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This article is a comment on Reisner et al. (2018), https://doi.org/10.1002/2017JD027331.

Comment on "Climate Impact of a Regional Nuclear Weapon Exchange: An Improved Assessment Based on Detailed Source Calculations" by Reisner et al.

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Key Points:
- Reisner et al. chose an area that included a golf course, playground, and individual houses with large yards, with little material to burn
- They made other assumptions that bring into question their conclusions, including not allowing moist convection and too strong winds
- Reisner et al. significantly underestimated the amount of smoke, and climate and agricultural impacts, likely after a nuclear war

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Abstract Reisner et al. revisited a study we had done modeling the climate impacts of a nuclear war between India and Pakistan, in which fires started by 100 15-kt atomic bombs would produce 5 Tg of soot injected into the upper troposphere, and subsequently lofted into the lower stratosphere. Their claim that there would be much less smoke than in our results is wrong for several reasons. They chose a target area of suburban Atlanta that includes a golf course, playground, and individual houses with large yards, with little material to burn, which is not representative of densely populated cities in India and Pakistan. The fire they modeled is not typical of the type of mass fire likely to result from a nuclear attack on cities. They used winds that are stronger than typical winds. They did not allow moist convection, which would be important in convective lofting of the smoke. Their claim that if they included convection the resulting rain would wash out the smoke is not supported by observations of pyrocumulonimbus injection of smoke into the stratosphere from forest fires. And they used a fire model that they have not made available for other scientists to try to reproduce their work, and which has not been shown to accurately simulate firestorms observed in Hamburg, Dresden, and Hiroshima during World War II. They significantly underestimate the amount of smoke, and climate and agricultural impacts likely after a nuclear war.

Reisner et al. (2018, hereafter Reisner et al.) revisit a study we had done (Mills et al., 2014) modeling the climate impacts of a nuclear war between India and Pakistan, in which fires started by 100 15-kt atomic bombs would produce 5 Tg of soot injected into the upper troposphere. When Reisner et al. repeated our climate model simulations with a 5-Tg soot injection, they reproduced the same climate response. Similar results have also been reported using different models (Mills et al., 2008; Pausata et al., 2016; Robock et al., 2007). However, using results from their simulation of a mass fire in suburban Atlanta with HIGRAD-FIRETEC, a model which is not available from them preventing others from recreating their calculations, Reisner et al. calculate that much less soot would be injected into the upper troposphere because the plumes from fires would not rise as high in the atmosphere, and therefore there would be less climate response. While we agree that this reduced smoke input would result in a much smaller climate response, we have serious concerns that the fire they modeled is not typical of the type of mass fire likely to result from a nuclear attack on densely populated cities in India and Pakistan and therefore their smoke estimate may significantly underestimate the amount of smoke likely to rise into the upper troposphere and lower stratosphere during a nuclear war.

Reisner et al. state that they are simulating a mass fire, presumably of the sort that would be expected in an urban area after a nuclear explosion. However, it is clear that they did not simulate a firestorm such as occurred in Hamburg, Dresden, and Hiroshima during World War II. Without them demonstrating that their model can accurately simulate these actual firestorms, it is difficult to interpret conclusions from their simulations. Firestorms have strong inflowing winds so that they have little spread, extremely tall convection columns or smoke plumes, and burn for long durations until all the fuel within their perimeter is consumed (e.g., Glasstone & Dolan, 1977). Numerous studies of firestorms (e.g., Badlan et al., 2017; Cotton, 1985; Penner et al., 1986; Small et al., 1989; Small & Heikes, 1988) show smoke rising into the stratosphere from simulated firestorms, and explore the dependence of smoke altitude on fire intensity, atmospheric stability, moisture, fire size, wind speed, and other parameters. In a nuclear conflict over a large country involving a large number of weapons many of the fires would be expected to develop into firestorms. Glasstone

Figure 1. Google Earth image of the location in suburban Atlanta targeted by the simulation of Reisner et al. The red circle has an area of 13 km^2, the area of the firestorm produced by the atomic bombing of Hiroshima on 6 August 1945. It is clear that this area includes a golf course, lake, school grounds, and widely spaced suburban homes.

and Dolan (1977) suggested, based on the experience with 69 mass fires in Japan and many others in Germany during World War II, that firestorms occur when the following criteria are met:

1. a minimum burning area of about 1.3 km^2;
2. half the structures in the area are on fire simultaneously;
3. a fuel load of at least 4 g/cm^2; and
4. ambient winds less than 3.6 m/s.

Glasstone and Dolan (1977) and results from Reisner et al. show that, assuming flat topography, a 15-kt weapon would ignite fires in a ~13-km^2 area including a majority of the structures within that area, thus fulfilling the first two criteria. However, the second two criteria were not met in the Reisner et al. study.

The fuel load in Reisner et al. is too small to generate a fire storm. Mills et al. (2014) used smoke estimates from Toon et al. (2007), who calculate fuel loads ranging from 12.6 to 94.5 g/cm^2 for the top 50 urban targets in India and Pakistan. These values are all significantly above the 4 g/cm^2 threshold value needed to support a firestorm. In their paper, Reisner et al. do not provide either the target location or the fuel loads used in their fire model. Rather they state that they visually examined Google images of Indian and Pakistani cities and chose a similar area of Atlanta. In personal communications, Jon Reisner did connect us with the provider of their fuel loads, Joseph Crepeau of Applied Research Associates, Inc., so that we could assess these critical data. Their ground zero is near the East Lake Golf Club in suburban Atlanta (33.750°N, 84.305°W), more than 5 km east of downtown Atlanta. A Google Earth map of this region (Figure 1) shows that this suburban region with a golf course looks nothing like a city in India or Pakistan (e.g., Figure 2). From their fuel load maps, we were able to calculate the average burnable fuel load in the 13 km^2 target area to be 0.14 g/cm^2 and in the 10-km × 10-km domain of their model to be 0.91 g/cm^2. Both of these values are well below the fuel load threshold for a firestorm, and the target area has 6 times less fuel density than the domain average.

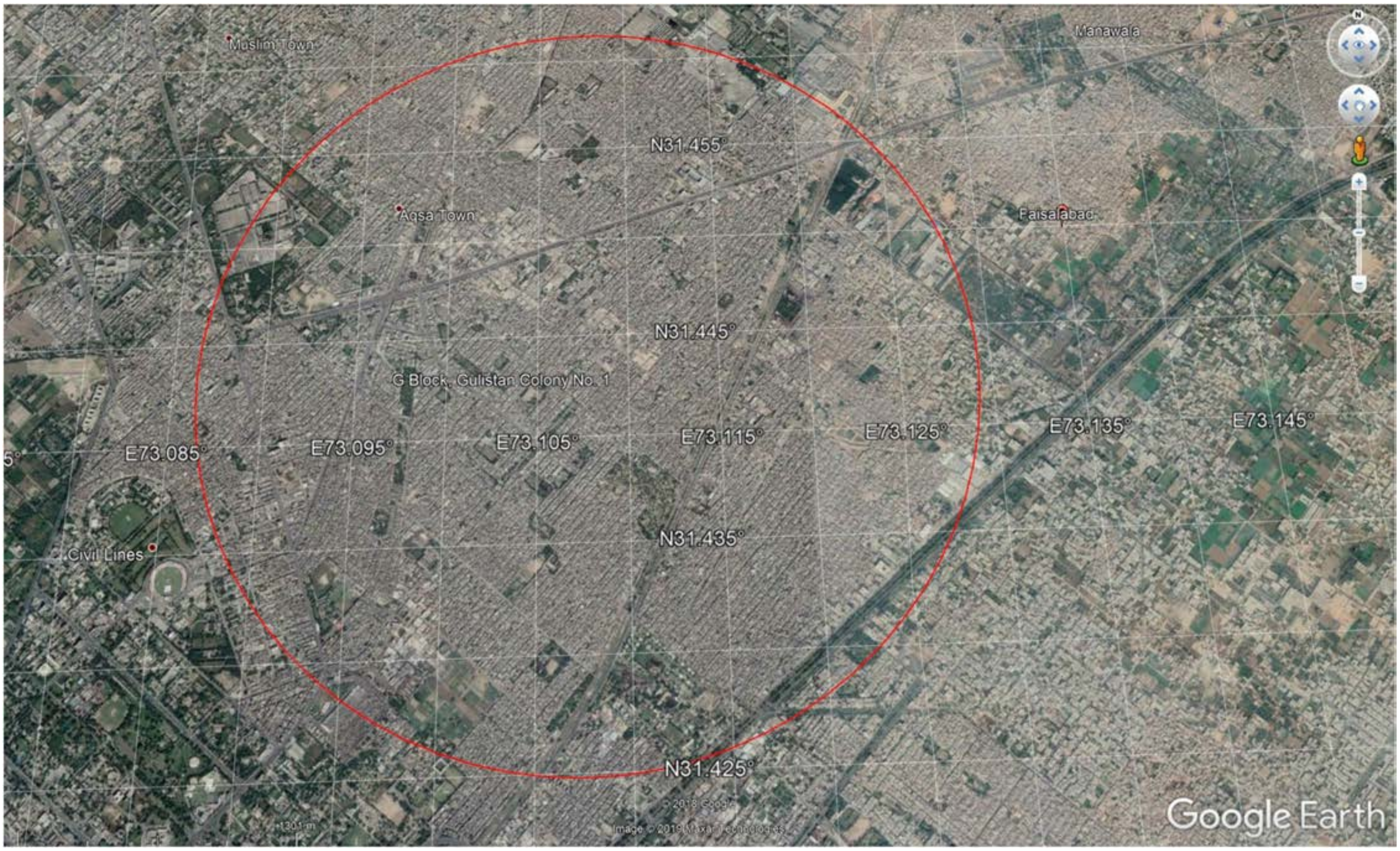

Figure 2. Google Earth image of Faisalabad, Pakistan, a city with a population of 4,100,000. The red circle has an area of 13 km^2, the area of the firestorm produced by the atomic bombing of Hiroshima on 6 August 1945. Densely packed buildings fill the area.

The fuel load for the target area is also well below the value calculated using maps of population density following Toon et al. (2007) of 0.87 g/cm^2. Fundamentally Reisner et al. simply chose a target with very little fuel. The 0.14 g/cm^2 value for the Reisner et al. target area is 15 to 110 times smaller than the top 50 targets in India and Pakistan which were considered in the Mills et al. (2014) study.

Reisner et al. assume a wind profile with 6–8 m/s winds in the boundary layer, which they call "very calm," but which are significantly above the threshold of 3.6 m/s for a firestorm. Toon et al. (2007) did not consider the effects of surface winds in assuming firestorm conditions. For the top targets in India and Pakistan, during May our own numerical simulations with the version of the WACCM model used by Mills et al. (2014) suggest that surface winds for likely targets would be expected to be above the firestorm threshold about 50% of the time, so assuming sufficient fuel loads, about half of the targets should develop into firestorms and half into conflagrations.

Because of the choice of target location and wind speed, Reisner et al. simulated a weak conflagration rather than a firestorm. Furthermore, for their climate simulation they assume that all 100 targets have the same smoke emissions as this case. In Toon et al. (2007), targets were identified and smoke production scaled by population density and thus each location injected a different amount of smoke proportional to the population. Figure 5 of Reisner et al. shows that their fire is blowing downwind. Conflagrations were observed in World War II mass fires, and indeed were desired in order to burn the largest possible area. They are also commonly observed in modern forest fires. Reisner et al. state "As indicated below, the simulations include various worst case assumptions with regard to the specification of the fuel, weather conditions, and height of burst of the device. Therefore, they serve as upper bounds with regard to the expected outcome of an urban mass fire caused by a nuclear detonation." We argue that the Reisner et al. simulation is clearly not a worst case. As we have already discussed Reisner et al. do not have a high fuel load, but one that is more than an order of magnitude smaller than even the lowest fuel loads in the urban areas of Pakistan and India considered in the Mills et al. (2014) study. Firestorms were also observed in World War II and lofted material to high altitudes (see Penner et al., 1986). Moreover, numerous conflagrations in forest fires with fuel densities similar to those assumed by Reisner et al. have produced smoke plumes that reached into the stratosphere (e.g., Peterson et al., 2018). In 2017 a fire in British Columbia produced a stratospheric smoke pall that was observed by satellites for 8 months (Yu et al., 2019). Aircraft studies have shown that debris from recent fires is common in the lower stratosphere (Ditas et al., 2018).

Reisner et al. neither compared their simulation with previous studies of mass fires, nor listed the basic parameters that would allow comparisons with past or future studies. They claim they have validated their model against observed mass fires, referring to their Figure 1 and three references (Linn, Canfield, et al., 2012; Linn, Anderson, et al., 2012; Pimont et al., 2009). However, two of these references (Linn, Canfield, et al., 2012; Pimont et al., 2009) and their Figure 1 focus on line fires emitting smoke into the boundary layer, which is not relevant to urban mass fires. The third reference (Linn, Anderson, et al., 2012) focuses on 150 m × 150 m or smaller burn plots, also not representative of a mass fire.

Unfortunately, Reisner et al. did not report where the fire they simulated was located, fuel loading, fraction of fuels burned, fire energy release, or energy release rate when simulations were terminated so their results could not be duplicated. They have subsequently provided us with the target location and fuel loads, which is an important first step to assessing their results and recreating their fire simulation in other models.

Additionally, Reisner et al. chose several parameters for their fire model that could suppress the vertical development of fires including: a stable boundary layer, a dry atmosphere, and a short simulation time. A less stable boundary layer (such as a daytime convective boundary layer) would support more upward motion. Water vapor allows for latent heat release when clouds form. Numerous studies have shown that sensible and latent heat release is essential to lofting smoke in either firestorms (e.g., Penner et al., 1986) or conflagrations (Luderer et al., 2006). Reisner et al. stated "A dry atmosphere was utilized, and pyrocumulus impacts or precipitation from pyro-cumulonimbus were not considered. While latent heat released by condensation could lead to enhanced vertical motions of the air, increased scavenging of soot particles by precipitation is also possible. These processes will be examined in future studies using HIGRAD-FIRETEC." By not considering pyrocumulonimbus clouds, which by the latent heat of condensation can inject soot into the stratosphere, they have eliminated a major source of buoyancy that would loft the soot. They seem to suggest that any lofting of soot would be balanced by significant precipitation scavenging, but there is no evidence for that assumption. In fact, forest fires triggered pyrocumulonimbus clouds that lofted soot into the lower stratosphere in August 2017 over British Columbia, Canada. Over the succeeding weeks, the soot was lofted many more kilometers, as observed by satellites, because it was heated by the Sun (Yu et al., 2019). This fire is direct evidence of the self-lofting process Robock et al. (2007) and Mills et al. (2014) modeled before. It also shows that precipitation in the cloud still allowed massive amounts of smoke to reach the stratosphere.

Reisner et al. stated that their fires were of surprisingly short duration, "because of low wind speeds and hence minimal fire spread, the fires are rapidly subsiding at 40 min." However, they do not show the energy release rate so that we can tell if the fuel has been consumed within 40 minutes. And their claims of low wind speed are erroneous, as they choose wind speeds higher than typically observed in Atlanta. Real-world experience with firestorms such as in Hiroshima or Hamburg during World War II or in San Francisco after the 1906 earthquake (London, 1906), and of conflagrations, such as after the bombing of Tokyo during World War II (Caidan, 1960), suggests that a 40-minute mass fire is a dramatic underestimate; most of these fires last for many hours. A longer fire would make available more heat and buoyancy to inject soot to higher altitudes. If their fire had a short duration, and did not simply blow off their grid, it was likely due to the low fuel load assumed in their target area and combustion that did not consume all of the available fuel.

The claim that observations and models of the effects of volcanic eruptions support their results is erroneous. They refer to a paper by Timmreck et al. (2010) who modeled the climate effects of the 74 BP Toba eruption, taking into account growth of sulfate aerosol particles due to large SO_2 emissions. This process represents completely different physics than would apply to black carbon aerosols. Black carbon (soot) is black, and highly absorptive of sunlight, causing lofting to the upper stratosphere and prolonging the lifetime in the stratosphere by years. This was shown in all our modeling work and observed after the 2017 British

Columbia pyrocumulonimbus event (Peterson et al., 2018; Yu et al., 2019). Soot aerosol particles grow as fractals, limiting the effects of mass on fall speed. Sulfate aerosols only weakly absorb sunlight, and their growth reduces their stratospheric lifetime. These differences do not support volcanic sulfate growth as an analog for soot in the stratosphere.

In summary, Reisner et al. (2018) modeled a fire in an area with much different characteristics than considered in our studies including the following:

1. targeting a sparsely populated suburb surrounding a country club, not a city center;
2. having a fuel load that is more than an order of magnitude less than any of the 100 urban areas of Pakistan or India considered by Robock et al. (2007) and Mills et al. (2014);
3. omitting factors known to be important to smoke lofting (e.g., latent heat release); and
4. failing to model the full duration of the event.

Because of these choices, they did not simulate firestorms, which would be expected in densely populated urban areas and are known to have high altitude smoke plumes. Critically, they have not shown that their model is capable of reproducing historic firestorms, thus making it impossible to interpret their failure to generate a classic firestorm. Reisner et al. do raise an important point that not all mass fires in a nuclear war will be firestorms; however, these mass fires cannot be assumed to be weak conflagrations, either. Accurate understanding of target locations, fuel loads, and the effects of meteorology on the fire and smoke injection heights are critical to understanding the climatic consequences of fires from a nuclear war. Fire models like HIGRAD-FIRETEC can be valuable tools for studying these issues, but the case presented by Reisner et al. is not typical of the conditions that would be expected in a nuclear war between India and Pakistan and certainly does not represent an upper bound on these effects.

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