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Global Famine after Nuclear War

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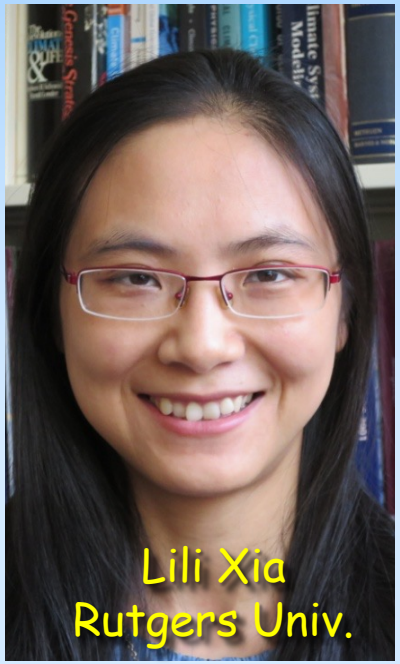
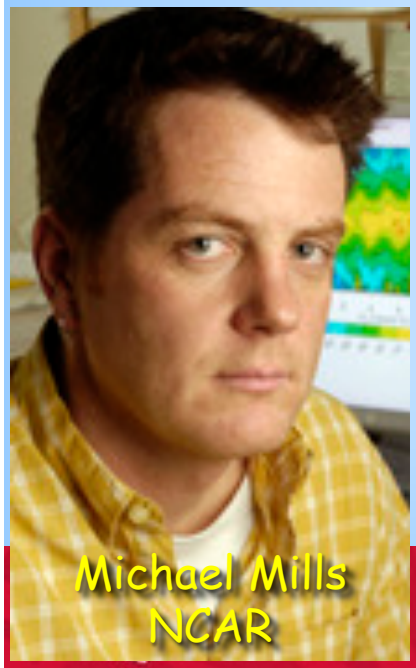
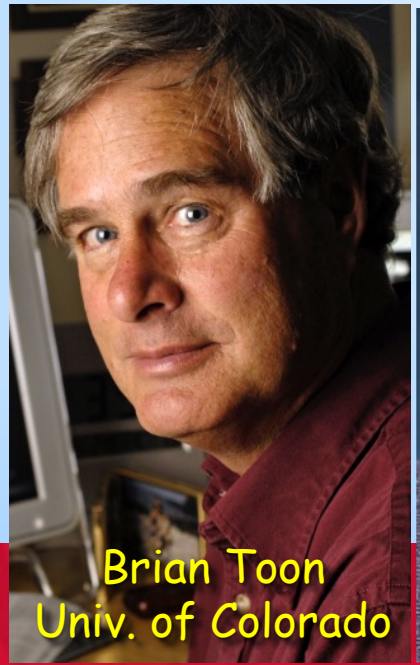
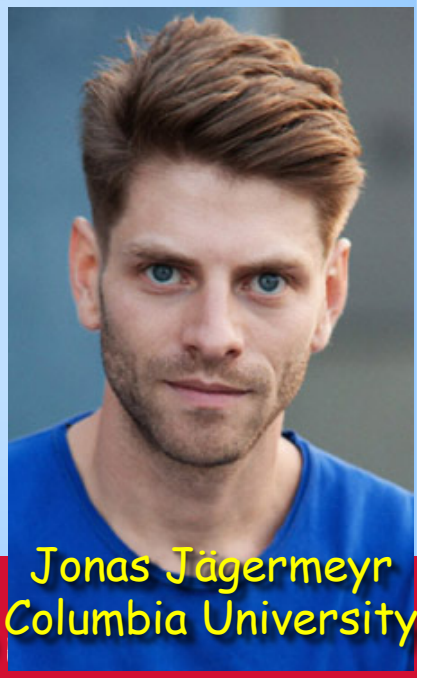
This work is a collaboration with









This presentation is based on the following recent peer-reviewed papers:

Bardeen, Charles G., Douglas E. Kinnison, Owen B. Toon, Michael J. Mills, Francis Vitt, Lili Xia, Jonas Jägermeyr, Nicole S. Lovenduski, Kim J. N. Scherrer, Margot Clyne, and Alan Robock, 2021: Extreme ozone loss following nuclear war resulting in enhanced surface ultraviolet radiation. *J. Geophys. Res. Atmos.*, in press, doi:10.1029/2021JD035079.

Coupe, Joshua, Charles G. Bardeen, Alan Robock, and Owen B. Toon, 2019: Nuclear winter responses to global nuclear war in the Whole Atmosphere Community Climate Model Version 4 and the Goddard Institute for Space Studies ModelE. *J. Geophys. Res. Atmos.*, **124**, 8522-8543, doi:10.1029/2019JD030509.

Coupe, Joshua, Samantha Stevenson, Nicole S. Lovenduski, Tyler Rohr, Cheryl S. Harrison, Alan Robock, Holly Olivarez, Charles G. Bardeen, and Owen B. Toon, 2021: Nuclear Niño response observed in simulations of nuclear war scenarios. *Communications Earth & Environment*, **2**, 18, doi:10.1038/s43247-020-00088-1.

Coupe, Joshua, and Alan Robock, 2021: The influence of stratospheric soot and sulfate aerosols on the Northern Hemisphere wintertime atmospheric circulation. *J. Geophys. Res. Atmos.*, **126**, e2020JD034513, doi:10.1029/2020JD034513.

Coupe, Joshua, Cheryl Harrison, Alan Robock, Alice DuVivier, Elizabeth Maroon, Nicole S. Lovenduski, Scott Bachman, Laura Landrum, and Charles Bardeen, 2023: Sudden reduction of Antarctic sea ice despite cooling after nuclear war. *J. Geophys. Res. Oceans*, **128**, e2022JC018774, doi:10.1029/2022JC018774.

Harrison, Cheryl S., Tyler Rohr, Alice DuVivier, Elizabeth A. Maroon, Scott Bachman, Charles G. Bardeen, Joshua Coupe, Victoria Garza, Ryan Heneghan, Nicole S. Lovenduski, Philipp Neubauer, Victor Rangel, Alan Robock, Kim Scherrer, Samantha Stevenson, and Owen B. Toon, 2022: A new ocean state after nuclear war. *AGU Advances*, **3**, e2021AV000610, doi:10.1029/2021AV000610.

Jägermeyr, Jonas, Alan Robock, Joshua Elliott, Christoph Müller, Lili Xia, Nikolay Khabarov, Christian Folberth, Erwin Schmid, Wenfeng Liu, Florian Zabel, Sam S. Rabin, Michael J. Puma, Alison C. Heslin, James Franke, Ian Foster, Senthold Asseng, Charles G. Bardeen, Owen B. Toon, and Cynthia Rosenzweig, 2020: A regional nuclear conflict would compromise global food security. *Proc. Nat. Acad. Sci.*, **117**, 7071-7081, doi:10.1073/pnas.1919049117.

Lovenduski, Nicole S., Cheryl S. Harrison, Holly Olivarez, Charles G. Bardeen, Owen B. Toon, Joshua Coupe, Alan Robock, Tyler Rohr, and Samantha Stevenson, 2020: The potential impact of nuclear conflict on ocean acidification. *Geophys. Res. Lett.*, **47**, e2019GL086246, doi: 10.1029/2019GL086246.

Robock, Alan, Owen B. Toon, and Charles G. Bardeen, 2019: Comment on "Climate impact of a regional nuclear weapons exchange: An improved assessment based on detailed source calculations" by Reisner et al. *J. Geophys. Res. Atmos.*, **124**, 12,953-12,958, doi:10.1029/2019JD030777.

Robock, Alan, Owen B. Toon, Charles G. Bardeen, Lili Xia, Hans Kristensen, Matthew McKinzie, R. J. Peterson, Cheryl Harrison, Nicole S. Lovenduski, and Richard P. Turco, 2019: How an India-Pakistan nuclear war could start-and have global consequences. *Bull. Atomic Scientists*, **75**:6, 273-279, doi:10.1080/00963402.2019.1680049.

Scherrer, Kim J. N., Cheryl S. Harrison, Ryan Heneghan, Eric Galbraith, Charles G. Bardeen, Jonas Jägermeyr, Nicole S. Lovenduski, August Luna, Alan Robock, Jessica Stevens, Samantha Stevenson, Owen B. Toon, and Lili Xia, 2020: Marine wild-capture fisheries after nuclear war. *Proc. Nat. Acad. Sci.*, **117** (47), 29,748-29,758, doi:10.1073/pnas.2008256117.

Toon, Owen B., Charles G. Bardeen, Alan Robock, Lili Xia, Hans Kristensen, Matthew McKinzie, R. J. Peterson, Cheryl Harrison, Nicole S. Lovenduski, and Richard P. Turco, 2019: Rapid expansion of nuclear arsenals by Pakistan and India portends regional and global catastrophe. *Science Advances*, **5**, eaay5478, doi:10.1126/sciadv.aay5478.

Xia, Lili, Alan Robock, Kim Scherrer, Cheryl S. Harrison, Jonas Jägermeyr, Charles G. Bardeen, Owen B. Toon, and Ryan Heneghan, 2022: Global food insecurity and famine from reduced crop, marine fishery and livestock production due to climate disruption from nuclear war soot injection. *Nature Food*, **3**, 586-996, doi:10.1038/s43016-022-00573-0.

Yu, Pengfei, Owen B. Toon, Charles G. Bardeen, Yunqian Zhu, Karen H. Rosenlof, Robert W. Portmann, Troy D. Thornberry, Ru-Shan Gao, Sean M. Davis, Eric T. Wolf, Joost de Gouw, David A. Peterson, Michael D. Fromm, and Alan Robock, 2019: Black carbon lofts wildfire smoke high into the stratosphere to form a persistent plume. *Science*, **365**, 587-590, doi:10.1126/science.aax1748.

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Illustration by Jon Lomberg

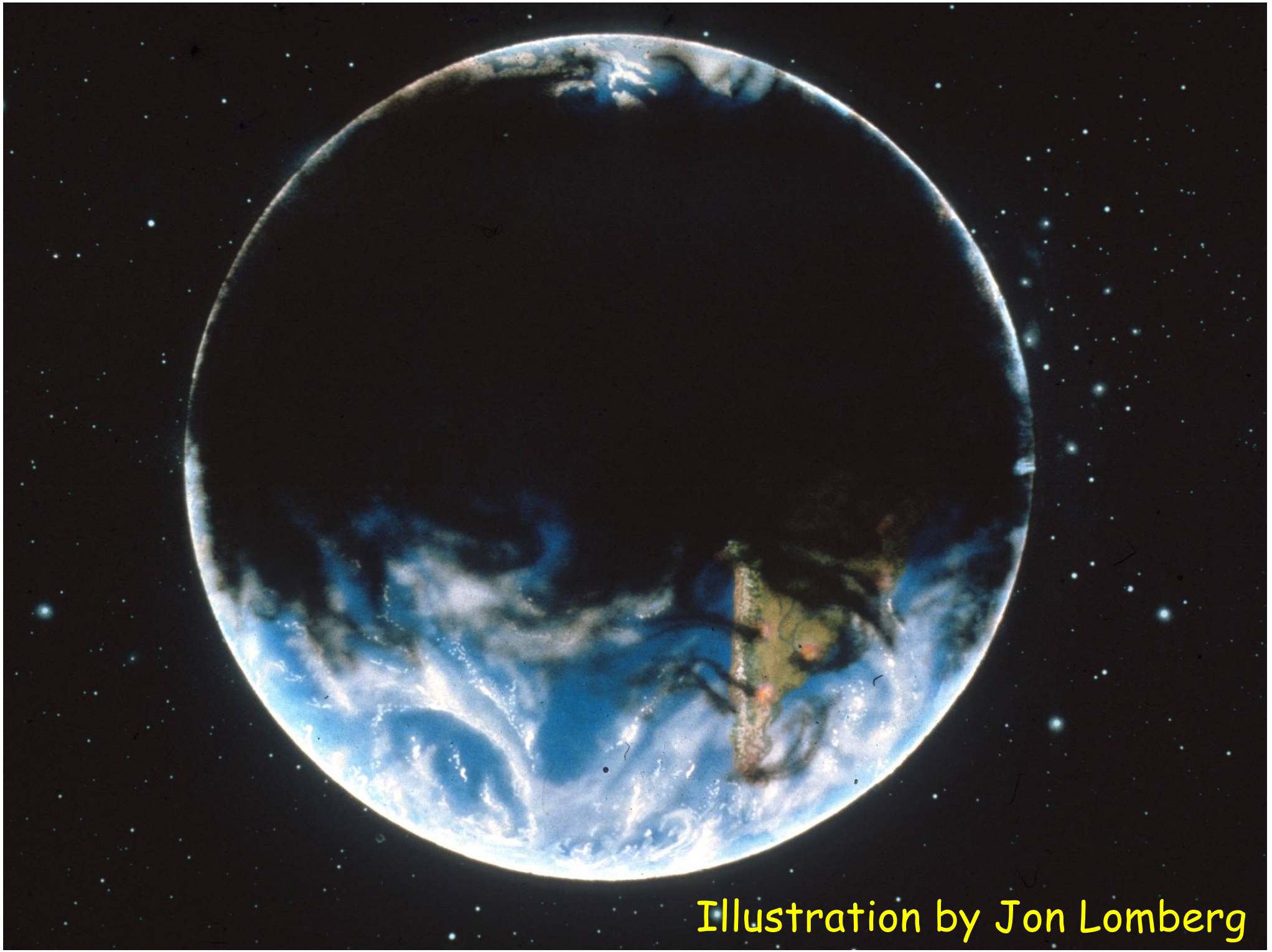


Illustration by Jon Lomberg

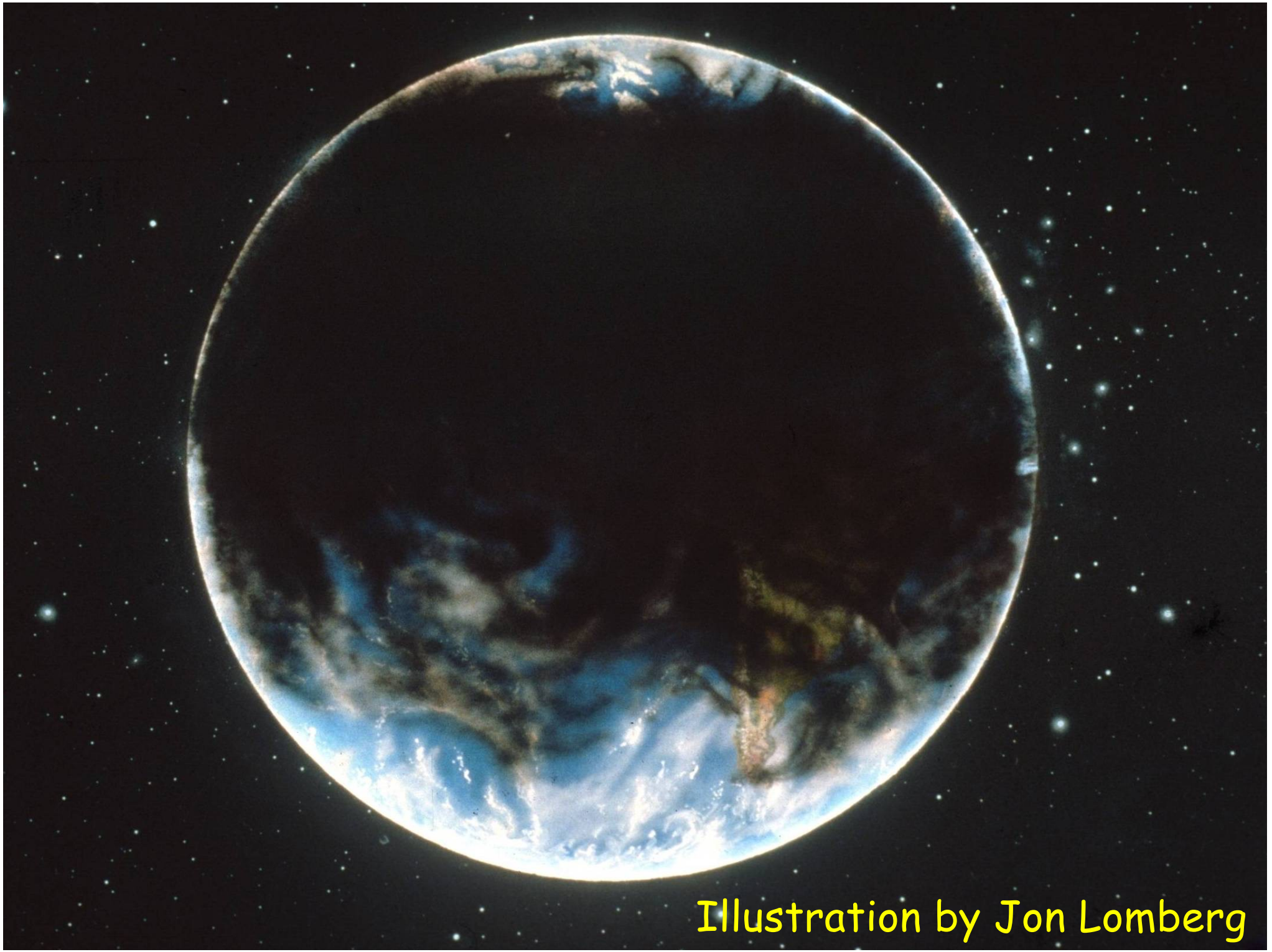
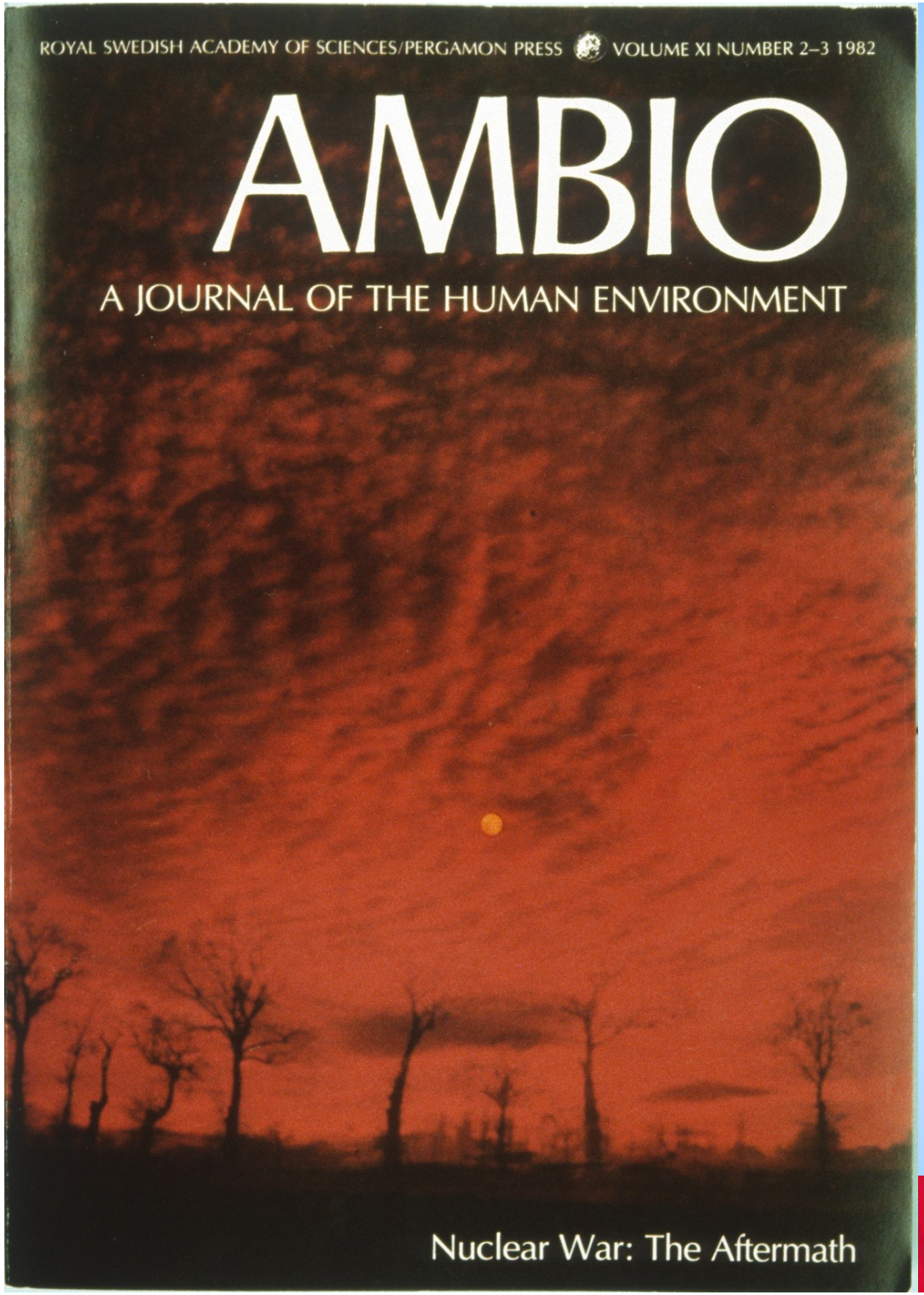


Illustration by Jon Lomberg


Nuclear Winter
Cold, Dry, Dark, and More UV
Crops Dying and Global Famine
© 2009 Scientific American Inc



Paul Crutzen
and **John Birks**
discussed the effects of a nuclear holocaust on ozone.

They were the first to point out that there would be massive fires, and that the smoke from these fires could change climate.

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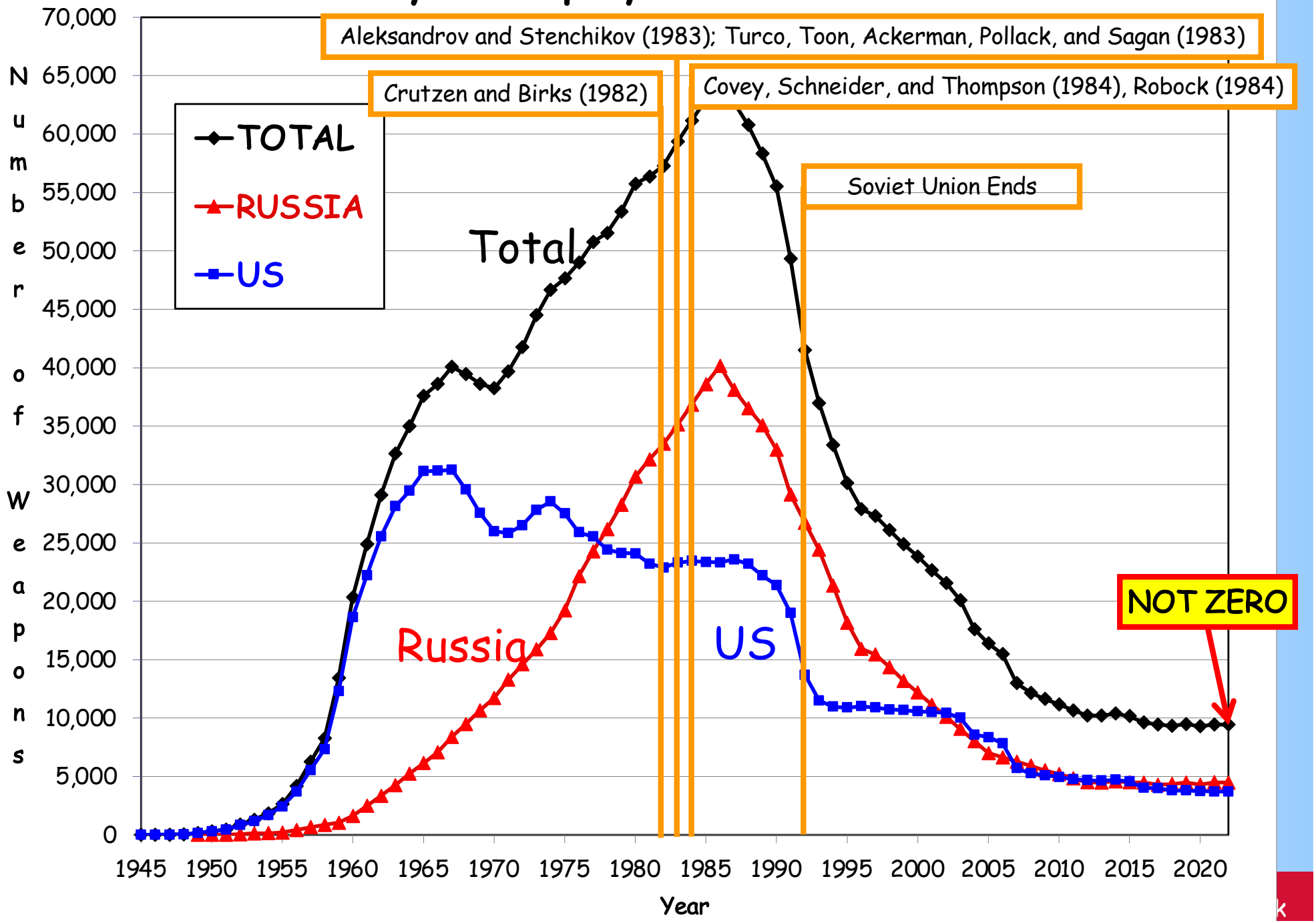
History of Deployed Nuclear Warheads



Kristensen, H. M., and R. S. Norris, 2015: *Bull. Atom. Scientists*, **69:5**, 75-81, updated.

Ronald Reagan:

When asked about the effects of nuclear war in a February 12, 1985 interview in the *New York Times* said,

"A great many reputable scientists are telling us that such a war could just end up in no victory for anyone because we would wipe out the earth as we know it. And if you think back to ... natural calamities - back in the last century, in the 1800's, ... volcanoes - we saw the weather so changed that there was snow in July in many temperate countries. And they called it the year in which there was no summer. Now if one volcano can do that, what are we talking about with the whole nuclear exchange, the nuclear winter that scientists have been talking about? It's possible ..."

http://www.nytimes.com/1985/02/12/world/transcript-of-interview-with-president-on-a-range-of-issues.html?pagewanted=all

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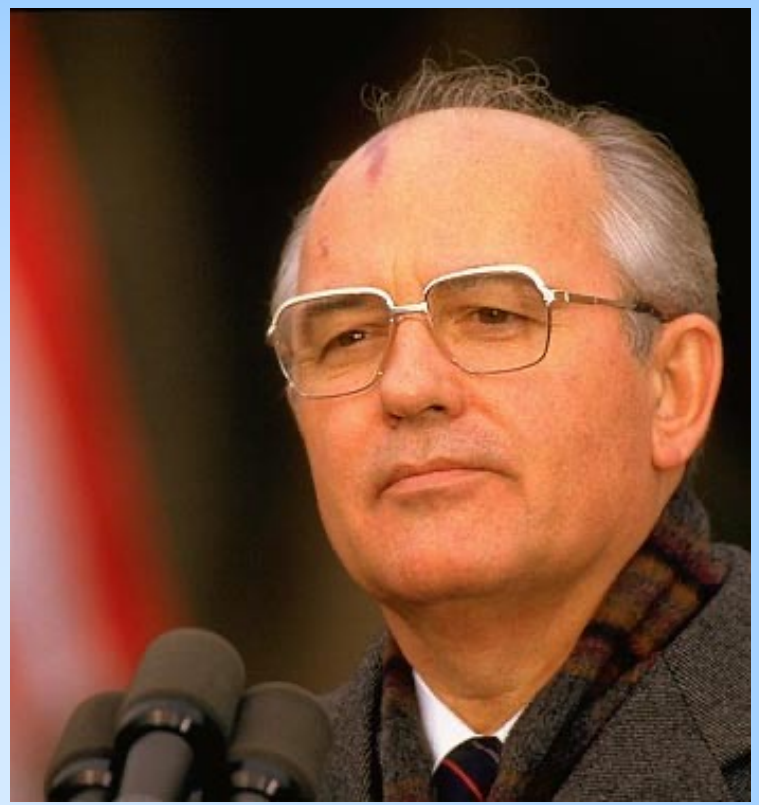
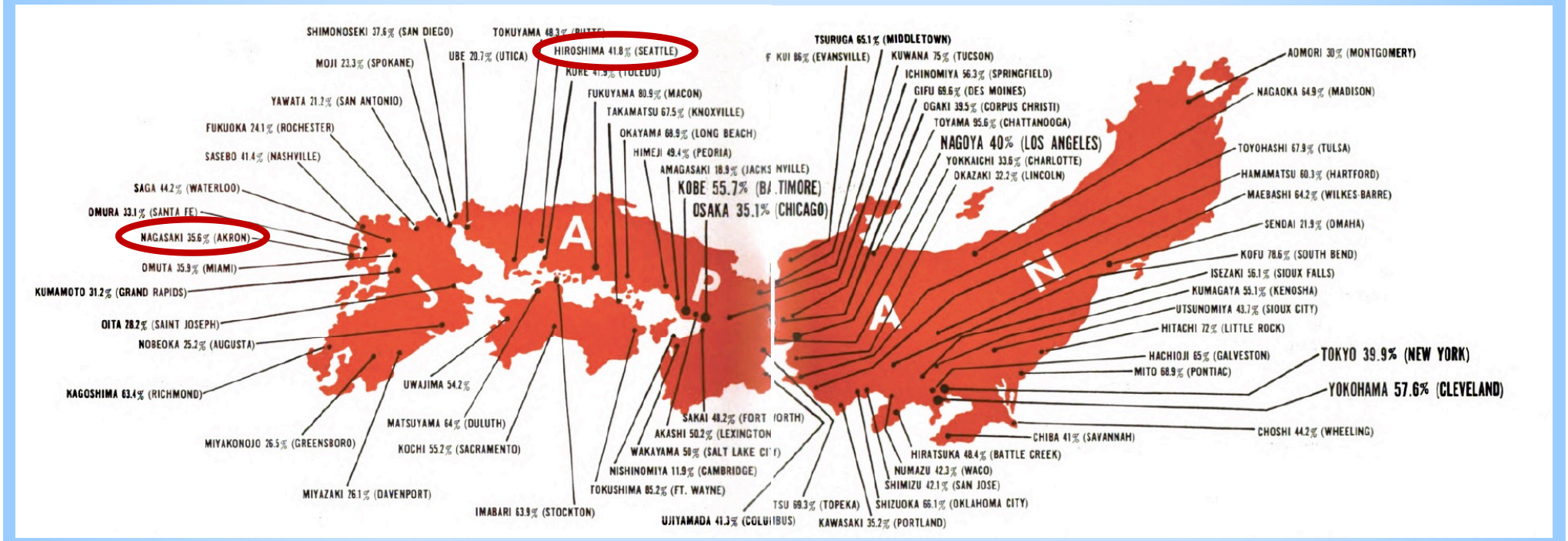
Mikhail Gorbachev:



"Mikhail Gorbachev explains what's rotten in Russia"
by Mark Hertsgaard
Salon.com, Sept. 7, 2000

"Models made by Russian and American scientists showed that a nuclear war would result in a nuclear winter that would be extremely destructive to all life on Earth; the knowledge of that was a great stimulus to us, to people of honor and morality, to act in that situation."

Principal Japanese cities firebombed by the US Army Air Force during the summer of 1945, with percent of each city destroyed. (In parentheses - US cities of same size.)



Third report of the Commanding General of the Army Air Forces to the Secretary of War, 12 November 1945.

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Hiroshima

August 6, 1945

A 15 kT bomb killed 150,000 people

Note: 15 kT = 0.015 MT = 1/1,000,000 of the 1985 world arsenal

= 3/1,000,000 of the current world arsenal

While current weapons are mostly more powerful than the initial one, if one Hiroshima-sized bomb were dropped every *two hours* from the end of World War II to today, it would still not use up the current arsenal.

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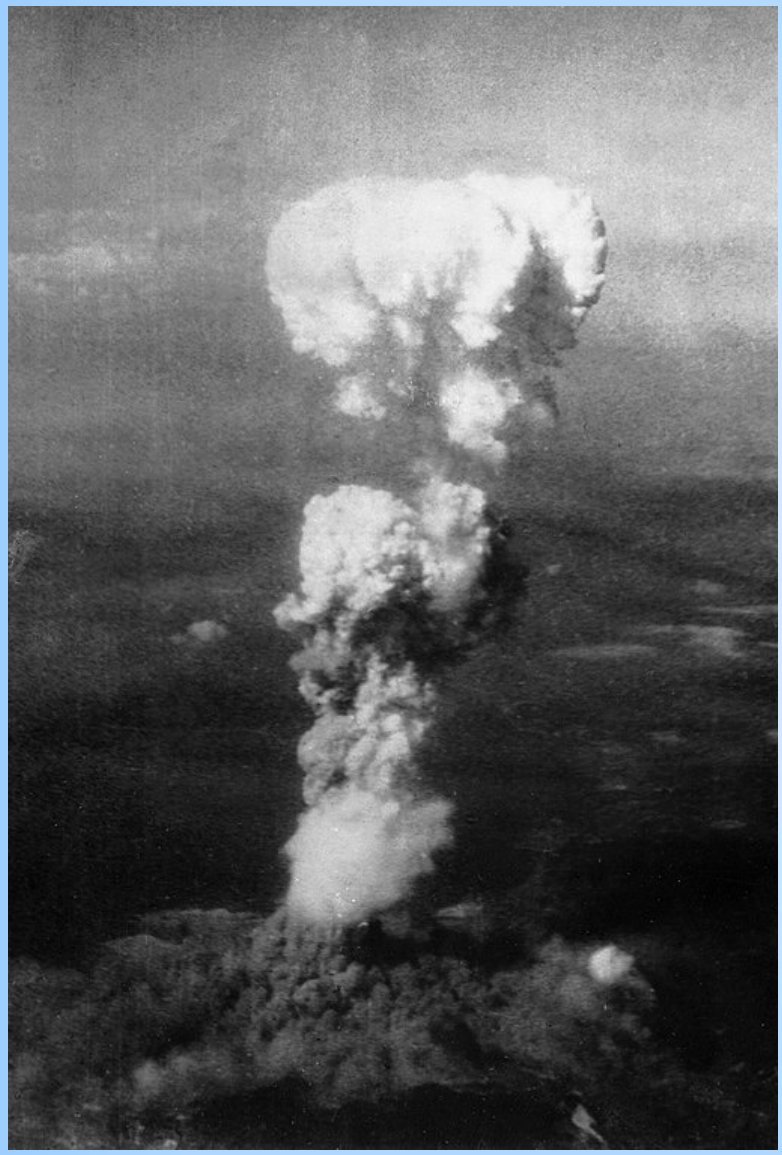
Mushroom cloud, minutes after the bombing, taken by Bob Caron, tail gunner of the Enola Gay



Pyrocumulonimbus smoke plume more than 3 hours after attack

https://www.nytimes.com/2016/05/24/science/hiroshima-atomic-bomb-mushroom-cloud.html

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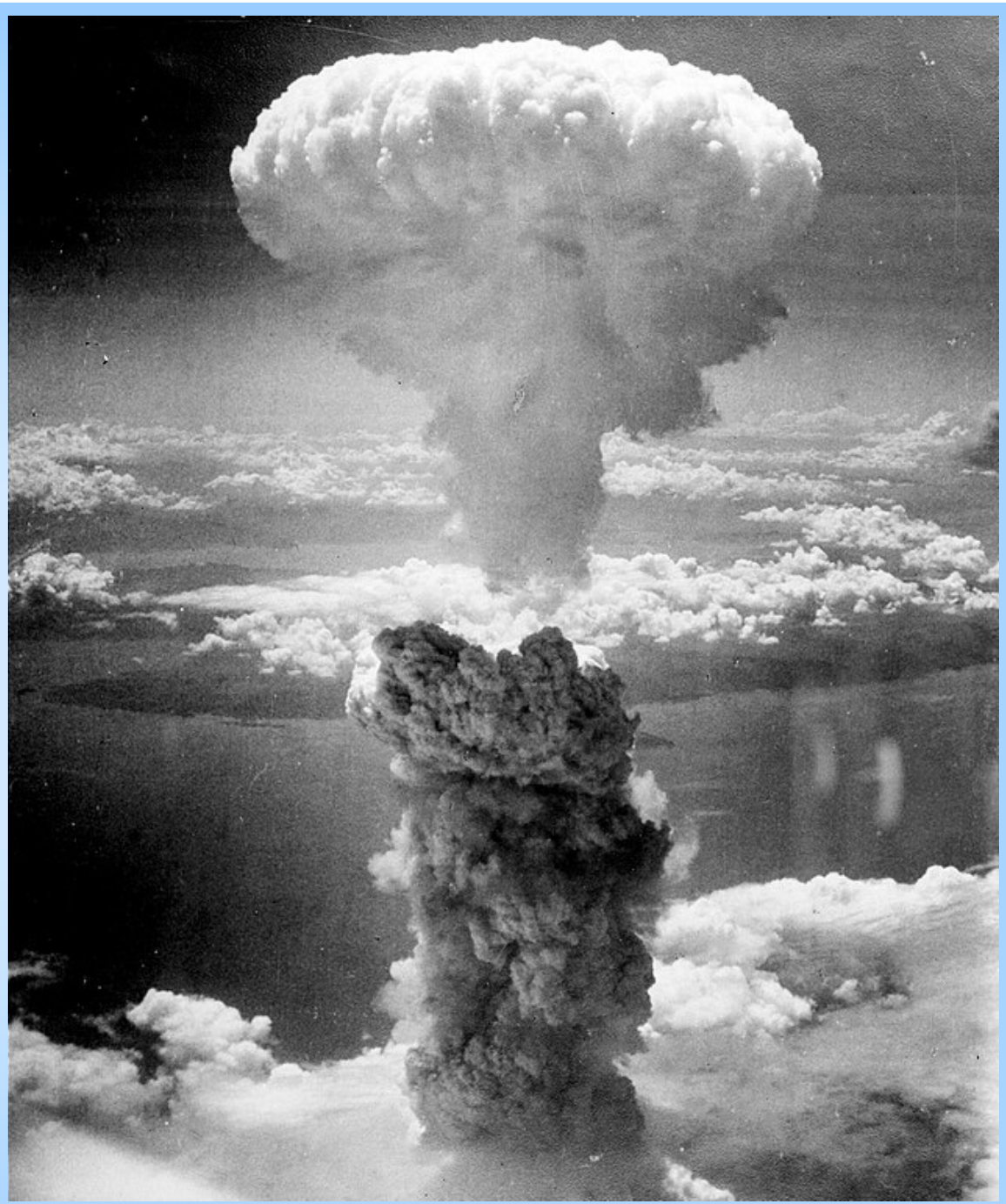
Nagasaki

Aug. 9, 1945

11:02 am



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The Urakami hypocenter area seen from the air
Looking from north to south.
The entire district was reduced to a burned wasteland.
The area slightly to the left of center is the hypocenter.

THE STORY OF AN EYEWITNESS

By Jack London

Collier's, the National Weekly

May 5, 1906

Within an hour after the earthquake shock the smoke of San Francisco's burning was a lurid tower visible a hundred miles away. And for three days and nights this lurid tower swayed in the sky, reddening the sun, darkening the day, and filling the land with smoke.

... I watched the vast conflagration from out on the bay. It was dead calm. Not a flicker of wind stirred. Yet from every side wind was pouring in upon the doomed city. East, west, north, and south, strong winds were blowing upon the doomed city. The heated air rising made an enormous suck. Thus did the fire of itself build its own colossal chimney through the atmosphere. Day and night this dead calm continued, and yet, near the flames, the wind was often half a gale, so mighty was the force.

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This photograph, taken from a series of kites five weeks after the great earthquake of April 18, 1906, shows the devastation brought on the city of San Francisco by the quake and subsequent fire. (photo courtesy of Harry Myers)

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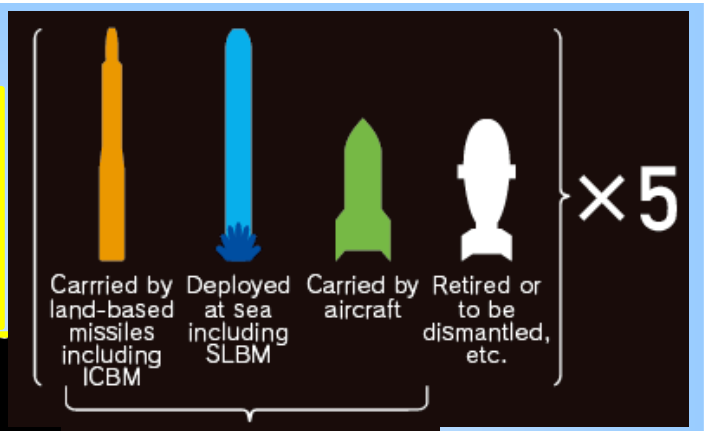
The World's Nuclear Warheads Count June 2023

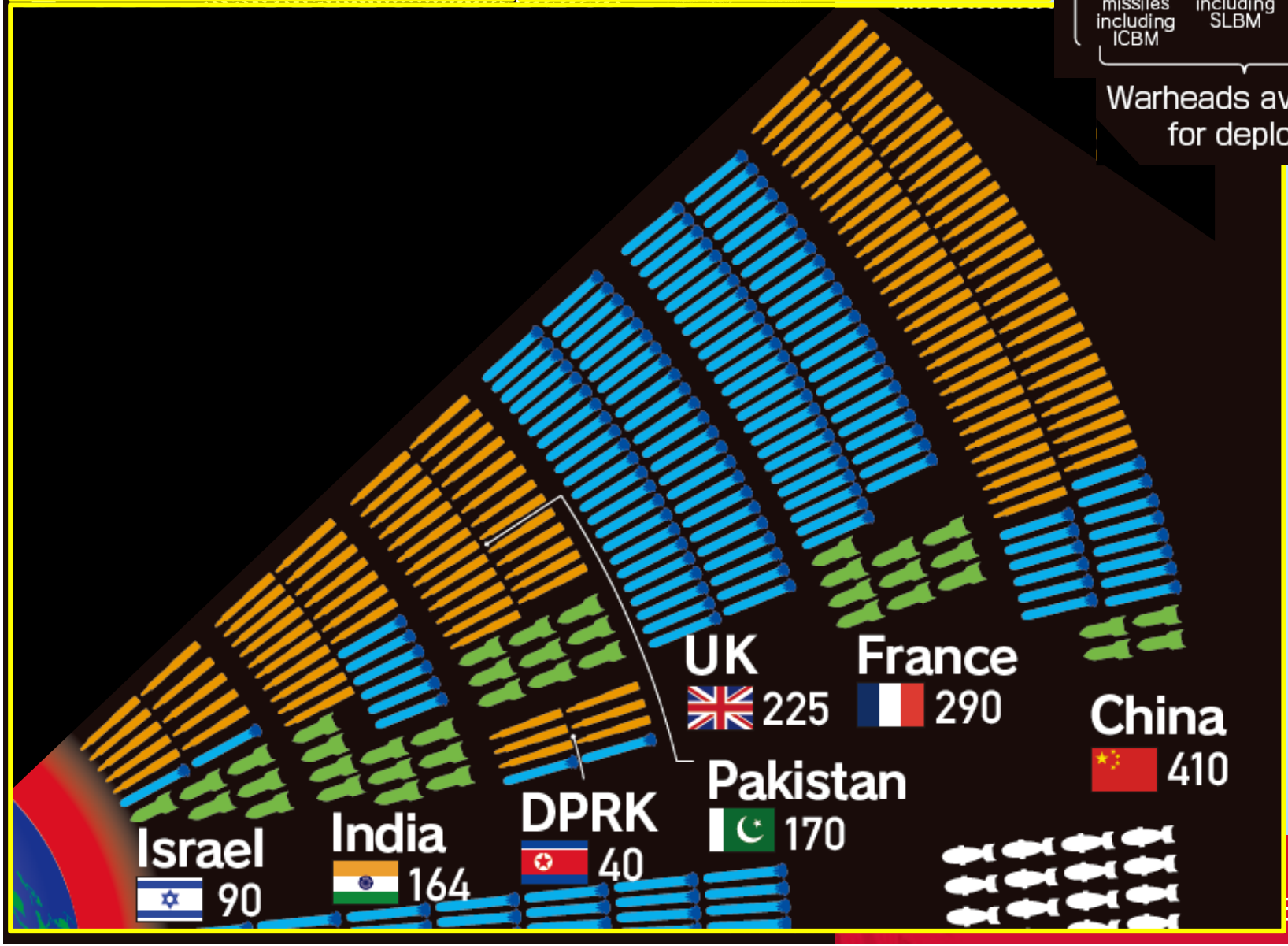
Russia 5,890

Warheads available for deployment 4,490
Retired or to be dismantled····· 1,400

US 5,244

Warheads available for deployment 3,708
Retired or to be dismantled····· 1,536





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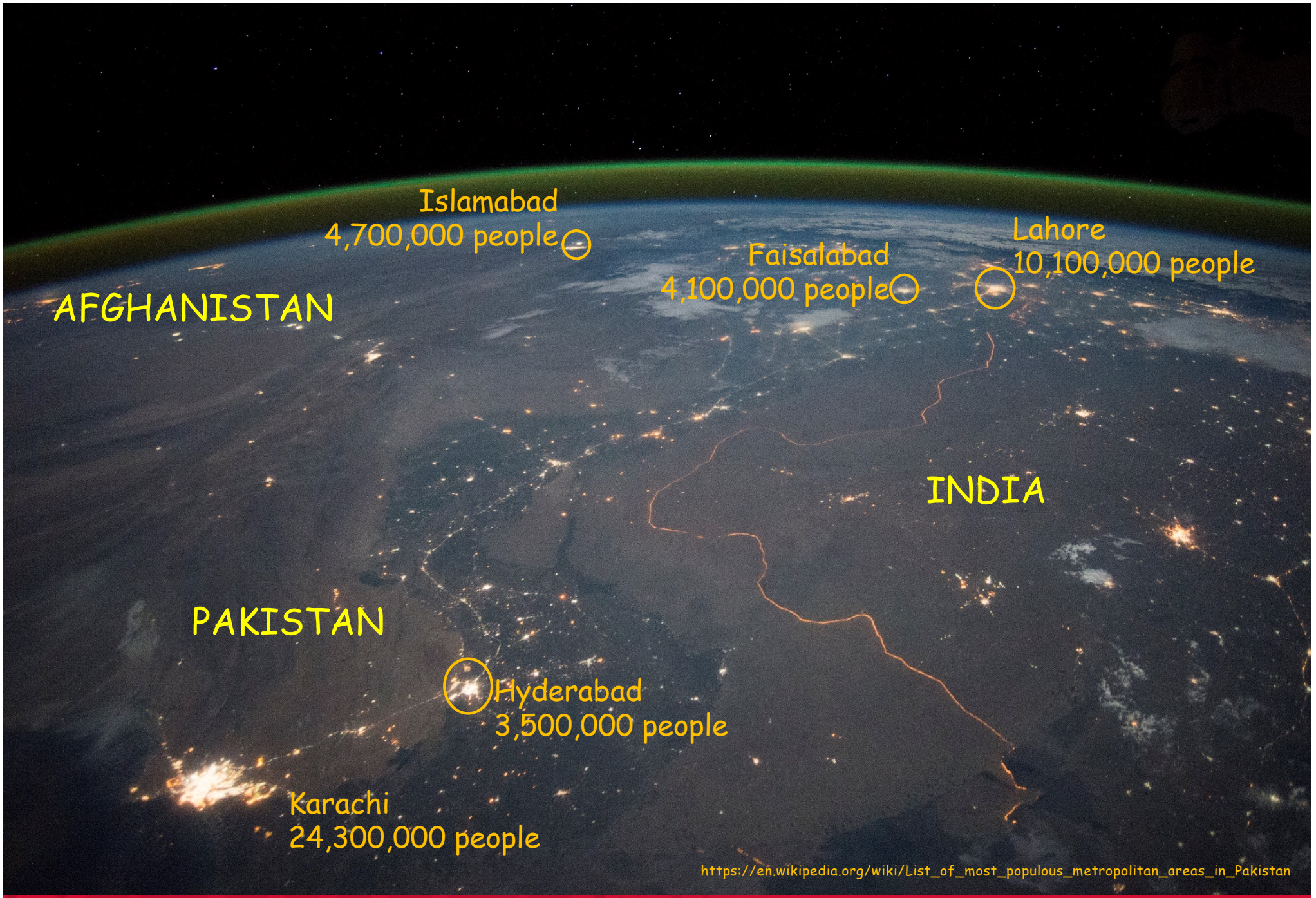

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https://earthobservatory.nasa.gov/IOTD/view.php?id=86725

September 23, 2015

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What if India and Pakistan had a nuclear war?

Imagine a skirmish in Kashmir escalating, due to poor communication, misunderstanding, panic, and fear.

http://upload.wikimedia.org/wikipedia/commons/0/0e/Kashmir_map.jpg

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What would be the consequences of an India-Pakistan nuclear war using 100 15-kT (Hiroshima-size) weapons?

Scenario: Weapons dropped on the 50 targets in each country that would produce the maximum smoke.

27,000,000 people would die from direct effects, half of the total fatalities from all of World War II.

5 million tons of smoke injected into the upper atmosphere, accounting for fuel loading, emission factors and rainout.

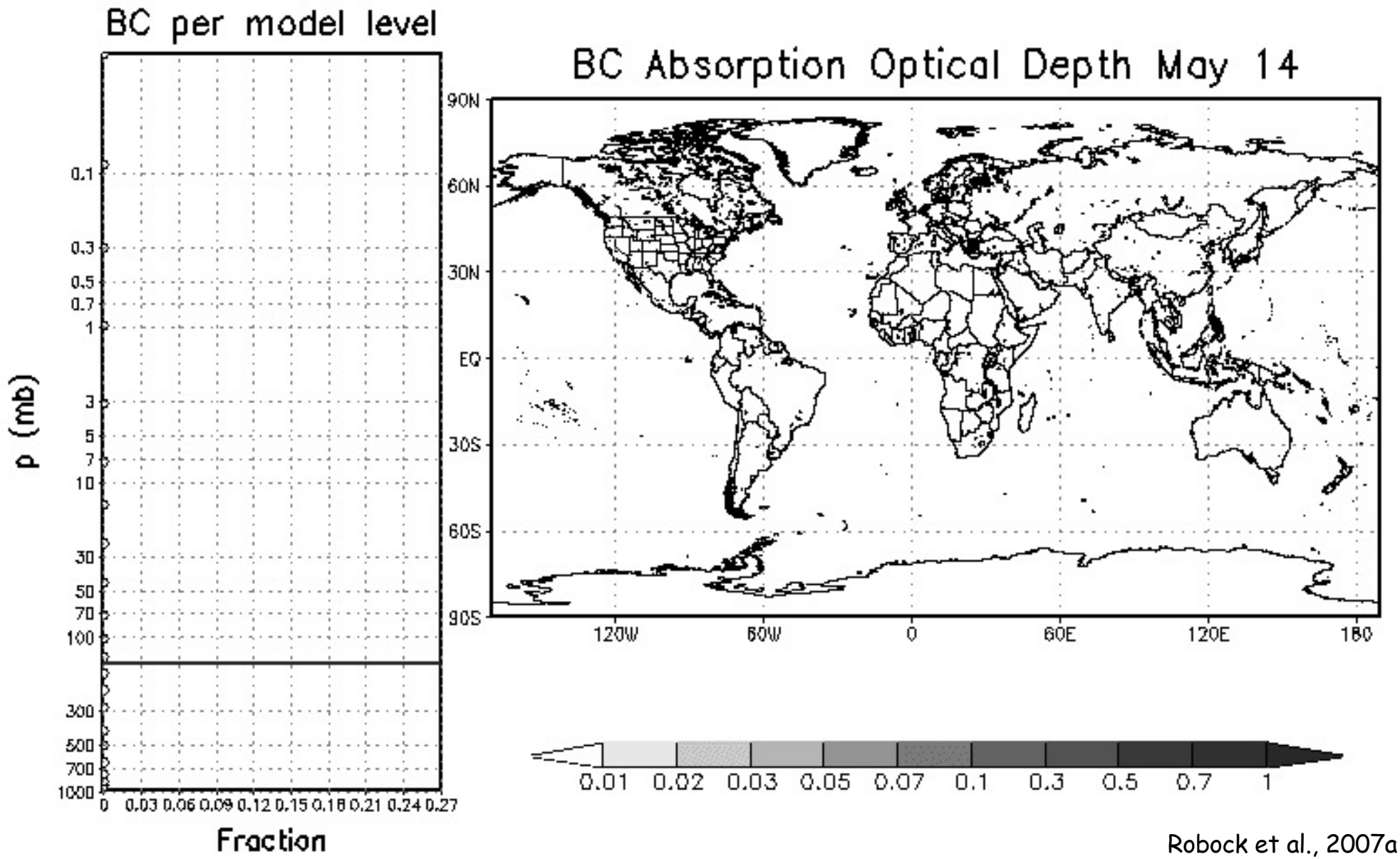
Robock, Alan, Luke Oman, Georgiy L. Stenchikov, Owen B. Toon, Charles Bardeen, and Richard P. Turco, 2007: Climatic consequences of regional nuclear conflicts. *Atm. Chem. Phys.*, **7**, 2003-2012.

What would be the consequences of a regional nuclear war using 100 15-kT (Hiroshima-size) weapons?

We use the NASA GISS ModelE atmosphere-ocean general circulation model.

- 4°x5° lat-lon horizontal resolution
- 23 vertical levels including stratosphere and mesosphere, extending 0-80 km, 13 layers in ocean
- 5 Tg of smoke into the 300-150 mb layer (upper troposphere) at 30°N, 70°E on May 15
- 30-yr control run
- 3-member ensemble for 10 yr

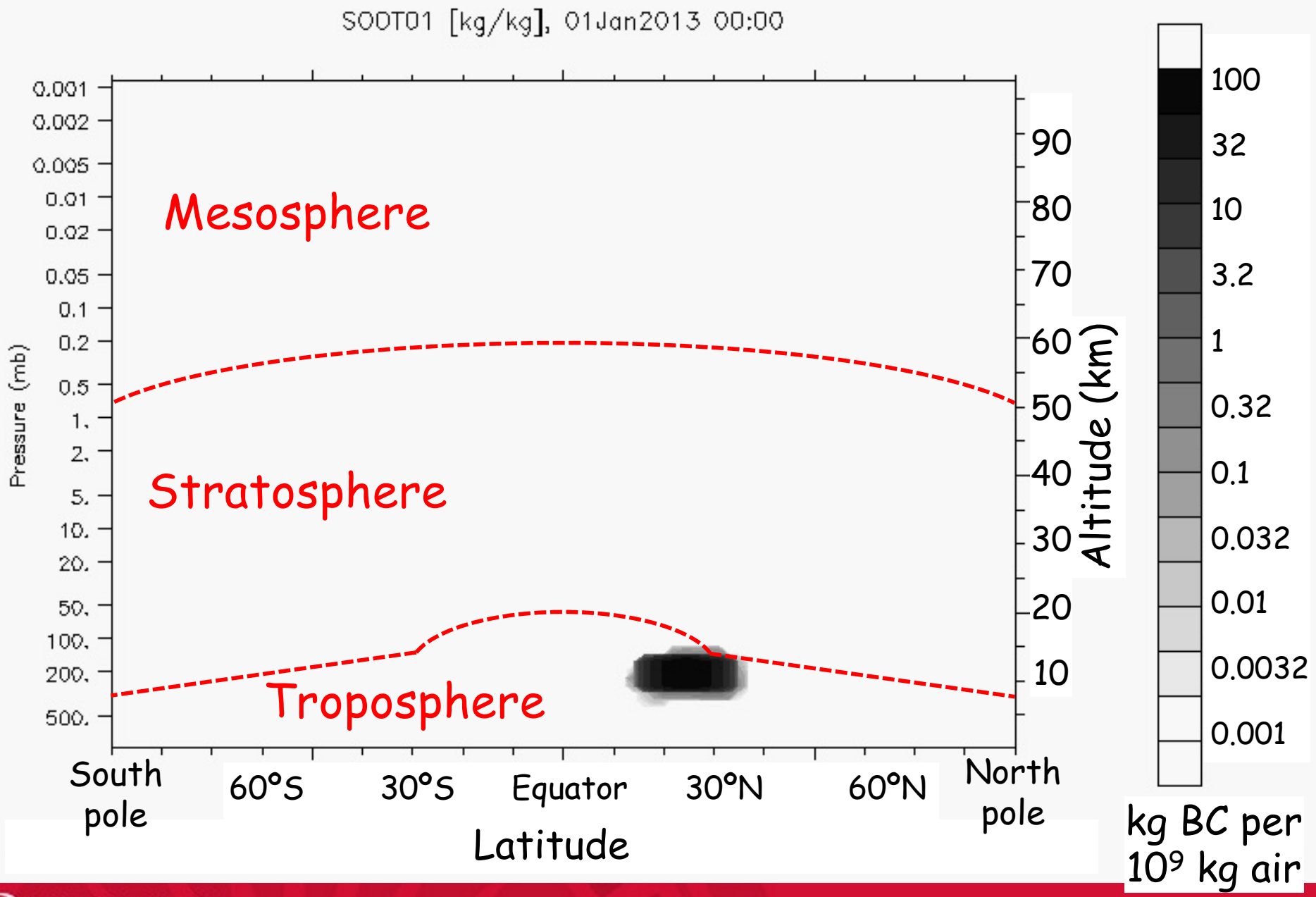
Robock, Alan, Luke Oman, Georgiy L. Stenchikov, Owen B. Toon, Charles Bardeen, and Richard P. Turco, 2007: Climatic consequences of regional nuclear conflicts. *Atm. Chem. Phys.*, **7**, 2003-2012.



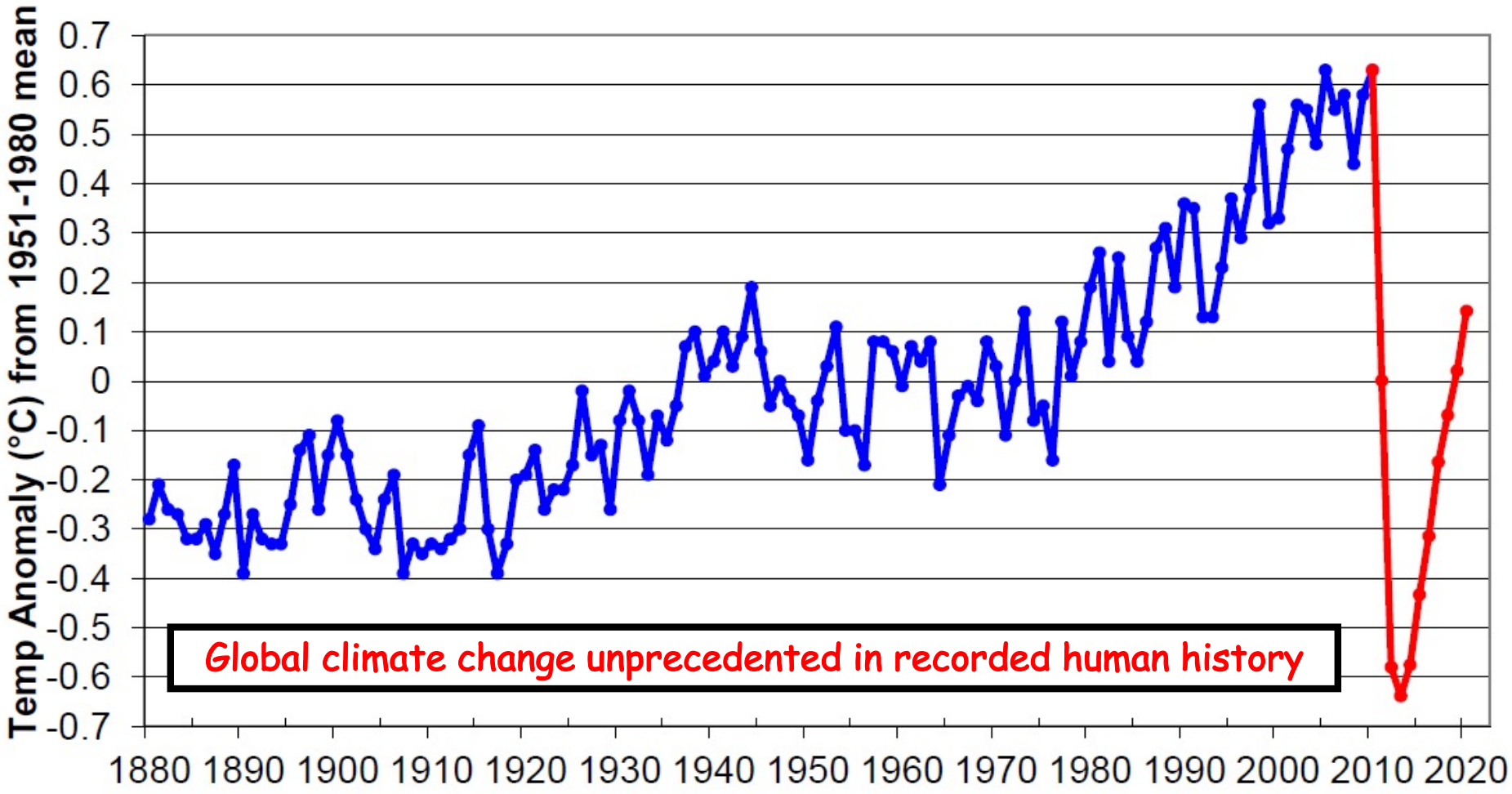
Robock et al., 2007a

Daily smoke loading from one ensemble member.
Absorption optical depth of 0.1 means that 90% of radiation reaches the surface.

Black carbon mass mixing ratio



GISS Global Average Temperature Anomaly
+ 5 Tg smoke in 2011



Robock et al., 2007a

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What would be the consequences of a full-scale nuclear war between the US and Russia?

We use the NASA GISS ModelE atmosphere-ocean general circulation model.

- 50 Tg or 150 Tg of smoke into the 300-150 mb layer (upper troposphere) over the US and Russia on May 15
- 30-yr control run, two 10-yr runs (50 Tg or 150 Tg)

What could produce 150 Tg of smoke?

- standard nuclear winter scenario of 40 years ago
- entire current arsenal if targeted the same way
- only 4000 weapons (2023 global arsenals of New START treaty)

Robock, Alan, Luke Oman, and Georgiy L. Stenchikov, 2007b: Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences. *J. Geophys. Res.*, **112**, D13107, doi:10.1029/2006JD008235.

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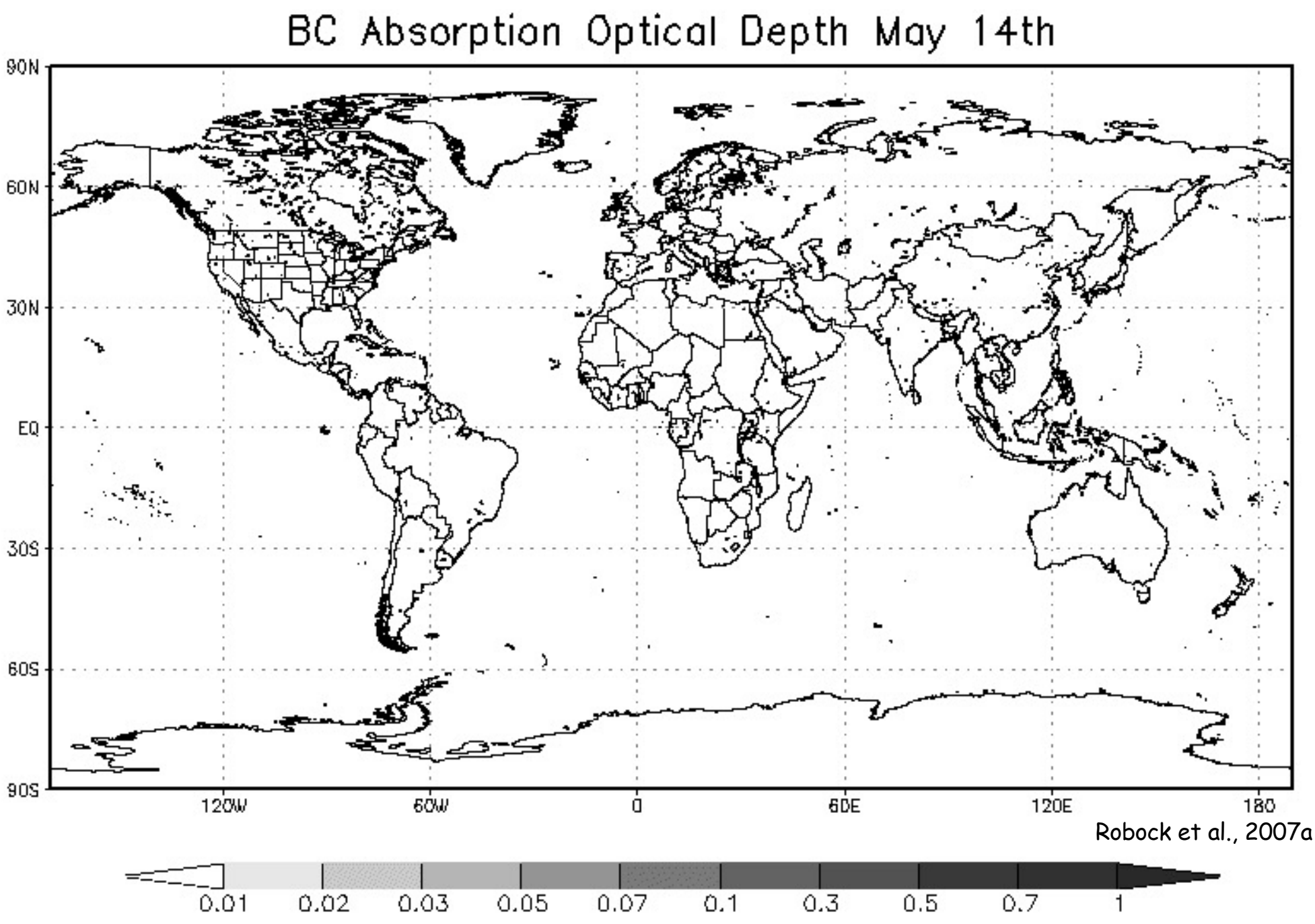
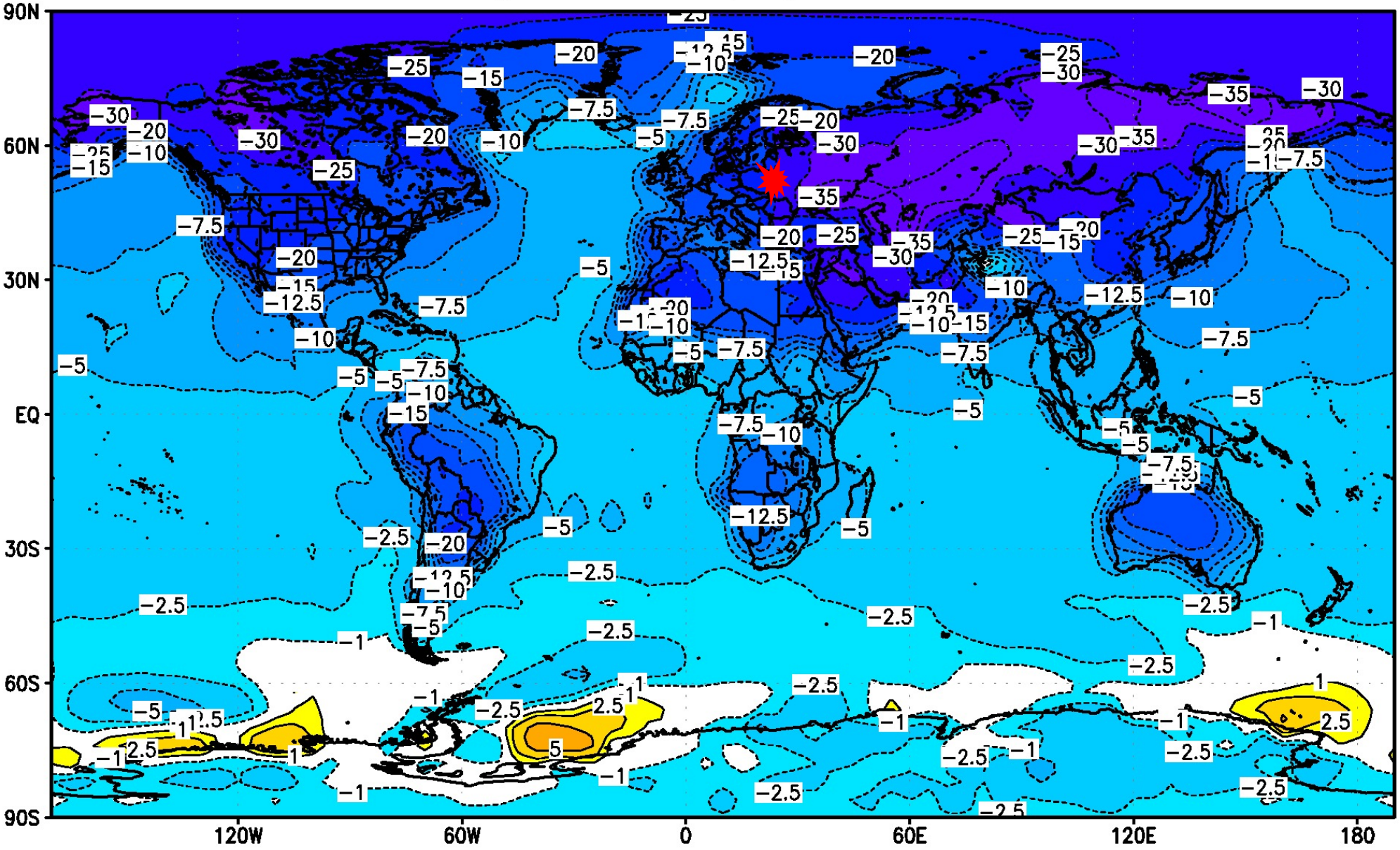
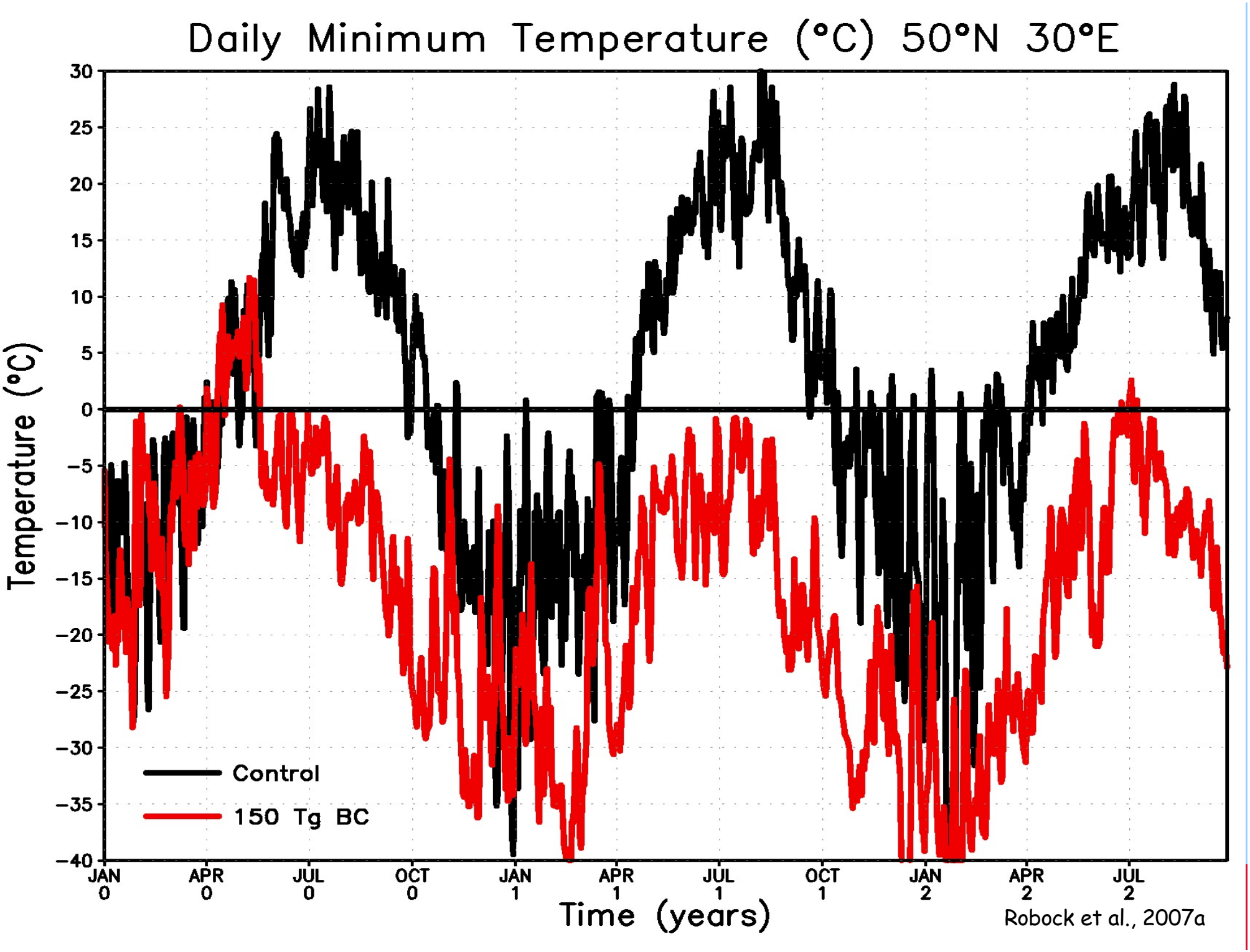


Robock et al., 2007a

Change in SAT (°C) JJA Year 1



Robock et al., 2007a


Daily Minimum Temperature (°C) 50°N 30°E
Temperature (°C)
30
25
20
15
10
5
0
−5
−10
−15
−20
−25
−30
−35
−40
JAN 0
APR 0
JUL 0
OCT 0
JAN 1
APR 1
JUL 1
OCT 1
JAN 2
APR 2
JUL 2
Time (years)
Control
150 Tg BC
Robock et al., 2007a

New simulations with the Whole Atmosphere Community Climate Model, version 4 (WACCM4)

- horizontal resolution of 1.9° × 2.5° (lat-lon)
- 66 vertical layers
- model top of 140 km
- transport and removal of soot from fires is handled by the Community Aerosol and Radiation Model for Atmospheres (CARMA), a sectional aerosol model that treats soot as fractal particles and allows them to grow

Coupe, Joshua, Charles G. Bardeen, Alan Robock, and Owen B. Toon, 2019: Nuclear winter responses to global nuclear war in the Whole Atmosphere Community Climate Model Version 4 and the Goddard Institute for Space Studies ModelE. *J. Geophys. Res. Atmos.*, **124**, 8522-8543, doi:10.1029/2019JD030509.

Toon, Owen B., Charles G. Bardeen, Alan Robock, Lili Xia, Hans Kristensen, Matthew McKinzie, R. J. Peterson, Cheryl Harrison, Nicole S. Lovenduski, and Richard P. Turco, 2019: Rapid expansion of nuclear arsenals by Pakistan and India portends regional and global catastrophe. *Science Advances*, **5**, eaay5478, doi:10.1126/sciadv.aay5478.

Pakistan and India may have 400 to 500 nuclear weapons by 2025 with yields from tested 12- to 45-kt values to a few hundred kilotons. If India uses 100 strategic weapons to attack urban centers and Pakistan uses 150, fatalities could reach 50 to 125 million people, and nuclear-ignited fires could release **16 to 37 Tg of black carbon** in smoke, depending on yield.

Toon, Owen B., Charles G. Bardeen, Alan Robock, Lili Xia, Hans Kristensen, Matthew McKinzie, R. J. Peterson, Cheryl Harrison, Nicole S. Lovenduski, and Richard P. Turco, 2019: Rapid expansion of nuclear arsenals by Pakistan and India portends regional and global catastrophe. *Science Advances*, **5**, eaay5478, doi:10.1126/sciadv.aay5478.

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Nuclear War Scenarios

[1 teragram (Tg) = 1 million tons]

Combatants	Number of weapons	Yield	Smoke	Number of direct fatalities
India - Pakistan	100	15 kt	5 Tg	27,000,000
	250	15 kt	16 Tg	52,000,000
	250	50 kt	27 Tg	97,000,000
	250	100 kt	37 Tg	127,000,000
	500	100 kt	47 Tg	164,000,000
U.S. - Russia	4400	100 kt	150 Tg	360,000,000

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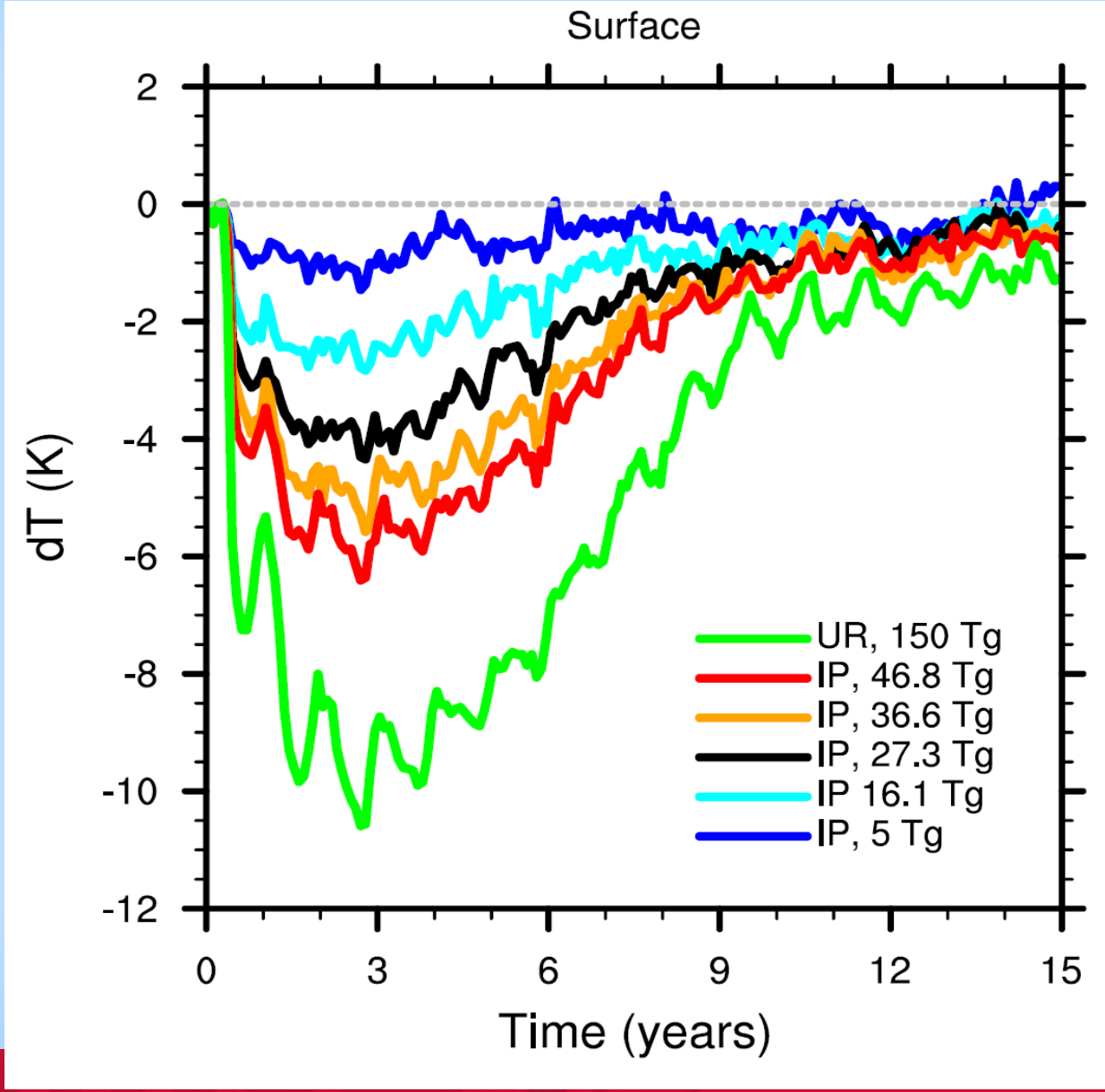
WACCM4 global average surface temperature changes for different soot amounts



Toon et al. (2019)

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HOW NUCLEAR WAR WOULD AFFECT AGRICULTURE

- Darkness
- Cold
  - Slower growth
  - Shortened frost-free growing season
  - Increased time for crop maturation
  - Cold spells during growing season that could kill crops
- Less rainfall

- Toxic chemicals in the atmosphere and soil
- Highly engineered genetic stocks
- Lack of fuel for machinery
- Lack of water supplies
- Lack of pesticides (but not of pests)
- Lack of distribution system
- Enhanced UV (later)

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nature food

Article | Open Access | Published: 15 August 2022

Global food insecurity and famine from reduced crop, marine fishery and livestock production due to climate disruption from nuclear war soot injection

Lili Xia, Alan Robock, Kim Scherrer, Cheryl S. Harrison, Benjamin Leon Bodirsky, Isabelle Weindl, Jonas Jägermeyr, Charles G. Bardeen, Owen B. Toon & Ryan Heneghan

https://www.nature.com/articles/s43016-022-00573-0

Food Calculations

We used the Community Land Model version 5 crop model in the Community Earth System Model version 2 to simulate maize, rice, soybeans, wheat, and grasses, and the Bioeconomic Marine Trophic Size-spectrum model to simulate marine fisheries.

For cattle and sheep, on average half are fed by pasture, and half are fed by crops and processed products. We used data for each animal and each country in our calculations.

We used Food and Agricultural Organization data for the calorie content of each food, and for the national import, export, and consumption of all the different foods.

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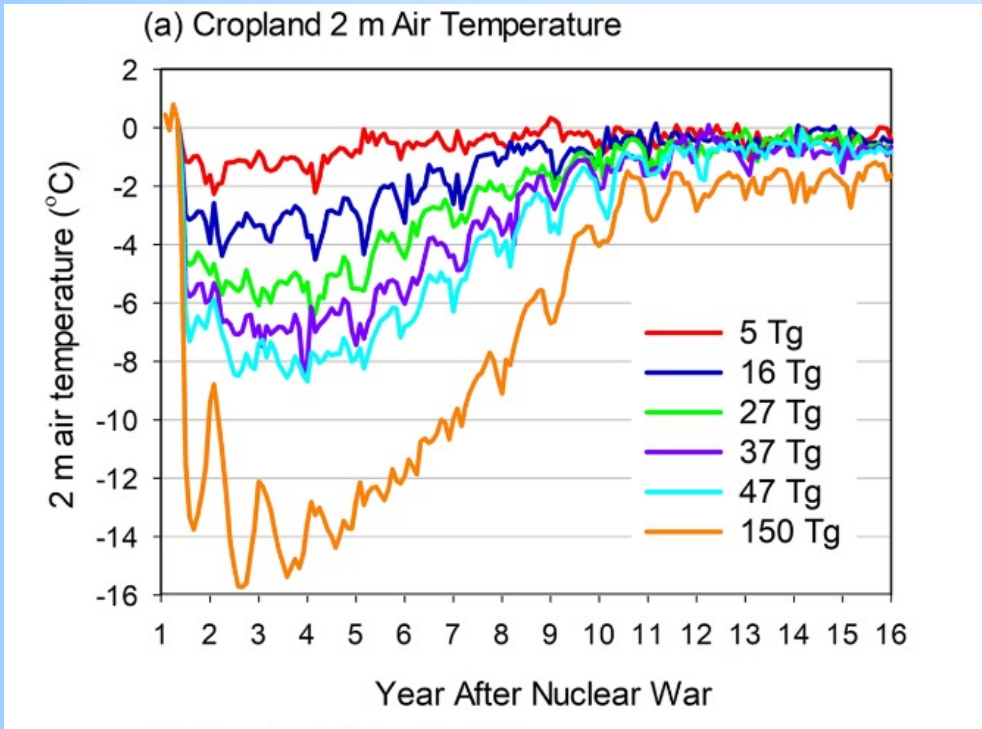
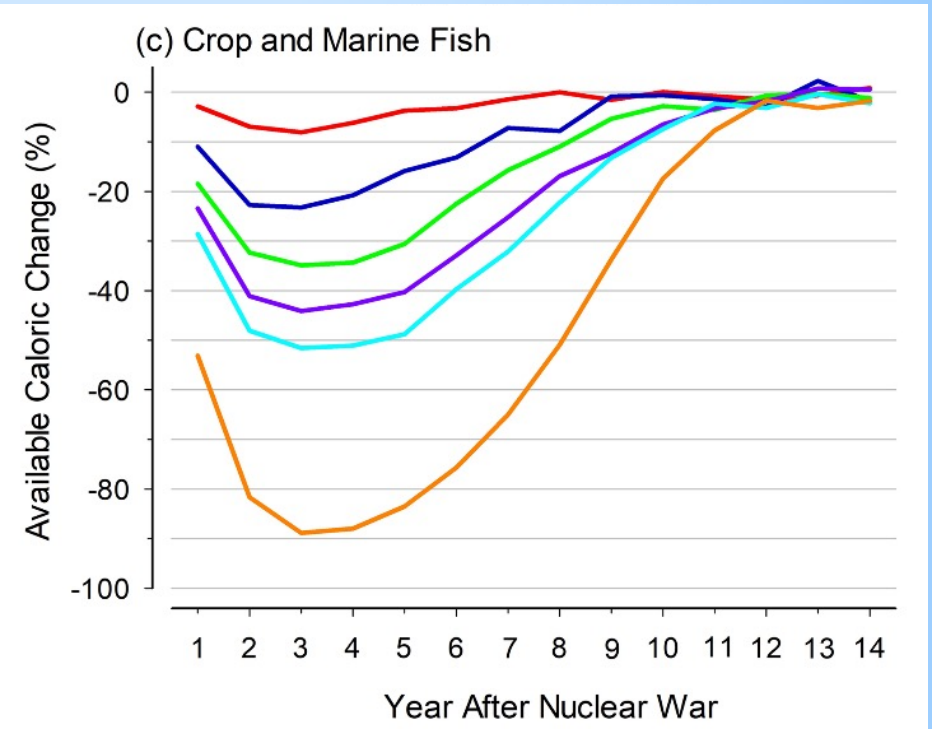
Cropland temperature



Available calories



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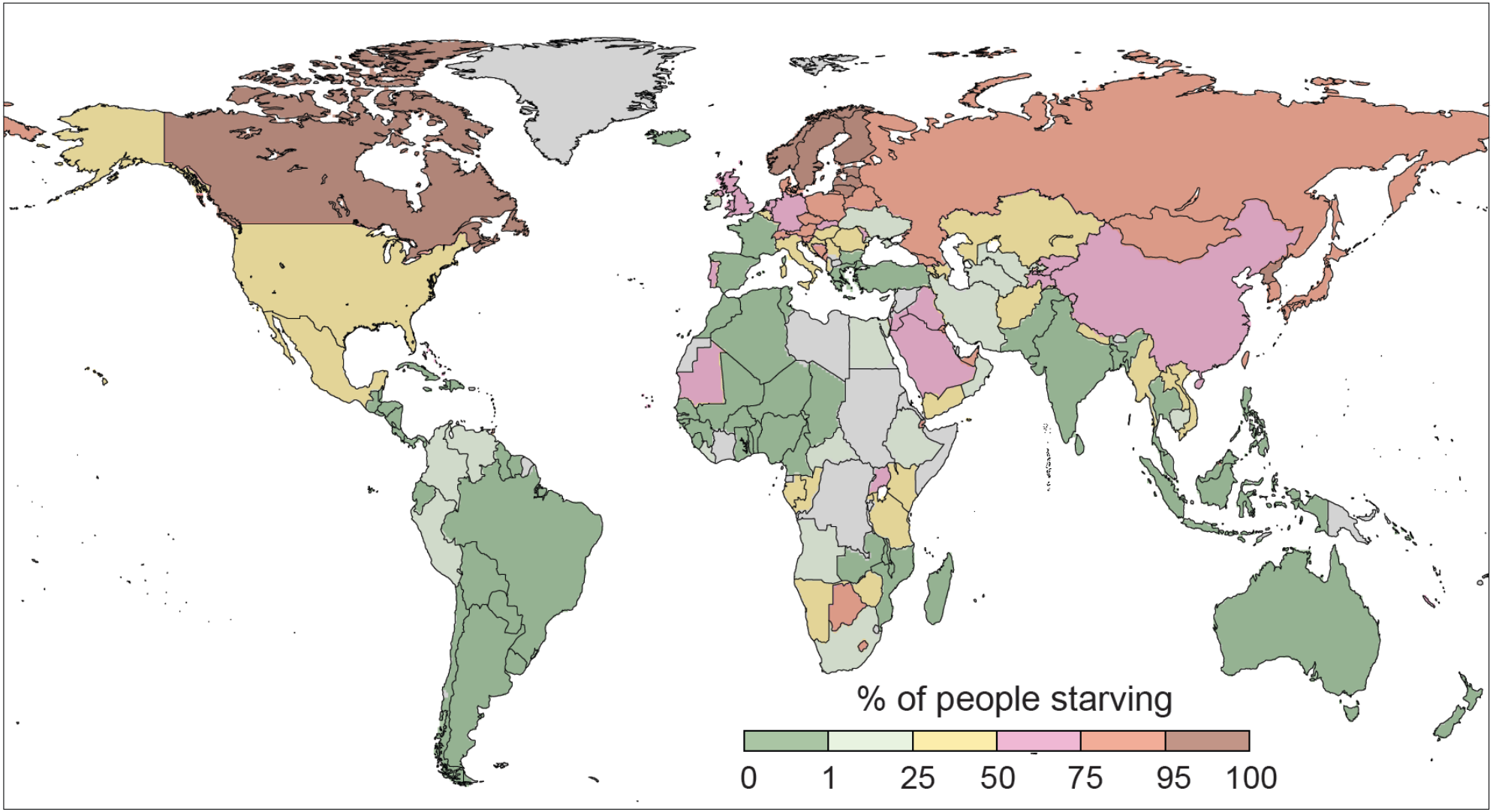
Proportion of population that would starve to death
Partial Livestock Case, 37 Tg, 50% livestock feed to human consumption, no trade



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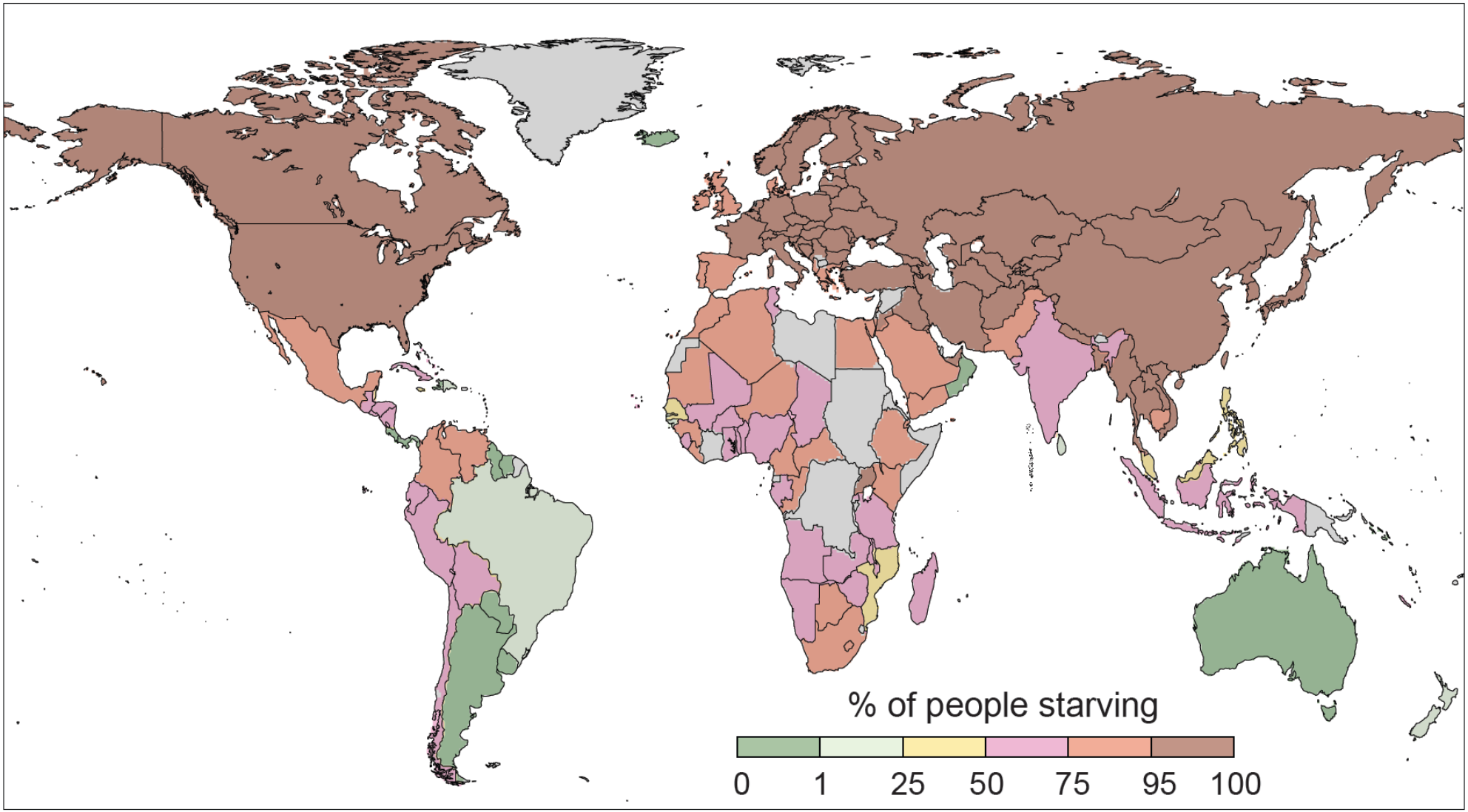
Department of Environmental Sciences

Proportion of population that would starve to death
Partial Livestock Case, 150 Tg, 50% livestock feed to human consumption, no trade



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Combatants	Number of weapons	Yield	Smoke	Number of direct fatalities	Number of people without food at the end of Year 2
India - Pakistan	250	15 kt	16 Tg	52,000,000	926,000,000
	250	100 kt	37 Tg	127,000,000	2,081,000,000
Russia-U.S.-NATO	4400	100 kt	150 Tg	360,000,000	5,341,000,000

A war between India and Pakistan could kill 1 to 2 billion people.

A Russia-U.S.-NATO war could kill most of Earth's population.

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Not yet considered in these calculations:

Effects of ultraviolet radiation

Effects of ozone changes

More complex economic responses, including:

- Some international trade
- Food distribution within countries
- Agricultural adaptations, including different crops

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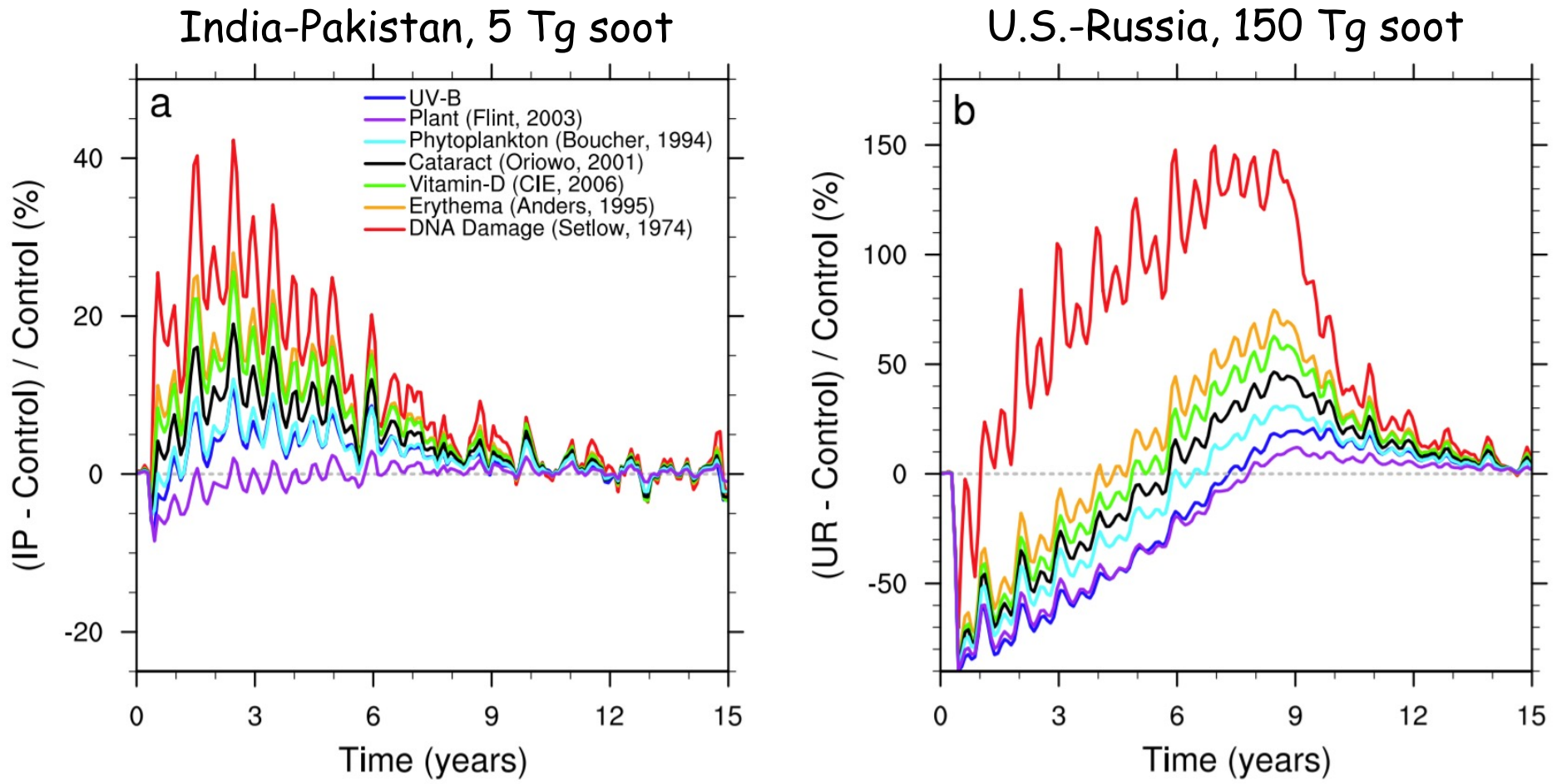

Figure 13. Evolution of the change in the global average surface values for ultraviolet-B compared with the action functions for plant growth, inhibition of phytoplankton, cataract formation, vitamin-D synthesis, erythema, and DNA damage for the India-Pakistan (IP) (left) and UR (right) cases. Note the different vertical scales for the two panels.

Bardeen, Charles G., Douglas E. Kinnison, Owen B. Toon, Michael J. Mills, Francis Vitt, Lili Xia, Jonas Jägermeyr, Nicole S. Lovenduski, Kim J. N. Scherrer, Margot Clyne, and Alan Robock, 2021: Extreme ozone loss following nuclear war resulting in enhanced surface ultraviolet radiation. *J. Geophys. Res. Atmos.*, **126**, e2021JD035079, doi:10.1029/2021JD035079.

The Future of Life Institute has just provided US$4,000,000 for new research in this area, starting September 1, 2023.

Our project:

Impacts of Nuclear War on Agriculture and Global Food Security

Alan Robock and Lili Xia

We will:

1. Work with other scientific teams to refine and advance our previous work by using multiple climate and crop models.
2. Use more comprehensive scenarios to examine the impacts of agricultural production changes, including the availability of fuel, fertilizer, and agricultural infrastructure; the effects of radioactive contamination; adaptation measures such as planting different crops; and assumptions about food distribution within nations and trade between nations.
3. Look at impacts on chocolate, coffee, wine, nuts, and tequila.
4. Create software for nuclear states to use so they can calculate and avoid civilian deaths depending on how they plan to use nuclear weapons.

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Department of Environmental Sciences

Impacts of Nuclear War on Agriculture and Global Food Security

nature food Xia et al., 2022

One Climate Model
One Crop Model
Simplistic Fire Emissions

Collaborating with different groups, providing bias corrected and downscaled climate forcing from a set of nuclear war scenarios

Multiple Crop Models

Phase I
Use same climate forcing as Xia et al. (2022)
- Temperature
- Precipitation
- Solar radiation

Multiple Climate Models

Phase I
Use same soot emissions as we used with WACCM and generate new
- Temperature
- Precipitation
- Solar radiation

Stratospheric Injection Development

Phase II
Urban fire models to provide better gas and aerosol inputs to stratosphere

Crop Model Development

Phase II
New crops, better response to UV, ozone, and diffuse light

Phase III: Repeats simulations with new data and models.

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Adding high-value crops in the crop model

Coffee beans	Grapes	Cocoa beans	Pistachios and other nuts

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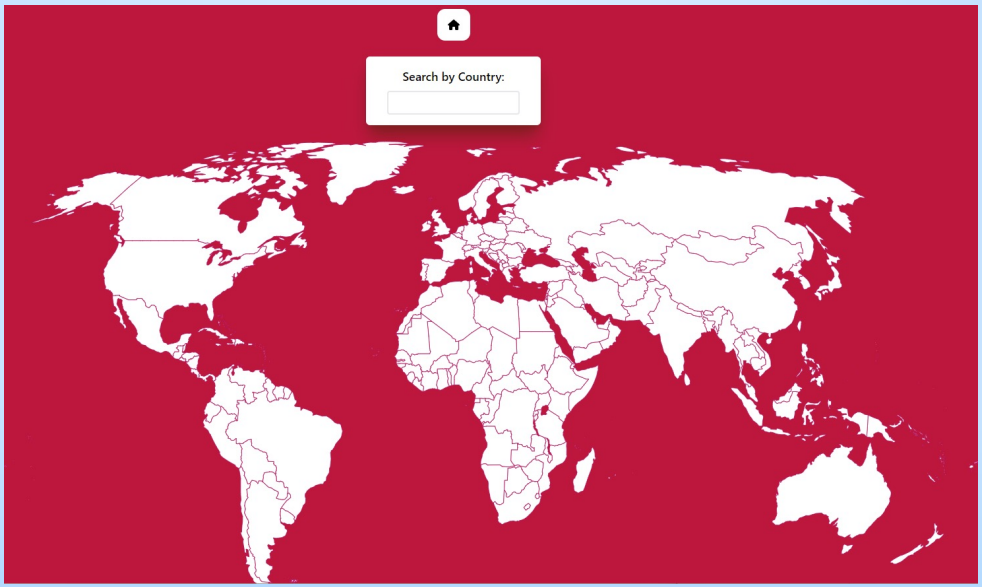
Impacts of Nuclear War on Agriculture and Global Food Security

An app to the policymakers and military planners of the nine nuclear states that will allow them to calculate, based on their secret nuclear targeting plans, how many people will die due to the direct and indirect effects of that use of nuclear weapons.

Set up nuclear war targets

- Current diet composition
- Current calorie intake
- Current trade
- Current livestock feed
- Current crop usage

Soot amount **Climate perturbation**



- Direct death
- Crop production changes
- Total crop calorie changes
- Livestock calorie changes
- Indirect death under different assumptions

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Nuclear Winter Analogs

- **Seasonal cycle**
- **Diurnal cycle (day and night)**
- **Firestorm: 1906 San Francisco earthquake**
- **Fires: World War II firestorms**
  - Dresden, Hamburg, Darmstadt, Tokyo ("conventional" bombs)
  - Hiroshima, Nagasaki (nuclear bombs)
- **Smoke and dust transport, Surface temperature effects**
  - Martian dust storms
  - Asteroid impact → dinosaur extinction
  - Forest fires
  - Saharan dust
  - Volcanic eruptions

Alan Robock
Department of Environmental Sciences

Black carbon lofts wildfire smoke high into the stratosphere to form a persistent plume

Pengfei Yu[1,2,3]*, Owen B. Toon[4,5], Charles G. Bardeen[6], Yunqian Zhu[5], Karen H. Rosenlof[2], Robert W. Portmann[2], Troy D. Thornberry[1,2], Ru-Shan Gao[2], Sean M. Davis[2], Eric T. Wolf[5,7], Joost de Gouw[1,8], David A. Peterson[9], Michael D. Fromm[10], Alan Robock[11]

Yu *et al.*, *Science* **365**, 587–590 (2019) 9 August 2019

In 2017, western Canadian wildfires injected smoke into the stratosphere that was detectable by satellites for more than 8 months. The smoke plume rose from 12 to 23 kilometers within 2 months owing to solar heating of black carbon, extending the lifetime and latitudinal spread. Comparisons of model simulations to the rate of observed lofting indicate that 2% of the smoke mass was black carbon. The observed smoke lifetime in the stratosphere was 40% shorter than calculated with a standard model that does not consider photochemical loss of organic carbon. Photochemistry is represented by using an empirical ozone-organics reaction probability that matches the observed smoke decay. The observed rapid plume rise, latitudinal spread, and photochemical reactions provide new insights into potential global climate impacts from nuclear war.

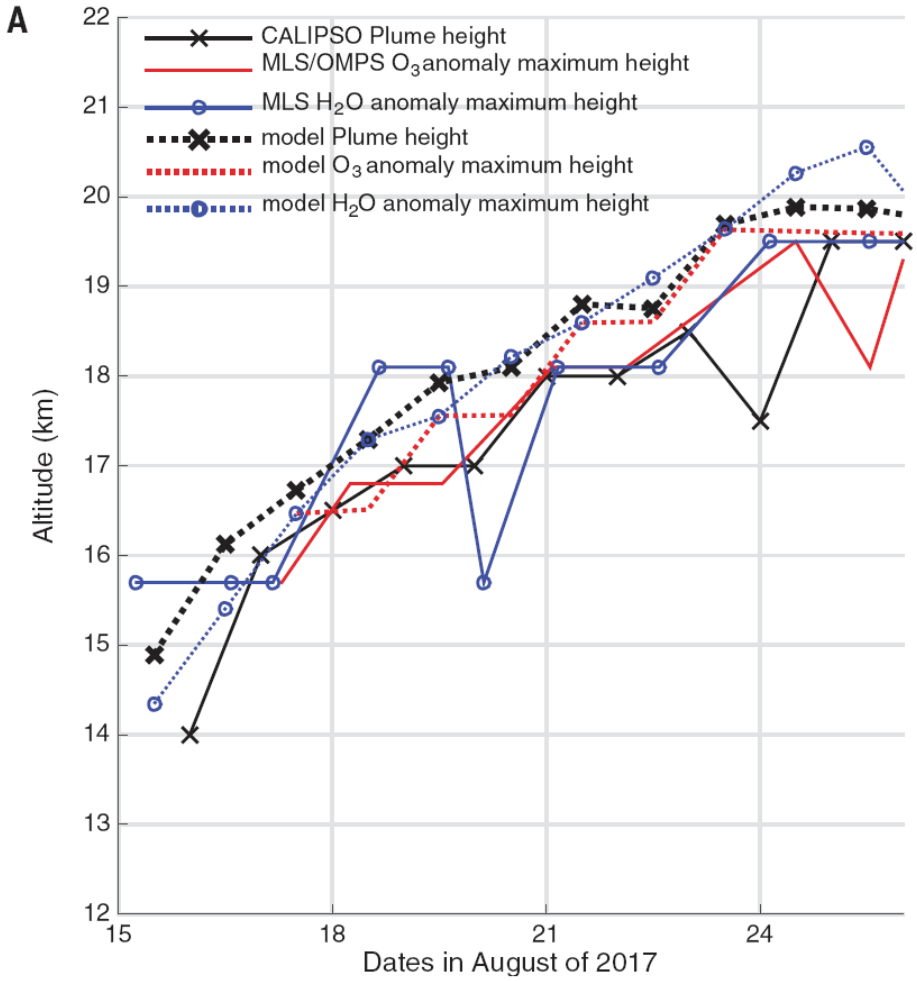

Fig. 3. Observed and modeled smoke transport in August 2017. (**A**) Maximum altitude of observed plume height by CALIOP in the region of interest in black lines with cross symbols; maximum altitude of observed significant O_3 negative anomaly (more negative than −0.3 ppmv) by MLS and OMPS in the region of interest (30° to 70°N, 80°W to 20°E) in red solid line; maximum altitude of observed water vapor positive

Yu *et al.*, *Science* **365**, 587–590 (2019) 9 August 2019

Rapid ascent in first 10 days, observed and modeled.

Alan Robock
Department of Environmental Sciences

Geophysical Research Letters (2020)

RESEARCH LETTER
10.1029/2020GL090831

Australian New Year's PyroCb Impact on Stratospheric Composition

Michael J. Schwartz[1], Michelle L. Santee[1], Hugh C. Pumphrey[2], Gloria L. Manney[3,4], Alyn Lambert[1], Nathaniel J. Livesey[1], Luis Millán[1], Jessica L. Neu[1], William G. Read[1], and Frank Werner[1]

Plain Language Summary Severe wildfires can trigger vigorous smoke-infused thunderstorms called pyrocumulonimbuses (pyroCbs) that rapidly loft polluted air from the surface, in the most extreme cases depositing it in the lower stratosphere (≳ 14 km altitude). Three times in the past 16 years, long-lived stratospheric plumes from major pyroCbs have been observed in a suite of biomass-burning products measured by the Microwave Limb Sounder on NASA's Aura satellite. Dark smoke in these plumes absorbs sunlight; the plumes rise because they are warmer than the surrounding air. The third, and by far the largest, of these plumes was produced by an extraordinary set of pyroCbs in Australia between 29 December 2019 and 4 January 2020, collectively known as the Australian New Year's event (ANY). The ANY plume core remained remarkably compact, circling the globe twice while rising from ~14 km to ~35 km altitude over a period of 4 months. Record-setting concentrations of five biomass-burning products were measured by MLS throughout the lower stratosphere. Plume fragments tended to move south but do not seem to have influenced ozone-hole chemistry. Differing gas mixtures suggest that several plumes in the first month originated in different pyroCbs. Careful comparison of plume gases requires consideration of the blurriness of the measurements.

Tambora in 1815, together with an eruption from an unidentified volcano in 1809, produced the "Year Without a Summer" (1816)

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Mean June temperatures at New Haven, Connecticut, for some early years.

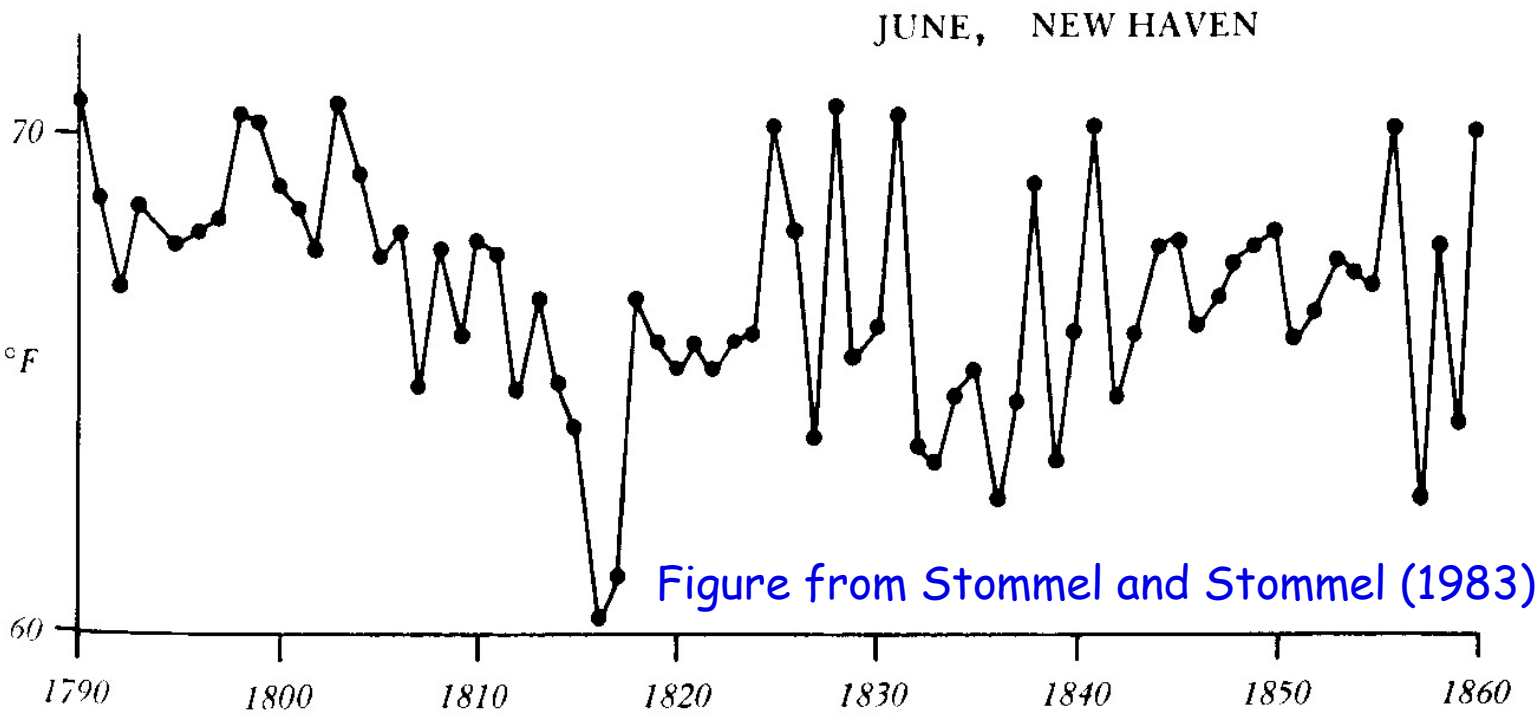

Figure from Stommel and Stommel (1983)

Gillen D'Arcy Wood, *Tambora: The Eruption That Changed the World* (2014): **"For three years following Tambora's explosion, to be alive, almost anywhere in the world, meant to be hungry."**

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Department of Environmental Sciences

Conclusions

The current nuclear arsenal can produce nuclear winter.

Nuclear winter could kill most of humanity. In a US-NATO-Russia nuclear war, more people could die in India or China than in the US or Russia, even if no bombs were dropped there.

Alan Robock
Department of Environmental Sciences

Nobel Peace Prizes for Advocating Nuclear Disarmament (from https://www.nobelprize.org/prizes/lists/all-nobel-peace-prizes)

Year	Nobel Laureates
1959	**Philip Noel-Baker** "He engaged in intense efforts to prevent nuclear war between the United States and the Soviet Union."
1962	**Linus Pauling** "He spoke and wrote against the nuclear arms race, and he was a driving force in the Pugwash movement. ... He was one of the prime movers who urged the nuclear powers the USA, the Soviet Union and Great Britain to conclude a nuclear test ban treaty."
1982	**Alva Myrdal** "She worked actively to persuade the superpowers to disarm. The nuclear race was a major concern, and she fought for nuclear weapons-free zones in Europe." and **Alfonso García Robles** "played a key part in the laborious efforts to make Latin America a nuclear-free zone. ... He was lauded as 'Mr. Disarmament.'"
1985	**International Physicians for the Prevention of Nuclear War** "IPPNW held annual congresses to tell the world about the consequences of nuclear war. Extensive nuclear explosions could prevent sunlight from reaching the earth. The resulting drop in temperature would cause a 'nuclear winter.' The organization recommended a nuclear test ban and demanded that the great powers should refrain from first use in conflict situations."
1995	**Joseph Rotblat and Pugwash Conferences on Science and World Affairs** "for their efforts to diminish the part played by nuclear arms in international politics and, in the longer run, to eliminate such arms"
2005	**International Atomic Energy Agency (IAEA) and Mohamed ElBaradei** "for their efforts to prevent nuclear energy from being used for military purposes and to ensure that nuclear energy for peaceful purposes is used in the safest possible way"
2017	**International Campaign to Abolish Nuclear Weapons (ICAN)** "for its work to draw attention to the catastrophic humanitarian consequences of any use of nuclear weapons and for its ground-breaking efforts to achieve a treaty-based prohibition of such weapons"

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"For the greatest benefit to mankind"
Alfred Nobel

The Norwegian Nobel Committee has decided to award the

2017 NOBEL PEACE PRIZE

to:

International Campaign to Abolish Nuclear Weapons (ICAN)

"for its work to draw attention to the catastrophic humanitarian consequences of any use of nuclear weapons and for its ground-breaking efforts to achieve a treaty-based prohibition of such weapons."

Nobelprize.org

Alan Robock
Department of Environmental Sciences

Beatrice Fihn
Executive Director of ICAN
Nobel Peace Prize Lecture
December 10, 2017

The story of nuclear weapons will have an ending, and it is up to us what that ending will be.

Will it be the end of nuclear weapons, or will it be the end of us? One of these things will happen.

The only rational course of action is to cease living under the conditions where our mutual destruction is only one impulsive tantrum away.

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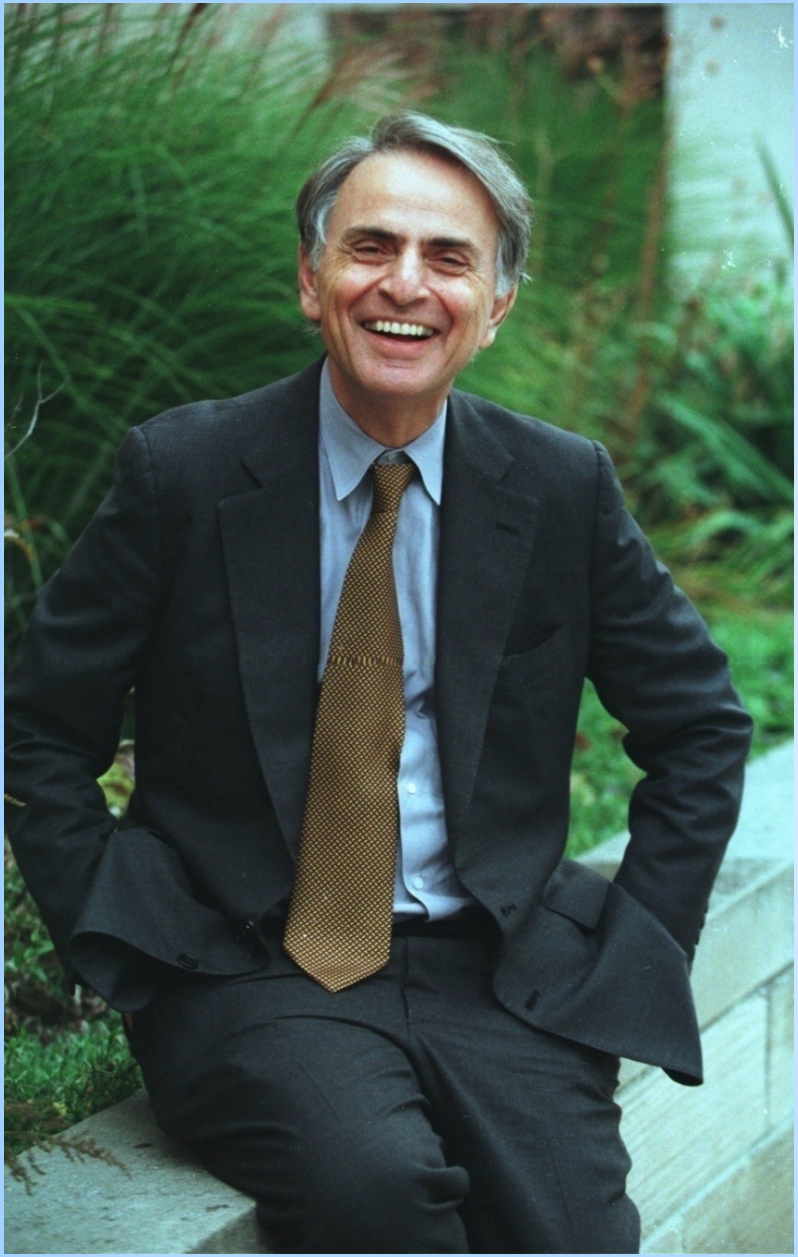

"For myself, I would far rather have a world in which the climatic catastrophe cannot happen, independent of the vicissitudes of leaders, institution, and machines. This seems to me elementary planetary hygiene, as well as elementary patriotism."

-Carl Sagan

"Elementary planetary hygiene" demands that we eliminate nuclear weapons faster than the current pace.

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For more about this work, go to

http://climate.envsci.rutgers.edu/nuclear/

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