NDACC 2025 Symposium Abstract Catalog – Oral Presentations

Symposium Keynotes:

K_S01: Susan Solomon – Opening Keynote

How A Few Ground-Based Measurements Coalesced into Remarkable Networks: NDSC and NDACC

Susan Solomon

Lee and Geraldine Martin Professor of Environmental Studies
Massachusetts Institute of Technology, Cambridge, MA

I will describe how early ground-based measurement methods developed and probed the global stratosphere, first as separate instruments developed by different groups, and later in coordinated campaigns. Independent measurements by different techniques complemented one another to amplify their scientific significance and impacts at key moments in the history of stratospheric science. This in turn led to the impetus to create a network of Network for the Detection of Stratospheric Change (NDSC) sites, to operate not in campaign mode but continuously in monitoring mode, and to ensure that coordinated and tested instruments were placed at sites distributed worldwide. Finally, I will illustrate how later measurements under the Network for the Detection of Atmospheric Composition Change (NDACC) continue to provide key insights into atmospheric science.

K_S02: Michael J. Kurylo – Dinner Keynote

A Walk Down NDSC/NDACC Memory Lane

Michael J. Kurylo

NASA Headquarters (retired)

I will take you on a brief journey to initially describe how a laboratory kineticist became educated about the intricacies of ground-based atmospheric measurements. Under the guidance of many talented instrumentalists and modelers, I was soon tasked with coordinating the US component for an international partnership to design and implement a coordinated network of well-calibrated atmospheric sensors. Thus, my talk will embellish on Susan Solomon's excellent opening presentation by walking you through the timing and details of the founding of the Network for the Detection of Stratospheric Change (NDSC). I will then outline some of the key organizational and operational changes and implementations that were made and the motivations behind them. Hopefully, you will see how 35 years of evolution have enabled the current Network for the Detection of Atmospheric Composition Change (NDACC) to be a successful contributor to atmospheric observations and to providing a sound foundation for international environmental policy.

K_S03: Wolfgang Steinbrecht & Jeannette D. Wild – Closing Keynote

NDACC, looking back and looking ahead

Wolfgang Steinbrecht[1] & ***Jeannette D. Wild***[2]

[1] German Weather Service, Observatory Hohenpeissenberg

[2] University of Maryland, ESSIC & NOAA NESDIS, STAR

The discovery of the Antarctic Ozone Hole in 1984 was a dramatic sign that something was wrong with the ozone layer. Pictures of the hole might have been instrumental for signing the Vienna Convention for the Protection of the Ozone-Layer in 1985, and for the eventual phase-out of Ozone Depleting Substances started in 1987 by the Montreal Protocol. Apart from the ozone hole, however, observations showing clear changes of the ozone layer outside of Antarctica were scarce. This may have triggered a 3-day workshop in Boulder, where a Network for the Detection of Stratospheric Change was conceived in March 1986. Three years later, after another workshop in November 1989 in Geneva, NDSC was born as a network of ground-based observations. Over the following 35 years, many things have changed, but a large part of the originally planned techniques, instruments and even stations has been implemented. Renamed as NDACC, the stations have provided valuable long-term records. Together with satellites and cooperating networks, NDACC data document that ozone-depleting chlorine is slowly decreasing, that ozone in the upper stratosphere has started to heal, that the stratosphere is cooling, how volcanic eruptions and large-scale wildfires inject aerosol and water vapor, changing radiative and chemical processes. The Montreal Protocol saved the ozone layer, but the patient is still weak and needs to be monitored. With the imminent gap in satellite data, NDACC needs to be an oasis in the data desert. The huge challenge for the future is climate change. It affects stratosphere and troposphere, and needs to be measured, by NDACC and by other networks.

Session A: Creating and improving long-term data: Instrumentation, processing and providing past, present and future data-streams

Conveners: Wolfgang Steinbrecht, Jim Hannigan

K_A01: Sophie Godin-Beekmann & Emmanuel Mahieu – Session A Keynote

Ups and downs in creating and maintaining decade-long high-quality ground-based observational data series

Sophie Godin-Beekmann (1) & ***Emmanuel Mahieu*** (2) – Session A Keynote

1: LATMOS/IPSL, Sorbonne Université, CNRS, UVSQ, Paris, France

2: GIRPAS, Université de Liège, Belgique

The celebration of the 35th anniversary of NDACC will offer a valuable opportunity to reflect on the network's scientific achievements and the collaboration it has fostered, as well as to revisit the key steps that led to its inception.

The various instruments at the Observatoire de Haute Provence (OHP), e.g. LIDAR, ozone sondes, Dobson spectrometers, and the FTIR instrumentation at the Jungfraujoch station, in the French and Swiss Alpine regions, predated the formal establishment of the network. They had already demonstrated at that time their ability to deliver reliable and relevant measurements for the routine characterization of the stratosphere, while pressing concerns were rising about the future of the ozone layer, shortly after the adoption of the Montreal Protocol. Both efforts naturally served as reference models when defining the objectives and structure of the network, then known as NDSC.

In this contribution, we will highlight the key developments that have shaped the multidecadal operation of these pioneering experiments. We will also present some of the major scientific findings derived from the OHP and Jungfraujoch long-term data records.

This retrospective will also be the occasion to ponder on the numerous financial, technical and human challenges associated with sustaining such monitoring activities in the very long term.

Finally, we will review the main scientific and technical advances that have enhanced the value and scope of the LIDAR and FTIR data over the decades.

O_A01: Alistair Bell

Continuous Monitoring and Development in Microwave Radiometry for Middle Atmosphere Sounding

***Alistair Bell*,** Gunter Stober, Adrianos Filinis, Witali Krochin, Guochun Shi, Klemens Hocke, Axel Murk

University of Bern

The University of Bern has developed and operated microwave radiometers to observe the composition, temperature, and winds of the middle atmosphere for several decades. Over time, advancements in technology have improved the measurement range, as well as the temporal and vertical resolution, and the precision of the retrieved profiles. In this presentation, an overview will be provided of both the long-standing remote sensing instruments operated by the University of Bern and the state-of-the-art instruments recently deployed.

O_A02: Michel Van Roozendael

Reassessment of the long-term trend in stratospheric BrO columns at Harestua (60° N) and Lauder (45° S) based on three decades of observations

Michel Van Roozendael (1), Alexis Merlaud (1), Martina M. Friedrich (1), Gaia Pinardi (1), Martyn Chipperfield (2), Richard Querel (3), Paul V. Johnston (3), Karolin Voss (4), Klaus Pfeilsticker (4)

1: Royal Belgian Institute for Space Aeronomy (BIRA-IASB)
2: University of Leeds
3: National Institute of Water and Atmospheric Research (NIWA)
4: University of Heidelberg

Bromine has been of high interest to atmospheric scientists, in particular since its role in the Antarctic ozone hole led to the 1992 Copenhagen Amendment to the Montreal Protocol. The atmospheric budget of active bromine (BrOx) and, to a large extent, the total inorganic bromine (Bry) is constrained by measurements of bromine monoxide (BrO) utilizing Optical Absorption Spectroscopy (DOAS) from high flying balloons, aircrafts and ground together with a suitable photochemistry-based correction of the Bry/BrO ratio. In a publication by Hendrick et al. (2008) the long-term trend in stratospheric BrO columns has been documented over the period from 1995 to 2005 using ground-based DOAS measurements at Harestua, Norway (60°N) and Lauder, New Zealand (45°S) showing the development of a decrease of about 0.5-1 % per year after 2001, consistent at both sites, and attributed to the decline of tropospheric organic bromine resulting from the Montreal Protocol and its Amendments. This analysis was then updated every four years for Harestua, to feed into successive WMO reports on ozone assessment.

In this work, we present a comprehensive re-evaluation of the data series, which now covers 30 years for both NDACC stations. This includes homogeneous reprocessing of the data using recently optimized retrieval settings and up-to-date spectroscopic data, as well as revisited vertical column inversions using a-priori information from a consistent run of the TOMCAT/SLIMCAT three-dimensional chemical transport model. A multivariate regression analysis is used to characterize the temporal evolution of stratospheric bromine in both hemispheres over the full observational period.

O_A03: Alberto Redondas Marrero

20 years of the Izaña Regional Calibration Center- Europe

Alberto Redondas Marrero (1), Virgilio Careño (1), Alberto Berjon Arroyo (2), Francisco Parra Rojas (3)

1: AEMET - Spanish State Meteorological Agency

2: TRAGSATEC

3: TRAGSA

Over the past two decades, the Regional Brewer Calibration Center (RBCC-E) has conducted numerous calibration campaigns, culminating in the commencement of the XX RBCC campaign this summer. This work serves as a comprehensive summary of the RBCC-E's accomplishments, challenges, and achievements during this 20-year period.

Established in November 2003 at the Observatory Izaña of the AEMET (Spanish National Meteorological and Hydrological Service) in the Canary Islands (IZO), RBCC-E possesses a comprehensive calibration and reference maintenance equipment. This equipment comprises three Brewer spectroradiometers, collectively known as the IZO Triad: a Regional Primary Reference (Brewer 157), a Regional Secondary Reference (Brewer 183), and a Regional Traveling Reference (Brewer 185).

Annual Brewer intercomparisons are conducted, alternating between Arosa, Switzerland, and the El Arenosillo Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA) in Huelva, Spain.

RBCC-E's participation in two pertinent projects significantly contributes to the accuracy and traceability of total ozone measurements. The ATMOZ project (Traceability for the Atmospheric Total Ozone) facilitates the validation and enhancement of calibration techniques for total ozone, culminating in the development of an uncertainty analysis that was finalized during the ESA-CALVAL activity. Additionally, the EUBREWNET cost action enables the central processing of Brewer measurements.

Following the cessation of Brewer instrument production, RBCC-E's primary focus shifts to maintaining the existing instruments and validating alternative instruments such as the BTS (Luca Egli's presentation) and Pandora. Recent comparisons with these instruments are also presented.

O_A04: Luca Egli (remote)

Improvements of the spectra of the BTS Solar instrument for total column ozone retrieval and global UV radiation measurements

Luca Egli (1), Ralf Zuber (2), Alberto Redondas (3), Voltaire Velazco (4), Xiaoyi Zhao (5), Tomi Karppinen (6), Kaisa Lakkala (6), Rigel Kivi (6), Rolf Rüfenacht (6), Gregor Hülsen (1), Julian Gröbner (1)

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3: Izaña Atmospheric Research Center, Agencia Estatal de Meteorología, Tenerife, Spain
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5: Air Quality Division, Environment and Climate Change Canada, Toronto, Canada
6: Finnish meteorological Institute, Space and Earth Observation Centre, Sodankylä, Finland

Over the past seven years, PMOD/WRC has evaluated a Gigahertz Optik BTS2048-UV-S-F array spectroradiometer with optical fiber setup for total ozone column (TOC) measurements. PMOD/WRC also developed the KoherentTOC software for the retrieval of TOC through a custom double ratio technique. In 2024, integrating the spectroradiometer into commercial BTS-Solar housing, confirmed the consistent measurement quality of the KoherentTOC retrieval algorithm.

Recognizing the need to evaluate third-generation TOC instrumentation beyond traditional Dobson and Brewer spectrophotometers, a WMO task force was established by the WMO-SAG O3/UV to evaluate a BTS-Solar (WMO-BTS) instrument at the challenging high-latitude site of Sodankylä (67.4° N), Finland. High-latitude sites experience high solar zenith angles and therefore high ozone slant path, particularly in spring and autumn.

This study details the advancements in spectral stray light reduction and corresponding low slant path dependency of the BTS Solar, achieved through newly developed firmware by Gigahertz Optik GmbH and PMOD/WRC. Validation of WMO-BTS spectra against the transportable reference solar UV spectroradiometer (QASUME) demonstrates good agreement for both direct sun and global UV measurements.

Additionally, the study shows the comparison and calibration of the WMO-BTS and the PMOD/WRC-BTS at the regional Brewer intercomparison 2025 in Spain using the KoherentTOC software allowing the calibration of TOC with standard reference instruments.

Finally, this paper presents mid-term comparisons of the PMOD/WRC-BTS using the improved firmware against long-term total column ozone data from the Dobson and Brewer triad operated at PMOD/WRC on behalf of MeteoSwiss, demonstrating significant consistency and reliability in TOC measurements.

O_A05: Sergey Shilov

Advanced Solutions for Monitoring of Air Quality and Greenhouse Gases

Sergey Shilov

Bruker Optics, USA

Air pollution and climate change pose critical challenges that affect global health and the environment. Addressing these issues starts with accurately identifying and quantifying air pollutants and greenhouse gas (GHG) emissions. This presentation reviews advanced analytical solutions, including a range of optical and mass spectrometers designed for real-time gas analysis and air monitoring. Instruments allow simultaneous quantification of multiple gases in a mixture without requiring extensive calibration. Passive and active remote sensing systems identify GHG gases and track pollutants from a distance. Infrared microscopy reveals the chemical composition and size of dust particles collected on a substrate. Statistical evaluation gives quantitative information on the level of particle contamination and helps to identify the origin of contamination.

O_A06: Kate Smith

The Balloon Baseline Stratospheric Aerosol Profiles (B2SAP) dataset for in situ measurements of stratospheric aerosol

K. Smith (1, 2), A. Baron (1,2), T. Thornberry (2), and the extended B2SAP team

1: Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, USA

2: Chemical Sciences Laboratory (CSL), National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado, USA

Understanding the size distribution of stratospheric aerosols is critical for determining the influence these particles have on the global radiation budget. A persistent aerosol layer exists between 15 – 30 km altitude above the earth's surface, and characterizing the background state and variability of these stratospheric aerosols is essential for predicting the climate response after stratospheric perturbations.

To have a comprehensive understanding of the role stratospheric aerosols have on chemical, dynamical and physical processes in situ measurements of the stratospheric aerosol loading are required.

The Balloon Baseline Stratospheric Aerosol Profiles (B^2SAP) project is an on-going, multi-year Earths Radiation Budget (ERB) initiative and was funded to define background stratospheric aerosol abundances and variability.

The B^2SAP dataset consists of aerosol size distribution observations from high-altitude balloons, at latitudinally dispersed locations. Regular vertical profiles from the surface to 28 km of aerosol data products such as: particle size distribution, surface area concentration, effective radius, are used to build up a global picture of the stratospheric aerosol layer and its variability. We discuss the data collection, calibrations, QA/QC and file processing behind the dataset. These observations can be used to constrain the global radiative budget and global climate models, validate and calibrate space-based sensors, as well as deepen our understanding of how perturbations (e.g. from explosive volcanoes, large wildfires) to the aerosol layer impact the radiative, chemical and microphysical properties of the stratosphere.

O_A07: Michael Sicard

Updates of OPAR NDACC site at Reunion Island (21ºS, 55ºE)

Michael Sicard

Laboratoire de l'Atmosphère et des Cyclones (LACy), France

The OPAR-Maido NDACC site at Reunion Island (21ºS, 55ºE) hosts 50+ instruments measuring a myriad of atmospheric variables from ground level up to the mesosphere. This talk will provide an update on the instruments run in the framework of NDACC. In particular, the recent upgrade of the OPAR-Maido aerosol and water vapor lidar will be presented, as well as the plans for the future tropospheric and stratospheric Ozone combined lidar. Data generation and flow of the lidar aerosol variables, the latest product submitted to NDACC affiliation at the end of 2024, will be presented. Some preliminary results on the aerosol vertical distribution in both tropospheric and stratospheric altitude levels for the latest 10 years of observation will be shown to illustrate the great contribution of the new dataset. In terms of application, some cal/val exercises against NDACC instruments at OPAR-Maido will be presented: for some recent aerosol variables retrieved by ESA's EarthCARE satellite, as well as past S5P/TROPOMI UV products.

O_A08: Andrea Pazmino

SAOZ network: more than 35 years of continuous O3 and NO2 total columns observations

Andrea Pazmino, Manuel Nunes-Pinharanda, Florence Goutail, Ariane Bazureau
LATMOS (UVSQ-CNRS), France

The first Système d'Analyse par Observation Zénithale (SAOZ) UVVIS instrument was installed at the Antarctic station of Dumont d'Urville (67°S, 140°E) in January 1988 after the signature of the Montreal Protocol. The SAOZ is a passive remote-sensing instrument that measures the sunlight scattered from the zenith sky. It was designed to allow observations of O_3 and NO_2 total vertical column amounts the whole year at the polar circle. For geometrical reasons, most precise measurements are performed twice a day during twilight (sunrise and sunset). Even if developed for polar regions, SAOZ instruments were deployed also at other mid-latitudes and tropical regions. The instrument is completely automatic and self-calibrated.

A central data processing (CDP) allows homogeneous retrieval of the different instruments of the network. Thanks to the operational capabilities of the SAOZ network and its near-real-time (NRT) distribution service, the SAOZ measurements are readily and intensively used as references for the operational validation services of different satellite missions and also for model validation.

Since 2020, different services were developed in the frame of the UVVIS SAOZ Unit of the Centre for Reactive Trace Gases Remote Sensing (CREGARS) of the European research infrastructure of Aerosols, Clouds and Trace Gases (ACTRIS). The quality control was improved and instrument on mobile platforms were incorporated in the CDP (e.g., SAOZ operational since 2021 onboard the Marion Dufresne ship). In the presentation the instrument will be described, the ACTRIS CDP explained. Different scientific results using SAOZ data will be shown.

O_A09: Louis Mirallié

Regional Bayesian composite of surface-based ozone partial columns

Louis Mirallié (1), E. Maillard Barras (1), C. Jonas (2), C. Vigouroux (2), R. Van Malderen (3), Irina Petropavlovskikh (4) P. Effertz (4), S. Godin-Beekmann (5), W. Steinbrecht (6), T. Leblanc (7), R.Ruefenacht (1), A. Haefele (1), J. Gröbner (8), G. Stober (9)

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7: Jet Propulsion Laboratory, California Institute of Technology, Wrightwood, California, USA
8: Physikalisch-Meteorologisches Observatorium Davos World Radiation Centre, Switzerland
9: Institute of Applied Physics, University of Bern, Bern, Switzerland

Ozone profile data records from surface-based instruments have been re-evaluated within the APARC/LOTUS project and individual MLR trends have been estimated over selected NDACC stations (Godin-Beckmann, ACP, 2022). These include Ozonesondes (O3S), Fourier-Transform InfraRed (FTIR) spectrometers, Umkehr observations from Dobson spectrophotometers, LIDAR systems, and Microwave Radiometers (MWR). Each technique can deliver partial-column information with specific uncertainties, but uneven station density motivates a regional merging to increase the confidence in derived trends.

The spatially coherent domains by atmospheric partial columns will be defined using Pearson correlation coefficients within grids of the Copernicus Atmosphere Monitoring Service (CAMS) reanalysis (Van Malderen, egusphere, 2024). For each domain, we produce two alternative data sets of partial ozone columns (surface– 100/147 hPa– 32 hPa– 10 hPa– 1 hPa and surface– 300 hPa– 64 hPa– 20 hPa– 1 hPa).

Partial column timeseries within selected regional domains will be merged over 2000 to 2024 period using the BAyeSian Integrated and Consolidated (BASIC) algorithm (Ball & Alsing et al., GL, 2019), considering individual uncertainties and inter-series covariances. The BASIC's prior month-to-month variability information has been updated with ML climatology. In addition, a PCA (principal component analysis) and the instrumental uncertainties have been used for building the records composite to optimize the amount of information extracted from the individual time series.

The regional merged composites are intended for estimation of MLR post-2000 trends. This study will show if the regional merging of coherent ozone partial columns reduces the timeseries uncertainties and increases the confidence in regional long-term trends across heterogeneous networks.

Session B: Validating atmospheric measurements from satellites and from other platforms

Conveners: Jean-Christopher Lambert, Elian Maillard Barras

K_B01: Daan Hubert & Tijl Verhoelst – Session B Keynote

A journey towards 50 years of NDACC cooperation with the atmospheric composition satellites

Daan Hubert & ***Tijl Verhoelst***

Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Belgium

Since its establishment in 1991, the Network for the Detection of Stratospheric Change (NDSC) / Network for the Detection of Atmospheric Composition Change (NDACC) has provided high-quality, long-term ground-based measurements that play a critical role in the validation of atmospheric composition data from satellites. In this contribution, we trace the role of NDSC/NDACC from its early vital contributions to the validation of ozone related observations by SAGE, SBUV, TOMS, UARS, GOME and ADEOS, through the expansion of satellite missions and thematic areas during the Odin, Envisat, SciSat, Aura, and MetOp era, to the current constellations of air quality and greenhouse gases sounders, and future landscape shaped by satellite-based information services such as Copernicus and by the emergence of New Space actors. Drawing on the network's diverse instrumentation – UV-visible DOAS, ozonesondes, FTIR, microwave radiometers, lidars, and more – and range of measured atmospheric states – from pole to pole – we demonstrate how these measurements continue to support the evaluation of satellite data accuracy, stability, and mutual consistency, from the troposphere up to the mesosphere.

Moreover, we describe how the NDACC network is integrating – and contributing to – the development of community practices for satellite validation, building on interoperability frameworks like QA4EO, EDAP and CEOS-FRM, on recommendations from gap analyses (GAIA-CLIM, CCVS, CEOS roadmaps), and on various preparatory projects for the wealth in upcoming missions. This includes ongoing work on the traceability of reference measurements, detailed uncertainty quantification, spatiotemporal harmonization, and optimized co-location strategies, targeting full uncertainty budget closure as this allows satellite-ground differences to be interpreted with increasing confidence, informing both product development, mission planning and satellite data user communities.

As the number and diversity of atmospheric satellite data products continue to grow in the coming decade(s), while other essential products will nevertheless cease to be monitored, NDACC's role is evolving toward more interoperable, multi-network, multi-satellite validation strategies. These include underpinning the maturity of the measurements as fiducial references, harmonization of practices with cooperating networks, cross-network data comparisons, constellation-based approaches to validation, and further developments toward near-real-time and operational capacity. Ensuring the continued effectiveness of NDACC until its golden jubilee in this context will require sustained support not only to long-term measurements but also to ongoing scientific development to address new challenges and benefit from new opportunities.

O_B01: Jiansheng Zou (remote)

Validation of ACE-FTS v5.3 ozone data with NDAAC ground-based instruments

Jiansheng Zou (1), Kaley A. Walker (1), Patrick E. Sheese (1), Chris D. Boone (2)

1: University of Toronto, Canada

2: University of Waterloo, Canada

ACE-FTS is a Fourier Transform Spectrometer (FTS) aboard the Canadian SCISAT satellite and, as the primary payload for the Atmosphere Chemistry Experiment (ACE) mission, it has been routinely measuring vertical profiles of over 70 atmospheric molecules and isotopologues using solar occultation since February 2004. To assess the quality of the recent ACE-FTS v5.3 ozone data, a suite of ground-based instrument measurement datasets collected within the framework of the Network for the Detection of Atmospheric Composition Change (NDAAC) is used to validate the ACE-FTS ozone profiles. Ozone data measured by global ozonesonde, lidar, FTIR, and microwave radiometer instruments are compared with the ACE-FTS ozone measurements. As required for individual comparison instruments, the specific measurement characteristics, including valid data altitude range, vertical resolution, and averaging kernel are taken into account. Conventional collocated data pairs are compared and used to derive statistical quantities such as correlations, biases, drifts and trends. These are used for quantifying the consistency between the ACE-FTS and NDACC measurements.

O_B02: Nigel Richards

Validation of OMPS Limb Profiler Ozone Retrievals Using Ground-Based Correlative Data

Nigel Richards (1,2), Natalya Kramarova (2)
1: UMBC, Maryland, USA
2: NASA GSFC, Maryland, USA

The Ozone Mapping and Profiler Suite (OMPS) Limb Profiler (LP) performs limb measurements of scattered solar radiation in the ultraviolet and visible wavelengths, which allow for the retrieval of high vertical resolution ozone profiles from 12.5km to 57.5km with full global coverage. The first LP was launched on board the Suomi-NPP (SNPP) satellite in 2011 and started operational observations in April 2012. The second LP was launched on the NOAA-21 satellite in 2022 and started operational observations in February 2023. Two more OMPS LP instruments are scheduled to be launched in the next decade providing decades of continuous OMPS LP high vertical resolution ozone profile observations.

The validation of remotely sensed observations is crucial, not only to give confidence in scientific conclusions drawn from their use, but to also build community trust in the data and thus encourage their wider use. In the past, OMPS LP profiles have generally been validated against other satellite observations such as MLS, ACE-FTS and SAGE III/ISS. However, in the near future, OMPS LP will likely be the only satellite instrument making high resolution vertical ozone profile measurements from space. We must therefore utilize other sources of correlative data with which to validate OMPS LP profiles. Ground-based networks such as NDACC offer an excellent opportunity to perform global validation of OMPS LP high vertical resolution ozone profiles. In this study we utilize ground-based global measurements from ozondesondes and lidars to validate ozone profile retrievals from both the SNPP-OMPS LP and NOAA-21 OMPS LP instruments.

O_B03: Jun Wang/David E. Flittner

SAGE III/ISS: an Anchor Standard for Monitoring Atmospheric Composition in the Upper Troposphere and Stratosphere

Jun Wang (1), Xi Chen (1), David Flittner (2)

1: The University of Iowa, Iowa, USA

2: NASA Langley Research Center, Virginia, USA

Occultation technique is widely regarded as one of the most accurate methods for remotely sensing atmospheric composition in the upper troposphere and stratosphere (UTS). Its high accuracy stems from the direct application of Beer's Law and the use of the solar disk as an intense, stable, and spatially homogeneous illumination source. As a result, vertical profiles of ozone, aerosols, clouds, water vapor, nitrogen dioxide, and other trace gases retrieved from the SAGE series since the late 1970s have been widely used as anchor standard datasets and are frequently combined with others to generate long-term atmospheric composition records in the UTS.

In the past half a century, the SAGE series has evolved significantly from SAGE I, a single-channel sunphotometer to SAGE III, a CCD-based spectrometer that measures solar radiation from 280 to 1040 nm with a spectral resolution of 1–2 nm. The broad UV–NIR spectral coverage enables SAGE III to retrieve atmospheric composition profiles with 0.5 km vertical resolution. This presentation will highlight recent progress of using SAGE III/ISS datasets to study the impacts of large-scale fires and volcanic emissions on atmospheric composition in the UTS. The synergistic use of SAGE III/ISS data with limb measurements from OMPS and MLS will be demonstrated. An outlook will also be provided on the emerging need for future occultation missions, such as the planned SAGE IV, and limb-sounding missions like STRIVE (Stratosphere Troposphere Response using Infrared Vertically-Resolved Light Explorer), currently under development.

O_B04 Invited: Juseon Bak (remote)

GEMS ozone profile retrieval: impact and validation of version 3.0 improvements (invited)

Juseon Bak (1), JaeHwan Kim (1), Arno Keppens (2)

1: Pusan National University, South Korea

2: Royal Belgian Institute for Space Aeronomy, Belgium

This study assesses the performance of the GEMS ozone profile product, focusing on the improvements introduced in the reprocessed version 3.0. The retrieval operates in the 310–330 nm spectral range and yields total degrees of freedom for ozone ranging from 1.5 to 3. Although the vertical sensitivity is limited and mostly distributed off-diagonally, GEMS achieves an effective vertical resolution of 5–10 km and is capable of separating tropospheric and stratospheric ozone layers. This work primarily highlights the substantial algorithmic and calibration enhancements introduced in version 3.0, including improvements to the slit function, wavelength calibration, and radiometric calibration. As a result, version 3.0 significantly reduces spectral fitting residuals, lowering them from 0.8% in version 2.0 to 0.2% under nominal conditions. This improvement also mitigates the altitude-dependent oscillating biases observed in the previous version, including up to 40 DU overestimation in the troposphere and 20 DU underestimation in the stratosphere, as compared with ozonesonde observations. The version 3 ozone profiles show agreement within 10 DU of ozonesonde measurements, with a mean bias of −7.6% in tropospheric ozone columns and within 5% in the stratosphere. Furthermore, version 3 successfully captures day-to-day vertical ozone structures, as demonstrated by comparisons with daily ozonesonde launches in February and March 2024. It also demonstrates improved agreement with Pandora measurements, with a mean bias of −3.6 DU, outperforming the GEMS total column ozone product.

O_B05: Arno Keppens (remote)

A constellation approach to the validation of tropospheric ozone observations from space

Arno Keppens, Daan Hubert, José Granville, Jean-Christopher Lambert, NDACC ozonesonde and tropospheric lidar instrument PIs, and satellite data representatives

BIRA-IASB, Belgium

Several families of satellite sounders provide tropospheric ozone observations, motivated by the need to monitor its impact on human health, vegetation and ecosystems (as a harmful agent) and climate (as a greenhouse gas). However, tropospheric ozone is highly variable over a wide range of spatial and temporal scales due to the interplay of dynamical, chemical, and radiative processes. Moreover, different sounding techniques and orbits offer different sensitivities to the tropospheric ozone distribution, resulting in non-negligible representativeness differences between satellite datasets. Between similar sounders, discrepancies between datasets arise as well due to instrument-specific calibration and retrieval uncertainties. Therefore, global and long-term assessments of tropospheric ozone from multi-sensor data require a coherent constellation approach to their characterization and validation.

In this work, we present the constellation approach that we have developed to validate consistently tropospheric ozone data from a dozen past and present satellite missions, as a contribution to the Tropospheric Ozone Assessment Report II (TOAR-II), ESA's Climate Change Initiative on ozone (Ozone_cci+) studies, and Copernicus Climate Change Service (C3S) procurement. As a basis, NDACC ozonesonde and tropospheric lidar observations serve as fiducial reference measurements (FRM). The different satellite and FRM datasets are made comparable and cross-interpretable despite their representativeness differences, by accounting for their observation geometry and their vertical range, resolution and sensitivity as far as possible. Harmonization approaches address tropopause definition, sampling and smoothing issues, and information content. We conclude by a reflection on the uncertainty budget closure and the use of multiple co-locations.

O_B06: Niko Fedkin

Assessment of TEMPO NO2 columns for monitoring emissions from oil and gas operations using comparisons with Pandora and SCOAPE-II campaign data

Niko Fedkin (1,2), Ryan Stauffer (2), Anne Thompson (3,2), Debra Kollonige (4,2), Holli Wecht (5), Thomas Hanisco (2), Bryan Place (6,2), Jonathan Gallegos (6), Laura Judd (7), Scott Janz (2)

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The Outer Continental Shelf (OCS) of the Gulf of America is a highly developed offshore region for oil and natural gas (ONG) production. Among the emissions produced by ONG operations is nitrogen dioxide (NO2), an air quality pollutant that is precursor to surface ozone. Monitoring NO2 from space is particularly vital in areas where there are no routine surface air quality measurements, such as offshore. The Department of Interior's Bureau of Ocean Energy Management (BOEM), with jurisdiction on the OCS west of 87.5 degrees longitude in the Gulf of America, funded NASA to conduct two ship campaigns in 2019 and 2024 called the Satellite Coastal and Oceanic Atmospheric Pollution Experiment (SCOAPE-I and -II). SCOAPE-I and -II assessed the feasibility of using satellite data products for monitoring ONG NO2 emissions, including validation of operational NO2 satellites. In 2023, the geostationary TEMPO satellite was launched and provides multiple hourly NO2 measurements over the Gulf of America each day. This work explores TEMPO's ability to detect NO2 from ONG activities both from a long-term perspective and in terms of diurnal patterns. Comparisons between Pandora column NO2 and UV-Vis satellite instruments (TEMPO, TROPOMI and OMI) will be presented for the BOEM's Monitoring Station in Cameron, LA, USA coastal Pandora site, as well as for the Pandora onboard the Point Sur research vessel, used during both SCOAPE campaigns. As part of this study, we also discuss uncertainties and differences between satellite instruments in attempting to obtain an accurate picture of NO2 from OCS ONG operations.

O_B07: Zachary Fasnacht (remote)

Validating High Spatial Resolution Trace Gas Retrievals from the PACE Ocean Color Instrument

Zachary Fasnacht (1,2), Joanna Joiner (1,2), Eric Bucsela (2), Gordon Labow (1,2), Matthew Bandel (1,2), Fei Liu (1,2), Lok Lamsal (3,2), Nickolay Krotkov (4,2)

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Satellite based observations of trace gases such as nitrogen dioxide (NO2) and ozone (O3) are important for monitoring air quality, atmospheric correction of surface reflectance including ocean color (OC) retrievals and improving chemistry transport models. Over the past few decades, trace gas instruments in low earth orbit have seen a steady progression of improving spatial resolution starting with GOME (40x320km2), then OMI (12x24km2), and more recently TROPOMI (5.5x3.5km2). Unlike these atmospheric composition spectrometers, which have high spectral resolution, the heritage OC instruments make a few multi-spectral measurements at higher spatial resolution. ~1km The PACE Ocean Color Instrument is the first polar orbiting hyperspectral OC instrument with a high spatial resolution of 1.2km2 x1.2km2. While the spectral resolution of PACE OCI at 5nm is coarser than traditional trace gas instruments, it provides a unique opportunity to explore the possibility to retrieve trace gases globally at higher spatial resolution. We utilize a machine learning approach to retrieve NO2 and O3 from PACE OCI at the high spatial resolution of 1.2km2 x1.2km2 utilizing well validated TROPOMI NO2 and O3 retrievals as input. Ground based measurements from Dobsons, Brewers, and Pandoras have been utilized to validate these new trace gas measurements from the PACE OCI instrument.

O_B08: Bojan R. Bojkov/Thierry Marbach

EUMETSAT's approach to Cal/Val Gap Analyses and Fiducial Reference Measurements

Bojan R. Bojkov, ***Thierry Marbach***

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Cal/Val has been an essential activity for all successful EO missions since the early 1960s. At EUMETSAT, a mission's Cal/Val activities are directly linked to a its End-User Requirements Document (EURD) and provide the characterization and uncertainties to help determine if the goals set out in the EURD are met over the lifetime of the mission. Over the last three decades, EUMETSAT has undertaken Cal/Val activities for its missions, driven by the operational needs in term of timeliness, data quality and data continuity. It has also supported targeted measurement and field campaigns, and participated in international and inter-governmental fora led by the WMO, CEOS, EUMETNET, EEA, etc.

Fiducial Reference Measurements (FRM) are bespoke, fully characterized measurements made to support specific EO mission Cal/Val needs. FRM may be a subset dataset of so-called "in-situ measurements", and may be multi-purpose in application (i.e. also for model validation). It is therefore important for EUMETSAT, as an operational agency with increasing global and thematic responsibilities, to ensure, as far as possible, Cal/Val data availability to meet its increasingly demanding EURD requirements.

As part of each mission's Cal/Val planning, EUMETSAT undertake in depth multi-mission Cal/Val data gap analyses for each EURD parameter without duplicating ground-based activities or activities coordinated through establishes entities such as NDACC, TCCON, ACTRIS, or the WMO/GAW. Gap analyses have already been performed for a number of missions and necessary FRM activities identified. Here, we present EUMETSAT's approach to FRM for the Cal/Val activities of its existing and upcoming missions.

Session C: NDACC synergistic environment in support of field campaigns and other chemistry and climate-observing networks

Conveners: Thierry Leblanc, Lizzy Asher

K_C01: Sergey Khaykin – Session C Keynote

Assessing the impact of Hunga eruption on the global stratospheric composition using a synergy of NDACC, GRUAN and satellite observations

Sergey Khaykin, NDACC Team, GRUAN Team
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The eruption of the submarine Hunga volcano on 15 January 2022 was associated with a powerful blast that injected water and sulfur throughout the stratospheric layer, leading to an unprecedented increase in the global stratospheric water mass by 13% as compared to climatological levels and a 5-fold increase in the stratospheric aerosol load, the highest in the last three decades. The unique nature and magnitude of the global stratospheric perturbation by the Hunga eruption ranks it among the most remarkable climatic events in the modern observation era.

In this study, we combine the data from a number of satellite instruments (MLS, OMPS-LP, CALIOP, SAGE III, ACE-FTS) with NDACC lidars at various locations and GRUAN balloon water vapour soundings to investigate the global transport and evolution of the Hunga sulfates and moisture during three years following the eruption. In particular, we address the following aspects: timescales of meridional and vertical progression of the moisture and aerosol-rich layers; bulk transport into the southern high-latitudes; episodes of in-mixing into the northern extratropics; growth and sedimentation of Hunga sulfates. In addition, we compare the Hunga stratospheric aerosol perturbation with those produced by moderate and major eruptions in terms of the e-folding time, spatial evolution and aerosol microphysical parameters.

O_C01: Roeland Van Malderen

Harmonization, Evaluation, and Trend Estimation of Ground-based Tropospheric Ozone Measurements from NDACC and IAGOS instruments

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Within the framework of the second phase of the Tropospheric Ozone Assessment Report (TOAR-II), the HEGIFTOM focus working group aimed at harmonizing (tropospheric) ozone profile measurements from 5 different ground-based techniques: ozonesondes, Lidar, FTIR, Dobson Umkehr (all belonging to NDACC), and In-service Aircraft for a Global Observing System (IAGOS) profiles. Amounts and uncertainties of total and partial tropospheric ozone columns are calculated for each network's homogenized datasets and inter-compared at collocated sites. We estimated trends (2000 to 2022) for the (partial) tropospheric ozone columns (TrOC) using Quantile Regression (QR) and Multiple Linear Regression (MLR) at 55 sites, including 6 multi-instrument stations. We found that TrOC trends fall within ±3 ppb/decade, with the greatest fractional increases occurring over most tropical/subtropical sites, and with decreases at northern high latitudes. As these patterns are not uniform, we also explored if a more consistent understanding of the geographical distribution of those trends can be obtained by focusing on regional trends calculated from the ground-based measurements. We obtained increasing (partial) tropospheric ozone column amounts over almost all Asian regions (median confidence), and negative trends over the Arctic regions (very high confidence). Trends over Europe and North America are mostly weakly positive or negative. We also conclude that for all regions, the pre-COVID trends (ending in 2019) are larger than the post-COVID trends. In summary, our analysis shows that high-quality, multi-instrument, harmonized data over a wide range of ground sites provide clear references for models and evolving tropospheric ozone satellite products.

O_C03: Bianca Baier / Markus Jesswein

Cross-network engagement opportunities between NDACC and NOAA's AirCore Program

Bianca Baier (1), Colm Sweeney (1), Jack Higgs (1), Jianghanyang Li (2), Markus Jesswein (3,1), Fred Moore (3,1), Tim Newberger (3,1), Sonja Wolter (3,1), Steven Borenstein (3,1)

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The balloon-borne AirCore sampling system passively captures a continuous, high-resolution air sample from the lower stratosphere (~25 km) to the Earth's surface. Cavity ring-down spectroscopy measurements of AirCores result in profiles of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO) and - circa 2019, nitrous oxide (N_2O) – all carefully tied to World Meteorological Organization (WMO) standard scales. NOAA's AirCore Program has launched balloons near-monthly from Boulder, CO since 2012, resulting in a unique record of surface-to-stratosphere profiles. Recently, the Program has expanded to measuring air samples via gas chromatography quarterly alongside NOAA ozone and water vapor balloon flights, providing profiles of CFCs, halons, N_2O and sulfur hexafluoride (SF_6) to complement the AirCore trace gas suite for seasonal, comprehensive profiling of additional long-lived atmospheric gases with varying photochemical lifetimes. NOAA's AirCore technology has been adopted by several other international entities, helping to spark a future AirCore Global network.

AirCores are uniquely suited for monitoring stratospheric composition and the potential for dynamical change in the Brewer-Dobson Circulation with climate, but are also a critical component of ground- and space-based remote sensing retrieval programs as profiles capture high-resolution variability throughout the atmospheric column. New opportunities exist for advancing cross-network synergy using these data in complementing, evaluating and establishing WMO-traceability for NDACC retrievals as well as advancing retrieval algorithm development. We highlight new developments in AirCore return technology that is aimed at furthering measurement capabilities in data-poor regions like the tropics, which can strengthen our understanding of atmospheric composition in climate-critical regions.

O_C04: Alexandre Baron

The NOAA Balloon Baseline Stratospheric Aerosol Profiles – In situ insight on the stratospheric aerosol layer

Alexandre Baron (1,2), Elizabeth Asher (1,2), Katie Smith (1,2), Troy Thornberry (2), and the B2SAP team

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Stratospheric aerosols play a crucial role in the climate system, but uncertainties persist in understanding the chemical, dynamical, and microphysical processes governing their distribution and variability. The chemical and radiative impacts of stratospheric aerosols hinge on particle size distribution. However, models exhibit significant variations in how they parameterize aerosol microphysical processes and simulate size distributions, leading to divergent predictions of the time evolution of radiative impacts from stratospheric aerosol perturbation events. To refine models for assessing the effects of potential climate intervention strategies, systematic measurements are crucial.

In pursuit of this understanding, the Balloon Baseline Stratospheric Aerosol Profiles (B2SAP) project utilizes compact, lightweight payloads carried by meteorological balloons. These payloads measure aerosol number density and size distributions, along with water vapor, ozone, and meteorological data from the surface to the middle stratosphere. The long-term goal of the B2SAP project is to generate climatologies of aerosol number and size distributions up to the middle stratosphere at latitudinally distributed measurement sites. These measurements provide a new record of in situ observations allowing to characterize the natural stratospheric aerosol burden, its variability, and responses to perturbations, providing essential data for refining models and aiding in the validation of satellite-based estimates.

In this context, we will present a subset of this growing database, emphasizing the discussion on the stratospheric aerosol layers in the North hemisphere and South hemisphere (SH) mid-latitudes. Perturbations following volcanic eruptions will also be investigated.

O_C06: Anne M. Thompson

Tropospheric Ozone Trends in the Tropics (1998-2023): An Overview of Observational and Statistical Perspectives

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The IGAC/TOAR II activity (Tropospheric Ozone Assessment Report, 2021-; dozens of publications at https://bg.copernicus.org/ articles/special_issue10_1256.html) includes analyses of tropospheric ozone over the past 20-30 years based on satellite estimates and ozone data from NDACC-affiliated ground-based (GB) instruments. For tropical and subtropical locations, GB measurements include profiles from 14 SHADOZ stations and from IAGOS commercial aircraft on 3 continents. We review complexities of satellite and GB data as they relate to TOAR II trends. First, comparisons among a number of satellite estimates cannot isolate "best" products (Keppens et al., 2025). Second, we summarize tropical and subtropical tropospheric ozone trends from TOAR II HEGIFTOM (Van Malderen et al., 2025; re-processed multi-instrument data at https://hegiftom.meteo.be/ datasets) and from SHADOZ and IAGOS profiles (Gaudel et al., 2024; Thompson et al., 2025). These three studies address uncertainties in trends due to: (1) data frequency and sampling number (SN); (2) statistical methods, Quantile Regression (QR) and Multiple Linear Regression (MLR). We carried out SN sensitivity studies and compared QR and MLR analyses at SHADOZ sites. In the former case, median trends from ~1998-2023 are statistically the same; uncertainties improve with higher SN, but at decreasing increments beyond 4 profiles/month. Median QR and MLR ozone trends are likewise statistically similar but QR and MLR methods are both required to interpret changes. QR trends pinpoint variability in the lowest (5%-ile) to highest-concentration ozone (95%-ile) populations. Monthly trends from MLR give vital seasonality information, implicating meteorological drivers in the tropics/subtropics (Stauffer et al., 2024; Millet et al., 2025).

O_C07: Steven Compernolle (remote)

Towards end-to-end validation of TROPOMI tropospheric data: A cross-network approach

Steven Compernolle (1), Jean-Christopher Lambert (1), Athina Argyrouli (2), Ronny Lutz (2), Maarten Sneep (3), Ann Mari Fjaeraa (4), José Granville (1), Daan Hubert (1), Arno Keppens (1), Diego Loyola (2), Ewan O'Connor (5), Alexander Cede (6), Gaia Pinardi (1), Fabian Romahn (2), Tijl Verhoelst (1), Ping Wang (3)

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The retrieval of tropospheric trace gases data products from satellite observations requires accurate knowledge of several intermediate quantities. A typical example is the retrieval of the tropospheric nitrogen dioxide (NO2) column which requires the intermediate retrieval of the total and of the stratospheric NO2 column, and of cloud properties (cloud top height, optical depth, fractional cover). The end-to-end validation approach recommended for satellite data obtained by a complex production chain needs a quality assessment of each of these intermediate quantities. Several of them can be validated using reference measurements acquired by NDACC instruments: the stratospheric NO2 column vs. zenith-scattered-light DOAS UV-Vis measurements, and the tropospheric NO2 column vs. MAX-DOAS UV-Vis measurements. To progress further towards an end-to-end quality assessment, a collaborative method has been developed with the ACTRIS-CLOUDNET and PGN networks to include validation of the cloud properties and the total NO2 column as well. A similar cross-network engagement has benefited the validation of other satellite data products such as ozone (O3) and formaldehyde (HCHO).

This paper describes the cross-network approach developed for the validation of Sentinel-5P TROPOMI tropospheric data, with particular emphasis on the need to incorporate quality evaluation of the cloud properties in the overall trace gas data validation process. As an illustration of the method and its benefits, it is shown that the product evolution of the TROPOMI cloud data quality - estimated using ACTRIS-CLOUDNET as a reference - controls the bias of TROPOMI tropospheric NO2 data derived from comparisons to the NDACC MAX-DOAS and PGN measurements.

O_C08: Ruud Dirksen (remote)

GRUAN: the road to long-term reference observations

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The GCOS Reference Upper Air Network (GRUAN) consists of approximately 30, globally distributed measurement sites that provide long-term reference observations of essential climate variables such as temperature and water vapour for the purpose of climate monitoring. For this purpose sites employ in situ (radiosondes, chilled mirror instruments -CMIs-) but also remote sensing techniques such as GNSS-PW, lidar and microwave radiometer to retrieve the atmospheric parameters.

Radiosondes provide in-situ profiles of temperature, humidity and pressure at high vertical resolution. However, data products from commercial radiosondes often rely on black-box or proprietary algorithms, which are not disclosed to the scientific user. Therefore, GRUAN data products (GDP) are developed, that employ open-source and well-documented corrections to the measured data, thereby complying with the requirements for reference data, which include measurement traceability and the availability of measurement uncertainties. Currently, GDPs have been developed for GNSS-PW and various radiosonde types, and the development of GDPs for CMIs, lidar and MWR is ongoing.

In case of radiosondes, the GRUAN data processing is applied to raw data of temperature, humidity, pressure and wind includes corrections to known error sources, such as for example solar radiation error for temperature and time lag for humidity measurements, and includes vertically resolved uncertainty estimates of e.g. the applied correction and the calibration of the sensors.

In this presentation we give an overview of GRUAN and the available GRUAN data, the steps needed to develop a GDP and an example of how to treat uncertainties.

Session D: Synergistic use of models with NDACC and its Cooperating Networks' data to interpret observations and support model development and verification

Conveners: Sarah Strode, Martine De Mazière

K_D01: Martyn Chipperfield – Session D Keynote

Combining NDACC data and global 3-D modelling to understand processes, variability and trends in stratospheric composition

Martyn Chipperfield

School of Earth and Environment, University of Leeds, UK

The Network for the Detection of Atmospheric Composition Change (formerly NDSC) has obtained and curated an impressive multi-decadal record of trace gas and aerosol observations from around the globe. The importance of these datasets grows as the continuous timeseries extend and they reveal more information about atmospheric variability and long-term change. The NDACC datasets have been central for many key areas of ozone layer science, for example documenting the growth and now decline of stratospheric chlorine. Over time the network has developed with the retrieval of more species and an extension to species of interest to tropospheric chemistry and greenhouse gas budgets. The importance of the network will also increase as we enter a period with little satellite composition data for the stratosphere.

I will summarize a range of studies from our group which have combined NDACC data and global 3-D model simulations to reveal information about trends and variability in atmospheric composition. Topics will include how column HCl, ClONO2 and HF data revealed multiannual hemispheric asymmetry in stratospheric dynamics, new retrievals of fluorinated climate gases, the contribution of short-lived species to stratospheric BrO and applications to tropospheric trace gases. I will also discuss the impact that the 2022 Hunga volcanic eruption has had (is having) on Antarctic ozone depletion.

O_D01 Invited: Daniele Minganti

Understanding stratospheric circulation changes using FTIR measurements (invited)

Daniele Minganti (1), Simon Chabrillat (1), Quentin Errera (1), Maxime Prignon (2), Irene Vanwynsberghe (3), Xinyue Wang (4), Douglas E. Kinnison (4), Rolando R. Garcia (4), Marta Abalos (5), Justin Alsing (6), Matthias Schneider (7), Dan Smale (8), Nicholas Jones (9), Emmanuel Mahieu (10)

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The Brewer-Dobson Circulation (BDC) is characterized by tropospheric air rising into the stratosphere in the Tropics, moving poleward and descending in the middle and high latitudes. Since the BDC cannot be measured directly, stratospheric long-lived traces (e.g., nitrous oxide, N2O) are used to infer BDC changes. We computed trends of N2O stratospheric columns at 4 FTIR NDACC stations: Lauder, Wollongong, Izaña and Jungfraujoch. We compared these N2O trends with those obtained from model simulations (WACCM) and the BASCOE CTM driven by 4 dynamical reanalyses and with the ACE-FTS satellite observations. The trends in the N2O stratospheric columns are generally larger above the SH than the NH. This reveals differences in the BDC between the hemispheres and is consistent with hemispherical differences in trends of HNO3, HCl and Fy columns measured at FTIR stations over the past decade.

FTIR measurements of N2O can be used also to evaluate the impact of extreme events on the BDC. The Hunga eruption of January 2022 injected unprecedented amount of water vapour into the stratosphere. Such large injection modified the temperature in the SH stratosphere and impacted the BDC. Using FTIR measurements at Lauder, we show that the Hunga eruption slows down the BDC, leading to a slower removal of N2O. Consequently, this results in an increase in N2O concentrations during July and August 2022 compared to previous years.

These results highlight the importance of FTIR measurements, and we remark the need of continuous FTIR observations in the upcoming observational gap period.

O_D02: Ivan Ortega

Advancing NDACC/IRWG FTIR CH4 and N2O retrieval strategies to strengthen atmospheric composition analyses and the evaluation of model simulations and satellite observations

Ivan Ortega (1), James W. Hannigan (1), Benjamin Gaubert (1), Mohammad Amin Mirrezaei (2), Bianca C. Baier (3), Kathryn McKain (3), Dan Smale (4)

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Accurate measurement of atmospheric methane (CH4) and nitrous oxide (N2O) is crucial for understanding their sources, sinks, and environmental significance. High-resolution Fourier Transform Infrared (FTIR) observations, as part of the NDACC/IRWG network, play a pivotal role in reliable global profiles of these gases. This study evaluates new retrieval strategies for CH4 and N2O using FTIR data from Boulder, Colorado by comparing them with independent airborne in situ measurements. We explore the impact of different spectroscopy databases, noting that while total column outcomes may be similar, variations in vertical profiles highlight the need for independent validation not available for many other species. By evaluating nearby independent multi-year AirCore and in situ aircraft profile measurements, we assess vertical distributions and biases in partial columns, which both show excellent agreement in relative differences with the optimized FTIR retrievals. We show HITRAN 2020 is best for N2O, while an alternate database ATM 2020 provides best results for CH4. Two regularization methods: Tikhonov and Optimal Estimation, yield comparable results with degrees of freedom between 2 and 2.5. We use these optimized retrievals to evaluate CAM-Chem model simulations at Boulder, CO and Lauder, New Zealand with particular emphasis on comparing prescribed- and emission-driven surface methane scenarios to improve constraints on source and sink processes. These results support the refinement of harmonized retrieval approaches across NDACC/IRWG sites to enhance the evaluation of model vertical profiles, particularly in distinguishing tropospheric and stratospheric contributions, and to contribute to improving satellite retrieval strategies.

O_D03: Beatriz Herrera (remote)

NH3 trends and model comparisons at 21 FTIR sites

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Atmospheric NH3 is involved in several chemical reactions, including PM formation, with direct consequences for the environment and human health. This work presents the seasonal and diurnal variability and the long-term trends of NH3 total columns retrieved from solar absorption measurements performed at 21 ground-based Fourier transform infrared (FTIR) sites. The sites are globally distributed in both hemispheres from 45°S to 80°N, most of them affiliated with NDACC. The FTIR variability and trends are compared to NH3 simulations from the GEOS-Chem High Performance (GCHP) chemical transport model and the Tropospheric Chemistry Reanalysis (TCR-2) NH3 product. The FTIR time series of NH3 total columns range from 0.11 to 19.2 x 10^15 molecules cm-2, with the smallest columns in the Arctic and at high-altitude sites, and larger columns in urbanized areas. NH3 enhancements were identified and attributed to biomass burning events. NH3 from volcanic eruptions was also observed at the Izana site. The seasonal patterns are similar across most sites and were generally captured by GCHP and TCR-2. The diurnal variability depends on the characteristics of each site with the models unable to capture most of this variability. Most of the sites reveal positive trends in the total column, ranging from 0.38 to 93 × 10^13 molecules cm-2 yr-1, while the equivalent trends derived from the models were generally negatively biased relative to the FTIR trends. GCHP exhibited better overall agreement with the FTIR observations than TCR-2; potential reasons for this are explored in this presentation.

O_D04: Christian Rolf

Project overview about the ISSI International Team on upper tropospheric and stratospheric water vapor

Christian Rolf (1), Felix Plöger (1), Peter Bechtold (2), Thomas Birner(3), Laura Braschoss (3), Gabriel Chiodo(4), Sean Davis (5), Peter Haynes (6), Michaela Hegglin (1), Peter Hoor (7), Patrick Konjari (1), Paul Konopka (1), Yun Li (1), Amanda Maycock (8), Andreas, Petzhold (1), Susanne Rohs (1), Michelle L. Santee (9), Patrick Sheese(10), Mengchu Tao (11), Holger Vömel (12), Hongyue Wang (1), Kaley Walker (10), Franziska Weyland (7)

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Recent research has shown evidence for water vapor variations in the upper troposphere and lower stratosphere (UTLS) to crucially affect atmospheric circulation and climate. Hence, it is the trends in the UTLS which dominate the climate effect, but water vapor in this region has not been under focus in past research activities. Furthermore, the water vapor budget in the UTLS is particularly challenging, as satellite and in-situ observations have large uncertainties and atmospheric models simulate largest biases in that region. The ISSI team includes experts from the different fields of satellite and in-situ observations, process and climate modelling, dynamics and process understanding to achieve a step-change in understanding, observing and simulating water vapor concentrations in the UTLS. The aims are: (i) explore capabilities of existing satellite and in-situ datasets, in particular in the UTLS region and regarding long-term trend estimation, (ii) assess the model representation of stratospheric water vapor in climate and weather forecast models, and (iii) consolidate on future needs for observations and models. Here, we present a project overview and first results of the observation and model assessment.

O_D05: Daniel Rauter (remote)

Spectral UV Irradiance and Total Ozone Trends in the Austrian Alps and Lowlands: A Multi-Decadal Analysis

Daniel Rauter, Stana Simic
BOKU University, Austria

Throughout Europe, long-term ground-based UV irradiation measurements show large regional variations, Solar ultraviolet radiation plays a critical role in human health and ecosystems, with its variability closely linked to changes in atmospheric ozone and other environmental factors.

In this study, we analyze nearly 30 years of high-quality, continuous measurements of high-resolution spectral UV radiation from two distinct Austrian sites affiliated with NDACC: an urban station near Vienna (156 m) and the high-altitude Sonnblick Observatory in the Austrian Alps (3106 m) which also features and total ozone measurements. We investigate long-term trends in erythemal irradiance, specific UV wavelengths, and total ozone column, comparing results between the two sites to assess the environmental influences. The unique conditions and reflective snow-covered terrain at Sonnblick offer a valuable contrast to the urban environment of Vienna.

We also compare ground-based measurements with satellite and modeled data to evaluate their accuracy in capturing UV irradiance and ozone variability under diverse environmental conditions. This comparison aims to identify potential biases, seasonal influences, and limitations in existing datasets, particularly over complex alpine terrain. Building on methodologies from recent European studies, this work advances our understanding of how changes in total ozone, atmospheric composition, and climate influence surface UV radiation. The findings offer valuable insights into the drivers of UV and ozone variability and support efforts to improve UV forecasting and satellite-based retrievals.

O_D06: Megan Lickley

Bias in the use of atmospheric lifetimes for 1-box emissions inference of ozone depleting substances measured at the surface

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Trends in the atmospheric lifetimes of ozone depleting substances (ODSs) arise from the disequilibrium between ODS mole fractions at the surface relative to those in the loss region. As mole fractions at the surface reach equilibrium, this disequilibrium leads to a decreasing trend in global atmospheric lifetimes of these gases, which converges towards the steady-state lifetime. Conversely, for many ODSs, their loss in the troposphere is due to dilution driven by exchange with the stratosphere and thus decreases over time as the stratosphere fills with ODSs emitted at the surface. As such, the effective tropospheric lifetime (i.e. tropospheric burden/tropospheric loss through strat-trop exchange) increases with time as total atmospheric lifetimes decrease. When a 1-box model of the atmosphere is used to infer global emissions, as is done in the policy chapter of the ozone assessment, a global atmospheric lifetime is generally applied. However, unbiased inference of global emissions from surface measurements of ODSs requires the use of the effective tropospheric lifetimes in a 1-box model. This work quantifies the bias of using the global atmospheric lifetimes in 1-box modeling and provides a correction to account for the effective tropospheric time-varying lifetime. We illustrate this bias and correction using emissions-forced simulations from the GSFC 2D model.

O_D07: Ralf Sussmann (remote)

On daytime increase of stratospheric NOx: New insights from FTIR measurements and photochemistry modeling

Ralf Sussmann (1), P. S. Mali (1), M. Rettinger (1), P. Nürnberg (2), M. Frey (1), O.E. Garcia (3), M. Grutter (4), F. Hase (1), W. Stremme (4), S. A. Strode (5,6)

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2: German Aerospace Center, DLR, Cologne, Germany
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4: Instituto de Ciencias de la Atmosfera y Cambio Clima´tico, Universidad Nacional Autonoma de Mexico, Mexico
5: Goddard Earth Sciences Technology and Research (GESTAR II), Morgan State University, Maryland, USA
6: NASA Goddard Space Flight Center, Maryland, USA

Solar absorption Fourier transform infrared (FTIR) spectrometry is one of the few techniques that allows for continuous sampling of NOx vertical distributions as a function of the time of the day. Thereby, this kind of observations can help to improve our understanding of daytime photochemistry, validate photochemistry models, and support the retrieval of tropospheric NO2 from satellite observations.

In this paper we present an innovative FTIR retrieval and data evaluation strategy optimized for the best possible separation of tropospheric and stratospheric NOx partial columns even in cases of tropospheric pollution. Based on this, we analyze FTIR measurements along a north-south transect of stations, i.e. Kiruna (67.8 N), Karlsruhe (49.1 N), Garmisch (47.4 N), Zugspitze (47.2 N), Izana (28.3 N), and Altzomoni (19.1 N). We infer the stratospheric NO2 and NO daytime increasing rates. For the first time, we were able to detect a significant seasonal variation of both NO2 daytime increasing rates and NO a.m. diurnal increasing rates experimentally. Based on this, we created a set of experiment-based scaling factors describing the diurnal changes of NO2 and NO as a function of solar zenith angle (SZA) in analogy to published simulation-based scaling factors. The simulation-based scaling factors show an excellent agreement with our experiment-based ones, i.e. for NO2 and NO the mean bias is only 0.02 %. Finally, we investigate the latitudinal dependence of the NOx daytime increase.

Session E: Linking changes in atmospheric composition, climate, and air quality

Conveners: Roland Van Malderen, Bärbel Vogel

K_E01: Susann Tegtmeier – Session E Keynote

Long-term changes of the Brewer-Dobson circulation and the impact on stratospheric composition

Susann Tegtmeier [1], K. Dubé [1], A. Bourassa [1], F. Ploeger [2], A. Chrysanthou [3], M. P. Chipperfield [4], J. Laube [2], A. Engel [5], L. N. Saunders [6], K. A. Walker [6], R. Hossaini [7], and E. Bednarz [8]

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2 Forschungszentrum Jülich, Jülich, Germany
3 Aristotle University of Thessaloniki, Thessaloniki, Greece
4 University of Leeds, Leeds, UK
5 Goethe University Frankfurt, Frankfurt am Main, Germany
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Stratospheric trace gases like HCl and N2O show a hemispheric asymmetry, with trends over the last decades having opposing signs in the Northern Hemisphere (NH) and Southern Hemisphere (SH). Some of this difference is due to hemispherically asymmetric changes in the rate of transport by the Brewer–Dobson circulation (BDC). These changes also impact stratospheric ozone, which has recovered more in the SH compared to the NH. Long term changes in transport further complicate the analysis of trends in stratospheric chlorine when compared to changes in surface emissions of ozone depleting substances (ODSs) regulated by the Montreal Protocol.

Here we use N2O as a proxy for the stratospheric circulation to calculate long-term trends in mean age of air (AoA), which is a common proxy for BDC transport. First, N2O observations from ACE-FTS are combined with results from CLaMS simulations to derive AoA anomalies. We find that air in the NH aged by up to 0.3 years per decade relative to the SH over 2004–2017 with the maximum hemispheric difference occurring near 30 hPa. The N2O proxy is then used to analyze how much of the decrease in stratospheric chlorine is related to transport variations and how much is driven by the reduction in chlorinated long-lived ODSs. We show that the observed decrease in stratospheric chlorine is 25%−30% smaller than expected based on trends of long-lived ODSs alone. This can be explained by the increase in chlorinated very short-lived substances, which offsets the long-term reduction of stratospheric chlorine by up to 30%.

Finally, the effects of AoA trends on ozone are examined revealing that negative ozone trends in the NH at lower levels cannot be explained by trends in ozone transport and are likely caused by some other mechanism. TOMCAT model simulations are used to quantify the sensitivity of ozone to long-term halogen changes and to show that the recent dynamically induced variation in halogen loading has, through chemical feedback, accentuated the ozone recovery signal in the SH and delayed it in the NH.

O_E01 Invited: Paul A. Newman

On the Breakup of the Antarctic Ozone Hole (invited)

Paul A. Newman (1,2), Leslie R. Lait (3), Lawrence Coy (2), Natalya Kramarova (2)

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3: NASA Ames Research Center, California, USA

The Antarctic ozone hole is caused by man-made substances that lead to substantial ozone depletion in the Austral August-October period. Ozone depletion is shut-down as the polar vortex warms during the September-October period. The ozone hole eventually breaks up in the November-December period when total column ozone values rise above a threshold of 220 Dobson Units. The breakup impacts the NDACC polar stations with respect to both column ozone and other stratospheric constituents. There is wide-variation in the ozone hole breakup date, ranging from mid-November to late-December. The ozone hole has broken down late in the last 5 years (2020-2024), perhaps suggesting unknown forcings or a climate driven secular trend. In this presentation we show that the breakup is principally driven by wave forcings caused by large-scale tropospheric waves propagating vertically into the stratosphere. We also show how late-breakups can modify the ozone trends resulting from decreasing levels of ozone depleting substances. Analysis of these forcings and wave structures has implications for future observations and monitoring strategies.

O_E02 Invited: Simone Tilmes (remote)

The effects of solar climate interventions on the ozone layer, benefits, risks, and uncertainties (invited)

Simone Tilmes

National Center for Atmospheric Research, Colorado, USA

With global surface temperatures reaching unprecedented highs and with these continuously increasing detrimental impacts on the Earth system, research on approaches complementary to mitigation and adaptation is required. Stratospheric aerosol injection (SAI) is at the moment one of the more effective technologies proposed to cool the Earth's Surface, and it is based on increasing the stratospheric aerosol layer to reflect some of the incoming sunlight. While global climate models show various benefits of potential SAI applications on the climate, they also point towards some unintended consequences, including impacts on the ozone layer. The WMO2022, for the first time, included a chapter on the effects of potential Solar Climate Intervention technologies on the ozone layer. Furthermore, Phase 2 of the Chemistry-Climate Model Initiative (CCMI-2022) included experiments to investigate the effects of SAI on stratospheric ozone in a multi-model framework. Recent modeling work also includes consideration of alternative materials that may impact the ozone layer differently than using sulfate aerosol. These come with larger uncertainties due to unknown chemical details. This presentation summarizes the current understanding of how SAI may impact stratospheric ozone and outlines other potential benefits, risks, and uncertainties.

O_E03: Xin Zhou (remote)

Stratospheric Water Vapour Perturbation from the 2022 Hunga Tonga Eruption: Transport and Removal

Xin Zhou (1), Martyn Chipperfield (2), Saffron Heddell (2), Sandip Dhomse (2), Wuhu Feng (3), Graham Mann (2), Hugh Pumphrey (4), Michelle Santee (5)

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3: National Centre for Atmospheric Science, University of Leeds
4: School of Geosciences, University of Edinburgh
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The January 2022 eruption of the Hunga volcano (20°S) injected ~150 Tg of water vapour (~10% of background) into the stratosphere—unprecedented in the satellite era. We use the TOMCAT 3-D chemical transport model, driven by ERA5 reanalyses, to assess the residence time of excess H_2O. Simulations with and without dehydration from sedimenting ice in polar stratospheric clouds (PSCs) are compared to Aura MLS satellite data and balloon observations from Scott Base (77.8°S).

TOMCAT reproduces the large-scale spread of Hunga H_2O through January 2025, although arrival at northern high latitudes lagged MLS observations. Both model and MLS data show sustained elevated H_2O followed by a decline starting in late 2023. The 2023 Antarctic vortex caused the first major (~20 Tg) dehydration-driven removal, although by late 2023 the modelled H2O anomaly in both model runs was similar. The no-dehydration run indicates further removal of the additional H_2O by stratosphere-troposphere exchange (STE) began in late 2023 and accelerated through 2024. This timing is linked to the arrival of the additional Hunga H_2O in the lower stratosphere via the slow BDC. This suggests both STE and Antarctic dehydration will govern long-term removal.

We will also discuss the possible occurrence of dehydration in the cold Arctic vortex of early 2025. This second Arctic winter with Hunga enhanced lower stratospheric H_2O had colder conditions than 2023/24, with temperatures below the ice point in late January 2025. The impact of any Arctic dehydration on the overall mass of stratospheric Hunga H_2O will be assessed.

O_E04: Hannah Clark

Long-term measurements of ozone and water vapour from IAGOS aircraft for air-quality and climate

Hannah Clark (1), Valérie Thouret (2), Susanne Rohs (3), Andreas Petzold (3), IAGOS Team
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3: Forschungszentrum Jülich GmbH, Germany

For thirty years, the European Research Infrastructure IAGOS (formerly known as MOZAIC) has been equipping commercial aircraft with instruments to monitor the composition of the atmosphere on long-haul flights around the world. Five European aircraft initially measured ozone, and water vapour along with meteorological parameters in the upper troposphere/lower stratosphere and during landing and take-off at many international airports. Some of these airlines have participated since the start of IAGOS leading to the continuous 30 year time-series over Europe. The range of species has been expanded to include ozone precursors, and greenhouse gases along with clouds and aerosols. The global reach of IAGOS has increased due to the participation of airlines beyond Europe, most notably in Asia and North America. In this talk, we will focus on the trends in ozone and water vapor from IAGOS in the upper troposphere and lower troposphere and highlight the natural and dynamical or anthropogenic pollution-driven causes for the variability and anomalous events. This talk will also demonstrate the importance of IAGOS to monitoring ozone and precursors in regions of interest where in-situ measurements are otherwise difficult to obtain. In particular, we focus on the Pacific Ocean, northern latitudes and South America where aircraft are essential to the long-term observing strategy. As the climate changes and extreme events become more frequent, the importance of setting such measurements in the long-term context becomes increasingly important.

O_E05: Sarah Strode

Evaluating Tropospheric Ozone Variability in GEOS-GMI with Ozonesonde Data and Quantifying its Drivers

Sarah Strode (1,2), Anne Thompson (3,2), Debra Kollonige (4,2), Ryan Stauffer (2)

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Multiple processes influence the interannual variability and ENSO response of tropospheric ozone and other constituents. These include dynamical changes such as shifts in convection as well as chemical changes due to changes in lightning NOx production and biomass burning emissions. Long time series of ozonesonde data provide valuable constraints on ozone variability for evaluating model performance, while model simulations provide insights into the sources of variability and allow us to separate the effects of different processes that covary with ENSO. We evaluate the interannual variability in tropical tropospheric ozone in a GEOS-GMI simulation against SHADOZ ozonesonde data for 1998 to 2020. We conduct two sensitivity simulations, one with fixed lightning NOx production, and one with lightning NOx and biomass burning and biogenic emissions all held fixed. Comparison of these sensitivity studies with the base simulation provides an estimate of the contributions from lightning and emission variability to the interannual and ENSO variability in ozone and other constituents. We quantify the contributions for different levels of the troposphere for the sonde locations and surrounding regions, providing a global context for the variability seen ozonesonde observations.

O_E06: Peter Effertz

Updated Total Column Ozone trends from Ground-based and satellite records derived using an optimized LOTUS regression model

Peter Effertz (1,2), Irina Petropavlovskikh (1,2), Jeannette D. Wild (3,4), Corinne Vigouroux (5), Glen McConville (1,2), Richard Querel (6)

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Stratospheric ozone levels have been closely monitored since the signing of the Montreal Protocol which banned ozone-depleting substances (ODS). To assess the effectiveness of the Protocol in driving positive ozone trends, Multiple Linear Regression (MLR) analysis statistical models (i.e. LOTUS, https://arg.usask.ca/docs/lotus_regression/) have been used. However, the LOTUS MLR code was optimized for analyses of zonal mean ozone records. To derive trends using long-term records from a ground-based station, MLR model optimization is needed to account for selection of proxies that can represent dynamical processes at each station. This approach can help with interpretation of meteorological and large-scale variability in ozone records and improve uncertainty in trends attributed to ODS-chemistry driven stratospheric ozone recovery. In this study, we use a stepwise elimination method to generate individualized models for each ground-based monitoring station. We will discuss the trends derived from ground-based (NDACC Dobson and FTIR) instruments and station-overpass satellite (NOAA Cohesive SBUV(/2) and OMPS) total column ozone records. We will discuss how the optimized model changes the magnitude of the trend estimates and uncertainties as function of latitude. In general, we find that the optimized model derives trends are closer to zero in the high northern latitudes. The uncertainties of the trends are also reduced as compared to traditional LOTUS results, especially at locations where month-to-month dynamical variability is high. If the ozone recovery trend continues, this method could lead to earlier detection of ozone recovery in places where ozone long-term trend is comparable to the inter-annual fluctuations.

O_E07: Victoria Flood (remote)

Utilizing over 20 years of measurements by the University of Toronto Atmospheric Observatory NDACC FTIR to assess air quality and composition

Victoria Flood (1), Kimberly Strong (1), Cynthia H. Whaley (2), Rebecca R. Buchholz (3), Jack Chen (2), Orfeo Colebatch (1), James R. Drummond (4), Lawson Gillespie (1), Grace Kuiper (5), Sheryl Magzamen (5), Nasrin Mostafavi Pak (1), Debra Wunch (1)

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2: Environment and Climate Change Canada. Canada
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4: Dalhousie University, Canada
5: Colorado State University, Colorado, USA

The University of Toronto Atmospheric Observatory (TAO), has been operating since 2002 and is a member of the Network for the Detection of Atmospheric Composition Change (NDACC). TAO reports partial columns and profiles of 16 trace gases (C_2H_2, C_2H_6, CH_3OH, CH_4, CHF_2Cl, CO, H_2CO, HCl, HCN, HCOOH, HF, HNO_3, N_2O, NH_3, O_3 and OCS). These data have been used to study atmospheric events such as polar vortex intrusions and biomass burning plumes. This talk will provide an overview of the TAO time series and major findings, in addition to highlighting recent work that assessed the air quality and composition in the Toronto area as a result of the record-breaking 2023 Canadian wildfire season. Plume transport and distribution are assessed for three events, in conjunction with HYSPLIT back-trajectories, and tropospheric enhancement ratios of C_2H_6, CH_3OH, HCN, HCOOH, NH_3, and O_3 relative to CO. The GEM-MACH FireWork model, operated by Environment and Climate Change Canada, is evaluated with respect to the tropospheric columns, surface values, and large-scale total column distribution of CO, NH_3 and O_3. Further, using CO measurements from 2004-2019, changes to the seasonal cycle are assessed in relation to wildfire activity. Public health risks of this change are examined using a difference-in-difference analysis of monthly hospital emissions for nine cardiovascular and respiratory diseases. Using satellite XCO as an exposure metric, findings are suggestive of a link between enhanced wildfire-related CO concentrations after 2012 and worsening health outcomes, with statistically significant results for six disease-province pairings in Ontario and Alberta.

O_E08: James Hannigan

Revised Long Term Global Carbonyl Sulfide Trends from the NDACC IRWG

James Hannigan (1), Ivan Ortega (1), Shima Shams (1), J. Elliott Campbell (2), Stephen Montzka (3)
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3: NOAA, Boulder, Colorado, USA

Carbonyl sulfide (OCS) is a non-hygroscopic trace species in the free troposphere and consequently the largest sulfur reservoir maintained by both direct oceanic, geologic, biogenic, and anthropogenic emissions and the oxidation of other sulfur-containing source species. With a relatively long tropospheric lifetime of 2-3y, it is the largest source of sulfur transported to the stratosphere during volcanically quiescent periods. OCS may be used as a proxy for CO2 transpiration, though for this, on a large scale background concentrations and drivers need to be accurately defined. In 2021 we developed and applied a network methodology for OCS vertical profile retrievals from middle infrared solar spectra from 22 globally dispersed NDACC IRWG FTIR instruments. We evaluated the non-monotonic trends in low- and free-tropospheric and stratospheric partial columns from 1986 to 2020 with regressions to geophysical parameters and bottom up anthropogenic emissions estimates to appropriate datasets. Stratospheric trends are evaluated using co-measured N2O as a dynamical proxy to provide a latitudinally discrete trend in the gaseous stratospheric OCS.

We also noted the strong inflection point toward negative trends seen globally after approximately 2016. Here we will show a revised analysis up through 2024 for tropospheric and stratospheric OCS to further evaluate these latest 8 years. These unique long-term measurements will continue to provide new and critical constraints on the global OCS budget.

Session F: Oases in the desert: Measurements that address the impending gaps in atmospheric data

Conveners: Gerald Nedoluha, Rennie Selkirk

K_F01: Ross J. Salawitch – Session F Keynote

The Need for Data from NDACC During the Upcoming Satellite-Based, Data Desert of Stratospheric Observations

Ross J. Salawitch

University of Maryland, College Park, USA

Data from the ACE-FTS on the Canadian Space Agency SCISAT-1 satellite and MLS instrument on the NASA Aura satellite have played an important role in advancing our understanding of stratospheric composition and the impact of human activity on Earth's protective ozone layer. Aura will be decommissioned no later than the middle of 2026, and SCISAT-1 is 18 years beyond its design lifetime. In this presentation, I will focus on the role that data from NDACC stations could play in addressing emergent, critical issues that affect the recovery of the ozone layer, such as possible changes in the strength of the Brewer Dobson Circulation, the role of very-short lived chlorine compounds not regulated by the Montreal Protocol, and perturbations caused by extreme events such as massive wildfires and major volcanic eruptions.

O_F01 Invited: Nathaniel J. Livesey

Two decades of observations and science from the Aura Microwave Limb Sounder (MLS) (invited)

Nathaniel J. Livesey (1), Michelle L. Santee (1), Lucien Froidevaux (1), Gloria L. Manney (2), Michael J. Schwartz (1), Luis F. Millán (1), Alyn Lambert (1), William G. Read (1), Frank Werner (1)

1: Jet Propulsion Laboratory, California Institute of Technology, California, USA

2: NorthWest Research Associates, California, USA

The Microwave Limb Sounder (MLS) instrument on NASA's Aura satellite, launched in 2004, makes daily, near-global, vertically resolved measurements of a range of trace gases from the upper troposphere to the mesosphere, along with observations of temperature, geopotential height, and cloud properties. MLS observations have been central to studies of processes affecting stratospheric ozone, humidity, and circulation. Most recently, MLS has provided a wealth of information on the significant perturbations to the stratosphere that resulted from the 2020 Australian New Year's fires and from the 2022 eruption of the Hunga undersea volcano. We review recent studies capitalizing on the long record of MLS observations to quantify trends and variability in stratospheric composition. In addition, we examine long-term variability in the statistical metrics of the MLS record, including variability and quantiles.

O_F02 Invited: Peter Bernath

Atmospheric Chemistry Experiment (ACE): Overview (invited)

Peter Bernath

Old Dominion University, Virginia, USA

The ACE satellite (http://www.ace.uwaterloo.ca/) [1] is measuring atmospheric composition by solar occultation from low Earth orbit. The primary ACE instrument is an infrared Fourier transform spectrometer (ACE-FTS). The current version of ACE-FTS processing (v5.3) measures 46 molecules including all major species associated with the Montreal Protocol on substances that deplete the ozone layer. With more than 20 years on orbit since launch in 2003, ACE measures trends in atmospheric composition. ACE-FTS also measures infrared spectra of aerosols and clouds by removing gas phase features to leave "residual" spectra. So far ACE-FTS has observed spectra of Polar Mesospheric Clouds (PMCs), Polar Stratospheric Clouds (PSCs), stratospheric smoke, sulfate aerosols, cirrus clouds and volcanic ash. We have discovered a new chemistry catalyzed by smoke particles injected into the stratosphere by extreme wildfires ("Wildfire fire smoke destroys stratospheric ozone" [2]). A mission overview will be presented.

[1] P. F. Bernath, The Atmospheric Chemistry Experiment (ACE), J. Quant. Spectrosc. Rad. Transfer 186, 3-16 (2017).
[2] P. Bernath, C. Boone and J. Crouse, Wildfire smoke destroys stratospheric ozone, Science 375, 1292-1295 (2022)."

O_F03 Invited: Martin Mlynczak

NASA SABER/TIMED measurements in the stratosphere (invited)

Martin Mlynczak (1), Jia Yue (2), Wandi Yu (3), Tom Marshall (4)

1: Space Environment Technologies, California, USA
2: Catholic University of America, Washington, DC, USA
3: Lawrence Livermore National Lab, California, USA
4: GATS Inc., Newport News, VA, USA

In this presentation, we will introduce the NASA Heliophysics Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) measurements. TIMED mission was launched in 2001 and SABER started continuous measurements in January 2002. Although TIMED mission focuses on the energetics and dynamics of the mesosphere and lower thermosphere region, among the four payloads, SABER is the only instrument that extends down to the stratosphere above ~20 km altitude. SABER has 10 infrared channels from 1.27 um to 17 um. Comparing to MLS and ACE-FTS, SABER is less known to the stratosphere science community. Among many measurements and data products, SABER water vapor, ozone and temperature are of most interest. We will compare those SABER measurements to other missions such as MLS, ACE-FTS, COSMIC, etc,, displaying its strengths and weaknesses. In particular, we will show studies of episodic events, such as the Tonga volcanic eruption. The TIMED satellite bus and SABER instrument are in healthy conditions and expect to continue for another decade or so. SABER could play a role in bridging the gap of global observations of stratospheric water vapor and temperature after MLS ends its mission.

O_F04 Invited: Natalya Kramarova / Nigel Richards

Filling the Gap: OMPS LP Ozone Profiles as a Successor to Aura MLS Observations (invited)

Natalya Kramarova (1), Zhong Chen (2), Stacey Frith (2), Glen Jaross (1), Jungbin Mok (2), ***Nigel Richards*** (3), Philippe Xu (4), Jerald Ziemke (5)

1: NASA GSFC, Maryland, USA
2: SSAI, Maryland, USA
3: UMBC, Maryland, USA
4: SAIC, Maryland, USA
5: Morgan State University, Maryland, USA

The Ozone Mapping and Profiler Suite (OMPS) represents the next generation of the U.S. ozone monitoring system and includes current missions (Suomi NPP, NOAA-20, NOAA-21) as well as upcoming ones (JPSS-3 and JPSS-4). The OMPS instrument suite comprises three ozone-measuring sensors—Nadir Mapper (NM), Nadir Profiler (NP), and Limb Profiler (LP)—to monitor the global ozone distribution in Earth's atmosphere. OMPS ozone measurements will serve as “an oasis in the desert” by filling observational gaps following the decommissioning of the Aura MLS and OMI instruments.

In this study, we provide an overview of stratospheric ozone profile measurements derived from two operational OMPS LPs. These profiles feature high vertical resolution (~1.9–2.5 km) and cover the vertical range between 12.5 km (or cloud tops) and 57.5 km. The OMPS LPs offer dense spatial sampling, with a ~110 km step along the orbit for Suomi NPP and ~50 km for NOAA-21. We discuss the quality of the LP ozone profile measurements and assess their suitability as an alternative for extending the Aura MLS ozone record for various applications. Additionally, we describe how ozone measurements from complementary OMPS nadir sensors can support the evaluation of OMPS LP retrievals. Finally, we examine the impact of increased stratospheric aerosol loading on OMPS LP ozone retrievals by analyzing observations following recent volcanic eruptions and wildfires that injected aerosols directly into the stratosphere.

O_F05 Invited: Katrin Müller (remote)

The Palau Atmospheric Observatory: A Decade of Monitoring in the Tropical Western Pacific (invited)

Katrin Müller (1), Tim Röpke (1), Xiaoyu Sun (2), Lisa Rüther (1), Adeline Schulte (1), Paola Serrano Aleman (1), Ingo Wohltmann (1), Markus Rex (1)

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2: University of Bremen, Germany

The Tropical Western Pacific (TWP) is a critical region for atmospheric chemistry and dynamics, yet continuous ground-based observations have been sparse. As a major entry point for air into the stratosphere during boreal winter, and a region of low tropospheric oxidizing capacity, the TWP plays a key role in determining the chemical composition of the stratosphere. In particular, the local cold-trap in the tropical tropopause layer (TTL) regulates global stratospheric water vapor levels.

The Palau Atmospheric Observatory (7°N, 134°E) has addressed this observational gap since 2016 (Müller et al. 2024a). It recently joined SHADOZ and is planned to become part of B2SAP and NDACC. The site's instrumentation includes an aerosol and cloud lidar (ComCAL), a Pandora-2S, an FTIR and a ground station for balloon soundings with radio- (RS41), ozone- (ECC-6A), water vapor- (CFH) and aerosol- (COBALD) sondes.

We present an overview of the existing time series, recent studies, and opportunities for future collaborations. Analyses by Müller et al. (2024b) and extended assessments reveal that while ENSO modulates humidity and ozone, the mid-tropospheric composition is mainly controlled by seasonal patterns: dry, ozone-rich air from tropical Asia between November and April, and a humid, ozone-poor background from July to October. Sun et al. (2025) link cirrus observed by ComCAL to TTL cold-trap processes.

With growing integration into global networks, the observatory is well-positioned to serve as a reference site for future satellite missions and contribute to long-term continuity in key stratospheric trace gas and water vapor measurements.

O_F06: Holger Vömel

20 years of tropical upper tropospheric and stratospheric water vapor monitoring at Costa Rica

Holger Vömel (1), Ryan Stauffer (2), Henry Selkirk (3), Julie Nicely (2), Jorge Andres Diaz (4), Ernesto Corrales (4), Alfredo Alan (4)

1: NCAR, Colorado, USA
2: NASA Goddard Space Flight Center, Maryland, USA
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Water vapor is one of the most important trace gases in the tropical upper troposphere and stratosphere. Satellite observations provide near global coverage but have low vertical resolution and rely on validation by in situ observations. Only a small number of stations routinely launch sondes that measure stratospheric water vapor for validation of satellite instruments. The cryogenic frostpoint hygrometer soundings by the Ticosonde project at the Universidad de Costa Rica are the only regular in situ measurements of stratospheric water vapor in the deep tropics. The Ticosonde record spans 20 years and is an important contribution to the validation of measurements by the Microwave Limb Sounder (MLS) on board the Aura satellite, and more recently measurements by the Stratospheric Aerosol and Gas Experiment on the International Space Station (SAGE III/ISS). These balloon-borne measurements will be an essential contribution to reduce the impact of the loss of water vapor monitoring by the Aura/MLS satellite in 2026.

The Ticosonde project at UCR detected the water vapor plume injected by the Hunga Tonga-Hunga Ha'apai volcanic eruption within one month after the eruption and the disruption of tropical lower stratospheric water vapor in 2022. Stratospheric water observed over the balloon altitude returned to normal levels within 18 months after the eruption.

As the balloons include ozone sondes, Ticosonde data are used to study the correlation between water vapor and ozone. The observations are also used to intercompare tropospheric water vapor measurements by radiosondes and enabled several other observational activities.

O_F07 Invited: Lyatt Jaeglé

The STRIVE Earth System Explorer Mission Concept (invited)

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We will present the Stratosphere Troposphere Response using Infrared Vertically-resolved light Explorer (STRIVE) mission concept, which was recently selected for a competitive Phase A Concept Study within NASA's 2023 Earth System Explorers Program. STRIVE fills a critical need for high vertical resolution profiles of temperature, ozone, trace gases, and aerosols in the upper troposphere and stratosphere with near-global horizontal sampling. The goal of STRIVE is to understand the processes controlling the composition and dynamics of the upper troposphere and stratosphere, thus constraining their critical influence on the predictability of weather, climate, the ozone layer, and air quality.

STRIVE will carry two synergistic instruments: a limb-scanning imaging Dyson spectrometer retrieving profiles of temperature, trace gas concentrations, aerosol extinction, and cloud properties during day and night; and a dual-spectral multi-directional limb profiling radiometer retrieving detailed aerosol properties during day. STRIVE will measure infrared radiation emitted and scattered from the atmospheric limb to provide profiles of temperature, O_3, H_2O, CH_4, N_2O, CFCs, CO, NO_2, HNO_3, $ClONO_2$, N_2O_5, HCN, cloud top height, polar stratospheric clouds, and aerosol properties with fine vertical resolution (1 km) and unparalleled horizontal sampling (>400,000 profiles each day). STRIVE has the novel ability to resolve small-scale vertical structures of atmospheric composition and temperature, enabling new insights into the processes of troposphere-stratosphere interactions. STRIVE will provide unique observations necessary to inform and evaluate next-generation global Earth system models in the upper troposphere and stratosphere.