C. R. Geoscience 350 (2018) 432–434

Contents lists available at ScienceDirect

Comptes Rendus Geoscience

www.sciencedirect.com

External Geophysics, Climate (Aeronomy and Meteorology)

NASA's contribution to ozone research and monitoring

Ken Jucks

NASA Headquarters, Program Scientist for Upper Atmosphere Research Program and NASA Aura Satellite, 20546 Washington DC, United States

ARTICLE INFO

Article history:
Received 22 February 2018
Accepted after revision 29 May 2018
Available online 11 October 2018

Handled by Irina Petropavlovskikh

Keywords:
NASA
Ozone
Satellites
Research
Observations

ABSTRACT

NASA has a long and significant history in observations and data analysis research for understanding the short- and long-term changes in ozone in the atmosphere. For nearly 40 years, NASA has overseen satellite observations of stratospheric ozone. These observations have been augmented by ground-based remote sensing, balloon borne, and aircraft observations of ozone and ozone-related species and by continuous observations of ozone depleting substances. Together, they form the evidential basis for understanding ozone changes over these past four decades. Also, NASA has continuously funded laboratory, modeling and data analysis activities to better understand the observations obtained by NASA and other programs. NASA has plans to continue these activities in the future, at a level consistent with available funding, other Earth Science observational priorities, and more importantly, with a goal of ensuring that data exist to understand changes in ozone in the future as the abundances of ozone depleting substances decrease and those of greenhouse gases increase.

Published by Elsevier Masson SAS on behalf of Académie des sciences.

1. Introduction

NASA has played many key roles in the understanding of atmospheric ozone for much of the past 40 years. These roles have been clearly demonstrated in many of the other presentations in these proceedings. In particular, the role of satellite observations has been critical over the past four decades, as described in the presentations in these proceedings by both Bhartia and McPeters who describe the powerful uses and careful nature of the analysis for the total column backscatter UV observations from TOMS through SBUV, to the current OMI instrument on the Aura satellite. These observations formed backbone of NASA activity. The early observations, as described by Bhartia, allowed NASA to obtain the first images of the ozone hole, and continue to be used each year for such research. This work continues with now and in the future with the OMPS instruments, which has similar capabilities.

Limb observations also play a key component for obtaining consistent altitude resolved information globally, as presented by Santee. These observations began with the LIMS observations in 1987 and 1988, which used filter bands in the IR in order to obtain vertical profiles of ozone as well as H_2O, HNO_3, and NO_2. This was followed a number of years later by the UARS satellite which obtained much more information from a combination of CLAES, HALOE, and the original MLS from 1991 to 2005. And these were followed by the MLS instrument on Aura in 2004 that continues today. These observations give us considerable information on the altitude distribution that allows significantly better conclusions on the processes that drive stratospheric ozone.

NASA has also played a key role in observations made from suborbital platforms. Kurylo described the key contributions NASA's field campaigns utilizing measurements from airborne, balloon-borne, and ground-based

Email address: kenneth.w.jucks@nasa.gov.

https://doi.org/10.1016/j.crte.2018.05.007
1631-0713/Published by Elsevier Masson SAS on behalf of Académie des sciences.

instruments had for clearly understanding the processes in the stratosphere, both mid latitude and polar. Such data provided key information relative processes that are not easy to infer from satellite information alone.

NASA has contributed to many of the international ground-based networks, including NDACC, which was summarized in Godin-Beekman's presentation, and the AGAGE network for ozone depleting substances as summarized by Reimann. These various NASA measurement capabilities comprise one of the most comprehensive integrated observational research programs for investigating changing atmospheric composition. AGAGE has been operating for more 40 years now and plans to keep operating long after that. These observations are the key to understanding changes to ozone depleting substances over time. And NASA has been part of NDACC since the very beginning when it was called NDSC, Network for Detection of Stratospheric Change.

Furthermore, NASA was an early and continuous contributor to the improvements and normalization of laboratory photochemistry and spectroscopy observations which are key the background data needed for modeling and data analysis of all of these observations, as summarized by Burkholder. Indeed, NASA funded research and observations are fundamental to all of the activities that have led to our understanding of ozone to date.

2. NASA's history and future plans for satellite observations

NASA now has a much more compete and systematic approach to Earth Science observations from space than it had when ozone observations began 4 decades ago. Observations cover numerous satellite instruments to understand a range of atmospheric chemical constituents and parameters as well as information on clouds, aerosols and weather. Numerous satellites study the Earth surface in ways that are used to understand land use, the physical and biological processes in the ocean, surface topography, the terrestrial ecology, the hydrological cycle, and the carbon cycle. Because of the extensive nature of the observations required in these other research focus areas, NASA cannot by itself continue to maintain the complete set of observations in the upper troposphere and stratosphere that are needed to track and understand the future evolution of the Earth's ozone layer. The limb viewing geometry observations have served a key role over time as they provide near global coverage of altitude resolved abundances of ozone along with key reactive gases and tracers of atmospheric transport. These observations have covered the time period from the early LIMS observations to the series of SAGE observations (including the SAGE-III recently deployed on the International Space Station) to the UARS satellite from 1991 to 2005, to the EOS Aura satellite from 2004 to present. As of now, the only future limb sounding observations of the stratosphere from NASA will be the continuation of the OMPS-Limb data. The current OMPS-limb instrument was deployed on the joint NASA-NOAA S-NPP satellite launched in 2012. The next will be on the NOAA JPSS-2 satellite in roughly 2021, along with the continued OMPS-nadir observations. There is not a limb instrument on the recently launched JPSS-1 satellite to go with the OMPS-nadir observations on that satellite.

NASA receives direction for future observations from space from three sources. The research community provides guidance to NASA through the US National Academy of Science led Decadal Survey process. The next Decadal Survey draft was released publically on 5 January 2018. Given the nature of the committees set up for that process, the atmospheric research community in the US did not have a strong influence on the process. Even with this being the case, there is a door that was opened for potential continuation of limb-observing observations. Given NASA's history with these observations, and the strong connection to changes in climate, this document suggests that such a mission is a potential "observable" that could be included as an "Explorer" class mission that would be open to a competitively selected process. This document can be found on-line at https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth. Any initial solicitation for this class of space missions would not be for 3–5 years given NASA's current funding profile. The second avenue for community input is through competitively selected, Principal Investigator-led, Earth Venture proposals that are regularly solicited from the research community. These cost and schedule constrained investigations have a limited budget which makes it difficult for studies that need a long time on orbit to meet scientific objectives. Hence stratospheric observations have yet to merit significant consideration from this avenue to date.

The third set of directions NASA receives is probably the most important, the US government budget funding process. This process requires agreements on priorities between the agency, and the executive and legislative branches of the government. Priorities are often set by factors beyond scientific need or questions, and can vary significantly depending on the political leadership in those branches of government. To date, there has been little discussion about the future of atmospheric observations, regardless of the political leadership in the US over the past decade.

NASA will do all it can to maintain the observations currently in operation, even though all but the SAGE-III on ISS are operating beyond their design lifetimes. All NASA missions that are beyond their primary mission lifetime go through a process called the Senior Review to ensure that each mission is still returning valuable science and that the technical risks of continued operations are acceptable. Aura has been operating for over 13 years and just went through the Senior Review with a highly rated evaluation, even though the TES instrument was recommended to discontinue operation. This strong review was based on the continued excellence of both the OMI and MLS instruments. Assuming no technical issues with the Aura satellite, it should continue operation for at least 4 more years. The current fuel would allow it to remain in the A-Train orbit until at least 2023. At that time, NASA will assess whether it is safe to allow the orbit of Aura to drift out of the A-train orbit to continue observations from either MLS or OMI. S-NPP, which contains the OMPS suite of instruments, is operated by NOAA as an operational weather satellite, and will probably continue operation as a backup for the JPSS system until at least the launch of the JPSS-2 satellite, allowing for continuation of the OMPS-Limb satellite. When SAGE-III on ISS is up for the next Senior Review, NASA will also need to consider whether there is a strong request for a different instrument to replace the SAGE-III instrument on its location on ISS. Fortunately, this location is one with a relatively low demand compared to other ISS locations, leaving this possibility as low for something other than SAGE-III will operate in that slot.

3. The strategy for the future

Because of the possibility of a discontinuity of observations of key upper tropospheric and stratospheric parameters from space in the future, networks like NDACC need to continue, and NASA's continued support is required to ensure that happens. Because this is funded by the NASA Earth Science research budget, there will always be budgetary pressure on ensuring their continuity. To do so will probably be at the financial expense of other research areas funded by the Upper Atmosphere Research Program. These areas include laboratory research and focused suborbital research campaigns.

For the laboratory research, NASA has traditionally led the kinetics data evaluation panel that is a key for all atmospheric photochemistry modelling. NASA intends to keep this activity going, and will fund a few key laboratory kinetics activities to ensure the ability to respond to changes in ozone depleting substance uses. Because of the lower dependence on sensing observations, particularly for gas phase observations, from NASA satellites, there will be a lower investment into spectroscopic laboratory studies than there had been in the past.

NASA has long maintained the US portion of the AGAGE network. AGAGE data are the key data record for understanding changes in ozone depleting substances. These data form the basis, along with NOAA flask data, for documenting the changes in ozone depleting substances and is a core observation for the ozone assessment every four years. The record is now nearly 40 years and must be maintained.

NASA's investment in a modeling and data analysis program for atmospheric composition forms a critical component of the Earth Science program. This is where all the observations come together in order to address the key science questions of the day. As a result, NASA's investment into ongoing research and analysis program will most likely be maintained at a level similar to recent history. Because there is more of an emphasis on satellite observations for air quality and tropospheric composition, the fraction of the funds has slowly shifted, and will likely continue to drift, towards studies that make the best use of the data at hand.

Overall funding for focused field campaigns across all Earth Science disciplines have gone down over time as NASA suborbital resources have slowly expanded to the full range of Earth Science topics over the past few decades relative to when the initial polar stratosphere campaigns occurred. Plus, the initiation of the Earth Venture Suborbital (EVS) investigations about 8 years ago have shifted available funds away from research program-initiated campaigns. To date, atmospheric studies have reviewed well in the EVS solicitations, but there is no guarantee that this will continue in the future solicitations. Plus, the EVS program could change pending recommendations from the next Decadal Survey.

In summation, NASA will maintain a significant contribution to the observations of ozone and the stratosphere from space, the ground, from aircraft, and balloons. The level will be sufficient to answer key questions regarding changes in upper tropospheric and stratospheric ozone, but probably at a lesser level than the research community has been accustom to from the past 40+ years.