2008 NOAA ESRL GLOBAL MONITORING ANNUAL CONFERENCE

David Skaggs Research Center, Room GC-402
325 Broadway, Boulder, Colorado 80305
May 14 and May 15, 2008

POSTER SESSION AGENDA
Room GC-402

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

Thursday, May 15th: 1615-1845

- ***Carbon Dioxide and Methane***

P-1 CO_2 Source/Sink Information from OCO Column CO_2 Data – *D.F. Baker (Woods Hole Oceanographic Institution)*
P-2 Temporal and Spatial Patterns in Regional and Continental-Scale CO_2 Mixing Ratio Measurements – *N.L. Miles (Pennsylvania State University)*
P-3 Decreasing Anthropogenic Methane Emissions in Europe and Siberia Inferred from Continuous Carbon Dioxide and Methane Observations at Alert, Canada and Barrow, USA – *D. Worthy (Environment Canada)*
P-4 Progress on Recent Carbon Cycle Studies in Oklahoma and California – *M.L. Fischer (Lawrence Berkeley National Laboratory)*
P-5 CO_2 and CH_4 Measurements from the CARIBIC Aircraft Observatory – *T.J. Schuck (Max Planck Institute for Chemistry)*
P-6 How Well Can We Measure Baseline CO_2 at Cape Kamukahi? – *S.C. Ryan (ESRL)*
P-7 Where do Those Numbers Come from, Again? Fossil-Carbon Emissions Estimates on Various Space and Time Scales – *T.J. Blasing (Oak Ridge National Laboratory)*
P-8 The Orbiting Carbon Observatory Development Status – *D. Crisp (JPL/Caltech)*
P-9 Beyond Kyoto: Why Climate Policy Needs to Adopt the 20-Year Impact of Methane – *E. Lombardi (Eco-Cycle)*
P-10 Estimating Measurement Uncertainties for Programmable Flask Package (PFP) Air Samples: A Mountaintop Intercomparison with the Cooperative Global Network Manual Sampler – *D. Neff (University of Colorado/CIRES)*
P-11 Results of Carbon Dioxide Measurements in the Atmospheric Boundary Layer in Obninsk, Russia – *T.J. Conway (ESRL)*
P-12 Introduction to Trace Gases Measurement in Mongolia – *O. Dugerjav (Institute of Meteorology and Hydrology)*
P-13 Increase in the Global Burden of CH_4 During 2007 – *E.J. Dlugokencky (ESRL)*
P-14 Applications of Lagrangian Particle Transport Modeling in the Top-Down Regional CO_2 Studies – *M. Uliasz (Colorado State University)*
P-15 Regional-Scale Carbon Dioxide Fluxes During the 2007 Growing Season Derived from Simultaneous Radon-222 and Carbon Dioxide Measurements in Oklahoma – *A.I. Hirsch (University of Colorado/CIRES)*
P-16 North American CO_2 Fluxes from a New Synthesis of Inverse Models – *A.R. Jacobson (ESRL)*
P-17 Spatial Structure in North American Regional CO_2 Fluxes Evaluated with a Simple Land Surface Model – *T.W. Hilton (Pennsylvania State University)*
P-18 Measurement and Monitoring of Surface Radiative Forcing from Individual Greenhouse Gases – *W.F.J. Evans (North West Research Associates)*

- ***Carbon Monoxide, Carbonyl Sulfide and ^{14}C***

P-19 Plant Uptake of Atmospheric Carbonyl Sulfide (COS) Over Tropical Latin America – *E. Campbell (Stanford University)*
P-20 Analyzing Gross Primary Production and Respiration of Terrestrial Ecosystems Using a Global Carbon Cycle Model that Includes Carbonyl Sulfide – *E. Campbell (Stanford University)*
P-21 Observational Evidence for a Long-Term Trend in Carbon Monoxide – *P.C. Novelli (ESRL)*
P-22 Latitudinal Gradients of Atmospheric $\Delta^{14}C$: A New Window onto Dynamical Controls of the Southern Ocean – *S.M. Fletcher (Princeton University)*
P-23 $^{14}CO_2$ as a Diagnostic for Vertical Transport in Atmospheric Transport Models – *J. Turnbull (Laboratoire des Sciences du Climat et de l'Environnement)*

- ***Ozone***

P-24 Observations of Ground-Level Ozone in Lithuania: Monitoring Network and Results – *R. Girgzdiene (Institute of Physics)*
P-25 Daily Ozonesonde Launches at Barrow, Alaska: April 1-20, 2008 – *B.J. Johnson (ESRL)*
P-26 Ozone Observations Over Mt. Kenya and Nairobi GAW (Global Atmosphere Watch) Stations – *J. Nguyo (Kenya Meteorological Department)*

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Thursday, May 15th: 1615-1845

- ***Halocarbons and SF_6***

P-27 Initial Results from the International Halocarbon in Air Comparison Experiment (IHALACE) – *B. Hall (ESRL)*
P-28 Measurement of Internal Stray Light within Dobson Ozone Spectrophotometers – *R.D. Evans (ESRL)*
P-29 Reconciling Estimates of SF_6 Emissions Using NOAA Observations – *M.J. Heller (University of Colorado/CIRES)*

- ***Aerosols and Radiation***

P-30 Forecast of UV Index by Means of an Empirical Model in the Republic of Panama – *A. Pino (University of Panama)*
P-31 U.S. Trends in Aerosol Optical Depth and Solar Radiation over the Past 10 Years – *J.A. Augustine (ESRL)*
P-32 Establishing Climatological Validation of Aerosol Impact at Barrow: 'Ground Truth' vs. Satellite Measurements – *G.P. Anderson (Air Force Research Laboratory)*
P-33 Temporal Variability of Aerosol Optical Properties, Ozone and CO Vertical Profiles over Rural Oklahoma – *E. Andrews (University of Colorado/CIRES)*
P-34 The NOAA ESRL Airborne Aerosol Observatory: The First Two Years of Operation – *P.J. Sheridan (ESRL)*
P-35 Comparison of RSS Spectral Measurements and LBLRTM/CHARTS Model Calculations for Clear Skies – *J.S. Delamere (ESRL)*
P-36 NEUBrew – The NOAA EPA Brewer Spectrophotometer UV Monitoring Network – *P. Disterhoft (University of Colorado/CIRES)*

- ***Observatories, Cooperative Measurements and Global Databases***

P-37 MPLNET Measurements of Polar Stratospheric Clouds at the South Pole in 2007 – *J.R. Campbell (Science Systems and Applications Inc.)*
P-38 Cloud Properties Observed by an All-Sky Camera System at the South Pole Station – *M. Shiobara (National Institute of Polar Research)*
P-39 Researcher and Educator Long Term Collaboration with NOAA Earth System Research Laboratory Regarding Atmospheric Ozone Changes at the South Pole through the NSF PolarTREC Program – *E. Bergholz (United Nations International School)*
P-40 Comparison of UV Climates at Summit, Greenland; Barrow, Alaska; and South Pole Station, Antarctica – *G. Bernhard (Biospherical Instruments Inc.)*
P-41 Results of Snowfall/Blowing Snow Observations in Barrow – *D. Yang (University of Alaska Fairbanks)*
P-42 Annual Cycles of Atmospheric Trace Gases in the Tropical Marine Boundary Layer: First Measurements from the Cape Verde Observatory – *K.A. Read (University of York)*
P-43 GEOSummit Baseline Measurements: Results and Interpretations of Year-Round Measurements – *R. Banta (Desert Research Institute)*
P-44 Circum Arctic Monitoring of the Environment from Research Aircraft – *R.S. Stone (University of Colorado/CIRES)*
P-45 A New Global Database of Trace Gases and Aerosols at High Vertical Resolution – *G.E. Bodeker (National Institute of Water and Atmospheric Research)*
P-46 The Global Atmosphere Watch World Data Centre for Aerosols: Progress in Integrating Regional Surface Observations of *In Situ* Aerosol Physical and Chemical Properties into a Global Network – *J. Wilson (European Commission DG Joint Research Centre)*
P-47 Inter-Comparisons of Satellite, Dobson Spectrophotometer and Ozonesonde Ozone Data Observations Over Nairobi, Kenya – C.C. Okuku *(Kenya Meteorological Department)*
P-48 The Nonhydrostatic Icosahedral Model – *A.E. MacDonald (ESRL)*

CO_2 Source/Sink Information from OCO Column CO_2 Data

D.F. Baker[1], H. Boesch[2], S.C. Doney[1], and D.M. O'Brien[3]

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NASA's Orbital Carbon Observatory (OCO) will hopefully be producing column CO_2 concentration data within the year. Unlike previous satellites, it has both good sensitivity down to the surface, where recently-emitted fluxes leave the largest signal, and a small (2.7 km^2) field of view, designed to find cloud-free scenes in even the cloudiest areas. Its sun-synchronous orbit takes measurements once a day at 1:30 pm local time, giving N/S ground tracks spaced roughly every 3º in longitude over a week. It thus has the potential to pin down near synoptic-scale CO_2 fluxes at truly regional scales (100s of km).

Here we use a variational data assimilation method to perform observing system simulation experiments (OSSEs) with the OCO data, solving for weekly surface CO_2 fluxes at a 2ºx5º resolution (lat/long). Carbon models are used to give realistic fluxes for the truth (used to generate the data) and the starting guess (Fig. 1a). New estimates of OCO column CO_2 retrieval errors from detailed radiative transfer simulations are added as measurement errors. RMS error statistics are collected over a full year's run by comparing the final estimate to the known truth. In glint mode, the OCO data is able to reduce errors in weekly regional fluxes by over 50% across much of the globe (Fig. 1b). Although we have used realistic cloud and aerosol coverage, as well as realistic orbital geometry and vertical weighting, in the calculation, the error reductions in Fig 1b are truly best-case, perfect-model values. The assimilation is considered to be perfectly "tuned": the assumed measurement and prior flux uncertainties have no errors in them. The transport model is assumed to be perfect and no measurement biases are added to the data. The success of the OCO mission will depend on how well these error sources can be identified and mitigated.

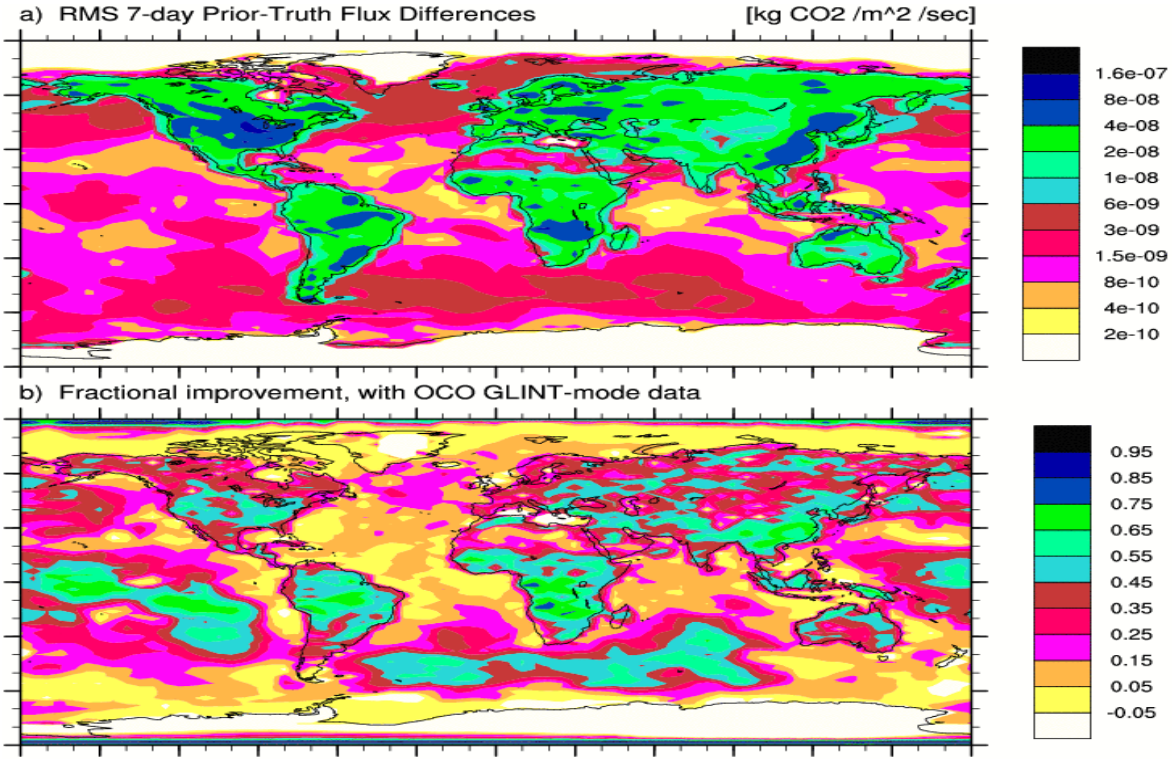

Figure 1. (a) The difference between the weekly true and *a priori* fluxes [kg CO_2 m^{-2} sec^{-1}], as RMS values over a full year, and **(b)** the fractional reduction in this due to assimilating OCO glint-mode measurements.

Temporal and Spatial Patterns in Regional and Continental-Scale CO_2 Mixing Ratio Measurements

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The study of the terrestrial carbon cycle is currently data limited, but the number of well-calibrated tower-based CO_2 mixing ratio measurements has increased dramatically within the last five years. We present results from two such datasets: a campaign-based group of five sites for the North American Carbon Program's (NACP) Mid Continent Intensive (MCI) and a long-term group of four sites at Ameriflux towers. The MCI CO_2 measurement systems ("Ring 2") are based on cavity ring-down spectroscopy, and the locations are regional in scale (surrounding the state of Iowa). If the measurements are shown to be spatially dense enough to over sample the CO_2 mixing ratio, the experiment will provide an upper bounds on the density of measurements required to produce the most accurate flux calculations possible with current atmospheric inversions; thus we are particularly interested in the spatial gradients between the sites. In Figure 1, the synoptic scale pattern in the daily daytime mean CO_2 mixing ratio (b) (the average of the sites shown in (a)) is associated with the passage of fronts through the region. For the month of July 2007, there are eight local extrema; these are correlated with the frontal passages. The change in site-averaged DDA per day is shown in (c). The variability amongst the sites (d) changes throughout the month as well, with some days having less than 5 ppm difference between the sites, whereas others having more than 20 ppm difference. The other dataset, the Ameriflux CO_2 measurement systems, are based on non-dispersive infrared sensors, and the locations are continental in scale. With the continental scale data, and incorporating the regional scale MCI data, we can also investigate seasonal patterns in the weekly mean data.

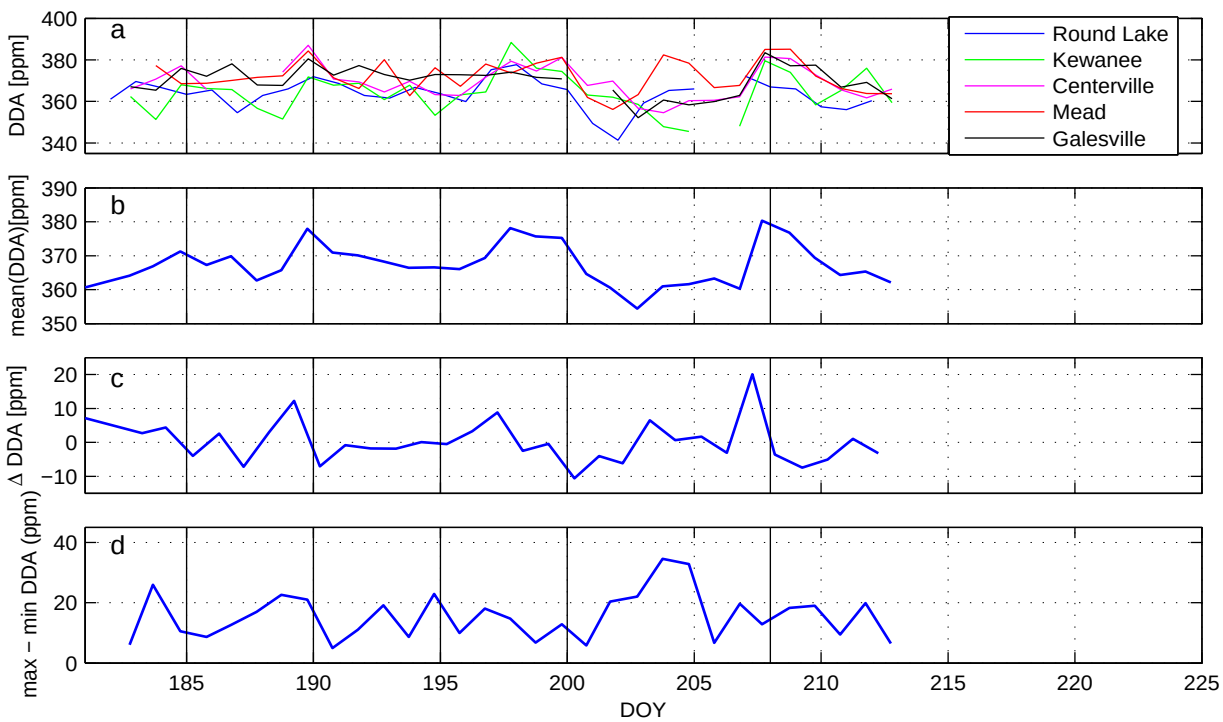

Figure 1. (a) Daily daytime average (DDA) CO_2 mixing ratio at the five "Ring 2" MCI sites for the month of July 2007. Vertical lines indicate approximate times of frontal passages through the region. **(b)** DDA averaged over the five sites. **(c)** Change in site-averaged DDA per day. **(d)** Difference between maximum and minimum DDA amongst the five sites.

Decreasing Anthropogenic Methane Emissions in Europe and Siberia Inferred from Continuous Carbon Dioxide and Methane Observations at Alert, Canada and Barrow, USA

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[3]Institut für Umweltphysik, University of Heidelberg, Im Neuenheimer Feld 229, D-69120 Heidelberg, Germany

Continuous measurements of CO_2 and CH_4 have been made from at the high arctic observatories at Alert, Nunavut since 1987 and from Barrow, Alaska since 1986. The time series of CO_2 and CH_4 at both sites are frequently highly correlated in winter during well-defined episodes lasting anywhere from 2 to 5 days, primarily due to synoptic meteorology, weak vertical mixing and rapid air mass transport of cohesive plumes of pollutants mainly from Siberian and/or European source regions. Ratios of CH_4/CO_2 during these well defined episodes consistently dropped (1988 to 2005) from ~20 ppb CH_4 per 1 ppm of CO_2 to ~12 ppb CH_4 per 1 ppm of CO_2, a decrease of 40%. To estimate the spatial and temporal change in the source emissions necessary to produce these observations, the atmospheric CO_2 and CH_4 concentrations at Alert and Barrow were simulated using the NIES atmospheric transport model and NCEP reanalysis meteorology, along with CO_2 sources (biospheric, oceanic fluxes and fossil fuel) and eleven individual CH_4 sources, including gas and coal. The results for Alert show, that on average, CH_4 emissions from Europe contribute more than 50% to the short-term variability of the simulated CH_4 signal with emissions from Siberia and Asia contributing the next highest average percentages of ~35% and 12% respectively. Emissions from all other regions, including North America, were negligible. In the absence of a change in the emissions of CH_4, modeled ratios of CH_4/CO_2 showed no change at both Alert and Barrow. In order to reproduce the trend in the ratio of CH_4/CO_2 observed in the data at both sites requires a reduction in emissions of CH_4 from Siberia and Europe on the order of 25 to 35 Tg, an amount large enough to account for the leveling of the atmospheric global CH_4 burden observed over the past 2 decades.

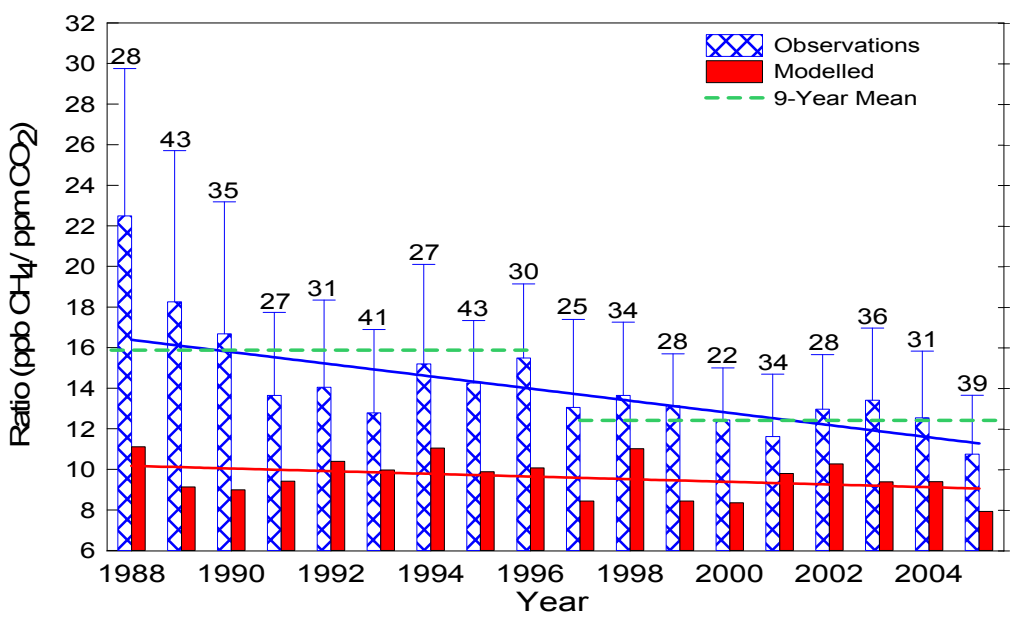

Figure 1. Showing the mean annual ratios of CH_4/CO_2 (in ppb ppm^{-1}) from 1988 to 2005 (blue – observed, red - modelled) at Alert. The blue error bars indicate the 1σ variability. The number of values used to calculate the annual mean is listed on top of the error bar.

Progress on Recent Carbon Cycle Studies in Oklahoma and California

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We report initial results from two collaborative regional carbon cycle studies. First, tower and aircraft measurements were performed as part of the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement Program's Cloud and Land Surface Interaction Campaign (CLASIC), during June 2007. Measured data include continuous CO_2, CO mixing ratios collected from a 60m tower and airborne platforms, continuous ^{222}Rn concentrations at the 60m tower, flask sampling for CO_2, N_2O, CH_4, and other species from tower and aircraft, and CO_2 heat and water fluxes from eddy flux towers. Here we describe horizontal transect and Lagrangian air-mass-following missions that will be used to quantify emissions from urban areas and regional photosynthetic uptake by vegetation. Second, in October, 2007, we began measurements at two tall towers in California, including continuous CO_2, CO, CH_4, and ^{222}Rn at the Walnut Grove tower near Sacramento, and twice daily flask sampling at both Walnut Grove and Sutro Tower above San Francisco. Initial estimates of emissions, based on the Walnut Grove measurements, demonstrate the presence of strong regional emissions of CO_2, CO, and CH_4, likely from multiple source sectors in the Bay and Sacramento Valley areas.

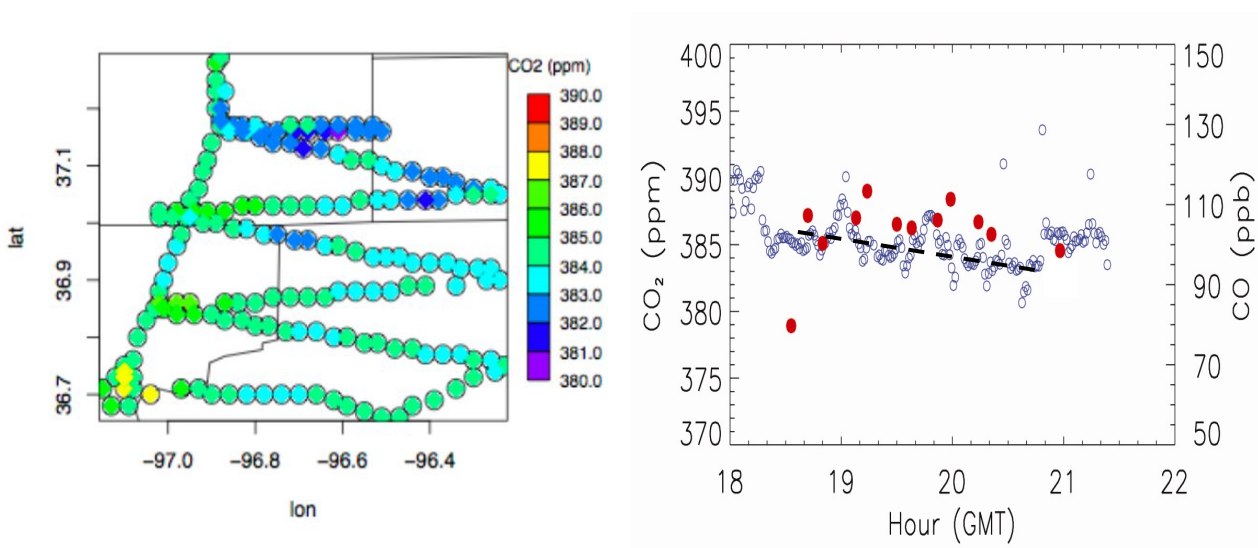

Figure 1. ***(left panel)*** Aircraft trajectory showing CO_2 mixing ratio measured during an air-mass following experiment, on June 22, 2007, and **(*right panel*)** the time series of CO_2 and CO (from flasks) measured during the flight. Following a climb from the airport Ponca City, Oklahoma (97.5W, 36.7N, lower left) to 2 km above ground level (agl) (near -96.5, 36.65N in dip near bottom of panel), the plane descended to 1 km agl (near -96.4, 36.8 on lower right) and flew a series of level legs in the boundary layer from south to north across the mean wind (from 18:40 to 20:45, indicated by dashed line on right panel), before returning to Ponca City. After observing higher CO_2 mixing ratios in the Ponca City airspace (yellow dots on left panel, time < 18:20), CO_2 gradually decreased by ~2 ppm during the Lagrangian portion of flight (along dashed line), and then rose by ~3 ppm when the plane started the return to Ponca (near 20:50 on right panel). CO mixing ratio (red dots on right panel), which serves as a tracer of combustion, was near 80 ppb at 2km (18:30 on right panel), increased to 100-115 ppb when the plane re-entered the boundary layer during the air mass following experiment, and remained near 100 ppb for the one flask collected during the return.

CO_2 and CH_4 Measurements from the CARIBIC Aircraft Observatory

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The new CARIBIC system (Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container, www.caribic-atmospheric.com) is based on a fully automated instrument package. Since December 2004 it is deployed monthly aboard a Lufthansa Airbus A340-600 passenger aircraft equipped with an advanced multiprobe inlet system. The cruising altitude of 9 to 12 km implies a frequent crossing of the tropopause at mid-latitudes (the ex-tropical UT/LS region). At lower latitudes the free tropical troposphere is probed.

In addition to real-time measurements of aerosols and various trace gases, including CO_2, air is sampled into glass flasks for laboratory analyses (greenhouse gases, NMHCs, halocarbons, CO_2 and H_2 isotopic composition). The main greenhouse gas analysis comprises GC measurements of CO_2, CH_4, N_2O and SF_6. Data quality is assured by regular calibration measurements based on four NOAA standards. The average precision is 0.03% CO_2 and 0.1% for CH_4. A comparison with the University of Heidelberg has shown good agreement of results.

In 2006 and 2007 monthly flights took place between Germany and East Asia and between Germany and North America. CO_2 and CH_4 data from this period will be discussed with emphasis on their correlation as a function of season and their relationship with other trace gases such as O_3 and CO. Furthermore, the CARIBIC data will be compared to ground station data from the ESRL Carbon Cycle Sampling Network and the CarboEurope network. A first comparison between the flask measurements and the continuous CO_2 measurements (LSCE, Paris) will also be shown.

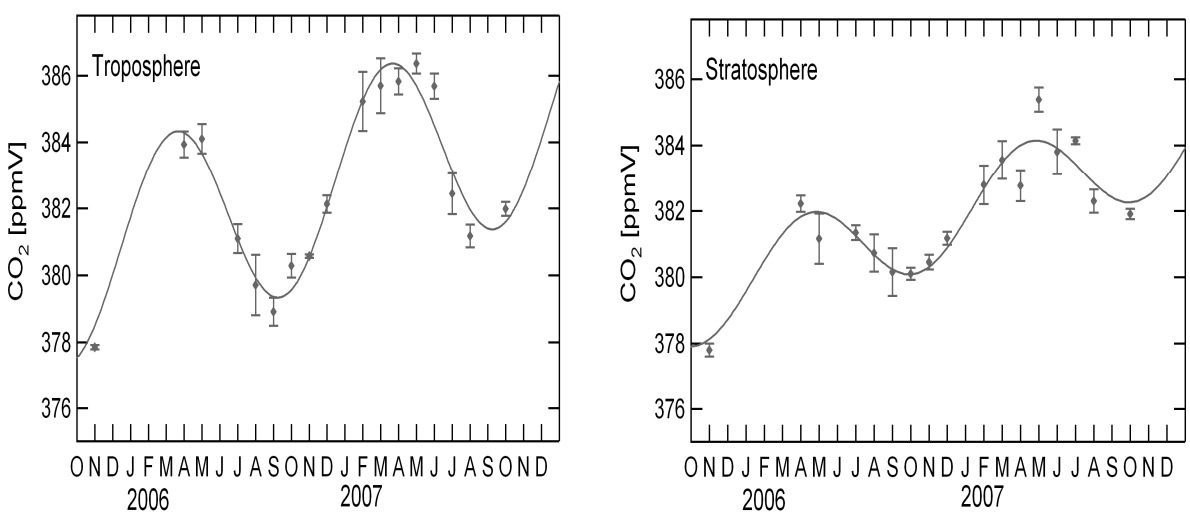

Figure 1. Time series of the CO_2 mixing ratio in the upper troposphere **(left)** and lowermost stratosphere **(right)** as measured aboard a passenger aircraft by the CARIBIC observatory in 2006 and 2007.

How Well Can We Measure Baseline CO_2 at Cape Kumukahi?

S.C. Ryan

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Weekly flasks have been routinely taken at Cape Kumukahi, Hawaii for thirty seven years, but until recently we did not know how local sources and sinks of carbon dioxide might influence these samples. This problem has been investigated by a campaign of continuous measurements of CO_2 and condensation nuclei at Cape Kumukahi between December 10, 2007 and February 25, 2008. Similar measurements were also made in the town of Hilo for four weeks in November 2007.

There is a persistent diurnal cycle of CO_2 at Cape Kumukahi with a consistent mixing ratio at night (6 PM to 7 AM) and a drop of about 2 ppm during the day, symmetrically centered at noon. This feature is present even under trade wind conditions. It may be caused by photosynthesis and respiration of CO_2 from plants growing near the building and on the 300 to 500 meter upwind fetch of land between the site and the shoreline. Local plant respiration and photosynthesis is also seen in the Barrow clean air sector in mid-summer (0.6 ppm at 10 meters) and in the non-baseline sectors at Samoa and Cape Grim (several ppm at 10 meters). At Cape Kumukahi, vegetation has been gradually recolonizing the areas covered by the 1960 lava flow, so it is possible that the diurnal CO_2 cycle has strengthened over time.

CO_2 increases of up to 25 ppm occurred at night at Cape Kumukahi. These are attributed to respired CO_2 from inland forests during periods of offshore winds. The probability of these events ranged from 20% after sunset to over 50% between 3 AM and sunrise. During the flask sample window between 9 AM and 11 AM, the probability was between 15% and 5%, and the amplitudes were only a few ppm. By comparison, excess CO_2 in Hilo at night was up to 80 ppm greater than during the day, due to the closer proximity of forests and the development of a stronger, more persistent offshore wind.

We have begun taking additional flasks from a sampling line on the top of the lighthouse tower to see if these are less affected by local vegetation CO_2 exchange than ground level flasks.

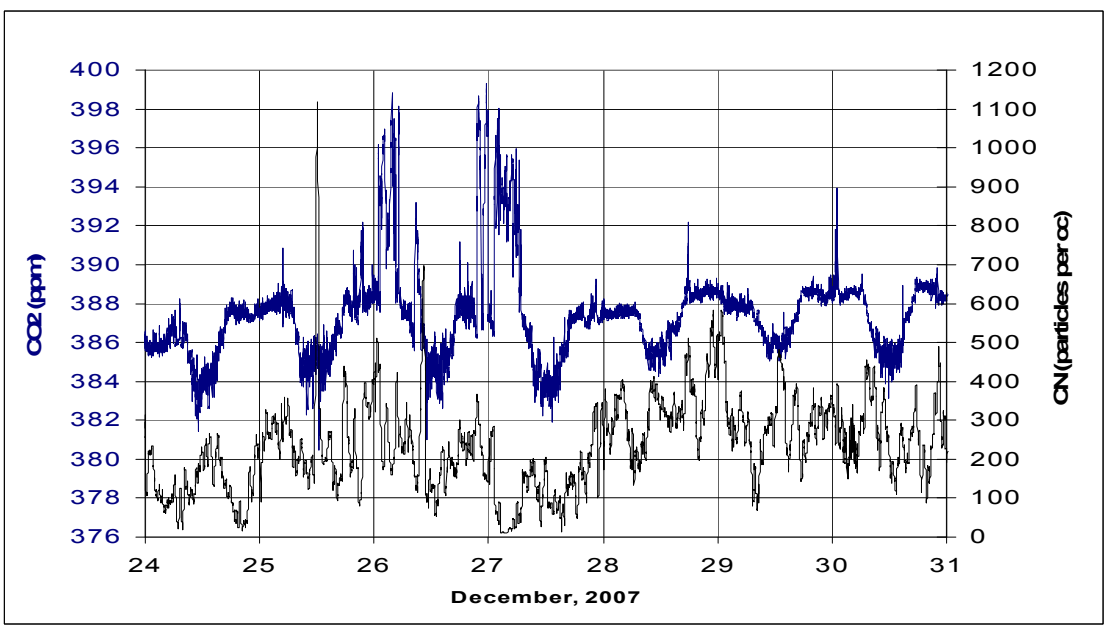

Figure 1. One week of continuous measurements of CO_2 (blue) and condensation nuclei (black) at Cape Kumukahi, Hawaii. Time grid lines are at midnight. The sampling inlet protruded from the west wall of the sampling building at a height of 3 meters. CO_2 mixing ratios are provisional pending reanalysis of two calibration gases used in the study.

Where do Those Numbers Come from, Again? Fossil-carbon Emissions Estimates on Various Space and Time Scales

T.J. Blasing and J. Miller

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Early investigations of fossil-carbon accumulation in the atmosphere required annual estimates of global emissions. Now, inverse modeling and other techniques for quantifying processes involved in the global carbon cycle require information on space and time scales corresponding to the daily cycle of emissions from specific urban areas (1). Mitigation issues have also raised the need for emissions estimates at fine space and time scales and for specific source classes (e.g., cement and steel manufacture). Additional applications that have emerged include identifying individual carbon "footprints" and carbon emissions attributable to large sporting events. These latter applications require specific information on emissions per passenger mile, emissions per kilowatt-hour of electricity consumed, and similar quantities which can vary on small space and time scales. Some history and details of estimating carbon emissions will be reviewed, particularly as they apply to CarbonTracker and similar NOAA projects.

Reference: (1) Gurney et al., 2007. Research Needs for Finely Resolved Fossil Carbon Emissions, EOS, 88 (49), pp 542-543.

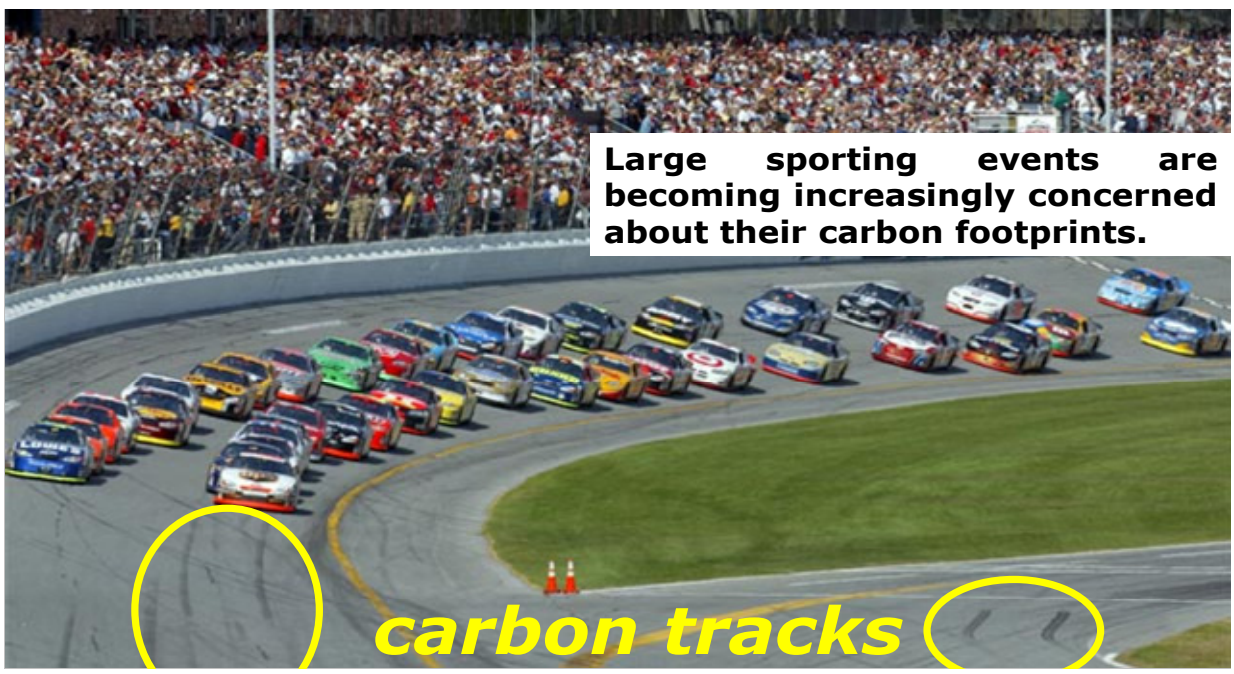

Figure 1. Large carbon emissions on small space and time scales.

The Orbiting Carbon Observatory Development Status

D. Crisp and the OCO Team

NASA Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109; 818-354-2224, Fax: 818-354-0966, E-mail: David.Crisp@jpl.nasa.gov

The Orbiting Carbon Observatory (OCO) is currently under development at the Jet Propulsion Laboratory, in preparation for a launch in December of 2008. This NASA Earth System Science Pathfinder (ESSP) mission will make global, space-based measurements of atmospheric carbon dioxide (CO_2) with the precision, resolution, and coverage needed to characterize CO_2 sources and sinks on regional scales. The Observatory consists of a dedicated spacecraft bus that carries a 3-channel, high resolution grating spectrometer. The column averaged CO_2 dry air mole fraction, X_{CO2} will be retrieved from coincident high resolution spectroscopic measurements of reflected sunlight in near-infrared CO_2 and molecular oxygen (O_2) bands. The instrument has recently completed its pre-launch testing and calibration in preparation for integration with the spacecraft bus. OCO will be launched from Vandenberg Air Force Base and will join the Earth Observing System Afternoon Constellation (A-Train) about 45 days later. This group of satellites files in a 98.8 minute, 705 km altitude, sun-synchronous orbit with a 16 day ground track repeat cycle. OCO will fly at the head of the A-Train with an ascending nodal crossing time of ~1:26 PM. Routine science operations are expected to begin in February of 2009. The OCO science data will be transmitted to the NASA Ground Network Stations in Alaska and Virginia, and then transferred to the OCO Ground Data System at JPL. There, the CO_2 and O_2 spectra will be analyzed by the OCO Science Team to retrieve spatially resolved estimates X_{CO2}. Calibrated, geolocated spectral radiances will be archived in a NASA Distributed Active Archive Center (DAAC) starting in the late summer of 2009. About 3 months later, an exploratory X_{CO2} product will start being delivered to the DAAC. These data will be validated against existing ground- and tower-based measurements using high resolution Fourier transform spectrometers (FTS's) from the Total Carbon Column Observing Network (TCCON) as the transfer standard (Figure 1).

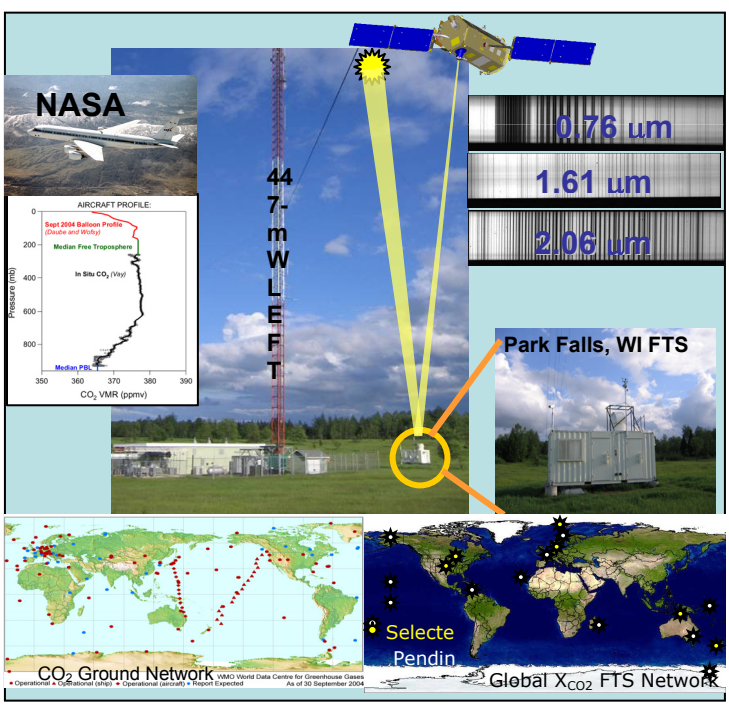

Figure 1. The OCO validation approach. OCO will acquire measurements over a TCCON FTS site roughly once each day. These FTSs measure X_{CO2} using the same spectral bands used by the flight instrument, but provide ~10 times the spectral resolution, and substantially greater signal-to-noise ratios. They are also relatively insensitive to optical Pathlength biases from cloud and aerosol scattering. X_{CO2} data from the TCCON sites at Park Falls, Wisconsin (shown) and Darwin, Australia have been validated against in-situ data collected by aircraft and balloons. Additional validation activities will be conducted during the operational phase of the mission.

Beyond Kyoto: Why Climate Policy Needs to Adopt the 20-Year Impact of Methane

E. Lombardi and K. Mangione

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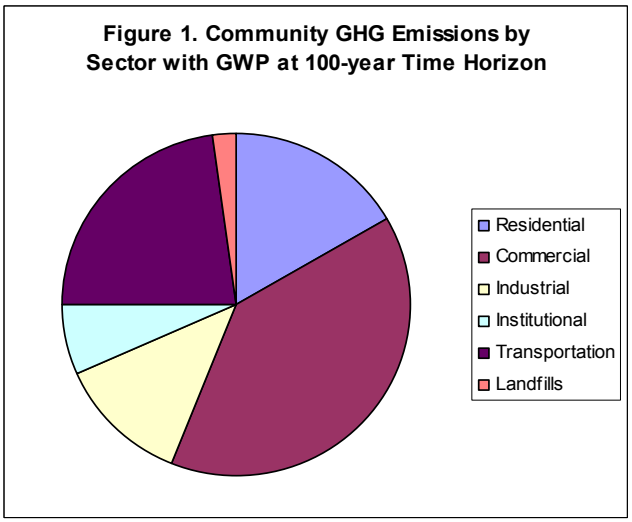
Current accounting protocols for greenhouse gas emissions fail to address the short-term risks and opportunities of methane (CH_4) emissions. To achieve the immediate, substantial greenhouse gas reductions that must occur within the next 10-15 years, not over the next century, we need to revise our analytical tools and adopt the 20-year time horizon for assessing global warming potential. Correcting the time horizon—a policy, not scientific decision—launches methane abatement from a climate afterthought to an essential first step forward, and recognizes landfill methane emissions as a source equivalent to 20% of U.S. coal-fired power plants.

The largest source of human-caused methane in the U.S. is landfills. Landfill methane results from the anaerobic decomposition of organic materials underground and can be completely prevented by keeping these materials out of the landfill through recycling and composting. These policies have been pursued across the European Union and in parts of Canada for more than a decade. On the national and local level, policymakers should prioritize programs that keep organic materials out of landfills and incinerators as a critical first step in immediately curbing greenhouse gas emissions in order to avoid potentially abrupt and dangerous implications of climate change.



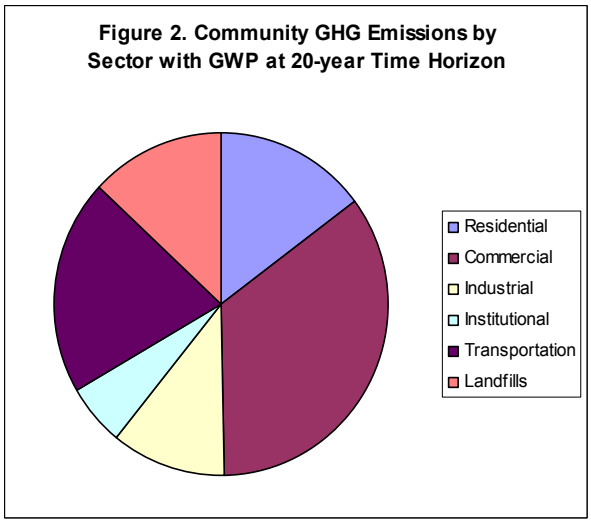


Figure 1. Illustrates the greenhouse gas breakdown by sector for an example community based on the 100-year time horizon for global warming potential (GWP) values.

Figure 2. Recalculates the emissions using the 20-year time horizon for GWP. As shown, the contribution of landfills to total community greenhouse gas emissions increases substantially when considered over the 20-year period. At this magnitude, landfill emissions are on par with emissions from the residential and industrial sectors and may warrant increased attention from community planners looking to decrease overall climate impacts, particularly over the short term.

Estimating Measurement Uncertainties for Programmable Flask Package (PFP) Air Samples: A Mountaintop Intercomparison with the Cooperative Global Network Manual Sampler

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Near-simultaneous real air samples were obtained near the summit of Mt. Evans (elevation ~4350 m; located ~50 miles west of Denver, Colorado) using both the ESRL GMD PFP sampling system and the manual 2.5L flask portable sampler (PSU). This general PSU design has been in use for more than 10 years in the ESRL/GMD Cooperative Global Air Sampling Network, and network measurements from PSU samples have been well characterized.

The mixing ratios of six atmospheric trace species (CO_2, CH_4, CO, H_2, N_2O, SF_6) were compared from these two systems to provide estimates of measurement uncertainties associated with the PFP for each of these six species and to look for potential biases between these two sampling systems. The field location was chosen in order to sample atmospheric air relatively free of influence from nearby sources or sinks, with low variability over the sampling timescale, in order to provide for better sample intercomparison.

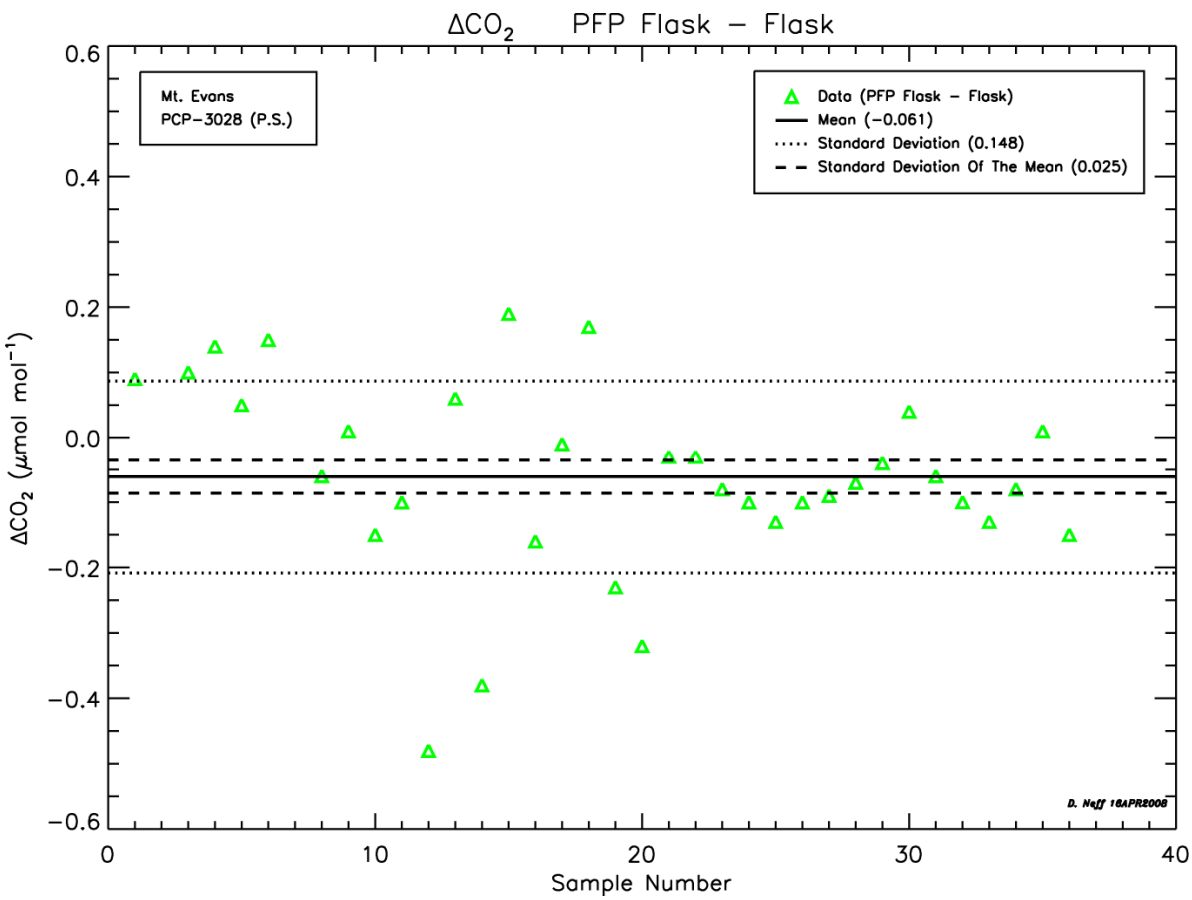

Figure 1. This plot displays the difference of ESRL/GMD measurements of the dry-air mole fraction between a series of near-simultaneous carbon dioxide samples from the PFP system and the manual sampling system. The mean, standard deviation, and the standard deviation of the mean of these measured differences are also indicated.

Results of Carbon Dioxide Measurements in the Atmospheric Boundary Layer in Obninsk, Russia

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From 1998 through 2007 CO_2 has been measured in the atmospheric boundary layer in Obninsk, Russia (55.11^0 N, 36.57^0 E, 183 m above sea level). The CO_2 mixing ratio is measured in air samples collected 4 m above the ground, and in samples taken at 25, 100, 200 and 300 m from the high meteorological mast. The absorption spectroscopy method consists of a Fourier-spectrometer, an optical multipass cell, and a sample handling system *[Baranov et al., 1999]*. The accuracy of the method was evaluated by comparing the results of analyses made in Obninsk and at NOAA ESRL of the same air samples collected several times during the year.

As is seen from the data presented in Fig. 1, the CO_2 time series is characterized by large short term variability caused by natural and anthropogenic sources and sinks. A simple averaging of measurement results to obtain mean daily, monthly and annual values does not allow one to reliably determine the contribution of anthropogenic sources to the temporal variability of CO_2 mixing ratio in the atmospheric boundary layer. The statistical method of smoothing selected data does not give optimal results either *[Thoning K.W. et al., 1989]*, because the number of measurements is sparse and there are gaps in the data series. Therefore, a preliminary analysis of measurement results was made to determine the minimum and maximum monthly values. This method is illustrated by Fig. 2, where the measurements of CO_2 mixing ratio in the air near the ground are given for every month of 2007. The maximum and minimum monthly values of CO_2 mixing ratio found in this way are presented in Fig. 3.

Minimum CO_2 mixing ratios are mainly determined by natural sources and sinks and may be used as indices of "regional background". Maximum CO_2 mixing ratios are determined by both natural and anthropogenic sources. The difference between them can characterize the anthropogenic contribution to the CO_2 content in the atmosphere. As is seen from the data in Fig. 3, the fraction of anthropogenic CO_2 has been decreasing during the last several years.

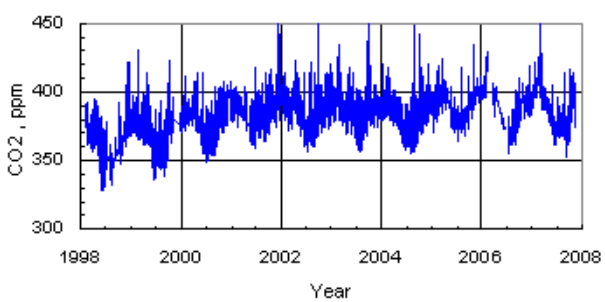

Figure 1. Variations of CO_2 mixing ratio in the air near the ground.

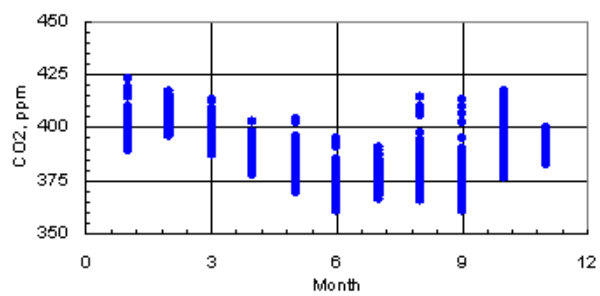

Figure 2. The range of CO_2 measurements during each month of 2007.

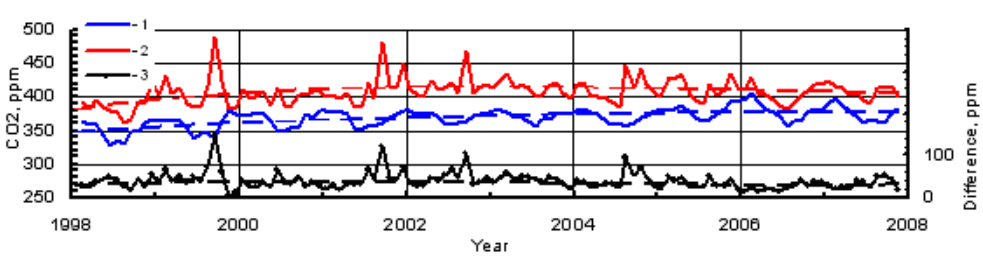

Figure 3. Variations of monthly minimum (1), maximum (2) CO_2 mixing ratios and the difference between them (3).

Introduction to Trace Gases Measurement in Mongolia

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The National Agency for Meteorology and Hydrology (NAMHEM) is responsible for air quality monitoring in Mongolia. There are 22 air quality monitoring stations (SO_2 and NO_2) in the residential areas of the country. In addition, the Russian Mongolian Center of Upper Atmospheric Research has measured total column ozone amounts using the M-124 ozone spectrometer from 1988 to 1992 at Sainshand, Mongolia. In 1992, NOAA ESRL started Greenhouse Gas (GHG) sampling with the Institute of Meteorology and Hydrology (under NAMHEM) of Mongolia in the southern desert area of Mongolia at Ulaan Uul. Since 2005, the Russian–Mongolian Expedition (BSC-IHM) has measured surface ozone concentrations in the desert region of Mongolia during summer periods. Also in 2005, NOAA ESRL (with Institute of Meteorology and Hydrology) started measurement of GHG and tropospheric ozone (vertical profiles) at Ulaanbaatar using light aircraft. The main focus of the Environmental Research Section of the Institute of Meteorology and Hydrology is air quality and GHG data analyses. Our monitoring results show that in the last 10 years SO_2 and NO_2 concentrations have increased 3 times in the capital city, and in the last 15 years GHG (data from NOAA) concentrations have increased 7 percent (20 ppm) in the Mongolian desert region.

Figure 1. NOAA ESRL pump and automated flask sampling pack prior to a sampling flight to collect air samples in flasks and measure the ozone profile upwind of Ulaanbaatar, Mongolia.

Increase in the Global Burden of CH_4 During 2007

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Methane (CH_4), with a direct radiative forcing of ~0.48 W m^{-2}, is responsible for ~20% of the total forcing for long-lived greenhouse gases. Indirect effects, as a precursor to production of tropospheric O_3 and from stratospheric H_2O formed during its oxidation there, add another 0.2 W m^{-2} to its forcing. Tropospheric CH_4 also impacts background air quality through its effects on O_3.

From 1999 to 2006, the global burden of atmospheric CH_4 remained nearly constant (see Figure), except for a small increase resulting from increased boreal biomass burning during 2003. A simple explanation for the stabilization of atmospheric CH_4 remains elusive, and it is likely the result of many contributing factors. Despite the lack of understanding of CH_4 trends during 1999 to 2006, it seems reasonable that atmospheric CH_4 will begin to increase again as suggested by scenarios of future emissions (e.g., IPCC Special Report on Emissions Scenarios). Rapidly growing economies in Asia have likely resulted in increased emissions from two important CH_4 sources: coal production and waste processing. Coal production, which is responsible for nearly 10% of global CH_4 emissions, has increased by nearly a factor of two in China since 2000. Also, the impacts of climate change on natural wetland emissions, particularly in the Arctic where estimates suggest as much as 900 Tg is stored as labile carbon in permafrost, would eventually result in increasing CH_4 emissions there. Evolution of the observed latitude gradient in CH_4 over time suggests that while mid-latitude emissions are increasing because of economic growth in Asia, we have yet to see an increase in the global burden, because increasing Asian emissions have been canceled by decreasing anthropogenic emissions of CH_4 at high northern latitudes from the former Soviet Union and Europe.

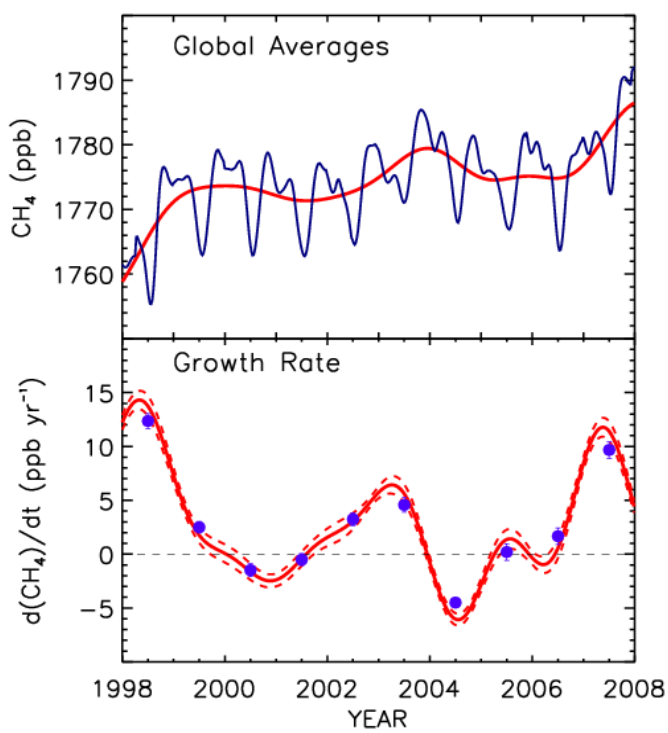

Figure 1. Preliminary globally averaged CH_4 mole fractions (blue) and trend (red) (top panel); instantaneous growth rate (red) and annual increase (blue) (bottom panel).

During 2007, globally averaged CH_4 increased by ~10 ppb, which is comparable to the observed increase in 1998 when anomalous wetland and biomass burning emissions contributed. NOAA CO data suggest there were no large biomass burning events in 2007, but measurements of $\delta^{13}C$ in CH_4 from Alert, Canada suggest greater than normal emissions from wetlands. Our data show clearly that CH_4 emissions in the tropics also increased. It is not yet clear if 2007 is anomalous, or it is the start of increasing emissions from Arctic ecosystems resulting from warm temperatures that increase emissions from wetlands and melting permafrost.

Applications of Lagrangian Particle Transport Modeling in the Top-Down Regional CO_2 Studies

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Atmospheric transport plays a critical role in top-down studies where observations from towers and/or aircraft are inverted to estimate net sources and sinks of CO_2 for the study area over short periods of time. Lagrangian particle dispersion models are well suited for this modeling task since they: (1) can be easily linked to any regional scale meteorological model, (2) can be run both forward or backward in time (in an adjoint model, (3) can accurately resolve any CO_2 observational system without limits of gridded transport models, and (4) can be applied to different spatial scales even across grids or domains of meteorological models. In the modeling framework developed at Colorado State University, the Lagrangian Particle Dispersion Model is linked to SiB-RAMS: Regional Atmospheric Modeling System combined with Simple Biosphere model. For our North America studies the SiB-RAMS domain extends over the entire continental U.S. with nested grids centered in the mesoscale area of interest. The CO_2 lateral boundary conditions are provided by a global transport model - PCTM (Parameterized Chemistry and Transport Model). Influence functions derived from the LPDM output allow us to quantify each CO_2 data point (e.g., concentration at a specific sampling time and tower) in terms of contributions from different sources: (1) surface fluxes, (2) inflow fluxes across domain boundaries and (3) initial CO_2 concentration in the domain at the beginning of the analysis period. The surface contributions can be further quantified by a physical process (respiration, assimilation or fossil fuel emission) and/or land cover type. Therefore, the influence function approach is very useful for interpretation of CO_2 observations and source apportionment, designing tower network and, finally, deriving source-receptor information for the inverse studies. We are going to review our modeling efforts based on the SiB-RAMS/ LPDM and the influence function approach to the meso- and regional scales from a few tens to several thousands of kilometers:

- Estimation of mesoscale CO_2 fluxes in the 300x300 km domain using the summer 2004 observations from the "ring of towers" in northern Wisconsin
- Extension of the previous work to a larger domain of the second "ring of tower" run in summer 2007 within the NACP's Midcontinental Intensive Study
- Deriving influence functions and transport characteristics for the US continental scale CO_2 inversions
- Quantifying both CO_2 concentration and flux measurements from real and hypothetical towers in the Tapajos River region in the Amazon using very high resolution SiB-RAMS simulations
- An attempt to quantify source areas for CO_2 observed at the BAO tower near Boulder, Colorado

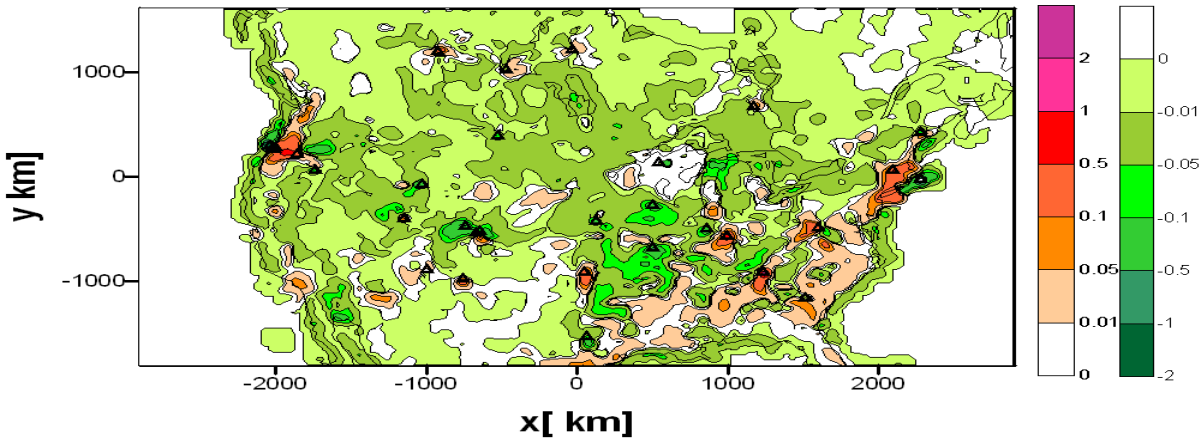

Figure 1. Influence function climatology for August 2004 showing contribution [in ppm] of surface CO_2 fluxes within the US domain into the average CO_2 concentration observed at 30 towers.

Regional-Scale Carbon Dioxide Fluxes During the 2007 Growing Season Derived from Simultaneous Radon-222 and Carbon Dioxide Measurements in Oklahoma

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Radon is a useful tracer of transport processes in the lower atmosphere. It is emitted ubiquitously from soils, it is chemically inert, and decays with a half life of 3.8 days. Radon concentrations in the planetary boundary layer have been used in conjunction with collocated carbon dioxide measurements to estimate regional carbon dioxide surface fluxes. This approach relies on the knowledge of regional radon fluxes. Direct flux measurements are rare and the flux is known to vary over small spatial and temporal scales as a function of soil water content and soil uranium content. No well tested continent-scale emissions maps exist for North America. However, continent-scale maps do exist of the factors thought to control soil radon emissions such as those mentioned above. Using a continuous time series of radon from the ARM-CART SGP facility in Oklahoma and the transport model FLEXPART, as well as soil water and uranium content data, we infer a dependence of radon emissions on these two variables (Figure 1). The radon fluxes calculated using the inferred relationships are evaluated using an independent atmospheric radon time series 400 miles south in Texas. We then apply the so-called "radon tracer" method to solve for monthly-mean regional-scale carbon dioxide fluxes from March-September 2007 using daily afternoon average boundary-layer radon and carbon dioxide measurements. By combining daily radon flux estimates into monthly averages, we achieve a high precision on the resulting carbon dioxide fluxes, though we cannot rule out biases caused by the transport model used to help estimate our radon fluxes.

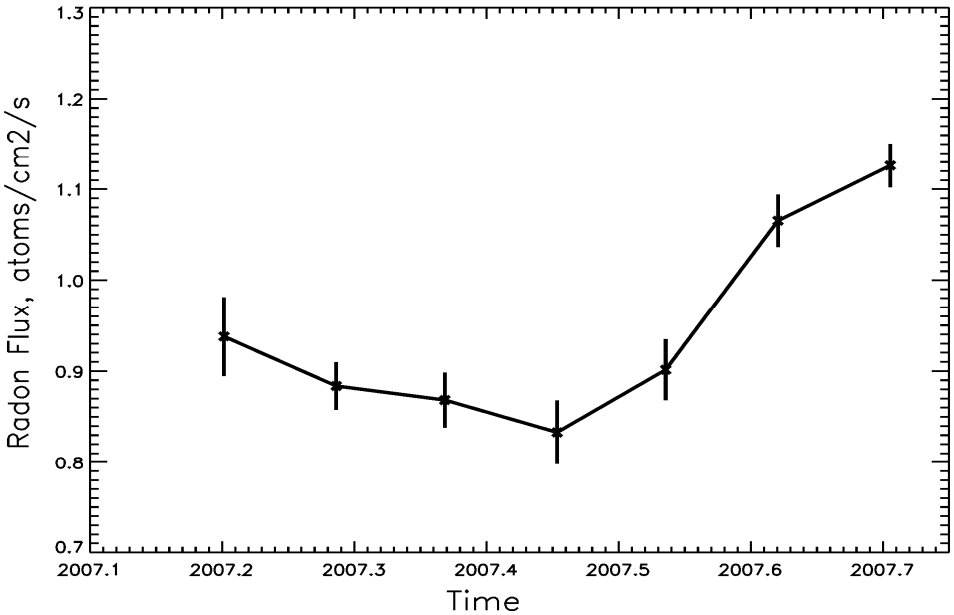

Figure 1. Monthly average radon-222 flux upwind of the ARM-CART SGP 60-m tower inferred from atmospheric radon measurements and datasets of soil ^{238}U (from USGS) and soil moisture (from NASA). Error bars represent the standard error of the daily radon flux estimates within a given month.

North American CO_2 Fluxes from CarbonTracker Compared with a New Synthesis of Inverse Models

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Inverse models of carbon dioxide exchange from terrestrial ecosystems tend to estimate much more interannual variability (IAV) in CO_2 flux than forward, or bottom-up, models. For instance, the bottom-up model used in CarbonTracker (CASA-GFED2 of van der Werf *et al.*, 2006), predicts a peak-to-peak IAV of 0.2 PgC/yr for North America over the period 2000-2005, whereas after optimizing to agree with atmospheric CO_2 observations, CarbonTracker finds about four times more IAV. The peak-to-peak variability of 0.8 PgC/yr in North American flux from CarbonTracker is in fact as large as its estimate of the long-term mean uptake over the same region (-0.8 PgC/yr). In part to investigate this difference, the North American Carbon Program is organizing a synthesis report to compare inverse and forward models' estimates of North American CO_2 exchange over the period 2000-2005. We will report here on early results from this effort, focusing on a collection of inversion flux estimates from diverse modeling groups around the world.

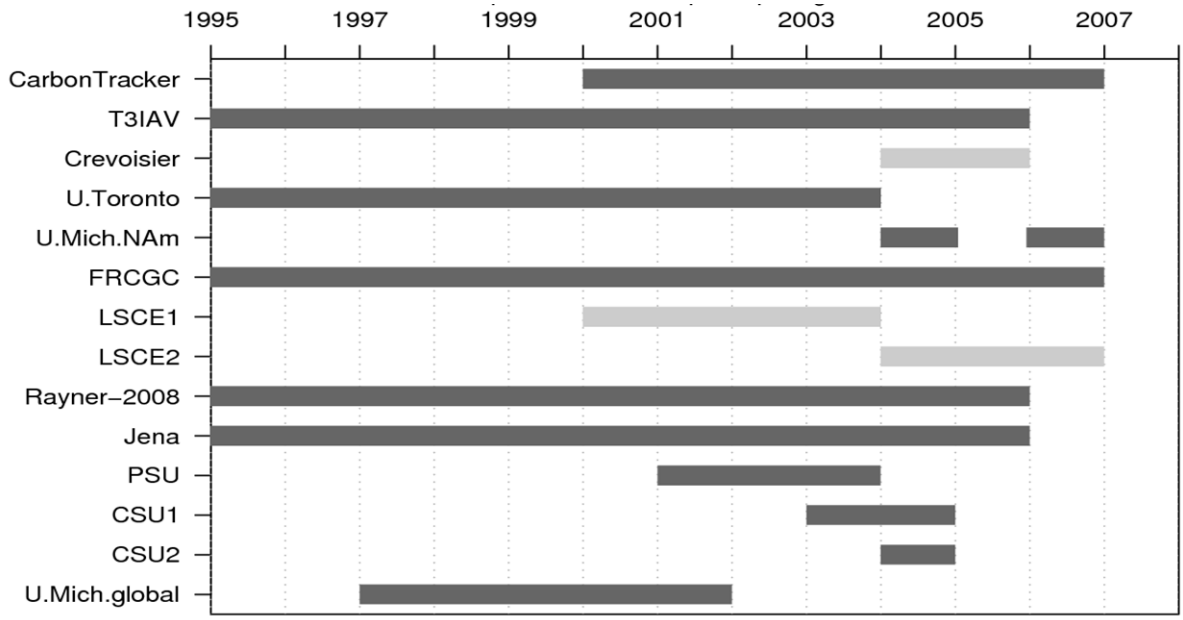

Figure 1. Temporal domains of inverse models participating in the NACP interim synthesis project (light gray bars represent provisional estimates).

Spatial Structure in North American Regional CO_2 Fluxes Evaluated with a Simple Land Surface Model

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We evaluate spatial structure in Ameriflux CO_2 flux observations using a simple diagnostic land surface model. The Vegetation Photosynthesis Respiration Model (VPRM) calculates NEE using locally observed temperature and PAR, and satellite-derived phenology and moisture. We use observed NEE from a group of Fluxnet eddy covariance tower sites spanning North America to optimize VPRM parameters for these sites. We use the spatial structure of VPRM errors to investigate spatial coherence in regional CO_2 fluxes at several different time scales. We show that VPRM residual correlation degrades with increasing spatial scale. This conclusion should impact the size of regions used in atmospheric inversion calculations.

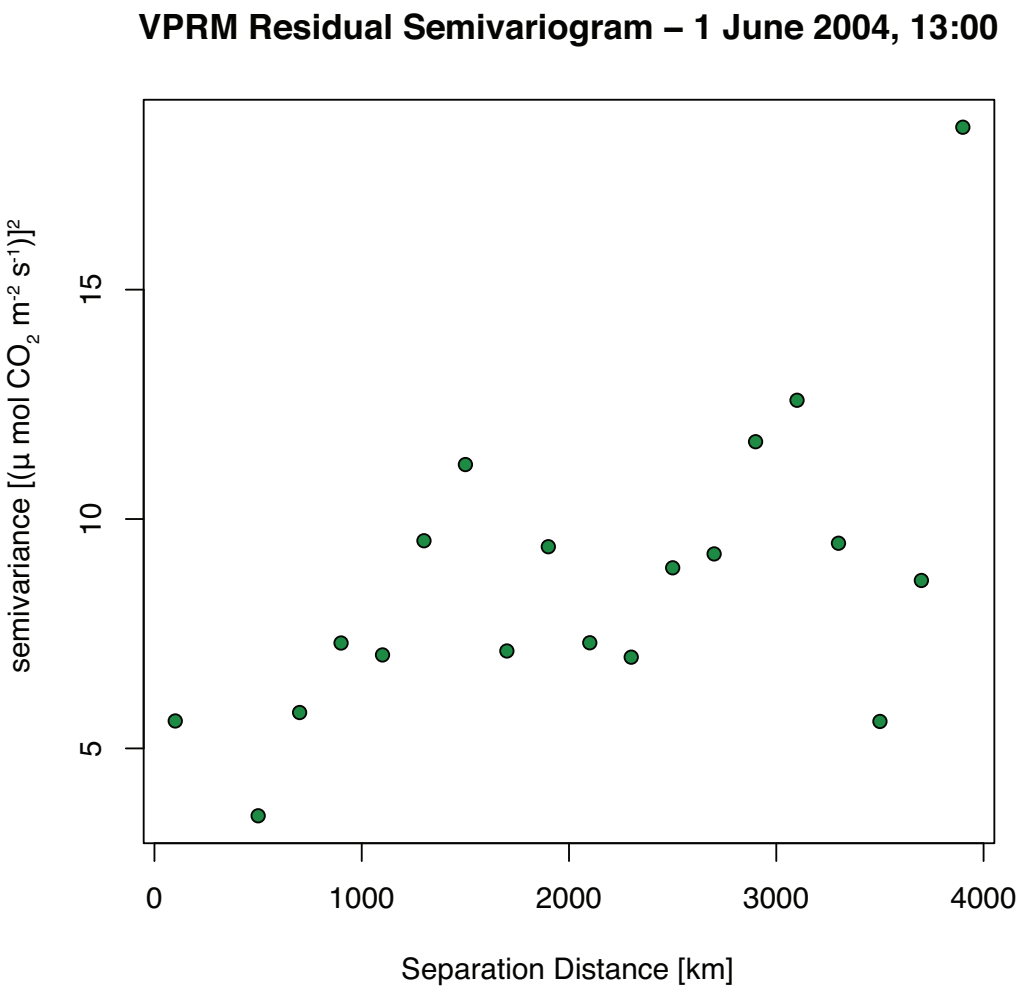

Figure 1. Semivariogram for VPRM residuals. Site pairs are grouped into bins by separation distance, with bin widths of 200 km. Bins containing at least 20 site pairs are shown. The increasing trend with distance shows that site-to-site residual correlation decays with increasing separation.

Measurement and Monitoring of Surface Radiative Forcing from Individual Greenhouse Gases

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A new network is proposed to monitor the radiative forcing of global warming by greenhouse gases. The calibrated spectrum of greenhouse radiation at the surface has been measured for the last 10 years in the Great Lakes area of Ontario, Canada. The surface radiative forcing flux from each greenhouse gas been extracted from these measurements. A 10-year record exists of the radiative fluxes from carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (CFCs). The increase of these fluxes represent the forcing function of global warming, which is an experimental version of radiative forcing similar to, but different from, the radiative forcing metric used by IPCC. It is proposed that this climate forcing be monitored like the ozone layer with a world monitoring network of instruments similar to Brewer and Dobson spectrophotometers. The AERI instrument already exists; 12 AERIs, manufactured by ABB BOMEM, are deployed around the world. The spectral measurements are being processed to extract the radiative forcing fluxes from each greenhouse gas; this is related to the work of Philipona et al. (2007) who measured the total radiative forcing increase due to all greenhouse gases with broadband instruments. The methodology will be to process the AERI infrared spectrometer measurements into the downward surface radiation flux in W/m^2 from each of the major greenhouse gases. Well calibrated infrared spectral measurements of the downward infrared long-wave radiation have been made routinely by the AERI at three DOE ARM Climate Research Facility (ACRF) sites for more than 7 years with a 12-year record at the Southern Great Plains (SGP) site. These measurements are being processed into longwave radiation fluxes from each of the major greenhouse gases using a methodology already developed for our similar measurements at 44° N in the Great Lakes area. Comparisons with surface radiation fluxes calculated from global climate models (GCMs) will be conducted using the methodology already successfully used to compare previous 44° N data with the Canadian and NCAR GCMs. The uses of the data would be to: investigate the seasonal and climate regime variations of the surface greenhouse radiation flux, compare the measurements with climate model simulations of the surface forcing radiation fluxes for each greenhouse gas, evaluate the reduction of the surface forcing radiation by various types of clouds by measuring the reduction in surface radiation forcing under cloudy conditions, conduct complementary measurements of surface radiative forcing with radiative trapping measured from space with overpasses of satellites and monitor the trends in the surface radiative forcing from each gas. This network will provide a new experimental dataset to complement the calculated radiative forcings from current climate models. It will provide the experimental capability to conduct long-term monitoring of increases in radiative forcings from individual greenhouse gases without using an intervening climate model and add a new climate observation that potentially could be used to compare changes in the longwave radiation balance of the atmosphere with other climate variables. The data from ACRF AERI sites, combined with the other existing AERI instruments deployed around the globe, would be a big step toward building a network to monitor radiative forcing.

Greenhouse Gas	Emission Band (cm^{-1})	GL Flux (W/m^2)	AERI Flux (W/m^2)
CFC-11	830 - 860	0.10	0.12
CFC-12	all bands	0.21	0.26
CFC-11 + 12	all bands	0.31	0.38
CH_4	1200 - 1400	1.02	1.21
N_2O	1200 - 1300	1.19	1.32
O_3	900 - 1100	3.34	3.02
CO_2	all bands	30.9	37.3

Figure 1. A comparison of Great Lakes and AERI SGP surface radiative forcing greenhouse fluxes in winter.

Plant Uptake of Atmospheric Carbonyl Sulfide (COS) over Tropical Latin America

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Atmospheric carbonyl sulfide (COS) contributes to stratospheric aerosol and is a potential tracer of gross primary production (GPP). Earth System Research Laboratory's (ESRL) measurements of COS and CO_2 suggest that plant uptake of carbonyl sulfide is closely related to GPP and is several times estimates used in previous modeling studies. Recent airborne measurements from the TC4 experiment over tropical Latin America provide further evidence of a GPP-based uptake of COS by plants. The enhanced sink then requires an enhanced source to balance the global budget. A global atmospheric model driven by the GPP-based plant uptake and an enhanced ocean source is consistent with measurements from ESRL and the tropical airborne campaign.

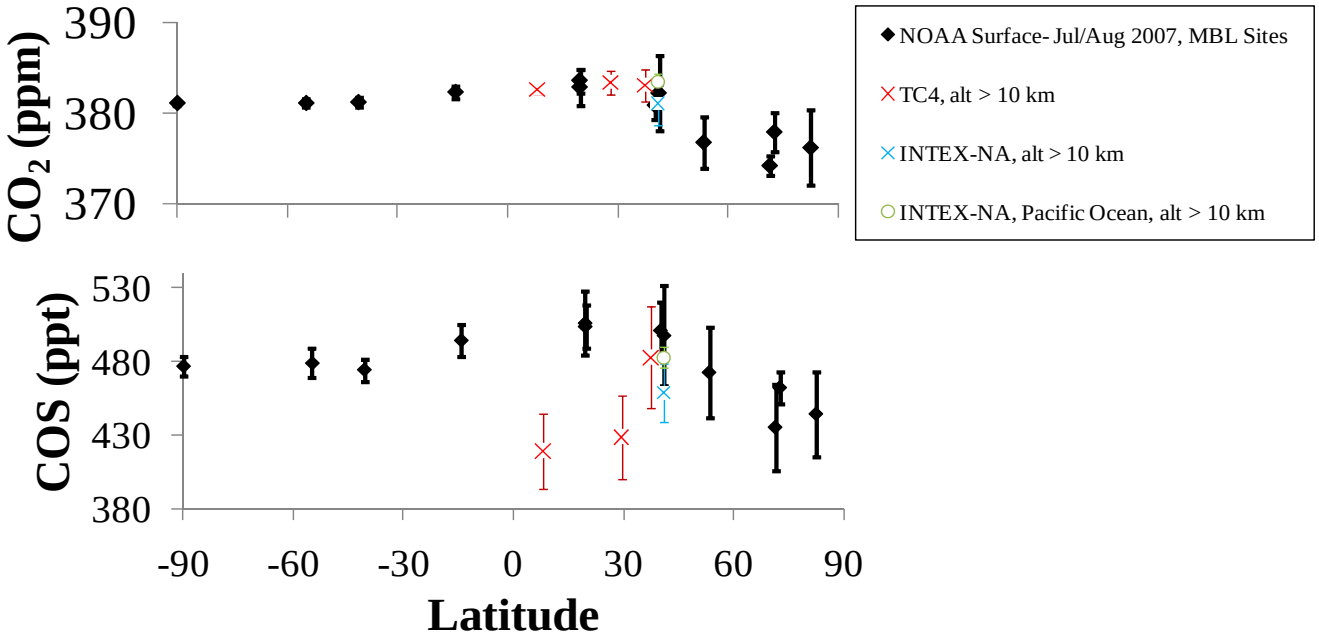

Figure 1. ESRL measurements of COS and CO_2 from MBL surface sites and NASA airborne measurements from the free troposphere. The COS latitudinal profile departs from the CO_2 profile for TC4 measurements over tropical Latin America where GPP is large relative to NEE and convective transport influences the free troposphere measurements.

Analyzing Gross Primary Production and Respiration of Terrestrial Ecosystems Using a Global Carbon Cycle Model that Includes Carbonyl Sulfide

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Carbonly sulfide (COS), an analog of CO_2, is emerging as a useful tracer of carbon cycle processes. Previous studies have shown that COS is taken up by leaves and that the rate of its uptake is closely linked to the rate of gross primary production (GPP). It has been suggested that COS uptake could be used as a direct measure of photosynthesis by terrestrial ecosystems on regional and continental scales. COS concentrations are being monitored in the background atmosphere at 13 sites and profiles of the lower atmosphere are being made at a number of continental sites. In addition, a number of atmospheric chemistry campaigns have measured COS and CO_2 concentrations. To help interpret these measurements, we have incorporated the biochemical and biophysical mechanisms controlling COS exchange into a land surface model (SIB) and we have used this new parameterization to simulate global COS and CO_2 fluxes and transported these together with other known sources and sinks in a chemical transport model (PCTM). Because the new terrestrial sink was larger and differently located than that used in previous studies (Kettle et al., 2002), we used an inversion approach to adjust the ocean flux to obtain a reasonable match to the annual mean concentration from the Arctic to the South Pole. The model exhibits reasonable skill in simulating observations of the seasonal cycle (Fig. 1a) and vertical profiles of COS and CO_2 concentration over North America (Fig. 1b) and in the tropics (not shown). Also shown is a profile simulated with and earlier parameterization of the terrestrial sink used by Kettle et al., (JGR, 107(D22), 4658, doi:10.1029/2002JD002187, 2002).

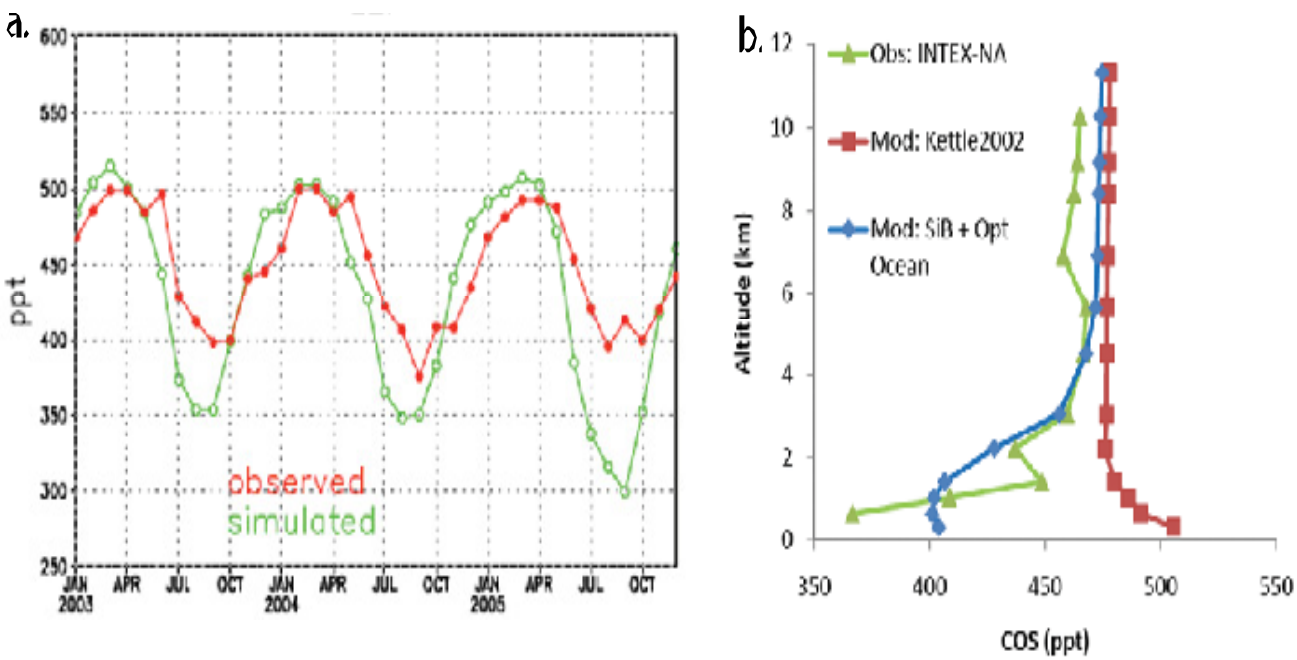

Figure 1. Seasonal cycle of observed and simulated COS at the WLF tower (left) and vertical profiles sampled by INTEX-NA (right) over Indiana and Illinois in July 2004 (mean monthly profile simulated vs mean of profiles sampled).

Observational Evidence for a Long-term Trend in Carbon Monoxide

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Through the reaction of carbon monoxide (CO) and the hydroxyl radical, changes in CO have potentially important effects on the oxidizing capacity of the troposphere. It is commonly accepted that carbon monoxide (CO) increased during the industrial era since two main sources, fossil fuel combustion and the oxidation of CH4, have increased. Yet there are relatively few CO measurements on which to base this conclusion. The positive trend is based on a few ice core studies, spectroscopic measurements of column abundances and surface time series. Close examination of the data raise questions of their representativeness. Long term measurements since the late 1980s have shown that inter-annual variations of the global annual average may exceed up to 25% and trends are sensitive to the time span used. This presentation will provide a re-examination of the data and evaluate a long-term trend in CO.

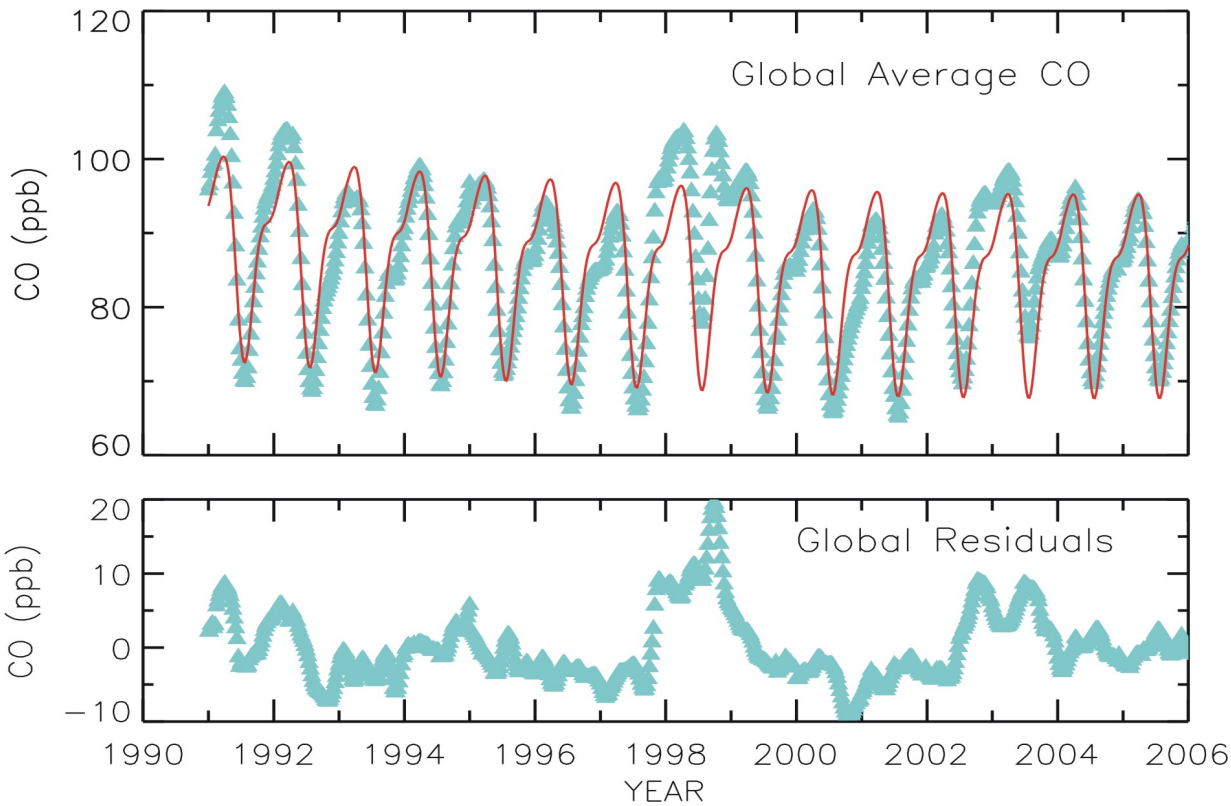

Figure 1. Globally-averaged CO mixing ratio in blue and smoothed curve in red **(top)** and residuals from a smooth curve **(bottom)**1991-2006. The effect of wildfires in 1997-1998 and 2002-2004 are seen in the timeseries.

Latitudinal Gradients of Atmospheric $\Delta^{14}C$: A New Window onto Dynamical Controls of the Southern Ocean

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Measurements of $\Delta^{14}C$ in tree rings indicate that there was a pre-industrial latitudinal gradient of atmospheric radiocarbon of 3.9- 4.5‰ (Hogg et al., 20002) and there was a substantial shift in this gradient between the Little Ice Age and the Medieval Warm period (Turney et al., 2007). Previous efforts to explain this shift in the latitudinal gradient have suggested that it is caused by changes in the frequency of ENSO in the tropics. We test the alternative hypothesis that the natural latitudinal gradient of $\Delta^{14}C$ is primarily controlled by ventilation of the Southern Ocean using fluxes from a suite of models based on the Modular Ocean Model version 3, which are used to force an atmospheric transport model. The results from this suite of simulations suggest that the atmospheric latitudinal gradient of $\Delta^{14}C$ is sensitive to wind stress in the Southern Ocean. Increased wind stress in this region leads to greater upwelling of strongly ^{14}C depleted waters to the surface, which take up more atmospheric ^{14}C. Plausible changes in the wind stress alone are sufficient to explain the observed changes in the latitudinal gradient between the Little Ice Age and Medieval Warm Period (Figure 1). These results may have significant implications for current efforts to use atmospheric radiocarbon observations to infer regional fossil fuel emissions.

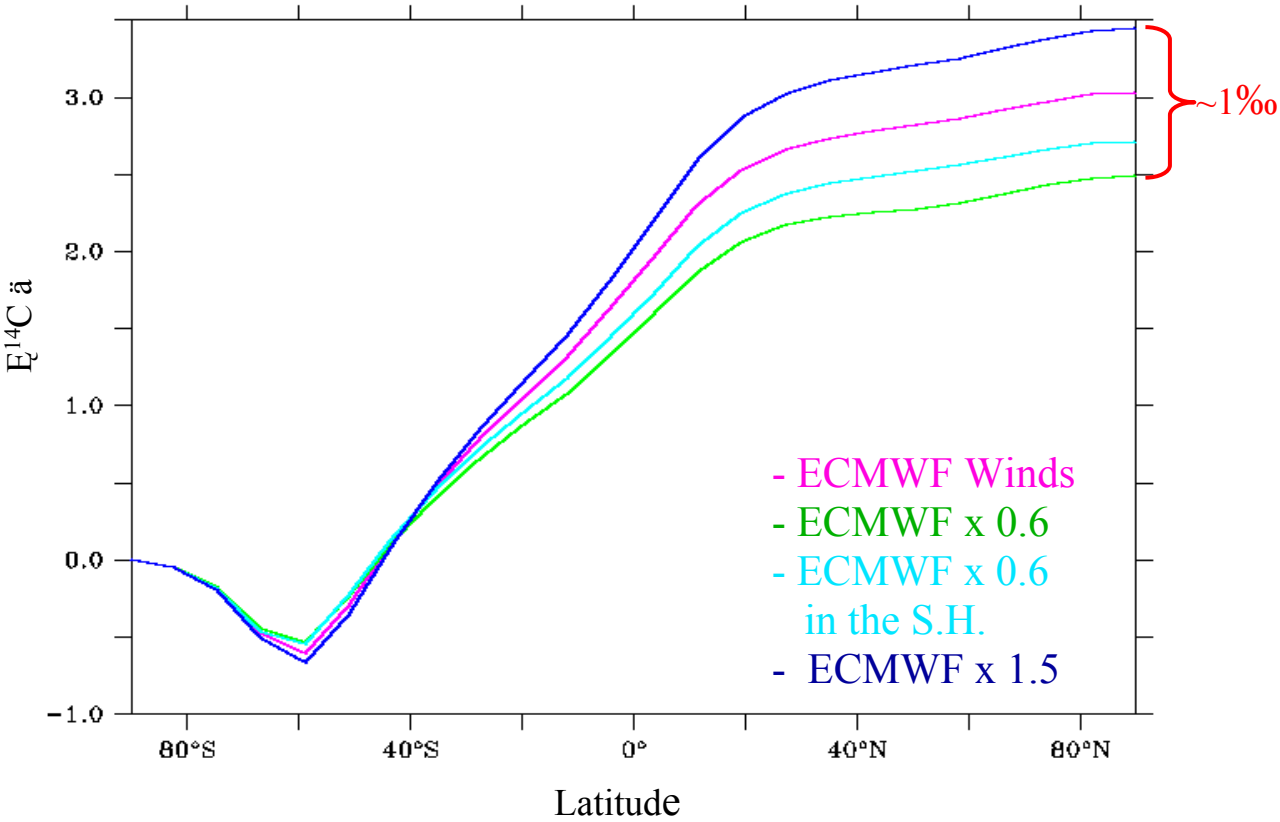

Figure 1. Preindustrial latitudinal gradient of atmospheric ^{14}C based on OGCM simulations in which the wind stress has been systematically increased from 0.6 times the ECMWF wind stress to 1.5 times the ECMWF wind stress. The range between the simulations is sufficient to explain the variability in the latitudinal gradient that has been observed in tree ring data.

$^{14}CO_2$ as a Diagnostic for Vertical Transport in Atmospheric Transport Models

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Atmospheric transport models can be used in combination with trace gas observations to infer sources and sinks of these gases. However, if the model transport is uncertain, this translates directly to uncertainties in the inferred sources and sinks. Recent studies indicate that the vertical transport in particular is poorly represented in most current models, especially over the continents. In the Transcom model intercomparison, the 12 different model estimates of the Northern Hemisphere land biosphere carbon sink ranged from 0.8 GtC/yr to 3.6 GtC/yr, with the differences likely attributable to differences in vertical transport.

Comparison of modeled and observed distributions of a surface-emitted tracer with a well-known flux distribution can be used to better constrain the vertical mixing. Observations of the radiocarbon content of atmospheric carbon dioxide ($\Delta^{14}CO_2$), as a proxy for fossil fuel CO_2 emissions, have the potential to be an excellent tool for this application.

Results from two atmospheric transport models (LMDZ and TM5) demonstrate that (^{14}C-free) fossil fuel CO_2 emissions are the dominant flux driving spatial variability in $\Delta^{14}CO_2$ over the Northern Hemisphere continents, contributing 90% of that variability.

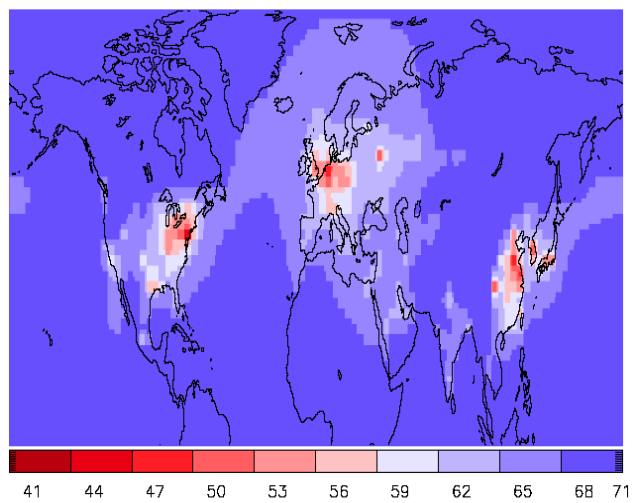

Figure 1. Mean annual Northern Hemisphere $\Delta^{14}CO_2$ surface distribution from LMDZ (for 2002-2007), demonstrating that the $\Delta^{14}CO_2$ distribution is dominated by the impact of fossil fuel CO_2 emissions, with low $\Delta^{14}CO_2$ values in regions where fossil fuel CO_2 is emitted, and values gradually increasing as the fossil fuel CO_2 is dispersed away from the source.

Other fluxes (including CO_2 fluxes from the terrestrial biosphere and oceans, and natural and anthropogenic ^{14}C production) have little impact on the $\Delta^{14}CO_2$ distribution in the Northern Hemisphere. However, different vertical mixing parameterizations in the models produce large differences in the simulated $\Delta^{14}CO_2$ spatial distribution (driven by the underlying fossil fuel CO_2 emissions), both in vertical profiles and surface transects, and these differences between models are large relative to uncertainties in the fossil fuel CO_2 flux. Recent advances in precision and sample size requirements for $\Delta^{14}CO_2$ measurements mean that $\Delta^{14}CO_2$ measurements can now be made routinely, using existing flask sampling networks, with sufficient precision to discriminate between model mixing scenarios. Initial $\Delta^{14}CO_2$ observations from a surface transect taken on the Trans-Siberian railway (TROICA-8 expedition), and for vertical profiles from several aircraft profiling sites, demonstrate the potential of this method.

Observations of Ground-Level Ozone in Lithuania: Monitoring Network and Results

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Emissions of the ozone precursors, nitrogen oxides and hydrocarbons, have decreased in many parts of Europe but the trend in ozone concentration does not necessarily follow the changes in precursors. To date, for a variety of reasons (e.g., geographical, meteorological and even economical conditions) the ozone concentration in Lithuania is more dependent on the ozone and its precursor levels in the neighboring countries than on the emission of the precursors in Lithuania itself. 13 stations are integrated into the ground-level ozone monitoring network in Lithuania. Nine stations are located in urbanized territories and four at the rural sites. The longest time series of ozone data is from the background station Preila. The increase of 0.95 $\mu g/m^3$ per year was found during the monitoring period of 1982-2007. The analysis of data during warm and cold periods showed a different growth rate. The ozone level during a cold period increases more than during a warm period. The KZ filter was applied to separate the ozone series components and to obtain an estimate of the long-term trend due to changes in emissions, removing the effect of meteorological conditions.

The experiment near the high-voltage transmission lines was conducted in September of 2007. The obtained results showed that they can be an important local source of ozone under certain meteorological conditions in the rural locality.

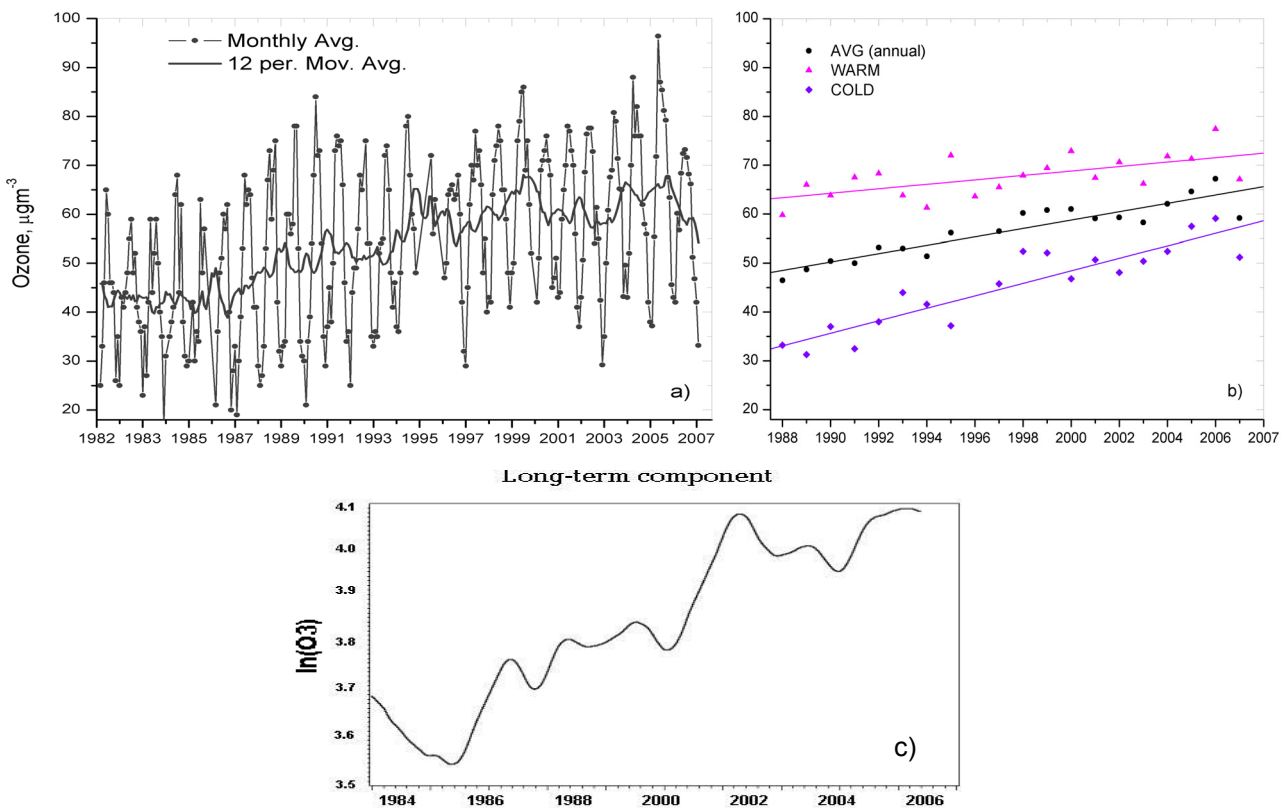

Figure 1. The variation of ozone concentration and its trend at the Preila station: **(a)** monthly average concentration and moving average, **(b)** linear trends of annual and average concentrations during warm and cold periods, **(c)** KZ filtered long-term component of ozone time series.

Daily Ozonesonde Launches at Barrow, Alaska: April 1-20, 2008

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NOAA ESRL, in partnership with Environment Canada, launched daily ozonesondes at 11 locations (see map below or http://croc.gsfc.nasa.gov/arcions/) from April 1-20, 2008, during the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) campaign, one of the most comprehensive examinations of the chemistry of the troposphere in the North American Arctic, carried out by researchers from NASA, various universities, and with collaboration from NOAA Earth System Research Laboratory scientists and Environment Canada (EC). Ozone profile data from the Barrow Observatory will be presented and compared to satellite and Dobson total column ozone. The ozonesonde balloon flights, going by the name Arctic Intensive Ozonesonde Network Study (ARCIONS), were coordinated with aircraft campaigns being conducted by NASA and NOAA during this time. In the spring phase of this project the focus of the ozonesonde measurements will be long-range transport into the Arctic, boundary layer ozone depletion over the Arctic Ocean, and stratosphere/troposphere exchange. The daily ozonesonde flights follow a model developed in the summers of 2004 and 2006 for earlier Intensive Ozonesonde Network Study (IONS) campaigns that provided a new understanding of the sources of tropospheric ozone over the mid latitudes of the US and Canada. In addition, these soundings provide valuable information for validation of satellite retrievals of tropospheric ozone profiles and for the flight planning for the campaign aircraft by providing a broad context of conditions in the Arctic.

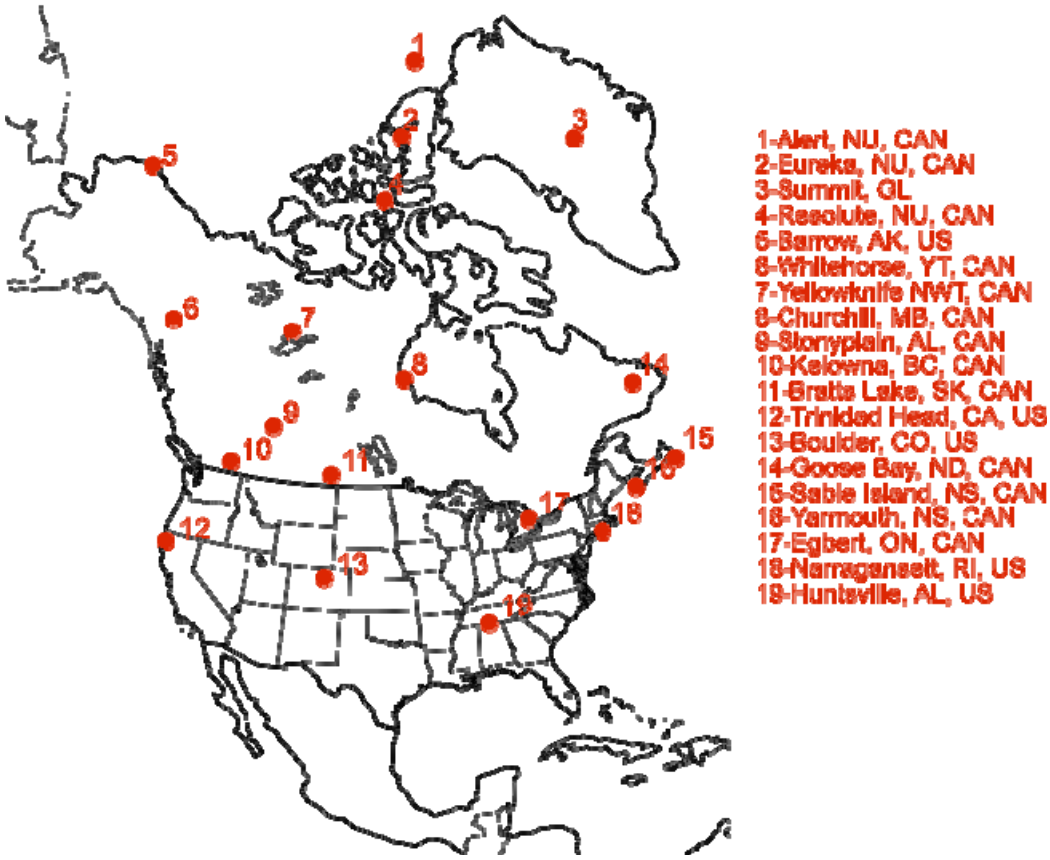

Figure 1. Arctic Intensive Ozonesonde Network Study (ARCIONS) ozonesonde sites.

Ozone Observations Over Mt. Kenya and Nairobi GAW (Global Atmosphere Watch) Stations

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The WMO/GAW stations Mt. Kenya and Nairobi are located close to the equator on the western end of the Indian Ocean. The Mt. Kenya station is a high-mountain site at 3678 m a.s.l., Nairobi is a NASA-SHADOZ ozone-sounding site at (1˚ 18S, 36˚ 45´E, 1795m asl. All sites are influenced seasonally by air masses from the W. Indian Ocean, biomass burning from southern Africa, and the Saharan/Arabian region, respectively. Measurements of the vertical profile of ozone concentration using balloon-borne ECC ozonesondes have been made weekly since 1996 at Nairobi weather observatory. There are 469 valid data among 509 samples. Carbon Monoxide observations and other trace gases are ongoing at Mt. Kenya GAW station since 2000. We present an analysis of trends and changes of the vertical distribution of ozone over Kenya. A statistical analysis of ozone profiles split into 3 layers reveals strong yearly variation in the free troposphere and the tropopause region, while ozone in the stratosphere appears to be relatively constant throughout the year. Total ozone measured by Dobson Spectrophotometer indicates lower values in OND [October, November, and December-*Rainy season*] and high values in JJA [June, July, August-*Cold dry season*]. The high altitude Mt. Kenya station Ozone is influenced by long range transport of air mass burning products from Southern Africa, Saharan and Arabian region. Diurnal cycles are consistent with up-slope winds and rising PBL during the day; and down-slope winds and inflow of free tropospheric air during the night. Ozone levels have shown to be higher on high altitude (Mt. Kenya) than Nairobi GAW observatory.

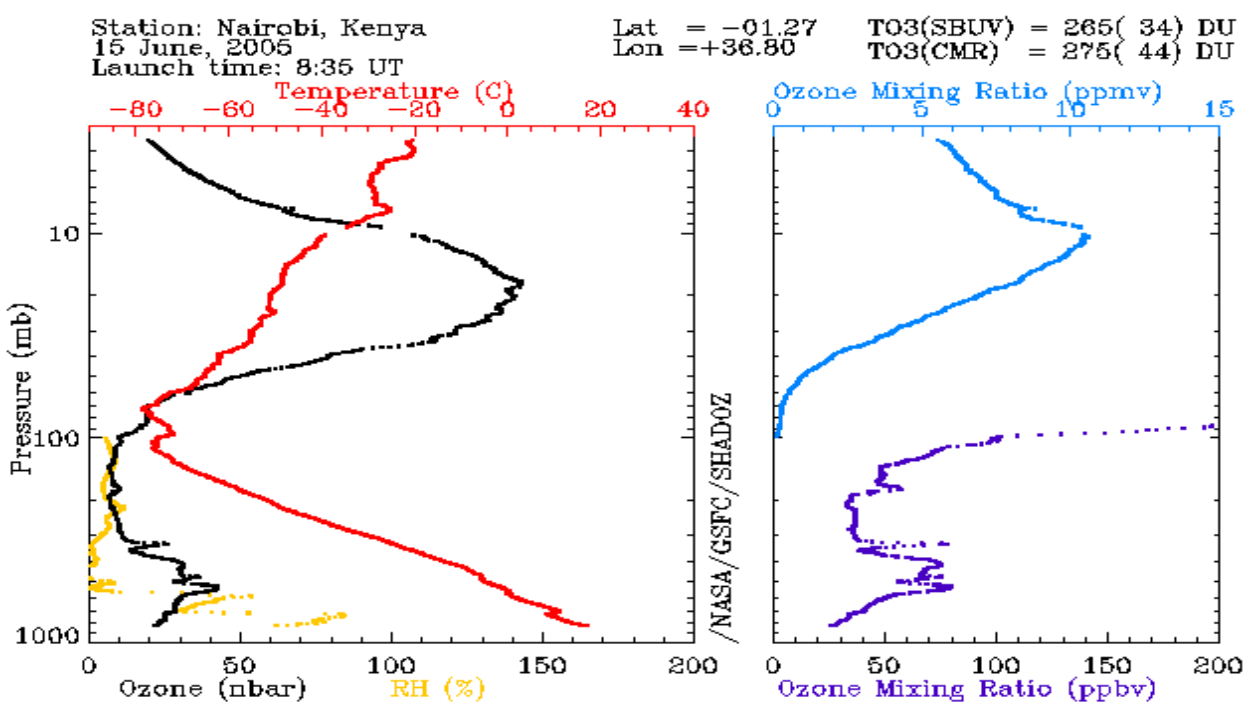

Figure 1. Ozone observations over Mt. Kenya and Nairobi GAW stations.

Initial Results from the International Halocarbon in Air Comparison Experiment (IHALACE)

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Chlorofluorocarbons and other halocarbons contribute to stratospheric ozone loss and can have large global warming potentials. Measurements of halocarbons and related compounds are being conducted by a number of groups in order to assess sources and sinks and to help verify the effectiveness of international treaties, such as the Montreal Protocol on Substances that Deplete the Ozone Layer. Many of these measurements are reported on independent calibration scales. Formal, well-established relationships between all major calibration scales have not been determined. Comparisons to date have been limited to bilateral experiments, exchange of data from co-located sampling sites, and a few limited round robin experiments. There is no formal international program for comparison or data quality management such as that for carbon dioxide. The International Halocarbon in Air Comparison Experiment (IHALACE), sponsored by NASA, World Meteorological Organization/Global Atmospheric Watch (WMO/GAW), and NOAA, involved the circulation of air samples in stainless steel cylinders among twenty one laboratories in nine countries from 2004-2007. Although the primary focus was on CFCs and related compounds, other trace gases, such as Nitrous Oxide (N_2O) and Sulfur Hexafluoride (SF_6) were also included. Preliminary IHALACE results will be presented.

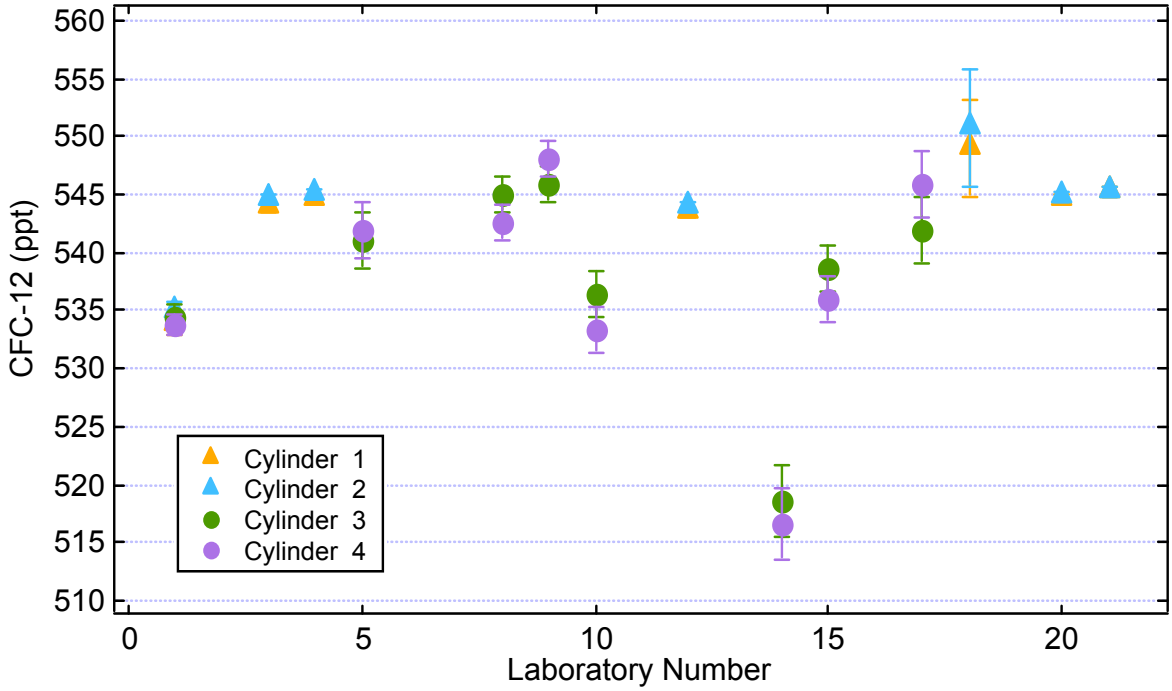

Figure 1. CFC-12 results reported from fourteen laboratories. Each laboratory received two cylinders containing background tropospheric air, hence two results were reported for each laboratory. NOAA ESRL served as the coordinating lab and analyzed all four cylinders.

Measurement of Internal Stray Light within Dobson Ozone Spectrophotometers

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Internal stray light within the Dobson ozone spectrophotometer limits the ability of the instrument to make accurate measurements at high total ozone amounts and high solar zenith angles (SZA). The effect is well known, and can be easily identified when observations are made on the direct solar beam over a half day at a northern high latitude site, especially in springtime. The effect is demonstrated by this: total ozone values calculated from the series of observations will show a sharp decrease after the SZA increases beyond a certain point. The actual SZA limit depends both on the quality of the individual instrument optics, the wavelength pairs used and the actual total ozone amount. The latter dependency on total ozone has made this a difficult problem to solve. Additionally, a recent analysis of comparative Dobson observations of the Umkehr effect (a SZA-dependent series of measurements on the clear zenith that are used to produce an ozone vertical profile) has shown that internal stray light produces incompatible results for compared instruments. We present a method of making the measurement of this internal stray light, using a small modification of the instrument, and an external filter. A change in the method of making the observations of the Umkehr effect and in the reduction of the data will likely be required to achieve the full benefit of this knowledge. The technique is also applicable to direct sun observations at high latitudes and high ozone.

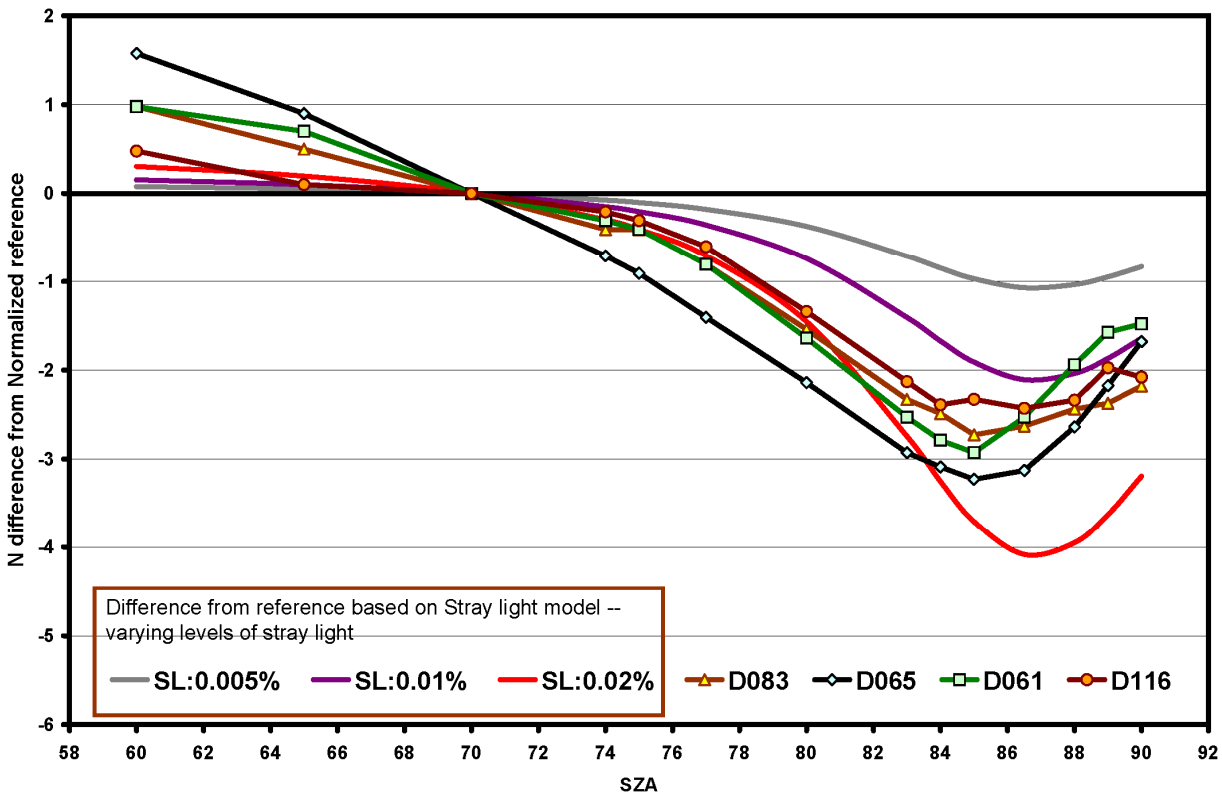

Figure 1. The difference curves (reference value minus observed value) from measurements made 27 Sept 2007, presented with the difference curves predicted from modeled straylight within the Dobson instrument.

Reconciling Estimates of SF_6 Emissions Using NOAA Observations

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The NOAA ESRL Carbon Cycle Group measures sulfur hexafluoride (SF_6) from discrete samples collected at ~60 sites globally. SF_6 is a strong absorber of terrestrial IR radiation, and it has a lifetime estimated at 3200 years. Taken together, these properties make SF_6 the strongest known greenhouse gas with a global warming potential of 22,800 over a 100 year time horizon. SF_6 sources include electricity distribution systems, magnesium production, manufacture of electronic circuit boards, automobile tires, and sneakers. SF_6 is inert in the lower atmosphere; its sinks are photolysis and reaction with electrons in the mesosphere.

SF_6 is the best known tracer for testing transport schemes used in atmospheric transport models. For example, Peters et al. [JGR, doi: 10.1029/2004JD005020, 2004] used an established emissions distribution in "Tracer Model 5" and found that the modeled latitudinal gradient was ~20% greater than the observations. To identify errors in transport, we need accurate estimates of the magnitude and distribution of SF_6 emissions globally.

Fortunately, we can assess the magnitude of emissions from observations, because the SF_6 lifetime is long enough, that all emissions remain in the atmosphere. SF_6 has increased from zero in pre-industrial times to more than 6 pmol mol^{-1} (ppt) in 2007. Since 1998, the average rate of increase in the global burden of SF_6 has been 0.21 ppt yr^{-1} (top panel), corresponding to 5.4 Gg SF_6 yr^{-1}. Our observations suggest that since the start of our measurements in 1997, SF_6 emissions have increased by ~15%. This increase in emissions has happened despite attempts to reduce SF_6 emissions under the Kyoto Protocol. Long-term measurements of SF_6 can be used to verify global emission inventories based on national statistics. SF_6 emissions calculated from the observed annual atmospheric increases (blue circles) are compared with emissions reported by Annex I countries (red triangles) to the United Nations Framework Convention on Climate Change (UNFCCC: http://unfccc.int). The large difference between the two estimates can be attributed to either a rapid increase in non-Annex I emissions or Annex I countries underestimating emissions reported to UNFCCC.

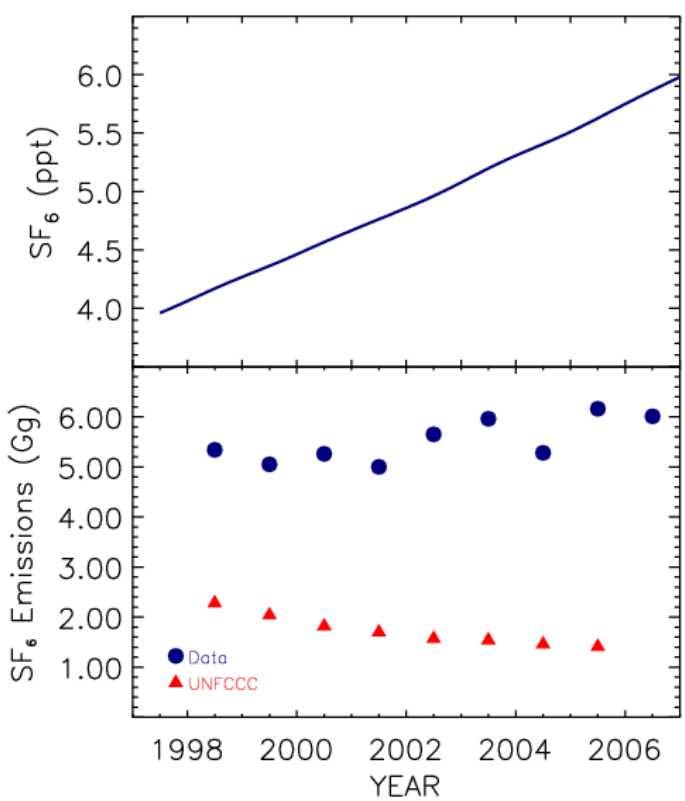

Figure 1. Globally averaged SF_6 trend from the NOAA ESRL global cooperative air sampling network (top). Global emissions of SF_6 calculated from annual increase (circles) and from emissions reported by Annex I countries to the UNFCCC (triangles). Annex I Parties include the industrialized countries that were members of the Organization for Economic Co-operation and Development (OECD) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

Forecast of UV Index by Means of an Empirical Model in the Republic of Panama

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Forecast of the UV Index can be accomplished by means of radiative transfer models as well as by means of empirical models. In general, radiative transfer models calculations are an important complement to measurements of UV irradiance from broad band meters. However, these models are an adequate forecasting tool, only under clear sky conditions. In the tropics, the main UV irradiance attenuation factor is cloudiness. Due to this fact, empirical models which take into account this factor are a more valuable tool for our latitude. The Laboratory of Atmospheric Physics scientific team at the University of Panama has developed an empirical model which predicts UV Irradiance and Index, at local solar noon. The input parameters for this model are: date, latitude, solar declination, terrestrial orbital eccentricity factor, and total ozone column.

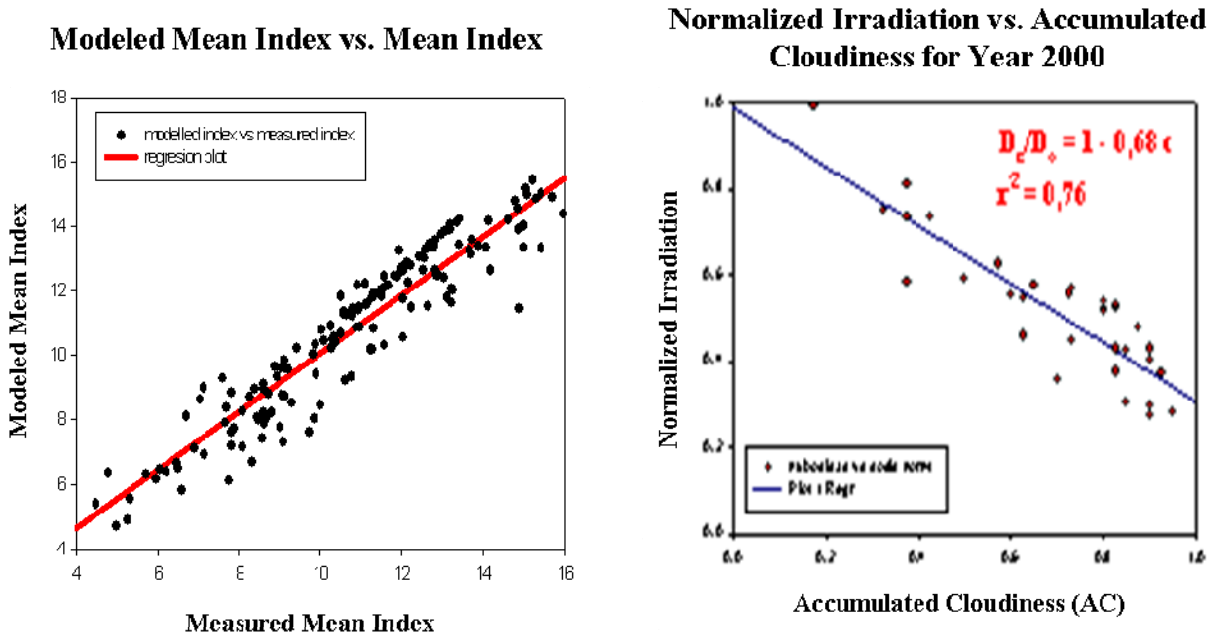

Figure 1. (left) Shows the model Mean UV Index at solar local noon vs the measured Mean UV Index. The correlation coefficient is $r^2 = 0.90$. **(right)** Shows the behavior of Normalized UV Irradiation or Dose vs Accumulated Cloud Cover Fraction. The correlation coefficient is $r^2 = 0.76$. UV-B radiation is measured in a continuous way, by means of broadband UV-B meters, model 501 UV-Biometers, installed at Panama City, David City and Santiago City.

U.S. Trends in Aerosol Optical Depth and Solar Radiation over the Past 10 Years

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[2]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309

Time series of network-wide annual averages were used to assess the 500 nm Aerosol Optical Depth (AOD) and solar radiation tendencies over the U.S. from 1997 through 2006. Station solar data were normalized as percent deviations from the station means before national annual averages were computed. Results show a solar "brightening" over the U.S. over the decade, which is consistent with brightening noted by others worldwide over the same period. Nationally, 500 nm AOD decreased through that period by about 0.02, which is comparable to decreases reported for the oceans and Europe. However, not all Surface Radiation (SURFRAD) stations exhibit AOD decreases over the decade. Eastern U.S. SURFRAD stations at Goodwin Creek, Mississippi and Penn State do show decreasing AOD, but the tendency at Bondville, Illinois was virtually stable, although its summertime AOD maxima did decrease over the last half of the decade. In the western U.S., where AOD levels are comparatively low, only Desert Rock, Nevada showed a decrease. Fort Peck, Montana and Table Mountain (near Boulder, Colorado) actually show slight increases that were highly influenced by wildfires from 2000 through 2006. When the years with the most abundant wildfires were removed from their AOD time series, decadal AOD tendencies for both stations went flat. If the decreasing AOD tendency in the eastern U.S. continues, both the direct and indirect effects of aerosols on incoming solar irradiance would diminish and contribute to the current solar brightening at the surface. Analogously, the cooling effect of the aerosols would also diminish. If climate change is causing drier conditions in the western U.S., then higher than normal numbers of wildfires are likely in the future and the resulting AOD increase in western U.S. AOD should continue.

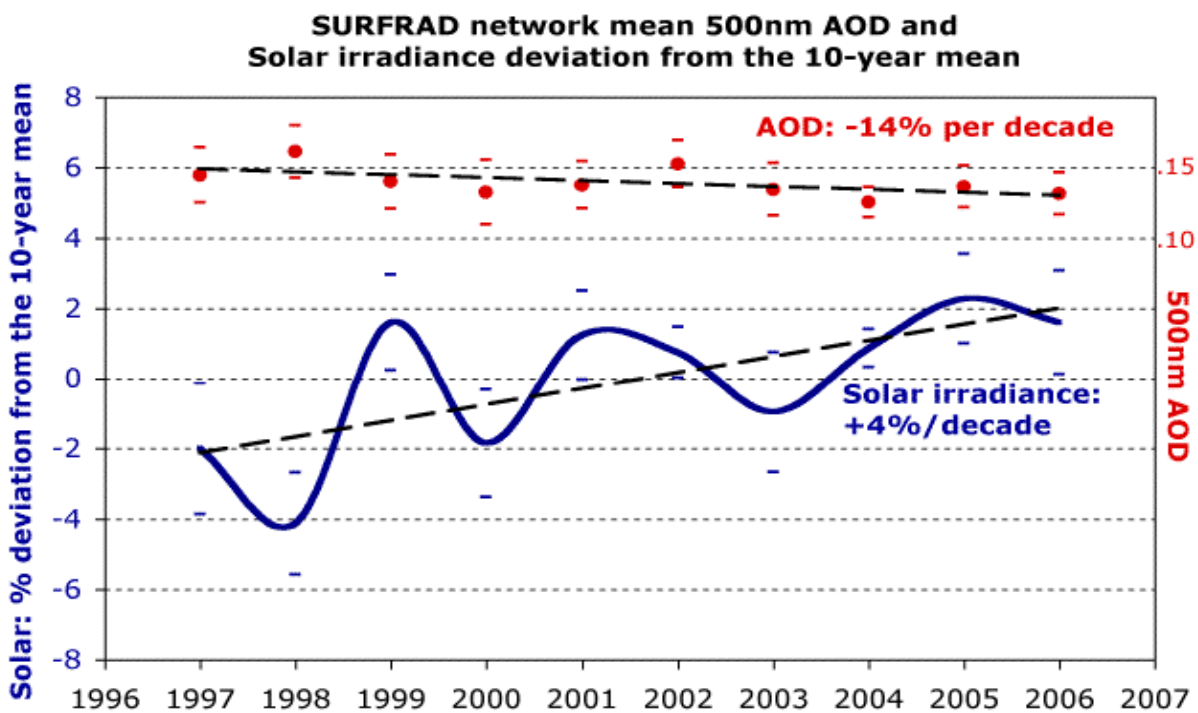

Figure 1. Decadal time series of 500-nm aerosol optical depth for all SURFRAD stations (red), and the trend in solar radiation, expressed as a deviation from the 10-year mean (blue) for the same stations. Dashes represent standard error of the annual means.

Establishing Climatological Validation of Aerosol Impact at Barrow: 'Ground Truth' vs. Satellite Measurements

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[4]Science Systems and Applications, Inc., Hampton, VA 23666
[5]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309
[6]Naval Research Laboratory, Remote Sensing Division, Washington, DC 20375
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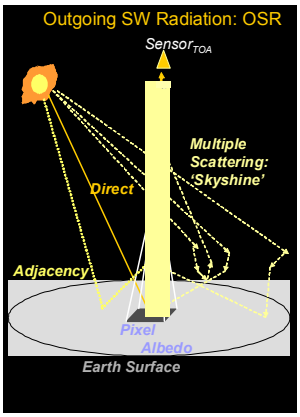
Recently, the 10th Anniversary Celebration for the Clouds and the Earth's Radiant Energy System (CERES) satellite mission was held at NASA. "The CERES data represent an entirely new generation of climate data accuracy and integration, both of which are critical to accurately predict future climate change." (B. Wielicki, Nov 27, 2007). Portions of the analyses of the CERES data are dependent upon data obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS), including aerosol optical depth and surface albedo; both instruments are aboard the polar orbiting Aqua and Terra satellites. Due to the differences in pixel size, ~25km vs. >1km, respectively, the matching of these analyses can be difficult, particularly over land. Additionally, the impact of aerosols upon climate change is not totally settled; aerosols in the atmosphere affect the earth's radiation budget in complicated ways, depending on their physical and optical characteristics and how they interact with solar and terrestrial radiation, as well as any indirect effects. The Barrow Observatory, located in a typically pristine background aerosol environment, provides the opportunity to assess the temporal impact of incursions of Eurasia dust and boreal smokes over an even smaller footprint, ~200 m, with decadal resolution. The comprehensive measuring systems in place near Barrow (NOAA ESRL and DOE ARM) present a unique opportunity to characterize the smoke and dust aerosols, both physically and optically. It is just these details that ultimately will provide critical 'ground truth' for the broader satellite-based climate change conclusions. Two Barrow events, each of approximately 3 days duration, of both dust and smoke, were captured by the full suite of NOAA and DOE surface instruments, such that the aerosol optical and physical properties could be established. Tying these events to overpasses of both CERES and MODIS, using an established radiative transfer (RT) code (MODTRAN™5), permitted a quasi-direct comparison, constrained primarily by the complex spatial footprints of each technique. Closure studies first replicated the surface measurements, and then reproduced the trends seen in the satellite data, including Direct Aerosol Radiative Forcing (DARF), outgoing shortwave radiation (OSR), Top-of-Atmosphere (TOA) albedo and net flux, all of which agree to within ~10% for both cases. Error analyses for both OSR and DARF show that the 10% differences arise primarily from the breadth of surface albedo variation and the determination of aerosol type.



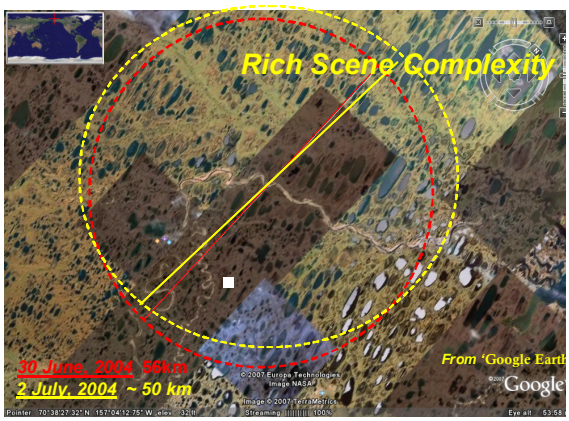


Figure 1. (a) The 'soda straw' pixel element for a radiative transfer code, including solar scattering and adjacency effects. The breadth of the range for adjacency is of order 1 km. **(b)** The larger red and yellow circles represent two overlapping CERES pixels over tundra. The albedo complexity is represented only by 1 value, after cloud clearing. The small white box depicts the MODIS pixel size, but the collection time is of order 1 week.

Temporal Variability of Aerosol Optical Properties, Ozone and CO Vertical Profiles over Rural Oklahoma

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Aerosol and gaseous constituents in the atmosphere influence the earth's radiative balance by scattering and/or absorbing radiation throughout the atmosphere. They also play a role in air quality with implications for human health, welfare and general aesthetics. In order to begin to understand how these atmospheric constituents affect radiative forcing and air quality it is necessary to know how much of each component is present and to connect that quantity with its impact. In the case of aerosol particles the impact is controlled not only by amount of particles present but also by inherent properties such as aerosol size and single scattering albedo. The spatial distribution (both horizontal and vertical) of these various gas phase and particulate components will also influence the atmospheric properties.

Here we present results from long-term measurements made by a light aircraft flying frequent vertical profiles over rural Oklahoma. The airplane was equipped with a suite of instruments including a nephelometer, a particle soot absorption photometer (PSAP) and an ozone monitor which provided continuous measurements of aerosol light scattering, aerosol absorption and ozone concentrations respectively. A programmable flask package (PFP) was also used to obtain discrete samples of various gas concentrations, including CO, at each flight level. Because of the long-term nature of this flight program we can address issues such as the seasonal variability of these constituents and look at how they co-vary with each other and various meteorological parameters.

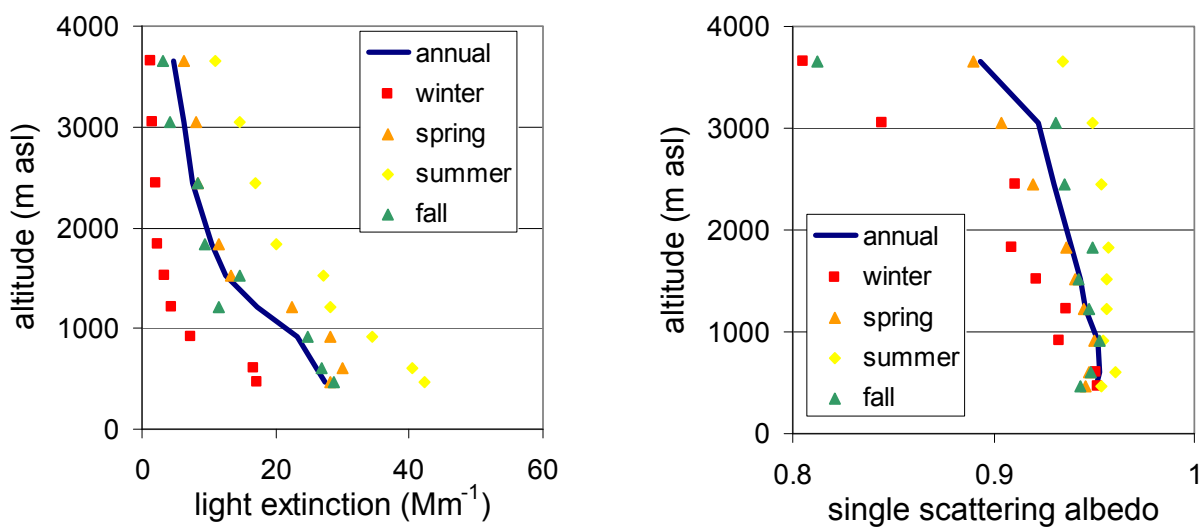

Figure 1. Median values of aerosol optical properties (extinction and single scattering albedo) plotted as a function of altitude and season.

The NOAA ESRL Airborne Aerosol Observatory: The First Two Years of Operation

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In June of 2006, ESRL began conducting regular (2-3 times per week) light aircraft measurements over central Illinois. The program is the Airborne Aerosol Observatory (AAO), and the platform is a Cessna T206H aircraft. The primary objective of this program is to obtain a climatology of aerosol properties aloft for evaluating aerosol radiative forcing and testing chemical transport models. During the first 18 months (through end of 2007) over 200 flights were conducted, with many of these near the Bondville, Illinois surface station. Statistical distributions and climatologies of aerosol properties have been compiled for the set of AAO research flights. Low altitude fly-bys of the Bondville station show that surface measurements of aerosol extinction are representative of aerosols in the lowest km of the column. Although individual profiles can be quite variable, the climatological profile of single-scattering albedo shows very little variation in the vertical. Comparisons of AAO aerosol data have been made with measurements collected on another Cessna 206 aircraft flying a similar aerosol package in profiles over Oklahoma. Examples of typical profiles and comparisons of profile climatologies at each site will be presented. Comparisons of AAO *in situ* measurements with Aeronet sunphotometer data will also be discussed.

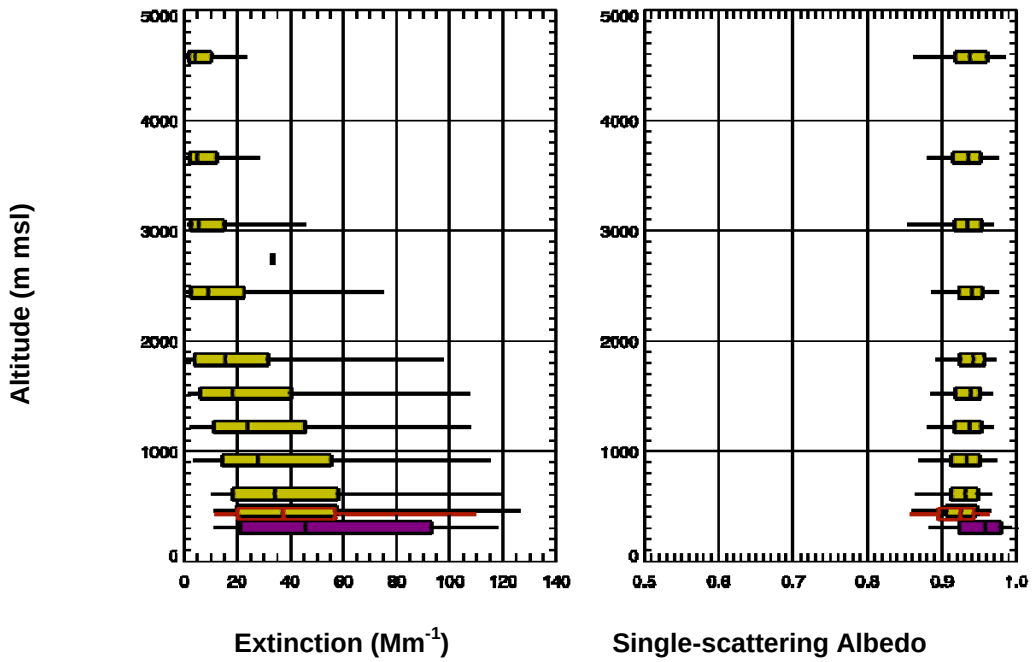

Figure 1. Statistical distributions of extinction (550 nm) and single-scattering albedo taken from AAO vertical profiles over Lodge, IL. Yellow boxes represent the distribution of data on the profile levels, purple boxes show the distribution of concurrent Bondville surface data, and the red outline boxes represent low-altitude Bondville station fly-by data. The surface extinction measurements agree well with aircraft data in the lowest km of the column after accounting for particle size sampling differences. Single-scattering albedo shows little variation in the vertical, but SSA at altitude is generally slightly lower than at the surface.

Comparison of RSS Spectral Measurements and LBLRTM/CHARTS Model Calculations for Clear Skies

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The visible/near-infrared rotating shadow-band spectroradiometer (RSS) was permanently deployed and has operated since May 2003 at the U.S. Department of Energy's Atmospheric Radiation Measurement program's central facility between Lamont and Billings, Oklahoma, USA. This paper focuses on the comparison between RSS measurements and line-by-line radiative transfer calculations with the model LBLRTM/CHARTS. The analysis of the spectral residuals is accomplished by examining the three components of this study: the radiation measurements, the calculations of the radiative transfer models, and the characterization of the atmospheric state. There are several critical inputs to the model in this wavelength range, including independent measurements of water vapor, ozone, and aerosol properties, as well as the spectral ground reflectivity. While aerosol optical depth can be derived from the RSS, this study uses an independent measurement from another sunradiometer at the SGP site; aerosol single scattering albedo and asymmetry parameters are derived from *in situ* measurements; the total water vapor column is obtained from a two-channel microwave radiometer; ozone is from the TOMS web site toms.gsfc.nasa.gov with supplemental ground-based data from the web site uvb.nrel.colostate.edu; and the spectral albedo is based on multi-filter radiometer measurements over pasture and over crops, the predominant surface types surrounding the site. To eliminate an additional source of uncertainty associated with the extraterrestrial spectrum, the analysis compares measurement-derived and modeled spectral direct and diffuse transmittances between 360 and 1070 nm, rather than irradiances. The RSS-transmittance is calculated by taking the ratios of the measured irradiances to the Langley-derived, top-of-the-atmosphere irradiances. A range of aerosol loading, surface conditions and solar positions are included in the study.

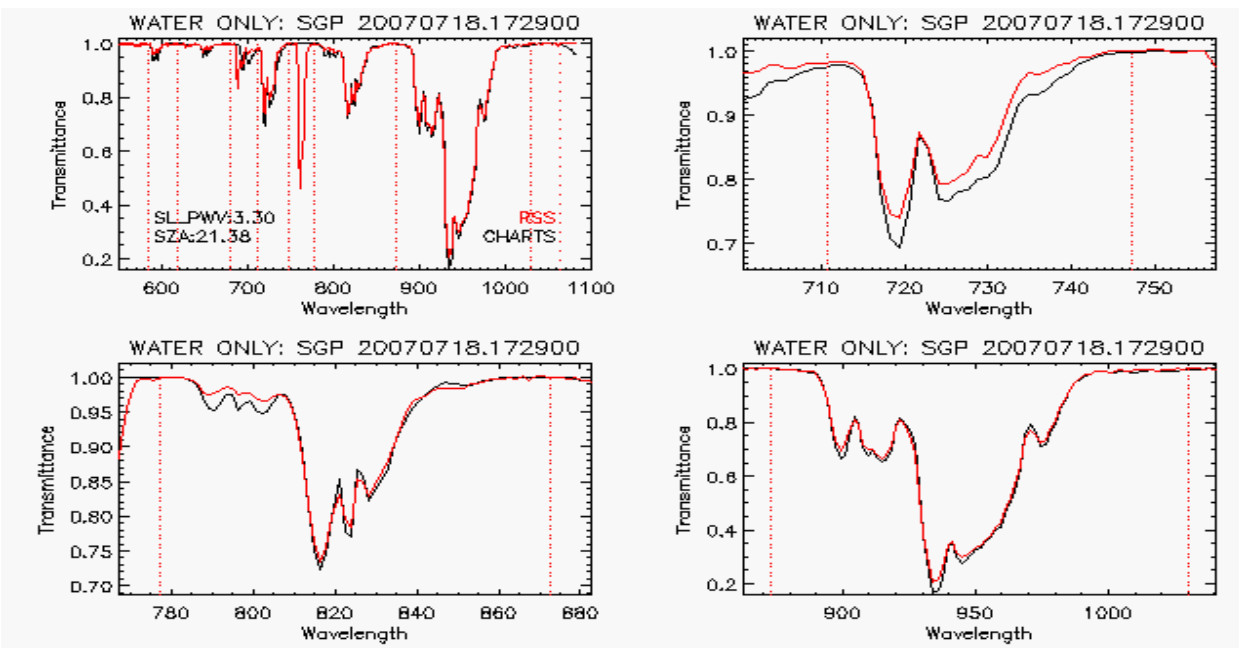

Figure 1. There are several strong water vapor absorption bands in the shortwave. To look at the consistency of the water vapor spectroscopic parameters and the precipitable water vapor measurements across each band, "water-only" LBLRTM/CHARTS clear-sky, direct-beam transmittance calculations are compared to those derived from the RSS for a case on July 18, 2007 at the ARM Southern Great Plain Central Facility. This figure illustrates in which bands the discrepancies exist. Many more cases have also been processed.

NEUBrew - The NOAA EPA Brewer Spectrophotometer UV Monitoring Network

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NEUBrew is a collaborative monitoring and research effort between NOAA ESRL and EPA's Office of Air Quality, Planning and Standards (OAQPS). The six station network is comprised of Brewer Mark IV spectrophotometers, chosen for their multi-function measurement capability. Presently the network is producing spectral UV irradiance, total column ozone, and ozone profile. Future data products will include UV-aerosol optical depths and total column abundance of NO_2 and SO_2. The NEUBrew network was established in 2006 with stations located at Ft. Peck, MT, Table Mtn, Boulder, CO, the University of Colorado's Mountain Research Station (MRS) lab at Niwot Ridge, CO, the University of Houston, Houston, TX, the Bondville Environmental and Atmospheric Research Site at Bondville, IL and the North Carolina State University's agriculture field site at Raleigh, NC. The sites were chosen with specific research goals and represent a mixture of clean, mildly polluted and heavily polluted locations. In addition to the Brewer Mark IV spectrophotometers each site is equipped with considerable ancillary instrumentation that allows for expanded research opportunities.

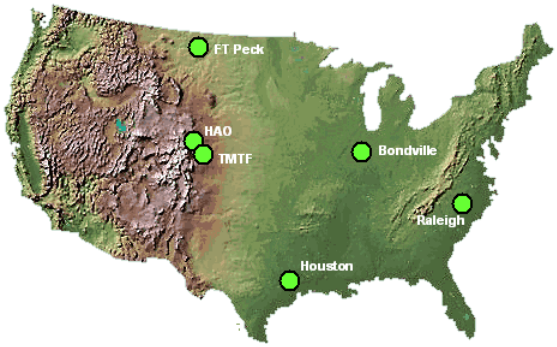

Figure 1. NEUBrew Network Stations

The NEUBrew website provides access to calibrated network data, data products, and on-line graphics displays for data and diagnostics. Daily Total Column Ozone (Figure 2), Instantaneous UV Index and Daily Erythemal Dose (Figure 3), Ozone Vertical Profiles, and Instantaneous UV Irradiance are examples of the data products currently available through the website.

Some research goals of the network are how tropospheric pollution (ozone and fine particles) affects surface UV levels, what effects clouds and other meteorological conditions have on surface UV levels, how surface UV levels are affected by stratospheric ozone concentrations, and how surface UV levels and total column ozone levels compare to similar ground-based systems as well as satellite measurements.

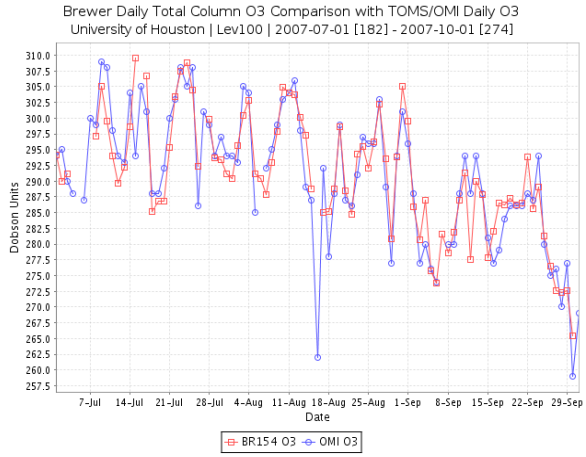

Figure 2. NEUBrew O_3 data comparison with OMI satellite data.

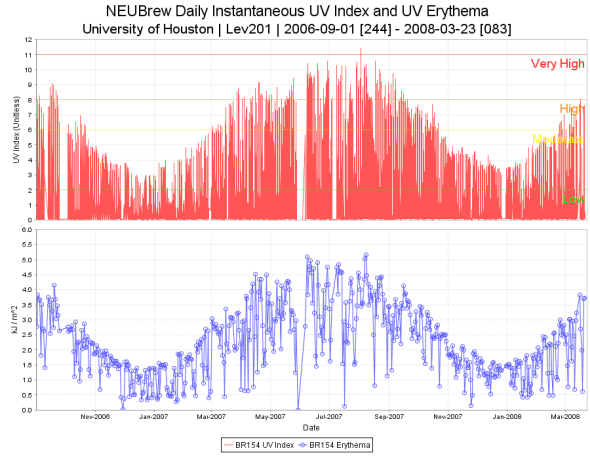

Figure 3. Long term NEUBrew UV Irradiance and Daily Erythemal Dose data.

MPLNET Measurements of Polar Stratospheric Clouds at the South Pole in 2007

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A NASA Micropulse Lidar Network instrument (MPLNET; 0.523 µm) collects full-time measurements of clouds and aerosols from the NOAA ESRL Atmospheric Research Observatory at the Amundsen-Scott South Pole Station (89.98˚ S, 24.80˚ W, 2.835 km MSL). In this talk, we describe polar stratospheric cloud (PSC) observations made during the recent 2007 season. PSC are ubiquitous at the South Pole from late-May through August, where climatological temperatures are coldest and most persistent of any point within the winter polar vortex. Their role in promoting catalytic ozone-loss chemistry in spring is well-known. PSC seasonal occurrence, including particle phase and composition, their vertical distribution and denitrification processes remain lingering aspects of the Ozone Hole paradigm that need reconciling so as to improve and validate numerical simulations of yearly ozone losses. Full-time MPLNET measurements, supplemented by on-site ozonesonde thermal and chemical profiles, are being processed to provide seasonal depictions of PSC macrophysical and thermodynamic structure. These data supplement satellite coverage of PSC and chemical concentrations near the Pole that are limited over the Antarctic Plateau by orbital tracks. We describe the 2007 dataset in relation to previous seasons (2000 and 2003-2006), highlight trends involving the relationship between PSC occurrence and ozone loss and introduce new data products available in May 2008.

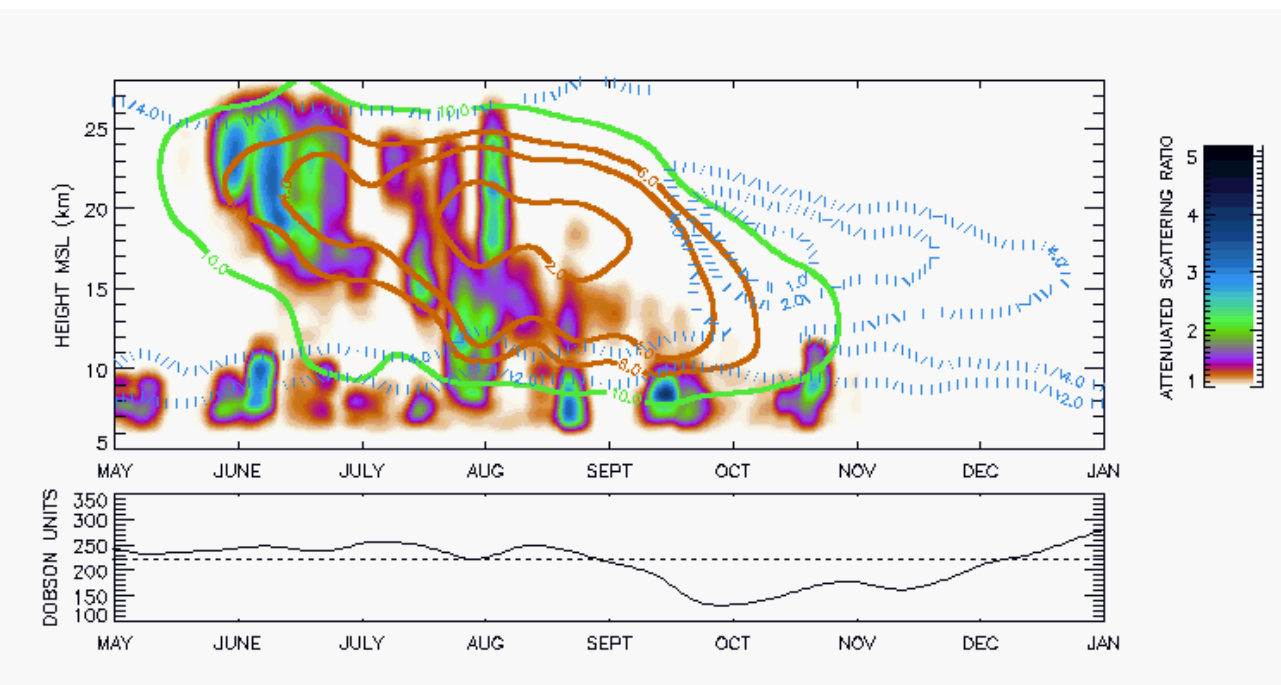

Figure 1. Smoothed MPLNET attenuated lidar scattering ratios for May – October 2007 at the South Pole from 5.0 - 28.0 km MSL. Overlaid for May - December are saturation isopleths for nitric acid trihydrate at 10.0 ppbv HNO_3/4.0 ppmv H_2O concentrations (green), ice frost-point isopleths for 6.0, 4.0 and 2.0 ppmv water vapor concentrations (red) and ozone partial pressure isobars for 4.0, 2.0 and 1.0 mPa (blue dashed). The bottom strip depicts Dobson Unit (DU) measurements for 2.85 km MSL, with the dotted line representing 220 DU, an approx. threshold for Ozone Hole conditions.

Cloud Properties Observed by an All-sky Camera System at the South Pole Station

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Since December 2005, an all-sky camera system is acquiring sky images for monitoring cloud conditions over the Atmospheric Research Observatory in the Amundsen-Scott South Pole Station as a collaborative research activity of NOAA ESRL and National Institute of Polar Research. The system includes a 3-color CCD camera with a fish-eye lens and a PC to process JPEG images for every ten minutes on a continuous basis during the polar daylight period. Such all-sky images are helpful not only for investigation of clouds and precipitation but also for judging clear/cloudy sky conditions in application to aerosol and/or radiation studies, although the observation is limited in November to March due to polar darkness and low temperature for normal operations. In this presentation, statistical features of the South Pole cloud properties, e.g., cloud amount and types, are shown from observation for three years in the Antarctic summer season.

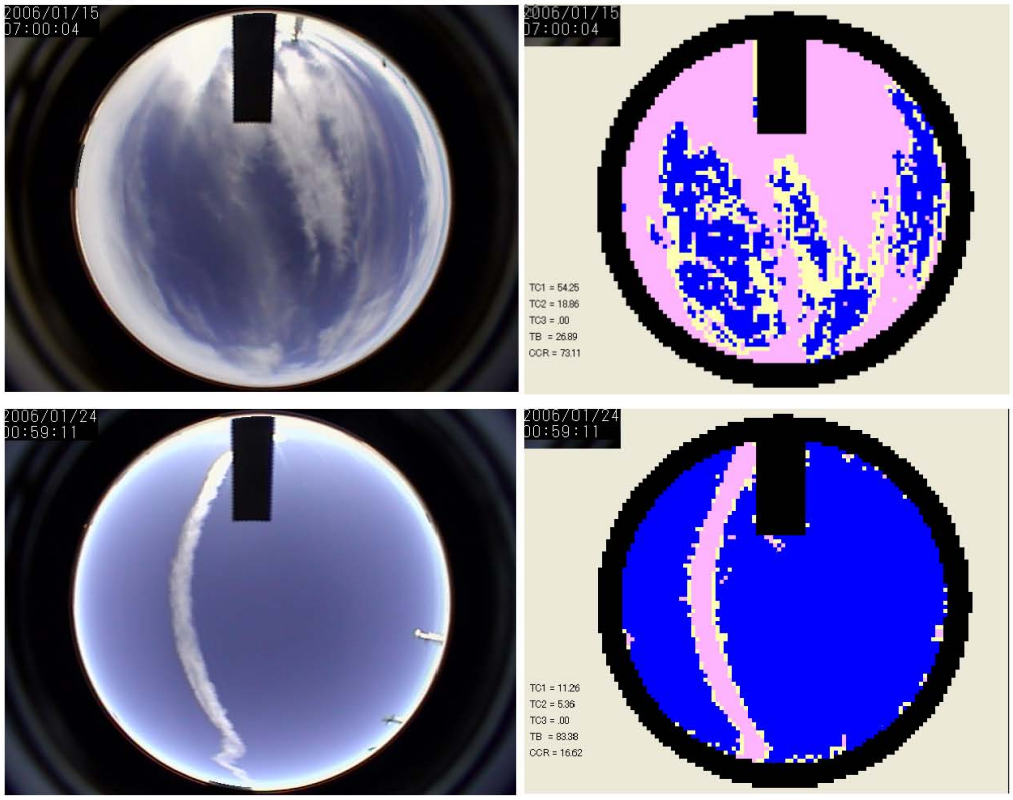

Figure 1. **Top:** all-sky image **(left)** of cirrus cloud over SPO taken by the Prede PSV-100 all-sky camera, 0700UTC, January 15, 2006, and cloud analysis image **(right)** corresponding to the left-hand side image. Cloud coverage was estimated to be 73 % from the analysis. **Bottom:** Same as the top panels but for contrail over SPO, 0059UTC, January 24, 2006. Cloud coverage was estimated to be 17 % from the analysis.

Researcher and Educator Long Term Collaboration with NOAA Earth System Research Laboratory Regarding Atmospheric Ozone Changes at the South Pole through the NSF PolarTREC Program

E. Bergholz[1], D.J. Hofmann[2], and B.J. Johnson[3]

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The NOAA ESRL team at South Pole has been monitoring the development of the annual ozone hole for over two decades using balloon-borne and ground-based instruments. Collaboration with educators has become an important aspect of NOAA ESRL to educate the public about ozone loss and ozone hole formation. Researcher Bryan Johnson and educator Elke Bergholz worked together at the South Pole in 1998/1999 as part of the NSF teacher outreach program called Teachers Experiencing Antarctica (TEA). It has been almost a decade when they collaborated again concerning the ozone changes at South Pole as part of the International Polar Year (IPY) and the PolarTREC (http://www.polartrec.com) teacher outreach program sponsored by NSF. The TEA and PolarTREC programs selected teachers to travel to polar locations to work with research scientists collecting data and running experiments at various Arctic and Antarctic field sites. While in the field, daily contact with classrooms and students around the globe was done through internet journals, answering emails from students, and webinars. This will be followed up with presentations to schools and the public relating Ms Bergholz's experience and new "hands-on" understanding of ozone measurements and ozone depletion over Antarctica, and discussing what changes in ozone we have seen at South Pole since the first outreach program nearly a decade ago.

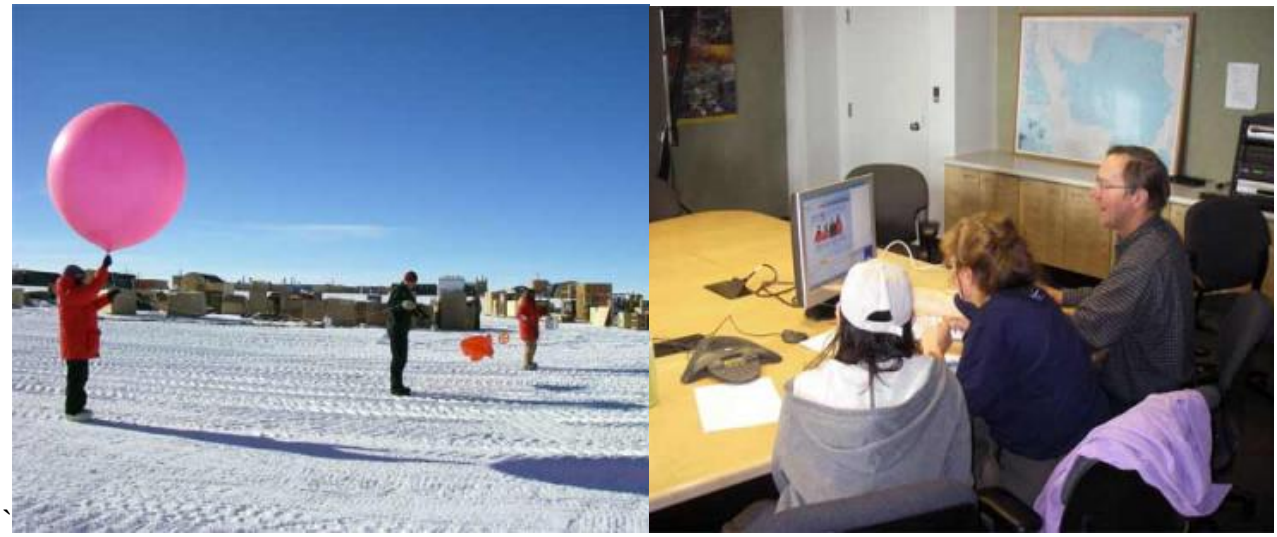

Figure 1. (left) South Pole ozonesonde launch during PolarTREC in December, 2007. **(right)** During one of the webinars, participants Amy Cox, Elke Bergholz, Bryan Johnson (shown here), and Dave Hofmann (in U.S.) show slides and answer questions about life and ozone science at the South Pole via internet connection from South Pole station.

Comparison of UV Climates at Summit, Greenland; Barrow, Alaska; and South Pole Station, Antarctica

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Spectroradiometric measurements of solar ultraviolet (UV) irradiance at Summit, Greenland; Barrow, Alaska; and South Pole are compared. Measurements of irradiance at 345 nm performed at equivalent solar zenith angles (SZAs) are almost identical at Summit and South Pole. The good agreement can be explained with the similar location of the two sites on high-altitude ice caps with high surface albedo. Clouds have little impact at both sites, but can reduce irradiance at Barrow by more than 75%. Clear-sky measurements at Barrow are smaller than at Summit by 14% in spring and 36% in summer, mostly due to differences in surface albedo and altitude. Comparisons with model calculations indicate that aerosols can reduce clear-sky irradiance at 345 nm by 4-6%; aerosol influence is largest in April. Differences in total ozone at the three sites have a large influence on the UV Index. At South Pole, the UV Index is on average 20-80% larger during the ozone hole period than between January and March. At Summit, total ozone peaks in April and UV Indices in spring are on average 10-25% smaller than in the summer. Maximum UV Indices ever observed at Summit and South Pole are 6.7 and 4.0, respectively. The larger value at Summit is due to the site's lower latitude. For comparable SZAs, average UV Indices measured during October and November at South Pole are 1.9 – 2.4 times larger than measurements during March and April at Summit. Average UV Indices at Summit are over 50% greater than at Barrow because of the larger cloud influence at Barrow.

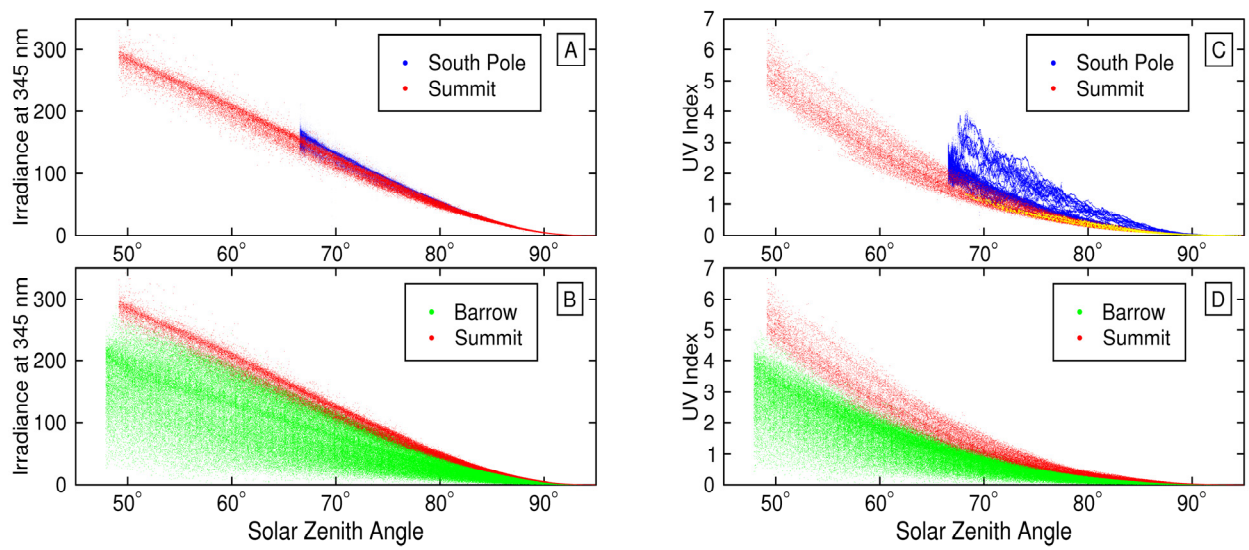

Figure 1. **Panel A:** Measurements of irradiance at 345 nm at South Pole and Summit in units of $\mu W/cm^2$. The slightly larger values at South Pole for equivalent SZAs are mostly due to the difference in Sun-Earth distance, with the Sun closer to the Earth during the austral summer. **Panel B:** Measurements of irradiance at 345 nm at Barrow and Summit. The region with the largest point-density in Barrow data is made up by clear-sky measurements during summer when albedo at Barrow is small. **Panel C:** UV Index at South Pole and Summit. Data from the South Pole fall into two groups: larger values than at Summit are measured in the austral spring (September – November) when the ozone hole greatly increases the UV Index at the South Pole. UV Indices measured between mid-December and March at the South Pole are similar to maximum UV Indices measured at Summit for equivalent SZAs at the two sites. **Panel D:** UV Index at Barrow and Summit.

Results of Snowfall/Blowing Snow Observations in Barrow

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Systematic errors caused by wind-induced undercatch, wetting and evaporation losses in precipitation measurement have long been recognized as affecting all types of precipitation gauges. The need to correct these biases especially for solid precipitation measurement has now been more widely acknowledged, as the magnitude of the errors and their variation among gauges became known and their potential effects on regional, national and global climatological, hydrological and climate change studies were recognized.

The Arctic climate is characterized by low temperature, generally low precipitation and high winds. Arctic precipitation events generally produce small amounts but they occur frequently and often with blowing snow. Because of the special condition in the Arctic, the systematic errors of gauge measured precipitation and the factor such as wind-induced undercatch, evaporation and wetting losses, underestimates caused by not accounting for trace amount of precipitation, and over/under measurement due to blowing snow, are enhanced and need special attention. Recognizing the importance of the precipitation data quality to cold region hydrological and climatic investigations, the Japan Frontier Research System for Global Change and the Water and Environmental Research Center (WERC), University of Alaska Fairbanks (UAF) have collaboratively undertaken a gauge intercomparison experiment and blowing/drifting snow observation study at Barrow Alaska ESRL research Lab. We installed the several precipitation gauges commonly used in the arctic regions for intercomparison, such as the Double fence intercomparison reference (DFIR), the Wyoming snow gauge system, the NOAA-ETI gauge, Hellmann gauge, the Russian Tretyakov gauge and US NWS 8" non-recording gauge. We also set up an automatic weather station for blowing/drifting snow observations in winter months to investigate blowing snow mass flux as functions of wind speed, air temperature, and height, and to evaluate their impact on gauge snowfall observations. This presentation will summarize the results of field observations and recommend future research needs.

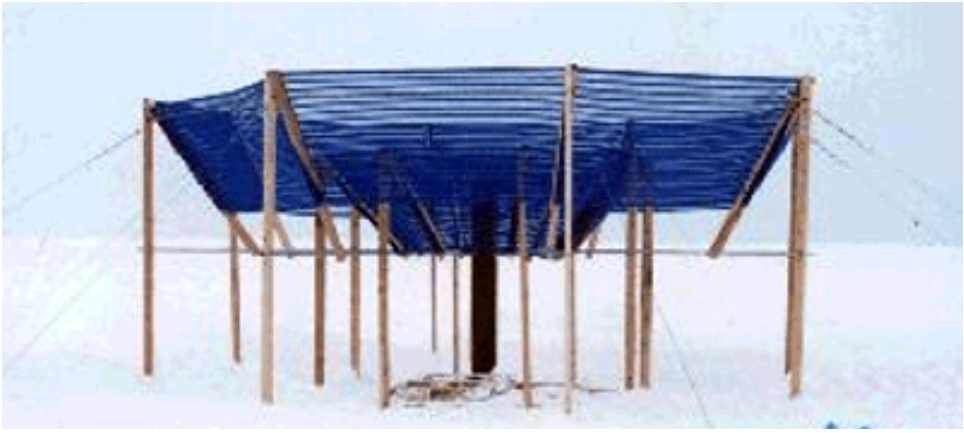

Figure 1. Wyoming-style snow fence/gauge at the Barrow ESRL site.

Annual Cycles of Atmospheric Trace Gases in the Tropical Marine Boundary Layer: First Measurements from the Cape Verde Observatory

K.A. Read[1], L.J. Carpenter[1], B.V.E. Faria[2], J.D. Lee[3], S. Moller[1], A.C. Lewis[3], L. Mendes[2], and M.J. Pilling[4]

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[2]Instituto de Naçional de Meteorologia and Geofisca, Delegação de São Vicente, Monte, CP 15, Mindelo, Cape Verde
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Long-term monitoring of atmospheric trace gas species has become a fundamental tool in the identification of key issues such as the globally increasing background concentration of tropospheric ozone (and also of aerosol), and in the understanding of the intercontinental transport of pollutants. Measurements of radiatively active species such as ozone along with the precursor compounds which lead to their presence have long been lacking in the tropical marine boundary layer, a crucial measurement region due to the high solar radiation and abundance of water vapour. The Cape Verde Observatory (16.848N, 24.871W) was established in October 2006, through the Natural Environmental Research Council (NERC) funded SOLAS (Surface Ocean Lower Atmosphere Study) initiative, as a long-term monitoring facility in order to address this lack of knowledge. Almost continuous measurements of ozone, carbon monoxide, nitric oxide, nitrogen dioxide, total reactive nitrogen, C_2-C_8 non-methane hydrocarbons, acetone, acetaldehyde, methanol, dimethyl sulphide and halocarbons have been obtained during its first 18 months of operation.

The observatory is additionally supported by the EU-funded project TENATSO (Tropical Eastern North Atlantic Time-Series Observatory) which contributes measurements of aerosol (physical and chemical characterization), and also of greenhouse gases including CO_2, CH_4, N_2O, and SF_6. Longer-term funding (until at least 2010) for the trace gas measurements will be through the NERC National Centre for Atmospheric Science (NCAS). The site has recently been given a WMO-GAW "global station" status for ozone, carbon monoxide and Volatile Organic Compounds (VOC) measurements.

Figure 1. The Cape Verde Observatory at Calhau on São Vicente, Cape Verde.

GEOSummit Baseline Measurements: Results and Interpretations of Year-Round Measurements

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[2]University of California, Davis, 105 Walker Hall, Davis, CA 95616
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Long term measurements of the Arctic atmosphere and surface snow provide insight to the relationship between aerosol and snow chemical compositions. Current research activities at the Summit Greenland Environmental Observatory (GEOSummit) include high temporal resolution year-round measurements of DRUM aerosol size and S-XRF elemental composition, snow accumulation and spatial variability, IC and/or ICP-MS trace element measurements of surface snow and snow pits, and other meteorological and snow properties. Year round snow samples allow for a better understanding of the magnitude and timing of seasonal cycles in aerosol elemental concentrations which are deposited and preserved in the snow pack. Several elements exhibit distinct seasonal timing of maximum concentrations found in surface snow samples (e.g., sea salts are largely deposited in the winter with dust predominantly deposited in the spring). Due to the high temporal sample resolution, unique events that transport dust or pollution from North America and/or Asia can be identified. The source regions of these unique events are identified using the Lagrangian Particle Dispersion Model (LPDM) FLEXPART. In addition, snow accumulation rates were measured over the snow sampling period, thus aiding the evaluation of wet and dry deposition as well as quantifying the inter-annual variability. Comparisons between surface snow and continuous ice core measurements indicate that the seasonal cycle of many of the elements are well preserved in ice cores, thereby allowing for better understanding of past atmospheric conditions reconstructed from the elemental records. Longer term records are necessary for comparisons to geophysical processes with multi-year periodicities (e.g. NAO, AMO, etc). Future plans include proposing to continue the Summit activities for another five years to better characterize annual to decadal variability in snowfall, elemental concentrations in aerosols and snow, and links with atmospheric circulations and transport.

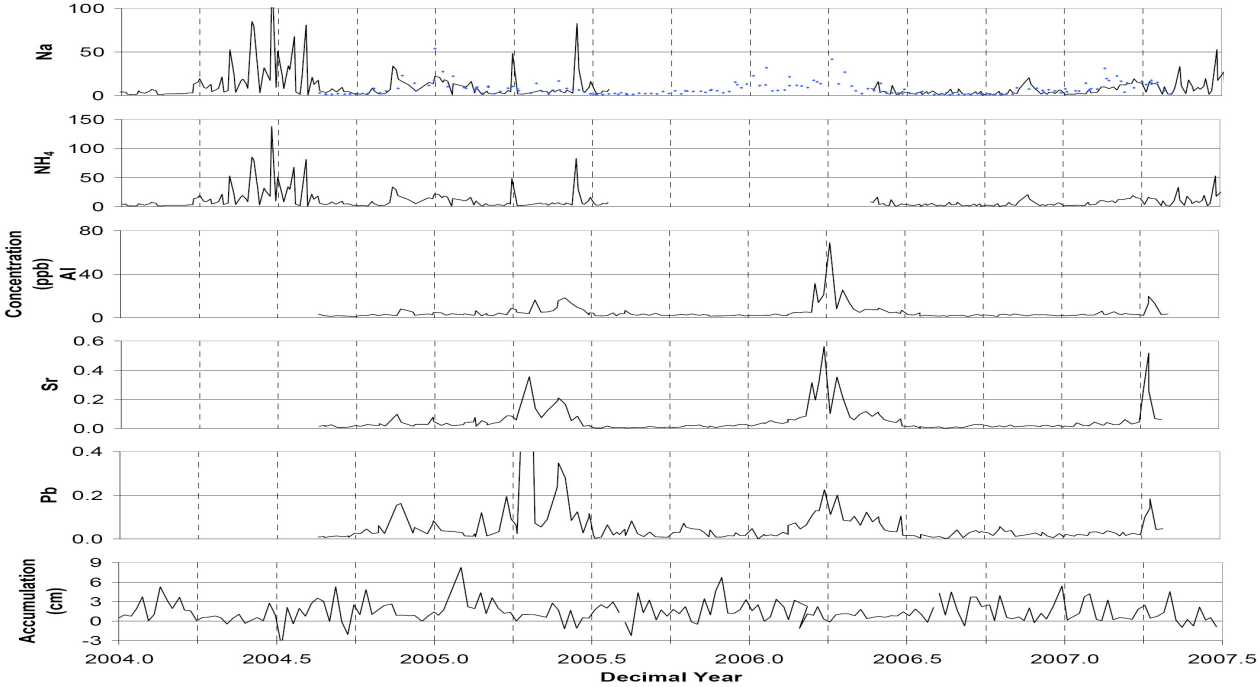

Figure 1. Example Subset of IC, HR-ICPMS and Accumulation Datasets.

Circum Arctic Monitoring of the Environment from Research Aircraft

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The Arctic is undergoing dramatic environmental changes as a consequence of global warming. Snow and sea ice cover have declined significantly in recent decades, resulting in a decrease in surface albedo, which has perturbed the energy balance of the earth-atmosphere system. Owing to a lack of observational data, the underlying processes that drive these interactions are not well understood and thus are inadequately parameterized in climate models. Monitoring and analyzing key geophysical processes in this remote region is a necessary step towards improving climate predictions on a global scale. While polar orbiters provide fair temporal and spatial coverage, satellite retrievals of atmospheric and surface properties require careful validation using in situ and ground-based measurements. CAMERA (Circum Arctic Monitoring of the Environment from Research Aircraft) is being proposed as a means to obtain data sets that can be used for a variety of important studies related to the Arctic climate system. Using a state-of-the-art research aircraft, the Alfred Wegener Institute (AWI) of Germany, with international partners, proposes to make circum Arctic flights to provide twice-yearly snapshots of sea ice conditions, aerosol and cloud properties and gas concentrations around the Arctic Basin. Unique, comprehensive data sets will be obtained for a myriad of investigations. NOAA ESRL has been invited to participate, specifically to monitor gases using their Programmable Flask Packages (PFP) and other devices to measure ozone, CO_2 and CH_4 continuously during these flights. In addition, NOAA will provide photometric measurements needed to characterize the horizontal and vertical properties of aerosols and evaluate their radiative impact on climate. The project will be described in terms of the primary goals of an April 2009 pilot flight, the tentative flight track (Figure 1), participating institutes, their deployments and what data sets will be obtained. The mission coincides with the culmination of the International Polar Year (IPY) and is being coordinated with ongoing ground-based and satellite observations being made at a network of Arctic observatories, several of which NOAA maintains monitoring programs. Finally, these flights will provide a test bed for developing systems that may one day be flown routinely on unmanned aircraft to monitor the Arctic environment.

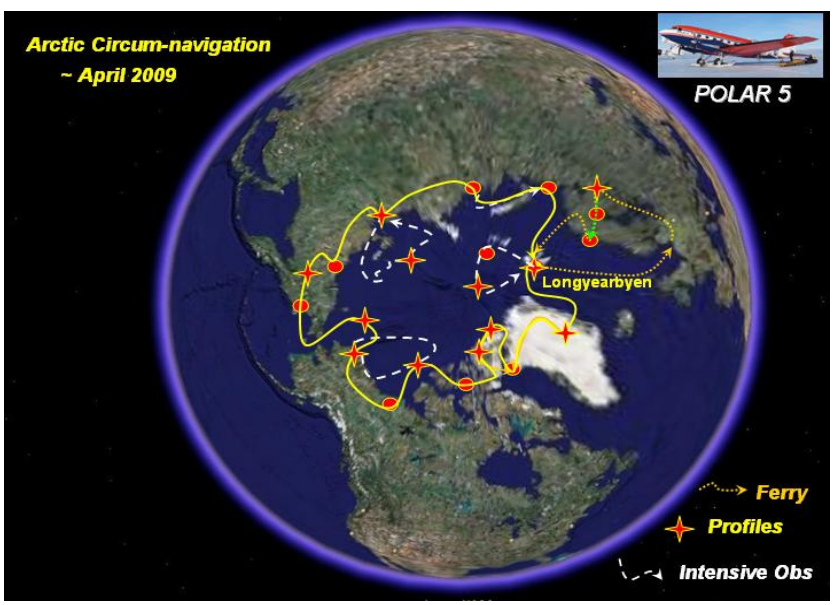

Figure 1. The tentative track of the AWI POLAR-5 circum Arctic flight planned for April 2009.

A New Global Database of Trace Gases and Aerosols at High Vertical Resolution

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A new database of trace gases and aerosols with global coverage, derived from high vertical resolution profile measurements, has been assembled; hereafter referred to as the 'Binary DataBase of Profiles' (BDBP). Version 1.0 of the BDBP includes measurements from different satellite- (HALOE, POAM II and III, SAGE I and II) and ground-based measurement systems (ozonesondes). In addition to the primary product of ozone, secondary measurements of other trace gases, aerosol extinction, and temperature are included. All data are subjected to very strict quality control and for every measurement a percentage error on the measurement is included. To facilitate analyses, each measurement is added to 3 different instances (3 different grids) of the database where measurements are indexed by: (1) geographic latitude, longitude, altitude (in 1 km steps) and time, (2) geographic latitude, longitude, pressure (at levels ~1 km apart) and time, (3) equivalent latitude, potential temperature (8 levels from 300K to 650 K) and time.

In contrast to existing zonal mean databases, by including a wider range of measurement sources (both satellite and ozonesondes), the BDBP is sufficiently dense to permit calculation of changes in ozone by latitude, longitude and altitude. In addition, by including other trace gases such as water vapour, this database can be used for comprehensive radiative transfer calculations. By providing the original measurements rather than derived monthly means, the BDBP is applicable to a wider range of applications than databases containing only monthly mean data. The presentation will describe the BDBP, show examples of the data stored in the data base (see Figure 1), and will discuss planned future applications of the data base including extending the database for use in constraining global climate model simulations.

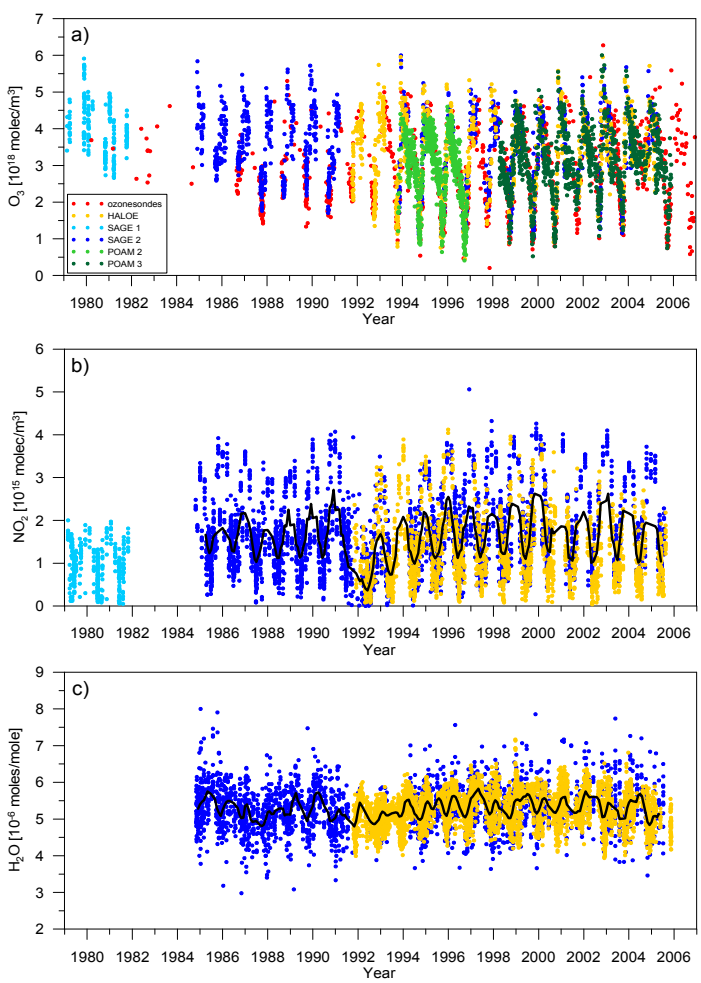

Figure 1. Individual data values extracted from the database for three different species. The different data sources are colour coded. **a)** Ozone (in 10^{18} molec/m^3) at 550K for equivalent latitudes south of 70°S. For clarity only every 5th data point of SAGE II, HALOE, POAM II and POAM III is plotted. **b)** NO_2 (in 10^{15} molec/m^3) at 25 km between 44-46°S. **c)** H_2O (in 10^{-6} moles/mole) between 7-9 hPa for 30-40°N. For clarity only every 5th data point from SAGE II and HALOE is plotted. The thick black lines represent the 3-month running mean of monthly means calculated from all data.

The Global Atmosphere Watch World Data Centre for Aerosols: Progress in Integrating Regional Surface Observations of *In Situ* Aerosol Physical and Chemical Properties into a Global Network

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The purpose and long-term goal of the WMO Global Atmosphere Watch (GAW) is to provide data, scientific assessments, and other information on the atmospheric composition and related physical characteristics of the background atmosphere from *all* parts of the globe. The atmospheric aerosol burden is a key atmospheric component, however characterizing the relevant aerosol properties involves a wide range of aerosol observations both extensive and intensive. The GAW Scientific Advisory Group for Aerosols has identified 5 *core continuous aerosol parameters* that need to be measured at global and regional stations (multiwavelength optical depth, mass in two size fractions, major chemical components in two size fractions, light scattering coefficient, light absorption coefficient) as well as additional continuous and intermittent measurements that are desirous for global and key regional stations. As well as individual stations, two collaborative efforts, the ESRL network of Baseline Regional and Cooperative stations and the EUSAAR (European Supersites for Atmospheric Aerosol Research) network provide the backbone of the GAW aerosol program worldwide. Both networks are actively reducing the uncertainties in observations, by promoting the use of consistent techniques, characterizing the precision and accuracy of the techniques through instrument inter-comparisons and working to harmonise meta-data descriptions. Both networks submit data to the GAW World Data Centre for Aerosols. EUSAAR data are collected centrally by the EMEP Chemical Coordinating centre in Norway and copied en-masse to the GAW World Data Centre for Aerosols (WDCA), using the NARSTO data exchange standard. A similar procedure is followed for the ESRL baseline and regional sites, the data are received by WDCA and then converted into the NARSTO data exchange standard for dissemination. This has several advantages, multiple data submissions are avoided, the resulting 'global' data sets are made available to the community in a consistent format and very importantly this format (the NARSTO data exchange standard) requires the co-provision of sufficient meta-data to allow informed use of the data sets. This last point is of great importance, where in the absence of a single harmonised global aerosol monitoring network, the characterization of the differences in techniques used to produce individual measurement datasets of the same parameter is crucial to understanding their comparability.

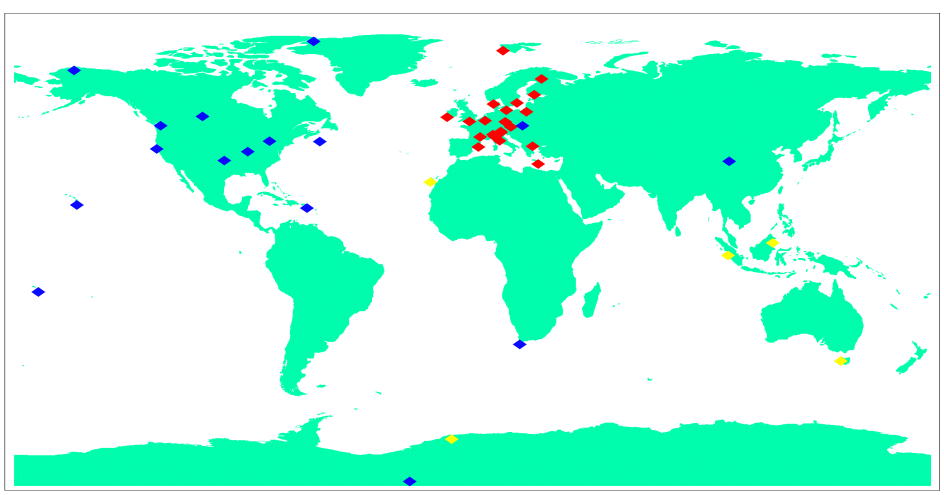

Figure 1. Map of combined EUSAAR (Red), ESRL and ESRL Collaborators (Blue) and Independent (Yellow) sites contributing to GAW.

Inter-Comparisons of Satellite, Dobson Spectrophotometer and Ozonesonde Ozone Data Observations Over Nairobi, Kenya

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The study sought comparison of satellite ozone data from 1985 to 2003 against ground based Dobson ozone spectrophotometer data from 1985 to 2001 and vertical profile Ozonesonde data from 1998 to 2003. The area of study was Nairobi Global Atmospheric watch station number 175 located at 1.30°S and 36.75°E at an altitude of 1660 meters (5450 feet) and the main objective was to ascertain the similarity of the three ozone data sets.

The inter-comparison was carried out by pairing two data sets of corresponding Julian day. The Root mean Square error, bias and percentage difference were used in order to achieve the objectives of the study. The root mean square (RMS) error for Dobson Satellite was between 3% and 15%, Percentage difference with Dobson as reference was between (0-20)%. Dobson Ozonesonde had RMS error of 27-93 %, Percentage difference of 0.5-17% with Ozonesonde as reference. While Ozonesonde/Satellite data sets yielded RMS error of 4-50%, Percentage difference of 4-50% with Ozonesonde as the reference.

In the three categories the RMS error was highly variable and large, i.e. between 3-93%. Percentage difference was equally variable ranging from 0.5-50% with ground based instruments, i.e. Dobson Ozonesondes. Bias was positive on average; otherwise it ranged between -2du to 19du. It is evident from the results that the three data sets are not comparable at the moment. There is serious need for strict and consistence reading of the ozone data on daily basis especially Dobson and the weekly Ozonesonde flights to allow further investigations and re-calibration of the three instruments. The Ozonesonde data had a lot of discrepancies partly because of vertical dynamics of Ozone and that of the Balloon carrying the Ozone sensors. Therefore during re-calibration the above should be considered.

Figure 1. Dobson D018 now is being operated at the Nairobi Kenyan Meteorological Department Facility.

The Nonhydrostatic Icosahedral Model

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ESRL is developing a new global finite-volume Nonhydrostatic Icosahedral Model, named the NIM, for earth system modeling, and weather and climate prediction. The model uses innovations in model formulation similar to those of the hydrostatic Flow-following Icosahedral Model (FIM) developed by ESRL and now being tested for future use by the National Weather Service as part of their operational global prediction ensemble. Innovations from the FIM used in the NIM include:

* A local coordinate system remapped to a plane for each grid point,
* Grid points in a linear horizontal loop that allow any horizontal point sequence,
* Flux Corrected Transport formulated based on the high-order (3rd Order) Adams-Bashforth scheme to maintain conservative positive definite transport,
* All differentials evaluated as line integrals around the cells,
* Strict conservation of passive tracers to the round-off limit, and
* Computational design to allow for scalability to hundreds of thousands of processors.

The FIM and NIM models use finite-volume techniques pioneered by S. J. Lin of GFDL. The NIM will use the vertically Lagrangian coordinate system developed by Lin. It will use the Earth System Modeling Framework and be part of a modeling system being developed by ESRL, GFDL and AOML. Numerical design goals of the NIM include the development of Piecewise Parabolic third order differencing and Vandermonde polynomials allowing high order approximations of local variables in the horizontal, and a Lagrangian Riemann Solver for vertical differencing. NIM will have the capability to run globally at kilometer scale resolution, which would allow convective macro-phenomena like the Madden-Julien Oscillation to be explicitly predicted. Other important properties include the high conservation needed for earth system modeling of chemistry and aerosols.

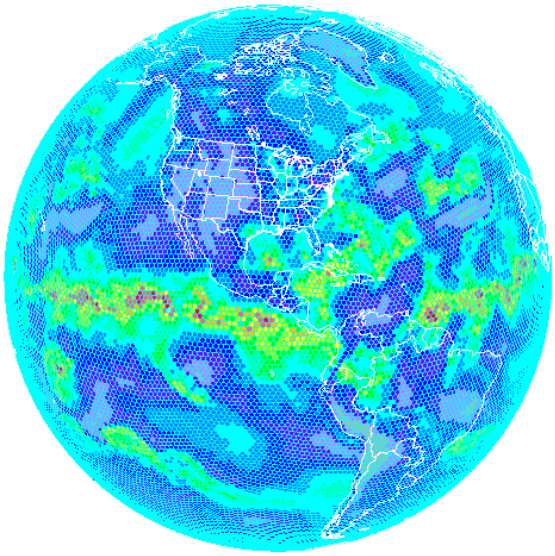
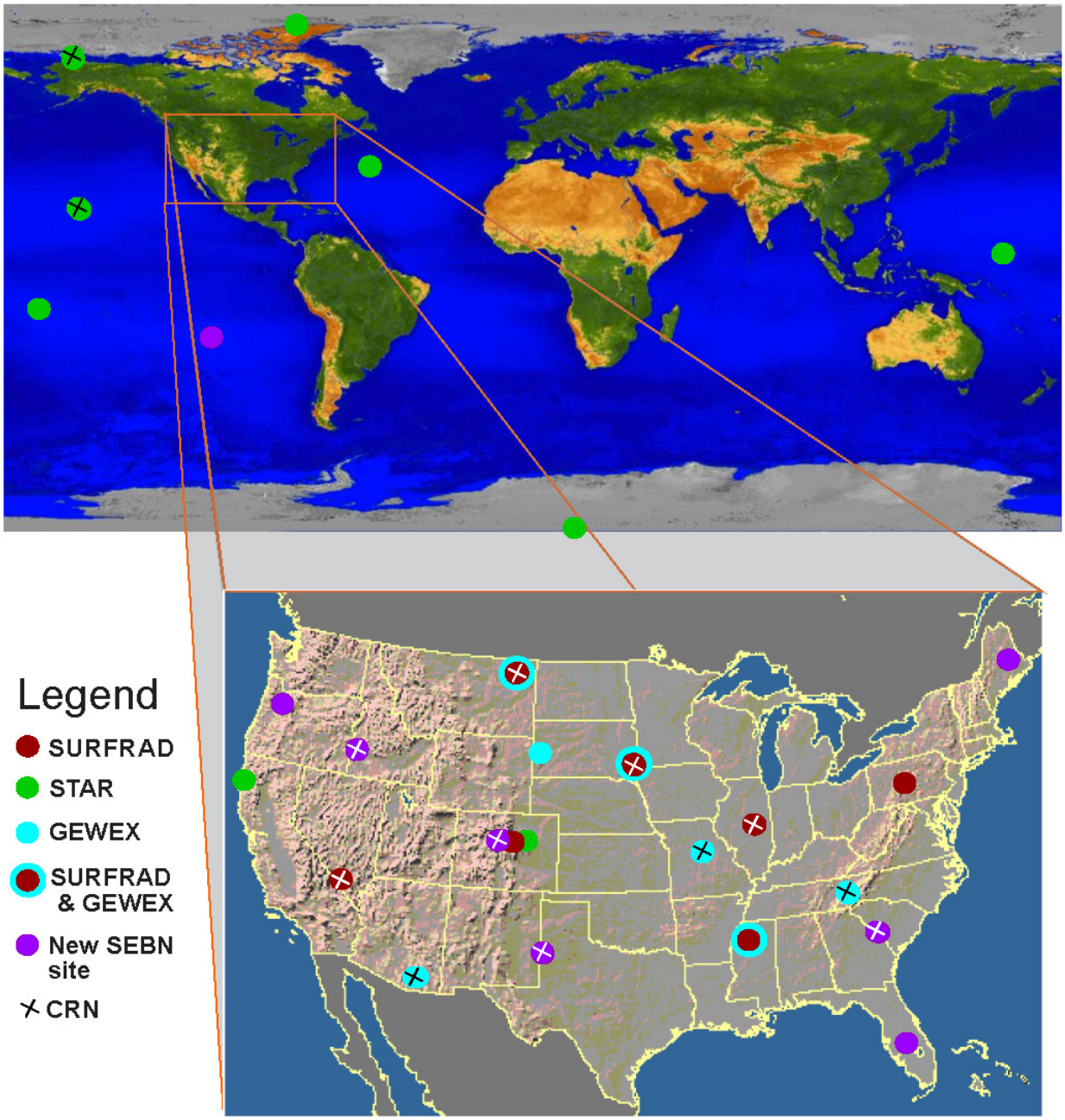


Figure 1. Shows FIM 24-h forecast integrated cloud water superimposed on icsoahedral grid.

NOAA Surface Energy Budget Network (SEBN)



Shown are the sites for the proposed NOAA OAR Surface Energy Budget Network (SEBN), and the current status of those sites. The SEBN will integrate two existing ESRL GMD surface radiation networks (STAR and SURFRAD) and a surface energy flux network (ARL/GEWEX) as well as overlap with the Climate References Network (CRN). Completely new sites will be added to enhance climatic-ecosystem representativeness and spatial coverage, as well as to better contribute to the international Baseline Surface Radiation Network (BSRN) sponsored by World Climate Research Program and the Global Climate Observing System, both components of GEOSS.