The Network for the Detection of Atmospheric Composition Change: 25 Years Old and Going Strong

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Introduction

The Network for the Detection of Atmospheric Composition Change (NDACC) is an international research and measurement program composed of more than 70 high-quality, remote-sensing research stations—as shown in **Figure 1.** The Network conducts long-term measurements for observing and understanding the physical and chemical state of the stratosphere and upper troposphere and for assessing the impact of stratosphere changes on the underlying troposphere and on global climate. The year 2016 marks 25 years of successful operations for NDACC, enabling and enhancing global atmospheric research through:

- analysis of long-term datasets from which trends and changes in atmospheric composition have been determined for international ozone and climate assessments;
- provision of ground-truth and correlative measurements for international satellite investigations;
- scientific collaboration in airborne and balloon campaigns for investigating stratospheric and upper tropospheric processes; and
- validation and development of atmospheric models.

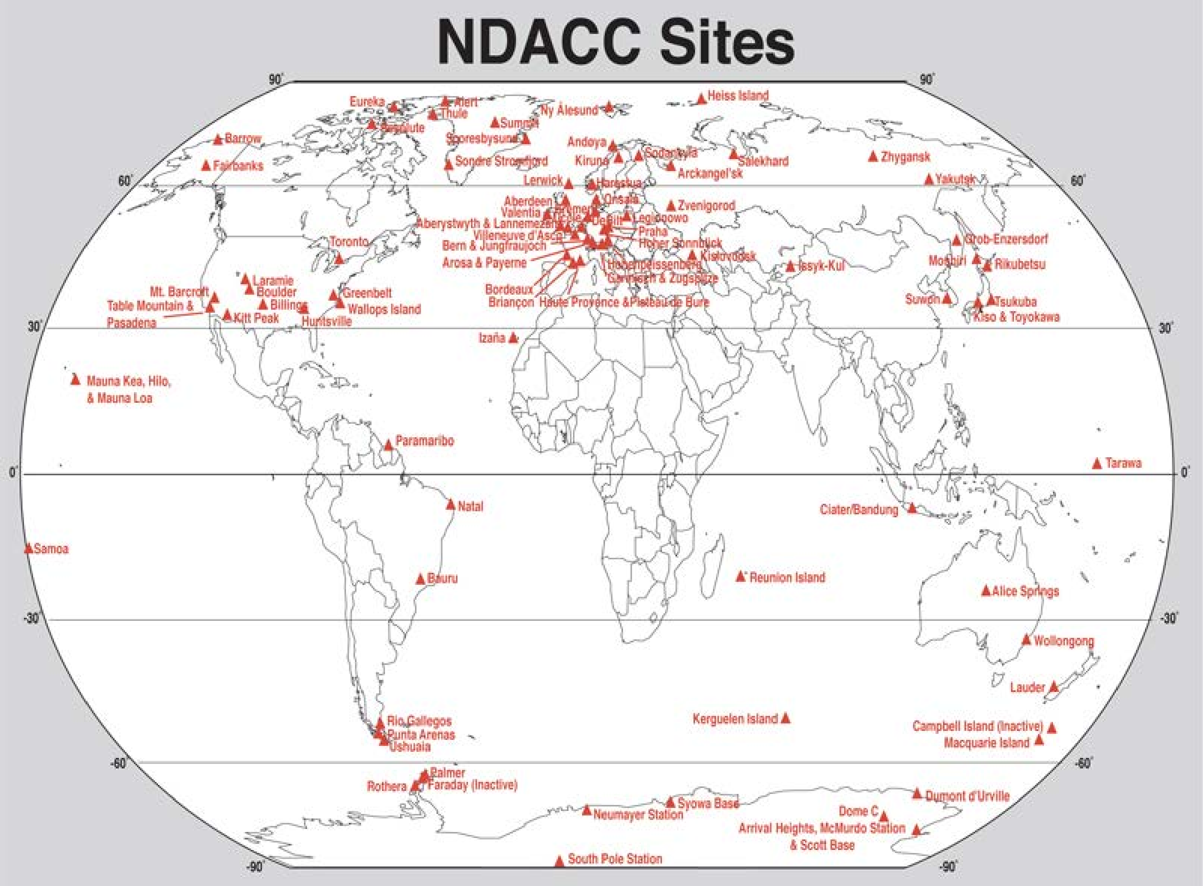

Figure 1. Global distribution of NDACC Measurement Stations **Image credit:** Geir Braathen [World Meteorological Organization]

This historic milestone provides an excellent opportunity to reflect on NDACC's history, assess where it is today, and to look to its future[1]. More-detailed information on the Network may be found at *http://www.ndacc.org*.

Historical Context for the Development of the NDACC[2]

As a result of a variety of factors, by the early-to-mid-1970s, the welfare of biological systems on our home planet became a common concern beyond the scientific community. NASA contributed to promoting this new interest in the environment by way of a series of photographs of Earth from its geosynchronous satellites and by astronauts on the Apollo missions, which provided the first global views of Earth in the late 1960s. Meanwhile, for the first time, scientists were reaching consensus that human beings now had the capacity to alter their global environment[3].

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NASA's interest in focused studies of Earth's atmosphere came about through research conducted under the Department of Transportation's (DOT) Climatic Impact Assessment Program (CIAP). CIAP was initiated in 1971 to address the scientific controversy over the potential adverse impact that exhaust emissions from the proposed supersonic transport fleet, which contained oxides of nitrogen (NO_x), could have on stratospheric ozone. Additional concerns were raised shortly thereafter regarding the catalytic destruction of ozone by chlorine released from several sources, including solid rocket propellants and industrial chlorofluorocarbons. Though CIAP fell under DOT's authority, from early on, the U.S. Congress made it clear that "figuring out the ozone mess was NASA's job[4]". This led to the establishment of a stratospheric ozone research program at NASA.

The Upper Atmosphere Research Program

NASA's 1976 authorization bill officially handed the agency the responsibility of understanding stratospheric ozone chemistry in the form of a mandate to perform research concerned with the possible depletion of the ozone layer by "conducting a comprehensive program of research, technology, and monitoring of the phenomena of the upper atmosphere." This led to NASA's establishment of the Upper Atmosphere Research Program (UARP). This mandate was further amplified through the Clean Air Act Amendments of 1990, which directed both NASA and the National Oceanic and Atmospheric Administration (NOAA) to "monitor stratospheric ozone and ozone-depleting substances (ODSs) and submit a report to Congress on the current average tropospheric concentrations of chlorine and bromine and on the level of stratospheric ozone depletion." Since then, UARP has sponsored and continues to sponsor a wide range of investigations including field measurements, laboratory kinetics and spectroscopy, modeling, and data analysis[5].

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[1] The results of many past and present measurements, analysis, and exploitation activities will be highlighted in a special interjournal commemorative issue of *Earth System Science Data, Atmospheric Chemistry and Physics*, and *Atmospheric Measurement Techniques,* as well as in oral and poster presentations during session A017 on Atmospheric Trace Species at the Fall 2016 Meeting of the American Geophysical Union. Additional information about NDACC as it is presently configured can be found at the NDACC website located at *http://www.ndacc.org*.

[2] Much of the historic context summarized in the first few paragraphs is drawn from Conway, Eric, 2008: NASA Atmospheric Research in Transition. *Atmospheric Science at NASA: A History.* The Johns Hopkins University Press, pp. 122-141.

[3] This was the consensus of a July 1970 workshop held at Massachusetts Institute of Technology (MIT) that was organized to provide input for a 1972 United Nations Conference on the Human Environment. The report from that workshop, "Man's Impact on the Global Environment: Report of the Study of Critical Environmental Problems," is considered a scientific classic.

[4] This was how Eric Conway summarized the content of a letter from Senator Clinton Andersen [D, NM—*Chairman of Senate Committee on Aeronautics and Space Sciences*] to NASA Administrator James Fletcher in June 1971—several months prior to enactment of the legislation that created CIAP. To learn more, see *Atmospheric Science at NASA: A History*, p. 133.

[5] The major results and advancements in understanding from the first decade of effort were summarized in World Meteorological Organization (WMO) Report No. 16, *Atmospheric Ozone 1985: Assessment of our Understanding of the Processes Controlling Its Present Distribution and Change*; NASA RP 1162, (1986), *Present State of Knowledge of the Upper Atmosphere: Processes that Control Ozone and other Climatically Important Gases*; and *WMO Scientific Assessment of Stratospheric Ozone: 1989*, Global Ozone Research and Monitoring Report No. 20.

Enter the Network for the Detection of Stratospheric Change

The discovery of the so-called "ozone hole[6]" made it clear that more detailed stratospheric observations were needed to help determine its origins. Such observations would require a measurement and analysis network specifically designed to provide the earliest possible detection of changes in the composition and structure of the stratosphere and—more important—the means to understand the causes of those changes. The development of new technologies—made possible in part because of UARP—made implementation of the network increasingly feasible.

In March 1986 NASA, NOAA, and the Chemical Manufacturers' Association (CMA) convened an international workshop in Boulder, CO, to evaluate the possibility of establishing such an observational network and to begin specifying its goals, measurement priorities and rationale, and operational requirements (i.e., instrument types and measurement locations). Workshop attendees agreed that the major goal of such a network would be focused, long-term observations. However, it also became clear that over the shorter term the proposed network would yield valuable scientific returns for other activities, including:

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- studying the temporal (diurnal, monthly, seasonal, and annual) and spatial (latitudinal) variability of atmospheric composition and structure;
- providing the basis for ground truth and complementary measurements for satellite systems such as NASA's Upper Atmosphere Research Satellite (UARS), which was scheduled for launch in the fall of 1991; and
- critically testing multidimensional stratospheric models and providing the broad database required for improved model development.

Long-term measurement stability and quality assurance as well as comprehensive measurement and data intercomparisons among various measurement systems (including those onboard satellites) were paramount in the construction of such a network. The idea that emerged from the Boulder meeting was that initial funding for such activities would come from NASA, NOAA, and CMA. However, participants quickly realized that in order to fully implement the network, international scientific, managerial, and financial collaboration among the numerous cosponsors would be needed, with monitoring complemented by other World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) activities. Thus, follow-on meetings were held to better define the international composition of the network. In particular, several European stations where many of the required facilities already existed were identified as potential network sites.

Finally, in 1991, following five years of planning, instrument design and development, and implementation, the Network for the Detection of Stratospheric Change (NDSC)—see *NDSC Organization* on page 7—began official operations endorsed by UNEP, the Global Atmosphere Watch (GAW) Programme of the WMO, and the International Ozone Commission (IO_3C) of the International Association of Meteorology and Atmospheric Sciences. This rapid implementation of NDSC benefitted from several years of instrument development under UARP and international sponsors. Addressing NASA's congressional mandate has required a full complement of measurements in the troposphere and stratosphere conducted from the ground, balloons, aircraft, and satellites, with NDSC providing vital observational continuity, as discussed in the next section.

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[6] In 1985 a group of scientists from the British Antarctic Survey made atmospheric science history when they reported a large seasonally recurring depletion of stratospheric ozone over the Antarctic region that has now become known as the *Antarctic ozone hole*. Shortly thereafter, NASA released the first satellite representation of the Antarctic ozone hole, which showed that the extent of the phenomenon was about the size of the continent itself.

NDSC: An Assessment after Ten Years of Operation

During its first decade of operations the NDSC had grown to include participation by more than 20 countries. The network celebrated its tenth anniversary with a symposium in Arcachon, France. The Symposium Report from that meeting lists several measurement and analysis results from the Symposium sessions, and can be found at *http://www.ndsc.ncep.noaa.gov/news/ndsc_01sym.html*.

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Over the next several years the NDSC continued to expand in both its atmospheric measurement capabilities and its contributions to understanding a broad spectrum of atmospheric science issues. Network activities included numerous instrument validations and intercomparisons (both within the network itself and with external measurement capabilities conducted by aircraft, balloons, and satellites). Of particular note was the proactive role of the Satellite Working Group in fostering synergy with the satellite community; specific examples of the results of these interactions are given in the *Significant Contributions and Results from 25 Years of NDSC/NDACC Operations* section on page 10. Many activities contributed to placing increasing trust in the data and analyses. Indeed, more than ten years of high-quality NDSC data were now contributing significantly to the international WMO/UNEP Ozone Assessments being conducted under the provisions of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. This Protocol was the first international agreement to apply limits to the production and consumption of the main chemicals causing the destruction of the Earth's protective ozone layer. Detailed information about network achievements during this period can be found in the 2003 and 2005 NDSC Newsletters, which can be downloaded from *http://www.ndsc.ncep.noaa.gov/news/archives*.

NDSC Organization

NDSC has embodied a simple and flexible organization that has contributed to the network's longevity and successful evolution since its inception. The original, principal components of the organization are still in place 25 years later under what has become the NDACC, as described on page 5. These components are the **Steering Committee** (SC) headed by a chair and vice-chair (now two co-chairs) and comprised of representatives from the instrument and other working groups, peer-review scientists, and *ex officio* representatives from the sponsoring or partnering international agencies or institutions; and the **Science Team**, consisting of the principal investigators (PIs) from all of the network sites.

As the primary managerial body of the Network, the Steering Committee is responsible for internal operational and scientific oversight and for recommending implementation and funding actions. The Science Team acts as the actual forum for conducting network research and analysis coordinated through the Instrument Working Groups (IWGs), which are organized around the instrument types. Initially, there were four certified instrument types: Fourier transform infrared (FTIR) spectrometers—for column abundances of many chemicals; lidars—for aerosols, temperature, and ozone (O_3); microwave radiometers—for chlorine monoxide (ClO), O_3, and water vapor; and ultraviolet (UV)/visible spectrometers—for column O_3 and nitrogen dioxide (NO_2) measurements. Three more instrument types were subsequently added: Dobson/Brewer spectrophotometers for column O_3, O_3 and aerosol sondes, and UV spectroradiometers. Each of the IWGs has the responsibility of setting actions to maximize internal consistency among the network data, which are archived at a dedicated Data Host Facility (DHF), hosted and supported by NOAA. A Theory and Analysis Working Group and a Satellite Working Group were also established to promote and enhance interactions with the modeling and satellite communities, respectively.

Measurement sites, at which a majority of the aforementioned NDSC-certified instrument types operated, were designated as Primary Stations. Sites equipped with a subset of such instruments and/or operating less regularly than the Primary Stations were designated as Complementary Stations and contributed to the global coverage of the network. These sites also provided substantial support during coordinated campaigns targeted at special process studies, at calibration and validation phases of space-based sensors, and at studying more regional and potentially subtle atmospheric characteristics. In the early 1990s NASA and NOAA provided support for more than a dozen U.S. investigator teams as well as for the operation of the Primary Station at Mauna Loa, HI, and the Complementary Station at Table Mountain, CA—shown in photo on front cover.

Evolution to the Network for the Detection of Atmospheric Composition Change

To better reflect the combined free tropospheric and stratospheric coverage of network measurement, analysis, and modeling activities as well as to convey the linkage to climate change, in 1995 the Steering Committee voted to change the name of the network to the Network for the Detection of Atmospheric Composition Change (NDACC). The committee intended the new name to reflect the expanded focus of the network while at the same time emphasizing that NDACC was not designed to be a climate-monitoring network, but rather an observational network that provided a broad suite of atmospheric data that contributed to understanding the interrelationship between changing atmospheric composition and climate. The set of objectives expanded to reflect the broadened scope of NDACC observations. These objectives included:

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- establishing long-term databases for detecting changes and trends in atmospheric composition and understanding their impacts on the stratosphere and troposphere;
- establishing scientific links and feedbacks between climate change and atmospheric composition;
- calibrating and validating atmospheric measurements from satellites and gap-filling critical satellite datasets;
- providing collaborative support to scientific field campaigns and to other chemistry and climate observing networks; and
- providing validation and development support for atmospheric models.

In addition, the labeling of NDACC measurement sites as "primary" or "complementary" was dropped and all sites became designated simply as NDACC Stations.

Continuing Evolution: NDACC Creates Cooperating Network Affiliation

With the expansion of its focus and the transition from NDSC to NDACC, the incorporation of new measurement capabilities and collaboration with existing capabilities whose heritage was developed external to the network became increasingly important. As the network entered its second decade of operations, increased scientific cooperation between NDACC and independently operating regional, hemispheric, or global networks of instruments became critical. These other networks typically had comparable quality assurance guidelines, operational requirements, and data-archiving policies, and independent national or international recognition. Thus, NDACC formalized a Cooperating Network affiliation—see **Table**—to foster the desired collaborative measurement and analysis activities, and developed a Cooperating Networks Protocol to cover the various aspects of such affiliations. Representatives from the Cooperating Network serve on the NDACC Steering Committee, where they work to promote internetwork scientific collaboration. Further details can be found in the Cooperating Network Section at the NDACC website at *http://www.ndsc.ncep.noaa.gov/coop*.

Table. The eight currently operating NDACC Cooperating Networks.

Cooperating Network	Website
AErosol RObotic NETwork (AERONET)	*http://aeronet.gsfc.nasa.gov*
Advanced Global Atmospheric Gases Experiment (AGAGE)	*http://agage.eas.gatech.edu/index.htm*
Baseline Surface Radiation Network (BSRN)	*http://www.bsrn.awi.de*
GCOS Reference Upper-Air Network (GRUAN)	*http://www.gruan.org*
Halocarbons and other Trace Species (HATS)	*http://www.esrl.noaa.gov/gmd/hats*

Table. (*cont*). The eight currently operating NDACC Cooperating Networks.

Cooperating Network	Website
NASA's Micro-Pulse Lidar Network (MPLNET)	*http://mplnet.gsfc.nasa.gov*
Southern Hemisphere Additional Ozonesondes (SHADOZ)	*http://croc.gsfc.nasa.gov/shadoz*
Total Carbon Column Observing Network (TCCON1)	*http://www.tccon.caltech.edu*

Moving Beyond the First 10 Years

As the network continued to mature, its intercomparison campaigns became more comprehensive, with the involvement of multiple instrument types in order to better understand measurement synergies. In addition, the capabilities of FTIR and UV/visible instruments expanded so that data for the first time would have some vertical resolution. Current NDACC observational capabilities are depicted in **Figure 2**.

With the increased recognition that NDACC was a source of long-term, high-quality data for multiple species and parameters of atmospheric interest, network data-based literature citations in subsequent WMO/UNEP Ozone Assessments increased significantly. Long-term UV data records were now available for the Polar Regions, where appreciable stratospheric ozone depletion was observed, and NDACC data were now being used extensively in the evaluation of Chemistry–Climate Models (CCMs). In addition, the now-extensive database (accessible by anonymous *ftp* at *ftp.cpc.ncep.noaa.gov/ndacc*) was gaining increased recognition by space agencies around the world (e.g., NASA, European Space Agency, Japan Aerospace Exploration Agency) and by the European Union as an important resource for satellite validation. Some of the network's contributions in these areas can be found in the *Significant Contributions and Results from 25 Years of NDSC/NDACC Operations* section on page 10.

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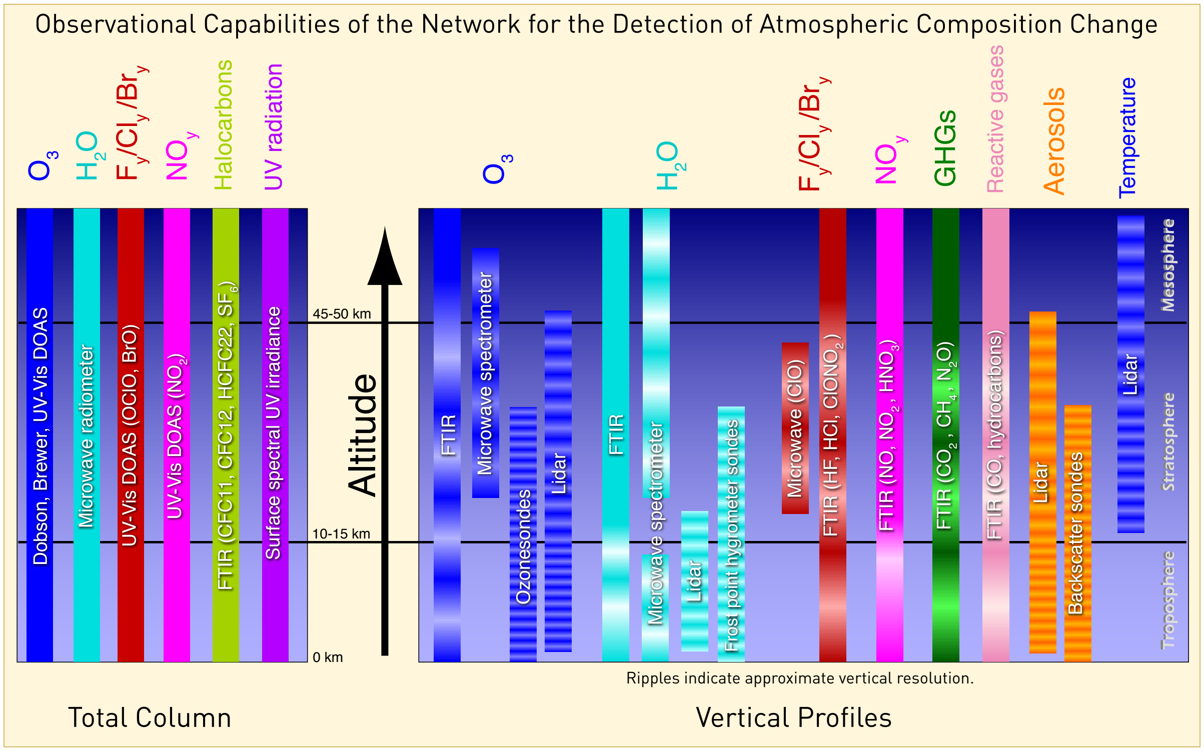

Figure 2. Summary of NDACC's measurement capabilities, including the species and parameters measured, the instrumental measurement techniques, and each measurement's approximate vertical resolution. Measurements are archived in the NDACC Data Host Facility. **Image credit:** Geir Braathen [WMO]

On the international stage, NDACC had become an important contributor to many initiatives. Of particular note is the recent use of NDSC/NDACC data in the SPARC/IO$_3$C/IGACO-O3/NDACC[7] Initiative on Past Changes in the Vertical Distribution of Ozone (SI^{2}N), which was undertaken to study and document those long-term changes and possibly enable attribution for observed ozone layer recovery.

Revisions to the network website paralleled this advancement, with links to "Hot News" articles, Working Group websites, and archives of the complete series of network *Newsletters*.

Twentieth Anniversary

In November 2011 a 20-Year Anniversary Symposium in Saint Paul, Île de la Réunion (an island NDACC Station east of Madagascar in the Indian Ocean), served as the forum for commemorating NDACC's first decade of scientific successes and two decades of combined NDSC/NDACC contributions to atmospheric science.

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Significant Contributions and Results from 25 Years of NDSC/NDACC Operations

The large number and broad scope of NDSC/NDACC contributions to-date that enable and enhance global atmospheric research make it difficult to single out individual results, not to mention those having the greatest impact. However, with help from the cochairs of the current NDACC Working Groups and from NDACC Station Representatives (a list of whom may be found at *http://www.ndsc.ncep.noaa.gov/organize/committee*) we have compiled the following list of achievements that exemplify the use of the high-quality data obtained from consistent, standardized, long-term measurements supported by the Network.

High-quality ozone datasets. High-quality ozone datasets from more than two decades of measurements by NDSC/NDACC Dobson/Brewer spectrometers, ozonesondes, lidars, microwave radiometers, and FTIR spectrometers have been instrumental in identifying the first two of the three stages of the predicted stratospheric ozone recovery resulting from the elimination of ODS mandated by the Montreal Protocol and Amendments, namely the slowing of ozone decline and the onset of increases. (Stage 3 would be "full recovery" to 1980 benchmark levels, projected to occur by midcentury in midlatitudes and in the Arctic and somewhat later for the Antarctic ozone hole.) Thus, NDSC/NDACC measurements, together with those from satellites, are critically important in verifying the successful implementation of the protocol requirements. **Figure 3** shows an example of some of those results.

Long-term dataset on ozone vertical profiles. The long-term NDSC/NDACC dataset on ozone vertical profiles has been used extensively in the SI^{2}N initiative aimed at better quantifying the past changes in the vertical distribution of ozone. This initiative demonstrated that stable, well-calibrated, ground-based measurements could be used to complement satellite observations and resulted in the production of a *merged* (i.e., combined satellite and ground-based data) ozone profile dataset. These latest datasets are being used in an attempt to differentiate between ozone increases due to declining ODS abundances and those attributable to changing climate.

Long-term monitoring of the vertical distribution of temperature and aerosols in the stratosphere. NDSC/NDACC lidars provide a unique capability for long-term monitoring of the vertical distribution of temperature and aerosols in the stratosphere, and thereby have provided independent verification and quantification of recent stratospheric cooling due to increasing greenhouse gases. Aerosol lidar data have quantified

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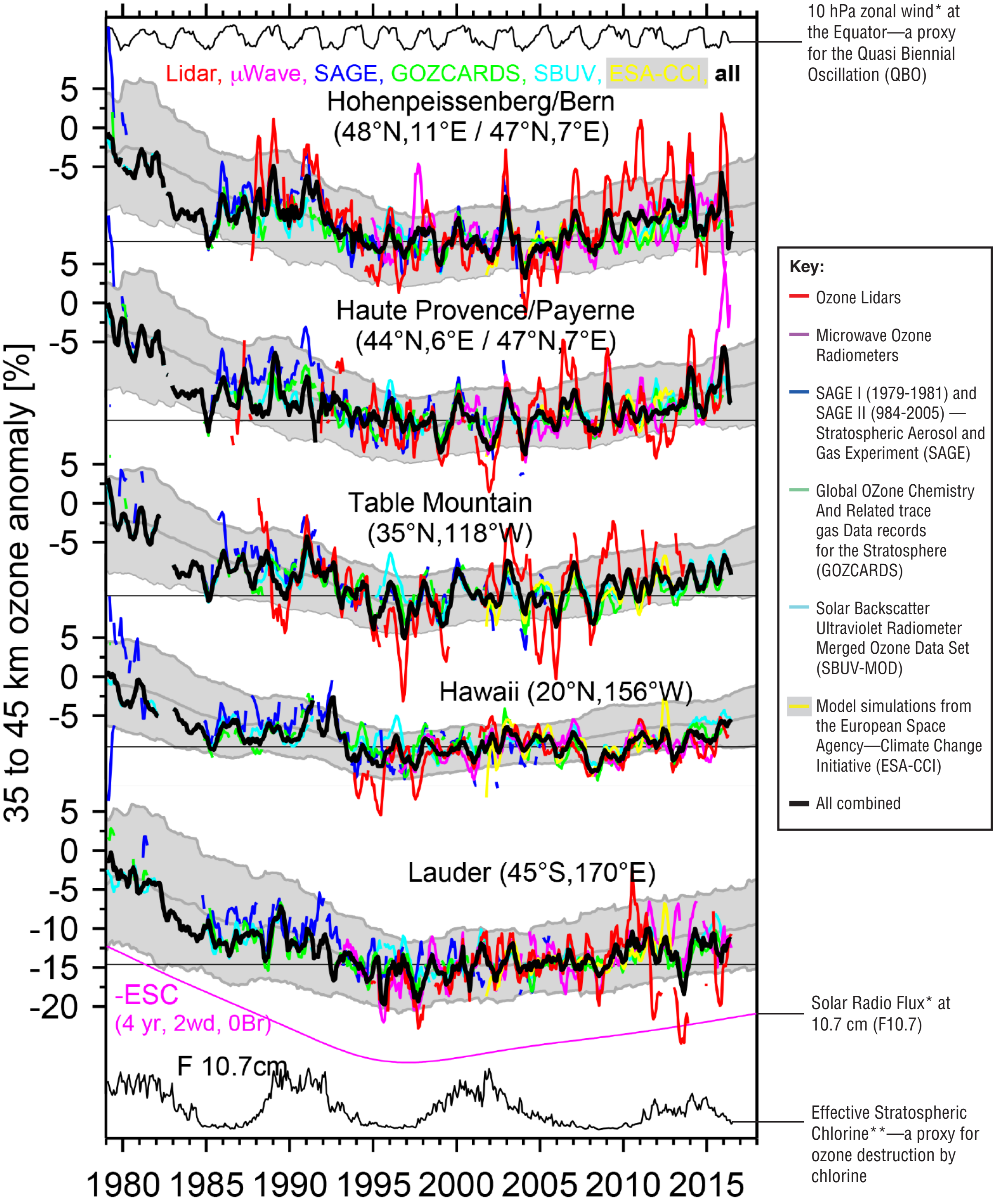
[7] SPARC is the Stratosphere-troposphere Processes And their Role in Climate project of the World Climate Research Program (WCRP). IGACO-O3 is the Integrated Global Atmospheric Chemistry Observations for Ozone and UV Radiation, an international project.



*Both QBO and Solar Radio Flux are natural sources of variation in ozone.
** See Newman et al., *Geophysical Research Letters*, 33, 2006.

Figure 3. These graphs show ozone anomalies—departures from the mean value measured between 1998 and 2008—in the upper stratosphere, for selected ground-based instruments and satellite-based datasets at several different NDACC stations. Annual cycle signal contributions have been removed. Such data lead to the conclusion that ozone in this region of the atmosphere is recovering from chemical destruction by stratospheric chlorine. **Image credit:** Adapted from Wolfgang Steinbrecht [German Weather Office, Deutscher Wetterdienst (DWD)].

stratospheric aerosol loading and its consequences after major volcanic eruptions (e.g., Mt. Pinatubo in 1991) as well as minor ones, and have provided up-to-the minute warnings on regional conditions and risks to air-traffic safety.

Correlative measurement campaigns. Beginning with NDSC and continuing through NDACC, the lidars, microwave radiometers, FTIR spectrometers, UV/Vis spectrometers, and sondes have participated extensively in correlative measurement campaigns for instruments on NASA's UARS and Aura platforms as well as for the NASA Total Ozone Mapping Spectrometer (TOMS) and Stratospheric Aerosol and Gas Experiment (SAGE) instruments. Similar activities have been conducted for international instruments, such as those onboard the Canadian Space Agency's SCISAT-1 and ESA's Envisat and MetOp satellites, and the multinational Odin satellite. NDACC data are now contributing to validation activities for the coming Joint Polar Satellite System era with the Suomi National Polar-orbiting Partnership satellite, launched in 2011. Through such validation and stability assessment activities, the network has become recognized as providing fiducial reference measurements to characterize satellite observations.

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Limiting the range of uncertainties in ozone absorption cross-sections. NDACC instrument scientists have helped to study, evaluate, and recommend the most suitable ozone absorption cross-section laboratory data to be used in atmospheric ozone measurements. Comparisons of NDACC ozone products generated by different instrument types have helped to determine the range of uncertainties associated with the stratospheric temperature dependence of the instrument-specific absorption cross-sections that are used operationally in deriving these data products, critical to supporting recommended spectroscopic standards.

Providing precise documentation of the multidecadal trends of many tropospheric and stratospheric constituents. High-resolution solar absorption spectra regularly recorded by NDACC FTIR spectrometers under cloud-free conditions provide precise documentation of the multidecadal trends of many tropospheric and stratospheric constituents. For example, the data records for hydrogen chloride (HCl) and chlorine nitrate ($ClONO_2$) are shown in **Figure 4**. These two substances are the primary reservoir compounds for stratospheric chlorine and these data help to confirm our understanding of the reaction cycles associated with the chemical destruction of stratospheric ozone.

Providing significant contributions to understanding atmospheric water vapor behavior. NDACC measurements have made significant contributions to understanding atmospheric water vapor behavior. Since 1996 millimeter-wave spectrometers have

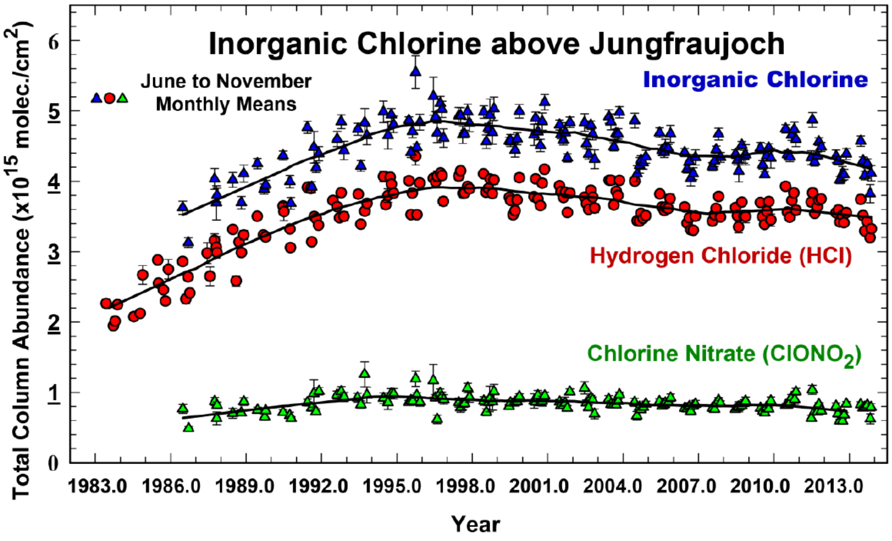

Figure 4. The graph shows a time series (from 1983 to 2012) of monthly-mean total column hydrogen chloride (HCl, red circles) and chlorine nitrate ($ClONO_2$, green triangles) concentrations, measured above the Jungfraujoch, Switzerland station (46.5° N). Total column inorganic chlorine (Cl_y, blue triangles) amounts were obtained by summing the corresponding HCl and $ClONO_2$ data points. **Image credit:** Emmanuel Mahieu, University of Liege, Belgium

measured significant interannual variations in water vapor, but only a small overall increase near the stratopause. Meanwhile, the FTIR long-term dataset on the variability in isotopic ratios of water has become an important tool for investigating different water cycle processes that are important in Earth's climate system.

Making major contributions to assessing atmospheric water vapor measurement techniques. The NDACC Working Group on Water Vapor participated extensively in an assessment conducted by the International Space Science Institute Working Group on Atmospheric Water Vapor of *in situ* and remote sensing techniques presently used to monitor the distribution of atmospheric water vapor. NDACC measurement and analysis experience played major roles in several sections of the report.

Bounding causative factors in latitudinal UV variation. Latitudinal variations in annual doses of UV-B and UV-A radiation have recently been assessed using data from NDACC UV spectroradiometers. Large differences between corresponding latitudes in the Northern and Southern Hemispheres have been attributed to differences in total ozone, cloudiness, aerosol loading, and sun–Earth separation. NDACC spectral UV measurements have also been used to compare surface UV levels derived from satellite observations, specifically from the Ozone Monitoring Instrument (OMI) on Aura and the Global Ozone Monitoring Experiment (GOME)-2 instrument on MetOp-A. However, the hemispheric differences have yet to be reproduced in satellite retrievals.

Evaluating coupled chemistry-climate models. NDACC data have been extensively used in the evaluating coupled Chemistry–Climate Models (CCMs) under the CCMVal activity conducted by the SPARC project of the World Climate Research Program (WCRP), in which the radiative, dynamical, transport, and chemical processes in the models were analyzed in unprecedented detail. In particular, the long time series of NDACC observations were crucial for evaluating the past trends produced by the models.

The Path Forward

Given the clear importance of the NDACC not only to its component organizations, but also to those working in other organizations whose activities are intimately dependent on the Network's results, moving forward in three specific areas becomes key: organizational flexibility, data access improvements, and data quality assurance.

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Organizational Flexibility

Continued successful contributions to worldwide atmospheric research have required constant evolution of the Network, the current configuration of which is summarized in **Figure 5**. Given the complexities of the topic areas and the organizational imperatives, oversight of such growth has been and continues to be a major responsibility of the NDACC Steering Committee. There is enough flexibility built into the structure of the organization to allow for near "on-the-fly" changes. For example, while the nine permanent NDACC Working Groups (see Figure 5) were organized around seven specific instrument types and two other relevant activities (Satellites and Theory and Analysis) as described earlier, the Steering Committee identified the need for new Theme Groups (three of which are shown in Figure 5). These can be of more limited duration and are organized around specific foci, with attendant flexibility in organizational response. Representatives from each Theme Group also serve on the NDACC Steering Committee.

Of particular note is the Water Vapor Measurement Strategy Theme Group that has been tasked with developing a network-wide measurement plan for atmospheric water vapor. The strategy includes all current NDACC water vapor measurements (i.e., lidar, microwave, FTIR, and frost-point sondes); its development is critical for NDACC to fulfill its objective of establishing the scientific links and feedbacks between climate change and atmospheric composition. Implementation of the strategy will likely enhance the relationship between NDACC and climate-focused networks such as GRUAN.

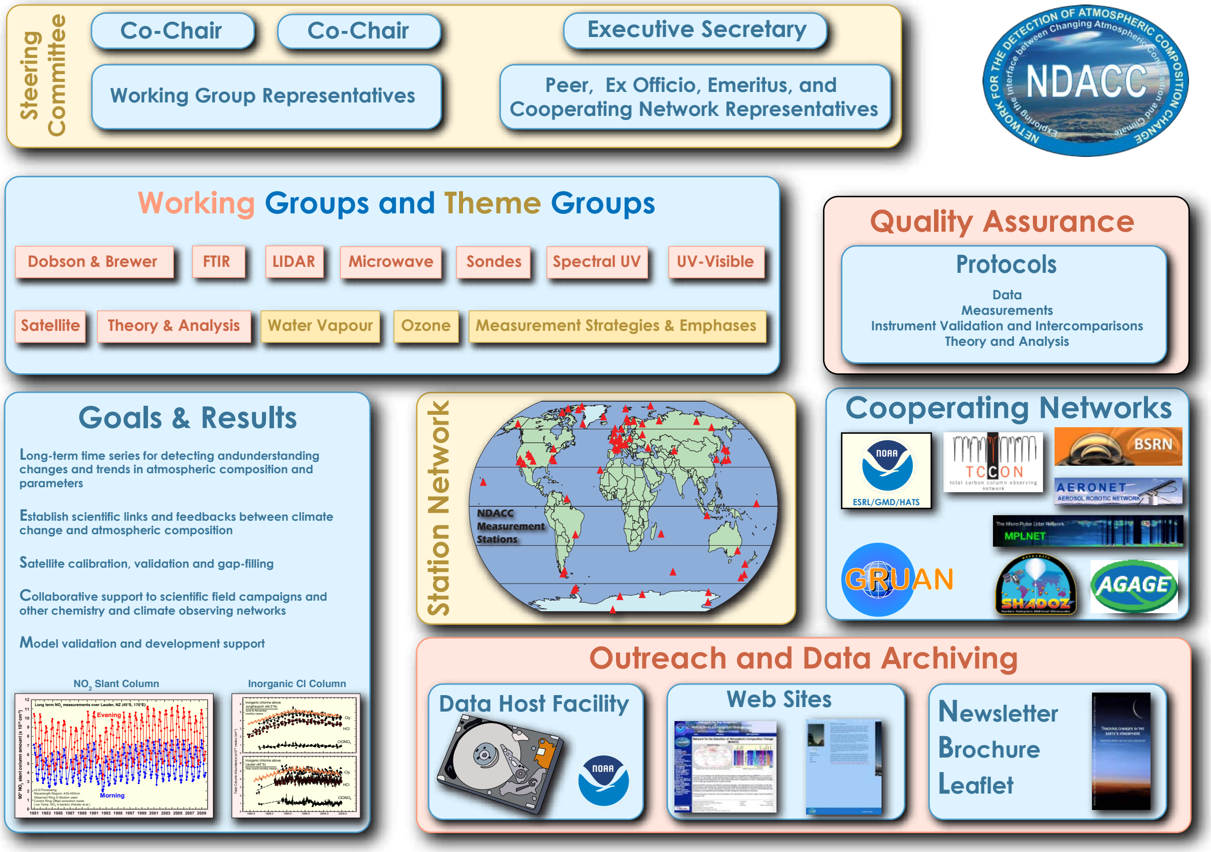

Figure 5. NDACC's current organizational structure is summarized here. Many of the elements are mentioned in this article including the Steering Committee, Working and Theme Groups, Quality Assurance Protocols, Cooperating Networks (detailed in Table), Data Host Facility, Website, and Newsletter. The Station Network map is a smaller version of the representation in Figure 1. **Image credit:** Geir Braathen [WMO]

Data Access Improvements

Timely access to data is a key factor for scientific endeavors, and the NDACC's holdings are no different. While the time scale for archiving verifiable network data at the DHF and for their public release is now one year, most PIs approve release of their data upon submission to the database. These data are available at *ftp.cpc.ncep.noaa.gov/ndacc/station*. In continuing efforts to make data not just available, but also trustworthy, the DHF itself is undergoing improvements to provide greater clarity for the data users. For example, more comprehensive information will be provided to reflect any changes in the data files themselves and the versions of the algorithms used in the data processing. The DHF manager will implement more thorough data-quality checks to ascertain formatting and gridding and to verify completeness of the metadata files. In addition, a dedicated directory has been established for submission of and access to Rapid Delivery Data, i.e., data that may be revised before entry in the full database.

In an effort to provide a clearer and more direct path to access NDACC data, the NDACC web page is being redesigned. Inclusion of a new "data search" page will guide users to their desired level of data query (species, measurement site or latitude range, instrument type, time period, etc.). Model output generated by the Theory and Analysis Working Group are also now available at the website. These model-generated data will help provide a better understanding of station data variability and representativeness (i.e., a bridge between individual stations and the global perspective) and a context for interpreting station observations. Model simulations produced by the group can be used to help set priorities for network expansion and/or instrument relocation. The model data—categorized by instrument type—may be accessed at *ftp://ftp.cpc.ncep.noaa.gov/ndacc/gmi_model_data*.

Data Quality Assurance

Each of the Instrument Working Groups is engaged in data reprocessing and enhancing data consistency and stability by homogenizing and possibly centralizing data-processing procedures, based on instrument type. The IWGs are also participating in several European projects to ensure measurement traceability, harmonize and quantify measurement uncertainties, and harmonize and document the traceability of retrieval methods. Such long-term quality assurance and up-to-date data archiving and availability are critical for continued international network recognition and data use. These groups also emphasize NDACC's utility in providing fiducial reference measurements for characterizing satellite observations—necessary conditions for a more complete understanding of our home planet's complex systems and the interactions between them.

Conclusion

As a major component of the international atmospheric research effort, NDACC stands as a shining example of what can be achieved through international cooperation and from continuity and quality assurance in measurements and their analyses. The critical roles of ground-based networks such as NDACC have been emphasized in the *Report of the Ninth Meeting of Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer* [WMO Global Research and Monitoring Project Report No. 54 (2014)]. For example, NDACC could become a singular resource for research and monitoring the chemistry of the upper atmosphere when NASA's Aura mission ends.

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This article has described NDSC/NDACC's many successes over the last 25 years, but the network is not resting on its laurels. As it has done for the past quarter-century, in order to remain a viable, international atmospheric-research effort in an era of more constrained budgets, the network must continue to refine its focus—and, as needed, evolve its measurement capabilities. NDACC is one of several networks that currently bring unique capabilities to the global observing system, and as a result there are instances where NDACC's activities and capabilities overlap with these other networks, thereby resulting in some duplication of effort. Some of this overlap is essential for quality assurance, but for optimum resource utilization it is also imperative for each network to "find its niche" and identify the degree to which it can and should take on a specific responsibility and to develop a long-term operational strategy for doing so. The NDACC Theme Group on Measurement Strategies and Emphases was established for this very purpose. With such responsiveness and the flexible structure that has been described herein, the NDACC Steering Committee and Science Team are confident that they can meet the challenges facing them, and look forward to continuing the network's important role for many years to come. ■