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). One more instrument in this series remains to be launched around Feb. 2009. 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. Neither of the algorithms is fully compatible with the SBUV and TOMS total ozone (version 8) algorithms. Most of the differences occur over bright clouds and at large solar zenith angles. NASA plans to reprocess SBUV, TOMS and OMI data using a common (version 9) algorithm by the end of this year. (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)

Dobson Network
Dobson total column ozone measurements in the U.S. are done through the NOAA/ESRL/GMD 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/ESRL/GMD, NASA)

UVB Monitoring and Research Programme (UVMRP)
Direct-sun column ozone is retrieved by UV Multi-Filter Rotating Shadowband Radiometers (UV-MFRSRs) at 33 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). (USDA)

NOAA-EPA Ultraviolet Brewer (NEUBrew) Network
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 derived from these measurements http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA/ESRL/GMD, EPA)

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, NO_2, 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/ESRL/GMD)

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 plans to reprocess data from the entire BUV instrument series, including OMI, using a consistent algorithm (version 9) by the end of this year. 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/CPC, 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. (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. 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. (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/ESRL/GMD, 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. This algorithm has been used to process Brewer Umkehr data on a selective basis. However, due to lack of availability of the Brewer raw radiance data it has not been possible to reprocess the Dobson/Brewer Umkehr data using a consistent algorithm. (NOAA/ESRL/GMD, 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 derived from these measurements http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA/ESRL/GMD)

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/ESRL/GMD)

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. (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 vapour profiles are also available. (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, H_2O, ClO, BrO, HCl, OH, HO_2, HNO_3, HCN, N_2O, and CO. HIRDLS is retrieving profiles of temperature, O_3, and HNO_3 at 1.2 km vertical resolution and will soon deliver profiles of H_2O, CH_4, N_2O, NO_2, CF_3Cl, CF_2Cl_2, and aerosols. TES is providing limited profile information for O3, CO, H2O, 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 Measurements
NOAA monitors upper tropospheric and stratospheric water vapour 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. Water-vapour profiles also are obtained on a campaign basis in Indonesia, the Galapagos, and Hawaii. NASA supports the flights of several balloon instruments (primarily on a campaign basis) capable of providing profile information for numerous atmospheric constituents. (NOAA/ESRL/GMD, 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 (Costa Rica AVE and TC4) have concentrated on the convection of source gases to the tropical upper troposphere and stratosphere with a goal of understanding the effects on stratospheric ozone. Currently, the international POLARCAT campaign with components from NASA, NOAA, DOE, and NSF are being executed looking at atmospheric processes in the Arctic troposphere. (NASA, NOAA, NSF)

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 two Northrop Grumman Global Hawks. This new technology will permit longer duration flights (up to 36 hours), flights over hazardous areas for pilots, crew, and scientists (polar regions and remote oceans), and flights incorporating repetitive tasks (drop radiosondes, routine weather observations, and trace gas observations). NOAA sponsored the NOAA UAS Demonstration in 2005 and operated a two airborne channel gas chromatograph (UCATS- UAS Chromatograph for Atmospheric Trace Species) that measured greenhouse gases, stratospheric ozone depleting gases, and air quality gases. It included a small ozone ultraviolet absorption spectrometer. Two atmospheric instruments, ARGUS and UCATS with a water vapour instrument added, flew on the NASA UAS Fire Mission in 2006. In FY 2009, NASA will sponsor several flights including a few new atmospheric instruments for Aura Validation using one of its Global Hawks, a jet powered high altitude UAS (NASA and 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 vapour, CFCs, HCl, HF, CH_4, and N_2O. (NASA, NOAA, DoD/NRL)

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/ESRL/GMD 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/ESRL/GMD networks and with other international collaborators are leading to an improved long-term database for many ozone- and climate-related gases (NOAA/ESRL/GMD, NASA)

UV Irradiance Measurements:

Broadband Measurements

SURFRAD Network
Seven Surface Radiation Budget Network (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 nine 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/ESRL/GMD)

NOAA/ESRL/GMD *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/ESRL/GMD)

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. (EPA, NOAA)

USDA UV-B Monitoring and Research Programme (UVMRP)
Thirty-seven YES UVB-1 radiometers are fielded under this programme. (USDA)

Narrowband Filter Measurements

Central Ultraviolet Calibration Facility
Currently 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. A YES UV-MFRSR is also deployed at the Central Ultraviolet Calibration Facility's High-Altitude Observatory at Niwot Ridge, Colorado. (NOAA/ESRL/GMD)

NOAA/ESRL/GMD Network
Narrowband radiometers (Biospherical Instruments, GUV, 305 nm, 313 nm, 320 nm, and 380 nm) are used at three sites in Alaska. These sites were established in 1998 and operated for about two years with initial funding, but have been operated in a minimal-maintenance mode since. One site was discontinued in 2003 when it was determined that the combination of on-site support and data communications problems were prohibitive. Initial and subsequent calibrations of the instruments have been performed by the manufacturer. Due to reductions in personnel and funding, since 2001 the instrument calibration schedules have been reduced and adequate quality control has not yet been applied to the data. The measurements were discontinued in 2006. (NOAA/ESRL/GMD)

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_data_products.html) (USDA)

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

NSF UV Monitoring Network
Biospherical Instruments (BSI) GUV-511 moderate bandwidth multi-channel radiometers are deployed at five of the seven network sites (McMurdo and Palmer Station in Antarctica, San Diego California, Barrow Alaska, and Summit Greenland). A BSI GUV-514 radiometer is deployed at the South Pole. (NSF)

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. (NOAA/ESRL/GMD)

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/ESRL/GMD)

NSF UV Monitoring Network
BSI SUV-100 high-resolution scanning spectroradiometers are deployed at all seven network sites (McMurdo Station, Palmer Station, and South Pole Station in Antarctica; San Diego California; Barrow, Alaska; Summit, Greenland; and Ushuaia, Argentina). A BSI SUV-150B spectroradiometer is also deployed at Summit, Greenland. (NSF)

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. (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 hour. http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA/ESRL/GMD, 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. (NASA, 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. (NOAA/ESRL/GMD)

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/ESRL/GMD)

Ground-Based In Situ Measurement Networks
Both the NOAA/ESRL/GMD 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/ESRL/GMD, 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 more than 80 UV instruments per year 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 standards. The secondary standards can be calibrated for operation in either the vertical or horizontal orientation. (NOAA/ESRL/GMD)

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)

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 when they do not. Such data sets have been produced using TOMS and SBUV total column ozone and profile records. (NASA)

Total Column Ozone

Trends in total column ozone from 10 two-dimensional and 4 three-dimensional models and solar backscatter ultraviolet-2 (SBUV/2) satellite observations were compared for the period 1979-2003. Trends for the past (1979-2000), the recent 7 years (1996-2003), and the future (2000-2050) were compared. Future trends are expected to be positive and less than half the magnitude of the past downward trends. (NOAA/ESRL/CSD, NASA)

Ozone Depletion & Recovery

Statistical analysis of the merged SBUV profile ozone data set from 1979 to June 1997 shows the largest negative trends in the upper stratosphere at high latitudes (-8.5% per decade at 47.5˚S and -7.5 per decade at 47.5˚N), and less negative trends in the tropics and below 30 hPa (-2 to -4% per decade). These trends are in general agreement with previous profile trend estimates from satellite and ground-based records. The downward trend of ozone in the upper stratosphere has not continued beyond 1997, suggesting that decrease of chlorine observed in the upper stratosphere may be having a positive impact on ozone.

Total ozone levels have remained relatively constant over the last decade (1998-2007). Northern midlatitude ozone reached a minimum of 8% 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 1.5% below the 1979-1980 values. Southern midlatitude ozone decreased steadily until the late 1990s, and has been nearly constant since at 4.5 - 5% below 1979-1980 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:

Chlorine Activation

Substantial chlorine activation near the midlatitude tropopause was inferred from an analysis of airborne measurements of chlorine monoxide and ozone. The analysis suggests that a

heterogeneous mechanism for the chlorine activation exists in volcanically quiescent periods and can impact ozone photochemistry in regions of the lowermost stratosphere. (NOAA/ESRL/CSD, NOAA/ESRL/GMD, NASA)

Rates of Chemical Reactions Important to Ozone Depletion

The rate of the reaction of hydroxyl radical (OH) with OClO has been studied. This rate affects the partitioning of chlorine into its active forms. The quantum yields for OH production in the photodissociation of nitric acid, a key reservoir species, were studied. (NOAA/ESRL/GMD)

Chemistry in Polar Stratospheric Clouds (PSCs)

High Altitude Balloon and Satellite Observations in the Polar Vortex

A January 2007 NASA balloon campaign from Kiruna, Sweden was conduction to validate of Aura observations in the polar vortex. A broad suite of Cl_y, NO_y, HO_x, and tracers measurements were made in PSCs detected by the HIRDLS and CALIPSO satellite instruments. These data are being analyzed to understand reactive radical partitioning in PSCs. (NASA)

Observations of Nitric Acid-Containing Particles

Airborne in-situ measurements revealed a new category of nitric acid-containing particles in the tropical lower stratosphere, most likely composed of nitric acid trihydrate. It is reasonable to expect that the tropical NAT particles and polar NAT particles nucleate via a similar process because of similar low temperatures; hence, the investigation of the tropical nucleation process is expected to further our understanding of particle nucleation in polar regions also. Observations of condensed-phase nitric acid in tropical subvisible cirrus clouds and in Arctic cirrus ice crystals have also been reported. (NOAA/ESRL/CSD, NOAA/ESRL/GMD, NASA)

Stratospheric Ozone - Climate Connection

Antarctic Ozone and Climate

Research has shown that the atmosphere's temperature structure is affected by decreases in stratospheric ozone. This has included the demonstration that the observed pattern of recent Antarctic surface temperature trends (cooling over the high plateau, accompanied by warming in the region of the Peninsula) is largely due to a change in Southern Hemisphere circulation that is related to the ozone hole.
(NOAA/ESRL/CSD)

Stratospheric Ozone and Climate Forcing

The indirect climate forcing associated with stratospheric ozone changes caused by 21st-century changes in the greenhouse gases carbon dioxide, methane, and nitrous oxide were computed using a two-dimensional radiative-chemical-dynamical model and radiative transfer models. For the various scenarios investigated, the range of future indirect radiative forcings from ozone were found to be small compared with the total direct radiative forcings of these greenhouse gases over the 2000-2100 time horizon. (NOAA/ESRL/CSD)

Ozone-Relevant Gases

Research has shown how the Montreal Protocol that protects Earth's ozone layer has also helped slow climate change. The double effect occurred because compounds that destroy the atmosphere's ozone layer also act as greenhouse gases. While protecting the ozone layer, the Montreal Protocol and its Amendments has also cut in half the amount of greenhouse warming caused by ozone-destroying chemicals that would have occurred by 2010 had these substances continued to build unabated in Earth's atmosphere. The amount of warming up to the year 2010 that was avoided is equivalent to 7-12 years of growth in radiative forcing by carbon from human activities. Earlier studies showed that continued growth in ozone-depleting substances would lead to significant warming of Earth's climate. The analysis quantifies the near-term climate benefits of controlling these substances. (NOAA/ESRL/CSD)

UV:

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 submitted for publication. Both positive and negative tendencies were detected ranging from –5% to +2% per decade. However, inter-annual variability was between 2 and 5%. (NOAA/ESRL/GMD)

USDA UVB Monitoring and Research Programme (UVMRP)

Analysis of nine years of broadband data indicates no statistically significant trend in UVB, though the author of this paper has recently begun to re-evaluate the results using more robust analysis methods. The difficulty in detecting the expected upward trend in UVB is due to calibration uncertainties, radiometric sensitivity drift, year-to-year variability due to changes in cloud cover, ozone, aerosols, albedo, etc. Improved quantification of these variables is essential for any trends analysis, and the UVMRP staff and researchers are, and have been, continuing the work to refine these parameters. (USDA)

A clear latitudinal gradient is seen in the data from North America, even though the range of selected latitudes (40^{o}N to 47^{o}N) is quite limited. At low altitudes, the peak values of erythemally weighted UV ($UV_{Ery)}$ increases by (2.5 ± 0.1)% per degree of latitude over the range of latitudes sampled. A clear altitudinal gradient is also evident. Near 41^{o}N, the peak value of UV_{Ery} increases by ~15% as the altitude increases by ~1 km. This rate of increase is about three times larger than expected for a Rayleigh atmosphere. The increase is smaller for an altitude change from 1.5 km to 3.2 km, indicating that boundary layer extinctions are largest at altitudes below 1 km. (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/ESRL/CSD and NASA)

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%. Although some ozone losses are apparent in the Arctic during particular years, the depth of the ozone losses in the Arctic are considerably smaller, and their occurrence is far less frequent. The observations demonstrate that the widespread and deep ozone depletion that characterizes the Antarctic ozone hole is a unique feature on the planet. (NOAA/ESRL/CSD)

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 are coordinated under a new SPARC initiative on "The Role of Halogen Chemistry in Polar Ozone Loss", which will undertake a comprehensive review of existing and ongoing laboratory studies, atmospheric observations, and modeling activities. (NASA, NOAA)

Ozone Forecasts
Mechanisms to improve the ozone production and loss chemistry in the operational NCEP/Global Forecast System (GFS) have been implemented resulting in decreased ozone forecast errors at all latitudes. Aura/OMI near-real-time total ozone data will begin to be assimilated into the NCEP/GFS in the Fall of 2008. This will greatly enhance the horizontal ozone coverage previously provided just from the nadir SBUV-2 data. Additionally, tests using ozone profile information from near-real-time versions of the Aura/MLS and Aura/HIRDLS and total ozone data from MetOP/GOME-2 are being conducted. (NOAA/CPC)

Lower Stratospheric Halogen Chemistry
Observations of HOCl, HO_2, and ClO from multiple instruments on high altitude balloons, in conjunction with Aura MLS observations of ClO, suggest that the rate of the HO_2+ClO reaction is faster than the rate currently used in stratospheric photochemistry models. This reaction has a significant contribution to ozone loss in the lower stratosphere. (NASA)

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 2006 WMO/UNEP Ozone Assessment. (NASA)

Ozone-Related Gases and Variables:
Environmental Properties of Atmospheric Gases
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. (NOAA/ESRL/CSD)

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/ESRL/CMD)

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 programme's web site at (http://uvb.nrel.colostate.edu/UVB/uvb_publications.html). (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. Cotton yields for the 14-state USA cotton 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
TOMS, SBUV and Aura data

In June 2004, a 2-DVD set containing the entire TOMS V8 data set was released. The data cover the period from November 1978 through August 2003. Similarly, a DVD containing SBUV V8 ozone profile data was released. Data are from Nimbus 7 (1978 to 1993), NOAA 9 (1985 to 1998), NOAA 11 (1988 to 2001) and NOAA 16 (2000 to 2003). In 2007 the entire Earth Probe TOMS data record (8/1996-12/2006) was reprocessed using a final correction for instrument degradation. Ozone data from Aura instruments (OMI, MLS, TES, 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). (NASA)

NOAA plans to provide a four-year incremental supplement extending the SBUV(/2) Version 8 ozone profile data record through the end of 2007 by using retrievals from the SBUV/2 instruments on NOAA-16, -17 and -18 POES in the Summer of 2008. (NOAA)

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 Data
Dobson Umkehr data processed using an SBUV-like algorithm are available at http://www.srrb.noaa.gov/research/umkehr/. (NOAA/ESRL/GMD, 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/ESRL/GMD, 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 2006 WMO/UNEP Scientific Assessment of Ozone Depletion, mandated under the provisions of the Montreal Protocol. (NOAA, NASA)

2005 IPCC Special Report
The 2005 Special Report of the Intergovernmental Panel on Climate Change (IPCC) and the Technology and Economic Assessment Panel (TEAP) was published (*IPCC/TEAP Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons). (NOAA, NASA, EPA, NIST, NSF)*

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, TES, 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). (NASA)

Ozone-Depleting Substance Data
Long-term data from the NOAA/ESRL/GMD 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/ESRL/GMD)

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/ESRL/GMD)

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. (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/ESRL/GMD 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 results are updated annually and posted at http://www.esrl.noaa.gov/gmd/odgi. (NOAA/ESRL/GMD)

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PROJECTS AND COLLABORATION

NOAA/ESRL/GMD

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. 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 (GO_3OS) 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. USDA researchers participated in the NSF MIRAGE Mexico City air quality study in February/March 2006. Collaborations also exist with DoE for providing aerosol optical depths and column ozone data. Agency personnel participated in the Norwegian filter radiometer intercomparison held in Oslo in May 2005.

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. (NASA)

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)

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)

NEUBrew Network

The NOAA/EPA Brewer spectrophotometer network (NEUBrew) consists of six stations located in the western, central, and eastern United States. Future plans include the addition of UV-aerosol optical depths, tropospheric ozone estimates and total column abundance of NO2 and SO2 data products. (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. (NASA)

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. (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. (NASA)

The only currently planned U.S. space-based ozone-monitoring instrument in the post-Aura era will be the NPOESS OMPS instrument, a limb scattering measurement with very little heritage. 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 2017, 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, HIRDLS and OMI are promising as they provide ozone profiles which are of greater resolution (MLS and HIRDLS) and of greater horizontal coverage (OMI). As these products are refined and made available in near-real-time, they will likely be 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. (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)

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Field Campaigns
Aircraft, balloon, and ground-based measurement campaigns for satellite validation and science are expected to continue. 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 Houston, TX in August 2006, and the development of real-time data streams will be attempted within the network. New interagency collaborations will include participation in the NSF MIRAGE air-quality study in Mexico City (February/March 2006), and the generation of aerosol atmospheric corrections for a NASA/USGS invasive-species study. (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
The WMO has requested that the CUCF become the WMO centre for UV calibrations.
However, funding for this within and outside NOAA has yet to be identified. Efforts to accomplish this are continuing. (NOAA/ESRL/GMD)

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, NO_2, 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
GO_3OS	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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