Book of Abstracts

Atmospheric Remote Sensing Group

Institute of Space and Atmospheric Studies

University of Saskatchewan

Session 1: Missions and Instrumentations

A Short History of Limb Observations at Saskatchewan

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The early limb observations by the ISAS personnel were made in the mid-sixties and extended in the seventies. Various extensions were proposed with an early Skylab experiment and in 1984 a Shuttle experiment was successfully flown. This was followed with ARIES and OSIRIS on Odin. This paper will expand on these ideas and present how the approach might have changed thinking on remote sensing of the Earth's atmosphere.

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Earth Science with the Stratospheric Aerosol and Gas Experiment III (SAGE III) on the International Space Station: Status Update

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In early February 2017 the Stratospheric Aerosol and Gas Experiment (SAGE) III was installed on the International Space Station (ISS), joining the family of space-based solar occultation instruments operated by NASA to investigate the Earth's upper atmosphere. One of three identical instruments, the SAGE III/ISS mission was restarted in 2009 with a major focus upon filling an anticipated gap in ozone and aerosol observation in the second half of this decade. Here we discuss the mission architecture, its implementation, and data that will be produced by SAGE III/ISS, including their expected accuracy and coverage. The 52-degree inclined orbit of the ISS is well-suited for solar occultation and provides near-global observations on a monthly basis with excellent coverage of low and mid-latitudes, similar to that of the SAGE II mission. The nominal science products include vertical profiles of ozone, nitrogen dioxide and water vapor, along with multi-wavelength aerosol extinction. Though in the visible portion of the spectrum the brightness of the Sun is a million times that of the full Moon, the SAGE III instrument is designed to cover this large dynamic range, performing lunar occultations on a routine basis to augment the solar products. The standard lunar products include ozone, nitrogen dioxide & nitrogen trioxide. Current status of the operational SAGE III/ISS will be presented.

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Mission Overview and Recent Results for the Atmospheric Chemistry Experiment (ACE)

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The Atmospheric Chemistry Experiment (ACE) is comprised of a Fourier transform spectrometer (ACE-FTS) operating in the infrared with broad spectral coverage (750 – 4400 cm-1) and high resolution (0.02 cm-1), a UV-Visible-NIR spectrophotometer (ACE-MAESTRO, Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) with wavelength coverage 280 – 1030 nm and resolution 1 – 2 nm, and a pair of imagers measuring at 525 and 1020 nm. Collecting solar occultation measurements since February 2004, ACE provides over 13 years' worth of atmospheric profiles for pressure, temperature, and the volume mixing ratios of more than 30 molecules, as well as volume mixing ratio profiles for more than 20 subsidiary isotopologues. Current FTS processing (version 3.5/3.6) is now in near real-time (2-day latency). A mission overview will be provided, along with a survey of recent scientific studies performed using ACE measurements and details of the upcoming processing version for the ACE-FTS.

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Limb Scatter Instrument Development at Honeywell - CATS and ALI

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A number of limb-scatter instrument concepts are currently under development at Honeywell, including the Canadian Atmospheric Tomography System (CATS) and the Aerosol Limb Imager (ALI), through the Canadian Space Agency's Space Technology Development Program (STDP). An elegant breadboard model (EBB) of the CATS instrument, which is a highly flight-representative prototype of a CATS optical model, is being assembled and tested. This EBB will be deployed on a stratospheric balloon flight in 2018. On the ALI project, a conceptual design of the payload has been developed and commercial versions of some key components, including an acousto-optical tunable filter (AOTF) and visible-extended InGaAs camera, are being procured and tested. Some of these components will later be incorporated into an EBB of the Spectral and Polarization (SPS) sub-system of the instrument, which will include an AOTF, broadband linear polarizers, and a broadband liquid crystal polarization rotator to allow solid state spectral and linear polarization filtering. This presentation provides an overview of the recent development activities, design characteristics and challenges, and future opportunities for the CATS and ALI projects.

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Development of the imagers for the MATS satellite

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We present the development of the Swedish research instrument MATS (Mesospheric Airglow/Aerosol Tomography and Spectroscopy), which a micro satellite scheduled for launch into a low Earth orbit in 2019. An off-axis reflective telescope with six channels will be used to capture the atmospheric scene in a limb configuration. In addition to the limb telescope, a single-channel refractive IR camera directed in the nadir direction will be used. The limb telescope is based on a three-mirror off-axis design. Metallic free-form mirrors are used to achieve excellent imaging performance over a relatively large field of view, 5.62° × 0.94° (object size: 250 km × 40 km). Following the tertiary mirror is a network of beamsplitters and filters are used to separate the signals in UV (270-300 nm) from the IR (754-772 nm). Sensitive CCDs with passive cooling are used as image sensors. Imaging performance is currently being tested at Omnisys. An off-axis reflective collimator is used to project test targets at an optical infinity. To avoid stray light issues, the design was made to maximize the length of the front baffle. Tests of a simplified full size baffle is ongoing in a newly built dark room optics lab at Omnisys. A maximum cleanliness level of 200-700 particles (size = 0.5 um) per cubic meter has been measured. Test results from these initial stray light measurements will be used as input when designing the actual baffle. The nadir camera will tested using a point source in the lab.

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Overview of Validation for the Atmospheric Chemistry Experiment

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On 13 August 2017, the Canadian-led Atmospheric Chemistry Experiment (ACE) will complete its fourteenth year in-orbit on board the SCISAT satellite. The long lifetime of ACE has provided a valuable time series of composition measurements that contribute to our understanding of ozone recovery, climate change and pollutant emissions. 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. The second instrument is a dual UV-visible-NIR spectrophotometer called ACE-MAESTRO (Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) which was designed to extend the ACE wavelength coverage to the 280-1030 nm spectral region. The ACE-FTS and ACE-MAESTRO instruments have been making regular solar occultation measurements for more than 13 years and, from these measurements, altitude profiles of over 30 different 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. This paper will describe the validation results for the current ACE-FTS and MAESTRO data sets and describe the drift analyses that are being undertaken to characterize the ACE-FTS data to enable the generation of climate data records.

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OSIRIS – Sixteen Years and Still Going Strong

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The Swedish led Odin spacecraft was launched in February of 2001 and the Canadian built Optical Spectrograph and InfraRed Imaging System (OSIRIS) began routine collection of spectrally dispersed limb scattered sunlight in the autumn of that year. Since then, these measurements have been used to infer the longest, currently active data record of ozone and nitrogen dioxide number density profiles and stratospheric aerosol extinction profiles. These measurements have been used extensively in international initiatives such as the SPARC-DI, the ozone_cci, the aerosol_cci, Si2N, LOTUS, OCTAV, CMIP-6 and SPIN as well as for validation and characterization of ENVISAT, OMPS-LP and SAGE III-ISS results. Although OSIRIS has shown signs of aging the data products are still as good as ever and due to the length of the mission with each new orbit the OSIRIS results become exponentially more valuable.

This talk will discuss briefly the history of OSIRIS and detail advances in radiative transfer modelling and retrieval technology that allowed the production of climate quality data records from OSIRIS measurements. Past and current uses of the OSIRIS operational data products will be discussed along with some very interesting unique scientific discoveries made with research quality data products derived from airglow and minor species absorption features. This talk will attempt to give credit to the small, diverse, international team of scientists, engineers and administrators who have made OSIRIS the success it is.

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The Looming Chasm in Spaceborne Limb Sounding Observations of Atmospheric Composition and Challenges to Filling It

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Understanding and tracking of key processes affecting atmospheric composition, and hence climate and human/ecosystem health, demand continued vertically resolved observations of atmospheric composition in the upper troposphere, stratosphere and mesosphere. Spaceborne limb sounding instruments measuring thermal emission or solar backscatter are the only means to obtain such measurements with the needed vertical resolution on a daily near-global basis. Solar (and lunar/stellar) occultation sounders making much sparser observations, though typically with better precision/resolution, provide complementary information. The past decade has arguably witnessed a "golden age" for limb and occultation observations, with, at peak, twelve instruments operating on eight different satellites. In stark contrast, although several new concepts are in development, only one limb sounder targeting the stratosphere is confirmed for launch in the coming decade (OMPS on JPSS-2/3, measuring only ozone and aerosol). Similarly, SAGE-III ISS, launched in 2017, is the only occultation sounder added since 2003, and no others are currently confirmed. The looming gap in limb observations of key species has been highlighted in multiple community reports over the years. Key science questions requiring a continued and augmented record of limb observations are articulated, as well as scientific and programmatic challenges to be faced by any mission/instrument proposing to make new measurements.

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Session 2: Stratosphere

Reprocessing of the Odin/SMR Dataset

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A complete reprocessing of the Odin/SMR data set is underway. The entire processing chain from raw satellite files to validated geophysical products has been reviewed with the aim to greatly improve data quality and consistency. As a first stage the calibration procedure at level 1 have been improved to avoid, for example, data from erroneous mirror positions from corrupting the spectra. The level 1-2 procedure has been completely revamped with optimal settings being derived for each observation mode. With the help of a sample dataset and a validation database, trends of the type reported for earlier versions have been identified and work in ongoing to understand the instrument changes that have led to these artefacts and remedy them. A part of the process a new data access portal has been produced with both visual and API access to the data set.

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GOMOS Retrieval of Stratospheric Aerosols and Gases Using AerGOM: Current Activities and Perspectives

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AerGOM is an alternative retrieval processor for the GOMOS/ENVISAT experiment, which was developed to optimize the retrieval of stratospheric aerosols. The ESA Aerosol_cci project is an opportunity to develop further the AerGOM algorithm and to use it for the production of stratospheric aerosol records matching the needs of the climate modelling community. The main product is the stratospheric extinction provided in the 350-750 nm range. In addition, the most recent version of the CCI-GOMOS dataset also provides the very first version of a set of aerosol parameters derived from the particle size distribution. Alongside aerosols, AerGOM also provides vertical profiles of trace gases and more particularly O_3, NO_2 and NO_3, which were not yet investigated into detail. We started exploring these aspects in EXPANSION, a new project with the purpose to assess and optimize AerGOM's performance in terms of trace gases retrieval. In this talk, we review the most recent progresses and draw perspectives for AerGOM activities concerning the retrieval of stratospheric aerosols and trace gases. Concerning the aerosol aspects, we detail the latest improvements and extensions of AerGOM, as well as the new developments of Level3 CCI-GOMOS gridded products, including size-related aerosol products. Validation and application to climate modelling will be shortly discussed. Concerning the trace gas retrieval by AerGOM, we will give an overview of the EXPANSION project and its current status.

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Spectral Characterization of SCHIAMACHY Spatial Straylight

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Between 2002 and 2012, the SCIAMACHY Instrument on ENVISAT performed measurements in limb geometry. In limb scanning mode, the SCIAMACHY instrument spectra are used to retrieve profile information for trace gases and aerosol extinction above the tropopause. One of the technical challenges that applies to limb measuring devices is the strong gradient of the measured radiance between surface and top of atmosphere. In case of SCIAMACHY this leads to a phenomenon described as spatial straylight: A small fraction of light from the lower atmosphere is scattered into the field of view at the scanning mirror, contributing to the measured signal. In this work we use measurements at high tangent height to characterise spectral features of two types of spatial straylight: In the northern hemisphere, when the sun is close to the field of view, measurements appear to be affected by spatial straylight originating directly from the Sun. The second type of spatial straylight is not restricted to Sun geometry, but could not be identified at wavelengths smaller than 300nm. Here, ozone absorption blocks contributions from the lower atmosphere, indicating that longer wavelengths are affected by spatial straylight, which originates from the lower atmosphere. Using radiative transfer simulations, we characterise the spatial straylight contributions for tangent heights below 90 km, focusing on the effect on measurements between 20 and 35 km which are used for retrieving aerosol extinction profiles.

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Satellite Observations of Phosgene ($COCl_2$) and Comparisons with SLIMCAT Chemical Transport Model Calculations

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The majority of chlorine in the atmosphere has arisen from anthropogenic emissions of 'organic' species such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Due to their long lifetimes, many of these species reach the stratosphere where they break down, liberating chlorine which catalyses the destruction of ozone. The principal degradation products of Cl-containing organic species are carbonyl chloride (phosgene, $COCl_2$), carbonyl chloride fluoride (COClF), and hydrogen chloride (HCl). Of these, phosgene is probably the most notorious, having been used as a chemical weapon in World War I. In the lower stratosphere, where the phosgene mixing ratios peak, the principal sources are the photolysis of carbon tetrachloride (CCl_4) and, to a lesser extent, methyl chloroform (CH_3CCl_3). Smaller contributions arise from very short-lived substances such as CH_2Cl_2, $CHCl_3$ and $C2Cl_4$. Observing and understanding phosgene in the stratosphere helps us better understand the chlorine budget. This work presents global distributions and trends of $COCl_2$ using data from two satellite limb instruments: the Atmospheric Chemistry Experiment Fourier transform spectrometer (ACE-FTS), and the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). Phosgene observations are compared with the output of SLIMCAT, a state-of-the-art offline three-dimensional chemical transport model (CTM), which contains a detailed treatment of stratospheric chemistry.

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Arctic winter 2015/2016: Denitrification, Dehydration and Ozone Loss as Simulated with the Chemistry-Climate Model EMAC and Observed by Aura/MLS

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The Arctic winter 2015/2016 was one of the coldest stratospheric winters in recent years. A stable vortex had formed by early December and the early winter was exceptionally cold. Temperatures dropped below the Nitric Acid Trihydrate (NAT) temperature, thus allowing Polar Stratospheric Clouds (PSCs) to form. The low temperatures in the polar stratosphere persisted until early March leading to chlorine activation and catalytic ozone destruction. Satellite observations indicate that sedimentation of PSC particles led to denitrification and dehydration of stratospheric layers. Model simulations of the Arctic winter 2015/2016 nudged toward European Center of Medium-Range Weather Forecast (ECMWF) analyses were performed with the atmospheric chemistry-climate model ECHAM5/MESSy Atmospheric Chemistry (EMAC). Chemical-dynamical processes such as denitrification, dehydration and ozone loss are investigated based on the EMAC simulation and satellite observations by the Aura Microwave Limb Sounder (Aura/MLS). Both model simulations and observations show that ozone loss was quite strong in 2015/2016, but not as strong as in 2010/2011; denitrification and dehydration were the strongest so far in the Arctic stratosphere.

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Validation of Ozone Profile Retrievals from NASA GSFC version 2.5 Against the Correlative Satellite Measurements

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The Limb Profiler (LP) is a part of the Ozone Mapping and Profiler Suite launched on board of the Suomi NPP satellite in October 2011. The LP measures solar radiation scattered from the atmospheric limb in UV and visible spectral ranges between the surface and 80 km. These measurements of scattered solar radiances allow for the retrieval of ozone and aerosol profiles from cloud tops up to 55 km. In this study we present validation and error analysis for ozone retrievals derived from the new NASA GSFC version 2.5 algorithm. There are several key changes that had been implemented in this new algorithm, including a pointing correction, new cloud height detection, explicit aerosol correction, and a reduction of the number of wavelengths used in the retrievals. Ozone profiles are retrieved independently from UV and VIS measurements. In this study we evaluate the algorithm performance based on the analysis of the internal characteristics (such as gain matrices and averaging kernels) and comparison against independent satellite profile measurements obtained from the Aura Microwave Limb Sounder (MLS), Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) and Odin Optical Spectrograph and InfraRed Imaging System (OSIRIS). In addition, we compare version 2.5 with ozone retrievals derived from the University of Saskatchewan algorithm (USask) using LP radiances. We document observed biases and check the long-term stability of the version 2.5 ozone record.

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Retrieval of Stratospheric Ozone Profiles from OMPS Measurements in Limb Viewing Geometry

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Due to its crucial role in the radiative budged of the stratosphere and its importance as an absorber of UV radiation, a continuous monitoring of the vertical and spatial distribution of stratospheric ozone still has a high priority for the scientific community. After the end of ENVISAT lifetime, this task was carried out by few satellite missions, among which the OMPS suite, launched at the end of 2011. The OMPS Limb Profiler enables the study of the vertical distribution of stratospheric ozone by analyzing the intensity of scattered solar light in limb viewing geometry. The focus of our study is to adapt the algorithm developed at the University of Bremen for the retrieval of ozone vertical profiles from SCIAMACHY limb measurements to OMPS observations, with the final aim to obtain a continuous data set from both instruments. The retrieval method is based on the optimal estimation technique in a 1D geometry; a fit of spectral windows at UV and visible wavelengths is carried out to retrieve ozone between 12 and 60 km. A cloud filter based on the Color Index Ratio is applied and surface albedo is retrieved simultaneously. Stratospheric aerosol extinction profiles are retrieved at a preliminary step. The algorithm is run over nine months (July 2016 – April 2017) using version 2.5 of L1 data and considering only the central slit of the instrument. Results are compared with the NASA retrieval product and validated using MLS and ozonesondes collocated observations.

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The SAGE III/ISS Mission and the Global Space-Based Stratospheric Aerosol Climatology

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SAGE III has begun its life aboard the International Space Station where we expect five or more years of high quality measurements of ozone and multiwavelength aerosol extinction coefficient profiles. As of this writing, the instrument is undergoing testing but episodic occultation measurements should begin within the next month. In this presentation, we will show early aerosol results from the solar occultation measurements and discuss their role in the long-term stratospheric aerosol climatology. Plans for incorporating SAGE III into the Global Space-based Stratospheric Aerosol Climatology (GloSSAC) are heavily dependent on comparisons with current instruments particularly OSIRIS and CALIPSO. This is clearly a crucial period for the continuity of the long-term record as both of these instruments are nearing the end of their operational lifetimes. In addition to discussing observation issues, we will discuss issues in the current version of GloSSAC. For instance, we need to understand the relative enhancement in the high latitude/lower stratosphere during the OSIRIS/CALIPSO period (2005-present) compared to similar periods in the SAGE II period (1984-2005).

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Analyses of Instraseasonal Ozone Variations

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Variability of ozone field depends on scale at which the phenomena are considered. This work is dedicated to ozone variability within a month and in 10 degrees latitude zones, which we referred to as intraseasonal variability (or climatological variability). We use ozone profiles by MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) and MLS (Microwave Limb Sounder) for detecting the spatio-temporal intraseasonal ozone variability. Realistic data uncertainty estimates and dense sampling allow accurate estimates of ozone variability. We investigate whether ozone variability is linked to dynamical processes in the atmosphere and compare our results with the previous estimates of climatologic ozone variability. We also study evolution of intraseasonal ozone variability with time versus evolution of ozone itself (trends).

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Partical Size Distribution of Stratospheric Aerosol Retrieved from SCHIAMACHY Limb Data

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This research focuses on stratospheric aerosol. We present a retrieval method, sensitivity studies and first results of aerosol particle size distribution parameters retrieval in stratosphere from SCIAMACHY limb measurements. SCIAMACHY was one of the spectrometers, which was operating on Envisat satellite from 2002 to 2012, and provided measurements of scattered solar light in the wide spectral range, which allows us to derive two of three particle size distribution characteristics (mode radius and distribution width). We analyzed the time series of the retrieved parameters for the whole SCIAMACHY operating period, and revealed the growth of the aerosol particles after the volcanic eruptions in the lower stratosphere right after eruption, as well as a time shift till the volcanic perturbation riches higher altitudes. To evaluate the uncertainty of the retrieval results, we compared the obtained results with the similar measurements from other satellite instruments, e.g. the difference between SCIAMACHY and SAGE II radii in the tropics is around 30 % at 20 km altitude and decreases with the height to 0% at 32 km. In addition we show the uncertainties in the aerosol extinction retrievals, which result from a wrong assumption of the aerosol particle size distribution parameters.

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Assessing the Impact of Limb Sounding on the Monitoring of Surface Nitrogen Dioxide

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It has been suggested that stratospheric profiles of nitrogen dioxide (NO_2) from limb sounding, when combined with total column observations from a nadir-viewing instrument, should allow for improved surface monitoring and, ultimately, improved forecasting. This presentation will discuss two investigations exploring this possibility. In the first, a variant of the limb–nadir matching technique was used to derive tropospheric NO_2 columns whereby the stratospheric component of the NO2 total slant column density (SCD) measured by the Ozone Monitoring Instrument (OMI) was removed using non-coincident profiles from the Optical Spectrograph and InfraRed Imager System (OSIRIS). A brief discussion of the methodology and an initial analysis will be presented. The second is a proposal to assess the benefit of limb sounding to the Environment and Climate Change Canada (ECCC) air quality forecasting system. Specifically, the idea is to score ECCC forecasts of surface pollutants against North American ground networks with and without assimilating OSIRIS NO_2 and ozone profiles.

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Assessment of OMPS Limb Profiler Aerosol Extinction Measurements

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The Ozone Mapping and Profiler Suite (OMPS) on board Suomi National Polar-orbiting Partnership (S-NPP) was launched on October 28, 2011. It consist of three instruments: Nadir Mapper (NM), Nadir Profiler (NP) and Limb Profiler (LP). The OMPS LP instrument is designed to provide high vertical resolution ozone and aerosol profiles from measurements of the scattered solar radiation in the 290-1000 nm spectral range. It collected its first Earth limb measurement in January 10, 2012, and continues to provide daily global measurements of ozone and aerosol profiles from the cloud top up to 60 km and 40 km respectively. The relatively high vertical and spatial sampling allow detection and tracking periodic events when aerosol particles are injected into the stratosphere, such as volcanic eruptions or meteor explosions. This presentation will describe recent changes implemented for the OMPS LP Version 1.0 aerosol products and provides initial validation of the data set with OSIRIS and CALIPSO. In general, the agreement with OSIRIS is within 20% with larger bias in the southern hemisphere. The instrument's spatial and temporal sampling enables extensive observation of volcanic eruption plumes and stratospheric dynamics. OMPS LP aerosol observations of the dispersal of volcanic aerosols in the stratosphere following the eruptions of Kelut and Calbuco, and the quasi-biennial oscillation QBO aerosol signature, will also be presented.

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Session 3: UTLS

Variations of Stratospheric Reactive Nitrogen and Ozone Related to the QBO

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The stratospheric quasi-biennial oscillation (QBO) dominates interannual variability of dynamical variables and trace constituents in the tropical stratosphere, and provides a natural experiment to test understanding of coupled circulation-chemistry interactions. We utilize limb satellite measurements of ozone (O_3), reactive nitrogen species (NO_x and HNO_3) and source gas N2O, to quantify interrelationships and links to the dynamical QBO, based on data spanning 2004-2015 (over four complete QBO cycles). Data include O_3, HNO_3 and N_2O from the Aura MLS, and NOx derived from OSIRIS NO_2 measurements combined with a photochemical box model (= NO_x*). Cross-correlations and composites with respect to the QBO phase show coherent out-of-phase relationships between reactive nitrogen species and source gas N_2O throughout the stratosphere, with the NO_x/HNO_3 ratio increasing with altitude. These anomalies propagate coherently downward with the QBO. Ozone is out-of-phase with reactive nitrogen in the middle stratosphere above ~ 28 km, due to NO_x control of ozone catalytic loss cycles. Quantitative comparisons of nitrogen partitioning and O_3 sensitivity to NO_x show good overall agreement between the diverse satellite observations and results from the WACCM chemistry-climate model.

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Airborne Limbe-Imaging Investigations of the Lowermost Stratosphere with GLORIA on HALO in Winter 2015/16

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Observations of the chemical composition of the upper tropospheric/lower stratospheric region at high northern latitudes are sparse: satellite datasets, as those derived from limb-sounding instruments are not capable of resolving this transition zone with adequate vertical resolution. This region was target of the HALO (High Altitude and Long Range Research Aircraft) campaign POLSTRACC in winter 2015/16. The Arctic winter 2015/16 was characterized by exceptionally cold stratospheric temperatures, leading to widespread polar stratospheric clouds that were observed from mid-Dec 2015 until the end of Feb 2016. We will analyse these conditions based on 2-D vertical/horizontal cross-sections of various trace species (HNO_3, $ClONO_2$, etc.) along the flight paths measured by the limb-imaging infrared spectrometer GLORIA (Gimballed Limb Observer for Radiance Imaging of the Atmosphere). The GLORIA remote sensing observations are validated with datasets obtained by other sensors on HALO. GLORIA observed significant redistribution of HNO_3 and a strong enhancement of $ClONO_2$ indicating that a notable fraction of active chlorine has been deactivated at lowest stratospheric levels. The observations will be compared to simulations by atmospheric models in order to assess their capability to reproduce nitric acid redistribution and chlorine deactivation in the Arctic lowermost stratosphere.

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Exploring the sampling capabilities of the Spatial Heterodyne Observations of Water instrument from a high altitude aircraft

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The Spatial Heterodyne Observations of Water (SHOW) instrument is being developed in collaboration between the University of Saskatchewan, ABB and the Canadian Space Agency to measure the vertical distribution of water vapor in the Upper troposphere and the lower stratosphere. The instrument combines an imaging system with a monolithic field-widened SHS to observe limb scattered radiation in a vibrational band of water (1363 nm – 1366 nm). SHOW is currently optimized for observations from NASA's ER2 high altitude aircraft and a measurement campaign is scheduled for July 2017. The goal of this mission is to demonstrate the SHOW measurement technique, and examine the sampling capabilities of the instrument. A model has been developed to simulate the SHOW measurements and retrievals from the ER-2 aircraft. This model utilizes the SASKTRAN radiative transfer model to simulate the limb scattered radiance. A three-dimensional water vapor profile, provided by Environment and Climate Change Canada is used to provide realistic spatial variability along the flight path. This paper presents the SHOW measurement technique and explores the sampling capabilities and sensitivity of the measurement and retrieval approach.

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Improved Ozone Retrieval from SCHIAMACHY Limb Measurements

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The Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCHIAMACHY) instrument is a UV-Visible-NearIR spectrometer operated on board the European ENVISAT Satellite from August 2002 to April 2012. In its limb viewing mode the instrument observed the Earth's atmosphere tangentially to the surface measuring the scattered solar light. One of the important products gained at the University of Bremen from SCHIAMACHY limb measurements are the vertical distributions of ozone. Due to its crucial role in governing the thermal balance of the Earth's atmosphere and shielding the harmful UV radiation, the ozone falls in the research focus of many groups during the last few decades. For most of the studies the quality and temporal stability of the data sets are crucial. During the last validation activities several issues concerning biases and drifts were identified in the previous retrieval version of SCHIAMACHY limb ozone (V2.X) raising a need for improvements. This study presents a new version of the SCHIAMACHY limb ozone retrieval (V3.5) developed at the University of Bremen which fixes previously identified issues and provides a new high quality ozone data set for 10 years of SCHIAMACHY operation period. The presentation discusses changes in the retrieval algorithm and presents selected illustrations for quality and stability of the new retrieval.

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Aerosol Characterization Through the Combination of Occultation and Limb Scattering Observations

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Occultation measurements of atmospheric transmission have provided several decades of aerosol extinction (AE) profiles in the stratosphere and upper troposphere. This dataset includes the variation of AE from UV to near IR wavelengths, which constrains (but does not uniquely determine) the aerosol size distribution (ASD). The ASD has a dominant influence on the aerosol phase function (APF), and therefore is of great importance for scattering-based aerosol retrieval techniques: The APF is typically assumed in order to estimate AE from limb scattered (LS) radiances, or to estimate the LIDAR ratio required for active techniques. The recent installation of SAGE III on the International Space Station provides an opportunity to combine aerosol information: Occultation observations provide the AE directly, which are then used to infer the APF from LS observations. SAGE III provides the unique capability to vary the LS viewing direction from orbit to orbit, allowing the APF at a given location to be sampled at a wide variety of scattering angles. The proposed combination of occultation + LS observations resembles the extinction + almucantar observations that have previously been combined to analyze AERONET data. In this presentation, we provide a plan to combine AE and APF information. The presentation specifies the most valuable LS observations for this purpose (i.e., scattering angle, wavelength, etc.), and quantifies the value of the resulting ASD constraint.

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Characterizing the climatological composition and intraseasonal and interannual variability of the Asian summer monsoon anticyclone based on 12 years of Aura Microwave Limb Sounder measurements

Michelle Santee

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Satellite measurements are invaluable for investigating the composition of the upper troposphere / lower stratosphere (UTLS) in the region of the Asian summer monsoon (ASM) anticyclone, which has been sparsely sampled by other means. The Aura Microwave Limb Sounder (MLS), launched in July 2004, makes simultaneous colocated measurements of trace gases and cloud ice water content (a proxy for deep convection) in the UTLS on a daily basis. Its dense spatial and temporal sampling, long-term data record, extensive measurement suite, and insensitivity to aerosol and all but the thickest clouds make Aura MLS uniquely suited to characterizing the climatological composition of the ASM region and quantifying the considerable spatial, seasonal, and interannual variability therein. Here we examine 12 years of version 4 MLS measurements of both tropospheric (H_2O, CO, CH_3Cl, CH_3CN, CH_3OH, HCN) and stratospheric (O_3, HNO_3, HCl) tracers, along with cloud ice, on four potential temperature surfaces in the UTLS (350–410 K) over the course of the complete ASM lifecycle, from April through October. In addition to describing the average evolution of the anticyclone during the monsoon season, we investigate intraseasonal and interannual variability in the UTLS response to the ASM. We explore the relationships between the observed trace gas behavior and variations in the strength or location of surface emissions as well as several meteorological factors and climate indices.

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Ozone trends from SAGE II, OSIRIS and OMPS

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The OSIRIS instrument has been in operation onboard the Odin spacecraft since the autumn of 2001. Since that time OSIRIS has routinely measured spectrally dispersed limb-scattered sunlight from which vertical ozone profiles have been derived. The length of the OSIRIS ozone data record makes it a valuable resource for the analysis of long term trends. However, on its own it is not of sufficient length to capture all of the relevant signatures required to completely understand important changes in the vertical distribution of ozone. In particular the 1997 turnaround is not captured within the OSIRIS time series. For this reason it is important that the OSIRIS measurements be combined, or merged, with other data records like the SAGE~II time series before a full analysis can be performed.

The Ozone Mapping Profiler Suite Limb Profiler (OMPS-LP) instrument has derived vertical ozone profiles in a similar manner since 2012 and is also combined with the OSIRIS data set as it increases the latitudinal coverage.

This presentation is focused on the merged SAGE II / OSIRIS / OMPS time series and the resulting trends. We will present analyses related to instrument drift, sampling biases and sensitivity to the method used to determine long term trends.

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2016: A Stratospheric HCN Oddity

Patrick Sheese

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In late 2015 and early 2016, a large amount of hydrogen cyanide (HCN) was emitted from Southeast Asia into the upper troposphere and lower stratosphere. Since the lifetime of HCN in this region is relatively long, on the order of months to years, the emitted HCN was then transported by the general circulation from the tropics to polar latitudes. By early 2016, the daily mean concentrations of HCN in the lower stratosphere at all latitudes, as measured by the ACE-FTS (Atmospheric Chemistry Experiment – Fourier Transform Spectrometer) instrument, were consistently the largest on record, on the order of 40-90% greater than the climatological mean, and on the order of 40% greater than the 2007 El Niño-driven values. By December 2016, HCN concentrations in the polar lower stratosphere were still on the order of 10-20% greater than the climatological mean. This study will examine the only available satellite measurements of HCN in the upper troposphere - lower stratosphere and will discuss likely sources.

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OSIRIS Observations of Upper Tropospheric NO_2 in the Northern Extratopics: Importance of Aircraft NO_x

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A 4-dimensional NO_2 climatology is generated from 15 years of OSIRIS observations. For the first time, enhanced NO_2 is observed in the upper troposphere and lower stratosphere in springtime over northern mid-latitudes at all longitudes in a 3-dimensional spatial pattern suggestive of aircraft NO_x (=NO+NO_2). Spring is chosen since lightning and deep convection of surface NO_x contribute less to upper tropospheric NO_x relative to summer. The change in NO_x between the 2001-2007 and 2008-2015 period on a 10° x 10° grid does not exhibit a coherent spatial pattern in any area in the northern hemisphere at 12.5 km. The data is being assimilated to obtain optimized aircraft NO_x emission estimates and the current status of this endeavour will be presented.

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On a Potential Solar 27-day Signature in Tropospheric Clouds

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Solar 27-day signatures have been identified in many different middle atmospheric parameters. In contrast, little is known about potential solar-driven 27-day signatures in tropospheric parameters. Recent studies suggest the existence of a solar-driven 27-day signature in outgoing longwave radiation (OLR) - particularly in the tropical pacific region – and attribute it to a 27-day signature in tropospheric clouds. In this contribution we employ OLR data in combination with tropospheric cloud top height and cloud fraction data based on limb and nadir observations with the SCIAMACHY instrument on the Envisat satellite to investigate the presence of potential solar-driven 27-day variations. We concentrate on low latitudes, where earlier studies identified potential 27-day signatures. We find OLR to be generally highly anti-correlated with cloud top altitude and cloud fraction, as expected. We also find coherent variations in cloud top height in the Indian and Pacific Ocean region with amplitudes of up to 2 km, and with periods generally in the 30 – 60 day range. These periods are indicative of the Madden-Julian-Oscillation (MJO). Although we cannot entirely rule out the possibility that part of the observed variability is caused by the solar 27-day cycle, it appears more likely that quasi 27-day signatures in OLR and cloud parameters are related to the MJO.

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Session 4: Agencies and Programmes

A Saunter Through the Labyrinth of Limb Scattering Technique

Pawan Bhartia,

NASA

The OMPS Limb Profiling (LP) instrument was launched on the Suomi NPP satellite in October 2011. The instrument measures limb-scattered (LS) radiances from surface to 80 km over a broad wavelength range (0.28-1.0 micron) with ~1.5 km vertical resolution. It was developed primarily to derive ozone vertical profiles in the stratosphere to continue the venerable Aura MLS record. My involvement in this project started about 5 years ago when the former project lead Didier Rault retired in early 2012. Since Didier had developed a working ozone algorithm prior to launch, and since MLS is still operating well after 13 years of continuous operation, I have had the luxury to essentially saunter thru the labyrinth of the LS technique over the past 5 years. In my talk I will discuss what I have discovered in this journey and will highlight several key issues that still need to be addressed by the LS community before one can consider this technique a viable low cost alternative to limb emission techniques, which can produce much larger number of high value scientific products than LS. These issues include: tangent height estimation accuracy, correction of internal stray light, understanding the impact of diffuse upwelling radiances on LS products, and aerosol extinction retrieval accuracy. Finally, if time permits I will discuss some potential LS products that will have high science value if one can produce them with sufficient quality to detect trends.

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The Stratosphere-troposphere Processes And their Role in Climate (SPARC) Project

Fiona Tummon, Neil Harris, Judith Perlwitz

SPARC

Stratosphere-troposphere Processes And their Role in Climate (SPARC) is a core project of the World Climate Research Programme (WCRP). Founded in 1992, SPARC has coordinated high-level research activities related to understanding Earth system processes for over two decades. More specifically, SPARC promotes and facilitates cutting-edge international research activities on how chemical and physical processes in the atmosphere interact with climate and climate change.

SPARC activities are organised under three overarching themes and result from an integration of process studies, observations, and modelling. These themes are atmospheric dynamics and predictability, chemistry and climate, and long-term climate records. Research is largely bottom-up driven and contributes significantly to international assessments, such as the assessments of ozone depletion by the World Meteorological Organisation (WMO) and United Nations Environmental Programme (UNEP), as well as the climate assessments of the Intergovernmental Panel on Climate Change (IPCC). SPARC products include scientific assessment reports, journal publications, newsletters, and datasets.

Long-term climate records underpin much of SPARC science and are the direct focus of a number of activities, including the recently completed SPARC Data Initiative as well as WAVAS-II, LOTUS, TUNER, PSC Initiative, TUNER, OCTAV-UTLS, FISAPS, and the Atmospheric Temperature Changes activities. This presentation will focus on recent advancements made in SPARC research topics as well as SPARC's key objectives for the coming years, particularly in relation to activities that make use of limb sounding observations.

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Towards Unified Error Reporting (TUNER)

Thomas von Clarmann

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Towards Unified Error Reporting (TUNER) has been selected as an emerging SPARC activity. Its goal is to make error estimates of existing satellite observations of atmospheric temperature and constituent profiles inter-comparable. Error estimates of measurements of atmospheric state variables are essential to judge whether differences between estimates of the atmospheric state can be explained or if they hint at unknown problems. While many recipes exist to calculate the error budget of an observation, the data user is faced with the problem that errors reported by various instrument groups are rarely consistent. In this talk, the following problems will be tackled:

(a) which error components should be included in the error budget;
(b) how should the content of prior information in the retrievals be dealt with;
(c) how can retrievals be characterized which were not produced via an optimal-estimation-like formalism and thus do not provide the usual diagnostics;
(d) how can error estimates which were generated using different approaches be made comparable, and
(e) what is to be considered when comparing with direct (non-remote) measurements. An action plan towards unified error reporting will be suggested.

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The SPARC Water Vapour Assessment (WAVAS) Activity, Phase II: Goals, Methods and Status

Gabrielle Stiller

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The first SPARC Water Vapour Assessment was published in 2000 (SPARC report no. 2) and dealt at that time with only a handful of satellite data sets. Since the beginning of the 21st century, a large number of satellite instruments observing the upper troposphere and stratosphere have been launched, and thus it was time to start another quality assessment of the water vapour data records they have provided. Within WAVAS-II we have assessed more than 40 different water vapour records from 15 satellite instruments. Profile comparisons were made to ground truth instruments like frost point hygrometers and microwave radiometers, and between co-located measurements of the satellites. Time series were analysed for drifts and their representativeness of shorter-term variability (seasonal cycle, QBO effects). A special focus was on the humidity of the upper troposphere, an area where large variability makes any assessment challenging. Isotopologues of water vapour have been inter-compared as well. In this talk an overview of the different methods will be given, and first results of the comparisons will be presented.

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The SPARC LOTUS Inititiative

Robert Damadeo

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WMO/UNEP Assessments on the state of the ozone layer require an accurate evaluation of long-term trends in ozone to determine the success of the Montreal Protocol in the stratosphere. However, the 2014 Ozone Assessment and another recent activity aimed at determining long-term ozone trends (SI2N) produced different results both in the potential recovery of stratospheric ozone and the statistical significance of those results. The reason for this discrepancy was a different evaluation of uncertainties in both trend studies and more particularly the consideration of satellite drifts in the SI2N study. For the WMO/UNEP 2018 Ozone Assessment, a clear understanding of ozone trends and their significance as a function of altitude and latitude is still needed and so the SPARC LOTUS (Long-term Ozone Trends and Uncertainties in the Stratosphere) Initiative was created. LOTUS activities are targeted at providing support to the next WMO/UNEP Ozone Assessment with the goal of updating stratospheric ozone trends while improving our understanding of crucial, yet poorly known, sources of uncertainties and investigating how these uncertainties interact and propagate through the analysis.

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Session 5: Mesosphere

Tomography in the Mesosphere

Ole Martin Christensen

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The concept of tomography has historically been applied to mesospheric studies through many different experimental setup. Ground based, rocket launched, as well as limb and nadir sounding instruments on board satellites have employed measurements from different angles with overlapping line-of-sights to retrieve information about 2D-, or 3D spatial structures in the atmosphere. The most common tomographic methods used for limb sounding are multiplicative algebraic reconstruction (mART) and some form of regularized least-squares (e.g. OEM). These methods differ in both priori assumptions, approach to regularization, computational demands, retrieval artifacts and error description, and hence choosing which method to use depend on the problem to be solved. Furthermore, the value added by performing 2D- or 3D reconstructions highly depend on the horizontal sampling of the instrument. For the upcoming MATS mission we have evaluated different methods and approaches to doing tomography in the mesosphere, using both simulated MATS data as well as measured data from Odin-OSIRIS. The results from these investigations will be presented and viewed through the lens of limb tomography in general.

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Energetic Particle Impacts on the Atmosphere: Observational Constraints

Bernd Funke

Instituto de Astrofísica de Andalucía

Precipitating energetic particles from the sun and the magnetosphere affect the ionization levels in the polar middle and upper atmosphere, leading to significant changes of the chemical composition. In particular, the production of NOx and HOx imposes changes of ozone via catalytic cycles, potentially affecting temperature and winds. Vertical coupling of this signal to the lower atmosphere could provide a link between space weather in the form of energetic particle precipitation (EPP) and surface climate: model studies and the analysis of meteorological data have indeed provided evidence for EPP-induced climate variations on the regional scale. This talk summarizes recent progress in constraining the chemical impact of EPP on the stratosphere and mesosphere with a special focus on observational results. Additionally, current capabilities and limitations in the representation of EPP impacts in climate studies will be discussed.

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$O_2(1\Sigma)$ and $O_2(1\Delta)$ volume emission rates in the mesosphere and lower thermosphere derived from SCIAMACHY MLT limb scans

Amirmahdi Zarboo[1], Stefan Bender[1], Miriam Sinnhuber[1], Johannes Orphal[1], John P. Burrows[2]

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Photolysis of ozone by solar radiation and the self-reaction of atomic oxygen produce electronically excited molecular oxygen. Collisional and radiational deexcitation then give rise to the oxygen airglow. This airglow therefore contains information about ozone and atomic oxygen abundances as well as other conditions of the mesosphere and lower thermosphere (MLT, 50--150 km) such as solar and chemical heating rates. Here we present the retrieval of volume emission rates (VER) from the SCIAMACHY special MLT limb scans. We derive the airglow of both daytime and twilight O_2 (1Σ) and O_2 (1Δ) emissions in the MLT region. We analyse the daily mean latitudinal distributions and the time series of the retrieved VERs from 53 to 149 km. The largest O_2 (1Δ) mesospheric (>80 km) emissions correlate with the amount of solar irradiance, in particular during high-latitude summer. The O_2 (1Σ) emissions show a similar correlation with additional high values during high-latitude winter and spring. This enhanced airglow may be related to downwelling of atomic oxygen, in particular after strong sudden stratospheric warmings. We further present a first look at the derived mesosphere temperatures, future uses may include inferring chemical characteristics such as ozone abundances and solar heating rates.

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Combining Noctilucent Cloud Data from OSIRIS Limb Tomography and CIPS Nadir Imaging: Challenges and Opportunities

Lina Broman, Susanne Benze, Jörg Gumbel, Ole Martin Christensen

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The OSIRIS spectrograph onboard Odin has provided observations of noctilucent clouds since 2001. During certain tomographic orbits, Odin was run in a special mesospheric mode with short limb scans. This special mode allowed for multiple line of sight scans through the same cloud volume, thus enabling tomographic retrievals of 2D clouds structures, combining the vertical dimension and the horizontal dimension along track. The resolution of the tomographic retrievals is as fine as 1 km in the vertical and 200 km in the horizontal. This enables detailed studies of cloud growth and destruction as well as gravity wave interactions with the clouds, especially in combination with lidar data or tomographic data from Odin's sub-millimetre Radiometer (SMR). In this project we investigate the accuracy of the OSIRIS tomographic NLC data set by comparing tomographic retrievals from OSIRIS for NH10 and NH11 to coincident, common volume observations from the Cloud Imaging and Particle Size (CIPS) instrument onboard the AIM satellite. While OSIRIS applies limb geometry to observe the NLCs and retrieves cloud properties with spectral analysis, CIPS observes the clouds in the nadir and utilizes phase function analysis to retrieve cloud properties. The unique challenges and opportunities of combining two satellite data sets using these different geometries and techniques are presented, together with the results of the comparison and a discussion of the uncertainties.

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Studying Mesospheric Physics and Chemistry Using Limb Observations of Airglow Emissions

Christian von Savigny, Martin Langowski, Olexandr Lednyts'kyy, Georg Teiser

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Apart from thermal emissions, the Earth's middle atmosphere is characterized by a large variety of non-thermal emissions in the optical spectral range, that are directly or indirectly excited by solar radiation - a phenomenon called "airglow". Ground-based or satellite observations of airglow emissions are an essential tool to investigate the physics and chemistry of the mesosphere. This contribution provides an overview or our recent work on

(a) using airglow emissions to remotely sense the mesosphere and
(b) to improve the understanding of airglow excitation mechanisms.

Despite the fact that airglow has been a subject of scientific studies for more than a century, the excitation mechanisms of many emissions are not fully understood. This contribution will particularly deal with SCIAMACHY limb observations of nightglow emissions by OH, atomic oxygen and sodium, as well as SCIAMACHY dayglow observations by mesospheric metal species.

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Mesospheric Nitric Oxide (NO) Time Series from SCIAMACHY and Analysis

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Solar, auroral, and radiation belt electrons as well as soft solar X-rays produce nitric oxide (NO) in the mesosphere and lower thermosphere (MLT, 50--150 km). NO downward transport during polar winters influences the lower atmosphere, in particular by catalytically reducing ozone. Long-term global continuous observations of NO in the mesosphere are rare and such data will help to better understand how solar and geomagnetic activity influence atmospheric composition and dynamics. We present the NO number density time series from the SCIAMACHY nominal (0--93 km) and MLT (50--150 km) limb scans. By combining the MLT (one day every two weeks from 07/2008 until 04/2012) and the nominal (daily from 08/2002 until 04/2012) data, we obtain a ten-year daily global NO number density data set from 60 km to 90 km. We use statistical methods to extract solar and geomagnetic forcing parameters: superposed-epoch analysis and multi-linear regression. In particular, we derive the production rates linked to geomagnetic disturbances (given by the AE index) and the corresponding life times in the mesosphere. The derived parameters constrain how solar and geomagnetic activity influences the NO content in the mesosphere and can be used to validate and improve chemistry climate models.

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PMC Observations with the Suomi NPP OMPS Limb Profiler

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NASA and NOAA are continuing the long-term monitoring of stratospheric ozone with the Ozone Mapping and Profiling Suite (OMPS) series of instruments. Regular OMPS measurements from the Suomi NPP satellite began in April 2012 and continue to the present. OMPS carries two instruments that can detect PMCs. The Limb Profiler (LP) makes limb scattering measurements looking backwards along the orbit using three parallel slits. The hyperspectral data cover 290-1000 nm spectrally, and from 0 km to 85-100 km in altitude. We use an adaptation of the SNOE PMC detection algorithm to characterize the altitude and brightness of PMCs in OMPS LP data. Because of the systematic variation in LP altitude coverage along the S-NPP orbit, we focus on Southern Hemisphere observations in this presentation. Some individual bright clouds can be detected every 125 km over 15-20 degrees in latitude along the orbit track, which offers exciting possibilities for tomographic analysis. The broad spectral coverage of OMPS LP also provides information about the relative particle size distribution in each PMC. The OMPS Nadir Profiler (NP) is similar to an SBUV/2 instrument in design, with a hyperspectral CCD detector. OMPS NP PMC data are consistent with current NOAA-19 SBUV/2 measurements. The LP center slit measurements observe the same location as the NP measurements 7 minutes later, so that OMPS has the capability to perform "common volume" PMC analysis along every orbit.

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SANOMA - Applications of an Empirical Model of Nitric Oxide in the Upper Mesosphere and Lower Thermosphere

Joonas Kiviranta

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Nitric oxide (NO) is produced by energetic particle precipitation (EPP) and soft solar X-rays in the lower thermosphere. NO can then be transported down to lower atmospheric regions during polar winter, where it can interact with ozone and thus affect the chemical, thermal and dynamical structure of the atmosphere. An empirical model for NO, called NOEM, was developed by Marsh and Solomon (2004) based on 2.5 years of measurements from the Student Nitric Oxide Explorer (SNOE). A new model is based on 12 years of Odin Sub Millimeter Radiometer (SMR) measurements, and includes both day- and nighttime observations. This new model, called the SMR Acquired Nitric Oxide Model Atmosphere (SANOMA) predicts the amount of NO as a function of altitude between 85-115km, magnetic latitude, and time. As inputs, it only requires the Kp-index, the solar declination, and the F10.7 cm flux for a given day. This presentation will validate the model against measured NO from the SCIAMACHY, MIPAS, ACE, and SOFIE instruments. Furthermore, it focuses on the possible applications of such a model, such as providing apriori information for retrievals of NO from satellite measurements, or being used as an input for chemistry climate models. Finally, this presentation discusses the future outlook of the applications of the SANOMA model, as well as the newest Odin-SMR NO dataset.

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Poster Session

What does the Polar Vortex PV look like?

Alan Manson, C.E. Meek, Zhenhua Li

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The Polar Vortices of each Winter, 2004/05 to 2016/17, are studied using a variety of GCM-models, radars and satellites. Such research has a long history, and that dominated by the vision of Professor Karen Labitzke [Free University, Berlin]. Meteorological radiosondes provided regular penetration into the middle stratosphere of Europe, 10hPa and 30km, delicately launched under her supervision. Unusually they regularly reached 10hPa, where the explosive and 'sudden stratospheric mid-winter warmings', SSW, also within the ozone-layer, became the focus of international and global attention.

We show with simple time sequences of northern 30km zonal-mean temperatures, E-W winds, near 60 and 80/90 degrees north and 30km altitude, also amplitudes of Planetary Waves PW [wave numbers 1,2] and meridional heat fluxes, the extraordinary variability of the stratospheric disturbances. Not just one, but as many as 5 peaks in Temperature T, December to March, normal values of 200K becoming over 250K in ~ 5 days, Eastward winds of +65/s becoming Westward of -35m/s. Wave Spectra, global wind reversals, all from Arctic explosive SSW warmings.

From Aura MLS, winter T contour plots from 8-90km, selected latitudes of 50, 60, 80 deg., for the Canada, Scandinavia-Europe and Siberia-Russia sectors/longitudes, stratopause Tmax of >285K where there is little to no UV solar radiation to form the ozone, or a radiational stratosphere! Vast variability and non-simultaneity or even non-occurrence of the SSW in a sector, then the stratopause 'layer' descending like a waterfall into the normal tropopause-region, cold air flooding into the middle atmosphere, as high as 80km. Reversals of winds, east to west and north to south, the summer Antarctic atmosphere becoming relatively colder…

We finish with selections from animations of hemispheric parameters u, v, Z, T from ground to 50km, and the Edges of the Polar Vortex. Peacefully these edges form a cylindrical "barotropic" structure, disturbed surfaces then quickly slide sideways like a dropped deck of cards, we say "baroclinic". Horizontal circles of motion become ellipses, the entire vortex slides away from the Pole into the North Atlantic or over PEARL-Eureka…or maybe because "it can", splits into two cyclones or a twined-vortex. The chaos… Are these hemispheric, even global disturbances?

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A 3D model for O_2 airglow pertubations induced by gravity waves in the upper mesosphere

Anqi Li

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To investigate the influence of atmospheric waves in the mesosphere, a new Swedish satellite MATS will be launched in 2019. It will observe infrared emissions at 762 nm from the O_2 airglow in the MLT region. As a part of the design work for the MATS project, an accurate forward model is needed to estimate what MATS is expected to measure. In this project, a gravity wave model and a photochemistry model were coupled to simulate both the day- and nightglow emission fields in three spatial dimensions and time. Simulated satellite images were generated taking into consideration the sphericity of the Earth and the limb-viewing geometry of MATS. Simulation parameters were set according to the preliminary design of the instrument. These satellite images were the first simulated airglow limb images made for the MATS project. By analysing the output data, the relations between wave parameters and airglow perturbations were investigated. It was shown that wave patterns can be easily observed between 88 − 105 km due to the relatively large perturbation in airglow emissions. The O_2 airglow emission field was found to be highly sensitive to atomic oxygen concentration field as an input. Furthermore, as expected, wave patterns projected on simulated satellite images largely depend on the horizontal orientation of the wave propagation. This implies that a tomographic reconstruction is needed when the angle between the wave front and the limb-viewing direction is large.

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Charged Particle Radiation Effects on Optical Birefringent Crystals for Space Borne Instrumentation

Barrett Taylor

University of Saskatchewan

Currently under development at the University of Saskatchewan is a prototype satellite instrument called Aerosol Limb Imager (ALI) version 2.0. ALI measures scattered sunlight from the limb of the Earth to determine contents of the atmosphere, specifically aerosols. The primary optical component of ALI is an Acousto-Optic Tunable Filter (AOTF) which allows the instrument to measure a specific wavelength of light with no moving parts. The main component of an AOTF is a crystal through which measured light propagates. The preferred material for these crystals is a birefringent crystal. The AOTF is tuned and calibrated based on crystal properties such as birefringence which is a physical property based on atomic structure. If the structure of an AO crystal is altered due to radiation damage, it could alter the birefringence and optical performance. Therefore, AOTF device materials need to be radiation tested.

Research into radiation damage for optical materials is similar to radiation hardened electronics; just different properties are under examination. For optical components, radiation can cause changes to many properties such as transmission, reflection, index of refraction, etc. Radiation can be generally classified as electromagnetic (photon) or particle radiation (charged particle, neutron, or electron). The focus of this research is radiation encountered in space, specifically positively charged particle radiation. This choice is based on the prevalence of charged particle radiation in space and the magnitude of damage that it can cause. The source of charged particle radiation is primarily from the Sun (low keV energy, 90% proton, 9% alpha [1]) in the solar wind and from radiation trapped in the Van Allen belts (high keV – low MeV energy, primarily protons and electrons [2]). The research will focus on effects of varying radiation levels and energies as well as the effect on optical properties that retained damage exhibits.

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T-STAR - Temperature from Star Field Imaging

Benjamin Marshall, Larry Gordley, Robert Stockwell, Kam Wan

GATS Inc.

This poster introduces a revolutionary sensor concept called T-STAR. T-STAR is designed to measure temperature fields from cloud-top to the lower mesosphere by observing the star field (SF) as it sets or rises relative to a balloon or orbiting satellite carrying the sensor. T-STAR is based on the GATS Inc. patented method of using two celestial points to measure light bending angles (refraction angles) as the two points are occulted by the atmosphere. This technique is currently operational on the SOFIE solar occultation instrument aboard the AIM satellite. SOFIE is in its 10th year of operation and has produced over 100000 temperature profiles. SOFIE includes an imaging FPA that tracks the sun as it sets or rises relative to the AIM satellite. Analysis of the FPA data provides a vertical profile of the angular separation of the top and bottom edges of the solar disk for each set or rise event. This data is used to derive altitude profiles of the index of refraction, which are directly converted to density profiles, and finally inverted to temperature vs. pressure profiles. While SOFIE has two celestial points (the top and bottom edges of the solar disk), T-STAR images could potentially provide hundreds of celestial points. This poster discusses the measurement technique as applied to SOFIE, presents results from SOFIE, and discusses the T-STAR extensions to that technique including expected performance.

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Oxygen A Band Emission in the SaskTran Radiative Transfer Framework

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Oxygen emission is a contributor to day glow in the mesosphere and lower thermosphere (MLT). The emissions occur in the atmospheric band of oxygen, which ranges from 629 nm to 762 nm, and corresponds to oxygen's second electronic excited state. There are three vibrational levels within the atmospheric band, with the A band representing the lowest level. Emissions in the A band are centred around 762 nm and are the most significant contributor to oxygen emissions in the atmospheric band. The SaskTran radiative transfer framework is a software model that simulates light propagation through the atmosphere to produce radiance profiles. While it currently includes oxygen absorption in the A band, oxygen emission has yet to be implemented. Modelling the volume emission rate of oxygen molecules in the A band by use of HITRAN data and photochemical processes will provide the information necessary to simulate oxygen emission with SaskTran. This work is also done in support of the Swedish satellite MATS (Mesospheric Airglow/Aerosol Tomography and Spectroscopy), which will take optical measurments of mesospheric gases. Understanding the process of oxygen A band emission through simulation and measurement will improve scientific understanding of the MLT and provide valuable data for other atmospheric study.

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The EXPANSION project: evaluation of GOMOS trace gas retrievals by AerGOM

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AerGOM is an alternative retrieval algorithm developed for GOMOS and is used to produce the stratospheric aerosol records in the framework of the ESA Aerosol_CCI project. While the main output provided by AerGOM is aerosol extinction in UV-Vis, ozone is also provided along with other gases such as NO_2 and NO_3. One of the main feature of AerGOM is the revision of the inversion approach to retrieve aerosols and trace gases simultaneously in a more consistent way, leading to a significant improvement of the aerosol extinction. It is therefore important to evaluate the quality of the gas profiles and see whether this algorithm could alone provide a suitable and fully consistent, global retrieval of all GOMOS species, or if it is better to use a combination of specialized retrieval algorithms. EXPANSION is an ESA Living Planet Fellowship project that seeks to explore the performance of AerGOM in the observation of ozone and other species in both the stratosphere and the mesosphere. The main goal is to obtain good quality vertical trace gas profiles, while keeping or improving the quality of aerosol extinction data. Cross-ECV consistency between stratospheric ozone and aerosol will also be assessed in the framework of ESA CCI. This presentation will show preliminary results, more specifically how retrieval parameters can affect the trace gas inversion, along with comparisons of AerGOM's retrievals with other datasets such as GOMOS-IPF, satellite and ground-based observations.

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Spatial Heterodyne Observation of Water (SHOW) Retrieval Development for the Upcoming ER-2 Campaign

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Spatial Heterodyne Spectroscopy (SHS) is a optical technique which can measure a spectrum of light with high resolution. The high resolution provided by SHS makes it is possible to accurately measure the spectral features of different atmospheric species, including water vapour. These absorption features can be used with remote sensing techniques to retrieve the density of water vapour at different altitudes in the atmosphere. The Spatial Heterodyne Observation of Water (SHOW) is a SHS instrument that is planned to fly on NASA's ER-2 science aircraft in mid-July 2017. The goal of this campaign is to observe water vapour absorption features in the upper troposphere - lower stratosphere (UTLS) region with limb viewing geometry. In preparation for the campaign a computer model was developed which simulates the raw data SHOW will provide on the ER-2 to predict the scientific outcome. The simulated data was analyzed and it is predicted that vertically resolved water vapor can be retrieved within an accuracy of 20% and a vertical resolution within 1 km.

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Ozone Tomography with the OMPS Limb Profiler

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Most limb scatter retrieval algorithms treat each vertical set of measurements separately, i.e. making the assumption that the atmosphere does not vary in the horizontal direction. This assumption can lead to biases in areas of large horizontal variability, such as on the edge of the polar vortex. Here we present a tomographic retrieval algorithm for limb scatter measurements which retrieves ozone for an entire orbit simultaneously, accounting for variations in the along orbital track dimension. The algorithm is applied to measurements from the Ozone Mapping and Profiler Suite Limb Profiler (OMPS-LP) to create a five year dataset of global vertically resolved ozone profiles. Preliminary validation efforts against the MLS v4.2 ozone data is also shown. The tomographic retrieval is found to agree better with MLS v4.2 than a similar one-dimensional retrieval.

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The Purpose of LIFE

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The Limb Imaging Fourier Transform Spectrometer Experiment (LIFE) is a prototype balloon instrument developed by the University of Saskatchewan under the FAST program. LIFE makes use of the HITE Michelson interferometer provided by ABB Inc in order to make thermal measurements in the spectral range of 700 cm^{-1} to 1400 cm^{-1}. The instrument is intended to take atmospheric measurements of ozone, water vapor, nitrous oxide and methane as target species. Thus far in the project, a forward model and instrument simulation have been created, and a preliminary retrieval code has been set up. Initial design and control systems for the hardware of the instrument has also been developed.

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Limb Infrared Spectroscopy at ABB

Fabien Dumont

ABB

Infrared limb spectroscopy is what launched ABB into space through its participation on the MIPAS project in 1990. Today, ABB is actively supporting the ATMOSAT effort in Germany and the Canadian experiments led by University of Saskatchewan SHOW and LIFE. The common denominator to all these systems is the high spectral resolution allowed by the Fourier Transform spectrometry.

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The 27 day solar rotation signal in OSIRIS tropical stratospheric ozone profiles

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The amount of solar radiation reaching the Earth's atmosphere varies with both the 11 year solar cycle and the 27 day solar rotation period. Ozone in the middle atmosphere is largely created through photolysis at ultraviolet wavelengths. The Optical Spectrograph and InfraRed Imager System (OSIRIS) has been in orbit on the Odin satellite since late 2001. OSIRIS ozone profiles were used to investigate the effect of changes in solar ultraviolet flux on stratospheric ozone concentrations. Analysis was done using the fast Fourier transform, continuous wavelet transform, and cross correlations between the ozone time series and a solar proxy. The effects of changes in temperature were also considered. Results were consistent with those from the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) from 2003 to 2008 and the Microwave Limb Sounder (MLS) from 2004 to 2007. For the time period from 2002 to 2015 a 0.3% change in ozone concentration occurred for a 1% change in solar ultraviolet flux. The validity of using OSIRIS data to analyze the effect of solar rotation on stratospheric ozone has been confirmed. This provides a larger data set and insight on the current relatively weak solar cycle that can be used in future climate modeling.

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Systematic errors in limb scatter aerosol retrievals

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Limb scatter instruments in the UV-Vis range have provided long-term global records of stratospheric aerosol extinction important for climate records and modelling.
While comparisons with occultation instruments show generally good agreement, the source and magnitude of the biases due to retrieval assumptions, radiative transfer modelling, and inversion techniques has not been thoroughly characterized.

This paper explores the biases between SCIAMACHY 1.4, OSIRIS 5.07 and SAGE II v7.00 aerosol extinctions through a series of coincident comparisons, simulation studies and retrieval studies to investigate the cause and magnitude of the various systematic differences.
The effect of a priori profiles, particle size assumptions, radiative transfer modelling, inversion techniques, and the different satellite datasets are explored.

It is found that the assumed a priori profile can have a large effect near the normalization point, as well as systematic influence of 5-10\% at lower altitudes for errors of 10^-6 \km at the normalization altitude.

The error due to particle size assumptions is relatively small when averaged over a range of scattering angles, but individual errors vary largely by scattering angle, particle size and measurement vector definition, with errors up to 100% for some OSIRIS geometries and 200% for some SCIAMACHY geometries.

Differences due to radiative transfer modelling introduce differences between the retrieved products of less than 10% on average, but can introduce vertical structure.
These simulations, along with application of both algorithms to both datasets help explain some of the systematic features such as the high altitude differences when compared to SAGE II.

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Development of a Multispectral Acousto-optic Imaging System for Measuring Aerosol from a Stratospheric Balloon

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The Aerosol Limb Imager (ALI) is a multispectral imaging system designed to have the sensitivity to measure thin localized aerosol layers in the atmosphere. These layers comprise one of the greatest unknown components of the radiative force balance in the atmosphere. An acousto-optic element provides wavelength filtering of two-dimensional (2D) limb images captured by the instrument. The 2D imaging capability meets the resolution requirements to include aerosol measurements into climate and weather models. The ALI instrument line is of current interest to the Canadian Space Agency as a possible candidate for a future low earth orbital mission. ALI Version 2 was built for testing on a stratospheric balloon platform from Alice Springs, Australia in the spring of 2017. This second version builds on the success of the first instrument, which was deployed on a similar platform in 2014. This new system improves upon the wavelength range sensitivity of the instrument while also providing polarization state selection in each measurement. These improvements will drastically increase sensitivity to aerosol microphysics and simplify cloud detection respectively. The technologies used to provide these improvements are a dual transducer acousto-optic tunable filter and a liquid crystal polarization rotator. This paper discusses the design details of ALI Version 2, pre-flight calibration testing and preliminary results from the balloon flight.

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Atmospheric Ozone Response to the Disrupted 2015-2016 Quasi-Biennial Oscillation

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The quasi-biennial oscillation (QBO) - a quasi-periodic alternation between easterly and westerly zonal winds in the tropical stratosphere - is a main driver of inter-annual ozone variability in the stratosphere. During the late-2015 through 2016 time period, the QBO experienced a major disruption unlike any observed since wind measurements began in 1953. We examined the ozone response to this QBO disruption using profile ozone measurements from the Aura Microwave Limb Sounder (MLS) and Ozone Mapping and Profiler Suite Limb Profiler and total column measurements from the Solar Backscatter Ultraviolet (SBUV) Merged Ozone Data Set (MOD). Positive anomalies in stratospheric equatorial O3 developed between 50 and 30 hPa in May-September of 2016, and negative ozone anomalies were observed in the subtropics of both hemispheres. As a consequence of this QBO disruption, extratropical total ozone values during the spring-summer 2016 were at or near seasonal record lows over the more than 40 years of the total ozone record, resulting in an increase of surface UV index during northern hemisphere summer. We found very consistent responses in all considered ozone observations in terms of time, amplitude and spatial patterns. We will show the ozone changes associated with this disrupted QBO throughout the winter and spring 2017.

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High Resolution (500m vertical, 10km along track) Tomography of UT/LS Water Vapor with Spaceborne Active Microwave Limb Sounding

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Resolution of many outstanding science questions in the Upper Troposphere and Lower Stratosphere (UT/LS) demands atmospheric composition observations with the continual near-global coverage attained by past and current passive limb sounders but with greater spatial resolution than currently achievable from space. We describe a new spaceborne active microwave occultation sounder system under development, making two-dimensional tomographic atmospheric composition observations with unprecedented spatial resolution (~500m vertical, 10km along track). The measurement approach employs multiple small (e.g., 6U-"CubeSat"-class) transmitters orbiting in the same plane and flight direction as a separate (larger) receiver instrument. The transmitters emit continuous distinct tones, and the receiver observes all transmitters simultaneously and continuously, in an occultation viewing geometry. The vertical resolution of the measurements is set, to first order, by the along-orbit spacing of the transmitters, with the horizontal resolution set by signal to noise and radiative transfer considerations. We review the underlying receiver and transmitter technologies being developed, along with our plan to test the measurement system in a balloon-to-balloon configuration. Specific science targets for such a measurement system include the contribution of overshooting convection to the budget of stratospheric water vapor.

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Satellite validation of CFCs over the High Arctic

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Atmospheric satellite data sets obtained in limb geometry play a key role in monitoring and surveying trace gas concentrations, for example ozone depleting substances. These datasets have to be validated thoroughly in order to show their reliability and encourage their application. For validation efforts of satellite data sets over the High Arctic, ground-based measurements obtained at the Canadian Arctic Research Station PEARL (Polar Environment Atmospheric Research Laboratory) provide a high-quality, if localized, view of the atmosphere within the High Arctic. I will present comparison results for ozone depleting substances obtained from several satellite instruments. The first is the CFC-11, CFC-12, and HCFC-22 dataset from the ACE-FTS instrument (Atmospheric Chemistry Experiment Fourier Transform Spectrometer) on SCISAT. The second instrument is HIRDLS (High Resolution Dynamics Limb Sounder) on Aura, which obtained profiles for CFC-11 and CFC-12.

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Building Limb Instruments for High Altitude Balloon Experiments

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Since 2014, the Atmospheric Research Group (ARG) has been involved in designing, building and flying atmospheric instruments on high altitude balloons. The high altitude balloon platform provides an ability to test new technology and/or techniques for future satellite instruments. To date ARG has flown three instruments. Within the next couple of years there are plans to re-fly one instrument and fly two new instruments.

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Polarization in the SASKTRAN Radiative Transfer Framework

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Techniques for remote sensing of atmospheric composition often involve the minimization of the residual between spectrally-resolved atmospheric radiometry and the output of a radiative transfer model which solves the equations of radiative transfer in a candidate atmosphere. Here, SASKTRAN, a framework of climatologies, optical property calculators, and scalar radiative transfer models specifically designed for modelling limb scattering observations, is upgraded to solve the vector radiative transfer equations. In particular, the Monte Carlo and High Resolution Successive Orders modules of the SASKTRAN framework are extended to handle polarized scattering of light in a fully spherical atmosphere, with the assumption of a Lambertian earth underneath. The fast, polarized, High Resolution module is validated against the statistically exact polarized Monte Carlo module for limb-scatter observations in the UV-visible-NIR spectral range and is found to be accurate to within 0.2% in its fully polarized mode. An approximate method to solve the vector radiative transfer equations is introduced; in this mode, the high resolution engine is accurate for limb-scatter geometries to within about 0.2% in almost all cases with minimal degradation in performance as compared to the scalar mode. The models are used to show that scalar simulations of limb-observed UV-vis radiances may contain absolute radiometric errors of up to 5% for typical stratospheric aerosol loads. Furthermore, limb-observed radiances may have nearly any linearpolarization, and this is in general altitude and wavelength dependent.

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Feasibility study to derive vertical ozone profile in the troposphere from ultraviolet, infrared and microwave measurements from space using synergetic retrieval technique

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Air pollution has been a serious global problem, and tropospheric ozone, one of the most harmful pollutants, has been increasing globally at rates of 0.3~1.0 ppb/year over few decades [Dentener et al., 2010]. It is important to monitor the ozone, especially in the lowermost troposphere (LMT). An advanced synergetic retrieval using several wavelength ranges has been applied to space-based nadir observations in ultraviolet (UV) and thermal infrared (TIR) spectral ranges [Fu et al., 2013; Cuesta et al., 2013], but the degree of freedom for signal (DFS) was less than unity. We performed a feasibility study to derive tropospheric ozone profile using a synergetic retrieval for twenty atmospheric scenarios in East Asia in summer and winter. The sensitivity of retrieved ozone in the upper troposphere (UT), middle troposphere (MT) and LMT was evaluated using DFS value, partial column error and averaging kernel based on the optimal estimation. We used the SCIATRAN, LBLRTM and AMATERASU forward models for the UV, TIR and MW spectral ranges, respectively. Our simulation showed the DFS value was increased by about 200% in the UT and 40% in the LMT by adding the MW limb measurements to the combination of UV and TIR nadir measurements. The MW limb measurement increased the DFS value, nevertheless it had no sensitivity in the LMT ozone. The DFS value was estimated to be larger than unity for the case of LMT ozone enhancement.

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