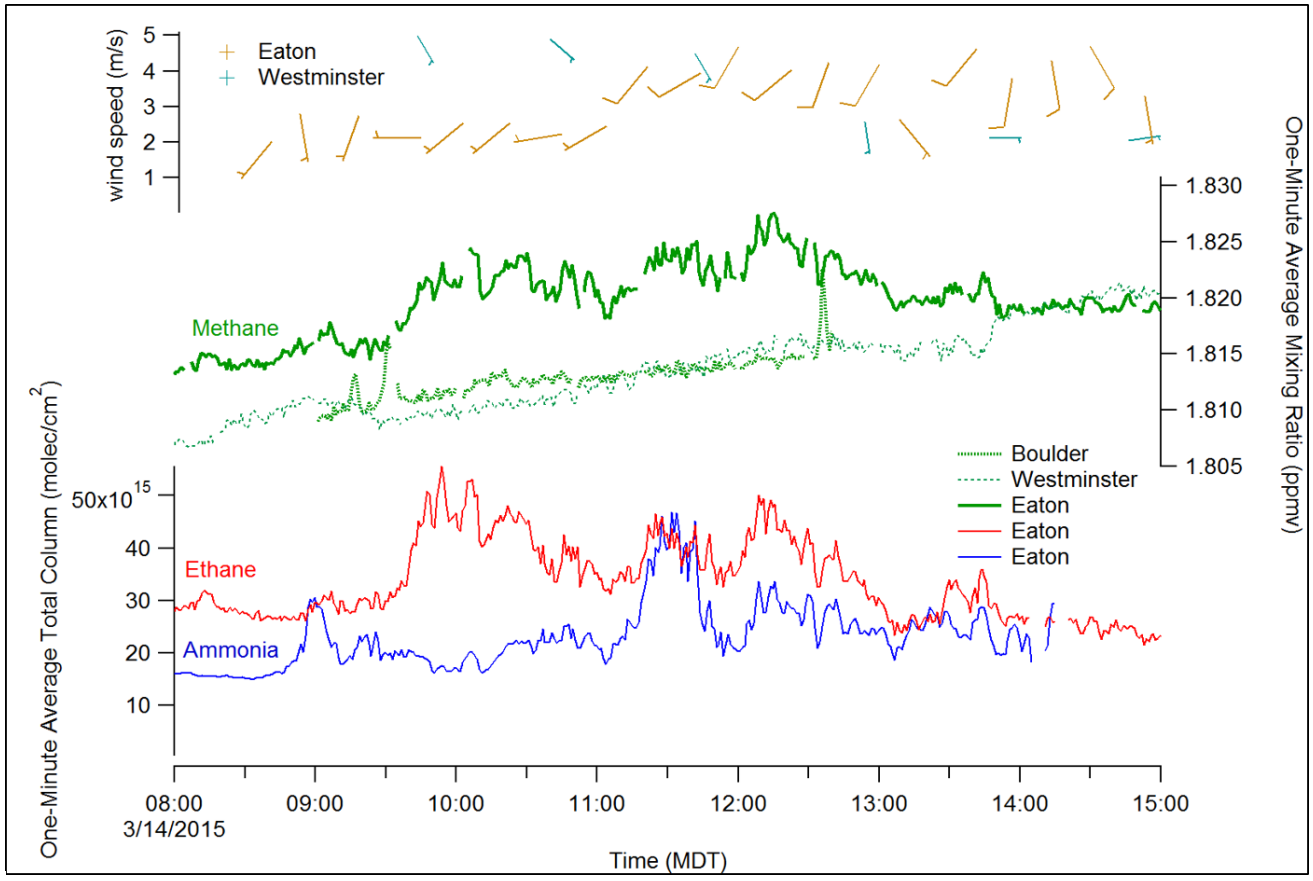

Figure 1. Time trace showing the correlation of methane, ethane, and ammonia VCD enhancements depending on wind direction on 14 March 2015.

Tower-based Measurements of CH_4 Dry Mole Fraction and Istopic Ratio ($^{13}CH_4/^{12}CH_4$) in the Northeastern Pennsylvania Marcellus Shale Gas Region

N. Miles[1], S. Richardson[1], D. Martin[1], C. Rella[2], T. Lauvaux[1], K.J. Davis[1] and K. McKain[3,4]

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[2]Picarro Inc, Santa Clara, CA 94054
[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

Fugitive emissions of atmospheric methane (CH_4) from natural gas drilling, production, processing, and distribution activities in the Marcellus Shale geologic formation have the potential to impact the current state of the climate. Thus, it is useful to quantify these emissions from natural gas as well as other sources, both biogenic and anthropogenic (e.g., wetlands, cattle, landfills). Regional emissions can be quantified using an atmospheric transport model with a Bayesian inversion to minimize differences between simulated and observed atmospheric CH_4 concentrations. Towards that end, high-accuracy atmospheric observations of CH_4 dry mole fractions and its stable isotope ($^{13}CH_4$) are made on four communications towers ranging in height between 46 and 61 m AGL. We present results from one year of measurements, focusing on characterizing the enhancements of CH_4 and the calibration technique for the isotopic ratio ($^{13}CH_4/^{12}CH_4$).

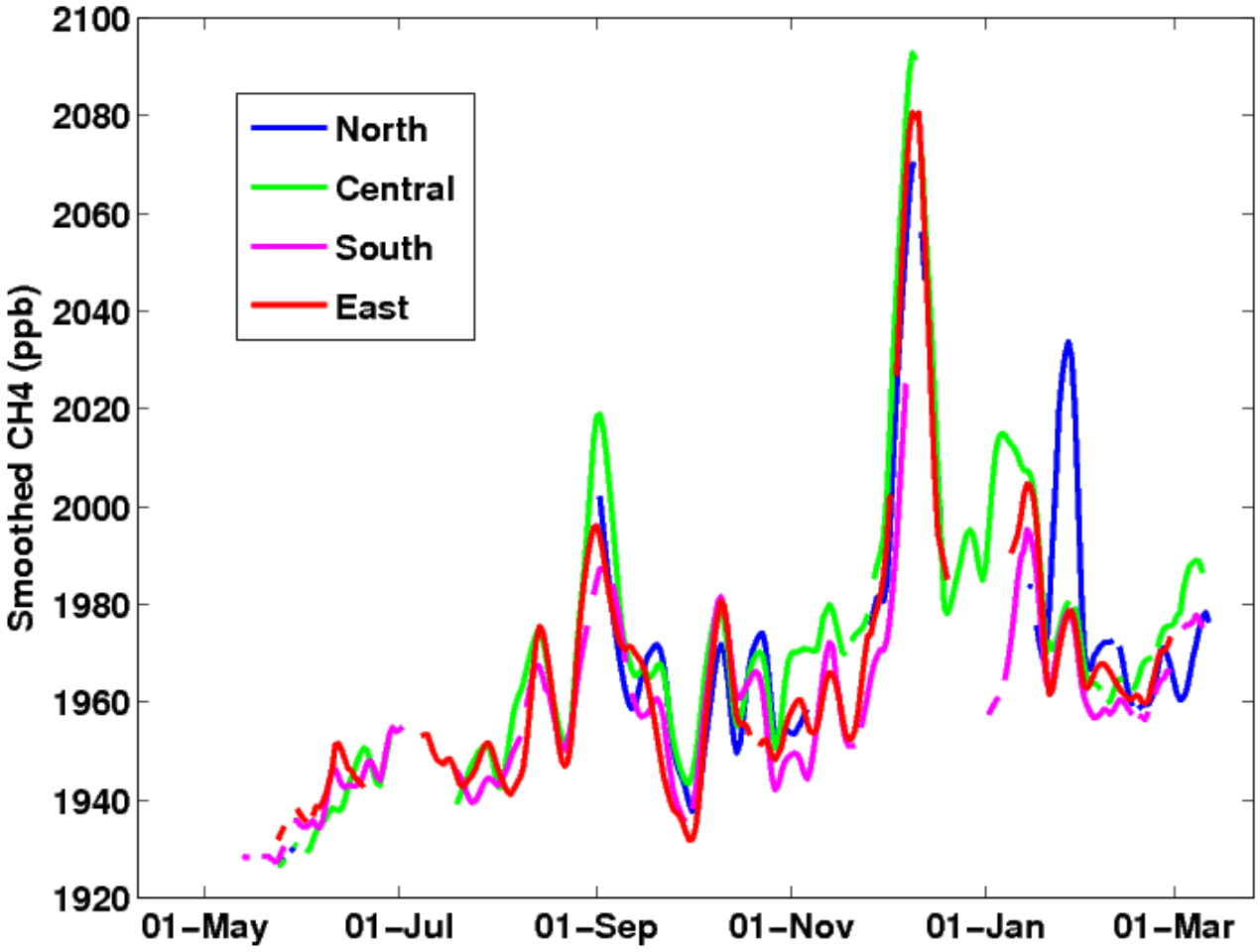

Figure 1. Time series of daytime CH_4 dry mole fractions measured at four towers in northeastern Pennsylvania, smoothed with a 15-day filter.

Aircraft-based Quantification of Individual Oil and Gas Facilities' Methane Emissions

S. Conley[1,2], S. Schwietzke[3,4], G. Petron[3,4], S. Wolter[3,4], S.C. Herndon[5], T.I. Yacovitch[5], C. Sweeney[3,4], W.B. Knighton[6] and I. Faloona[2]

[1]Scientific Aviation, Roseville, CA 95661; 916-217-1107, E-mail: sconley@scientificaviation.com
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[5]Aerodyne Research Inc., Billerica, MA 01821
[6]Montana State University, Bozeman, MT 59717

Inventory-based (bottom-up) estimates of methane (CH_4) emissions from oil and gas operations have been evaluated recently in the U.S. using atmospheric data (top-down). Since top-down estimates are consistently larger than those from bottom-up approaches, more research is needed to explain this difference. This work focuses on top-down emission estimation at the facility-level using aircraft measurements. We estimated emission rates of isolated facilities by measuring CH_4, ethane (C_2H_6), and carbon dioxide (CO_2) dry air mole fractions in a closed circular path around each facility at multiple altitudes, and by employing Gauss's theorem to integrate the trace gas flux normal to the flight path. This presentation focuses on measurements conducted to evaluate the estimation method: emission rate quantifications from (i) controlled (known) releases of C_2H_6, and (ii) power plants using published, plant-specific, hourly CO_2 emission rates. Existing results indicate that the method can accurately quantify emissions within less than 25% error.

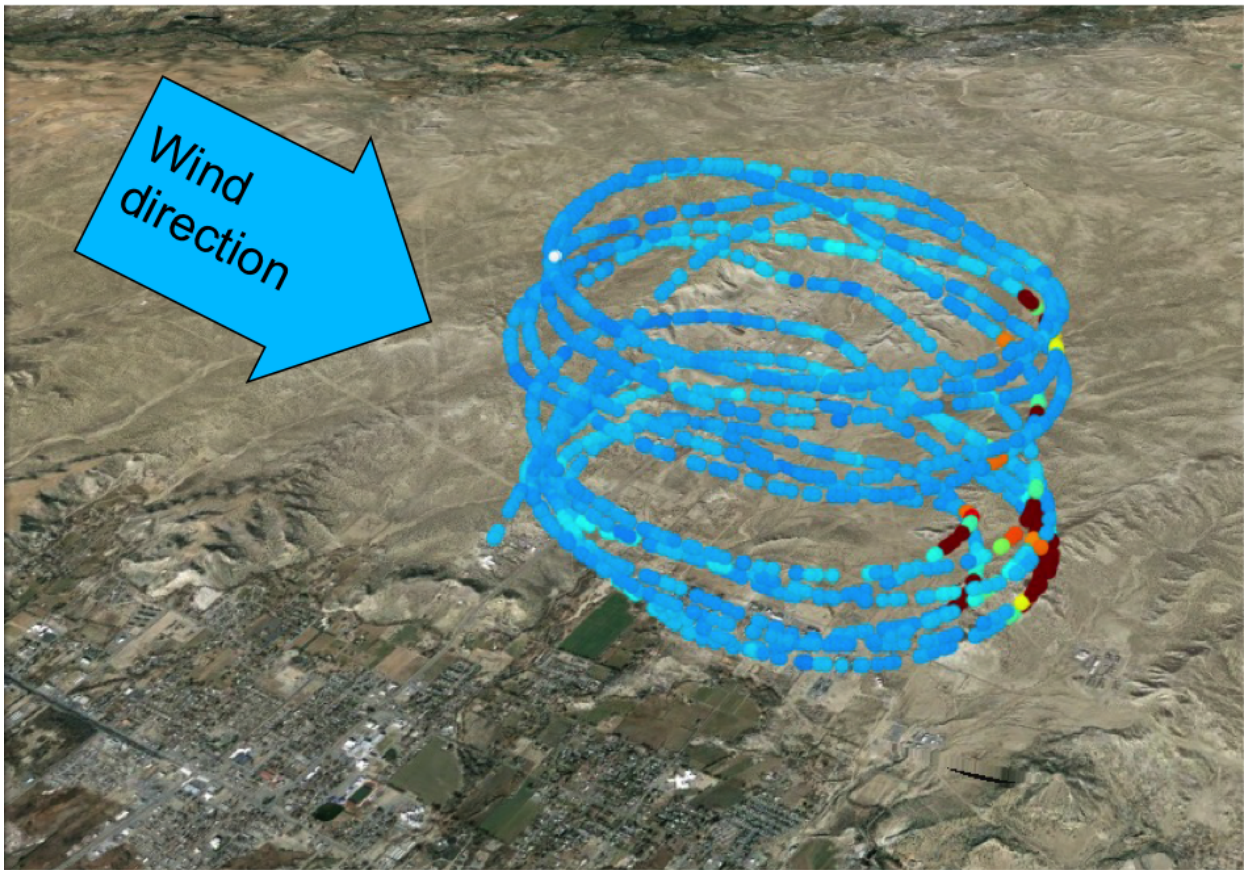

Figure 1.

Flight path and CH_4 levels (color-coded) above an oil and gas facility indicating an isolated CH_4 source.

Global Inventory of Natural Gas Molecular and Isotopic Compositions

O.A. Sherwood[1], S. Schwietzke[2,3], G. Etiope[4] and J.B. Miller[3]

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[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
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Top-down models of the global atmospheric methane budget use isotopic and/or molecular data to constrain source-specific emissions. These models are sensitive to end-member signatures (delta-$^{13}C_{CH4}$, delta-D_{CH4}, ethane:methane ratios) for the three main source categories, microbial methanogenesis, biomass burning, and fossil fuels. However, the end-member values are poorly constrained and based on data of unknown or limited sample count, regional extent and global representation. For fossil fuels in particular, few modeling studies reference primary data, despite a vast literature in petroleum geology reporting on the isotopic and molecular composition of natural gas. To address this problem, we compiled a database of 8,734 natural gas analyses from peer-reviewed literature, government reports and databases, with data on the molecular (C_1-C_6) and isotopic delta-$^{13}C_{C1-C5}$ and delta-D_{C1-C5} composition of conventional oil and gas, coal and shale gas. The data comprise 45 countries, representing 82% of global natural gas production and 80% of global coal production. Raw delta-$^{13}C_{CH4}$ values averaged -44.0 ± 0.1 ‰ (1 STDERR., n = 6080) for conventional oil and gas, -49.5 ± 0.3‰ (n = 1402) for coal, and -42.5 ± 0.3‰ (n = 646) for shale gas. All three categories of fossil fuel have left-skewed or bimodal delta-$^{13}C_{CH4}$ distributions, reflecting microbial methanogenesis in a significant fraction of the world's oil- and gas-producing reservoirs (e.g. giant Cenomanian gas fields of western Siberia), and in relatively shallow coal-bearing formations. These fossil-fuel end-member values have significant implications for top-down models of regional and global methane budgets. The database will be published in the public domain.

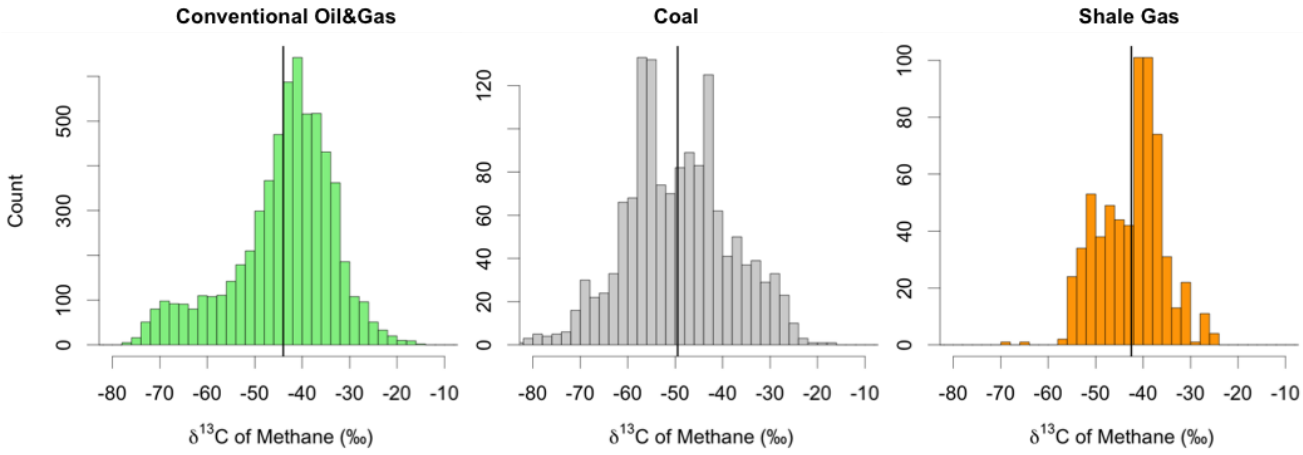

Figure 1. Histograms of the delta-$^{13}C_{CH4}$ of conventional oil&gas, coal and shale gas from the global database. Vertical lines represent mean values for each category.

Methane and Nonmethane Hydrocarbons in the Denver-Julesburg Basin of Colorado: from Source Signatures to Regional Impacts

G. Petron[1,2], B.R. Miller[1,2], E. Thorley[1,2], I. Mielke-Maday[1,2], J. Kofler[1,2], O. Sherwood[3], B. Vaughn[3], S. Schwietzke[1,2], S.A. Montzka[2], C. Sweeney[1,2], A. Karion[4], P.P. Tans[2], A.E. Andrews[2], E. Dlugokencky[2], P.M. Lang[2], T. Newberger[1,2], S. Wolter[1,2], B.D. Hall[2], P. Novelli[2], D. Kitzis[1,2], S. Conley[5,6], D. Wolfe[1,7] and R.C. Schnell[2]

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[5]Scientific Aviation, Roseville, CA 95661
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NOAA/ESRL and the Univeristy of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES) have conducted a number of intensive measurement campaigns in Colorado's NE Front Range since 2008. The study region is centered on the most densely drilled region (> 24,000 active wells) of the Denver-Julesburg basin, which is also the home of large animal feeding operations. Here we report on the analysis of air samples collected in the area with a mobile sampling van, at the Boulder Atmospheric Observatory tall tower site and from aircraft flights between 2008 and 2014. All samples were analyzed in the ESRL/GMD laboratories for over 50 trace gas species. We compare the emission ratios observed close downwind of sources with the tower and airborne samples that have a larger spatial footprint. We also compare the observed atmospheric chemical signatures with raw natural gas composition data reported to the Colorado Oil and Gas Conservation Commission.

Figure 1. NOAA GMD Mobile Laboratory

CO_2, CO, and CH_4 Surface *In Situ* Measurement Network in Support of the Indianapolis FLUX (INFLUX) Experiment

S. Richardson[1], N. Miles[1], K.J. Davis[1], T. Lauvaux[1] and J. Turnbull[2,3]

[1]The Pennsylvania State University, University Park, PA 16802; 814-574-3232, E-mail: srichardson@psu.edu
[2]GNS Science, National Isotope Centre, Lower Hutt, New Zealand
[3]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305

A 12-station surface-based measurement network measuring carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4) has been deployed in and around the Indianapolis, IN metropolitan area as part of the Indianapolis Flux Experiment (INFLUX). Measurements began in 2010 with network installation completed in 2013. Observations are made at heights ranging from 39-m to 130-m above ground level using existing communication towers. Several towers in the network include measurements at multiple levels. Not all species are measured at all sites: two sites measure CO_2, CO, and CH_4, three sites measure CO_2 and CO, three sites measure CO_2 and CH_4, and four sites measure only CO_2 (in 2014 the four CO_2-only sites were upgraded to CO_2 and CH_4). Cavity ring-down spectrometers are used at all 12 sites and each site has at least one calibrated reference tank sampled daily. Real time data communications are achieved via cellular phone modems and data is transmitted daily for processing and quality assurance checks. This paper discusses the instrument calibration procedures used prior to deployment in the field, the air sampling strategy used at each site, and the use of the on-site calibrated reference tank in data post-processing. Long-term instrument stability/drift is examined as is total data availability. Finally, six sites in the network also collect flask samples and a comparison with them is presented, along with results from two round-robin tests in which three or four calibrated reference tanks were sampled at all 12 sites over the period of a week.

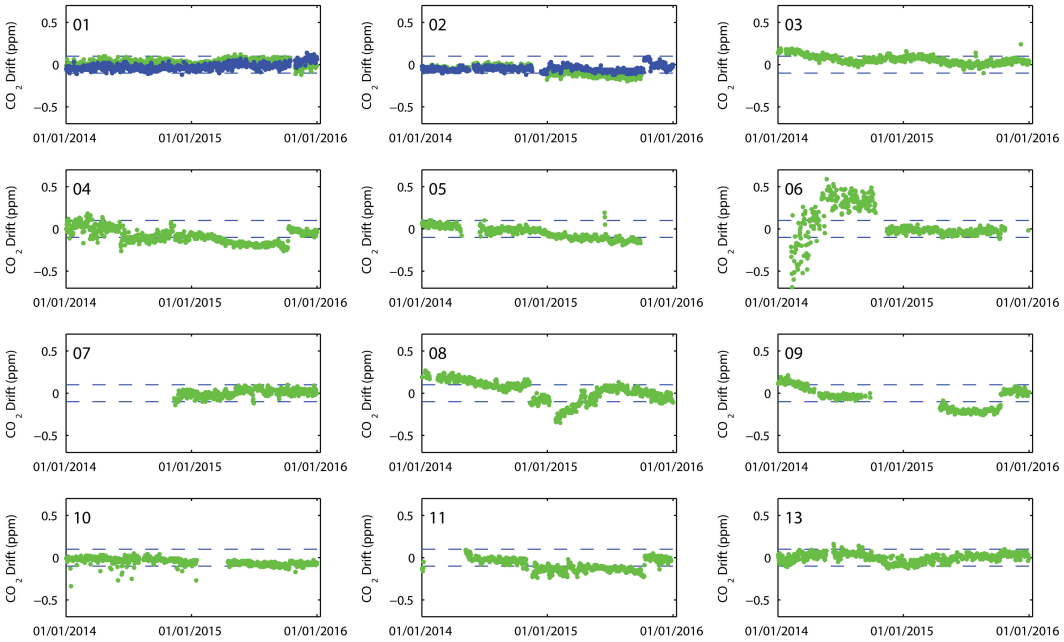

Figure 1. CO_2 target tank error (ppm, tank sampled every 23 hours) for 2014 and 2015 for all INFLUX sites. Sites 01 and 02 had two tanks, all other sites had one.

Stable Isotopic Analysis of Carbon Monoxide During Two Summers at Indianapolis, Indiana

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[2]GNS Science, National Isotope Centre, Lower Hutt, New Zealand
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[4]Department of Earth and Environmental Sciences, University of Rochester, Rochester, NY 14627

We present results from a study of carbon monoxide (CO) stable isotopes done at Indianapolis, Indiana as part of the INFLUX project. One of the goals of this project is to seek out measurement techniques best suited to characterizing urban emissions, in order to compare top-down measurement results with bottom-up inventory and modeling results. One species of interest in this study is fossil fuel produced carbon dioxide (CO_2). Characterizing fossil fuel emissions of carbon dioxide has been done at Indianapolis through radiocarbon measurements, and these measurements have been compared to fossil fuel CO_2 estimates calculated using carbon monoxide as a correlate tracer. These results found CO to be a poor tracer during the summer months due to significant contributions to the CO budget from non-fossil combustion sources. These sources are thought to be biogenic non-methane hydrocarbons (NMHC's) produced largely during the growing season and summer months. Stable isotopic measurements of CO are being used to try to better characterize these sources of CO at Indianapolis.

Here, we present a preliminary analysis of the Indianapolis carbon monoxide budget during two summers. We aim to better understand the variability of biological NMHC-derived CO, and separate the NMHC-CO and fossil fuel CO signals. This result will provide insight into the combustion CO:CO_2 relationship during the summer at Indianapolis, which may improve estimates of fossil fuel produced CO_2 from CO correlate tracer methods.

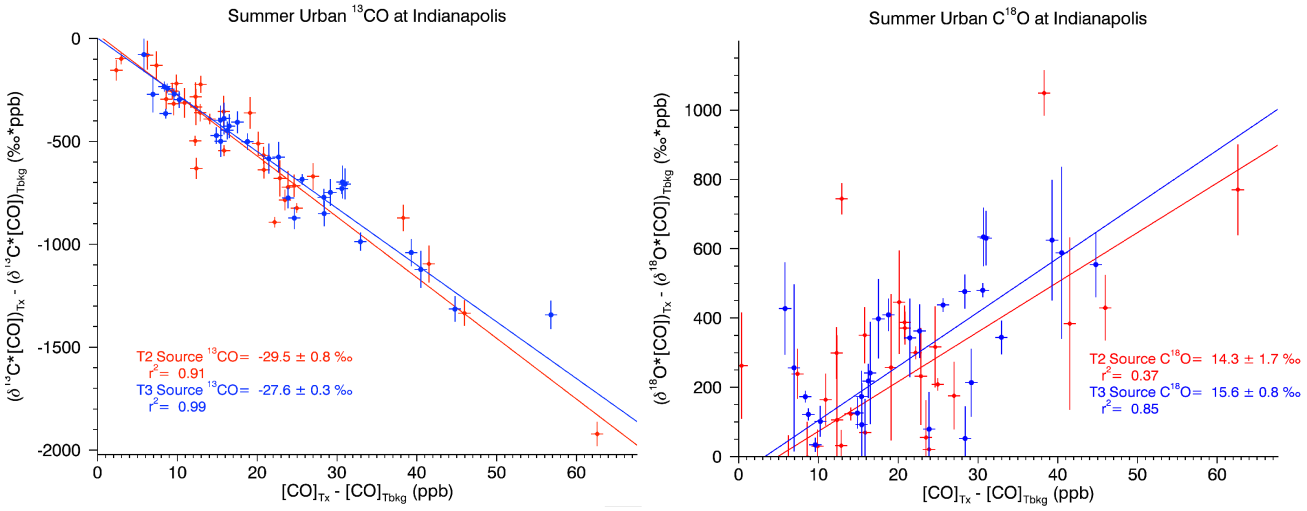

Figure 1. Preliminary determination of carbon monoxide d^{13}CO (left), and dC^{18}O (right) source signatures at two tall towers within the INFLUX network using regression analysis (Miller and Tans, 2003). T2 indicates 'Tower 2' and is shown in red, and T3 indicates 'Tower 3' and is shown in blue. 'BKG' indicates the measured values at a background site (Tower 1). Tower 1 is located west of the city, and samples were taken when the wind was from the west. Tower 2 is on the eastern edge of the city, and tower 3 is located near the center of the city. Fits were done using multiple OLS regressions in a Monte Carlo simulation.

Spatiotemporal Patterns of Urban Trace Gases and Pollutants Observed with a Light Rail Vehicle Platform in Salt Lake City, UT

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Urban environments are characterized by both spatial complexity and temporal variability, each of which present challenges for measurement strategies aimed at constraining estimates of greenhouse gas emissions and air quality. To address these challenges we initiated a project in December 2014 to measure trace species (CO_2, CH_4, O_3, and Particulate Matter) by way of a light rail vehicle (Utah Transit Authority) whose fixed route traverses the entire Salt Lake Valley in Utah on an hourly basis through commercial, residential, suburban, and rural typologies. Light rail vehicles offer three advantages as a measurement platform: the absence of *in situ* fossil fuel emissions, repeated transects across urban typologies that provides both spatial and temporal information, and relatively low operating costs. We present initial results of the spatiotemporal patterns of greenhouse gases and pollutants across the Salt Lake Valley from the first year of operations.

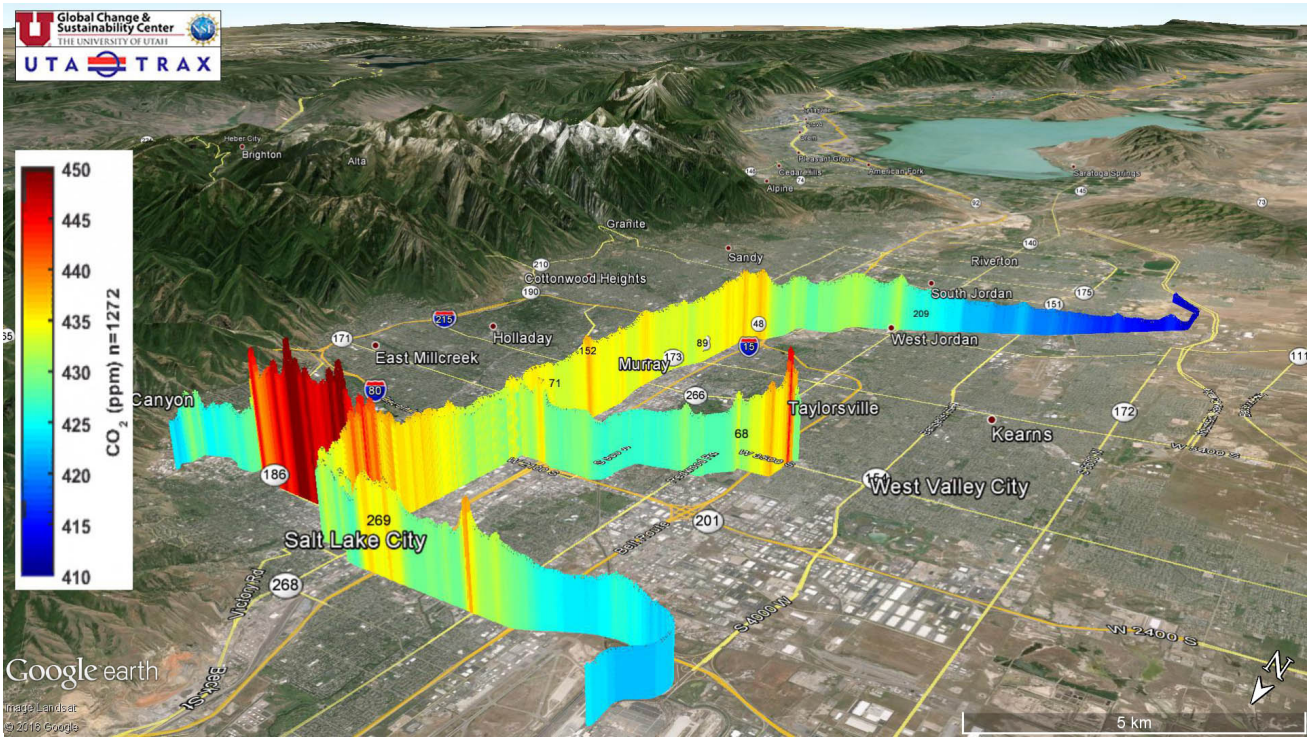

Figure 1. Preliminary observations of the spatio-temporal average CO_2 mixing ratios across the Salt Lake metropolitan area (averaged over Dec 2014 to Nov 2015).

Imprint of Urban CO_2 Emissions Detected by OCO-2 Observations of Total Column CO_2

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Independent verification of carbon dioxide (CO_2) emissions over urban area is a critical need for implementing effective mitigation strategies of CO_2 emissions from fossil-fuel energy consumption. With global coverage, space-based observations of total column averaged CO_2 concentration (XCO_2) are expected to have an important role in constraining the surface CO_2 fluxes using atmospheric inversion methods. Although the potential of satellite XCO_2 retrievals for global or regional scale flux inversions has been examined based on assimilation of realistic observations as well as observation system simulating experiments, only few studies demonstrated their potential applicability at urban scale. In this study, we investigate the potential of XCO_2 measurements retrieved from the NASA Orbiting Carbon Observatory-2 (OCO-2) in the context of multi-city inversions of CO_2 emissions for Riyadh, Cairo, and Los Angles. Enhancements in XCO_2 induced by urban fossil-fuel CO_2 emissions and atmospheric transport are examined through OCO-2 retrievals and compared to that from forward transport model simulations using the Weather Research and Forecasting model with chemistry (WRF-Chem) and the Open-source Data Inventory for Anthropogenic CO_2 (ODIAC). By simulating urban CO_2 plumes for different meteorological conditions, we evaluate the availability of OCO-2 retrievals for detecting urban emission signals. Taking transport model error and boundary inflow into consideration, we discuss the implications of the detected signals on constraining urban fossil-fuel CO_2 emissions and its potential for trend detection at the city scale.

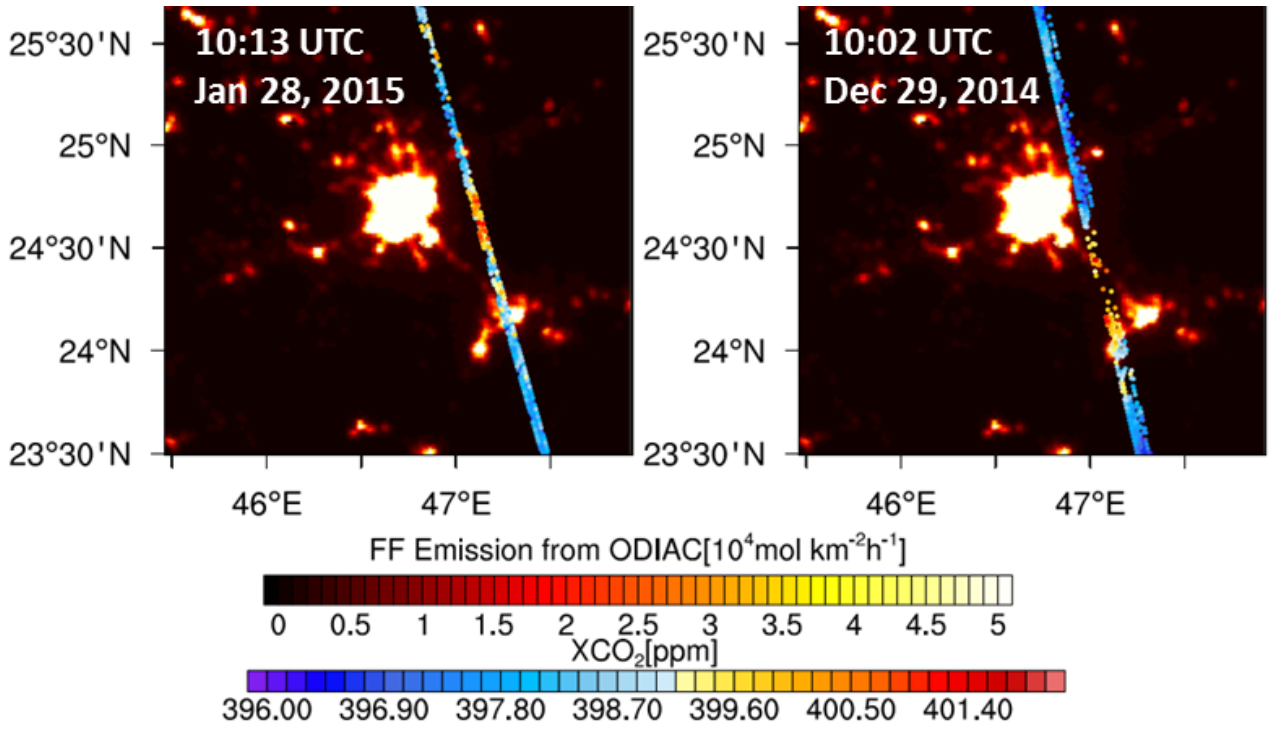

Figure 1. OCO-2 XCO_2 observations overpassing Riyadh, Saudi Arabia at about 10:13 UTC January 28, 2015 and 10:02 UTC December 29, 2014 and maps of urban CO_2 emissions for corresponding months derived from the Open-source Data Inventory for Anthropogenic CO_2 (ODIAC).

Atmospheric Carbon and Transport – America: A NASA Earth Venture Mission Dedicated to Improving the Accuracy, Precision and Resolution of Atmospheric Inverse Estimates of CO_2 and CH_4 Sources and Sinks

K.J. Davis[1], D.F. Baker[2], J. Barrick[3], J. Berry[4], K. Bowman[5], E. Browell[3], L. Bruhwiler[6], A. Chatterjee[7], G. Chen[3], H. Chen[1], Y. Choi[3], S. Crowell[8], A. Deng[1], S. Denning[9], L. Diaz-Isaac[1], J. DiGangi[3], J. Dobler[10], S. Feng[1], B. Gaudet[1], A. Jacobson[11,6], K. Keller[1], T. Lauvaux[1], B. Lin[3], M. McGill[7], B. Meadows[3], A. Michalak[4], N. Miles[1], J.B. Miller[6], B. Moore[8], A. Nehrir[3], L. Ott[7], M. Obland[3], C.W. O'Dell[2], S. Pal[1], R. Pauley[7], S. Pawson[7], G. Petron[11,6], S. Richardson[1], A. Samaddar[1], A. Schuh[9], D. Stauffer[1], C. Sweeney[11,6], P.P. Tans[6], Y. Wei[12], D. Wesloh[1], M. Xue[8] and F. Zhang[1]

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The Atmospheric Carbon and Transport-America (ACT-America) mission will demonstrate a new generation of atmospheric inversion systems for quantifying CO_2 and CH_4 sources and sinks at regional scales to 1) evaluate and improve terrestrial carbon cycle models, and 2) monitor carbon fluxes. ACT-America will deploy two instrumented aircraft to observe how mid-latitude weather systems interact with CO_2 and CH_4 sources and sinks to create atmospheric CO_2/CH_4 distributions on five 6-week campaigns across four different seasons and 3 years (2016-2019). A model ensemble will be used to predict CO_2 and CH_4 distributions. We will prune model ensemble to those members best able to simulate the measured CO_2 and CH_4 distributions. The pruned ensemble will form the basis of the next generation of atmospheric inversion systems.

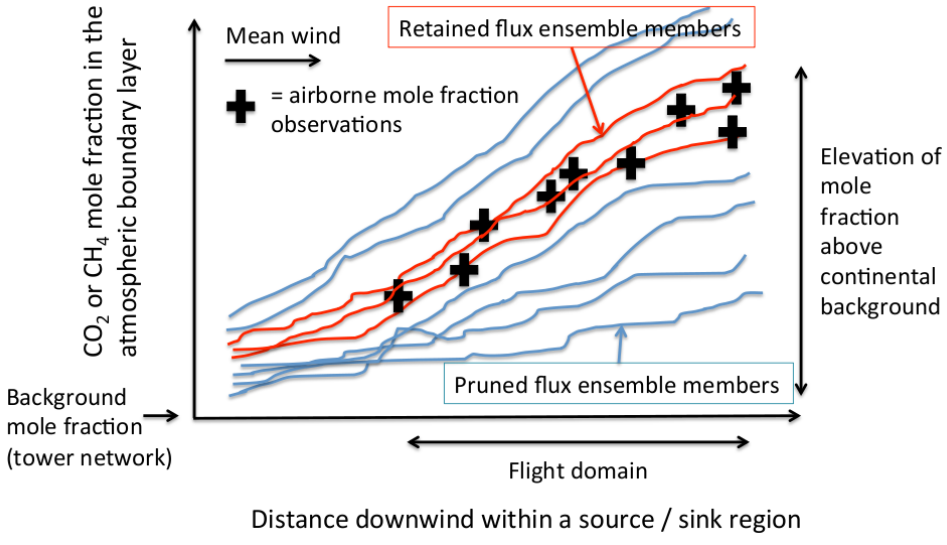

Figure 1. Conceptual model of how ACT-America airborne measurements will aid in refining atmospheric inversion modeling systems.

Using *In Situ* CO_2 Measurements to Help Understand GOSAT and OCO-2 Column CO_2 Retrievals

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In situ measurements of atmospheric carbon dioxide (CO_2) have provided much of our understanding of the workings of the global carbon cycle (GCC). However, we still do not understand which processes are most important in driving the observed interannual variability of the GCC; as a result, it is unlikely we will be able to predict accurately its response to climate change in the future. We lack insight into these processes because we lack information on fluxes at the regional scales at which they operate, because of the sparse coverage of *in situ* CO_2 measurements over much of the globe. Measurements of CO_2 from satellite are meant to provide the spatial and temporal coverage to surmount this problem.

Measuring CO_2 from space at the required sub-ppm accuracy is challenging: radiative transfer must be modeled, including scattering from clouds and aerosols, and systematic errors can occur. To help understand such errors, we compare retrievals of column CO_2 from the GOSAT and OCO-2 satellites to corresponding values from a suite of forward transport model runs forced to agree with *in situ* CO_2 data. We present the CO_2 fluxes obtained when the satellite CO_2 data are assimilated with global atmospheric transport models, show how they vary when errors in the satellite data are corrected, and compare them to fluxes implied by the surface CO_2 data.

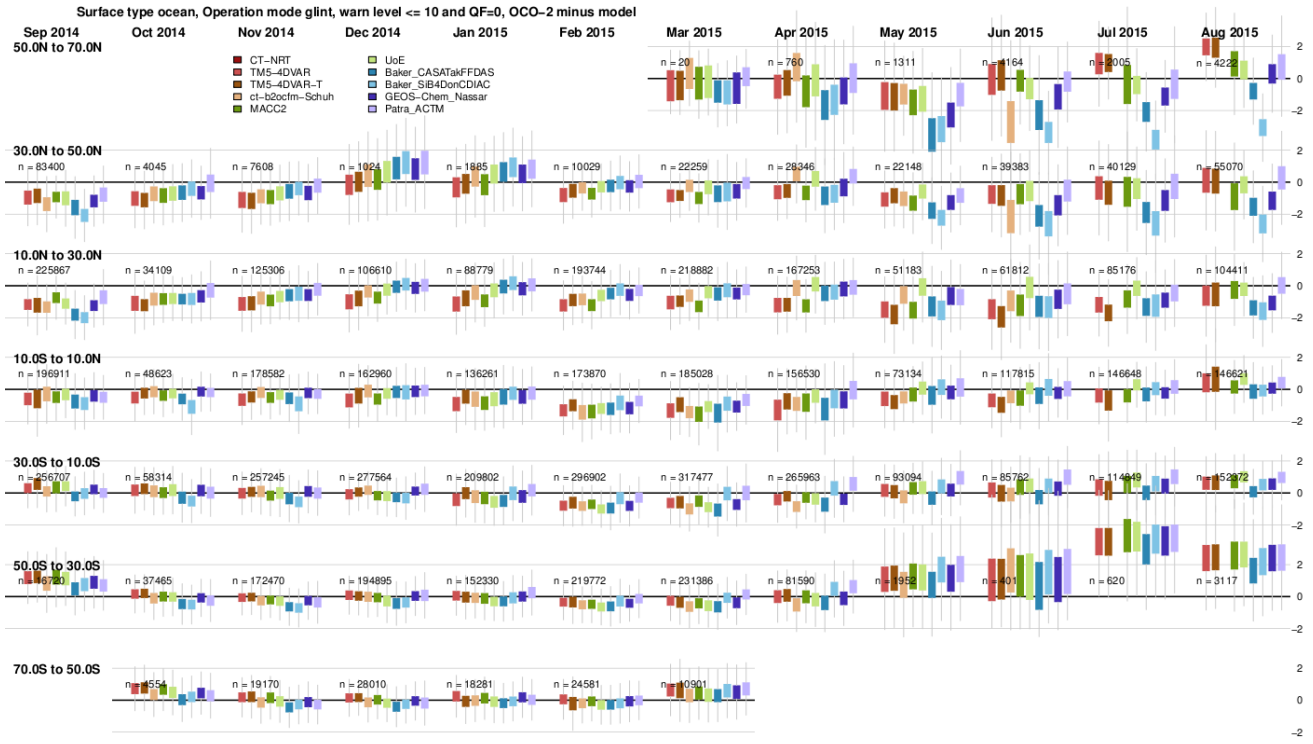

Figure 1. The difference [ppm] between column dry air mixing ratio of CO_2 (X_{CO2}) retrieved by the OCO-2 satellite in ocean glint viewing mode and corresponding values from a suite of atmospheric transport model runs forced to agree with *in situ* CO_2 data, averaged across months and latitude bands. Hints of a positive bias in the OCO-2 data at high solar zenith angles emerge.

A Multi-sensor Approach to Cloud and Aerosol Detection in Support of OCO-2 XCO_2 Retrieval Validation

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The Orbiting Carbon Observatory-2 (OCO-2) satellite is the first dedicated to remote sensing of carbon dioxide. Accurate measurements of the column-averaged dry-air mole fraction of carbon dioxide (XCO_2) require scenes that are sufficiently clear of scattering material, making effective cloud and aerosol screening very important. The strategic placement of OCO-2 in the A-Train satellite constellation allows co-located comparisons with other instruments that have effective cloud and aerosol detection capabilities. This work uses both the Moderate Resolution Imaging Spectrometer (MODIS) aboard the Aqua platform and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) lidar aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite to evaluate OCO-2 cloud screening.

Using a customized cloud mask derived from the MODIS cloud product for four 16-day periods in winter (December) and spring (April-May), Taylor et al. [AMT, 2016] found approximately 85% agreement in cloud detection between OCO-2 and MODIS. Disagreement between the sensors was separated into two cases with approximately 10% of soundings identified as clear by MODIS and cloudy by OCO-2 (Type 1 error) and approximately 5% identified as cloudy by MODIS and clear by OCO-2 (Type 2 error).

Our goal is to understand and characterize these cloud detection discrepancies by adding CALIOP cloud and aerosol measurements to this analysis. Specifically, we seek to answer the following questions:

1. For Type 1 error soundings where the OCO-2 cloud screeners identify a cloud while MODIS says it is clear, should the sounding be passed into the retrieval algorithm?
2. In cases of Type 2 error where MODIS identifies a cloud but OCO-2 identifies a clear scene, which MODIS cloud flags contribute to this conclusion?
3. What is the quality of the OCO-2 XCO_2 retrieval in areas of Type 2 error?

This work provides preliminary responses to these questions based on an in-depth case study analysis.

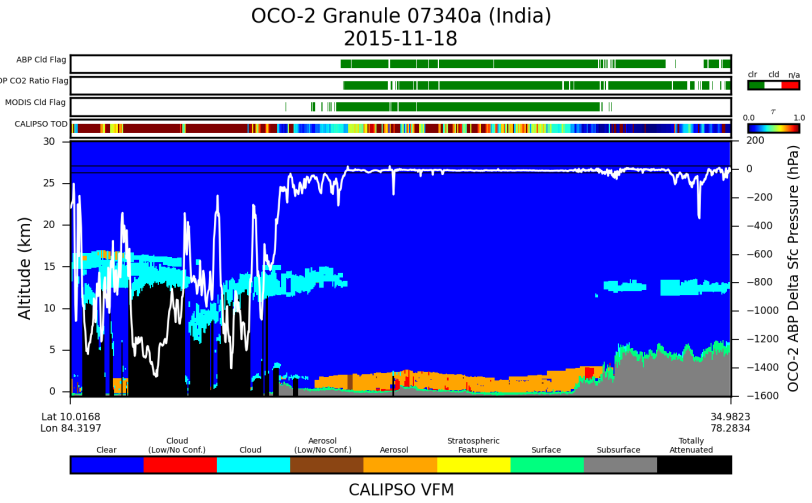

Figure 1. CALIPSO Vertical Feature Mask and 5-km Total Optical Depth, OCO-2 ABP and IDP cloud screening flags and delta surface pressure, and custom MODIS cloud flag from Taylor et al. [AMT, 2016]

Toward Continuous Monitoring of Climate Pollutant Emissions at Site- to Regional- Scales

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Continuous, high-precision monitoring of anthropogenic emissions of climate pollutants faces tradeoffs between cost, coverage and precision. This is particularly true for the detection of methane leaks that can occur during natural gas production, processing, and distribution. Large-scale, continuous monitoring of atmospheric methane by satellite or as part of the NOAA/ESRL network of tall-tower sampling provides invaluable information about regional methane concentrations, but tools do not currently exist for attributing atmospheric enhancements at large scales to leaks at individual sites or facilities. On the other hand, high-intensity measurement campaigns, using point sensor or LIDAR measurements of methane at or near natural gas facilities can provide high-fidelity leak detection and sizing, but the cost and man-power requirements of such campaigns preclude them from being reasonable long-term solutions for continuous monitoring. We present a new solution for methane leak monitoring that can provide continuous, long-term, and high-precision monitoring of all natural gas facilities within a >12 km^2 area with one instrument, leading to relatively low per-site costs. We position a dual-frequency comb spectrometer (DCS) in the center of a field of gas wells, and orient retroreflectors (small reflective mirrors) 0.1 to 2+ km away from the DCS in the area of well sites to be monitored. We measure atmospheric methane with the DCS by sending light to the retroreflectors at many near-infrared wavelengths where methane is known to absorb. The laser light is reflected back to a detector co-located with the spectrometer, and the measured absorption is used to infer the average methane concentration along the length of the beam path (from the spectrometer to the retroreflector). Recent measurements with the DCS indicate a measurement precision of approximately 4 ppb-km (precision scales with the length of the light path) for a measurement averaged over 90 seconds. A separate sensor provides 2-D wind speed and wind direction data as DCS measurements are taken, such that atmospheric inversions can be performed with an atmospheric transport model based on the local meteorological data. Initial tests of this novel measurement configuration using synthetic data with real noise parameters have shown the ability of the system to accurately locate and size leaks of 3.17E-5 kg/s within an 18-day period. We will present our observing system design configuration, background estimation methods, inversion methodology, and results of synthetic data testing at the Boulder Atmospheric Observatory site, where we will begin taking measurements of controlled methane releases in summer 2016.

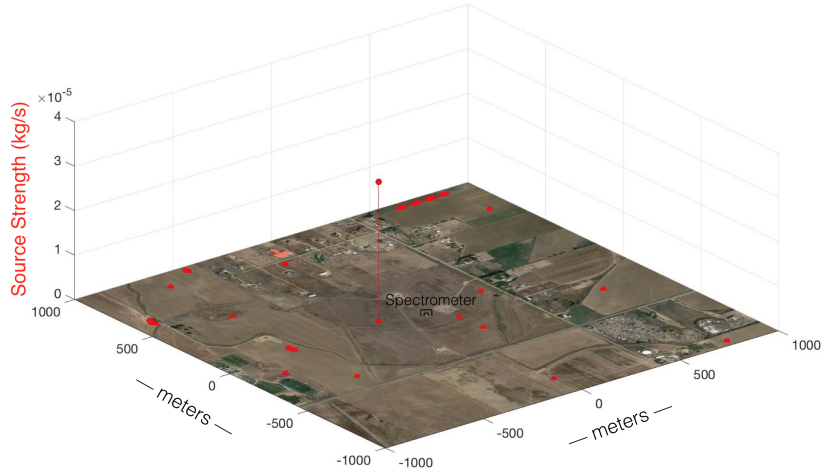

Figure 1. Natural gas wells (red points) in a 2km x 2km area near the BAO site in Erie, Colorado (data from the Colorado Oil & Gas Conservation Commission). The strength of a theoretical leak is shown on the vertical axis. Such a leak would be detectable using a system of retroreflectors and 1 spectrometer (shown as a box in the middle of the domain).

Reconstructing Urban Fossil Fuel Carbon Dioxide emissions Utilizing the Radiocarbon Composition of Tree Rings from the Wellington Region, New Zealand

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This study demonstrates the utility of tree ring radiocarbon analysis to quantify a temporal record of recently-added fossil fuel-derived carbon dioxide (CO_{2ff}) in the urban atmosphere, to retrospectively measure emissions and potentially validate local emissions inventories. Measurements of the carbon-14 (^{14}C) content of cellulose from the annual tree rings of a Kauri tree (*Agathis australis*), located in the downtown area of the Wellington suburb of Lower Hutt, have been used to reconstruct a retrospective record of CO_{2ff}. We compare this record with tree rings from two Kauri located at a nearby coastal site and the long-term clear air $^{14}CO_2$ record from Baring Head, 11km from the test site.

This study showed increasing trends of CO_{2ff} over time at the urban location, which becomes apparent from the mid-1980s. The observations were compared qualitatively with meteorological data and socioeconomic variables (census tract, population and vehicle statistics) to assess mechanisms of variability of CO_{2ff}. With this study we aim to demonstrate how this technique can be used to assist municipalities to ensure accurate emissions quantification, allowing appropriate reduction and development strategies to be established.

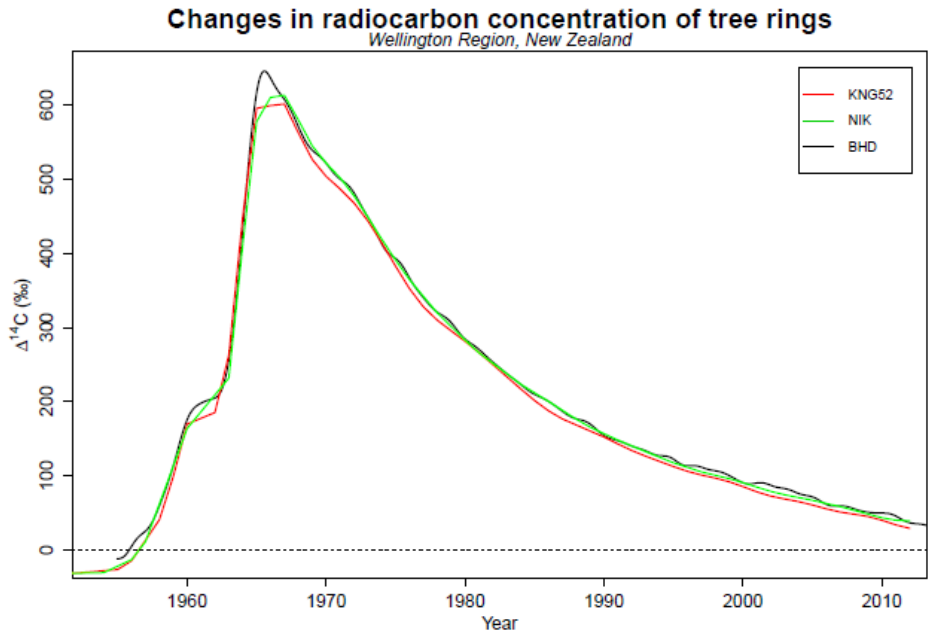

Figure 1. $\Delta^{14}CO_2$ of urban tree rings (KNG 52; red) compared with the Baring Head clean air record (BHD; black) and tree ring measurements representative of background atmosphere (NIK; green). The KNG52 record exhibits a decrease in $\Delta^{14}CO_2$ corresponding to an increase in ^{14}C-depleted fossil fuel emissions in the Wellington Region, New Zealand. Pre-1960, a natural level of ^{14}C existed – with cosmogenic production balancing radioactive decay. The "bomb spike" produced by atmospheric weapons testing occurs at 1965 due to the site location in the Southern Hemisphere. The post-bomb era sees uptake of bomb ^{14}C by oceans and terrestrial biosphere. Additions of ^{14}C-depleted CO_{2ff} becomes dominant in the KNG52 record from 1980 onwards.

Influence of Subgrid Terrain Variability on Simulated Planetary Boundary Layer Depths in Large-scale Transport Models

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The difficulty of modeling atmospheric transport and mixing processes introduces significant uncertainties in the fluxes estimated with inverse carbon transport models. An important diagnostic for vertical transport and mixing is the planetary boundary layer (PBL) depth, the height above the surface up to which surface fluxes of heat, moisture, momentum, and trace gases such as carbon dioxide (CO_2) are transported and mixed on a diurnal time scale. Current transport models used for CO_2-flux estimations are typically run on coarse grid spacing and therefore may miss terrain information needed for a correct CO_2-budget estimation. In an effort to reduce the uncertainty in these large-scale transport models, we compare the PBL depths from a Weather Research and Forecasting (WRF) simulation with coarse grid spacing ('coarse' simulation) with PBL depths from a WRF simulation with fine grid spacing ('fine' simulation) for the same domain size. We focus on a domain with considerable terrain height variability in and around the Salt Lake Valley area and examine the influence of the terrain variability on the PBL depth. We also perform a comparison with PBL depths observations and with PBL depths simulated using TM5, the transport model currently used in CarbonTracker. For a case study (Figure 1), differences in PBL depth between the 'coarse' and the 'fine' simulations become smaller with an increase in terrain height variability. In other words, PBL depth differences are largest for relatively flat terrain in this particular case study. In the poster, we will compare the results of this case study with results for a 2-year period from June 2012 to June 2014. We will also demonstrate the importance of understanding spatio-temporal variability and representativeness of PBL depths over complex terrain for carbon cycle studies.

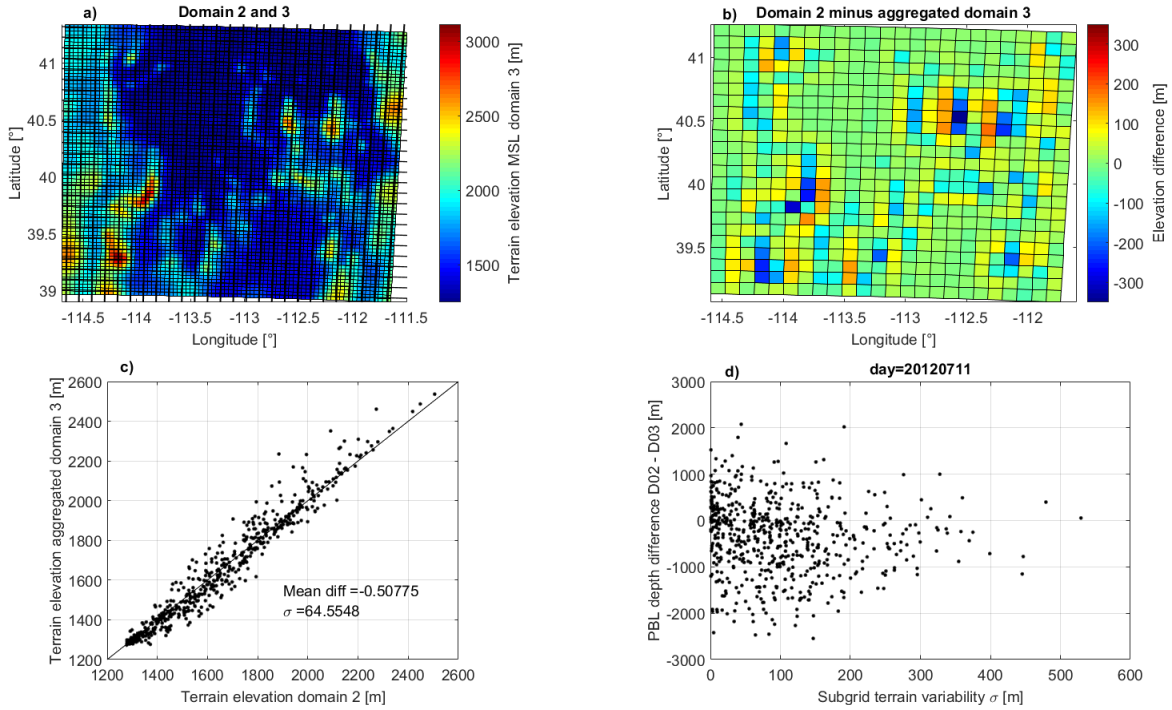

Figure 1. WRF model terrain height and its impact on PBL-depth for the Salt Lake valley area. a): Grid cell representation of domain 2 (thick lines, 10x10 km) and its aggregated domain 3 (thin lines, 3.3x3.3 km). b) and c): Terrain elevation difference between coarse and fine grid spacing (ratio 1:3) where domain 3 is aggregated to domain 2. d) The impact of subgrid terrain variability on afternoon PBL-depth.

Sensitivity and Uncertainty Analysis of Physical Parameterization and Initial Conditions on Meteorological Variables and CO_2 Mole Fractions

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Atmospheric transport model errors are one of the main contributors to the uncertainty affecting CO_2 inverse flux estimates, but have not been quantified thoroughly. This study aims to assess the transport errors over the Mid-Continental Intensive domain with an ensemble of simulations created with the Weather Research and Forecasting (WRF) mesoscale model using different physical parameterizations (e.g., planetary boundary layer (PBL) schemes and land surface models (LSMs), cumulus parameterizations and microphysics parameterizations). Modeled meteorological variables and atmospheric CO_2 concentrations were compared to observations (e.g., radiosondes and CO_2 mixing ratio towers) during the summer of 2008. The model-data mismatch for several meteorological variables (i.e., wind speed, wind direction and PBL height) was used to examine the spread of the ensemble and identify the model configurations that were systematically biased. Then we present a study of the sensitivity of atmospheric conditions to the choice of physical parameterization, to identify the parameterization driving the model-to-model variability in atmospheric CO_2 concentrations at the mesoscale over the MCI domain. Preliminary results show that wind speed and wind direction are influenced by choice of PBL schemes, whereas the PBL height bias is influenced by the choice of PBL scheme and LSM. Finally, our sensitivity test shows that all physical parameterizations drives the model-to-model variability in atmospheric CO_2 concentrations except for the microphysics parameterization. Future work will be to describe these transport errors in the regional atmospheric inversions using this ensemble, for the year of 2008.

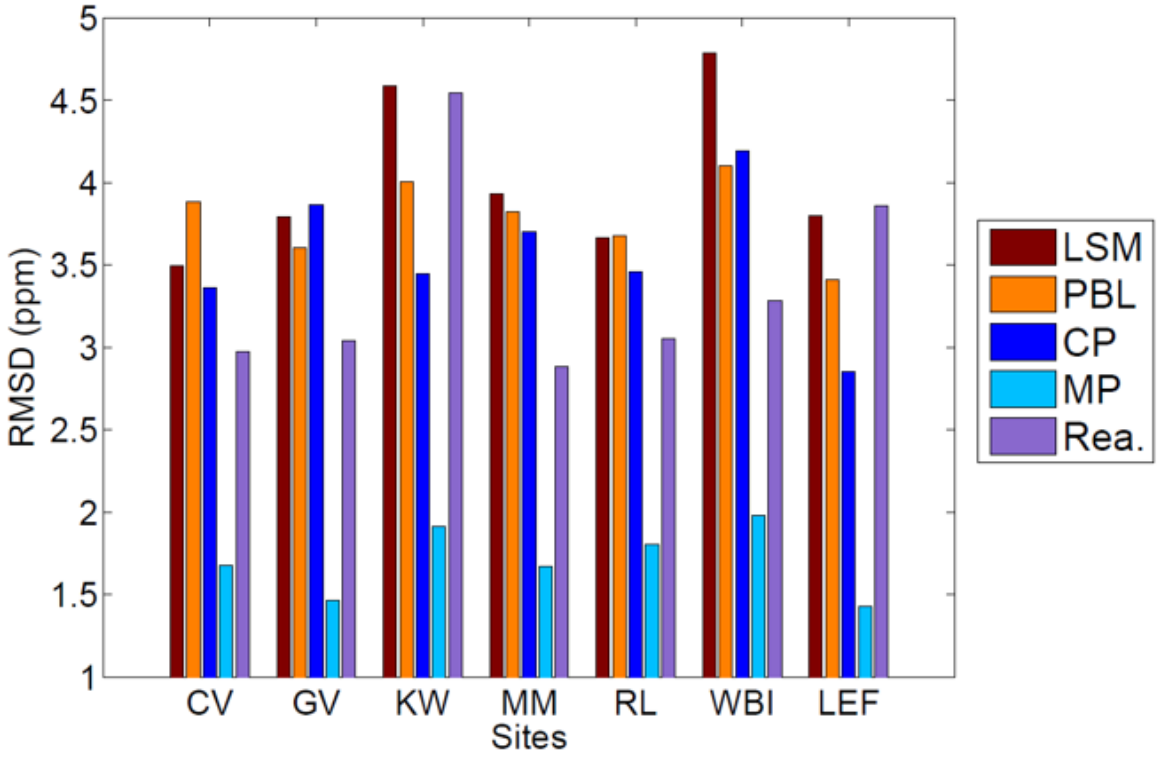

Figure 1. Root mean square difference (RMSD) of the CO_2 mixing ratio for each of the physical parameterizations (e.g., planetary boundary layer (PBL) schemes and land surface models (LSMs), cumulus parameterizations (CP) and microphysics parameterizations (MP)) and reanalysis.

Assimilation of GOSAT XCO_2 Retrievals in CarbonTracker

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[2]National Institute of Meteorological Research, Jeju, South Korea

In this study, surface carbon dioxide (CO_2) fluxes were estimated by assimilating column-averaged dry air mole fraction (XCO_2) of satellite-based CO_2 measurements into the CarbonTracker (CT2013B) which is an inverse modeling system for estimating surface CO_2 flux based on an ensemble Kalman filter. The XCO_2 used was derived from Atmospheric CO_2 Observations from Space retrievals of the Greenhouse Gases Observing SATellite (ACOS-GOSAT). The inversion experiments were conducted with and without GOSAT XCO_2 retrievals in addition to conventional surface CO_2 concentration measurements.

Figure 1 shows the average biosphere and ocean CO_2 fluxes from July 2009 to May 2010. The results show that the global balance of sources and sinks of surface CO_2 fluxes was maintained for the experiments with and without GOSAT XCO_2, whereas the magnitudes of the optimized surface CO_2 fluxes in subcontinental regions were changed. The surface CO_2 uptake over Europe increased, whereas the surface CO_2 uptake in Eurasian Boreal (Northern part of Asia continent) decreased. These results are consistent with the previous studies using GOSAT XCO_2 retrievals to estimate surface CO_2 fluxes. The modeled XCO_2 simulated by the optimized surface CO_2 fluxes with GOSAT XCO_2 were more consistent with the GOSAT XCO_2 compared to the modeled XCO_2 without GOSAT XCO_2, which implies that data assimilation system developed for satellite observations performed appropriately.

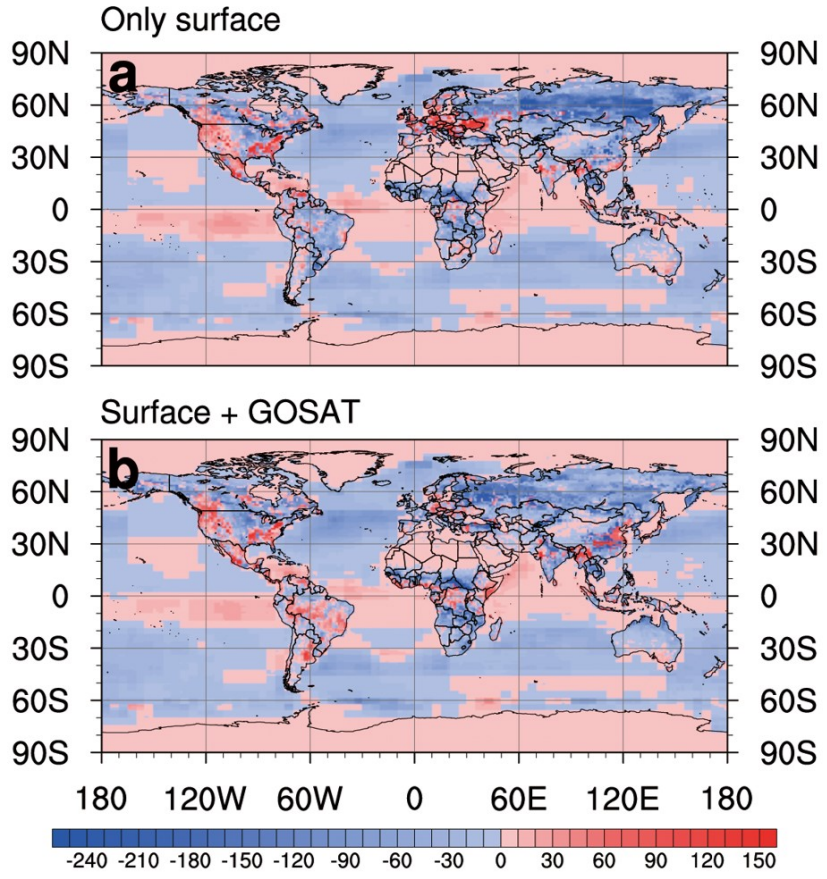

Figure 1. Average biosphere and ocean CO_2 fluxes (gC m^{-2} yr^{-1}) from July 2009 to May 2010 inferred from (a) only conventional surface CO_2 concentration observations and (b) GOSAT XCO_2 retrievals in addition to conventional surface CO_2 concentration observations.

A Re-examination of the WMO X2007 CO_2 Calibration Scale

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The NOAA ESRL/GMD serves as the Central Calibration Laboratory for the World Meteorological Organization (WMO) Global Atmospheric Watch program for carbon dioxide (and other greenhouse gases). The WMO carbon dioxide (CO_2) scale is defined and maintained using an absolute manometric method. Certified reference materials are provided to WMO partners, with values assigned relative to a well-defined reference scale, known as WMO-CO2-X2007. In 2016 we will participate in a comparison among National Metrology Institutes (NMI) to compare different mole fraction scales, or primary reference standards. In preparation for that comparison, we have started to re-examine our methods and associated uncertainties. We have recently discovered that CO_2 appears to be diffusing across an o-ring seal during measurement of the pressure and temperature of the extracted CO_2 sample, a critical step in the manometric process. While we believe that current measurements are consistent with the X2007 scale, the loss of CO_2 may indicate a small bias in the scale. Based on the example shown in the Figure, the correction to the WMO scale at 380 ppm would be about +0.08 ppm. However, the correction will be mole fraction dependent because the loss rate is mole fraction dependent, and may have changed with time. We first need to establish a consistent method for reprocessing historical data, and apply that method to data going back to the mid-1990s. We will present preliminary results from a re-evaluation of our methods and uncertainties, and possibly propose a X2016 scale revision. Any scale revision would likely be minor (~0.1 ppm) but could be important with respect to comparison with NMIs.

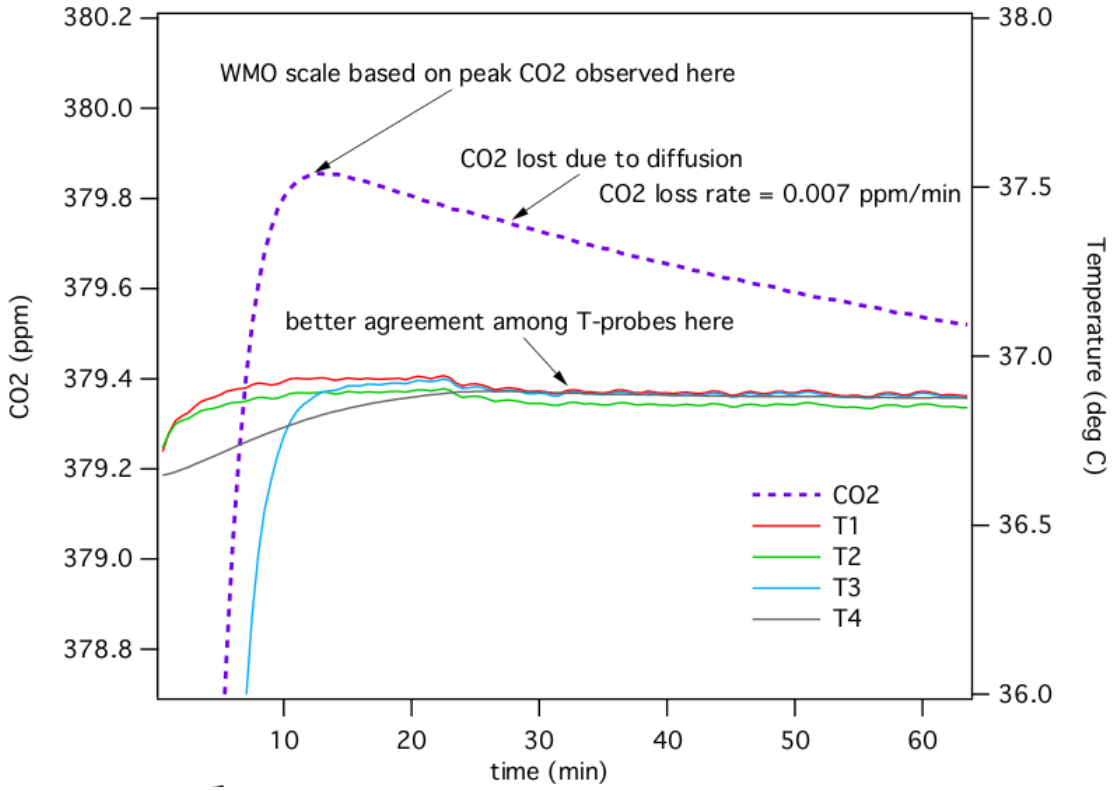

Figure 1. Calculated CO_2 and observed temperature during the final step in the determination of the mole fraction of CO_2 in air using the NOAA manometer. A small amount of CO_2 is likely lost prior to the "peak" CO_2, which forms the basis for the WMO CO_2 scale. A minor scale update may be necessary.

Ensuring High-quality Data from NOAA's Cooperative Global Air Sampling Network

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The GMD Carbon Cycle Greenhouse Gases (CCGG) group Cooperative Global Air Sampling Network collects weekly air samples from ~60 sites. This global network spans in latitude from the South Pole (90°S) to Alert, Canada (82.45°N). Nearly all studies of global budgets of carbon dioxide (CO_2), methane (CH_4),nitrous oxide (N_2O), sulfur hexafluoride (SF_6), and carbom monoxide (CO) include observations from this network. To be most effective, the data must be spatially and temporally consistent.
In 2015, more than 6,000 discrete air samples collected in flasks were measured for atmospheric CO_2, CH_4, CO, hydrogen (H_2), N_2O, and SF_6. Data quality assurance (QA) and quality control (QC) are a fundamental part of our long-term data records. QA is performed in the CCGG measurement lab with daily control flasks, weekly field samples, short-term target tanks analyzed every two weeks, and long-term target tanks analyzed twice per year. QC is completed with software developed in CCGG to look at raw analysis files, time series plots, and trend plots. These tools, and other plotting routines, help us identify sample collection problems (Fig. 1). Following QC, statistical methods are used to ensure data are representative of large well-mixed volumes of the atmosphere. This presentation will discuss our QA/QC strategies and findings.

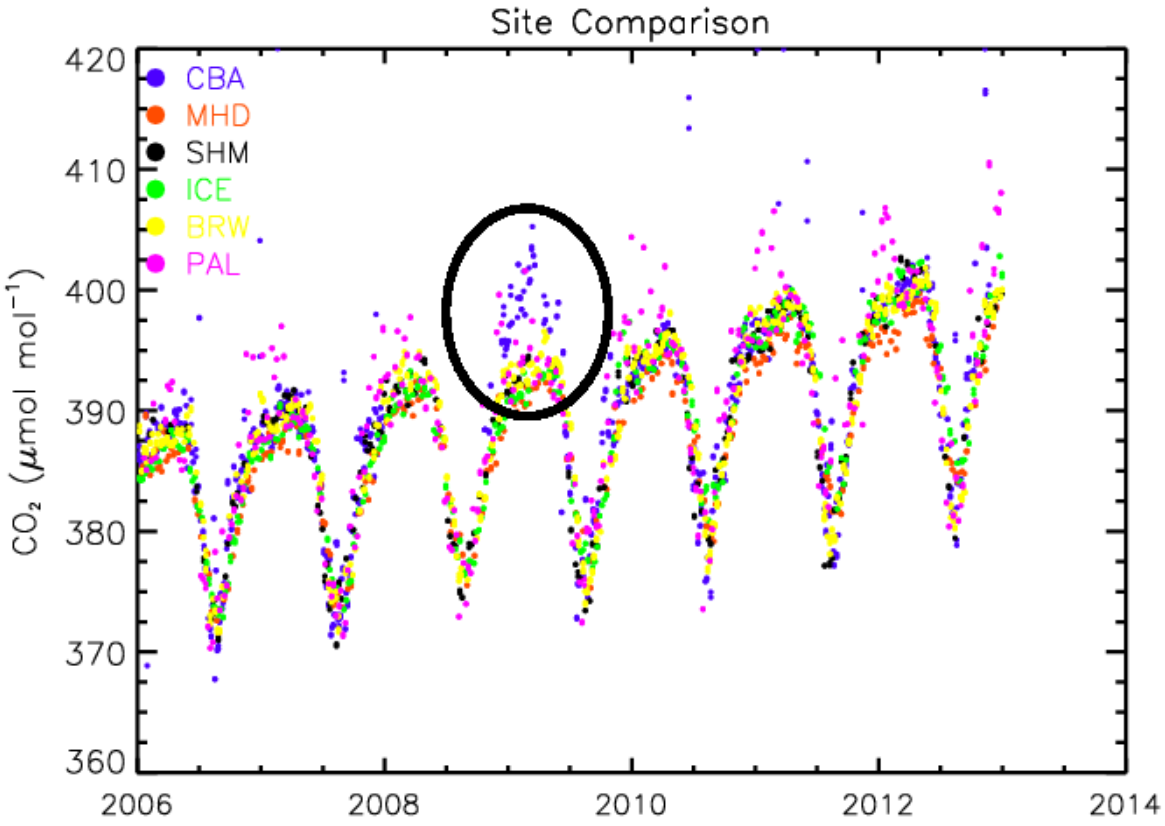

Figure 1. GMD measurements of CO_2 at Cold Bay, Alaska (CBA), Mace Head, Ireland (MHD), Shemya Island, Alaska (SHM), Storhofdi, Iceland (ICE), Barrow, Alaska (BRW), and Pallas-Sammaltunturi, Finland (PAL). Sample collection problem at CBA is circled in black.

Comparison of CH_4 Monitoring Methods at GEOSummit

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Our understanding of the global methane (CH_4) budget continues to have large uncertainties as methane is affected by both natural and anthropogenic sources that vary spatially and with time. Arctic observations of atmospheric methane are considered a critical component in deciphering the global methane budget and for investigating the potential for increasing methane sources in the Arctic rising from permafrost thawing. This study compares three independent atmospheric methane monitoring projects at the Greenland Environmental Observatory, Summit Station (GEOSummit), to determine consistency between measurements and for evaluation of research applications from these parallel data sets. The three methods are 1) *in situ* gas chromatography-flame ionization detection (GC-FID) with 2-3 hour time resolution conducted by the Institute of Arctic and and Alpine Research (INSTAAR), 2) *in situ* gas chromatography (GC) with electron capture detection (ECD) with 1-hour time resolution on the ESRL/GMD Halocarbons And other Trace Species (HATS) GC, and 3) GC-FID analysis of bi-weekly whole air samples collected within the NOAA GMD Global Greenhouse Gas Reference Network (GGGRN) after shipment to Boulder, CO. Monthly medians/averages from these different monitoring methods agree by -0.3 ± 2.8 nmol mol^{-1} (mean±1s), and trends derived from the data to within 0.2 nmol mol^{-1} yr^{-1}. The higher time resolution *in situ* data show enhancements and reductions in methane on the order of 30-40 nmol mol^{-1} from mean seasonal methane levels, illustrating the influence of transport of air from different source regions with elevated/depleted methane to Summit.

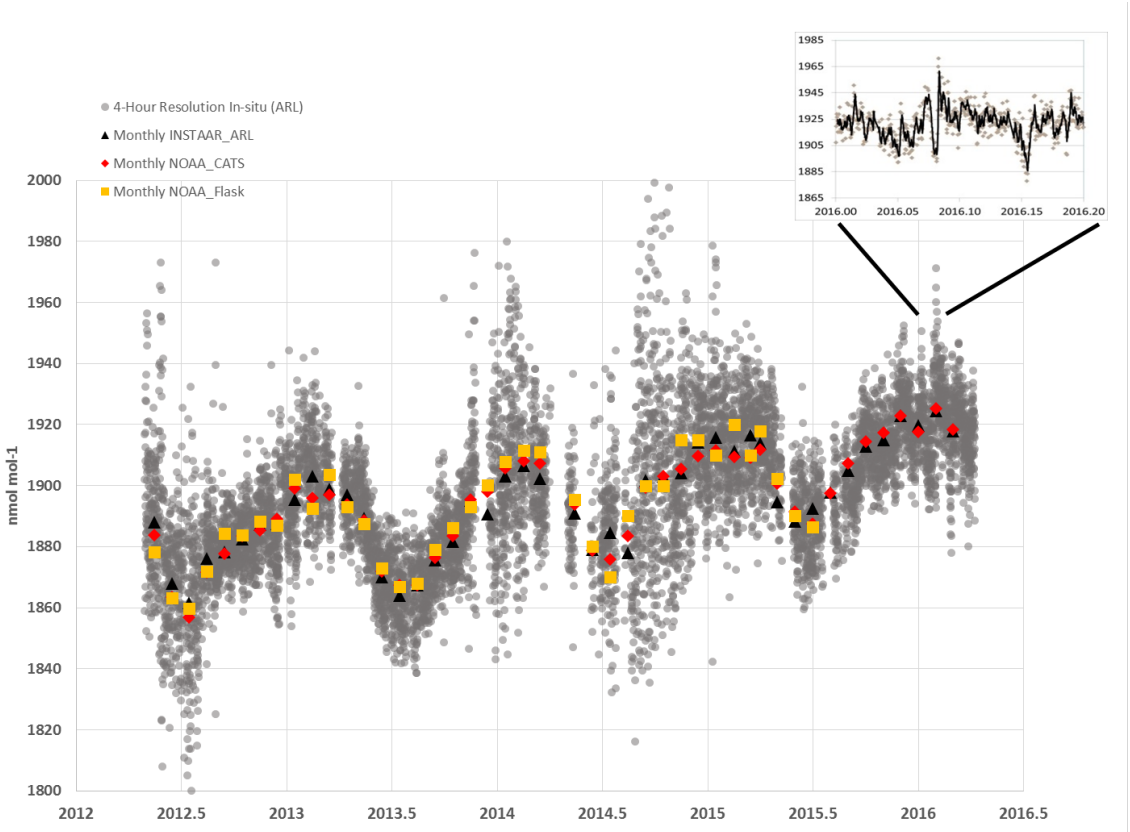

Figure 1. Monthly medians of methane by three measurement methods, underlain by 4-hour resolution *in situ* INSTAAR data, at GEOSummit from 2012 to mid 2016.

Characteristics of Atmospheric CO_2 and CH_4 at the Shangdianzi Regional Background Station in China

M. Liang

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Atmospheric carbon dioxide (CO_2) and methane (CH_4) have been continuously measured at the Shangdianzi regional background station (SDZ) in China from 2009 to 2013. Based on the influences of local surface wind and long-distance transport, the observed records were flagged into locally influenced, Beijing-Tianjin-Hebei (BTH) influenced, and Russia, Mongolia, and Inner Mongolia autonomous region (RMI) influenced. ~ 81.4% of CO_2 and ~75.6% of CH_4 mole fractions were flagged as locally representative, indicating that the atmospheric CO_2 and CH_4 at SDZ were strongly influenced by local sources and sinks. Cluster analysis of back trajectories proved that the atmospheric CO_2 and CH_4 were influenced by air masses from northwest (RMI) or from south and southeast (BTH). The CO_2 and CH_4 mole fractions in BTH are always higher than in RMI, with the largest difference of 11.5 ± 0.3 ppm for CO_2 and 102 ± 1 ppb for CH_4 in July. The annual growth rates of CO_2 and CH_4 in BTH are 3.8 ± 0.01 ppm yr^{-1} and 10 ± 0.1 ppb yr^{-1}, respectively, which are apparently higher than those of the RMI and the global means. The long-term trends of CO_2 and CH_4 in BTH are deviating from those in RMI, with ratios of ~1.0 ppm yr^{-1} for CO_2 and ~2 ppb yr^{-1} for CH_4, indicating the strength of CO_2 and CH_4 emission in Beijing-Hebei-Tianjin plain increased more than 20% every year.

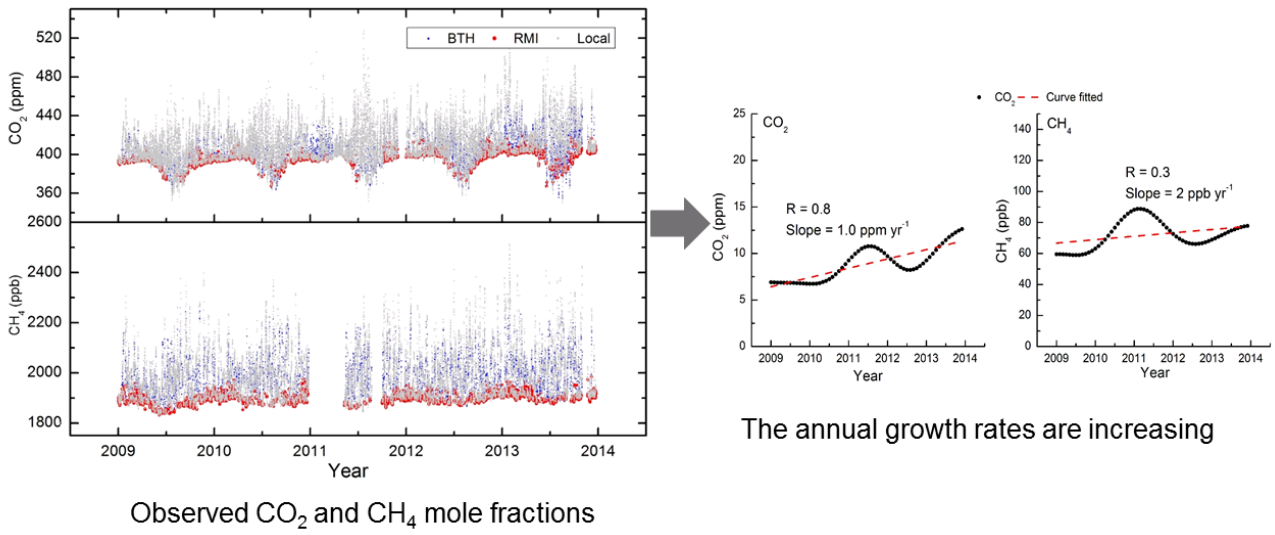

Figure 1. Shangdianzi Station (SDZ) in northeast China. Left: Observed CO_2 and CH_4 mole fraction. Right: The annual growth rates are increasing.

A Compact Cavity Ring-down Spectroscopy Analyzer for *In Situ* Measurements of Carbon Dioxide, Methane, and Water Vapor

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High-quality measurements of greenhouse gases in remote locations require instruments that are precise, versatile, robust, and most importantly have power requirements that are not as limited by location, i.e. low enough power consumption to run off of batteries or even solar array. Here we present a battery-operated, full greenhouse gas analyzer that utilizes a novel method of Cavity Ring-Down Spectroscopy (CRDS) to measure carbon dioxide (CO_2), methane (CH_4) and water vapor (H_2O). The instrument consumes only 25 W and still maintains long-term stability to allow for averaging time of over 3 hours. Measurements have a 1-σ precision of 30 ppb for CO_2 and 300 ppt of CH_4 with 5 minutes of averaging; and with measurements of 3-hour averages reaching precisions down to 40 ppt of methane. Additionally, this new flavor of CRDS has allowed for an overall increase in measurement dynamic range from traditional Continuous-Wave Cavity Ring-Down Spectroscopy (CW-CRDS) measuring methane up to 1000 ppm and carbon dioxide up to several percent. We will present supplemental data acquired using this <11 kg analyzer, including soil respirations using closed static chambers and 10m tower measurements from Santa Clara, CA.

Figure 1. Picarro G4301 Compact CO_2/CH_4 Analyzer

Integrated Path Differential Absorption (IPDA) LIDAR Measurement of CO_2, CH_4, and H_2O

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We present Integrated Differential Absorption (IPDA) LIDAR measurements of carbon dioxide (CO_2), methane (CH_4), and water (H_2O) using a ground-based system developed at the National Institute of Standards and Technology (NIST). The transmitter of the system is based on an external cavity diode laser (ECDL) which is spectrally filtered, rapidly scanned using electro-optic sidebands, and amplified using a booster optical amplifier. The transmitter is operating at eye-safe power levels. The tuning range covers 37.5 GHz across absorption features of CO_2, CH_4, and H_2O in the wavelength region of 1602 nm and 1645 nm.

Nighttime IPDA LIDAR measurements of CO_2, CH_4, and H_2O over a path length of 5.5 km were performed in October 2015 in Boulder, CO, USA. Simultaneously, the atmospheric boundary layer was monitored during the IPDA LIDAR measurements using a backscatter LIDAR at 1064 nm. IPDA LIDAR concentrations of CO_2, CH_4, and H_2O were compared with those obtained from a commercial cavity ring-down instrument (Picarro G2301 [(*)]).

Further details of the IPDA LIDAR system and measurements will be presented at the conference.

[(*)] Certain equipment, instruments or materials are identified in this paper in order to adequately specify the experimental details. Such identification does not imply recommendation by the National Institute of Standards and Technology nor does it imply the materials are necessarily the best available for the purpose.

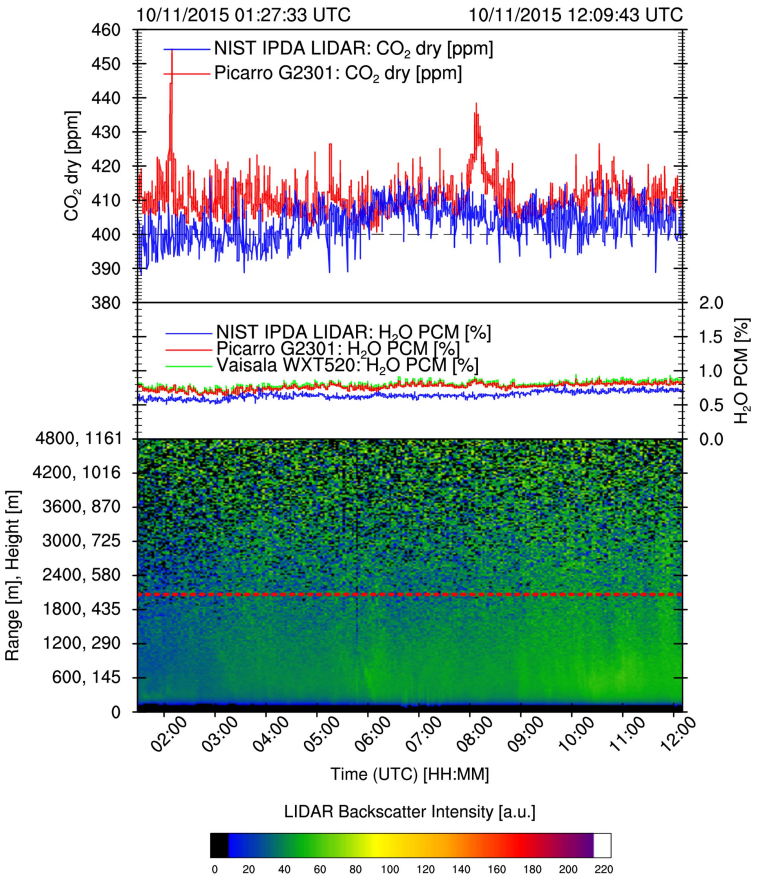

Figure 1. The nighttime CO_2 dry air mixing ratios measured using the IPDA and CRD instruments (top panel) on October 11, 2015 (UTC). The water concentrations measured with the IPDA system are shown in the middle panel together with the data from the CRD and humidity sensors. The background- and range-corrected signal intensity of the backscatter LIDAR is shown in the lower panel.

An Ultra-stable and High-precision N_2O/CO Analyzer for Continuous Ambient Monitoring

F. Dong, J. Zhou, J. Hoffnagle, S. Tan, G. Leggett, C. Rella, Y. He, Y. Huang and D. Kim-Hak

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With a global warming potential of nearly 300 times that of carbon dioxide (CO_2) at a 100-year time horizon, nitrous oxide (N_2O) has become a critically important greenhouse gas with a contribution of ~5 % of the U.S. total GHG emissions. It is also well-known that N_2O has been one of the most important species that has been causing stratospheric ozone depletion and will be remain in the atmosphere for centuries due to its long life time. Agriculture soil management practices are the dominant source of anthropogenic N_2O emissions, contributing nearly 75 % of U.S. N_2O emissions. In urban areas, vehicle tailpipe emissions and waste water treatment plants are significant sources of N_2O. However, the variation of N_2O in the atmosphere is very small with an average growth rate of <0.8 ppb per year. Therefore, an inter-laboratory comparability goal of ±100 ppt is recommended by WMO for ambient monitoring of N_2O.

We report here a new mid-infrared laser-based cavity ring-down spectrometer (Picarro G5310) that was recently developed to simultaneously measure two key greenhouse gas species, N_2O and carbon monoxide (CO) with both high precision and high stability. It combines a quantum cascade laser with a 3-mirror optical cavity. Over an 8-day continuous measurement of a stable source without any calibration, the peak-to-peak variation is 53 ppt for CO and 33 ppt for N_2O. With such a high precision and unparalleled stability, the analyzer is a promising tool for long-term global monitoring of N_2O/CO in ambient air.

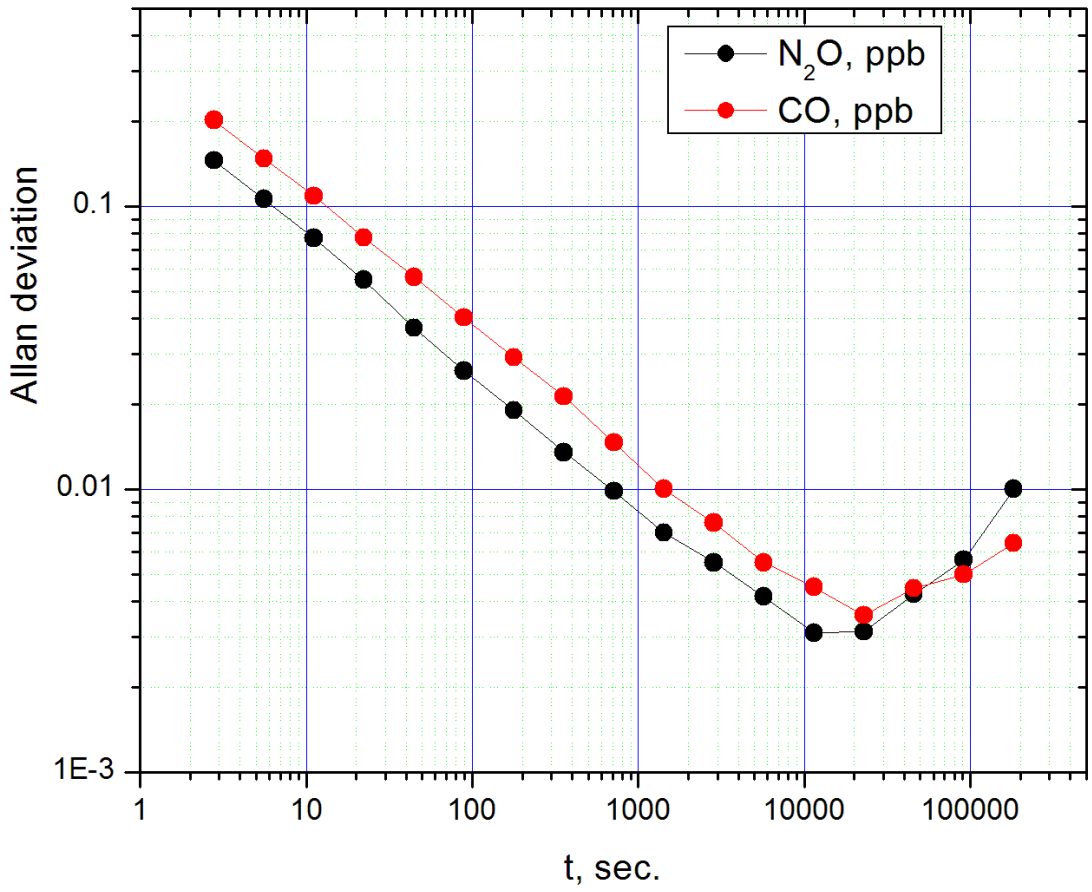

Figure 1. Allan Deviation plot of measured N_2O and CO in dry air.

Atmospheric Measurements of Methane, Isotopic Methane, and Ethane Using a Cavity Ring-down Spectrometer

I. Green, N. Saad, D. Fleck, J. Hoffnagle and C. Rella

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Atmospheric methane (CH_4) has a powerful short-term global warming impact, and comes from a variety of natural and anthropogenic sources. Methane sources include wetlands, landfills, oil/gas/coal extraction activities, and urban emissions from leaks in the natural gas distribution system. Constraining the magnitude and distribution of these emissions spatially and temporally is critical to understanding the present and future climate impacts of CH_4. There are two tracer molecules that are often employed to investigate relative importance of various methane sources (and sinks): delta 13 carbon ($\delta^{13}C$) in CH_4 and ethane (C_2H_6). Biogenic sources of methane have lighter isotope ratios relative to thermogenic sources, although the ranges for each type of source are fairly broad and can overlap with each other. Atmospheric ethane is primarily a product of fossil fuel extraction, transport, or consumption. The ethane-to-methane ratio from these sources can vary dramatically, depending on the source C2/C1 signature in the geologic formation, and where in the extraction process the emissions originated. In combination, these two tracers can provide a wealth of information about the sources of methane contributing to the emissions.

Generally, measurements of these two tracers are made via off-line analysis of flask samples. In this study we present a novel, field-deployable instrument based on Cavity Ring-Down Spectrometer (CRDS) that is capable of real-time atmospheric measurements of mixing ratios of CH_4, C_2H_6, and $\delta^{13}C$ in CH_4, along with water vapor and carbon dioxide. This instrument is capable not only of Global Atmosphere Watch-quality methane measurements, but this highly sensitive analyzer can provide sub-permil measurements of $\delta^{13}C$ in CH_4 and sub-ppb measurements of ethane. The spectrometer is based on rugged near-infrared optical technology that is as well-suited regional monitoring networks as it is to making mobile measurements for real-time attribution of fugitive methane emissions.

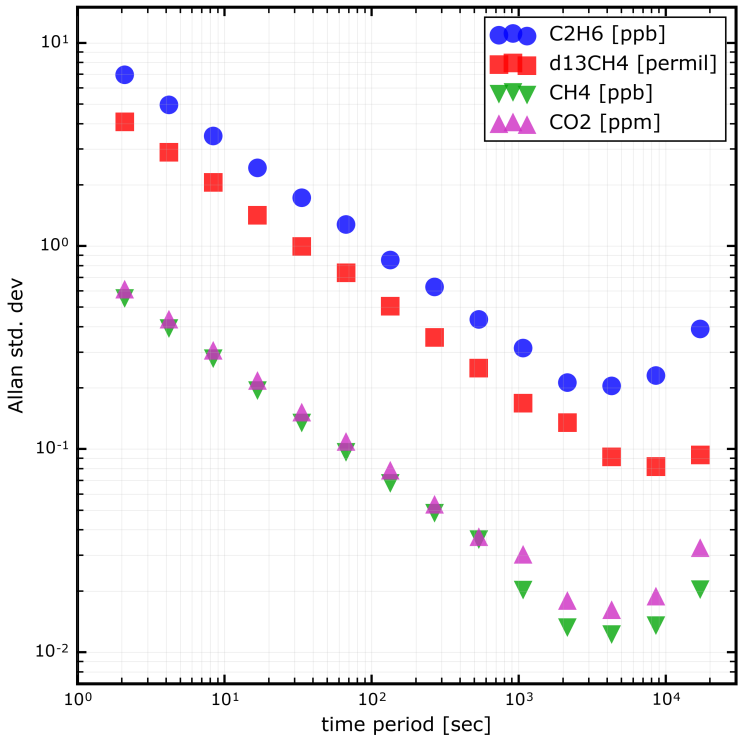

Figure 1. Allan standard deviation from the CRDS analyzer for key analyte species. Units are in the legend for each species.

Adaptation of a Commercial Greenhouse Gas Analyzer for Expanded Altitude Range

K. McKain[1,2], C. Sweeney[1,2], T. Newberger[1,2] and E. Wahl[3]

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[3]Picarro Inc, Santa Clara, CA 94054

The commercial availability of the Picarro cavity ring down spectrometer has advanced our community's ability to make highly stable and precise measurements of CO_2 and CH_4 mixing ratios in the atmosphere. We have expanded the Picarro's operating altitude range through a software modification to lower its cell pressure set point. This approach avoids the need for significant engineering of auxiliary systems, such as for upstream sample pumping or pressure control. We characterize the modified analyzer's performance through a series of laboratory tests, controlled field tests, and on an aircraft campaign that sampled at altitudes up to 14 km (150 mbar). The concept of a flexible cell pressure set point, without significant reductions in pressure control or measurement precision, opens up new possibilities for airborne platforms from which we can make continuous greenhouse gas measurements with minimal operational requirements.

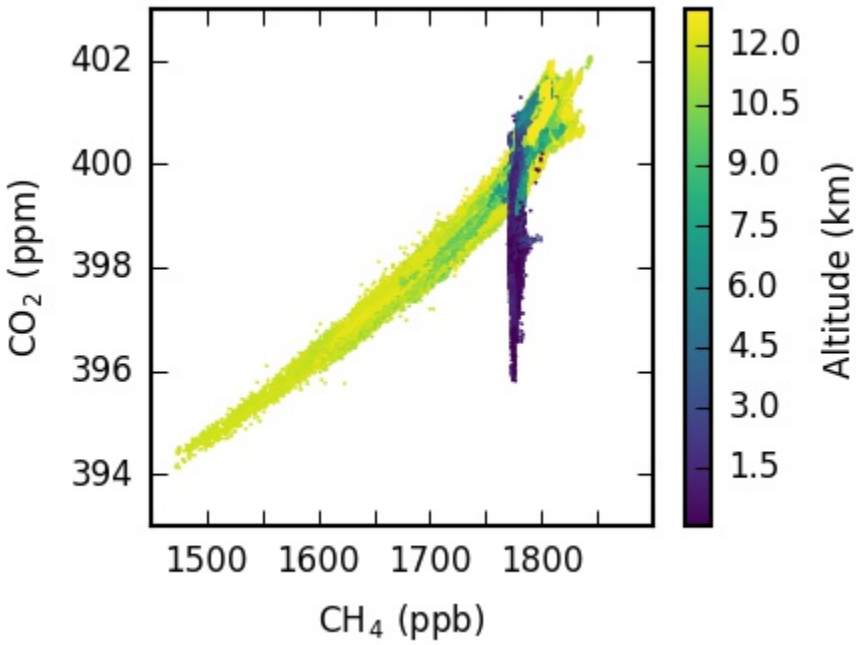

Figure 1. Unfiltered 1-second measurements of atmospheric CO_2 versus CH_4, colored by altitude, made by the modified Picarro analyzer during the ORCAS campaign over the Southern Ocean (30-75° S, 50-90° W) in January-February, 2016. The high-precision and stability of the low-pressure analyzer allow for the rendering of tight CO_2-CH_4 relationships across the broad altitudinal (0-13 km) range sampled of the campaign.

Characterization of a Quantum Cascade-Tunable Infrared Laser Differential Absorption Spectrometer (QC-TILDAS) for Atmospheric Ethane and Methane Field Measurements

I. Mielke-Maday[1,2], T.I. Yacovitch[3], S. Conley[4,5], C. Sweeney[1,2], T. Newberger[1,2], J. Kofler[1,2], P. Handley[2], S.C. Herndon[3], G. Frost[6], B.R. Miller[1,2], B.D. Hall[2], D. Kitzis[1,2], V. Vaida[1], G. Petron[1,2] and P.P. Tans[2]

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[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
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Ethane, the second most abundant hydrocarbon in the atmosphere and a tropospheric ozone precursor, has the potential to influence regional air quality. Ethane can also help to inform the understanding of climate forcing, as measurements of ethane are of interest for use as a constraint on methane emissions attribution. The emission ratios of ethane and methane from oil and natural gas operations, a major source of both compounds, can be used to constrain methane emissions in large-scale modeling and for methane source attribution on smaller scales, such as in oil and natural gas basins. Here we characterize a tunable infrared laser differential absorption spectrometer (TILDAS), a mini laser trace gas monitor manufactured by Aerodyne Research, Inc. The quantum cascade laser at 2990 cm^{-1} allows for measurement of both ethane and methane mole fractions, eliminating the need for additional instruments, calibration of multiple instruments, and post-deployment time alignment. The fast response (1 Hz or less) of the instrument permits deployment on various mobile platforms. We present results from tests conducted in the laboratory and aboard ground-based and airborne platforms. Configuration and parameters needed to optimize deployment on these mobile platforms are discussed. Characterization of instrument response time, noise, calibration drift, and potential interferences will be presented. Complete characterization of this instrument will allow for its use for various applications, including for the purpose of long-term monitoring or in intensive field campaigns.

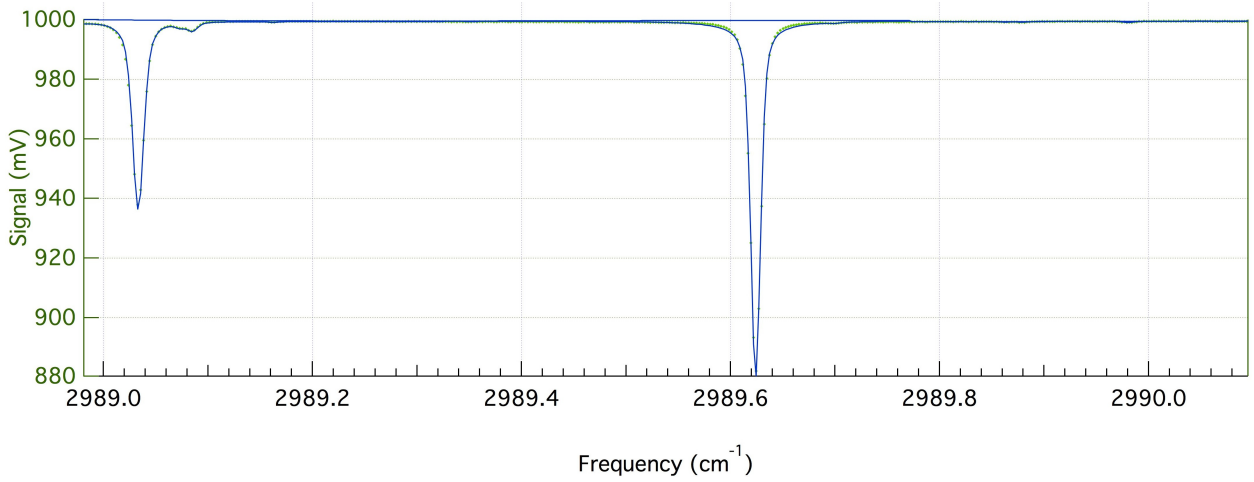

Figure 1. The 2990 cm^{-1} laser in the Aerodyne TILDAS can be used to measure methane, ethane, and water vapor.

Global Warming Is Real - Highlights of the Data

P. Morris

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Mankind has had an enormous impact on the planet. We dominate the planet from the North Pole to the South Pole. In this poster I highlight some of the important data and other factors effecting our environment and tie them together to show how human activities have brought this about. At the very foundation of global warming is the Greenhouse Effect. The Greenhouse Effect is a natural phenomena caused by the presence of the Greenhouse Gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) whose molecular structure allows them to trap energy from the sun in the form of heat energy here on the planet. The levels of the greenhouse gases have been increasing for the last 240 years. This being the case, global temperatures must also be increasing. Since 1880 global mean surface temperature has increased by 0.85ºC (1.53ºF). Data from the Law Dome ice core in Antarctica gives further support to temperature increases (not shown) and increases in the levels of atmospheric greenhouse gases. Both started an upward trend after 1750 with the advent of the Industrial Revolution**.** Since about 1978 satellites have been orbiting the Earth. There are satellites looking out measuring the amount of energy incoming and others looking in measuring how much energy is leaving. The results indicate that the Earth is keeping in more energy than is escaping into space. Climate researchers have been looking for the components of the Earth's atmosphere that are responsible. The big culprits are the three greenhouse gases, CO_2, CH_4 and N_2O. The current energy imbalance is about 2.3 W/m^2. Who is responsible? I show how human CO_2 emission from the burning of fossil fuels has increased over the past 150 years. In 2010 we emitted about 37 billion tons and by 2030 it is projected we will be emitting 45 billion tons of CO_2. These are massive amounts. To illustrate this point I compare 40 billion tons/year to the weight of the human race. 40 billion tons is a shocking 114 times larger than the total weight of the human race living on the planet today. We can see from the Maun Loa Observatory data that atmospheric levels of CO_2 are showing a steady increase. This data correlates very will with the amounts of fossil fuels we are using. Who is responsible? It sure looks like we are! What is driving our increasing usage of fossil fuels? I looked at the growth of the human population. It is clearly increasing at a rapid pace. In addition there is a growing desire for a higher standard of living in many regions of the planet. The current data show that the net increasing in the human population is about 75 million additional people each year. This means more fossil fuels will be used and as a result larger emissions of CO_2 into the climate system. Are there other possible causes of Global Warming? The three most commonly mentioned are the Sun, Orbital Forcing and Volcanoes. I show data to demonstrated that they or not major factors. That leaves the human race. What will be the outcome of our massive use of fossil fuels? I show data from the IPCC's RCP 2.6 and 8.5 scenarios. We are currently on the path of RCP 8.5 which as been dubbed the "business as usual" scenario. If the IPCC's projection for global temperatures for 2100 are on target the future might not turn out well for the human race.

Summary: RCP 8.5 **Reference Point in 1750 is 56.84°F**

Projected Atmospheric CO_2		**Global Mean Surface Temperature °C Temp Anomalies & (mean in actual °F)**		
2050	2100	2050	2100	2300
540 ppm	935 ppm	**2.0°C (60.44°F) Warming Zone**	**3.7°C (63.5°F) Danger Zone**	**≥ 8.0°C (71.24°F) Danger!**

Figure 1. Warming projected from the IPCC's RCP 8.5 Scenario.

Uncertainties in Total Ozone Retrievals from Dobson Zenith Sky Observations

K. Miyagawa[1,2], R.D. Evans[3,2], I. Petropavlovskikh[3,2] and G. McConville[3,2]

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The Dobson Ozone Spectrophotometer is used for measurements of total column ozone between the instrument and the outer edge of the atmosphere. The retrieval of ozone from measurements on the direct solar beam is based on the physics of transmission of light in an absorbing media (Beer-Lambert Law). Measurements of the zenith skylight are converted to total column ozone based on a statistical relationship established by analysing zenith and direct sun measurements made close in time. The original method was based on a table look-up algorithm derived from charts made from Canadian measurement campaigns in the 1950s and 1960s. The new method is a polynomial fitting routine between the direct sun results and various parameters of the zenith measurement. There are several types of zenith sky measurements available from Dobson that differ in selection of wavelength pair (AD or CD) and in the amount of the cloudiness (ZB: zenith blue sky or ZC: zenith cloudy). The recent re-analyses of the long-term NOAA Dobson total column ozone data records provided opportunity to assess the reliability of the original method to derive total ozone. Zenith sky data for NOAA stations have been reprocessed using an updated statistical method and comparing the results to the previous version of zenith sky data processing. The new method improves results so that ~90% of the time a zenith sky determined total ozone (using ADZB) is within +/-2% of a co-incident direct sun ozone column (ADDS).

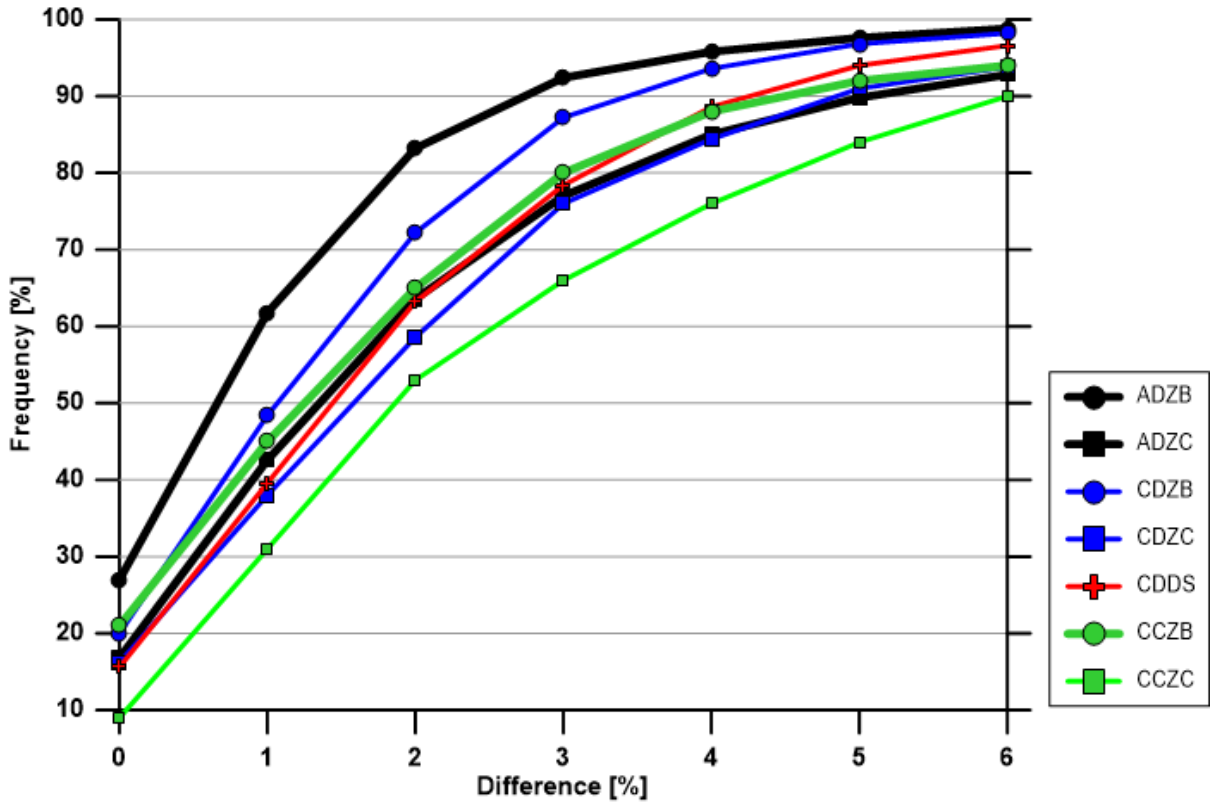

Figure 1. Distribution of differences between results from direct sun compared to zenith measurements on the same day. The frequency of compared Zenith and AD-DS (Direct Sun) total ozone (shown on y-axis) is accumulated between 1 to 6 % (shown on the X-axis). Results are shown for other types of zenith sky measurements denoted by colors in the legend.

Centuries of Data: the U.S. Dobson Station Network Reevaluated

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

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309; 303-818-2677, E-mail: robert.d.evans@noaa.gov
[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
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The United States government has operated Dobson Ozone Spectrophotometers at various sites, starting during the International Geophysical Year (July 1, 1957 to December 31, 1958). An effort for long-term monitoring of the total column content (thickness of the ozone layer) of the atmosphere was started in the early 1960s at several sites, creating an ESRL/GMD Dobson stratospheric ozone monitoring network that eventually grew to 16 stations, 15 of which are still operational. Recent modernization of the Dobson ozone data processing presented a challenge of identifying potential changes in the re-processed ESRL/GMD ozone record. To evaluate significance of this change, the entire data record of the long-term observations for each station was reprocessed in the new software, and compared to the original data record archived in the World Ozone and UV Data Center (WOUDC) in Toronto, Canada. The history of the individual stations, the instruments used, the method of reduction of observations on the zenith sky to total column ozone and the calibration procedures were re-evaluated using data quality control tools built into the new software. At the completion of the evaluation (expected in 2016), the new data sets will be archived in the WOUDC, and the entire data record will become available to the scientific community for further evaluation.

The procedures of the Dobson data reprocessing and results of the re-analysis with regards to the archived record will be presented in this poster for 15 ESRL/GMD stations. A validation of the updates to the record will be performed by referencing the updated Dobson ozone station record to several satellite total ozone record sampled spatially and temporally to represent total column for the same geographical location as the Dobson station.

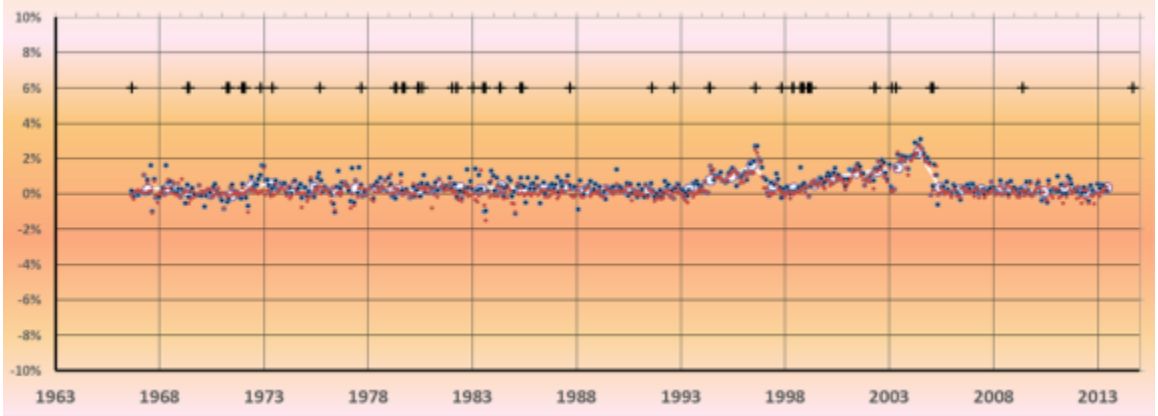

Figure 1. Displayed as an example is the difference between the existing 1966 - 2013 Archive data set for Boulder, and the new data set from Windobson (WD) processing as monthly averages. The blue points are monthly averages using all observations, the red are from Direct Sun (DS) observations only. The Plus symbols are calibration of instrument changes. The differences are discussed in the text.

Long-lived Stratospheric Ozone Depletion Over The South Pole During Spring 2015

G. McConville[1,2]

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Stratospheric ozone loss during the Antarctic spring has been observed for several decades. The physical and chemical conditions leading to this loss are well understood, and in recent year some researchers have pointed to signs of recovery. Although the severity of ozone loss is usually gauged by the lowest amount of total column ozone (TCO), it could also be assessed by its geographical size, or persistence. During the Antarctic spring of 2015 the vortex surrounding the hole was unusually stable and measurement of TCO made with the Dobson spectrometer showed the longest-lived depletion period ever.

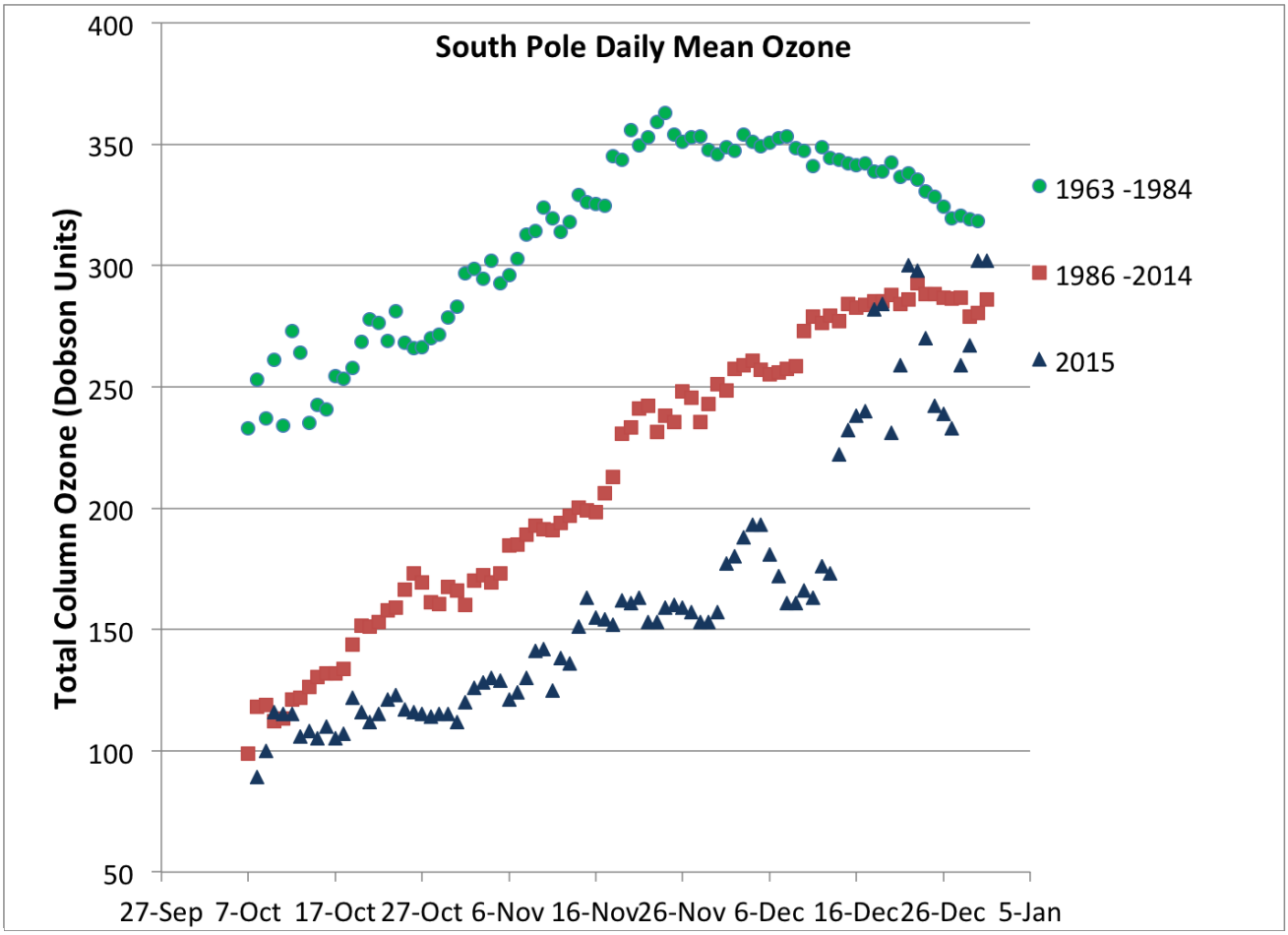

Figure 1. Plot of South Pole daily mean ozone by time period.

Total Column Water Vapor from OCO-2

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Measurements of atmospheric water vapor provide useful information for a wide range of applications including hydrological cycle studies, radiation budget studies, weather forecasting, and climate change studies. While many existing ground-based networks provide highly precise and accurate measurements of water vapor, the large temporal and spatial variability of water vapor results in the need for additional information on a global scale. Currently, global spaced-based information on water vapor comes from a number of satellite instruments in the microwave (Special Sensor Microwave Imager [SSM/I], Advanced Microwave Scanning Radiometer for Earth Observing System 2 [AMSR-E/2], TRMM Microwave Imager [TMI]), thermal infrared (Atmospheric Infrared Sounder [AIRS], Infrared Atmospheric Sounding Interferometer [IASI], Cosmic Ray Isotope Spectrometer [CrIS], High-resolution Infrared Radiation Sounder [HIRS]), and visible (Moderate Resolution Imaging Spectrometer [MODIS], Medium Resolution Imaging Spectrometer [MERIS]). However, all of these have limitations in terms of both accuracy and spatial coverage.

In this work we investigate the accuracy of Orbiting Carbon Observatory-2 (OCO-2) total column water vapor measurements by comparing them to independent observations, including those from SuomiNet, which is a ground-based Global Positioning System (GPS) network. Though OCO-2's primary mission is to measure the total column of atmospheric carbon dioxide (XCO_2), it also measures total column water vapor with the NASA Atmospheric CO_2 Observations from Space (ACOS) XCO_2 retrieval algorithm using information contained in two near-infrared absorption bands at 1.6 and 2.0 μm. The information in these bands primarily concerns CO_2, but several water vapor lines in each band enable the retrieval of water vapor simultaneously with XCO_2. We assess the overall ability of OCO-2 to measure total column water vapor, and examine patterns and biases in both time and space. Initial results are promising, as they show an improvement relative to European Center for Medium range Weather Forecasting (ECMWF) Integrated Forecasting System (IFS) total column water vapor estimates.

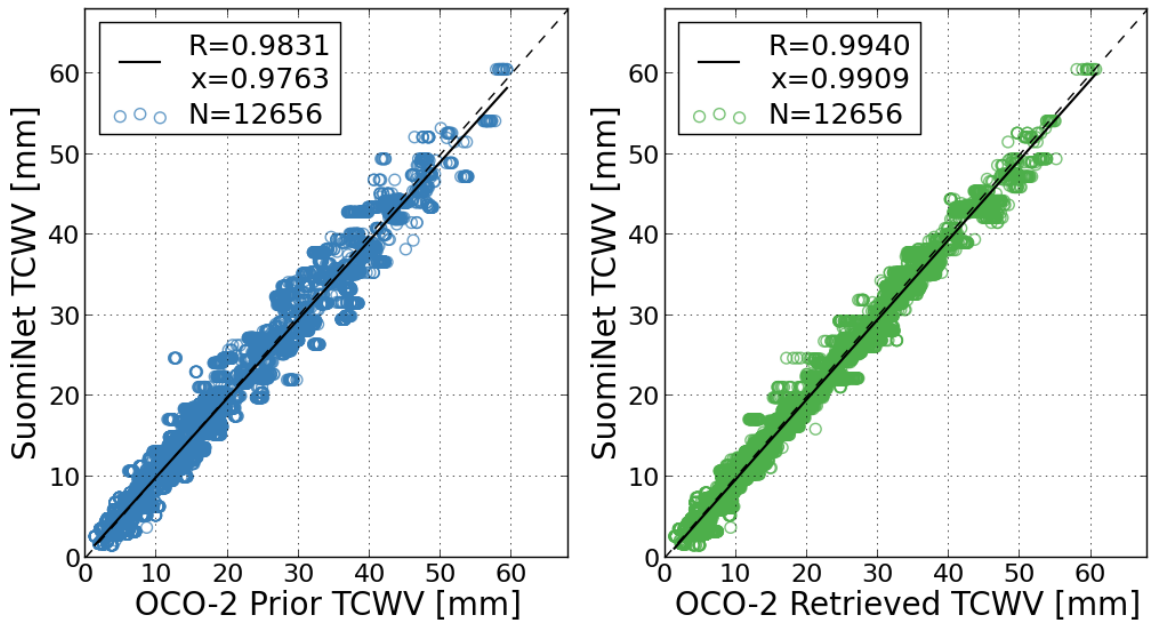

Figure 1. ECMWF IFS (used as the OCO-2 prior; left panel) and OCO-2 retrieved (right panel) total column waver vapor (TCWV) vs. SuomiNet TCWV co-located to within 0.1° and 30 min.

Introducing the EXC³ITE Project: EXploring Stratospheric Composition, Chemistry and Circulation with Innovative TEchniques

E. Leedham Elvidge[1], J. Kaiser[1], W.T. Sturges[1], P. Heikkinen[2], R. Kivi[2], T. Laurila[2], J. Hatakka[2], C. van der Veen[3], T. Roeckmann[3], H. Chen[4] and J.C. Laube[1]

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In recent years debate has arisen over the potential impact of global climate change on stratospheric mean meridional circulation (the Brewer-Dobson circulation, BDC). Models predict an increase in the strength of the BDC, although substantial uncertainties still surround our understanding of past and future changes in this region. Previous studies have been limited by the cost of sampling, resulting in patchy temporal and seasonal coverage, and the limitations of satellites with respect to their precision and vertical resolution, as well as the number of relevant species they can quantify.

Recent work at University of East Anglia (UEA) has found initial evidence for substantial past stratospheric changes which implies a large and persisting change in the BDC. Acceleration of the BDC would have an impact on chemical and physical processes in the stratosphere; notably altering the removal of ozone-depleting substances (ODSs), which are exclusively broken down in the stratosphere.

The EXC³ITE project will run from 2016 to 2021 and aims to increase our understanding of changing stratospheric dynamics by combining a novel, cost effective measurement technique, "AirCore" (a long narrow-bore sampling tube launched as a payload on a small balloon), with state of the art analysis via UEA's highly sensitive (detection limits of 0.01-0.1 pmol mol^{-1} in 10 ml of air) gas chromatography mass spectrometry system which has the capability of measuring >30 atmospherically important species. EXC³ITE will combine at least 45 stratospheric balloon flights with an unprecedented investigation of stratospheric air archives spanning 40 years and >50 trace gases. First results will be presented (Fig. 1). As well as improving our understanding of stratospheric circulation changes, EXC³ITE will also provide: (1) observations of ODSs not currently controlled by the Montreal Protocol but currently increasing in the atmosphere, e.g. short-lived chlorocarbons; (2) observations of hydrofluorocarbons and perfluorocarbons – strong greenhouse gases; (3) crucial calibrations and validations of satellite instruments; (4) new diagnostic tools (e.g. improved mean ages of air from multiple tracers); and (5) a detailed comparison with state-of-the-art models to identify the implications for future climate.

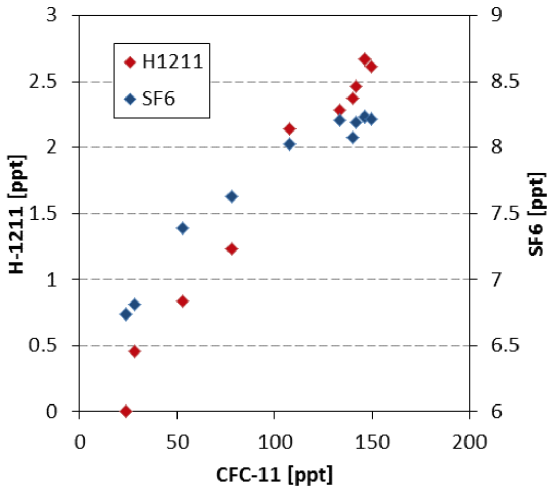

Figure 1. ODS mole fraction ratio correlations from initial Aircore samples collected above Finland in early 2016. Average precisions were 0.2%, 0.6% and 1.5% for CFC-11, sulfur hexafluouride, and H-1211 respectively.

Intercomparison of Total Ozone Column Observed by Pandora and Brewer Spectrophotometers at Taipei

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A long-term record (1965 to present) of total ozone (O_3) column was observed at Taipei made by the Central Weather Bureau (CWB) in Taiwan. Our instrument setup began with Dobson spectrophotometer and was replaced by Brewer spectrophotometer in 1985, and two Brewers are presently operating. In 2013, we performed an intercomparison experiment of total ozone by using the NASA Pandora and CWB Brewer to understanding the performance of new instruments in the subtropical climate. The results show that Pandora and Brewer have good linear correlation (correlation coefficient is 0.74) and the tendency of daily variability is similar. The mean value of total ozone column for Pandora and Brewer are 270 DU and 283 DU, respectively, suggesting that Pandora could have low bias. However, when we compare to Aura satellite measurement, Pandora shows better results. Furthermore, we compared total ozone column with surface ozone concentration measured by nearby air quality station. We found that the daily trend shows mostly in accordance between columnar and surface ozone, implying the main influence of the total ozone change in Taipei comes from the surface. In addition, Pandora provides higher temporal resolution compared to Brewer, which is particularly important for the evaluation of some highly variable species [e.g: O_3, nitrogen dioxide (NO_2), aerosols] in the lower troposphere or boundary layer.

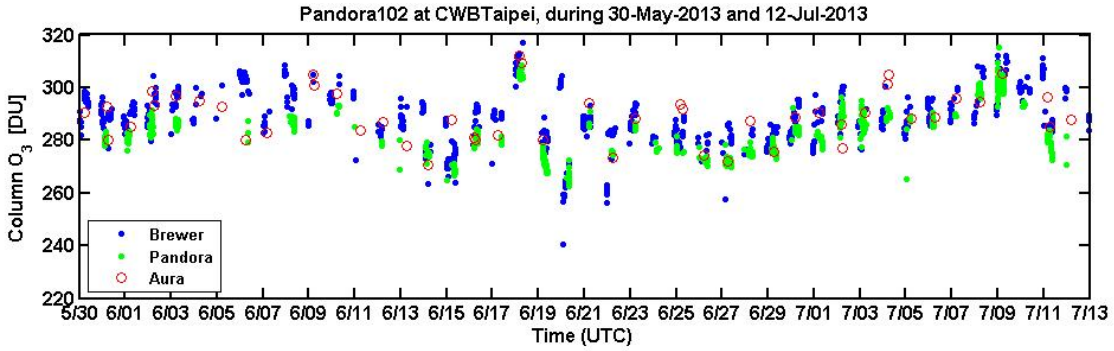

Figure 1. The results from intercomparison experiment of Brewer and NASA Pandora.

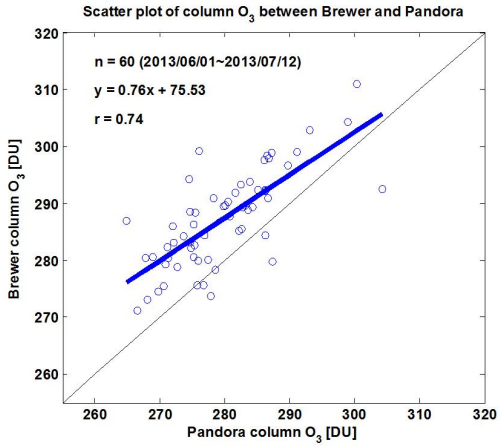

Figure 2. Scatter plot of total ozone column observed by Brewer and NASA Pandora.

First Look at the NOAA Aircraft-based Tropospheric Ozone Climatology in Colorado

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The Global Greenhouse Gas Reference Network Aircraft Program of ESRL/GMD has, for over a decade, sampled spatial and temporal variability in atmospheric trace constituents, including ozone, in Northern America. The method to derive tropospheric ozone climatology from the light aircraft measurements equipped with the 2B Technology instruments is described in this paper. Since ozone instruments at most of aircraft locations are flown once a month, this raises the question of whether the low sampling frequency allows for a representative vertical ozone climatology that can adequately capture tropospheric seasonal and vertical variability over various locations in U.S. and west coast Canada. An interpretation the representativeness of seasonal and vertical variability of tropospheric ozone climatology is derived from these under-sampled observations using hindcast simulations conducted with the Geophysical Fluid Dynamics Laboratory chemistry-climate model (GFDL-AM3). This study focuses on ozone measurements from monthly aircraft profiles over the Front Range of Colorado and weekly ozonesondes launched in Boulder, CO. The climatology is presented as monthly values separated in 5th, 25th, 50th, 75th, 95th percentiles, and averaged at three vertical levels: lower (1.6-3 km), middle (3-6 km), and upper (6-8 km) troposphere. The aircraft-based climatology is compared to the climatology derived from the co-located ozonesondes launched from Boulder, Colorado, from GFDL-AM3 co-sampled sparsely in time, and from GFDL-AM3 continuous daily samples. This study analyzed the limit in the sampling frequency that is recommended for ozone profile measurements in order to obtain adequate representation of ozone climatology in the free troposphere. The 3-hour sampled AM3 model was used as the benchmark reference for comparisons with less frequent sub-sampled time series. It was found that a minimum of 3 soundings per month was required to match the 95% confidence level of the fully sampled ozone climatology (12 monthly mean values) for vertical profiles averaged over 1.6-3 km. One sounding per month was sufficient frequency for obtaining a monthly climatology for 3-6 km averaged ozone that matched the 95% confidence limit of the daily sampled climatology, while 8 soundings limit was required for ozone climatology averaged over 6-8 km layer. It was also found that months March, April, and May have the highest ozone variability in the Colorado Front Range area that is observed at the altitudes between 6 and 8 km. This concludes that a once-a-month ozone profiling by the light commercial aircraft flown over the Colorado Front Range from 2005 through 2014 provides 95% confidence in the ozone climatology constructed from measurements limited to the altitudes from 3 to 6 km.

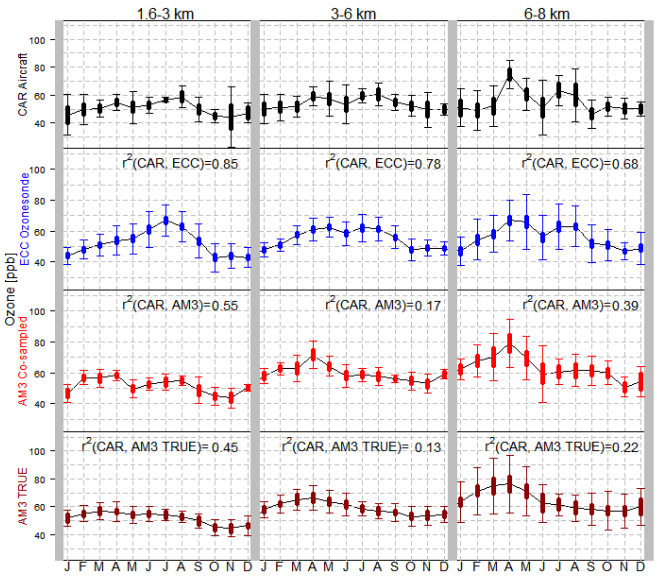

Figure 1. Seasonal ozone climatology along Front Range, CO. Shown are monthly median climatologies derived from ECC ozonesonde observations (O_3So) (blue), simulated results of the continuously daily sampled (O_3AM3) (red) and co-sampled GDFL AM3 model (O_3AM3S) (dark blue). The model is co-sampled to match the dates of ozonesonde flights. The box and arrow plots represent the standard error and standard deviation for each monthly median value. Climatologies are taken at altitudes of 1-6-3 km, 3-6 km, and 6-8 km. Climatologies are compared from 2004 to 2014.

Analysis, Determination and Reprocessing Methods Used For Homogenization of the NOAA Long-term ECC Ozonesonde Time Series

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The NOAA electrochemical concentration cell (ECC) ozonesonde network has been taking measurements for nearly 40 years and extends to nine sites worldwide. These vertical ozone profiles are used in a wide range of applications by many institutions and individuals. During this time period, many instrument configurations, solutions, and processing changes have occurred. These changes have introduced systematic biases into the data record. In order to reduce uncertainty, recover original raw data, and analyze and calculate the remaining random uncertainties, the Ozonesonde Data Quality Assessment (O3S-DQA) was initiated by the ozonesonde community. NOAA's network is unique due to the large number of sites, length of record, and unique solutions and instrument types used. NOAA has generally followed the homogenization guidelines published in the World Meterological Organization Global Atmosphere Watch Report #201 [2014]. However, the uniqueness of NOAA's data record required us to develop our own transfer functions. The Boulder, CO station is used here as an example to illustrate NOAA's reprocessing system and the method used to determine the appropriate corrections. Initially, ozone soundings were processed from the raw data in order to recover and record the cell current and original measured backgrounds in the data files. Next, the ozonesonde cell current backgrounds were systematically reduced and pressure offsets were applied to radiosondes. Flowrate corrections and pump temperature corrections were applied when necessary. NOAA has developed transfer functions to remove biases created by solution changes. In order to determine appropriate transfer functions, 1% Full Buffer and 2% No Buffer solutions were compared to the 1% 1/10th buffer solution and an ozone photometer via dual ozonesonde flights and testing in atmospheric chambers. The final piece of the data homogenization process was implementing a robust, bottoms up uncertainty calculation. The instrumental uncertainty of the ozonesonde measurement is a composite of the contributions of the individual uncertainties of the different instrumental parameters, namely, the measured sensor current, background current, conversion efficiency, pump temperature, and pump flowrate. The uncertainty calculation takes into account the added uncertainty of implementing transfer functions. This data homogenization effort improves the agreement in total column ozone between ozonesondes, co-located Dobson spectrophotometers, and satellites (AURA's Ozone Monitoring Instrument and Microwave Limb Sounder and NOAA-9 through NOAA-19).

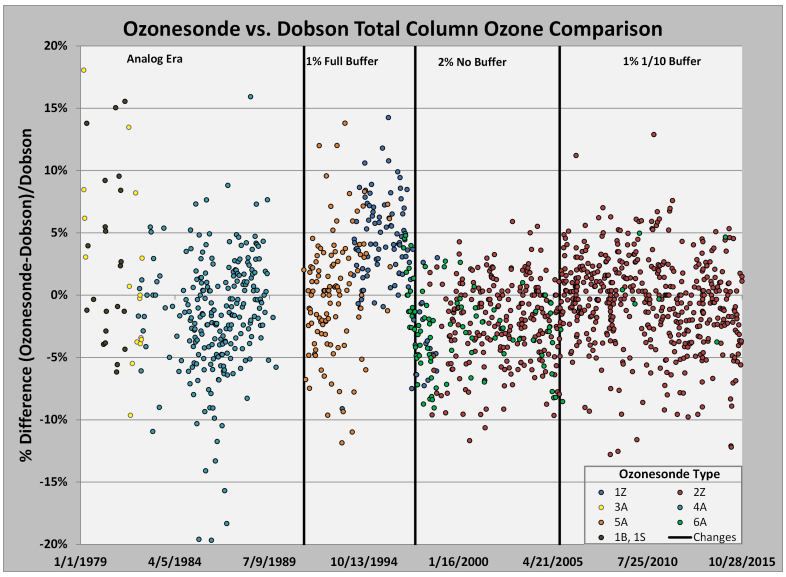

Figure 1. Time series of ozonesonde vs dobson total column ozone for Boulder, CO pre-homogenization.

The First Reprocessing of SHADOZ (Southern Hemisphere ADditional OZonesondes) Data Records

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Long-term ozonesonde data records support satellite validation, model evaluation and studies of atmospheric pollution and dynamics. The SHADOZ (Southern Hemisphere ADditional OZonesondes) network is a NASA Goddard Space Flight Center project in collaboration with the ESRL/GMD, and international partners from Asia, Africa and Europe to archive long-term ozonesonde records from tropical stations. Started in 1998, SHADOZ has archived over 6000 ozone and P-T-U (pressure-temperature-humidity) profiles from over a dozen tropical and subtropical stations with a launch frequency of 2-4 soundings per month. Like many long-term sounding stations, SHADOZ has been characterized by variations in operating procedures, instrumentation, sensing solution, and data processing. Thus, there are variations in agreement with satellite ozone and biases among stations and within the data record of an individual station. These contribute to measurement uncertainty and may limit the reliability of ozone profile trends. A major milestone for 2016 is the first major SHADOZ re-processing that accounts for these changing techniques in ozonesondes. The extent of re-processing varies from station to station. Complete re-processing can be restricted due to unavailable or incorrect metadata, instrument version, and limited software capabilities in the historic record. These factors explain most changes observed in each stations' re-processed ozone time series when compared to its original time series. Such differences can be as high as ±4 DU and are most evident in the stratospheric portion of the profile. We use ozone products from Aura's OMI (Ozone Monitoring Instrument) and MLS (Microwave Limb Sounder) to quantify the impacts of re-processing on the agreement with the satellite data. The overall agreement between ground-based column ozone from Dobsons, OMI, and sondes is improved significantly in several stations largely due to corrections in the background current of the ozonesonde and pump efficiency correction factors (PCF) in the stratosphere. All stations show better agreement with MLS in the midstratosphere due to corrections in the PCF.

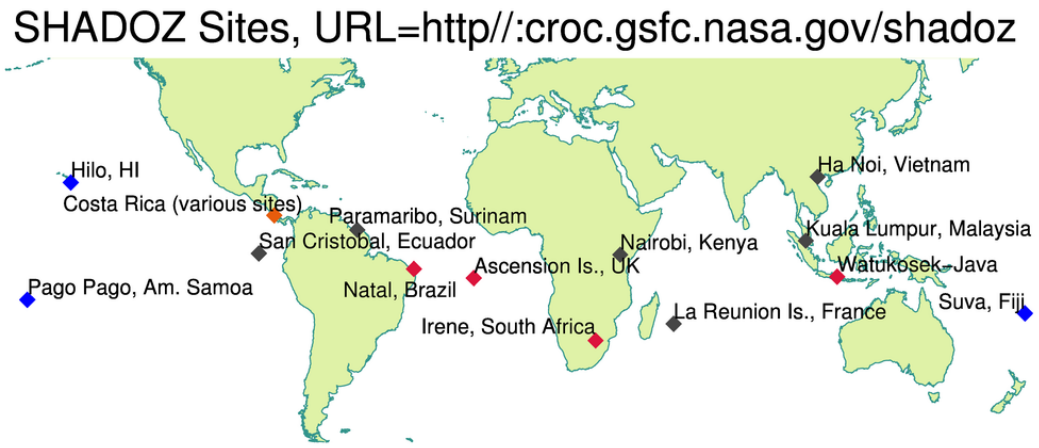

Figure 1. Map of SHADOZ ozonesonde stations.

Results from Balloon Launches at the Maïdo Observatory On Réunion Island

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As Upper Troposphere-Lower Stratosphere (UTLS) composition plays an important role on Earth's climate system, upper-air observations for climate have been given more attention in recent years. However estimates of UTLS composition (e.g. water vapor, aerosols) are almost entirely based on data from the Northern Hemisphere. The Southern Hemisphere (SH) is a challenging place for climate research. Its vast oceans and the lack of landmass make it particularly difficult to collect information about present climate.

The location of Reunion island (21°S, 55°E) is ideal to study UTLS processes as there are very few multi-instrumented stations in the tropics and stations are particularly lacking in the SH. Since the nineties, atmospheric measurement systems have been deployed at Reunion Island, mainly for monitoring the atmospheric composition in the framework of Network for the Detection of Stratospheric Change/Network for the Detection of Atmospheric Composition Change. In 2012, a new observatory was commissioned in Maïdo at 2200 m a.s.l. on the west side of the island. The Maïdo Observatory hosts various instruments for atmospheric measurements, including LiDAR systems, spectro-radiometers, *in situ* gases/aerosols measurements, and balloonsonde observations. Balloonsonde observations of water vapor, aerosols, and other trace gases in the UTLS are important as they reveal fine-scale features that are below the vertical resolution of satellite sounding systems.

We will present balloon-borne vertical profile measurements of water vapor (CFH) and aerosols (COBALD, POPS) from the Maïdo Observatory since 2014. The balloon measurements are analysed using FLEXible PARTicle dispersion model (FLEXPART) Lagrangian backtrajectories driven by the ECMWF high-resolution operational analyses. Finally, we will present the Flexpart cOnvective Outflow Tool (FOOT) forecasting tool that is used to optimize balloon launch at the observatory. This forecast tool provides an array of FLEXPART Lagrangian trajectories and METEOSAT 7 geostationary satellite observations on a daily basis for the Indian Ocean.

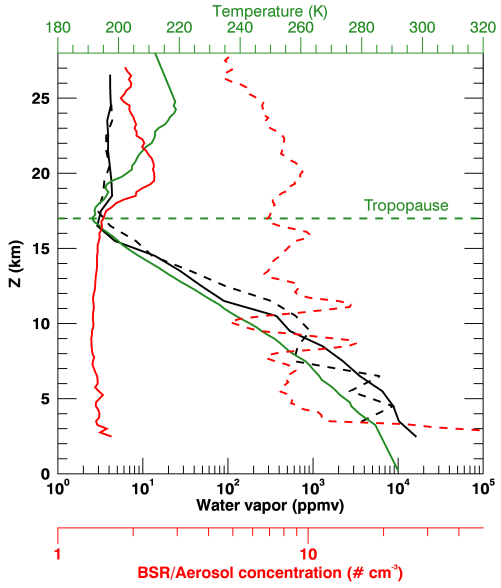

Figure 1. CFH Water vapor profiles on January 25, 2016 (black solid line) and March 23, 2016 (black solid dashed line). COBALD backscatter ratio (BSR) at 940 nm on January 25, 2016 (solid red line) and POPS total aerosol concentration on March 31, 2016 (dashed red line). The mean temperature of 2 flights (January 25 and March 31) is also displayed in green as well as the position of the mean cold point tropopause (dashed green line).

Ozone and Other Trace Gases in the Tropical Tropopause Layer over the Pacific Ocean

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[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
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The distribution of ozone in the tropics is influenced by both chemistry and transport, and in turn affects the oxidation rate of a large number of organic species, including shorter-lived ozone depleting substances (ODS) such as organic bromine compounds. The NASA Airborne Tropical Tropopause Experiment (ATTREX) mission was designed to study trace gases, clouds, dehydration, and transport in the tropical tropopause layer (TTL; ~14-18.5 km) over the Pacific Ocean, one of the primary entry points of air from the troposphere into the stratosphere, in order to better understand how water vapor and ozone-depleting gases reach the lower stratosphere or are removed in the TTL. Field campaigns were carried out on the NASA Global Hawk aircraft, with about 200 vertical profiles in the TTL over the central and eastern tropical Pacific (ATTREX-1 and 2; 2011 and 2013) and the western Pacific in January-March 2014 (ATTREX-3). The National Science Foundation/National Center for Atmospheric Resarch (NSF/NCAR) GV and British BAe-146 aircraft also participated in flights from Guam during ATTREX-3, along with ozone and water vapor sondes, providing coverage of the atmosphere from the boundary layer to 19 km. Ozone was consistently low (10-40 ppb) in the lower TTL over the western Pacific, with low values extending up to the cold point tropopause, particularly in March 2014. Ozone over the central and eastern Pacific in February-March 2013 often averaged 40-50 ppb, and typically increased slowly with height from about 14 km to the tropopause. The results are consistent with frequent but not uniform deep convection, bringing low-ozone air from the marine boundary layer directly to the upper troposphere over the western tropical Pacific. During the winter 1987 STEP mission, the NASA ER-2 aircraft made several profiles at Guam during transit flights, which included very low values of ozone, lower than observed at their principal study site in Australia. ATTREX-3 results also showed gradients in ozone and other trace gases between northern and southern hemispheres, but with lower values of ozone in the southern hemisphere. Results will be presented on ozone distributions, other trace gases, and northern hemisphere/southern hemisphere differences.

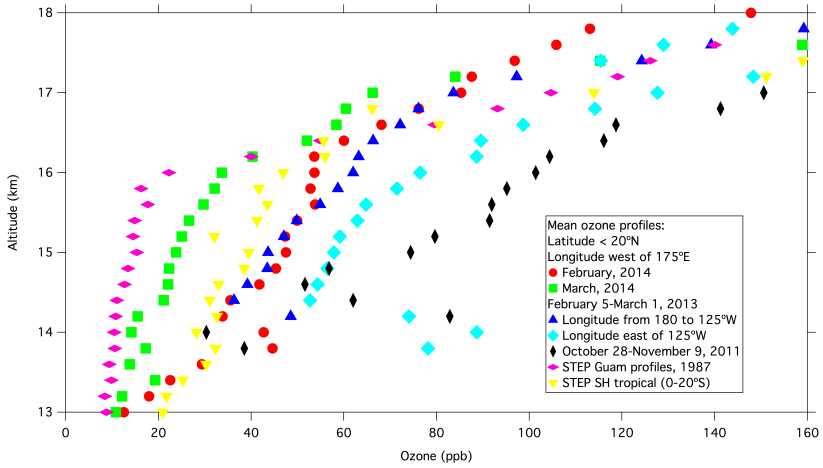

Figure 1. Average ozone profiles in the tropics for STEP and ATTREX flights over the Pacific.

Investigating Below-cloud Rain Evaporation and Boundary Layer Moisture Recycling by Coupling Stable Water Isotopes in Vapor and Precipitation to Raindrop Size Distributions at the Boulder Atmospheric Observatory Site

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[2]University of Colorado, Department of Atmospheric and Oceanic Sciences, Boulder, CO 80309
[3]Oregon State University, College of Earth, Ocean and Atmospheric Sciences, Corvallis, OR 97331

The moisture balance of the continental boundary layer plays an important role in regulating the exchange of water and energy between the surface and the atmosphere, yet the mechanisms associated with moistening and drying are both poorly observed and modeled. Measurements of stable water isotope ratios can provide insights into air mass origins, convection dynamics and mechanisms dominating atmosphere-land surface water fluxes. Profiles can be exploited to improve estimates of boundary layer moistening associated with evaporation of falling precipitation and contributions from surface evapotranspiration. We present two years of *in situ* tower-based measurements of isotope ratios of water vapor (δD and $\delta^{18}O$) and raindrop size distributions from the Boulder Atmospheric Observatory (BAO) tall tower site in Erie, Colorado at the surface and 300m. Isotope vapor measurements were made at 1 Hz with a full cycle from the surface to 300 meters recorded every 80 minutes. In addition, water samples were collected during precipitation events at the surface and 300m. Raindrop size and velocity measurements were made continuously during precipitation events using Parsivel instruments located at the surface and 300m. Aggregate raindrop size measurements suggest that the profile shifts from smaller raindrops at 300m to larger raindrops at the surface, contrary to what is expected for rain evaporation. We use this unique suite of measurements and, in particular, exploit the differences between the surface and 300m observations on an event-by-event basis to constrain the hydrological mass balance during and after rain events, and evaluate parameterization choices for rain evaporation and moisture recycling processes in current climate models.

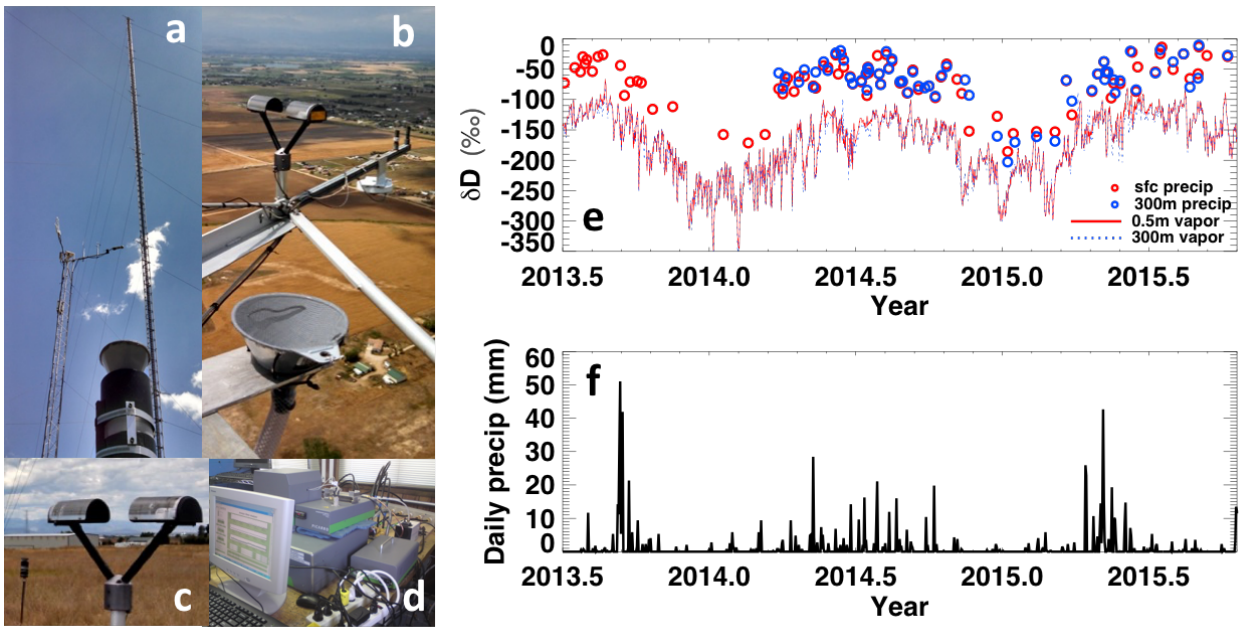

Figure 1. (a) Surface precipitation collector & University of Colorado meteorology tower at BAO site; Collector and Parsivel at (b) 300m & (c) surface; (d) Picarro water vapor isotope analyzer set-up at BAO; (e) Isotope ratios in precipitation and vapor at surface and 300m; (f) Daily total precipitation at BAO.

Geographical and Temporal Differences in NOAA Observed Surface Ozone in the Arctic

A. McClure-Begley[1,2], I. Petropavlovskikh[1,2], S.M. Crepinsek[1,3], T. Uttal[3], D. Hageman[1,2], A. Jefferson[2] and S.J. Oltmans[1,2]

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The Arctic region is rapidly gaining interest and support for scientific studies to help understand and characterize the processes, sources, and chemical composition of the Arctic environment. In order to understand the Arctic climate system and the changes that are occurring, it is imperative to know the behavior and impact of atmospheric constituents. Surface level ozone in the Arctic is variable in both time and space and plays an essential role on the oxidation capacity of the atmosphere. The ESRL/GMD maintains continuous measurements and long-term records of ground-level ozone from Barrow, Alaska (since 1973), Summit, Greenland (since 2000), and Tiksi, Russia (since 2009). Measurements taken by Thermo-Scientific ozone monitors are collected and examined with the ESRL/GMD Aerosol LiveCPD system. This system of data acquisition and processing allows for data to be quality checked and investigated with regards to wind conditions and aerosol loading. These quality controlled data are used to develop seasonal climatologies, understand diurnal variation, and analyze differences in stations specifics by addressing spatial variability in the Arctic. Once typical ozone behavior is characterized, anomalies in the record can be defined and investigated. Increased ozone events associated with transported pollution and photochemical production of ozone, and ozone depletion episodes related to sea-ice halogen release and chemical destruction of ozone are the primary processes which lead to deviations from expected ground-level ozone conditions. The measurements taken from Barrow, Summit, and Tiksi are critical observations of ground-level ozone to provide fundamental understanding of the behavior and trends of ground-level ozone in the Arctic.

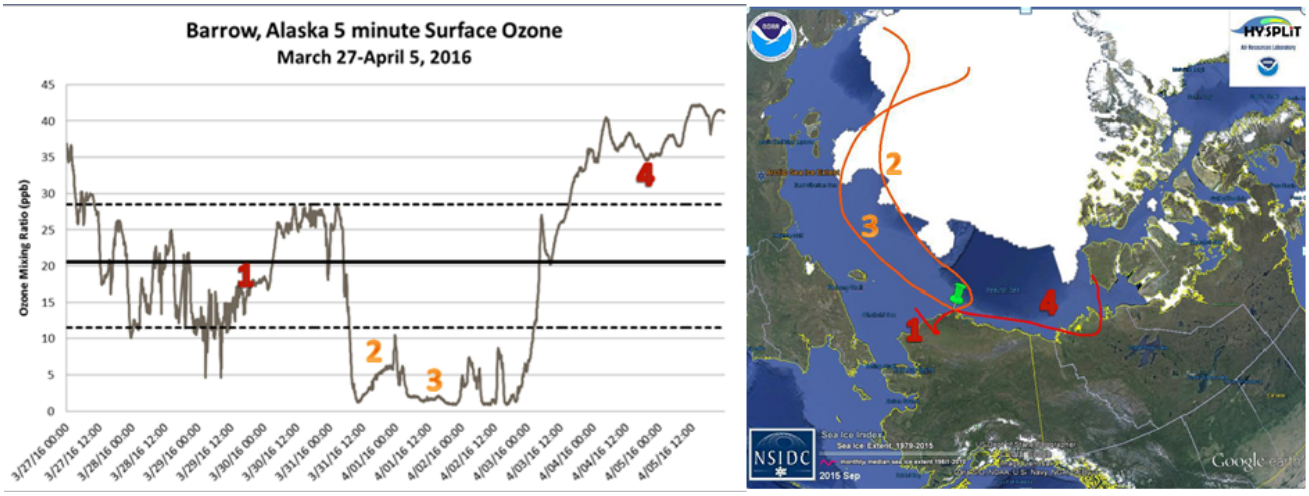

Figure 1. Barrow, Alaska surface ozone data from March 27, 2016 to April 5, 2016 is shown (grey line) with the average, 30th, and 70th percentiles from this time period displayed for reference. NOAA Hybrid Single Particle Langrangian Integrated Back Trajectory analysis is shown for four different time periods. This creates a visualization of the path which the air mass traveled before reaching the measurement station. The ozone depleted air masses have origins over the arctic sea where they were influnced by bromine released from the melting sea ice.

Using Box Models to Quantify Zonal Distributions and Surface Emissions of Halocarbons in the Background Atmosphere

J.W. Elkins[1], D. Nance[2,1], G.S. Dutton[2,1], S.A. Montzka[1], B.D. Hall[1], B.R. Miller[2,1], J.H. Butler[1], D. Mondeel[2,1], C. Siso[2,1], F.L. Moore[2,1], E.J. Hintsa[2,1], S. Wofsy[3] and M. Rigby[4]

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NOAA's GMD began measurements of the major chlorofluorocarbons (CFC-11, CFC-12, CFC-113) and nitrous oxide in 1977 from flask samples collected at five remote sites around the world. Our program has expanded to over 40 gases at 15 sites, which includes six i*n situ* instruments and 15 flask sites. The Montreal Protocol for Substances that Deplete the Ozone Layer and its subsequent amendments has helped to decrease the concentrations of many of the ozone depleting compounds in the atmosphere. Our goal is to provide zonal emission estimates for these trace gases from multi-box models and their estimated atmospheric lifetimes in this presentation and make the emission values available on our web site. We used our measurements to compare emissions estimated from the Harvard 5-box Model to the Advanced Global Atmospheric Gases Experiment 12-box Model. The emissions do not agree for some gases so our next step is to use our airborne measurements to calibrate the exchange times between the boxes for 5-box and 12-box models using sulfur hexafluoride (SF_6), because its emissions are better understood.

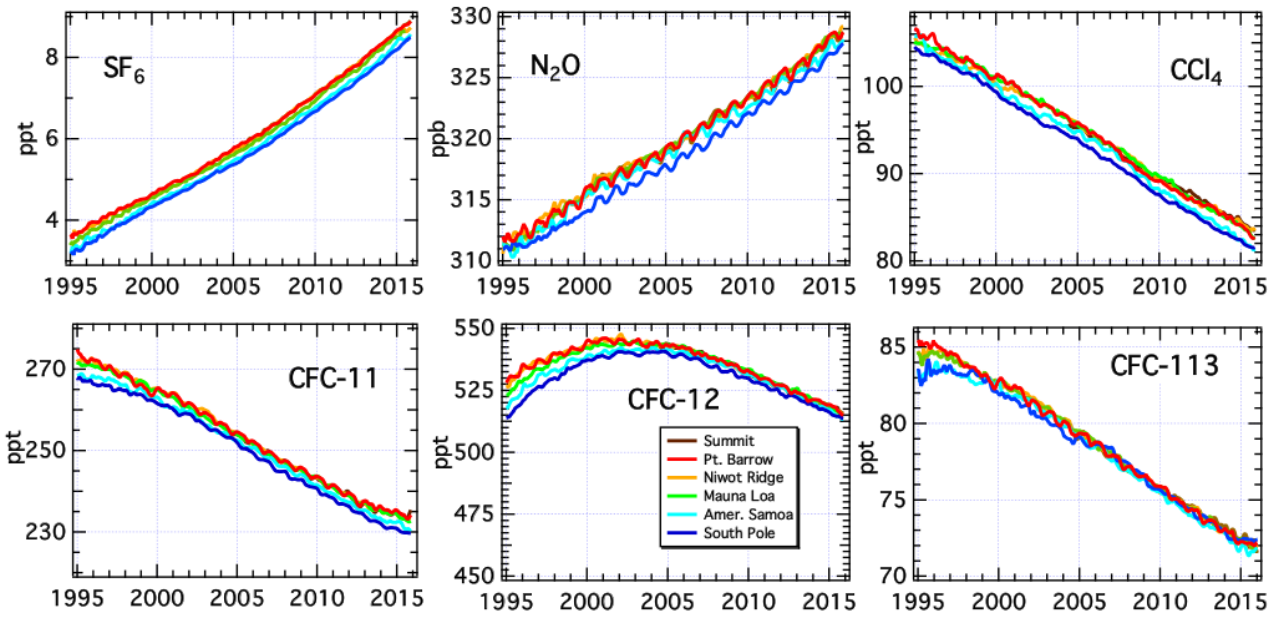

Figure 1. Monthly means of important trace gases from the GMD's halocarbon monitoring network (combined data from flasks and *in situ* gas chromatographs) versus time used to calculate emissions from two box models.

Halogenated Trace Gases and Volatile Organic Compounds at the Global Atmospheric Watch Observatory Schneefernerhaus/Zugspitze, Germany

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Halocarbons and hydrocarbons (C_2 - C_8) are being monitored at the German Global Atmosphere Watch (GAW) Global Station Zugspitze/Hohenpeissenberg (2670 m a.s.l.), Germany. At the summit, atmospheric chemical measurements have been performed since the late 1970's. In 1998, measurements for the United Nation's GAW program moved to the environmental research station Schneefernerhaus, 300 m below the summit, where they support the study of greenhouse gases, reactive gases and aerosols. In 2013, an automated, remotely controlled gas chromatography/mass spectrometry (GC/MS) analytical system was installed for the monitoring of chlorofluorocarbon and other halocarbon trace gases. Monitoring of volatile organic compounds was added in 2015. Ambient samples are taken daily at 2:00 am local time, followed by measurements of a standard and zero air. 2.8-liter samples are dried to a dew point of -45°C and pre-concentrated onto an adsorbent trap of CarboxenÒ 1000 and 1016 at -40°C. Samples are then injected onto the GC column by flash heating the trap. Over 70 compounds are identified and routinely monitored; of these, 53 are quantified based on availability of standards. These include compounds regulated by the Montreal Protocol, such as CFC-11, CFC-12, carbon tetrachloride, HCFC-22, HFC-134a, and HFC-152a. Monitored volatile organic compounds include C_2-C_6 alkanes, alkenes, benzene, toluene, and o-xylene. Quantified results of selected compounds will be compared to the results from Advanced Global Atmospheric Gases Experiment (AGAGE) measurements, in particular those from the nearby Jungfraujoch, Switzerland.

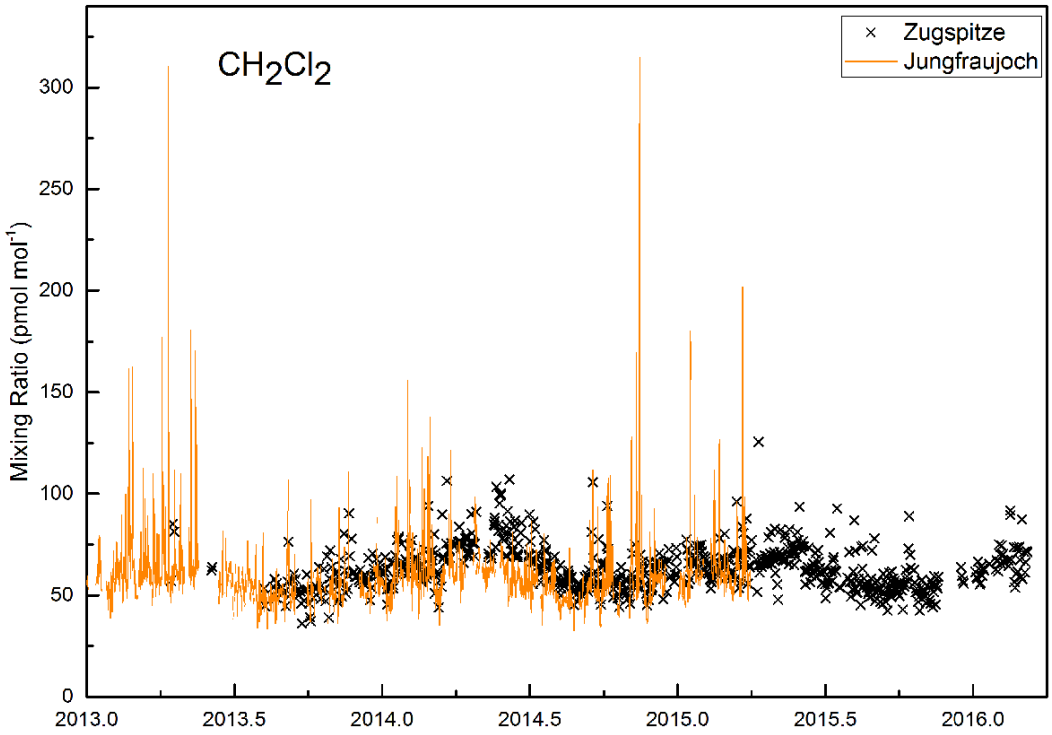

Figure 1. Ambient mixing ratio of dichloromethane (CH_2Cl_2) measured at Zugspitze from 2013 to early 2016. The results from AGAGE measurements at Jungfraujoch station are plotted for comparison (Jungfraujoch data, http://agage.eas.gatech.edu/data_archive/agage/gc-ms-medusa/complete/jungfraujoch/, curtesy of Martin Vollmer and Stefan Reimann).

GMD's GC/MS Analytical System for Preconcentration of Environmentally Relevant Species (PERSEUS)

B.R. Miller[1,2], D. Guenther[1,2], P.K. Salameh[3], B.D. Hall[2], M.J. Crotwell[1,2], C. Siso[1,2], S.A. Montzka[2], J. Kastengren[1], D. David[1] and P.P. Tans[2]

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The development of PERSEUS represents a significant advancement, relative to existing instrumentation of its kind, in the analysis of atmospheric samples for a wide range of halocarbons, hydrocarbons and sulfur-containing compounds at part-per-quadrillion (ppq) to part-per-billion (ppb) mole fractions. Having demonstrated two years of reliable performance, the first version of this instrument 'PR1' is now the 'work horse' instrument for analysis of the samples collected by the Global Greenhouse Gas Reference Network (GGGRN) in their programmable flask packages (PFP) in tall towers, small aircraft and other mobile platforms of the North American sampling programs, and also provides analyses of weekly flask pairs collected globally in the more remote surface troposphere for the Halocarbons and other Trace Atmospheric Species group. Now adding more than a dozen new analytes to the monitoring database, including ethane, perfluorocarbons (PFCs) and toluene, PR1 also provides significantly higher reproducibilities and higher sample throughput relative to previous gas chromatography/mass spectroscopy (GC/MS) instrumentation used for PFP analyses. The lower sample pressure requirements of PR1 permit analyses of GGGRN's 2.5-L glass flask pairs collected in the Cooperative Network. Examples of several new datasets will be presented.

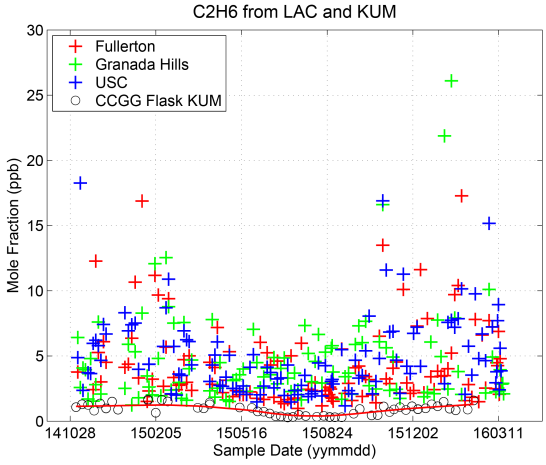

Figure 1. Example new dataset from PERSEUS. (left) Time series of ethane (C_2H_6) mole fractions observed using PFP flasks from three sites of the Los Angeles MegaCities (LAC) program. The C_2H_6 abundances using Cooperative Network flasks from Cape Kumukahi (KUM), HI are the assumed 'background' air masses with respect to LAC.

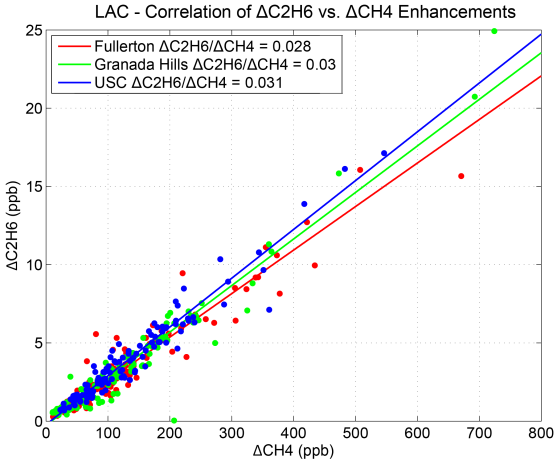

Figure 2. Correlation plot of ΔC_2H_6 vs. ΔCH_4 enhancements (i.e., KUM subtracted from LAC) observed at LAC during period October 2014 to March 2016. Slopes reflect the C_2H_6/CH_4 composition of the natural gas distributed in the L.A. basin, plus additions of CH_4 from landfills, wastewater treatment and agriculture (i.e., cattle).

Infrared Spectra and Radiative Efficiencies of Atmospherically Persistent Perfluoroamines

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Perfluoroamines (PFAms) are a class of compounds used primarily in electronic testing and heat transfer applications, which may lead to their release into the atmosphere (e.g. perfluorotributylamine, $N(C_4F_8)_3$, was observed in Toronto (Hong et al., 2013) with an atmospheric mixing ratio of ~0.18 ppt). The atmospheric loss processes of perfluoroamines are presently not well characterized, but they are expected to be atmospherically persistent compounds with lifetimes greater than 500 years. Perfluoroamines are potent greenhouse gases due to their strong infrared absorption in the atmospheric window region. A thorough understanding of the environmental impacts of PFAms necessitates further laboratory studies of the optical and chemical properties of this class of compound.

In this study, the infrared absorption spectra and radiative efficiencies (RE) of a homologous series of aliphatic perfluoroamines, $N(C_XF_{2X+1})_3$ with x = 2-5, were evaluated. Infrared spectra were measured using Fourier transform infrared spectroscopy between 600-4000 cm^{-1} and radiative efficiencies were calculated using estimation methods. The infrared absorption spectra of PFAms have received little attention to date with only the infrared spectrum of $N(C_4F_9)_3$ being reported by Hong et al. (2013) and Godin et al. (2016). The present results are compared with these previous results and trends in the PFAm REs are discussed. Potential atmospheric loss processes of PFAms, atmospheric lifetimes, global warming potentials and future laboratory studies will also be discussed.

Godin, P. J., A. Cabaj, S. Conway, A. C. Hong, K. Le Bris, S. A. Mabury, and K. Strong (2016), Temperature-dependent absorption cross-sections of perfluorotributylamine, J. Mol. Spectrosc., doi:10.1016/j.jms.2015.11.004

Hong, A. C., C. J. Young, M. D. Hurley, T. J. Wallington, and S. A. Mabury (2013), Perfluorotributylamine: A novel long-lived greenhouse gas, Geophys. Res. Lett., 40, 6010-6015, doi:10.1002/2013GL058010.

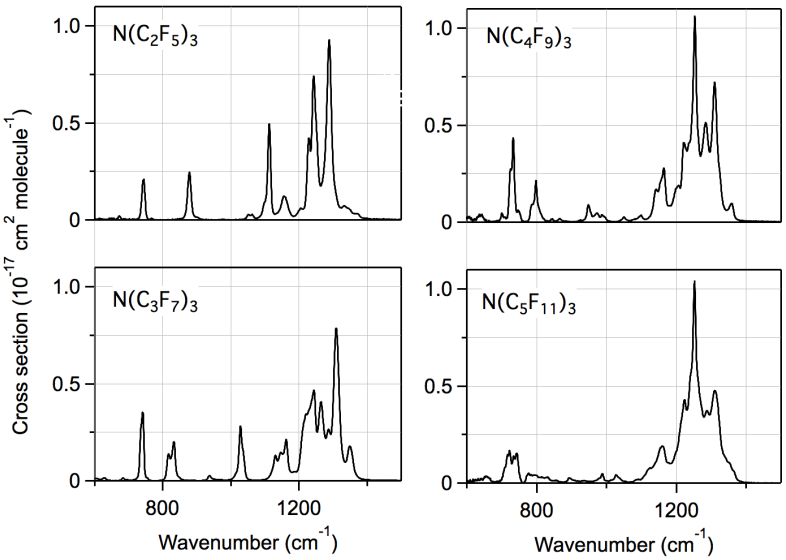

Figure 1. Infrared absorption spectra (base e) of several perfluoroamines.

Evaluation of Environmental and Logistic Conditions at Yushan Station in Taiwan for an Outdoor Radiation Calibration Facility

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There is a critical need for atmospheric radiation calibration in Taiwan. In this presentation, we purpose to set up an outdoor radiation calibration facility at Yushan weather station (23.49ºN, 120.95ºE; 3858m), which is the highest site in Taiwan, as well as in East Asia. The site is located within the free troposphere and can prevent aerosol (air pollutants) from local influences. The site is located on the mountain peak, which provides a wide open sky for radiation measurements. Considering to the solar position, the early summer to autumn will be the best seasons for outdoor radiation calibration. According to our historical measurements, we frequently observed showers in the summer afternoon and clear sky days in autumn. There are several logistic issues making site operation challenging. First, this is not a vehicle reachable site. Eight hours climbing one way is required. Therefore, how to ship instruments to the site could be a problem that may need to be solved. Second, we rely on solar power as the only electrical source. The power issue will be discussed in this presentation. We are planning to set up the facility by this summer and start to operate calibration procedure this autumn.

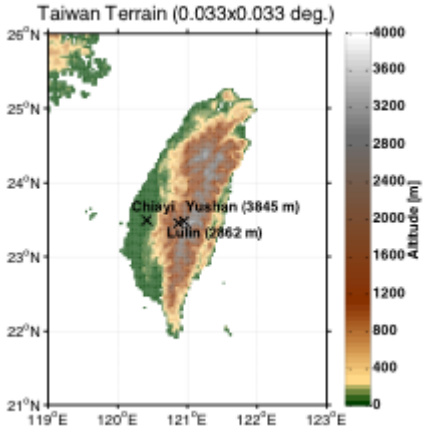

Figure 1. Geographic location of Mt. Yushan and the Yushan weather station.

Figure 2. Photo of Yushan Weather station

The NOAA Global Monitoring Division's UV Monitoring Networks: Update on Antarctica and NEUBrew

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[3]Biospherical Instruments Inc, San Diego, CA 92110

The 2015 Antarctic ozone hole was large even by current standards. Depending on the baseline, it was at least the 4th largest on record. This extreme event was not consistent with the prevailing trend of ozone holes over the last ten years. The ramifications of large ozone depletion over a large area are increased ultraviolet (UV) irradiance at the surface. The dynamic aspect of the hole shifting and rotating in addition to changing cloud conditions cause rapidly changing surface UV, which impacts the biological systems. One of the derivative products of the spectral UV irradiance measured at each station is the UV index. The index is a measure of the sun-burning ability of the irradiance. Palmer station, on the Antarctic peninsula incurred large UV index values on multiple days. The World Meteorological Organization has declared UV indexes of 11 or greater as extreme. UV indices at Palmer station exceeded 12 several times this past austral spring. These measurements are important for understanding the effects on the biological systems influenced by the rapidly changing UV irradiance levels.

The NOAA-EPA Brewer Spectrophotometer UV and Ozone (NEUBrew) network operates Brewer Mark IV spectrophotometers at each station. This is a multi-functional instrument that measures UV irradiance, total column ozone and the ozone profile. The Mark IV utilizes a solar blind nickel sulfate ($NiSO_4$) crystal sandwiched between two UG-11 colored glass filter. The filter performs order sorting and greatly reduces out-of-band straylight. Unfortunately, the $NiSO_4$ filter is very hygroscopic and its operating characteristics change as it takes on or sheds water molecules. This results in unstable UV calibrations. A new variant of the $NiSO_4$ is now available and is more thermally stable than its predecessor. Eight of the ten NEUBrew network Brewers were outfitted with the new UVC-7 filter in October 2014. The other two Brewers were left with their original NiSO4 filters. Long-term testing of the new filter's stability vs. the original units was performed. The results of those tests are presented here.

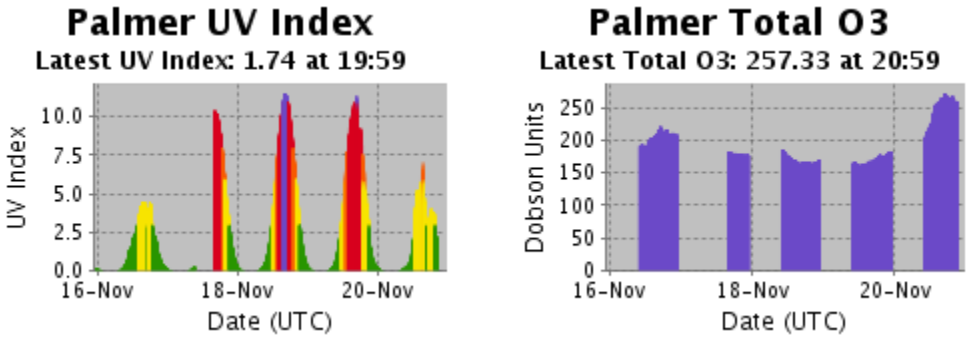

Figure 1. The two plots above are of UV Index (a measure of the sun-burning ability of solar UV radiation) and total column ozone measurements made by ESRL/GMD's Global Radiation's Antarctic UV Monitoring program. Palmer experienced UV indices greater than 12 this last season.

Synthesis of Aerosol Physical, Chemical, and Radiative Properties from Various Sources: Consistency and Closure

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Aerosol direct radiative forcing is determined from a set of optical properties -- aerosol optical depth, single scattering albedo, and asymmetry parameter -- which can be obtained from a range of different measurement techniques. Every technique has unique limitations, thus uncertainty and bias in radiative forcing estimates can vary widely depending on the measurement approach used. Given that a small fraction of these observations are most widely used for climate change studies, a comprehensive assessment of the interrelationship among all measurements would be of benefit. We present a synthesis of Atmospheric Radiation Measurement (ARM) aerosol products from ground-based *in situ* and remote sensing techniques together with the NASA Aerosol Robotic Network (AERONET) and satellite observations with the goal of testing these products for consistency. Physical (size distribution) and chemical composition data are used to derive aerosol optical properties and the results are compared to observations from the nephelometer and particle/soot absorption photometer instruments as well as derived products from the ground-based radiometers. Dependence on humidity related particle growth is included in the analysis. We furthermore present results from a closure study in which the above properties are used to derive surface broadband shortwave radiative fluxes from a model and compared to the analogous measurements. To obtain the latter we reconstruct vertical profiles of aerosol properties by combining ground-based *in situ* aerosol measurements with remotely sensed vertical information of atmospheric properties. The primary objective of this work is to provide greater confidence in the characterization of aerosol optical properties in different regimes in order to better constrain observationally-based and modeled aerosol radiative forcing estimates. Understanding how aerosol optical properties and radiative forcing vary, and covary, in different regions of the globe can improve assumptions required for retrievals and products from satellite-based observations. Understanding how these radiative quantities covary with chemical composition can help to relate that information to processes parameterized in models that address the climate impact of aerosols.

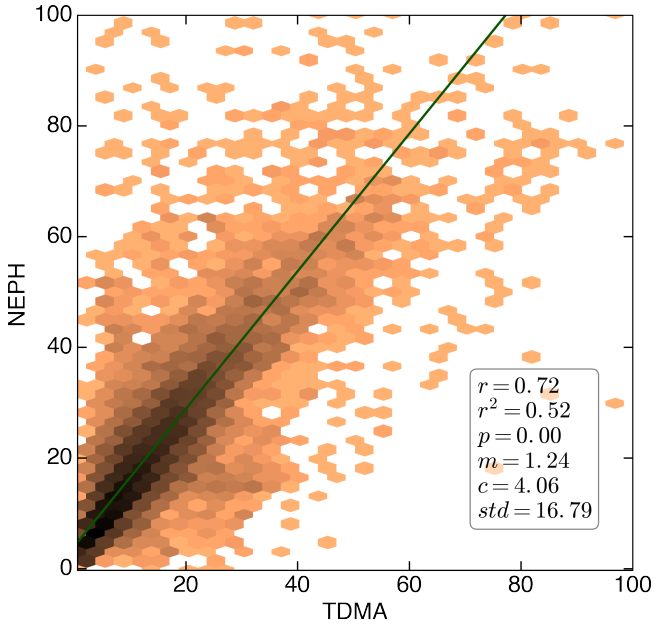

Figure 1. Correlation between aerosol scattering coefficients as measured and derived from particle size distributions at the ARM's Southern Great Plains site.

Pioneering Detector Technology and Architecture Used in a Next Generation Pyranometer Yielding Negligible Thermal Offsets and Sub-second Response

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[2]EKO Instruments Europe B.V., The Hague, Netherlands
[3]EKO Instruments Co., Ltd, Tokyo, Japan

The last 100 years of pyranometer development has seen very little change from the original optical and physical design. This lack of innovation has forced limits on measurement accuracy and stunted the proliferation of high-quality sensors crucial to understanding a changing global climate. EKO Instruments recently developed a new pyranometer (MS-80) with a novel architecture that allows for true cosine response and a thermally isolation of the detector. This thermal isolation provides negligible zero offset A and B without resorting to expensive quarts or sapphire domes. In addition to this new architecture, a novel detector technology was developed allowing for a response time of 0.5 seconds (at 95%). Since the detector is deep within the remarkably sealed sensor body rather than at the sensor surface, the effects due to changes in humidity, barometric pressure, temperature, and exposure to radiation are insignificant resulting in enhanced long-term stability allowing for greater time (≥5 years) between calibrations. Through improvements to all of the ISO 9060 specifications, the measurement uncertainty of this pyranometer has been greatly reduced compared to previous secondary standard sensors allowing for faster trend analysis. Indoor and outdoor data from Japan will be presented as well as data taken from the Surface Radiation Research Laboratory at the National Renewable Energy Laboratory in Golden, CO.

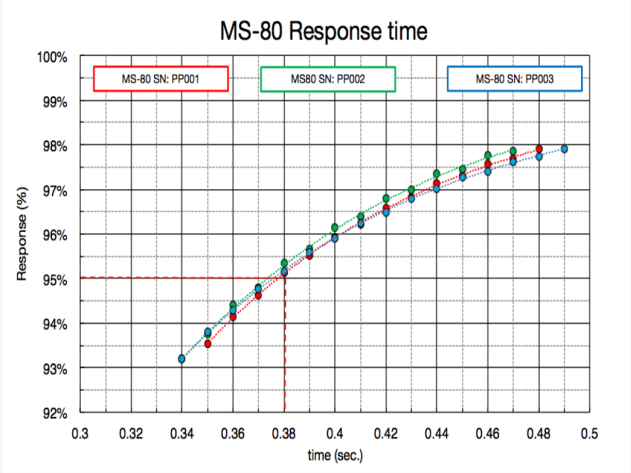

Figure 1. MS-80 Pyranometer Response Time.

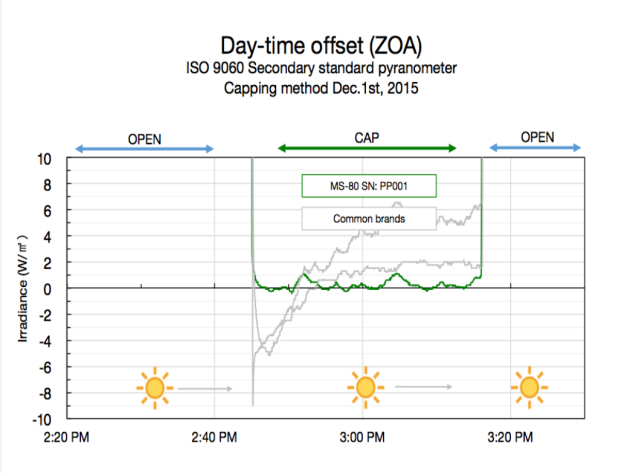

Figure 2. MS-80 Pyranometer Zero Offset A Measured Using Capping Method.

Annual Evolution of Surface Energy Flux at Summit, Greenland

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[2]University of Colorado, Department of Atmospheric and Oceanic Sciences, Boulder, CO 80309
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[4]Oregon State University, College of Earth, Ocean and Atmospheric Sciences, Corvallis, OR 97331

The Greenland ice sheet surface temperatures and melt processes are controlled by an exchange of energy at the surface, which includes radiative, turbulent and conductive heat fluxes. In order to constrain the relevant ice sheet/atmosphere energy exchange processes, observations of all the terms are needed at once for a range of conditions and months. Here, we leverage data collected by multiple projects, to calculate diurnal estimates of all the surface energy budget (SEB) terms at Summit, Greenland, for an annual cycle from July 2013 - June 2014 (Figure 1).

Clouds exert a strong radiative influence on the surface energy budget, warming the surface throughout the year. Generally, the other SEB terms respond to changes in net radiation, compensating for an increase in the total radiation due the presence of clouds. Substantial surface warming from these clouds typically leads to the degradation of a surface-based temperature inversion and a change from a stable to unstable regime near the surface. Relationships between radiative forcing terms and non-radiative surface fluxes are investigated at Summit, Greenland throughout the annual cycle.

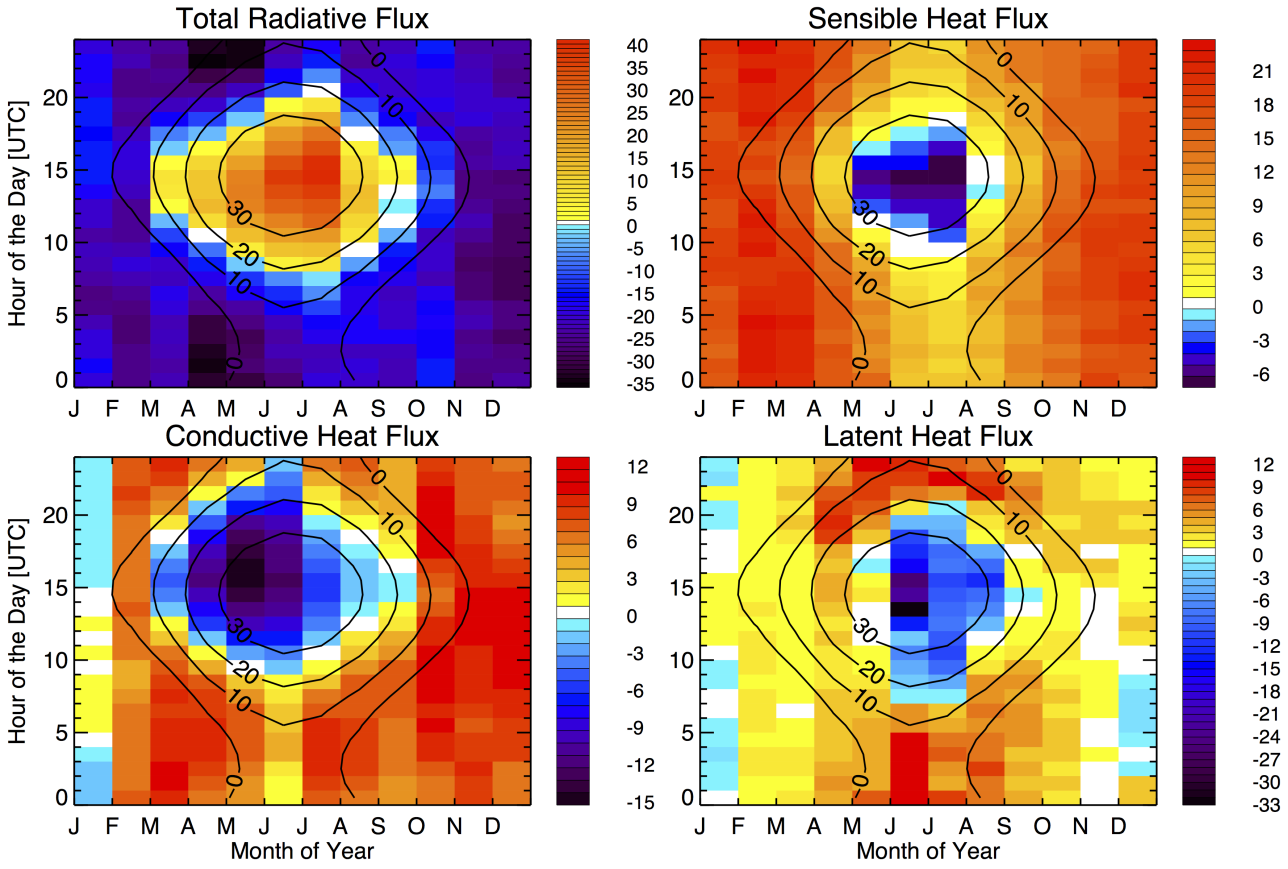

Figure 1. Hourly mean values from July 2013 - June 2014. Black contour lines indicate the solar elevation angle. Units on the colorbars are all in W m^{-2}.

A Method to Correct Longwave Radiation Measurements Corrupted by a Bad Thermistor

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The ESRL/GMD SURFace RADiation (SURFRAD) network has been operational for over 20 years and has the longest tenure of any previous national surface radiation network. Measurements of upwelling and downwelling LongWave (LW) radiation are integral components of the Surface Radiation Budget (SRB) -- the focus of SURFRAD. Missing any of the four components of the SRB nullifies the primary product of the network until the bad instrument is replaced or repaired, leaving a gap in the SRB time series. Retrieval of the LW signal requires three measurements by the pyrgeometer: the thermopile signal under the filtered dome, the temperature of the instrument body (case temperature), and the temperature of the insturment's dome. The case and dome temperature measurements are made by thermistors and account for over 80% of the LW signal. Because those temperatures are raised to the 4th power in the LW retrieval, small measurement errors came make for large LW errors (~20 Wm-2 per 1°C error). A method has been developed to correct a bad thermistor measurement that adds only 1-2% extra error to the LW retrieval. It is based on the relationship between the case-dome temperature difference and the thermopile signal. If one thermistor temperature is good, the other can be recovered using the linear relationships shown in the figure below, which are based on a period of good data from the affected instrument. Thermistor errors of < 1°C are difficult to perceive in data quality control and can persist for months. These situations have occurred several times in the SURFRAD network and many months of SRB data have been saved owing to this correction method.

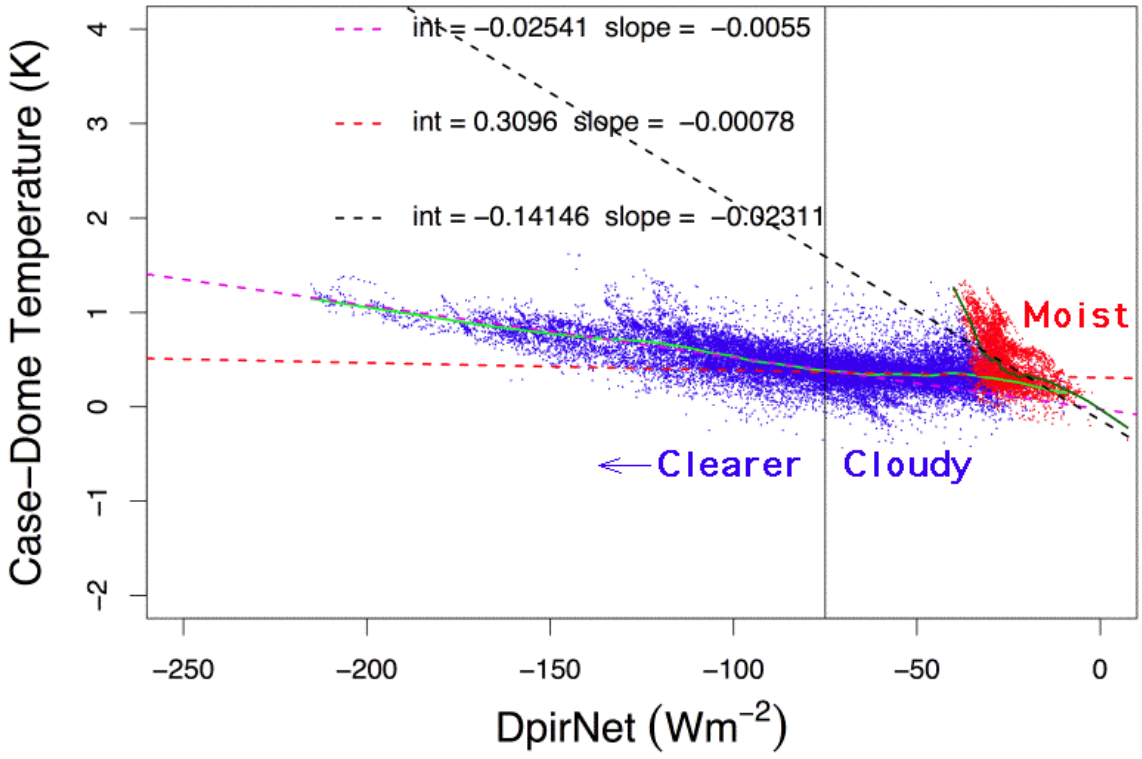

Figure 1. Case – dome temperature difference versus the thermopile voltage of a normal operating upward-looking pyrgeometer at the Fort Peck SURFRAD surface radiation budget station. The three linear relationships shown can be used to recover longwave data if one of the instrument's thermistors goes bad.

Aerosol Climatology at Mt. Lulin: AERONET and *In Situ* Measurements

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The Lulin Atmospheric Background Station (LABS) located at Mt. Lulin (2862m) in central Taiwan was established to monitor the atmospheric compositions and radiation in the lower free troposphere of East Asia since 2006. Our aerosol measurement suite, including Cimel sun-photometry, aerosol *in situ* system (i.e. particle soot absorption photometer, continuous light absorption photometer, AE31, TSI Nephelometer, TSI Condensation Particle Counter), has been operated based on NASA Aerosol Robotic Network (AERONET) and NOAA Earth System Research Laboratory (ESRL) Global Monitoring Division (GMD) protocols, respectively. In this presentation, we will focus on the overall climatology of aerosol optical depth (AOD) and aerosol microphysics at LABS. The annual mean AOD is 0.07 with the maximum value of 0.2 observed in March. The higher AOD is associated with high loading of biomass-burning aerosols transported from Indochina in spring. In comparison with other AERONET high-elevation sites, the Lulin site shows a significant seasonal variation and is relatively sensitive to influences of continental outflows. In addition to AERONET data, we will also present the aerosol data from ESRL/GMD aerosol system at Lulin and compare several key optical parameters (i.e., aerosol absorption coefficient, scattering coefficient, as well as single-scattering albedo) to AERONET climatology. The different between columnar and *in situ* aerosol optical properties will also be discussed in the presentation.

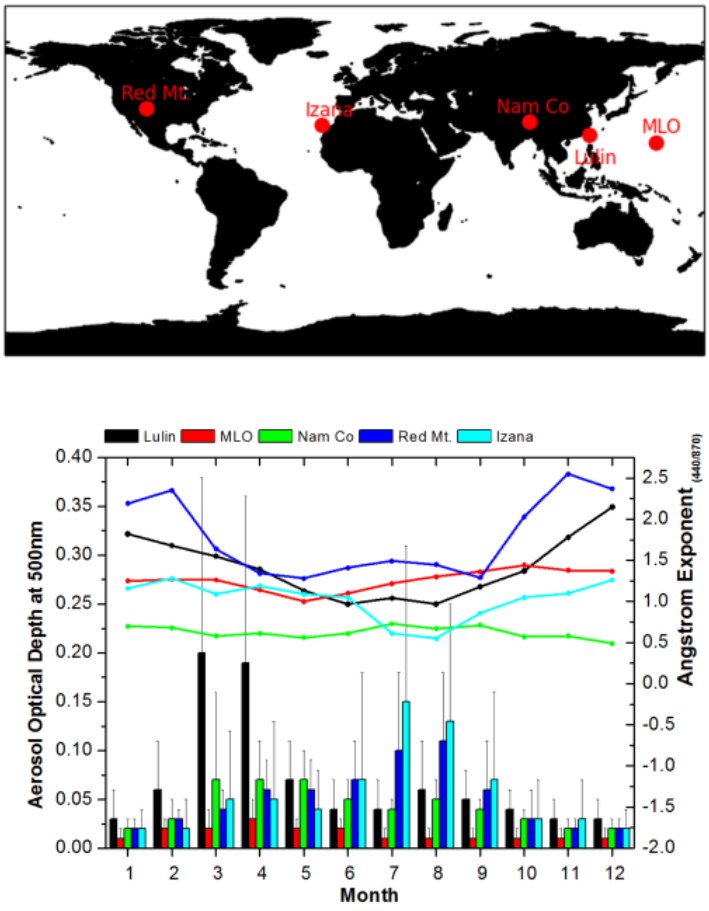

Figure 1. Comparisons of AOD and Angstrom between 5 high-elevation AERONET sites in the northern hemisphere.

Multi-year Measurements of Aerosols at Jaipur, a Site in Northwestern India

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[2]National Aeronautics & Space Administration (NASA), Goddard Space Flight Center, Greenbelt, MD 20771

During the period from April 2011 to March 2015, *in situ* measurements of aerosol optical properties were conducted at an urban site in Jaipur, Northwestern, India as a part of research initiative at Birla Institute of Technology Mesra, Jaipur campus with support from Department of Science and Technology, Govt of India over Jaipur (26.9°N, 75.8°E, 450m asl), located near to Thar Desert in the state of Rajasthan, India.

In this study, the variations in Aerosol Optical Thickness (AOT) and its spectral properties, especially in summer and winter seasons, from year 2011 to 2014 are analyzed. The NASA Aerosol Robotic Network (AERONET) Level 2 quality controlled data is also used in the present study. The seasonal trends in AOT together with particle sizes are evaluated with respect to the two primary contrasting seasons in the present study. The mean AOT is greater in the summer (>0.5) with a corresponding low angstrom exponent (AE) values due to dust episodes. A high AOT is also observed in winter but with high AE value denoting the contribution of secondary particle due to local pollution. The intercomparison of the results from other monitoring networks across Indo gangetic Plains (IGP) will also be presented.

Keywords: Aerosols, AOT, Size distribution

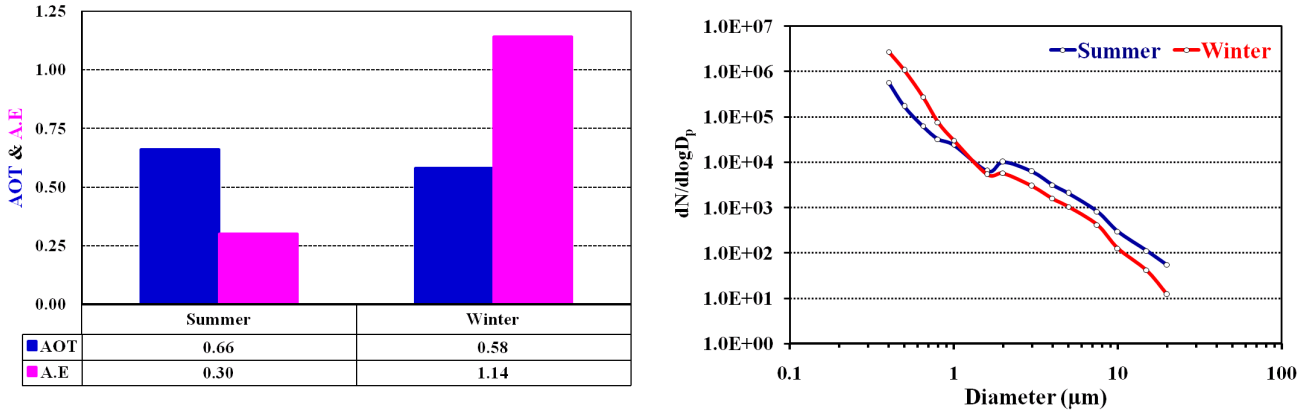

Figure 1. The mean AOT and ANC during summer and winter over Jaipur (Northwestern, India).

Mitigation of Particulate Matter Problem Caused by Vegetation Fires in Thailand

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Vegetation fires are an important source of particulate matter in the atmosphere. Every year in the fire season from February to April, the dry and stagnant weather in the north of Thailand allows the PM_{10} (particulate matter with an aerodynamic diameter ≤10 μm) from vegetation fires to accumulate in the atmosphere at levels higher than the national ambient standard of Thailand of 120 μg/m^3. This affects the health of people in terms of respiratory illnesses and premature deaths and necessitates fire management from the Government.

This study used a meteorological mesoscale model (MM5) and an air quality model (CALifornia PUFF: CALPUFF) to find causes and solutions for the fire emissions problem so as to meet Thai air quality standard. The study period during 26 February to 1 March 2012 was used to simulate various scenarios. The land-use types of fire sources were classified for finding the main source of the smoke problem including neighboring countries, village, agricultural and forest areas. The PM_{10} loadings from each land-use type of vegetation fire source were estimated by the numbers of hotspots which were derived from satellite fire-active products with Moderate Resolution Imaging Spectroradiometer. Results from the model simulation showed that PM_{10} from nearby countries was less affected than the local PM_{10}. Most of the fire locations occurred within a range of 1 to 4 kilometres of villages and agricultural areas. In addition, meteorology is an important factor for the smoke problem in this study area. A few hot spots in the area can have high concentrations of PM_{10} because the average mixing heights of these areas were less than 500 metres which were low mixing heights. Meteorological inversions lead to stagnant air, causing the fire smoke to be trapped near the ground surface.

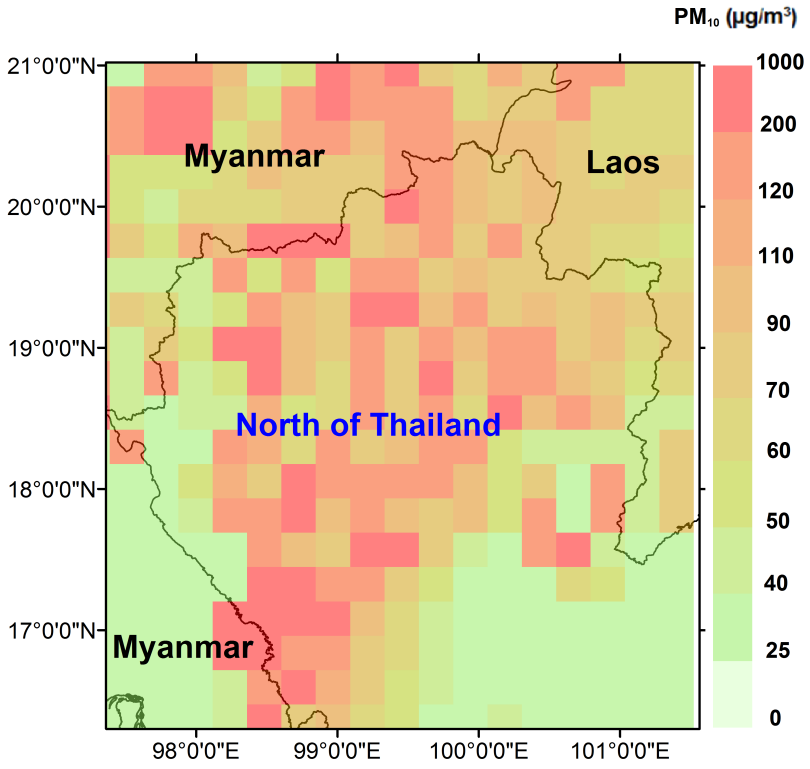

Figure 1. The result of estimated PM_{10} concentrations caused by vegetation fires in the north of Thailand and neighboring countries in 28 February 2012 by CALPUFF model.

Source Influences on the Aerosol Size Distribution and Cloud Condensation Nucleus (CCN) Activity at the Resolute Bay Ground Site in Canada

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Aerosol measurements at the Canadian Aerosol Baseline Measurement station at Resolute Bay began in May 2013 with the main objective of estimating the influence of shipping emissions on the physical and optical properties of the measured aerosol. The on-going measurements are particle light absorption, particle light scattering, particle size distribution, sulfur dioxide (SO_2), ozone (O_3), mono nitrogen oxides (NO_x) and fine particles ($PM_{2.5}$). During the July, 2014 NETCARE POLAR 6 campaign, measurements of cloud condensation nucleus (CCN) number concentrations were also made at the site. Here the focus is on the observations of small particles (10-100 nm), their CCN activity and observed growth that may enhance their CCN activity at supersaturations between 0.4% and 1%. The observations will be considered for different potential sources: ship plumes, local sources (e.g. garbage burns), regional biogenic sources and long-range transported aerosols (including wild fires).

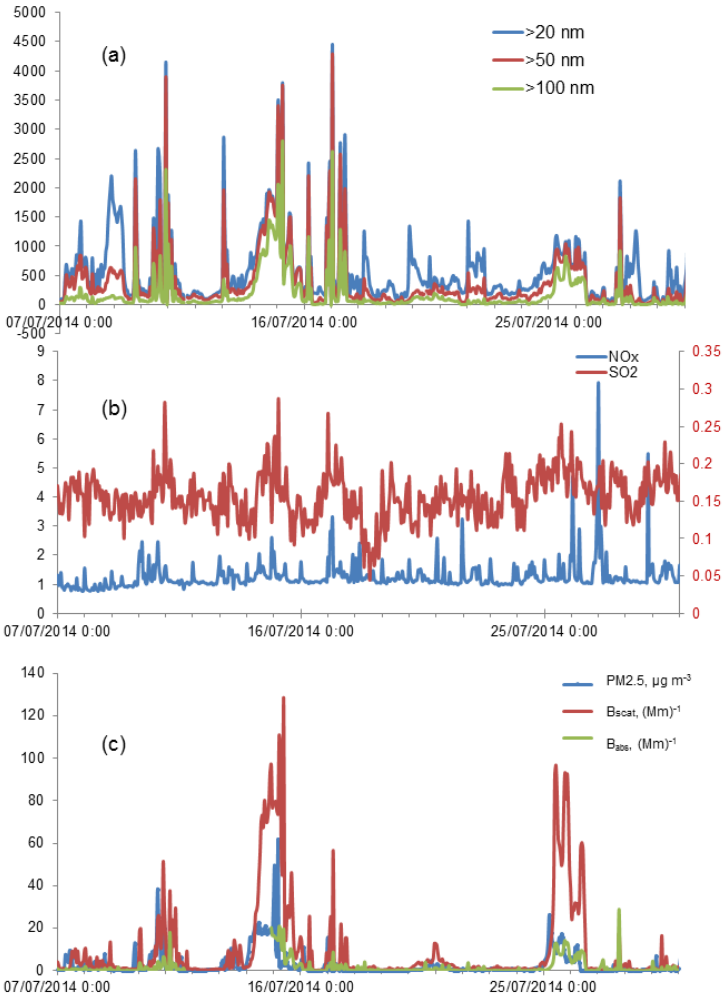

Figure 1. Particle number concentrations (cm^{-3}) in >20, 50 and 100 nm sizes show new particle formation and wild-fire event influences with episodic increases on particle formation. b) shows NO_x and SO_2 levels for anthropogenic influences and c) shows light absorption and scattering measurements (550 nm) and $PM_{2.5}$ mass at Resolute Bay (74.6°N, 94.9°W), Nunavut, Canada.

A Comparison of Inlet Setups at Storm Peak Laboratory

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For many years, the NOAA ESRL/GMD has helped to operate and maintain numerous field sites for measuring and collecting data on ambient aerosol conditions, often in collaboration with other research institutions. One of these field sites, Storm Peak Laboratory in Steamboat Springs, operated by the Desert Research Institute, has been a key mountain site measuring aerosol optical properties continuously since 2011. During this time, a couple of inlet configurations have been used to collect aerosol data, using a variety of instrumentation. The first inlet was installed in 2001 (to present), and the second inlet was installed in 2012. In order to make sure that these instruments are performing correctly while on these different inlet setups, this study makes comparisons of these various arrangements. The first configuration occurred while two instrument racks were connected to the same inlet (different ports, displaced horizontally), while the second occurred while the two instrument racks were on separate inlet systems. Ideally, across both arrangements, the instruments should agree very well, but this is not the case for every scenario. In this study we present hypotheses as to why discrepancies exist between the two inlet setups (specifically size cuts), and why not all hypotheses presented can be rejected.

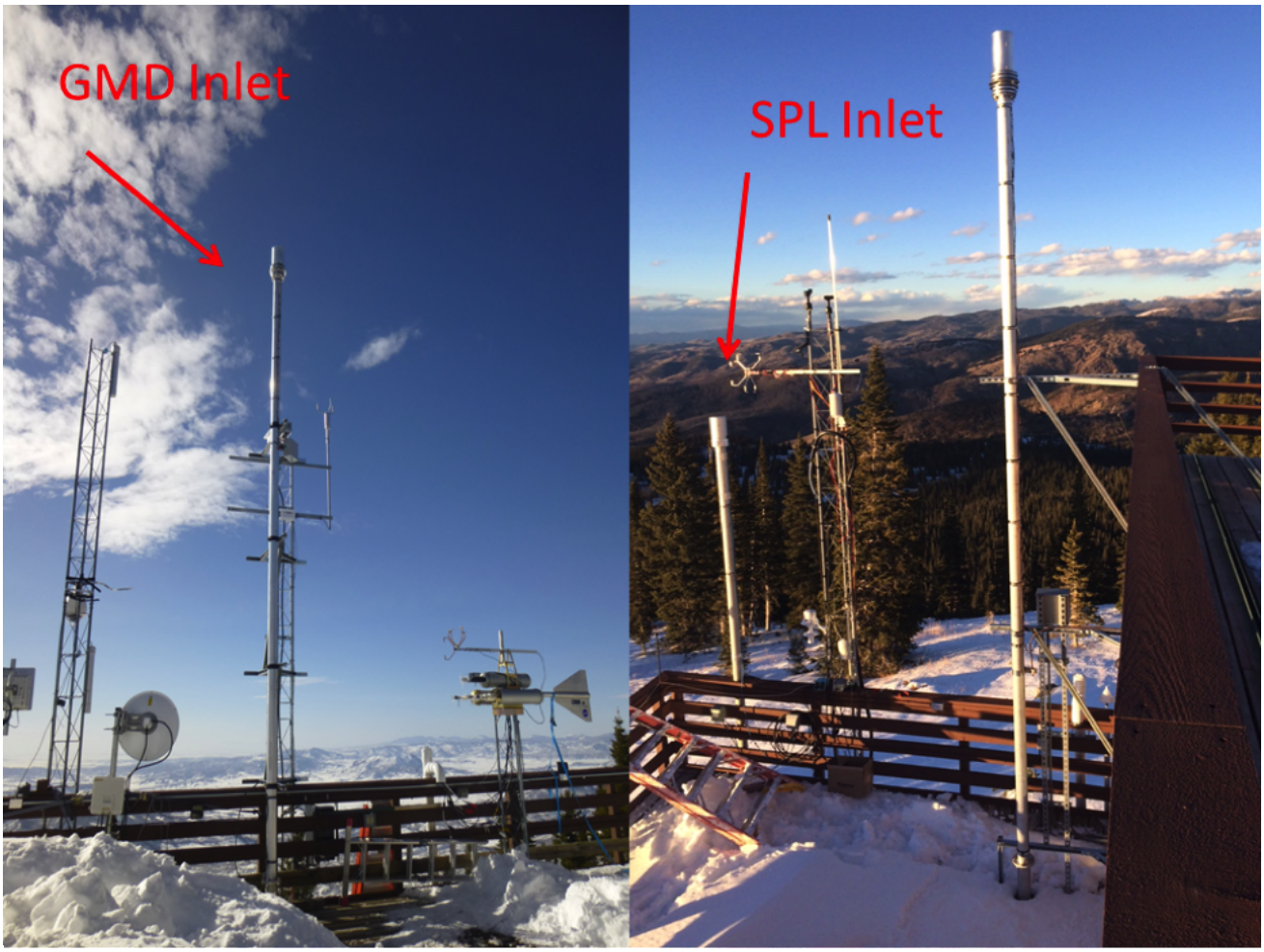

Figure 1. Photographs of both inlets at Storm Peak compared in this study.

Design of a Novel Aircraft Open-path Cavity Ring-down Spectrometer

G. Adler[1,2], N.L. Wagner[1,2], B.J. Mason[1,2], M. Richardson[1,2], C. Brock[2], F. Erdesz[1,2], T. Gordon[1,2] and D. Murphy[2]

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Aerosols and their effect on the radiative properties of clouds contribute one of the largest sources of uncertainty to the Earth's energy budget. Many current global assessments of atmospheric aerosol radiative forces rely heavily on remote sensing observation; therefore, *in situ* aircraft and ground-based measurements are essential for validation of remote sensing measurements. Cavity Ring-Down spectrometers (CRD) measure aerosol extinction and are commonly used to validate remote sensing observations. These instruments have been deployed on aircraft-based platforms over the years, thus providing the opportunity to measure these properties over large areas in various conditions. However, deployment of the CRD on an aircraft platform has drawbacks. Typically, aircraft-based CRDs draw sampled aerosol into a cabin-based instrument through long lengths of tubing. This limits the ability of the instrument to measure:

1) Course mode aerosols (e.g. dust)

2) Aerosols at high relative humidity (above 90%)

Here we describe the design of a novel aircraft-based open path CRD. The open path CRD is intended to be mounted external to the cabin and has no sample tubing for aerosol delivery, thus measuring optical properties of all aerosol at the ambient conditions. However, the design of an open path CRD for operation on a wing-mounted aircraft platform has certain design complexities. The instrument's special design features include 2 CRD channels, 2 airfoils around the open Path CRD and a configuration which could be easily aligned and rigid at the same time. This novel implementation of cavity ring-down spectroscopy will provide a better assessment of the accuracy of remote sensing satellite measurements.

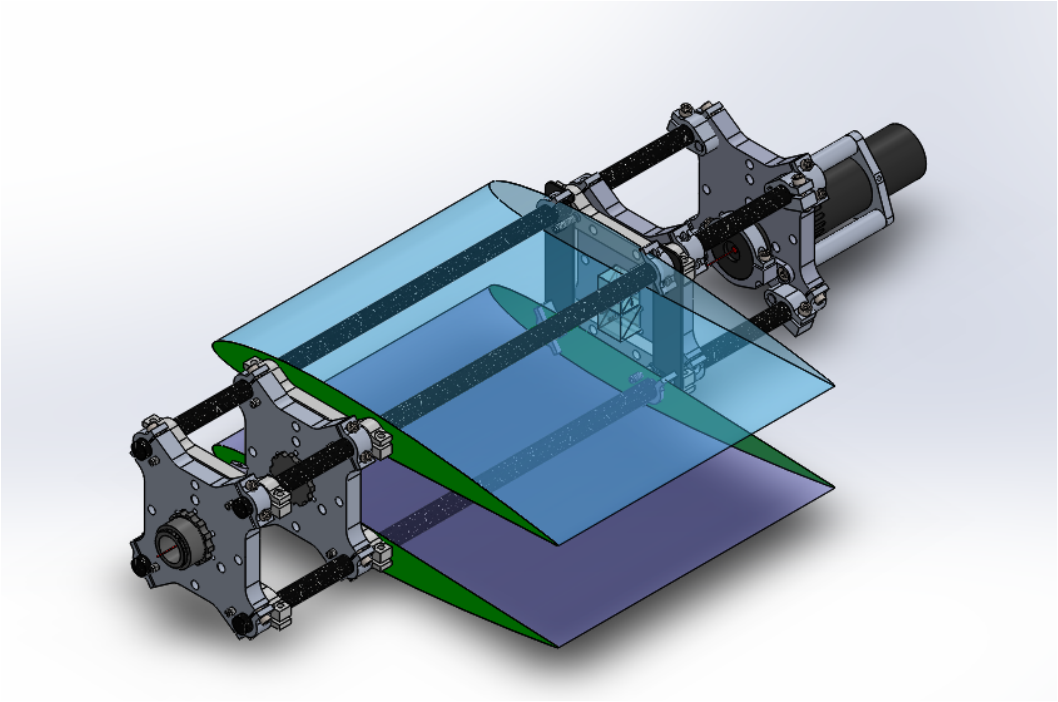

Figure 1. Drawing of the aircraft open-path cavity ring-down system

A "MAGIC" Water Condensation Particle Counter

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[2]Aerosol Devices Inc., Fort Collins, CO 80524

A portable, water-based condensation particle counter (WCPC) uses a new temperature-moderated laminar flow condensation method with a self-sustaining wick. It operates in any orientation, and can function for extended periods without addition of working fluids. Called MAGIC, for moderated aerosol growth with internal water cycling, this miniature WCPC operates from a combination of the water vapor recovered from the sampled airstream, and from that recovered internally. There are no water reservoirs, yet it is capable of days to weeks of unattended operation. It may be tipped or shaken without affecting the measurement.

The sustained operation is achieved through MAGIC's three-stage design, with a single wetted wick throughout. As described by Hering et al (2014), the first stage is a "conditioner" and is generally operated with slightly cooled walls to regulate the temperature and relative humidity of the flow. The second stage, referred to as the "initiator", is relatively short with walls that are warmer than that of the conditioner. This initiator stage provides the water vapor that creates the super-saturation to initiate droplet growth. The third stage, called the "moderator", has cool walls similar to the first stage. This third stage captures the water vapor released by the initiator stage without significant change to the saturation profiles. The stages are lined with single wick that provides wetted surfaces throughout. Once the wick is wet, instrument operation is sustained through a combination of water vapor removed from the sampled air flow and internal capture of added water vapor.

Calibration data are shown in Figure 1, where the reference is the TSI Model 3025, an ultrafine butanol-based condensation particle counter (CPC). The test aerosol is ammonium sulfate. MAGIC was operated with a temperatures of 5°C, 45°C and 5°C, for the conditioner, initiator and moderator, respectively. The detection efficiency is 50% at 4.5 nm.

For two weeks of unattended operation, and without addition of water, the portable WCPC was compared to the TSI-3788 ultrafine WCPC while sampling ambient air. During the first 48 hours of this period the correlation between the portable WCPC gives R2>0.99, with regression slope of 0.95. Over the entire two-week period the correlation decreases to R2=0.97, with regression slopes of 0.89.

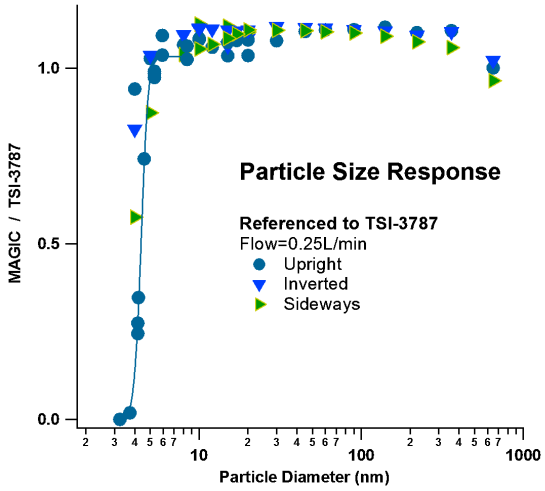

Figure 1. Calibration of the MAGIC CPC with ammonium sulfate aerosol, as compared to a TSI-3025 ultrafine, butanol-based counter.

Boundary Layer Observations at Mauna Loa Observatory, Hawaii

J.E. Barnes[1,2] and N.C.P. Sharma[3]

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[3]Department of Physics and Engineering Physics, Central Connecticut State University, New Britain, CT 06053

The NOAA Mauna Loa Observatory is an atmospheric monitoring station on the North side of Mauna Loa Volcano (4169 m summit) located at an altitude of 3396 m. The bright sun, dark lava surface, and the seven percent grade of the mountain create a surface radiation wind that changes from upslope in the daytime to downslope after sunset. The radiation wind has a magnitude of 2.5-3.0 m/s. The off-island wind interacts with the mountain to create a barrier wind. The radiation wind dominates when the off-island winds are low and opposite is true when the off-island winds are strong. Temperature inversions form at sunset in the first 50 meters above the ground. Aerosol profiles, measured with a unique technique called CLidar or camera lidar, often increase and show a peak between 60 and 160 meters. The aerosol generally decreases to upper tropospheric values with a distinct change in the rate of decrease at 600 m above the ground. At night the region between the aerosol peak and 600 m is often flowing upslope, counter to the downslope surface flow. The source of the air in this counter flow region is not well understood, but appears to come from levels below the station altitude at least occasionally. This possibly would impact the interpretation of some of the air samples taken during this period.

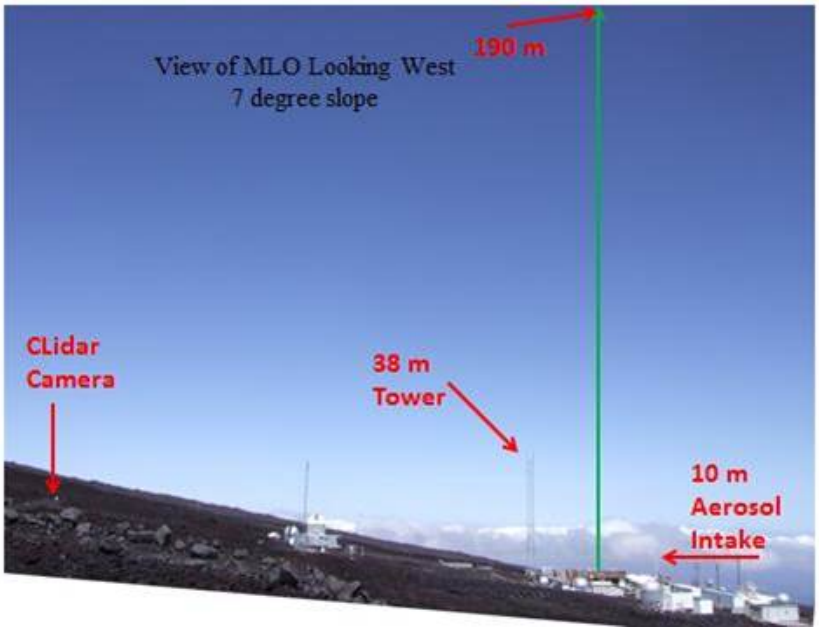

Figure 1. View of Mauna Loa Observatory showing the layout of the station on the dark lava, the position of the lidar laser (green beam) imaged by the CLidar camera, and the tower.

The Calbuco Chronicle: Volcanic Aerosols in the Post-Pinatubo Stratosphere

R.A. Keen

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The brightness of the moon during a total lunar eclipse depends on, among other things, the presence of volcanic aerosols in the stratosphere. Following the eruptions of Agung, Chichón, and Pinatubo in 1963, 1982, and 1991, the effect was striking, and allowed accurate determination of globally averaged aerosol optical depths (AOD) from each volcano. The most recent lunar eclipse, on 28 September 2015, was seen by many observers to be about 33 percent dimmer than predicted (for an aerosol-free stratosphere). While initially this slight dimming was thought to be within the range of observational error, sightings of "volcanic twilights" around the time of the eclipse suggested that the dimming was volcanic in origin.

The source of the aerosols was traced to the eruption of Calbuco in Chile 5 months earlier. The global AOD derived from the eclipse observations, 0.010, is close to the value by Steve Albers (NOAA) derived from twilight observations.

The detection of Calbuco in the eclipse record suggests that other events with small AOD in the 0.010 range could be found (keeping in mind the likely uncertainties could be half this value). Six such events are tentatively identified in the post-Pinatubo era. It should be noted that because of the timing of lunar eclipses - with occasional gaps of two years - other similar AOD events may have "slipped through the cracks" and were not detected.

R. Keen, Volcanic Aerosol Climate Forcing, 1979-2015,
http://www.esrl.noaa.gov/gmd/publications/annual_meetings/2015/posters/P-48.pdf

T. Phillips, Lunar Eclipse Detects Global Cooling (but only a little),
http://www.spaceweather.com/archive.php?view=1&day=06&month=10&year=2015

S. Albers, Volcanic Twilight Sky, http://laps.noaa.gov/albers/allsky/twilight_volcanic.html

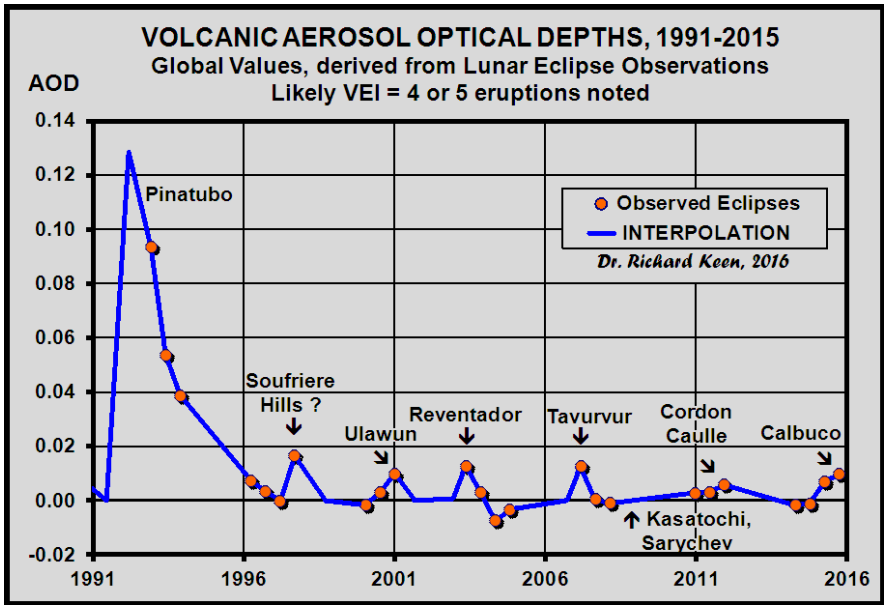

Figure 1. 1991-2015 Volcanic Aerosol Optical Depths.

Environmental Change in Barrow, Alaska Resulting from a 2015 Record Heat Wave

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[6]USGS Alaska Science Center, Juneau, AK 99801

The May 2015 average temperature at the NOAA ESRL/GMD Barrow Observatory (BRW), Alaska, set a 90+ year record high, averaging -2.2°C, nearly 5°C above average. The 2015 spring transition in Barrow was notable with the second earliest date of snow melt on record (JD 148, May 28) and earliest ice-free conditions on a local lagoon (JD 178, June 27). Anomalous early snowmelt was also observed at nearby Cooper Island where a colony of sea birds, the Black Guillemot, nests each year once snow disappears. The appearance of "first egg" is well correlated with the date of snowmelt at BRW, as is the ice-out date at the Isaktoak Lagoon (ISK) (*see Figure*). In 2015, the first egg was observed on JD 159 (June 8), the earliest in the 41-year record (source: *Friends of Cooper Island,* http://cooperisland.org/).

Each day of advance in the melt date at BRW results in a significant increase in net radiation at the surface, which in turn influences biogeochemical cycles, permafrost temperatures, and potentially the release of stored carbon and methane and the production of chloroform.

The 2015 melt at BRW was very early due mainly to an unusually intense heat wave affecting all of Alaska. In 2015, BRW permafrost temperatures were warmer than the three previous years; the active layer depth was ~6 cm deeper than in 2014; and the temperature at 120 cm was ~0.5ºC warmer. The anomalous warmth that prevailed during spring 2015 across Alaska is attributed to a combination of factors. Abnormal warmth of the North Pacific and a perturbed jet stream combined with a pattern of circulation that favored the advection of warm air into the Arctic. Warming was likely amplified regionally as the early melting of snow increased absorption of solar radiation.

Key factors contributing to the anomalous 2015 spring at BRW and the impact early melt had on the 2015 summer surface radiation budget will be presented. The role of circulation anomalies reported by reanalysis data over the course of the Barrow observational record will be presented. Analysis of interactions underlying this anomaly will aid in developing strategies for improving predictability of interannual variability of the melt season both over land and the adjacent seas.

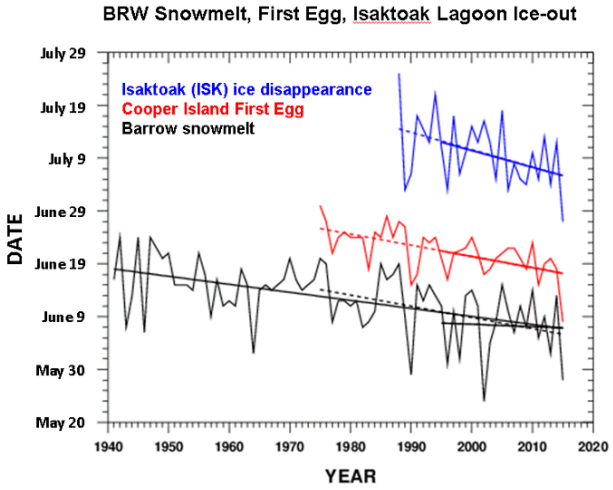

Figure 1. Correlated but independent time series, fitted linearly, showing how the annual snow/ice cycle has changed in the vicinity of Barrow. 2015 was a record or near record year for respective periods of observation.

Seasonal and Latitudinal Variations of Surface Fluxes and Meteorological Variables at Arctic Terrestrial Sites

A.A. Grachev[1,2], T. Uttal[2], O. Persson[1,2], E.A. Konopleva-Akish[3,2], S.M. Crepinsek[1,2], C.J. Cox[1,2], C.W. Fairall[2], G. Lesins[4], A.P. Makshtas[5] and I.A. Repina[6]

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This study analyzes and discusses seasonal and latitudinal variations of surface fluxes and other ancillary data based on *in situ* measurements made at two long-term research observatories near the coast of the Arctic Ocean. The hourly averaged data collected at Eureka (Canadian territory of Nunavut) and Tiksi (East Siberia) located at two quite different latitudes (80.0° N and 71.6° N respectively) are analyzed in details to describe the seasons in the Arctic. The primary driver of latitudinal and seasonal variations in temperature and other parameters is the seasonally varying pattern of incident sunlight. The solar radiation at the 'top' of the atmosphere is a function of latitude (and time of year) and the higher latitudes (e.g., Eureka) generally receive the least cumulative amount of net solar radiation than lower latitudes (e.g., Tiksi) over the entire year. However, because of the combined effects of day length and solar zenith angle, Eureka receives more the incoming solar radiation than Tiksi in the middle of Arctic summer. Although Eureka and Tiksi are located at the different continents and at the different latitudes, the annual course of the surface meteorology and the surface fluxes are qualitatively very similar. The air and soil temperatures display the familiar strong seasonal trend with maximum of measured temperatures in midsummer and minimum during winter. According to our data, variation in incoming short-wave solar radiation led the seasonal pattern of the air and soil temperatures, and the turbulent fluxes. A length of the warm season (Arctic summer) is shorter and mid-summer amplitude of the turbulent fluxes near solar noon is generally less in Eureka than in Tiksi. During the dark Polar nights, long-lived stable boundary layers can last several months and air/ground temperatures are strongly controlled by long-wave radiation associated generally with cloud cover. The fact that Eureka receives more the total daily amount of the incoming solar radiation than Tiksi throughout the summer months, leads to some differences in the structure of the atmospheric boundary layer and the uppermost ground layer at the two Arctic stations in summer. This study describes a long-lived convective boundary layer (CBL) observed at Eureka during 2009-2014 summer seasons. Long-lived CBL is associated with almost continuous unstable stratification and upward sensible heat flux. However, such long-lived CBL is not observed in Tiksi. It was also found that the active layer (or thaw line) is deeper and the soil temperatures are higher at Eureka than at Tiksi.

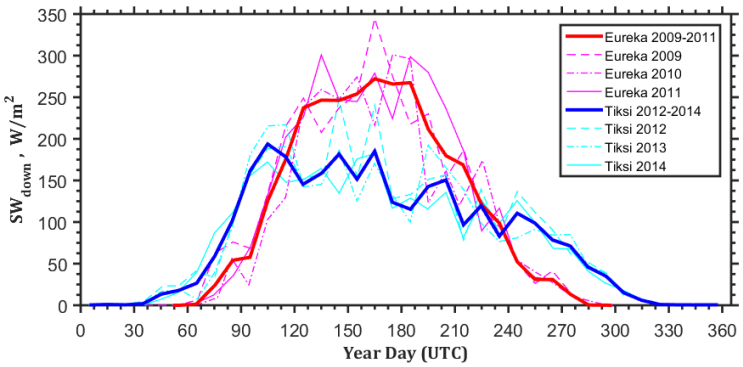

Figure 1. Annual cycle of short-wave (SW) downwelling radiation observed at Eureka in 2009-2011 and Tiksi in 2012-2014. The data are based on 10-day averaging of 1-hr radiation measurements.

Definition of Summer Monsoon Index for Vietnam Region

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[2]Center for Meteorology, Hydrology and Environment Science and Technology, Hanoi, Vietnam

One way to identify the summer monsoon's activities is based on the summer monsoon index. Basically, for the creation of the summer monsoon index, it is necessary to base on the definition and physical characteristics of monsoon and also the typical domain and parameters chosen. To characterize the summer monsoon's activities over Vietnam region, we had a study on definition of summer monsoon index for Vietnam. The important thing, this index has to be presumed as a good/useful index if it can characterize the variability of large-scale circulation and local climate in Vietnam. From the empirical orthogonal function analysis for the 850 hPa zonal wind in 1981-2010 of Climate Forecast System Reanalysis, the summer monsoon index for Vietnam (VSMI) was proposed. The VSMI index is defined as the mean zonal wind at 850 hPa over 5°N-17°N and 100°E -110°E.

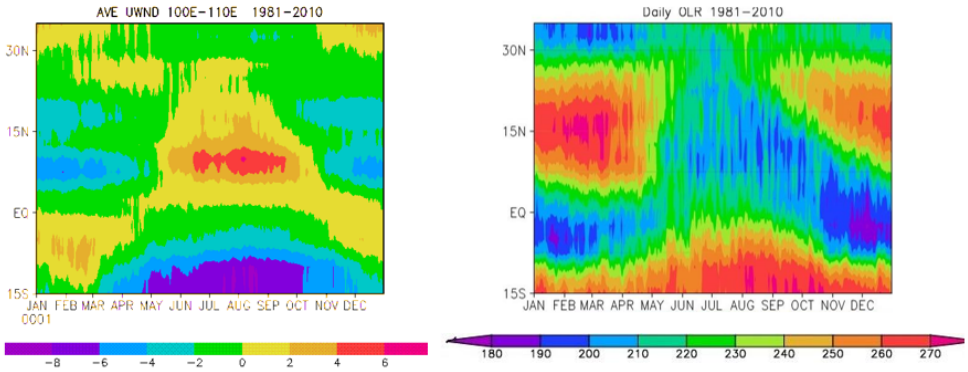

Figure 1. Hovmöller diagram for (a) 850hPa zonal wind and (b) mean OLR in 1981-2010

Figure 1. Figure 1 shows that both of westerlies and low values of outgoing longwave radiation (OLR) occur during the onset of summer monsoon in May; whereas, in October, wind reverses from westerlies to easterlies indicating the break of summer monsoon; nonetheless, OLR keeps low value until the end of December.

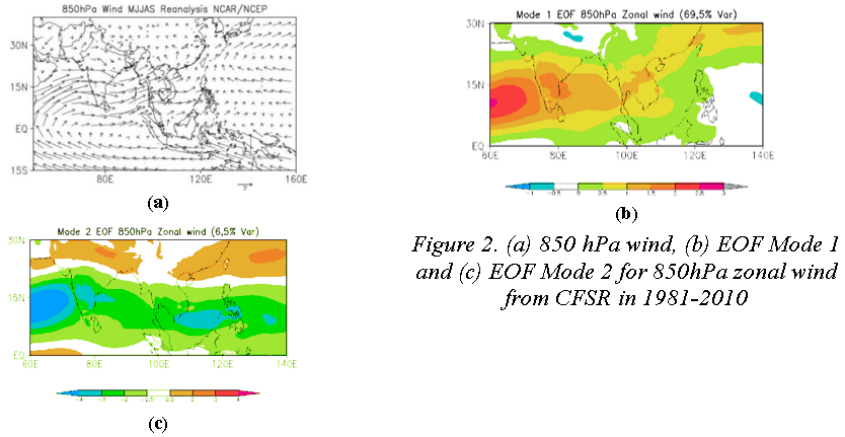

Figure 2. (a) 850 hPa wind, (b) EOF Mode 1 and (c) EOF Mode 2 for 850hPa zonal wind from CFSR in 1981-2010

Figure 2. For average in the summer, Mode 1 presents 65.9% from East Africa Coast to Philippine; Mode 2 presents 6.3% from west Pacific Ocean to Indochinese Peninsula (Fig 2b,c). The results show that Vietnam is affected by both factors.

ARM North Slope of Alaska Research Facilities

J. Hardesty, M. Ivey, D. Lucero, F. Helsel, D. Dexheimer, T. Houchens, D. Archuleta and A. Bendure

Sandia National Laboratories, Albuquerque, NM 87185; 505-844-8388, E-mail: joharde@sandia.gov

The Department of Energy Atmospheric Radiation Measurement program (ARM) has provided scientific infrastructure and data to the international Arctic research community via its sites on the North Slope of Alaska (NSA) since 1997. These facilities are operated by Sandia National Labs to maintain systems and protect instruments for continuous measurements of clouds, aerosols, precipitation, energy, and typical meteorological variables; as well as coordination and support of research field campaigns. The earliest site began operations at Barrow (1998), followed by a small facility in Atqasuk (1999-2010), with operation of the third ARM Mobile Facility at Oliktok Point begun in October 2013. Instruments maintained at both Barrow and Oliktok include: scanning precipitation radars, scanning cloud radars, Raman lidars, eddy correlation flux systems, ceilometers, manual balloon sounding systems, atmospheric emitted radiance interferometers, micro-pulse lidars, millimeter cloud radars and standard meteorological measurement systems. In addition to these instruments, the AMF3 operates a Raman lidar and an upgraded ceilometer; while Barrow additionally operates Doppler lidar, an automatic balloon sounding system, and a high spectral resolution lidar. The infrastructure at Oliktok is designed to be mobile and it may be relocated in the future to support other ARM science missions. Currently, unmanned aerial system (UAS) and tethered balloon system operations near Oliktok are enabled by using Federal Aviation Administration-designated (FAA) restricted air space (R2204) and international warning area (W220) activated by Sandia. UAS operations out of Barrow have also been done with FAA approval. The ARM facilities at Barrow have had many improvements over time to provide valuable datasets that cover nearly 20 years. Data from these ground-based and in-flight instruments is placed in the ARM data archives for use by the international research community. Located 70 miles south of Barrow, Atqasuk is adjacent to the Meade River. While not currently active, it is available for researchers to observe an Arctic climate that is much more continental than that of Barrow or Oliktok Point. Having these three Arctic sites within the ARM program allows for operations as a Megasite complex – where coordinated observations from the multiple sites enable broader regional data collection and comparison to support studies and modeling. With the growing capabilities in UAS operations and a broad network of partners, the ARM NSA facilities are poised to support scientific campaigns across multiple disciplines and agencies. This poster will introduce the atmospheric instruments at the ARM NSA facilities, the challenges of continuously operating these remote High Arctic sites with limited infrastructure, and future plans to improve or expand operations.

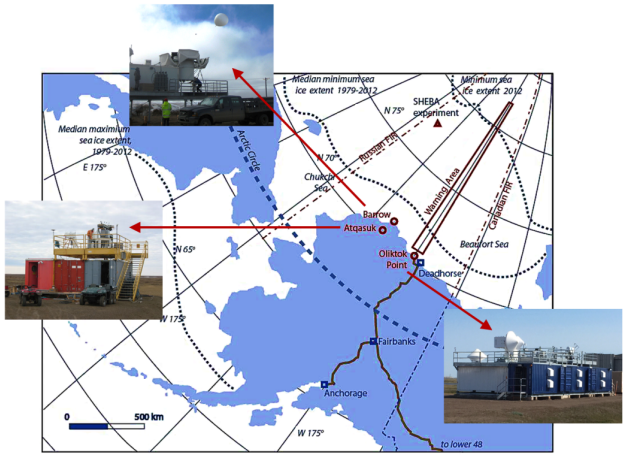

Figure 1. ARM North Slope Alaska facility site locations and Controlled airspaces.

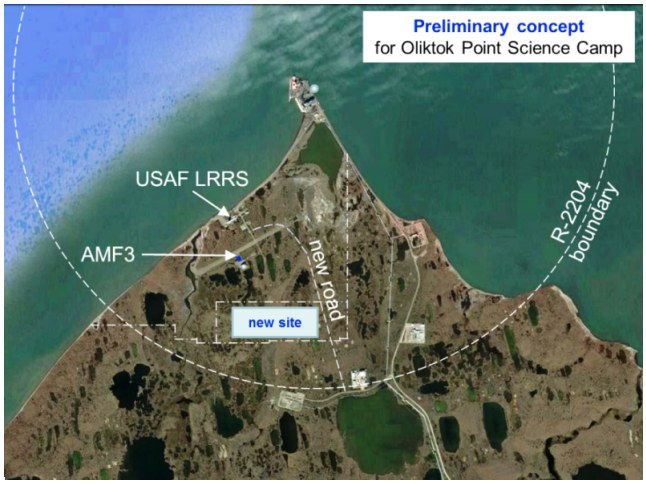

Figure 2. Schematic Plan of Proposed Oliktok Point Science Facility.

The Pikes Peak Observatory

D. Klebe[1,2], M. Miesch[3] and R. Sallee[4]

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[2]Solmirus Corporation, Woodland Park, CO 80863
[3]National Center for Atmospheric Research (NCAR), High Altitude Observatory, Boulder, CO 80307
[4]Pikes Peak Observatory, Colorado Springs, CO 80949

The Pikes Peak Observatory (PPO), Inc. proposes a 1-meter research-quality telescope and climate monitoring instrumentation that will offer 600,000 annual visitors to Pikes Peak an unmatched educational experience with public viewing and interpretive exhibits that celebrate astronomical and atmospheric research on the peak, past, present, and future. The Observatory can be visited by tourists during the day and operated remotely from the Colorado Springs or other locations, day or night, supporting research and contributing to the education and research missions at the Air Force Academy, Colorado College, Denver University, and the University of Colorado.

Integral to this project will be a smaller telescope incorporated into the Mobile Earth and Space Observatory (MESO) currently under development. MESO is a “science center on wheels” to engage and excite students, teachers, and local residents with hands-on educational and research activities focused on weather, climate, space sciences, renewable energy, and scientific instrumentation.

PPO is working with the City of Colorado Springs to evaluate siting options on the Peak and prepare a U.S. Forest Service special-use permit application to build and operate the observatory synergistic with the new Summit Complex design.

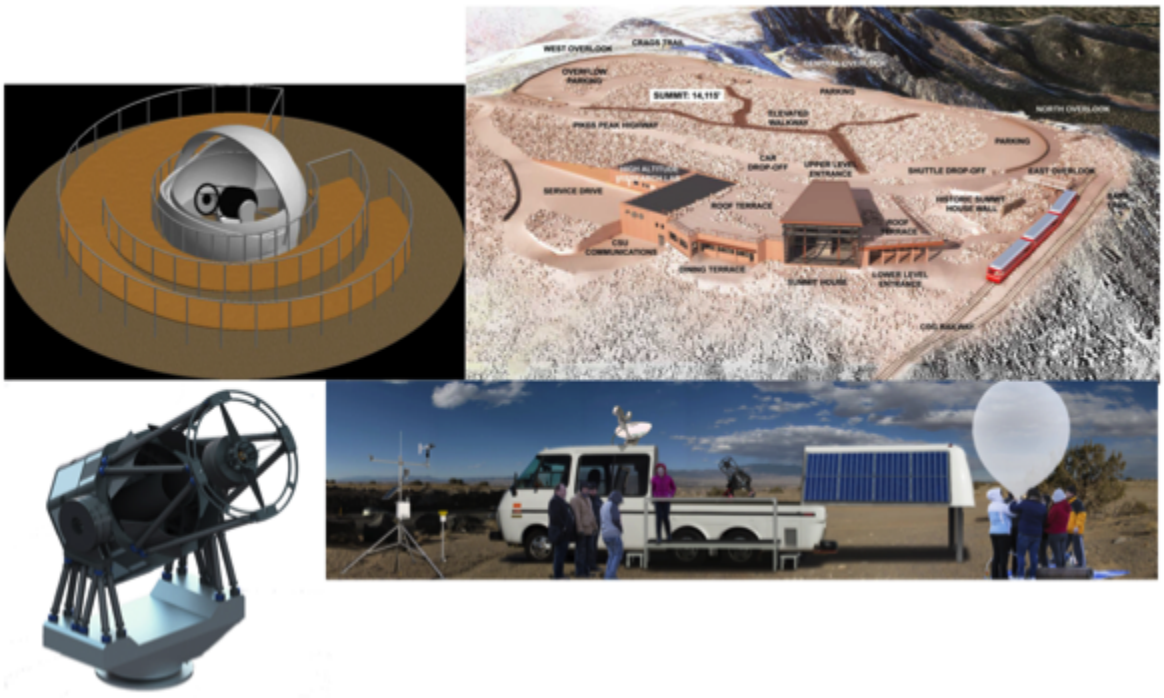

Figure 1. Proposed 1-meter telescope facility, Pikes Peak Summit Complex, and Mobile Earth and Space Observatory.

Wind Sensor Comparison – Lufft Ventus-UMB vs. RM Young 5103, Summit Station Greenland – July 2015 to April 2016

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[2]NOAA Earth System Research Laboratory, Global Monitoring Division (GMD), Boulder, CO 80305
[3]University of Colorado, Department of Aerospace Engineering Sciences, Boulder, CO 80309
[4]School of Earth and Environment National Centre for Atmospheric Science, University of Leeds, Leeds LS2 9JT, United Kingdom

NOAA ESRL/GMD has been conducting a side-by-side comparison of a Lufft Ventus-UMB heated ultrasonic wind sensor and a RM Young model 5103 wind monitor at Summit Station, Greenland since July 2015. We compared the performance of three instruments on the tower, located next to the Temporary Atmospheric Watch Observatory. The instruments are co-located at 9, 10 and 14.5 meter heights on the tower. Our analysis shows comparable performance for all wind speeds above 5 m/s but substantial discrepancies below 5 m/s. During the observation period, our analysis also demonstrates that the 5103 wind monitor under-reported the wind speeds 17% of the time. It also reported conditions that unnecessarily required curtailed station operations for a total of 7.5 days. Our findings indicate the 5103 wind monitor is not reliable below 5 m/s in Arctic conditions.

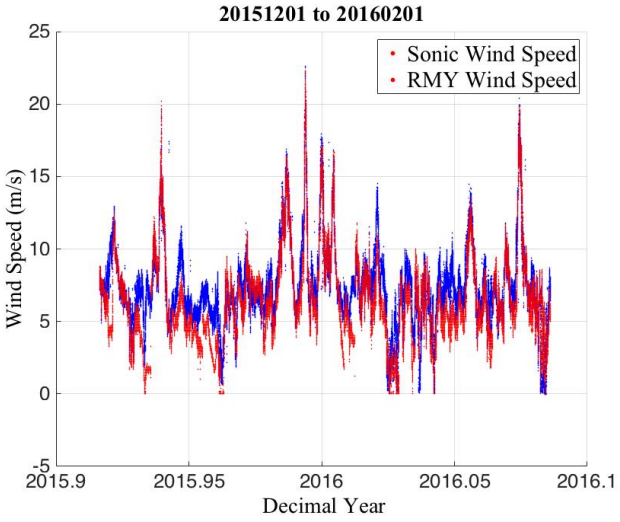

Figure 1. Sonic and RM Young Time Series.

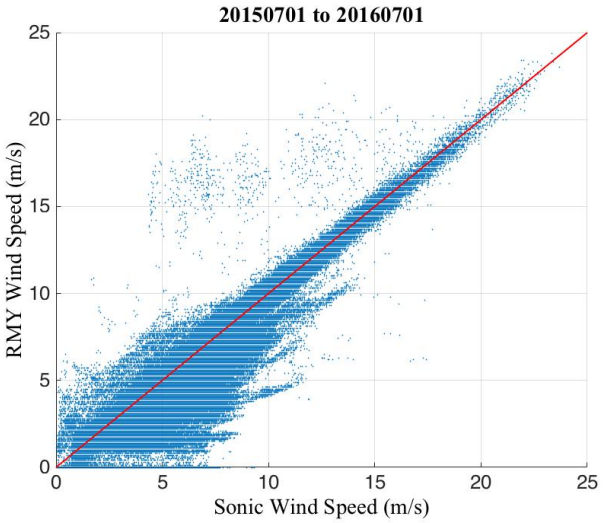

Figure 2. Sonic Wind Speed vs. RM Young Wind Speed.

Normalized Distribution Function: A Statistical Analysis of Surface Temperature for the Investigations for Seismic Precursor During the Large Ferndale, California Earthquake (M=6.8)

R. Shrivastava, D.D.K. Sondhiya, D.S. Raghuwanshi and P.A.K. Gwal

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In the present study we have analyzed the surface temperature variations during the major and large (M≥6) earthquake in Northern California region for the investigation of possible connection between surface thermal anomaly and seismic activities. For this intention, the probability mass normal distribution function methodology has been used during the Ferndale, California earthquake (M=6.8) occurred on March 10, 2014. In the surface air temperature enormous increase in normal distribution function has been recorded on March 3, 2014 as filtered with μ±2σ, which is showing the strong precursor for this seismic activity. Similar anomalous disturbances have also been shown in thermal infrared images from satellite. The surface air temperature data has been taken from the American Samoa Observatory (14.2474° S & 170.5644° W) and satellite based thermal infrared weekly images have been taken from the NOAA Ocean Watch for 41 days time window. The anomalous behavior of surface temperature prior to seismic activity is mainly because of the ionization of air in the earthquake preparation area due to radon exhalation.

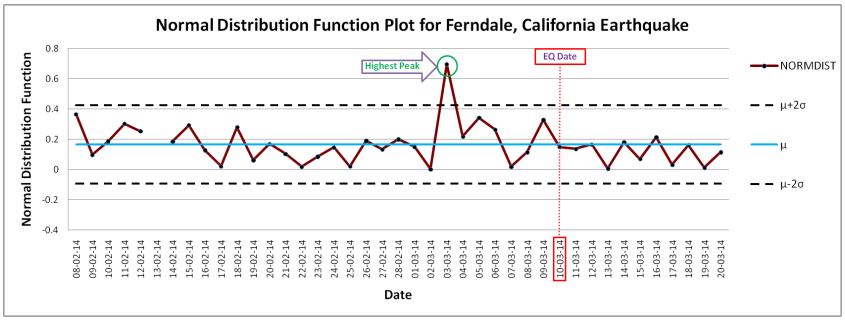

Figure 1. Daily normal distribution function plot from February 8, 2014 to March 20, 2014 during the Ferndale, California earthquake.

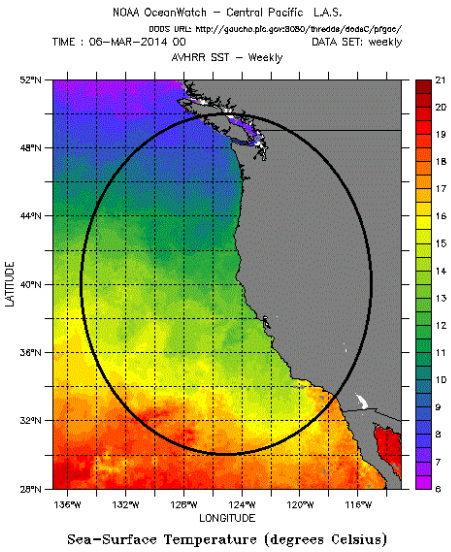

Figure 2. Satellite thermal infrared image from March 6, 2014 to March 12, 2014 during the Ferndale, California earthquake. [Image Courtesy: NOAA Ocean Watch].

SOS Explorer™: Interactive Visualizations for Museums and Classrooms

E. Hackathorn[1], J. Joyce[2], H. Peddicord[2], B. Russell[2], J. Schneider[1] and J. Smith[3]

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[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309
[3]Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO 80521

SOS Explorer™ (SOSx) is a flat screen version of the popular Science On a Sphere® (SOS). The software takes SOS datasets, usually only seen on a 6-foot sphere in large museum spaces, and makes them more accessible. The visualizations show information provided by satellites, ground observations and computer models. More information can be found at http://sos.noaa.gov/SOS_Explorer/

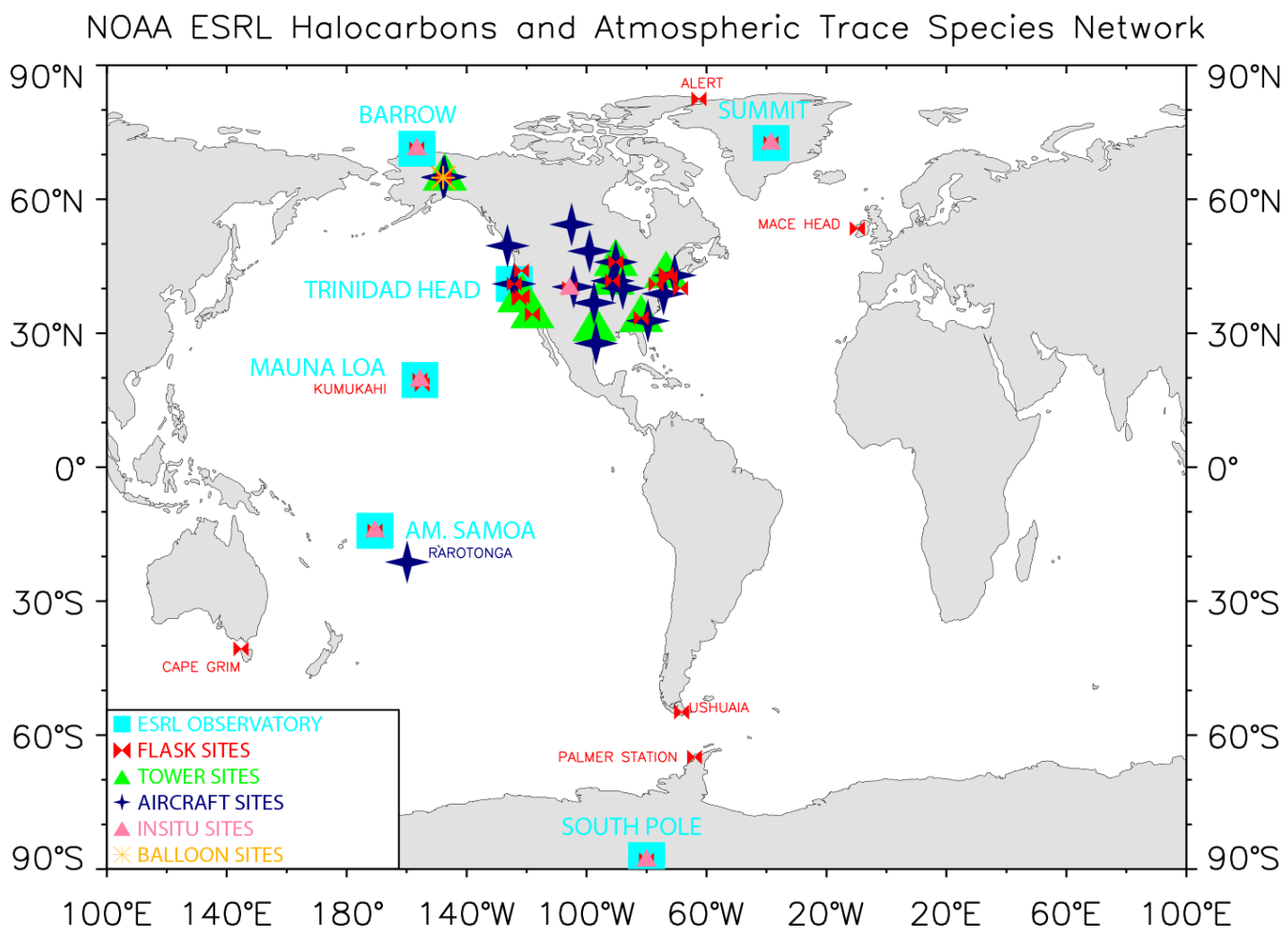
SOS Explorer™ was developed by the Exploratory Visualization and Outreach (EVO) section of NOAA's GSD which is also the home of Science On a Sphere® (SOS). Wanting to build off of the success of SOS and expand the reach of SOS into classrooms and homes as well as museums who don't have the physical space for a full Science On a Sphere®, developers created a flat screen version of SOS called SOS Explorer™ (SOSx).

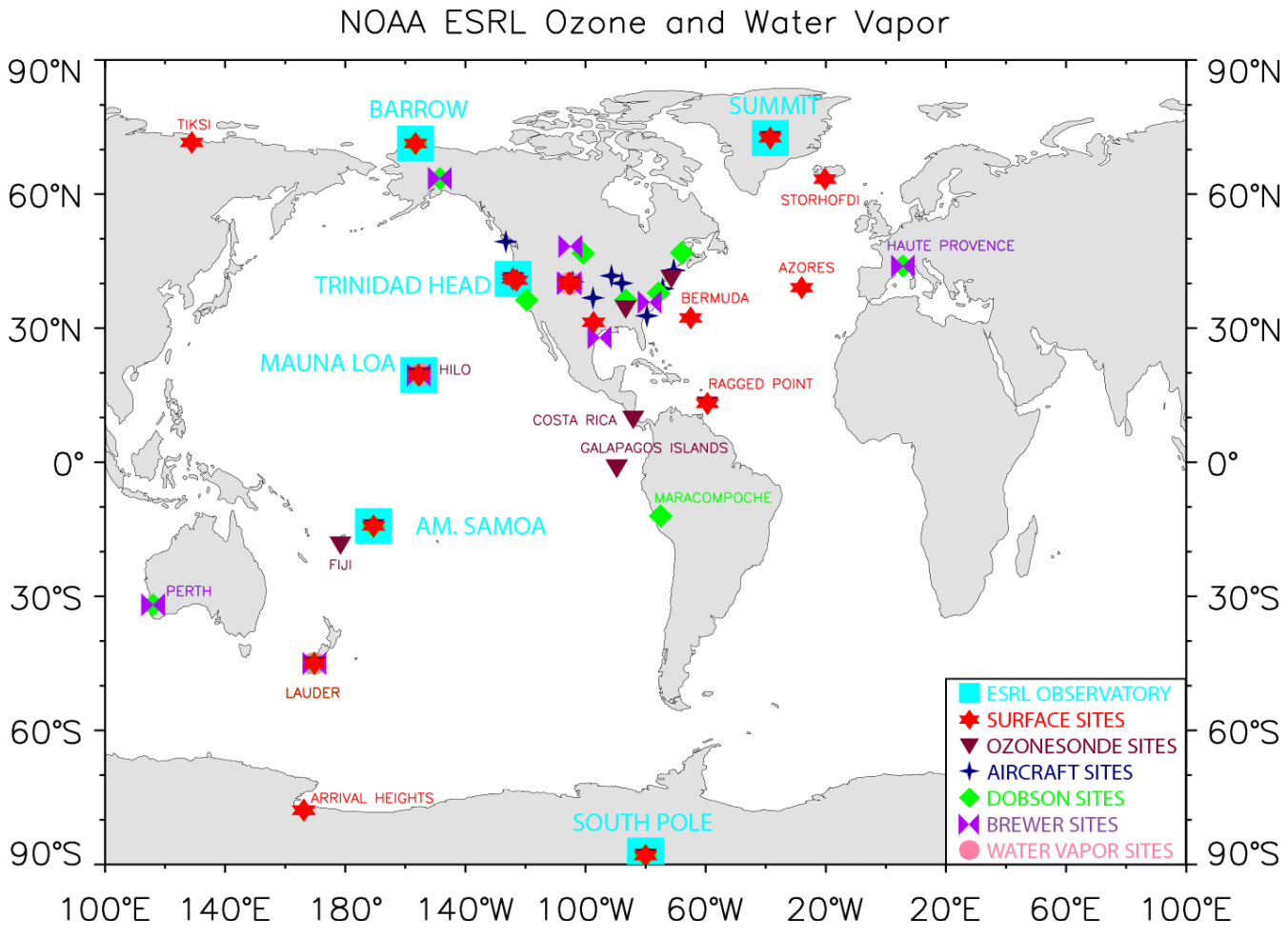
Several factors came together at the right time to lead to the development of SOSx. After field trips to see NOAA's SOS, many teachers asked how they could bring the same experience of viewing global data into their classrooms. Most of the teachers didn't have a budget for installing SOS into their schools and needed other options. A flat screen version that could be displayed on computer monitors and projectors seemed like an obvious solution.

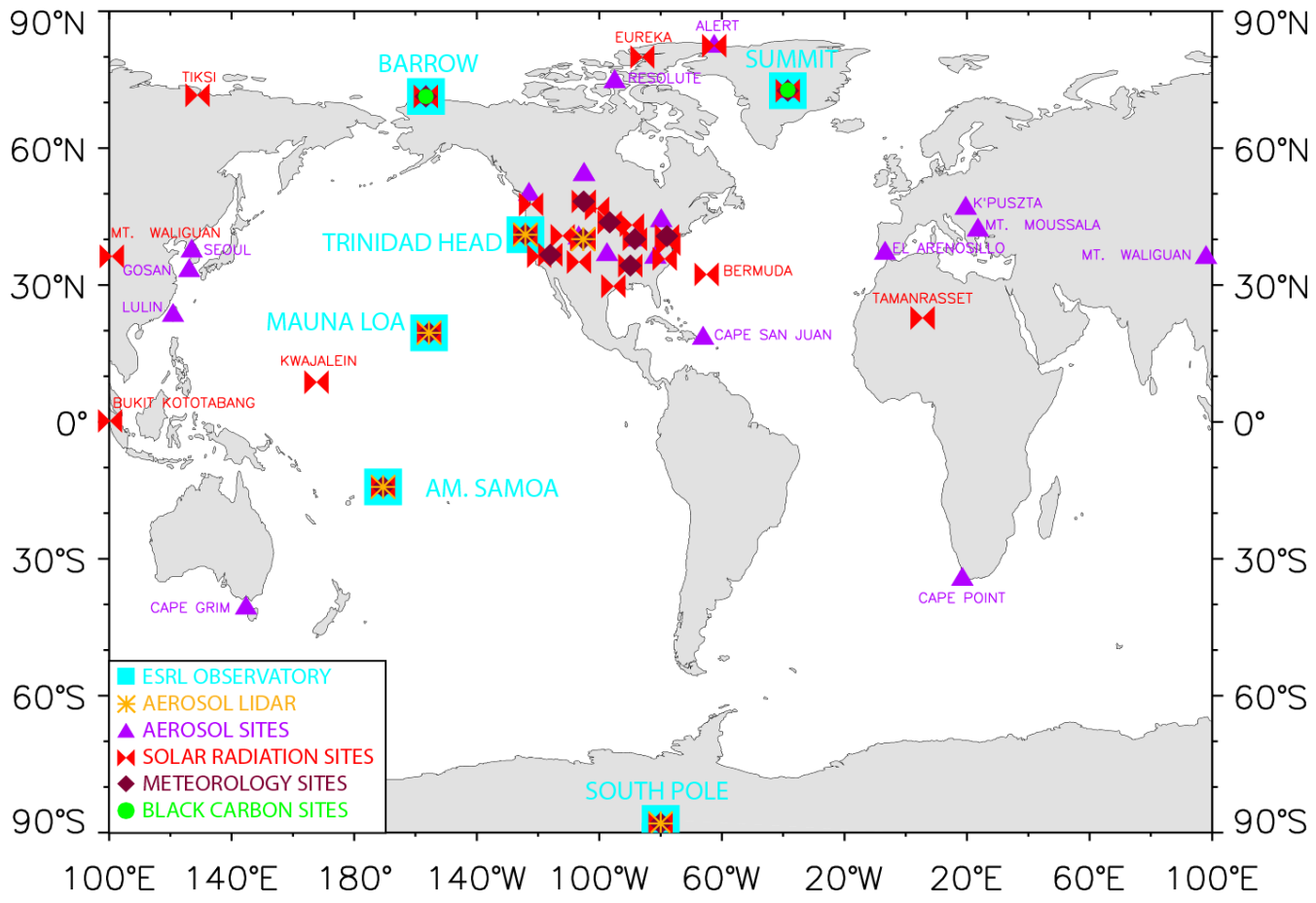
Figure 1. A visitor experimenting with the SOSx in the David Skaggs Research Center lobby.

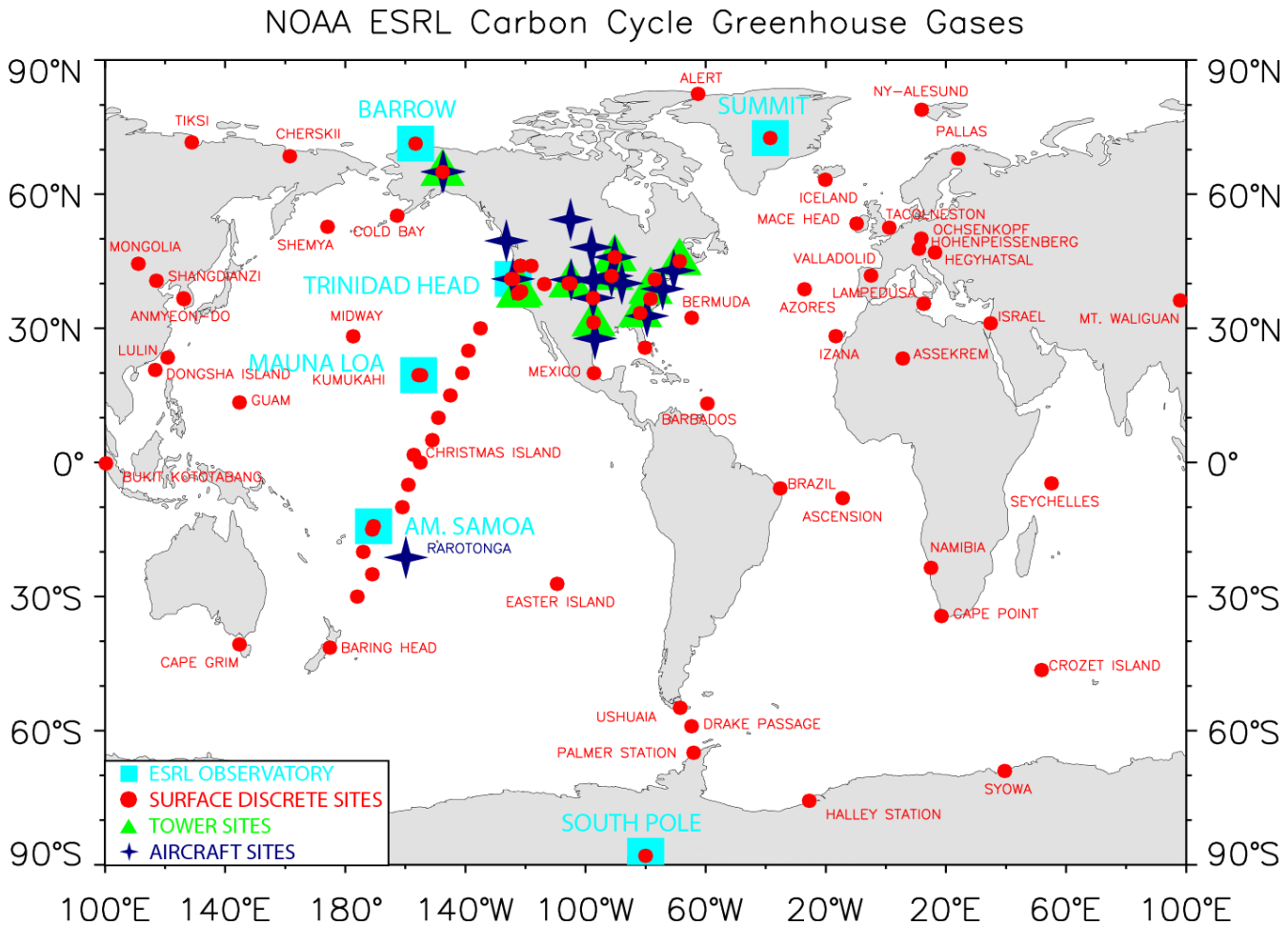
Notes:

Notes:


NOAA ESRL Halocarbons and Atmospheric Trace Species Network
90°N
60°N
30°N
0°
30°S
60°S
90°S
100°E
140°E
180°
140°W
100°W
60°W
20°W
20°E
60°E
100°E
ALERT
BARROW
SUMMIT
MACE HEAD
TRINIDAD HEAD
MAUNA LOA
KUMUKAHI
AM. SAMOA
RAROTONGA
CAPE GRIM
USHUAIA
PALMER STATION
SOUTH POLE
ESRL OBSERVATORY
FLASK SITES
TOWER SITES
AIRCRAFT SITES
INSITU SITES
BALLOON SITES


NOAA ESRL Ozone and Water Vapor
90°N
60°N
30°N
0°
30°S
60°S
90°S
100°E
140°E
180°
140°W
100°W
60°W
20°W
20°E
60°E
100°E
TIKSI
BARROW
SUMMIT
STORHOFDI
HAUTE PROVENCE
AZORES
TRINIDAD HEAD
BERMUDA
MAUNA LOA
HILO
RAGGED POINT
COSTA RICA
GALAPAGOS ISLANDS
MARACOMPOCHE
AM. SAMOA
FIJI
PERTH
LAUDER
ARRIVAL HEIGHTS
SOUTH POLE
ESRL OBSERVATORY
SURFACE SITES
OZONESONDE SITES
AIRCRAFT SITES
DOBSON SITES
BREWER SITES
WATER VAPOR SITES


NOAA ESRL Aerosols, Solar Radiation, Meteorology and Black Carbon
90°N
60°N
30°N
0°
30°S
60°S
90°S
100°E
140°E
180°
140°W
100°W
60°W
20°W
20°E
60°E
100°E
BARROW
SUMMIT
TRINIDAD HEAD
MAUNA LOA
AM. SAMOA
SOUTH POLE
TIKSI
EUREKA
ALERT
RESOLUTE
MT. WALIGUAN
SEOUL
GOSAN
LULIN
KWAJALEIN
BUKIT KOTOTABANG
CAPE GRIM
BERMUDA
CAPE SAN JUAN
K'PUSZTA
MT. MOUSSALA
EL ARENOSILLO
TAMANRASSET
CAPE POINT
ESRL OBSERVATORY
AEROSOL LIDAR
AEROSOL SITES
SOLAR RADIATION SITES
METEOROLOGY SITES
BLACK CARBON SITES


NOAA ESRL Carbon Cycle Greenhouse Gases
90°N
60°N
30°N
0°
30°S
60°S
90°S
100°E
140°E
180°
140°W
100°W
60°W
20°W
20°E
60°E
100°E
BARROW
SUMMIT
TRINIDAD HEAD
MAUNA LOA
AM. SAMOA
SOUTH POLE
TIKSI
CHERSKII
ALERT
NY-ALESUND
PALLAS
ICELAND
MACE HEAD
TACOLNESTON
OCHSENKOPF
HOHENPEISSENBERG
HEGYHATSAL
VALLADOLID
LAMPEDUSA
AZORES
ISRAEL
MT. WALIGUAN
IZANA
ASSEKREM
MONGOLIA
SHANGDIANZI
ANMYEON-DO
SHEMYA
COLD BAY
MIDWAY
LULIN
DONGSHA ISLAND
KUMUKAHI
GUAM
MEXICO
BERMUDA
BARBADOS
BUKIT KOTOTABANG
CHRISTMAS ISLAND
RAROTONGA
EASTER ISLAND
BARING HEAD
CAPE GRIM
BRAZIL
ASCENSION
SEYCHELLES
NAMIBIA
CAPE POINT
CROZET ISLAND
USHUAIA
DRAKE PASSAGE
PALMER STATION
HALLEY STATION
SYOWA
ESRL OBSERVATORY
SURFACE DISCRETE SITES
TOWER SITES
AIRCRAFT SITES


Global Monitoring
NOAA
2016
Annual Conference