UNITED STATES OF AMERICA

OBSERVATIONAL ACTIVITIES

Column Measurements

Ozone

US Satellites

Long-term dataset of total column ozone continues to be produced from the SBUV/2 instruments on the NOAA polar orbiting environmental satellites (NOAA-16, 17, 18 & 19). The SBUV record extends back to April, 1970 with a data gap between 1974 and 1978. The TOMS total ozone series started in October 1978 and ended in December 2006. All TOMS data have been reprocessed by applying an empirical correction based on the SBUV/2 record. Hence the SBUV total ozone record is considered the primary record for trend analysis. (NASA, NOAA)

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. (NASA)

Ozone Estimates from Infrared Sensors

NOAA produces estimates of total ozone by using information in the 9.7 micron channel of HIRS. The retrieval products are combined with SBUV/2 information to generate global maps of column ozone. See http://www.osdpd.noaa.gov/PSB/OZONE/TOAST/. (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 16 locations, including 10 national sites in the continental U.S. and Hawaii. Five other sites are collaborative international programmes (South Pole, Perth, Lauder, Samoa, OHP). Data are used for satellite validation and 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)

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).

NOAA-EPA Ultraviolet Brewer (NEUBrew) Network
NOAA and the EPA have established a network of Brewer Mark IV UV spectrometers that were deployed at six U.S. locations. The six stations have been operating continuously since the fall of 2006 with funding from the EPA and NOAA. The network Brewers http://esrl.noaa.gov/gmd/grad/neubrew/ take a daily average of 25 total column ozone measurements. (NOAA, EPA)

The total ozone column and Umkehr profile daily data from the NOAA-EPA Brewer and NOAA Dobson network, as well as ozone-sounding profiles will be used in the validation activities of the total column ozone data collected by the soon-to-be-launched satellite under the NOAA's National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) and the following Joint Polar Satellite System JPSS program. The NPP launch is scheduled for October 25, 2011. The Ozone Mapping and Profiler Suite (OMPS) on board NPP will monitor the global distribution of ozone on the daily basis. Much of the work in preparation for the validation activities include algorithm development, data quality control, instrument automation, calibration, trending analysis and maintenance, data archiving, and web page and satellite validation updates. (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, and sulphur dioxide. (NASA)

GOME-2 Instrument on MetOp-A
NOAA is working to implement additional operational products from the GOME-2 Level 1 data. These include aerosols, nitrogen dioxide, and sulphur dioxide. (EuMetSat/NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
This international ground-based remote-sensing network was formed to provide a consistent, standardized set of long-term measurements of atmospheric trace gases, 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 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, NO2, BrO, and OClO; FTIR spectrometers for a wide variety of source and reservoir compounds; and Dobson and Brewer

spectrometers for ozone. Additional information on the NDACC is available at http://www.ndacc.org. (NASA, NOAA)

Profile Measurements

Ozone

BUV Instrument Series (10 Instruments)

The SBUV/2 instruments on NOAA satellites continue to measure ozone vertical profiles in the upper stratosphere (1-30 hPa) with vertical resolution varying from 6 to 8 km. (This technique also provides accurate estimates of the partial column ozone between 30-700 hPa.) This data record extends back to April 1970, with a data gap between 1974 and 1978. Profile datasets are also being produced from the OMI instrument. OMI provides full daily coverage compared to SBUV which provides daily coverage in approximately two weeks. OMI profiles have similar information content as SBUV in the upper stratosphere (1-30hPa) but have higher vertical resolution (~10 km) at lower altitudes. The long-term ozone profile record from the SBUV/2 instrument series has been significantly affected by drifting orbits. Analysis of these effects is currently in progress. NASA has reprocessed data from the entire BUV instrument series, including OMI, using a consistent algorithm (version 9). Current and archived Version 8 ozone profile data are being used in the NOAA/NCEP Climate Forecast System Reanalysis and Reforecast, a successor of the NCEP/DOE Reanalysis 2. (NOAA, NASA)

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 will be resumed in 3-4 years from the existing SAGE-III instrument when it is deployed on the International Space Station. (NASA)

Aura Satellite Instruments

Ozone profiles from 0.5- 200 hPa with about 3 km vertical resolution have been produced by the Microwave Limb Sounder (MLS). The high resolution dynamic limb sounder (HIRDLS), which suffers from a partial obscuration of the field of view that occurred during launch, has recently reprocessed the ozone profile data. These data have 1 km or higher vertical resolution in the stratosphere. This data series ended in 2008. Two other instruments on Aura Tropospheric Emission Spectrometer (TES) and OMI produce lower vertical resolution ozone profiles but they measure lower into the troposphere than either HIRDLS or MLS. A new activity to combine the radiances from TES and OMI to obtain better profile information in the troposphere is ongoing. (NASA)

Balloonborne Measurements

NOAA routinely conducts ozonesonde measurements at nine locations (5 domestic, 4 international). NASA, in collaboration with NOAA and numerous international partners, supports the operations of the Southern Hemisphere Additional Ozonesonde (SHADOZ) network of ozonesonde launches from several locations in the tropics and southern

subtropics. NASA also flies ozonesondes and an ozone photometer as components of moderate-scale balloon campaigns that also utilize a submillimeter/millimeter-wave radiometer, an infrared spectrometer, and a far-infrared spectrometer. (NOAA, NASA)

Dobson Umkehr
Profiles are obtained from six automated Dobson instruments using the Umkehr technique (Lauder, Perth, Hawaii, Boulder, OHP, Fairbanks). Through collaboration between NASA and NOAA, a new ozone-profile algorithm has been developed to process Dobson Umkehr data. This algorithm is similar to the SBUV V8 algorithm, and has been optimized for deriving trends. (NOAA, NASA)

Brewer Umkehr
Brewer Mark IV UV spectrometers were deployed at six U.S. locations in the last half of 2006 with funding from the EPA and NOAA. Total column ozone and ozone profiles using the Umkehr technique are regularly derived from these measurements. All raw and processed data are posted on the open access NOAA/NEUBrew web-site: http://esrl.noaa.gov/gmd/grad/neubrew/. 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. It is also made available for the Brewer Umkehr data processing world-wide and has been implemented at several stations (Check republic) . However, due to lack of availability of the Brewer raw radiance data at the WOUDC archive, it has not been possible to reprocess all currently operational Brewer Umkehr data using a consistent algorithm. The WMO SAG-O3 and the WOUDC has made an effort to reach out to operators of the Brewer instruments and offered to archive raw data (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
NDACC lidars (whose retrievals are limited primarily to the stratosphere) and microwave radiometers (whose retrievals are limited primarily to the stratosphere) are providing long-term ozone profile measurements. Ozonesondes routinely launched at many NDACC stations also provide ozone-profile data. In addition, several of the high-resolution FTIR spectrometers are beginning to yield ozone-profile information. (NASA, NOAA)

Brewer Umkehr
NOAA-EPA Brewer Spectrophotometer UV and Ozone Network
The NOAA/EPA Brewer Spectrophotometer Network (NEUBrew) consists of six stations located in the western, central and eastern United States. Brewer MKIV instruments provide twice daily ozone vertical profiles based on Umkehr scans. Data is available online with a latency of one day. http://esrl.noaa.gov/gmd/grad/neubrew/ (EPA, 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 will be resumed in 3-4 years from the existing SAGE-III instrument when it is deployed on the International Space Station. (NASA)

Aura Satellite Instruments

The four Aura instruments provide profile measurements of numerous atmospheric constituents and parameters in the stratosphere and troposphere. MLS is delivering profiles of temperature, H2O, ClO, BrO, HCl, OH, HO2, HNO3, HCN, N2O, and CO. HIRDLS retrieved profiles of temperature, O_3, HNO_3, aerosols, CFC11, and CFC12 at1.2 km vertical resolution and will soon deliver profiles of H_2O, CH_4, N2O, and NO_2, TES is providing limited profile information for O_3, CO, H_2O, and HDO from its nadir viewing owing to it's high spectral resolution. (NASA)

Combined NASA Satellite Data

Past global space-based measurements of atmospheric composition (e.g., from SAGE, SBUV, UARS, and TOMS) are being extended via observations available from the Aura satellite and other A-Train satellites. These new measurements are providing an unprecedented global characterization of atmospheric composition and climate parameters. Efforts are underway to produce merged data sets connecting these recent measurements to past satellite observations of the atmosphere. (NASA)

Balloonborne Water Vapor Measurements

NOAA monitors upper tropospheric and stratospheric water vapor using cryogenic, chilled-mirror hygrometers that are flown with ozonesondes on a biweekly schedule in Boulder, CO, and at Lauder, New Zealand, in collaboration with NIWA, and monthly at Hilo, Hawaii starting in 2010. Water-vapor profiles also are obtained on a campaign basis in Indonesia and, the Galapagos. NASA supports the flights of several balloon instruments (primarily on a campaign basis) capable of providing profile information for numerous atmospheric constituents. (NOAA, NASA)

Airborne Measurements

NASA-sponsored airborne campaigns, using both medium- and high-altitude aircraft, have been conducted with NOAA, NSF, and university partnerships, with a focus on satellite validation and scientific study of ozone and climate change. While designed more for process study than for trend determinations, the airborne measurements have provided a unique view of changes in atmospheric composition at various altitudes in response to source forcings. The most recent campaigns are the GLOPAC mission using the new NASA Global Hawk and the MACPEX campaign using the NASA WB57 have concentrated on the processes that control the concentrations source gases in the upper troposphere and stratosphere with a goal of understanding the effects on stratospheric ozone. The international POLARCAT campaign with components from NASA, NOAA, DOE, and NSF was executed looking at atmospheric processes in the Arctic troposphere. (NASA, NOAA, NSF)

Researchers have completed three deployments of the HIAPER Pole-to-Pole Observations of Greenhouse Gases (HIPPO) mission, with two further deployments scheduled for 2011. HIAPER – the High-performance Instrumented Airborne Platform – is the National Science Foundation's Gulfstream V research aircraft. The HIPPO program is providing unprecedented seasonal pole-to-pole snapshots of greenhouse gases and ozone-depleting gases in the troposphere, data that will permit climate modelers to verify models and improve models projections of future climate change and the future ozone layer. The program will provide the *first* comprehensive, global survey of atmospheric trace gases, covering the full troposphere in all seasons and multiple years. (NSF; NOAA)

Among the objectives of the Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) airborne field campaign is an extensive intercomparison of instruments for measuring atmospheric water vapor, as well as understanding the properties of cirrus clouds at mid latitudes. The MACPEX campaign took place in March and April 2011 and is focused on central North America. (NASA and NOAA)

New Aircraft Technologies: Unmanned Aircraft Systems (UAS)
NASA Dryden has obtained new resources in Unmanned Aircraft Systems including General Atomics Aeronautical Systems (GAAS) Altair (leased), Predator-B (IKHANA), and three Northrop Grumman Global Hawks. The first civilian scientific use of the Global Hawk UAS was the Global Hawk Pacific Experiment (GloPac) and was completed in May 2010. There were instruments on board that measured ozone and ozone depleting. GloPac completed a series of UAS flights over the Pacific bearing a variety of instruments to measure ozone, aerosols, and other substances. Three successful science flights showed the impressive range (9700nm), hazardous duty over the Arctic, altitude (65,200 ft) and duration (28.6 hours) capability of the UAS, including one flight from Dryden to the North Pole and back. (NASA, 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. (NASA, NOAA, DoD/NRL)

Special campaigns to validate satellites
NASA recently (March/April 2011) sponsored a ground-based campaign with a number of DOAS instruments from Fairbanks Alaska. The goal was to compare direct and all sky angle DOAS observations with the OMI instrument to understand the high values of BrO retrieved by OMI, in conjunction with Ozone observations. (NASA)

Ground-Based In Situ Measurement Networks
Both NASA and NOAA support in situ sampling of ozone- and climate-related trace gases via networks of flask sampling and real time in situ measurements. These data provide the basis for determining global tropospheric trends and for computation of effective equivalent chlorine (EECl) in the atmosphere. The NASA Advanced Global

Atmospheric Gases Experiment (AGAGE) network has the longest continuous observational record for such species, extending back almost three decades for some CFCs. New NASA and NOAA instrumentation permits the monitoring of many of the CFC replacements, thereby enabling a tracking 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. (NOAA, NASA)

UV Irradiance Measurements

Broadband Measurements

SURFRAD Network

Seven Surface Radiation (SURFRAD) sites operate Yankee Environmental Systems, Inc. (YES) UVB-1 broadband radiometers. The ISIS network of solar measurements includes broadband Solar Light 501 UVB biometers 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 calibration reference Solar Light 501 UVB biometers. Several other broadband UV radiometers also are operated at the Table Mountain site. These include a Scintec UV radiometer, two types of Kipp & Zonen broadband UV radiometers, an EKO UV radiometer, and a Solar Light 501 UVA biometer. (NOAA)

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 also are operated and can be used to interpret accurately the broadband 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)

Narrowband Filter Measurements

Central Ultraviolet Calibration Facility

Currently instruments that have been operating at the Table Mountain test facility in Colorado are a Biospherical Instruments GUV-511 UV radiometer, a Smithsonian 18-channel UV narrow-band radiometer, and two YES UV-MFRSRs. The Smithsonian instrument was removed from operation in 2010 and the two YES UV-MFRSRs were removed from operation at Table Mountain in 2009. A YES UV-MFRSR is deployed at

the Central Ultraviolet Calibration Facility's High-Altitude Mountain Research Station at Niwot Ridge, Colorado. (NOAA)

USDA UVB Monitoring and Research Programme (UVMRP)
UV-MFRSRs deployed within this 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) (USDA)

NEUBrew Network
Each NEUBrew station has a Yankee UV-MFRSR and visible MFRSR collocated with the Brewer spectrophotometer. (EPA, NOAA)

NOAA Antarctic UV Monitoring Network
NOAA/GMD has assumed operations of the Antarctic portion of the former NSF UV Monitoring Network. There are Biospherical Instruments (BSI) GUV-511 moderate bandwidth multi-channel radiometers deployed at two of the Antarctic stations, McMurdo and Palmer and a GUV-541 radiometer deployed at the South Pole. (NOAA)

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. (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)

NSF (AON Grant to the University of Chicago)UV Monitoring Network
BSI SUV-100 high-resolution scanning spectroradiometers are deployed at; San Diego, California; (sub-tropical location) and Barrow, Alaska; A BSI SUV-150B spectroradiometer is deployed at the Summit, Greenland. (NSF)

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.

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/EPA 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, EPA)

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 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 and TOMS data after applying soft and hard calibrations. (NOAA)

Dobson Network

World Standard Dobson No. 83 is maintained at NOAA/ESRLGMD as part of the World Dobson Calibration Facility, and regularly participates in international intercomparisons of regional and national standards. Since 2006, intercomparisons have been held in Melbourne, Australia; Tsukuba, Japan; Buenos Aires, Argentina (twice) and Irene, South Africa. Investigations into the correct characterization of the Dobson instruments are continuing.(NOAA)

Ozone Soundings

NOAA calibrates balloons according to the developed procedures. It participates in international intercomparisons of ozone sonde measurements (chamber tests) and develops methods to resolve instrument related differences. It is done to homogenize 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 Ozone Sondes, Research Centre Juelich Institute for Chemistry and Dynamics of the Geosphere: Troposphere. These chamber calibration tests were held in 1996 and 2000. The last calibration campaign was a field (balloon) project at Laramie Wyoming called BESOS in 2004: http://croc.gsfc.nasa.gov/besos/ (NASA, NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)

Several operational protocols have been developed to insure 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 ppt and ppb levels for the major and minor long-lived ozone-depleting gases. In addition, both networks are developing reliable calibration scales for the short-lived halogen-containing gases that have been introduced as CFC replacements. (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. 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/EPA 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. 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. (EPA, NOAA)

RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozone

Merged Satellite Datasets

Since there are often biases between different satellite instruments it is necessary to create consistent long-term data sets by cross-calibration of different records when they overlap and by using ground-based data (including NOAA ground based networks) when they do not. Such data sets have been produced using TOMS and SBUV total column ozone and profile records. Several new efforts to provide long term merged data sets of ozone columns and stratospheric profiles of ozone and other trace gases are ongoing. (NASA, NOAA)

Ozone Depletion & Recovery

Statistical analysis of the Umkehr ground based data, FTIR and merged SBUV profile ozone data set from 1979 to June 1997 shows the largest negative trends in the upper stratosphere (35-45 km) at middle latitudes at -10 % per decade at both Southern and

Northern Hemispheres. The middle stratosphere (20-25 km) trends are derived from ozonesonde, satellite and FTIR records indicate -7 % per decade decline at both Southern and Northern middle latitudes and less negative trends are found at lower stratosphere (12-15 km) at -9% per decade in the Northern Hemisphere (no information for Southern hemisphere)These trends are in general agreement with previous profile trend estimates from satellite and ground-based records. Since 1997, ozone between 12 and 15 km (lower stratosphere) in the Northern middle latitudes has increased at a larger rate that is expected based on the decline in the ODS abundances. The middle and upper stratospheric ozone has been increasing at some locations at the Northern middle latitudes since 1997, but it is not observed globally. Ground-based and satellite ozone measurements taken at the upper stratosphere since 1997 also indicate positive trends that are consistent with leveling off of the ODS concentrations. However, the derived trends are not always statistically significant, since the natural ozone variability, stratospheric cooling and measurement uncertainties make analyses less certain.

Total ozone levels have remained relatively constant over the last decade (1998-2007). Northern midlatitude ozone reached a minimum of 5.5% below 1979-1980 mean values in 1993 because of forcings from the Mt. Pinatubo eruption and the solar cycle minimum. From 1992-1998 total ozone levels recovered from the effects of the Mt. Pinatubo eruption to about 3% below the 1979-1980 values. In the years since, the northern midlatitude total ozone has been highly variable, but has increased on average, to about 3.5% below the 1964-1980 values. Southern midlatitude ozone decreased steadily until the late 1990s, and has been nearly constant since at 6% below 1964-1980 average values. There are no significant ozone trends over the tropics. (NASA, NOAA)

Antarctic Ozone Hole

Since approximately 1997, the underlying trend of Antarctic ozone (i.e., the trend after removal of the effect of natural variability in vortex temperatures) has been zero. This cessation of the downward trend in ozone is consistently seen at 60ºS to 70ºS in TOMS total ozone columns, SAGE/HALOE stratospheric columns, ozonesonde ozone columns at Syowa (69ºS), and Dobson total column measurements at 65ºS and 69ºS. The cessation of the downward trend is primarily a result of the saturation of the losses, and not due to decreasing levels of stratospheric chlorine. Antarctic ozone depletion is primarily controlled by inorganic chlorine and bromine levels (effective equivalent stratospheric chlorine, EESC), and secondarily controlled by Antarctic stratospheric temperatures. Fits of various ozone hole diagnostics to temperature and chlorine and bromine levels suggest that the ozone hole is very slowly improving. However, detection of this slow improvement is masked by the large natural variability of the Antarctic stratosphere. (NASA)

Ozone Maps

Daily maps of total ozone and monthly total ozone anomalies are being produced, as well as routine updates of the SBUV-2 total ozone change utilizing a statistical model that includes the 1979 to 1996 trend, the trend-change in 1996, plus ancillary variables of solar variation (f10.7), QBO, and AO/AAO. In addition, twice-yearly (Northern and

Southern Hemisphere) winter summaries of selected indicators of stratospheric climate are generated. (NOAA/CPC)

Ozone-Related Gases and Variables

Stratospheric Ozone - Climate Connection

A recent analysis of observations has been combined with radiative transfer considerations to show that changes in stratospheric water vapor have made significant contributions to recent decadal rates of warming of the Earth's surface climate. Stratospheric water vapor concentrations decreased by about 10% after the year 2000. The study shows that this acted to slow the rate of increase in global surface temperature over 2000-2009 by about 25% compared to that which would have occurred due only to carbon dioxide and other greenhouse gases. The findings show that stratospheric water vapor represents an important driver of decadal global surface climate change. (NOAA)

UV

Instrumentation

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 and is on-going.

UV Trends

SURFRAD Network

A paper co-authored with Colorado State University (CSU) UVB researchers analyzing trends in solar UV irradiance at eight stations in the CSU-USDA network stations over the period 1995 to 2006 has been published in JGR Atmospheres (2008). Both positive and negative tendencies were detected ranging from –5% to +2% per decade. However, inter-annual variability was between 2 and 5%. (NOAA)

USDA UVB Monitoring and Research Programme (UVMRP)

The multidecadal change of ozone from 1979 to 2005 was investigated using four UVMRP ground stations, WA01, CO01, MD01, and AZ01. The UV index has increased at the four stations while total ozone has decreased in continental USA. Spatial distribution of ozone shows substantial variation from coastal zones to the Midwest, yet the tendency toward recovery of the ozone layer in the continental USA cannot be fully confirmed. (Gao et al., 2010)

Scientists analyzing UV-B flux over the continental USA using NASA TOMS data and UVMRP network data found that "ground-based in-situ measurements, like those from the UVMRP network, are indispensible in monitoring atmospheric status and not totally replaceable by space-based remote sensing retrievals". The incorporation of these ground-based measurements with current satellite algorithms has improved UV retrievals for the latest satellite package (OMI). (Xu et al., 2010) (USDA)

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-Layer Recovery Estimates

Equivalent effective stratospheric chlorine (EESC) is a convenient parameter to quantify the effects of halogens (chlorine and bromine) on ozone depletion in the stratosphere. EESC has been extensively used to evaluate future scenarios of ozone-depleting substances (ODSs) on the stratosphere. Research has led to a new formulation of EESC that provides revised estimates of ozone layer recovery. The work shows that ozone levels will recover to 1980 levels in the year 2041 in the midlatitudes, and 2067 over Antarctica, assuming adherence to international agreements that regulate the use of ODSs. The researchers assessed the uncertainties in the estimated recovery times. The midlatitude recovery of 2041 has a 95% confidence uncertainty from 2028 to 2049, while the 2067 Antarctic recovery has a 95% confidence *uncertainty from 2056 to 2078.* (NOAA and NASA) In recent research, hypothetical reductions in future emissions of ODSs and nitrous oxide (N_2O) have been evaluated in terms of effects on EESC, globally-averaged total column ozone, and radiative forcing through 2100. The findings show that due to the established success of the Montreal Protocol, these actions can have

only a fraction of the impact on ozone depletion that regulations already in force have had. If all anthropogenic ODS and N_2O emissions were halted beginning in 2011, ozone is calculated to be higher by about 1 to 2% during the period 2030–2100 compared to a case of no additional restrictions. (NOAA)

Antarctic and Arctic Ozone Loss

Contrasts between ozone depletion at the poles have been investigated in a recent study that used available long balloon-borne records and ground-based records that cover multiple decades. Antarctic ozone observations reveal widespread and massive local depletion in the heart of the ozone "hole" region near 18 km, frequently exceeding 90%. The depth of the ozone losses in the Arctic are considerably smaller, and their occurrence is far less frequent. However, the 2011 Arctic Polar vortex was uncharacteristically stable and cold allowing record stratospheric ozone depletion to occur in the late winter and early spring as reported by the Alfred Wegener Institute for Polar and Marine Research (AWI). This was based on their analysis from an ongoing international network of about 30 cooperative ozone sounding stations in the Arctic and Subarctic. Similar studies are being done with satellite data from the MLS instrument. (NOAA, NASA)

SPARC Initiative on Halogen Chemistry and Polar Ozone Loss

NASA and NOAA scientists are working with international colleagues to examine the effects of new laboratory data on the photolysis rate of the ClO dimer (ClOOCl) on the quantification of polar ozone depletion. These efforts were coordinated under a new SPARC initiative on "The Role of Halogen Chemistry in Polar Ozone Loss". The work resulted in publication of a report that gives a comprehensive review of existing and ongoing laboratory studies, atmospheric observations, and modeling activities. (NASA, NOAA)

Decadal Analyses and Simulations

Simulated fields of atmospheric constituents derived using NASA's Global Modeling Initiative (GMI) Chemical Transport Model (CTM) are being used in comparison with Aura data to evaluate the transport and photochemical processes in the upper troposphere and lower stratosphere. These simulations are being used along with trajectory calculations to interpret aircraft measurements of chlorofluorcarbons and to develop better estimates of their atmospheric lifetimes. In addition, 25-year time-slice simulations have been done in which specific years (in terms of halogen amounts) are repeated in order to get better mean distributions and estimates of variability for ozone and relevant chemical compounds. These simulations have been included in the Chemistry Climate Model Validation (CCMVal) exercise and were part of the 2010 WMO/UNEP Ozone Assessment. (NASA)

Ozone-Related Gases and Variables

Environmental Properties of Atmospheric Gases

Chemistry Related to Ozone Depletion

Laboratory work determined the chlorine monoxide radical (ClO) yields in the reaction of $O(^1D)$ with Cl_2, HCl, chloromethanes, and chlorofluoromethanes. The formation of the reactive ClO is particularly important in the stratosphere due to its influence on ozone

abundance (e.g., the Antarctic ozone hole) through its participation in the ClO*x* catalytic ozone destruction cycle as well as the ClO dimer (Cl2O2) cycle, which plays an important role in polar stratospheric ozone chemistry. (NOAA)

Laboratory work has been completed on the kinetics of the ClO + ClO reaction over a range of temperatures and pressures. Rate constants obtained are larger than current recommended values, and modeling work will be done to determine the impact of the new results on ozone-related chemistry in the stratosphere. The reaction is a key step in catalytic cycles that destroy stratospheric ozone in both polar and non-polar regions. (NOAA, NASA).

The abundance and atmospheric lifetimes of nitrous oxide (N_2O) and carbon tetrachloride (CCl_4) are important to understanding stratospheric ozone recovery and climate change as well as the linkage between these issues. Laboratory work has determined updated values for the UV absorption cross sections of these gases, and to determine the temperature dependence of these values, for which there are few previous studies. The information will help reduce the uncertainties in calculations of the atmospheric lifetimes of these species, which are inputs to atmospheric models. The reduced uncertainties in the N_2O and CCl_4 absorption cross section data, and in photolysis lifetimes, will enable improved model calculations of ozone recovery. (NOAA)

Chemistry of Potential ODS Replacements

Laboratory and theoretical work has provided information about the ozone-layer friendliness and climate friendliness of candidate replacements for ozone-depleting substances used for a variety of societal applications such as refrigeration, air conditioning, electronics manufacture, and fire protections. Early information about the suitability of a proposed substance is needed by industry before costly development investments are made. These results provide important input parameters for model calculations of the future vulnerability of the ozone layer, and are used together with industrial production-and-use information to analyze the growth of such chemicals in the atmosphere. (Recent studies have focused on unsaturated partially fluorinated compounds, as well as methoxy perfluorinated heptenes. A modeling study of the degradation products of a potential substitute for HFC-134a is in progress. A particular focus on the yield of trifluoroacetic acid (TFA), a compound that has possible ecological implications. (NOAA)

The Montreal Protocol with its subsequent amendments and adjustments have led, and will likely continue to lead, to the replacement of chlorofluorocarbons (CFCs), Halons (brominated chemicals) and hydrochlorofluorocarbons (HCFCs) with chemicals that are shorter lived or do not contain either chlorine or bromine. Over the past two decades, potential substitutes with lifetimes as short as a few days have been considered. Researchers have developed a new approach for calculating the fraction of very-short lived substances (VSLS) emitted at the surface (and their degradation products) that reach the stratosphere, and have used those fractions to estimate Ozone Depletion Potentials (ODPs) of several short-lived compounds. Calculated values show large regional and seasonal variability. (NOAA)

A recent study has provided the first calculation of the Ozone Depletion Potential (ODP) of nitrous oxide (N_2O), a gas long recognized as the primary source gas for nitrogen oxides in the stratosphere. The concept of the ODP, which is used extensively in characterizing the relative roles of halogen-containing ODSs, had not previously been applied to N_2O. The study's analysis uses the ODP to show that nitrous oxide has now become the largest ozone-depleting substance emitted through human activities, and is expected to remain the largest throughout the 21st century. (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 3 Aura instruments (OMI, MLS, and HIRDLS)), past TOMS instruments, 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 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. Brewer Umkehr data are available for 6 NEUBrew sites at the http://esrl.noaa.gov/gmd/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-EPA network are available at the web site http://esrl.noaa.gov/gmd/grad/neubrew/ (NOAA, EPA)

Maps
All daily SBUV/2 total ozone hemispheric analyses generated from NOAA-16, NOAA-17, and NOAA-18 observations are available on the Climate Prediction Center's stratospheric web pages at http://www.cpc.ncep.noaa.gov/products/stratosphere/sbuv2to/. The raw data from the SBUV/2 are available from NESDIS. Additionally, the NCEP/GFS total ozone analysis and forecast fields out to five days are available at http://www.cpc.ncep.noaa.gov/products/stratosphere/strat_a_f/. (NOAA/CPC)
Daily maps from the Version 8 total ozone algorithm processing of GOME-2 data are available from NOAA Operations at http://www.osdpd.noaa.gov/PSB/OZONE/gome.html (NOAA/CPC)

Assessments
NASA and NOAA scientists played key roles as reviewers and authors for various chapters in the 2010 WMO/UNEP Scientific Assessment of Ozone Depletion, mandated under the provisions of the Montreal Protocol. Other scientists from the U.S. and around the world contributed to the report, which was given to the Parties to the Montreal Protocol in late 2010 and is available in print form and on the UNEP and NOAA websites. (NOAA, NASA)

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)

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

Long-term data from the NOAA network are updated every six months on the website (http://www.esrl.noaa.gov/gmd/) and submitted annually to 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 (firn-air studies, ocean flux studies), are posted shortly after mission completion. Data on very short-lived gases from ocean research cruises are posted for use on the NOAA/GMD website. (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), based on Effective Equivalent Chlorine (EECl) measured globally in the NOAA network, has been implemented. EECl and WMO/UNEP ozone-depleting gas scenarios are used to estimate the progress towards ozone recovery (ODGI = 100 on January 1, 1994 when EECl reached its maximum value and 0 at recovery). The method was published, where the results are updated annually and posted at http://www.esrl.noaa.gov/gmd/odgi. (NOAA)

Relevant Scientific Papers (2008-present)

Aceltuno, P., F. Achard, C. Acheberger, S.A. Ackerman, E.J. Alfaro, R. Allan, J.A. Amador, J. Antonov, I Ashik, S.M Attaher, J. Baez, L.S. Bal, R.A. Ballard, M.O Baringer, S. Barreira, E. Barripedro, E. Barholome, L.M Beal, J.J. Behrenfeld, G.D. Bell, M.A Bell, N. Bellouin, A.S. Belward, R. Dennartz, R. Benson, U.S. Bhatt, I. Bhattachary, M. Bidegain, P. Bissolli, E. Blake, D. Boudet, L.C. Bowling, J.E. Box, T.P. Boyer, A.B. Brink, D.H Browmwich, R. Brown, H.L. Bryden, O.N. Bulygina, B. Calderon, S.J. Camargo, J. Cappelen, E. Carmack, D. Chen, J.R. Christy, C.A.S. Coelho, S. Colwell, J.E. Comiso, S.A. Cunningham, J.P. Cupo, V. Cutie, V. Davydova-Belitskaya, D. Decker, C. Derksen, H. Diamond, A.G. Dickson, N. DiGirolamo, E. J. Dlugokencky, K. Dohan, G. S. Dutton, J. W. Elkins, H.E. Epstein, R.A. Feely, B.M. Fekete, C. Fenimore, X. Fettweis, R. Fogt, C.K Folland, C. Fonseca-Rivera, M.J. Foster, I. Frolov, M.S. Gamedze, S. Gill, K.L. Gleason, N. Gobron, S.B. Goldenberg, G.J Goni, I. Gonzalez, J. Gottschalck, C.C. Gouvela, C.P Guard, Y. Guo, L. Haimberger, D. Hall, M.S. Halpert, E. Hanna, G. Harris, J. Haywood, A.K. Heidinger, R.R. Helm, M. Hernandex, K.A. Hilburn, J. Hirschi, E. James, G.J. Jia, W.E. Johns, G.C. Johnson, A. Jones, G.S. Jones, K. Kabidi, T.O. Kanzow, J.J. Kennedy, A.A. Khalil, A. Kholodov, M. Khoshkam, T. Kimberlain, J.A. Knaff, J. Knight, N.N. Korshunova, D.P. Kratz, R. Krishfield, A. Kruger, M.C. Kruk, M. L'Heureux, R.B. Lammers, M.A. Lander, C.W. Landsea, B. Lapinel, R. Lawford, H. Lee, G. Leon, E. Leuliette, D.H. Levinson, S. Levitus, J.M. Levy, H. Liu, D. Long, H.R. Longworth, R. Lumpkin, J. Luo, J.M. Lyman, A.M. Macdonald, B.C. Maddux, G. Malkova, S. Marchenko, J.A. Marengo, S. Maritorena, J. Marotzke, R. Martinez, A. Mascarenhas, R.A. Massom, C. McBride, S. McGree, F. McLaughlin, M. McPhee, C.A. Mears, M.A. Medany, W Meier, C.S. Meinen, M.A. Merrifield, A.S. Mhanda, L. Miller, G.T. Mitchum, A.J. Monaghan, S. A. Montzka, J. Morison, T. Mote, A.B. Mullan, C. Mutasa, R.S. Nerem, P.A. Newaman, S.V. Nghiem, L. Njau, R.T. O'Malley, N. Oberman, A Obergon, L. Ogallo, C. Oludhe, B. Osman-Elsha, J. Overland, D. Pabon, M. Palmer, D.E. Parker, R. Pasch, M.S. Pelto, R. Perez-Suarez, D.K. Perovich, T.C. Peterson, A.B. Pezza, D. Phillips, I. Polyakov, A. Proshuntinskey, J. Quintana, A. Quintero, F. Rahimzadeh, M. Rajeevan, D. Rayner, M.K. Raynolds, V.N. Razuvaev, P. Reid, J. Revadekar, R.W. Reynolds, J. Richter-Menge, E.R. Rivera, D.A. Robinson, M. Rogers, V. Romanovsky, F. Romero-Cruz, J. Ronchail, S. Rossi, W.B. Rossow, M. Rusticucci, C.L. Sabine, M.J. Salinger, A. Sayouri, A.A. Scaife, T.A. Scambos, J. Schemm, C. Schmid, R. C. Schnell, R. Sebbari, D.J. Seidel, S. Sensoy, M. Sharp, A.

Shiklomanov, K. Shimada, M. Shulski, D.A. Siegel, M. Skansi, V. Sokolov, J.M. Spense, P.W. Stackhouse, S. Stammerjohn, M. Steele, S.E. Stephens, T.S. Stephenson, P.A. Stott, T. Takahashi, M.A. Taylor, M. Tedesco, W.M. Thiaw, P.W. Thorne, M.L. Timmermans, J. Toole, B.C. Trewin, R.M. Trigo, J. Turner, R. van de Wal, M. van den Broeke, L. Vincent, D.A. Walker, J. Walsh, A. Walther, J. Wang, L. Wang, L. Wang, M. Wang, S. Wang, X. Wang, R. Wanninkhof, B. Ward, A.B. Watkins, M. Weber, T. Weingartner, R.A. Weller, J. Weyman, R. Whitewood, A.C. Wilber, J.K. Willis, G. Wolken, T. Wong, R. Woodgate, P.L. Woodworth, Y. Xue, L. Yu, W. Zhakata, L. Zhang and S. Zhao (2009), State of the Climate 2008, *Bulletin of the American Meteorological Society*, *90*(8), S13+.

Arndt, D.S., M.O. Baringer, and M.R. Johnson, Eds., State of the Climate in 2009. ***Bull. Amer. Meteor. Soc***., 91 (7), S1-S224, 2010.

Augustine, J. A., G. B. Hodges, E. G. Dutton, J. J. Michalsky and C. R. Cornwall (2008), An aerosol optical depth climatology for NOAA's national surface radiation budget network (SURFRAD), *Journal of Geophysical Research Atmospheres*, *113*(D11204), 10.1029/2007JD009504.

Aydin, M., S.A**.** Montzka, M. O. Battle, M.B. Williams, W. J. DeBruyn, J. H. Butler, K. R. Verhulst, C. Tatum, B. K. Gun, D. A. Plotkin, B.D. Hall, and E.S. Saltzman, Post-coring entrapment of modern air in some shallow ice cores collected near the firn-ice transition: Evidence from CFC-12 measurements in Antarctic firn air and ice cores (2010), *Atmos. Chem. Phys*., 10, 5135-5144.

Baasandorj, M., G. Knight, V.C. Papadimitriou, R.K. Talukdar, A.R. Ravishankara, and J.B. Burkholder, 2010, Rate coefficients for the gas-phase reaction of the hydroxyl radical with CH_2=CHF and CH_2=CF_2, *J. Phys. Chem. A*, *114* (13), 4619-4633, doi:10.1021/jp100527.

Bencherif, H., et al. "Analysis of a rapid increase of stratospheric ozone during late austral summer 2008 over Kerguelen (49.4S, 70.3E)," Atmos. Chem. Phys. 11, 363-373, 2011.

Barnes, J. E., T. Kaplan and H. Vomel (2008), NASA/AURA/Microwave Limb Sounder Water Vapor Validation at Mauna Loa Observatory by Raman Lidar, *Journal of Geophysical Research.*

.

Barnes, J., T. Kaplan, H. Vömel and W. G. Read (2008), NASA/Aura/Microwave Limb Sounder water vapor validation at Mauna Loa Observatory by Raman lidar, *Journal of Geophysical Research-Atmospheres*, *113*(D15), D15S03, 10.1029/2007JD008842.

Biago, C.D., et al. "Evolution of temperature, O3, CO, and N2O profiles during the exceptional 2009 Arctic major stratospheric warming as

observed by lidar and millimeter-wave spectroscopy at Thule (76.5N,

68.8W), Greenland," J. Geophys. Res. 115, D24315, doi:10.1029/2010JD014070, 2010

Bönisch, H., A. Engel, T. Birner, P. Hoor, D.W. Tarasick, and E.A. Ray, 2010, On the structural changes in the Brewer-Dobson circulation after 2000, *Atmos. Chem. Phys. Discuss.*, *10,* 28399-28430, doi:10.5194/acpd-10-28399-2010.

Boucher, O., J. Daniel, D. Lee, N.J. Muthama, B. O'Neill, G.-K. Plattner, and S. Smith, Meeting Report of the Expert Meeting on the Science of Alternative Metrics, 75 pp., Oslo, Norway, (2009).

Boxe, C. S., J. R. Worden, K. W. Bowman, S. S. Kulawik, J. L. Neu, W. C. Ford, G. B. Osterman, R. L. Herman, A. Eldering, D. W. Tarasick, A. M. Thompson, D. C. Doughty, M. R. Hoffmann and S. J. Oltmans (2010), Validation of northern latitude Tropospheric Emission Spectrometer stare ozone profiles with ARC-IONS sondes during ARCTAS: sensitivity, bias and error analysis, *Atmospheric Chemistry and Physics*, *10*(20), 9901-9914, 10.5194/acp-10-9901-2010.

Brioude, J., R. W. Portmann, J. S. Daniel, O. R. Cooper, G. J. Frost, K. H. Rosenlof, C. Granier, A R Ravishankara, S. A. Montzka and A. Stohl (2010), Variations in ozone depletion potentials of very short-lived substances with season and emission region, *Geophysical Research Letters*, *37*(L19804), 1-5, 10.1029/2010GL044856.

Brioude, J., R. W. Portmann, J. S. Daniel, O. R. Cooper, G. J. Frost, K. H. Rosenlof, C. Granier, A. R. Ravishankara, S. A. Montzka, and A. Stohl, Variations in ozone depletion potentials of very short-lived substances with season andemission region (2010), *Geophys. Res. Lett.*, 37, L19804, doi:10.1029/2010GL044856.

Brioude, J., R.W. Portmann, J.S. Daniel, O.R. Cooper, G.J. Frost, K.H. Rosenlof, C. Granier, A.R. Ravishankara, S.A. Montzka, and A. Stohl, 2010, Variations in ozone depletion potentials of very short-lived substances with season and emission region, *Geophys. Res. Lett.*, *3* (L198704), doi:10.1029/2010GL044856.

Brodin, M., D. Helmig and S. J. Oltmans (2010), Seasonal ozone behavior along an elevation gradient in the Colorado Front Range Mountains, *Atmospheric Environment*, *44*(39), 5305-5315, 10.1016/j.atmosenv.2010.06.033.

Butler, J. H., T.G. Bell, B. D. Hall, B. Quack, L.J. Carpenter and J. Williams (2010), Technical Note: Ensuring consistent, global measurements of very short-lived halocarbon gases in the ocean and atmosphere, Atmospheric Chemistry and Physics, 10(2), 327-330.

Chauhan, S., et al. "MIPAS reduced spectral resolution UTLS-1 mode measurements of temperature, O3, HNO3, N2O, H2O and relative humidity over ice: retrievals and comparison to MLS," Atmospheric Measurement Techniques 2, 337-353, 2009.

Coffey, M.T., J. W. Hannigan, A. Goldman, et al. Airborne Fourier transform spectrometer (FTS) observations in support of EOS Aura validation, 2008, J. of Geophy. Res. 113 D16S42 10.1029/2007JD008833.

Chang, N.B., R. Feng, Z. Gao, and W. Gao (2010), Skin cancer incidence is highly associated with ultraviolet-B radiation history, International Journal of Hygiene and Environmental Health, 213, 359-368.

Cooper, O. R., D. D. Parrish, A. Stohl, M. Trainer, P. Nedelec, V. Thouret, J. P. Cammas, S. J. Oltmans, B. J. Johnson, D. Tarasick, T. Leblanc, I. S. McDermid, D. Jaffe, R. S. Gao, J. Stith, T. B. Ryerson, K. C. Aikin, T. Campos, A. Weinheimer and M. A. Avery (2010), Increasing springtime ozone mixing ratios in the free troposphere over western North America, *Nature*, *463*(7279), 344-348, 10.1038/nature08708.

Cooper, O. R., M. Trainer, A.M. Thompson, S. J. Oltmans, D.W. Tarasick, J.C. Witte, A. Stohl, S. Eckhardt, J. Lelieveld, M.J. Newchurch, B. J. Johnson, R. W. Portmann, L. Kalnajs, M.K. Dubey, T. Leblanc, I.S. McDermid, G. Forbes, D. E. Wolfe, T. Carey-Smith, G.A. Morris, B. Lefer, B. Rappenglück, E. Joseph, F. Schmidlin, J. F. Meagher, F. C. Fehsenfeld, T.J. Keating, R.A. Van Curen and K. Minschwaner (2007), Evidence for a recurring eastern North America upper tropospheric ozone maximum during summer, *Journal of Geophysical Research-Atmospheres*, *112*, D23304, 10.1029/2007JD008710.

Corr, C. A., N. Krotkov, S. Madronich, J. R. Slusser, B. Holben, W. Gao, J. Flynn, B. Lefer, and S. M. Kreidenweis, 2009, Retrieval of aerosol single scattering albedo at ultraviolet wavelengths at the T1 site during MILAGRO, Atmos. Chem. Phys. Discuss., 9, 4971-5008

Dall'Amico, M., L.J. Gray, K.H. Rosenlof, A.A. Scaife, K.P. Shine, and P.A. Stott, 2009, Stratospheric temperature trends: Impact of ozone variability and the QBO, *Clim. Dyn.*, *34* (2-3), 381-398, doi:10.1007/s00382-009-0604-x.

Dall'Amico, M., P.A. Stott, A.A. Scaife, L.J. Gray, K.H. Rosenlof, and A.Y. Karpechko, 2009, Impact of stratospheric variability on tropospheric climate change, *Clim. Dyn.*, *34* (2-3), 399-417, doi:10.1007/s00382-009-0580-1.

Daniel, J.S., E.L. Fleming, R.W. Portmann, G.J.M. Velders, C.H. Jackman, and A.R. Ravishankara, 2010, Options to accelerate ozone recovery: Ozone and climate benefits, *Atmos. Chem. Phys.*, *10* (16), 7697-7707, doi:10.5194/acp-10-7697-2010.

Daniel, J.S., S. Solomon, T.J. Sanford, M. McFarland, J. Fuglestvedt, and P.

Friedlingstein, 2011, Limitations of single-basket trading: A lesson from the Montreal Protocol for climate policy options, *Clim. Change*, *in press.*

Deshler, T., J. L. Mercer, H. G. J. Smit, R. Stubi, G. Levrat, B. J. Johnson, S. J. Oltmans, R. Kivi, A. M. Thompson, J. Witte, J. Davies, F. J. Schmidlin, G. Brothers and T. Sasaki (2008), Atmospheric comparison of electrochemical cell ozonesondes from different manufacturers, and with different cathode solution strengths: The Balloon Experiment on Standards for Ozonesondes, *Journal of Geophysical Research-Atmospheres*, *113*(D4), D04307, 10.1029/2007JD008975.

Dessler, A.E., "Clouds and water vapor in the Northern Hemisphere summertime stratosphere," J. Geophys. Res. 113, D00H09, doi:10.1029/2009JD012075, 2009.

Dlugokencky, E. J., L. Bruhwiler, J.W.C. White, L.K. Emmons, P.C. Novelli, S.A. Montzka, K.A. Masarie, P.M. Lang, A.M. Crotwell, J.B. Miller, and L.V. Gatti. (2009), Observational constraints on recent increases in the atmospheric CH_4 burden, Geophys. Res. Lett., 36, L18803, doi:10.1029/2009GL039780.

Dunlea, E.J., R.K. Talukdar, and A.R. Ravishankara, 2010, Kinetics and products of the reaction $O_2(^1\sum_g^+)$ with N_2O, *Zeitschrift für Physikalische Chemie*, *224*, 989-1007, doi:10.1524/zpch.2010.6137.

El Amraoui, L., et al. "Midlatitude stratosphere – troposphere exchange as diagnosed by MLS O3 and MOPITT CO assimilated fields," Atmos. Chem. Phys. 10, 2175-2194, 2010.

Eisele, F., D.D. Davis, D. Helmig, S. J. Oltmans, W. Neff, G. Huey, D. Tanner, G. Chen, J. Crawford, R. Arimoto, M. Buhr, L. Mauldin, M. Hutterli, J. Dibb, D. Blake, S.B. Brooks, B. Johnson, J. M. Roberts, Y. Wang, D. Tan and F. Flocke (2008), Antarctic Tropospheric Chemistry Investigation (ANTCI) 2003 Overview, *Atmospheric Environment*, *42*(12), 2749-2761, 10.1016/j.atmosenv.2007.04.013.

Elkins, J. W. and G. S. Dutton. Nitrous Oxide and Sulfur Hexafluroride *in [State of the Climate in 2008]*. *Bull. Amer. Meteor. Soc.* **90**, (2009).

Elkins, J. W. and G. S. Dutton. (2010) Nitrous Oxide (N_2O) and Sulfur Hexafluoride (SF_6) in [*State of the Climate in 2009*]. Bull. Amer. Meteor. Soc. **91**, S44-S46.

Engel, A., T. Mobius, H. Bonisch, U. Schmidt, R. Heinz, I. Levin, E. Atlas, S. Aoki, T. Nakazawa, S. Sugawara, F. Moore, D. F. Hurst, J. W. Elkins, S. Schauffler, A. E. Andrews and K. Boering (2009), Age of stratospheric air unchanged within uncertainties over the past 30 years, *Nature Geosciences, DOI: 10.1038/NGEO388,* 14 December 2008.

Englert, C.R., et al. "Spatial Heterodyne Imager for Meospheric Radicals on STPSat-1," J. Geophys. Res. 115, D20306, doi:10.1029/2010JD014398, 2010.

Evans, R. D., G. McConville, S. J. Oltmans, I. Petropavlovskikh and D. Quincy (2009), Measurement of internal stray light within Dobson ozone spectrophotometers, International Journal of Remote Sensing, *30*(15), 4247-4258, 10.1080/01431160902825057.

Fahey, D.W., A.R. Douglass, V. Ramaswamy, and A.-M. Schmoltner, Chapter 4 - How Do Climate Change and Stratospheric Ozone Loss Interact?, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A.R. Ravishankara, M.J. Kurylo, and C.A. Ennis, pp. 111-132, Dept. of Commerce, NOAA National Climatic Data Center, Asheville, North Carolina, (2008).

Feierabend, K., D. Papanastasiou, and J. Burkholder, 2010, ClO radical yields in the reaction of $O(^1D)$ with Cl_2, HCl, chloromethanes and chlorofluoromethanes, *J. Phys. Chem.*, *114,* 12052–12061.

Fioletov, V. E., G. Labow, R. D. Evans, E. W. Hare, U. Köhler, C. T. McElroy, K. Miyagawa, A. Redondas, V. Savastiouk, A. M. Shalamyansky, J. Staehelin, K. Vanicek and M. Weber (2008), Performance of the ground-based total ozone network assessed using satellite data, *Journal of Geophysical Research*, *113*(D14), D14313, 10.1029/2008JD009809.

Flury, T., et al. "Ozone depletion, water vapor increase, and PSC generation at midlatitudes by the 2008 major stratospheric warming," J. Geophys. Res. 114, D18302, doi:10.1029/2009JD011940, 2009.

Fueglistaler, S., et al. "The Tropical Tropopause Layer," Rev. Geophys. 47, RG1004, doi:10.1029/2008RG000267, 2009.

Flint, S.D., R. J. Ryel, T. J. Hudelson, M.M. Caldwell, 2009, Serious complications in experiments in which UV doses are effected by using different lamp heights. Journal of Photochemistry and Photobiology B: Biology 97:48-53.

Flynn, L. E., D. McNamara, C. T. Beck, I. Petropavlovskikh, E. Beach, Y. Pachepsky, Y. P. Li, M. Deland, L. K. Huan, C.S. Long, C.S. Seftor, R. Tiruchirapalli and S. Taylor (2009), Measurements and products from the Solar Backscatter Ultraviolet (SBUV/2) and Ozone Mapping and Profiler Suite (OMPS) instruments, *International Journal of Remote Sensing*, *30*(15), 4259-4272, 10.1080/01431160902825040.

Froidevaux, L., Y.B. Jiang, A. Lambert, N.J. Livesey, W.G. Read, J.W. Waters, R.A. Fuller, T.P. Marcy, P.J. Popp, R.S. Gao, D.W. Fahey, K.W. Jucks, R.A. Stachnik, G.C. Toon, L.E. Christensen, C.R. Webster, P.F. Bernath, C.D. Boone, K.A. Walker, H.C. Pumphrey, R.S. Harwood, G.L. Manney, M.J. Schwartz, W.H. Daffer, B.J. Drouin, R.E. Cofield, D.T. Cuddy, R.F. Jarnot, B.W. Knosp, V.S. Perun, W.V. Snyder, P.C. Stek, R.P. Thurstans, and P.A. Wagner, 2008, Validation of Aura Microwave Limb Sounder HCl measurements, *J. Geophys. Res.*, *113* (D15S25), doi:10.1029/2007JD009025.

Fromm, M., E.P. Shettle, K.H. Fricke, C. Ritter, T. Trickl, H. Giehl, M. Gerding, J. Barnes, M. O'Neill, S.T. Massie, U. Blum, I.S. McDermid, T. Leblanc and T. Deshler (2008), Stratospheric impact of the Chisholm pyrocumulonimbus eruption: 2. Vertical profile perspective, *Journal of Geophysical Research-Atmospheres*, *113*(D8), D08203-D08203, 10.1029/2007JD009147.

Fu, Q., S. Solomon, and P. Lin, 2010, On the seasonal dependence of tropical lower-stratospheric temperature trends, *Atmos. Chem. Phys., 10, 2643-2653*, doi:10.5194/acp-10-2643-2010.

Fujiwara, M., H. Vömel, F. Hasebe, M. Shiotani, S.-Y. Ogino, S. Iwasaki, N. Nishi, T. Shibata, K. Shimizu, E. Nishimoto, J. M. Valverde Canossa, H. B. Selkirk and S. J. Oltmans (2010), Seasonal to decadal variations of water vapor in the tropical lower stratosphere observed with balloon-borne cryogenic frost point hygrometers, *Journal of Geophysical Research-Atmospheres*, *115*(D18304), 1-15, 10.1029/2010JD014179.

Gao Z., W. Gao, and N.B. Chang (2010), Comparative Analyses of the Ultraviolet-B flux over the Continental US with NASA TOMS data and USDA Ground-based measurements, Journal of Applied Remote Sensing, Vol. 4,043547, doi: 10.1117/1.3507249.

Gao, W., D. Schmoldt, and J. R. Slusser (2009), UV Radiation in Global Climate Change: Measurements, Modeling and Effects on Ecosystems, Springer-Verlag and Tsinghua University Press

Gao, Z. and W. Gao (2010), Comparative analysis of UVB exposure between Nimbus 7/TOMS satellite estimates and ground-based measurements. Remote Sensing and Modeling of Ecosystems for Sustainability VII, edited by Wei Gao, Thomas J. Jackson and Jinnian Wang, Proc. of SPIE, Vol. 7809, 78090Q-1, doi: 10.1117/12.858452.

Gao, Z., W. Gao, and N.B. Chang (2010), Detection of Multidecadal Changes in UVB and Total Ozone Concentrations over the Continental US with NASA TOMS Data and USDA Ground based Measurements, Remote Sens.,2, 262-277, doi:10.3390/rs2010262
Gilman *et al*., Ozone variability and halogen oxidation within the Arctic and sub-Arctic springtime boundary layer (2010), *Atmos. Chem. Phys., 10*, 10223-10236.

Gille, J., et al. "High Resolution Dynamics Limb Sounder (HIRDLS): Experiment Overview, recovery and validation of initial temperature data," J. Geophys. Res. 113, D16S43, doi:10.1029/2007JD008824, 2008.

Hassler, B., G.E. Bodeker, S. Solomon, and P.J. Young, 2011, Changes in the polar vortex: Effects on Antarctic total ozone observations at various stations, *Geophys. Res. Lett.*, *38* (L01805), doi:10.1029/2010GL045542.

Hegglin, M.I., et al. "Multimodel assessment of the upper troposphere and lower stratosphere: Extratropics," J. Geophys. Res. 115, D00M09, doi:10.1029/2010JD013884, 2010.

Helmig, D., B. J. Johnson, M. Warshawsky, T. Morse, W. Neff, F. Eisele and D. D. Davis (2008), Nitric oxide in the boundary-layer at South Pole during the Antarctic Tropospheric Chemistry Investigation (ANTCI), *Atmospheric Environment*, *42*(12), 2817-2830, 10.1016/j.atmosenv.2007.03.061.

Hendrick, F., J.-P. Pommereau, F. Goutail, R. D. Evans, D. Ionov, A. Pazmino, E. Kyrö, G. Held, P. Eriksen, V. Dorokhov, M. Gil and M. Van Roozendael (2010), NDACC UV-visible total ozone measurements: improved retrieval and comparison with correlative satellite and ground-based observations, *Atmospheric Chemistry and Physics Discussions*, *10*(8), 20405-20460, 10.5194/acpd-10-20405-2010.

Hicke, J. A., J. Slusser, K. Lantz and F. G. Pascual (2008), Trends and interannual variability in surface UV-B radiation over 8-11 years observed across the United States,

Hicke, Jeffrey A., J. Slusser, K. Lantz, F. G. Pascual (2008), Trends and interannual variability in surface UVB radiation over 8 to 11 years observed across the United States. Journal of Geophysical Research, Vol. 113, D21302

Hofmann, D. J. and S. A. Montzka (2009), Recovery of the Ozone Layer: The Ozone Depleting Gas Index, *EOS Transactions American Geophysical Union*, *90*(1), 1-12, 10.1029/2009EO010001.

Hofmann, D. J., B. J. Johnson and S. J. Oltmans (2009), Twenty-two years of ozonesonde measurements at the South Pole, *International Journal of Remote Sensing*, *30*(15), 1-14, DOI: 10.1080/01431160902821932.

Hofmann, D. J., J. Barnes, M. O'Neill, M. Trudeau and R. Neely (2009), Increase in background stratospheric aerosol observed with lidar at Mauna Loa Observatory and Boulder, Colorado, *Geophysical Research Letters*, *36*, L15808, 10.1029/2009GL039008.

Hofmann, D.J., and S.A. Montzka, Recovery of the Layer: The Ozone Depleting Gas Index, EOS Trans., 90, 1, 2009.

Huang, F.T., et al. "Ozone diurnal variations in the stratosphere and lower mesosphere, based on measurements from SABER and TIMED," J. Geophys. Res. 115, D24308, doi:10.1029/2010JD014484, 2010.

Huang, J., A. Golombek, R. Prinn, R. Weiss, P. Fraser, P. Simmonds, E.J. Dlugokencky, B. Hall, J. Elkins, P. Steele, R. Langenfelds, P. Krummel, G. Dutton, and L. Porter, Estimation of Regional Emissions of Nitrous Oxide from 1997 to 2005 Using Multi-network measurements, A Chemical Transport Model, and a Kalman Filter, submitted to *J. Geophys. Res., 113, D17313, doi:10.1029/2007JD009381.*

Hulsen, G., J. Grobner, A. Bais, M. Blumthaler, P. Disterhoft, B. Johnsen, K. O. Lantz, C. Meleti, J. Schreder, J. M. Vilaplana Guerrero and L. Ylianttila (2008), Intercomparison of erythemal broadband radiometers calibrated by seven UV calibration facilities in Europe and the U.S.A, *Atmospheric Chemistry and Physics*, *8*(16), 4865-4875.

Hurst, D.F., S.J. Oltmans, H. Vömel, K.H. Rosenlof, S.M. Davis, E.A. Ray, E.G. Hall, and A.F. Jordan, 2011, Stratospheric water vapor trends over Boulder, Colorado: Analysis of the 30 year Boulder record, *J. Geophys. Res.*, *116* (D02306), doi:10.1029/2010JD015065.

Isaksen, I.S.A., G. Myhre, M. Gauss, T.K. Berntsen, R. Benestad, P. Bousquet, W.D. Collins, R.A. Cox, S.B. Dalsøren, V. Eyring, D. Fowler, S. Fuzzi, C. Granier, P. Jöckel, Z. Kilmont, P. Laj, U. Lohmann, M. Maione, P. Monks, A.S.H. Prevot, F. Raes, A. Richter, B. Rognerud, M. Schultz, D. Shindell, D.S. Stevenson, T. Storelvmo, W.-C. Wang, M. van Weele, M. Wild, and D. Wuebbles, 2009, Atmospheric composition change: Climate-chemistry interactions, *Atmos. Environ.*, *43* (33), 5138-5192, doi:10.1016/j.atmosenv.2009.08.003.

Jiang, J.H., et al. "Five-year (2004-2009) Observations of Upper Tropospheric Water Vapor and Cloud Ice from MLS and Comparisons with GEOS-5 analyses," J. Geophys. Res. 115, D15103, doi:10.1029/2009JD013256, 2010.

Jin, J.J., et al. "Comparison of CMAM simulations of carbon monoxide (CO), nitrous oxide (N2O), and methane (CH4) with observations from Odin/SMR, ACE-FTS, and Aura/MLS," Atmos. Chem. Phys. 9, 3233-3252, 2009.

Johnson, B. J., D Helmig and S. J. Oltmans (2008), Evaluation of ozone measurements from a tethered balloon-sampling platform at South Pole Station in December 2003, *Atmospheric Environment*, *42*(12), 2780-2787, 10.1016/j.atmosenv.2007.03.043.

Jones, C.E., S. J. Andrews, L. J. Carpenter, C. Hogan, F. E. Hopkins, J. C. Laube, A. D. Robinson, T. G. Spain, S. D. Archer, N. R. P. Harris, P. D. Nightingale, S. J. O'Doherty, D. E. Oram, J. A. Pyle, J. H. Butler and B. D. Hall (2011), Results from the first national UK inter-laboratory calibration for very short-lived halocarbons, Atmos. Meas. Tech. Discuss., 4, C52–C54, 2011.

Karpechko, A., A. Lukyanov, E. Kyro, S. Khaikin, L. Korshunov, R. Kivi and H. Vömel (2007), The water vapour distribution in the arctic lowermost stratosphere during Lautlos campaign and related transport processes including stratosphere-troposphere exchange, *Atmospheric Chemistry and Physics*, *7*, 107-119.

Karpechko, A.Y., N.P. Gillett, B. Hassler, K.H. Rosenlof, and E. Rozanov, 2010, Objective assessment of ozone in chemistry-climate model simulations, *Atmos. Chem. Phys.*, *10* (3), 1385-1400.

Kawa, S.R., R.S. Stolarski, P.A. Newman, A.R. Douglass, M. Rex, D. J. Hofmann, M.L. Santee and K. Frieler (2009), Sensitivity of polar stratospheric ozone loss to uncertainties in chemical reaction kinetics, *Atmospheric Chemistry and Physics*, *9*(22), 8651-8660.

Kiedron, P., M. Beauharnois, J. Berndt, P. Disterhoft, L. Harrison, J. Michalsky, G. Scott, J. Schlemmer and J. Slusser (2008), Calibration, data processing, and maintenance of the United States Department of Agriculture high-resolution ultraviolet spectroradiometers, *Applied Optics*, *47*, 6142-6150, 10.1364/AO.47.006142.

Kim, S. -W., S. -C. Yoon, E. G. Dutton, C. Wehrli and B. Holben (2008), Global Surface-based Sun Photometer Network for Long-term Observations of Column Aerosol Optical Properties: Intercomparison of Aerosol Optical Depth, *Aerosol Science and*

Kinnison, D.E., J. Gille, J. Barnett, C. Randall, V.L. Harvey, A. Lambert, R. Khosravi, M.J. Alexander, P.F. Bernath, C.D. Boone, C. Cavanaugh, M. Coffey, C. Craig, V.C. Dean, T. Eden, D. Ellis, D.W. Fahey, G. Francis, C. Halvorson, J. Hannigan, C. Hartsough, C. Hepplewhite, C. Krinsky, H. Lee, B. Mankin, T.P. Marcy, S. Massie, B. Nardi, D. Packman, P.J. Popp, M.L. Santee, V. Yudin, and K.A. Walker, 2008, Global observations of HNO_3 from the High Resolution Dynamics Limb Sounder (HIRDLS): First results, *J. Geophys. Res.*, *113* (D16S44), doi:10.1029/2007JD008814.

Ko, M., J.S. Daniel, J.R. Herman, P.A. Newman, and V. Ramaswamy, Chapter 5 - The Future and Recovery, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A.R. Ravishankara, M.J. Kurylo, and C.A. Ennis, pp. 133-154, Dept. of Commerce, NOAA National Climatic Data Center, Asheville, North Carolina, (2008).

Konopka, P., et al. "Annual cycle of ozone at and above the tropical tropopause: observations versus simulations with the Chemical Lagrangian Model of the Stratosphere (CLaMS)," Atmos. Chem. Phys. 9, 121-132, 2010.

Kort, E. A., J. Eluszkiewicz, B. B. Stephens, J. B. Miller, C. Gerbig, T. Nehrkorn, B. C. Daube, J. O. Kaplan, S. Houweling and S. C. Wofsy (2008), Emissions of CH4 and N2O over the United States and Canada based on a receptor-oriented modeling framework and COBRA-NA atmospheric observations, *Geophysical Research Letters*, *35*(18), L18808, 10.1029/2008GL034031.

Kroon, M. (editor) Final Report of the OMI Calibration and Validation Announcement of Opportunity (joint effort by ESA, NIVR and KNMI) PR-OMIE-KNMI-823 Iss. 5, Final AO Report Version 1.0 (2010), http://eopi.esa.int/esa/esa?topSelectedNavigationNodeId=AOS&sideNavigationType=AO&aoid=300&ts=1295529243613&cmd=aodetail&

Kroon, M., I. Petropavlovskikh, R. Shetter, S. Hall, K. Ullmann, J. P. Veefkind, R. D. McPeters and P. F. Levelt (2008), OMI Total Ozone Column Validation with Aura-AVE CAFS Observations, *Journal of Geophysical Research-Atmospheres*, *113*(D15S13), 10.1029/2007JD008795.

Krotkov, N., G. Labow; J. Herman; J. Slusser; R. Tree; G. Janson; B. Durham; T. Eck; B. Holben (2009), Aerosol column absorption measurements using co-located UV-MFRSR and AERONET CIMEL instruments, Proceedings of SPIE Volume: 7462.

Laj, P., J. Klausen, M. Bilde, C. Plaß-Duelmer, G. Pappalardo, C. Clerbaux, U. Baltensperge, J. Hjorth, D. Simpson, S. Reimann, P.-F. Coheur, A. Richter, M. De Mazière, Y. Rudich, G. McFiggans, K. Torseth, A. Wiedensohler, S. Morin, M. Schulz, J.D. Allan, J.-L. Attié, I. Barnes, W. Birmili, J.P. Cammas, J. Dommen, H.-P. Dorn, D. Fowler, S. Fuzzi, M. Glasius, C. Granier, M. Hermann, I.S.A. Isaksen, S. Kinne, I. Koren, F. Madonna, M. Maione, A. Massling, O. Moehler, L. Mona, P.S. Monks, D. Müller, T. Müller, J. Orphal, V.-H. Peuch, F. Stratmann, D. Tanré, G.S. Tyndall, A. Abo Riziq, M. Van Roozendael, P. Villani, B. Wehner, H. Wex, and A.A. Zardini, 2009, Measuring atmospheric composition change, *Atmos. Environ.*, *43* (33), 5351-5414, doi:10.1016/j.atmosenv.2009.08.020.

Lamarque, J.F., and S. Solomon, 2010, Impact of changes in climate and halocarbons on recent lower stratosphere ozone and temperature trends, *J. Clim.*, *23,* 2599-2611, doi:10.1175/2010JCLI3179.1.

Lanconelli, C., M. Busetto, E. G. Dutton, G. König, M. Maturilli, R. Sieger, V. Vitale and T. Yamanouchi (2011), Polar baseline surface radiation measurements during the International Polar Year 2007-2009, *Earth System Science Data*, *3*(1), 1-8, 10.5194/essd-3-1-2011.

Langford, A.O., K.C. Aikin, C.S. Eubank, and E.J. Williams, 2009, Stratospheric contribution to high surface ozone in Colorado during springtime, *Geophys. Res. Lett.*, *36* (L12801), doi:10.1029/2009GL038367.

Lantz, K., P. Disterhoft, J. Slusser, W. Gao, J. Berndt, G. Bernhard, R. Booth, J. Ehramjian, L. Harrison, G. Janson, P. Johnston, P. Kiedron, R. McKenzie, M. Kimlin, P. Neale, M. O'Neill, V. V. Quang, G. Seckmeyer, T. Taylor, S. Wuttke and J. Michalsky (2008), The 2003 North American Interagency Intercomparison of Ultraviolet Monitoring Spectroradiometers: Part A. Scanning and Spectrograph Instruments, *Journal of Applied Remote Sensing*, *2*(23547), 10.1117/1.3040299.

Lee, D.S., D.W. Fahey, P.M. Forster, P.J. Newton, R.C.N. Wit, L.L. Lim, B. Owen, and R. Sausen, 2009, Aviation and global climate change in the 21st century, *Atmos. Environ.*, *43* (22-23), 3520-3537, doi:10.1016/j.atmosenv.2009.04.024.

Liao, J., H. Sihler, L.G. Huey, J.A. Neuman, D.J. Tanner, U. Friess, U. Platt, F.M. Flocke, J.J. Orlando, P.B. Shepson, H.J. Beine, A.J. Weinheimer, S.J. Sjostedt, J.B. Nowak, D.J. Knapp, R.M. Staebler, W. Zheng, R. Sander, S.R. Hall, and K. Ullmann, 2011, A comparison of Arctic BrO measurements by chemical ionization mass spectrometery and long path-differential optical absorption spectroscopy, *J. Geophys. Res.*, *116* (D00R02), doi:10.1029/2010JD014788..

Lin, P., Q. Fu, S. Solomon, and J.M. Wallace, 2009, Temperature trend patterns in

Southern Hemisphere high latitudes: Novel indicators of stratospheric change, *J. Clim.*, *22* (24), 6325-6341, doi:10.1175/2009JCLI2971.1.

Liu, J., C. Schaaf, A. Strahler, Z. Jiao, Y. Shuai, Q. Zhang, M. Roman, J. A. Augustine and E. G. Dutton (2009), Validation of Moderate Resolution Imaging Spectroradiometer (MODIS) albedo retrieval algorithm: Dependence of albedo on solar zenith angle, *Journal of Geophysical Research-Atmospheres*, *114*(d1), D01106-D01106, 10.1029/2008JD009969.

Liu, J., C. Schaaf, A. Strahler, Z. Jiao, Y. Shuai, Q. Zhang, M. Roman, J. A. Augustine and E. G. Dutton (2009), Validation of Moderate Resolution Imaging Spectroradiometer (MODIS) albedo retrieval algorithm: Dependence of albedo on solar zenith angle, *Journal of Geophysical Research*, *114*(D01106), 10.1029/2008JD009969.

Liu, X., et al. "Validation of Ozone Monitoring Instrument (OMI) ozone profiles and stratospheric ozone columns with Microwave Limb Sounder (MLS) measurements," Atmos. Chem. Phys. 10, 2539-2549, 2010.

Liu, X., P.K. Bhartia, K. Chance, R.J. D Spurr, and T.P. Kurosu Ozone profile retrievals from the Ozone Monitoring Instrument, 2010, Atmos. Chem. Phys. 10 2521-2537

Livesey, N.J., M.J. Filipiak, L. Froidevaux, W.G. Read, A. Lambert, M.L. Santee, J.H. Jiang, H.C. Pumphrey, J.W. Waters, R.E. Cofield, D.T. Cuddy, W.H. Daffer, B.J. Drouin, R.A. Fuller, R.F. Jarnot, Y.B. Jiang, B.W. Knosp, Q.B. Li, V.S. Perun, M.J. Schwartz, W.V. Snyder, P.C. Stek, R.P. Thurstans, P.A. Wagner, M. Avery, E.V. Browell, J.-P. Cammas, L.E. Christensen, G.S. Diskin, R.-S. Gao, H.-J. Jost, M. Loewenstein, J.D. Lopez, P. Nedelec, G.B. Osterman, G.W. Sachse, and C.R. Webster, 2008, Validation of Aura Microwave Limb Sounder O_3 and CO observations in the upper troposphere and lower stratosphere, *J. Geophys. Res.*, *113* (D15S02), doi:10.1029/2007JD008805.

Long, C. N., E. G. Dutton, J. A. Augustine, W. Wiscombe, M. Wild, S. A. McFarlane and C. J. Flynn (2009), Significant decadal brightening of downwelling shortwave in the continental United States, *Journal of Geophysical Research-Atmospheres*, *114*, D00D06-D00D06, 10.1029/2008JD011263.

Lovejoy, S., A.F. Tuck, D. Schertzer, and S.J. Hovde, 2009, Reinterpreting aircraft measurements in anisotropic scaling turbulence, *Atmos. Chem. Phys.*, *9* (14), 5007-5025, doi:10.5194/acp-9-5007-2009.

Lovejoy, S., A.F. Tuck, D. Schertzer, and S.J. Hovde, 2009, Reply to comment by Igor Esau on "Do stable atmospheric layers exist?", *Geophys. Res. Lett.*, *36* (L11812), doi:10.1029/2008GL034980

Lovejoy, S., A.F. Tuck, S.J. Hovde, and D. Schertzer, 2008, Do stable atmospheric layers exist?, *Geophys. Res. Lett.*, *35* (L01802), doi:10.1029/2007GL032122.

Lovejoy, S., A.F. Tuck, S.J. Hovde, and D. Schertzer, 2009, Vertical cascade structure of the atmosphere and multifractal dropsonde outages, *J. Geophys. Res.*, *114* (D07111),

doi:10.1029/2008JD010651.

Manney, G.L., et al. "Aura Microwave Limb Sounder Observations of Dynamics and Transport During the Record-breaking 2009 Arctic Stratospheric Major Warming," Geophys. Res. Lett. 36, doi:10.1029/2009GL038586, 2009.

Manney, G.L., et al. "Satellite Observations and Modelling of Transport in the Upper Troposphere through the Lower Mesosphere During the 2006 Major Stratospheric Sudden Warming," Atmos. Chem. Phys. 9, 4775-4795, 2009.

Manney, G.L., M.I. Hegglin, W.H. Daffer, M.L. Santee, E.A. Ray, S. Pawson, M.J. Schwartz, C.D. Boone, L. Froidevaux, N.J. Livesey, W.G. Read, and K.A. Walker, 2011, Jet characterization in the upper troposphere/lower stratosphere (UTLS): Applications to climatology and transport studies, *Atmos. Chem. Phys.*, *submitted.*

McPeters, R., M. Kroon, G. Labow, E. Brinksma, D. Balis, I. Petropavlovskikh, J. P. Veefkind, P. K. Bhartia and P. F. Levelt (2008), Validation of the Aura Ozone Monitoring Instrument Total Column Ozone Product, *Journal of Geophysical Research-Atmospheres*, 10.1029/2007JD008802.

Mebarki, Y., et al. "More evidence for very short-lived substance contribution to stratospheric chlorine inferred from HCl balloon-borne in situ measurements in the tropics," Atmos. Chem. Phys. 10, 397-409, 2010. Reprint

Meek, C.E., and A.H. Manson, "Summer planetary-scale oscillations: Aura MLS temperature compared with ground-based radar wind," Annales Geophysicae 27, 1763-1774, 2009.

Michalsky, J. J. and P. Kiedron (2008), Comparison of UV-RSS spectral measurements and TUV model runs for clear skies for the May 2003 ARM aerosol intensive observation period, *Atmospheric Chemistry and Physics*, *8*, 1813-1821.

Michalsky, J. J., F. Denn, C. Flynn, G. B. Hodges, P. Kiedron, A. Koontz, J. Schlemmer and S. E. Schwartz (2010), Climatology of aerosol optical depth in north-central Oklahoma: 1992â□“2008, *Journal of Geophysical Research-Atmospheres*, *115*(D07203), 1-16, 10.1029/2009JD012197..

Michalsky, J. J., J. A. Augustine and P. Kiedron (2009), Improved broadband solar irradiance from the multi-filter rotating shadowband radiometer, *Solar Energy*, *83*(12), 2144-2156, 10.1016/j.solener.2009.08.007.

Miller, B. R. et al., HFC-23 (CHF_3) emission trend response to HCFC-22 ($CHClF_2$) production and recent HFC-23 emission abatement measures (2010), Atmos. Chem. Phys., 10, 7875.

Miller, B.R., R. F. Weiss, P. K. Salameh, T. Tanhua, B. R. Greally, J. Mühle, and P. G.

Simmonds, "Medusa: A Sample Preconcentration and GC/MS Detector System for in Situ Measurements of Atmospheric Trace Halocarbons, Hydrocarbons, and Sulfur Compounds (2008), *Anal. Chem., 80,* 1536-1545.

Miloshevich, L., A Paukkunen, H. Vömel and S. J. Oltmans (2004), Development and validation of a time-lag correction for Vaisala radiosonde humidity measurements, *Journal of Atmospheric and Oceanic Technology*, *21*(9), 1305-1327.

Minschwaner, K.R., et al. "Hydroxyl in the stratosphere and mesosphere - Part 1: Diurnal variability," Atmos. Chem. Phys. 11, 955-962, 2011.

Miyagawa, K., T. Sasaki, H. Nakane, I. Petropavlovskikh and R. D. Evans (2009), Reevaluation of long-term Umkehr data and ozone profiles at Japanese stations, *Journal of Geophysical Research Atmospheres*, *114*(D07108), 10.1029/2008JD010658.

Montzka, S. M. ,(2009) Ozone-depleting gases and their replacements in [*State of the Climate for 2008*]. *Bull. Amer. Meteor. Soc.* **90**, S36-S37.

Montzka, S. M. (2009) Ozone-depleting gases and their replacements in [*State of the Climate for 2008*]. *Bull. Amer. Meteor. Soc.* **90**, S36-S37.

Montzka, S. A. (2010) The combined influence of long-lived trace gases on the radiative balance of the atmosphere—in [*State of the Climate in 2009*]. **91**, S44-S45.

Montzka, S. A. and G. S. Dutton. (2010) Changes in atmospheric abundances of ozone-depleting gases and their replacements in [*State of the Climate in 2009*].. *Bull. Amer. Meteor. Soc*. **91**, S43-S44 (2010).

Montzka S.A., L. Kuijpers, M.O. Battle, M. Aydin, K.R. Verhulst, E.S. Saltzman, D.W. Fahey, Recent increases in global HFC-23 emissions, *Geophys. Res. Lett*. (2010), L02808, doi:10.1029/2009GL041195.

Montzka, S. A., B. D. Hall and J. W. Elkins (2009), Accelerated increases observed for hydrochlorofluorocarbons since 2004 in the global atmosphere, *Geophysical Research Letters*, *36*(3), L03804-L03804, 10.1029/2008GL036475.

Montzka, S. A., J. S. Daniel, J. Cohen and K. Vick (2008), Chapter 2 - Current Trends, Mixing Ratios, and Emissions of Ozone-Depleting Substances and Their Substitutes, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A R Ravishankara, M.J. Kurylo and C. Ennis, pp. 29-78, Dept. of Commerce, NOAA's National Climate Data Center, Asheville, North Carolina.

Montzka, S. A., L. Kuijpers, M. O. Battle, M. Aydin, K. R. Verhulst, E. S. Saltzman and D. W. Fahey (2010), Recent increases in global HFC-23 emissions, *Geophysical Research Letters*, *37*(2), L02808, 10.1029/2009GL041195.

Montzka, S. A., M. Krol, E. J. Dlugokencky, B. D. Hall, P. Jockel and J. Lelieveld (2011), Small Interannual Variability of Global Atmospheric Hydroxyl, *SCIENCE*, *331*(6013), 67-69, 10.1126/science.1197640.

Montzka, S.A., B.D. Hall, J.W. Elkins, Accelerated increases observed for hydrofluorocarbons since 2004 in the global atmosphere (2009), Geophys. Res. Lett., 36, L03804, doi:10.1029/2008GL036475.

Montzka, S.A., L. Kuiipers, M.O. Battle, M. Aydin, K.R. Verhulst, E.S. Saltzman, and D.W. Fahey, 2010, Recent increases in global HFC-23 emissions, *Geophys. Res. Lett.*, *37* (L02808), doi:10.1029/2009GL041195.

Montzka, S.A**.,** M. Krol, E. Dlugokencky, B. Hall, P. Jockel, J. Lelieveld (2011), Small interannual variability of global atmospheric hydroxyl, *Science*, *331*, 67-69.
Montzka, S**.A.,** Reimann, S. (Coordinating Lead Authors), S. O'Doherty, A. Engel, K. Krüger, W.T Sturges, D. Blake, M. Dorf, P. Fraser, L. Froidevaux, K. Jucks, K. Kreher, M. J. Kurylo, W. Mellouki, J. Miller, O.-J. Nielsen, V. L. Orkin, R. Prinn, R. Rhew, M. L. Santee, A. Stohl, D. Verdonik, Ozone-depleting substances (ODSs) and related chemicals, Chapter 1 in Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project—Report No. 52, World Meteorological Organization, Geneva, 2011.

Morgenstern, D.W. Toohey, T.J. Wallington, D.J. Wuebbles, H. Akiyoshi, A.F. Bais, E.L. Fleming, C.H. Jackman, L.J.M. Kuijpers, M. McFarland, S.A. Montzka, M.N. Ross, S. Tilmes, M.B. Tully, A Focus on Information and Options for Policymakers, Chapter 5 in Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project—Report No. 52, World Meteorological Organization, Geneva, 2011.
Muhle, J., A.L. Ganesan, B. R. Miller et al., Perfluorocarbons in the global atmosphere: tetrafluoromethane, hexafluoroethane, and octafluoropropane (2010), Atmos. Chem. Phys., 10, 5145-5164.

Nardi, B., et al. "Initial validation of ozone measurements from the High Resolution Dynamics Limb Sounder," J. Geophys. Res. 113, D16S36, doi:10.1029/2007JD008837, 2008.

Nassar, R., J. A. Logan, H. M. Worden, I. A. Megretskaia, K. W. Bowman, G. B. Osterman, A. M. Thompson, D. W. Tarasick, S. Austin, H. Claude, M. K. Dubey, W. K. Hocking, B. J. Johnson, E. Joseph, J. Merrill, G. A. Morris, M. Newchurch, S. J. Oltmans, F.ço. Posny, F. J. Schmidlin, H. Vömel, D. N. Whiteman and J. C. Witte (2008), Validation of Tropospheric Emission Spectrometer (TES) nadir ozone profiles using ozonesonde measurements, *Journal of Geophysical Research-Atmospheres*, *113*(D15), D15S17, 10.1029/2007JD008819.

Nedoluha, G.E., et al. "Ground-based measurements of ClO from Mauna Kea and intercomparisons with Aura and UARS MLS," J. Geophys. Res. 116, D02307, doi:10.1029/2010JD014732, 2011.

Nedoluha, G.E., et al. "Ground-based microwave measurements of water vapor from the midstratosphere to the mesosphere," J. Geophys. Res. 116, D0230, doi:10.1029/2010JD014728 , 2011.

Neuman, J.A., J.B. Nowak, L.G. Huey, J.B. Burkholder, J.E. Dibb, J.S. Holloway, J. Liao, J. Peischl, J.M. Roberts, T.B. Ryerson, E. Scheuer, H. Stark, R.E. Stickel, D.J. Tanner, and A. Weinheimer, 2010, Bromine measurements in ozone depleted air over the Arctic Ocean, *Atmos. Chem. Phys.*, *10* (14), 6503-6514, doi:10.5194/acp-10-6503-2010.

Nevison, C. D, E. Dlugokencky, G. Dutton, J. W. Elkins, P. Fraser, B. Hall, P. B. Krummel, R. L. Langenfelds, R. G. Prinn, L. P. Steele, and R. F. Weiss, Abiotic and biogeochemical signals derived from the seasonal cycles of tropospheric nitrous oxide (2010), Atmos. Chem. Phys. Discuss., 10, 25803–25839.

Novelli, P. C., A. M. Crotwell and B. D. Hall (2009), Application of Gas Chromatography with a Pulsed Discharge Helium Ionization Detector for Measurements of Molecular Hydrogen in the Atmosphere, *Environmental Science & Technology*, *43*(7), 2431-2436, 10.1021/es803180g.

Olsen, M.A., et al. "Interannual variability of ozone in the winter lower stratosphere and the relationaship to lamina and irrerversible transport," J. Geophys. Res. 115, D15305, doi:10.1029/2009JD013004, 2010

Oltmans, S. J., B. J. Johnson and D Helmig (2008), Episodes of high surface-ozone amounts at South Pole during summer and their impact on the long-term surface-ozone variation, *Atmospheric Environment*, *42*(12), 2804-2816, 10.1016/j.atmosenv.2007.01.020.

Oltmans, S.J., A.S. Lefohn, J.M. Harris, D.W. Tarasick, A.M. Thompson , H. Wernli, B.J. Johnson, P.C. Novelli, S.A. Montzka, J.D. Ray, L.C. Patrick, C. Sweeney, A. Jefferson, T. Dann, J. Davies, M. Shapiro, B.N. Holben, Enhanced ozone over western North America from biomass buning in Eurasia during April 2008 as seen in surface and profile observations (2010), *Atmos. Environ*, *44*, 4497-4509.

Papadimitriou, V.C., R.K. Talukdar, R.W. Portmann, A.R. Ravishankara, and J.B. Burkholder, 2008, $CF_3CF{=}CH_2$ and (Z)-$CF_3CF{=}CHF$: Temperature dependent OH rate coefficients and global warming potentials, *Phys. Chem. Chem. Phys.*, *10* (6), 808-820, doi:10.1039/b714382f.

Papadimitriou, V.C., R.W. Portmann, D.W. Fahey, J. Mühle, R.F. Weiss, and J.B. Burkholder, 2008, Experimental and theoretical study of the atmospheric chemistry and global warming potential of SO_2F_2, *J. Phys. Chem. A*, *112* (49), 12657-12666, doi:10.1021/jp806368u.

Papadimitriou, V.C., Y.G. Lazarou, R.K. Talukdar, and J.B. Burkholder, 2011, Atmospheric chemistry of $CF_3CF{=}CH_2$ and (Z) $CF_3CF{=}CHF$: Cl and NO_3 Rate Coefficients, Cl Reaction product yields and thermochemical calculations, *J. Phys. Chem.*, *115* (2), 167–181, doi: 10.1021/jp110021u.

Park, S., E. L. Atlas, R. Jiménez, B. C. Daube, E. W. Gottlieb, J. Nan, D. B. A. Jones, L. Pfister, T. J. Conway, T. P. Bui, R. S. Gao and S. C. Wofsy (2010), Vertical transport rates and concentrations of OH and Cl radicals in the Tropical Tropopause Layer from Observations of CO2 and halocarbons: implications for distributions of long- and short-lived chemical species, *Atmospheric Chemistry and Physics Discussions*, *10*(3), 6059-6684, 10.5194/acpd-10-6059-2010.

Peterson, T.C., and M.O. Baringer, Eds., State of the Climate in 2008. *Bull. Amer. Meteor. Soc*., *90*, S1–S196, 2009.

Petropavlovskikh, I., E. A. Ray, S. Davis, K. H. Rosenlof, G. Manney, R. Shetter, S. R. Hall, K. Ullmann, L. Pfister, J. Hair, M. Fenn, M. Avery and A. M. Thompson (2010), Low-ozone bubbles observed in the tropical tropopause layer during the TC4 campaign in 2007, *Journal of Geophysical Research-Atmospheres*, *115*(15), D00J16, 10.1029/2009JD012804.

Petropavlovskikh, I., L. Froidevaux, R. Shetter, S. Hall, K. Ullmann and P. K. Bhartia (2008), In-flight validation of Aura MLS ozone with CAFS partial ozone columns, *Journal of Geophysical Research-Atmospheres*, *113*(D16S41), 10.1029/2007JD008690.

Petropavlovskikh, I., R. D. Evans, G. McConville, K. Miyagawa and S. J. Oltmans (2009), Effect of the out-of-band stray light on the retrieval of the Umkehr Dobson ozone profiles, *INTERNATIONAL JOURNAL OF REMOTE SENSING*, *30*(24), 6461-6482, 10.1080/01431160902865806.

Pickett, H.M., et al. "Validation of Aura Microwave Limb Sounder OH and HO2 measurements," J. Geophys. Res. 113, D16S30, doi:10.1029/2007JD008775, 2008.

Pittman, J.V., L.L. Pan, J.C. Wei, F.W. Irion, X. Liu, E.S. Maddy, C.D. Barnet, K. Chance, and R.-S. Gao, 2009, Evaluation of AIRS, IASI, and OMI ozone profile retrievals in the extratropical tropopause region using in situ aircraft measurements, *J. Geophys. Res.*, *114* (D24109), doi:10.1029/2009JD012493.

Pitts, M.C., et al. "CALIPSO polar stratospheric cloud observations: second-generation detection algorithm and composition discrimination," Atmos. Chem. Phys. 9, 7577-7589, 2009.

Popp, P J, T P Marcy, R. S. Gao, L. A. Watts, D. W. Fahey, E. C. Richard, S. J. Oltmans, M. L. Santee, N. J. Livesey, L. Froidevaux, B. Sen, G. C. Toon, K. A. Walker, C. D. Boone and P. F. Bernath (2009), Stratospheric correlation between nitric acid and ozone, *Journal of Geophysical Research Atmospheres*, *114*(D03305), 10.1029/2008JD010875.

Popp, P.J., T.P. Marcy, R.S. Gao, L.A. Watts, D.W. Fahey, E.C. Richard, S.J. Oltmans, L. Santee, N.J. Livesey, L. Froidevaux, B. Sen, G.C. Toon, K.A. Walker, C.D. Boone, and P.F. Bernath, 2009, Stratospheric correlation between nitric acid and ozone, *J. Geophys. Res.*, *114* (D03305), doi:10.1029/2008JD010875.

Randel, W. J., Park, M. Emmons, L. et al. Asian Monsoon Transport of Pollution to the Stratosphere, 2010, Science 328(5978) 611-613 10.1126/science.1182274

Ravishankara, A R, M.J. Kurylo, J. S. Daniel, D. W. Fahey, J.R. Herman, S. A. Montzka, M. Ko, P.A. Newman and R. Stolarski (2008), Chapter 6 - Implication for the United States, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A.R. Ravishankara, M.J. Kurylo and C.A. Ennis, pp. 155-166, Dept. of Commerce, NOAA's National Climate Data Center, Asheville, North Carolina.

Ravishankara, A R, M.J. Kurylo, R. Bevilacqua, J. Cohen, J. S. Daniel, A.R. Douglass, D. W. Fahey, J.R. Herman, T. Keating, M. Ko, S. A. Montzka, P.A. Newman, V. Ramaswamy, A.-M. Schmoltner, R. Stolarski and K. Vick (2008), Executive Summary, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A.R. Ravishankara, M.J. Kurylo and C.A. Ennis, pp. 15-22, Dept. of Commerce, NOAA's National Climate Data Center, Asheville, North Carolina.

Ravishankara, A.R., J.S. Daniel, and R.W. Portmann, 2009, Nitrous oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st Century, *Science*, *326* (5949), 123-125, doi:10.1126/science.1176985.

Ravishankara, A.R., M.J. Kurylo, and A.-M. Schmoltner, Chapter 1 - Introduction, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A.R. Ravishankara, M.J. Kurylo and C.A. Ennis, pp. 23-28, Dept. of Commerce, NOAA National Climatic Data Center, Asheville, North Carolina, (2008).

Ravishankara, A.R., M.J. Kurylo, and C.A. Ennis (editors), U.S. Climate Change Science Program, Subcommittee on Global Change Research, *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, 240 pp., Dept. of Commerce, NOAA National Climatic Data Center, Asheville, North Carolina, (2008).

Ravishankara, A.R., M.J. Kurylo, J.S. Daniel, D.W. Fahey, J.R. Herman, S.A. Montzka, M. Ko, P.A. Newman, and R. Stolarski, Chapter 6 - Implication for the United States, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A.R. Ravishankara, M.J. Kurylo and C.A. Ennis, pp. 155-166, Dept. of Commerce, NOAA National Climatic Data Center, Asheville, North Carolina, (2008).

Ravishankara, A.R., M.J. Kurylo, R. Bevilacqua, J. Cohen, J.S. Daniel, A.R. Douglass, D.W. Fahey, J.R. Herman, T. Keating, M. Ko, S.A. Montzka, P.A. Newman, V. Ramaswamy, A.-M. Schmoltner, R. Stolarski, and K. Vick, Executive Summary, in *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*, edited by A.R. Ravishankara, M.J. Kurylo and C.A. Ennis, pp. 15-22, Dept. of Commerce, NOAA National Climatic Data Center, Asheville, North Carolina, (2008).

Ray, E. A., F. L. Moore, K. H. Rosenlof, S. M. Davis, H. Boenisch, O. Morgenstern, D. Smale, E. Rozanov, M. Hegglin, G. Pitari, E. Mancini, P. Braesicke, N. Butchart, S. Hardiman, F. Li, K. Shibata and D. A. Plummer, Evidence for Changes in Stratospheric Transport and Mixing Over the Past Three Decades Based on Multiple Datasets and Tropical Leaky Pipe Analysis (2010), *J. Geophys. Res.*, 10.1029/2010JD014206.
Ray, E.A., F.L. Moore, K.H. Rosenlof, S.M. Davis, H. Boenisch, O. Morgenstern, D. Smale, E. Rozanov, M. Hegglin, G. Pitari, E. Mancini, P. Braesicke, N. Butchart, S. Hardiman, F. Li, K. Shibata, and D.A. Plummer, 2010, Evidence for changes in stratospheric transport and mixing over the past three decades based on multiple data sets and tropical leaky pipe analysis, *J. Geophys. Res.*, *115* (D21304), doi:10.1029/2010JD014206..

Rhew, R., B. R. Miller**,** and R. F. Weiss, Chloroform, carbon tetrachloride and methyl chloroform fluxes in southern California ecosystems (2008), *Atmos. Environ., 42,* 7135-7140.

Riffault, V., J.M. Clark, J.C. Hansen, A.R. Ravishankara, and J.B. Burkholder, 2010, Temperature dependent rate coefficients and theoretical calculations for the OH + Cl_2O reaction, *Chem. Phys. Chem.*, *11* (18), 4060-8.

Rontu Carlon, N., D.K. Papanastasiou, E.L. Fleming, C.H. Jackman, P.A. Newman, and J.B. Burkholder, 2010, UV absorption cross sections of nitrous oxide (N_2O) and carbon tetrachloride (CCl_4) between 210 and 350 K and the atmospheric implications, *Atmos. Chem. Phys.*, *10* (13), 6137-6149, doi:10.5194/acp-10-6137.

Rontu Carlon, N., D.K. Papanastasiou, E.L. Fleming, C.H. Jackman, P.A. Newman, and J.B. Burkholder, 2010, UV absorption cross sections of nitrous oxide (N_2O) and carbon tetrachloride (CCl_4) between 210 and 350K and the atmospheric implications, *Atmos. Chem. Phys.*, *10*, 6137-6149, doi:10.5194/acp-10-6137-2010.

Roscoe, H., and K. Rosenlof, 2011, Revisiting the lower stratospheric water vapour trend from 1950s to 1970s, *Atmospheric Science Letters*, *submitted.*

Rosenlof, K.H., and G.C. Reid, 2008, Trends in the temperature and water vapor content of the tropical lower stratosphere: Sea surface connection, *J. Geophys. Res.*, *113* (D06107), doi:10.1029/2007JD009109,

Rosenlof, K.H., and G.C. Reid, 2009, Reply to Comment by John R. Lanzante on "'Trends in the temperature and water vapor content of the tropical lower stratosphere: Sea surface connection", *J. Geophys. Res.*, *114* (D12105), doi:10.1029/2008JD011265.

Salawitch, R. J., T. Canty, T. Kurosu, K. Chance, Q. Liang, A. da Silva, S. Pawson, J. E. Nielsen, J. M. Rodriguez, P. K. Bhartia, X. Liu, L. G. Huey, J. Liao, R. E. Stickel, D. J. Tanner, J. E. Dibb, W. R. Simpson, D. Donohoue, A. Weinheimer, F. Flocke, D. Knapp, S. A. Montzka, J. A. Neuman, J. B. Nowak, T. B. Ryerson, S. J. Oltmans, D. R. Blake, E. L. Atlas, D. E. Kinnison, S. Tilmes, L. L. Pan, F. Hendrick, M. Van Roozendael, K. Kreher, P. V. Johnston, R. S. Gao, B. J. Johnson, T. P. Bui, G. Chen, R. B. Pierce, J. H. Crawford and D. J. Jacob (2010), A new interpretation of total column BrO during Arctic spring, *Geophysical Research Letters*, *37*(L21805), 1-9, 10.1029/2010GL043798.

Salawitch, R.J., T. Canty, T. Kurosu, K. Chance, Q. Liang, A.d. Silva, S. Pawson, J.E. Nielsen, J.M. Rodriguez, P.K. Bhartia, X. Liu, L.G. Huey, J. Liao, R.E. Stickel, D.J. Tanner, J.E. Dibb, W.R. Simpson, D. Donohoue, A. Weinheimer, F. Flocke, D. Knapp, D. Montzka, J.A. Neuman, J.B. Nowak, T.B. Ryerson, S. Oltmans, D.R. Blake, E.L. Atlas, D.E. Kinnison, S. Tilmes, L.L. Pan, F. Hendrick, M.V. Roozendael, K. Kreher, P.V. Johnston, R.S. Gao, B. Johnson, T.P. Bui, G. Chen, R.B. Pierce, J.H. Crawford, and D.J. Jacob, 2010, A new interpretation of total column BrO during Arctic spring, *Geophys. Res. Lett.*, *37* (L21805), doi:10.1029/2010GL043798.

Santee, M.L., et al. "Constraining the chlorine monoxide (ClO) / chlorine peroxide (ClOOCl) equilibrium constant from Aura Microwave Limb Sounder measurements of nighttime ClO," Proc. Nat. Acad. Sci. 107, 15, 6588-6593, doi:10.1073/pnas.0912659107, 2010.

Santee, M.L., et al. "A study of stratospheric chlorine partitioning based on new," J. Geophys. Res. 113, D12307, doi:10.1029/2007JD009057, 2008.

Santee, M.L., et al. "Validation of the Aura Microwave Limb Sounder ClO Measurements," J. Geophys. Res. 113, D15S22, doi:10.1029/2007JD008762, 2008.

Santer, B.D., P.W. Thorne, L. Haimberger, K.E. Taylor, T.M.L. Wigley, J.R. Lanzante, S. Solomon, M. Free, P.J. Gleckler, P.D. Jones, T.R. Karl, S.A. Klein, C. Mears, D. Nychka, G.A. Schmidt, S.C. Sherwood, and F.J. Wentz, 2008, Consistency of modelled and observed temperature trends in the tropical troposphere, *Int. J. Climatol.*, *28* (13), 1703-1722, doi:10.1002/joc.1756.

Sarkissian A., J. Slusser (2009), Water vapor total column measurements using the Elodie Archive at Observatoire de Haute Provence from 1994 to 2004, Atmos. Meas. Tech. Discuss., 2, 1075-1097.

Scherer, M., H. Vömel, S. Fueglistaler, S. J. Oltmans and J. Staehelin (2008), Trends and variability of midlatitude stratospheric water vapour deduced from the re-evaluated Boulder balloon series and HALOE, *ATMOSPHERIC CHEMISTRY AND PHYSICS*, *8*(5), 1391-1402.

Schoeberl, M.R., et al. "Comparison of lower stratospheric tropical mean vertical velocities," J. Geophys. Res. 113, D24109, doi:10.1029/2008JD010221, 2008.

Schoeberl, M.R., et al. "QBO and Annual Cycle Variations in Tropical Lower Stratosphere Trace Gases from HALOE and Aura MLS Observations," J. Geophys. Res. 113, D05301, doi:10.1029/2007JD008678, 2008.

Schwartz, M.J., et al. "Characterization of MJO-Related Upper-Tropospheric Hydrological Processes Using MLS," Geophys. Res. Lett. 35, L08812, doi:10.1029/2008GL033675, 2008.

Schwartz, M.J., et al. "Validation of the Aura Microwave Limb Sounder

Temperature and Geopotential Height Measurements," J. Geophys. Res. 113, D15S11, doi:10.1029/2007JD008783, 2008.

Schnell R. S. and **S.** A. Montzka, 4. Halocarbons In: *State of the Climate in 2007*, [Levinson, D. H., and J. H. Lawrimore, (eds)], *Bull. Amer. Meteorol. Soc.***,** Volume 89, Issue 7, DOI: 10.1175/BAMS-89-7-StateoftheClimate, pp. S28–S29, July 2008.

Schwartz, S. E., R. J. Charlson, R. A. Kahn, J. A. Ogren and H. Rodhe (2010), Why Hasn't Earth Warmed as Much as Expected?, *Journal of Climate*, *23*(10), 2453-2464.

Severinghaus, J.P., M.R. Albert, Z.R. Courville, M.A. Fahnestock, K., Kawamura, **S.A.** Montzka, J. Muhle, T.A. Scambos, E. Shields, C.A. Shuman, M. Suwa, P. Tans**,** R.F. Weiss, Deep air convection in the firn at a zero-accumulation site, central Antarctica, *Earth and Planet. Sci. Lett. (2010), 293*, 359-367.

Smith, W.K., W. Gao, H. Steltzer (2009), Current and future impacts of ultraviolet radiation on the terrestrial carbon balance, Frontiers of Earth Science, 3(1): 34-41.

Smith, W.K., W. Gao, H. Steltzer, M. Wallenstein and R. Tree (2010), Moisture availability influences the effect of ultraviolet-B radiation on leaf litter decomposition. Global Change Biology, 16(1): 484-495. doi: 10.1111/j.1365-246.2009.10973.x.

Solomon, S., J.S. Daniel, R.R. Neely III, J.P. Vernier, E.G. Dutton, and L.W. Thomason, 2011, The persistently variable "background" stratospheric aerosol layer and global climate change, *Science*, *submitted.*

Solomon, S., K.H. Rosenlof, R.W. Portmann, J.S. Daniel, S.M. Davis, T.J. Sanford, and G.-K. Plattner, 2010, Contributions of stratospheric water vapor to decadal changes in the rate of global warming, *Science*, *327*, 1219-1223, doi:10.1126/science.1182488.

SPARC (Stratospheric Processes And their Role in Climate), *The Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion*, report from the June 2008 Cambridge UK Workshop for an Initiative under the Stratospheric Processes and Their Role in Climate (SPARC) Project of the World Climate Research Programme, authored by M.J. Kurylo, B-M. Sinnhuber, N.R.P. Harris, M. von Hobe, P.A. Newman, D.W. Fahey, R.S. Gao, R.J. Salawitch, M.P. Chipperfield, J.G. Anderson, M.L. Santee, T.P. Cantu, R. Müller, R. Schofield, R.M. Stimpfle, F. Stroh, D.W. Toohey, J. Urban, S.R. Kawa, D.J. Hofmann, K.W. Hoppel, M. Rex, K.D. Bayes, D.A. Dixon, K.W. Jucks, S.P. Sander, J.U. Grooss, and D.E. Kinnison, 48 pp., available at http://www.atmosp.physics.utoronto.ca/SPARC/HalogenChem_Final_20090213.pdf, 2009.

Stark, H., S.S. Brown, J.B. Burkholder, M. Aldener, V. Riffault, T. Gierczak, and A.R. Ravishankara, 2008, Overtone dissociation of peroxynitric acid (HO_2NO_2): Absorption cross sections and photolysis products, *J. Phys. Chem. A*, *112* (39), 9296-9303, doi:10.1021/jp802259z.

Stimler, K., S. A. Montzka, J. A. Berry, Y. Rudich, and D. Yakir, Relationships between

carbonyl sulfide (COS) and CO_2 during leaf gas exchange (2010), *New Phytol., 186*, 869-878, doi:10.1111/j.1469-8137.2010.03218.x.

Strahan, S.E., et al. "The impact of tropical recirculation on polar composition," Atmos. Chem. Phys. 9, 2471-2480, 2009.

Su, W., E. G. Dutton, T. Charlock and W. Wiscomb (2008), Performance of Commercial Radiometers in Very Low Temperature and Pressure Environments Typical of Polar Regions and of the Stratosphere: A Laboratory Study, *Journal of Atmospheric and Oceanic Technology*, *25*(4), 558-569, 10.1175/2007JTECHA1005.1.

Tarasick, D. W., J. J. Jin, V. E. Fioletov, G. Liu, A. M. Thompson, S. J. Oltmans, J. Liu, C. E. Sioris, X. Liu, O. R. Cooper, T. Dann and V. Thouret (2010), High-resolution tropospheric ozone fields for INTEX and ARCTAS from IONS ozonesondes, *Journal of Geophysical Research-Atmospheres*, *115*(D20301), 1-12, 10.1029/2009JD012918.

Thomason, L.W., et al. "An evaluation of the SAGE III Version 4 aerosol extinction coefficient and water vapor data products," Atmos. Chem. Phys. 10, 2159-2173, 2010.

Thompson, A. M., S. J. Oltmans, D.. W. Tarasick, P. von der Gathen, H. G.J. Smit and J. C. Witte (2010), Strategic ozone sounding networks: Review of design and accomplishments, *Atmospheric Environment*, 1-19, 10.1016/j.atmosenv.2010.05.002. (In Press)

Thompson, D.W.J., and S. Solomon, 2009, Understanding recent stratospheric climate change, *J. Clim.*, *22*, 1934-1943, doi:10.1175/2008JCLI2482.1.

Tilmes, S., L. L. Pan, P. Hoor, E. Atlas, M. A. Avery, T. Campos, L. E. Christensen, G. S. Diskin, R. S. Gao, R. L. Herman, E. Hintsa, M. Loewenstein, J. Lopez, M. E. Paige, J. V. Pittman, J. R. Podolske, M. R. Proffitt, G. W. Sachse, C. Schiller, H. Schlager, J. Smith, N. Spelten, C. Webster, A. Weinheimer and M. A. Zondlo (2010), An aircraft-based upper troposphere lower stratosphere O3, CO, and H2O climatology for the Northern Hemisphere., *Journal of Geophysical Research*, *115*(D14303), 1-16, 10.1029/2009JD012731.

Tilmes, S., L. L. Pan, P. Hoor, E. Atlas, M. A. Avery, T. Campos, L. E. Christensen, G. S. Diskin, R.-S. Gao, R. L. Herman, E. J. Hintsa**,** M. Loewenstein, J. Lopez, M. E. Paige, J. Pittman, J. R. Podolske, M. Proffitt, G. W. Sachse, N. Spelten, C. Webster, A. Weinheimer, E. M. Weinstock, M. A. Zondlo (2010), An aircraft based upper troposphere lower stratosphere O3, CO and H2O climatology for the Northern hemisphere, J. Geophys. Res.,115, D14303, doi:10.1029/2009JD012731.
Tong, Q.X., X.W. Chen, A. Huang, and W. Gao (2006), Remote Sensing and Space Technology for Multidisciplinary Research and Applications, Proceedings of SPIE, Volume 6199, 250 pages.

Tuck, A.F., and S.J. Hovde, The Winter Polar Vortex in the Lower Stratosphere: A Flow

Reactor, in *Celebration of the 20th Anniversary of the Montreal Protocol*, edited by C. Zerefos, Springer, Berlin, 2008.

Tuck, A.F., *Atmospheric Turbulence: A Molecular Dynamics Perspective*, 176 pp., Oxford University Press, 2008.

Tuck, A.F., D.J. Donaldson, M.H. Hitchman, E.C. Richard, H. Tervahattu, V. Vaida, and J.C. Wilson, 2008, On geoengineering with sulphate aerosols in the tropical upper troposphere and lower stratosphere, *Clim. Change*, *90* (3), 315-331, doi:10.1007/s10584-10008-19411-10583.

Turnbull, J.C., A. Karion, M.L. Fischer, I. Faloona, T. Builderson, S.J. Lehman, B.R. Miller, J.B. Miller, S. Montzka, T. Sherwood, S. Saripalli, C. Sweeney, and P.P. Tans, Assessment of fossil fuel carbon dioxide and other anthropogenic trace gas emissions from airborne measurements over Sacramento, California in spring 2009 (2011), *Atmos. Chem. Phys., 11*, 705-721.

Turnbull, J.C., J.B. Miller, S.J. Lehman, D. Hurst, W. Peters, P.P. Tans, J. Southon, S.A. Montzka, J.W. Elkins, D.J. Mondeel, P.A. Romashkin, N. Elansky and A. Skorokhod, Spatial distribution of $\Delta^{14}CO_2$ across Eurasia: measurements from the TROICA-8 expedition (200(), Atmos. Chem. Phys., 9, 175-187.

Van Thien, L., et al. "Comparison of Aura MLS Water Vapor Measurements with GFS and NAM Analyses in the Upper Troposphere-Lower Stratosphere," Journal of Atmospheric and Oceanic Technology 27, 274-289, doi:10.1175/2009JTECHA1317.1, 2010.

Velders, G.J.M., D.W. Fahey, J.S. Daniel, M. McFarland, and S.O. Andersen, 2009, The large contribution of projected HFC emissions to future climate forcing, *Proc. Nat. Acad. Sci. U.S.A.*, *106* (27), 10949-10954, doi:10.1073/pnas.0902817106.

Wang, W., S. Liang and J. A. Augustine (2009), Estimating High-Spatial Resolution Clear-Sky Land Surface Upwelling Longwave Radiation from MODIS Data, *IEEE Transactions on Geoscience and Remote Sensing*, *47*(5), 1559-1570, 10.1109/TGRS.2008.2005206.

Weinstock, E.M., et al. "Validation of the Harvard Lyman-alpha in situ water vapor instrument: Implications for the mechanisms that control stratospheric water vapor," J. Geophys. Res. 114, D23301, doi:10.1029/2009JD012427, 2009.

Watts, L.A., S. Ciciora, T. Thornberry, D. Fahey, and R. Gao, 2009, Monitoring Atmospheric Ozone on the Global Hawk Unmanned Aeronautical Vehicle with NI CompactRIO, *National Instruments* magazine.

Wild, M., B. Trüssel, A. Ohmura, C. N. Long, G. König-Langlo, E. G. Dutton and A. Tsvetkov (2009), Global dimming and brightening: An update beyond 2000, *Journal of Geophysical Research-Atmospheres*, *114*, D00D13-D00D13, 10.1029/2008JD011382.

Wilson, J.C., S.-H. Lee, J.M. Reeves, C. A. Brock, H.H. Jonsson, B.G. Lafleur, M. Loewenstein, J. Podolske, E. Atlas, K. Boering, G. Toon, D. W. Fahey, T.P. Bui, G. Diskin and F. Moore (2008), Steady-state aerosol distributions in the extra-tropical, lower stratosphere and the processes that maintain them, *Atmospheric Chemistry and Physics*, *8*(22), 6617-6626.

Wofsy, S., B.C. Daube, R. Jimenez, E. Kort, J.V. Pittman, S. Park, R. Commane, B. Xiang, G. Santoni, D. Jacob, J. Fisher, C. Pickett-Heaps, H. Wang, K. Wecht, Q.-Q. Wang, B.B. Stephens, S. Shertz, P. Romashkin, T. Campos, J. Haggerty, W.A. Cooper, D. Rogers, S. Beaton, R. Hendershot, J.W. Elkins, D.W. Fahey, R.S. Gao, F. Moore, S.A. Montzka, J.P. Schwarz, D. Hurst, B. Miller, C. Sweeney, S. Oltmans, D. Nance, E. Hintsa, G. Dutton, L.A. Watts, J.R. Spackman, K.H. Rosenlof, E.A. Ray, M.A. Zondlo, M. Diao, R. Keeling, J. Bent, E.L. Atlas, R. Lueb, M.J. Mahoney, M. Chahine, E. Olson, P. Patra, K. Ishijima, R. Engelen, J. Flemming, R. Nassar, D.B.A. Jones, and S.E.M. Fletcher, 2011, HIAPER Pole-to-Pole Observations (HIPPO): Fine-grained, global scale measurements of climatically important atmospheric gases and aerosols, *Phil. Trans. Roy. Soc.London A*, *369* (1943), 2073-2086, doi:10.1098/rsta.2010.031.

Wunch, D., G. C. Toon, P. O. Wennberg, S. C. Wofsy, B. B. Stephens, M. L. Fischer, O. Uchino, J. B. Abshire, P. Bernath, S. C. Biraud, J.-F. L. Blavier, C. Boone, K. P. Bowman, E. V. Browell, T. Campos, B. J. Connor, B. C. Daube, N. M. Deutscher, M. Diao, J. W. Elkins, C. Gerbig, E. Gottlieb, D. W. T. Griffith, D. F. Hurst, R. Jiménez, G. Keppel-Aleks, E. Kort, R. Macatangay, T. Machida, H. Matsueda, F. Moore, I. Morino, S. Park, J. Robinson, C. M. Roehl, Y. Sawa, V. Sherlock, C. Sweeney, T. Tanaka, and M. A. Zondlo, Calibration of the total carbon column observing network using aircraft profile data (2010), Atmos. Meas. Tech., 3, 1351-1362, 2010, www.atmos-meas-tech.net/3/1351/2010/doi:10.5194/amt-3-1351.

Wu, D.L., et al. "Validation of the Aura MLS Cloud Ice Water Content (IWC) Measurements," J. Geophys. Res. 113, doi:10.1029/2007JD008931,2008.

Xiao, X, R. G. Prinn, P.J., Fraser, R.F.Weiss, P.G. Simmonds, S. O'Doherty, B.R. Miller, P.K. Salameh, C.M. Harth, , P. B. Krummel, , A. Golombek, L.W. Porter, J. H.Butler, J.W. Elkins, G.S. Dutton, B. D. Hall, L.P. Steele, R.H.J. Wang, and D.M. Cunnold (2010), Atmospheric three-dimensional inverse modeling of regional industrial emissions and global oceanic uptake of carbon tetrachloride. *Atmos. Chem. Phys., 10* 10434 (21) - 10421, issn: 1680-7316, ids: 680CQ, doi: 10.5194/acp-10-10421-2010
.

Xiao, X., R.G. Prinn, P.J. Fraser, P.G. Simmonds, R.F. Weiss, S. O'Doherty, B.R. Miller, P.K. Salameh, C.M. Harth, P.B. Krummel, L.W. Porter, J. Mühle, B.R. Greally, D. Cunnold, R. Wang, S.A. Montzka, J.W. Elkins, G.S. Dutton, T.M. Thompson, J.H. Butler, B.D. Hall, S. Reimann, M. K. Vollmer, F. Stordal, C. Lunder, M. Maione, J. Arduini, and Y. Yokouchi, Optimal estimation of the surface fluxes of methyl chloride using a 3-D global chemical transport model, *Atmos. Chem. Phys*., *10*, 5515-5533, 2010.

Xiong, X., C. Barnet, E. Maddy, C. Sweeney, X. Liu, L. Zhou and M. Goldberg (2008), Characterization and validation of methane products from the Atmospheric Infrared

Sounder (AIRS), *Journal of Geophysical Research-Atmospheres*, *113*, G00A01, 10.1029/2007JG000500.

Xiong, X., C. D. Barnet, Q. Zhuang, T. Machida, C. Sweeney and P. K. Patra (2010), Mid-upper tropospheric methane in the high Northern Hemisphere: Spaceborne observations by AIRS, aircraft measurements, and model simulations, *Journal of Geophysical Research-Atmospheres*, *115*(D19), 10.1029/2009jd013796.

Xu, M., X.Z. Liang, W. Gao, and N. Krotkov (2010), Comparison of TOMS retrievals and UVMRP measurements of surface spectral UV radiation in the United States (2010), Atmospheric Chemistry and Physics, 1-15, doi:10.5194/acp-10-1.

Yang, E.-S., D. M. Cunnold, M. J. Newchurch, R. J. Salawitch, M. P. McCormick, J. M. Russell, J. M. Zawodny and S. J. Oltmans (2008), First stage of Antarctic ozone recovery, *Journal of Geophysical Research-Atmospheres*, *113*(D20), D20308, 10.1029/2007JD009675.

Young, P.J., S. Solomon, D.W.J. Thompson, K.H. Rosenlof, and J.-F. Lamarque, 2011, The seasonal cycle and interannual variability in stratospheric temperatures and links to the Brewer-Dobson circulation: An analysis of MSU and SSU data, 1979-2005, *J. Clim.*, *submitted*.

Young, P.J., S. Solomon, D.W.J. Thompson, S.C. Sherwood, K.H. Rosenlof, Q. Fu, and J.-F. Lamarque, 2011, Changes in stratospheric temperatures and their implications for changes in the Brewer-Dobson circulation, 1979-2005, *J. Clim.*, *submitted*.

Yvon-Lewis, S. A., E. Saltzman and S. A. Montzka (2009), Recent trends in atmospheric methyl bromide: analysis of post-Montreal Protocol variability, *Atmospheric Chemistry and Physics*, *9*, 5963-5974

Zhang, H., H-L Huang, A. Lim, R. Holz, S. Dutcher, F. Nagle, L. Gumley, J. Wang, R. Shi and W. Gao (2010), Analysis and characterization of the synergistic AIRS and MODIS cloud-cleared radiances, Frontiers of Earth Science in China, Volume 4, Number 3, 363-373, doi: 10.1007/s11707-010-0023-7

Zhang, Y., C. N. Long, W. B. Rossow and E. G. Dutton (2010), Exploiting diurnal variations to evaluate the ISCCP-FD flux calculations and radiative-flux-analysis-processed surface observations from BSRN, ARM, and SURFRAD, *Journal of Geophysical Research-Atmospheres*, *115*(D15), D15105, 10.1029/2009JD012743.

Ziemke, J.R., et al. "A new ENSO index derived from satellite measurements of column ozone," Atmos. Chem. Phys. 10, 3711-3721, 2010.

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, DoE) and universities (University of Colorado, Harvard, Princeton, Humboldt State University, etc.) is maintained through both global monitoring and field missions including support for satellite validations. 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, and the NDACC Data Host Facility.

NASA:

NASA collaborates extensively with several NOAA laboratories in all areas of ozone and UV research, including space-based, airborne, balloonborne, and groundbased 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 assisting NOAA in the implementation of the OMPS nadir and limb instruments on the NPOESS Preparatory Satellite (NPP) by developing the limb operational algorithms 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.

EPA:
The NOAA/EPA Brewer spectrophotometer network (NEUBrew) consists of six stations located in the western, central, and eastern United States. The NEUBrew network has deployed two Brewer Mark IV spectrophotometers to Brisbane, Australia. The data gathered from this location will be used for atmospheric research and human health effects studies.

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. New algorithms to utilize multi-wavelength Brewer zenith sky measurements for improved ozone profile retrieval are underway. The work on improvement of optical characterization of Dobson and Brewer instruments for stray light minimization and new ozone cross-section implementation is underway. (NOAA, NASA)

According to the ACSO (WMO GAW Ad Hoc Expert team on Absorption Cross-sections of Ozone - ACSO) analysis of the impact of a possible change of ozone absorption cross-sections from Bass and Paur to Brion/ Daumont /Malicet (BDM) on Dobson and Brewer total ozone measurements, SAG-Ozone (Activity A9 within the ICAGO-O3/UV implementation plan) recommended to develop procedure to apply ozone cross section changes to processed total ozone data from Dobson and Brewer observations. A NOAA group will proceed to convert retrieved total ozone measurements and submit results to the WOUDC. (NOAA)

Ozone profiles from Dobson/ Brewer Zenith-Sky Measurements
NOAA GMD will convert retrieved 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 BDM cross-section. Results from the NEUBrew instruments will be posted on the network website http://esrl.noaa.gov/gmd/grad/neubrew/, with the follow up submission to the WOUDC Brewer archive. Also, all B-files will be submitted to the WOUDC Brewer archive in accordance with the SAG-Ozone Activity (NOAAESRL/GMD)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. The algorithm will 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 next Vertical ozone workshop 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 Antartic 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 stabilizied 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.

Ozone-Relevant Gases/Variables:

OMPS and CrIS on NPP and NPOESS
The Ozone Mapping and Profiler Suite will become the operational US ozone monitoring instrument in the NPOESS 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 will fly on the NASA NPOESS Preparatory Project Mission in 2010. The OMPS was design to include a third detector, the limb profiler, to provide high-vertical resolution ozone profiles. This instrument was de-manifested due to cost issues. It has been restored on NPP and options for future flights are under consideration. The Cross-track Infrared Sounder is a hyperspectral IR instrument with spectral coverage including the ozone lines around 9.7 microns. NOAA has implemented ozone retrieval algorithms with the AIRS instrument on EOS, and plans to use similar algorithms with the IASI on MetOp-A and the CrIS on NPP and NPOESS. (NOAA, NASA)

NASA Earth Venture (EV) Investigations and missions
NASA selected 5 investigations (EV-1)that will last for 5 years to use suborbital platforms for sustained investigations of Earth System processes. 2 of these selected studies have direct relevance to Ozone related science, the Airborne Tropical Tropopause Experiment (ATTREX) and the Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) investigation. These activities started in 2010 and will continue until 2014. Two new competed space mission Announcements of Opportunities (AOs) will be released in 2011. One is for a cost constrained stand alone space mission (EV-2), and one for a cost constrained space based Instrument of Opportunity (EV-Instrument). (NASA)

NEUBrew Network
Future plans for the NEUBrew network are to process historical direct-sun measurement data for total column abundance of NO_2 and SO_2 data products. (NOAA, EPA)

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. (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 will be obtained by the OMPS Limb instrument on NPP during the next 3-5 years. But these observations will not be continued on the following JPSS platforms. OMPS-Limb will be followed by the SAGE-III on the International Space Station, which may provide useful data to about the end of the lifetime of ISS (~2020). (NASA)

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)

The only currently planned U.S. space-based ozone-monitoring instruments in the post-Aura era will be the NPOESS OMPS instrument, a limb scattering measurement with very little heritage, and the SAGE-III experiment on the ISS. In order to provide a calibration source for OMPS so that the data will be of sufficient quality for scientific studies and trend analysis, consideration should be given to adding a simple solar occultation instrument to NPOESS. (NASA/NOAA/DOD)

NASA has two Earth Science Decadal Survey satellite missions recommended in the future. One (GEO-CAPE) is a geosynchronous orbit and designed to study North American air quality, but should also provide column ozone. The second (GACM) is described as a follow up to Aura with analogous instrumentation using more advanced technology. This will provide profiles for ozone and numerous trace gases in the stratosphere and troposphere. Neither project is planned to be launch until some time after 2020, leaving a large gap between Aura and the next mission. (NASA)

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. Current workforce limitations prevent the development and propagation of gas standards on as rapid a schedule as required by these networks to keep up with the increasing number of new chemicals of scientific interest. In addition, expanded efforts are needed for data analysis as more and more chemicals are being measured. An intercomparison study, IHALACE, for halocarbon standards between measurement groups that has examined differences in the individual gases was completed and a paper summarizing the results has been submitted for publication. The work found that most independent calibration groups agreed well for most compounds (<5%), but groups using the same calibration standards did not transfer the calibration. (NASA, NOAA)

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.

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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 in it's Extended Mission phase now. 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)

Calibration and Validation
It is now well established that the ratio of UVB and UVA can be predicted accurately under clear conditions and to within a few percent in cloudy conditions wherever quality column ozone data exist. Absolute measurements of ozone amounts from satellites are accurate to 2% resulting in a 2% error in UV irradiance at 310 nm and an 8% error at 305 nm with larger errors at higher latitudes. UVA variability is known to correlate with variations in clouds, NO2, and aerosols, some of which are also measured by satellites. Ground based intercomparisons studies are using long time averages to simulate the spatial footprint of satellites. Further studies are required to determine the effectiveness of this approach. (NASA)

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.)
GMD Global Monitoring Division (formerly 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)
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
NPOESS National Polar-Orbiting Operational Environmental Satellite System
NPP NPOESS Preparatory Satellite
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

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