**Climate Change Science Program Workshop on the**
***Scientific Assessment of Ozone Depletion - 2006***

NOAA Science Center
SSMC4 Building
1305 East-West Highway
Silver Spring, MD 20910
Wednesday 11 July 2007 – 9:00 am to 4:00 pm

# List of Participants:

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| **Paul Newman** | NASA, Goddard |
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| **Richard Stolarski** | NASA |
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# 1. STATE OF THE KNOWLEDGE

## 1.1. Ozone-Depleting Substances

a) The total combined abundances of anthropogenic ozone-depleting gases in the troposphere continue to decline from the peak values reached in the 1992-1994 time period. The shorter-lived gases (e.g., methyl chloroform and methyl bromide) continue to provide much of the decline in total combined effective abundances of anthropogenic chlorine-containing and bromine-containing ozone-depleting gases in the troposphere and will soon be insignificant in the atmosphere. The early removal of the shorter-lived gases means that later decreases in ozone-depleting substances will likely be dominated by the atmospheric removal of the longer-lived gases.

b) The combined stratospheric abundances of the ozone-depleting gases show a downward trend from their peak values of the late 1990s, which is consistent with surface observations of these gases and a time lag for transport to the stratosphere.

c) Brominated (and chlorinated) very short-lived substances are believed to make a significant contribution to total stratospheric bromine (and chlorine) and its effect on stratospheric ozone. Bromine is now estimated to be approximately 60 times as effective as chlorine in global ozone depletion, on a per-atom basis. Atmospheric total bromine concentrations peaked in the lower atmosphere around 1998 and are now decreasing.

d) Hydrochlorofluorocarbons (HCFCs) continue to increase in the atmosphere. In 2004 they contributed 6% to the lower atmospheric chlorine burden, compared to 5% in 2000. HCFC-22 is the most abundant of the HCFCs and is increasing at 3.2% per year.

e) During the recent period of near-constant abundances of ozone-depleting gases, variations in meteorology have been particularly important in influencing the behavior of ozone over much of the polar and extrapolar (60°S-60°N) regions.

## 1.2. Polar Ozone

a) Springtime polar ozone depletion continues to be severe in cold stratospheric winters. Meteorological variability has played a larger role in the observed variability in ozone, over both poles, in the past few years.

b) The Antarctic ozone hole now is not as strongly influenced by moderate decreases in ozone-depleting gases, and the unusually small ozone holes in some recent years (e.g., 2002 and 2004) are attributable to dynamical changes in the Antarctic vortex.

c) Arctic ozone depletion exhibits large year-to-year variability, driven by meteorological conditions. Over the past four decades, these conditions became more conducive to severe ozone depletion because of increasingly widespread conditions for the formation of polar stratospheric clouds during the coldest Arctic winters. This change is much larger than can be expected from the direct radiative effect of increasing greenhouse gas concentrations. The reason for the change is unclear, and it could be because of long-term natural variability or an unknown dynamical mechanism.

## 1.3. Global Ozone ($60^0$S-$60^0$N)

a) The decline in abundances of extrapolar stratospheric ozone seen in the 1990s has stopped.

b) The contribution of polar ozone depletion to midlatitude ozone depletion is substantial; the extent of the contribution is estimated to be about one-third in the Northern Hemisphere and one-half in the Southern Hemisphere. The larger contribution in the Southern Hemisphere is to be expected, given the larger polar ozone depletion in the Antarctic relative to the Arctic region, and may explain the differences in magnitude and seasonality of the long-term ozone changes in midlatitudes between the two hemispheres.
c) Observations together with model studies suggest that the essentially unchanged column ozone abundances averaged over 60°S-60°N over roughly the past decade are related to the near constancy of stratospheric ozone-depleting gases during this period.
d) Total column ozone over the tropics (25°S-25°N) remains essentially unchanged.

**1.4. Stratospheric Temperature and Surface UV Radiation**

a) The stratospheric cooling observed during the past two decades has slowed in recent years. Large interannual variability in polar stratospheric temperatures complicates the interpretation of temperature trends.
b) Measurements from some stations in unpolluted locations indicate that UV irradiance (radiation levels) has been decreasing since the late 1990s, in accordance with observed ozone increases. However, at some Northern Hemisphere stations UV irradiance is still increasing, as a consequence of long-term changes in other factors that also affect UV radiation.
c) In polar regions, high UV irradiances lasting for a few days have been observed in association with episodes of low total ozone.

**1.5. Impact of Climate Change**

a) Future increases of greenhouse gas concentrations will contribute to the average cooling in the stratosphere.
b) Chemical reaction rates in the atmosphere are dependent on temperature, and thus the concentration of ozone is sensitive to temperature changes.
c) Changes to the temperature and circulation of the stratosphere affect climate and weather in the troposphere.
d) Updated datasets of stratospheric water vapor concentrations now show differences in long-term behavior.

**1.6. The Future of the Ozone Layer and Surface UV Radiation**

a) Over the past 10 years, changes in equivalent effective stratospheric chlorine (EESC) have likely contributed to the slowing of midlatitude total column ozone decline and the leveling off of column ozone.
b) The decline in EESC has not caused the large annual variations observed in Arctic ozone depletion. These large interannual variations, driven by changes in meteorology, are likely to preclude the detection of the first stage of recovery.
c) It is unlikely that total ozone averaged over the region 60°S-60°N will decrease significantly below the low values of the 1990s, because the abundances of ozone-depleting substances have peaked and are in decline. Although the decrease in ozone-depleting substances is the dominant factor in the expected return of ozone levels to pre-1980 values. Changes in climate will influence whether, when, and to what extent ozone will return to pre-1980 values in different regions.

d) The Antarctic ozone hole is expected to continue for decades. Antarctic ozone abundances are projected to return to pre-1980 levels around 2060-2075, roughly 10-25 years later than estimated in the 2002 Assessment.
e) Large ozone losses will likely continue to occur in cold Arctic winters during the next 15 years.
f) Human activities are expected to affect stratospheric ozone through changes in tropospheric emissions of trace gases. Enhanced methane emission is expected to enhance ozone production in the lower stratosphere, whereas an increase in nitrous oxide emission is expected to reduce ozone in the middle and high stratosphere. Also, changes in non-methane hydrocarbons and NOx emissions are expected to affect the tropospheric concentrations of hydroxyl radical and, hence, impact the lifetimes and concentrations of stratospheric trace gases such as methane and organic halogen species.
g) Climate change will also influence surface UV radiation through changes induced mainly to clouds and the ability of the Earth's surface to reflect light.
h) Future changes of stratospheric water vapor concentrations are uncertain. If water vapor concentrations increase in the future, there will be both a radiative and a chemical effect. Modeling studies suggest increased water vapor concentrations will enhance odd hydrogen (HOx) in the stratosphere and subsequently influence ozone depletion. Increases in water vapor in the polar regions would raise the temperature threshold for the formation of polar stratospheric clouds, potentially increasing springtime ozone depletion.

### 1.7. Implications for Policy Formulation

a) Our basic understanding that anthropogenic ozone-depleting substances have been the principal cause of the ozone depletion over the past decades has been strengthened.
b) The Montreal Protocol is working: There is clear evidence of a decrease in the atmospheric burden of ozone-depleting substances and some early signs of stratospheric ozone recovery.
c) Long-term recovery of the ozone layer from the effects of ozone-depleting substances is expected to span much of the 21st century and is estimated to occur later than projected in the previous Assessment (2002).
d) Failure to comply with the Montreal Protocol would delay, or could even prevent, recovery of the ozone layer.
e) The role of very short-lived halogenated substances (especially brominated) in stratospheric ozone depletion is now believed to be of greater importance than previously assessed.
f) Understanding the interconnections between ozone depletion and climate change is crucial for projections of future ozone abundances.

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## 2. NEXT STEPS IN THE RESEARCH DOMAIN

### 2.1. CCSP Strategic Plan

a) The general research agenda put forth in Strategic Plan continues to be relevant. There are, however, some areas that warrant additional attention. See below.

## 2.2. Residence Time

b) Atmospheric residence times of ODSs need to be re-evaluated. If chemistry/climate models are to project future recovery then they should include feedback of changing lifetime due to GHG-forced speed up of residual circulation. This will not work unless observed lifetimes are consistent with models.
c) The uncertain size of ODS banks could be improved with better lifetime estimates.
d) Uncertain decomposition rates in the stratosphere ('fractional release rates') influence reactive halogen recovery projections.

## 2.3. Ozone and Climate

a) Coupling between ozone and climate (particularly for the SAM). Need to include ozone in climate models (key to future projections):
    - How ozone has influenced Southern Hemisphere climate in the past few decades? What about the future?
    - Need to better understand enhanced warming in the Antarctic Peninsula linked to ozone (and GHGs).

b) How should the critical linkages between ozone and climate be addressed?
    - Better understanding of observation: nature and drivers of vortex changes
    - Better representation in future projections: requires interactions with climate modelers/analysts to develop improved tools for near-term

c) The stratosphere has been key to recent advances in vertical temperature profilesbut there are remaining issues and they are important for climate change.

d) There is a need to better understand present and past ozone and temperature observations:
    - 3D models will play an increasingly important role

e) Stronger Brewer/Dobson circulation? How will this warm the polar stratosphere, and how will it influence ozone depletion in both polar regions?

f) Climate effect of CFC (banks) and HCFCs and on the natural fluxes of ODSs particularly $CH_3Cl$ and $CH_3Br$, but also very short-lived ODSs

## 2.4. "Signal to Noise" Problem

a) To confirm the effectiveness of the Montreal Protocol, we need to determine the ozone changes due to ODS. But the "signal to noise" problem confounds this. A few of the key issues are: defining an appropriate baseline from the short and noisy data; and, assessing the extent to which other signals, including climate change, are playing a role. So far, the noise is not well characterized

b) The "signal to noise" problem also complicates the question of whether the ozone increase at midlatitude is due to a decrease in halogen-induced loss and/or transport as seen in recent studies.

### 2.5. Emissions

a) The degree of compliance with the Protocol (HCFC use).
b) Trends in non-regulated uses (QPS, Feedstock, CUEs of $CH_3Br$ and others), and uncharacterized sources ($CH_3Br$, $CCl_4$).
c) Trends in non-regulated GHGs emission and other gases with potential effects on ozone chemistry (e.g. NOx, NOy, Sox…).

## 3. <u>Decision Support and Policy Related Aspects of Ozone Assessment</u>

### 3.1. Policy-relevant science questions or issues

a) Definition of "recovery" and implications of using 1980 levels of $O_3$ as a baseline
   - Poor record of $O_3$ variability pre-1980
   - Possibility of meaning of "super-recovery"
   - Uneven "recovery"

b) Accounting for impacts of non-regulated or poorly regulated ODSs, including uncharacterized or unregulated sources, short-lived species, HCFCs, and new substances.

c) "Banked" materials – how to deal with these banks, service needs into the future, implications for accidental or deliberate release, creative thinking about economically and environmentally efficient clean-up, rationale for destruction under the precautionary principle.

d) Better linking between climate and ozone, including benefits for climate and ozone layer realized as a result of rapid phase-out of ODSs and effects of GHGs on ozone.

e) Need support (conceptual and monetary) for long-term observations and monitoring of chemical cycles, impacts of climate change, and chemistry of emerging compounds
   - CCSP Strategic Plan may help set the tone for the importance of ongoing support for observations
   - Continual monitoring was a key concern of many parties at Nairobi MOP
   - Money is not the only problem – also losing expertise and institutional memory when people retire or move to other projects

### 3.2. "Twenty Questions and Answers about the Ozone Layer" has been well-received and serves as an informal and formal tool for communicating with public and policy makers (e.g., use by EPA as a part of reporting under Clean Air Act)

a) Attempts to tell the ozone "story" and to counter technical misunderstandings and misinformation.

b) Translation into languages other than English will raise the potential for information to be more widely read and dispersed.

c) The document is broadly structured to best serve all of the parties at MOP – it may be worthwhile to engage US stakeholders (Congress, etc.) via CCSP to determine how they use the document and if there are any needs that it does not meet.
d) Format may be considered for other assessment activities such as SAPs (e.g., IPCC WGI created a FAQ, as did EEAP).
e) There is a continuing need for documents that educate newcomers and non-specialists in the assessment process.

**3.3. Balancing assessments between providing information useful and relevant to policy makers and remaining policy neutral.**

a) Need for credible, scientific, policy-neutral reports that identify the problems and various solutions or paths forward.

**3.4. Interactions between stakeholders and assessment team**

a) Must be early and continual.
b) In some cases, scientists have a better/more clear understanding of an issue than policy makers realize – thus scientists and science communicators need to do a better job of getting the message across
c) Often times existing materials can be helpful in answering policy makers questions, and CCSP may be able to assist in eliciting policy makers' questions and matching these questions to materials already available

**3.5. How $O_3$ Assessment is used by government**

a) EPA
   - Tracking progress and "healing" of the ozone layer – are regulatory programs effective?
   - Informing the planning process for new and revised regulatory and voluntary programs
   - Regulatory impact assessments
   - Data and figures used in EPA reports to public and industry
   - Developing environmental indicators
   - Planning and identifying research needs
   - PART reports
   - Addendum to reporting under §603 of the Clean Water Act
   - Developing policy positions for the US delegation to the MOP
   - Placing $O_3$ programs in the context of climate change

b) State
   - Providing context and continuing emphasis on the ozone issue (fairly regular turnover of delegation members)
   - Often not obvious how reports are used – but they are read and science remains an important driver
   - Support for US contributions to Montreal Protocol Multilateral Fund (>$500M)

**3.6. How $O_3$ Assessment is used by industry**

a) 1985 assessment played an important role in DuPont's support of international convention on ozone

b) Subsequent assessments were important in DuPont's decision to phase out production of CFCs and HCFCs

**3.7.US leadership of assessment processes**

a) Susan Solomon will not be leading WG1 for AR5 and both US co-leads of $O_3$ Assessment have retired – thus there is a need for US to rapidly step forward to fill these positions and retain a leading role

**3.8.Interactions between and among assessments**

a) Ozone and IPCC are on different time schedules, so sometimes it is possible to feed model outputs and other information between the processes, while other times the modelers and others are overtaxed.
    - A potential role for WCRP (with assistance from WCRP) may be to look at what models are needed for ozone and IPCC and how the two timetables affect the way that models are built and analyzed.

b) Eventually there may be a need or ability to better phase or combine $O_3$ and IPCC assessments, but current MP timetable requires an ozone assessment in 2010 – and any decision to change timing and scope is the responsibility of the policy community.

c) SAP 2.4 has been able to draw on IPCC, TEAP, Ozone Assessment, and new peer reviewed publications, allowing the time/ability to craft a U.S. focused chapter in the report.

**3.9.Evolution of assessments**

a) The relationship between science assessments and policy should be carefully considered. On the one hand, it is important for the outcomes of science assessments to be independent of policy pressures. On the other hand, it is important for assessments to address both policy-relevant issues as well as outcomes from curiosity-driven science.

b) The most recent IPCC assessment has brought us beyond global mean temperature to the doorstep of considering the whole earth system, which could be a new frontier for AR5.

c) We may see more emphasis on sector-based special reports (e.g., aerosols, aviation).

# <u>Agenda:</u>

- **9:00 am:** Introduction to the workshop; "Why this workshop?" Chet Koblinsky (10 minutes)

**<u>Session 1 – Ozone Assessment Overview</u>**

- **9:10-10:45am (Chair Paul Newman)**: State of the Knowledge:
  a. 2006 Ozone Assessment
     - Major messages and new findings - A. R. Ravishankara (20 minutes)
     - Communicating the ozone issues - 20 questions about the ozone layer. - David Fahey (10 minutes)
  b. Synthesis and Assessment Product 2.4 – Mike Kurylo (20 minutes)
  c. Panel discussion on key emerging science issues - Susan Solomon, Ted Shepherd, Rich Stolarski Stephen Montzka, Paul Newman, and Malcolm Ko (45 minutes).

Coffee Break (15 minutes)

- **11:00-12:30 (Chair Thomas Land):** Users' perspectives, current status and future needs from:
  a. US policy community - John Thompson and Thomas Land (20 minutes).
  b. Industry - Mack McFarland (15 minutes).
  c. Other assessment panels of Montreal Protocol - Janet Bornman and Stephen Andersen (25 minutes)
  d. Panel discussion on how to identify and address user's needs- John Thompson, Mack McFarland, Cindy Newberg, Steve Andersen (30 minutes).

Lunch Break / General Discussion (12:30 to 1:30pm)

**<u>Session 2 – Ozone Assessment and CCSP: Mapping out assessment needs, emerging issues, and future research</u>**

- **1:30 to 2:00 pm (Chair – Chet Koblinsky)**: - Panel discussion on international assessments' contributions to CCSP (and vice versa) - Susan Solomon, and Peter Schultz (30 minutes).
- **2:00 to 2:30 pm (Chair - Peter Schultz)**: - Overview of the current CCSP *Strategic Plan* to set the stage for discussion of future directions (Illustrative Research Questions and Research Needs, see Appendix I) - A.R. Ravishankara (co-chair, Atmospheric Composition IWG) (30 minutes).
- **2:30-3:45pm (Chair A.R. Ravishankara)**: How should the Ozone Assessment inform the next round of strategic planning? Panel discussion – Susan Solomon, Mike Kurylo, Paul Newman, Mack McFarland, and Peter Schultz.

  Questions to be answered in specific and actionable ways:
  - Are there areas in the current strategic plan that we can begin to de-emphasize?
  - Are there any brand new areas we should be exploring?
  - Are there adjustments or refinements that should be made in the current observational, modeling, and decision support approaches?
  - Are there areas in which enhanced integration across disciplines would be helpful?
- **3:45-4pm (Chair A.R. Ravishankara & - Peter Schultz)**: Wrap up.
- **4pm**: Adjourn.