PATHWAYS, IMPACTS, AND POLICIES ON SEVERE AEROSOL INJECTIONS INTO THE ATMOSPHERE

2011 Severe Atmospheric Aerosols Events Conference

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Huge amounts of aerosols can be generated by volcanic eruptions, forest fires, and asteroid impacts. They would also occur as a result of nuclear weapon explosions and subsequent fire storms. Climate engineering might make use of the strong effects of large amounts of aerosols with the goal of reducing the solar radiation that warms the atmosphere. These events were topic of an international conference[1] of the Research Group Climate Change and Security (CLISEC) of KlimaCampus at the University of Hamburg and the King Abdullah University of Science and Technology, Saudi Arabia (KAUST). It was at the KlimaCampus of the University of Hamburg that, for the first time, one meeting included discussions of all kinds of aerosol sources in all aspects, from pathways and impacts to policies. The conference was divided into four sessions, each dealing with different aspects of large aerosol injections, and included a lecture by O. B. Toon about severe atmospheric aerosol events along the geologic time scale. The following summarizes the sessions.

2011 SEVERE ATMOSPHERIC AEROSOLS EVENTS CONFERENCE

WHAT: Geologists, meteorologists, physicists, and numerous scientists from other disciplines met to discuss climatic and environmental changes as a result of various kinds of huge injections of aerosols into the atmosphere and the possible consequences for the world population.
WHEN: 11–12 August 2011
WHERE: Hamburg, Germany

LIFE CYCLE OF LARGE AEROSOL INJECTIONS. The first session dealt with the life cycle of large aerosol injections from particle generation, injection into the atmosphere, vertical transport mechanisms, and transfer into the stratosphere, as well as various kinds of removal processes. H.-F. Graf reported on a simulation of volcanic and biomass-burning plumes with a very high resolving numerical model. D. Kunkel talked about the risk

[1] This conference was organized by the Carl Friedrich von Weizsäcker Centre for Science and Peace Research (ZNF) in cooperation with the Max-Planck-Institute for Meteorology, the Research Group Climate Change and Security (CLISEC) of KlimaCampus Hamburg, and the King Abdullah University of Science and Technology, Saudi Arabia (KAUST). It was supported by the Cluster of Excellence Integrated Climate System Analysis and Prediction (CliSAP).

of radioactive exposure after a nuclear power plant accident. G. Stenchikov presented his research (Robock et al. 2007a,b) about the simulation of dispersion and self-lofting of large smoke plumes. A presentation about radiative heating of aerosols as a self-lifting mechanism in the Australian forest fires was given by J. de Laat. M. Toohey discussed the question of how the impact of tropical volcanic eruptions depends on the eruption season. U. Niemeier talked about geoengineered sulfate aerosols. The final talk of the session was given by U. Lohmann and was about the impact of aerosols settling from stratosphere on cirrus clouds.

The presentations in general showed that models that consider just the emission source and neglect important transport processes do not adequately represent the event. For example, H.-F. Graf showed that cloud-resolving plume models, such as the Active Tracer High Resolution Atmospheric Model (ATHAM), that consider atmospheric conditions, for example, temperature and humidity, are more suitable to predict the volcanic plume height and dispersion than one-dimensional models.

Absorption of solar radiation plays a significant role in smoke plume lifting, and explains the high rise of forest fire ash in Australia and Canada. G. Stenchikov pointed out that the absorbing smoke plumes in the upper troposphere can be partially mixed into the lower stratosphere because of the solar heating and lofting effect. This effect is scale dependent. It was seen in the large-scale forest fires in Canada but was weak for the smaller-area Kuwait oil fires in 1991.

The global model simulations of nuclear winter take into account smoke plume lifting, but probably underestimate it because of their coarse spatial resolution.

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Another example of the importance of environmental conditions was given by M. Toohey. With a series of global aerosol model simulations he could demonstrate that the aerosol optical depth and clear-sky anomalies after tropical volcanic eruptions are independent of the geographical longitude of the volcano but strongly dependent on the season of the eruption. However, all sky flux anomalies are dependent only on the eruption season for very large volcanic eruptions.

In summary, identifying the synergies between different emission models, for example, fire and volcanic eruption models, can definitely shed more light on the life cycle of large aerosol injections, for example, urban fires and nuclear conflicts, and their environmental effects on a regional and global scale.

ENVIRONMENTAL CONSEQUENCES. The second session focused on environmental consequences, considering both direct climate impacts, which include changes in temperature, precipitation, ozone depletion, etc., and secondary environmental impacts, which are relevant for the biosphere, for example, conditions for agriculture and intensity of ultraviolet radiation. The impact of historic volcanic eruptions on the climate is still debated. In particular, it is still unclear to what extent the Younger Toba Tuff eruption contributed to the decrease in average surface temperatures, as discussed by C. Timmreck. New simulations of a nuclear conflict show a much stronger "nuclear winter" than previous studies, even if the number of nuclear weapons involved in the conflict is reduced. Other severe aerosol events, like widespread forest fires and asteroid impacts, may also have a tremendous impact on the environment.

M. Mills investigated the impact of a regional nuclear war on the ozone layer. He found that the ozone losses are significantly greater compared to previous calculations, which he explained by an improved representation of stratospheric plume rise. The results suggest that temperature drops following the strategic exchange are almost twice as strong as those predicted by previous studies.

In his talk about the global impact of volcanic activity, S. Self underlined that the strength of eruptions is reducing from past to present. However, the risk of strong volcanic eruptions is still significant. Taking into account the magnitude and strength of a volcanic eruption, one should scientifically focus on eruptions similar to the 1815 eruption of Tambora.

C. Timmreck reported that the global mean temperature anomaly following the Young Toba Tuff eruption are 3 times weaker than suggested by previous studies because of the consideration of aerosol growth. D. Metzner analyzed the Southern Hemisphere climate response to an extremely large volcanic eruption and found a positive anomaly of the southern annular mode for at least 1 year. H. Schmidt showed results for a multimodel approach of an artificial reduction of the solar constant (climate engineering). This would decrease global mean precipitation with respect to both future climate change and preindustrial conditions, and lead to a decrease in the temperature in low latitudes but an increase in the temperature in high latitudes with respect to preindustrial conditions temperature. These disruptions could result in a global famine.

A. Robock demonstrated in his presentation that even with a much smaller number of nuclear warheads launched in a hypothetical conflict, the climatic consequences of a "nuclear winter" are unavoidable. The results strongly depend on the highly uncertain total amount of soot released into the atmosphere from city fires. Further uncertainties arise from aerosol particle properties (initial size distribution, coagulation, and chemical interactions) and their vertical motion. Model simulations that account for stratospheric plume rise show an unprecedented global mean cooling that lasts for more than 10 yr, even in a moderate scenario of soot release. The temperature and precipitation changes, however, are just one aspect of the climatic signature of nuclear winter. Future research should focus on other critical aspects, such as the collapse of crop production. A. Robock discussed that numerical simulations with a detailed crop production model show a reduction of up to 40% in the United States, resulting from decreased growing seasons.

Finally, A. Ginzburg gave an overview about the extreme atmospheric aerosol events in 2010 (the Eyjafjallajökull eruption and forest fires in Russia and California), concentrating on the heat wave in Russia.

SOCIOECONOMIC CONSEQUENCES. The third session discussed the potential socioeconomic consequences of large-scale aerosol emissions. The presentations dealt with medical implications, extinction of species, loss in agricultural productivity, and spread of famine. Significant uncertainties are inherent to all these issues. The consequences of the Younger Toba Tuff eruption were discussed from the view of multiple disciplines by S. Ambrose, for example, abrupt climate change detected by geological data from soil and lake sediments. Archeology plays its part by adding data about the following species migration and possible distinction. However, as pointed out in the discussion, it is not clear whether the signal is related to the supereruption or to an already ongoing cooling trend.

A. Schmidt analyzed the potential hazard if a Laki-style eruption were to happen today. Based on the fact that air pollution was one of the causes for 21% mortality in Iceland after the Laki eruption in 1783–84 A.D., a Global Aerosol Model (GLOMAP) with two scenarios is used to assess an excess mortality of 29,000 due to short-term and 142,000 due to long-term exposure to particles smaller than 2.5 μm in diameter. Humanity demands urgent preparations for low-probability–high-impact events (Schmidt et al. 2011).

J. Goldhammer investigated several case studies in the United States, Canada, and Russia to assess the losses that natural and man-made fires cause in the environment and to society.

L. Xia assessed the impacts of nuclear war on agriculture in China by the Decision Support System for Agrotechnology Transfer (DSSAT). The rice yield and production both show decreases in most parts of China, especially in the climate sensitive areas.

More case studies in different areas of socioeconomic consequences are needed to better understand the bias in the modeling and observation as well as regional pattern discrepancies.

POLICY IMPLICATIONS. In the final session the experts reflected on actions for mitigation and adaptation of aerosol events. Because of the severe consequences for human security, significant challenges facing regional and global governance will have to be tackled. The experts agreed that the risks of various hypothetical severe aerosol events are often either ignored or underestimated and have not yet been adequately taken into account.

Counterforce plans and high-speed decision-making processes to launch nuclear weapons on a large scale still exist and create the risk of an unintended (accidental) nuclear war. There is a considerable urgency for politicians to move beyond Cold War rhetoric and come to grips with the scientifically predicted consequences of a nuclear conflict.

S. Starr noted that the United States and Russia still keep more than 1700 strategic nuclear warheads at launch-ready status, ready to fire with only a few minutes of warning. The long-term environmental consequences of the detonation of these weapons, as predicted by the studies of A. Robock, O. B. Toon and G. Stenchikov (Robock et al. 2007a,b), would probably eliminate growing seasons for many years, making global famine inevitable. Starr emphasized that none of the nuclear weapon states have publicly acknowledged or discussed these scientific predictions, and they have never evaluated what the long-term consequences of a war fought with their nuclear weapons would have upon global ecosystems and human agriculture.

As a result, the international political discussions regarding nuclear weapons still focus on the number of weapons, rather than the consequences of their use. This has resulted in a general failure, on the part of both leaders and the general public, to fully comprehend the absolute danger that existing nuclear arsenals pose to continued human existence. Thus, it is of the utmost importance that the predictions of atmospheric scientists be recognized, considered, and discussed by those who control the global nuclear arsenals, before a failure of nuclear deterrence results in nuclear war.

V. Yarynich discussed the computer simulations he had published in *Foreign Affairs* (Blair et al. 2010), which modeled the outcomes of U.S.–Russian nuclear exchanges and demonstrated that there was always a nonzero probability of unacceptable retaliation to the aggressor nation. Yarynich suggested that environmental consequences could be incorporated into this model, which would surely strengthen the negative consequences of nuclear war. He asked if the scientists at the conference would consider helping with such an addition to his models.

A different political strategy is to focus more on the friendly relations between nations instead of intense simulations of hostile scenarios, as indicated by H. Grassl. J. Scheffran added that cooperative approaches help countries to jointly move forward on a peaceful path and reduce the necessity for keeping operational nuclear weapons. One example of scientists shaping the political progress is the "Model Nuclear Weapons Convention" that has been codesigned by the International Network of Engineers and Scientists Against Proliferation (INESAP), together with other experts.

Regulatory instruments such as the already existing "Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques" are necessary to successfully deal with deliberately triggered large aerosol events, said Scheffran. However, it is impossible to prevent any natural disasters, such as the impact of an asteroid or a volcanic eruption, with legal measures. Therefore, it is necessary to set up either mitigation or adaptation of at least small aerosol events for protecting societies. From a political point of view it has to be considered that if scientists could come up with local mitigation or adaptation strategies, politicians may have fewer incentives to actually ensure the prevention of large aerosol injections under all circumstances, Grassl pointed out. Technically, the prevention and mitigation of at least natural extreme events, such as those caused by the impact of an asteroid, could be improved through more focused and specially funded science on discovering all dangerous asteroids and their orbits to prevent any possible future impact, as, for example, an impact of "Apollo" Apophis in 2036.

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