NDACC 2025 Symposium Abstract Catalog – Poster Presentations

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

Conveners: Wolfgang Steinbrecht, Jim Hannigan

P_A01: Ankie Piters (remote)

Twenty-five years of Paramaribo upper air observations

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The tropical NDACC station Paramaribo in Suriname, South America, has performed upper-air measurements for more than twenty-five years. Weekly ozone sondes have been launched since 1999, with only few gaps. The dataset has been analyzed, using multiple linear regression (MLR), to determine height-resolved trends in temperature, water vapor, ozone and (zonal) wind. Special care is given to account for the effect of instrumental and operational changes.

First analyses show a significant tropospheric warming of 1° to 2°C (surface to upper troposphere) from 1999-2024. This is about twice as much as the average warming for the tropics (20°N-20°S) found in recent literature. Tropospheric relative humidity shows no significant change over 2006-2024, but total column water vapor values increase with 9% for the observed and 7% for the saturated water column, corresponding with a dew-point temperature increase of 1°C. Warm and dry vs. cooler and moist weather in Paramaribo normally coincide with El Nino vs. La Nina phases. Zonal wind shows a positive trend (more Westerlies) at and above the tropopause that might contribute to the occurrence of the Quasi-Biennial Oscillation disruptions reported in 2016 and 2020. We observe an increase in ozone partial pressure in the troposphere below 5km over the analysed 25-year period.

P_A02: Joshua Richards

Data Homogenization and Improvements to the Beltsville, MD, USA, 20-year Ozonesonde Record

Joshua Richards (1), Ryan Stauffer (2), Debra Kollonige (3), Anne Thompson (1,2), Belay Demoz (1), Ricardo Sakai (4), Adrian Flores (4)

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Understanding the vertical distribution of ozone concentration is important for diagnosing human, vegetation, and global radiation impacts. Balloon-borne ozonesondes (and attached radiosondes) represent the only instrument with the capability to measure the complete profiles of ozone, pressure, temperature, and relative humidity from the surface to 10hPa (~30 km) at ~100m resolution. Long-term ozonesonde data records are relied upon to validate model output and satellite retrievals of ozone as well as for calculating vertically-resolved trends. The Howard University Beltsville Campus (HUBC; NDACC water vapor sonde station) near Washington, DC, USA, has collected nearly 400 ozonesonde profiles since 2004. Following best practices outlined by global ozonesonde experts through the Assessment of Standard Operating Procedures for Ozonesondes 2.0 (ASOPOS 2.0), we summarize the ongoing "homogenization" effort for the HUBC ozonesonde dataset that accounts for variations in sonde preparation and procedures in the HUBC record and provide an overview of tropospheric ozone profiles in the Washington, DC, region. Comparisons with ancillary satellite datasets that verify the accuracy of the ozonesonde data will be shown. Our examination of this dataset also provides the first multidecadal analysis of near-surface and tropospheric ozone in the DC region which can be compared to the nearby Wallops Island, VA, USA, NDACC ozonesonde station that has operated for more than 50 years.

P_A03: Wolfgang Steinbrecht

Ozone profile time series from NDACC lidars, microwave radiometers, FTIRs, Umkehr, and sondes

Wolfgang Steinbrecht (1), Sophie Godin-Beekmann (2), Thierry Leblanc (3), Richard Querel (4), Eliane Maillard-Barras (5), Klemens Hocke (6), Gerald Nedoluha (7), Emmanuel Mahieu (8), Ralf Sussmann (9), Jim Hannigan (10), Dan Smale (4), Irina Petropavlovskikh (11)

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Ground-based NDACC instruments are providing some of the longest ozone profile records. The ozone lidar at Haute Provence, for example, provides routine ozone profile data starting in July 1985. Many NDACC ozone time series start in the 1990s, when stratospheric ozone depletion was near its maximum. FTIR ozone profile time-series typically start after 2000. Although not strictly NDACC, the Arosa Umkehr record starts in 1956. In this presentation we will present and compare time series from nearby instruments at Hohenpeissenberg, Bern, Zugspitze, Arosa; Haute Provence, Payerne, Jungfraujoch; Table-Mountain and Boulder; Mauna Loa; Lauder. Despite different vertical resolution, measurement ranges, and very different measurement principles, all these NDACC instruments show similar long-term evolution of the ozone profiles. In the annually recurring ozone section of BAMS State-of-the Climate, multi-instrument averages of the NDACC data are consistent also with satellite zonal means. For the NDACC Symposium, we want to have a closer and more critical look at the individual time series, show where they agree, and where they disagree.

P_A04: Eliane Maillard Barras

Processing of the Payerne ozonesonde timeseries with the time response correction (TRC) method: validation and post-2000 trend estimation

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Ozonesondes measure atmospheric in-situ ozone concentration from ground up to 30 km. ENSCI ECC sondes are launched three times a week from Payerne (46.82 °N - 6.92 °E), forming one of the very valuable datasets of NDACC. The timeseries has been processed according to the recommendations of ASOPOS2.0: the pump flow is measured as part of the calibration process and corrected for pump temperature and moistening effect, the ML climatology is used to determine the residual O3 column, and the background current is measured under zero ozone 20 minutes after the end of the 5uA ozone exposure.

We will first present the homogenization of the Payerne ECC timeseries performed at the auxiliary measurements level (background current and flow rate calibration) in order to compensate for technical changes issues.

We further present the reprocessing of the dataset according to the time response correction (TRC) method where the ozone partial pressure is obtained from the fast response current with subtraction of the background current before exposure to ozone (Smit, AMT, 2024). Application of this method results in a mean ozone increase compared to the profile calculated by the conventional method. The increase is pressure dependent and lies within +1-2% up to 20 hPa, and up to 6% above.

The validation of the timeseries with collocated MWR (Payerne), Dobson Umkehr (Arosa/Davos) and overpasses of MLS will be presented. The effects of the TRC processing on the post-2000 trends will be estimated by MLR based on traditional and dynamical explanatory variables.

P_A05: Sachiko Okamoto / Sophie Godin-Beekmann

Correction of the Observatoire Haute Provence electrochemical concentration cell (ECC) ozonesonde data record

Sachiko Okamoto, Gérard Ancellet, ***Sophie Godin-Beekmann***
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The Observatoire Haute Provence (OHP) station is one of the few long-term measuring stations for vertical ozone profiles in southern Europe. Since 1991, vertical ozone distribution has been monitored by the OHP weekly electrochemical concentration cell (ECC) ozone soundings. In this study, we present a correction made on the ECC datasets for the period from 2002 to 2007. Mean ozone concentration of ECC sondes for the period from 2002 to 2007 was lower 4.0 % and 6.4 % than that of stratospheric lidar and Microwave Limb Sounder (MLS), respectively. The internal pump temperature showed a sudden drop of 18K at 25 km for the period 2002–2007 compared to the period from 1991 to 2001. Taking into account the long term trends of the ECC current and stratospheric lidar ozone concentration at 25 km as well as the ECC pump speed trend, we show that the observed ECC temperature change between 2005 and 1995 is too low by at least -10 K at 25 km. The internal pump temperature for the period from 2002 to 2007 has been corrected accordingly by 0 K at 15 km and 10 K at 30 km and the bias at 25 km with the stratospheric lidar and MLS have been reduced to -1.1 % and -3.6 %, respectively for the 2002-2007 period. The impact of this correction on the comparisons at various altitudes with other measurements performed at OHP, and on ozonesonde long-term trends will be presented.

P_A06: Matt Tully (remote)

Comparison of Science Pump Corporation and EnSci Ozonesondes at Broadmeadows

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The Bureau of Meteorology operates three long-term ozonesonde stations in the southern hemisphere, Broadmeadows (37.69° S, 144.95° E), Macquarie Island (54.50° S, 158.95° E) and Davis (68.58° S, 77.97° E). The NDACC site Broadmeadows (a suburb of Melbourne) continues the program previously located at Aspendale (1965-1982) and Laverton (1983-1998).

Ozonesondes manufactured by Science Pump Corporation (SPC) were used exclusively at Broadmeadows until February 2024 when the supplier was changed to EnSci. A series of fifteen dual-ozonesonde flights were performed in April to August of 2024 to assess the agreement between the two types. The results from this campaign suggest a low bias of the EnSci ozonesondes against SPC at all altitudes ranging from 2-7%. The evident low bias is also seen in comparisons of total ozone with the co-located Dobson, and comparisons of stratospheric ozone profiles with Aura-MLS overpasses, in both cases outside the previous range of variability.

This result may have implications for the previously reported "Ozonesonde Dropoff" seen at many stations within the global network.

The twenty-year record of comparisons with Aura-MLS overpasses and Dobson total ozone also show broadly consistent periodic fluctuations in agreement, which in some cases can be linked to systematic changes in background current measured during preparation.

References:

Stauffer, R. M., Thompson, A. M., Kollonige, D. E., Witte, J. C., Tarasick, D. W., Davies, J., et al. (2020). A post-2013 dropoff in total ozone at a third of global ozonesonde stations: Electrochemical concentration cell instrument artifacts? Geophysical Research Letters, 47, e2019GL086791. https://doi.org/10.1029/2019GL086791"

P_A07: Voltaire A. Velazco

From Legacy to Future: Advancing Long-Term Total Ozone Column Observations at Hohenpeissenberg

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The Meteorological Observatory Hohenpeissenberg (MOHp) of the German Weather Service (DWD) maintains one of the longest continuous records of ground-based total ozone column (TOC) measurements, with Dobson and Brewer observations dating back to 1967 and 1984, respectively. This contribution presents recent efforts to improve the long-term consistency of the MOHp TOC dataset by applying the new standard procedure recommended by Voglmeier et al. (2024), which incorporates updated ozone absorption cross-sections from IUP-Bremen. Initial results underscore the importance of revised spectroscopy for robust trend assessments.

We also report on the integration of the BTS-Solar CCD spectroradiometer into the ozone monitoring program. In operation since 2019, this modern and automated instrument is being evaluated as a potential supplementary system to the Brewer. We present comparisons, operational experiences, and strategies for its possible inclusion in the NDACC framework.

Our work aims to ensure continuity and quality in ozone monitoring by combining rigorous reprocessing of legacy data with the adoption of innovative instrumentation aligned with NDACC goals.

P_A08: Coline Mahob / Christof Jansenn (remote)

Towards new laser-based UV absorption cross sections around 308 nm for traceable atmospheric remote sensing of ozone

Coline Mahob (1,2), ***Christof Jansenn*** *(2),* Gerard Ancellet (3), Ariane Bazureau (3), Marie-Renée DeBacker (4), Hadj Elandaloussi (2), Sophie Godin-Beekmann (3), Ruizhe Gu (5), Adèle Hilico (6), Pascal Jeseck (2), Patrick Marie-Jeanne (2), Sachiko Okamato (3), Andrea Pazmiño (3), Christian Rouille (2), Giorgio Santarelli (5), Thomas Zanon (2)

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Accurate ozone measurements in the atmosphere depend heavily on spectroscopic data, particularly in the UV range. Recently, the ozone absorption cross section at 253.65 nm—used in standard reference photometers (SRPs) for calibrating ambient ozone instruments—was re-evaluated, with a newly recommended value aligning with current UV-VIS absorption cross section standards for atmospheric remote sensing. However, high-precision laboratory measurements at 325 nm and at room temperature suggest that current recommendations may be biased by a few percent in the Huggins band region, which may explain discrepancies with respect to SAOZ and IASI observations in the VIS and IR.

Since Huggins band spectral region is critical for several ozone measurement platforms—including stratospheric LIDARs, Brewer and Dobson spectrophotometers operated within the NDACC, and satellite missions—we propose new, precise laser-based absorption cross section measurements in this range. The measurements will be traceable to the photometric reference at 253.65 nm, and fully traceable to SI standards with wavelength uncertainties under 10^{-4} nm.

Unlike earlier laser studies limited to a few UV wavelengths, our setup enables high-resolution data collection across the 308–320 nm range. We present preliminary results at 308 nm and detail the measurement setup, including two tunable laser systems: one narrowband for 307.8–308.2 nm, and one broadly tunable across the full 308–320 nm range. Our goal is to achieve absorption cross section uncertainties below 1% across a temperature range of –90°C to +30°C. The implications for stratospheric LIDAR measurements are also discussed.
This work is funded by the French ANR under grant number (ANR-22-CE01-0007).

P_A09: Yann Poltera (remote)

Observations of water vapor in the UT/LS of unprecedented accuracy with nonequilibrium corrected low-GWP frost point hygrometers

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Measurements of water vapor, ozone and aerosol are of pivotal importance for the study of dynamical, microphysical and chemical processes in the upper troposphere and lower stratosphere (UT/LS). In particular, measuring water vapor is most challenging in that region, requiring high SNR and high accuracy at low air density and at water vapor mixing ratios of only a few parts per million volume (ppmv). Balloon-borne frost point hygrometers (such as CFH or FPH) easily measure in the UT/LS, however they use R23, and with the phase down of HFCs, future-proof cooling methods are needed.

In this work, we present new developments of frost point hygrometers with low global warming potential (GWP) coolant, together with the “Golden Points” and nonequilibrium correction, a new retrieval protocol for chilled mirror hygrometer measurements under rapidly changing humidity conditions that enables balloon-borne water vapor mixing ratio measurements from the ground to the middle stratosphere with an unprecedented 4 % accuracy.

We showcase this new retrieval protocol on CFH-DIA (CFH with dry ice and alcohol) and PCFH (Peltier Cooled Frostpoint Hygrometer), which have been measuring post Hunga-Tonga stratospheric water vapor over central Europe since 2023 as part of the Swiss H2O Hub project. We find that, while CFH-DIA can be used as alternative reference for Swiss H2O Hub, the newly developed PCFH with a cascaded PID controller is an instrument of equal performance, but with a future-proof design, no cold liquids involved and significantly less preparation efforts.

P_A10: Simone Brunamonti (remote)

ALBATROSS – a laser spectrometer for balloon-borne measurements of UTLS water vapor

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Water vapor (H2O) in the upper troposphere-lower stratosphere (UTLS) is of great importance to the Earth's radiative balance, yet accurate measurements of H2O in this region (~8–25 km altitude) are still highly challenging. We developed ALBATROSS, a compact (< 3.5 kg) laser spectrometer for balloon-borne measurements of UTLS H2O. The instrument is based on a mid-IR quantum-cascade laser and a custom designed segmented-circular multipass cell with an optical path length of 6 m within a diameter of 10.8 cm. The performance of the spectrometer was assessed at UTLS-relevant conditions using SI-traceable reference gases generated by a dynamic-gravimetric permeation method. The results show that ALBATROSS achieves an accuracy better than ±1.5 % at all investigated pressures (30–250 hPa) and H2O mixing ratios (2.5–35 ppm), and a precision better than 0.3 % at 1 s resolution. The instrument was further validated under a wide range of environmental conditions at the AIDA climate chamber during the AquaVIT-4 intercomparison. Recently, ALBATROSS was deployed in a series of atmospheric test flights in tandem with a cryogenic frostpoint hygrometer (CFH). Good agreement within ±10 % was found between the two instruments up to 25 km altitude. The substantially faster response time of ALBATROSS with respect to CFH was also observed. Overall, our results demonstrate the outstanding capabilities of mid-IR laser spectroscopy for in-situ measurements of UTLS H2O. This is particularly relevant considering the ongoing reconception of the cooling method used by CFH, due to the phasing-out of the cooling agent (fluoroform) required by this technique.

P_A11: Pierre Fogal (remote)

PEARL: The Polar Environment Atmospheric Research Laboratory – A platform for ground-based measurements of the High Arctic Atmosphere and Environs

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The atmosphere above the polar regions continues to be largely under-sampled in comparison to that at mid-latitudes. The harsh local conditions, coupled with at best sparse populations, makes it difficult to support substantial measurement programs. In the Arctic, the most northerly available sites are found on islands surrounding the Arctic Ocean. An example is the Polar Environment Atmospheric Research Laboratory (PEARL), operated by the Canadian Network for Detection of Atmospheric Change (CANDAC) and located on Ellesmere Island near the Environment and Climate Change Canada Eureka Weather Station. PEARL and Eureka are located beyond commercial air service, accessible only by charter aircraft and a yearly sealift, resulting in a significant logistical challenge. PEARL is a geographically extended facility with three main facilities that make available a range of conditions, allowing for atmospheric sampling from 10m altitude to 620m, above and below the boundary layer, and the local temperature inversion. We will present a synopsis of the twenty-year span of PEARL activities, touching on the facilities and support of the array of instruments including infrared, ultraviolet-visible, and lidar-based atmospheric composition measurements as part of NDACC, as well as TCCON measurements, aerosol measurements with the AERONET network, micro-pulse lidar measurements with the Micro-Pulse Lidar Network, radar measurements, polar night optical measurements, and more.

P_A12: Tomoo Nagahama (remote)

Long-term variation in isoprene column amount retrieved from the NDACC high-resolution FTIR dataset measured in Rikubetsu, Japan

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Hydrocarbons in the atmosphere during the daytime produce tropospheric ozone, an air pollutant, through chemical reaction processes with nitrogen oxides. Most hydrocarbons are emitted as volatile organic compounds, and approximately one-third is isoprene. Therefore, it is essential to assess the distribution of isoprene in the atmosphere to understand air pollution and to monitor its long-term variation. In this study, the column amount of isoprene in the troposphere was analyzed from solar absorption spectra obtained by ground-based high-resolution FTIRs, which were conducted as NDACC monitoring observations. We used data in the 11 micron wavelength band of solar absorption spectra obtained from FTIRs operated in Rikubetsu, Japan, since 1995, together with the National Institute for Environmental Studies. Using the analysis software SFIT4 (version 1.0.14), the vertical distribution of isoprene was determined simultaneously with CO2, H2O, CFC-12, HCFC-142b, NH3, and HNO3 to obtain the column amount. The initial guesses of isoprene and other constituents were based on the mean altitude distribution over land of the WACCM simulations from 1980 to 2040. The spectroscopic parameters of isoprene were adopted from pseudo-spectroscopic parameters by the NASA/JPL group.

The result showed that the isoprene column amount was (2-8)×10^14 cm-2, and the value in winter was smaller than that in other seasons. The observed column amounts varied widely and showed no significant long-term trend. This presentation reports variations in the observed isoprene column amount over various time scales.

P_A13: Hideaki Nakajima

First retrieval of HFC-125 by ground-based FTIR in Tsukuba, Japan

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After the discovery of the Antarctic ozone hole in 1980s, artificial CFCs and HCFCs were banned by the Montreal protocol, and their replacement HFCs were started to use for refrigerants and forming agents. The major HFCs currently in use are: R-404A (HFC-143a (52%) + HFC-125 (44%) + HFC-134a (4%)), R-410A (HFC-32 (50%) + HFC-125 (50%), HFC-134a, and HFC-245fa. Within them, HFC-134a have already retrieved with ground-based FTIR spectra. Here, we introduce the first retrieval result of HFC-125 with ground-based FTIR spectra taken at Tsukuba, Japan. The HFC-125 has relatively strong absorption features around 1100-1250 cm-1 region. We used sfit4 spectrum fitting code to retrieve HFC-125 profiles. We developed a new pseudo-line-list for HFC-125, which comes from the results of Di Lonardo and Masciarelli (2000) and Harrison et al (2025). We used two micro-windows (MW#), i.e., MW#1 (1140-1147 cm-1) and MW#2 (1200-1210 cm-1) to retrieve HFC-125. O3, H2O, HDO, H218O, CH4, N2O, CFC-12, HCFC-22, HCFC-142b, HNO3, and SO2 are considered as interfering species. Time series of spectra between 2014 and 2024 were retrieved. As a result, increasing trend of HFC-125 was found. The comparison with ground-based sampling measurements will be discussed in the meeting.

P_A14: Hao Fu/ Christof Jansenn (remote)

A new NDACC-IRWG site at Paris: More than 10-year measurements of ethane and carbon monoxide over a European megacity

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The European megacity of Paris, home to 11 million residents, provides a unique platform for atmospheric and air quality research. Since 2011, our team has been operating a high-resolution Fourier-Transform infrared Spectrometer (FTS-Paris) to monitor the atmospheric composition over the city center of Paris, France. Measurement configurations alternate between near-infrared observations for the TCCON network, of which the Paris FTS has been an official member since 2014, and thermal infrared observations for the NDACC-IRWG network, of which the Paris site has been formally accepted as of July 2024. We present retrieval strategies for determining the abundances of NDACC-IRWG species using the SFIT4 radiative transfer code and report seasonal variations and long-term trends of the total atmospheric columns of CO, C_2H_6, HCl, N_2O, CH_4, HF, and HCN. In the analysis which we combine with air mass back-trajectories from the HYSPLIT model, we focus on ethane and carbon monoxide, and in particular on the ratio of the seasonal excess signals ΔCO and ΔC_2H_6. Their correlation coefficient is similar to other sites on the Northern Hemisphere, but shows interesting features. The highest excess values and large short term and intra-day variations correlate with stagnant meteorological conditions, indicating that emissions from nearby sources can accumulate significantly.

P_A15: Gennadi Milinevsky (remote)

The simultaneous atmospheric ozone and carbon monoxide measurements by microwave 110/115 GHz radiometer in Changchun, northeast China

Gennadi Milinevsky (1), Shi (2), Xiaopeng Sun (1), Oleksandr Pylypenko (3), Volodymyr Reshetnyk (4)

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The design and measurements of the ground-based microwave radiometer RSO3CO-120-1 developed for long-term monitoring of O_3/CO (110.8/115.3 GHz) in the upper stratosphere and mesosphere are presented. Installed in Changchun (43.85°N, 125.33°E), northeastern China, this instrument fills a critical gap in atmospheric research for the region. The radiometer's design prioritizes simultaneous O_3/CO profile retrieval with maximal altitude coverage. We developed the graphical user interface ARTSGUI for radiometer measurements processing to simplify the microwave radiometer data development. The daily and annual changes in the O3/CO molecular profiles were revealed over 2020–2024. Summer CO concentrations are exceptionally low in the region, falling below the radiometer's current detection threshold. The ozone spectral line undergoes significant daily and annual changes, with peak intensity in April and October. The results were checked for consistency with the Aura MLS measurements, showing that the difference between O3 and CO measurements made by the two instruments was about 15%. Two new microwave radiometers have been designed and assembled: one is MWR-120-PCFE with Peltier cooling front-end technology, and the second is a cryogenic radiometer, MWR-120-CryoCFE. Both instruments acquire the dual-channel design for the simultaneous measurement of microwave radiation at 110/115 GHz of O3 and CO molecules, as well as mesospheric wind.

P_A16: Chaonan Lv (remote)

2D MAX-DOAS Observation Network in China

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Our research team at the Anhui Institute of Optics and Fine Mechanics (AIOFM), Hefei Institutes of Physical Science, Chinese Academy of Sciences, has deployed a ground-based Stereoscopic monitoring network within China using independently developed 2D MAX-DOAS (Multi-Axis Differential Optical Absorption Spectroscopy) instruments. The network is routinely operated and maintained to ensure continuous and stable performance. To date, more than 20 observation sites have been deployed, with 12 currently in operation, covering key regions such as Beijing-Tianjin-Hebei (BTH), the Yangtze River Delta (YRD), and the Pearl River Delta (PRD). Several sites have been operating continuously for over five years.

Each MAX-DOAS instrument features the following technical specifications: a wavelength range of 290–450 nm, a spectral resolution of 0.4 nm, and observation capabilities including adjustable azimuthal scanning from 0° to 360° and elevation angle from 0° to 90°. All instruments undergo laboratory calibration using Hg lamps prior to deployment, and are regularly maintained during operation to ensure high data quality.

All devices are equipped with automated retrieval algorithms capable of processing observational data in real time. After undergoing rigorous quality control, the system reliably outputs vertical column densities and vertical profiles for eight atmospheric constituents: aerosol, O_3, NO_2, HCHO, SO_2, H_2O, CHOCHO, HONO, and BrO. These data are primarily used for studies on the formation mechanisms of secondary pollution, research on regional pollution transport, and validation of satellite data products.

P_A17: Weiwei Hu (remote)

Spatiotemporal distribution and formation mechanisms of HONO based on long-term observations from the MAX-DOAS network in China

Weiwei Hu

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Nitrous acid (HONO) plays a key role in the atmospheric oxidation process, which significantly affects air quality and climate change. In this study, we carried out long-term observations of the vertical distribution of HONO, NO_2 and aerosols in typical areas such as rural, urban, highland, plain and coastal areas, based on the Multi-Axis Differential Optical Absorption Spectrometer (MAX-DOAS) remote sensing observation network in China with a multi-point layout. The spatial and temporal distribution characteristics of HONO in different regions of China, as well as its potential sources and generation mechanisms, were systematically analyzed. The preliminary results show that the concentration of HONO is low in the plateau area, while it is significantly high in the plains and rural areas, and the overall trend is decreasing with increasing altitude, showing obvious near-surface enrichment characteristics. Its daily variation showed a double peak in the morning and evening, and the interannual variation showed a trend of high in winter and low in summer. Especially in the agricultural area, the concentrations of HONO, NO_2 and aerosol in the near-surface layer (0.05 km) increased significantly within 2 weeks before and after the application of fertilizer, with the maximum increases of up to 1500 %, 200 % and 700 %, respectively, and the trends of the three variations also showed a positive correlation, which indicated that there was a certain degree of correlation between HONO, NO_2 and aerosol. This study reveals HONO pollution's spatiotemporal characteristics and causes, supporting research on atmospheric oxidation capacity evolution.

P_A18: Alexis Merlaud (remote)

Towards centralized stratospheric BrO profile retrieval within the FRM4DOAS system

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Bromine monoxide (BrO) is one of the main drivers of stratospheric ozone depletion. BrO has been measured from the ground at several stations across the globe using its absorption in the UV spectral range. Zenith spectra taken at twilight are analyzed with the Differential Optical Absorption Spectroscopy (DOAS) technique to retrieve differential slant column densities (dSCDs), which are then used to retrieve stratospheric vertical column density profiles by inverse modeling, using a radiative transfer code and an Optimal Estimation method (OEM). Both steps require a priori knowledge of the atmosphere. One key aspect of the BrO retrieval is the need to consider photochemical variations, which create local two-dimensional concentration gradients at twilight.

BIRA-IASB has developed a well-demonstrated stratospheric BrO retrieval scheme that was applied to long-term measurements in Harestua (e.g. Hendrick et al., GRL, 2008). For these retrievals, a-priori atmospheric profiles are based on the SLIMCAT chemical-transport model, coupled to one-dimensional box-model (PSC-Box) simulations for the photochemical variations. Within the ESA FRM4DOAS project, we will update and operationalize the existing retrieval scheme to allow its application at the global scale. This development is primarily driven by the need to provide suitable reference data for the validation of the forthcoming Altius satellite instrument, planned for launch in 2027. We present the progress developing the new algorithm, including work undertaken to optimize the BrO dSCDs retrieval. First results applying the new retrieval scheme to data from the CINDI-3 campaign as well as a few selected FRM4DOAS stations are shown and discussed.

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

Conveners: Jean-Christopher Lambert, Elian Maillard Barras

P_B01: Tijl Verhoelst

NDACC ZSL-DOAS instruments: the backbone of satellite stratospheric NO_2 data record validation

Tijl Verhoelst (1), J. Granville (1), G.Pinardi (1), S. Compernolle (1), J.-C. Lambert (1), A. Pazmiño (2), A. Bazureau (2), F. Goutail (2), M. Nunes-Pinharanda (2), A.Richter (3), F.Wittrock(3), D. Smale (4), R. Querel (4), K. Strong (5), R. Alwarda (5), K. Joshy (5), A. M. Fjæraa (6), T. Svendby (6), M. Navarro Comas (7), M. Yela González (7), R. Kivi (8), U. Friess (9)

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2: LATMOS, UVSQ Université Paris-Saclay/Sorbonne Université/CNRS, France
3: Institute of Environmental Physics (IUP), University of Bremen, Germany
4: National Institute of Water and Atmospheric Research (NIWA), New-Zealand
5: University of Toronto, Canada
6: Norsk Institutt for Luftforskning (NILU), Norway
7: National Institute for Aerospace Technology (INTA), Spain
8: Finnish Meteorological Institute (FMI), Finland
9: University of Heidelberg, Germany

The NDACC network of zenith-scattered-light DOAS (ZSL-DOAS) instruments produces high-quality stratospheric NO_2 column data records since the 1980s. These multi-decadal datasets, supported by standardized protocols and harmonized retrievals, span diverse observational and geophysical conditions enabling robust trend analysis and comprehensive satellite validation. Several instruments, and in particular the SAOZ network, offer automated provision of near-real-time data facilitating operational satellite validation.

We present NDACC-based validation results for recent L2 and L3 satellite stratospheric NO_2 records developed/validated in the ESA CCI+ precursor project, in ESA's S5P MPC, and in the EUMETSAT AC-SAF, and built on data from GOME, SCIAMACHY, GOME-2, OMI, and TROPOMI. State-of-the-art co-location techniques using 3D observation operators and model-based photochemical corrections minimize mismatch errors in time and space.

Overall, differences between satellite and ZSL-DOAS observations are mostly within combined uncertainties. Satellite sounders typically show low biases of 0.1–0.2 Pmolec/cm² and a dispersion around 0.3–0.4 Pmolec/cm². Larger discrepancies arise under extreme conditions—high solar zenith angles or surface albedo—and vary between sounders and data versions. Co-located NDACC FTIR and PGN Pandora comparisons at clean sites confirm the ZSL-DOAS-based validation but also reveal a ~10% offset between IR and UV techniques, pointing to residual spectroscopic uncertainties and vertical-sensitivity differences.

Despite the demonstrated value of this reference network, its sustainability is at risk. Station closures and loss of technical expertise due to funding and staffing pressures threaten long-term continuity. Given the NDACC ZSL-DOAS network's unique strengths for global, long-term satellite validation, preserving its legacy and capacity is an urgent priority.

P_B02: Meike K. Rotermund (remote)

Validating MAX-DOAS Surface VMRs and Tropospheric Columns of NO2 and HCHO in Toronto, Canada

Meike K. Rotermund (1), Martina M. Friedrich (2), Michel Van Roozendael (2), Xiaoyi Zhao (3), Kimberly Strong (1), Victoria Flood (1)

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3: Air Quality Research Division, Environment and Climate Change Canada

We present surface volume mixing ratios (VMRs) and tropospheric vertical column densities (VCDs) of NO2 and HCHO from an EnviMes MAX-DOAS instrument located on a roof at the Environment and Climate Change Canada (ECCC) Downsview headquarters near the northern boundary of Toronto. This newly NDACC-affiliated dataset is centrally processed by the FRM4DOAS processor and includes measurements from November 2016 until the present. The NO2 surface VMRs are validated with the nearby National Air Pollution Surveillance Program (NAPS) in situ surface instrument while NO2 tropospheric VCDs are validated with the established Pandora direct-sun (DS) instrument co-located on the same roof at ECCC as the EnviMes instrument. The EnviMes MAX-DOAS NO2 surface VMRs (representing an average over the lowest 200m layer) behave similarly to NAPS in situ data however they have a consistent low bias. The EnviMes detected 14-26% larger NO2 tropospheric VCD yearly means than Pandora DS in earlier years (2017-2021) but has very close agreement (between 1-4%) in recent years (2022-2024). For HCHO, the EnviMes MAX-DOAS surface VMRs are validated with a Fourier transform infrared spectrometer located in downtown Toronto while the tropospheric VCDs are validated with the same Pandora DS instrument at ECCC. The EnviMes data are analyzed monthly to assess the seasonal trends, by SZA and hourly to determine daily trends, and lastly looking at yearly changes over the long-term. Once the EnviMes surface VMR and tropospheric VCD datasets are validated for both NO2 and HCHO, then distinct individual events such as wildfires can be investigated.

P_B03: Karin Kreher (remote)

CINDI-3 (3rd Cabauw Intercomparison of UV-Vis DOAS Instruments): Overview and Campaign Highlights

Karin Kreher (1), Arnoud Apituley (2), Martina M. Friedrich (3) Michel Van Roozendael (3) and the CINDI-3 team

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3: Royal Belgian Institute for Space Aeronomy, Brussels, Belgium

The third Cabauw Intercomparison of UV-Vis DOAS Instruments, CINDI-3, took place from 21 May to 24 June 2024 at the Cabauw Experimental Site for Atmospheric Research (CESAR), a semi-rural observation facility located between the cities of Rotterdam and Utrecht in the Netherlands.

One of its key objectives was to compare differential slant column densities (DSCDs) of different trace gases, obtained from measurements made using a range of UV-VIS (MAX-)DOAS instruments. The formal semi-blind intercomparison is based on measurements from 34 instruments taken during the 18-day period of 2-19 June 2025. The intercomparison focuses on the following 10 target products: NO2 (VIS, VIS-SMALL, UV), O3 (VIS, UV), O4 (VIS, UV), HONO, HCHO and HCHO-WIDE which are analysed using 3 different reference types (daily, fix and sequential). The outcome of the intercomparison is discussed with particular emphasis on the relevance for the NDACC UV-visible network.

We also discuss a range of additional activities, complementing the stationary remote sensing UV-vis observations, including measurements from ozone and aerosol lidars, NO2 and ozone sondes, long-path DOAS and in-situ instruments. Furthermore, we briefly present results from mobile measurements made around Cabauw, De Bilt and Rotterdam during selected days with favourable weather conditions using cars and bikes as well as a small research aircraft, to provide a more complete picture of the distribution of pollutants from the industrial and urbanised area around Rotterdam.

P_B04: Fernanda Cabello (remote)

Estimating the cloud thermodynamic phase over King George Island during austral summer with MicroPulseLidar measurements

Fernanda Cabello (1), Raúl R. Cordero (2), Edgardo Sepúlveda Araya (3), José Jorquera (4), Braulio Valdevenito (4)

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3: University of Arizona, USA
4: University of Chile, Chile

The estimation of the atmospheric energy budget in current modelling presents considerable uncertainty over the Southern Ocean and Antarctica. The lack of cloud phase measurements in this region is considered one of the causes of this bias.

In this research, we aim to estimate the predominant thermodynamic phase in the cloudiness of the northern region of the Antarctic Peninsula, specifically in Fildes Bay, King George Island (62.20°S, 58.97°W), using Lidar instrumentation (MicroPulseLidar or MPL). The analysis covers data collected during austral summers from late 2017 to early 2022, obtained during the Antarctic Scientific Expeditions carried out jointly by the Antarctic Research Group of the University of Santiago and the Chilean Antarctic Institute (INACH) at Escudero Base. Following previous studies, the depolarization ratio profile produced by the MPL was used to estimate the cloud phase distribution in three vertical layers of the Antarctic troposphere: a lower level (1-4km), an intermediate level (4-7km), and a high level (7-10km).

The results indicate a major predominance of the liquid phase in the lower level. Regarding the mixed phase, presented an increase from December to February, with a higher occurrence in January. And, a skewed distribution was observed for the ice phase, with mean values not exceeding 26%. In addition, we estimated the Supercooled Liquid Fraction (SLF) for five isotherms to evaluate the agreement between the ground-based measurements and the Vertical Feature Mask product by CALIOP satellite retrievals. On average, the SLF presents a decreasing trend as altitude increases, ranging from 54% to 25%.

P_B05: Corinne Vigouroux

Validation of all S5P ozone products (total columns, profiles, and tropospheric columns) using the FTIR NDACC network

Corinne Vigouroux, Bavo Langerock, Martine De Mazière, and the FTIR observation team
Royal Belgian Institute for Space Aeronomy, Belgium

Ground-based Fourier Transform Infrared (FTIR) instruments from NDACC provide long-term measurements of many trace gases at over 20 stations. This network is already used in S5P validation of CO, CH4 (Sha et al., 2021), HCHO (Vigouroux et al., 2020), and NO2 (https://mpc-vdaf.tropomi.eu/).

Ozone is a key FTIR species, with a harmonized retrieval strategy within the network recently updated (Bjorklünd et al., 2024). Although these data are used in many trend studies, they have seen limited application in satellite validation, due to historical preference for Brewer/Dobson instruments and the higher vertical resolution of sondes and lidars, better for Limb satellites.

However, FTIR ozone products are well suited for validating Nadir sounders like S5P. FTIR retrievals provide precise total columns (<2% uncertainty) and profiles with ~4 degrees of freedom for signal (DOFS), comparable to S5P's (~5 DOFS). The FTIR sensitivity extends up to ~45 km, exceeding the 30 km limit of the sondes, and it captures well the troposphere (1 DOFS) allowing S5P tropospheric column validation, although few FTIR stations are located within 20°S – 20°N, where this S5P product is provided.

We present validation results for the three S5P products: total columns, profiles, and tropospheric columns. Profile comparisons are made in four vertical layers following FTIR DOFS. Our results (accuracy and precision of S5P) will be put in perspective with earlier S5P validation studies (Garane et al., 2019; Hubert et al., 2021, Keppens et al., 2024).

This work supports future FTIR use in validating geostationary missions like S4/S5 or TEMPO.

P_B06: Gaia Pinardi (remote)

Intercomparison of MAX-DOAS, FTIR and direct sun DOAS HCHO retrievals in Xianghe (China)

Gaia Pinardi (1), Martina M. Friedrich (1), Michel Van Roozendael (1), Bavo Langerock (1), Corinne Vigouroux (1), Isabelle De Smedt (1), Martine De Mazière (1), Ting Wang (2), Pucai Wang (2), Minqiang Zhou (2), Thomas Wagner (3), Steffen Beirle (3)

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2: Institute of Atmospheric Physics, Chinese Academy of Sciences (IAP-CAS)

3: Max-Planck-Institut für Chemie (MPIC)

MAX-DOAS, direct sun DOAS and FTIR measurements are increasingly used as fiducial reference measurements (FRM) for validating HCHO satellite observations. Understanding their strengths and limitations, and assessing their consistency is crucial for robust and consolidated validation results.

In this study, we take benefit of the co-location of MAX-DOAS and FTIR instruments at the Xianghe station (39.75° N, 116.96° E), which is influenced by strong biogenic and anthropogenic VOC emissions, to compare HCHO vertical columns (VCDs) retrieved over one year. In addition to its standard MAX-DOAS geometry, the IAP/BIRA instrument also provides regular direct sun measurements. The UV and IR direct sun measurements show an excellent agreement and serve as a reliable HCHO VCD reference.

We assess MAX-DOAS HCHO VCDs retrieved using the MMF and MAPA algorithms as currently implemented within the FRM4DOAS processing system, comparing them against the direct sun reference. Both MAX-DOAS datasets show a strong correlation (~0.96) but a systematic underestimation of about 20%. This bias is partly attributed to MAX-DOAS's reduced sensitivity above 4 km. Replacing MMF's a priori profiles with monthly averaged CAMS or TM5 profiles reduces the bias by 10–15%. Further accounting for the vertical sensitivity differences between FTIR and MAX-DOAS measurements lowers the residual bias to about –2%.

P_B07: Mary Cate McKee

SAGE III/ISS Validation methods

Mary Cate McKee (1,2), Kevin Leavor (1,2), David Flittner (2)

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2: NASA LaRC, Virginia, USA

Spatiotemporal collocation of measurements between instruments is an essential yet challenging component of the data validation process. Traditional methods of collocation may simply consider length of time and physical distance between measurements. However, the distribution of atmospheric constituents may change rapidly over time and space, so care must be taken to ensure that matched measurements represent the same geophysical environment and do not introduce unnecessary bias. More advanced collocation methods may consider additional physical parameters to minimize inappropriate matches caused by the non-uniform distribution of the stratosphere. One such parameter is equivalent latitude, a Lagrangian coordinate based on potential vorticity contours that define isentropic surfaces along which stratospheric transport occurs, especially near the polar vortex. Because mixing across these contours is limited, assessing matches by difference in equivalent latitude provides a more relevant framework to ensure that matched air masses share similar properties. Additionally, backward trajectory modeling can be used to confirm the origin of each air mass, further constraining matches by eliminating profiles from air masses with different source regions. Advanced collocation methods are applied to validation exercises comparing data from the Stratospheric Aerosol and Gas Experiment onboard the International Space Station (SAGE III/ISS) with observations from NDACC's extensive network of ground stations, and results are assessed against traditional collocation methods.

P_B08: Kaley A. Walker (remote)

More than Two Decades of the Canadian Arctic ACE/OSIRIS Validation Project at PEARL

Kaley A. Walker (1), Kimberly Strong (1), Pierre Fogal (1), James R. Drummond (2), on behalf of the Canadian Arctic ACE/OSIRIS Validation Campaign Team

1: University of Toronto, Canada

2: Dalhousie University, Canada

Ground-based measurements provide critical data to validate satellite retrievals of atmospheric trace gases and to assess the long-term stability of these measurements. As of February 2025, the Canadian-led Atmospheric Chemistry Experiment (ACE) satellite mission has been making measurements of the Earth's atmosphere for 21 years and Canada's Optical Spectrograph and InfraRed Imager System (OSIRIS) instrument on the Odin satellite has been operating for over 24 years. As ACE and OSIRIS continue to operate far beyond their planned two-year missions, there is an ongoing need to validate the trace gas profiles from the ACE-Fourier Transform Spectrometer (ACE-FTS), the Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation (ACE-MAESTRO) and OSIRIS.

To date, twenty-one Canadian Arctic ACE/OSIRIS Validation Campaigns have been conducted during the spring period (February - April from 2004 to 2025) at the Polar Environment Atmospheric Research Laboratory (PEARL) in Eureka, Nunavut (80N, 86W) in collaboration with the Canadian Network for the Detection of Atmospheric Change. The spring period coincides with the most chemically active time of year in the Arctic, as well as a significant number of satellite overpasses. A suite of as many as 13 ground-based instruments, as well as frequent balloon-borne ozonesonde and radiosonde launches, have been used in each campaign. This presentation will focus on an overview of the measurements made by the ground-based, balloon-borne and satellite-borne instruments during the ACE/OSIRIS Arctic Validation campaigns (both in-person and remote) and highlight how these campaign measurements have been used for satellite validation.

P_B09: David E. Flittner / Mary Cate McKee

The "Comparisons" tab: a public avenue to view SAGE III/ISS data against NDACC observations

David E. Flittner (1), Kevin Leavor (1,2), ***Mary Cate McKee*** (1,2), Richard Farmer (1,2), Marilee Roell (1)

1: NASA Langley Research Center, Virginia, USA

2: Analytical Mechanics Associates, Virginia, USA

The Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE III/ISS) has been observing Earth's stratosphere and upper troposphere since June 2017 with the solar/lunar occultation technique, to enhance our understanding of ozone layer recovery and other processes impacting chemistry and climate. This stable method does not need an external calibration, but independent data product evaluation is essential to provide consumers with confidence in using the dataset. The mid-inclined ISS orbit allows near global coverage within a month, but with an evolving slight change in observation time/place. Since commencing on-orbit operations, the SAGE III/ISS mission has collaborated with NDACC stations to maximize the coincidence of the two measurement sets by sharing predicted dates/times of future SAGE events in a station's vicinity. This can also be done by anyone using the Predicts tool.

The SAGE III/ISS Validation team recently deployed a portal displaying comparisons of mission data products against available data from the NDACC repository. Focusing first on trace gas profiles, the team created summary plots for ozone and water vapor from sonde measurements, and earlier this year expanded to lidar profiles. These can be seen by navigating to the Quicklook page at SAGE III/ISS Level 2 QuickLook Browse Images and then selecting the Comparisons tab.

This presentation reviews this resource for the upper atmospheric community and current conclusions using the information available at the "Comparisons" tab. In a qualitative sense both measurement systems compare well with each other. Quantitative results will be discussed in the presentation.

P_B10: Daan Hubert

Ground-based observations: a treasure trove to assess stratospheric ozone observations by nadir and limb-viewing sensors

Daan Hubert, Arno Keppens, José Granville, Jean-Christopher Lambert, CCI/C3S satellite data providers and ground-based station PIs and staff (NDACC, SHADOZ, WMO/GAW)
BIRA-IASB, Belgium

The Ozone Essential Climate Variable has been integral to ESA's Climate Change Initiative (CCI) and the EU's Copernicus Climate Change Service (C3S, https://climate.copernicus.eu) since their inception. These programmes collaborate to develop, mature, generate and sustain harmonised, consistent and validated multi-decadal satellite ozone time series tailored for climate modelling, climate research and climate monitoring applications. The stratospheric ozone profile portfolio under CCI and C3S relies on observations from over 20 nadir, limb and occultation sensors launched since the early 1980s.

To evaluate the quality of these satellite-derived ozone profiles—ranging from single-sensor Level-2 retrievals to multi-sensor Level-3 merged data—we employ fiducial reference measurements from ozonesondes, stratospheric lidars, and ozone microwave radiometers operated by NDACC, WMO GAW, and SHADOZ. We will present selected results from our assessment of the bias, dispersion, and temporal stability of the latest nadir- and limb-based stratospheric ozone data by CCI/C3S, following traceable and standardized validation practices. Furthermore, our extensive experience in validating multiple complementary satellite datasets provides insights into the capabilities and limitations of ground-based observations as reference data. We discuss the necessity as well as key challenges in using ground-based data for e.g. satellite validation and long-term trend analyses.

We acknowledge the PIs and staff at the ground-based stations as well as the satellite EO community for their sustained effort on maintaining high-quality measurements and for valuable scientific discussions.

P_B11: Gordon J. Labow

Pandora Total Column Ozone Measurements Compared to Measurements from a Brewer Spectrophotometer

Gordon J. Labow (1,2), Thomas Hanisco (2), Apoorva Pandey (3), Bryan Place (4)

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3: UMBC, Maryland, USA
4: SciGlob Instruments, Maryland, USA

Pandora instruments have been taking total column ozone measurements at NASA's Goddard Space Flight Center since 2018. These data have been compared to a reference Brewer Double Spectrophotometer located nearby (within 200 meters). Performance of the Pandora instruments will be evaluated. Comparisons were made as a function of time, total column ozone amount, solar zenith angle and aerosol amount (column aerosol optical depth). Preliminary comparisons show that the agreement is within 1% over the overlapping time period.

Both ground-based ozone data sets will also be compared to the OMPS Nadir Mapper overpass data.

P_B12: Jonguk Park

Variabilities of NO2 and HCHO from Pandora observations and the assessment of their surface concentrations using ground-based in-situ observations

Jonguk Park (1), Thomas F. Hanisco (1), Sang-Woo Kim (2)

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2: Seoul National University, South Koria

Nitrogen dioxide (NO2) and formaldehyde (HCHO) are the two key elements constituting the ozone (O3) pollution, as they can effectively represent NOx and volatile organic compound reactivity in the atmosphere. The ground-based ultraviolet–visible Pandora spectrometer measures vertical column densities (VCDs) of these species through direct-sun observations, while vertical profiles and surface concentrations can also be estimated from multi-axis diffuse-sky measurements. This study investigates the spatial and temporal variability of NO2 and HCHO using Pandora observations across diverse environments (e.g., urban, rural), and evaluates surface concentrations retrieved from Pandora against ground-based in-situ measurements. The temporal variability of NO2 VCDs is generally greater than that of HCHO, with a notable increase in urban atmospheres (e.g., Seoul), presumably due to the spatial inhomogeneity of NOx emissions and near-surface advection. This is further illustrated by comparisons among multiple Pandora observations within a megacity, where significant differences in measured NO2 VCDs are observed even between nearby stations and are predominantly influenced by the near surface wind field. The dependency of observed VCDs to Pandora viewing geometry (i.e., viewing azimuth direction) is found significant, especially for NO2 in urban areas. Therefore, variations in direct-sun viewing geometry, as well as the viewing azimuth angle of diffuse-sky measurements, can serve not only as a significant source of uncertainty in satellite validation but also influence the spatial representativeness of surface concentrations retrieved from Pandora. In line with this consideration, the accuracy of Pandora surface concentration retrievals is evaluated using an intensive ground-based in-situ observation network in South Korea.

P_B13: Jean-Christopher Lambert

A Decade of NDACC Support to the Sentinel-5P TROPOMI Operational Validation Facility

Jean-Christopher Lambert (1), Steven Compernolle (1), Bavo Langerock (1), Ann Mari Fjæraa (2), José Granville (1), Sander Niemeijer (3), Daan Hubert (1), Arno Keppens (1), Gaia Pinardi (1), Mahesh K. Sha (1), Tijl Verhoelst (1), Corinne Vigouroux (1), Kai-Uwe Eichmann (4), Katerina Garane (5), Deborah Stein Zweers (6), Thomas Wagner (7), Angelika Dehn (8)

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2: Norwegian Institute for Air Research (NILU), Norway
3: Science [&] Technology Corporation, The Netherlands
4: IUP, University of Bremen, Germany
5: Aristotle University of Thessaloniki (AUTH), Greece
6: Royal Netherlands Meteorological Institute (KNMI), The Netherlands
7: Max Planck Institute for Chemistry (MPI-C), Germany
8: European Space Agency (ESA), Italy

Launched in October 2017 on an early afternoon polar orbit, Sentinel-5 Precursor (S5P) is the first atmospheric composition mission of the Copernicus Earth Observation programme. Its payload TROPOspheric Monitoring Instrument (TROPOMI) measures on a daily basis and at unprecedented horizontal resolution the global distribution of atmospheric species related to air quality, climate, natural hazards, stratospheric ozone, and UV radiation. S5P contributes observational data to a range of applications including environmental assessments and operational information facilities like the Copernicus Atmosphere Monitoring Service (CAMS).

Quality and fitness-for-purpose of the S5P operational data products are scrutinized methodically by the ESA/Copernicus Atmospheric Mission Performance Cluster (ATM-MPC). The ATM-MPC Routine Operations Validation Service integrates complementary validation approaches, including comparisons of S5P data to NDACC data serving as fiducial reference measurements. Comparisons to Brewer, DOAS, Dobson, FTIR, lidar, microwave and ozonesonde data from NDACC and cooperating networks produce a list of S5P data quality indicators maintained publicly on the TROPOMI validation facility (http://mpc-vdaf.tropomi.eu). In recent years a growing number of instruments and stations have upscaled their data processing and QA/QC to operational capacity, facilitating the automated production and reporting of S5P quality information and earlier detection of quality changes.

After a brief introduction to the ESA/Copernicus ATM-MPC validation service and its Automated Validation Server, this contribution reviews latest validation results of the S5P TROPOMI data products, with emphasis on the essential contribution of NDACC data, expertise and network evolution to the operational validation capacity for the atmospheric Copernicus Sentinels.

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

Conveners: Thierry Leblanc, Lizzy Asher

P_C01: Nis Jepsen (remote)

Autonomous Retrieval of Atmospheric Sounding Systems Using the Meteoglider Platform

Nis Jepsen, Guisella Gacitúa

Danish Meteorological Institute, Denmark

We present a novel approach to atmospheric sounding that enables the autonomous retrieval of radiosondes using a lightweight, AI-assisted glider platform—referred to as the meteoglider system. In this system, the sounding equipment is lifted by a weather balloon. Upon balloon burst at high altitude, the meteoglider navigates back to its launch site, carrying the instrument payload for potential reuse. Prior to launch, the onboard AI system incorporates wind forecasts from the GFS model to assess the feasibility of a successful return trajectory. An upcoming field campaign in August 2025 will test radiosonde deployment with the meteoglider in Copenhagen, Denmark, with future plans to extend testing to ozonesondes and aiming for future implementation in Greenland, where DMI conducts operational launches. This innovative system facilitates the recovery and reuse of sounding instruments and represents a significant step toward reducing environmental impact and material waste in atmospheric research.

P_C02: Kimberly Strong (remote)

Synergistic Network Measurements of the Arctic Atmosphere at the Polar Environment Atmospheric Research Laboratory

Kimberly Strong (1), Kaley A. Walker (1), James R. Drummond (2), Pierre Fogal (1), Robert J. Sica (3), Norm O'Neill (4), Ramina Alwarda (1), Darby Bates (1), Petra Duff (1), Kevin Joshy (1), Erin McGee (1)

1: University of Toronto, Canada
2: Dalhousie University, Canada
3: Western University, Canada
4: Université de Sherbrooke, Canada

The Polar Environment Atmospheric Research Laboratory (PEARL) at Eureka, Nunavut is located at 80N, 1100 km from the North Pole. Eureka has been home to an Environment and Climate Change Canada Weather Station since 1947, and the Arctic Stratospheric Ozone Observatory (AStrO), built in 1992, was a component of the original Primary Arctic Station of the Network for the Detection of Stratospheric Change. In 2005, a group of university and government researchers operating as the Canadian Network for the Detection of Atmospheric Change (CANDAC) substantially expanded the research infrastructure and scientific scope of AStrO to establish PEARL, which operates as an all-year atmospheric observatory. More than 20 instruments are currently installed at PEARL, spread across three facilities. These include FTIR and UV-Visible Spectrometers and a Stratospheric Ozone Lidar that are affiliated with NDACC. The facility also hosts instruments associated with four other global networks: two AERONET/AEROCAN Cimel Sun Photometer/Sky Radiometers, a TCCON FTIR, an MPLNET/ MPLCAN mini-MicroPulse Lidar, and two Pandora Spectrometers in the Pandonia Global Network. Additional instruments are brought to PEARL on a campaign basis, particularly during the springtime Canadian Arctic ACE/OSIRIS Validation Campaigns that began in 2004. The large number of complementary measurements at PEARL offers opportunities for synergistic studies of a variety of atmospheric phenomena related to climate, pollutant transport, and ozone, providing a unique window on the High Arctic atmosphere. This presentation will provide an overview and some highlights of atmospheric composition measurements made at PEARL, both within NDACC and in collaboration with other networks.

P_C03: Joseph Hung (remote)

Filling the polar night gap in High Arctic FTIR trace gas measurements

Joseph Hung (1), Lei Liu (2), Mathias Palm (3), Zen Mariani (2), Gloria L. Manney (4), Luis. F. Millan (5), Kimberly Strong (1)

1: University of Toronto, Canada
2: Environment and Climate Change, Canada
3: Institute of Environmental Physics, University of Bremen, Germany
4: Northwest Research Associates; New Mexico Institute of Mining and Technology, New Mexico, USA
5: Jet Propulsion Laboratory, California Institute of Technology, California, USA

Trace gases in the High Arctic play an important role in the energy balance of the region, particularly in relation to the prolonged periods of darkness and daylight. This interaction is especially important in the far- and mid-infrared spectrum, where the terrestrial emission is significant. At the Polar Environment Atmospheric Research Laboratory (PEARL) in Eureka, Canada (80°N, 86°W), solar measurements, including those affiliated with NDACC (a Bruker 125HR FTIR and two UV-VIS Triax-180 spectrometers), are paused during the four months of polar night. To help fill this annual data gap, we evaluate spectra recorded by an Extended-range Atmospheric Emitted Radiance Interferometer (E-AERI), which has been in operation since October 2008, and provides year-round measurements of the downwelling infrared spectral radiance from the atmosphere between 400 and 3000 cm−1.

We will present retrievals of O3, CO, CH4, and N2O from E-AERI spectra from 2008 to 2022. These are analyzed using the optimal-estimation-based SFIT4 retrieval algorithm, modified to allow for analysis of emission spectra, including an addition to account for the emission contribution from the water vapour continuum in the far and mid-infrared. Validation is presented against several co-located observations at PEARL including the NDACC FTIR and UV-VIS records during sunlit periods and weekly ozonesondes. Intra-annual variability and decadal trends of the four retrieved gases are also quantified. Particular attention is given to the sensitivity of the E-AERI to Arctic springtime stratospheric ozone depletion events (as in 2011 and 2020), and to CO as a tracer for wildfire plumes (as in 2017).

P_C04: Bärbel Vogel

Does the Asian summer monsoon play a role in the stratospheric aerosol budget of the Arctic?

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The Asian summer monsoon has a strong convectional component with which aerosols are able to be lifted up into the lower stratosphere. Due to usually long lifetimes and long-range transport aerosols remain there much longer than in the troposphere and are also able to be advected around the globe. Our aim of this study is a synergy between simulations by Chemical Lagrangian Model of the Stratosphere (CLaMS) and KARL (Koldewey Aerosol Raman Lidar) at AWIPEV, Ny-Ålesund in the Arctic, by comparing CLaMS results with exemplary days of lidar measurements as well as analyzing the stratospheric aerosol background. We use global three-dimensional Lagrangian transport simulations including surface origin tracers as well as back trajectories to identify source regions of the aerosol particles measured over Ny-Ålesund. We analyzed lidar data for the year 2021 and found the stratosphere generally clear, without obvious aerosol layers from volcanic eruptions or biomass burnings. Still an obvious annual cycle of the backscatter coefficient with higher values in late summer to autumn and lower values in late winter has been found. Results from CLaMS model simulations indicate that from late summer to early autumn filaments with high fractions of air which originate in South Asia – one of the most polluted regions in the world – reach the Arctic at altitudes between 360 and 380 K potential temperature. Hence we demonstrate that the Asian summer monsoon is a weak but measurable source for Arctic stratospheric aerosol in late summer to early autumn.
https://doi.org/10.5194/acp-24-7535-2024

P_C05: Martine De Mazière

NDACC showcases global interoperability for trace gas and aerosol remote sensing in the CARGO-ACT project

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The overarching goal of the Horizon Europe project 'Cooperation and Agreements enhancing Global inter-Operability for Aerosol, Cloud and Trace gas research infrastructures' (CARGO-ACT) project is to deliver a clear roadmap for sustainable global cooperation between key organizations around the globe to provide all users, in the scientific community and beyond, with the best possible services for accessing and using information from monitoring climate- and air quality-relevant properties of aerosol, cloud and trace gases in the atmosphere.

As a first step towards a global Research Infrastructure, CARGO-ACT involves the European Research Infrastructure on short-lived Aerosol, Cloud and Trace Gases (ACTRIS) and the US agencies representing the networks ARM (Atmospheric Radiation Measurements), MPLNET (Micro-Pulse Lidar network) and NFAN (NOAA Federated Aerosol Network). The Memorandum of Understanding (MoU) between ACTRIS and the global Network for the Detection of Atmospheric Composition Change (NDACC) outlines how protocols and procedures for ensuring acquisition, processing, management and dissemination of high-quality data for target species that are common to both are shared with mutual acknowledgement.

This presentation will highlight the exchanges of expertise, protocols and data between NDACC and ACTRIS and the efforts to be undertaken to ensure global interoperability and FAIR (Findable, Accessible, Interoperable and Reusable) data sharing, and achieving common scientific objectives.

P_C06: Tuukka Petäjä

ACTRIS – High Quality Atmospheric data to All Users

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ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure) is a European environmental research infrastructure that provides high-quality data, services, and access to facilities for studying short-lived atmospheric constituents—mainly aerosols, clouds, and trace gases—and their role in climate and air quality.

ACTRIS is composed of National Facilities (NFs), which are ground-based observational stations and exploratory platforms in various European countries. They perform in-situ and remote-sensing measurements of atmospheric components. The observation parameters include aerosol properties (optical, microphysical, and chemical), cloud characteristics (height, structure, droplet size) and trace gases (NOx, VOCs). The role of Central Facilities (CFs) is to provide standard operating procedures, data analysis support and quality assurance, instrument calibration and technological and scientific developments. The CFs include six Topical Centres (TCs) for specific expertise areas (in-situ & remote sensing for aerosol, cloud, and trace gases), a Data Centre (DC) for the management and distribution of validated data and metadata and a Head Office (HO) for coordinating governance, integration, centralised access to facilities, and communication activities.

The presentation will introduce the ACTRIS concept and underline ACTRIS' key contributions to the scientific insights in air quality and climate applications in recent years. We will also provide future aspirations regarding harmonized long-term atmospheric observations with ground-based in-situ and remote sensing technologies, including e.g., ACTRIS contributions to air quality policy in Europe, climate change research globally and satellite calibrations and validations.

P_C07: Thierry Leblanc

Centralized Data Processing as an added value to multi-network data integration: From standardized uncertainty budget to traceability and consistency, lessons learned from the development of the Global Lidar data Analysis Software Suite (GLASS)

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For decades, NDACC and other groundbased networks have struggled to provide consistent, standardized products, easy to access, understand and use, tailored to all users, eventually enabling unambiguous scientific interpretation. The path to the ideal network data product is challenging: data providers must adapt to changing instrument performance over time, to new formats, new standards, and to a wide range of algorithms, units and definitions. As a result of this apparent chaos, it is sometimes difficult to interpret differences between two datasets: are the differences due to instrumental bias, data processing algorithms or actual geophysical processes? Centralized data processing allows us to unambiguously remove the data processing algorithm component from this equation. It also allows us to identify potential biases of a given instrument with respect to the others, and it eventually provides a comprehensive standardized framework in which all results can be accessed, used, and interpreted consistently.

As part of a long-term commitment to provide highest quality products, NDACC, GRUAN, and TOLNet have combined efforts to develop a centrally-processed version of the lidar measurements obtained within these networks, namely the Global Lidar data Analysis Software Suite, or GLASS. This presentation will review the development of the GLASS software, with example ozone, temperature, water vapor and aerosol profiles obtained from NDACC, GRUAN, and TOLNet lidar instruments. It will highlight and discuss the strengths and weaknesses of such centralized processing, and will provide insights towards the next generation of networked instruments and data processors.

P_C08: Debra E. Kollonige

Southern Hemisphere Additional Ozonesondes (SHADOZ) Network Updates: 2025 Activities and Ozone Trends Analysis

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The Southern Hemisphere Additional Ozonesondes (SHADOZ) network, jointly operated by NASA-Goddard Space Flight Center (GSFC), NOAA's Global Monitoring Lab (GML) and international partners, collects and archives ozonesonde-radiosonde data records for 16 operating stations in the tropics and subtropics. There are now over 10,000 ozone and pressure-temperature-humidity (P-T-U) profiles with 100m vertical resolution at the SHADOZ archive (https://tropo.gsfc.nasa.gov/shadoz/Archive.html) with data from 1998-2025. The focus of this presentation is a 2025 update on the SHADOZ Project and Data Archive activities including: (1) the addition of 2 new stations, Palau and Quito (Ecuador), with over 5 years of ozonesonde launches on the archive, (2) the success of hosting virtual regional SHADOZ station meet-ups in 2025, organized by the NASA-GSFC team, to foster improved communication with station Principal Investigators and staff, and (3) present 25 years of tropospheric ozone trends from the SHADOZ network (Thompson et al., 2025; Van Malderen et al., 2025), used for evaluation of model and satellite products as a part of the Tropospheric Ozone Assessment Report (TOAR-II) Activity. This presentation summarizes our overarching goal of maintaining the continuity of long-term global ozonesonde records in the tropics and subtropics and ensuring that the best quality ozone data reach end users.

Thompson, A. M., Stauffer, R. M., Kollonige, D. E., et al.: Tropical Ozone Trends (1998 to 2023): A Synthesis from SHADOZ, IAGOS and OMI/MLS Observations, EGUsphere, https://doi.org/10.5194/egusphere-2024-3761, 2025.

Van Malderen, R., et: Global Ground-based Tropospheric Ozone Measurements: Reference Data and Individual Site Trends (2000–2022) from the TOAR-II/HEGIFTOM Project, EGUsphere, https://doi.org/10.5194/egusphere-2024-3736, 2025.

P_C09: Herman G.J. Smit (remote)

Quality Assurance of the Global Ozonesonde Network: A Continuous Process of Reporting and Assessing the Sondes Measurement Quality on their Consistency and Uncertainties

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Ozonesondes are balloone borne small electrochemical sensors which are widely used by 60 stations in the global observation networks of GAW and NDACC, having made accurate measurements of ozone from the ground to 35 km for more than 50 years. The high resolution data are used extensively for trend analyses and for evaluation of satellite and model products; they also provide climatologies that are used as a priori data for satellite retrievals. They are essential as a transfer standard when merging shorter satellite-derived time series, and are the most important source of trend-quality long-term records below about 18 km.

We report on a conceptual QA framework of ozonesondes as developed in the Assessment of Standard Operating Procedures for Ozone Sondes (ASOPOS 2.0; WMO/GAW Report #268) which is based on reporting and assessing the measurement quality of long term global ozonesonde records in terms of consistency (internal and external), data quality indicators, uncertainty budget and data archiving, including the meta data necessary to re-process the long term records. New in-sights on the performance of the ECC ozone sensor have led to the development of new data processing procedures, including updated calibration functions, that allow ozonesonde data to be traceable to one common reference standard and resulting in uncertainties better than 5%. An outlook with outstanding issues will be given, emphasizing also the limitations we face when bringing metrological principles such as instrumental and in-situ uncertainties, and traceability to a primary standard into practice of the long term global ozonesonde network.

P_C10: Katherine R. Wolff

High Quality Ozonesonde Datasets for Ozone Trends Studies: Using NASA Wallops Flight Facility and SHADOZ Dual Soundings and Long-term Records for Demonstration

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The NASA Wallops Flight Facility (WFF; Wallops Island, VA., USA; 37.9N, 75.5W) is the longest continuously operating ozonesonde station in the continental United States (since 1970) and the SHADOZ Natal station (Natal, Brazil; 5.4S, 35.4W) is the longest running ozonesonde measurement station in the tropics (since 1978). Both stations are a part of NDACC and use similar instrumentation for their soundings including the Science Pump Corporation (SPC) electrochemical concentration cell (ECC) ozone sensors. WFF and Natal ozone teams have participated in the WMO-sponsored Juelich Ozonesonde Intercomparison Experiments (JOSIE) since their initiation in 1996. Dating back to the digital measurement era (since 1995 for WFF), the WFF and Natal ozone profiles are reprocessed and homogenized based on WMO GAW guidelines to remove known biases, improve overall accuracy of the dataset, and provide uncertainties for each profile (Witte et al., 2018; Witte et al., 2019; available in SHADOZ V06 format: https://tropo.gsfc.nasa.gov/shadoz/). WFF has a legacy of evaluating ozonesonde performance with dual-sonde launches that have tested Standard Operating Procedures (SOPs), radiosonde/ozonesonde systems and various combinations of ECC sensors and sensing solution type (SST) formulae. We present comparisons from multiple dual-sonde launches in 2021-2024 at WFF and Natal during their transition from Lockheed Martin Sippican (LMS) to Vaisala radiosonde system (RS41) paired with SPC ozonesondes, ensuring a smooth transition in operations. With over 20 years of ozonesonde data from both stations, we also show tropospheric column ozone trends (Van Malderen et al., 2025) that serve as a reference for model and satellite datasets.

P_C11: Ryan Stauffer

Satellite, Ship, and Aircraft-based Views of US Gulf Coast Air Quality: The June and October 2024 SCOAPE-II Project

Ryan Stauffer (1), Anne Thompson (2,1), Niko Fedkin (3,1), ***Debra Kollonige (4,1),*** Joshua Richards (2), Nikolay Balashov (5,1), Martin Cadirola (6), Holli Wecht (7), Andrew Thorpe (8), Michael Eastwood (8), Adam Chlus (8), Robert Green (8), Jonathan Gallegos (9), Tom Hanisco (1), Bryan Place (9), Laura Judd (10), Scott Janz (1)

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Seven years ago, the Department of Interior's BOEM (Bureau of Ocean Energy Management), the Agency with Air Quality (AQ) jurisdiction over the offshore waters off the Louisiana (US) Gulf coast, asked NASA to determine the feasibility of using satellite data to measure offshore emissions in a region of concentrated oil and natural gas (ONG) operations. To study this issue NASA and BOEM conducted the May 2019 Satellite Coastal and Oceanic Atmospheric Pollution Experiment (SCOAPE) cruise in the Gulf. SCOAPE addressed both technological and scientific issues related to measuring nitrogen dioxide (NO2, a common air pollutant) over the Gulf, including contrasting near-shore and deepwater regimes (Thompson et al., 2023; https://doi.org/10.1029/2022EA002473). The SCOAPE strategy included collecting unique ground-based and shipboard measurements from three Pandora instruments (part of Pandonia, one of NDACC's Cooperating Networks) and ozone profiles from ozonesondes (as per the ASOPOS protocol, developed with one of NDACC's Instrument Working Groups) for satellite validation. Given the April 2023 launch of the geostationary TEMPO (Tropospheric Emissions: Monitoring of Pollution) AQ satellite, a June and October 2024 SCOAPE-II was conducted in the Gulf with ship (June) and aircraft methane (AVIRIS-3; June) and aircraft NO2 (GCAS; October) measurements. We discuss results from SCOAPE-II where the near-shore NO2 pollution was generally higher than over deepwater (similar to 2019) and highlight the dozens of emissions plumes measured near numerous shallow and deepwater platforms.

P_C12: Christian Rolf

Investigation of water vapour transport processes in the extratropical lowest stratosphere with the JUelich Modular Balloon Observatory (JUMBO)

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Variations in the chemical composition of the UTLS region crucially impact on the Earth's radiation budget, atmospheric circulation and surface climate. In particular, increases in stratospheric water vapor cause strong radiative effects and a positive climate feedback. The most critical region for these radiative effects is the extratropical lowermost stratosphere, and water vapor variations in this region were projected to account for about 75% of the positive stratospheric water vapor climate feedback. It is therefore essential to understand the contributions of various transport processes such as convection and the outflow from the Asian monsoon that influence the water vapor budget in the lowermost stratosphere.

Here, first results of the JUMBO balloon campaign will be presented. The campaign focuses mainly on analyzing the changes of the water vapor budget in the lower stratosphere from end of May to beginning of October. During the weekly balloon launches, in-situ measurements of water vapor are taken with the CFH instrument, ozone with an ECC probe, and one to two AirCore systems from Jülich (western Germany). The AirCore air samples are analyzed for various trace gases such as methane, carbon dioxide, carbon monoxide, SF6, and some CFCs. These additional trace gases can be used to analyze the origin of the air masses and the mean age of the air to better constrain the water vapor transport pathway.

P_C13: Maurice Roots

Synergistic Tropospheric Ozone Observations from Ground-Based, Airborne, and Balloon Platforms during the 2023 AGES+ Campaign

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As part of the 2023 AGES+ field initiative, a collaborative effort involving AEROME, STAQS, CUPiDS, and other partner campaigns, this study highlights the combined deployments and coordination of TOLNet tropospheric ozone profiles observations over the New York City Metropolitan region. Leveraging ground-based lidars, aircraft in-situ sensors, and ozone-sondes, we assess ozone formation and transport in a complex coastal urban environment. The work exemplifies the synergistic use of multi-instrument observations to understand tropospheric composition and pollution dynamics. Following intercomparison and bias characterization, we use the integrated datasets to analyze ozone distributions over the region, interpreting observed patterns in relation to meteorological drivers, plume transport, and emissions variability. This study provides insight into the best practices for network and campaign-based deployments contributing to more harmonized and effective observational strategies. This work also highlights the importance of deployment strategies incorporating disparate observations to form a more complete understanding of vertical and horizontal spatio-temporal variability especially in regions with complex terrain like coastal boundaries.

P_C14: Jason St. Clair

A new US network for ground-based remote sensing of carbon dioxide, methane, and CO

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The utility of ground-based remote sensing of CO2 and CH4 has been well established by the Total Column Carbon Observing Network (TCCON), with its data used for satellite validation, inverse model ground-truthing, and carbon cycle scientific studies. Because TCCON sites are expensive and physically large, their number (~28) is limited. The introduction of the compact EM27/SUN by Bruker and Karlsruhe Institute of Technology led to the Collaborative Carbon Column Observing Network (COCCON), with the potential for a much higher number of deployed network sites, which will benefit the satellite validation, inverse modeling, and carbon cycle communities. We present plans for a major contribution to ground-based greenhouse gas remote sensing in the United States with 14 EM27/SUNs deployed by NASA and other agency partners (NOAA, NIST, EPA), anchored by a new TCCON site at NASA Goddard Space Flight Center.

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

P_D01: Hyungyu Kang

Comparison of Daily Ozonesonde Measurements and Chemical Reanalyses over South Korea Based on 2021 Pre-ACCLIP Data: An Ozone Intrusion Case

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This study investigates an ozone intrusion event observed during Pre-Asian Summer Monsoon Chemical & Climate Impact Project (Pre-ACCLIP) in 2021 using consecutive daily ozonesonde measurements. A pronounced enhancement in total column ozone was observed between August 17 and 19, and ozonesonde data revealed that approximately 60% of the increase is explained by the ozone intrusion event in the upper troposphere–lower stratosphere (UTLS). The upper tropospheric circulation pattern demonstrates a clear signature of anticyclonic Rossby wave breaking (AWB) on the northeastern edge of the Asian summer monsoon anticyclone, where the summertime jet stream is located. Downward transport of stratospheric ozone into the upper troposphere is facilitated by a cut-off low and tropopause folding accompanied by the AWB. In addition, the ozone variability is investigated in two chemical reanalysis datasets: Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) and ECMWF Atmospheric Composition Reanalysis 4 (EAC4). MERRA-2 and EAC4 capture the ozone intrusion event with relevant synoptic-scale circulation patterns and ozone variability. However, ozone data in the chemical reanalyses present notable differences in the vertical structure during the intrusion event and persistence biases in the troposphere. MERRA-2 better represented the secondary ozone peak in the UTLS but underestimated lower-tropospheric ozone. In contrast, EAC4 exhibited a systematic positive bias especially in the stratosphere and near the surface. Continued integration of temporally high-resolution ozone measurements is beneficial for understanding synoptic-scale ozone variability and evaluating emerging chemical reanalyses.

P_D02: Teaghan Knox

Tropopause Trends Over Boulder, Colorado and the Potential Impact on Upper Tropospheric/Lower Stratospheric Ozone Trends

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The tropopause is the dynamic boundary between the troposphere and stratosphere. It has a wide range of quantitative definitions based on inflection points in temperature and chemical composition. Ozone is abundant in the stratosphere, where it provides important UV shielding, as compared to the troposphere where it is a trace pollutant. Since the 1987 Montreal Protocol banning ozone depleting chemicals went into effect, levels of ozone in the upper stratosphere have been increasing as expected. However, trends in the lower stratosphere near the tropopause have been less clear, and in some cases show continued decline in ozone concentrations.

In this analysis, seasonal trends in tropopause height from 1980-2020 in the Denver/Boulder area were examined using both the World Meteorological Organization (WMO) recommended lapse rate definition and the cold point definition of the tropopause. Analyses were performed using model data from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) reanalysis product along with local, in situ radiosonde (IGRA-2) and ozonesonde measurements. Preliminary results show that despite seasonal differences, the tropopause height is consistently rising in the region, and the cold point tropopause is rising faster than the WMO tropopause. The observed trend in increasing tropopause height potentially offers a dynamically-based explanation for why lower stratosphere ozone has not increased as predicted. If tropospheric air masses with lower ozone concentrations are increasingly found at higher altitudes formerly dominated by ozone-rich stratospheric air masses, long-term ozone trends near the tropopause may be distorted, for reasons unrelated to ozone-depleting chemicals.

P_D03: Erin McGee (remote)

Using NDACC and TCCON to evaluate short-lived climate forcers in the Arctic

Erin McGee (1), Victoria Flood (1), Kimberly Strong (1), Cynthia Whaley (2), Kaley A. Walker (1), Thomas Blumenstock (3), James W. Hannigan (4), Rigel Kivi (5), Johan Mellqvist (6), Justus Notholt (7), Mathias Palm (7), Amelie N. Röhling (3), the AMAP SLCF Modelling Team

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Short-lived climate forcers, atmospheric species with climate impacts and lifetimes shorter than that of CO2, were a main topic of interest of the 2021 Assessment Report on Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality, and Human Health by the Arctic Monitoring and Assessment Programme (AMAP). While observational data in the Arctic remain sparse, they are essential for evaluating and improving model performance. This study adds value by incorporating an additional Arctic dataset to strengthen model validation in a region where measurements are limited. The outputs of a suite of models provided by the AMAP Modelling team were compared to NDACC and TCCON FTIR data for carbon monoxide and methane, and to NDACC FTIR data for ozone. Measurements from five NDACC stations (Eureka, Thule, Ny Ålesund, Kiruna, and Harestua) and three TCCON stations (Eureka, Ny-Ålesund, Sodankyla), all located in the Arctic, were used. NDACC data products used are the 0-7 km partial columns, and TCCON data products are column-averaged dry air mole fractions, also known as Xgas. We find that many models underestimate carbon monoxide in the Arctic, and that this underestimation is particularly strong in the troposphere. Model simulations of methane are in better agreement with the measurements, although still biased low on average, and tropospheric ozone is also underestimated by the models. This presentation will provide an overview of these two recent model evaluation studies of short-lived climate forcers in the Arctic.

P_D04: Sieglinde Callewaert (remote)

WRF-GHG Simulations of methane (CH_4): comparing column-averaged and profile observations over East Asia

Sieglinde Callewaert (1), Minqiang Zhou (2), Isamu Morino (3), Isao Murata (4), Kei Shiomi (5), Martine De Mazière (1)

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High-quality reference observations from networks such as NDACC and TCCON are essential for interpreting atmospheric variability and evaluating the performance of atmospheric models. In this presentation, we highlight recent and ongoing work using WRF-GHG model simulations to investigate methane (CH_4) variability over East Asia, with a particular focus on the Xianghe site in North China (39.75° N, 116.96° E). This site, which has been affiliated with TCCON (Zhou et al., 2022), hosts a Bruker 125HR spectrometer that provides solar absorption spectra in the infrared. In addition to TCCON products, NDACC–IRWG-type retrievals are also performed at Xianghe (Ji et al., 2020), offering complementary vertical sensitivity.

Building on previously published model simulations (Callewaert et al., 2024), we explore how regional atmospheric transport modelling can provide added value in interpreting both column-averaged mole fractions (XCH_4) and CH_4 vertical profile data. We focus on the capacity of WRF-GHG to reproduce observed temporal variability and vertical structures, and examine the consistency between model output and reference observations across networks. To broaden the context, we extend our comparison to other sites within the model domain, such as Tsukuba (36.05° N, 140.12° E), a station affiliated with both TCCON and NDACC-IRWG, and Saga (33.24° N, 130.29° E, affiliated with TCCON). By synthesizing data from both observing networks and model simulations, we aim to demonstrate the utility of such integrated approaches for source attribution, model evaluation, and network intercomparisons.

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

Conveners: Roland Van Malderen, Bärbel Vogel

P_E01: Irina Petropavlovskikh

Tropospheric ozone trends at Boulder (2000-2022): Insights from multiple NDACC instruments

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The TOAR-II Harmonization and Evaluation of Ground-based Instruments for Free-Tropospheric Ozone Measurements (HEGIFTOM) project evaluated changes in partial tropospheric ozone columns (<300 hPa) using 2000-2022 globally distributed ozone records using Quantile Regression (QR) and Multiple Linear Regression (MLR) methods (Van Malderen et al, 2025). The trends over Boulder were derived from ozonesondes, Fourier-Transform Infrared spectrometer (FTIR), and Dobson Umkehr records that are of high quality and maintained according to the Network for Detection of Atmospheric Composition Change protocols (www.ndacc.org). Still, the intermittent biases and gaps were found in instrumental records that likely lead to the differences in the derived trends.

In this paper we investigate mean ozone biases related to the instrument-related temporal sampling and to the vertical sensitivity of retrieved ozone by FTIR and Umkehr methods as determined by their respective Averaging Kernels. The difference in long-term trends will be assessed with focus on seasonal patterns, gaps/shifts and record's start/end dates. Statistical model (LOTUS) will be used for interpretation of inter-annual variability in co-located ozone records to assess impacts of the long-range transport and emission changes on the tropospheric ozone abundances over Boulder. The strategy for future intercomparisons between surface-based instruments measuring ozone will be also discussed.

P_E02: Sachiko Okamoto (remote)

Ozone trends from ground -based measurements and merged satellite datasets at Observatoire Haute Provence (OHP)

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Since the mid-1980s, stratospheric ozone has been monitored at Observatoire de Haute-Provence (OHP) by a variety of instruments: ozone total column measurements are provided by Dobson and SAOZ spectrometers and ozone vertical distributions are provided by lidar, ozonesonde, and Umkehr measurements. This study provides an updated evaluation of stratospheric ozone trends at OHP by using ground-based ozone records and merged satellite measurements obtained in the vicinity of the station, with a focus on the ozone recovery period post-2000. The long-term trends of ozone vertical distribution as well as total columns is performed by the Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) regression model, using different predictors for the evaluation of short-term variability of ozone. Total column ozone records show negative trends (approximately -0.5 % per decade) except for SAOZ dataset. Additional predictors (tropopause pressure and accumulated Arctic Oscillation Index) improve the model fit and reduce trend uncertainties of total column ozone. In the upper stratosphere, equivalent latitude improves the model fit, and the increase of ozone is confirmed by multiple ground-based and merged satellite datasets. In the lower stratosphere, tropopause pressure and accumulated Arctic Oscillation Index improve the model fit. However, the trend uncertainties are still quite large. The contributions of predictors to the observed trends in total and vertical distribution of will be presented.

P_E03: Caroline Jonas (remote)

Looking for ozone recovery in the Arctic

Caroline Jonas (1), Robin Björklund (1), Corinne Vigouroux (1), Bavo Langerock (1), Martine De Mazière (1), Anne Boynard (2), James Hannigan(3), Nis Jepsen (4), Rigel Kivi (5), Norrie Lyall (6), Johan Mellqvist (7), Mathias Palm (8), Viktoria Sofieva (9), Kimberly Strong (10), David Tarasick (11), Yana Virolainen (12), Irina Petropavlovskikh (13,14), Peter Effertz (13,14), Glen McConville (13,14)

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Polar regions are strategic in the study of stratospheric long-term ozone trends as they are highly impacted by the effective-chlorine levels. The ozone recovery expected from the reduced emissions of ozone depleting substances (Montreal Protocol) should thus be observed most easily there. However, contrary to the Antarctic, positive ozone trends have not yet been observed in the Arctic (WMO 2022) due to the higher natural variability of ozone in that region. Moreover, we consider tropospheric ozone trends in the Arctic, because beyond the intrinsic interest in ground-level ozone as one of the main greenhouse gases, those can help in reconciling total and stratospheric ozone trends.

Using long-term ozone data from Fourier Transform Infrared (FTIR) spectrometers, ozone sonde instruments and Umkehr observations from Dobson/Brewer spectrophotometers provided by the NDACC, we present long-term trends (2000-2023) for total, stratospheric and tropospheric ozone from seven FTIR ground-based stations, seven ozone sonde stations and two Dobson/Brewer stations in the Arctic. Based on a representativeness study, we obtain regional trends with reduced uncertainties by combining different instruments and stations. Annual and seasonal trends are calculated using a multiple linear regression technique involving a set of proxies that represent physical processes influencing the natural ozone variability. Using those ground-based measurements, we further validate tropospheric and stratospheric ozone trends in the Arctic as derived from satellite observations (MEGRIDOP, IASI).

P_E04: Abby Scharf

Six decades of ozonesonde measurements over Antarctica

Abby Scharf, Susan Solomon, Kane Adam Stone, Peidong Wang
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Ozonesonde observations from the Syowa and the South Pole stations over more than 60 years are described and intercompared. Observations from the two sites reveal remarkable agreement, supporting and extending the understanding gained from either individually. Both sites exhibit extensive Antarctic ozone losses in a relatively narrow altitude range from about 12 to 24 km in October beginning in the late 1970s through the late 1990s. Both sites also show greater ozone losses in the lowermost stratosphere after the volcanic eruption of Mt. Pinatubo, supporting the view that surface chemistry can be enhanced by volcanic perturbations and that the very deep ozone holes observed in the early 1990s reflected such enhancements. The influence of the later volcanic eruption of Calbuco in 2015 can also be discerned, as can the effects of the 2020 Australian wildfire smoke and the 2022 Hunga Tonga eruption, each with effects occurring for multiple years. These data also show that recent changes in ozone indicate ozone recovery likely linked to changing chlorine abundances. The influences of the shifting position of the polar vortex will also be briefly discussed, both for ozone profiles and total column observations from Syowa, South Pole, Halley, and Faraday/Vernadsky.

P_E05: Jian Guan

Human Influence on the Ozone Layer Detectable by the 1960s

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The Antarctic ozone hole was first reported in 1985, and small ozone losses at the global scale were also observed in the late 1980s. The combination of field and laboratory measurements, together with modelling, quickly established anthropogenic chlorofluorocarbons (CFCs) as the cause of both the Antarctic and global ozone depletion. However, when, why and where the earliest ozone depletion could have been detected has not been determined. Here, we conduct a thought experiment to investigate when human-induced ozone depletion could have first been detectable, assuming the availability of accurate stratospheric ozone observations from 1950 onward. We find that human-caused ozone depletion was likely identifiable as early as 1957 in the tropical upper stratosphere. This region's low internal variability enables the earliest detection of the anthropogenic signal, even though tropical ozone losses in the upper stratosphere were smaller than those in higher-latitude regions. Our results highlight the key role of considering both internal variability ("noise") and the forced response ("signal") in detection studies. Further, while CFCs are widely recognized as the primary drivers of current ozone depletion, we find that early ozone loss was primarily caused by human-made carbon tetrachloride (CCl_4), used mainly as a solvent. These findings suggest that a clear human influence on the stratospheric ozone layer began nearly 70 years ago, even before substantial emissions of CFCs from spray cans or air conditioning.

P_E06: Ja-Ho Koo (remote)

Wintertime ozone vertical profile patterns in South Korea from multiple data obtained in the ASIA-AQ campaign

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In this study, we compared ozone vertical profile measured by multiple platforms in the ASIA-AQ campaign: ozonesonde and aircraft (DC-8) in-situ and lidar measurements. In addition, ozone profiles from the satellite dataset (GEMS), chemical transport model (GEOS-Chem), and reanalysis dataset (MERRA-2) were also compared. The research period and regions (ASIA-AQ campaign) are February and March in the west coast of Korean peninsula, meaning that our study shows the vertical profile of wintertime ozone in the downwind area. Since ozone is usually produced through the photochemistry, this kind of comparison of wintertime ozone profile were not conducted. This first evaluation of wintertime ozone profile in South Korea, however, can show the background pattern of ozone, which is significantly considered recently in terms of high level and increasing trend of ozone in East Asia. We considered the ozone vertical profile from the ozonesonde as a standard. In this angle, ozone profiles from the HSRL measurements (onboard G-III aircraft) are close to those from ozonesonde measurements. One interesting feature is that their agreement is much better with consideration of the 'mean pattern' of whole aircraft measurement at the day of ozonesonde launching, but rather different with comparing the 'snapshot' ozone profile measured in the closest time to the ozonesonde launching. Ozone profiles from the modeling and satellite can follow the basic shape of ozonesonde measurement, but not catch sudden variations in a local scale.

P_E08: Kevin Joshy (remote)

25+ Years of NDACC UV-Visible Measurements at 80°N

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Since 1999, UV-visible spectroscopic measurements have been made at Eureka, Nunavut, Canada (80.05°N, 86.42°W), initially at Environment and Climate Change Canada's Arctic Stratospheric Ozone Observatory, and since 2005 at the Polar Environment Atmospheric Research Laboratory (PEARL) Ridge Lab. Two UV-visible grating spectrometers currently deployed at the PEARL Ridge Lab are: (1) the University of Toronto Ground-Based Spectrometer (UT-GBS), installed in 1999 for springtime measurements and year-round since 2010, and (2) the PEARL-GBS, installed in 2006 on a permanent basis. The GBS instruments are affiliated with the Canadian Network for the Detection of Atmospheric Change (CANDAC) and with NDACC. Over the years, both GBS instruments have performed combinations of Zenith-Scattered-Light (ZSL) and Multi-AXis Differential Optical Absorption Spectroscopy (MAX-DOAS) measurements, with the target species being NO2, O3, O4, OClO, and BrO. The long-term GBS dataset, and consistent data quality established through yearly calibrations, has enabled a variety of studies focusing on stratospheric O3, tropospheric BrO, and satellite validation. Events of interest include enhanced BrO concentrations during springtime bromine explosion events observed over several years at Eureka, as well as significant stratospheric ozone depletion in 2011 and 2020. This talk will provide an overview of the 25+ years of GBS measurements and how they have been used to characterize the atmospheric state over Eureka.

P_E09: Petra Duff (remote)

NDACC FTIR Measurements of Tropospheric Composition in the Canadian High Arctic

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The Polar Environment Atmospheric Research Laboratory (PEARL) at Eureka, Nunavut (80N, 86W) is an NDACC site that has housed a Bruker 125HR Fourier transform infrared (FTIR) spectrometer since 2006. Vertical profiles and columns for twenty trace gases are retrieved using the SFIT4 algorithm. This presentation will provide an overview of the measurements made by this FTIR, highlighting several recent and current studies. These include an investigation of the inter- and intra-annual variabilities of carbon monoxide, acetylene, ethane, methanol, formaldehyde, formic acid, and peroxyacetyl nitrate (PAN) in the high Arctic region as indicators of wildfire pollution transport. The study shows negative trends for CO, C2H2, CH3OH, and HCOOH, and positive trends for C2H6, H2CO, and PAN. A 19-year simulation with the GEOS-Chem High Performance model v14.1.1 for the period 2003-2021 was evaluated using the FTIR total columns, resulting in general agreement in seasonality but negative biases relative to the measurements. Another study that will be highlighted is the development of a new water vapor data product using the PEARL FTIR spectra.

P_E11: Akriti Masoom

The climatological variation of NO2, its underlying cause and effect on aerosol properties measurements

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NO_2 exhibits high spatiotemporal variations having shorter lifetime, with regional confinement near its source. We analyzed the climatological variation of NO_2 tropospheric and stratospheric vertical column density (TVCD and SVCD, respectively) using Ozone Monitoring Instrument (OMI) from 2004-2023 and Global Ozone Monitoring Experiment from 1996-2003 satellite observations. We observed substantial negative trends in the NO_2 TVCD over United states, Europe, and east Aisa, and an increasing trend in NO_2 TVCDs over southeast Asia and the Middle east. There is also observed variation in the trends on a monthly scale indicating changes in seasonality in the NO_2 TVCDs with implications on aerosol retrievals.

The NO_2 variation has impact on aerosol optical depth (AOD) measurements from Aerosol Robotic Network (AERONET) at NO_2 absorption affected bands with the highest impact on 380 nm (Drosoglou et al., 2023; Masoom et al., 2024). AOD is systematically overestimated if NO_2 absorption is not considered. We used decadal AERONET AOD measurements from Level 2.0 algorithm. In comparison to the existing and a decade old satellite based NO_2 database currently used in AERONET operation, the climatological monthly mean NO_2 values were considered in this analysis. The differences between these NO_2 treatments led to differences and improvement in AOD and Ångström Exponent products from AERONET.

We would like to acknowledge the NASA Postdoctoral Program and Oak Ridge and Associated Universities for sponsoring this research as an educational program.

Drosoglou, T., et al., 2023, Atmos. Meas. Tech.
Masoom, A., et al., 2024, Atmos. Meas. Tech.

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

Conveners: Gerald Nedoluha, Rennie Selkirk

P_F01: Pamela Wales

Continuing the Goddard Earth Observing System (GEOS) Composition Reanalysis Beyond Aura MLS

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The MERRA-2 Stratospheric Composition REanalysis with Aura MLS (M2-SCREAM; Wargan et al., 2023) assimilates stratospheric trace gas profiles of O3, N2O, HCl, HNO3, and H2O from the Microwave Limb Sounder (MLS) onboard the Aura satellite. This reanalysis has the benefit of providing vertically resolved fields on a regular horizontal grid, lending insight into long-term trends and anomalies of stratospheric constituents. The upcoming GEOS Composition Reanalysis will build upon M2-SCREAM, carbon reanalysis, and the GEOS Composition Forecast system to produce historical records of nine trace gases over the 21st century. Since this reanalysis is planned to continue beyond the end of the Aura, Aqua, and Terra missions, a new suite of observations will need to be included.

For multiple stratospheric trace gases, there will not be a near-term replacement for the near-global, daily observations provided by MLS. The Stratospheric Aerosol Gas Experiment (SAGE) III instrument onboard the International Space Station (ISS) was found to be a useful, but limited, replacement for MLS in stratospheric water vapor assimilation with validation provided in part by the NDACC frost-point hygrometer sonde network (Knowland et al., 2025). Following the end of the MLS record, the reanalysis will not have observational constraints for N2O, HCl, HNO3, and these fields will be the result of the GEOS model, assimilated meteorology, and the GEOS-Chem chemical model. Long-term records of these constituents and related trace gases provided by the NDACC Fourier-Transform Infrared Spectrometers (FTIR) provide an opportunity to assess the performance of reanalysis and modeled fields.

P_F02: Richard Querel

Past, present, and future of New Zealand's Lauder atmospheric research station

Richard Querel

National Institute of Water & Atmospheric Research (NIWA), New Zealand

Established in 1961, the Lauder atmospheric research station has continued to evolve over decades. Lauder started with auroral and ionospheric research, and slowly the region of interest moved down in the atmosphere to include stratospheric composition, and UV and solar radiation, and now tropospheric and even surface effects. In the early days of NDSC/NDACC, Lauder was selected as a Primary station, and we continue to produce important measurements for the global scientific community from our data sparse part of the world.

P_F03: Thierry Leblanc

Validation of the Small Mobile Ozone Lidar with eXtended Capability (SMOL-X) measurements during the instrument's first NDACC Deployment in Lauder, New Zealand

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The initial validation of SMOL-X took place at its home institution (JPL Table Mountain Facility, California) during the NDACC-sponsored campaign STOIC-2024, showing that SMOL-X can measure ozone throughout the lower and mid-stratosphere (up to 36 km) with a precision better than 10% for a time resolution of a few hours. As a first step towards NDACC affiliation, SMOL-X will be deployed in the second half of 2025 to the NDACC station of Lauder, New Zealand where its measurements will be compared with co-located measurements from ozonesonde, from an ozone lidar and from an aerosol lidar. Preliminary results from this first field deployment will be presented. SMOL-X will then be deployed in early 2026 to the Antarctic NDACC station of Arrival Heights, where it will start a multi-year monitoring of polar ozone and polar stratospheric clouds. The compact, low cost and automated remote operation concept used for SMOL-X has become critical as we approach an era of reduced spaceborne stratospheric ozone monitoring capability, and the successful validation of SMOL-X in New Zealand should demonstrate its potential for a significant new contribution to NDACC if multiple units can be deployed at several other sites across the network.

P_F04: Justus Notholt

FTIR and microwave trace gas observations by the University of Bremen

Justus Notholt, Mathias Palm, Thorsten Warneke, Matthias Buschmann, Christof Petri, Xiaoyu Sun, Denghui Ji

University of Bremen, Germany

In 1992, the University of Bremen began trace gas observations as part of the NDACC, at that time named NDSC. Currently, we operate four sites, in Bremen (Germany), Ny-Ålesund (Spitsbergen), Orléans (France), and Nicosia (Cyprus). For several years, we have also maintained sites in Paramaribo (Suriname) and Białystok (Poland). Additionally, since 1994, we have participated in several ship cruises to study the latitudinal variability of trace gases. Since 2015, we have operated a tropical site in Koror (Palau in the Western Pacific), which has not yet been officially accepted into NDACC. Throughout the talk, we will present a few results from our observations. Finally, an outlook on our future activities will be provided.

P_F05: Michael D. Himes (remote)

A machine learning approach to continue the stratospheric water vapor record using OMPS LP measurements

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Since May 2024, stratospheric water vapor (SWV) measurements have been spatiotemporally limited due to the Aura Microwave Limb Sounder (MLS) SWV product's reduced coverage to around 6 days per month. Following Aura's expected decommission next year, SWV measurements will be primarily continued by the Stratospheric Aerosol and Gas Experiment III (SAGE III) and Atmospheric Chemistry Experiment (ACE) occultation instruments, which have significantly reduced geographical coverage compared to MLS. The Ozone Mapping and Profiler Suite Limb Profiler (OMPS LP) has spatiotemporal coverage comparable to MLS and shows weak sensitivity to SWV despite not being designed to measure it, offering a potential way to fill this data gap until a successor to MLS is launched. We detail our neural network-based approach to retrieve SWV from OMPS LP, present comparisons with MLS, SAGE, and ACE, and discuss the limitations of our method.

P_F06: Henry B. Selkirk

The Role of Frostpoint Measurements of Stratospheric Water Vapor in the Impending Stratospheric "Data Desert"

Henry B. Selkirk

NASA Earth Science Division, USA

Balloonsonde measurements of water vapor with frostpoint hygrometers have been critical for validation of measurements of water vapor from space, and long-term records such as the 40+ year NOAA program at Boulder serve as critical transfer standards between spaceborne instruments. They also are pressed into service to bridge temporal gaps in satellite coverage. Indeed, an extended period without global satellite coverage of water vapor will commence with the end of the NASA Aura mission; it is not known how long this water vapor gap in water vapor observations – part of the so-called "Data Desert" of Salawitch et al. (2025) – will continue as there is as yet no confirmed mission in development to measure water vapor by any space agency. NASA projects that Aura will be able to generate sufficient solar power to make science observations well into 2028. However, NASA may be directed to terminate the Aura mission in 2026 and likewise the SAGE III instrument on the ISS, thus extending the "Data Desert" by two years. However long the impending data gap will last, to bridge the gap and monitor changes in stratospheric water as global warming proceeds apace, we will be forced to rely on a small number of frostpoint sounding sites around the world. Of paramount importance is measurement of water vapor in the lower tropical stratosphere, and at the tropopause in particular, as it is closely related to the changes in the general circulation and the climate. We review here the small global network of frostpoint hygrometer launch programs and how their observations, limited in space and in time, can best be employed in the impending "Data Desert".

P_F07: Elizabeth Asher

Balloon measurements can help address impending UTLS water vapor data gaps

Elizabeth Asher (1, 2), Emrys Hall (2), Alex Fritz (1, 2), Bradley Boyadjiev (3), Darin Toohey (4), Lars Kalnajs (4)

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Monitoring the abundance of upper tropospheric and lower stratospheric (UTLS) water vapor is vital because its changes on intra-decadal timescales can have radiative impacts of comparable magnitude to increases carbon dioxide, affecting surface temperatures. Yet impending temporal and spatial data gaps in UTLS water vapor are expected due to the anticipated loss of NASA satellites, such as the AURA microwave limb sounder in 2026, the 190 GHz channel of which provides ~3500 near global retrievals of stratospheric water vapor measurements when in operation. Continued funding for the NASA Stratospheric Aerosol and Gas Experiment onboard the international space station, which provides ~ 30 profiles per day between northern and southern hemisphere midlatitudes, is also uncertain. Monthly long-term in situ water vapor NOAA frost point hygrometer (FPH) records in the UT and stratosphere over Boulder, Hilo and Lauder are 45.0, 14.4 and 20.6 years in length, respectively. Frost point records have been instrumental in validating satellite retrievals of water vapor, identify biases and drifts in satellite records and minimizing biases between satellite datasets before merging them into longer timeseries.

NOAA began transitioning away from the Trifluoromethane (R-23) cryogen in consideration of the Kigali amendment to the Montreal Protocol with the development of the dry ice and alcohol (DIA) NOAA FPH in 2019. More recently in 2023, our team developed a liquid nitrogen (LN2) FPH. Results from near simultaneous launches of R-23 and alternative cryogen (DIA and LN2) NOAA FPHs from Boulder, successful DIA and LN2 FPH launches in the tropics in 2023 and 2024, and regular FPH launches from Boulder show excellent agreement between NOAA FPHs with all three cryogens and good operation in cold and humid challenging measurement conditions in the tropical tropopause layer. Finally, comparisons of the Vaisala RS41 radiosonde over the past 10 years and the newly developed CU tunable-diode laser absorption spectrometer (TDLAS) to the NOAA FPH are promising and suggest that more high-quality in-situ measurements of UTLS water vapor are or will soon be available.

P_F09: Robin Wing (remote)

Using Resonance Fluorescence Lidars to Monitor Space Debris in the Upper Mesosphere and Lower Thermosphere, Case Study Falcon 9 Re-entry on 19 February 2025

Robin Wing, Michael Gerding, Gerd Baumgarten
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Since 2021, the emergence of "Space Age 2.0" has been marked by the rapid deployment of commercial satellite mega-constellations in Low Earth Orbit (LEO). These small, mass-produced satellites are designed for short operational lifetimes and typically re-enter Earth's atmosphere within 2 to 5 years. Consequently, the proportion of artificial to natural mass entering the atmosphere is projected to rise exponentially from 2.8% in 2020 to ~40% by 2030 (Schultz et al., 2021).

Unlike natural meteoroids, these satellites contain elements uncommon in the middle atmosphere, including lithium (Li), aluminium (Al), copper (Cu), niobium (Nb), silver (Ag), hafnium (Hf), and lead (Pb). The chemical and catalytic impacts of these materials on atmospheric processes, particularly on ozone and polar stratospheric clouds, remain poorly understood.

Motivated by recent aircraft-based laser mass spectrometer measurements detecting atmospheric pollution from re-entered debris (Murphy et al., 2023), the Leibniz Institute of Atmospheric Physics (IAP) is developing a new multi-metal resonance lidar to inventory atomic metals entering the atmosphere. We present an overview of the system and preliminary measurements of metal species.

We also describe a case study of an uncontrolled re-entry of a Falcon 9 upper stage, during which the existing lidar detected lithium in the debris plume. These observations were supported by local meteor radar wind data and high-resolution UA-ICON model simulations. Back trajectories of the lithium-containing air masses intersect the Falcon 9 re-entry path. This case highlights the potential of lidar-based lithium detection as a sensitive tracer for anthropogenic space debris.

P_F10: Jeannette D. Wild

The NDACC Database and Web Pages – 35 years of operations

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The Data Host Facility for the Network for the Detection of Stratospheric Change began operations in 1991, and has offered continuing service for the Network for the Detection of Atmospheric Composition Change. The associated website began in 1994. This poster explores the challenges and successes of serving the international research effort in the ever-expanding network through a period of significant technical advances and internet connectivity. We present our early operations, growing pains, metadata standardization, expanding collaborations and current network of shared tools and resources for the Atmospheric Composition community.