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Oral Abstracts

Global and Seasonal Variations in Gravity Wave Momentum Fluxes: A Comparison of Observations and Climate Models

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We report on a first formal comparison of gravity wave momentum fluxes in global models and in global observations. The observations include HIRDLS and SABER satellite observations and Vorcore superpressure balloon observations. The models include three climate models with parameterized gravity waves and two gravity wave resolving high resolution models. Measurements generally show similar magnitudes as in models, except that the fluxes derived from satellite measurements fall off more rapidly with height. This is likely due to limitations on the observable range of wavelengths, although other factors may contribute. When one accounts for this more rapid fall-off, the geographical distribution of the fluxes from observations and models compare reasonably, except for certain features that depend on the specification of the non-orographic gravity wave source functions in the climate models. For instance, both the satellite-derived fluxes and those in the high-resolution models are very small at summer high latitudes, but this is not the case for some of the climate models. This first comparison between gravity wave fluxes from climate models, high-resolution models, and fluxes derived from observations indicates that such efforts offer a promising path toward improving specifications of gravity wave sources in climate models.

Precipitating radiation belt electrons and enhancements of mesospheric hydroxyl - observations and modeling

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Energetic particle precipitation affects the middle atmospheric neutral chemistry and ozone balance, e.g. through production of odd hydrogen (HOx). Using measurements from the Microwave Limb Sounder (MLS/Aura) and Medium Energy Proton and Electron Detector (MEPED/POES) between 2004-2009, we study the effect of energetic electron precipitating from radiation belts on nighttime OH at geomagnetic latitudes 55 – 65°. Our correlation analysis indicates that electron precipitation has a clear effect on mesospheric OH mixing ratios during time periods when high electron count rates are observed. We also investigate the longitudinal distribution of the OH changes, compare the results with MEPED precipitation maps, and discuss the similarities and differences. Using the Sodankylä Ion and Neutral Chemistry model (SIC) and electron fluxes derived from satellite observations, we show that the modeled OH increase is in most cases in a reasonable agreement with MLS measurements. The precipitation-induced increase in OH is typically accompanied by a decrease in mesospheric ozone, both in model results and observations.

Three Blind Men Touching the Elephant: CALIOP (lidar), CloudSat (radar) and MLS (microwave) all look at Ice Clouds in the Tropical Tropopause Transition Layer

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Knowledge of the ice water content in thin, high-altitude cirrus ice clouds in the upper troposphere and lowermost stratosphere in the Tropics are important for quantifying the atmospheric radiative budget and the total water budget. However these thin ice clouds are difficult to measure. Here are only limited in situ measurements of these clouds from high-altitude aircraft. In this presentation we show global measurements of these tenuous clouds from the Microwave Limb Sounder (MLS) on AURA, the Cloud Physics Radar (CPR) on CloudSat, and the Clouds and Aerosol Lidar with Orthogonal Polarization (CALIOP) on CALIPSO. For good measure, we also compare some of the derived cloud optical properties with the Medium resolution Imaging Spectroradiometer (MODIS). CALIOP measures the ice water content in tenuous cirrus clouds with more sensitivity than MODIS or CloudSat, and with cloud-resolving spatial resolution. MLS and CALIOP have very similar sensitivity to cloud ice water content in the Tropical UT/LS, but very

different spatial resolution. CALIOP and CPR have similar spatial and temporal resolution, but very different sensitivity to small cloud particles as can be found in high –altitude cirrus clouds. To illustrate how differently these instruments view Tropical high-altitude cirrus clouds, examples from the TC4 aircraft field campaign, Tropical Cyclone Choi-wan and the Asian Monsoon recent climatology will be shown in this presentation.

Errors in evaluating chemistry transport models with UV/Vis satellite retrievals: how to avoid them?

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Satellite observations of tropospheric gases are increasingly being used for the evaluation of atmospheric models. In particular, tropospheric columns from UV/Vis solar backscatter instruments have shown a wide appeal within the atmospheric chemistry community. Atmospheric modelers are using satellite measurements of tropospheric columns of NO_2, SO_2, and HCHO to test various model aspects including the chemical and physical lifetimes, possible trends in surface emissions, and various estimates for anthropogenic and natural sources. When comparing model simulations to satellite measurements, both model errors and measurement errors are usually taken into account. Measurement errors can be reasonably well characterized, but model errors are often more difficult to establish, because models cannot represent the true state of the atmosphere. But apart from model error and measurement error, one also needs to account for comparison errors associated with the fact that model simulations and satellite measurements represent different atmospheric quantities. One example is the temporal and spatial smoothing intrinsic to the model because of its finite time step and spatial resolution. In contrast, satellite measurements represent snapshots at a particular local time, and can resolve variability at length scales smaller than a model grid cell. With the trend towards increasingly higher temporal and spatial resolution in space borne observations, developing methods that minimize these comparison errors is critical. For example, it is essential that satellite measurements are transformed to represent the smooth model state as much as possible, and that the model is sampled as close as possible to the satellite measurement time. This is particularly relevant for short-lived species that have a high spatial and diurnal variability such as NO_2, HCHO, and CHOCHO. In this presentation we will show a number of common pitfalls that ought to be avoided by modelers when using UV/Vis satellite data products. In some cases, satellite observations reveal small-scale processes that are not represented in global models. Emission of pollution by ships is a good illustration. Global models not only have difficulty in the spatial and temporal allocation of these moving sources, but also with the appropriate representation of non-linear chemistry occurring in the evolution of the ship's pollution plume. In order to interpret the observations of ship NO_2 pollution, global models need to improve their description of ship emissions and subsequent plume chemistry. We will conclude by showing our recent efforts to resolve ship plume chemistry in the GEOS-Chem model, subsequently using the model to infer ship NOx emissions from OMI NO_2 measurements along the densely travelled shipping routes in European waters.

Minor Trace Gas Measurements by the Tropospheric Emission Spectrometer (TES)

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The high spectral resolution and good SNR provided by the TES instrument allow for the detection and retrieval of numerous trace species. Advanced optimal estimation algorithms have been developed to retrieve three of these, ammonia, methanol and formic acid, from TES radiances. Ammonia is currently a standard TES operational product, while methanol and formic acid will be standard products in the next TES software update (V006). Given the lack of global knowledge on the spatial and temporal variability of ammonia due to its highly reactive nature, the large uncertainty in global emissions of methanol, and the large biases between measured and modeled formic acid, the air quality community has a pressing need for global information on these species; there is great interest in using these new satellite derived products, but there is often no clear idea on the information they provide. We will present a short summary of the characteristics of the retrieved products, then results from validations and applications of the data for each species. We will compare TES formic acid retrievals with measurements from aircraft campaigns (MILAGRO, INTEX-B, BORTAS) and surface FTS measurements, as well as with GEOS-Chem model output. Previous results have suggested that GEOS-Chem severely underestimates formic acid, and this analysis shows that TES confirms this underestimation. We will compare global TES methanol measurements with output from the GEOS-CHEM model, and show that GEOS-Chem overestimates methanol in wet regions and underestimates it in dry regions. We will present results from the application of inverse methods using TES ammonia to constrain model emissions, an area of research

that has showcased the value provided by satellite data. Finally, we will demonstrate the potential of a sensor with TES characteristics on a geostationary platform to provide high quality data sufficient to evaluate models of the ammonia bi-directional exchange at the surface.

A-Train measurements and modeling of the 2011 Nabro (Eritrea) volcanic eruption

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The period since the 1991 Pinatubo and Cerro Hudson eruptions has been devoid of major (VEI ≥ 5) sulfur-rich eruptions, but several lower magnitude (VEI ≤ 4) events have resulted in a systematic increase in stratospheric aerosol levels since 2002 [Vernier et al., GRL, 2011]. Detailed studies of the pathway by which sulfur dioxide (SO_2) emitted by moderate volcanic eruptions enters the stratosphere are therefore warranted. The June 2011 eruption of Nabro volcano (Eritrea), its first in recorded history, is among the most sulfur-rich eruptions measured since 1991, particularly in the subtropics, and resulted in a significant stratospheric impact in the northern hemisphere [Bourassa et al., Science, 2012]. We use A-Train data and a chemistry-transport model (CTM) to elucidate the emission and transport of SO_2 and its conversion to sulfate aerosol following the Nabro eruption. The initial, explosive phase of the eruption began on June 12, 2011 and was SO_2-rich, with a preliminary estimated SO_2 burden of ~1-2 Tg based on Ozone Monitoring Instrument (OMI) and Atmospheric Infrared Sounder (AIRS) data from the Aura and Aqua satellites. Infrasound measurements from Djibouti provide constraints on the timing and intensity of volcanic emissions during the eruption. Based on satellite observations, most of the Nabro volcanic cloud was initially transported to the north-west and then eastwards by the subtropical jet, and then became confined in a region extending from the Middle East to East Asia. This dispersion pattern has been ascribed to the Asian summer monsoon circulation, a strong anticyclonic vortex found in the upper troposphere and lower stratosphere (UTLS) during the boreal summer, linked to the elevated topography of the Tibetan Plateau. The monsoon circulation has been suggested as an effective route for anthropogenic pollution (and water vapor) from Asia to enter the stratosphere, and seems to have played a role in enhancing the stratospheric impact of the Nabro eruption [Bourassa et al., Science, 2012]. Continued emissions of SO_2 from Nabro were detected by OMI through mid-July, but were largely confined to the lower troposphere. To further investigate the transport and fate of the Nabro SO_2 emissions, we use the GEOS-Chem global CTM. The OMI and AIRS SO_2 observations, coupled with plume altitude constraints from advanced OMI retrieval algorithms and NASA A-Train data, are used to initialize volcanic cloud simulations in GEOS-Chem. The GEOS-Chem sulfate aerosol simulations will be compared to available satellite observations of aerosol (e.g., CALIPSO, Odin/OSIRIS) and to ground-based lidar measurements (e.g. EARLINET, MPLNET).

NO_2, Wind Speed, and the Chemical Removal Rate of Tropospheric NOx

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The exponential decay of NO_2 observed downwind of cities and power plants offers the tantalizing possibility that we will be able to extract the chemical loss rate of NOx and associate that loss with OH concentrations. Here we describe progress toward that goal using OMI NO_2 measurements. Effects of wind speed, PAN formation and spatial resolution on the interpretation of the downwind decay of NO_2 will be discussed.

Understanding the short- and long-term variations in stratospheric water vapor

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The regulation of stratospheric water vapor is a classic problem in atmospheric sciences. We present here simulations of stratospheric water vapor using a Lagrangian forward-trajectory model of the stratosphere covering the period 1987-2011. Comparisons to Aura MLS and other satellite measurements show good agreement with the model, giving confidence in the accuracy of the model. We find that decadal variations in water vapor are controlled by decadal variations in the Brewer-Dobson circulation, and that short-term variations are due to the QBO. The eruption of Mt. Pinatubo increased stratospheric water vapor by ~0.4 ppmv, while ENSO has little effect on stratospheric water vapor.

Operational use of observations from the Aura mission in MACC-II and the future GMES Atmospheric Service

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The Monitoring Atmospheric Composition and Climate project (MACC-II) is the current pre-operational atmospheric service of the European GMES programme. MACC-II provides data records on atmospheric composition for recent years, data for monitoring present conditions and forecasts of the distribution of key constituents for a few days ahead. MACC-II combines state-of-the-art atmospheric modelling with Earth observation data to provide information services covering air quality and atmospheric composition, climate forcing, the ozone layer and UV radiation, solar energy, and emissions and surface fluxes. MACC-II uses a wide array of satellite and in-situ data observing both meteorological and atmospheric composition variables to provide a best estimate of the current state of the atmosphere on a daily basis. These analyses are then used as initial conditions for 5-day global forecasts of atmospheric composition and 4-day European air quality forecasts (http://www.gmes-atmosphere.eu). For the monitoring and forecasting of global atmospheric composition, MACC-II currently uses the ECMWF numerical weather prediction (NWP) data assimilation system coupled to the Mozart chemical transport model (CTM). Emissions are prescribed with the exception of the emissions due to fire activity, which are produced daily by the MACC-II Global Fire Assimilation System (GFAS). Observations from various satellite instruments are used to constrain the system through assimilation of the Level-2 retrieval products in a near-real-time configuration. The MACC-II European air quality forecasts consist of an ensemble of regional models that all take their boundary conditions from the global system. This ensures a consistent transfer of information from the global system, which is mostly constrained by satellite observations, to the regional systems, which mostly constrain their forecasts with in-situ observations. This presentation will illustrate the use of satellite observations in general and data from the AURA mission in particular in the MACC-II global and regional systems. With the recent loss of the ENVISAT mission, the role of especially OMI and MLS has become even more important to the success of the MACC-II system. MLS provides an important constraint on the vertical distribution of ozone, while OMI provides near-real-time information on ozone, nitrogen dioxide, and sulphur dioxide, all key components of the MACC-II forecasting system.

A New A-Train Collocated Cloud Product Combining MODIS and OMI Cloud Information onto the OMI footprint

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The NASA A-Train offers an excellent opportunity to examine and combine radiance information and derived cloud properties from instruments covering different spectral regions onboard two different satellites. This presentation describes a new collocated cloud product that combines statistical cloud information from the Aqua MODerate-resolution Imaging Spectroradiometer (MODIS) derived from thermal infrared through visible wavelengths with cloud fields from the two Aura Ozone Monitoring Instrument (OMI) cloud products at the OMI ground footprint. MODIS Science Data Sets (SDS) includes cloud top pressure, cloud optical thickness, cloud emissivities and cloud phase. The two OMI cloud products include cloud optical centroid pressure from the OMCLDRR algorithm that utilizes the effects of rotational-Raman scattering in the UV and the OMCLDO2 algorithm that utilizes oxygen dimer absorption at visible wavelengths. One derived product is the detection of multi-layered and vertically-extended convective clouds within the OMI field-of-view. Understanding the effects of different cloud types on the radiative transfer through the troposphere is essential for accurate satellite retrievals of trace gas and aerosols concentrations. This new merged product will be of interest to algorithm developers and can be used in the general study of cloud structure and climatology.

Long-term data records of stratospheric composition from the GOZCARDS Project: Variations in HCl, O_3, and H_2O

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The main goal of the Global OZone Chemistry And Related trace gas Data records for the Stratosphere (GOZCARDS) project is to provide a commonly-formatted Earth Science Data Record (ESDR) for stratospheric composition, of relevance to the issue of ozone decline and recovery, as well as climate change. We present results from the generation of merged data records for stratospheric HCl, H_2O, and O_3, a subset of the GOZCARDS work. The data records are monthly zonal means, drawn from satellite-derived global stratospheric composition measurements from 1979 to the present, including on-going measurements from the Aura Microwave Limb Sounder (MLS) and the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) on SciSat-1. Sample diagnostics regarding the correlations between various datasets are presented. The current status of our comparisons with other independently-merged datasets (for O_3 and H_2O from NOAA) and reprocessed/merged Solar Backscatter Ultraviolet/2 (SBUV/2) instrument datasets (for O_3) will be presented, in terms of biases and differences in anomalies, and longer-term change. GOZCARDS provides individual instrument-specific (source) data records as well as merged data records, in the form of netCDF files. In addition to average abundance values, the files include standard deviations, as well as average offsets that were used to adjust the source datasets in the merging process. Upcoming plans for GOZCARDS will also be mentioned.

Surface ozone observation from Aura satellite using multispectral (TIR and UV) retrievals

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Using spectral radiances simultaneously measured by the TES (thermal infrared) and OMI (ultraviolet) instruments on EOS-Aura satellite, we demonstrate the first estimation of surface ozone from space. We evaluate the ozone concentration from multiple spectral retrievals against ozonesonde data that were measured during the time period spanning from 2004 to 2008 and the Environmental Protection Agency Air Quality System (EPA-AQS) surface measurements in August 2006. We present sample retrievals for locations with matching ozone sondes and show improvements in both error characteristics and vertical resolution compared to the measurements using UV or TIR alone. Examining retrieval diagnostics such as degrees of freedom for signal and averaging kernels for the multispectral retrievals, we see substantial improvement in the lowest tropospheric and total tropospheric sensitivity. Comparison with EPA-AQS's surface monitoring data indicates that multispectral observations capture the variation of ozone concentration at the lowest troposphere (surface to 700 hPa) due to the enhanced sensitivity.

Understanding convection-aerosols interaction through joint use of Aura, A-Train and ISCCP satellites datasets

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Convection plays a key role in the transport of aerosols to the upper troposphere (UT) and aerosols can either invigorate or weaken convection through delaying precipitation process or by stabilizing the atmosphere. Most of the previous studies have focused on the role of aerosols-cloud microphysical processes. To our knowledge, the potential role of convective system dynamics and life cycle has not been explored previously. We have combined along-track Aura MLS, OMI, Calipso, CloudSat and MODIS with the ISCCP convective tracking data and MERRA reanalysis over the tropical South American, African and Asian continents to address this question. Our analysis shows that the height of aerosols layers is generally consistent with that of the convective detrainment layers, suggesting a link between them. The occurrence of aerosol layers in the UT generally increases with number of the convective cores in the meso-scale convective systems, ambient wind shear, and during the development phases of the convective life cycle. Our results also suggest that stronger increases of smaller cirrus cloud particles with an increase of aerosol layers in the UT, number of convective cores, height and radius of convective systems occur during the development phase of the convective systems, relative to their mature and decaying phases. We will report the results of our ongoing evaluation on the relationships between ambient relative humidity, aerosols types and optical depth and occurrence of aerosols layers in

the middle and upper troposphere, as well as the potential influences of aerosols on the life cycle and vertical structure of the meso-scale convective systems over both wet and dry regions over the tropical continents.

Observations and Interpretation of Descent and Mixing in the Northern Hemisphere Brewer Dobson Circulation

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In 1929 Brewer proposed that the motions now known as the Brewer-Dobson (BD) circulation were responsible for the observed high values of ozone at high latitudes, far from their low-latitude region of formation. Here data from the High Resolution Dynamics Limb Sounder (HIRDLS) instrument, with 1 km vertical resolution and 100 km along track spacing are used examine how this circulation creates that distribution and its seasonal variation through the interactions between the overturning motions of the BD circulation and isentropic mixing in the lower and lowermost stratosphere (350-450K). Isopleths of ozone in equivalent latitude-potential temperature coordinates illustrate the high-latitude descent, controlled by diabatic cooling, from September to the lowest altitudes in January and February. This descent creates large gradients along isentropic surfaces, where mixing above ~ 360K is weak at this time. The strength of mixing is taken to be the effective diffusivity Deff as formulated by Nakamura [1996]. By late winter into spring the BD circulation weakens, as does the transport barrier near 35° associated with the sub-tropical jet. These processes allow strong equator-ward mixing, leading to progressively smaller latitudinal ozone gradients on the isentropes, and the rising and flattening of the ozone isopleths. By the end of the summer the isopleths show only small slopes, preparatory for the next cycle. Interannual variability will be noted. These results for the ozone dynamics are similar, but not identical, to those obtained with NCAR's Whole Atmosphere Community Climate Model (WACCM) Version 4.

Update on OMI formaldehyde total column retrievals at the Smithsonian Astrophysical Observatory

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Recent changes in the formaldehyde SAO OMI retrieval are reported. Formaldehyde cross sections have being corrected to the HITRAN recommended values. The row anomaly correction has been implemented. Direct formaldehyde total column retrievals using the newly calculated AMF look up tables are being implemented. Progress on these will be presented.

Top-of-the-atmosphere shortwave flux estimation from UV observations: An empirical approach using A-Train Satellite data

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Measurements of top of the atmosphere (TOA) radiation are essential for the understanding of Earth's energy budget and climate system. Clouds, aerosols, water vapor, and ozone (O_3) are among the most important agents impacting the Earth's short-wave (SW) radiation budget. There are several sensors in orbit that provide independent information related to the Earth's SW radiation budget. Having coincident information from these sensors is important for understanding their potential contributions. The A-train constellation of satellites provides a unique opportunity to analyze near-simultaneous data from several of these sensors. They include the Clouds and the Earth's Radiant Energy System (CERES) instrument, on the NASA Aqua satellite, that makes broadband measurements in both the long-wave and short-wave region of electromagnetic spectrum, and the Ozone Monitoring Instrument (OMI), on the NASA Aura satellite, that makes TOA hyper-spectral measurements from ultraviolet (UV) to visible wavelengths. Top of the atmosphere SW fluxes are estimated using a combination of data from CERES and the Aqua MODerate-resolution Imaging Spectroradiometer (MODIS). OMI measurements have been successfully utilized to derive information on trace gases (e.g., O_3, NO_2, and SO_2), clouds, and absorbing aerosols. In this paper, OMI retrievals of cloud/aerosol parameters and O_3 have been collocated with CERES TOA SW flux retrievals. We use this collocated data to develop a neural network that estimates TOA shortwave flux globally over ocean using data from OMI and meteorological analyses. The input data include the effective cloud fraction, cloud optical centroid pressure (OCP), total-column O_3, and sun-satellite viewing geometry from OMI as well as wind speed and total column water vapor from the Goddard Earth Observing

System 5 Modern Era Retrospective-analysis for Research and Applications (GEOS-5 MERRA) along with a climatology of chlorophyll content from SeaWiFs satellite. We train the neural network using a subset of CERES retrievals of TOA SW flux as the target output (truth) and withhold a different subset of the CERES data to be used for validation. Our comparison of OMI-estimated TOA SW flux with independent CERES retrievals shows a high degree of correlation (R>0.96) between the two. About 85% of all the analyzed OMI flux data falls within ±5% of the CERES observations and global mean biases are less than ±3% over the entire year. We further examine the sensitivity of the neural network SW flux estimation to the choice of input parameters. Application of our neural network to OMI heritage measurements from the Total Ozone Mapping Spectrometer (TOMS) series can potentially provide a unique long term global record of estimated TOA SW flux starting in late 1978.

TES Validation and New Species in V05

Robert L. Herman (JPL/CalTech; robert.l.herman@jpl.nasa.gov) and the TES Science Team

The latest version of the Aura TES data is V05. Here, we present the latest validation comparisons for ozone, carbon monoxide, water vapor, methane, and other TES standard level 2 products. We also introduce new species that are measured by TES in this version.

Tropospheric Ozone Transport in the Pacific Northwest

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Tropospheric ozone profiles from Aura/OMI (available as a research data product) (Liu et al., 2010) and Aqua/AIRS (v. 5.2.2) are compared to ozone sondes from Trinidad Head, CA. Tropospheric ozone columns from OMI derived from Liu et al., (2010) are also compared to OMI tropospheric ozone derived by Ziemke (2006). These OMI ozone data products along with AIRS ozone and AIRS CO are then used to investigate the source of high ozone transport events in 2008. Using measurements of CO, ozone, and water vapor from the summit of Mt. Bachelor, OR, differentiation of UT/LS folding from long-range transport events can be made (Ambrose et al., 2011) and the measurements are shown to concur with satellite retrievals of CO and ozone. The WSU AIRPACT-3 air quality modeling system for the US Pacific Northwest, with dynamic boundary conditions derived from MOZART-4 simulations with assimilated MOPITT CO, is used to estimate potential impacts on surface ozone from these polluted air masses entering the model domain.

The NASA Air Quality Applied Sciences Team (AQAST): exploitation of Aura data

Daniel J. Jacob (Harvard U.; djacob@fas.harvard.edu) representing AQAST

AQAST was formed in May 2011 by the NASA Applied Sciences Program to increase the value of Earth Science data for air quality management. AQAST members work on a wide portfolio of projects involving satellite data, suborbital data, and models. All projects are done in partnership with local, state, regional, and national air quality agencies. A number of projects involve exploitation of Aura satellite data. I will present recent accomplishments from these projects and describe future plans.

Characterizing Aerosols above Cloud using Satellite-based UV and Visible Measurements

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The Angstrom Absorption Exponent (AAE) is a parameter commonly used to characterize the wavelength-dependence of aerosol absorption optical depth (AAOD). The magnitude of AAE is closely related to aerosol composition. Aerosols containing Black carbon (BC) yield AAE values near unity, whereas Organic carbon (OC) aerosol particles are associated with values larger than 2. Even larger AAE values have been reported for desert dust aerosol particles. Knowledge of spectral AAOD is necessary for the calculation of direct radiative forcing effect of aerosols and for inferring aerosol composition. We have developed a satellite-based method of determining the spectral AAOD of absorbing aerosols. The technique uses multi-spectral measurements of upwelling radiation from scenes where absorbing aerosols lie above clouds as indicated by the UV Aerosol Index. Under such conditions, the overlaying aerosols absorb the upwelling radiation from the cloud top. The satellite measurements for these scenarios, therefore, can be related to the AAOD using the Beer's Law (BL) approximation. The upwelling reflectance at the cloud-top in an aerosol-free atmospheric column is mainly a function of cloud optical depth (COD). In the proposed method of AAE derivation, the first step is determining COD which is retrieved using a previously developed color-ratio based approach. In the second step, corrections for molecular scattering effects are applied to both the observed and the calculated cloud reflectance terms, and the spectral AAOD is then derived by an inversion of the BL approximation. The proposed technique will be discussed in detail and application results making use of OMI multi-spectral measurements in the UV-VIS will be presented.

Using Aura MLS and other A-Train satellite observations to diagnosis and improve cloud and water vapor simulations in post-CMIP5 climate models

Jonathan H. Jiang (JPL/CalTech), H. Su, J. Shen, and C. Zhai

Recent studies have highlighted the large spread among climate model simulations of cloud and water vapor that were submitted to the CMIP5 [e.g. Jiang et al., 2012]. The model spread in the upper troposphere is much greater than that in the middle and lower troposphere. It was demonstrated that improvements to climate models are sorely needed. Since the submission of CMIP5 model results, many models have undergone significant changes. We will examine the status of clouds and water vapor simulations in the post-CMIP5 versions of GISS ModelE, UKMO HadGem and CCCMA AM models using the bi-variate metrics (clouds and water vapor) as in Jiang et al. [2012], and study the large-scale regime dependency of clouds and water vapor simulations using the "conditional sampling" approach [e.g., Su et al., 2012]. Our study will examine the linkage of changes in parameterizations with changes of cloud and water vapor simulations in the models.

Global ozone-CO correlations from OMI and AIRS as constraints on ozone sources and transport

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The correlation of ozone with carbon monoxide (CO) has long been used as a tool to constrain the sources and transport of ozone. The ability to derive these correlations from space has been demonstrated in recent literature, but these studies have been limited by data sparsity. Here we present a new database of ozone-CO correlations using ozone retrievals from the Ozone Monitoring Instrument (OMI) on Aura and CO retrievals from the Atmospheric Infrared Sounder (AIRS) on Aqua. These two instruments aboard the NASA A-Train observe the same scenes at the same time and with similar vertical sensitivities. The near-daily global coverage of both instruments allows us to generate ozone-CO correlations with much less error and a finer scale than previous satellite studies. This gives us in particular the ability to probe interannual variability of global ozone-CO relationships for the first time. We present global ozone-CO correlations for each season of 2008 in addition to the correlations simulated by the GEOS-Chem chemical transport model (CTM). We test the sensitivity of the ozone-CO relationship in the model to different processes such as combustion precursors, biogenic emissions, lightning NOx, and stratospheric intrusions. Comparison to the observed relationships allows us to place new constraints on the factors controlling tropospheric ozone including the role of precursor emissions, photochemistry, and transport.

Improved OMI NO_2 standard product: algorithm, evaluation, and results

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Improved satellite retrievals of NO_2 column density are needed for a better understanding of the sources and chemistry of nitrogen oxides – important ozone and aerosols precursors in the troposphere. We have released a new OMI NO_2 Standard Product (OMNO2, version 2.1), which represents a substantial improvement over the original Standard Product (version 1). The latest V2.1 retrieval includes improved instrument calibration correction, measurement-based stratospheric estimation and air mass factor calculation, while maintaining minimal a priori model input. Several changes are made in the data product format and ancillary information for better usability in science and applications, including scattering weight profiles, which can be used in comparisons with independent datasets and models. The new product has been thoroughly evaluated using independent datasets (in situ and DOAS aircraft measurements, ground-based PANDORA and MF-DOAS measurements, in situ surface measurements, and satellite observations) and compared with CTM simulations. Compared to previous versions, the new OMI stratospheric NO_2 has realistic spatial structure and temporal variation, which improves the tropospheric column product, leading to better agreement with independent observations. Gridded level 2 and improved level 3 data products are now available for the broader user community. Using these new data we present high-resolution NO_2 maps, and provide top-down constraints on the source strength of NOx emissions.

Constraints on tropospheric CO_2 from TES and ACOS-GOSAT assessed with TCCON and HIPPO measurements

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Obtaining accurate estimates of surface fluxes of atmospheric CO_2 requires an improved understanding of the processes controlling the global distribution of CO_2. We investigate the global distribution of CO_2 through the assimilation of Aura-TES and ACOS-GOSAT into the GEOS-Chem model. The assimilated fields are compared against HIPPO aircraft profiles and TCCON column observations, which are non-coincident with the satellite sampling. We find that column observations from GOSAT and free tropospheric CO_2 from TES provide complementary information with TES assimilation improving the model values in the summertime when uptake is a maximum. In contrast we find that GOSAT XCO2 most significantly improves the overall model bias.

Climate impacts of non-CO_2 gases and aerosols and satellite measurements

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In this talk, I will review the state of the science on the quantification of forcing. I will focus on the non-CO_2 gases and aerosols and will make use of the recent CMIP5 model simulations, including the Atmospheric Chemistry and Climate Model Intercomparison (ACCMIP). These will be used to define areas of overlap between modeling and satellite observations.

Exploiting Sentinel 5's synergy with IRS and 3MI on METOP-SG for Protocol Monitoring and Air Quality-Climate Interaction

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Last Year's unprecedented low ozone episode in the Arctic (March 2011) made again clear that it is important to continue to monitor the ozone layer in support of the Montreal Protocol. Although scientists showed that the developments at the Arctic could be fully understood and explained by the same heterogeneous chemistry as is used for the SP hole (G. Manney et al., Nature, 2011), an ozone destruction of that order was not seen before at the NP. Continuation of monitoring the Ozone Layer in order to detect the expected recovery of the ozone layer is therefore of paramount importance. Both S5-Precursor (S5P)/TROPOMI as well as Sentinel5 will play a crucial role in that monitoring capacity. A new capacity of sentinel 5 will be synergistic use of data and synergistic retrievals from Sentinel 5, the IRS instrument and 3MI, all mounted on the same METOP-SG platform. Combination of CO, O_3 and CH_4 measurements of the Sentinel 5 and IRS instrument will enable distinction of lower tropospheric, PBL related, concentrations from free tropospheric amounts. These combined retrievals will largely benefit from the fact that the same air mass is sensed at the same time. Synergistic analyses of the aerosol measurements of 3MI and the AQ pollutants measured by Sentinel 5 and IRS will for the first time provide a co-located and synergistic data base that can be used for studying secondary aerosol formation. Secondary aerosol formation is the largest unknown contribution to the total aerosol load of the atmosphere, which is in turn the largest unknown factor in the anthropogenic climate forcing. Moreover, these co-located trace gas and aerosol measurements are essential for further understanding of the relation between climate change and air quality (Shindell, Science, 2009). 3MI will be the only instrument in that timeframe with the needed detailed aerosol detection capacity for this type of analyses. The presentation will elaborate on the importance of the monitoring capacity of Sentinel 5 and S5P, and the new insights the synergistic use of the data sets of Sentinel 5, IRS and 3MI will provide for air quality and climate change.

Identifying and forecasting deep stratospheric ozone intrusions over the western United States from space

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Recent studies have shown that deep stratospheric ozone intrusions can episodically enhance ground-level ozone above the health-based standard over the western U.S. in spring. Advanced warning of incoming intrusions could be used by state agencies to inform the public about poor air quality days. These naturally occurring events also need to be identified to determine whether a historic exceedance may be exempted from counting towards a violation. Here we explore the potential for using ozone retrievals at UT/LS levels and in total column from space-based instruments to identify stratospheric intrusions and forecast the eventual surface destination of transported stratospheric ozone. Preliminary analysis of Aura OMI (2004-2008) and Aqua AIRS (2003-2011) ozone retrievals with potential vorticity and ozonesondes shows that both products are likely useful for this purpose given their vast spatial coverage at near-daily intervals and their ability to capture the variability of UT/LS ozone associated with meteorological conditions favorable for stratospheric intrusions. We further explore the correlation of AIRS daily total ozone columns at each 1ºx1º grid box ~1-3 days prior to stratospheric enhancements to daily maximum 8-hour average ozone at a selected surface site using datasets from April to June in 2003-2011. The surface stratospheric enhancements are estimated by the GFDL AM3 chemistry-climate model which includes full stratospheric and tropospheric chemistry and is nudged to reanalysis winds. Our earlier work shows that the model presents deep stratospheric intrusions over the Western U.S. consistently with observations from AIRS, surface networks, daily ozone sondes, and aircraft lidar available in spring of 2010 during the NOAA CalNex field campaign. For the 15 surface sites in the U.S. Mountain West considered, a correlation coefficient of 0.4-0.7 emerges with AIRS ozone columns over 30º-50ºN latitudes and 125º-105ºW longitudes - variability in the AIRS column within this spatial domain indicates incoming intrusions. For each "surface receptor site", the spatial domain can narrow to an area ~5ºx5º northwest of the individual site, with the strong correlation (0.5-0.7) occurring when the AIRS data is lagged by 1 day from the AM3 stratospheric enhancements in surface air. The spatial pattern of correlations is consistent with our process-oriented understanding developed from case studies of extreme intrusions. Surface observations during these events show that the sites experiencing elevated ozone levels are typically located over the southeastern side of the enhanced ozone columns captured by AIRS ~12 hours to 1 day prior. This first scoping study suggests there is potential to use near-daily global coverage of ozone in total column or in UT/LS levels from space-

based instruments to serve as a qualitative early-warning indicator of incoming stratospheric intrusions with a lead time of ~1-3 days. There is more skill in ~12 hours to 1 day as to where the intrusion will reach the surface, particularly during the ENSO years (i.e. 2003, 2008, 2010, 2011) when deep intrusions are more likely to occur as compared to other years. We are working to explore OMI, MLS, and other Aura data for this forecasting capability and plan to discuss preliminary results at the Aura Science Team Meeting.

Impact of meteorology and emissions on the interannual variation of tropospheric ozone over the South America and surrounding oceans

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We analyzed the interannual variation (IAV) of tropospheric ozone (O_3) column data retrieved from OMI/MLS and ozone from TES, together with tropospheric CO from TES and MOPITT between January 2005 and December 2010 over South America and downwind oceans. Both TES and MOPPIT show large interannual variations with the strongest peaks in CO in late 2005, 2007 and 2010, resulting from drought-induced severe burning over South America. The IAV of the tropospheric ozone is small, showing relatively weak peaks in these years. We used the GEOS-Chem chemistry-transport model to examine the individual and combined impacts of meteorology and emissions on the IAV of tropospheric ozone over South America and surrounding oceans from 2005 as observed by the satellite instruments. The model generally reproduces the observed IAV of CO. The simulated IAV of O_3 is weaker than that in the observations, but the model captures the observed O_3 maximum in 2010. We explored the influence of the emissions and meteorology in sensitivity runs (e.g., with emissions for 2009 and meteorological fields for each year). Our results suggest that the O_3 anomaly caused mainly by enhanced biomass burning in 2010 (relative to 2009) is located primarily within south America, in the equatorial East Pacific (caused by easterly transport), and in the subtropical south Atlantic (caused by transport in the westerlies) during the peak burning months (August and September). The effects of changes in transport are almost neutral over South America and the South Atlantic in these months, but slightly negative over the East Pacific, compensating for the influence from emissions. During the wet season, the meteorology/transport changes contribute most to the IAV of tropospheric ozone. We also examined the tropospheric O_3-CO correlation over South America and surrounding oceans to understand the influence of pollutants and long-range transport on the O_3 distribution. The TES data show the strongest O_3-CO correlations along the equatorial East Pacific in September, downwind of the burning region, with the highest dO_3/dCO enhancement ratios (~0.3 mol mol-1). Over South America, although O_3-CO shows high correlations, the dO_3/dCO enhancement ratio is very small (<0.1 mol mol-1), which may reflect the suppression of ozone formation because of the high smoke.

Updates on OMI Ozone Profile Retrievals and Validation with Ozonesonde Observations

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An ozone profile algorithm has been developed to retrieve ozone profile including tropospheric ozone from OMI ultraviolet measurements. Ozone profiles are retrieved in 24 layers from the surface to ~60 km with retrieval precision generally ranging from 0.5-2% in the middle stratosphere to within 10% in the troposphere. The retrieved tropospheric ozone has sufficient accuracy to see ozone perturbations caused by convection, biomass burning and anthropogenic pollution, and to track their transport spatiotemporally. Tropospheric, stratospheric and total ozone columns can be accurately retrieved to typically within the few Dobson unit ranges. In this study, we further optimize ozone profile retrievals including improved slit function characterization, solar irradiance, fitting window, Ring correction, forward model simulation, radiometric calibration, and ozone profile climatology. Monthly mean solar irradiances rather than a 3-year average solar irradiance are used to reduce the effects of instrument degradation on retrievals. Retrievals in the Upper Troposphere and Lower Stratosphere are significantly improved by using a tropopause-based ozone profile climatology and tropopause height from NCEP FNL (Final) operational global analysis. The improved retrievals are compared with available ozonesonde observations during the 2004-2010 time period with a focus on the retrievals in the troposphere and lower stratosphere.

Upper Troposphere/Lower Stratosphere (UTLS) Jet and Tropopause Characteristics Over Boulder, Colorado, USA: Context for Ground-Based Ozone Measurements

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The UTLS jets and extra-tropical tropopauses have been characterized using 33+ years of GMAO's GEOS-5 Modern-Era Retrospective analysis for Research and Applications (MERRA) reanalysis to elucidate the climatology and variability of the tropopauses and UTLS jets. This jet and tropopause information is being used to help interpret trace gas variability in the extra-tropical UTLS. Here we focus on the climatology of jets and tropopauses around Boulder, Colorado, USA (40N, 105W). The western United States and eastern Pacific are regions associated with complex, rapidly changing patterns of subtropical and polar upper tropospheric jets, and accompanying tropopause variations. At Boulder's longitude, it is common to observe several upper tropospheric jets; large poleward excursions of the subtropical jet associated with strong ridges frequently occur in winter. Boulder's location makes it subject to the influence of both polar and subtropical jets at different times. Information on jet and tropopause climatology and variability at Boulder will be used to provide context for and to help interpret variations in ozonesonde and Umkehr ground-based ozone measurements in the UTLS. Satellite ozone data, including those from NASA's Aura Microwave Limb Sounder instrument, will be used to provide global and regional context for variations seen in the ground-based measurements. Viewing Boulder ozone measurements in relation to the UT jets, tropopauses, and global ozone fields will allow us to assess the relationships of phenomena such as stratospheric and tropospheric intrusions, multiple tropopauses, and variations in the lowest part of the stratospheric polar vortex to ozone variability and climatology at Boulder.

The Ca II K and Mg II Solar Indices from OMI: the Unusual Cycle 24

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Direct observation of long-term variations in solar ultraviolet irradiance from satellites is challenging because of the difficulty of accurately tracking instrument response changes. Proxy indices based on core-to-wing ratios of solar Fraunhofer lines, such as the Mg II doublet at 280 nm, can minimize instrumental biases to better monitor solar UV activity. The high quality of OMI irradiance measurements allows us to construct daily indices for the Mg II, Ca II K (393.4 nm), Ca II H (396.8 nm), Mg I (285.2 nm) lines. The new OMI Ca II K index is capable of identifying anomalous values in National Solar Observatory data. Continued OMI solar measurements will be important for close monitoring of the unusual Solar Cycle 24.

Using OMI HCHO observations to test biogenic and anthropogenic emission inventories in Africa

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We use observations of formaldehyde (HCHO) from OMI to (1) estimate biogenic isoprene emissions in Africa and (2) assess the extent of pollution in Nigeria associated with biofuel use, oil and gas extraction and industrial activity. Isoprene, which undergoes rapid oxidation to form HCHO, is a precursor of ozone and aerosols, impacting human health, air quality and climate. We isolate a biogenic signal of HCHO by filtering out biomass burning HCHO with MODIS fire counts and OMI aerosol optical depth (AAOD) in the slant column data. HCHO produced from gas flaring is removed using gas flare fire counts retrieved from the AATSR sensor. We have developed a new algorithm that allows for conversion of vertical column HCHO to isoprene emissions in low-NOx environments using the global chemical transport model (CTM) GEOS-Chem. We use our OMI-derived isoprene emissions to better understand the response of isoprene to environmental variables such as temperature, solar insolation, leaf phenology and soil moisture. In our first study we identified a large HCHO signal in Nigeria not associated with oxidation of isoprene. Due to the lack of surface observations in this region we use an ensemble of satellite products to identify sources of pollution. We isolate an anthropogenic HCHO signal by removing biomass burning HCHO as was done previously. We estimate and remove biogenic HCHO using our OMI-derived isoprene emissions and the HCHO yields we obtain from GEOS-Chem. We find that anthropogenic HCHO hotspots occur in the Niger Delta, city centers such as Lagos and Abuja, and across central Nigeria. Gas flaring, industrial activity and biofuel use appear as sources of pollution from enhancements in

SCIAMACHY methane (CH4), OMI nitrogen dioxide (NO2), and AIRS carbon monoxide (CO). Preliminary results indicate that anthropogenic emission inventories are unable to reproduce the anthropogenic HCHO observed from space.

Correlations Between Partial Column Ozone Amounts in the Troposphere to the Near-Surface Ozone: Implications for Geostationary Satellite Retrieval Applications

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An investigation of the vertical variability of ozone was conducted as part of NASA's Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) summer 2011 campaign in the Baltimore/Washington D.C. metropolitan region. Ozonesondes were launched at two sites, a coastal site (Edgewood, MD) and a terrestrial site (Beltsville, MD). Over the terrestrial site, significant correlations were observed between the ozone partial column amounts near the surface (1-3 km) and those from layers aloft up to 10 km. The ozone in the lower free troposphere over the coastal site were decoupled from the surface, highlighting the complex thermal internal boundary layers from the marine surface and the emission sources that impact the coastal site. However, at both sites, significant correlations were observed between the partial column ozone in the mid-troposphere (7-10 km) and the near-surface layer and the correlation statistics are similar at both sites. These correlations give encouragement that near-surface ozone can be inferred from partial column satellite measurements in the mid-troposphere.

A multi-decadal study of cirrus in the upper troposphere

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Changes in the distributions of cirrus in the upper troposphere during the last 25 years (1985-2011) are quantified using five independent data sets. Stratospheric Aerosol and Gas Experiment (SAGE II), Halogen Occultation Experiment (HALOE), Cryogenic Limb Array Etalon Spectrometer (CLAES), High Resolution Dynamics Limb Sounder (HIRDLS), and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data from 1985 – present are used to determine cirrus frequency of occurrence and tropical-width trends in the upper troposphere. The full-width at half-max (FWHM) of cirrus geospatial distributions at 100 hPa are calculated for each experiment. The FWHMs have a 2σ trend of 0.38 ± 1.4 ° decade-1. This statistically insignificant trend is similar to those calculated by Davis and Rosenlof (J. Climate, 25, 2012) based upon analyses of reanalysis tropopause height and tropopause latitudinal gradients near 100 hPa.

An examination of air quality over the Canadian oil sands using Aura observations

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Large deposits of bitumen (a vicious form of oil) reside in the North-east corner of Alberta, Canada. Only in the past decade has this form of oil become economically viable and, as a result, both capital investments and the rate of extraction have increased rapidly since 2000. Results from an initial assessment of air quality over this area using observations of NO_2 and SO_2 from the Ozone Monitoring Instrument (OMI) will be presented. High-resolution OMI maps indicate a clear enhancement in both species over a small (30×50 km^2) region of intensive surface mining comparable to what is seen over large coal-burning power plants. NO_2 is seen to be increasing at a rate of roughly 10%/year. The NO_2 data also suggest that a significant fraction of the NOx emissions are from the transportation sector. In addition, special observations by the Thermal Emission Spectrometer (TES) over the oil sands began in July 2012. A preliminary analysis of these transects will be presented with a focus on the NH_3 observations.

Satellite observations of a seasonal cycle in NOx emission factors from fires in the African savanna

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Nitrogen oxide (NOx) emissions from wildfires account for ~15% of the global total, inducing large fluctuations in the chemical production and loss rates of O_3 and CH_4 and thereby affecting Earth's radiative balance. NOx emissions from fires depend on fuel N content, combustion stage, and total biomass burned; sparse observations limit current understanding of the variability in these factors across biomes. Here we use measurements from the Ozone Monitoring Instrument (OMI) and Moderate Resolution Imaging Spectroradiometer (MODIS) to study emission coefficients (ECs), a value proportional to emission factors i.e. NOx emitted per unit of biomass burned, from fires in African savannas. NOx ECs decrease steadily across the fire season, rather than remaining constant as is currently assumed. We speculate that this is due to reallocation of nutrients, including N, to plant roots after the growing season. We account for the observed cycle in the GEOS-Chem chemical transport model to show the impacts on monthly tropospheric ozone.

Fast Daily Emission Estimates in China Constrained by Satellite Observations

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Emission inventories of air pollutants are crucial information for policy makers and form important input data for air quality models. Unfortunately, bottom-up emission inventories, compiled from large quantities of statistical data, are easily outdated for emerging economies such as China, where rapid economic growth change emissions accordingly. Top-down emission estimates from satellite observations of air constituents have important advantages of being spatial consistent, having high temporal resolution, and enabling updates shortly after the satellite date becomes available. However, constraining emissions from observations of concentrations is computationally challenging. We present a new algorithm, DECSO (Daily Emission estimates Constrained by Satellite Observations), specifically designed for fast daily emission estimates of short-lived atmospheric species on a mesoscopic scale (0.25 × 0.25 degree) from satellite observations of column concentrations. The algorithm needs one forward model run from a chemical transport model to calculate the sensitivity of concentration to emission, using trajectory analysis to account for transport away from the source. By using a Kalman filter in the inverse step, optimal use of the a priori knowledge and the newly observed data is made. We apply the algorithm for NOx emission estimates of East China, using the CHIMERE chemical transport model together with tropospheric NO2 column retrievals of the OMI and GOME-2 satellite instruments. Closed loop test show that the algorithm is capable of reconstructing new emission scenarios from synthetic satellite data. Real observations are used to construct a monthly emission time series, which reveal important emission trends in China, such as the emission reduction measures during the Olympic Games 2008, and the economic downfall and recovery afterwards. The algorithm is also able to detect emerging sources (e.g. new power plants) and improve emission information for areas where proxy data are not or badly known (e.g. shipping emissions). A better correlation between observations and simulations based on the updated emission inventory facilitates improved air quality forecasts.

The Response of Lower Atmospheric Ozone to ENSO in Aura Measurements and a Chemistry-Climate Simulation

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The El Nino-Southern Oscillation (ENSO) is the dominant mode of tropical variability on interannual time scales. ENSO appears to extend its influence into the chemical composition of the tropical troposphere. Recent work has revealed an ENSO-induced wave-1 anomaly in observed tropical tropospheric column ozone. This results in a dipole over the western and eastern tropical Pacific, whereby differencing the two regions produces an ozone anomaly with an extremely high correlation to the Nino 3.4 Index. We have successfully reproduced this feature using the Goddard Earth Observing System Version 5 (GEOS-5) general circulation model coupled to a comprehensive stratospheric and tropospheric chemical mechanism forced with observed sea surface temperatures over the past 25 years. An examination of the modeled ozone field reveals the vertical contributions of tropospheric ozone to the column over the western and eastern Pacific region. We will show composition sensitivity in observations from NASA's Aura satellite Microwave

Limb Sounder (MLS) and the Tropospheric Emissions Spectrometer (TES) and a simulation to provide insight into the vertical structure of these ENSO-induced ozone changes. The ozone changes due to the Quasi-Biennial Oscillation (QBO) in the extra-polar upper troposphere and lower stratosphere in MLS measurements will also be discussed.

Impacts of Assimilating MLS Temperature on the Upper Stratosphere in GEOS-5

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Standard configurations of the GEOS-5 data assimilation system use nadir infrared and microwave sounders that provide deep-layer constraints on the thermal structure in the stratosphere. In the upper stratosphere, this information is currently provided by the Advanced Microwave Sounding Units (AMSU-As) on NOAA's polar-orbiting satellites. The highest peaking AMSU-A channel (14) peaks near 2.5hPa. Evaluation of the upper stratosphere reveals substantial biases in the temperature, cased in part by biases in the underlying GCM, and difficulties in representing the stratopause structure under disturbed conditions. This work demonstrates, unsurprisingly, that the assimilation into GEOS-5 of temperature profiles derived from EOS-Aura MLS leads to a substantially better representation of the stratopause structure from a climatological perspective and for disturbed events. Future plans with GEOS-5 include a reanalysis that includes numerous "research" datasets alongside the operational NOAA datasets that were used in MERRA. As preparation for this reanalysis, the present study examines how assimilating the MLS observations impact the error statistics for the AMSU-A instruments. Discussion will address the issue of bias correction for the AMSU-A Channel 14 radiances, which is presently turned off in GEOS-5 because of the absence of accurate temperature observations that can anchor the GEOS-5 analyses. The issue of what can be done in periods when no limb-sounder data are available will also be addressed.

Estimates of Lightning NOx Production from OMI NO2 Observations during DC3

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A specialized retrieval algorithm for OMI tropospheric column NO2 estimates from lightning was developed for the Deep Convective Clouds and Chemistry (DC3) field program, conducted during May and June 2012. The retrievals were run on a near-real-time basis during the field mission. The algorithm improves upon previous work we have performed for case studies in the Costa Rica/Panama region and over the continental United States. Estimates of stratospheric and tropospheric background NO2 columns are subtracted from the OMI total column observations and an air mass factor representative of a convective outflow regime was used to convert the residual to vertical columns of lightning NO2 (LNO2). The tropospheric background is computed from a combination of OMI climatology and output from simulations of NASA's Global Modeling Initiative (GMI) chemical transport model run with and without lightning. We first review the daily maps of the LNO2 product over the DC3 study period and link areas of LNO2 enhancements with specific regions of deep convection using back trajectories. We then select case study storms that were observed in DC3 to estimate LNOx production based on a combination of the number of moles of LNO2 indicated by OMI, the flashes recorded by the National Lightning Detection Network and Lightning Mapping Arrays, and the NOx/NO2 ratio in the upper troposphere from the GMI model. We compare the OMI LNOx estimates with NASA DC-8, NCAR G-V, and DLR Falcon aircraft observations.

Quantifying tropical dehydration using MLS water vapor and temperatures from GPS radio occultation

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Stratospheric water vapor is controlled by freeze-drying across the tropical cold point tropopause. We explore the detailed behavior of dehydration using high vertical resolution measurements of tropopause temperature from GPS measurements, together with stratospheric water vapor from the Aura Microwave Limb Sounder (MLS). These analyses use daily gridded MLS data for 2004-2011, together with overlapping daily gridded GPS measurements from 2006-2011. Results show strongest correlated behavior (i.e. water vapor following temperatures) in areas of coldest tropopause temperatures, and we quantify the regions of active dehydration (where calculated relative humidity is greater than 100%). There is a strong seasonality to dehydration, occurring primarily in the tropics during boreal winter. If only the coldest regions are considered, the observed variations of water vapor during 2006-2011 are strongly correlated with tropical tropopause temperatures.

Improvements in Surface Ozone in the Eastern U.S. During the Past 4 Decades: Success of Air Quality Regulation Revealed by Surface, Satellite and Emission Monitoring

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We examine surface ozone observations obtained in the Mid-Atlantic region of the Eastern United States during the past 40 years in terms of air quality violations and the climate penalty factor (CPF). The CPF is based on the variation of surface ozone with temperature and has been suggested to serve as a surrogate for how air quality will respond to global warming. Surface data reveal a steady decline in the number of ozone exceedances (8 hr surface O3 > 75 ppb) as well as the CPF over the past 4 decades, with a sharp decline in 2003 due to steep reductions in nitrogen oxide emissions from coal power plants. We relate these improvements in surface ozone to measurements of NOx ($NO+NO_2$) and CO recorded by the surface instruments, space-borne spectrometers (OMI, MOPITT, and SCIAMACHY) and continuous emission monitoring of coal power plants and industrial boilers. The suite of observations are used to demonstrate the success and future challenge of regulations implemented to limit surface ozone. Future challenges in space-based observations of air quality will be addressed.

Methyl Chloride from the Aura Microwave Limb Sounder: Validation and First Global Climatology in the Uppermost Troposphere / Stratosphere

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Methyl chloride (CH_3Cl), the largest natural source of stratospheric chlorine, currently accounts for about 16% of chlorine-catalyzed ozone destruction in the stratosphere. Its importance is expected to increase, however, as emission controls alter the relative contributions from natural and anthropogenic halogen sources. Thus a quantitative understanding of the CH_3Cl distribution and variability will be valuable in enhancing our prognostic capability for ozone layer stability. With the release of the version 3 (v3.3) data processing algorithms, the Aura Microwave Limb Sounder (MLS) now provides the first daily global observations of CH_3Cl. The unprecedented scope of the MLS data set makes it uniquely suited to studying the spatial, seasonal, interannual, and longer-term variations in the distribution of CH_3Cl in the uppermost troposphere and stratosphere. We will present validation results to substantiate the quality of the v3.3 MLS CH_3Cl measurements and their utility for scientific studies. The first global climatology of CH_3Cl, assessment of the variability in its distribution, and comparison of its behavior with that of other species measured by MLS will be shown.

Retrieval of the global water vapor distribution from satellite observations in the blue spectral range

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Water vapor is involved in many important chemical reactions in the atmosphere and contributes most to the natural greenhouse effect. Its atmospheric abundance is highly variable. Thus observations of the spatio-temporal variation on a global scale are of great importance. Satellite observations of water vapor observations are made in different spectral ranges, e.g. in the microwave, thermal IR or near IR and visible (red) spectral range. Satellite measurements in the red spectral range have the advantage that they are sensitive for the whole atmospheric column and that they provide global coverage. In this study we exploit the potential to retrieve the global water vapor distribution from satellite observations in the blue spectral range. Although the water vapor absorption in this spectral region is rather weak, such retrievals also have their advantages: First, because of the weak absorption, no corrections for spectral saturation effects (like in the red spetral region) have to be applied. Second, the surface albedo in the blue spectral region is very similar for land and ocean. Third, the water vapor distribution can be retrieved also from satellite instruments, which do not cover the red spectral range (like e.g. OMI or the future Sentinel missions). Here we show a comparison of the water vapor retrievals in the blue and red spectral range from the GOME-1 instrument on ERS-2. It turns out that the sensitivity in the blue spectral range is good enough to retrieve the water vapor column density even at high latitudes (exceptions are very dry conditions in polar winter). We also show first global maps of the water vapor distribution retrieved from OMI on Aura.

Aerosol Effects on the Stratospheric Water Vapor

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Previous studies suggested that aerosols might increase the water vapor entry from the troposphere to the stratosphere through their radiative heating in the upper troposphere and interaction with the microphysics of cirrus clouds. It is not clear how variations of aerosols, especially those of anthropogenic sources, play a role in affecting the long-term trend of the stratospheric water vapor (SWV). In this study, we analyze several CMIP5 atmosphere-ocean coupled model simulations under different forcing scenarios to understand the mechanisms that control the SWV variability and quantify the aerosol effects on the historical trends of the SWV in the models. We find that global-mean SWV simulated by CMIP5 models differ by a factor of ~3, but the multi-model mean approximately agrees with the observations. Models produce an increasing trend of SWV since 1850 under reasonable natural and anthropogenic historical forcings. Such an increasing trend in SWV is associated with increasing cold-point temperature and is a result of increasing greenhouse gases. Increasing aerosols primarily cause a cooling of the surface and a decrease of tropopause temperature, thus counteracting the effect of greenhouse gases. The moistening effect of aerosols to the stratosphere is rather weak in the model simulations; however, the increasing aerosols over Asia since 1980s appear to have a different impact on the SWV from the historical increase of aerosols over other industrial regions.

Bayesian uncertainty quantification for OMI

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The importance of proper uncertainty quantification is nowadays generally acknowledged also in remote sensing. In addition to measurement noise, uncertainties are typically caused by uncertainties in forward modeling or various simplifications and assumptions made in solving the inverse problem. In this presentation we discuss, in particular, Bayesian methodologies for studying uncertainties. We study the model uncertainty in OMI aerosol optical depth retrieval. The aerosol model is selected from a look-up table corresponding to a set of fixed aerosol properties. In order to account for the uncertainties in the look-up table we model the error by Gaussian processes, which can allow for smooth deviations of the fitted reflectances from the observed one. The prior properties for model discrepancy can be determined empirically by observing residuals of an ensemble of model fits. This method will make the error bars of the retrieved AODs wider and effectively account for the model uncertainty. In addition, in OMI ozone profile retrieval Monte Carlo sampling methodologies are studied for both forward model simulation and for solving the Bayesian posterior distribution.

Tropospheric Column and UT/LS Ozone from Aura OMI, TES, MLS & HIRDLS: Improving geographic pattern matching using a CTM to achieve pseudo-coincident data.

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Aura observations of UT/LS ozone are rarely coincident, and the CTM provides a transfer standard to study seasonal patterns, including the imprint of the Walker and monsoon circulations on ozone. In the case of TCO (60°S-60°N) for the two years (2005-2006) of high-resolution model simulations, we have 1,200,000 coincidences monthly for OMI-CTM, 5,500 for TES-CTM, and 2,600 for TES-OMI (daytime only). In the case of UT/LS ozone, we identify latitude-longitude patterns in the Aura ozone instruments (MLS, HIRDLS, TES) and compare separately with the CTM. The paired Aura-CTM L2 observations are shown as scatter plots for TCO, but, for the most part, they are averaged monthly in 5°x5° or larger regions, creating L3 data set but including only coincident observations in each comparison. The relatively noise-free (but not bias-free) CTM bridges the OMI and TES measurements and improves their cross-validation to better precision than comparisons with the extremely limited number of ozonesondes, which are not always coincident within the hour. Previous validation studies of TES TCO versus ozonesondes found a bias of about +4 Dobson Units (DU) for large regions. This three-way comparison, with a far greater number of coincidences, indicates that monthly mean OMI-TES TCO biases are much less, and thus we can estimate OMI TCO bias as a few DU. For small regions, and particularly in the tropics, monthly mean OMI-TES differences can exceed ±10DU, due we believe to the different vertical sensitivities of the two instruments. The CTM-TES comparison can split day-night observations and show no apparent bias in TES at very low levels, ±1DU, confirming the excellent instrument design and algorithms. The use of coincident data is essential in this analysis, because the CTM predicts day-night differences of several DU due to sampling bias. OMI-TES-CTM comparisons highlight the importance of the a priori ozone profiles used in satellite retrievals and identify occasionally false agreement due to similarities between the a priori (MOZART CTM) and our CTM. From the UT/LS observations on a zonal mean basis, HIRDLS is biased high relative to MLS and TES in the tropics at 180–100 hPa, whereas MLS is low relative to HIRDLS and TES near 20°S at 100 hPa, suggesting inconsistency across different instruments. The CTM is biased high against all Aura instruments, by >50%, in a wide swath through the stratosphere from 200 hPa at 50°S to 50 hPa at 15°N. This is caused by a known defect, a too vigorous Brewer-Dobson circulation in the 40-layer version of the ECMWF meteorological fields. In the tropical UT HIRDLS reports 25%-50% greater abundances than the CTM at 200–100 hPa, including unrealistic tropospheric values > 100 ppb. CTM biases with respect to MLS and TES are much smaller and have different geographic patterns. The UT (147 hPa) ozone structures in the deep tropics show relatively large longitudinal variability driven by the Walker circulation for TES, MLS, HIRDLS and CTM. The correlation coefficients between CTM and MLS or TES (>0.3) indicate some skill in matching the variability. CTM-Aura comparisons are specific to each instrument (i.e., the plotted CTM values change) as only the L2 coincidences are used. Low ozone abundances occur near deep convection over maritime continent near 150°E. MLS and HIRDLS report higher ozone abundances than the CTM while agreeing on the shape. For TES-CTM comparisons, we find that (i) the TES retrievals are similar to its priori the TES, and (ii) processing our CTM profile with the TES averaging kernel results in unphysical tropospheric ozone abundances (>100 ppb) caused by the differences in the two stratospheric profiles. These latter two results are worrisome and warrant further analysis.

HOx partitioning in the mesosphere during solar proton events

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Solar coronal mass ejections lead to atmospheric proton precipitation, ionization, and production of odd hydrogen (HOx = H + OH + HO_2). HOx species are important in the atmosphere, because they participate in catalytic ozone destruction. The order-of-magnitude HOx enhancements caused by large solar proton events (SPEs) in the mesosphere provide a good opportunity to test our understanding of the HOx chemistry. In this paper, we study the SPEs of January 2005 and December 2006 and compare the OH and HO_2 increases predicted by the Sodankylä Ion and Neutral Chemistry (SIC) model to those from the Microwave Limb Sounder (MLS/Aura). We show that although the results indicate a reasonable agreement on total HOx increase and daytime HOx partitioning, there is a clear disagreement on HOx partitioning at night. As a result, SIC overestimates the OH amount at 60-70 km by up to 100% compared to MLS during periods of intense proton forcing. We discuss the possible reasons for the HOx partitioning differences, noting that the SIC results are similar to those from the Whole Atmosphere Community Climate Model (WACCM). A statistical analysis of the standard HOx chemistry indicates that the observed nighttime HOx partitioning is not produced from SIC by any combination of rate coefficients varying within their current uncertainty limits.

Attributing 2005-2010 increases in free tropospheric ozone to rising anthropogenic NOx emissions over eastern Asia with the TES and OMI sensors and the TM5 chemistry transport model

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Tropospheric ozone is an important greenhouse gas and a global air pollutant originating from photo-chemical oxidation of precursors such as volatile organic compounds (VOCs) and CO in the presence of NOx, and from stratosphere-troposphere ozone exchange. Spaceborne sensors are excellent tools to map spatio-temporal patterns in tropospheric ozone. Thanks to extensive spatial coverage and frequent overpasses of satellite instruments, the complex interplay of varying spatio-temporal emissions of precursors together with meteorological conditions and stratospheric intrusions might be better observed. Advanced chemical transport models (CTMs) are invaluable in understanding observations of tropospheric ozone concentrations. In this study we evaluate time series of tropospheric ozone observed from space by TES (Tropospheric Emission Spectrometer onboard NASA's EOS-Aura satellite) with the TM5 CTM using six years (2005-2010) of observations and model simulations for eastern Asia. Validation of TES tropospheric zone observations with WOUDC sonde data for the period 2005-2010 shows that TES overestimates ozone by ~2.5 ppb in the tropics and ~7.0 ppb in the northern mid-latitudes. Based on time series analysis of the TES-sonde biases, no hints were found for degrading retrieval quality making TES suitable for trend analysis. To date, eastern Asia has the fastest growing ozone precursor emissions and much of this pollution is exported eastwards towards western North America during springtime, leading to increased FT ozone concentrations over western Canada and the United States. In this study we show a clear increase of ozone mixing ratios in the free troposphere over eastern China itself (20-45˚N, 112-120˚E) for the period 2005-2009 using TES observations. On average at the 464 hPa level, a significant (p-value < 0.05) yearly increase of ±0.70 ppbv is observed for deseasonalized ozone data (using monthly data: +1.06 ppbv/yr). To better understand what drives the tropospheric ozone increases, a TM5 reference run - using ECMWF meteo data and fixed RETRO & REAS anthropogenic emission inventories for the year 2006 - was conducted for the period 2005-2010 and compared with the TES measurements of FT ozone. TM5 data were sampled at TES overpass times and the TES averaging kernel was applied on TM5 in order to conduct a proper evaluation. The TM5 simulations with constant 2006 NOx emissions reproduce part of the observed increase in FT ozone (+0.7 ppbv/yr). We use OMI NO_2 observations to infer a more realistic magnitude and temporal pattern in the NOx emissions over China. By implementing these improved NOx emission estimates in the TM5 model, we obtain much better agreement for the simulated NO_2 columns as well as the FT ozone concentrations with the observations from the EOS-Aura instruments. The TM5 simulation now indicates a trend in FT ozone of +1.1 ppbv/yr over China, consistent with the trend in the TES data. Our findings suggest that the increase of surface emissions of NOx in China explain approximately 40% of the observed increases in FT ozone concentrations over China.

Broadband surface solar irradiance derived from SCIAMACHY and OMI

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Surface solar irradiances (SSI) are an important component of the surface energy budget. In order to monitor climate change, long term accurate SSI values are needed. The advantage of the SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY) and OMI (Ozone Monitoring Instrument) satellite spectrometers are their accurate calibration and the stability of the instruments. Therefore, broadband surface solar irradiances (0.2-4 μm) are derived from SCIAMACHY and OMI satellite measurements. The retrieval algorithm is based on the Heliosat method in which the cloud index is replaced by the effective cloud fraction derived from the O_2 A band and the O_2- O_2 cloud retrieval algorithms. The MAGIC (Mesoscale Atmospheric Global Irradiance Code) algorithm is used to calculate clear-sky SSI. The SSI products are validated against the globally distributed BSRN (Baseline Surface Radiation Network) measurements. Because of different overpass time between SCIAMACHY (10:00 local time) and OMI (1:30 local time), the daily mean monthly mean SSI data are derived from combined SCIAMACHY and OMI product and compared with ground-based and other independent satellite surface solar radiation data.

Vertical Profile of the Solar Cycle Induced Variability in Atmospheric OH and the Implications on Ozone

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Solar irradiance variability during the 11-year solar cycle has been shown to have strong impacts on Earth's atmospheric composition and climate. Wang et al. [PNAS, 2012, under review] extracted the solar cycle signal in atmospheric hydroxyl radical (OH) from ground-based and satellite observations, which shows excellent correlation with the variability in solar UV parameters such as total Mg II index and Lyman-alpha. The observed 7-10% variability in total OH abundance in mid-latitude is larger than model simulations (~3% and ~6-7% for model runs using solar spectral forcing from reconstruction by Naval Research Laboratory (NRL) model and measurements by Solar Radiation and Climate Experiment (SORCE), respectively). In the present study, we examine in detail the vertical profile of the solar cycle signal in OH and its major source species based on global observations from Aura Microwave Limb Sounder (MLS) and comparison with model simulations. The general shape of the observed OH vertical profile response to solar cycle is close to model simulations using solar forcing from SORCE measurements, showing a primary peak response in the mesosphere and a small secondary peak response in the upper stratosphere. The latitudinal dependence of this variability will also be presented. The corresponding impacts on ozone will be discussed. The HOx catalytic chemistry and its variability associated with the solar cycle are likely to dominate the upper stratospheric ozone response to solar forcing.

Global Assimilation of EOS-Aura Data as a Means of Mapping Ozone Distribution in the Lower Stratosphere and Troposphere

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Ozone in the lower stratosphere and the troposphere plays an important role in forcing the climate. However, the global ozone distribution in this region is not well known because of the sparse distribution of in-situ data and the poor sensitivity of satellite based observations to the lowermost of the atmosphere. The Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) instruments on EOS-Aura provide information on the total ozone column and the stratospheric ozone profile. These data have been assimilated into NASA's Global Earth Observing System, Version 5 (GEOS-5) data assimilation system (DAS). We will discuss the results of assimilating three years of OMI and MLS data into GEOS-5. These data were assimilated alongside meteorological observations from both conventional sources and satellite instruments. Previous studies have shown that combining observations from these instruments through the Trajectory Tropospheric Ozone Residual methodology (TTOR) or using data assimilation can yield useful, yet low biased, estimates of the tropospheric ozone budget. We show that the assimilated ozone fields in this updated version of GEOS-5 exhibit an excellent agreement with ozone sonde and High Resolution Dynamics Limb Sounder (HIRDLS) data in the lower stratosphere in terms of spatial and temporal variability as well as integrated ozone abundances. Good representation of small-scale vertical features follows from combining the MLS data with the assimilated meteorological fields. We then demonstrate how this information can be used to calculate the Stratosphere - Troposphere Exchange of ozone and its contribution to the tropospheric ozone column in GEOS-5. Evaluations of tropospheric ozone distributions from the assimilation will be made by comparisons with sonde and other in-situ observations.

Update on the Atmospheric Chemistry Experiment (ACE) Satellite Mission

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The Canadian-led Atmospheric Chemistry Experiment (ACE) mission completed its ninth year in orbit on board the SCISAT satellite in August 2012. SCISAT/ACE uses infrared and UV-visible spectroscopy to investigate the chemistry and dynamics of the Earth's atmosphere. The primary instrument on board, the ACE Fourier Transform Spectrometer (ACE-FTS) is a high-resolution (0.02 cm-1) infrared FTS operating between 750 and 4400 cm-1. It also contains two filtered imagers (0.525 and 1.02 microns) to measure atmospheric extinction by clouds and aerosols. The second instrument is a dual UV-visible-NIR spectrophotometer called ACE-MAESTRO (Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) which was designed to extend the ACE wavelength coverage to the 280-1030 nm spectral region. The ACE-FTS and ACE-MAESTRO have been making regular solar occultation measurements for the past 8.5 years. From these measurements, altitude profiles of atmospheric trace gas species, temperature and pressure are obtained. The 650-km altitude, 74-degree circular orbit provides global measurement coverage with a focus on the Arctic and Antarctic regions. In addition to the instrument and mission status, a review of current science results from the ACE mission will be presented.

High-resolution inverse modeling of methane sources in North America using satellite observations (SCIAMACHY, TES, GOSAT)

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Satellite retrievals of methane columns from SCIAMACHY, TES, and GOSAT offer a unique resource for constraining and monitoring methane emissions using adjoint inverse modeling. We validate these methane retrievals using INTEX-A, HIPPO and NOAA/GMD aircraft observations. We also evaluate the consistency between the different satellite instruments with respect to the GEOS-Chem chemical transport model (CTM) as an intercomparison platform. We derive fine-scale constraints on methane sources through a four-dimensional variational (4D-VAR) inversion using the adjoint of GEOS-Chem with $1/2^{o} \times 2/3^{o}$ ($\sim 50 \times 50$ km^2) horizontal resolution over North America. Boundary conditions over the oceans are optimized as part of the inversion, thus preventing any global model bias from impacting the North American GEOS-Chem domain. In situ observations from aircraft campaigns and ground-based networks are used to evaluate the inversion results. We find that current inventories overestimate emissions from natural wetlands and underestimate emissions from natural gas production and enteric fermentation. By performing the inversion with and without TES observations, we measure the value of TES for quantifying methane emissions.

Quantifying surface emissions of methanol using observations from the Tropospheric Emission Spectrometer

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Methanol is the most abundant non-methane organic compound in the atmosphere, and a precursor of carbon monoxide, formaldehyde and ozone. Biogenic emissions from terrestrial plants constitute the largest fraction of the global methanol source, while biomass burning and anthropogenic emissions can make significant contributions on a regional scale. The recent availability of tropospheric methanol observations from space provides a powerful new constraint for understanding methanol emission processes on a global scale. Here we employ two years of global methanol observations from the Tropospheric Emission Spectrometer (TES) with the adjoint of the GEOS-Chem CTM to quantify the surface methanol flux, and interpret the results in terms of emission rates from different plant functional types. The satellite data imply a downward revision of the model emissions in portions of the tropics, and an upward revision in midlatitudes. The largest increases to the model emissions occur in areas that are dominated by shrubs and grasses, suggesting a refinement in methanol emission factors as a function of plant functional type. Applying the optimized emission rates in the model results in an improvement of the simulation as compared to an ensemble of airborne and ground-based observations.

Top-down and bottom up estimates of methane emissions from the 2006 Indonesian peat fires using Aura TES satellite observations of CH_4 and CO and GEOS-Chem

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Tropical fires represent a highly uncertain source of atmospheric methane (CH_4) because of the variability of fire emissions and the dependency of the fire CH_4 emission factors (g/kg dry matter burned) on fuel type and combustion phase. In this presentation we use new observations of atmospheric CH_4 (as well as CO) in the free troposphere from the Aura Tropospheric Emission Sounder satellite instrument to place constraints on the role of fire emissions versus microbial production (e.g. wetlands and livestock) on the tropical atmospheric methane distribution during a time of significant peat fire emissions from Indonesia in the fall of 2006. We first evaluate the global CH_4 distributions from TES and GEOS-Chem and find that biases between observation and model are consistent with previous validation studies of TES data using aircraft measurements. Comparisons account for the vertical resolution and a priori constraints associated with the TES CH_4 and CO estimates. Tropospheric averages of CH_4 and CO are calculated and the slopes of these distributions are compared to similar distributions calculated by the GEOS-Chem model. For the Indonesia peat fires, we find that TES and GEOS-Chem CH_4 distributions as well as the slopes of the observed and modeled CH_4/CO distributions are consistent (within the TES observation error). These comparisons provide confidence in the total CH_4 emissions used in GEOS-Chem from Indonesia of 4 Tg with 2.8 Tg coming from the peat fires.

On the role of the Aura HIRDLS and MLS vertical resolutions in the constraining stratospheric climate variations

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The paper discusses impacts of the vertical resolutions of HIRDLS and MLS observations in constraining equatorial and extra-tropical climate variations of ozone and temperature in the stratosphere. It demonstrates impacts of the data assimilation of HIRDLS and MLS ozone data in the UTLS by comparing results of the ozone analyses with and without data assimilation of limb-viewing observations. Needs for the Resolution-Dependent Assimilation (RDA) of nadir ozone columns and sub-columns are discussed to achieve the positive impacts of the multi-year OMI and SBUV observations in the ozone data analysis. The RDA preserves the thin-layer ozone vertical structures and anomalies associated with stratospheric ozone dynamics and chemistry confirmed by the independent high-resolution ozone observations, including HIRDLS and MLS. In the tropics RDA of nadir ozone data preserves the quasi-biennial ozone oscillations. As shown, in the Arctic and Antarctic during the late winter and spring the thin layers of ozone losses should be accurately recreated after assimilation of ozone data with restricted vertical resolutions. The limb-viewing Aura sensors also indicate that in the mid-latitudes, the frequency of ozone laminas associated with intrusions of air masses across the tropopause should be adequately reproduced in the analyzed ozone products. The role of the latest versions of HIRDLS and MLS data in the evaluation of ozone reanalysis products (MERRA, ERA-Interim and CFSR) is highlighted.

A link between tropical intraseasonal variability and Arctic stratospheric ozone observed by Aura measurements

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Previous studies using satellite measurements showed evidence that subtropical upper troposphere/lower stratosphere ozone (O_3) can be modulated by tropical intraseasonal variability, the most dominant form of which is the Madden–Julian oscillation (MJO). Here we further study the MJO modulations in Arctic O_3 using Aura measurements from the Microwave Limb Sounder (MLS), Tropospheric Emission Spectrometer (TES), and Ozone Monitoring Instrument (OMI). All three measurements show consistent results. Dominant signals (13–20 Dobson units) are found over regions polewards of 30°N in the northern hemisphere. Over the Arctic, the O_3 anomalies are dominated by wavenumber-2–3 structures and are anticorrelated with the geopotential height (GPH) anomalies at 250 hPa, similar to the findings in the previous studies over subtropics. The latter indicates that the O_3 anomalies are associated with dynamical motions near the tropopause over the Arctic. The teleconnection from the tropics to the Arctic is likely through barotropic propagation

of planetary waves at 250 hPa, which then affects the tropopause height at high latitudes, and the effect manifests itself through atmospheric composition observable by satellites.

Inter-annual variability of tropospheric ozone and implications for stratosphere-troposphere exchange

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Chemistry climate models (CCMs) predict long-term increases in tropospheric ozone from increases in stratosphere-troposphere exchange (STE). The increases in STE in the CCMs are caused by increases in the Brewer-Dobson Circulation and lower stratospheric ozone as the ozone recovers over time. Satellite ozone measurements beginning August 2004 from the Aura OMI and MLS instruments are combined to study the inter-annual variability of tropospheric ozone and its relation to STE. Inter-annual variability of STE from our calculations is about 10-20% which is comparable to what CCMs predict, but the CCMs indicate such changes over ~50 years or more depending on the model. Our hypothesis is that if the inter-annual variability of our calculated STE is really as large as this then it makes sense to look for similar signatures of inter-annual variability in tropospheric ozone. For zonal mean tropospheric column ozone the inter-annual changes are at most about 1-2 DU implying small overall influence from STE; however, regional changes in tropospheric ozone can be much larger. Our discussion will include isolating storm track regions where STE is likely to be highest and to determine if there are tropospheric ozone signals in these regions and if present to study how they evolve.