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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Stratospheric ozone trends for 1985–2018: sensitivity to recent large variability" *by* William T. Ball et al.

Anonymous Referee #2

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GENERAL COMMENTS

This paper presents a compelling update to the earlier work of Ball et al., and a much awaited response to the Chipperfield paper. While the science is excellent, unfortunately the writing is often too curt and the reader has to guess at what is being referred to (see many examples below). The writing, in many places, indicates a lack of clarity of thought, or perhaps just that the author is not writing what he means to say. I would strongly recommend that the author improves the quality of the writing. There are no major changes required for this paper to be ready for publication. Most of my suggested changes below are relatively minor. It is an excellent piece of analysis. Now it just needs to be communicated to its audience clearly.

SPECIFIC COMMENTS

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Discussion paper

Line 1: I would suggest replacing 'The Montreal Protocol' with 'The Montreal Protocol, together with its amendments and adjustments'.

Line 3: I would suggest that you reserve the word 'recovery' strictly to talk about the recovery of ozone from the effects of ODSs. When you are talking more generally about ozone increases, whether driven chemically or dynamically, talk rather about 'ozone increases' rather than 'ozone recovery'.

Line 12: I am struggling a bit with this 'still likely lower than in 1998 (probability ∼80%)'. Surely it is either lower or it isn't. OK , maybe I will get to see later how this is nuanced by some statistical significance.

Lines 16-17: With regard to the sentence 'These decreases do not reveal an inefficacy of the Montreal Protocol', an important point that can, and perhaps should, be made here is that tropical stratospheric ozone is almost certainly recovering (from the effects of ODS), and hence the Montreal Protocol is successful, while simultaneously still declining (due to other influences). The point to make is that recovery and declining ozone are not mutually exclusive.

Line 33: You need to be clear here what you mean by 'significant'. Do you mean statistically significantly different from zero at the 2 sigma level, or do you mean a more general 'significant' as in 'large'. It matters a lot in this specific context so I think that you should be clear.

line 59: I think it would be plausible to say that climate change may be exacerbating some specific dynamical mechanism (or more than one) that affects ozone, but it feels incongruous to state that climate change, in and of itself, could be a mechanism for dynamically affecting ozone.

Line 125: Delete 'point the reader to Laine et al. (2014) for details on this method and' since you have anyway cited the Laine et al., 2014 paper.

Line 135: This essentially assumes that the sensitivity of ozone to the regressors is

time-dependent. What support is there for this assumption? Why might ozone have a certain sensitivity to EESC in 1985 and then a different sensitivity in 1995, or 2005? This ability for DLM to accommodate changes in the sensitivity of ozone to the regressors is presented as an advantage of DLM over MLR but I am not convinced that it is. In choosing DLM over MLR you are making some significant assumptions and I am not sure that you have support for those assumptions. Or is it just the amplitude and phase of the seasonal cycle that you allow to vary with time?

Line 138-139: Well, unless EESC is selected as a descriptor of the long-term secular trend in which case it is a much more natural and appropriate descriptor than any pure statistical descriptor.

Lines 143-144: I don't be believe it is true that 'in practice MLR is often performed by first subtracting an estimated mean seasonal cycle'. I certainly don't. Most MLR-based analyses I have seen fit the annual cycle as a series of Fourier expansions along with all of the other regressors.

Line 151: What is MCMC? I have not seen this acronym defined anywhere.

Line 170: Can you give some indication of why the SAOD time series is not available beyond 2016?

Line 196: It wasn't clear to me what was meant by 'this group of spatial responses'. Responses of what to what? Are you referring the latitude/pressure resolved trends plotted in Figure 1?

Line 214: But the latitudinal extent of the changes you are seeing in observations is much wider than what is seen in the CCMs right?

Line 240: But only in the lower stratosphere right?

Line 253: I think that you need to read and cite Gray, L.J. and Pyle, J.A., A two-dimensional model of the quasi-biennial oscillation of ozone, J. Atmos. Sci., 46, 203-220, 1989. Another paper that might be relevant is Bodeker, G.E.; Garny, H.; Smale,

D.; Dameris, M. and Deckert, R., The 1985 Southern Hemisphere mid-latitude total column ozone anomaly, Atmos. Chem. Phys., 7, 5625–5637, 2007, especially if you are seeking clarification of the origin of the large mid-latitude changes in ozone that occur every few years.

Line 311: It is not clear to me what you mean by 'governing each other'? Do you just mean 'governing each'?

Line 325: This is worded in a very confusing way - please rewrite.

Line 329: As *what* in years prior to 2010 are essentially unaffected by the addition of 2017 and 2018? Ozone in 2013 is unaffected by the addition of 2017 and 2018? You are referring to something being unaffected by the addition of 2017 and 2018 but I am not sure what that something is.

Line 334: You need to make it clear that you are referring to the minimum in the DLM fit and not a minimum in the observed ozone.

Line 336: Do you mean mid-latitude ozone excursions depend on the phasing of the QBO phase from westerly to easterly (or vice versa) on the phase of the annual cycle in ozone? If so, please consider wording as such. If not, please reword to be more clear.

Line 337: Can't you just have cross-terms in your regression model i.e. a QBO basis function modulated by a phase dependent seasonal cycle?

Line 338: I don't think that is true. They can, they just need to include the appropriate regression model basis functions. Perhaps many MLR models currently in use do not, but that does mean that they fundamentally can't.

Line 358: Uncertainties in what are consistently large?

Line 359-360: The upper stratosphere is also sensitive to what in the tropics? Too often the explicit subject of a sentence or phrase is omitted in your writing which requires the

reader to constantly be guessing at what you are referring to. This makes deciphering the narrative very tiring. There are many examples of this in my comments. The next one is on the same line (360):

Line 360: What has 'shifted from negative to positive'. And what, exactly is uncertain?

Line 361: Uncertainties in what are smaller? And smaller compared to what?

Line 361: There has been a general shift in what towards more positive and significant increases? Please read the sentence that starts on line 359 and ends on line 362 i.e. "The upper stratosphere is also sensitive....SH and quasi-global estimates" and see whether, read as it stands, it would make sense to someone. Take that sentence to a colleague and ask them to tell you what it means. They may be horrified to read that the stratosphere has shifted from negative to positive. Maybe they always thought that the stratosphere was positive and may be alarmed that it has become negative. But at least they will know that whatever happened, its (whatever it is) is always uncertain. I would strongly suggest that you write in a way that prevents the reader from having to guess at things.

Line 367: The statement that 'The quasi-global lower stratosphere continues to exhibit a monotonic decline' is not true. There are many things in the quasi-global lower stratosphere that are not continuing to exhibit a monotonic decline. A good example would be CO2. Please work to improve the precision of your writing.

Line 368: I was shocked to read that 'the whole stratosphere continues to remain lower than in 1998'! Is the sky really falling? https://www.youtube.com/watch?v=NO04VXBIS0M. Is there nothing we can do to lift the stratosphere?

Line 374: Regarding 'changes prior to the last five years are largely unaffected in the partial columns'. I would be horrified if it was possible that ozone prior to the last five years was affected by the addition of recent years. It would mean that someone,

somewhere, has invented time travel. But perhaps that's not what you mean? It might be a good idea then to write *exactly* what you mean.

Line 403: So are you really saying that the Montreal Protocol is working only in the upper stratosphere and not in the lower stratosphere. This will hugely concern policy-makers. They will wonder why all the hard work they have done since 1987 in reducing emissions of CFCs, halons, HCFCs and other ODSs has only decreased their concentrations in the upper stratosphere. Could I put it to you that the Montreal Protocol has been effective in reducing ODS concentrations, and thereby concentrations of Cly and Bry throughout the atmosphere, and that, as a result, ozone throughout the atmosphere, including the lower stratosphere, is recovering from the effects of those ODSs. Is this recovery apparent in observations in the upper stratosphere? Apparently yes. I say apparently only in that (at least in this paper) a thorough attribution of the drivers of those ozone increases has not been done. Is this recovery apparent in observations in the lower stratosphere? No, clearly not? Why not? Well because other factors have been affecting ozone (not diagnosed in this paper) that are likely (we cannot be sure since a thorough attribution has not been done) overwhelming the increases brought about by reductions in concentrations of Cly and Bry. Wouldn't that be a more accurate picture to communicate to policy-makers?

Line 412: What does it mean to be 'confident in the evolution of stratospheric ozone'? You're confident that ozone is evolving? I'm pretty confident it is too. It always has been. I don't need your paper for that. Maybe you mean that the aim of this work is to build confidence in our quantitative understanding of trends, and other long-term variability, in upper, middle and lower stratospheric ozone?

Line 414: I think that the best tools for studying long-term changes in ozone, and attributing the causes of those changes to known drivers, is the application of regression models to observations. Yes, models can be useful for attribution but they have little role, if any, in detecting the changes in the first place. I think that chemistry-climate models are the best tools for making projections of how ozone may change in the

future.

Lines 423-425: This sentence blurs the lines between observations and model output. Were the 2017 data from Chipperfield CTM output or observations? If it was model output I would suggest replacing 'found lower stratospheric ozone had rapidly increased in 2017 back to 1998 levels' with 'found that model simulated lower stratospheric ozone increased in 2017 back to 1998 levels'.

Line 429: Any idea why the CTM got it so wrong?

Line 438: Does it enhance the positive trend in ozone, or does it enhance the recovery of ozone from ODSs - noting that those are two very different things?

Lines 439-440: How can the 'recovery' display a 'reduction'. That makes no sense to me. I can understand how ozone can reduce. I can even understand that ozone can reduce while simultaneously recovering from the effects of ODSs (I am not saying that that's what is happening here, but it is conceivable).

Line 447: By 'continues at all latitudes north of 30°S' do you mean continues to decrease at all latitudes north of 30°S?

Line 449: The seasonal-dependence of the QBO on what? Or do you mean the seasonal dependence of ozone on the QBO?

Line 455: This is the first mention of 'return dates'. What is meant by this? What is the 'return date' in a CCM?

Lines 456-457: What, exactly, do you mean by 'numerical inaccuracies'? Can you please add a sentence or two that elucidates this.

Line 460-461: Wait a minute. I have seen no evidence anywhere that there has been a 'halt in the recovery in total column ozone' from the effects of ODSs. I have seen plenty of evidence that ozone in different regions of the atmosphere continues to decline (including this paper) but no attribution of this declines such that one could conclude that

ozone is not recovering from the effects of ODSs. In fact it would devastate our understanding of atmospheric chemistry if it was found that decreasing concentrations of Cly and Bry had no impact whatsoever on the Cly and Bry cycles that destroy ozone. I see chemists leaping from buildings. So I strongly reject your conclusion that ozone, anywhere in the atmosphere, is not recovering from the effects of ODSs as you have presented no evidence at all to that effect. To make that call, you would need to do a robust attribution of changes in ozone to date and demonstrate that the ozone changes attributed exclusively to changes in Cly and Bry have been negative. And that you have not done.

Line 464: Do you mean predictions or projections? I think that it is very dangerous to use models to make predictions.

Line 468: Do you mean total column ozone or do you mean ozone in all parts of the atmosphere?

Line 470: I have no idea what you mean by 'super-recovery'. I fully understand how ozone can recover from the effects of ODSs. But I can't understand how it can 'super-recover'. I can understand how ozone could become higher than it was in the 1960s, but this has nothing to do with ODSs, and therefore nothing to do with 'recovery'. It results from CO2-induced cooling of the upper stratosphere. What then is 'super-recovery'?

Line 475: Ah, so the Montreal Protocol has effected a recovery in ozone from the effects of ODSs since the late 1990s? Your paper is communicating very mixed messages. Let me ask a very simple question: Is ozone in the lower stratosphere recovering from the effects of ODSs? If you answer yes, then what you have written elsewhere in the paper is wrong. If you answer no, then what you have written here is wrong because here you say that ozone declines would have been far worse without the Montreal Protocol which, to me, says that the Montreal Protocol has effected a recovery of ozone from the effects of ODSs. Please write clearly what you mean.

GRAMMAR AND TYPOGRAPHICAL ERRORS

Line 2: Replace 'work suggests' with 'work has suggested'.

Line 6: Replace 'wiped out' with 'offset'. 'wiped out' is too colloquial. Likewise on line 72.

Line 10: Replace 'hemispheric' with 'hemisphere'.

Line 18: Replace 'protocol's' with 'Protocol's'.

Line 30: Replace 'its amendments' with 'its amendments and adjustments' just to be complete.

Line 31: Replace 'coincided with' with 'led to'. They can't be coincident if they are separated by 11-13 years.

Line 60: Replace 'negative trends' with 'negative trends in ozone'.

Line 96: Replace 'This data was' with 'These data were'.

Line 98: Replace 'in context' with 'in the context'.

Line 105: Replace 'the averaging the two products' with 'the averaging of the two products'.

Line 128: Be consistent in the way you spell timeseries.

Line 204: I would suggest replacing 'increase' with 'increase in SH mid-latitude lower stratospheric ozone' just to be completely clear (or whatever region Chipperfield reported the change over).

Line 210: Replace 'as more data is added' with 'as more data are added'.

Line 232: Either 'the identification criteria were' or 'the identification criterion was'. The word criteria is plural.

Line 277: Replace 'in context of these' with 'in the context of these'.

Line 250: Replace 'Equatorial variability related' with 'Equatorial variability in ozone related'.

Line 251: Replace 'decreases' with 'decreases in ozone'.

Line 251: Replace 'to that of the' with 'to that at'.

Line 311: Replace 'Whilst' with 'While', unless you really do want to be very British.

Line 317: I would suggest replacing 'DLM trends estimated' with 'DLM trends in lower stratospheric ozone estimated' just to be totally clear.

Line 351: Replace 'large resurgence in 2017' with 'large resurgence in ozone in 2017'.

Line 357: Replace 'that the middle-stratosphere exhibits' with 'that ozone trends in the middle-stratosphere exhibit'.

Line 365: Replace 'have made' with 'has made'.

Line 387: Replace 'tropical' with 'tropics'.

Line 393: Replace 'indicated' with 'indicate'.

Line 396: Replace 'exclude, 50–60°' with 'exclude 50–60°,'

Line 412-414: This sentence needs a lot of help.

Line 420: delete 'extremely'.

Line 454: Replace 'spread on' with 'spread in'.

Line 467: Replace 'is likely' with 'are likely'.

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