

EOS Aura Science Team Meeting
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Plenary Abstracts

The NASA GEO-CAPE Mission

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The NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission was recommended for launch in the second phase of missions (2013-2016) by the 2007 U.S. National Research Council Earth Science Decadal Survey, "Earth Science and Applications from Space." The mission's purpose is to identify human versus natural sources of aerosols and ozone precursors, track air pollution transport, and understand the short-term dynamics of coastal ecosystems. In this talk we will summarize the current status of GEO-CAPE mission study activities. Science working groups are developing and prioritizing the requirements for atmospheric composition and coastal ocean objectives. Studies of preliminary instrumentation and mission implementation alternatives are expected to begin in 2010.

O₃-CO Correlations in Boreal Biomass Burning Plumes During ARCTAS-B Observed by TES

Matthew J. Alvarado and Jennifer A. Logan

Aircraft observations of boreal biomass burning plumes during the ARCTAS-B campaign showed little ozone enhancement within the plumes, consistent with low enhancements of NO_x observed within fresh plumes from the Canadian fires. This is in contrast to several previous studies which reported positive ozone enhancements in boreal smoke. Here we examine the correlations between CO and O₃ in boreal smoke plumes using TES special observations and the GEOS-Chem model. We focus on early July 2008, when smoke from eastern Siberian fires was transported across the Pacific to North America. Our preliminary analysis suggests that TES shows no clear pattern of ozone enhancement within these plumes, consistent with the aircraft studies. Furthermore, observations of tropospheric NO₂ from OMI do not show a strong signal from these summer Siberian fires, which is also consistent with the aircraft results. Previous reports of positive ozone enhancements in boreal smoke plumes may have sampled smoke predominantly from flaming combustion, resulting in higher NO_x emissions and higher O₃ formation than was the case for ARCTAS-B. We explore the sensitivity of ozone production from boreal fires in the model to the emission factors assumed for NO_x.

Validation of OMI-TOMS and OMI-DOAS total ozone column using five Brewer spectroradiometers at the Iberian Peninsula

M. Antón, M. Kroon, M. López, J. M. Vilaplana, R. McPeters, M. Banón, and A. Serrano

This work focuses on the comparison of the total ozone column data from the Ozone Monitoring Instrument (OMI) flying aboard the NASA EOS-Aura satellite platform with ground-based measurement recorded by Brewer spectroradiometers located at five Spanish remote sensing ground stations between January 2005 and December 2007. The satellite data are derived from two algorithms: OMI Total Ozone Mapping Spectrometer (OMI-TOMS) and OMI Differential Optical Absorption Spectroscopy (OMI-DOAS). The largest relative differences between these OMI total ozone column estimates reach 5% with a significant seasonal dependence. The agreement between OMI ozone data and Brewer measurements is excellent. Total ozone columns from OMI-TOMS are on average a mere 2.0% lower than Brewer data. For OMI-DOAS data the bias is a mere 1.4%. However, the relative difference between OMI-TOMS and Brewer measurements shows a notably lower seasonal dependence and variability than the differences between OMI-DOAS and ground-based data. For both OMI ozone data products these relative differences show significant dependence on the satellite ground pixel solar zenith angle for cloud-free cases as well as for cloudy conditions. However, the OMI ozone data products are shown to reveal opposite behavior with respect to the two antagonistic sky conditions. No significant dependency of the ground-based to satellite-based differences with respect to the satellite cross-track position is seen for either OMI retrieval algorithm.

Testing and improving DOMINO tropospheric NO₂ using observations from the DANDELIONS and INTEX-B Validation Campaigns

K.F. Boersma, J. Hains, and many others

We present a sensitivity analysis of the Dutch OMI tropospheric NO₂ retrieval using measurements from the DANDELIONS and INTEX-B campaigns held in 2006. These unique campaigns covered a wide range of pollution conditions and provided detailed information on the vertical distribution of NO₂. During the DANDELIONS campaign, tropospheric NO₂ profiles were measured with a lidar in a highly polluted region of the Netherlands. During the INTEX-B campaign NO₂ profiles were measured using laser induced fluorescence onboard an aircraft in a range of meteorological and polluted conditions over the Gulf of Mexico and the East Pacific. We present a comparison of measured profiles with a-priori profiles used in the OMI tropospheric NO₂ retrieval algorithm. We examine how improvements in surface albedo estimates improve the OMI NO₂ retrieval. From these comparisons we find that the absolute average change in tropospheric columns retrieved with measured profiles and improved surface albedos is 23% with a standard deviation of 27% and generally lead to a better match with the validation data. We will also show results from intercomparisons to surface data in Switzerland and the Po Valley, and to simulations from regional Air Quality Models over Europe. These comparisons provide a fairly comprehensive overview of the validity of DOMINO tropospheric NO₂ columns, and clearly indicate where the DOMINO retrieval algorithm should be improved.

The 2008-2009 cluster of North Pacific volcanic eruptions: A-Train observations and OMI validation

S.A. Carn, T. Lopez, M. Pfeiffer, M. Doukas, P. Kelly, C. Werner, N.A. Krotkov, K. Yang, A.J. Prata, R. Kivi, T.P. Kurosu, and A.J. Krueger

In the summer of 2008 a spate of elevated volcanic activity began in the North Pacific, with major eruptions of Okmok and Kasatochi (Aleutian Islands) in July-August 2008, Redoubt (Alaska) in March 2009, and Sarychev Peak (Kurile Islands) in June 2009. This sequence of high-latitude eruptions, unprecedented in recent years, undoubtedly influenced stratospheric aerosol loading and has also provided rare opportunities to validate OMI SO₂ columns in volcanic clouds. We present A-Train observations of the eruption clouds, and show new results from SO₂ validation efforts during the Kasatochi, Redoubt and Sarychev Peak eruptions. The Kasatochi and Sarychev Peak eruptions were notable for their SO₂ emissions, releasing ~1.4 Tg and ~1 Tg (preliminary estimate) of SO₂ into the upper troposphere and lower stratosphere, respectively. The Kasatochi eruption also produced the first volcanic BrO cloud measurable from space by OMI and GOME-2. No BrO was detected in the Sarychev Peak eruption cloud, despite comparable SO₂ loading to the Kasatochi eruption. In the Kasatochi plume, we find good agreement between OMI SO₂ columns and Brewer direct-sun UV SO₂ data as the cloud drifted over Sodankyla (Finland). The Kasatochi SO₂ cloud was also captured by static ground-based UV correlation spectrometer (COSPEC) SO₂ measurements from Vancouver (WA, USA). Airborne SO₂ measurements were made to attempt validation of OMI SO₂ data in a lower tropospheric plume (~3 km altitude) from Redoubt on June 3, 2009. Plume transects covering several OMI ground-pixels were measured downwind of Redoubt. In mid-June 2009 the Sarychev Peak eruption cloud drifted over Alaska, and ground-based COSPEC SO₂ measurements were made during several OMI overpasses. Analysis of these datasets and comparison with coincident OMI SO₂ columns is in progress. These and other opportunistic measurements provide correlative SO₂ data for higher SO₂ column amounts than those measured during the successful Okmok SO₂ validation using ground-based DOAS in July 2008. They also permit a valuable assessment of OMI's efficacy for monitoring volcanic degassing.

Some new uses of OMI NO₂ observations

R.C. Cohen

In this talk I will present a brief survey of some new directions in the interpretation of OMI NO₂ measurements. These will include 1) examination of the S/N and contrast of measurements at 3km native resolution (without averaging adjacent detectors), 2) a study of interannual variation of agricultural NO_x emissions and of and rain induced pulsing of agricultural NO_x on daily time scales and 3) a study of NO₂ in fire plumes.

Observing the troposphere with IASI: emission, chemistry and transport

Pierre-François Coheur, Lieven Clarisse, Daniel Hurtmans, Federico Karagulian, Ariane Razavi, C. Wespes, Cathy Clerbaux, Maya George, Juliette Hadji-Lazaro, Anne Boynard, Matthieu Pommier, and Claire Scannell

Since about one decade, starting with the launch of MOPITT in 1999, thermal infrared (TIR) optical sounders are providing measurements of several reactive species, such as carbon monoxide or ozone, with good sensitivity to the troposphere. They add to the products available from UV-visible satellite sounders and these altogether contribute in drawing a more complete picture of the tropospheric composition, its changes over space and time, and its impact on the global environment. There is currently a suite of TIR instruments in operation, with very different instrumental designs, driven by specific science objectives. Among these, IASI, the Infrared Atmospheric Sounding Interferometer onboard MetOp satellite, has the advantage as an operational mission supporting Numerical Weather Predictions, of a relatively high spatial resolution (12 km footprint at nadir) and high spatial and temporal sampling. It covers an extended portion of the thermal infrared (645-2760 cm^{-1}) without gaps, and therefore offers unprecedented possibilities for the sounding of the troposphere and for capturing sudden changes in the atmosphere. This presentation gives an overview of the IASI achievements after two years of operation. The chemistry products available from the mission are reviewed, with detailed characterizations and preliminary validations for some. They include global distributions of CO, O₃, CH₄, HNO₃ and NH₃ and preliminary distributions of VOCs. Based on these, the capabilities of IASI to contribute to several aspects of atmospheric chemistry, from the identification of local sources to the long-range transport of pollution, are discussed with concrete examples. The presentation also includes the first steps made in using IASI data for operational applications (monitoring of fires, volcanoes, air quality).

Polar Mesospheric Cloud (PMC) Local Time Variations Observed by Aura OMI

Matthew DeLand, Eric Shettle, Gary Thomas, John Olivero, Pieter Levelt, and Matthew Kowalewski

The Ozone Monitoring Instrument (OMI) is a hyperspectral nadir-viewing spectrometer that has been flying on the EOS Aura spacecraft since July 2004. OMI near-UV data in the spectral range 265-300 nm can be analyzed using a modified version of the Solar Backscatter Ultraviolet (SBUV) polar mesospheric cloud (PMC) detection algorithm. OMI's smaller pixel size (13 km x 48 km at nadir) and 110° cross-track viewing geometry provide observations for 6-8 consecutive orbits, covering 11-13 hours in local time, at locations between 70° and 90° latitude on a daily basis. This capability allows the first direct examination of PMC local time variability in occurrence frequency and brightness as a function of latitude and longitude. We have recently modified the OMI PMC detection algorithm to significantly improve the quality and cross-track continuity of the data analysis. OMI data show a distinct difference in PMC local time variations between Northern Hemisphere and Southern Hemisphere data. Northern Hemisphere data show a strong mid-morning (6-8 h LT) peak up to 75°N that diminishes rapidly at higher latitudes. Southern Hemisphere data show a minimum in the early evening (18-20 h LT) and strong increases towards early morning (> 2 h LT) and late morning (< 12 h LT) at all latitudes up to the pole. These local time signatures have implications for the derivation of long-term trends in PMC occurrence frequency and brightness from the 30-year SBUV PMC data record, as well as the observed latitude dependence of PMC properties.

Global Modelling of NH₃ and the first comparison with satellite observations

Frank Dentene and Lieven Clarisse

The need to feed the growing world's population has led to intensification of agriculture. Ammonia emissions- mainly associated with agriculture- have as a consequence doubled since pre-industrial times- and may further increase in future. Moreover, with some exceptions in Europe and the US, there are currently no abatement policies, so that the emissions may substantially grow in the future. NH₃ plays a role in acidification and eutrophication issues (with consequences for ecosystem plant species diversity), NH₃ deposition may enhance uptake of CO₂ in land and oceans, but on the other hand also stimulate N₂O release. Last but not least, NH₃ may become increasingly important in the formation of nitrate particles.

We will present modeling work of the global NH₃ cycle using the high resolution TM5 model. We present the first comparisons of the model results with the recently published IASI retrievals (Clarisse et al., 2009), and will discuss further potential and limitation of satellite observation to improve our knowledge on atmospheric NH₃.

Observations of the tropical dehydration and monsoon hydration in the upper troposphere and lower stratosphere

A.E. Dessler and S. Wong

We have produced maps identifying where hydration and dehydration is taking place in the tropical tropopause region. To do this, we use a find pairs of Aura MLS water vapor measurements taken in the same air mass a day apart using a trajectory model. This allows us to measure the change in water vapor in each air mass in the time between the measurements. Given a large number of these pairs of measurements, we can produce global maps of where dehydration and hydration are occurring. We can unambiguously see dehydration occurring in the deep tropics in regions where relative humidity is high, and monsoonal moistening occurring in mid-latitudes, where relative humidity is lower. By looking at the variations of dehydration during a MJO cycle, we see that dehydration seems to follow convection.

Observed and Modeled Profiles of Trace Gases and Aerosol Optical Properties over the Eastern US

Russell Dickerson

For the past 15 years, the University of Maryland has conducted aircraft flights over the Eastern US during summer smog events. We have developed a chemical climatology of meteorological variables, aerosol optical properties, O₃, CO, and SO₂. This fall we will expand the program to include NO₂ and aerosol composition. Among the interesting findings include the regional nature of ozone and haze pollution, the role of mixing between the planetary boundary layer and lower free troposphere, and the impact of controls on power plant NO_x emissions on ozone concentrations. Comparison to numerical simulations such as CMAQ and WRFchem and to satellite observations can help evaluate models and remote sensing. Results are used to formulate State Implementation Plans to reduce pollution and comply with air quality standards.

The Sensitivity of U.S. Surface Ozone Formation to NO_x and VOCs as Viewed from Space

Bryan N. Duncan, Yasuko Yoshida, Sanford Sillman, Christian Retscher, Kenneth E. Pickering, Randall V. Martin, and Edward A. Celarier

We investigated variations in the sensitivity of surface ozone formation in summer to precursor species concentrations of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) as inferred from the ratio of tropospheric columns of formaldehyde and nitrogen dioxide from the Aura Ozone Monitoring Instrument (OMI). The data indicate that ozone formation became: 1. more sensitive to NO_x over most of the U.S. from 2005 to 2007 because of substantial decreases in NO_x emissions primarily from stationary sources, and 2. more sensitive to NO_x with increasing temperature, in part because emissions of highly reactive, biogenic isoprene increase with temperature, thus increasing the total VOC reactivity. Based on our interpretation of the data, current strategies implemented to reduce unhealthy levels of surface ozone should focus more on reducing NO_x emissions, except in some downtown areas which have historically benefited from reductions in VOC emissions.

Air Quality Modeling in Europe and the use of satellite data

Henk Eskes

In my presentation I will discuss recent air quality forecasting, modeling and data assimilation initiatives in Europe. Especially in the context of the GMES project there is a major effort to provide detailed and high-quality air pollution information to the citizens. There are two relevant projects. Within PROMOTE an "Integrated Air Quality Platform for Europe" has been set up, an ensemble forecast based on the output from four different air quality models. Within GEMS (2005-2009) this model ensemble approach is further developed with a contribution from about ten regional models. The "GMES Atmosphere Service" precursor project MACC (2009-2011) will build on the PROMOTE and GEMS work, and will set up an operational air pollution forecasting system. Advanced assimilation approaches will be developed to exploit the available near-real time observations from surface networks and from satellites. In the presentation these projects will be introduced. I will show examples of the use of air-quality relevant satellite data (OMI, IASI) in GEMS. The experiences with the assimilation of OMI NO₂ data in the Dutch Lotos-Euros model will be discussed.

GOZCARDS (Global Ozone Chemistry and Related Trace gas Data Records for the Stratosphere): Plans and early results.

L. Froidevaux, R. A. Fuller, M. L. Santee, M. J. Schwartz, G. L. Manney, N. J. Livesey, J. Anderson, H.-J. Wang, D. Cunnold, P. Bernath, K. A. Walker, R. J. Salawitch, T. Canty, I. Fiorucci, G. Muscari, and S. Pawson

We describe plans and early results for this multi-year NASA MEAsURES project, aiming to provide a commonly-formatted Earth system data record (ESDR) for stratospheric composition, of high relevance to the issue of ozone decline and recovery. The data records are drawn primarily from satellite-derived global stratospheric composition measurements from 1979 to the present, including on-going measurements from Aura MLS and ACE-FTS, as well as temperatures and potential vorticity from GMAO MERRA. These data records will provide time series for stratospheric ozone (O₃), hydrogen chloride (HCl), chlorine monoxide (ClO), nitric acid (HNO₃), water vapor (H₂O), nitrous oxide (N₂O), nitrogen dioxide (NO₂), nitrogen oxide (NO), methane (CH₄), and hydrogen fluoride (HF). Additional "derived data records", using a constrained photochemical model, will be provided for active chlorine (ClO_x) and odd nitrogen (NO_x). These data records will be provided as averages versus latitude on a common vertical grid, with time resolution of one month as a standard, and one day when possible. Data records binned in equivalent latitude and potential temperature will also be provided. We will provide both instrument-specific records and merged data records, with community access (website and data center).

Transport of Fire Generated Tracers to the Tropical Tropopause Layer as detected by A-Train Measurements

Rong Fu, Lei Huang, Jonathan Jiang, and Yan Zhang

Agricultural burning and forest fires have a significant influence on the chemical composition of the tropical tropopause layer (TTL). Although transport of biomass burning pollutants to TTL has been examined previously, a systematic characterization of how convective vertical structure and intensity influence the pollutant transport remains elusive, due to lack of adequate observations. We explore use of CloudSat, Aura, TES and AIRS and MODIS to characterize the convective transport of CO as a function of convective structure and large-scale thermal and dynamic conditions. We will present results based on our investigation of the convective transport in Africa and South America during late boreal summer and summer for 2007.

Potential Vorticity as a Barrier to Exchange Between the Upper Tropical Troposphere and Lowermost Stratosphere

John Gille, Svetlana Karol, Valery Yudin, Douglas Kinnison, and Bruno Nardi

The high vertical resolution of HIRDLS measurements has provided unique data on thin layers characterized by low or high concentrations of ozone and other species in the Upper Troposphere Lower Stratosphere (UTLS). Displayed on potential temperature (PT) surfaces, these layers, or laminae, extend toward high or low latitudes respectively, suggesting that they may lead to stratosphere-troposphere exchange. To assess the contribution of these features, HIRDLS ozone mixing ratios on PT surfaces in the upper UTLS (340-380K) have been averaged on equivalent latitude circles. These calculations were enabled by use of potential vorticity (PV) contours and tropopause locations from the Goddard Modeling and Assimilation Office (GMAO) EOS Observing System (GEOS) Version 5 data. During winter in each hemisphere, it is found that low ozone values at low latitudes are constrained equatorward of the PV = 4 PVU (1 PVU = 10⁻⁶ m²K/kg s) contour, while higher values from high latitudes are constrained poleward of the PV = 6 PVU contour. The thermal tropopause lies between these PV contours. Ozone mixing ratios on equivalent latitudes just poleward of the tropopause do not change during winter. The results indicate that the PV contours act as elastic membranes that experience considerable latitudinal deformation driven by baroclinic waves, but they permit very little cross contour transport. Calculation of the equivalent length, an indicator of the locations and strengths of transport barriers as well as regions of strong mixing, leads to distributions very similar to those shown by Haynes and Shuckburgh's (2000) modeled values. The values are also in broad agreement with calculations based on runs of the WACCM model. Calculations of equivalent length at lower altitudes, based on WACCM model runs, indicate weaker barriers, allowing more exchange, consistent with the calculations of Nakamura (2007)

The Advanced Limb Infrared Chemistry Experiment (ALICE)

John Gille, Bruno Nardi, Helen Worden, Tim Valle, Steven Massie and Brian Johnson

ALICE is the concept for a low-cost, low-resolution grating spectrometer operating from 6 to 15 mm in the infrared, with 1 km vertical resolution. It is designed to address such questions as: how does climate change affect cloud formation, amounts and altitudes; is the expansion of the tropics changing the amount and extent of stratosphere-troposphere exchange; are the sources and forcing due to atmospheric gravity waves and tropical waves changing; is stratospheric ozone recovering as expected; and do we understand the distributions of chemical trace species with a broad variety of chemical lifetimes? We outline the design, which uses previously developed and off-the-shelf components. It is thus suitable for a Venture Class mission.

NPP Atmospheric Data Products

James F. Gleason, James J. Butler, N. Christina Hsu, K. Chance, and R. McPeters

The five instruments, Visible-InfraRed Radiometer Suite (VIIRS), Cross-track Infrared Sounder (CrIS), Advanced Technology Microwave Sounder (ATMS) and Ozone Mapping and Profiler Suite (OMPS), Clouds and the Earth's Radiant Energy Suite (CERES), on the NPOESS Preparatory Mission (NPP) will provide 30 data products to two primary user communities; operational users in the weather and environmental conditions forecasting communities requiring guaranteed access to real-time data and scientific users primarily interested in studying longer-term climate processes. This presentation will focus on the atmospheric data products that provide data continuity between past, present and future satellite instruments. The data product requirements, algorithm development and product validation processes will be presented.

Reconciliation of essential process parameters for an enhanced predictability of arctic stratospheric ozone loss and its climate interactions (RECONCILE)

Jens-Uwe Groöf

An overview about the RECONCILE project activities will be given. RECONCILE is an EU-funded project that addresses open questions especially in the chemistry leading to polar ozone depletion. It is funded under EU FP7 and involves 18 international partner institutions and it is coordinated by Forschungszentrum Jülich. The project covers a wide range of scientific activities including laboratory experiments, an intensive measurement campaign with the Geophysica aircraft in 2010 and model simulations. Insights from lab and campaign results will be used to optimize parametrisations of relevant processes in chemistry climate models. To optimize the scientific output of the measurement flights, model forecasts will be used for the flight planning. For that, a collaboration with the AURA-MLS and ACE-FTS teams is planned. E.g. the CLaMS model will be initialized and validated using most recent available AURA-MLS and ACE-FTS data.

CEOS and Future Atmospheric Composition Measurements

Ernest Hilsenrath and Claus Zehner

The Committee for Earth Observation Satellites (CEOS) was established in 1984, in response to a recommendation from a Panel of Experts on Remote Sensing from Space, under the aegis of the G7 Economic Summit. CEOS provides a forum for 28 space agencies to coordinate Earth science mission that includes algorithm development, cal/val, and data sharing principals and standards. The Constellations, for four Earth science disciplines, were formed to provide improved coordination and focus on the GEO SBA. The Atmospheric Composition Constellation (ACC) focuses on observations needed to understand and improve predictive capabilities for changes in the ozone layer, climate forcing, and air quality (AQ). At the present time, ten space agencies are collaborating in ACC to demonstrate how added value can be obtained by combining satellite data sets. This talk will summarize the status and outcomes of several Constellation demonstration projects including the development of an atmospheric composition portal, a Requirements and Gap Analysis, and two subsequent workshops on impacts of AC data gaps on climate model predictions and interactions of air quality. The workshop also resulted in a set of recommendations, recently submitted to CEOS, on future missions that address these issues.

Intercomparison methods for satellite sensors: application to tropospheric ozone and CO measurements from Aura

Daniel J. Jacob, Lin Zhang, and Monika Kopacz

We will analyze mathematically three different methods for validating and intercomparing satellite instrument retrievals of vertical concentration profiles, and apply the methods to tropospheric ozone retrievals from TES and OMI as well as CO retrievals from TES. The first method (in situ method) involves the use of in situ vertical profiles for absolute instrument validation; this approach is limited by the paucity of in situ data. The second method (Rodgers/Connor method) involves processing the retrieved profile from one instrument with the averaging kernel matrix of the other; this method underestimates the actual bias between instruments and is subject to additional error from the choice of a priori. The third method ("CTM method") uses a chemical transport model (CTM) as intercomparison platform between instruments; we show that this method closely approximates the results from the in situ method provided that the CTM errors are not too large. The CTM method has three major advantages: (1) it allows intercomparison of satellite instruments over the full range of operating conditions; (2) it enables absolute validation against in situ data using the CTM as transfer function, (3) it exploits the satellite data for CTM evaluation and inverse analyses. We will show how the CTM method provides insights into tropospheric ozone simulation biases in the GEOS-Chem CTM, and extend it to a global full-year inversion of CO sources using the adjoint of GEOS-Chem and multi-sensor satellite observations from TES, AIRS, MOPITT, and SCIAMACHY.

Aerosol-CO Relationship and Aerosol Effect on Ice Cloud Particle Size: Analyses from Aura MLS and Aqua MODIS Observations

Jonathan H Jiang, Hui Su, Steven Massie, Peter Colarco, Mark Schoeberl and Steven Platnick

We examine the relation between Aqua MODIS aerosol optical thickness (AOT) and Aura MLS upper tropospheric (UT) carbon monoxide (CO) to address when CO can be used as a proxy for aerosols. Ice cloud effective radii (r_e), also from Aqua MODIS are also analyzed to investigate possible aerosol effects on ice clouds. Our analysis focuses on five regions where ice clouds are collocated with high UT CO loading: South America (SAM), Southern Africa (SAF), Northern Africa (NAF), South Asia (SAS) and East Asia (EAS). We find three levels of AOT to CO sensitivity. High AOT sensitivity to CO is characterized by a rapid increase of AOT when CO increases. SAM in Aug-Sep-Oct-Nov and SAF in Jun-Jul-Aug-Sep fall into this category. Moderate AOT sensitivity to CO is characterized by moderate increase of AOT with CO. It includes SAF in Oct-May, NAF in Jan-Mar, SAS in all months, and EAS in Aug-Sep. The other months for each region fall into the low sensitivity category. The variations of sensitivity in different regions and seasons are result from different emission sources coupled with dynamic influence. CO can be used as an aerosol-proxy for the "high" and "moderate" sensitivity cases. During those times, r_e for polluted clouds is smaller than that for clean clouds, suggesting an indirect effect of aerosol on ice clouds. CO is not a good aerosol index in the "low" sensitivity cases, in which polluted clouds defined by CO loadings does not show significant differences from clean clouds in r_e .

Detection of multi-layer and vertically-extended clouds using OMI, MODIS, and CloudSat

Joanna Joiner, Alexander Vasilkov, P. K. Bhartia, Gala Wind, Steve Platnick, and Paul Menzel

The detection of multiple cloud layers using satellite observations is important for retrieval algorithms as well as climate applications. We will describe a relatively simple algorithm to detect multiple cloud layers and distinguish them from vertically-extended clouds. The algorithm is applied using the following data from the A-train: cloud-top pressure, cloud optical thickness, and the multi-layer flag from the Aqua MODerate-resolution Imaging Spectroradiometer (MODIS) and the optical centroid cloud pressure from the Aura Ozone Monitoring Instrument (OMI). The cloud classification algorithms applied with different sensor configurations compare reasonably well with each other as well as with data from the CloudSat radar. We compute monthly mean fractions of pixels containing multi-layer and vertically-extended clouds for January and July 2007 at the OMI spatial resolution and at the 5km x 5km MODIS IR cloud algorithm resolution. There are seasonal variations in the spatial distribution of the different cloud types. The fraction of pixels containing multi-layer cloud is a strong function of the pixel size (approximately 20% and 5% for OMI and MODIS pixels, respectively). There are much smaller differences in the fractions of pixels containing vertically-extended clouds (~20% for OMI and slightly less for MODIS), suggesting larger spatial scales for these clouds. We also find significantly higher fractions of vertically-extended clouds over land as compared with ocean, particularly in the tropics and summer hemisphere. These results have implications for the planning of future instruments of this type.

JEM/SMILES observation onboard International Space Station

Yasuko Kasai

A new generation of sub-millimeter-wave receivers employing sensitive SIS (Superconductor-Insulator-Superconductor) detector technology will provide new opportunities for precise remote sensing measurements of minor constituents in atmosphere. Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) was designed to be onboard the Japanese Experiment Module (JEM) on the International Space Station (ISS) as a collaboration project of National Institute of Information and Communications Technology (NICT) and Japan Aerospace Exploration Agency (JAXA). SMILES scheduled to launch in September 11, 2009 by the H-II Transfer Vehicle (HTV). Mission Objectives are: i) Space demonstration of superconductive mixer and 4-K mechanical cooler for the submillimeter limb emission sounding, and ii) global observations of atmospheric minor constituents. JEM/SMILES will allow to observe the atmospheric species such as O₃, H₃₅Cl, H₃₇Cl, ClO, BrO, HOCl, HO₂, and HNO₃, CH₃CN, and Ozone isotope species from upper troposphere to the mesosphere.

PREMIER: a proposed satellite mission to observe processes controlling atmospheric composition in the height region of particular importance to climate

B.J. Kerridge

The PREMIER (PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation) mission is one of three remaining candidates for ESA's 7th Earth Explorer Mission (due for launch in 2016), for which Phase A system studies are to be undertaken. This mission proposes to observe structure in the mid/upper troposphere and lower stratosphere on the finer scales needed to quantify processes controlling global composition in this height range, which is of particular importance to climate. PREMIER would comprise an infrared limb-imaging spectrometer to observe 3D fields of trace gases, alongside a millimetre-wave limb sounder to observe in the presence of cirrus and to observe complementary trace gases. In addition, co-located data from EPS-MetOp would be combined with that from PREMIER, to extend into the lower troposphere and explore links to surface emissions and pollution. In this presentation, the PREMIER mission concept will be introduced and initial simulations of its capabilities will be described

Monitoring Air quality in Asia-Pacific region from MP-GEOSAT (Multi Purpose Geostationary Satellite): bringing OMI into GEO

Jhoon Kim, R. Park, P.K. Bhartia, S.S. Yong, C.K. Song, Y. Hong, S. Lee, S. Ryoo, J.H. Woo, Y.J. Kim, C.H. Song, J.H. Kim, K.M. Lee, C.H. Ho, S.K. Park, Y. Lee, J.B. Lee, M. Kim, and S. Paek

Asia, where both anthropogenic and natural source of pollutants dominate throughout the year, is an important region in understanding the globalization of tropospheric air pollution. To date, extensive datasets have been produced to measure air quality including O₃, NO₂, SO₂, HCHO, CO from successful missions including OMI, GOME, SCHIAMACHY, MOPITT, and TES. These measurements have provided daily to annual changes of pollutant distributions, but lack of capability in monitoring the diurnal variation and providing constraints on the emission. A scanning UV-Visible Spectrometer, named GEMS (Geostationary Environment Spectrometer) is being planned onboard a geostationary satellite, MP-GEOSAT to be launched in 2017-2018 by KARI(Korea Aerospace Research Institute), Korea, together with ABI(Advanced Baseline Imager) and GOCI (Geostationary Ocean Color Imager)-2. Synergized measurements of air quality together with the meteorological variables and ocean color information are expected to contribute to understand the distribution and transboundary transportation of air pollution, and to study interaction between meteorology and air chemistry in the Asia-Pacific region. This mission will improve the accuracy of air quality forecasting and reduce current large discrepancy between the model and observation. Furthermore, constellation of the MP-GEOSAT with GEOCAPE in America and Sentennial-4 in Europe with launch in 2017- 2018 period can enhance significantly our understanding in globalization of tropospheric pollution.

The analyses of satellite-derived HCHO measurements with statistical approaches

Jae H. Kim, S. M. Kim, and M. J. Newchurch

By comparing temporal and spatial patterns of formaldehyde (HCHO) along with our understanding of atmospheric chemistry, we analyzed satellite data to assess the impact of global temperature changes on the biosphere using satellite observations (OMI, GOME, CIMACHY, MOPITT, ATSR) of trace gases (HCHO, CO, NO₂, O₃) and fire counts along with model calculations. We have observed an increasing trend of HCHO over the tropics where the trend of biomass burning varies with regions and over the USA where some anthropogenic activity appears to be decreasing as deduced from NO₂ changes. The inventory of HCHO depends strongly on isoprene from biogenic activity and on the background level of CH₄ oxidation. Various models suggest surface temperature is responsible for the increasing HCHO over the USA. We will discuss to use novel EOF/SVD analyses techniques to investigate whether the increasing trend of HCHO can be used to identify and estimate the impact of global temperature changes on HCHO.

Ozone Profiles from the Ozone Monitoring Instrument: First Validation and Initial Science Results

M. Kroon, J. F. de Haan, J. P. Veefkind and P. F. Levelt

In this paper we present the results of validation and science of the vertical ozone profiles retrieved from the nadir observations by the ozone monitoring instrument OMI aboard the NASA EOS Aura platform. The advantages of the nadir sounding of the ozone profile is the high spatial resolution and coverage, while the vertical resolution is limited to 6-7 km. With an updated version of the KNMI ozone profile algorithm the complete OMI mission has been reprocessed. Validation and scientific results of this dataset will be presented. Comparisons with MLS provide an excellent opportunity for the validation of the OMI ozone profile product, because of the large amount of good collocated profiles. In addition to validation with MLS, also comparisons with OMI total ozone data and sondes will be presented. The lowest layers of the retrieved OMI ozone profile provides information on the tropospheric ozone column. First results of the tropospheric ozone column will be presented and compared to other satellite products and chemistry transport model data.

New discoveries enabled by OMI SO₂ measurements

N. Krotkov, K. Yang, S. Carn, A. Krueger, K. Pickering, J. Witte, C. Li, R. Dickerson, C. Wei, C. Lee, R. Martin, G. Carmichael, D. Streets, Q. Zhang, and E. Hughes

The Ozone Monitoring Instrument (OMI) on NASA Aura satellite makes global daily measurements of the total column of sulfur dioxide (SO₂), a short-lived trace gas produced by fossil fuel combustion, smelting, and volcanoes. This talk highlights most recent science results enabled by using OMI SO₂ data. OMI daily contiguous volcanic SO₂ data continue 25+ climatic record by its predecessors (Total Ozone mapping Spectrometers 1978-2005), but higher SO₂ sensitivity allows measuring volcanic plumes for a longer time as well as measuring passive volcanic degassing from space. New algorithm development first allows direct estimating of SO₂ plume heights to refine SO₂ tonnages in largest volcanic plumes important for climate applications. Interplay between volcanic and anthropogenic SO₂ emissions resulted in highly variable SO₂ pollution levels in Peru and Mexico City. OMI first enabled daily detection of SO₂ burdens from individual smelters as well as observed SO₂ pollution lofting from boundary layer and long-range transport in free troposphere. We have updated our copper smelter analysis, which showed interesting new trends. Combining OMI data with trajectory models and aerosol/cloud measurements by A-train sensors (MODIS, CALIPSO) allowed tracking long-range transport of volcanic and anthropogenic aerosol/SO₂ plumes. These studies placed new constraints on conversion rates of SO₂ to sulfate at different heights from free troposphere to the lower stratosphere. New results on inverse trajectory modeling of the OMI SO₂ data allow deriving information on the altitude distribution of SO₂ and the emission time-series. Quantitatively, anthropogenic SO₂ is more difficult to measure from space, since ozone absorption and Rayleigh scattering reduce sensitivity to pollutants in the lower troposphere. We describe new techniques for spatial and time averaging that have been used to determine the global distribution of anthropogenic SO₂ burdens, and the efficacy of abatement strategies. OMI seasonal to multi-year average images clearly show the world-highest consistent SO₂ pollution in eastern China. China is the world's largest SO₂ emitter, mostly due to the burning of high-sulfur coal in its many coal-fired power plants, which lack the technology used in many other countries to remove sulfur from smoke stack emissions. Recently, China's government has instituted nationwide measures to control SO₂ emissions through the adoption of flue-gas desulfurization technology on new power plants; and even greater measures were adopted in the Beijing area in anticipation of the Olympic Games. To study the environmental effects of the emission controls we compared OMI SO₂ time series over eastern China for 2005 through 2009. By mid-March 2008 OMI first observed substantial periods of lower SO₂ values compared to 2007, and by mid June the 2008 values were consistently lower than 2007 and prior years. The decline is widespread with highest SO₂ typically located to the south

and southwest of Beijing in regions with large clusters of power plants and also around Shanghai. The decline also lasted beyond the Olympic season through summer 2009. Combining model provided SO₂ and aerosol vertical profile shapes allows refining satellite columns as well as estimating surface SO₂ concentrations for air-quality applications. Finally we present our plans to use the OMI SO₂ columns to provide a top-down constraint on SO₂ regional emissions.

Characterization of Tropospheric Emission Spectrometer (TES) CO₂ for carbon cycle science

Susan Kulawik, Kevin Bowman, Dylan Jones, Ray Nassar, John Worden, F.W. Irion, and the TES team

We present retrievals of carbon dioxide from the Tropospheric Emission Spectrometer (TES) aboard the NASA Aura spacecraft launched in 2004. The optimal estimation strategy is described with a particular focus on the interference from temperature and water vapor. The northern and southern hemispheric distributions are compared against both in situ and aircraft data. We find that the observed yearly and seasonal variations are consistent with in situ data. An observing system simulation experiment (OSSE) used to assess the information content of TES retrievals to constrain CO₂ sources relative to the existing surface networks finds that TES 20 x 30 degree x 1 month averaged data will increase accuracy of flux estimates.

Future European Atmospheric Missions

Joerg Langen

While Envisat and Odin are still providing high quality global data on atmospheric composition and EPS (Metop) has started a long time series of continuous monitoring of atmospheric species, European Agencies are planning for future missions. In ESA's Earth Explorer programme, there are currently two atmospheric missions in development: ADM-Aeolus, a wind-profiler mission using a Doppler lidar, and EarthCare, a mission investigating cloud and aerosol processes in Earth's atmosphere by means of radar, lidar, imager and radiometer observations. PREMIER, a mission to investigate processes primarily in the UTLS with relevance to climate-chemistry interactions, and featuring a mm-wave limb-sounder and an infrared limb imaging FTS at high 3-D resolution, is now in phase A, in competition with two other missions, aiming at the quantification of biomass and the observation of snow. The Global Monitoring for Environment and Security (GMES) programme, a common initiative by the European Union and ESA, includes a set of 5 "Sentinel" missions, two of which are dedicated to monitoring of atmospheric composition for applications relating to climate, air quality and stratospheric ozone. Sentinel 4 will be a UV-VIS-near IR spectrometer for observation of air quality over Europe, to be embarked on Eumetsat's Meteosat Third Generation sounder platform, next to a medium-resolution FTIR. The Sentinel 5 mission will use a UV-VIS-near IR – short wave IR spectrometer, an FTIR and make use of imager data and possibly directional polarization imager data, and will be accommodated on Eumetsat's post-EPS platforms. A Sentinel 5 precursor mission, co-funded by the Netherlands and carrying a UV-VIS- near IR – short wave IR spectrometer, will bridge the gap between Envisat/Aura and Sentinel 4/5 and will fly on a dedicated platform in loose formation with NPP. ©

Aura Microwave Limb Sounder Observations of the Middle Atmosphere: From the Mesosphere to the Upper Troposphere

Jae N. Lee, Dong L. Wu, Gloria L. Manney, Michael J. Schwartz, Alyn Lambert, Nathaniel J. Livesey, Hugh C. Pumphrey, William G. Read, and Michelle L. Santee

The Aura Microwave Limb Sounder (MLS) measurements in the entire middle atmosphere between 316 hPa (~9 km) and 0.001 hPa (~90 km) show strong wintertime dynamical connection through the Northern Hemisphere Annular Mode (NAM). This NAM represents ~70% of wintertime variability at pressures between 100 and ~0.1 hPa, suggesting strong dynamic coupling between the lower and upper atmospheres. It is the first report of the NAM structure in the entire middle atmosphere including the mesosphere. Time evolution of the NAM suggests that NAM anomalies typically appear first in the mesosphere, preceding the stratospheric signals, and progress downward during stratospheric sudden warming (SSW) periods. The NAM also affects the MLS trace gases substantially, such as H₂O, and CO. During the prime SSW phases, when the stratospheric NAM index is strongly negative, the polar vortex is associated with a strong descent in the stratosphere but not much in the mesosphere. However, in the decaying stage of the SSWs, the polar vortex start to form in the mesosphere, showing a strong descent there but not much in the stratosphere. Similar to the NAM, the Southern Annular Mode (SAM) appears to be robust during austral winter and it accounts for a less (~40%) variance than the NAM during boreal winter in the middle atmosphere before further decreasing in the upper mesosphere.

TROPOMI: A new Dutch instrument for measuring the troposphere

P.F. Levelt, E.A.A. Aben, J.P. Veeffkind, M. Dobber, M. van Weele, R. Hoogeveen, J. de Vries, H. Visser, and G. Otter

For understanding climate change and air quality, global atmospheric changes need to be taken into account. Especially the global inventory of emission sources play a key role in understanding and modelling the troposphere in relation to climate change and air pollution. Also regional and long-range transport of pollution, as well as the rapid development of pollution levels during the day, are important for understanding air quality and climate change and their interaction. The atmosphere therefore needs to be studied and monitored with an integrated observing system, in which satellites play a key role due to the global nature of their measurements. Sensing the troposphere from space is a rapid development during the last decade in satellite remote sensing. Measurements from GOME and SCIAMACHY revealed the first averaged tropospheric nitrogen dioxide maps. OMI performed unprecedented measurements from space by measuring tropospheric pollution NO₂ maps on a daily basis with urban scale resolution. The greenhouse gas methane and the air pollutant CO were measured by SCIAMACHY. Techniques to provide tropospheric ozone and aerosol index maps were applied to GOME, SCIAMACHY and OMI data. In this presentation the challenges and future developments for sensing the troposphere from space will be discussed, resulting in the presentation of a new satellite instrument (TROPOMI). TROPOMI measures several tropospheric constituents relevant for climate change and air pollution (ozone, NO₂, HCHO, SO₂, CO, CH₄ and aerosols) with unprecedented spatial resolution (smaller than 10 x 10 km²), providing valuable information for amongst others emission identification. The science questions in terms of contribution to climate and air quality research and potential operational use of TROPOMI will be presented. TROPOMI will fly on ESA's sentinel 5 pre-cursor mission targeted to be launched in 2014.

The impacts of dynamics on tropical tropospheric CO inferred from the Aura Satellite data and GEOS-Chem model

Junhua Liu and Jennifer Logan

We use CO mixing ratios observed by the Tropospheric Emission Spectrometer (TES) and the Microwave Limb Sounder (MLS) to evaluate transport in the tropics in the GEOS-Chem model and to investigate causes of discrepancies with the observations. The model in this study is driven by two different versions of assimilated meteorology from the Goddard Earth Observing System, GEOS-4 and GEOS-5. We focus on transport during the southern biomass burning season, and on particular on vertical mixing at end of the dry season when convection moves over the source region. Measurements of CO in both the lower and upper troposphere allow us to diagnose deficiencies in horizontal and vertical transport, and provide valuable insights into how dynamics influence the CO distribution. The model reproduces the timing of the observed CO maximum over South America and South Africa during the biomass burning season from August to November in 2005 and 2006 in the lower troposphere. However, in the upper troposphere, the model CO maximum with GEOS-4 over South America occurs ~1 month later than the observed maximum, while with GEOS-5 it occurs ~2 months later. A comparison between vertical profiles of convective and advective mass fluxes indicates that the deep convective mass flux in GEOS-5 decays at a lower altitude than does that in GEOS-4. Most convective outflow over South America in both meteorological fields ends below 200 hPa. Therefore the CO around 215 hPa is mainly accumulated by slow vertical ascent, causing the lag of the CO maximum in the model compared to observations. The lag in GEOS-5 is greater in part because the convection decays at a lower altitude, and in part because the convection moves southward later than in GEOS-4. Compared to the GEOS-5 model, the GEOS-4 model has a larger CO overestimate in the east equatorial Pacific, resulting from stronger local convection, and stronger easterly winds in GEOS-4 in the lower altitude. Both GEOS-4 and GEOS-5 match the timing of the CO maximum over Indonesia.

Comparison of Direct Ozone Profile Retrievals and Trajectory Mapping OMI/MLS Tropospheric Ozone Residuals

Xiong Liu, Mark Schoeberl, Pawan K. Bhartia, and Kelly Chance

In the last two decades, various techniques have been developed to extract Tropospheric Ozone Column (TOC) using the Tropospheric Ozone Residual (TOR) method, subtracting Stratospheric Ozone Column (SOC) from the Total Ozone Column (TOZ). Prior to the launch of Aura, most of the TOR products were monthly means in the tropics. This is largely because of the poor spatiotemporal resolution/coverage or inadequate accuracy in coincidentally measured SOC data and the large geophysical variability in SOC at higher latitudes. With the launch of Aura, SOC can be accurately retrieved from MLS, simultaneously with TOZ from OMI. Global distributions of TOC have been derived daily from OMI and MLS data, with the use of advanced techniques (e.g., trajectory mapping) to improve the coverage of MLS observations. Meanwhile, ozone profiles including tropospheric ozone have been directly retrieved backscattered

radiance spectra in the Hartley and Huggins bands measured by GOME and OMI. Despite coarse vertical resolutions (7-10 km in the stratosphere and 10-14 km in the troposphere), TOZ, SOC and TOC can be retrieved accurately with retrieval errors (due to random-noise and smoothing errors) typically 0.2-3, 1.5-4, and 2-5 DU, respectively, under solar zenith angles less than 80°. The launch of both OMI and MLS on the AURA platform provides an excellent opportunity to validate retrievals from both methods. In this study, we will compare SOC and TOC from the trajectory mapping OMI/MLS TOR and direct OMI ozone profile retrievals, and also validate them with collocated ozonesonde observations. Preliminary comparison shows excellent agreement between these two methods. Both TOC agrees very well with ozonesonde observations. The OMI/MLS TOR shows a systematic negative bias of 5-6 DU relative to ozonesonde observations likely due to a combination of negative biases in OMI TOR and positive biases in MLS SOC. The direct retrievals show some latitudinal biases relative to ozonesonde observations likely due to residual straylight errors and approximation in forward modeling.

NASA's Global Atmospheric Composition Mission (GACM) Concept

N. J. Livesey, P. K. Bhartia, J. C. Gille, and colleagues

Resolution of important outstanding questions in air quality, climate change and ozone layer stability demands global observations of multiple chemical species with high horizontal and vertical resolution from the boundary layer to the stratopause. We present a mission concept that delivers the needed atmospheric composition observations, along with cloud ice and water vapor data needed for improvements in climate and weather forecasting models. The mission comprises ultraviolet, infrared and microwave instruments viewing in the nadir and limb, observing wide swaths each orbit. This concept can serve as the "Global Atmospheric Composition Mission" (GACM) recently recommended by the National Academy of Sciences decadal survey as one of 17 priority earth science missions for the coming decade.

Analysis of five years of Aura data for tropospheric NO₂, CO, and ozone in the biomass burning season in the tropics: comparison with GFED2 emissions and model results (GMI and GEOS-Chem)

Jennifer A. Logan, Junhua Liu, and Inna Megretskaya

We use the DOMINO tropospheric NO₂ column to reveal in detail the spatial and interannual variability (IAV) in biomass burning emissions in the tropics. The spatial patterns are remarkably constant from year to year in most regions, but there is substantial IAV in the NO₂ column in South America, Indonesia, and Australia, and occasional anomalously high NO₂ in SE Asia. We use the NO₂ data to evaluate the spatial patterns and IAV in GFED2 fire emissions. The IAV in TES ozone at ~700 hPa is generally small in the burning regions and is not strongly related to the magnitude of precursor emissions. The IAV in model ozone driven by IAV in biomass burning emissions is largest in the boundary layer where TES has lowest sensitivity. The models match TES ozone better in the upper troposphere than in the lower troposphere.

Global Monitoring for Environment and Security (GMES)

D.E. Lolkema and D.P.J. Swart

GMES, Global Monitoring for Environment and Security, has now entered its operational stage. Started off with the four themes Land, Water, Atmosphere and Security, the implementation of the core and downstream services has now started. For the Atmosphere theme, the core services will be implemented by the project MACC, Monitoring Atmospheric Composition and Climate. The Atmosphere core services encompass the themes "Air Quality", "Climate" and "Ozone, UV and Solar Energy". GMES includes both ground-based and satellite observations. This presentation will focus on the current (operational) stage of GMES and the role of current and future satellite missions for the Atmosphere theme.

Interpretation of Aura Satellite Observations of CO and Aerosol Index related to the December 2006 Australia Fires

M. Luo, C. Boxe, J. Jiang, R. Nassar, J. Logan, and N. Livesey

Enhanced Carbon Monoxide (CO) in the upper troposphere (UT) is shown by collocated Tropospheric Emission Spectrometer (TES) and Microwave Limb Sounder (MLS) measurements near and down-wind from the known wildfire region of SE Australia, December 12th-19th, 2006. Enhanced UV aerosol index (AI) derived from Ozone Monitoring Instrument (OMI) measurements correlate with these high CO concentrations. HYSPLIT model back trajectories trace selected air parcels to the SE Australia fire region from the initial locations with enhanced TES CO in the upper and lower troposphere. Simultaneously, they show a lack of vertical advection along their tracks. TES retrieved CO vertical profiles in the higher and lower southern latitudes are examined together with the averaging kernels and show that TES CO retrievals are most sensitive at approximately 300-400 hPa. The enhanced CO observed by TES at the upper (215 hPa) and lower (681 hPa) troposphere are therefore influenced by mid-tropospheric CO. GEOS-Chem model simulations with an 8-day emissions inventory as the wildfire source over Australia, are sampled to the TES/MLS observation times and locations. These simulations only show CO enhancements in the lower troposphere near and down-wind from the wildfire region of SE Australia with drastic underestimates of UT CO. Although CloudSat along-track ice-water content curtains are examined to see whether possible vertical convection events can explain the high UT CO values, sparse observations of collocated Aura CO and CloudSat along-track ice-water content measurements for the single event precludes any conclusive correlation. Vertical convection that uplift fire-induced CO (i.e., most notably referred to as pyro-cumulonimbus (pyroCb)) is likely responsible for the TES/MLS observations. The PyroCb mechanism is currently not incorporated in GEOS-Chem, thus providing a potential explanation for the incongruence between its simulations and TES/MLS observations of enhanced CO in the UT.

Stratospheric and Tropospheric Jet Characterization and Analyses of Satellite and Aircraft Data in the Context of Jet Structure

G.L. Manney, M.I. Hegglin, W.H. Daffer, M.L. Santee, E. Ray, K.A. Walker, P.F. Bernath, L. Pan, N.J. Livesey, B. Nardi, and S. Pawson

We describe a method for categorizing the location and characteristics (including relationship to the tropopause) of upper tropospheric jets (UTJs) and of the lower reaches of the stratospheric polar night jet (PNJ). We show examples using the method with Goddard Earth Observing System Version 5 (GEOS-5) analyses to explore the climatology and variability of the UTJs and their relationship to the lowest part of the PNJ. Satellite trace gas measurements from satellite instruments, including the Aura Microwave Limb Sounder (MLS), Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE-FTS), and aircraft campaigns, including the START-08 and Winter Storms campaigns, are examined with respect to the UTJs, PNJ and tropopauses to characterize trace gas transport in the context of jet structure.

Surface Air Quality parameters from satellite data

Randall Martin, Aaron van Donkelaar, Lok Lamsal, Chulkyu Lee, Ed Celarier, Folkert Boersma, Ruud Dirksen, Nick Krotkov, and Xiong Liu

Large spatial gaps exist in measurements of surface air quality, especially outside of North America and Europe. These gaps impede assessment of air pollution impacts on public health. Satellite observations are well suited to provide information about pollution exposure, in conjunction with a chemical transport model to relate column observations into surface concentrations. Satellite observations are also well suited to provide information on emissions through inverse modelling, and in turn improve simulations of ground-level air quality. This talk will present recent efforts to apply satellite observations for air quality.

The relationship between HIRDLS tropical cirrus and deep convection

Steven Massie, Cheryl Craig, Rashid Khosravi, John Gille, and John Barnett

Cirrus near the tropopause is involved in the processes that determine the amount of water that is transported into the lower stratosphere. Cirrus is formed by several processes: blow-off from deep convection, in-situ formation by rising humid layers, and dynamical waves (cold temperature perturbations). This presentation uses back trajectory analyses to

relate cirrus observations to deep convection, and comments on the relative partitioning of the formation mechanisms. HIRDLS observations of cirrus during 2006 and 2007 and ECMWF analyses of winds on isentropic surfaces are used in trajectory calculations. Back trajectories encounter deep convection during a five day time period more frequently in winter (December-February) than summer (June-August) in the tropics. This seasonality is reflected in the seasonality of deep convection, as indicated by Climate Diagnostic Center outgoing longwave radiation (OLR) data, which is more prevalent during winter. The frequency of occurrence is also noted as a function of cloud structure type (i.e. thin cirrus layers in the upper troposphere versus cloud structures of larger vertical depth). Back trajectories of cirrus layers encounter deep convection (i.e. low OLR) during a five day time period less frequently than the back trajectories of cloud structures that have a larger vertical depth. These frequency differences give insight on the relative partitioning of the formation mechanisms.

Reductions of NO₂ Detected from Space During and After the 2008 Beijing Olympic Games

Bas Mijling, Ronald van der A, and Folkert Boersma

During the 2008 Olympic Games (from August 8 to August 24), the Chinese authorities took extensive air quality measures in Beijing and surrounding provinces to improve the air quality in the city. Industrial activities and traffic were reduced to decrease emissions. Cars, for example, were only allowed to circulate on days corresponding to their number plate. The AMFIC project (Air Quality Monitoring and Forecasting in China) monitors and forecasts the air quality in China by combining satellite measurements, ground measurements and chemical transport model simulations. Within the AMFIC framework the effect of the air quality measures in Beijing during the Olympic Games was studied by using NO₂ tropospheric column retrievals from the satellite instruments OMI and GOME-2. Interpretation of the satellite retrievals over Beijing during the Olympic Games is not straightforward. The cloudiness in this period reduces the number of useful satellite retrievals considerably, and the regular rainfall makes it difficult to attribute a less polluted sky over Beijing to wet deposition or the effect of the air quality measures. To take the meteorological effects (deposition, transport) into account we compare the satellite NO₂ tropospheric columns with simulated columns by a chemical transport model. We implemented the regional model CHIMERE for East China, running with the 2006 INTEX-B emission inventory (by Qiang Zhang and David Streets) and the ECMWF meteorological forecast. The increased bias between satellite measurements and model values shows us a direct indication of the effectiveness of the air quality measures. Analysis of the comparison shows a strong reduction of the tropospheric NO₂ column concentrations of about 60% above Beijing during the Olympic period. The air quality measures were especially effective in the Beijing area, but also noticeable in surrounding cities of Tianjin and Shijiazhuang. In the two-month period after the Olympic events the NO₂ concentrations still show a 40% reduction; one year later the NO₂ concentrations return to slightly below their pre-Olympic level.

Photochemistry and Transport of Carbon Monoxide in the Southern Polar Stratosphere: Constraints from Satellite Observations and Trajectory Calculations

K. Minschwaner, G. L. Manney, N. J. Livesey, H. C. Pumphrey, H. M. Pickett, and L. Froidevaux

We present an analysis of the photochemistry and transport of CO during late winter in the Southern Hemisphere stratosphere using a combination of data from the Aura Microwave Limb Sounder (MLS), and results of parcel trajectory calculations based on the GEOS-5 meteorological analysis. Aura-MLS measurements include most of the reactive species involved in regulating the photochemical production and loss of carbon monoxide, providing tight constraints on CO photochemistry along individual parcel trajectories. The impact of photochemistry on the vertical distribution and evolution of vortex average CO can be quantified using this technique. For example, the net loss of CO averaged over all vortex parcels on the 1200 K surface is about 20% over a 16-day period in September 2005.

Using Tropospheric Emission Spectrometer (TES) CO₂ observations to improve inverse modeling estimates of carbon fluxes

Ray Nassar, Dylan B.A. Jones, Susan S. Kulawik, Jing M. Chen, Robert J. Andres, Parvatha Suntharalingam

The capability to retrieve CO₂ profiles from Tropospheric Emission Spectrometer (TES) observations has recently been developed. Using a Bayesian inversion approach and the GEOS-Chem chemical transport model with updated fossil fuel emission inventories, we compare the information provided by CO₂ measurements from TES and data from the GLOBALVIEW- CO₂ network for constraining estimates of CO₂ terrestrial and ocean fluxes in 2006. Although the sensitivity of TES CO₂ observations peak in the mid-troposphere (511 hPa) and TES CO₂ accuracy and precision are

lower than those of GLOBALVIEW, the coverage provided by satellite-based observations provides an important benefit for flux inversions. We investigate methods for combining TES and GLOBALVIEW data to take advantage of the strengths of each observational approach in order to provide additional constraints for reducing the uncertainty in estimates of CO₂ sources and sinks.

Improved constraints on North American air quality through assimilation of satellite observations of ozone and its precursors

M. Parrington, D. B. A. Jones, K. W. Bowman, L. Lamsal, D. B. Millet, R. V. Martin, Thomas Walker, Zhe Jiang, A. M. Thompson, and D. W. Tarasick

We present results from the integration of data from different satellite instruments in August 2006 to assess the constraints that they provide on North American surface ozone abundances. Using the GEOS-Chem model we assimilate observations of tropospheric O₃ from the Tropospheric Emission Spectrometer (TES) with emissions of isoprene derived from formaldehyde observations from the Ozone Monitoring Instrument (OMI) and emissions of NO_x derived from NO₂ measurements from the SCanning Imaging Absorption SpectroMeter for Atmospheric CHartography (SCIAMACHY). We find that the assimilation significantly reduces the mean bias in surface ozone across North America relative to surface ozone data from the US EPA Air Quality System (AQS) and the Environment Canada National Air Pollution Surveillance (NAPS) network. For example, at Pinnacles National Monument, California, the bias is reduced from -6.36 ppb to -0.68 ppb, while at Narragansett, Rhode Island, the bias is reduced from 8.1 ppb to 1.8 ppb. Our results show that the information from the satellite observations provides a strong constraint on background ozone transported into the boundary layer as well as on ozone produced within the North American boundary layer.

Assimilating EOS-Aura OMI and MLS Data in GEOS-5

Steven Pawson, Philippe Xu, Anne R. Douglass, Mark Olsen, Susan Strahan, J. Eric Nielsen, Nicole McKee, Meta Sienkiewicz, and Krzysztof Wargan

Data assimilation is a potentially powerful method of extracting the maximum amount of information from observed data by combining their information with models. In this application, we will use stratospheric ozone profiles retrieved from EOS MLS and total column amounts retrieved from OMI along with the GEOS-5 GCM, that includes a representation of ozone chemistry and transport. The presentation will discuss how well we can derive tropospheric ozone column information in this system, including its sensitivity to model errors and some assumptions made in the assimilation system. We discuss also ozone structures in the tropopause region and their sensitivity to model resolution and other factors.

Methane from the Tropospheric Emission Spectrometer

Vivienne Payne, Mark Shephard, Janusz Eluskiewicz, Karen-Cady Pereira, Eric Kort, Steven Wofsy, Hanqin Tian, Christopher Pickett-Heaps and the JPL TES team

Methane (CH₄) is an important greenhouse gas and plays a crucial role in tropospheric chemistry. The Tropospheric Emission Spectrometer (TES) on the EOS Aura satellite makes global measurements of infrared radiances that are used to derive profiles of species such as O₃, CO, H₂O, HDO and CH₄ as routine standard products. The TES CH₄ retrievals contain between 0.5 and 2.0 degrees of freedom for signal, depending on season and location. Although the peak sensitivity is in the mid-to-upper troposphere, maps of the data are suggestive of local surface influences in certain regions of the globe, particularly at high northern latitudes. Here we present recent validation work against aircraft and ground-based measurements as well as comparisons with up-to-date output from a global chemical model (GEOS-Chem). We will also present recent work on quantifying surface influences on the TES methane observations. In order to quantify these influences, we have simulated the short-term surface contributions to the TES measurements by convolving footprint maps computed using a Lagrangian particle dispersion model (WRF-STILT) with representative estimates of CH₄ fluxes from anthropogenic and natural sources. For a case study over North America in August 2007, our results show that the surface contributions exceed 0.05 parts per million by volume (ppmv) for about 14% of the TES measurements. Also, in 50% of the cases in this study, the TES methane measurement is most sensitive to surface points within 350 km and 15 hours. Our Lagrangian regional modeling framework is naturally extensible to other regions of the globe as well as other instrument designs. The pilot study presented here establishes a reference point for future work on utilizing satellite data in inverse estimates of greenhouse gas fluxes on regional, policy-relevant scales.

Height Resolved Ozone Hole Structure as Observed by GOME-2

J. van Peet, A.T.J. de Laat, O.N.E. Tuinder, and R.J. van der A.

We present GOME-2 ozone profiles that were operationally retrieved with the KNMI OPERA algorithm for the period September-December 2008. It is shown that for the first time it is possible to accurately measure the vertical distribution of stratospheric ozone for Antarctic ozone hole conditions from nadir spectra measured at ultraviolet and visible wavelengths. Comparisons with ozone sonde observations from the Neumayer station at the Antarctic coast show an excellent agreement for various ozone profile shapes representing different phases of the annual ozone hole cycle. A time series analysis shows the development and recovery of the ozone hole in great detail. Around the time of maximum ozone depletion in the middle of October we created latitudinal and longitudinal cross sections of the atmosphere centered on the Neumayer station. These cross sections give a clear view of the extent of the ozone hole in both North-South and East-West direction and its dynamics. A preliminary analysis of the three-dimensional structure of the ozone hole shows for example that at the vortex edges ozone rich mid-latitude middle and upper stratospheric layers are superimposed over ozone depleted lower stratospheric 'ozone hole' layers. These Antarctic ozone profile observations combined with the daily global coverage of GOME-2 enables the monitoring of the three-dimensional structure of the ozone hole on a daily basis.

Use of OMI Data in Monitoring Air Quality Changes Resulting from NO_x Emission Regulations over the United States

K. Pickering, R. Pinder, A. Prados, D. Allen, S. Ehrman, E. Celarier, and J. Gleason

EPA's NO_x Budget Trading Program has led to substantial NO_x emission reductions at power plants in the eastern and central United States. Surface measurements to track the resulting changes in NO_x concentrations are not sufficient because of interferences in the measurement, inability of surface measures to track the transport of NO_x aloft, and gaps in the surface measurement networks. Therefore, we focus on use of the tropospheric column NO₂ data from the OMI instrument on NASA's Aura satellite to monitor these changes. In addition, CMAQ model output can be used to attribute the regions where air quality changes are detected by satellite to specific clusters of power plants. We examine changes in OMI tropospheric NO₂ in the summers of the years from 2005 to 2008. NO₂ decreases of 10 to 40% are found in a broad swath from northern Ohio and southern Michigan stretching westward to Nebraska, Kansas and Oklahoma. A pronounced region of NO₂ increase (up to 60%) is found over western and central Pennsylvania, accompanied by decreases (5 – 30%) in the corridor stretching from northern New Jersey to northern Virginia. We compare these ambient air quality changes with the changes seen in the Continuous Emissions Monitoring System data from major point sources. Prior to using CMAQ in conjunction with the OMI data in interpreting these emission and air quality changes, the addition of lightning NO emissions and improvement of the soil NO emissions in the model are being performed.

The Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments, CINDI

Ankie Piters and the CINDI organization team

In June-July 2009 about thirty different in-situ and remote sensing NO₂ measuring instruments from all over the world came together in the Netherlands for the Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments, CINDI. The main objective of this campaign was to intercompare NO₂ measuring instruments that can be used for validation of tropospheric NO₂ from satellites. The campaign should result in an estimate of the accuracy of the NO₂ tropospheric columns and profiles for the participating instruments under different atmospheric conditions (clouds/aerosols) and viewing geometries. Apart from NO₂, other parameters have been measured and will be intercompared, among which O₃, aerosol, HCHO, CHOCHO, and BrO. Additional measurements have been performed to study the spatial variability of NO₂ within a satellite pixel.

MLS observations of emissions from the Australian bush fires of February 2009

Hugh C. Pumphrey

The large bush fires which occurred in southeast Australia in February 2009 were unusually destructive. However, they were also unusual in the amounts of various combustion products which were injected directly into the stratosphere. We report the observations by MLS of some of these combustion products. The highest quality observations are of CO;

these clearly show a large region of enhanced mixing ratios to the north of New Zealand which remains in that region for about ten days before drifting westwards and finally dissipating over the Atlantic about a month after the fire. Back trajectories run from the points where MLS observes enhanced CO pass close to the site of the fire. The MLS observations of CH₃CN and HCN resemble those of CO except for their poorer vertical resolution and more limited vertical range. This is the only event of this type and magnitude in the 5-year MLS record.

Results from the first two years of GOME-2 measurements

Andreas Richter

Satellite measurements of the backscattered radiation in the UV and visible spectral range can be used to retrieve information on atmospheric composition by using absorption spectroscopy. Target species include trace gases relevant for stratospheric ozone chemistry (O₃, OClO, BrO, NO₂) but also species of tropospheric importance such as NO₂, HCHO, glyoxal or H₂O. With their global coverage, satellite data sets are a unique data source for model validation, atmospheric monitoring and also the inversion of emission fluxes. Over the last years, the GOME, SCIAMACHY and OMI instruments have become operational, all of them providing UV/vis measurements with sufficient spectral coverage and resolution for trace gas retrievals. In October 2006, the GOME-2 instrument was launched on the MetOp platform, and with its two identical follow-up instruments a consistent time series of 15 years of measurements will become available. In this presentation, results from the two first years of measurements of the GOME-2 instrument will be presented and compared with results from other sensors. The focus will be on tropospheric species, including case studies of NO₂ from anthropogenic pollution, SO₂ from volcanic emissions, HCHO and glyoxal from biogenic emissions and BrO in polar spring. As the main aim of the GOME-2 project is to provide long-term data sets, the combination of these data with results from current and future missions will also be discussed.

Constraining the ClO / ClOOCl Equilibrium Constant from Aura MLS Measurements of Nighttime ClO

M.L. Santee, S.P. Sander, N.J. Livesey, L. Froidevaux, and G.L. Manney

The primary ozone loss process in the cold polar lower stratosphere hinges on ClO and its dimer, ClOOCl. Measured abundances of ClO in darkness can be used to constrain the value of the equilibrium constant, Keq, which governs the partitioning between ClO and ClOOCl. Both laboratory studies and analyses of atmospheric observations have suggested lower values of Keq than are currently recommended in JPL [2006]. The Aura Microwave Limb Sounder (MLS) observes significant nighttime enhancements in lower stratospheric ClO poleward of about 60 degrees in both Arctic and Antarctic winters. We investigate the temperature dependence of the polar nighttime ClO enhancements observed by MLS. Results indicate that the observed temperature dependence of the nighttime ClO is generally in line with that of the theoretical ClO / ClOOCl equilibrium relationship. None of the previously-published values of Keq consistently produces ClO abundances that match the observations well under all conditions. Estimating the thermal equilibrium constant directly from the nighttime MLS ClO data, we find a lower value of Keq than currently recommended, consistent with earlier studies.

The Chemical and Aerosol Sounding Satellite (CASS)

Mark Schoeberl, Jose M. Rodriguez, Charles Jackman, Kaley Walker, Patrick McCormick, Joseph Zawodny, and Anne Douglass

CASS is a proposed solar occultation mission to continue NASA trace gas and aerosol profile measurements of stratosphere and upper troposphere. The mission would joint with the Canadian Space Agency. CASS consists of two instruments, SAGE III and ACE II. SAGE III was built for the space station but never flown. It is currently be refurbished at NASA Langley. ACE II would be a copy of ACE I currently flying on SCISAT. The orbit inclination of CASS would be 58° providing better coverage of the tropics than SCISAT while still covering the polar region. The launch date for CASS would be 2014.

TES Observations of Tropospheric Ammonia

Mark W. Shephard, Mingzhao Luo, Karen Cady-Pereira, Robert W. Pinder, Daven Henze, John Walker, Curtis P. Rinsland, Reinhard Beer, and Vivienne H. Payne

Global high-spectral resolution nadir measurements from TES-Aura enable the simultaneous retrieval of a number of tropospheric pollutants and trace gases in addition to the TES standard operationally retrieved products (e.g. carbon monoxide, ozone). Ammonia (NH₃) is one of the additional species that can be retrieved in conjunction with the TES standard products, and is important for local, regional, and global tropospheric chemistry studies. Ammonia emissions contribute significantly to several well-known environmental problems, yet the knowledge of the magnitude and seasonal/spatial variability of the emissions is severely limited. In the atmosphere, a substantial fraction of fine particulate matter is composed of ammonium nitrate and ammonium sulfate. These particles are statistically associated with health impacts. When deposited to ecosystems in excess, reactive nitrogen, including ammonia, can cause nutrient imbalances, changes in ecosystem species composition, algal blooms and hypoxia. The greatest uncertainty in atmospheric transport of reactive nitrogen is in the rates of ammonia emission from all sources, at all scales (Galloway et al., 2008). In-situ ammonia measurements are challenging and not available in many regions. Limiting factors in improving the emission inventory are infrequent and sparse in-situ observations and the reliance of previous inversion methods using a limited number of available condensed-phase measurements (Gilliland et al., 2006; Henze et al., 2008). Satellite observations of ammonia are therefore highly desirable. Beer et al., (2008) demonstrated that tropospheric ammonia is detectable in the TES spectra and presented some corresponding preliminary retrievals over a very limited range of conditions. Here we evaluate/validate the retrieval results utilizing long term in-situ surface observations (e.g. EPA /NC State) and chemical models (e.g. GEOS-Chem and CMAQ) over a much broader range of conditions. We also discuss the estimated impact of TES retrievals on quantifying emission sources through inverse modeling.

OMI Observations of PMCs Compared with Coincident MLS Temperature and Water Vapor Measurements

E.P. Shettle, G.E. Nedoluha, M.T. DeLand, G.E. Thomas, J.J. Olivero, and Pieternel Levelt

Polar Mesospheric Clouds (PMC) form in the upper mesosphere (~ 80 to 86 km) poleward of 50° latitude during the summer season in each hemisphere. These clouds are formed of water ice particles, and thus can form only in regions where the temperatures are cold enough for water vapor to be saturated relative to ice. We can verify this assumption by comparing observations of PMCs made by the Ozone Monitoring Instrument (OMI) with coincident measurements of atmospheric temperature and water vapor made by the Microwave Limb Sounder (MLS) instrument. Because both instruments are flying on the Aura satellite, the large cross-track swath of the OMI measurements with sampling every 13 km along track ensures that there will be several ~13 km x 48 km OMI pixels overlapping with the footprint of each MLS measurement (200 km x 12 km for temperature and 300 km x 6 km for water vapor). Since the MLS measurements look forward at the atmospheric limb along the satellite track and the OMI measurements look downward, there is about a seven minute time lag between the MLS measurement and the coincident OMI measurements. This difference is short enough to ensure that there are no significant changes in the local atmospheric properties between observations. We calculate the saturation ratio with respect to ice from the MLS measurements of temperature and water vapor at a nominal PMC altitude of 0.006 mb (or about 83 km). The probability of OMI detecting a PMC and the brightness of these PMCs increases with decreasing temperatures and with increasing saturation ratio, as expected. The PMC events occurred at higher saturation ratios than the non-PMC events, and nearly all PMCs corresponded to MLS temperatures less than 160 K. The temperatures tend to be warmer in the Southern Hemisphere (SH) with correspondingly lower saturation ratios, resulting in fewer PMCs than in the NH. However, even controlling for temperature and saturation ratio there are still more and brighter PMCs in the NH than the SH. We will discuss possible explanations for this North/South asymmetry.

Ozone Temperature Correlations in the Upper Stratosphere as a Measure of Chlorine Content

Richard S. Stolarski, Anne R. Douglass, Ellis Remsberg, and Nathaniel Livesay

We use data from the Limb Infrared Monitor of the Stratosphere (LIMS) for the years 1978 and 1979 together with data from the Upper Atmosphere Research Satellite Microwave Limb Sounder (UARS MLS) for the years 1993 to 1999 and the Aura MLS for the years 2004 to 2007 to examine ozone-temperature correlations in the upper stratosphere. We find that the sensitivity coefficient of ozone response to temperature decreases as chlorine has increased in the stratosphere. We suggest that these data can be used to track the impact of chlorine added to the stratosphere and also to track the recovery of the stratosphere as chlorine is removed under the provisions of the Montreal Protocol. We caution that the sensitivity coefficient is a strong function of altitude and latitude and that care must be taken in selection of data.

Radiative effects of upper tropospheric clouds observed by Aura MLS and CloudSat and their impacts on tracer distributions in the upper troposphere and lower stratosphere

Hui Su, Jonathan Jiang, William G. Read, Yu Gu, and Nathaniel J. Livesey

Radiative heating associated with cirrus clouds in the tropical tropopause layer (TTL) can significantly impact the mass transport rate from the troposphere to the stratosphere and thus the tracer distributions in the upper troposphere and lower stratosphere (UT/LS). Quantification of cirrus radiative heating rates requires synthesizing cloud measurements from different sensors. We examined the radiative effects of upper tropospheric (UT) clouds observed by Aura Microwave Limb Sounder (MLS) and CloudSat during June-July-August 2008 and combined the two instrument measurements to investigate the role of cirrus cloud radiation in the UT/LS tracer transport. We find that the UT cloud occurrence frequency observed by MLS is more than CloudSat by 4–10% in the tropical average and by 40–60% near the tropopause in the deep convective regions. The clouds detected by MLS but missed by CloudSat (denoted as TCC) typically have visible optical thickness less than 0.2. TCC produce a tropical-mean net warming of 3.5 W/m² at the top-of-atmosphere and net cooling of 1.2 W/m² at the surface. They induce a net radiative heating in the UT. Their heating rate at 200 hPa is ~0.35 K/day in the tropical-mean and ~0.8 K/day over South Asia, which is about 3–4 times the clear-sky radiative heating rate. The impacts of such increased radiative heating and thus enhanced upwelling on the UT/LS tracer distributions are examined using a 2-D TTL model and a global general circulation model (GCM).

Combined use of OMI, MODIS and CALIOP for accurate aerosol absorption characterization

Omar Torres, Zhong Chen, and Santiago Gassó

Aerosol particles are an important atmospheric component, significantly affecting both climate and air quality. The climate related effects of aerosol scattering and absorption take place primarily in the visible and near IR spectral region, whereas the same processes in the UV hold great importance for atmospheric chemistry. The inversion of measurements of backscattered near UV radiation at the top of the atmosphere is the only proven technique for the detection and characterization of aerosol absorption from satellite observations. The use of OMI near-UV measurements with those of other aerosol sensors in the A-train (i.e. MODIS and CALIOP) allows for a more accurate characterization of aerosol absorption by providing direct measurements of other aerosol parameters or atmospheric variables known to introduce uncertainty in the OMI aerosol absorption observations. Information on aerosol layer height independently obtained by CALIOP, and in some instances, aerosol optical depth from MODIS can be used to constrain the OMI retrieval. In this presentation we will discuss the combined use of OMI and CALIOP observations to assess the accuracy of current OMI algorithm assumptions on aerosol layer height. We will also briefly discuss the use of OMI and MODIS observations to test a new algorithmic approach that makes use of MODIS measured aerosol optical depth as input to an OMI inversion procedure that derives aerosol single scattering albedo and layer height, eliminating the need of layer-height assumptions.

ESA CAMELOT study: Challenges in future operational missions for GMES atmospheric monitoring, Sentinel 4 and 5

Pepijn Veefkind, Pieternel Levelt and the CAMELOT Team

The Sentinel 4 and 5 (precursor) missions are dedicated operational missions to monitor the atmospheric composition in the 2013-2020 timeframe and onward. The user requirements for the sentinel missions focus on monitoring the atmosphere from an environmental point of view (ozone layer, air quality and climate). ESA's CAMELOT (Composition of the Atmospheric Mission concEpts and SentineL Observation Techniques) study is the follow-on study to ESA's CAPACITY study finished in 2005. The general objective of the CAMELOT study is to further contribute to the definition of the air quality and climate protocol monitoring parts of the GMES Sentinel 4 and 5 missions. Key issues in the CAMELOT study are: (1) trade-offs between different observation strategies (spectral ranges, polarization, direction etc) for aerosols and several trace gases, (2) a quantitative assessment of the requirements for spatio-temporal sampling taking into account the contamination of nadir-viewing observations by clouds, (3) optimizing several orbit scenario's (leo, inclined leo, geo or any combination) and a contribution from the user's perspective to the trade-off between different orbits. In order to address these issues a large European consortium, lead by KNMI, has been formed by 9 European institutes (KNMI, RAL, U.Leicester, SRON, FMI, BIRA-IASB, CNR-IFAC, NOVELTIS and RIU-U.Koeln). In the presentation an overview will be given of the CAMELOT study, including specific results for combined retrievals, cloud statistics for different orbit geometries and retrievals for several orbit scenarios.

Energetic particle precipitation and mesospheric odd hydrogen

P. T. Verronen, A. Seppälä, E. Kyrölä, J. Tamminen, H. M. Pickett, M. L. Santee, C. J. Rodger, M. A. Clilverd, and E. Turunen

Energetic particle precipitation (EPP) affects the composition of the middle atmosphere. For example, solar proton events can dramatically increase the ionization rate so that large amounts of odd hydrogen ($\text{HOx} = \text{H} + \text{OH} + \text{HO}_2$) and odd nitrogen ($\text{NOx} = \text{N} + \text{NO} + \text{NO}_2$) are subsequently produced. Increase in HOx and NOx concentration leads to decrease of ozone in the mesosphere and upper stratosphere through catalytic reaction cycles. MLS/Aura is the first satellite instrument capable of observing mesospheric OH and HO₂. Using MLS observations, we demonstrate how OH concentration responds to EPP. Further, it is shown that the observed changes in OH can be reproduced with reasonable success in atmospheric models, if the chemistry of positive and negative ions is taken into account. Finally, we discuss the possibilities of using OH observations as a spatio-temporal proxy for the flux of EPP.

BrO observations from ground based and satellite instruments

Thomas Wagner and Ulrich Platt

Due to their influence on the ozone budget and the atmospheric oxidation capacity (AOC) bromine compounds, in particular bromine monoxide, BrO are important species in stratospheric and tropospheric chemistry. During the recent two decades large progress was made in the remote sensing of BrO by active or passive DOAS observations from various platforms. From ground based zenith-viewing and satellite nadir viewing instruments the total atmospheric BrO column is measured. It always contains a stratospheric contribution, but sometimes also large signals from the boundary layer or the free troposphere are observed. However, typically it is rather difficult to disentangle these contributions (e.g. by comparison with stratospheric model results). More specific information on the spatial BrO distribution can be derived by DOAS observations from other platforms (e.g. from aircraft or balloon) or from various (slant) viewing directions (e.g. Multi-Axis-DOAS from ground or limb viewing geometry from satellite). In addition, active DOAS observations allow to quantify BrO concentrations even on small spatial scales. In our presentation we report on recent DOAS observations of stratospheric and tropospheric BrO. We discuss the relationships between the results from different viewing geometries and platforms (in particular made from ground and satellite) and the consistency of the results with respect to different hypotheses on the vertical distribution of atmospheric BrO and draw some conclusions about the influence of BrO on AOC.

Mission Status and Results from the Atmospheric Chemistry Experiment (ACE): After Six Years in Orbit

Kaley A. Walker, Chris Boone, Peter F. Bernath, C. Thomas McElroy, Sean D. McLeod, and Ryan Hughes

On 13 August 2009, the Canadian-led Atmospheric Chemistry Experiment (ACE) satellite mission completed its sixth year in-orbit. This is Canadian-led scientific satellite that 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) FTS operating between 750 and 4400 cm⁻¹. It also contains two filtered imagers (0.525 and 1.02 microns) to measure atmospheric extinction due to 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 extends 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 5.5 years and, 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 in this paper.

Inter-comparison of TES water vapor isotope measurements with In Situ Measurements from Mauna Loa

John Worden

We present an inter-comparison between satellite observations of water vapor and its isotopes from the Aura Tropospheric Emission Spectrometer (TES) and in-situ measurements of the isotopic composition of water taken at the Hawaii Mauna Loa Observatory during October 2008. The in-situ measurements of the HDO/H₂O ratio show a strong diurnal variation between -350 to -100 parts per thousand relative to the isotopic composition of ocean water (SMOW) with the most depleted values during the night when the boundary layer is below the observatory. Analysis of the TES

data indicate that the TES observations are primarily sensitive to the free troposphere and would only be able to observe at most about 25 parts per thousand of this diurnal variability. Comparison of the distribution of TES data to the nighttime in situ data reveal about a 4% bias in the HDO/H₂O ratio, consistent with prior expectations discussed in Worden et al., JGR, 2006.

Retrievals of upper-tropospheric ice cloud microphysical properties with the A-Train MLS, CALIPSO and CloudSat

Dong L. Wu, Jung H. Chae, Alyn Lambert, and William G. Read

Uncertainties about ice microphysics in the upper troposphere remain to be one of the large error sources in cloud remote sensing. Due to lack of in-situ observations and reliable climatology about ice microphysics, poorly-constrained assumptions made in Aura MLS and CloudSat cloud ice retrievals can result in a factor of 2-3 differences in the retrieved cloud ice. To reduce the uncertainties, we analyze the A-Train MLS, CALIPSO, and CloudSat data since May 8, 2008 when the footprints of these measurements begin to collocate to each other within +/- 10 km along the orbit plane. The collocated data provide an unprecedented opportunity to study cloud-induced radiance (Tcir), backscatter (beta), and reflectivity (Ze) measurements jointly on a point-by-point basis. By computing the integrated quantity of these measurements on the MLS measurement volumes, we are able to derive the Tcir-beta and Tcir-Ze relationships, as well as their relationships to ice water content (IWC) near the upper troposphere. In this paper we will present the new results from this multi-sensor analysis and its applications to climate research.

CO multi-sensor products, solving the TIR-CO puzzle

V. A. Yudin

There are several needs for benchmarking of CO "optimal" estimation algorithms to unify/combine CO Thermal InfraRed (TIR) products and produce unbiased estimation of CO surface emissions. In this talk I will demonstrate weaknesses of traditional method for intercomparison of CO-TIR measurements from A-train sensors (AIRS-V5, TES-V4, MOPITT-V3 and MOPITT-V4) and IASI-METOP that relies on the linear characterization of retrieved CO by averaging kernels and a priori. The algorithmic errors in the direct solution of the inverse problem for CO profiles create "false" vertical sensitivity and extra-resolution of CO products in the so-called data-null space. These algorithmic errors may result in the corrupted averaging (resolution) kernels. For example, the vertical profiles of erroneous kernels can substantially deviate from profiles of CO weighting functions that show the sensitivity of measured radiances to CO. The violation of the core principle of the resolution-dependent analysis/retrievals, "constrain only scales or layers visible to the sensor", leads to the high sensitivity of retrieved "profiles" to the choice of a priori (errors and profiles) and creates biased products as highlighted by systematic data-data differences (between sensors and versions). The set of the simple benchmarks for linear and non-linear CO retrievals is proposed to make steps towards combined A-train CO nadir products. The sequential assimilation of NIR and TIR CO, as well as adding limb CO from Aura/MLS is briefly outlined to demonstrate how the resolution-dependent analysis of data with different vertical resolution can be performed in practice.

Global and regional trends in the presence of absorbing aerosol using OMI OMAERO Aerosol Index data

D. C. Stein Zweers, J. P. Veeffkind, and P. F. Levelt

The Aerosol Index (AI) as derived from OMI OMAERO data provides daily, global information about the presence of aerosol in the atmosphere. Positive values of the aerosol index indicate the presence of absorbing aerosol including desert dust, volcanic ash, and smoke particles from biomass burning. The moderately high spatio-temporal resolution of AI data is useful for tracking the distribution and transport of aerosol plumes. Because aerosol distribution is often episodic in nature, it is not always well represented by monthly mean fields. In order to more fully describe monthly and annual variability in aerosol presence, we evaluate the mean and standard deviation of AI values for individual grid boxes based on a relatively fine 1 by 1 degree grid. Histograms of AI values are also calculated for each monthly grid box and are used to interpret what is driving the mean AI values and variance. This is a computationally affordable method for storing additional, descriptive statistical information for monthly and annual grid boxes which cover most of the globe and span multiple years. This method of evaluation is useful for better understanding global areas of annually persistent aerosol as well as seasonal episodic aerosol presence especially for regions affected by biomass burning. The description of these trends can be used for the interpretation of regional radiation balance and for better understanding variability of aerosol source regions.