UNITED STATES OF AMERICA

OBSERVATIONAL ACTIVITIES

Column Measurements

Ozone
US Satellites

Total ozone data from the Ozone Monitoring Instrument (OMI) on the EOS Aura satellite is available beginning October, 2004. Two independent algorithms are used to produce OMI total ozone data, one developed by NASA the other by KNMI, NL. NASA now has reprocessed SBUV, TOMS and OMI data using a common (version 9) algorithm. Total Ozone is also available from the two nadir instruments within the Ozone Mapping and Profiler Suite (OMPS) on the Suomi NPP (S-NPP) satellite as well as the Joint Polar Satellite System-1 (JPSS-1 and JPSS-2). S-NPP ozone data have been available since April 2013, with the NOAA-20 record starting in 2017, and NOAA-21 in 2022. The three OMPS nadir instruments are very similar to those on SBUV and TOMS that have a record that goes back to 1970. These OMPS nadir observations will continue under the US operational satellite JPSS program. (NASA, NOAA)

Ozone Estimates from Infrared Sensors
NOAA produces estimates of total ozone by using information in the 9.7 micron channel of Cross-track Infrared Sounder (CrIS). The retrieval products are combined with SBUV/2 information to generate global maps of column ozone. See https://www.ospo.noaa.gov/Products/atmosphere/etoast/index.html. (NOAA)

Total ozone products from thermal emission spectrometers also exist from both the TES instrument on the EOS Aura satellite and the AIRS instrument on the EOS Aqua satellite. These data are available on the NASA GSFC DAAC at http://disc.gsfc.nasa.gov/. (NASA)

Dobson Network
Dobson total column ozone measurements in the U.S. are done through the NOAA Cooperative Network at 14 geographical locations, including 5 continental U.S. sites and 5 sites in other US territories or states (Hawaii, Alaska (2 instruments), Samoa, and South Pole. Four other sites are collaborative international programs (BoM at Perth, Australia; Lauder, NIWA in New Zealand; Marseille-Provence Astronomical Observatory (OAMP) federation at Observatoire de Haute-Provence, France; and Meteorological and Hydrological National Service (SENAMHI) at Maracompoche, Peru). An instrument in Perth, Australia has been operated by BoM for NOAA since 1984, but this instrument stopped operating in 2016. NOAA performed full refurbishment and new automation of the instrument in 2023 and the record has been restarted. . Dobson data are used for satellite validation and for determining ozone trends for the WMO/UNEP Ozone Assessments. NASA also supports Dobson measurements within the U.S. under the

auspices of the Network for the Detection of Atmospheric Composition Change (NDACC). (NOAA, NASA)

Pandonia network

This network is a collaboration between NASA and ESA. Pandora TO column ozone observations have been obtained consistently since 2013 from 165 sites in 35 countries. . Pandora data are processed in near-real-time by the Pandonia group. Data are used in satellite validations (i.e. TROPOMI, GEOMS, TEMPO, etc.), primarily for air quality purposes, as they provide measures of column, total tropospheric and near-surface ozone, NO_2. and CH2O (NASA , NOAA, EPA and US universities).

UVB Monitoring and Research Programme (UVMRP)
Direct-sun column ozone is retrieved by UV Multi-Filter Rotating Shadowband Radiometers (UV-MFRSRs) at 34 U.S. sites, 2 Canadian sites, and 1 New Zealand site within the U. S. Department of Agriculture (USDA) UV-B Monitoring and Research Programme (UVMRP). New algorithm was developed for to calibrate UV-MFRSR for total column and aerosol optical depth (Michalsky, J. and McConville, G. 2024.)

NOAA-Environmental Ultraviolet-ozone Brewer (NEUBrew) Network
NOAA has established a network of Brewer Mark IV UV spectrometers that were deployed at six U.S. locations. NOAA has operated the six stations continuously since the fall of 2006 with instruments after taking over the network from the EPA. The network Brewers http://gml.noaa.gov/grad/neubrew/ are currently focused on taking spectral UV irradiance measurements in the 286-363 nm wavelength range 5 times per daylight hour and total column ozone measurements 2-3 times per hour of daylight. Absolute spectral UV irradiance, instantaneous UV index, and daily erythemal dose time series are available online with a latency of one day. (NOAA)

The near-real time total ozone column and Umkehr profile daily data are made available from the NOAA NEUBrew network. Six Brewer instruments were calibrated against the Canadian traveling standard in 2015, followed by Langley calibrations performed monthly. Brewer ozone data is used in the validation activities of the total column and profile ozone data collected by the Suomi NPP OMPS satellite and the following Joint Polar Satellite System JPSS program. (NOAA)

Ozone-Relevant Gases and Variables

Ozone Monitoring Instrument (OMI) on the Aura Satellite
In addition to its primary focus on column ozone, OMI measures tropospheric columns of aerosols, nitrogen dioxide, formaldehyde, and sulfur dioxide. NASA also launched the Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite from Geostationary

orbit in 2023 to observe Ozone and other UV relevant trace gasses over much of North America on a roughly 1 hour interval. (NASA)

Network for the Detection of Atmospheric Composition Change (NDACC)
This international ground-based remote-sensing and balloon observation network was formed in 1991 to provide a consistent, standardized set of long-term measurements of atmospheric trace gasses, particles, and physical parameters via a suite of globally distributed sites. While the NDACC maintains its original commitment to monitoring changes in the stratosphere, with an emphasis on the long-term evolution of the ozone layer its priorities have broadened considerably to encompass the detection of trends in overall atmospheric composition and understanding their impacts on the stratosphere and troposphere, establishing links between anthropogenic pollution sources (i.e. stratospheric albedo modifications), extreme events (i.e., Hunga volcanic eruption and pyro-fires), climate change and atmospheric composition, calibrating and validating space-based measurements of the atmosphere, supporting process-focused scientific field campaigns, and testing and improving theoretical models of the atmosphere. NDACC instruments that are particularly suited for column measurements include UV/Visible spectrometers for ozone, NO_2, BrO, and OClO; FTIR spectrometers for a wide variety of source and reservoir compounds; and FTIR, Dobson and Brewer spectrometers for total column ozone information. Vertical distributions of ozone, water vapor and aerosols are also available from ozonesonde, and water vapor sonde, lidar, microwave and FTIR instruments. Additional information on the NDACC activities and archived data is available at http://www.ndacc.org. (NASA, NOAA)

Profile Measurements

Ozone

Stratospheric Aerosol Measurement (SAM) and Stratospheric Aerosol and Gas Experiment (SAGE) Instrument Series (4 Instruments)
The SAM/SAGE series of instruments has provided the longest data set on the vertical profile of ozone in the stratosphere. Near-global coverage has been provided on a near-monthly basis for the periods 1979 to 1981 and 1984 to 2005. This series is now being obtained by the SAGE III/ISS instrument that has been deployed on the International Space Station since 2017. (NASA)

OMPS Limb Measurements
The OMPS Limb instrument within the OMPS suite on Soumi-NPP has been producing vertically resolved ozone and aerosol concentrations since April 2013. These observations are also a part of the JPSS-2, and onward, satellites starting in 2022. (NASA, NOAA)

Microwave Limb Sounder (MLS) on the Aura Satellite
Ozone profiles from 0.5- 200 hPa with about 3 km vertical resolution have been produced by the Microwave Limb Sounder (MLS). At this time, NASA intends to let the orbit drift

to allow MLS to continue operation until roughly 2025. At this time, the satellite will most likely not be able to produce enough power to maintain operation of the satellite. MLS data are also combined with total ozone data from instruments like OMI, OMPS, and TropOMI to obtain information on tropospheric ozone globally. (NASA)

Balloonborne Measurements

NOAA routinely conducts weekly ozonesonde measurements at five locations: Boulder, CO; Hilo, HI; American Samoa; Trinidad Head, CA; and South Pole Station, Antarctica. In 2017, The ozonesonde launches were discontinued from Huntsville, Alabama and Summit, Greenland due to lack of funding within NOAA. Trinidad head station was able to continue weekly ozonesondes from 2017-2019 when funding from California Air Resources Board (CARB) became available. Huntsville, Alabama continues balloon launches intermittently to calibrate an ozone lidar system, which is supported by NASA. NASA also collaborates with NOAA and numerous international partners providing support for the Southern Hemisphere Additional OZonesonde (SHADOZ) network of ozonesonde launches from several locations in the tropics and southern subtropics. NASA periodically launches multi-instrument balloon-borne platforms in conjunction with various satellite observations. The instruments on these balloons obtain profiles of up to 45 key molecules. (NOAA, NASA).

Dobson Umkehr

Profiles are continuously obtained with automated Dobson instruments using the Umkehr technique at five sites (Lauder, Hawaii, Boulder, OHP, Fairbanks). Observations at Perth, Australia were restarted in 2023, as mentioned above. At operational sites, the software was updated recently to account for stray light and instrumental interferences. The Umkehr ozone records at 5 NOAA sites were homogenized in 2022. . . In addition, in collaboration with MeteoSwiss, Umkehr data from Arosa, Switzerland were re-processed in 2023. In collaboration with the NDACC working group ozone profiles from Umkehr, ozonesonde, FTIR, Microwave and lidar records at Lauder New Zealand were intercompared and trends were detected (Bjorkland et al, 2024). These records were also used for the SPARC LOTUS activity since 2018 (i.e. Godin-Beekmann et al, 2022) and for the 2018 and 2022 WMO Ozone assessments. . This project also involves homogenization of SBUV and OMPS satellite ozone profile records for trend assessment of zonally averaged and station overpass records. . (NOAA, NASA)

Brewer Umkehr

NOAA Environmental Brewer Spectrophotometer UV and Ozone Network

Total column ozone and ozone profiles using the Umkehr technique are regularly derived from the Brewer spectrometer around sunrise and sunset. All raw and processed data are posted on password protected archive accessible from the NOAA/NEUBrew web-site: http://gml.noaa.gov/grad/neubrew/. The Dobson Umkehr ozone profile retrieval algorithm has been modified to process Brewer Umkehr data on a selective basis. It is implemented at all NOAA operated sites. NOAA collaborates with the EUropean BREWer NETwork (EUBREWNET) network through partnership and shares its expertise in data network operations and data processing. The software can be found at

http://www.o3soft.eu/o3bumkehr.html, which was updated in 2023 . It is optimized to incorporate instrumental parameters, stray light corrections, test data quality and archive retrieval prognostic information. Within the second phase of the European Space Agency IDEAS+ framework (2022-2023) NOAA, CIRES, Aristotle University of Thessaloniki, Greece, and ERATOSTHENES Centre of Excellence, Cyprus University of Technology, Limassol, CYPRUS improved the operational Umkehr data processing and provides homogenized dataset optimized for the validation of the ozone profile observations by space-borne sensors such as S5P/TROPOMI and GOME2 on the MetOp platforms. The updated Umkehr retrieval methods have been applied to Umkehr ozone profile measurements for a total of 9 ground-based stations (4 Brewer and 5 Dobson), and the timeseries of the ground-based stations were extended to the end of 2022 (https://zenodo.org/records/10550453). Implementation of the algorithm to the entire EUBrew and other networks is pending on determination of instrumental parameters for individual instruments that is currently not performed on routine bases. The development of in-field calibration tools is in progress through collaboration between NOAA and EU COST action projects (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
NDACC lidars and microwave radiometers (whose retrievals are limited primarily to the upper stratosphere) are providing long-term ozone profile measurements. Ozonesondes routinely launched at many NDACC stations and through the Southern Hemisphere ADditional OZonesondes(SHADOZ) collaboration also provide ozone-profile data. In addition, several of the high-resolution FTIR spectrometers have been routinely collecting ozone-profile information since 2000. (NASA, NOAA)

Ozone-Relevant Gases and Variables
Stratospheric Aerosol Measurement (SAM) and Stratospheric Aerosol and Gas Experiment (SAGE) Instrument Series (4 Instruments)
The SAM/SAGE series of instruments has provided the longest data set on the vertical profile of aerosols in the stratosphere. Near-global coverage has been provided on a near-monthly basis for the periods 1979 to 1981 and 1984 to 2005. Water vapor profiles are also available. This series has resumed with 2017 deployment of the existing SAGE-III instrument on the International Space Station. (see above) (NASA)

Aura Satellite Instruments
Microwave Limb Sounder (MLS) on the Aura Satellite
Ozone profiles from 0.5- 200 hPa with about 3 km vertical resolution have been produced by the Microwave Limb Sounder (MLS). MLS produces profile information on Ozone, H_2O, N_2O, HCl, HNO_3, ClO, HO_2, HOCl, BrO, and several other minor trace molecules. The Aura satellite, which also hosts the OMI instrument, is now in a drifting orbit as it no longer has the fuel necessary to maintain a sun-synchronous orbit. NASA intends to let the orbit drift to allow MLS to continue operation until roughly 2025. At this time, the satellite will most likely not be able to produce enough power to maintain operation of the satellite. At that time, satellite derived profiles of several key species, like N_2O, HCl,

and ClO will cease to be produced by any satellite that is expected to be in operation at that time. TES discontinued operation in 2018. (NASA)

Balloonborne Water Vapor Measurements
NOAA monitors upper tropospheric and stratospheric water vapor using cryogenic, chilled-mirror hygrometers that are routinely flown with ozonesondes monthly in Boulder, CO, Lauder, New Zealand, in collaboration with NIWA, and at Hilo, Hawaii. The launch site in Boulder, CO is a WMO/GCOS GRUAN program certified facility. Additional water vapor profiles are also obtained periodically during campaigns in support of NOAA research aircraft missions or from sites of interest following large volcanic eruptions (e.g., the Hunga eruption in 2022). NASA supports the flights of several balloon instruments either through the TICOsonde activity in Costa Rica or on a campaign basis. (NOAA, NASA).

Airborne Measurements
NASA-sponsored airborne campaigns, using both medium- and high-altitude aircraft, have been conducted in collaboration with NOAA, NSF, and university partnerships, and a focus on satellite validation and scientific study of ozone and climate change. While designed more for process studies than for trend determinations, the airborne measurements have provided a unique view of changes in atmospheric composition at various altitudes. The most recent campaigns are ACCLIP (done jointly with the National Science Foundation), and DCOTSS investigation selected through the Earth Venture Suborbital-3 solicitation to understand the effects of deep convection within the North American Monsoon on the stratosphere. These two investigations have highly complementary science goals. (NASA, NOAA, NSF)

For nearly two decades NOAA has supported an additional ongoing program to regularly measure vertical profiles of ozone-depleting substances and substitute gases (including hydrofluorocarbons or HFCs) from light aircraft at a suite of approximately 20 sites across North America and above the central Pacific ocean basin site Rarotonga. The program began in 2004 and involves sampling up to 12 flasks at altitudes ranging from ~100 m above ground to ≤ 8 km above sea level. The data from this aircraft sampling program is used along with surface measurement to provide measurement-based quantification of U.S. emissions for ozone-depleting substances, their substitutes, and long-lived greenhouse gases. The U.S. EPA uses these atmosphere-based estimates in creating and assessing annual estimates of U.S. greenhouse gas emissions and sinks (https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks), and their reporting of those emissions to the United Nations Framework Convention on

Climate Change (UNFCCC). Ozone profile observations, together with temperature and humidity profiles were taken on most flights (10 locations) starting in 2004, but only three locations continue to collect ozone data in the most recent years. (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
Several of the NDACC remote sensing instruments provide profile data for a variety of ozone- and climate-relevant gases and variables. These observations continue the long term trends for ozone, water vapor, CFCs, HCl, HF, CH_4, and N_2O. The data are archived at www.ndacc.org. (NASA, NOAA, DoD/NRL)

Surface Measurements

Ground-Based In Situ Measurement Networks
Both NASA and NOAA support in situ sampling of ozone-depleting and climate-related trace gases via networks of flask sampling and real time in situ measurements at a number of sites distributed across the globe. These data provide the basis for determining global tropospheric trends and emissions of these gases, and for computing effective equivalent chlorine (EECl) in the lower atmosphere based on measurements of chlorine- and bromine-containing ozone-depleting substances. The NASA Advanced Global Atmospheric Gases Experiment (AGAGE) network has the longest continuous observational record for some gases, extending back more than three decades for some CFCs, methyl chloroform, and carbon tetrachloride. Newer NASA and NOAA instrumentation permits the monitoring of many of the CFC replacements, thereby enabling a tracking of the global atmospheric concentrations of such chemicals from their first appearance in the atmosphere. Measurement and standards intercomparisons between the AGAGE and NOAA networks and with other international collaborators are leading to an improved long-term database for many ozone- and climate-related gases. Both of these networks provided essential data related to the recent discovery of increased emissions of CFC-11 as well as the continued emission of carbon tetrachloride. (NOAA, NASA)
In addition to the global-scale information (concentrations, emissions, and their changes over time) provided by both AGAGE and NOAA, these ongoing measurement programs have been augmented over time to enable estimates of trace gas emission magnitudes on regional scales. The AGAGE and affiliated network effort relies on high-frequency measurements to provide information for a few regions distributed across the globe, while the NOAA effort (regular aircraft profiling mentioned above, plus, since 2007, approximately daily flask sampling at 16 tower locations) is focused on providing measurement-based emission magnitudes representative of the entire United States.

UV Irradiance Measurements

Broadband Measurements
SURFRAD Network

Seven Surface Radiation Network (SURFRAD) sites operate Yankee Environmental Systems, Inc. (YES) UVB-1 broadband radiometers. The Integrated Solar Irradiance Study (ISIS) network of solar measurements includes YES UVB-1 radiometers at each of seven sites. Other instrumentation (located at the Table Mountain test facility near Boulder, Colorado) includes a triad of calibration-reference YES UVB-1 broadband radiometers and two reference UVE Kipp&Zonen radiometers.

NOAA *Network*

Supplemental measurements of UV-B using YES UVB-1 instruments continue at Boulder, Colorado and Mauna Loa, Hawaii, where high-resolution UV spectroradiometers (UV5 and UV3 respectively) also are operated and can be used to accurately interpret the broadband instrument measurements. (NOAA)

NEUBrew network

Each NEUBrew station has a Yankee UVB-1 broadband radiometer collocated with the Brewer spectroradiometer. The UVB-1 provides measurements of Erythemal daily dose. The NEUBrew Mountain Research Station also includes a broadband Yankee UV-A instrument. (EPA,NOAA)

USDA UV-B Monitoring and Research Programme (UVMRP)

Thirty-eight YES UVB-1 radiometers are fielded under this programme. (USDA)

USDA UVB Monitoring and Research Programme (UVMRP)

UV-MFRSRs deployed within this 37 station network measure total and diffuse horizontal and direct normal irradiance at nominal 300, 305, 311, 317, 325, 332, and 368 nm with a 2.0 nm bandpass. In addition, vis-MFRSRs are deployed with nominal 415, 500, 610, 665, 862 and 940 nm wavelengths with 10.0 nm bandpass. These 13 measurements are used to create a continuous synthetic spectra model which can then be convolved with specific weighting functions to meet researcher's needs. Access to the synthetic spectra is found on the UVMRP web site at: (http://uvb.nrel.colostate.edu/UVB/uvb_dataaccess.jsf). Direct-sun column ozone is retrieved using the UV Multi-Filter Rotating Shadowband Radiometers (USDA, CSU)

NEUBrew Network

Four NEUBrew stations have a Yankee UV-MFRSR and all stations have visible MFRSRs collocated with the Brewer spectrophotometer. (NOAA)

NOAA Antarctic UV Monitoring Network

NOAA operates the UV Antarctic Network at three sites https://gml.noaa.gov/grad/antuv/ using Biospheric Instruments (BSI) SUV-100 scanning spectroradiometers and GUV-511 moderate bandwidth multi-channel radiometers deployed at three Antarctic stations: McMurdo, Palmer, and South Pole. These instruments also provide measurements of total ozone at all the three of these sites. (Bernhard et al., 2022)

Spectroradiometer Measurements

Central Ultraviolet Calibration Facility
A high-precision UV spectroradiometer and a UV spectrograph are located at the Table Mountain Test Facility in Colorado under the auspices of this programme. The UV spectrograph was removed from operation in August 2009 due to equipment failure. It had been in operation since June 2003 (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
State-of-the-art, high-resolution spectroradiometric UV observations are conducted as a part of the NDACC at several primary and complementary sites. In particular, U.S. collaboration with NIWA (New Zealand) enables such measurements at Mauna Loa, HI and Boulder, CO. The measurements at Mauna Loa were started in 1995, those in Boulder began in 1998, and they continue to the present. (NOAA)

NOAA Antarctic UV Monitoring Network
NOAA has assumed operations of the NSF UV Antarctic Network. BSI SUV-100 scanning spectroradiometers are deployed at the three Antarctic stations, McMurdo, Palmer, and South Pole. The scanning range of these instruments is from 290-600 nm.

UV-Net Programme
Brewer Mark IV spectrometers that measure the spectrum between 290 and 325 nm are deployed at all 21 network sites located in 14 U.S. national parks and 7 urban areas around the U.S. This network ceased operation in 2004 and all 21 Brewers were removed from their network sites. (EPA)

NEUBrew Network
The NOAA Environmental Brewer Spectrophotometer Network (NEUBrew) consists of six stations located in the western, central and eastern United States. Brewer MKIV instruments provide UV irradiance over the range 286.5 nm to 363 nm with 0.5 nm resolution up to 20 times per day. Absolute spectral UV irradiance , instantaneous UV index, and daily erythemal dose time series are available online with a latency of one day. http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA)

Satellite-based Estimation
Surface UV radiation can be estimated using satellite-measured total column ozone and top-of-the-atmosphere radiance at a non-ozone absorbing UV wavelength as input to a radiative transfer code. Such methods have been applied to estimate both the spectral irradiance as well as UVB from the TOMS instrument series. Similar data are being produced by the Finnish Meteorological Institute (FMI) using OMI data. Since the cloud effects vary at very short spatial and temporal scales, the satellite derived UVB data are most useful for making estimates of monthly average UVB and spectral irradiance at ~100 km grid scales. An outstanding problem in the estimation of UVB from satellites is the strong UV absorption of most aerosols, most notably dust and secondary organics. An aerosol absorption correction is applied to the TOMS UVB record (but not to the OMI record) using TOMS-derived aerosol index (AI). Though the AI can correct for elevated plumes of dust and smoke, it is not sensitive to aerosols near the surface. As a result, the

satellites can overestimate UVB by up to 30% in polluted areas. However, this error is largely localized to urban areas and shouldn't significantly affect regional averages. (NASA)

Calibration Activities

Satellite BUV instruments

The UV instruments have very high susceptibility to degradation in the space environment with unpredictable variability from one instrument to another. In addition, some instruments have had non-linear detector response as well as hysteresis and spectral stray light problems. The EP/TOMS instrument developed a complex cross-track dependent response after several years. NASA has for several decades supported the calibration of NOAA SBUV/2 instruments both before and after launch. The post launch activities include both hard calibration (by monitoring on-board calibration data and the solar irradiance), as well as soft calibration. Soft calibration techniques include analysis of spectral and spatial patterns in measured radiances to separate geophysical effects from instrumental effects. NASA flew the SSBUV instrument 8 times on the Space Shuttle to provide calibration of NOAA SBUV/2 instruments. Other satellite instruments such as SAGE, and currently the MLS instrument on Aura, are also providing useful calibration information. However, ground-based data have not been used for satellite calibration, except for the BUV instrument that operated on the Nimbus-4 satellite from 1970 to 1974. However, NASA uses Dobson/Brewer ozone network and ozone soundings to verify SBUV/2, TOMS and OMPS data after applying soft and hard calibrations. (NOAA)

Dobson Network

World Standard Dobson No. 83 is maintained at NOAA/ESRL/GML as part of the World Dobson Calibration Facility. It is used to maintain calibration of the NOAA Dobson network and regularly participates in international intercomparisons of WMO Dobson regional and national standards. In July and August of 2021 Dobson 083 was shipped to NOAA GML's observatory in Mauna Loa Hawaii where it underwent an absolute calibration to confirm the accuracy of the current calibration. The WMO region VI standard (D064) was calibrated against the secondary world standard D065 at Hohenpeissenberg, Germany in 2021. In December of 2022, the Australian Bureau of Meteorology hosted an intercomparison at its Broad Meadows facility near Melbourne and Dobson 083 participated in intercomparisons. WMO Region V standard Dobson (D105), and Region II standard Dobson (D116) were calibrated during that event. Due to a volcanic eruption at Mauna Loa, Hawaii and inaccessibility of the observatory, the absolute calibration of D083 was moved to the Izana observatory on the Spanish island of Tenerife. The results from clear days showed the existing calibration to be valid. An intercomparison in Buenos Aires, Argentina is planned for November of 2024. Dobson 083 will travel to support intercomparisons and calibrate the Region IV standard Dobson D070 at that time. (NOAA)

Ozone Soundings

NOAA prepares ozonesonde instruments and follows pre-flight checks according to WMO standard operating procedures. It participates in international intercomparisons of ozonesonde measurements (environmental simulation chamber tests) and develops methods to resolve instrument related differences . The intercomparisons and dual ozonesonde flights at NOAA provide key information on developing a homogenized time series of balloon measurements at each NOAA site. WMO Global Atmospheric Watch sponsors the ozonesonde calibrations where various international groups are invited to the World Calibration Centre for Ozonesondes at the Juelich Research Centre (Smit et al, 2021). Ozonesonde homogenization project started in 2016 and about 40+ station records are homogenized by this date, including SHADOZ station records. Ongoing effort is to understand recent, since ~2016, stratospheric ozone changes observed at some stations that seems to be related to the ozonesonde manufacturing (Stauffer et al., 2020; Stauffer et al., 2022). The warning was issued for ozonesonde data users that the data should not be used starting from 2016 to avoid misinterpretation of derived trends in the middle stratosphere. (NASA, NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)

Several operational protocols have been developed to ensure that NDACC data is of the highest long-term quality as possible within the constraints of measurement technology and retrieval theory at the time the data are taken and analyzed. Validation is a continuing process through which instruments and their associated data analysis methods must be validated before they are accepted in the NDACC and must be continuously monitored throughout their use. Several mobile intercomparators within the various NDACC instrument types exist to assist in such validation. (NASA, NOAA)

Ground-Based In Situ Measurement Networks

Both the NOAA and NASA/AGAGE networks independently develop and maintain highly accurate and precise calibration scales at trace gas mole fractions of parts per trillion (ppt) and parts per billion (ppb) levels for the major and minor long-lived ozone-depleting gases and substitute chemicals such as HFCs. Both networks are developing reliable calibration scales on an ongoing basis for other halogen-containing gases that have been newly introduced, such as HFOs. (NOAA, NASA)

Central Ultraviolet Calibration Facility

The Central Ultraviolet Calibration Facility (CUCF) is located in NOAA's David Skaggs Research Center in Boulder, Colorado. The CUCF calibrates UV instruments for several U.S. Government agencies and other UV research concerns, both national and international. The CUCF also measured spectral response and angular response (critical for direct beam retrieval) for broadband and narrowband instruments. In addition to laboratory calibrations, the CUCF has developed a portable UV field calibration system that allows laboratory-grade calibrations to be made at spectroradiometer field sites. The CUCF also produces secondary standards of spectral irradiance that are directly traceable to NIST primary transfer standards. The secondary standards can be calibrated for operation in either the vertical or horizontal orientation. (NOAA)

USDA UVB Monitoring and Research Programme (UVMRP)

NOAA CUCF lamp calibrations performed in horizontal and vertical position using NIST traceable 1000-W halogen lamps are used to calibrate 51 USDA UV-MFRSRs and 52 UVB-1 broadbands. A U-1000 1.0-m double Jobin Yvon with 0.1-nm resolution and 10^{-10} out-of-band rejection is used as a reference spectroradiometer to transfer lamp calibration to a broadband triad. The UV-MFRSR radiometer spectral response and its angular response (critical for direct beam retrieval) are measured. The Langley calibration method is employed to provide additional absolute calibration of UV-MFRSRs and to track radiometric stability *in situ*. (USDA)

NEUBrew network

The NOAA Environmental Brewer spectrophotometer network (NEUBrew) consists of six stations located in the western, central, and eastern United States. Each Brewer Mark IV spectrophotometer is calibrated for absolute spectral UV irradiance at least one per calendar year. (EPA, NOAA) All six of the network Brewers were originally calibrated by International Ozone Services by comparing to the WMO Brewer transfer standard #017. Brewer 017 is directly traceable to the WMO Brewer Ozone Triad located at Environment Canada in Toronto, Ontario, Canada. In 2015 Brewer 017 traveled to Boulder to calibrate several Brewers after filter changes. Data quality evaluation with regards to measurement stability is ongoing after the filter changes.

In the summer of 2014 all NEUBrew Brewers were removed from their monitoring sites and returned to Boulder, Colorado for refurbishment and ozone calibration. For the refurbishment many of the NEUBrew Brewer's had a new solar-blind filter installed. The original NiSO4 filter was replaced by INRAD's new UVC-7 filter, a chemical variant of the original. The new filter is more thermally stable than the original and less hygroscopic. Eight out of 10 of the network Brewers received the new UVC-7 filter while two instruments kept the original NiSO4 filters. Two of the Brewers are operating side by side at Table Mountain, USA, one with the original $NiSO_4$ filter and the other with the UVC-7 filter. During October 2014 while all ten network Brewers were operating side by side they were calibrated against the WMO transfer standard, Brewer 017, by International Ozone Services.

Two methods of tracking any drift from those original calibrations are employed by NEUBrew. The first is to adjust the extra-terrestrial constant (ETC) calibration constant by using the internally generated R6 value and the second is by performing Langley regressions on the ozone data to derive the ETC. Data quality evaluation is ongoing after the filter changes regarding instrumental drift and measurement stability (NOAA)

RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozone

Tropospheric Ozone Assessment Report

NASA and NOAA researchers participated in the first phase of the IGAC sponsored Tropospheric Ozone Assessment Report (TOAR) (2014-2019), and continue to contribute to the ongoing TOAR-II activity (2020-2025) that includes 16 working groups. . The

new report will provide an updated assessment of tropospheric ozone's global distribution and trends based on numerous types of observations, such as ground based air quality monitors, aircraft, ozonesondes, lidars and satellites. The observations will be used to evaluate the global atmospheric chemistry models that are used for budget and attribution studies. The results from the first study found inconsistent trends, depending on the type of data used for the trends, and the updated assessment aims to reconcile these discrepancies. New research papers have been submitted to the TOAR-II Community Special Issue hosted by six Copernicus journals (https://acp.copernicus.org/articles/special_issue1256.html); the forthcoming assessment papers will be based upon these new results and other papers published in the peer-reviewed literature (NASA, NOAA)

Australian Fire studies

A significant number of papers were published regarding the effects of the Australian wildfires event in early 2020 on the stratosphere. These effects include significant changes in stratospheric transport, changes in aerosols abundances, changes in the types of aerosols, and most importantly, changes in the heterogeneous reactions that led to significant, and unexpected ozone loss. This was a very unique event that gave researchers a peek into what may happen if these types of events become more frequent. (NASA, NOAA, NRL)

Hunga Tonga Volcano eruption studies

In January 20 2022, a massive volcanic eruption occurred known as the Hunga Tonga volcano eruption. The effects have been widespread, unique in the modern observation era, and unprecedented in the amount of water vapor injected into the stratosphere. Numerous papers have now been published on this effect. The evolution of both the water vapor in the stratosphere has been monitored by satellite, ground based monitoring instruments and specific field campaigns. Many follow up modeling studies have been taken advantage of this wealth of data. A SPARC/APARC assessment of all these manuscripts is now in progress. (NASA, NOAA)

Long-term record of stratospheric ozone above the South Pole.
Balloon-borne ozonesondes launched weekly from South Pole Station (1986–2021) measure high-vertical-resolution profiles of ozone and temperature from the surface to 30–35 km altitude. Ozone minimum values and September loss rate trends have been improving (less severe) since 2001. The 2019 anomalous vortex breakdown was followed by two stable and cold polar vortex years during 2020 and 2021.
Validation of the ozonesonde observations is conducted through the ongoing comparison of total column ozone measurements with the South Pole ground-based Dobson spectrophotometer. The ozonesondes show a more positive bias of 2 ± 3 % (higher) than the Dobson following a thorough evaluation and homogenization of the long-term ozonesonde record completed in 2018 (NOAA, NASA, NSF).

The available records of focused Moon (FM) observations by Dobson and Brewer spectrophotometers at the Amundsen-Scott South Pole Station (for the periods 1964–2022 and 2008–2022, respectively) as well as integrated ozonesonde profiles (1986–2022) and MERRA-2 reanalysis data (1980–2022) were used to estimate the total ozone variability and long-term changes over the South Pole. The wintertime ozone values over the South Pole during the last 20 years were about 12 % below the pre-1980s level, i.e. the decline there was nearly twice larger than that over southern midlatitudes (NOAA, NASA, NSF).

The anomalous Quasi Biannual Oscillation event of 2015-6

The QBO in 2015-16 behaved significantly differently in 2015-16 than it has in the past, where the normal downward propagation did not occur. The signature of this anomalous QBO was investigated using profiles of Ozone, H2O, HCl from MLS along with total ozone from SBUV. This year, the anomalous QBO resulted in a much lower ozone column in the tropics and much lower water vapor entering the stratosphere. Such observations should be considered when looking at the climatic signals in trends in Ozone and water vapor. (NASA, NSF)

Continued high emissions of HFC-23 derived from atmospheric observations.

A recent study (Park *et al*., 2023) shows that emissions of HFC-23 from eastern China have not decreased as expected based on available reporting to the Ozone Secretariat's Multilateral Fund for the Implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer. HFC-23 emissions from eastern China account for about half of ongoing global emissions that add to the substantial continued increase in the global atmospheric abundance of this potent greenhouse gas. This byproduct of production of HCFC-22 can be destroyed by incineration in the production process, and recent reporting suggests this is happening as expected, so the cause of the ongoing emissions in recent years is not well understood. (NASA, NOAA)

Anomalous CFC trends in emissions and atmospheric concentrations

The global slowdown in the decline of CFC-11 was investigated using observations from NOAA and AGAGE global measurement networks and the Gosan AGAGE monitoring station. The anomalous and unexpected emissions that were detected in 2018 appear to have substantially decreased in following years. Much of the global emission increase (~60%) was attributed to two provinces in eastern China. Updated results from the Gosan station suggest that emissions from those two Chinese provinces appear to have returned to pre-2013 levels. It thus appears that a substantial delay in ozone-layer recovery has been avoided, perhaps owing to the above timely reporting (NASA, NOAA).

Increases in global emissions and global mean atmospheric concentrations of five other long-lived CFCs have also been detected by atmospheric measurements. The causes for these increases (CFC-13, CFC-112a, CFC-113a, CFC-114a and CFC-115) are not understood, but for some they may relate to by-production and feedstock use in the manufacturing of HFCs and other chemicals (NASA, NOAA).

Increase Emissions of Short Lived Chlorinated Species

Growing emissions of unregulated short-lived anthropogenic chlorocarbons are offsetting reductions in ozone-depleting substances mandated by the Montreal Protocol on Substances that Deplete the Ozone Layer. In that regard, **An et al.**(2021) report an average annual increase of 13% increase in emissions from China of the chlorocarbon dichloromethane (CH_2Cl_2), and this overall increase is of the same magnitude as the global emission rise of 354 (281–427) Gg yr^{-1} over the same period. If global CH_2Cl_2 emissions remain at 2019 levels, they could lead to a delay in Antarctic ozone recovery of around 5 years compared to a scenario with no CH_2Cl_2 emissions. (NASA, NOAA)

2023 Antarctic Ozone Hole

The 2023 Antarctic ozone hole was analyzed using the NDACC South Pole ozonesonde record, MLS, and SNPP OMPS ozone satellite profiles, and NASA MERRA-2 temperature data. The beginning of the 2023 austral spring was marked by a lack of planetary wave activity that resulted in a cold and stable polar stratospheric vortex, creating favorable conditions for ozone depletion. The 2023 Antarctic ozone hole appeared earlier than in recent years and exceeded 20 x 106 km2 by 2 September. Following the 2022 SH vortex breakup, the Hunga plume was advected to Antarctic polar latitudes (Manney et al., 2023, Santee et al., 2024). Despite exceptional WV from the Hunga eruption and earlier onset of chlorine activation at the beginning of austral winter, the 2023 Antarctic ozone hole was quite ordinary. Meteorological conditions in the lower Antarctic stratosphere and the area of the ozone hole were close to average from late September to mid-November. Weak wave activity in late austral spring slowed the seasonal transition to summer, similar to the situation in the 3 previous years (2020, 2021, and 2022). As a result, lower stratospheric temperatures were below average and the ozone hole persisted longer than usual in 2023, breaking up on 20 December (the 1990–2019 average breakup date is 9 December). Record low ozone values in late austral spring and early summer led to unusually high levels of ultraviolet (UV) radiation in the region south of 60°S. (NASA, NOAA)

Homogenization of Ozone Sondes

Recent papers reanalyzed ozone sondes to ensure that they are all analyzed using the same techniques (Smit et al. 2021). This allows the proper use of these data to observe ozone trends in both the troposphere and stratosphere. This was a significant effort that combines all the data from the SHADOZ network and related sonde data, and allows future data to be analyzed in the same fashion. (NASA, NOAA)

Merged Satellite Datasets

NASA and NOAA scientists were part of a large international effort to homogenize Ozone profile records as part of an effort called LOTUS sponsored by SPARC, WMO,

and IO3C. The outcome is a better understanding of the data sets and uncertainties for producing such a data set. The third phase for LOTUS has commenced since 2022 in preparations to the 2026 Ozone assessment and the data updates have been requested. (NASA, NOAA)

UV.

UV and Health

NOAA/GRAD and NOAA/NWS/NCEP/CPC in collaboration with Klein Buendel, Inc a health research company developed a prototype for a smart-phone application that utilizes NOAA's UV forecast. The application is a tool for managing and providing information on sun-burning potential and vitamin D production. The project was funded by the National institute of Health.

UV Trends

SURFRAD Network

Work by Colorado State University (CSU) UVB researchers continued for analyzing trends in solar UV irradiance at eight stations in the CSU-USDA network stations. Both positive and negative tendencies were detected ranging from –5% to +2% per decade. However, inter-annual variability was between 2 and 5%. (NOAA)

UV Forecasts and Exposure

UV Forecasts and Alert System

NOAA/CPC is producing UV forecasts and has developed a UV Alert system with the EPA. The UV Index forecasts are on a gridded field covering the entire globe. Forecast fields are generated at one hour frequency out to five days. The UV Index forecasts include the effects of Earth-Sun distance, total ozone, solar zenith angle, surface albedo (inclusive of snow/ice), cloud attenuation, and climatological aerosol conditions. The gridded fields are freely available on the NCEP ftp site. The UV Alert system is designed to advise the public when UV levels are unusually high and represent an elevated risk to human health. The UV Alert system consists of a graphical map displaying the daily UV Alert areas, as well as additional information included in the EPA's UV Index ZIP Code look-up web page and via the EPA's AIRNow EnviroFlash e-mail notification system. The criteria for a UV Alert are that the noontime UV Index must be at least a 6 and must be 2 standard deviations above the daily climatology. (NOAA/CPC, EPA)

Effects of UVB Exposure

A major limitation in predicting the impacts of UVB irradiance on humans, plant leaves and flowers, and aquatic organisms is the difficulty in estimating exposure. An analysis of the spatial variability in the daily exposure to narrowband 300- and 368-nm and broadband 290- to 315-nm (UVB) solar radiation between 12 paired locations in the USDA UV-B Climatological Network over two summer growing seasons has been completed. The spatial correlation of the UVB, 300- and 368- nm daily exposures between locations was approximately 0.7 to 0.8 for spacing distances of 100 km. The

300-nm daily exposure was typically more highly correlated between locations than the 368-nm daily exposure. (USDA)

THEORY, MODELING, AND OTHER RESEARCH

Ozone:

Ozone-Related Gases and Variables

Measurements of HFCs have been analyzed to derive estimates of global concentration variability for the hydroxyl radical. These estimates enable a more accurate representation of loss rates (and lifetimes) for HFCs and HCFCand their variability interannually (NASA, NOAA)

Results from models and information related to stratospheric dynamics have been used to better understand the role of dynamical variability on ODS and HFC concentrations measured in the global surface networks so that global emission rates are better estimated (NASA, NOAA).

UV.

UV Instrumentation

The temperature dependence of the Brewer UV spectrometer has been studied in order to improve the quality of data for UV trends. (NOAA)

UV Effects

The UVMRP supports research studying UVB effects on plants and ecosystems. Numerous publications document the results of these on-going studies, and are listed on the program's web site at (http://uvb.nrel.colostate.edu/UVB/uvb_pubs.jsf). (USDA)

UV Model Comparisons

The UVMRP's modeling group, "The Center of Remote Sensing and Modeling for Agricultural Sustainability" has published preliminary results of their coupled climate-crop modeling system. Validation and system refinement is underway and has shown promising results. Corn yields for the 16-state USA corn belt over the 27 year span (1979-2005) agree to within +/-10% of the actual yields. This modeling effort is being expanded to evaluate precipitation, temperature and UV effects on the yields, with the ultimate goal of developing a system that will be capable of both achieving credible and quantitative assessments of key stress factors, and evaluating alternative cultural practices for sustainable agriculture production. (USDA)

DISSEMINATION OF RESULTS

Data Reporting

Ozone

Ozone data from Aura instruments (OMI, MLS, and HIRDLS)), past TOMS instruments, the OMPS nadir and Limb instruments on Suomi-NPP, and the AIRS instrument are routinely distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) at http://disc.sci.gsfc.nasa.gov/acdisc. Both level 2 (measured) data and level 3 (grid averaged) data are distributed in HDF format. OMI level 3 data are distributed in ASCII format via the TOMS web site (http://toms.gsfc.nasa.gov). Ozone data for the TES instrument on Aura and the new TEMPO satellite can be found on the NASA Langley DAAC at http://eosweb.larc.nasa.gov/. (NASA)

Aura Validation Data Center (AVDC)

Preliminary and near real-time total ozone, ozonesondes, ozone profiles from LIDAR and microwave radiometers are archived from US Government Agencies and investigators worldwide. In addition, the AVDC (http://avdc.gsfc.nasa.gov/) also archives and distributes NASA and NOAA total column, profile and tropospheric satellite data subsets. The collected preliminary ozone data are restricted to participants in Aura validation teams, ESA OMI announcement of opportunity participants, and international validation contributors, while the satellite data is freely available (http://avdc.gsfc.nasa.gov/Data/). (NASA)

Umkehr Dobson Data

Dobson Umkehr data processed using UMK04 algorithm are available from the WOUDC archives. Dobson Umkehr data for six NOAA sites are also available at the web address: https://gml.noaa.gov/aftp/data/ozwv/Dobson/AC4/Umkehr/. Brewer Umkehr data are available for 6 NEUBrew sites at the web address: https://gml.noaa.gov/grad/neubrew
(NOAA, NASA)

World Ozone and Ultraviolet Radiation Data Center (WOUDC)

Total ozone, Umkehr, and ozonesonde data are reported to the WOUDC from U.S. Government agencies and institutions. Ozone data from sites that are part of the NDACC and the SHADOZ network are available from the programme web sites (http://www.ndacc.org/ and http://croc.gsfc.nasa.gov/shadoz/, respectively), and also are imported to WOUDC. (NOAA, NASA).

NEUBrew Data

UV spectra, total column ozone and Umkehr ozone profile data from the NOAA Environmental network are available at the web site https://gml.noaa.gov/grad/neubrew / (NOAA)

Assessments

NASA and NOAA scientists, along with other scientists from around the world, are playing key roles as editors, authors, reviewers and contributors to the current SPARC Report on the effects from the Hunga-Tonga volcanic eruption.. NASA and NOAA scientists also played lead roles in the planning and writing of the 2022 WMO/UNEP Scientific Assessment of Ozone Depletion report and providing leadership in the

upcoming 2026 SAP report, which is mandated under the provisions of the Montreal Protocol. US scientists led and contributed to the SPARC/IO3C/WMO LOTUS report that assessed stratospheric ozone trends and developed combined record uncertainty estimates. The results were used in WMO Ozone Assessment 2022. (NOAA, NASA)

BAMS State of the climate reports. US scientists contribute to the annual reports on stratospheric ozone recovery globally and over the Antarctic. (NASA, NOAA).

WMO Greenhouse gas bulletin—uses NOAA and AGAGE data on a range of greenhouse gases including CO2, CH4, N2O, and halocarbons.

Stratospheric Winter Hemisphere Bulletins
Following each hemisphere's winter, an assessment of the stratospheric dynamics and chemistry are presented from a NOAA perspective. The southern hemisphere's winter bulletin focuses upon the ozone hole formation and longevity. Relevant thermal and dynamical attributions are presented. The northern hemisphere's winter bulletin will discuss ozone loss conditions and stratospheric warmings.
http://www.cpc.ncep.noaa.gov/products/stratosphere/winter_bulletins/ (NOAA/CPC)

NASA maintains the Ozone Watch web site at NASA GSFC (https://ozonewatch.gsfc.nasa.gov/) which contains daily updates on the satellite images of column ozone and polar stratospheric meteorological conditions, and near term forecasts. (NASA)

Ozone-Related Gases and Variables
Aura Data
Gas and Aerosol constituent data from Aura instruments (OMI, MLS and HIRDLS) are routinely distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) at http://disc.sci.gsfc.nasa.gov/acdisc. Both level 2 (measured) data and level 3 (grid averaged) data are distributed in HDF format. OMI level 3 data are distributed in ASCII format via the TOMS web site (http://toms.gsfc.nasa.gov). Data for the TES instrument on Aura can be found on the NASA Langley DAAC at http://eosweb.larc.nasa.gov/ (NASA)

Ozone-Depleting Substance Data
Ongoing measurement data for ozone-depleting substances from the NOAA sampling network are updated at least every six months on the website (https://gml.noaa.gov/dv/data/) and are submitted annually to and posted by the World Data Centre and to the World Data Center for Atmospheric Trace Gases at the Carbon Dioxide Information Analysis Data Center (CDIAC). Data from field missions (*e.g.*, the Atmospheric Tomography Experiment Campaign), are posted shortly after mission completion. (NOAA)

Long-term data from the NASA/AGAGE network are reviewed on a semi-annual basis by the Science Team, and are archived every six months with Carbon Dioxide

Information and Analysis Center (CDIAC) <http://cdiac.esd.ornl.gov/>. Data from the UCI flask sampling network are also archived at CDIAC. (NASA)

UV Data
SURFRAD Network Data
UV data from the SURFRAD Network are available on the NOAA/SRRB website (http://www.srrb.noaa.gov/). (NOAA)

NEUBrew Network UV Data
Spectral UV irradiances are available from the NEUBrew website
http://esrl.noaa.gov/gmd/grad/neubrew/ (NOAA)

NOAA Antarctic UV Data
Spectral UV irradiances, derivative UV products, and GUV data will be available from NOAA's Antarctic UV website.
http://esrl/noaa.gov/gmd/grad/antuv (NOAA)

USDA UV-B Monitoring and Research Programme (UVMRP)
UV, visible and ancillary data from the UVMRP network is available next-day on the UVMRP website (http://uvb.nrel.colostate.edu/).

UVB-1 broadband data and UV-MFRSR data from this network are regularly submitted to the WOUDC. (USDA)

Information to the Public

Ozone
TOMS and OMI Data

Near-real-time ozone data from the OMI instrument on Aura is routinely distributed via the NASA web site (http://toms.gsfc.nasa.gov/). Data are usually available within 48 hours, though faster access can be arranged. The site provides online access to both TOMS (1978-2006) and OMI (2004-present) data. While used mostly by scientists, educators and students also use the site extensively. An Ozone Hole Watch web site, http://ozonewatch.gsfc.nasa.gov/ provides information for anyone interested in the Antarctic ozone hole. Near real time Ozone profile data from MLS now exist, and are available at http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/MLS/ml2o3_nrt.002.shtml. (NASA)

Merged TOMS/SBUV Total and Profile Ozone Data
Merged TOMS/SBUV total and profile ozone data sets are available on the Internet (http://hyperion.gsfc.nasa.gov/Data_services/merged/index.html). (NASA)

UV
Forecasts

Noontime UV forecasts are made available to the public via several formats. One is a text bulletin for 58 cities in the U.S. The other is a map displaying the UV Index forecast at each of the 58 cities' locations. These can be found at http://www.cpc.ncep.noaa.gov/products/stratosphere/uv_index/. Additionally, gridded fields of the noontime forecast for the U.S. and Alaska are made available via the NOAA/CPC and NOAA/NCEP ftp sites. UV Index forecast gridded fields covering the entire globe at one hour increments out to five days are available on the NCEP ftp site: ftp.ncep.noaa.gov/pub/data/nccf/com/hourly/prod. (NOAA/CPC)

Advisories
The primary UVR advisory in the United States is the UV Index, operated jointly by NOAA and EPA. Currently, the UV Index computer model processes total global ozone satellite measurements, a rough cloud correction factor, and elevation to predict daily UVR levels on the ground and the resulting danger to human health. This model assumes zero pollution levels. UV Index reports are available in local newspapers and on television weather reports. The EPA also issues a UV Alert when the UV Index is predicted to have a high sun-exposure level and is unusually intense for the time of year. UV Alert notices can be found at EPA's SunWise web site (http://www.epa.gov/sunwise/uvindex.html), in local newspapers, and on television weather reports. (EPA)

Ozone-Depleting Gas Index
An ozone-depleting gas index (ODGI) tracks overall changes in ozone-depleting halogen concentrations that provides a measure of progress towards healing the ozone layer. The ODGI is derived from estimates of Effective Equivalent Stratospheric Chlorine (EESC) That are derived from NOAA's global surface measurements of ODSs. The observation-derived EESC values, combined with WMO/UNEP ozone-depleting gas scenarios, are referenced to EESC maxima values and 1980 values (taken as the value for "recovery") in the Antarctic and mid-latitude stratosphere. The ODGI for 2023 was 72.8 for Antarctica and 47.1 for mid-latitudes, indicating substantial progress in ODS reductions. The index is updated annually and posted at http://www.esrl.noaa.gov/gmd/odgi. (NOAA)

U.S. total and regional emissions of ODSs, HFCs, and SF6 are regularly derived from an ongoing and extensive atmospheric measurement network across the U.S. (https://gml.noaa.gov/hats/US_emissiontracker/?gas=HFC134a). Results are posted on line and, for some gases, updated annually (NOAA)

Data visualization
Atmospheric concentration trends for

PROJECTS AND COLLABORATION

NOAA
The Dobson and ozonesonde measurements are included in the WMO Global

Atmosphere Watch (GAW) and in the NDACC. Significant collaboration with federal agencies (NASA, NSF, DoE, EPA), state agencies (CARB, CDPHE) and universities (University of Colorado, Harvard, Princeton, Humboldt State University, U. of Hunstville, etc.) is maintained through both global monitoring and field missions including support for satellite validations. The World standard Dobson instrument is maintained and calibrated by NOAA under the WMO GAW program. It provides calibration to regional Dobson standards at 4 Regional centers. The NOAA Environmental Brewer spectrophotometer network (NEUBrew), initially established in collaboration with the EPA, consists of six stations located in the western, central, and eastern United States.

The CUCF is designated by a Memorandum of Understanding to be the national UV calibration facility by agreement among the following organizations: NOAA, USDA, EPA, NASA, National Institute of Standards and Technology (NIST), NSF, National Biological Service, and the Smithsonian Institution. The CUCF compared secondary standards of irradiance with the Joint Research Centre's European Union UV Calibration Centre's (ECUV) ultraviolet spectral irradiance scale in Ispra, Italy. The CUCF's irradiance scale is directly traceable to the NIST spectral irradiance scale, while the ECUV's irradiance scale is traceable to that of the German national standards laboratory, Physikalisch-Technische Bundesanstalt (PTB).

NOAA/CPC
Activities include participation in several initiatives of Stratospheric Processes and their Relation to Climate (SPARC), i.e., stratospheric temperatures, ozone, UV, climate change; collaboration with the EPA on the UV Index and the UV Alert system; collaboration with NASA in ozone monitoring, calibration of the SBUV/2 instruments, dynamical processes influencing ozone changes, and ozone assimilation; collaboration with the surface radiation monitoring efforts of NOAA/OAR and USDA-CSU for the validation of UV forecasts and NCEP/GFS surface radiation products. The NDACC Data Host Facility now resides at NASA Langley.

NASA:
NASA collaborates extensively with several NOAA laboratories in all areas of ozone and UV research, including space-based, airborne, balloon-borne, and ground-based measurements, as well as in various modeling and analysis activities. NASA often supports research activities within these laboratories, including support for NOAA groundbased measurements for satellite validation. The NDACC, which is championed by NASA and NOAA within the U.S., is a major contributor to WMO's Global Ozone Observing System (GO3OS) within the frame of its Global Atmosphere Watch (GAW) Programme. NASA is closely collaborating with KNMI (Netherlands) and FMI (Finland) on processing data from the Aura OMI instrument. NASA is collaborating NOAA in the implementation of the OMPS nadir and limb instruments on the Soumi-NPP satellite by producing the limb operational data products and by performing assessments of the nadir operational products.

USDA:
USDA is actively collaborating with the NASA TOMS and AERONET groups on aerosol absorption using UV-MFRSR and Cimel instruments.

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FUTURE PLANS

Ozone

Column Ozone from Dobson/ Brewer Zenith-Sky Measurements
The operational zenith-sky total ozone algorithm for Dobson and Brewer instruments is based on empirically derived tables. NASA has developed a TOMS-like algorithm to process these data, which has the potential to substantially improve data quality. There are plans to process all historical zenith-sky data using this algorithm.

In 2015-2016 NOAA performed a thorough assessment of all its historical Dobson datasets. Some inconsistencies were found in the total and Umkehr data submitted to the WOUDC and NDACC archives. NOAA is preparing to resubmit the revised dataset in 2017.

New algorithms to utilize multi-wavelength Brewer zenith sky measurements for improved ozone profile retrieval require detailed information on optical parameters of individual instruments (i.e., band-pass and stray light filters). The work on improvement of optical characterization of Dobson and Brewer instruments for stray light minimization will continue through in-lab and in-field characterization of the instruments in the WMO network.

NOAA will work to implement Serdyuchenko et al (2014) ozone cross-section datasets for its Dobson and Brewer ozone data processing. The future work will be focused on developing methods to incorporate daily and climatological variability in stratospheric temperature into the ozone data processing. (NOAA, NASA)

Ozone profiles from Dobson/ Brewer Zenith-Sky Measurements
NOAA GMD will continue to retrieve ozone profiles from the NOAA operated stations, and will submit results for Dobson stations to the WOUDC, and will make the amendment to the UMK04 algorithm to replace the look-up tables for the SER (2014) cross-section. Results from the NEUBrew instruments will be posted on the network website http://esrl.noaa.gov/gmd/grad/neubrew/. The set up for automatic submission of raw NEUBrew data (B-files) to the WOUDC Brewer archive depends on the future funding for the NEUBrew network.

A new multi-wavelength ozone profile retrieval algorithm for processing Brewer Umkehr measurements (similar to the SBUV retrieval) will be made available for the WOUDC and scientific communities after the optical characterization of instruments for stray light and polarization parameters becomes part of the recurrent calibration routine in the operations of the Brewer networks. The pass forward is through a NOAA collaboration with the European Joint Research Project Consortium. The future activity is in line with the ATMOZ (Traceability for atmospheric total column ozone) project under the European Metrology Research Program that focuses on assessing the accuracy in total column and profile ozone measurements. Optical characterization of instruments (in the lab and in the field) allows developing schemes to compare and reconcile differences in ozone column data derived from different instruments, including in applications for satellite validation projects.. The proposed multi-spectral Brewer algorithm is expected to

significantly reduce operational time for the zenith sky measurements as compared to the established "Umkehr" measurements schedule in Brewer operations. It will also allow to process historical data that were not available for standardized processing due to shortness of the solar zenith range coverage. The data processed by the new algorithm will be archived at the WOUDC (NOAA).

The Brewer Umkehr data set series from NOAA and other international ground-based stations will be compared to other available co-incident ozone profile data from ozone-sondes, microwave, lidar and Dobson Umkehr profile data. Results will be reported at the LOTUS SPARC activity aimed at understanding of past changes in the vertical distribution of ozone, and will be made available for the next UNEP/WMO Scientific Assessment of Ozone Depletion. (NOAA)

Archiving of the "raw" data at the WOUDC
According to the SAG-Ozone recommendations NOAA will participate in the international effort at the finalization of formats for the storage and reporting of ECC ozonesonde measurements at WOUDC, archiving of R-values of Dobson measurements and related calibration information as well as B-files and relevant information for Brewer measurements. It will provide the updated and modified algorithms used to process these data. NOAA will assist WOUDC with changes of ozone absorption cross sections or other changes that may demand the reprocessing of data records. (NOAA)

Ozone in Climate Forecast Models
NCEP has modified and extended its synoptic forecast model (GFS) to time scales of three weeks to nine months. Ozone forecasts as well as stratospheric temperatures and heights have significant errors in these forecasts. Experiments modifying the model's physics and structure will need to be conducted in order to improve these forecasts. (NOAA/CPC)

Ozone in the NCEP/Climate Forecast System Reanalysis
NCEP is replacing the NCEP/DOE Reanalysis 2 (R2) with the Climate Forecast System Reanalysis (CFSR). The CFSR improves upon the R2 in many ways. One is by using ozone profile information from the SBUV/2. The CFSR is being rerun from 1979 to present and will continue as the model for NCEP's Climate Data Assimilation System (CDAS). The CFSR should be the reanalysis of choice to study ozone-dynamics interactions. (NOAA/CPC)

NOAA Antarctic UV Network
Future plans are to deploy two NEUBrew Mark IV spectrophotometers to the McMurdo and Palmer stations to provide daily total column ozone and overlapping spectral UV measurements. The two Brewers will be temperature stabilized and modified for Antarctic operation. Before deployment both Brewers will be converted to "red" Brewers to facilitate ozone retrievals in the Chappuis band. After conversion and before deploying they will be operated at the CUCF's Table Mtn Test Facility (Lat 40 N) over the boreal winter to determine the quality of ozone retrievals from this solar spectral region when compared to direct-sun retrievals from the Hartley-Huggins band.

NASA Ozone satellites
NASA will continue to operate the Aura satellite through the end of its lifetime, assumed to be near the end of 2025. NASA will also continue to operate the SAGE-III satellite on the ISS through the three-year design lifetime of the instrument and will continue beyond that if the science value is determined to be high and no other instrument is scheduled to assume the location on the ISS that SAGE-III is occupying. (NASA)

Ozone-Relevant Gases/Variables:

OMPS and CrIS on NPP and JPSS
The Ozone Mapping and Profiler Suite is the operational US ozone monitoring instrument in the JPSS period. The suite consists of two nadir detectors; one with coverage in the 310 to 380 nm range to provide daily global total column ozone maps, and the other with coverage from 250 to 310 nm to provide nadir ozone profiles to continue the SBUV(/2) record. The first OMPS has been on the NASA Suomi-NPP since 2010. The Cross-track Infrared Sounder is a hyperspectral IR instrument with spectral coverage including the ozone lines around 9.7 microns. These instruments are also operating on the JPSS-1 operational satellite. (NOAA, NASA)

Ground based networks
NASA and NOAA plan on continuing investment into the ground-based networks supported by the NOAA Global Monitoring Laboratory as well as the Network for Detection for Atmospheric Composition Change, SHADOZ ozone sondes, and AGAGE. (NOAA and NASA)

NASA competed Investigations and missions
NASA is in the process of selecting new Earth Venture Suborbital investigations. These will be 5 year studies for science questions that require sustained observations. Stratospheric related science often reviews well in this solicitation as 2 were selected within the first 3 EVS solicitations. New selections should be announced soon.

The Earth Explorer announcement of opportunity has limb sounding of the stratosphere as one of the 6 areas of focus for consideration in this medium sized space mission solicitation. Announcements of selections of the missions to be considered for Phase A studies should be announced soon. NASA expected to select 2 missions for implementation and that final decision will occur roughly 1 year after the initiation of the Phase A studies. (NASA)

UV

UV Index Forecast
Aerosols and clouds are the greatest cause of UV Index forecast errors. NCEP and NESDIS are working together to improve the skill of forecasting aerosols. When model

generated forecasts of Aerosol Optical Depth and Single Scattering Albedo become available they will be included in the UV Index forecast system. (NOAA/CPC)

NEEDS AND RECOMMENDATIONS

Ozone

Column Ozone
Column ozone observations from ground stations and satellites provide the foundation for trend studies. Future levels of total ozone will be modulated by climate change effects. The current predictions of total ozone from state-of-the-art models suggest polar ozone recovery in the 2060-2070 period, and midlatitude recovery in the 2040-2050 period. It is a primary requirement to continue this data record and to enable retrieval improvements of the observations.

Column ozone data produced by satellite and ground-based instruments agree well in cloud-free conditions and at solar zenith angles less than 70º. However, the data quality of all measuring systems degrade under cloudy conditions and at large solar zenith angles, with differences of 10% or larger. Given the need for accurate ozone trends in the polar regions, it is important to improve the quality of ground-based data in these regions, and to focus future calibration and data intercomparison efforts accordingly. The work on improvement of optical characterization of Dobson and Brewer instruments for stray light minimization, and therefore improved accuracy at low sun and large total ozone conditions, are under development. In addition, the new ozone cross-section implementation in the Dobson and Umkehr data processing is underway. The improvement in Dobson daily ozone retrievals also depends on the stratospheric temperature variability. The methods to incorporate temperature corrections to the Dobson total ozone retrievals is of importance for reducing Dobson total ozone seasonal biases. The methods for the temperature correction applications (i.e. climatological vs. daily corrections) have yet to be validated. (NASA, NOAA)

Profile Ozone
Ozone profile information has critical importance for both ozone recovery and climate change. The vertical structure of ozone (~ 1 km resolution) near the tropopause is crucial to calculating the radiative forcing of ozone on climate. Furthermore, polar ozone recovery should first manifest itself in the 20-24 km region of the polar stratosphere. Models of ozone suggest that the cooling of the stratosphere will accelerate ozone recovery in the upper stratosphere leading to a “super-recovery”. Hence, observations of the vertical structure of ozone have a bearing on two key scientific issues: ozone recovery and climate change. Some of these profile observations have been provided by MLS and OMI instruments aboard the AURA satellite since 2004 and, since 2013, by the OMPS Limb instrument on NPP as well as the new OMPS limb observations on the JPSS-2 platform. OMPS-Limb is joined by the SAGE-III on the International Space Station, which may provide useful data to about the end of the lifetime of ISS (~2029)

There is a vast amount of unprocessed Brewer Umkehr data residing in the archives. A concerted effort should be made to process these data using a common Dobson/Brewer algorithm, which is necessary for trend studies. The new Brewer Umkehr algorithm to derive ozone profiles under low sun condition is also in works (NASA, NOAA)

In order for ozone forecasts to improve in the NCEP/GFS, higher quality and greater numbers of ozone profiles need to be available for assimilation than what is available from the current nadir viewing SBUV/2. Ozone profiles from the Aura/MLS and OMI are promising as they provide ozone profiles of greater resolution (MLS) and of greater horizontal coverage (OMI). These products are now available in near-real-time, and are being assimilated into the NCEP/GFS. (NOAA/CPC)

Ozone-Relevant Gases and Variables

Ozone- and Climate-Related Trace-Gas Measurements
There is a need to maintain and expand the existing *in situ* networks, both geographically and with improved instrumentation. Such improvements are needed to supply relevant and timely updates to quantifying changes in global trends in atmospheric concentrations and emissions of ozone-depleting gases and their substitute HFCs. Global emissions of long-lived gases are fairly well determined over 1 to 3 year periods; however, additional improvements in scientific understanding and observation density are required to accurately quantify year-to-year variations in global total emissions free from the influences of varying atmospheric dynamics, particularly the exchange between the troposphere and stratosphere. Furthermore, the current observational network is not able to quantify regional emission magnitudes and their time dependence from many industrialized and chemical producing regions of the world that are contributing substantially to global totals. These significant gaps in the network prevent a complete regional accounting of global emissions and their changes over time (e.g., consider the issue of the anomalous increase in CFC-11 emissions; only slightly more than half of the global emission increase was attributable to a particular region). These gaps also prevent a more accurate accounting of global total emissions of very short-lived gases, like the hydrofluoro-olefins, as chemicals with very short lifetimes prevent the accurate determination of global emissions from abundances measured at remote locations. Current workforce limitations prevent the development and propagation of gas standards on as rapid a schedule as required by some of these networks to keep up with the increasing number of new chemicals of interest to the Montreal Protocol. In addition, expanded efforts are needed for data analysis as the list of chemicals of interest lengthens. (NASA, NOAA)

The latest (2017) Decadal Survey from the US National Academy of Sciences does not have any future missions recommended for NASA to definitely put into formulation in the near future to observe atmospheric trace gases. There was a recommendation that such a mission be included as a possible science topic for a competitively selected mission under a newly recommended “Explorer Class” concept with a moderate cost limit. It was one of 6 potential science areas where such a mission was recommended NASA include in a future Explorer solicitation. As of now, there is no budget profile that

allows NASA to release such a solicitation. No other agency has a mission to obtain profiles of trace gases besides Ozone in their plans. As a result, data records of trace gas profiles in the stratosphere will likely have a gap. NASA takes the Decadal Survey recommendations very seriously, but can only implement what the budget allows. As of now, there is no solution to this issue. (NASA)

Aerosol Absorption Optical Thickness (AAOT)
There are currently no operational ground-based instruments that provide AAOT in UV. AAOT from the AERONET network is limited to wavelengths longer than 440 nm. NASA has improved a long-standing technique to derive AAOT in UV by combining measurements from AERONET and UV Shadowband radiometers. Efforts to utilize this methodology for deriving AAOT in the UV should be implemented. (NASA)

NEUBrew Network
Future plans for the NEUBrew network are for algorithm development for aerosol optical thickness retrievals and direct-sun data processing to provide aerosol optical thickness estimates at the five direct-sun measured UV ozone and five visible NO_2 wavelengths.

Field Campaigns
Aircraft, balloon, and ground-based measurement campaigns for satellite validation and science are expected to continue, but at a much lower level than in the past since Aura is approaching the anticipated end of its operational life. These campaigns will provide important validation data for ozone and ozone- and climate-related trace gases and parameters for Aura and other satellite sensors. They also will address high-priority science questions associated with atmospheric ozone chemistry and transport. (NASA)

UV

USDA UV-B Monitoring and Research Programme (UVMRP)
A new site was installed at the University of Texas at El Paso (UTEP) in November 2008. (UDSA)

Geographical Measurement Coverage
UV monitoring in the tropics is very limited. Relatively inexpensive broadband UV instruments could be set up easily at installations launching ozonesondes (e.g., SHADOZ) in the tropical region. Such efforts should be coordinated with the NDACC. In this way, UV at the surface under aerosols/pollution can be linked with the ozone profiles measured by the ozonesondes and ground-based profiling instruments. (NOAA/CPC)

Only seven of the EPA Brewers are currently deployed in or near densely populated areas. Satellite-derived UVR is less reliable for urban locations, because satellite instruments do not adequately characterize pollutants at ground level. Because of the deficiency of current urban UVR data, health researchers conducting local studies are sometimes making their own UVR measurements as needed, with instruments that are

often not easily compared with those from any of the existing UVR networks. Thus, better ground-level measurements collected in locations close to air-quality monitors are required. Finally, many sites have data gaps and inconsistencies. Only a limited number of ground-based sites provide historically continuous UV records. More analyses of available data and improved calibration could fill gaps in coverage**.** (EPA)

Effects Research

Although the effects of UV exposure drive UV monitoring activities, only limited resources historically have been targeted towards UVB effects research. Expansion of UVMRP activities in this critical area is needed at a multi-agency level. (USDA)

Acronyms and Abbreviations

AAOT aerosol absorption optical thickness
ACIA Arctic Climate Impacts Assessment
AERONET Aerosol Robotic Network
AGAGE Advanced Global Atmospheric Gases Experiment
AIRS Atmospheric Infrared Sounder
AO/AAO Arctic/Antarctic oscillation
BSI Biospherical Instruments
BUV Backscatter Ultraviolet
CAFS CCD Actinic Flux Spectroradiometer
CCD charge-coupled device
CDIAC Carbon Dioxide Information Analysis Data Center
CFC chlorofluorocarbon
COADS Comprehensive Ocean-Atmosphere Data Set
CPC Climate Prediction Center (NOAA, U.S.)
CrIS Cross-track Infrared Sounder
CSD Chemical Sciences Division (formerly the Aeronomy Lab, NOAA, U.S.)
CSD Chemical Sciences Division (NOAA,US)
CSU Colorado State University (United States)
CTMs chemical transport models
CUCF Central Ultraviolet Calibration Facility
DAAC Distributed Active Archive Center (NASA Langley, U.S.)
DISC Data and Information Services Center (NASA Goddard, U.S.)
DoD Department of Defense (United States)
DoE Department of Energy (United States)
DOAS Differential Optical Absorption Spectroscopy
ECD electron capture detector
ECMWF European Centre for Medium-Range Weather Forecasts (United Kingdom)
ECUV European UV Calibration Center
EECl effective equivalent chlorine
EESC effective equivalent stratospheric chlorine
EOS Earth Observing System
E EuMetSat European Organization for the Exploitation of Meteorological Satellites

P Earth Probe
EPA Environmental Protection Agency (United States)
ESRL Earth System Research Laboratory (NOAA, US)
FMI Finnish Meteorological Institute (Finland)
FTIR Fourier transform infrared
GAW Global Atmosphere Watch
GC Gas Chromatograph
GCM general circulation model
GCMS Gas Chromatography Mass Spectrometry
GES Goddard Earth Sciences
GFS Global Forecast System
GMAO Global Modeling Assimilation Office (NASA Goddard, U.S.)
GML Global Monitoring Laboratory (formerly GMD and CMDL – NOAA, U.S.)
GOES Geostationary Operational Environmental Satellite
GO3OS Global Ozone Observing System (WMO)
GOME Global Ozone Monitoring Experiment
GOMOS Global Ozone Monitoring by Occultation of Stars
GSFC Goddard Space Flight Center (NASA, U.S.)
HALOE Halogen Occultation Experiment
HIRDLS High-Resolution Dynamics Limb Sounder
HIRS High-resolution Infrared Radiation Sounder
IHALACE International Halocarbons in Air Comparison Experiment
IASI Infrared Advanced Sounding Interferometer
JPL Jet Propulsion Laboratory (United States)
JPSS Joint Polar Satellite System (United States)
KNMI Koninklijk Nederlands Meteorologisch Institut (The Netherlands)
MetOp Meteorological Operational Satellite
MFRSRs Multi-Filter Rotating Shadowband Radiometers
MIPAS Michelson Interferometer for Passive Atmospheric Sounding
MIRAGE Megacity Impacts on Regional and Global Environments
MLS Microwave Limb Sounder
NASA National Aeronautics and Space Administration (United States)
NAT nitric acid trihydrate
NCAR National Center for Atmospheric Research (United States)
NCEP National Centers for Environmental Prediction (NOAA, U.S.)
NDACC Network for the Detection of Atmospheric Composition Change
NDIR non-dispersive infrared
NESDIS National Environmental Satellite, Data, and Information Service (NOAA, U.S.)
NIST National Institute of Standards and Technology (United States)
NIWA National Institute of Water and Atmospheric Research (New Zealand)
NOAA National Oceanic and Atmospheric Administration (United States)
NOGAPS Navy Operational Global Atmospheric Prediction System
NRL Naval Research Laboratory (United States)
NSF National Science Foundation (United States)
NWS National Weather Service (NOAA, U.S.)

ODGI ozone-depleting gas index
ODSs ozone-depleting substances
OHP Observatoire de Haute-Provence (France)
OMI Ozone Monitoring Instrument
OMPS Ozone Mapping and Profiler Suite (NPOESS)
OMS Observations of the Middle Stratosphere
OSIRIS Optical Spectrograph and Infrared Imaging System
PEM Particle Environment Monitor
POAM Polar Ozone and Aerosol Measurement
POES Polar Orbiting Environmental Satellites
PSCs polar stratospheric clouds
PTB Physikalisch-Technische Bundesanstalt (Germany)
QBO quasi-biennial oscillation
SAGE Stratospheric Aerosol and Gas Experiment
SAM Stratospheric Aerosol Measurement
SBUV Solar Backscatter Ultraviolet
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SHADOZ Southern Hemisphere Additional Ozonesonde (Network)
SOLSTICE Solar Stellar Irradiance Comparison Experiment
SPARC Stratospheric Processes and Their Role in Climate