

Opinion: Stratospheric Ozone – Depletion, Recovery and New Challenges

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When I was offered this manuscript for review I gladly agreed, since the title and the authors made me expect a promising contribution. Unfortunately, my expectation was in parts not met. The manuscript is not mature in its present form. It is not balanced and the core of the work does not really contain new insights or ideas for future ozone research. The principle idea for this work is good, but for publication this “opinion” needs to be consolidated and sharpened. The aspects presented and discussed by the authors are so far correct, however the discussed points (i.e. the challenges) must be presented in context: For example, which open scientific questions (regarding the future evolution of the ozone layer) have been on the agenda for years, which are new (recent events), and why they are important for a better understanding of factors influencing the stratospheric ozone layer.

From my point of view, it needs a clear revision before this “opinion” can be published. The overall motivation for writing this opinion is clear, but, as already said, I think that the currently available manuscript is not finished. It needs a clearer structure (outline) and message. In general, I would like to say that this opinion paper, as it has been presented so far, has no real golden thread throughout. At present it is a conglomeration of known information and basic knowledge, but in keeping with the aim of this opinion (i.e. looking at the depletion of stratospheric ozone and the future evolution of the ozone layer in the light of new emerging challenges), a sharpening of the arguments for further (strengthened) observational and modelling efforts is needed. I would expect some (more concrete) ideas for future strategies at the end, for instance which (global) observations are of elementary importance (for monitoring the evolution of the ozone layer) and how Chemistry-Climate Models (CCMs) or Earth-System Models (ESMs) can be used here with an appropriate strategy.

Below are my general points and major caveats.

Section 1, the introduction is very brief. So far, some key references supporting the given statements are missed (for instance at the end of lines 25, 26, 34, 36, 39, 43). I think a short summary of the last 100 years of stratospheric ozone research is very appropriate, including the important contributions of the Nobel Prize winners (Crutzen, Molina and Rowland). From my point of view, the Section 2 (A century of ozone layer research) should be shortened and included in the Introduction part. For instance, the larger passages about Paul Crutzen’s work are far too long compared to other parts here (e.g. about the ozone research of Molina and Rowland). There are the (already mentioned) two essays appreciating Crutzen’s scientific contributions by Solomon (2021) and Müller (2022), who have already done this excellently. The appropriate references are sufficient. On the other hand, the important contribution by Marcel Nicolet (about the role of HO_x with respect to stratospheric ozone in the 1950s) is missing. A short paragraph about the importance/success of the Montreal Protocol including the expected recovery of the ozone layer would be (from my point of view) also fitting in the introduction section.

Then a specific section about current (persistent) uncertainties with respect to stratospheric ozone recovery (over time, regional differences) could focus for instance on the role of climate change (uncertainties of different climate scenarios), the role of VSLs, CCl₄, iodine, etc. Another important aspect is the meaning of unforeseen (unexpected) emissions of regulated substances in the Montreal Protocol (the story of CFC11; Montzka et al.), indicating the importance of monitoring ODSs. And, of course, the role of explosive volcanic eruptions in the past (Agung, El Chicon, Pinatubo), which strongly affected stratospheric ozone. The volcanic eruptions of Calbuco and Raikoke must also be discussed here accordingly. Such information is provided (in parts) in Section 3 and the beginning of Section 4.

Furthermore, in a following section, the “newly emerging challenges”, i.e. the Australian wildfires (ANY), and the extra-ordinary eruption of Hunga Tongo – Hunga Ha’apai (HTHH) should be discussed in more detail, explaining the scientific (new) challenges, why they need to be addressed and scientifically explored more in depth and that this is also important with regard to basic understanding. The information is (so far) given in Sub-sections 4.2 and 4.3 (a Sub-section 4.1 is missing). But the text passages (paragraphs) are sometimes kept very short, they sometimes seem like individual fragments, unlike a coherent text. The connections need to be better explained.

Finally, these changes would lead to a chapter/section where future activities (incl. measurements, observational capacities, techniques, methods, models) would be suggested and discussed. This part of the paper would be (in my view) the central part of this opinion paper. An opinion about the role of CCMs/ESMs in connection with global observations (monitoring of specific chemical, physical and dynamic quantities) would be helpful, for instance regarding the questions whether such model systems should be prepared in advance for considering “all extra-ordinary” situations, or if it is sufficient that the models can explain the observed features afterwards (a nice example was the explanation of the millennium water drop in the lower tropical stratosphere in 2000 in the following years, e.g. by Randel et al. and other related papers).

Many of the mentioned points in the manuscript are important and correct, but some of them have been thrown together or mixed up. As said in the beginning, it needs a clearer structure and, at the end, a clearer message. This message should be (in my view): Global monitoring of the Earth’s atmosphere (i.e. of key-species and other quantities) is absolutely vital and necessary. Numerical models (like CCMs or ESMs) can support the analyses of relevant processes and can help with the interpretation of observations and reveal weaknesses in understanding of the atmospheric system.