

Annual Greenhouse Gas and Ozone Depleting Indices: New Products of NOAA Research

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In 2005, NOAA introduced the Annual Greenhouse Gas Index (AGGI). The AGGI is designed to enhance the connection between scientists and society by providing a normalized standard that can be easily understood and followed. The contribution of long-lived greenhouse gases to climate forcing is well understood by scientists and has been reported through international assessments. Nevertheless, the language of scientists often eludes policy makers, educators, and the general public. This index is designed to help bridge that gap. Measurements of the long-lived greenhouse gases – carbon dioxide, methane, nitrous oxide and halocarbons (mainly CFCs) have minimal scientific uncertainty, are independent of climate models, and thus provide a climate benchmark free of controversy. To provide the data required for the AGGI, continuous measurements from NOAA's Baseline Observatories at Pt. Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and at the South Pole are maintained. In addition, flask air samples are collected through several global networks, including a cooperative program for carbon-containing and other greenhouse gases that provides samples from globally widespread clean air sites. All measurements are reported on World Calibration Scales, produced and maintained by NOAA/ESRL in Boulder. These data are used to calculate annual global average concentrations from which changes in radiative forcing of the global climate since the pre-industrial era (1750) are determined. This includes all major greenhouse gases and 10 minor halogenated gases. Results are normalized to radiative forcing in 1990 to produce the AGGI. This index will be updated for 2005. In addition, a new index, the Ozone Depleting Gas Index (ODGI), will be introduced. It is determined from the global measurements of chlorine and bromine compounds.

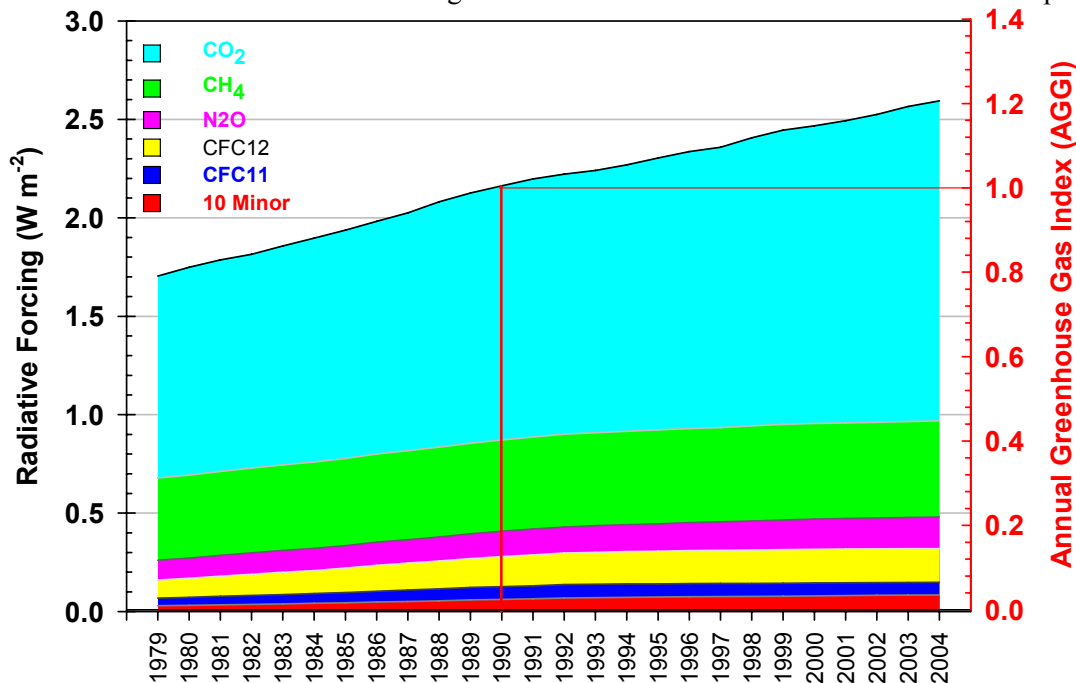


Figure 1. The cumulative contributions to radiative climate forcing by long-lived greenhouse gases relative to the pre-industrial era. The AGGI (red scale on the right) is indexed to 1 in 1990 and had a value of 1.20 in 2004.

Acceleration of the Rate of Growth of Atmospheric Carbon Dioxide.

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When Dave Keeling started continuous measurements of CO₂ on Mauna Loa in 1958 the observed mean growth rate for 1959 through 1963 was approximately 0.76 ppm/year, while the average rate of fossil fuel consumption was 2.5 GtC (billion metric tons of carbon)/year. The mean growth rate for 2001 through 2005 is 2.1 ppm/year, and a preliminary estimate for the rate of fossil fuel burning is 7.3 GtC/year. It appears that over several decades the atmospheric increase maintains an almost constant proportion to the rate of fossil fuel burning, except during the early 1990s. This is actually surprising given what we expect the ocean response to the historical atmospheric CO₂ increase to be.

We have compiled a second growth rate estimate based on global marine air data since 1980. Mauna Loa tracks the global rate well. One standard deviation of the differences between the two is 0.26 ppm/year. There is considerable year-to-year variation in the atmospheric increase measured at Mauna Loa, with a standard deviation of 0.46 ppm/year. The interannual variation is visibly related to global temperature anomalies. We have constructed from the data a delayed response curve of the CO₂ growth rate to temperature. The response changes sign at a delay of about 0.5 year. We could not detect a response to other global or regional climate anomalies such as precipitation. Subtraction of the calculated response of CO₂ to temperature anomalies significantly decreases the “unexplained” part of the interannual variation of the CO₂ growth rate.

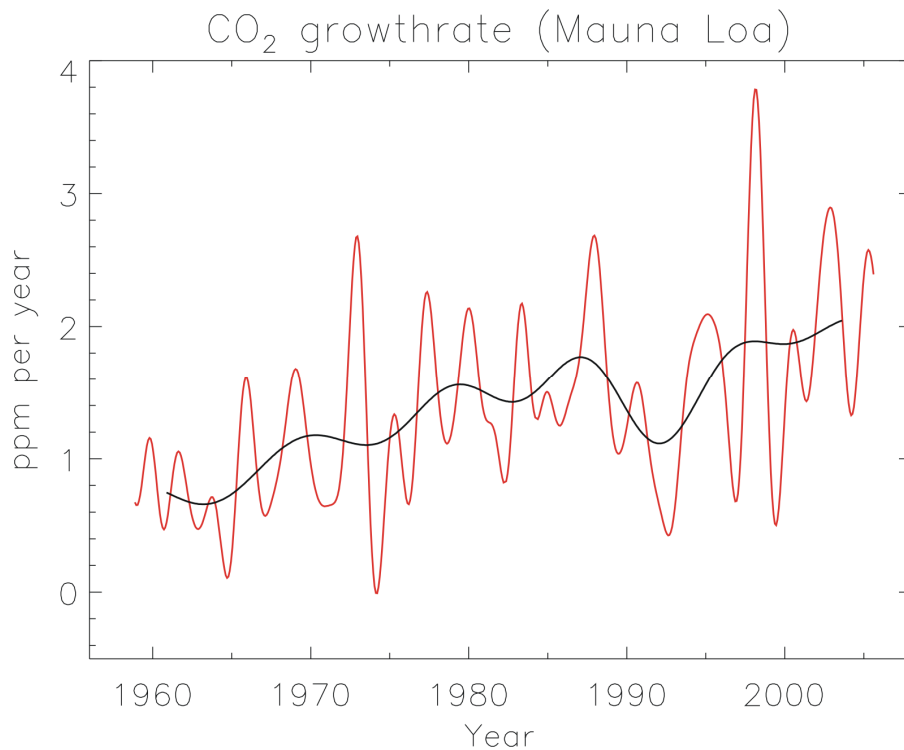


Figure 1. After removal of the seasonal cycle the rate of growth of carbon dioxide at Mauna Loa has been smoothed with a digital filter with a width of approximately one year (red line). The black line represents a similar filter with a width of five years.

Aerosol-Cloud Interactions as Observed by Remote Sensors and In-situ Aerosol Measurements

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Over the past years we have demonstrated first measurements of aerosol-cloud interactions using ground-based remote sensors at a continental US site. The response of a cloud to changes in the aerosol is quantified in terms of a relative change in cloud drop effective radius for a relative change in aerosol under conditions of equivalent cloud liquid water path. This is done in a single column of air at a temporal resolution of 20 s (spatial resolution of ~ 100 m). Cloud drop effective radius is derived from a cloud radar, microwave radiometer, and/or, a multifilter rotating shadowband radiometer. Aerosol properties are derived either from lidar (extinction) or from surface aerosol measurements acquired by NOAA's Global Monitoring Division. This is a process-based approach, in which we selectively sample updrafts, at scales appropriate to cloud drop activation. In this talk we will give a brief overview of the method and present a sample of results.

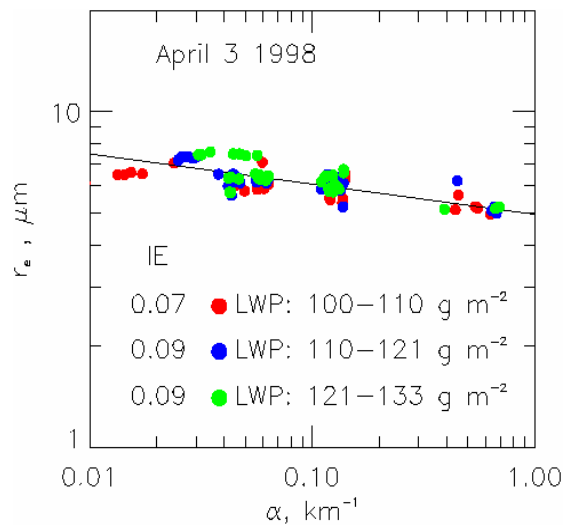


Figure 1. Drop effective radius as a function of aerosol on April 3 1998 for three different LWP bands as indicated in the legend. Drop size r_e is retrieved from radar and microwave radiometer. Extinction α is measured by the lidar at an altitude of 350 m. The slope of the lines, which is a measure of the cloud microphysical response to changes in aerosol, is given by IE.

Tropopause Folds: Results from the NOAA Unmanned Aircraft System (UAS) Demo and Network Observations

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The transport of air masses from the troposphere to the stratosphere affects the concentrations of anthropogenic gases, like the chlorofluorocarbons (CFCs) that form catalysts that subsequently destroy stratospheric ozone. Similarly, transport of high ozone and high potential vorticity (PV) stratospheric air downward can increase the concentration of tropospheric ozone, a measure of air quality, and decrease potential vorticity. Tropopause folds are events where incursion of stratospheric air into the troposphere occurs beneath a tropospheric jet stream. Tropospheric folds are the most efficient and dominate short-term (days to week) mechanism for stratosphere-troposphere exchange (STE) in the midlatitudes.

On 19 April 2005, the UAS Altair, observed high ozone, low CFC-11 air (Figure 1a.) over Palmdale, California during the NOAA Unmanned Aircraft Systems (UAS) demonstration (<http://uas.noaa.gov/altair/index.html>). At high altitudes (~12 km), the ozone mixing ratios (Figure 1a, B) resembled values observed in polar stratospheric air after the springtime breakup of the stratospheric polar vortex (Figure 1b.). High ozone and low CFC-11 (Figure 1a, A) mixing ratios were observed at ~4 km. A classical tropopause fold shown in the potential vorticity cross-section plot (Figure 1c.) is the cause of the event.

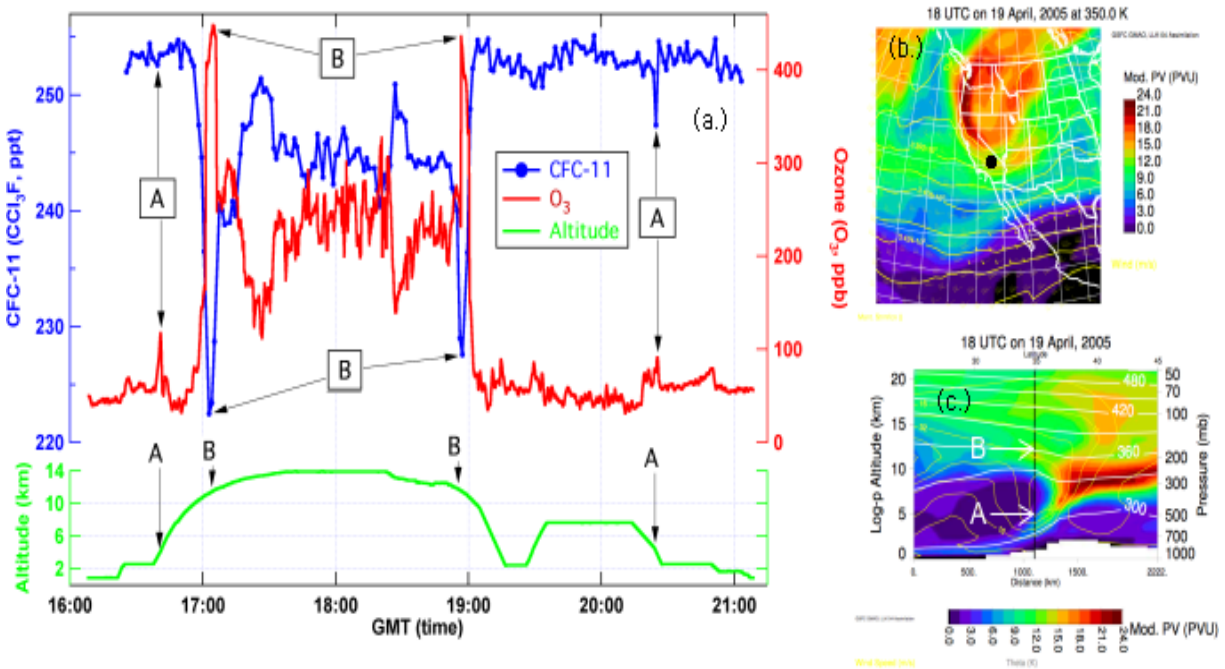


Figure 1. Mixing Ratios of CFC-11 (blue), O₃ (red), and altitude (green) versus time during (b) a polar stratospheric air southern projection of high PV air, and (c) tropopause fold.

Enhanced Understanding of Aerosol Climate-forcing Properties through Global Monitoring

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Measurements of aerosol climate-forcing properties, both from short-term field campaigns and long-term monitoring programs, reveal large variability in space and time. Global model calculations of aerosol forcing of climate require values of aerosol optical properties as input, and the values used are typically held constant or only allowed to vary depending on the aerosol type (e.g., mineral dust, soot, industrial pollution). One goal of ESRL's aerosol monitoring program is to provide regionally-representative values of aerosol optical properties for use in global model calculations of aerosol forcing. The scope of ESRL's aerosol monitoring network has been expanded substantially in the past two years through collaborations with outside partners with similar interests, involving stations in Canada, China, Puerto Rico, and South Africa. This talk will give an overview of the results from the collaborative stations, and contrast them with aerosol properties at ESRL's baseline and regional aerosol monitoring stations.

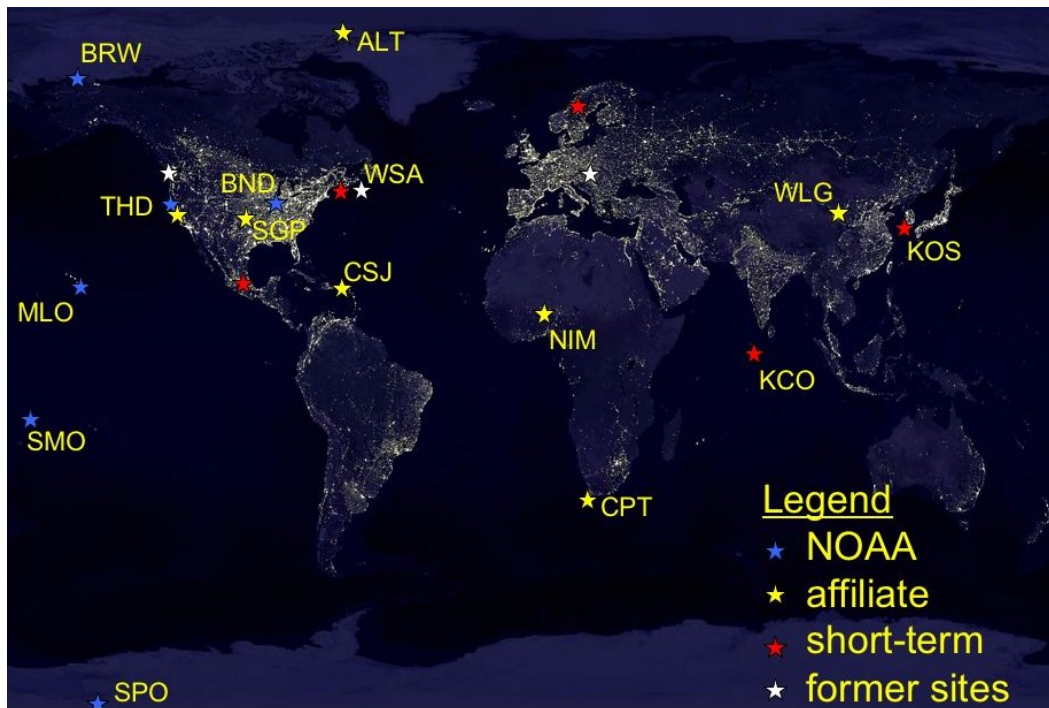


Figure 1. Collaborative stations (yellow symbols) greatly enhance the geographic scope of the ESRL network.

GPS Water Vapor Observations at Mauna Loa Observatory in 2005

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Results from a year of ongoing GPS water vapor observations at Mauna Loa Observatory are presented for the first time. The ESRL Global Systems Division, with the assistance of GMD in Boulder and the Staff of Mauna Loa Observatory, installed a GPS receiver at MLO in November 2004. The purpose of this joint effort is to evaluate the utility of ground-based GPS water vapor observations for long-term climate monitoring. Figure 1 compares integrated precipitable water vapor measurements retrieved from tropospherically-induced signal delays in the GPS radio signals (1-A) with observations from the Naval Research Laboratory Water Vapor Millimeter-wave Spectrometer (1-B), and PW derived from the Hilo Radiosonde (1-C) at and above the altitude of MLO. The least squares fit to each data set (Figure 2) agree within 0.8 mm (~ 20%), with GPS wet, RAOBS dry, and WVMS somewhere in between.

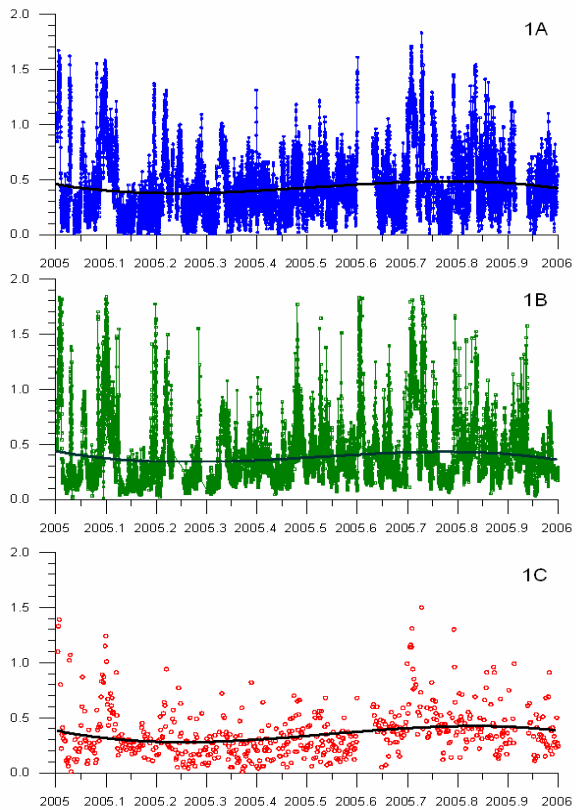


Figure 1. Integrated (total atmospheric column) precipitable water vapor time series at Mauna Loa Observatory in 2005. 1A is ESRL/GSD GPS, 1B is NRL Water Vapor Millimeter-wave Spectrometer, and 1C is from Hilo Radiosonde. The solid black line is least squares fit to all observations.

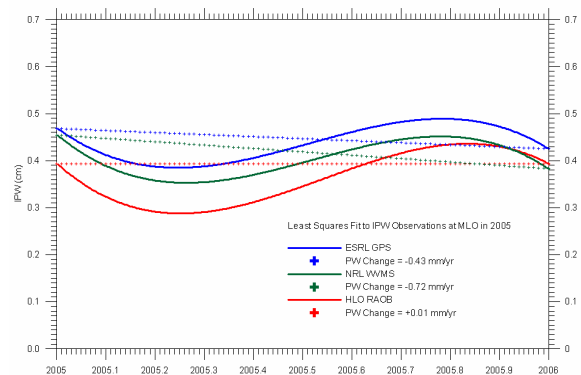


Figure 2. Least squares fit to observations shown in Figure 1. Blue is GPS, green is WVMS, and red is RAOBS. The lines connecting the end points of the curves have slopes of -0.43 mm/yr for GPS, -0.72 mm/year for WVMS, and $+0.01$ mm/year for RAOBS.

Acknowledgements

We would like to acknowledge the assistance of the following individuals and organizations in carrying out this experiment: John Barnes and Darryl Kuniyuki, MLO, Hawaii; Gerald Nedoluha, NRL, Washington, D.C.; and Russell Schnell and Thomas Mefford, ESRL/GSD, Boulder, CO.

Is the Tropospheric Ozone Entering the U.S. West Coast Changing? - Trinidad Head, California as a Site for Measuring Background Tropospheric Ozone

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The tropospheric ozone content of air entering the west coast of the U.S. may play a role in enhancing background ozone over the U.S. and thus influence the ability of some states to meet air quality standards. Ozone is also an important and greenhouse. Ozone profile measurements have been made from Trinidad, California since August 1997 and continuous surface observations have been made from the ESRL/GMD Observatory at Trinidad Head since April 2002. Winter and spring are the seasons of strongest flow to the U.S. west coast with the potential of carrying air influenced by emissions in Asia. Rapid economic development in east and south Asia has the potential for producing ozone precursor emissions that could lead to rising tropospheric ozone levels that may in turn be transported into the U.S. Using surface ozone data from four years of hourly observations at Trinidad Head keyed to back trajectories shows that almost all elevated ozone concentrations (mixing ratios ≥ 50 ppb) seen in the spring at Trinidad Head come from air entering the west coast of the U.S. unaffected by North American sources. Two longer-term ozone time series from Eureka, California (near the Oregon border) and Olympic National Park, Washington, suggest that springtime ozone at these sites has not increased. These sites are investigated using trajectories to determine to what extent the data are representative of air entering the U.S., since unlike the Trinidad Head site they are not located immediately on the coast. Ozone data from Trinidad, CA gives a picture of how surface ozone on the west coast is influenced by air from aloft. Ozone profiles along with other species measured regularly from small aircraft as part of the North American Carbon Program provide a unique opportunity to investigate the sources of ozone entering the west coast of the U.S.

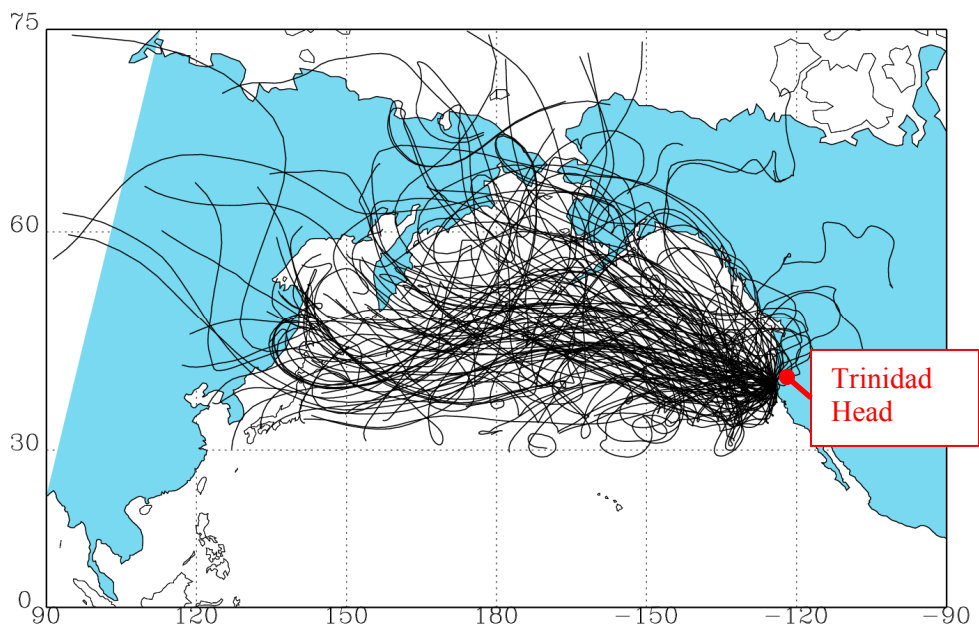


Figure 1. Ten-day back trajectories for air parcels reaching Trinidad Head, California during April 2002-2005 on days when hourly ozone concentrations were ≥ 50 ppb.

Preliminary Satellite Estimates of Annual Global Gas Flaring Volumes: 1992-2004

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It has been known since the mid-1970's that large gas flares can be detected in nighttime low light imaging data collected by the U.S. Air Force Defense Meteorological Satellite Program (DMSP). NGDC serves as the long term archive for DMSP data and has recently completed processing of the first global time series of annual cloud-free nighttime lights. NGDC extracted the aggregate brightness of gas flares by country and is developing a calibration for estimating gas flaring per country by year based on national gas flaring estimates for twenty nations provide by the World Bank Group. Nigeria is widely cited as the country having the largest volume of gas flaring. However, the preliminary DMSP results indicate that Russia flares substantially more gas than Nigeria and more than all other countries combined (Figure 1). The DMSP record of global gas flaring indicates that overall flaring has been quite steady over this time period, despite efforts such as the World Bank Global Gas Flaring Reduction Initiative.

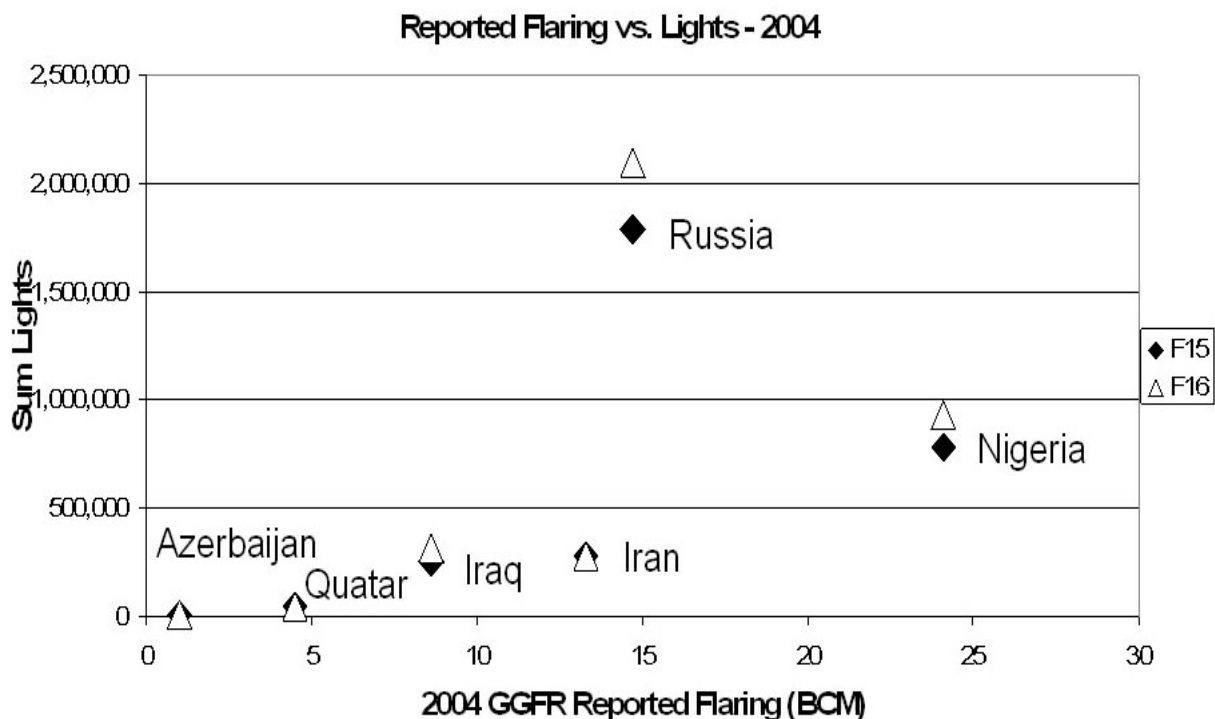


Figure 1. Preliminary results showing World Bank reported gas flaring from six countries for 2004 versus the associated sum of lightning index developed by NGDC. Note that the DMSP data indicate that Russia has substantially more flaring than reported.

Climatic and Biospheric Effects of Changing Patterns of Fossil-fuel CO₂ Emissions

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Climate warming and population shifts to warmer climates have resulted in an increasing percentage of the USA population living in a warmer environment. In addition, there has been an increasing reliance on air conditioning in all regions of the country. The result is an increase in energy demands for summer cooling and a decrease in energy demands for winter heating, along with corresponding seasonal trends in fossil-fuel CO₂ emissions. When winter decreases are combined with summer increases, the net contribution to USA fossil-fuel carbon emissions is relatively small and negative, but is projected to change sign before 2025, so as to contribute to projected increases.

An important result for carbon-cycle modeling is that an increasing fraction of annual fossil-fuel CO₂ emissions is being emitted during the growing season (Figure 1), when the terrestrial biosphere removes CO₂ from the atmosphere via photosynthesis. At the global scale, these anthropogenic changes in atmospheric CO₂ are very small compared to the natural variations due to photosynthetic removal each summer. However, most fossil-fuel CO₂ emissions occur over a very small percentage of the earth's surface, so the greatest ecological effects of changing the temporal distribution of fossil-fuel CO₂ emissions are expected to occur near the emissions sources, where the CO₂ emissions are most highly concentrated. This partly explains the need to understand the processes involved at very small time and space scales, and to integrate the results, in order to balance the global carbon budget.

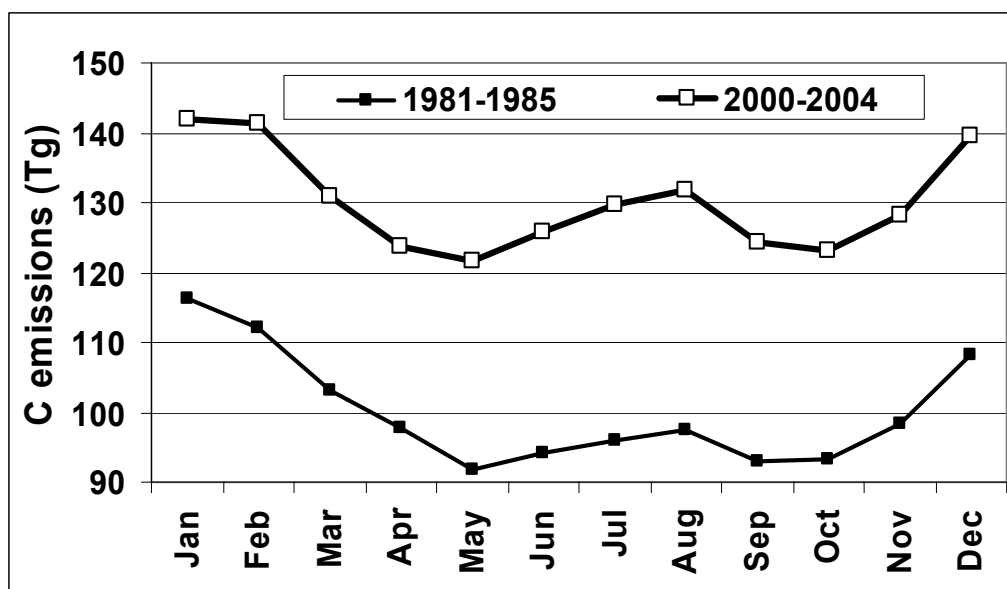


Figure 1. Five-year averages of monthly carbon emissions (as CO₂) for early and recent periods, showing increased peaking during the summer months.

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Limitations of NOAA ESRL Measurements of Atmospheric CH₄ for Source Attribution

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Direct and indirect components to anthropogenic radiative forcing by atmospheric CH₄ are estimated to be 0.7 W m⁻², or about ½ the contribution of CO₂. Through its chemistry, methane also affects the abundance of tropospheric ozone, a strong oxidant and greenhouse gas. It is estimated that the increase in atmospheric methane abundance over the past 200 years is responsible for half the increase in background tropospheric ozone levels; moderate ozone levels affect human respiratory function, while higher levels lower agricultural crop yields and damage natural ecosystems. Policies aimed at mitigating the potential environmental effects of atmospheric CH₄ require a detailed understanding of the global CH₄ budget by emission sector and how emission rates are changing with time.

During the past 2 decades, the globally averaged CH₄ growth rate decreased from ~14 ppb yr⁻¹ in 1984 to near zero recently (Figure 1). Since 1999, the global methane budget appears to be at steady state, with emissions and sinks each at ~550 Tg CH₄ yr⁻¹. This large-scale constraint on the global CH₄ budget is one of many strengths of the GMD CH₄ measurements. Even at regional scales, the data can usefully constrain emissions. For example, analysis of changes in the N/S gradient of atmospheric CH₄ indicate that widespread concerns of substantially increased emissions from melting permafrost have not yet been

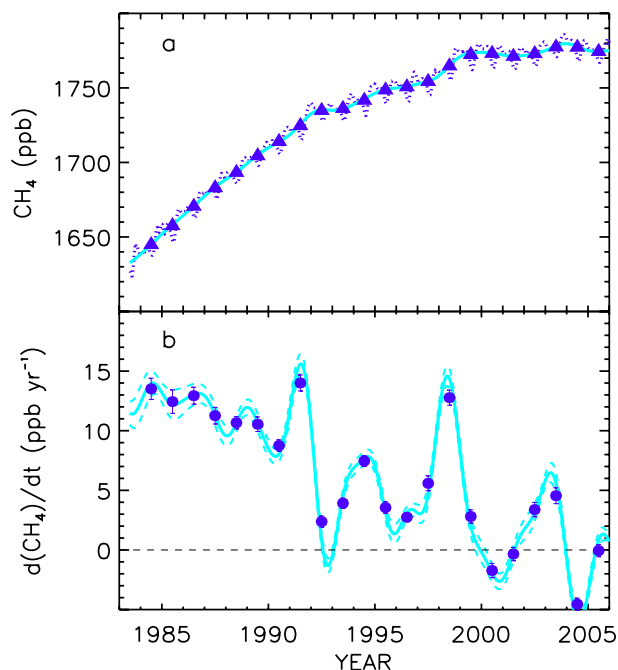


Figure 1. a) Globally-averaged CH₄ is plotted as a dotted line; solid line is the deseasonalized trend and triangles are annual means. b) Rate of increase from (a); uncertainties are 1σ. 2005 is preliminary.

realized, and increases in these emissions on the order of 10 Tg CH₄ yr⁻¹ can be observed with the existing network. On the other hand, our sampling network is insensitive to two new results concerning CH₄ emissions in the tropics. One of these studies indicates that CH₄ emissions from vegetation, particularly in the tropics, is a large newly discovered source. Other work suggests that commonly used distributions of CH₄ emissions from wetlands in S. America are wrong, and significantly more CH₄ is emitted from the Amazon Basin relative to the Pantanal region further to the south. In these cases, the GMD surface measurements are limited by relatively few sites, all far from source regions, and strong vertical transport that quickly dilutes surface signals. The GMD surface measurements will continue to provide strong constraints on the global CH₄ budget, but further advances in understanding regional scale emissions, especially in the tropics, will require satellite measurements such as those from AIRS and SCIAMACHY. Satellite measurements will be especially useful when they are validated by GMD vertical profiles, especially those in the tropics.

Global Observations of Carbon Monoxide, Methane, and Carbon Dioxide in the Free Troposphere Derived from the Atmospheric Infrared Sounder (AIRS)

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The Atmospheric Infrared Sounder (AIRS), launched in May of 2002, has the capability to measure trace gases, including ozone, carbon monoxide, methane, carbon dioxide, nitric acid, nitrous oxide, and sulfur dioxide. These products can also be derived from future sounders such as the Infrared Atmospheric Sounding Interferometer (IASI), the Cross-track Infrared Sounder (CrIS), and Hyperspectral Environmental Suite (HES), to be launched in 2006, 2009, and 2012, respectively. Together these instruments can provide measurements of the mid-tropospheric concentration of these gases for at least two decades. Monthly maps of carbon trace gas concentrations from multi-year AIRS reprocessing experiments have been produced along with the associated vertical retrieval weighting functions. Results from these experiments will be discussed with an emphasis on the utility and limitations of these datasets in modeling. Comparisons of the AIRS ozone products with in-situ measurements taken during the Stratospheric-Tropospheric Analysis of Regional Transport (START) experiment will also be shown as an example of remotely sensed trace gas measurements.

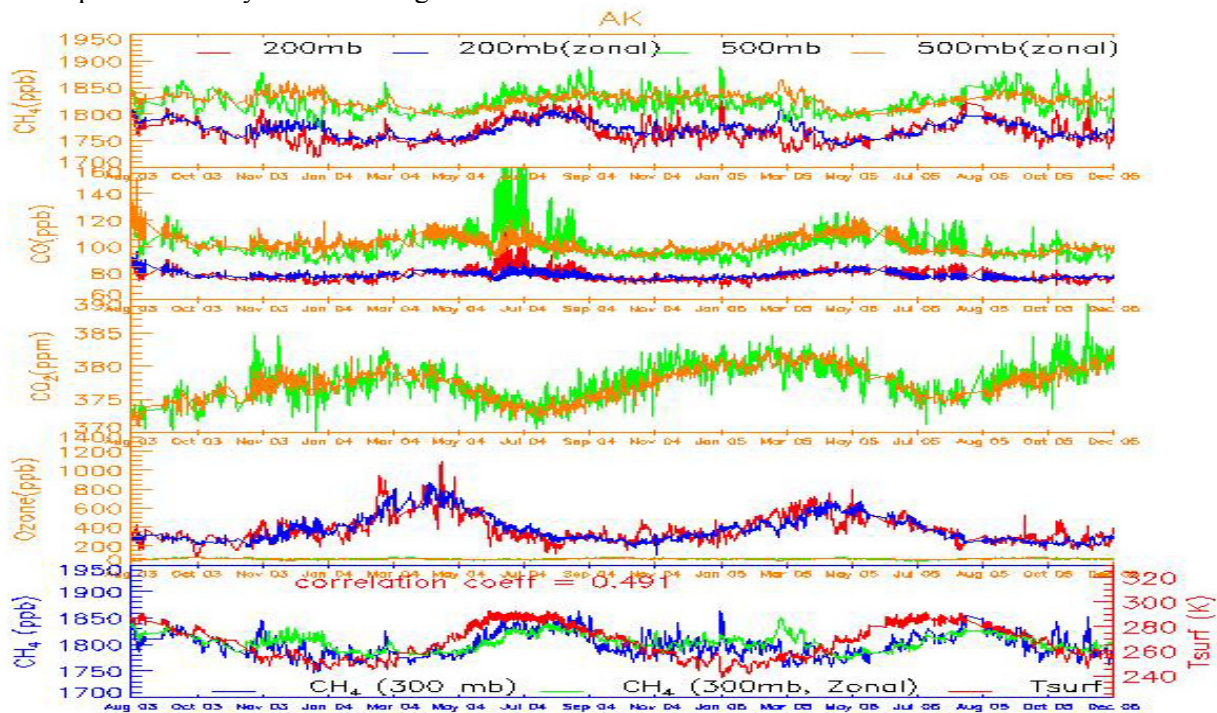


Figure 1. AIRS retrieval of methane (top panel), carbon monoxide (panel 2), carbon dioxide (panel 3), and ozone (panel 4) from August 2003 through Dec. 2005. Retrieved values are shown for the zonal average between 60 to 70 degrees latitude for 200 milli-bar (blue lines) and 500 mb (gold lines) and for the Alaska/Canada region (-165 to -90 latitude) for 200 milli-bar (red) and 500 milli-bar (green). The Alaska forest fires in July of 2004 are evident in the CO time-series as well as the strong seasonal variability of ozone, methane and carbon dioxide. The bottom panel shows the correlation between the seasonal methane signal at 300 mb and surface temperature implying that the release of methane is may be related to wetlands emission in the summer/fall seasons.

NOAA/ESRL Aircraft Network Update

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The NOAA/ESRL Global Monitoring Division (GMD) Aircraft Network has been in existence for more than 10 years and in 2006 underwent additional expansion. Efforts over the last year have focused on finding errors induced by the programmable flask package sampling system; developing instrumentation for in situ measurements of CO₂, temperature, humidity, and location; optimizing the sample network, including through the addition of new aircraft sites; and increasing the number of species measured.

(Figure 1) shows a broad shift in the aircraft network site locations from a focus on the mid-continent to sites to one that optimizes our ability to resolve sources and sinks of CO₂ and CH₄ over the whole North American continent. While this distribution of sites has been shown to be helpful for resolving the biologically productive summer months in the continental United States, more sites are needed along the boundaries and in land areas of Southern Canada. We also continue to look to areas such as Churchill, Manitoba in Canada where we hope to monitor rapid change due to permafrost melt.

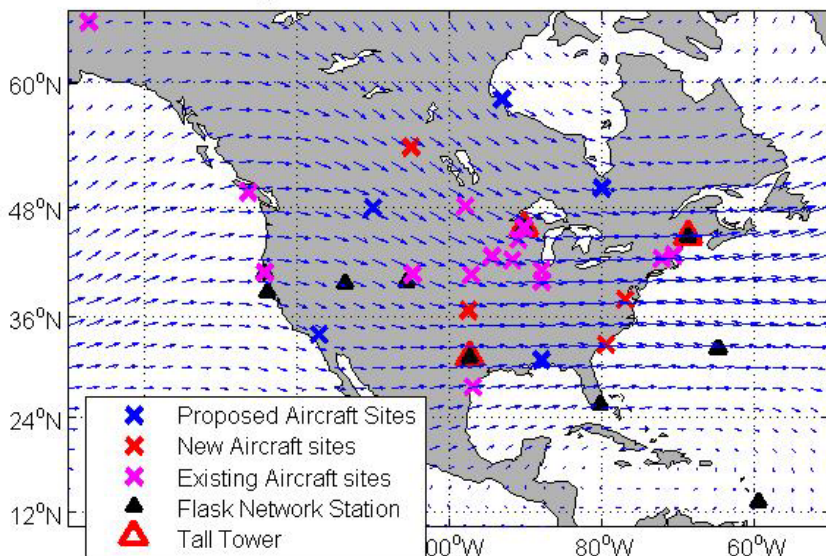


Figure 1. The NOAA/ERSL/GMD aircraft network as of March, 2006. New Aircraft sites are defined as those that have been implemented in the last year. With funding cuts 3 mid-continent sites of the sites have been terminated and our initial efforts to do profiles weekly has been scaled back at every site to at least every two weeks and at the mid-continent sites every three weeks. Vectors represent average 500 mbar NCEP re-analysis winds for January.

A Revised Tall Tower Dataset for LEF, WKT and AMT for 2004-Present: Automated Data Processing and Quality Assurance Algorithms for Continuous CO₂ and CO Measurements

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Data from LEF, WKT, and AMT for the period 2004-present has been reprocessed using a new set of data processing and quality assurance software for continuous CO₂ and CO measurements. The new algorithms compute the mixing ratio and an estimate of the uncertainty for each measured value. The new algorithms are being converted to IDL and in the near future will be run each day and new data will automatically be added to the GMD database along with the uncertainties. Our goal is to make the tall tower data available to the community in near real time. The uncertainty estimates will allow us to identify instrument problems quickly and pinpoint their origin. Sources of uncertainty that are addressed by the new algorithms include drift in the baseline and the gain of the sensors, dilution error associated with residual water vapor in the dried sample airstream, curve-fitting errors, uncertainty in the calibration scale, the extent to which standards and air samples are equilibrated at the end of the sampling interval, and errors caused by calibration curve extrapolation outside of the range of the standards. We have applied these algorithms to two years of data from the LEF, WKT and AMT tower sites and will present an overview of the data and uncertainties for this period along with a comparison to network flask data. We will also present results from one of our new tower trace gas measurement systems that is currently deployed on Kohler Mesa.

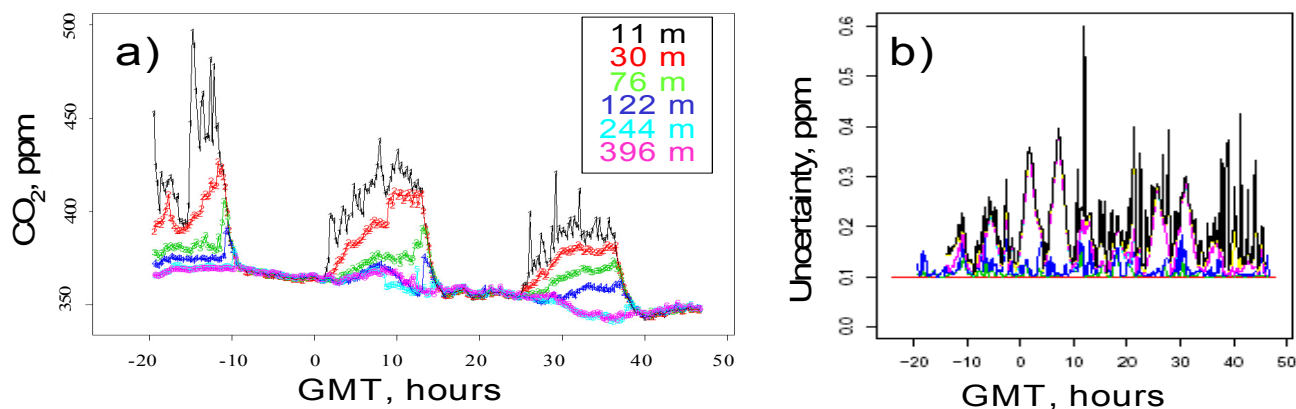


Figure (a) Time series of CO₂ data from the WLEF tower for August 5-7 2005. (b) Corresponding cumulative uncertainty plot for the 396 m level. The red curve is the baseline uncertainty corresponding to the 0.1 ppm uncertainty stated for the WMO scale, the additional curves represent the addition of individual terms in the uncertainty estimate with the black curve representing the total uncertainty.

Seasonal Variations in Vertical Profiles of Carbonyl Sulfide, Halocarbons, and Benzene over North America

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A NOAA sampling program to measure vertical profiles of CO₂, CH₄, N₂O, and other gases within the lower atmosphere has been expanded to allow measurements of carbonyl sulfide (COS), CFCs, HCFCs, HFCs, chlorocarbons, bromocarbons, methyl halides, and benzene. Bimonthly to monthly profiles for these gases have been obtained since September 2004 from flasks collected onboard aircraft at altitudes up to 8 km above sea level at multiple continental and coastal sites in North America. The wide range of gases being measured aid in identifying many different influences on sampled air, such as combustion, input from the oceans, urban emissions, non-urban terrestrial emissions, uptake by vegetation and soils, and vertical mixing. Based upon co-elevated mixing ratios of halocarbons and carbon monoxide or halocarbons and C₂Cl₄, we anticipate that this sampling program has the potential to provide continental-scale emissions estimates for non-CO₂ gases that are currently regulated, for example by the Clean Air Act and the Montreal Protocol of Substance that Deplete the Ozone Layer, and for gases listed in the Kyoto Protocol that may be regulated in the future.

In addition to the observation of urban pollution and burning plumes, strong and persistent vertical gradients have been observed that vary with season for COS, methyl halides, and chloroform as presented in Figure 1. The results for COS are particularly dramatic, as they show substantially reduced mixing ratios in the continental boundary layer during the growing season. The spatial patterns and seasonality are qualitatively consistent with uptake of COS by photosynthetically active vegetation.

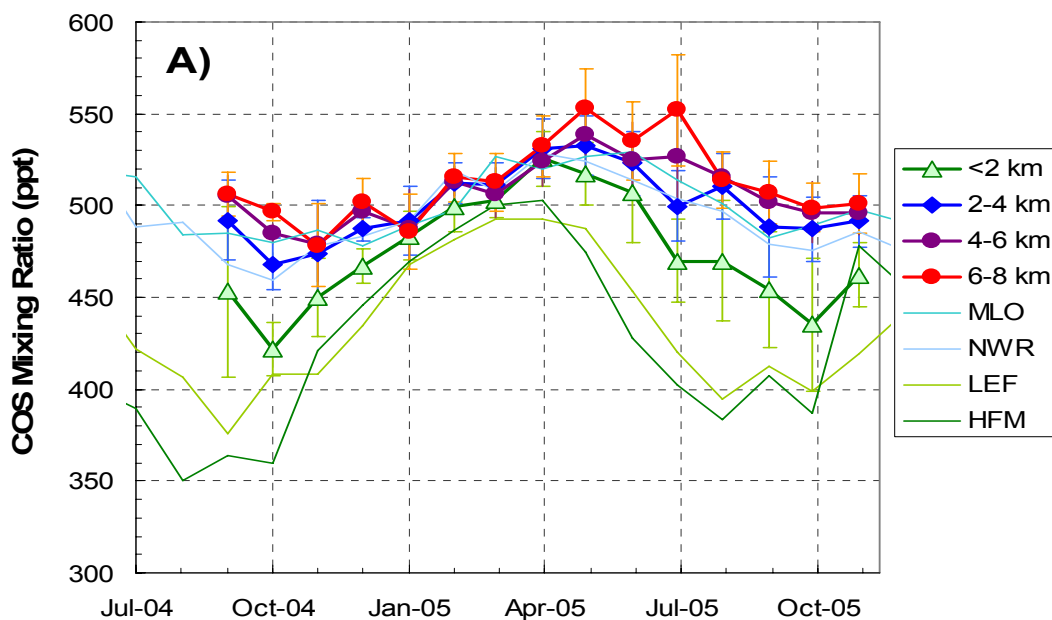


Figure 1. Mixing ratios of carbonyl sulfide from aircraft samples collected over the continental US (binned by month and sampling altitude) compared to results from NOAA surface sites MLO (Hawaii), NWR (Colorado), LEF (Wisconsin), and HFM (Massachusetts). Large gradients are observed at the surface sites and vertically above the continent from April-May through October-November.

Estimating Biomass in a Combined SiB and CASA Model Using Data Assimilation

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Weather and climate dominate inter-annual variability in carbon flux, but whether the land surface model produces a long-term carbon source or sink depends entirely on the assumed initial amount of biomass. Most models assume initial biomass is in climate equilibrium, where biomass input from photosynthesis balances losses due to microbial decay. Essentially, the models start with a completely mature forest, where trees grow and die at the same rate. However, biomass is not in climate equilibrium because of agriculture, timber harvest, and biomass burning, resulting in high uncertainty in the long-term simulated fluxes.

To estimate initial biomass, we used data assimilation of observed CO₂ fluxes from the Ameriflux eddy covariance flux tower network and the Simple Biosphere/Carnegie-Ames-Stanford Approach (SibCasa) model. SibCasa simulates the terrestrial carbon cycle as the flow of carbon from one biogeochemical pool to another. We used the Maximum Likelihood Ensemble Filter ensemble-based data assimilation technique. Data assimilation minimizes the difference between modeled and observed fluxes by iterating initial biomass in various pools.

Our results indicate modeled fluxes are most sensitive to changes in initial wood biomass, as seen by comparing simulated and observed fluxes at Walker Branch, Tennessee (Figure 1). In forest ecosystems, the wood pool has the longest turnover time (35-80 years) and has by far the most carbon. As trees die and decay, the carbon is transferred to the coarse woody debris and other litter and soil pools, which have much shorter turnover times (5 years or less). In young, growing forests typically of the eastern United States, the faster pools reach equilibrium with respect to wood long before the forest matures and the wood pool reaches equilibrium with climate. This means to obtain reasonable model estimates of North American carbon flux, we only need to know the amount of wood rather than a complete carbon budget in all pools.

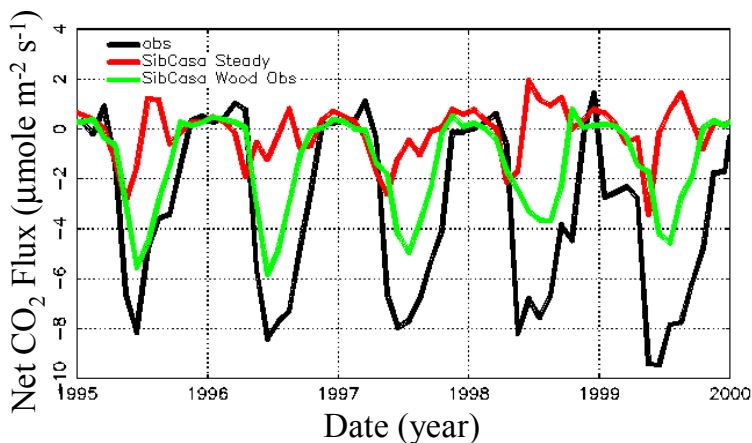


Figure 1. Observed net CO₂ flux (black), equilibrium flux (red), and optimal wood biomass flux (green) at Walker Branch, Tennessee. A positive net CO₂ flux indicates a net release into the atmosphere. Walker Branch is a young forest (<50 years old) that clearly shows a net sink over time. Optimizing for wood biomass greatly improves the simulated fluxes from SibCasa.

Regional Scale Inverse Modeling of North American Carbon Fluxes

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Geostatistical inverse modeling is a numerical technique that can be used to infer finely-resolved patterns of biosphere-atmosphere exchange from atmospheric mixing ratio data. In this study we employed this technique in a regional framework to characterize the spatial and temporal information about biospheric carbon fluxes that can be extracted from continuous mixing ratio data simulated at six tall tower locations (3 existing, 3 planned) across the United States. We inferred the monthly average net ecosystem exchange (NEE) and the monthly-mean diurnal cycle of NEE predicted by the Simple Biosphere Model-2 (SiB-2) biogeochemical model for the month of September at the spatial scale of $1^\circ \times 1^\circ$, using four measurements per day from each tower. The Stochastic Time-Inverted Lagrangian Transport (STILT) model was used to generate the simulated time series of CO_2 at the towers and the transport information used in the inversion. We also used the geostatistical technique to infer the monthly average sensitivity of NEE to solar radiation and temperature in a very simple NEE model. The results show that the spatial pattern of the flux is accurately retrieved near the towers and that the aggregated monthly NEE is accurately retrieved up to 1000 km from the towers (a total area of ~ 10 million km^2), with a substantial reduction in the uncertainty of the aggregated flux.

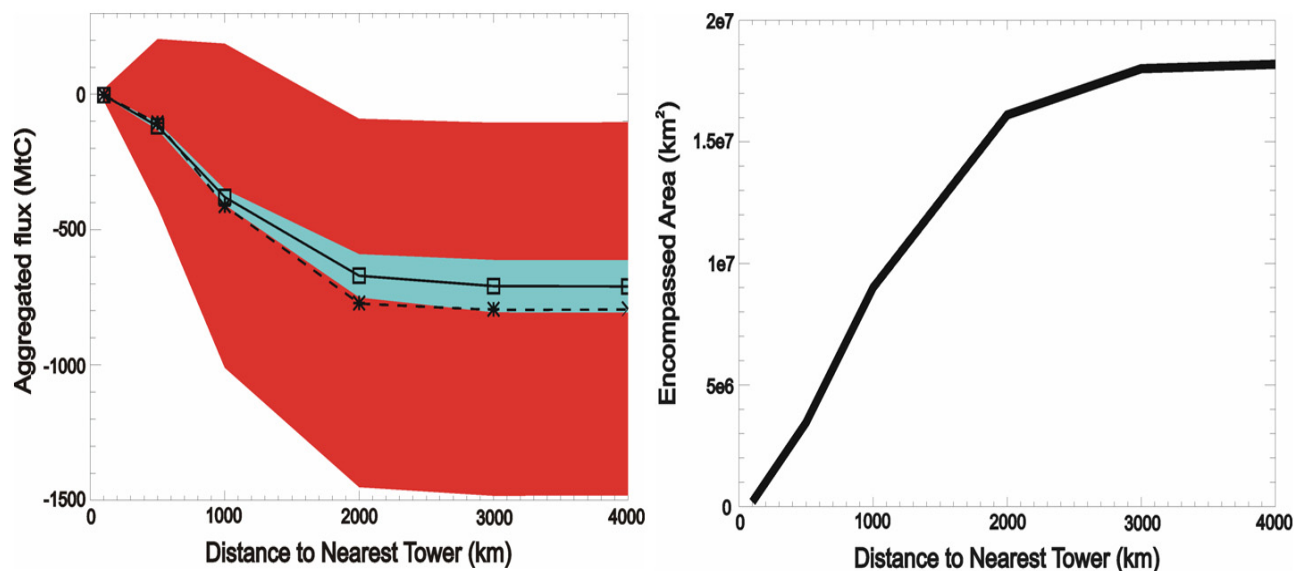


Figure 1. Left panel shows a comparison between the aggregated prescribed flux (dashed line and red $\pm 1\sigma$ uncertainty bounds) and aggregated inferred flux (solid line and blue uncertainty bounds), in millions of tons of carbon for the month of September. The aggregation was performed by adding the flux from all grid cells within 100, 500, 1000 (etc.) of the 6 tall tower locations. The right panel shows the area encompassed within the different distances, in square kilometers.

Terrestrial Carbon Fluxes for North America Estimated from NOAA-ESRL CO₂ Observations

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We present an analysis of terrestrial net CO₂ fluxes for the period 2000-2004. These fluxes consist of weekly global maps at ~70km×100km resolution that are consistent with observed atmospheric CO₂ mixing ratios, as well as with varying climatic conditions across different ecosystems. The flux maps are created in a newly developed ensemble data assimilation system that consists of the atmospheric Transport Model v5 (TM5), simple descriptions of terrestrial and oceanic carbon exchange, and an efficient Bayesian least-squares algorithm to optimize the net CO₂ fluxes from different ecoregions against CO₂ mixing ratios from the NOAA/ESRL/GMD observing network. Our analysis shows a terrestrial carbon uptake in North America of 0.49±0.57 PgC/yr over this period, partitioned 70/30% between the temperate and Boreal regions. Strongest uptake is attributed to areas dominated by mixed crop- and grasslands in the US Midwest, and evergreen forests in the east of the US, although our system can not fully separate ecosystem fluxes reliably in this period due to the sparsity of the network. Terrestrial carbon sinks in Europe and Boreal Eurasia averaged 0.28±0.64 PgC/yr and 0.89±0.93 PgC/yr respectively. Although qualitative agreement is seen with reduced uptake in Europe related to summer droughts in 2003, the size of the anomaly is smaller than observed from ground-based instruments likely due to the sparsity of European mixing ratio sites in our current configuration. We expect the increased 2005 network, combined with the extensive set of CarboEurope observations to put stronger constraints on the estimated exchange.

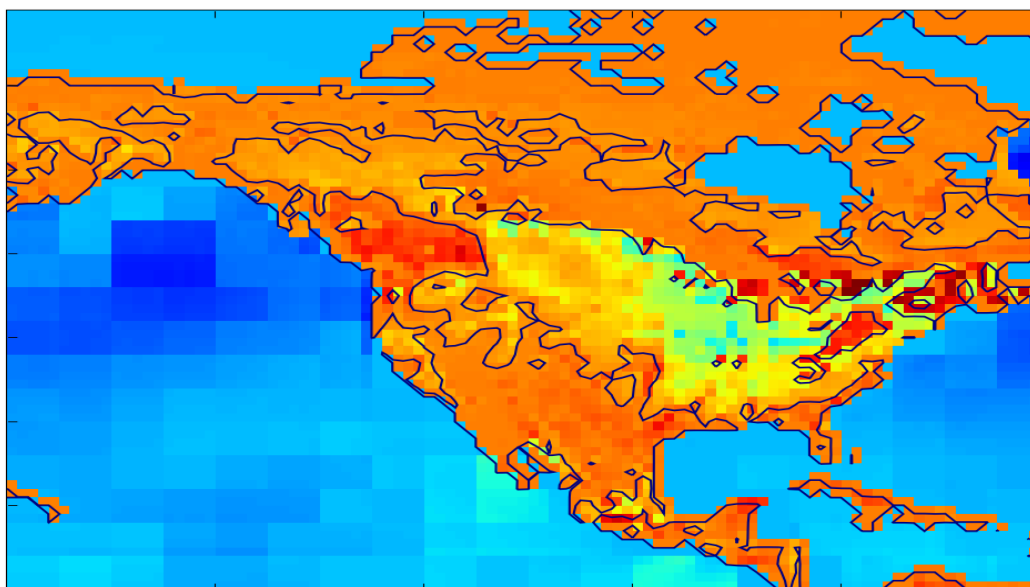


Figure 1. The annual mean pattern of net CO₂ exchange over North America for 2003 as derived from our data assimilation system. The zero-contour is in blue, maximum uptake in green corresponds to 0.7 μmol/m²/s. Total terrestrial uptake for 2003 is 0.45±0.57 PgC/yr, partially offsetting the estimated 1.6 PgC/yr of fossil fuel release.

The *Medusa* Automated Cryofocusing Gas Chromatograph–Mass Spectrometer System for the Measurement of Atmospheric Trace Gases

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The *Medusa* automated gas chromatograph–mass spectrometer (GC-MS) instrument has been developed and deployed as part of the Advanced Global Atmospheric Gases Experiment (AGAGE) ground-based tropospheric measurement network. This instrument measures over 40 atmospheric trace gases ranging in concentration from 0.1 to 550 of parts-per-trillion (ppt), with emphasis on anthropogenic and biogenic trace gases which modulate stratospheric ozone and/or the radiative forcing of climate. The heart of the system is a programmable temperature trapping, distilling and cryofocusing system which concentrates these analytes from 2-liter air samples for injection into a customized Agilent 5973 GC-MS. More abundant interfering species are removed from the samples prior to injection onto the separating columns. Care is also taken to avoid chemical and bleed-through losses of analytes on the traps and co-elution interferences in the MS, and to quantify instrumental blanks. Instrument control and data acquisition are by custom computer software, which also provides important performance diagnostics and Internet data transmission and backup. Measurement time is 1 hour, and sample and standard injections are alternated. Measurement precisions range from about 0.1% above 100 ppt to a few percent below 1 ppt.

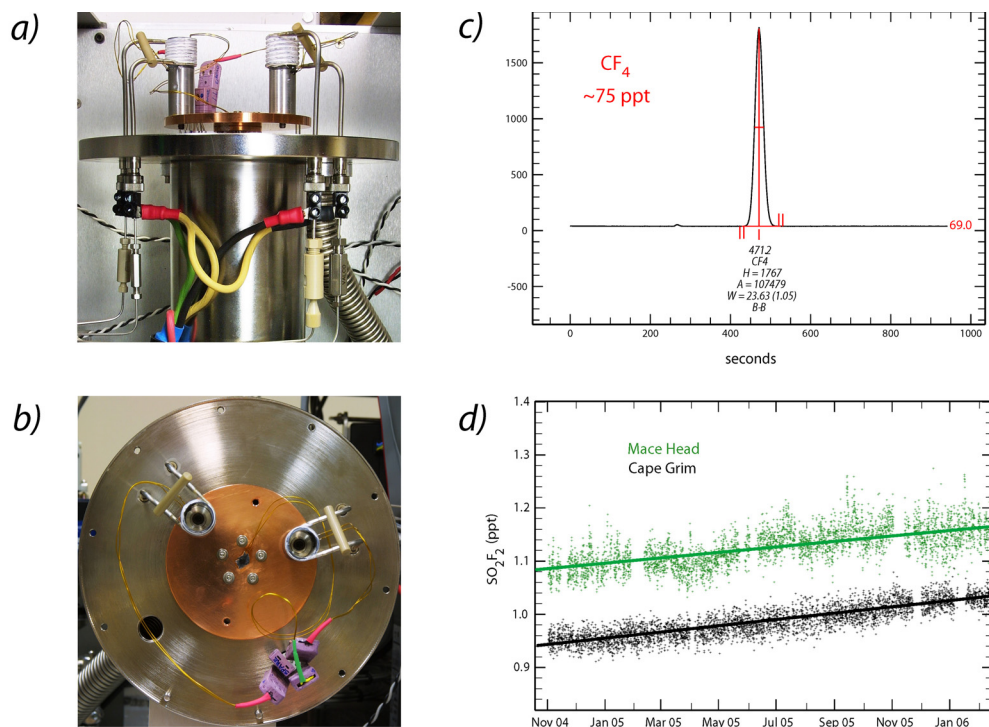


Figure 1. The AGAGE *Medusa* GC-MS instrument system employs custom-designed cryofocusing traps shown in plan view (a) and front view (b). These traps can be programmed individually at any temperature between -175°C and $+200^{\circ}\text{C}$ to trap, distill and cryofocus a wide range of trace gases from large air samples. Among the most difficult measurements made by the *Medusa* is the highly volatile carbon tetrafluoride (CF_4). Its chromatographic peak is well-resolved (c), and is measured with a typical precision of 0.15%. The anthropogenic fumigant sulfonyl fluoride (SO_2F_2) is present in the background troposphere at about 1 part-per-trillion (d). Its global distribution and trend are among the new discoveries made possible by the *Medusa*.

CLidar Profiling of Aerosols at Mauna Loa Observatory

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CLidar (camera lidar) is a method of profiling boundary layer aerosols that has been developed at Mauna Loa Observatory (MLO). The method uses wide angle optics (100 degrees) to image a laser beam onto a CCD camera. The image is then analyzed for aerosol and molecular scattering using geometry to assign altitudes to the image pixels. The advantage over the standard lidar method is the very high vertical resolution all the way to the ground. There is no overlap function and the dynamic range needed is much less than in lidar detection. The equipment is also simpler than that required by the lidar method. In August, 2005 a solar powered camera was deployed above MLO for weekly observations. The measurements were usually right after sunset often profiling the transition from upslope air laden with local aerosols to clean upper tropospheric air. The plot below (Figure 1) shows the scattering ratio (aerosol/molecular) for a three hour period at MLO during such a transition. The vertical profiles were taken every 5 ½ minutes and the vertical resolution is less than 1 meter near the surface (bin 0). The clean free tropospheric air initially starts above 400 meters (bin 380) but reaches the surface by the end of the three hour period.

A more sensitive, lower noise CCD camera and wide angle lens have been tested with a significant improvement in performance. In addition, a shutter (chopper) has been constructed to block background light between laser shots in preparation for boundary layer measurements in Hilo where background light will be much greater than at MLO.

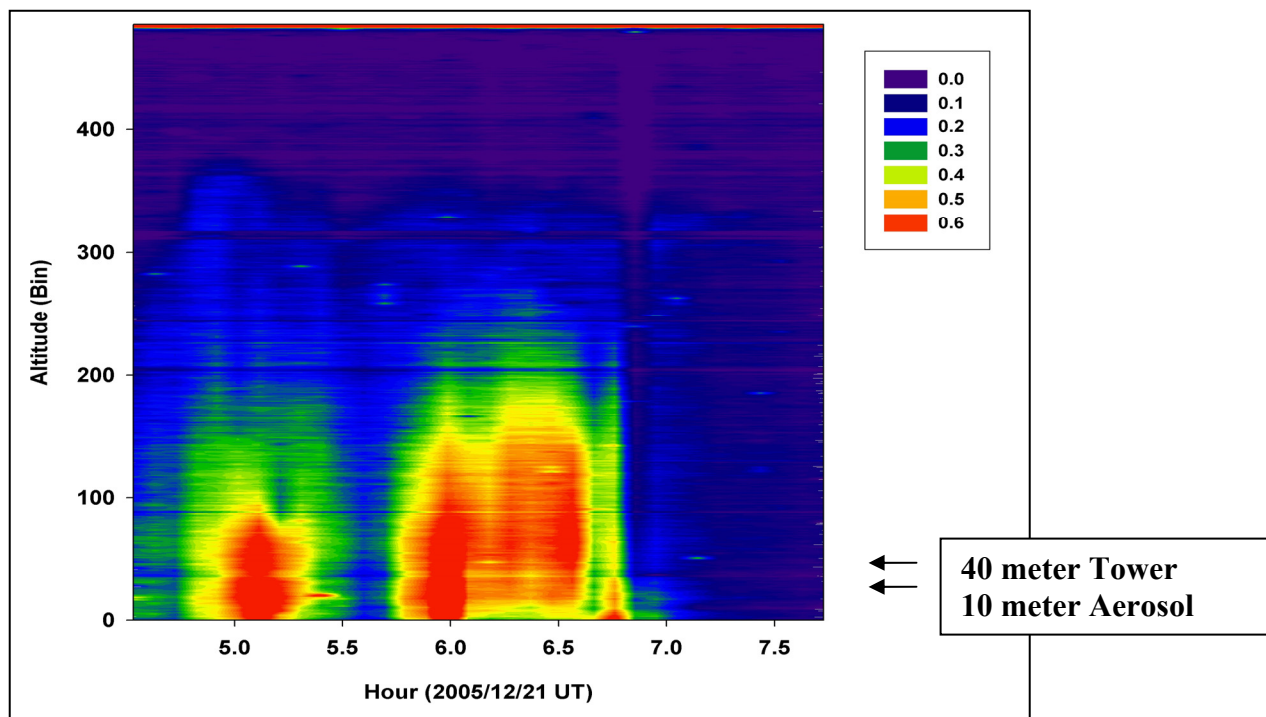


Figure 1. Scattering ratio (aerosol/molecular) for a three hour period at MLO showing the transition from upslope air (prior to 7 UT) to clean down slope air (after 7 UT).

Aerosol Light Scattering Measured by Nephelometry Compared to that Derived from Cavity Ring-down Aerosol Extinction Spectroscopy (CRD-AES)

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Tropospheric aerosols play a critical role in the Earth's radiation balance because they scatter and absorb incoming short-wave radiation (i.e., aerosol direct effect). Traditional in-situ measurement techniques of aerosol optical properties (e.g. extinction, scattering, and absorption) have provided important results; however higher accuracy, better sensitivity, and improved time resolution are needed to reduce the uncertainties in the optical parameters of ambient aerosol and hence, the uncertainty in radiative forcing.

In this work, we compare the performance of a commercial three wavelength integrating nephelometer (TSI, model 3563) and a four wavelength cavity ring-down aerosol extinction spectrometer (CRD-AES) developed in NOAA/ESRL/CSD. The former has been a 'standard' method for the past few decades to measure light scattering. The latter is a new instrument for direct measurement of light extinction. Using dry, non-absorbing, sub-1 μm laboratory generated aerosols and comparison between the nephelometer and CRD-AES we have investigated the uncertainty, wavelength conversion, correction factor, and time resolution associated with traditional aerosol optical property measurements. Our analysis includes: the angstrom exponent dependence, size dependence, signal linearity, spherical vs. non-spherical particles, and calibration procedure. These results are important to evaluate the capabilities and application of these instruments. One application of particular interest is whether the difference between aerosol extinction determined using CRD-AES and scattering determined using an integrating nephelometer is appropriate for (a) use in validation and calibration of absorption instruments and (b) determination of absorption of ambient atmospheric aerosol. With improved understanding of our instrument assumption and limitations we can improve our estimates of aerosol optical property uncertainties.

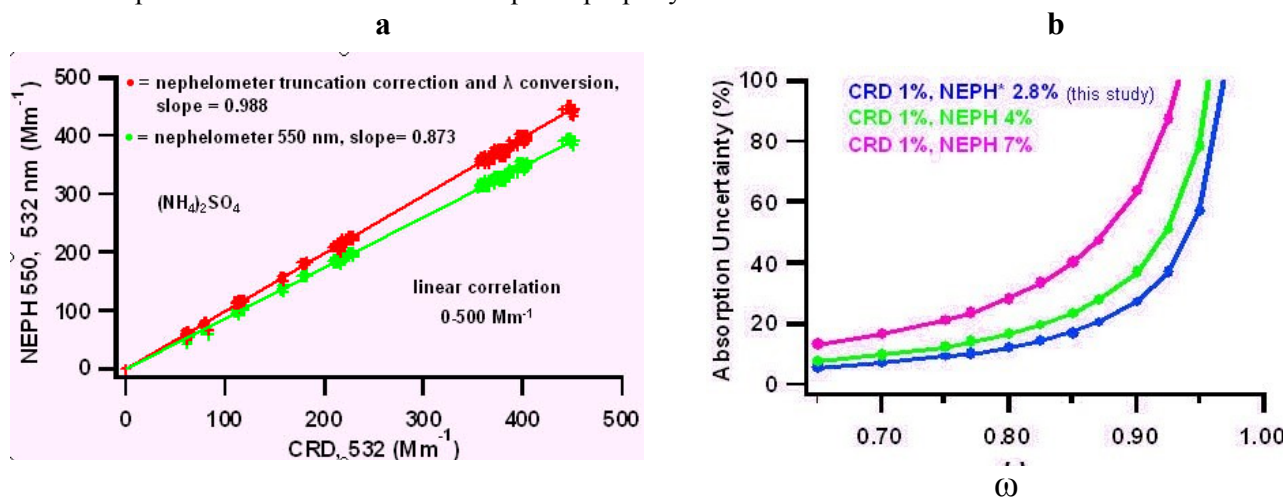


Figure 1. (a) Correlation between CRD and nephelometer (non corrected and corrected) response for non absorbing aerosols.(b) Propagated uncertainty in absorption by using 1% CRD uncertainty and nephelometer uncertainties from literature and the integrated approach (this study)

Observed Multi-decadal Variations in Surface Irradiance (radiation budget) Records

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As key components of the earth's energy budget, which is involved in the maintenance and perturbation of global climate, variations in the incoming solar and terrestrial radiant energy (irradiance) at the earth's surface are of considerable importance. For over three decades (50 years in some cases), GMD and its predecessors have continually observed radiation quantities at selected surface sites with the intention of documenting and understanding their magnitude, variability, and broader-scale implications. With known astro-geometrical causes dominating the solar irradiance variations that drive diurnal to seasonal weather and climate variations, identification of inter-decadal irradiance variations is a daunting task, which was embarked upon those decades ago following a much earlier recognition of the scientific problem. Sufficient data now exist to begin investigations of potential inter-decadal variations in annual means. Anticipated variations are small to non-existent on the global scale but numerous reports of interannual and inter-decadal variations of 2% to 4 % dec⁻¹ at various surface observing sites have been made. The data from the GMD program show some autocorrelated variability that tends to support those reports but over limited time scales thereby more realistically bounding the earlier reported variations. The value of those observations on a broader-scale is examined. The spatial representativeness of the solar data is indicated as autocorrelations between the sites' and shorter global satellite records, figure below. Further observations to document the evolving state of this fundamental climate and weather component are needed to better understand underlying and related climate variations and feedbacks.

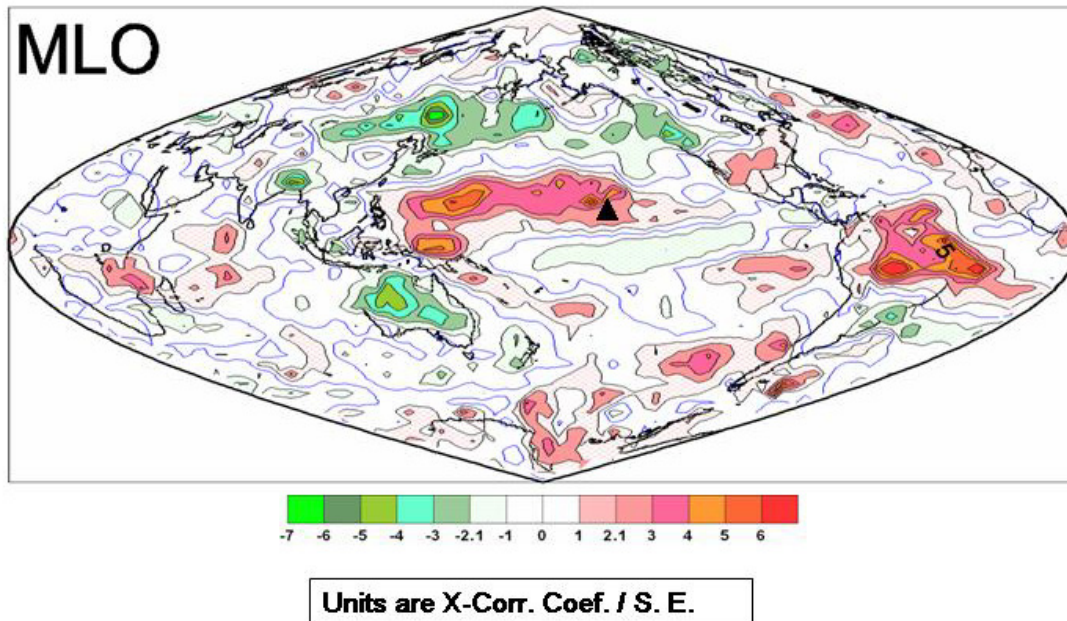


Figure 1. Cross correlation between a subset (1984-2000) of annual-mean surface solar irradiance at Mauna Loa and those from the longest available satellite record (ISCCP) for the entire planet. Plotted quantity is the ratio of cross-correlation to its standard error at each grid point. Note the black triangle at the Mauna Loa location.

Broadband and Spectral Shortwave Radiation Model and Measurement Comparisons

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Shortwave radiation models and measurements have a problem in that models over-predict the measured diffuse irradiance while matching the measured direct beam irradiance. In 2003 an intensive observation period (IOP) to study aerosols over the ARM central site in northern Oklahoma (36.61° N, 97.49° W) was conducted between May 5th and May 30th. Redundant measurements of aerosol properties were made at and above the surface. The first part of this talk summarizes those results and remarks on lessons learned from comparing six models to the surface irradiance measurements. The second part of the talk focuses on efforts to compare measurements and models spectrally. During the IOP two rotating shadowband spectroradiometers acquired data in the ultraviolet, visible, and near-infrared out to about 1.06 μm . A major hurdle in spectral comparisons is matching spectral resolution. Since we will use measurements as the standard we match their resolution, which involves experimentally determining the slit function at every wavelength, and then multiply a sufficiently high-resolution model spectrum by this function and integrate over the slit function to get the resolution to be similar. (Figure 1) shows this a typical comparison in the visible/near-infrared spectrum. The discrepancies and physics behind them will be discussed.

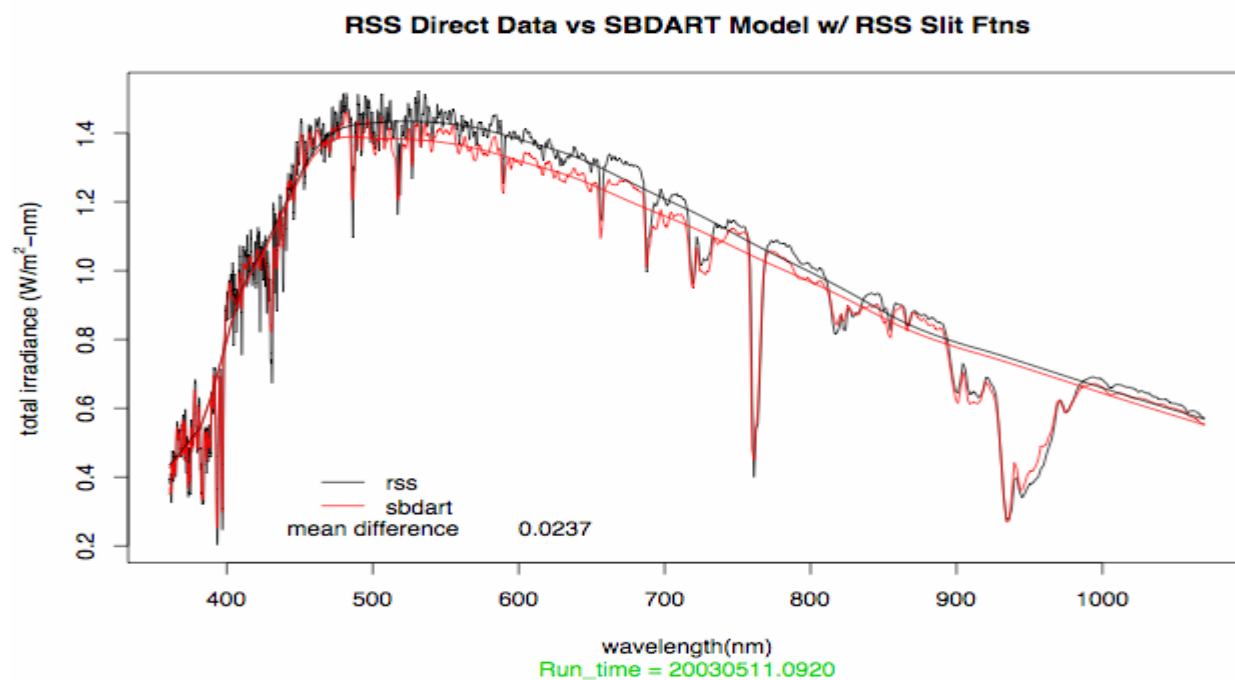


Figure 1. The SBDART-modeled direct solar spectral irradiance using simultaneous measurements of the needed model inputs, most importantly, aerosol, water vapor, and ozone (in red) is compared with measurements from the rotating shadowband spectroradiometer (in black) during the ARM Aerosol Intensive Observation Period (AIOP) in May 2003.

An Aerosol Optical Depth Algorithm for the SURFRAD Network

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The new multi-spectral Aerosol Optical Depth (AOD) analysis method recently developed for NOAA's Surface Radiation Budget network (SURFRAD) includes several unique features that minimize error and facilitate the calibration and AOD calculation procedures. The once painstaking task of identifying calibration Langley plots is uniquely automated by cross-referencing the Multi-Filter Rotating Shadowband Radiometer (MFRSR) measurements with the SURFRAD clear-sky identification product. Use of the clear-sky product ensures that only the most pristine cloud-free conditions are used for Langley calibrations. Identifying mean channel-specific calibrations that represent two-month periods and grouping them over two-year periods allows for the resolution of, and removal of, the temperature dependence of the MFRSR (see figure), thus further reducing error in the ultimate product. Finally, the use of measured station pressure at the SURFRAD station for accurate molecular scattering calculations at the resolution of the measurements, and the automatic acquisition of daily total ozone over each station from NASA's TOMS website for ozone absorption calculations, further improve the accuracy of the SURFRAD AOD algorithm. Provisional AOD data for SURFRAD stations can now be computed. However, before a final product can be released, the central wavelengths of the MFRSRs that have been used at SURFRAD stations must be checked and verified.

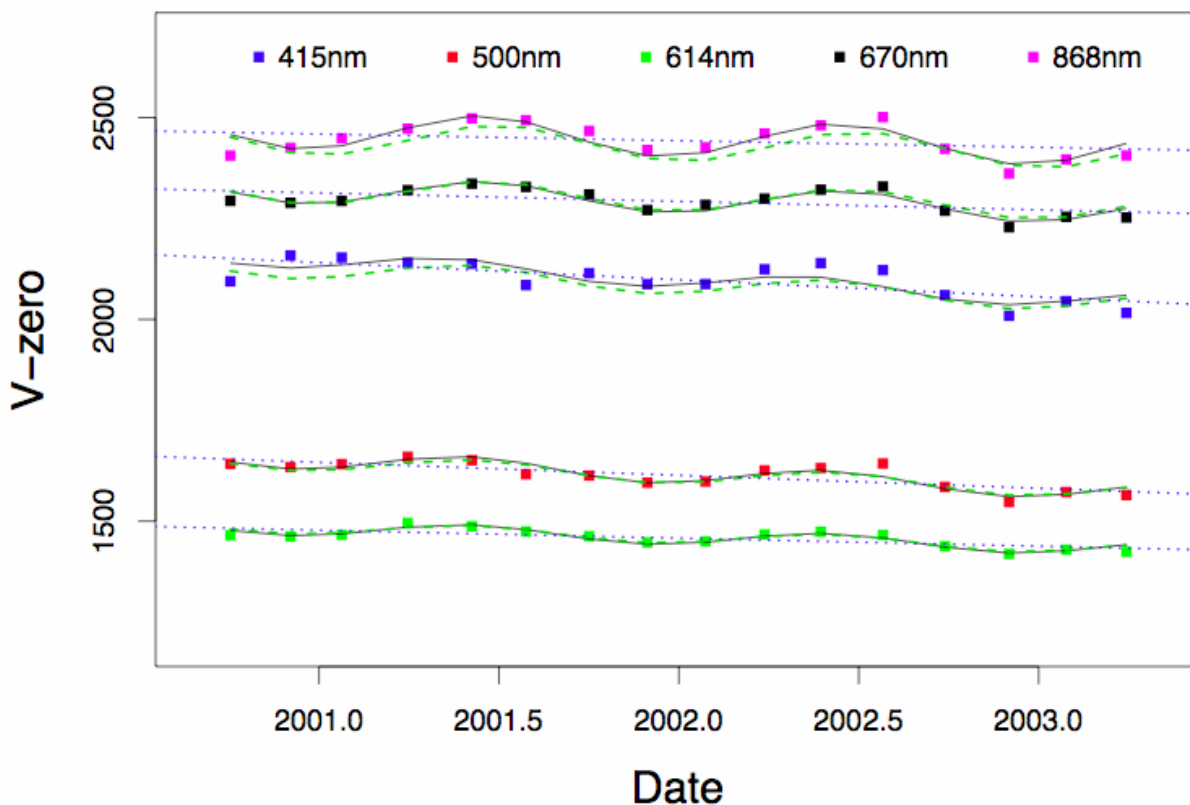


Figure 1. Time Series of Langley V_0 calibrations for five visible spectral channels of the MFRSR at the Table Mountain SURFRAD station near Boulder, Colorado. Plotted points represent approximately two-month mean V_0 's. The solid line is the best-fit function that is used to generate daily V_0 calibrations in the AOD algorithm. The dashed green fit is weighted by the error of each point, and the dotted straight line is the best linear fit, shown for reference.

Ozone Measurements in Australia

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The Australian Bureau of Meteorology maintains a network of five Dobson stations measuring total column ozone – Brisbane, Darwin, Melbourne, Macquarie Island and Perth (operated on behalf of NOAA). Ozone profiles are also measured at Melbourne and Macquarie Island with weekly ozonesonde flights, with a reduced program of sonde flights also operating at Davis Base in Antarctica (in conjunction with the Australian Antarctic Division).

Together these sites cover a wide range of latitudes across the relatively data sparse Southern Hemisphere, and possess data records of various lengths.

I will give a brief overview of the network and then present some features of the data record, including ozone climatologies and trend analyses.

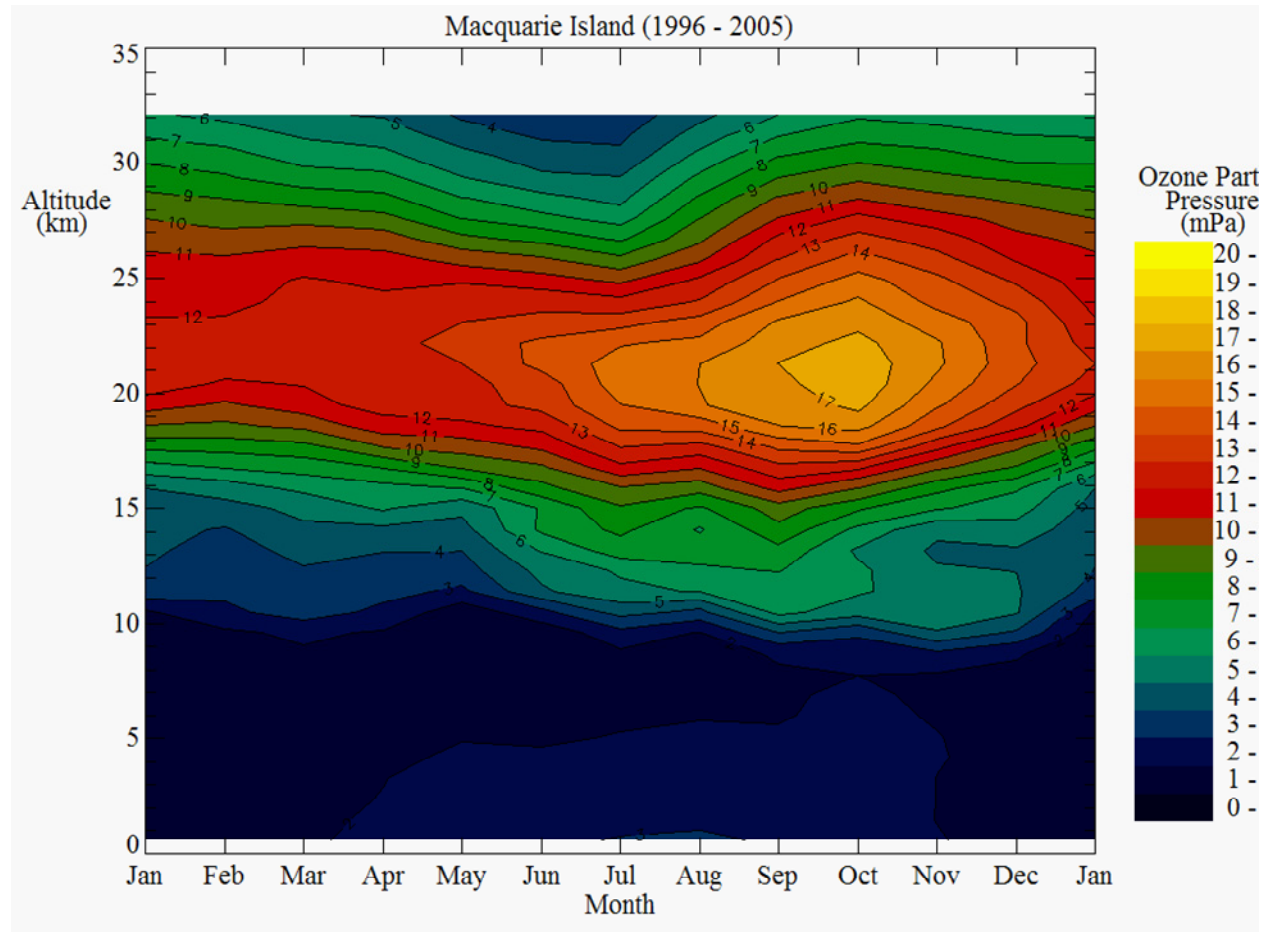


Figure 1. Mean ozone partial pressure by month and altitude as measured by the Bureau of Meteorology's ozonesonde program at Macquarie Island (55°S 159°E) from 1996 to 2005.

Constraining Estimates of Future Emissions of Ozone-Depleting Substances with Measurements

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Projections of future emissions of ozone-depleting substances (ODSs) are based on estimates of current and impending production, predominantly in Article 5(1) (developing) countries, and on estimates of current and future emissions from the reservoirs (banks) of these chemicals that exist in developed countries. Production of CFCs and halons in developing countries is currently diminishing in anticipation of their 2010 production deadline, however the demise of global manufacture will not rapidly eradicate emissions of these ODSs because their world-wide banks are believed large. A recent reassessment of global ODS banks, based on inventories of equipment and products containing ODSs, has more than doubled an earlier bank estimate for CFC-11, and increased a previous CFC-12 bank estimate of 60 Gg (in 2000) more than tenfold. These new estimates make it clear that the majority of future emissions of CFCs and halons will emanate from existing banks, not from impending production. Accordingly, projections of future emissions and ozone layer recovery rely strongly on estimates of the sizes and release rates of contemporary ODS banks.

Measurement-based estimates of modern-day ODS bank releases can help constrain projections of future emissions. For example, a recent measurement-based emission estimate of 16 ± 4 Gg CFC-12 for the USA and Canada in 2003 is contrary to a previous (2000) global bank size estimate (60 Gg) that implied the CFC-12 bank would be exhausted by 2002. As global production winds down, changes in the global atmospheric burdens of ODSs, as measured by ESRL/GMD, provide increasingly accurate information about global bank emissions that will lead to more accurate projections of future ODS emissions and ozone layer recovery.

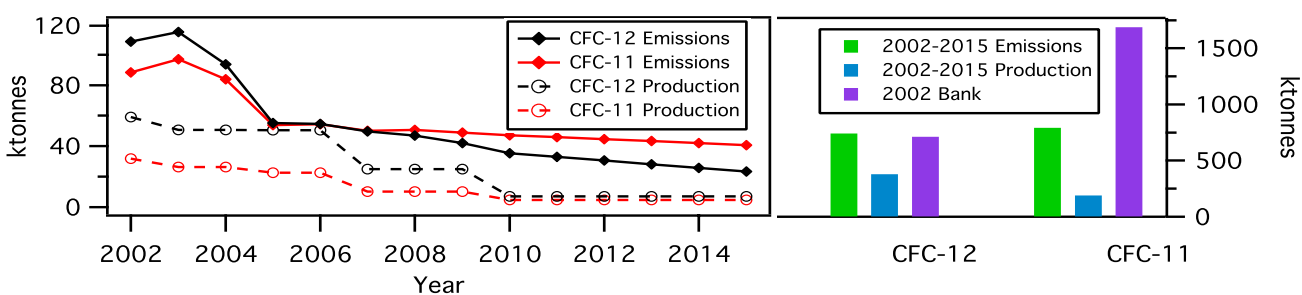


Figure 1. Though CFC-11 and CFC-12 production is expected to drop 80-85% during 2005-2015 (left panel), their estimated emissions will diminish only 25-50% because of large banks. A comparison of the recent bank size estimates for 2002 to the projected cumulative emissions and production during 2002-2015 (right panel) reveals that the predominance of future emissions will emanate from banks.

Two Years of Water Vapor Observations Using New Cryogenic Frost point Hygrometer (CFH)

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The Cryogenic Frost point Hygrometer (CFH), which has been developed at the Cooperative Institute for Research in Environmental Sciences of the University of Colorado, allows a high density of observations with significantly improved accuracy in the extremely difficult to probe tropical upper troposphere and lower stratosphere. Of 150 soundings, which have been launched over the past 2.5 years, more than 60 have been launched by the Universidad Nacional at Heredia, Costa Rica. The first intensive campaign showed the importance of Rossby gravity wave events for dehydration in the tropical tropopause layer (TTL) during the boreal summer months. The same data set provides important observations for the validation of AURA MLS and HIRDLS stratospheric and upper tropospheric water vapor retrievals and identified a serious dry bias of the Vaisala RS92 in the upper troposphere. The second intensive campaign in Costa Rica, together with the CFH/lidar campaign at Biak, Indonesia, provided important information about the dehydration in the TTL during the boreal winter. In addition, this campaign quantified the disagreement with the WB-57 instruments measuring water vapor. A higher density of observations combined with a significantly improved accuracy is able to extend trend observations from the lower stratosphere into the upper troposphere, which has been previously out of reach for trend observations.

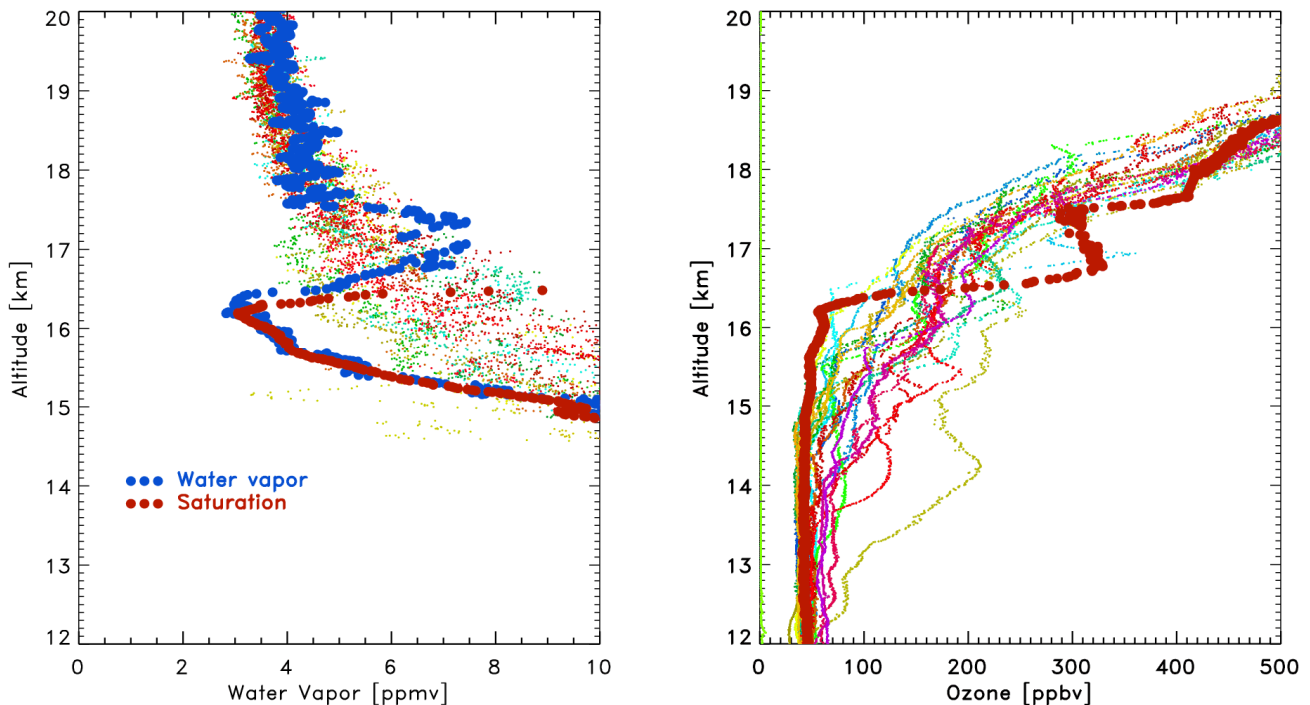


Figure 1. Water vapor and ozone profiles of 16 soundings between 8 July and 25 July 2005. The highlighted profile (thick dots) was obtained on 19 July. The cold temperatures (low saturation mixing ratio), low water vapor and low ozone concentrations at the tropopause are the result of a Rossby gravity wave event that propagated downward over the previous days and ultimately caused local dehydration during the warm tropopause season.

Oceanic Distributions and Emissions of Short-lived Halocarbons

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Recent attention has focused on short-lived halogenated gases as potentially significant contributors to stratospheric ozone depletion. Traditionally thought of as weak or non-existent participants in stratospheric ozone chemistry, these gases or their breakdown products could be delivered from the marine boundary layer to the lower stratosphere via rapid, deep convection. Their potential contribution is underscored by a substantial excess (~20-35%) of bromine in the stratosphere that cannot be accounted for by the longer-lived brominated gases

Using intercalibrated data from 7 cruises over a 10 year span, we report marine boundary layer mixing ratios, degrees of surface seawater saturation, and air-sea fluxes of several short-lived halocarbons that are potentially significant in stratospheric chemistry. CHBr_3 , CH_2Br_2 , and CH_3I were all highly supersaturated virtually. Under-saturations were noted at some locations in the Southern Ocean, owing to mixing of surface and subsurface waters, not biological or chemical sinks. Highest saturations of the two polybrominated gases were observed in coastal waters and areas of upwelling such those near the equator and along ocean fronts. CH_3I distributions reflected its different chemistry and cycling in both the water and the atmosphere. The high supersaturations, fluxes, and marine boundary layer mixing ratios in the tropics are consistent with the suggestion that tropical convection could deliver some portion of these gases and their breakdown products to the upper troposphere and lower stratosphere.

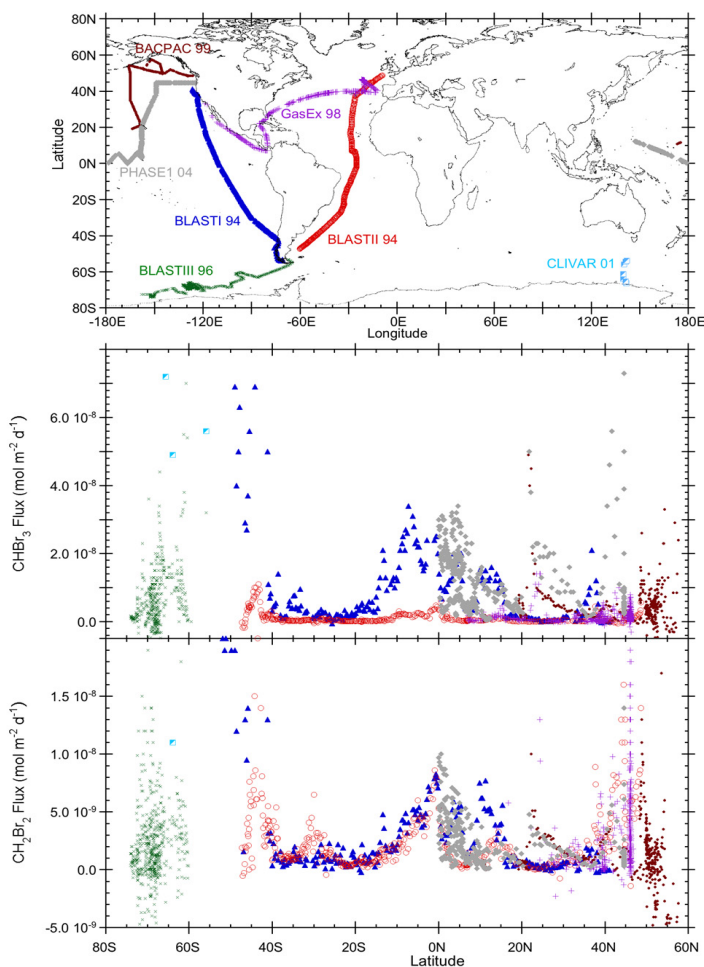


Figure 1. Plots of the oceanic fluxes of CHBr_3 and CH_2Br_2 into the marine boundary layer based upon data from 7 research cruises between 1994 and 2004.

PAN Measurements Across the Tropopause

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PANTHER (PAN and other Trace Hydrohalocarbons ExpeRiment) is an airborne 6-channel Gas Chromatograph that measures approximately 20 important atmospheric trace gases whose changing burdens impact air quality, climate change and stratospheric-tropospheric ozone. We have acquired data in the tropics, the mid-latitudes, the high-latitudes and the isolated northern vortex. Our current scientific goals include the validation of trace gases measurements by the Aura satellite and the use of tracer data to diagnose key atmospheric transport processes such as the dynamical couplings between the lower stratosphere (LS), the upper troposphere (UT) and the Tropical Tropopause Layer (TTL). Of particular interest are some of the recently added molecules that include CH₃Br, CH₃I, CH₃Cl, COS, CS₂ and HFC-134a measured by the mass spectrometer channel, and peroxyacetyl nitrate (PAN) that is measured by an electron capture detector. Many of these molecules have tropospheric gradients that are sensitive to convective transport and have the ability to distinguish between land and marine source and sink regions. PAN may represent a missing source of nitrogen for the NO_x chemical cycle in the UT and LS. PAN may also be a unique tracer for convective transport studies because of its rapidly changing lifetime with altitude and a relatively large, if not stable, boundary layer value. PAN levels of 10's of ppt were measured in the UT/LS regions. Potential instrumentation loss and contamination at these low levels is under current investigation.

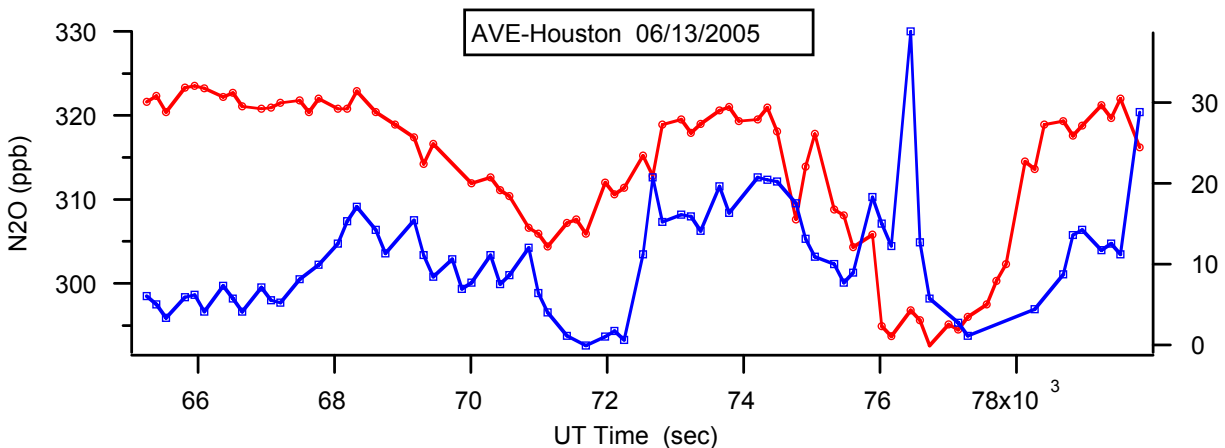


Figure 1. In this flight over the continental US, PAN data in blue is shown to increase slightly on ascent through the tropopause and then approach zero as the WB-57 aircraft climbs to a maximum altitude of 18 km. N₂O values below 320 ppb indicate stratospheric air.

The World Meteorological Organization Global Atmospheric Watch (WMO/GAW) Volatile Organic Compound (VOC) Network

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Next steps in the implementation of a global VOC measurement program were developed at the VOC WMO/Workshop on Volatile Organic Compounds (VOCs) in Geneva, Switzerland, Jan. 30–Feb. 1, 2006. The VOC network will rely on 1. A series of monitoring stations that will provide continuous, in-situ gas chromatography (GC) measurements, and 2. Existing regional and global flask sampling programs. INSTAAR's ongoing Non-Methane Hydrocarbon (NMHC) monitoring in flasks from the NOAA greenhouse gas sampling network was identified as a potential centerpiece of this network. Other important components of the WMO/GAW VOC program include the establishment of a calibration standard scale and coordinated calibration and intercomparison efforts between the continuous GC stations and participating flask network laboratories and a GAW-VOC data center.

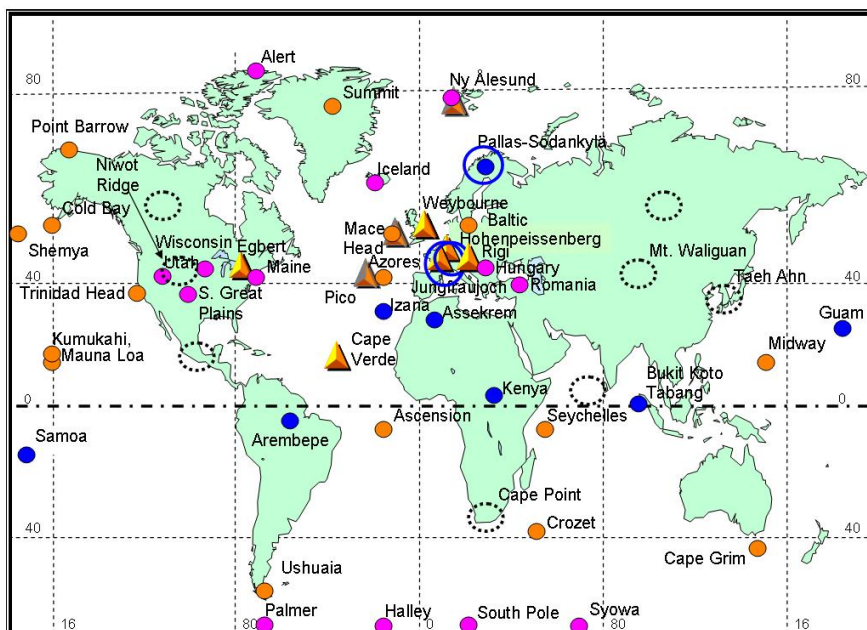


Figure 1. Proposed WMO VOC network with currently operating (▲) stations (Hohenpeissenberg, Rigi, Egbert), intermittent programs (▲), Pico, Mace Head) and continuous GC stations under development (▲), Weybourne, Cape Verde). Sites that are currently monitored in the NOAA/INSTAAR NMHC flask program are marked with colored dots (orange: start in April 2005, pink: November 2005, blue: spring 2006). Circled (dashed) areas are WMO desired locations that are not yet included. Blue circles mark overlap between NOAA, the EMEP flask network and continuous GC stations.

Surface Energy Budget, Boundary Layer Structure and Synoptic/Orographic Influences at Arctic Climate Observatories for the Study of Environmental Arctic Change (SEARCH)

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Beginning in 2004 instrumentation was installed at Alert (82.5°N, 62.3°W) and Eureka (80.0°N, 85.9°W), Ellesmere Island, Canada, to help understand the processes changing Arctic climate. These enhancements are being made in collaboration with Environment Canada, and supplement data from Barrow, AK, and data previously obtained on the pack ice during the Surface Heat Flux of the Arctic Ocean (SHEBA) experiment in 1998. The installations include a Baseline Surface Radiation Network suite of instruments (<http://bsrn.ethz.ch/>), a soil temperature probe to monitor active layer, and a sonic anemometer at Alert to measure the complete surface energy budget; and cloud radar and lidar systems at Eureka to monitor the cloud macro- and microphysical properties. Additional measurements at Alert include basic meteorological observations, spectral optical depth, all-sky images, condensation nuclei counter, three-channel nephelometer and a Particle Soot/Absorption Photometer to monitor aerosol light absorption as part of a Global Atmosphere Watch facility (http://www.wmo.ch/web/arep/gaw/gaw_home.html).

In addition, meteorological stations have existed near both of these sites for many years, and include synoptic sounding measurements. Analyses suggest that significant differences in the individual surface energy budget terms, which often represent different physical processes, exist between the pack ice site and the land sites (Figure 1). Furthermore, the high meso-alpha scale terrain features (100-500 km) have a dominant influence to direct the synoptically-driven, boundary-layer airflow at both Eureka and Alert, and this airflow is further modulated by the local terrain. The diagnosis and understanding of the atmospheric processes local to these sites are crucial for the future interpretation of how the trends in the near-surface climatological measurements at these sites are related to Arctic and global climate changes.

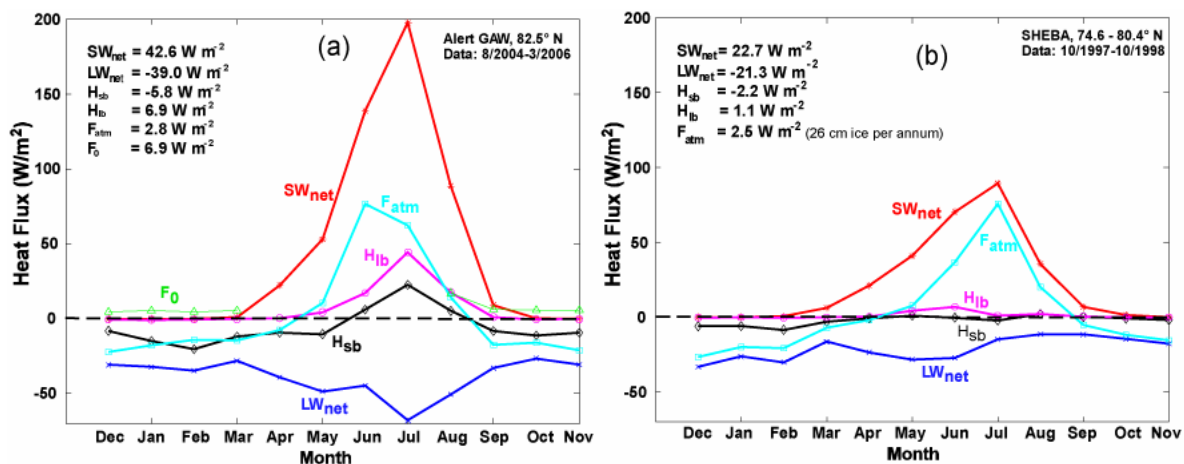


Figure 1. Annual cycle of monthly mean surface energy budget terms at a land site (a, Alert) and a pack ice site (b, SHEBA). Even though the net atmospheric flux at the surface (F_{atm}) is nearly the same for the two sites, the land site shows much greater net shortwave radiation because of the lower summer albedo. This is offset by the greater longwave radiative loss and turbulent latent heat flux at the land site due to the warmer summer surface temperatures and the less frequent occurrence of summertime clouds. The net annual F_{atm} at SHEBA accounted for about 75% of the measured net loss of 35 cm of ice that year (20% of the original ice thickness). The net annual F_{atm} at Alert likely went into melting the 48 cm of snow (~17 cm ice equivalent) and as a net heat flux (F₀) into the soil.

Forest Fire Smoke Screens Arctic Warming

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Aerosols in the atmosphere affect the Earth's radiation budget in complicated ways, depending on their physical and optical characteristics and how they affect cloud nucleation. While the Arctic atmosphere is generally very clean, spring incursions of haze and dust from Eurasia perturb the surface radiation balance. During summer time boreal forest fires emit plumes of combustion gases and carbonaceous particles into the atmosphere as smoke. From mid-June through July 2004 hundreds of fires burned across eastern Alaska and the Yukon and smoke was advected across the Arctic into Europe. The comprehensive measuring systems in place near Barrow (NOAA/GMD and DoE/ARM) present a unique opportunity to characterize the smoke aerosol physically and optically permitting quantification of its direct radiative forcing. Using photometric measurements of aerosol optical depth (AOD), smoke particle size spectra are inferred. Applying Mie scattering theory, the critical optical properties of smoke are estimated and ported into the AFRL-MODTRAN5TM radiative transfer code. Initialized on this basis, MODTRAN can simulate with reasonable consistency what is observed empirically. Because measured and analytic calculations of the direct aerosol radiative forcing are comparable, results give a reliable indication that smoke plumes significantly cool the surface during summer. Should Boreal forests expand in area and/or dry due to global warming, natural fires may become more frequent, widespread and intense in the future. Annually, the fire season may also be prolonged. Thus, enhanced cooling by smoke in the atmosphere constitutes a potential negative feedback in the climate system that must be given consideration when making future climate assessments.

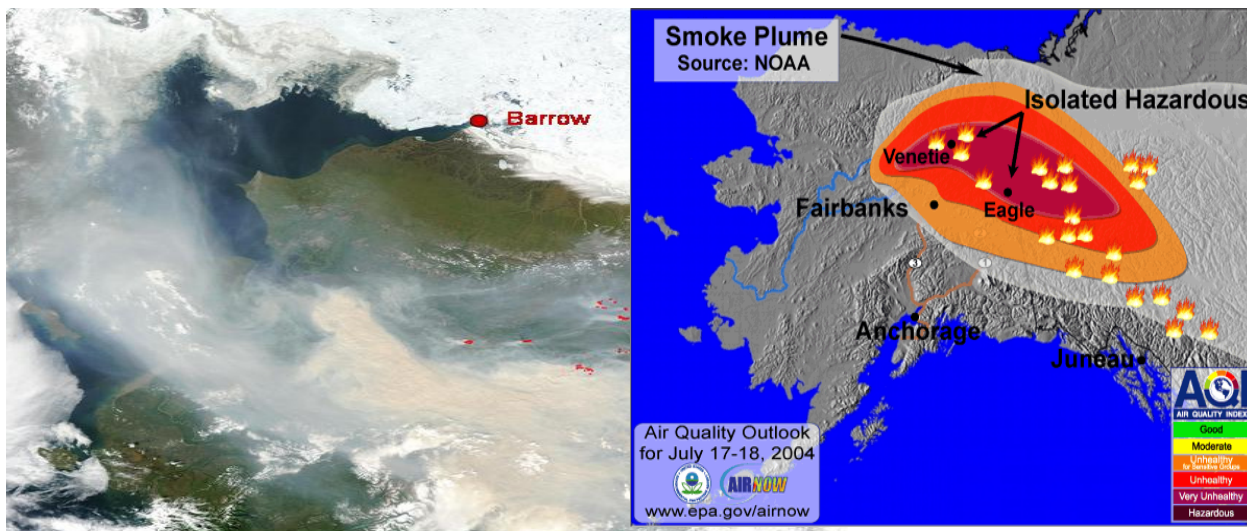


Figure 1. *Left*, MODIS image for 30 June 2004 showing fire locations and smoke plumes across Alaska. *Right*, Air quality into late July 2004 was still ‘very unhealthy’ to ‘hazardous’ over the Alaskan source region as smoke advected eastward as far as Europe.

NOAA Measurements at Summit, Greenland: Past, Present and Future

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NOAA began weekly trace gas air sampling in paired glass flasks in 1997 at the Summit, Greenland (72° N, 38° W; 3208 m) ice core drilling camp. Since 1997, the site has been unstaffed for a number of periods ranging up to a seven months in duration. Since the summer of 2003, the site has been staffed continuously. The trends in four trace gases collected at Summit are presented in Figure 1 where it may be observed that CO₂ and SF₆ show steadily increasing concentrations, CH₄ a lesser increasing trend, and no discernable trend in CO concentrations. Continuous surface ozone measurements began in 2000 and firn air trace gas measurements collected in summer 2004 and 2005. Continuous aerosol black carbon measurements began in 2003 that, along with surface ozone measurements, have proven to be excellent indicators of long range transport of air pollution from Europe, and for forest fire smoke from Russia and Alaska. Ozonesonde measurements were initiated at Summit in spring 2005 in response to the formation of an exceptionally cold polar vortex; some of the lowest stratospheric ozone values ever recorded in the Arctic were measured in the spring of 2005 above Summit. In February 2005, NOAA/GMD supplied a staff member for the Summit observatory for a six month period and again for November 2005 through May 2005. Since Summit is the only high altitude polar atmospheric observatory that measures free tropospheric air, Summit is being considered for additional NOAA instrumentation and staffing towards the view of developing a NOAA Atmospheric Baseline Observatory operation in cooperation with the National Science Foundation in the manner of the South Pole Baseline Observatory.

Summit Trace Gas Trends

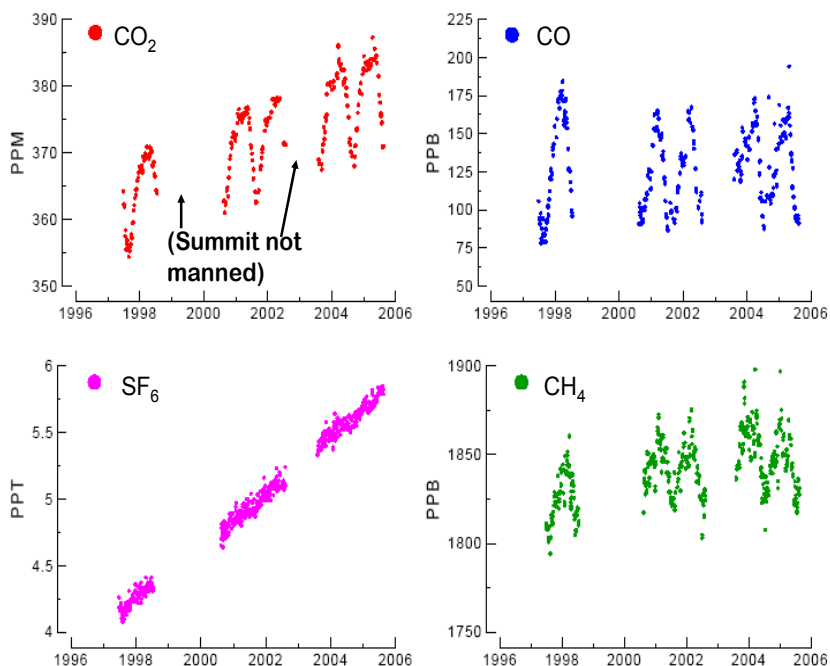


Figure 1. Trace gas trends for CO₂, CO, SF₆, and CH₄ from weekly glass flask air samples collected from the Summit, Greenland station. The blank periods are for times that the station was unmanned or flasks were not collected. CO₂ and SF₆ exhibit steadily increasing concentrations with CO₂ being the largest contributor to total atmospheric radiative forcing from trace gases. SF₆ is the strongest radiative forcing trace gas on a molecule-to-molecule basis, but SF₆ concentrations are relatively low in the atmosphere.

Sodankylä Total Column Ozone Intercomparison Campaign, March and April 2006

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The Sodankylä Total Column Ozone Intercomparison is a cooperative international project to assess the algorithms that measure total column ozone at large solar zenith angles and high total column ozone amounts. The campaign will take place just north of the Arctic Circle in Sodankylä, Finland (N 67°21'48.0" E 26°37'36.0") at the Finnish Meteorological Institute's Arctic Research Centre, from March 27-April 14, 2006. The NOAA/ESRL/GMD World Dobson Calibration Center, Boulder, CO will provide on-site data from the Secondary World Standard Dobson Spectrophotometer, D065, and European scientists will provide similar data from the European Standard Dobson Spectrophotometer, D064. These two instruments will produce base data sets that will be compared with satellite observations as well as balloon borne instruments and LIDAR measurements. The campaign will also test the accuracy of the corrections currently used to determine ozone under these specific conditions in Arctic regions (Figure1). The overall goal of the campaign is to define baseline measurement methods as well as to outline high latitude and ozone specific algorithms for all ozone related instruments recording under these extreme conditions. The overall result of the campaign will be to improve data sets and accuracy in measuring Arctic ozone depletion.

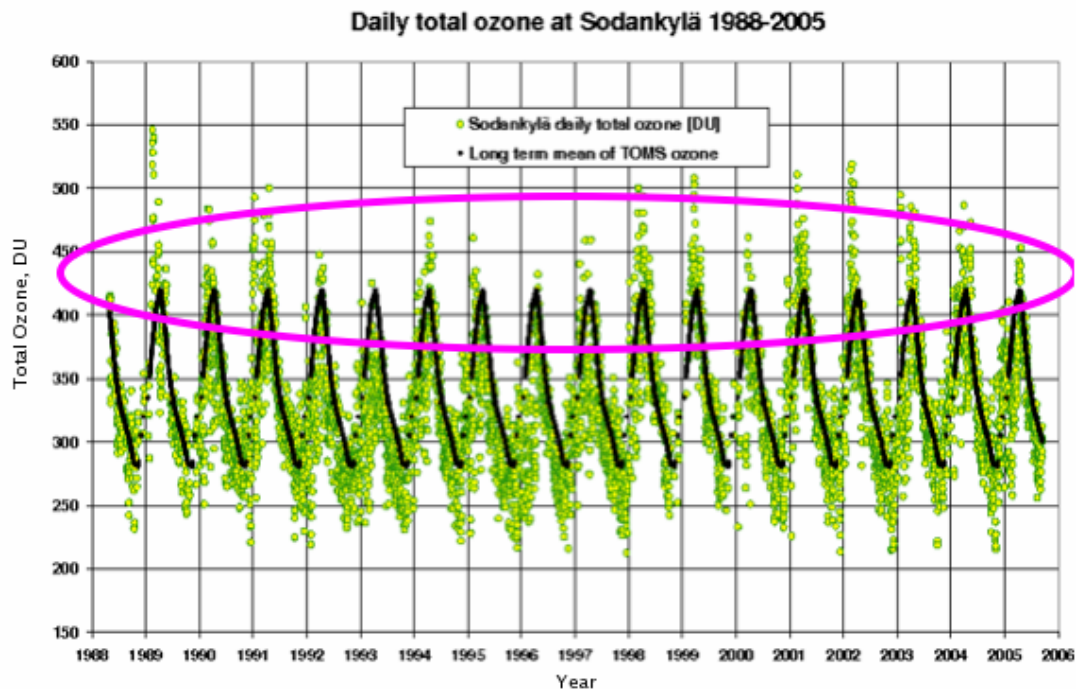


Figure 1. Springtime levels of total column ozone are consistently above 400 DU over Sodankylä, demonstrating that the location (N 67°21'48.0", E 26°37'36.0") is ideal for the conditions under which Arctic ozone can be measured effectively. (E. Kyrö, FMI-ARC)

Validation of OMPS Ozone Profile Data with Expanded Dataset from a Brewer and Automated Dobson Network

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The first NPOESS satellite is scheduled to be launched in 2010 and will carry the Ozone Mapping and Profiler Suite (OMPS) instruments for ozone monitoring. Prior this, the OMPS instruments and algorithms will be tested by flight on the NPOESS/NPP satellite, scheduled for launch in 2008. Pre-launch planning for validation, post launch data validation and verification of the nadir and limb profile algorithm are key components for insuring that the NPOESS will produce a high quality, reliable ozone profile data set. The heritage of satellite instrument validation (TOMS, SBUV, GOME, SCIAMACHY, SAGE, HALOE, ATMOS, etc) has always relied upon surface-based observations. While the global coverage of satellite observations is appealing for validating another satellite, there is no substitute for the hard reference point of a ground-based system such as the Dobson or Brewer network, whose instruments are routinely calibrated and intercompared to standard references. The normalization of measurements at different solar zenith angle (SZAs) to the measurement at the smallest SZA cancels out many calibration parameters, thus providing a "self-calibrating" technique in the same manner relied upon by the occultation sensors on satellites. Moreover, the ground-based Umkehr measurement is the only technique that provides data with the same altitude resolution and in the same units (DU) as do the UV-nadir instruments (SBUV-2, GOME-2, OMPS-nadir), whereas occultation instruments measure ozone density with height. The newly developed Umkehr algorithm (Petropavlovskikh et al, 2005) will enhance the information content of the retrieved profiles and extend the applicability of the technique. Automated Dobson and Brewer instruments offer the potential for greatly expanded network of Umkehr observations once the new algorithm is applied. We will discuss the new algorithm development and present results of its performance in comparisons of retrievals between co-located Brewer and Dobson ozone profiles measured at Arosa station in Switzerland.

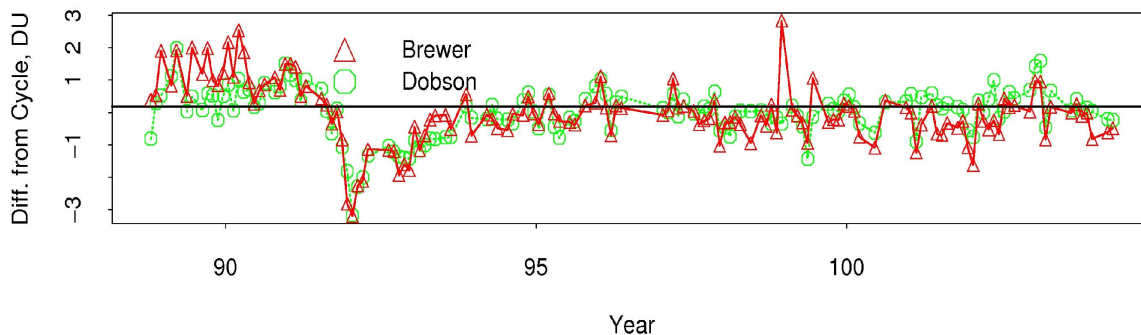


Figure 1. Time series of the ozone at 40 km retrieved from co-incident Dobson and Brewer data at Arosa station. Nearly the same inter-annual ozone variability is observed by the two systems in both the lower and upper atmosphere.

Ozone Profiles Measured at South Pole Station During the 2005 Ozone Hole

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Vertical profiles of ozone and temperature have been measured for 20 consecutive years at Amundsen Scott South Pole Station using balloon-borne electrochemical concentration cell (ECC) ozonesondes. The measurements have made an important contribution to understanding and monitoring the yearly development of the springtime ozone hole over Antarctica. Balloon flights are done each week during the entire year, with 2 to 3 per week flown during the ozone hole period in September and October. The severity of ozone depletion depends on active chlorine concentrations in the stratosphere, wintertime stratospheric temperatures, and the stability of the polar vortex. Each year, in early September, ozone declines rapidly in the peak region of the ozone layer from 12-24 km. Comparing to the 20 year record, the 2005 springtime Antarctic ozone hole was the 10th lowest in minimum total column ozone, dropping to 110 Dobson Units (DU) on September 28, 2005. This represents a 59% loss compared to the August 7th pre-ozone hole value of 266 DU. The main similarity of the 2005 measurements to other severe ozone hole years was that the 14-21 kilometer layer once again showed nearly complete ozone destruction.

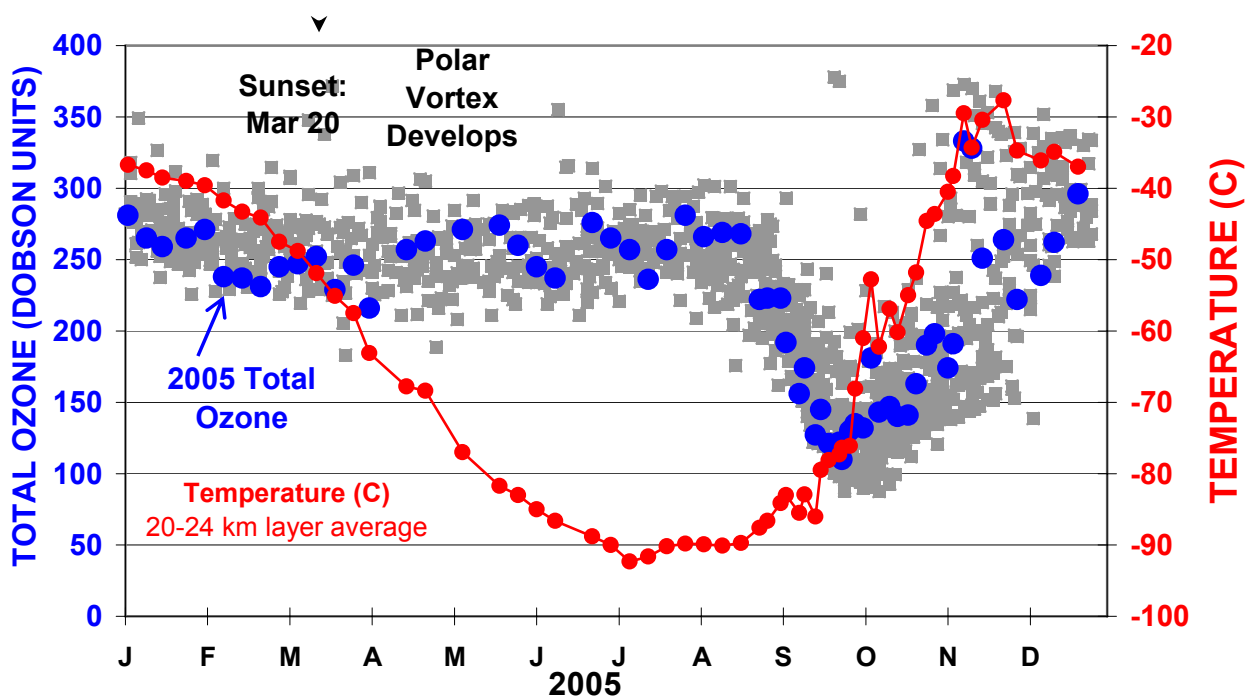


Figure 1. Summary of 2005 ozonesonde total column ozone measurements and stratospheric temperatures measured in 2005. Gray blocks show the 1986-2004 total column ozone observations.

Comparison of Total Column Ozone Retrievals from a UV Spectroradiometer with those from a Dobson Spectrophotometer at Two Locations

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The Earth Systems Research Laboratory's Global Monitoring Division operates UV Spectrophotometers at Mauna Loa, Hawaii (MLO; 19.533°N, 155.578°W, 3.4 km), and Boulder, Colorado (BDR 39.99°N, 105.261°W, 1.62 km). The MLO UV spectroradiometer (UV3) installed in July of 1995 is operated as part of the Network for the Detection of Stratospheric Change (NDSC). To provide an additional site for these studies a UV spectroradiometer (UV5) was installed at BDR in June 1998. Both of these sites also have long term records of total column ozone measurements from Dobson Ozone Spectrophotometers made under all-sky conditions. The Dobson ozone values were used as the reference in an examination of the UV retrieved ozone data set. Each of these locations also makes high quality Aerosol Optical Depth (AOD) measurements that were used to determine the periods when comparable observations were made during clear sky conditions. Using ozone values derived from the UV data during a two year period (January 2004 till December 2005) shows that for clear sky conditions and Solar Zenith Angles less than 65 degrees, the retrieved ozone values from the UV spectroradiometer lie within the uncertainty (~2%) of the retrieved Dobson ozone values. The accuracy of the UV retrieved ozone values decreases with corresponding increases in the AOD during non-clear sky conditions.



Figure 1. UV5 UV Spectroradiometer built by NIWA, Lauder, New Zealand and operated in Boulder.

Introduction to the NOAA/EPA Brewer Spectrophotometer UV Monitoring Network

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The Surface Radiation Research Branch of NOAA's Global Monitoring Division and EPA's Office of Air Quality, Planning and Standards (OAQPS) are establishing a monitoring network for solar spectral UV irradiance using Brewer spectrophotometers. The network will consist of six sites located within the continental United States. The six sites are Ft. Peck, MT, Table Mtn, Boulder, CO, the University of Colorado's MARS lab at Niwot Ridge, CO, the University of Houston, Houston, TX, the Bondville Environmental and Atmospheric Research Site, Bondville, IL and the North Carolina State University's agriculture field site at Raleigh, NC. The sites were chosen with specific research goals in mind and represent a mixture of clean, mildly polluted and heavily polluted areas. Each monitoring location will be equipped with a Brewer Mark IV spectrophotometer in addition to ancillary instrumentation currently operating there. Three of the six sites are collocated with existing NOAA's Surface Radiation Budget (Surfrad) sites. A few of the research goals of the collaborative effort are to determine how tropospheric pollution (ozone and fine particles) affect surface UV levels, what effects clouds and other meteorological conditions have on surface UV levels, how are surface UV levels affected by stratospheric ozone concentrations and how do the surface UV levels compare to satellite measurements.

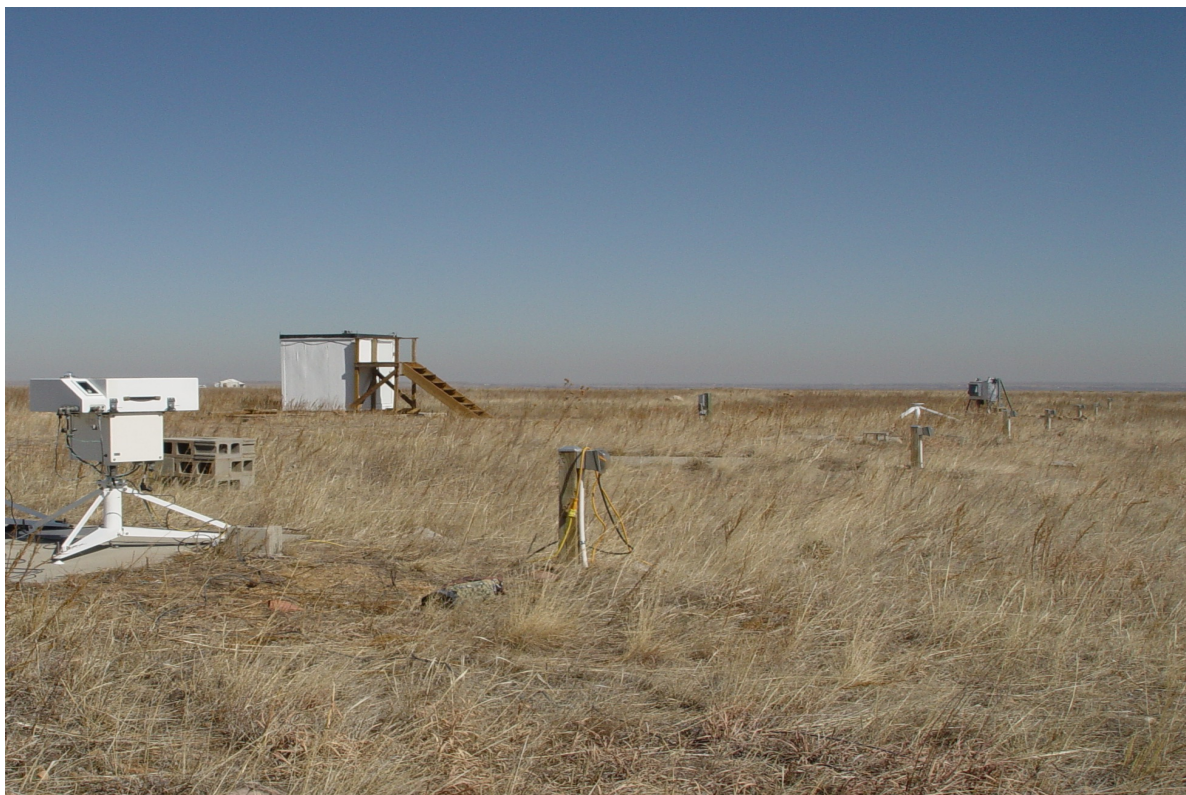


Figure 1. Brewer Spectrophotometer 93-101 operating at the Table Mountain Test Facility, Boulder, Colorado. The Brewer is collocated with the USDA's reference UV spectroradiometer and the State University of New York's UV-rotating shadowband spectroradiometer.

Autonomous Instrumentation for CO₂ Measurements on Remote Coastal Towers

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The North American Carbon Plan (NACP) specifies several priorities including: 1) monitoring atmospheric CO₂ and other trace gases crossing the land/coastal boundary and 2) understanding energetic coastal processes that influence atmospheric carbon dioxide in the marine atmospheric boundary layer. In Figure 1 we show preliminary data from a prototype tower-based ocean and atmospheric CO₂ observing system located 3 miles off the coast of Martha's Vineyard, Massachusetts on Martha's Vineyard Coastal Observatory (MVCO). In the future, this ocean tower system will not only measure atmospheric CO₂ traceable to WMO primary standards, but also will directly measure air-sea fluxes of CO₂ using high flow eddy covariance techniques. To perform these tasks the system was designed and constructed to meet the following criteria: 1) low power consumption (60 W); 2) high accuracy (0.1 ppm); 3) thermal stability ($dT/dt < 0.1$ C/hr); 4) ability to maintain the water vapor concentration difference between sample and standards to levels that are undetectable to CO₂ measurements (<180 ppm water vapor) and 5) ability to operate remotely for long periods (> 6 months).

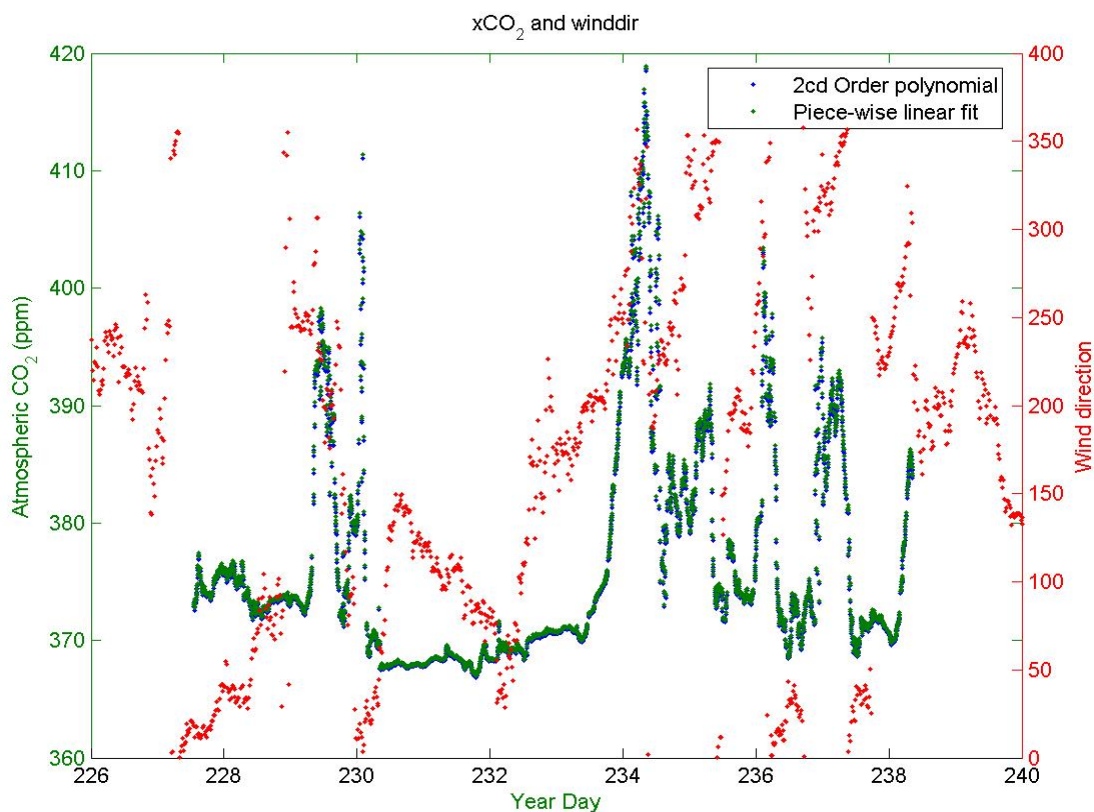


Figure 1. Seventeen day segment of data collected between October 7 and 24, 2005 indicate a strong correlation between wind direction and atmospheric CO₂ concentration. While southeasterly breezes bring in low and steady concentrations of CO₂ from offshore, point sources from land to the west bring in extremely high and variable concentrations of CO₂ indicating air masses traveling more than 100 km are not well mixed.

Ecosystem CO₂ Exchange and Anthropogenic CO₂ from American Samoa 1976-2005

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A study of the diurnal CO₂ exchange and photosynthesis of the Samoa tropical forest was published in 1990 using data from a three day period when the observatory was continuously downwind of eastern Tutuila Island (Ryan, *Global Biogeochemical Cycles*, V4, No.1, p69-84). This analysis is now extended to the entire 29 year SMO record. The data are divided into sectors based on wind direction: Anu'u Island (165° to 179°), local Tutuila (186° to 236°), and distant Tutuila (237° to 270°). Respiration and photosynthesis cause a diurnal change in atmospheric CO₂ from all three sectors. Samoa was hit by hurricanes in 1990, 1991, and 2004, perturbing the ecosystem CO₂ exchange for over a year afterwards. Excess CO₂ at night has increased significantly in all three sectors since the late 1990's some of which can be attributed to human activity. A 125 kw generator was installed on Anu'u Island in 1999, resulting in a 1 ppm increase above baseline at night from that sector. Since the mid-1990's, biomass burning has become widespread across Tutuila, which may be responsible for much of the 0.5 to 1 ppm increase in CO₂ coming from the Tutuila sectors since 2000.

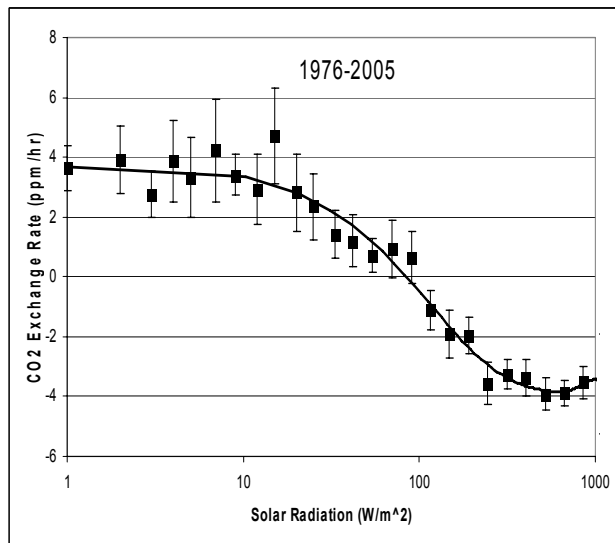


Figure 1. Photosynthesis curve averaged over the entire record. Ecosystem respiration balances photosynthesis at 90 W/m²

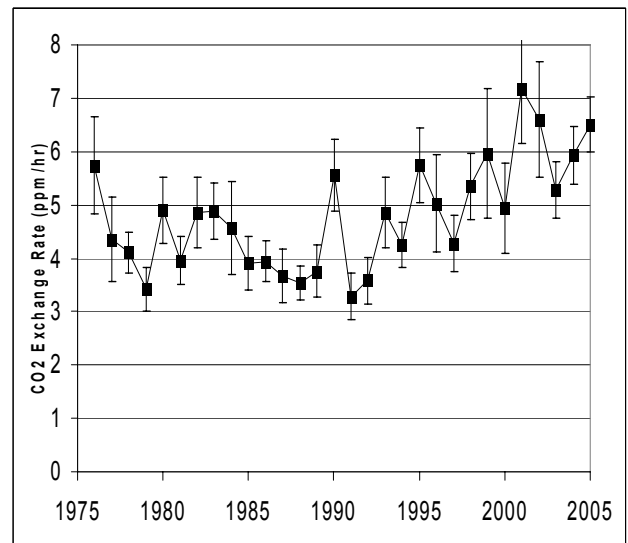


Figure 2. CO₂ exchange rate (baseline differenced CO₂ divided by residence time over land) in the local Tutuila Sector.

Moving Towards Improved Fossil Fuel Emission Inventories for the Carbon Cycle

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Monthly energy statistics for fossil fuel production and use have been compiled by the International Energy Agency since the early 1970s on a per country or region basis. Until recently however, national and global fossil fuel emissions inventories were built on an annual basis only. Blasing *et al.* [2005] have derived a 21 year-long time-series of monthly USA CO₂ emissions based on the US DOE/Energy Information Administration energy statistics reports. They showed that the national emissions due to natural gas have a pronounced annual cycle, emissions due to coal exhibit a double peak (one in summer and one in winter) and emissions related to liquid fuels have no significant seasonality. To study the carbon cycle at finer temporal and spatial scales, one needs to take into account the fossil fuel emissions variability on hourly, to seasonal, to inter-annual time scales. We are developing a 1x1 degree map of the USA CO₂ fossil fuel emissions with varying time resolution: hourly to monthly. For this we rely on the EPA CEMS data for power plants emissions and on EPA/MOBILE 6 and DOE/EIA for other sources such as transportation, residential and industrial use of fossil fuels. We will first investigate the impact of the derived time-varying emissions on the simulated CO₂ distribution and then perform high resolution inverse modeling studies with the improved fossil fuel emissions.

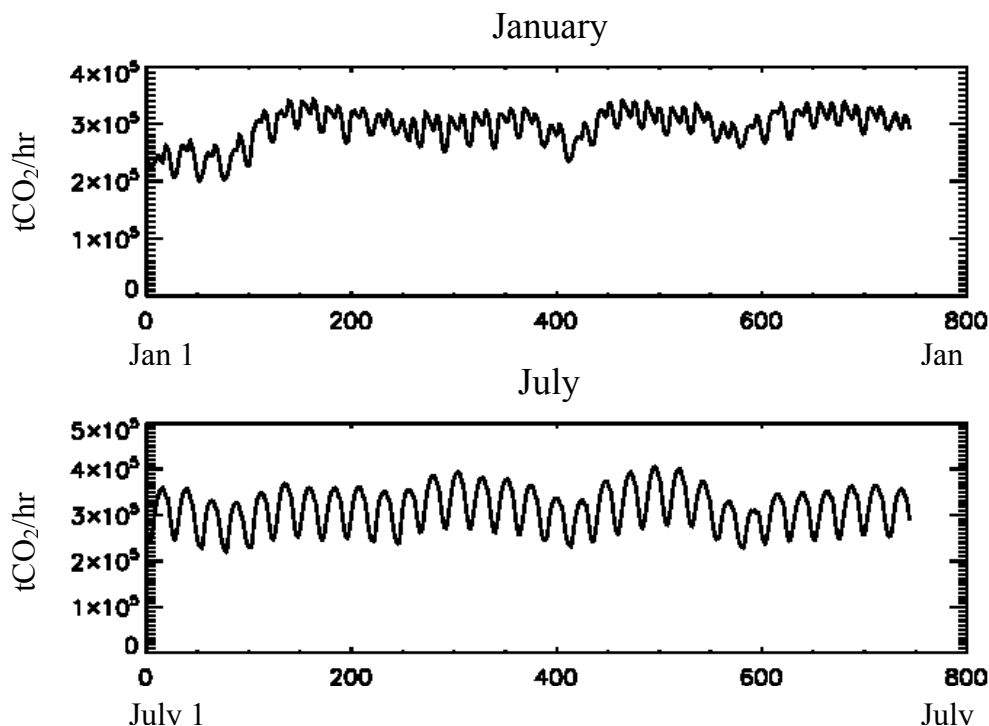


Figure 1. Hourly EPA/CEMS CO₂ emissions (tCO₂/hr) for January 2004 (top) and July 2004 (bottom) used to drive the fossil fuel emissions 1x1 degree map model.

The Evolution of the GMD Carbon Cycle Greenhouse Gases Cooperative Global Aircraft Sampling Network

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The GMD Carbon Cycle Greenhouse Gases Cooperative Global Aircraft Sampling Network has undergone numerous transformations since its inception in the 1960s. What was initially a land-based air sampling network (the GMD Cooperative Global Air Sampling Network) has evolved into a network comprised of land-based air sampling, tall tower data collection, and the use of programmable flask packages (PFPs) in the Aircraft Sampling Network.

The intent of this poster is to provide background information of the evolution of the GMD Carbon Cycle Greenhouse Gases Cooperative Global Aircraft Sampling Network extending from the inception of the program to the present (1960s to 2006). Although improvements to this network were not confined to the PFPs, e.g., improvements in sample analysis and reference tank calibrations, for the purpose of this poster the focus will be on how various upgrades to the program were made in the pursuit of more precise measurements. Included are comparisons of flask types, aircraft, softwares (Hyperterminal, Operations Manager, and LabVIEW), and aircraft sites. In addition, opportunities to expand the network to other platforms will be explored. Finally, we will present graphic data to illustrate the growth of the network.

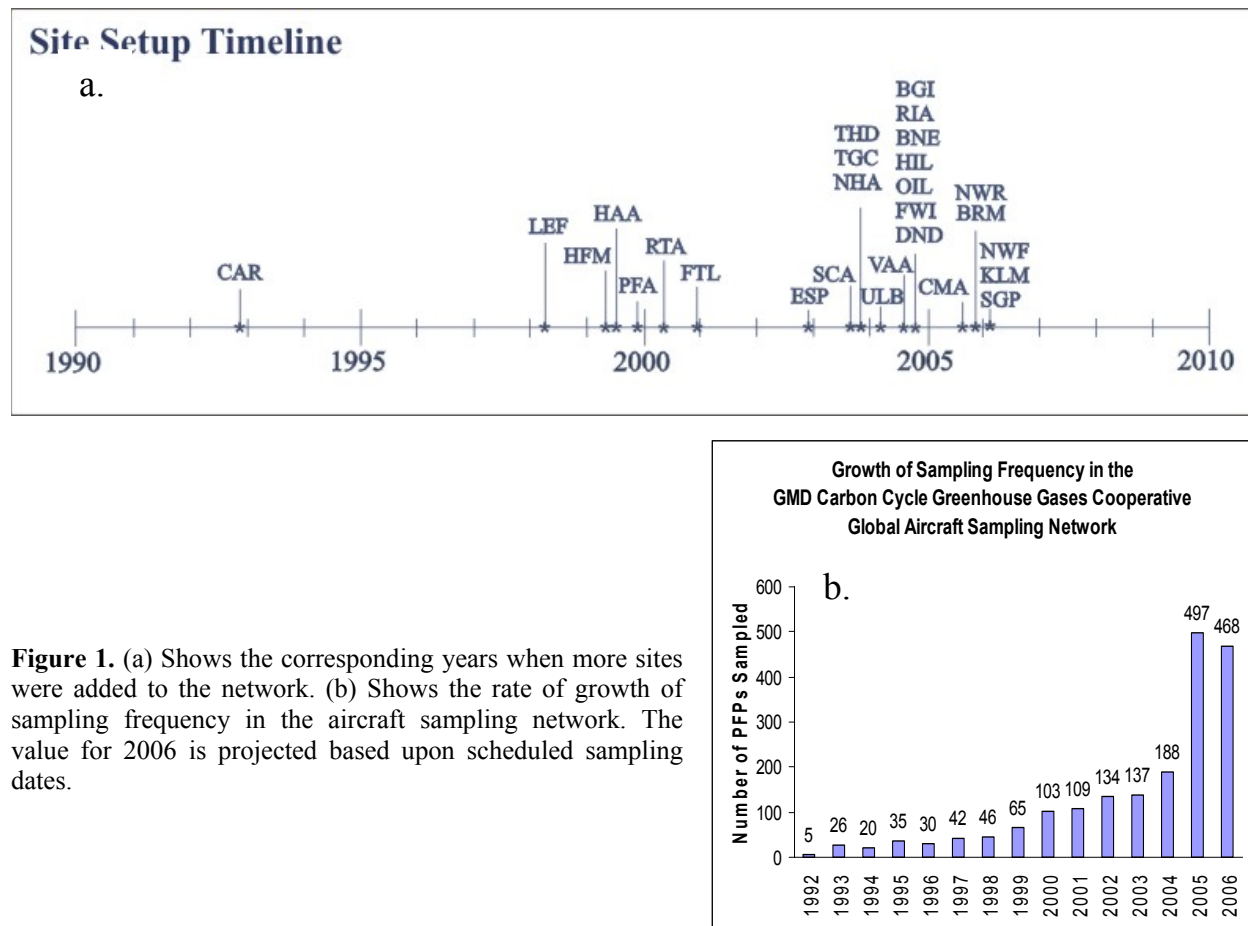


Figure 1. (a) Shows the corresponding years when more sites were added to the network. (b) Shows the rate of growth of sampling frequency in the aircraft sampling network. The value for 2006 is projected based upon scheduled sampling dates.

Northern Hemisphere Trends in Carbon Monoxide: Effects of Anthropogenic Emissions and Biomass Burning

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The magnitude and direction of long-term changes of carbon monoxide (CO) in the NH are still debated; although it is most likely that there have been extended periods of increase and decrease, overlaid with much shorter lived changes. The most compelling evidence for a long-term trend results from a comparison of column measurements above the Swiss Alps in the early 1950s and in the mid-1980s. These suggested an linearized increase of $\sim 1\%$ CO yr⁻¹ (1). Measurements above Europe and Russia show increasing abundances in the 1970s and 1980s, after which CO decreased through the mid-1990s (2).

CO has been measured in air samples collected by the Cooperative Air Sampling Network since 1988. The results provide a spatial and temporal picture of CO in the marine boundary layer. Figure 1 shows trends determined for the high and low Northern Hemisphere (HNN, 30°-90°N; LNH, 0°-30°N) and the global mean. The primary sources of NH CO are fossil fuel combustion (FF, 30%), CH₄ oxidation (25%) and biomass burning (BB, 25-35%); its major sink is OH (90%) (3). NH FF emissions of CO have decreased by $\sim 1.6\%$ yr⁻¹ through the 1990s (4). Extreme periods of biomass burning occurred in 1998 and 2002-2003, increasing emissions 50-75% above average (5).

In this paper we examine how changes in FF and BB emissions have impacted CO. The effects of wildfires in 1994, 1998, and 2002-03 are clearly evident in the zonal time series. The background decrease in CO (that calculated without effects of the 1998/2003 fires) is consistent with decreased FF emissions. Rates of decrease in the high latitudes are greatest in winter when the signature of anthropogenic emissions from the extra-tropics is maintained. Year to year variability in CO emissions from BB is large, and extremes in seasonal burning can dramatically enhance zonal CO for a year or more.

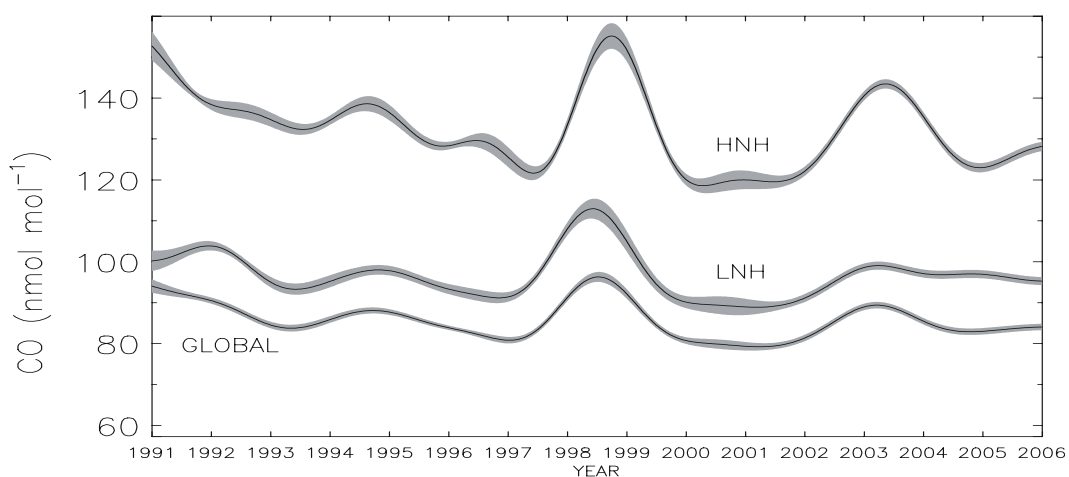


Figure 1. Zonal time series for the HNN, LNH and global mean. The HNN is derived from 12 sites, the LNH from 11, and smoothed in time and space as described in (5a). The thick black lines represent the trend plus 1σ .

References. (1) Zander et al., JGR, 94, 1989; (2) Mahieu et al., J. Atmos. Chem., 28, 1997; Yurganov et al., Rec. Devel. Geophys.2002. (3) Logan et al, JGR, 86, 1981; pers. comm., 1995; (4) EDGAR 32FT2000; (5) A. Novelli et al., JGR, 108, 2003, B. Kasischke et al, 19, GBC, 2005

A New Instrument for Tall Tower Continuous Measurements of CO and CO₂

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To better understand land based sources and sinks of carbon, NOAA's Global Monitoring Division (GMD) is expanding the tall tower network to from three sites to twelve as part of the North American Carbon Program (NACP). For this expansion a well-designed instrument is the key to maintaining uninterrupted high accuracy measurements of CO (<10 ppb) and CO₂ (<0.1 ppm) mixing ratios from 3 tower levels at each tower site with a minimum of maintenance. A new instrument occupying one instrument rack was developed to meet these goals (Figure 1). Important features of the new instrument include a data logger control system, a two-stage drying system, modular components for easy replacement and repair, and temperature and pressure controlled CO and CO₂ infrared analyzers. The system is built from commercially available off the shelf parts. The analyzers are the Licor LI7000 for CO₂ and the Thermo Electron 48C for CO. Temperature control of the analyzers and the drying system produces stable measurements eliminating the need for complex algorithms to remove temperature and pressure fluctuations in the sample and calibration data. Preliminary results from measurements in the laboratory and at Kohler Mesa field station in Boulder, Colorado show a target accuracy (measured – assigned) of 0.01ppm ± 0.024 ppm for CO₂.



Figure 1: Four new tall towers measurement systems constructed at ESRL/GMD.

A Web-based Application to Manage Carbon Cycle Network Operations

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The GMD Carbon Cycle program has expanded considerably in the past few years. Since 2004, the surface network has added 4 fixed sites and 3 ocean crossings. The aircraft network has doubled in size with the addition of 12 sampling locations in North America. In 2005, more than 16,000 discrete samples were collected and analyzed for CO₂, CH₄, CO, H₂, N₂O, SF₆, and the stable isotopes of CO₂ and CH₄. Approximately 2500 aircraft samples were also analyzed for an additional 28 compounds by the GMD HATS group. VOCs were also measured by INSTAAR, University of Colorado (CU) in nearly 1300 surface samples.

Operating a discrete measurement program that includes 62 surface sites, 26 aircraft sites, 5000 network flasks, 100 surface samplers, and 150 aircraft samplers is increasingly difficult. Logistics are further complicated as the number of laboratories measuring the air samples and the number of compounds measured increases. A high degree of organization and automation is essential to ensure that field sites have a steady supply of flasks and reliable equipment; and in Boulder, that samples are routed to the appropriate analytical systems and critical operational information is readily accessible to researchers.

To help manage the logistical and operational tasks of the carbon cycle observing network, we developed a web-based “Operations Manager”. From any location, GMD and CU researchers have web-based access to the carbon cycle measurement and meta database. We will demonstrate several key features with emphasis on tasks which are likely relevant to other measurement programs.

The screenshot shows a web browser window titled "NOAA CMDL CCGG - Flask Manager - Mozilla". The page header includes the NOAA logo, "Global Monitoring Division", "Carbon Cycle Greenhouse Gases", and "Operations Manager Flask". The main content area is titled "Event Description" and contains a table with columns "Available - 2", "Selected - 1", and "Notes".

Available - 2	Selected - 1	Notes
NWR 1059-99 NWR 1060-99	NWR 1059-99	** MEASUREMENT ** If 2 pair of flasks have the same sample date, one pair is analyzed using the default measurement path, the other pair is routed to MAGICC2 (CO ₂ only) and CO2C14. Stamp the MAGICC CO ₂ , CO2C14 sample sheets MAGICC2-CO ₂ and CO2C14. ** FLASK ** [1059-99] Mon Aug 1 09:20:23 2005: Please Pull for a 24Hr test. SS

Below the table is a form for entering sample collection details:

Date [09Feb2004] 13Mar2006
Time [0143] 1630 UTC
Method [D] N
Wind Speed [-99.9] 5.9 m/s
Wind Direction [999] 270 Degrees
Latitude [99 99S] 40 2N Degrees
Longitude [999 99W] 105 34W Degrees
Altitude [-99999] 3526 masl
Comment

Measurement Path:

- MAGICC
- co2c13
- ch4c13
- co2c14
-
-
-
-
-
-
-
-

Buttons: Accept, Discard, Clear, Recall, Defaults, Cancel

Figure 1. Entering sample collection details and the analysis path in Operations Manager.

Carbon Dioxide: Analysis of Variability

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Measurements of carbon dioxide both globally and locally are key to much of the work on climate change. The measurements show a near-monotonic increase over the last decades, but there are still important questions about what governs the interannual variability. Questions remain about the shape of the trend (linear, quadratic or exponential) and are important to be able to make projections of CO₂ levels into the future. Differences in the seasonal nature of trends that exist are not fully explained at the current time. A variety of efforts are underway to understand the existing variability. The analysis shows that the interannual variability is highest in the winter season and lowest in the summer. The trends are similarly dependent on season with the highest trends observed in the winter over the last decade.

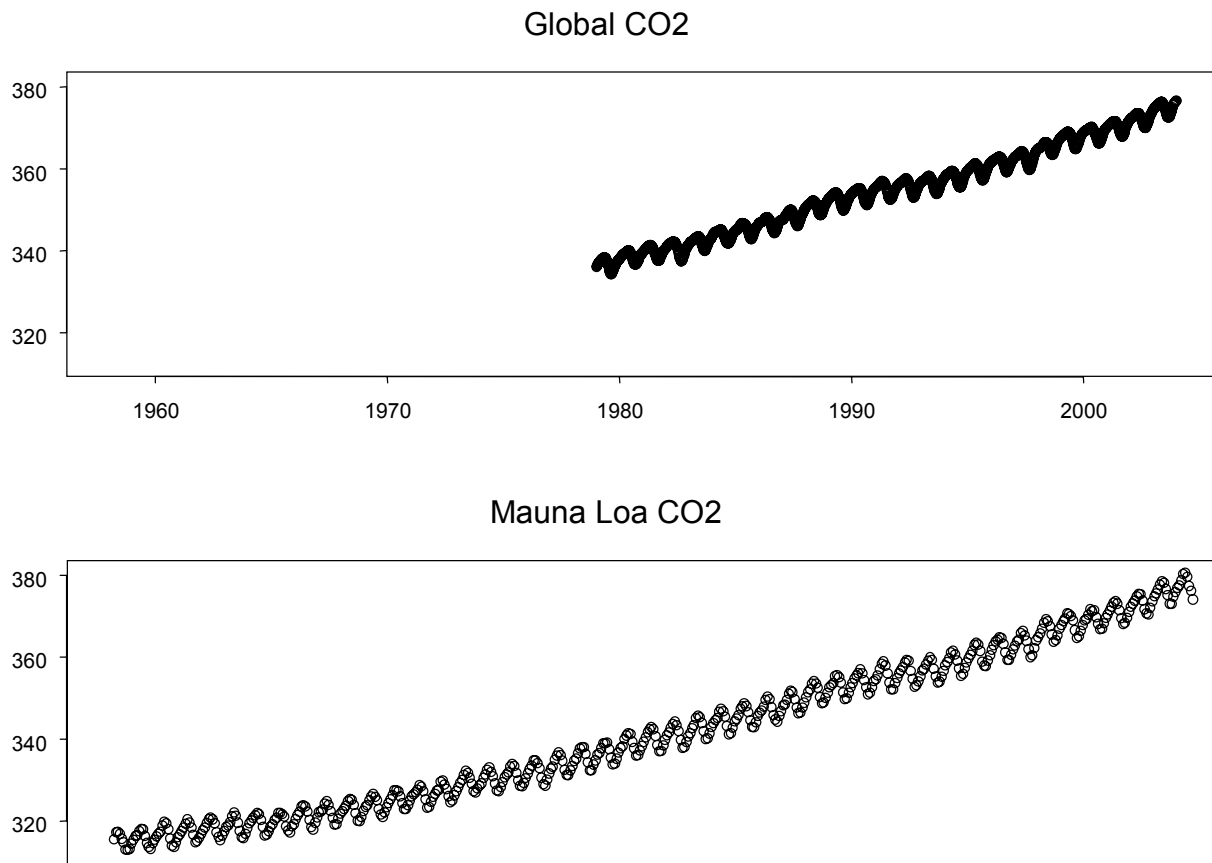


Figure 1. Global and Mauna Loa CO₂ records show clear increases over the recording period. However much of the interannual variability is unexplained. Closer examination of the data show that the trends have been somewhat uneven and that the interannual variability is seasonally dependent.

Recent Advances in the Preparation of Gravimetric Compressed Gas Standards

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The ability to maintain consistent, reproducible calibration scales is a critical component of any atmospheric measurement program. Most trace gases measured by the Global Monitoring Division of the NOAA Earth Systems Research Laboratory are referenced to compressed gas standards prepared by gravimetric methods. A number of calibration scales, each defined by a unique set of gravimetric standards, have been developed over the last couple of decades. New standards are prepared as older standards are depleted, or as better analytical techniques are developed.

In the last 18 months, new gravimetric standards related to six calibration scales were prepared. A new scale was developed for HFC-152a (CH_3CHF_2) and standards for CS_2 are under development. Existing scales for CFC-12 (CCl_2F_2), HCFC-22 (CHClF_2), N_2O , SF_6 , and halon-1211 were improved. The motivation to improve these scales was the fact that many of these scales were based on standards that were nearing the end of their useful lives. Furthermore, the acquisition of a new electronic balance, a new dilution manifold, and a developmental GC-MS offered improvements in quality control. Preliminary analysis suggests that these recent standards are much more consistent than their earlier counterparts. Calibration scales developed from these new standards will improve (a) the results of CFC-12 comparison experiments between NOAA and other laboratories, (b) our knowledge of linearity issues associated with halon-1211 measurements, (c) our ability to measure SF_6 , (d) our ability to maintain the WMO N_2O reference scale at a level near that requested by the N_2O measurement community, and (e) previously uncalibrated measurements of HFC-152a and CS_2 .

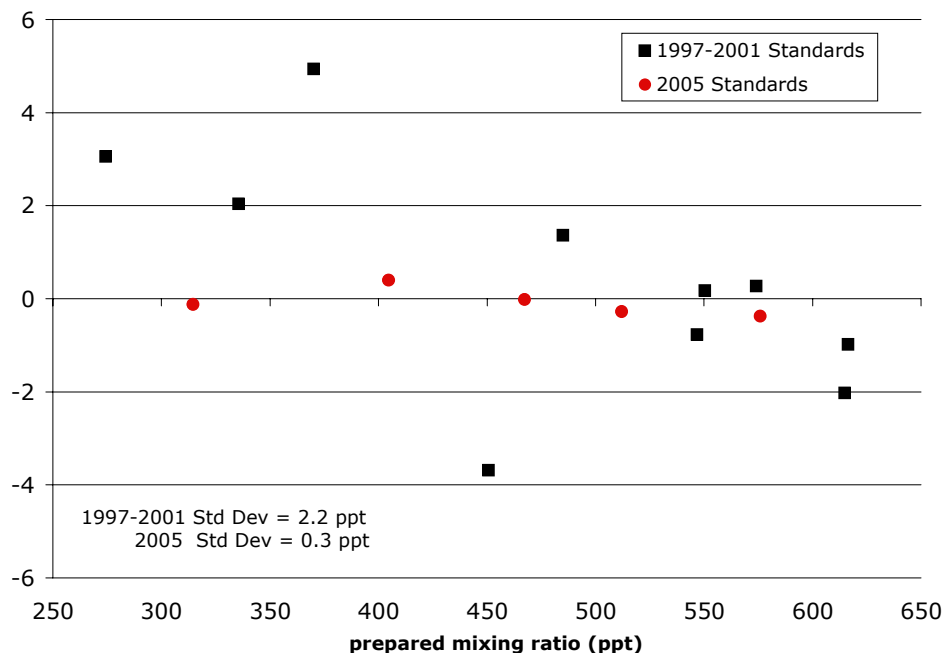


Figure 1. Comparison of residuals for recent (red symbols) and previous (black symbols) CFC-12 standards. Residuals are defined as the difference between assigned and prepared mixing ratios, where assignments were derived from a polynomial fit of response vs. prepared mixing ratio.

Two Decades of ESRL/GMD In Situ Trace Gas Measurements

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From 1986-87 the GMD Halocarbons and other Atmospheric Trace Species (HATS) group deployed a global in situ trace gas measurement program. Motivated by the signing of the Montreal Protocol in 1987, the HATS group focused on frequently measuring some of the regulated ozone depleting and greenhouse gases such as chlorofluorocarbons (CFC-11 and CFC-12), methyl chloroform (CH_3CCl_3), carbon tetrachloride (CCl_4) and nitrous oxide (N_2O). The original in situ program, the Radiatively Important Trace Species (RITS) program, focused on these five gases. The RITS gas chromatographs (GCs) were deployed to the NOAA baseline observatories and the University of Colorado station at Niwot Ridge, Colorado and remained in operation for the next 13 years.

Throughout the 1990s, the HATS flask and RITS programs documented the steady decline in global growth rates of the major chlorinated solvents and chlorofluorocarbons as a result of the Montreal Protocol. Widespread use of the replacement compounds to the now banned CFCs prompted improvements to the HATS in situ program. The RITS instruments were replaced from 1998-2000 by the four-channel Chromatograph for Atmospheric Trace Species (CATS) GCs. In addition to the gases measured by RITS, the CATS GCs added nine compounds including CFC alternatives such as HFC-142b and HCFC-22.

Since the RITS instruments have been taken offline, efforts have been focused on finalizing this important data set. A number of calibration scale changes and improvements with the data reduction algorithms have facilitated comparing and combining the RITS and CATS data sets.

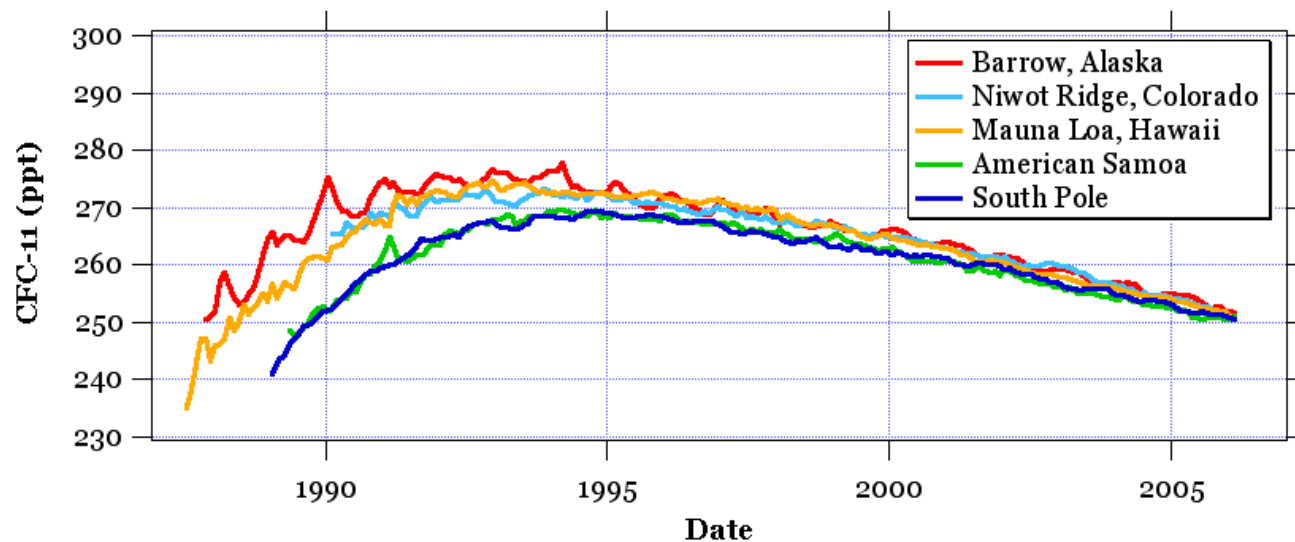


Figure 1. Combined RITS and CATS CFC-11 monthly means calculated from hourly measurements at five stations spanning the globe. The turn around in CFC-11 concentration in the early 1990s is attributed to reductions in production and use by developed countries as agreed upon by the Montreal Protocol.

A New Polar Nephelometer Design for Measurements of the Angular Distribution of Light Scattered by Atmospheric Aerosols

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A polar nephelometer is under development for measurements of the angular distribution of light scattered by ambient populations of atmospheric aerosols. This is a new design that employs commercially available optical components and has few moving parts, offering the potential for a reliable, low-cost field instrument. Conventional integrating nephelometers measure total light scattering and the ratio of backscatter to total scatter. Polar nephelometers measure the entire angular scattering function, which can then be used to calculate other integral properties, such as the asymmetry parameter. The purpose of the project is to use the polar nephelometer in a network of global monitoring stations to provide radiative transfer models with additional aerosol scattering information, in the form of continuous measurements of the aerosol scattering distribution and asymmetry parameter, to improve aerosol radiative forcing estimates.

A photo of the instrument is shown below. The light source is a Nd:Yag laser at a wavelength of 532 nm. The laser beam traverses the perimeter of an air filled sample chamber. Molecules and airborne particles in the path of the beam scatter light in all directions, and a panoramic mirror positioned near the laser reflects the light to a CCD camera looking down on the mirror. The distribution of scattered light in the sample chamber is recorded as a CCD image. The instrument is approaching the end of the first year of development. The poster will discuss the current state of the project and present some preliminary data.

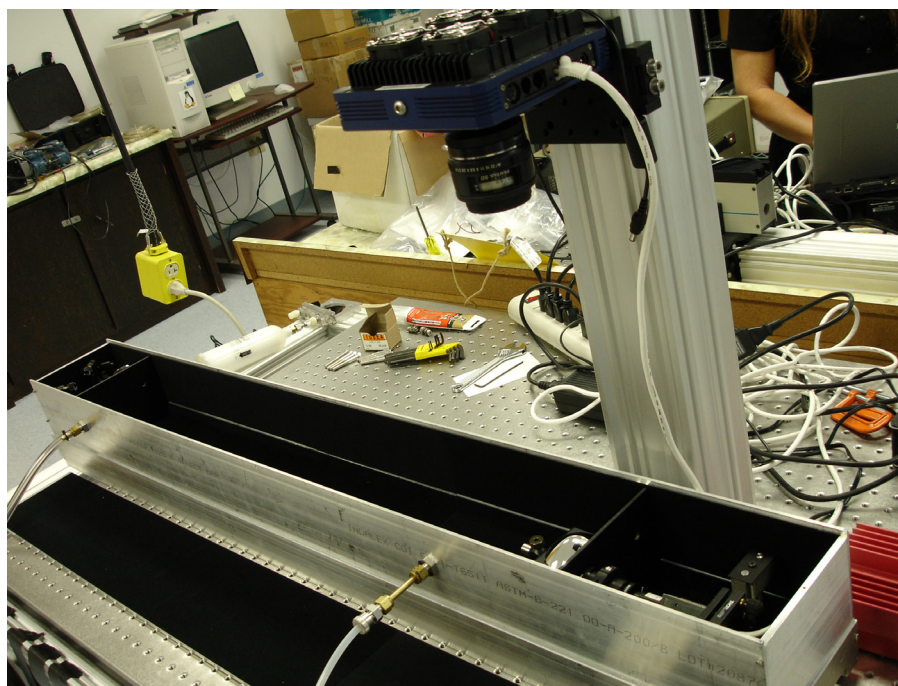


Figure 1. The photo above shows the polar nephelometer under construction. The Nd:Yag laser and beam stop can be seen in the foreground, partitioned from the panoramic mirror and sample chamber. The CCD camera is positioned above the panoramic mirror.

Improvements and Expanded Capabilities in GMD Aircraft-Based Aerosol Measurements

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It is well known that unlike the major long-lived gases, aerosols are not distributed uniformly in the troposphere. In order to estimate global aerosol radiative forcing and the effects of aerosols on the global climate, measurements of the aerosols are being made by GMD at many surface locations. Very few long term measurement efforts, however, have been made at altitude. Over the past year, GMD conducted a major upgrade to an ongoing light aircraft sampling program sponsored by the US Department of Energy (DOE). The current light aircraft sampling program, conducting regular vertical aerosol profiles over the DOE Cloud and Radiation Testbed (CART) site in Oklahoma since early 2000, was expanded to include several new measurements, including trace gases and an improved measurement of aerosol hygroscopic growth. The aircraft platform was changed from a Cessna 172 to a larger TU206F model to accommodate the increased payload and desire to sample higher altitudes. A new inlet system permits the efficient sampling of significantly larger particles than the previous system, which should permit better comparisons with surface- and satellite-based column measurements.

In a second aircraft measurement program, the NOAA Office of Global Programs funded GMD scientists to develop a similar platform to conduct regular vertical profiles of aerosol properties over a site in the central US. The same inlet, rack, and power systems, along with a very similar Cessna T206H aircraft, were acquired and developed for this platform. The payload for the NOAA aircraft is slightly different than for the DOE Cessna. Aerosol optical, microphysical, and chemical properties will be measured continuously on the NOAA aircraft, as well as trace gases; Figure 1 shows the current design. Both of these aircraft measurement programs will use standard GMD sampling protocols and the normal suite of instruments, making measurements from both platforms directly comparable with each other and with the GMD surface stations.

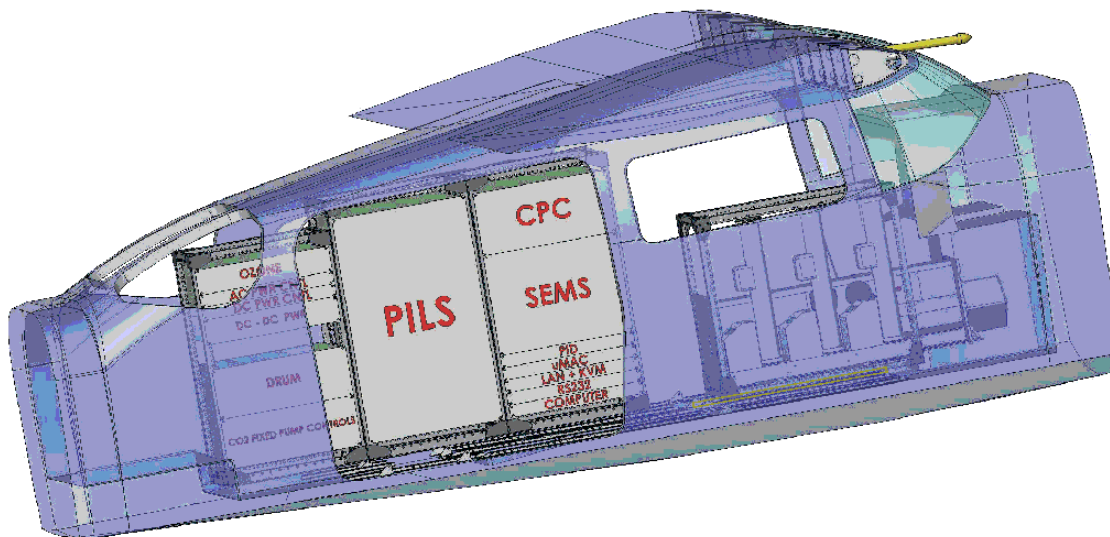


Figure 1. Three-dimensional schematic of the new NOAA Airborne Aerosol Observatory, showing orientation of inlet and major measurement systems.

Effect of Humidity on Filter-Based Measurements of Aerosol Light Absorption

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The absorption coefficient σ_{ap} is an important parameter characterizing the optical properties of aerosol particles. Together with the scattering coefficient σ_{as} it determines the single scattering albedo, which is a key parameter governing aerosol radiative forcing. Very often σ_{ap} is measured by a filter-based method, where absorption is derived from the change in light attenuation (ATN) through a filter on which the particles have been collected. For the two most common commercially available instruments of this type, the Particle Soot Absorption Photometer (PSAP) and the Aethalometer, empirical correction schemes were developed to provide a calibration of the measurement and to reduce artifacts present in any filter-based absorption measurement. However, none of these corrections takes into account artifacts related to enhanced or changing relative humidity (RH). Such artifacts have been reported, but have not been thoroughly studied so far. We present the first results of our respective investigations.

Panel (a) of Figure 1 shows the effect of sudden RH changes on σ_{ap} as measured with an Aethalometer. It can be seen that rapid RH increases cause large positive σ_{ap} spikes, whereas rapid RH decreases lead to large negative σ_{ap} spikes. The larger the RH step, the larger the σ_{ap} spike. The reason for these spikes is the increase of the ATN with increasing RH, cf. panel (b). We believe that it is due to water entering the filter which may cause the filter fibers to swell and/or increase light scattering. The RH effect on the ATN shows almost no wavelength dependence. It is reversible and repeatable. Furthermore, the effect does not depend on the amount of soot loaded on the filter, indicating that it is a pure filter artifact. The situation is similar for the PSAP. RH jumps lead to spikes in the σ_{ap} data due to changes in the ATN. Up to RH \approx 60 the effect is less pronounced than for the Aethalometer, cf. panel (b). However, for higher RH there is no clear relationship between RH and ATN. This distinct different behavior is attributed to the different filter materials used in the two instruments. For unloaded filters and filters containing only soot, enhanced but constant RH slightly increases the noise levels but does not affect the performance of the two instruments otherwise. This may not be true if a lot of hygroscopic material is present in the filters.

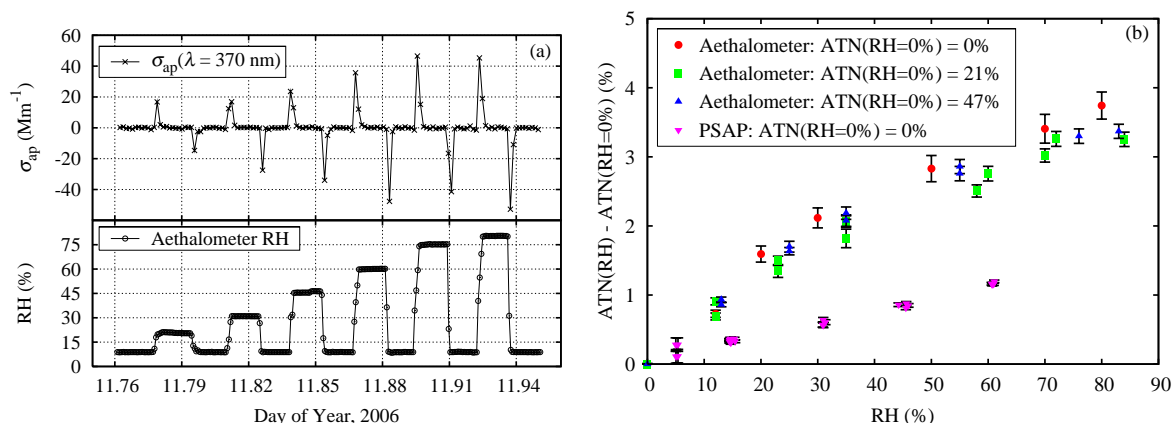


Figure 1. Effect of humidity on Aethalometer and PSAP measurements. (a) Aethalometer aerosol light absorption coefficient of filtered (i.e., particle-free) air and RH in the instrument as a function of time. Measurements were made with an unloaded filter. (b) $ATN(RH) - ATN(RH=0\%)$ as a function of RH for sampling particle-free air with an Aethalometer on filters previously loaded with different amounts of Palas soot and for sampling particle-free air with a PSAP on an unloaded filter. In case of the Aethalometer the data represent averages over all wavelengths.

Preliminary Results of in-situ Measurements of Aerosol Optical and Water Uptake Properties from the ARM Mobile Facility in Niger

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The second deployment of the ARM Mobile Facility was in November of 2005 to Niamey, Niger. The year-long deployment is part of the AMF Radiative Divergence using AMF, GERB and AMMA Stations (RADAGAST) field campaign. The goal of this campaign is to provide direct estimates of the divergence of solar and thermal radiation across the atmosphere as well as study the role of clouds, aerosol and water on surface solar radiation. The site in Niger is located in the Sahel at the southwestern edge of the Sahara Desert. The aerosol of this region is a mix of desert dust and smoke from biofuel burning. Changes in the air mass between the wet and dry seasons will allow us to look at the influence of the aerosol on direct, clear-sky, radiative forcing as well as how cloud processing and wet deposition influence aerosol properties.

We show preliminary results from the first three months of in-situ aerosol measurements of aerosol light scattering and absorption, water uptake properties of the particles and their ability to act as cloud condensation nuclei. The winter months are during the dry season. Aerosol loading is relatively high with average scattering coefficients for the sub 10 μm size aerosol at 550 nm near 100 Mm^{-1} . Most of the aerosol scattering resides in the super micron size mode. The Ångstrom exponent for the 550/700 nm pair for sub10 μm size aerosol is between -0.5 and 0.5, indicating a large particle size. The aerosol single scattering albedo at 550 nm indicates a relatively dark aerosol with values ranging from 0.55-0.8 for subum size aerosol and 0.7 to 0.95 for sub 10 μm size aerosol.

The water uptake properties of the particles are important in determining both direct and indirect aerosol radiative forcing. The hygroscopic growth factor, which is a measure of the increase in the aerosol scattering coefficient for a relative humidity increase from 40 to 85%, is remarkably low for both sub10 μm and submicron size particles, averaging about 1.0 and 1.2, respectively. Cloud condensation nuclei (CCN) are measured at five supersaturations. We observe a distinct diurnal variation in the CCN number concentration that coincides with observer observations of nighttime biofuel burning.

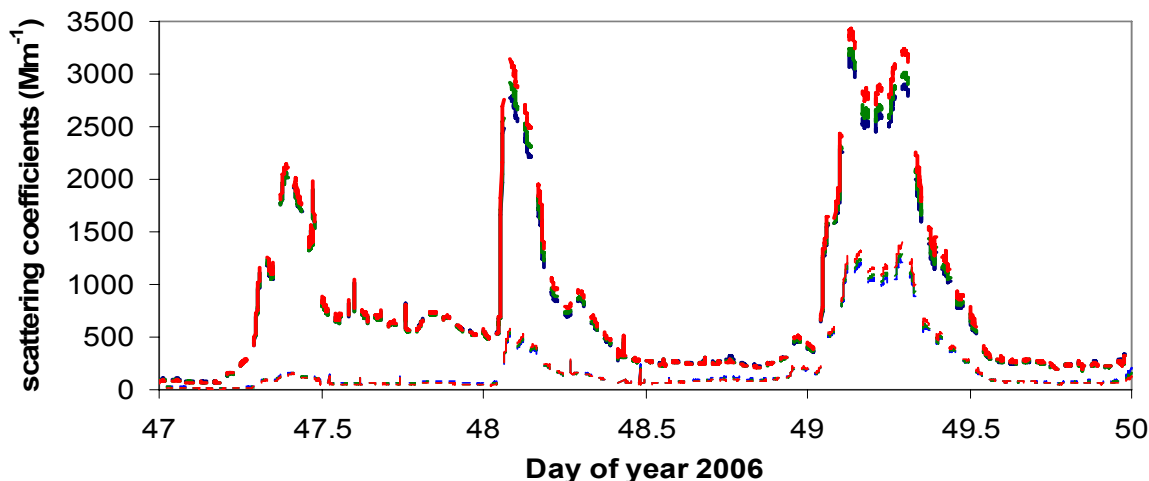


Figure 1. Aerosol sub μm (lower traces) and sub 10 μm (upper traces) scattering coefficients at 450 (blue), 550 (green) and 700 (red) nm from Feb. 16-18 of 2006 depicting three large dust events.

Expansion of Facilities on the North Slope of Alaska in Time for the International Polar Year

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The International Polar Year (IPY; 2007-2008) will stimulate research in both polar regions, primarily focusing on the rapid climate-related changes occurring at high latitudes. In part in preparation for the IPY, facilities at the NSA ACRF (North Slope of Alaska- ARM Climate Research Facility) are undergoing expansion. In addition, with funding through NOAA, Phase 1 of the planned \$60M Barrow Global Climate Change Research Facility at the former Naval Arctic Research Laboratory is presently under construction. Dedication is scheduled for spring, 2007. The new facility is expected to bring many more potential ACRF users to the North Slope of Alaska.



Figure 1. Additions to an existing deck near the main ARM Barrow instrument shelter, 9/05. Side by side shelters with deck above for upward-looking instrumentation. Addition doubles shelter space for instrumentation at the ARM Climate Research Facility, Barrow, which is adjacent to the NOAA GMD Barrow Station.