stratosphere. After the initial period of growth the perturbations have the same structure as the unperturbed atmosphere. Although the forcing is restricted to the northern hemisphere the perturbations encompass the whole atmosphere and develop on the same time scale on both hemispheres.

Perturbations grow with time squared both when zonal mean and single cell values are considered. Such a power law growth suggest the existence of a finite predictability time which is independent of the initial perturbation as long as it is small.

In the unperturbed atmosphere the stratospheric variability has the form of downward propagating stratospheric vacillations. However, in the initial period of growth the perturbations do not propagate downward and seem in general uncoupled to the background vacillations. This suggests that the downward propagation is a robust feature determined more by the processes in the troposphere than the state of the stratosphere. We note that downward propagation may still be a source for enhanced predictability of near-surface weather.

A22B-09 1555h INVITED

Long-term Solar Forcing of the Arctic Oscillation/North Atlantic Oscillation

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We examine the climate response to solar irradiance changes between the late 17th century Maunder Minimum and the late 18th century. Global average temperature changes are small (≈0.3–0.4 K) in both a climate model including stratospheric ozone feedbacks and in empirical reconstructions. Regional temperature changes, however, are quite large. In the model, these occur primarily through a forced decrease in the amplitude of the Arctic Oscillation/North Atlantic Oscillation (AO/NAO) variability pattern. This leads to colder temperatures over the Northern Hemisphere (NH) continents, especially in winter (1–2 K), in agreement with historical records and proxy data for surface temperatures.

A22B-10 1615h

Simulated excitation of the Arctic Oscillation by orbital forcing

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The observed solar forcing over the past 165,000 years is imposed on an atmosphere model coupled to a mixed layer ocean to study the response of the Arctic Oscillation to orbital forcing. The orbitally-forced changes in the surface pressure field project strongly onto the typical spatial patterns associated with both the Pacific and Atlantic centers of action of the Arctic Oscillation. Thus orbital forcing excites preferentially the characteristic mode of variability exhibited by the unforced climate system. Feedbacks between eddies and the mean flow are responsible for this, just as they are responsible for the existence of Arctic Oscillation in the unforced climate. When orbital forcing intensifies or weakens the northern hemisphere jet stream through an change in the equator-to-pole temperature gradient, the anomaly of the jet stream is reinforced where eddy activity is large. This results in a larger pressure signal in the storm track regions. Thus perturbations to the mean flow, whether internally-generated or orbitally-forced, are amplified the most in the storm track regions. These results have interesting implications for past variations of the Arctic Oscillation and NAO, particularly over the past 10,000 years.

A22B-11 1630h

Mechanisms of Arctic Oscillation response to volcanic aerosols and ozone changes caused by the 1991 Mt. Pinatubo eruption

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All strong equatorial volcanic eruptions during the period of instrumental observations have forced a positive phase of the Arctic Oscillation (AO) for one or two years following each eruption. The conventional view is that the volcanic effect on the AO is caused by aerosol heating in the tropical lower stratosphere that produces a stronger polar vortex that prevents the propagation of planetary waves into the polar stratosphere. A shift from transparent to reflective (for planetary waves) stratosphere changes the "top boundary condition" for the tropospheric flow and affects the tropospheric circulation. Here we study the response of Arctic Oscillation to aerosols and observed ozone changes after the June 15, 1991 Mt. Pinatubo eruption in the SKYHI GCM to test the AO mechanism.

An enhanced positive phase of the AO is reproduced in the model when forced with either aerosols or ozone. For the ozone case, stratospheric cooling, caused by ozone depletion in winter and early spring in the north polar region, increases the temperature gradient between the pole and midlatitudes in the lower stratosphere strengthening the polar vortex and the AO.

Experiments without aerosol absorption (stratospheric heating) show as strong an AO response as with the total aerosol forcing. This suggests that aerosol stratospheric warming in the tropical lower stratosphere is not the dominant AO mechanism. Stratospheric aerosols can also affect the AO by cooling of the land surface and the lower troposphere. This cooling, which is strongest in low latitudes especially in winter, reduces the tropospheric meridional temperature gradient, which leads to a decrease of the mean zonal energy and amplitudes of planetary waves in the troposphere. The corresponding decrease of decelerating Eliassen-Palm flux into the lower stratosphere causes a strengthening of the polar vortex and triggers the "wave feedback," as previously discussed. We suggest that this mechanism can also be applicable to a long-term AO trend caused by greenhouse gases, because they, due to polar amplification, also weaken the tropospheric temperature gradient.

A22B-12 1645h

Anomalous Atmospheric Circulations Forced by Volcanic Aerosols

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A Principal Component Analysis (PCA) and Combined PCA (CPCA) is applied to 30 mbar and 300 mbar Northern Hemisphere geopotential height fields, with temperature as the combined field. In the stratosphere, CPCA is found to extract a strong volcanic signal. This method and the resulting volcanic modes are compared to the traditional PCA which extracts only a weak volcanic signal. The stratospheric volcanic modes, found with CPCA, are different patterns from the leading linear PCA mode, or Arctic Oscillation (AO), suggesting that the system's response to the volcanic forcing is not obvious. No clear volcanic signal can be extracted from a tropospheric analysis, due in part to the weaker volcanic influence, the more chaotic nature of the lower atmosphere, and other forcings such as El Nino. However, a vertical CPCA, combining 30 mbar and 300 mbar heights, extracts the volcanic modes at both levels. The resulting tropospheric volcanic mode is shown to have similarities to a composite map of 300 mbar heights representing the difference between years with a strong polar night jet and years with a weak one.

A31A MC: 123 Wednesday 0830h

The Arctic Oscillation and the North Atlantic Oscillation: Ocean Coupling and Climate Change *(joint with OS)*

Presiding: **J Wallace,** University of Washington**; D Shindell,** NASA Goddard Institute for Space Studies

A31A-01 0830h INVITED

Tropical Origins for Recent North Atlantic Climate Change

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Using large ensembles of climate model simulations, evidence is presented that North Atlantic climate change since 1950 is linked to a progressive warming of tropical sea surface temperatures. The ocean changes alter the pattern and magnitude of tropical rainfall and atmospheric heating, the atmospheric response to which includes the spatial structure of the North Atlantic Oscillation (NAO). The slow, tropical ocean warming has thus forced a commensurate trend toward one extreme phase of the NAO during the last half-century.

A31A-02 0850h

A Simple Model of the Arctic Ocean Response to Annular Atmospheric Modes

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A simple, analytic, model of an idealized Arctic Ocean is solved. The model is an annular, rotating disk of constant-density fluid (1-layer f-plane), which is subjected to annular wind-stress forcing. The forcing is scaled to simulate the observed trend between 1979 and 1993 in geostrophic winds over the Arctic, which has been tied to the essentially annular atmospheric mode, the Arctic Oscillation. The model includes top and bottom Ekman layers, and is solved for sea-surface tilt and the interior flow. The results are compared with the sea-surface height anomalies from the same period from (1) a high-resolution general circulation model and (2) tide gauge data. The simple model agrees reasonably well, quantitatively, with the observations and the numerical integration. We propose that the model reveals a straightforward dynamical mechanism, consistent with the observed variability in Arctic hydrography, which links the Arctic Ocean variability with large-scale atmospheric modes.

A31A-03 0905h

A Large Ensemble Modeling Study of the Atmospheric AO/NAO Pattern and the Role of Surface Perturbations in Wintertime Atmospheric Variability

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Recent studies hypothesize surface boundary conditions (SST and snow) and other atmospheric dynamical mechanisms that serve as the principal forcings of the AO/NAO atmospheric mode. Although these mechanisms have all demonstrated statistical relationships with the NAO/AO, no single mechanism has yet emerged as the dominant and causal factor. In this study, a pair of large ensemble atmospheric GCM simulations is conducted to investigate the degree to which wintertime extratropical Northern Hemisphere climate variability is driven by interannual variability in surface boundary conditions. Empirical orthogonal analysis of the results suggests that the NAO/AO is not an externally forced mode, but rather a fundamental internal mode of the atmospheric system that exists regardless of many variations in external boundary conditions. Nevertheless, interannual variations in snow cover and snow mass generated by the GCM are found to exert a modulating influence on the pre-existing NAO/AO mode. Snow variations excite the regional NAO pattern over the North Atlantic sector, disrupt the magnitude and phase of the NAO/AO mode in a given year, produce equivalent barotropic features associated with the AO, and cause the winter NAO/AO mode to originate as an autumn sea level pressure anomaly over Siberia. These numerical modeling results are consistent with previous observational analyses which link the NAO/AO mode with the Siberian High and associated snow cover variations, via poleward surface pressure system migration pathways.

A31A-04 0920h

An energy balance view of the North Atlantic Oscillation

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A different approach to look at the role of the ocean in the time evolution of the NAO is proposed here, by studying the interannual variations in the energy budget of the atmosphere / ocean system in the atmospheric reanalysis products and in - situ ocean measurements.

It is shown that in a positive NAO phase, the atmosphere, in a zonally averaged sense, transports less energy northward in midlatitudes (40N-60N). The corresponding anomalous equatorward energy transport is just the one required to balance the anomalous differential heating (cooling) of the atmosphere found over the subpolar (subtropical) gyre of the North Atlantic ocean.

It is found that the gyres store the corresponding anomalous amount of energy in their surface layers at short (monthly to interannual) timescales. However, this storage scenario can not explain the pronounced low frequency (decadal) component displayed by the observed net heat flux at the ocean surface (FS). Indeed, in the absence of ocean dynamics, surface storage becomes of weak amplitude on long timescales, so that the FS spectra are expected to be blue (as predicted by various stochastic models of thermal coupling between the atmosphere and ocean). However, observed spectra (from Da Silva et al., 1994) are slightly red, suggesting a role for oceanic heat transport rather than storage in the NAO energetics. Direct measurements of ocean heat transport made in 1958 (IGY year), 1981, and the 1990s (WOCE years) suggest an enhancement of the oceanic heat transport at the intergyre boundary (48N) since the 1960s. This might balance the strengthening of the surface cooling of the ocean observed over the subpolar gyre during the last 30 years or so, reflecting a compensation between atmospheric and oceanic heat transports in midlatitudes.

A31A-05 0935h

The interaction between the NAO and North Atlantic SST: Evidence of feedback

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It was recently suggested that an eddy mediated feedback exists between the atmosphere and midlatitude SST. This feedback enhances the amplitude and persistence of low-frequency atmospheric variability. We examine observational data and GCM output for evidence for such interaction, by following the monthly evolution of the North Atlantic Oscillation, its related SST anomalies, and the anomalies in the Atlantic storm track. This analysis suggests that a coherent evolution of these three components is intensifying throughout the cold season, indicative of a weak positive feedback.

A31A-06 0950h

Interannual Variability and Trends in the Southern Hemisphere Annular Mode

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The leading mode of month-to-month and interannual variability of the Southern Hemisphere circulation in the troposphere and stratosphere is an annular mode, associated with opposite variations of pressure between the polar cap and middle latitudes. A brief review will be presented of this SH annular mode in the troposphere and lower stratosphere, including its links to variations of zonal wind, temperature and total ozone.

Recent observed trends in the SH annular mode will be described, including variations of the zonal flow in the troposphere and strengthening of the polar vortex in the lower stratosphere. Possible mechanisms for the trends in the lower stratosphere and troposphere will be described, including stratospheric ozone depletion and greenhouse climate change. The possibility of feedbacks between these two mechanisms and dynamical links between the troposphere and the lower stratosphere in the SH will be discussed.

A31A-07 1030h

On the Dominance of the Arctic Oscillation During Recent Springs in the Western Arctic

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In contrast to studies which emphasize the Arctic Oscillation (AO) in winter, we find that over the western Arctic, centered on north Alaska and the Beaufort Sea, the shift in the AO near the end of the 1980s had its greatest amplitude at the end of winter in March, and had its greatest impact on lower-tropospheric temperatures in April. Based on the TOVS Path-P data set and the NCEP/NCAR Reanalysis, low-level spring warming in the 1990s is seen as an increase in the frequency of warm Aprils, and contrasts to the previous four decades and other months. Although horizontal temperature flux divergence was highly episodic, it contributed the major warming to the lower tropospheric heat budget during four March - April events in the 1990s (+47 K), compared to four cooling events in the 1980s (-28 K). This change was coincident with shifts in the low-level circulation associated with strengthening of the polar vortex and cooling in the lower stratosphere, taken as a signature of the AO. Low-level impacts depended on both the strength and location of the lower stratospheric polar vortex. Since spring may be important with respect to air chemistry and surface albedo feedbacks, the persistence of the polar vortex into March/April may be a critical indicator of local Arctic change.

A31A-08 1045h

Separating Secular Change and Climate Variability

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Observed NAO, AO and AAO indices show year-to-year fluctuation, low-frequency modulation and, in recent decades especially, apparent secular change. These data have been interpreted as indicating that these variability modes are increasingly favoring one phase over the other, a situation which some GCMs predict will persist into the future. Here we re-evaluate this interpretation using a new technique applied to an ensemble of transient GCM simulations. In these simulations the variability modes are essentially unchanged from 1900-2100, and the secular behavior displayed in their indices is purely artificial. In light of these results we revisit the apparent secular change seen in the indices of the observed variability modes.

A31A-09 1100h

Dynamical Forcing of the Annular Mode and its Recent Upward Trend

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Recent wintertime warming of North America and Eurasia poleward of 40 N has been driven largely by a trend in atmospheric circulation resembling the annular mode's (AM) positive, high-index phase. Though varying strongly on synoptic time scales in response to intrinsic midlatitude atmospheric driving, evidence now exists that this recent AM trend is not due to stochastic effects alone. We present results from atmospheric GCM simulations that indicate the observed AM trend can be explained as a forced response to the slow changes in the world-wide sea surface temperatures, especially the warming of tropical oceans. The dynamics of this link are analyzed, from which it is shown that intensification of the Northern Hemisphere circumpolar vortex from the surface into the lower stratosphere (positive AM phase) results from enhanced convection over the equatorial Indian ocean.

A31A-10 1115h

The Role of Stratospheric Resolution in Simulating the Arctic Oscillation Response to Greenhouse Gas Increases

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We investigate the atmospheric response to doubled CO_2 in a series of experiments with a stratosphere-resolving general circulation model coupled to a thermodynamic 'slab' ocean model, and compare this response with that of a model more typical of those currently used for climate change simulations. Both models show a significant increase in the Arctic Oscillation index in response to a doubling of CO_2, but the increase is no larger in the model with an upper boundary at 0.01 hPa than in the standard model with a top level at 5 hPa. These models also show a general stratospheric cooling in response to doubling CO_2, reaching a maximum of over 15 K in the upper stratosphere in winter. However we find no cooling in the Arctic winter vortex below around 10 hPa in the stratosphere-resolving model, and a weakening of the zonal winds throughout this region. This effect is due to enhanced wave driving in the doubled CO_2 simulation. Thus surface westerlies strengthen as stratospheric westerlies weaken in our model, suggesting that the observed Arctic Oscillation increase has its origins outside the stratosphere.

URL: http://www.atm.ox.ac.uk/user/gillett/

A31A-11 1130h

A Mechanistic Model of the Northern Annular Mode

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The Northern Annular Mode (NAM) is the leading mode of variability in the Northern Hemisphere. The NAM consists of a meridional dipole of the zonal mean zonal wind that extends into the stratosphere during the winter season. During the high index state of the NAM, high latitude westerly winds are stronger than normal leading to a stronger and colder polar vortex. Over the past few decades, observations show a trend toward higher NAM index values. To investigate

whether this trend is a result of natural variability or is related to greenhouse warming, a mechanistic model is developed that provides a simple analogue of the NAM. The model represents the interaction between the zonally symmetric flow and planetary waves for two meridional modes of variation. Greenhouse warming is specified in the model by varying the radiative equilibrium meridional temperature gradient. Variations in the second meridional mode qualitatively resemble those of the observed NAM. Model runs that correspond to larger greenhouse gas concentrations yield on average higher NAM index values. Additional model runs have been performed to investigate the dependence of NAM variability on the height of the upper boundary. These simulations reveal that the amplitude of the NAM signal gradually weakens as the upper boundary is lowered below 30 km. With the upper boundary at 10 km, essentially no NAM variability exists in the model. These results from the mechanistic model will be discussed in relation to other more complex Mechanistic Circulation Model (MCM) and General Circulation Model (GCM) simulations.

A31A-12 1145h

Relationship Between Climate and Atmospheric Chemical Species Modulated by Arctic Oscillation

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The relationship between the interannual variability of climate variables, such as geopotential height, temperature and zonal wind, and the interannual variability of chemical species, such as ozone, methane and nitrous dioxide, in the northern winter high latitudes was investigated using two 15-year equilibrium simulations of the University of Illinois at Urbana-Champaign Coupled Climate/Chemistry Model and the NCEP/CPC reanalysis data. Temporal Empirical Orthogonal Function analysis was used to define the dominant (first) mode of the different quantities interannual variability. A sensitivity of the first mode to the solar UV radiation enhancement in at the top of the atmosphere was also studied. Analysis showed that in the polar winter, when the Arctic Oscillation is the dominant pattern of the geopotential height variability, the relationship between the different quantities first modes could be recognized in correspondence with a geopotential height phase change. Namely, in the stratosphere a change in the geopotential height at one height occurs with: (1) changes of the same sign in temperature and ozone at lower altitudes, and a temperature change of opposite sign at the higher altitudes; (2) the same sign changes in methane and nitrous oxide at the same height, and the opposite methane and nitrous oxide changes at lower altitudes. The imposed enhancement of the solar UV radiation, which affects the daytime photodissociation rates of the chemical reactions and the radiative heating of the atmosphere, did not modify much the relationship between variables. However, the correlation between the dominant modes in the middle stratosphere increased for most variables and an appearance of the years with intensive polar vortex decreased. Also, the polar middle and lower stratosphere become slightly cooler, and the concentrations of the ozone and methane decreased there. The amplitude of the variables interannual variability decreased and the polar circulation becomes more zonal.

A31B MC: 133 Wednesday 0830h

Advances in Aerosol Science and Technology I

Presiding: **S S Cliff,** University of California**; R Arimoto,** New Mexico State University

A31B-01 0830h INVITED

Three Compact, Robust Chemical Characterization Systems Suited To Sensitive, High Time Resolution Measurements Of Atmospheric Aerosols

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In the past decade, the advancement of compact, robust and sensitive instrumentation to measure the chemical characteristics of atmospheric aerosols has lagged behind their physical characterization. There is a need for chemical instrumentation with these three qualities for use on airborne platforms and at infrequently attended ground level surveillance sites. Now chemical techniques are appearing that promise to fill this need.

We discuss three chemical characterization systems that are emerging in atmospheric chemistry and climate research applications. These are: (i) the Aerodyne mass spectrometer for real time measurement of particle composition and two post-collection analysis techniques (ii) non-destructive, multi-elemental chemical analysis of size-resolved samples by high spatial resolution synchrotron x-ray and proton beams (S-XRF/PIXE/PESA/STIM) (iii) single particle characterization by automated scanning electron microscopy with energy-dispersed detection of X-rays (SEM/EDX).

The key to post-collection analysis is automated aerosol sizing and collection systems and automated chemical analysis systems. Together these techniques provide unique, comprehensive information on the organic and inorganic composition and morphology of particles and yet are easy to deploy in the field. The sensitivity of each technique is high enough to permit the rapid sampling needed to resolve spatial gradients in composition from a moving platform like the Battelle Gulfstream-159 aircraft, traveling at 100m/s.

A31B-02 0850h INVITED

Mass Independent Isotopic Compositions of Aerosol Sulfate and Nitrates

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For nearly a half-century stable isotope ratio measurements have been utilized as a tool to understand sources, fates, and transformation mechanisms of atmospheric molecules. Carbon and oxygen (δ^{13}C and δ^{18}O) measurements of CO_2 have been instrumental in providing specific details of the carbon cycle. Without these measurements, understanding of the carbon cycle and transfer rates between reservoirs would be considerably diminished. Deuterium and oxygen isotopic measurements of atmospheric water has similarly enhanced the ability to model the atmospheric and geochemical recycling of the hydrologic cycle. Other molecules investigated include, for example, CO, CH_4, N_2O, SO_4, NH, and Cl. The ability to interpret these high precision isotope ratio measurements relies upon a fundamental understanding of the basic physical-chemical processes which produce the alteration of the stable isotope ratio. Such processes typically include thermodynamics (viz a viz isotope exchange), kinetics, and evaporation-condensation. Though the mechanism by which these alterations occur, they all depend in some fashion upon mass differences in the isotopically substituted atoms.

In 1983, Thiemens and Heidenreich (1) demonstrated that a chemical process is capable of producing an alteration of stable isotopes which was independent of mass. Subsequent to that time, it has been shown that measurements of mass independent isotopic compositions provide a new view of atmospheric process which may not be derived from single isotope ratio measurements (reviews by (2), (3)). In the past few years, mass independent isotopic compositions have been utilized to understand ancient atmospheres on both Earth and Mars (review by (4)).

It has been known for decades that atmospheric sulfate is an extraordinary species. It participates in climate change in its capacity as a cloud condensation nuclei and it is a human and environmental health hazard. By the same token, aerosol nitrate is an environmental health hazard and also is known to produce changes in biodiversity. In spite of decades of high quality measurements and models there remain significant gaps in understanding. For example, the relative proportion of homo vs heterogeneous SO_2 oxidation to sulfate and the extent of long range transport are issues where further insight is needed. Likewise, these are key issues for nitrate.

For both nitrate and sulfate, mass independent isotopic compositions have recently been observed. These anomalous isotopic signatures have now provided a new measure to widen our understanding of the atmospheric sulfur and nitrate cycles. The mechanisms of chemical transformation and long range transport have been further elucidated. In addition, measurement of these species in polar ice samples have provided a means by which global oxidative processes have varied on 100,000 year time scales.

(1) Thiemens and Heidenreich (1983) Science 219, 1073.

(2) Thiemens (1999), Science 283, 341.

(3) Weston (1999) chem. Rev. 99, 2115.

(4) Thiemens, Savarino, Farquhar, Bao (2001) 34, 645.

A31B-03 0910h INVITED

The new MODIS -Terra, and the proposed COBRA mission: First global aerosol distribution and properties over land and ocean, and plans to measure global Black Carbon absorption over the ocean glint

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The MODIS instrument was launched on the NASA Terra satellite in Dec. 1999. Since last Oct, the sensor and the aerosol algorithm reached maturity and provide global daily retrievals of aerosol optical thickness and properties. MODIS has 36 spectral channels in the visible to IR with resolution down to 250 m. This allows accurate cloud screening and multi-spectral aerosol retrievals. We derive the aerosol optical thickness over the ocean and most of the land areas, distinguishing between fine (mainly man-made) and coarse (mainly natural) aerosol particles. New methods to derive the aerosol absorption of sunlight are also being developed. These measurements are use to track different aerosol types, sources, transport and the radiative forcing at the top and bottom of the atmosphere. However MODIS or any present satellite sensor cannot measure absorption by black carbon over the oceans, a critical component in studying climate change and human health. For this purpose we have proposed a satellite mission that observes the ocean sun-glint. Using both on glint and off glint measurements of spectrally polarized light, for wavelengths up to 2.1 m, we can derive the aerosol absorption.

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Comprehensive Laboratory Measurements of the Emissions From Fires in African and Other Globally Significant Fuels Measured by FTIR, PTR-MS, and GC

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Biomass burning is one of the most important influences on the global atmosphere. Field experiments have yielded much useful knowledge about fires, but are often limited by lower S/N, lack of fuels data, and the challenges imposed by operating in remote tropical locations. In large-scale laboratory experiments at the U. S. Forest Service (USFS) Fire Sciences Laboratory we captured and measured all the emissions produced by 54 separate fires in 16 fuel types from southern Africa, Indonesia, Canada, the U. S., and Germany. Fuels included Dambo grass, Miombo litter, and Indonesian rice straw and peat. The fires were carefully simulated to match (as closely as possible) actual fires observed primarily during SAFARI-2000 and in Indonesia. Fuel C:H:N content was measured and fuel mass loss was continuously monitored. Total pressure, temperature, and flow of trace gases was monitored at the sampling platform in the stack above the fires. Trace gases were speciated by an impressive array of instrumentation. Both a closed cell and open-path FTIR were deployed by the UM group to quantify CO2, CO, CH4, NMHCs, oxygenated VOCs, NOx, HCN, and NH3 above ppb levels yielding a broad overview of the major smoke constituents. A proton-transfer reaction mass spectrometer (PTR-MS) from MPI was used to measure VOCs at