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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism" *by* O. B. Toon et al.

O. B. Toon et al.

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Response to Dr. M. MacCracken We appreciate the detailed and thoughtful comments of Dr. MacCracken. We have repeated his comments below in {}, and our responses are in regular fonts.

{1. As a general comment, I found it quite confusing to have the reference be to Pittock et al., 1989 rather than the 1985 edition-it just fouls up the time history of the storyline through the nuclear winter period. I would strongly recommend using the date of the first edition of the book, and then if you want note the date of the second edition (which, as I recall had few changes) in the references. Same goes for Harwell et al. references-using the later date really throws off the reader to when the studies were actually done.}

Good point, we changed all the dates, and referred to the second edition in the reference as well.

{2. Bottom of page 11747-top of 11748: Regarding this indication that a region would be uninhabitable, I think it would be helpful to make very clear that this is for surface/nearsurface bursts, given that Hiroshima and Nagasaki, for which there were air bursts, were rather quickly reinhabited. I certainly agree that terrorist-caused explosions might well be surface bursts, so this is quite plausible.} Good point we added "Early radioactive fallout from small nuclear ground bursts would leave large sections of target areas contaminated and effectively uninhabitable. (Hiroshima and Nagasaki were attacked by airbursts, which will not deposit large amounts of local radiation unless it is raining. They were continuously inhabited.)"

{3. Page 11754 and following: Regarding the various scenarios, this notion that the regional conflicts (so presumably one nation attacking another) will focus on centers of population seems to me rather far-fetched-it is essentially suicidal to go after the population centers instead of the other side's weapons. The original scenarios considered by TTAPS (done as is noted by others on page 11757) targeted, as I recall, the cities of the world by order of population-and was considered so implausible a scenario that I think it really caused much more of an adverse reaction to the paper than was justified by the issue being raised. I worry about that for this analysis as well-while terrorists might go for population centers, it seems to me very unlikely they would have access to the number of weapons being suggested as ultimately causing the climatic influence, and I just don't think nations are really suicidal (though the rhetoric of some leaders is certainly disturbing). It seems to me it would help the paper to be more nuanced on this.} We agree that it is difficult to know the warfighting strategy that might be used. We added a reference to Lavoy and Smith, who considered the reasons that a war might start between India and Pakistan since some readers have questioned the possibility of a war at all. We did not mean to exclude military targets, which just didn't locate them which could be difficult as well as controversial. So we assume some weapons

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would be used against military targets, but most against urban centers. We also assume that that many military sites will be in urban areas, but some will not. We ignore those casualties. We added the following: “In our computations we have assumed that the densest population centers in each country are targeted. There are many circumstances that could trigger a regional-scale nuclear conflict, and many scenarios for the conduct of the ensuing war. For instance, analysts (Lavoy and Smith, 2003) suggest Pakistan and India could get into a nuclear war because a conventional conflict threatened to overwhelm the strategic conventional forces or command and control structure of either side. Alternatively they might launch a nuclear war to preempt a nuclear attack, real or imagined, by their adversary. Iran and Israel, and numerous other countries, might exchange nuclear weapons for similar reasons in the future. In our analysis we assumed that the densest population centers in each country-usually in megacities-are attacked. Such an urban attack might be conducted to inflict maximum damage. It is likely that military targets would also be attacked. We have not attempted to locate specific military targets, and ignored casualties related to such targets, but note that many military targets are in cities. Hence the “small” wars assumed here are similar in principle, if not in scale, to the strategies for all out nuclear warfare and war fighting embraced by the superpowers in the mid-20th century in the context of “mutually assured destruction”.”

{4. Page 11756: On this issue of city fires being ignited, across the Middle East with its dry climate, the buildings are mainly concrete and adobe and not wood. During massive earthquakes, fires are not getting ignited, and I really wonder if in such cities there is anywhere near the concentrated fire load being assumed. In developed world cities, again, there is much more concrete and many taller buildings-while lots of damage can be done, can massive fires get ignited? Consider the World Trade Center-sure, there were fires while the building was standing, but none once it collapsed or in adjacent buildings, etc., and a nuclear explosion would likely knock the nearby buildings down.}

We certainly agree that we need more information on the fuel loads in cities in the

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developing world. Even in the developed world such studies required large amounts of work and have only been carried out by a few groups. We added the following

The fuel loading per person in the developed world may be greater than that in the developing world, so that the values of C in Eq. 5 may be less than unity. We have found little direct work on fuel loading in countries such as Iran, India and Pakistan. Tall buildings in megacities are not likely to be composed of wood. For example consider Tehran, a modern megacity with a population near 10 million. Tehran has large museums, art centers, palaces and a modern subway system. About 66% of the buildings are unreinforced masonry (which poses a great earthquake hazard), 27% are steel construction, and 4% reinforced concrete (EMI, 2006). The masonry buildings contain little wood in their construction (Maheri, 2005). Similar structures in the U.S. include the World Trade Center Buildings. These are estimated to have contained a fuel loading, per floor, of 1.4 to 1.9 g/cm2 but the average fuel loading could have been as large as 4.6 g cm2 since it was an office building with possibly lots of paper (Rehm et al., 2002). Kumar and Rao (2005) measured fuel loads in Indian office buildings and found an average value corresponding to 1.9 g/cm2, per floor, which is very similar to values from Britain. Hence what data we have suggest fuel loads in the developing world are similar to those in the developed world, and that the fuel is in building contents as opposed to building structures. While we have found no specific detailed analysis of fuels in megacities in developing countries a variety of relevant indirect data available for large urban areas worldwide has been considered to assess the possible variance in CĚ

{5. Page 11758, first paragraph: While it may be true in a numerical sense that the superpowers have enough weapons to explode one in all the major cities of the world, such a scenario is implausible in the extreme-there would be no reason for it and I really think it damages the credibility of the analysis to make such statements-it sounds like naive scientists considering military scenarios that just would have no real world credibility. And it is not at all clear, in any case, that there are enough deliverable weapons

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for Russia and the US to successfully hit all significant military targets, given needs for multiple targeting, mobile systems, etc. (that was the whole basis of MAD- even if one fired all one's weapons, there would be a massive retaliation on the other side's cities, etc.-so I do not think the comment makes any military sense-in any case, the comment really does not serve much purpose. I just find the writing about these war strategies as not very well thought through if the intent is to really communicate with leaders of the world instead of simply trying to stir up a controversy 6. Page 11758: Just to note that in the second paragraph, line 10, it should be "principle"} We did not mean to imply anyone would attack every city in the world. We are trying to point out that the reason these scenarios kill so few people and create so little smoke per kton of yield is that many of the weapons are used on the same targets. We replaced these two paragraphs with: In our computations we have assumed that the densest population centers in each country are targeted. There are many circumstances that could trigger a regional-scale nuclear conflict, and many scenarios for the conduct of the ensuing war. For instance, analysts (Lavoy and Smith, 2003) suggest Pakistan and India could get into a nuclear war because a conventional conflict threatened to overwhelm the strategic conventional forces or command and control structure of either side. Alternatively they might launch a nuclear war to preempt a nuclear attack, real or imagined, by their adversary. Iran and Israel, and numerous other countries, might exchange nuclear weapons for similar reasons in the future. In our analysis we assumed that the densest population centers in each country-usually in megacities-are attacked. Such an urban attack might be conducted to inflict maximum damage. It is likely that military targets would also be attacked. We have not attempted to locate specific military targets, and ignored casualties related to such targets, but note that many military targets are in cities. Hence the "small" wars assumed here are similar in principle, if not in scale, to the strategies for all out nuclear warfare and war fighting embraced by the superpowers in the mid-20th century in the context of "mutually assured destruction".

{7. Page 11761: The comment about rainout seems pretty well hidden. This was an issue a number of scientists at Livermore raised in the 1970s or 80s (or maybe earlier)

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about what would happen in the event of a so-called tactical war in Europe-one would have really severe contamination. I would think that issue might well be much more serious than the climatic effects that are postulated.} We agree that local fatalities can be significantly impacted by radiation in rainout. We discuss it further below. However, we do not consider it in our fatality estimates for airbursts. The climate effects impact the rest of the world, the radiation has to be deposited in the first day to have a great effect, so they cannot extend too far.

{8. Page 11766: I am a bit surprised at this notion that inhabitants might not return to a blast area (presuming it was not a surface burst and there was no rain)-certainly the residents of Hiroshima and Nagasaki did. Cities are generally there for a reason, and the blast does not destroy that reason-just the facilities developed and a lot of people. But others seem likely to come back. It might well be appropriate to analyze what this might mean. 9. Page 11766: On this notion of economic consequences and national and interna- S6415 tional economic disruption, that was, I thought, one of the key points in the studies in the 1980s-that is, after the direct effects, the main consequence might well be the breakdown of national economies and international trade. I would think that point should be made more forcefully.} We eliminated this paragraph from the paper. However we moved the thought about more studies of economic effects to the conclusions.

{10. Page 11770 and following: I think this issue of fuel load and the likelihood of it burning intensely over a short time is a real question-are the materials mentioned really in close proximity or spread out, will they be covered by debris or available to burn, etc.? The numbers that result just seem very high}. We are simply using the values that were obtained after a decade of research in the 1980s. We agree however, that much further research could be done in this area.

{11. Page 11778: Is there any evidence that the smoke from the Hamburg and major forest fires lofted into the stratosphere. It would be helpful to give an indication (and on page 11780, line 3, what is the “deep stratosphere”?).} We added: The midlatitude

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lower stratosphere has potential temperatures that allow air to be transported horizontally into the equatorial troposphere, so material injected into the lower stratosphere tends to be removed within a few months. However, material injected above about 18 km has potential temperatures that are high enough to cause material to remain inside the stratosphere at all latitudes, and thus have a much longer residence time. Observations clearly show that forest fire smoke does quickly reach the deep stratosphere where it will have a long residence time(Jost et al., 2004; Fromm and Servranckx, 2003; Fromm et al., 2000). And we added As we discussed above there have been numerous cases in which stratospheric smoke has been observed following large forest fires. These observations rely on modern high altitude aircraft and satellites, which were not available during WWII. There were several mass fires during WWII. The best known of these were in Dresden, Hamburg, Tokyo, Hiroshima and Nagasaki. While the Dresden, Tokyo, Hiroshima and Nagasaki fires occurred within a few months of each other in 1945, the Hamburg mass fire occurred in 1943. These five fires potentially placed 5% as much smoke into the stratosphere as our hypothetical nuclear fires. The optical depth resulting from placing 5Tg of soot into the global stratosphere is about 0.07, which would be easily observable even with techniques available in WWII. However 5% of that optical depth is only 3.5x10-3, which would not have been possible to observe, either remotely or by in situ techniques, at that time.

{12. Page 11781: As I recall, there were a number of model experiments done of burning cities in various cloud models, yet I did not see a reference to these.}

Penner (1986), Small and Heikes (1988) and Heikes (1990) were the last such studies. I did not attempt to review the early models on this problem, but they are referred to in these works.

{13. Page 11783: I don't quite understand what is meant by saying that the CO emissions represent about 2% of the "global inventory"-is this the amount in the atmosphere on average? Comparing to estimates of global emissions might be more useful.} I changed this to read: The combustion of 63 to 313 Tg of fuel will lead to the emission

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of 1-5 Tg of soot, about 13 Tg of CO (or ˜1% of the global annual source)

{14. Page 11786, top lines: This sentence summarizing your targeting assumptions again seems to me to make the scenario quite implausible. And to suggest that, except for a US-Russia war, that explosion of 50 to 100 nuclear weapons represents only a small number -for any other power, this would be a very large number (well, maybe not for China). And to say it is a small fraction of the total yield also seems to be mixing things up-sure, a global war between the US and Russia would be terrible, and this is the only way to get to a large fraction of the yield going off. For terrorists or small nations, these would be huge undertakings-not a pittance.}

We modified the paragraph as follows: There are many uncertainties in the analysis presented here. Some of them can be reduced relatively easily. For instance, surveys of fuel loading in developing nations would reduce the uncertainty in the amount of smoke produced by urban fires. Numerical modeling of urban mass fires, would reduce the uncertainty in smoke plume heights. Investigations of smoke removal in pyrocumulus would reduce the uncertainty in smoke injections. The major uncertainties, however, are likely in our choices of scenario. We have considered only the casualties in urban zones, and we have assumed they would be attacked on the basis of population. Instead, one might target as many cities as possible irrespective of population in order to spread the damage, or target those with important economic assets. Military targets likely would also be to be attacked, but we have not included them in our analysis. However, we have also used a very small number of low yield weapons within the range of those controlled by the smallest current nuclear states. Larger numbers of weapons, and larger yield weapons, are possible. Many scenarios can be constructed, some of which will lead to fewer casualties, less radioactivity and less smoke emitted. The trivial example is that no effects will occur if no weapons are used. Other scenarios will lead to more casualties, more radioactivity and more smoke. Our example uses less than 0.1% of the yield of nuclear weapons that exist on the planet. For instance, a war between China and India likely would lead to more weapons of higher yield being

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used than assumed here. The current build up of nuclear weapons in an increasing number of states points to scenarios in the next few decades that are more extreme than the one we considered. Each of these potential hazards deserves careful analysis by governments worldwide advised by a broad section of the scientific community, as well as widespread debate.

{15. I also was surprised that the paper had no references to a number of the major climate papers-e.g., of the NCAR and LLNL groups-but did cite the Aleksandrov study, which was much more limited.}

The LLNL climate modeling work is referenced in the Robock paper. I tried to cite only the earliest papers, and the last ones that reviewed the previous work. We did cite the Penner work from LLNL. I am not aware of any work from NCAR on smoke source functions, only climate modeling. We also cited the Los Alamos group for its ozone related work. I would be happy to add references if you had specific suggestions related to the topic of this paper.

{16. Table 2: This table really seems a bit over the top-suggesting that Belgium or Switzerland has the potential for of order 2000 Pu weapons just seems to make even more clear how far out the consideration is in this paper of what is being analyzed. To sort of imply that Brazil and Argentina might have a regional conflict of the type being considered, etc. is really reaching. Just having plutonium is not really the issue-it is having the capability and intent to use it. Why not say that there is enough plutonium for every person on Earth to die from inhaling it-again, likely true, but rather irrelevant in any logical sense as there is no delivery system to make this come close to happening. In general, I thought that by jumping to a rather extreme worst case presumptions (or even possibilities), the paper tended to obscure the point that the explosion of only one or a few could have devastating consequences-especially for a surface burst or in situations that would lead to early rainout (or even distant rainout, as happened with Chernobyl). I thus think that the paper is more likely to be dismissed for considering such unrealistic scenarios than for carefully documenting how even a single explosion

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could cause widespread death and devastation-and quite possibly have long-range environmental and economic impacts as well.}

It is easy to argue that people are going to be rational and that you know what is going to happen so that we needn't worry. However, if you read the recent book by Drell, or the recent letters to the editors of the Wall Street Journal by Shultz et al, and Gorbachev you will see that experienced political and policy leaders are very concerned about the expansion of nuclear powers. Countries make nuclear weapons for a lot of reasons beyond simple defense. For example, many of them seek international recognition as a world power. Let's take Brazil and Argentina. They both had nuclear weapons programs up until they signed a treaty in the 1990s. Brazil in particular was subject to considerable scrutiny in 2004 when it temporarily closed its new uranium enrichment facility to IAEA inspection. It is certainly notable that Taiwan, South Korea and Japan could easily make nuclear weapons since if any of them did so it would create a significant international problem. While few would imagine Switzerland would make nuclear weapons (though it once had a nuclear weapons program) it is certainly true they have the material to do so, which is what the Table says and despite your statement the Table is correct. The Table does not say they plan to make weapons. A country that has the material to make large numbers of weapons, also has the potential to loose some of its material without it being easily noticed. We might have scrubbed this table to just those countries we felt were actually threatening to do something, or considering it. However, we do not feel that we can predict the future intentions of nations, so we listed all those who have considered a nuclear weapons program, and all those with material already on hand. We imagine many readers will be as surprised by this list as we were.

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