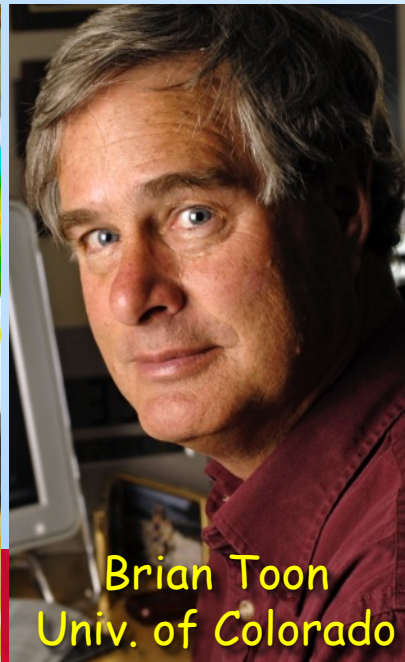
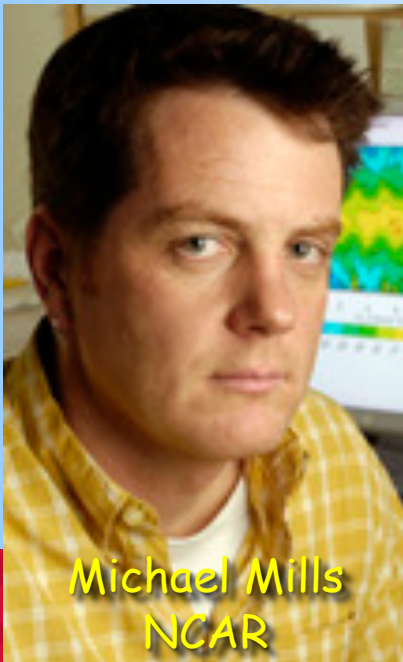
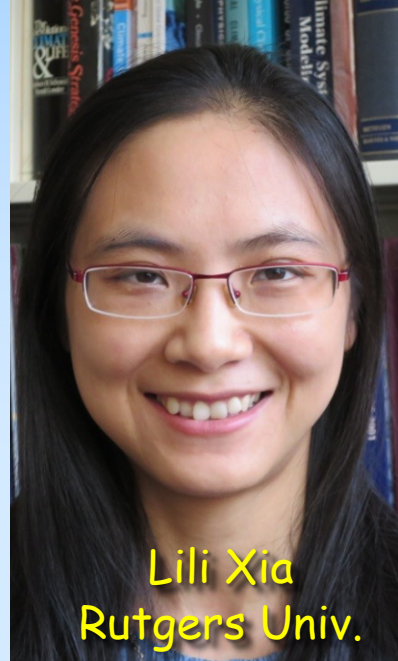


Global Famine after Nuclear War

Alan Robock

*Department of Environmental Sciences
Rutgers University, New Brunswick, New Jersey USA
roboc@envsci.rutgers.edu*

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.



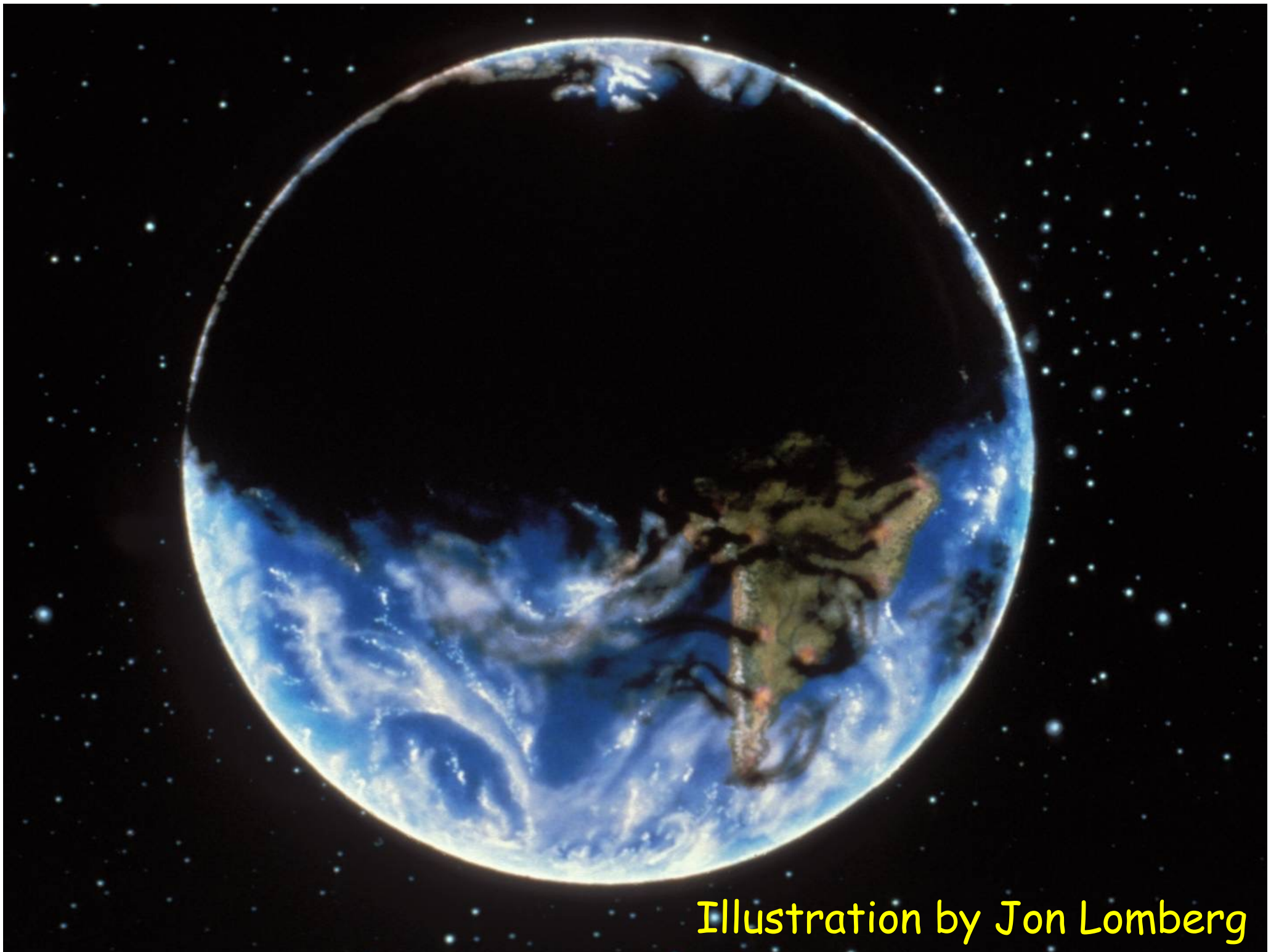


Illustration by Jon Lomborg

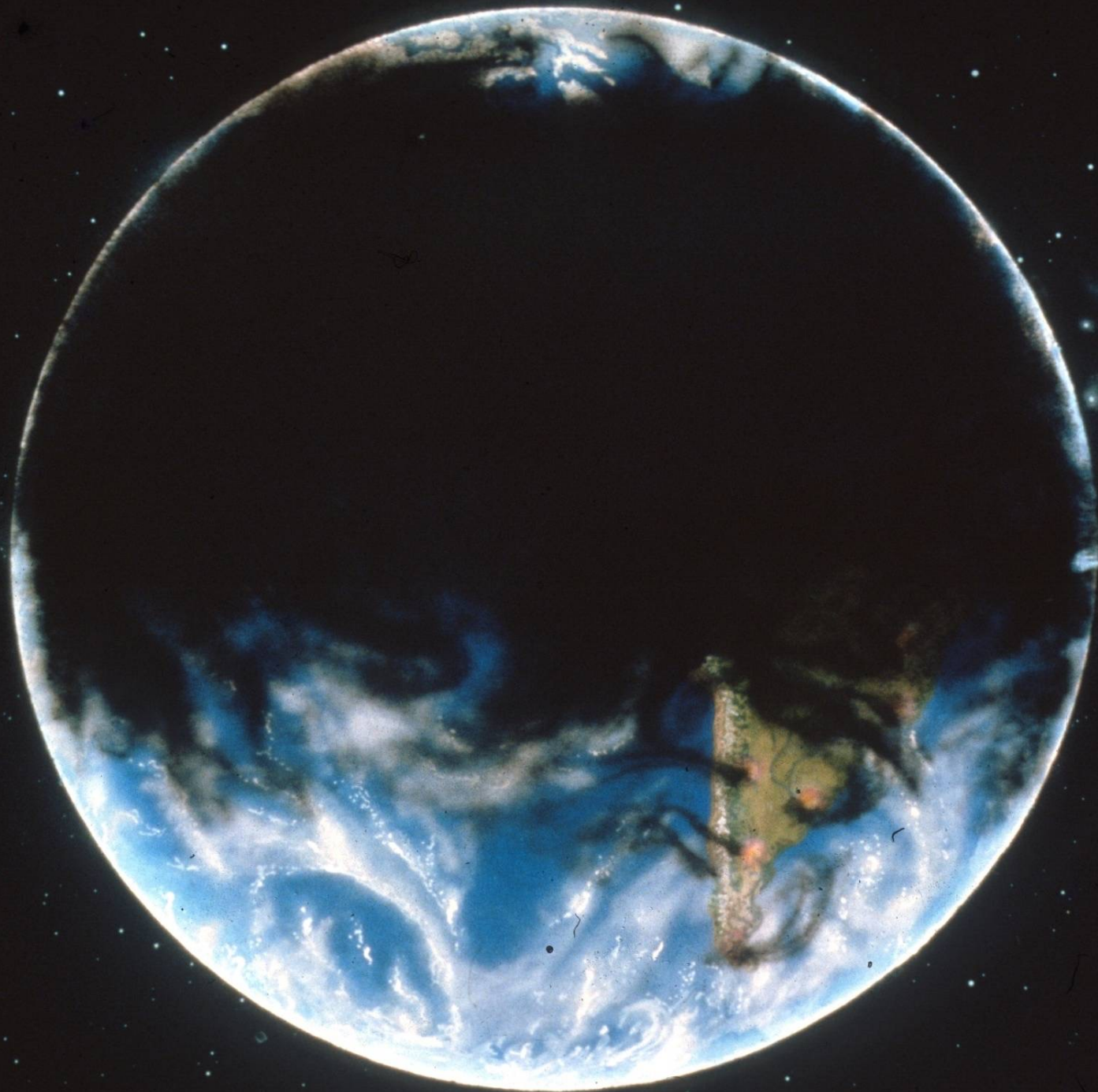


Illustration by Jon Lomborg

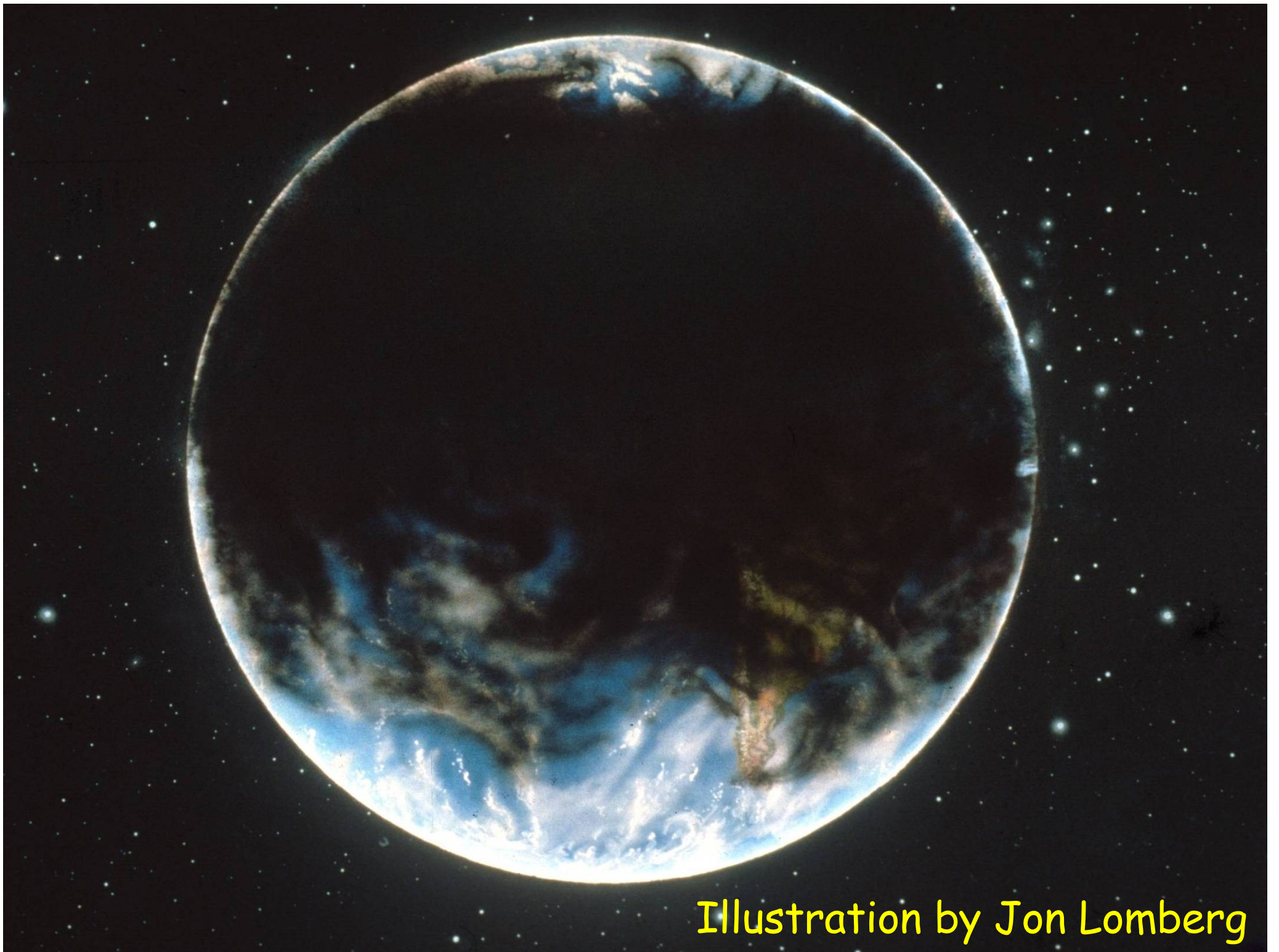


Illustration by Jon Lomborg

A dark, ominous sky with a dim, reddish sun and a person standing in a field of dead crops. The scene is a rural landscape with a barn and trees in the background. The overall mood is one of desolation and despair.

Nuclear Winter

Cold, Dry, Dark, and More UV
Crops Dying and Global Famine

AMBIO

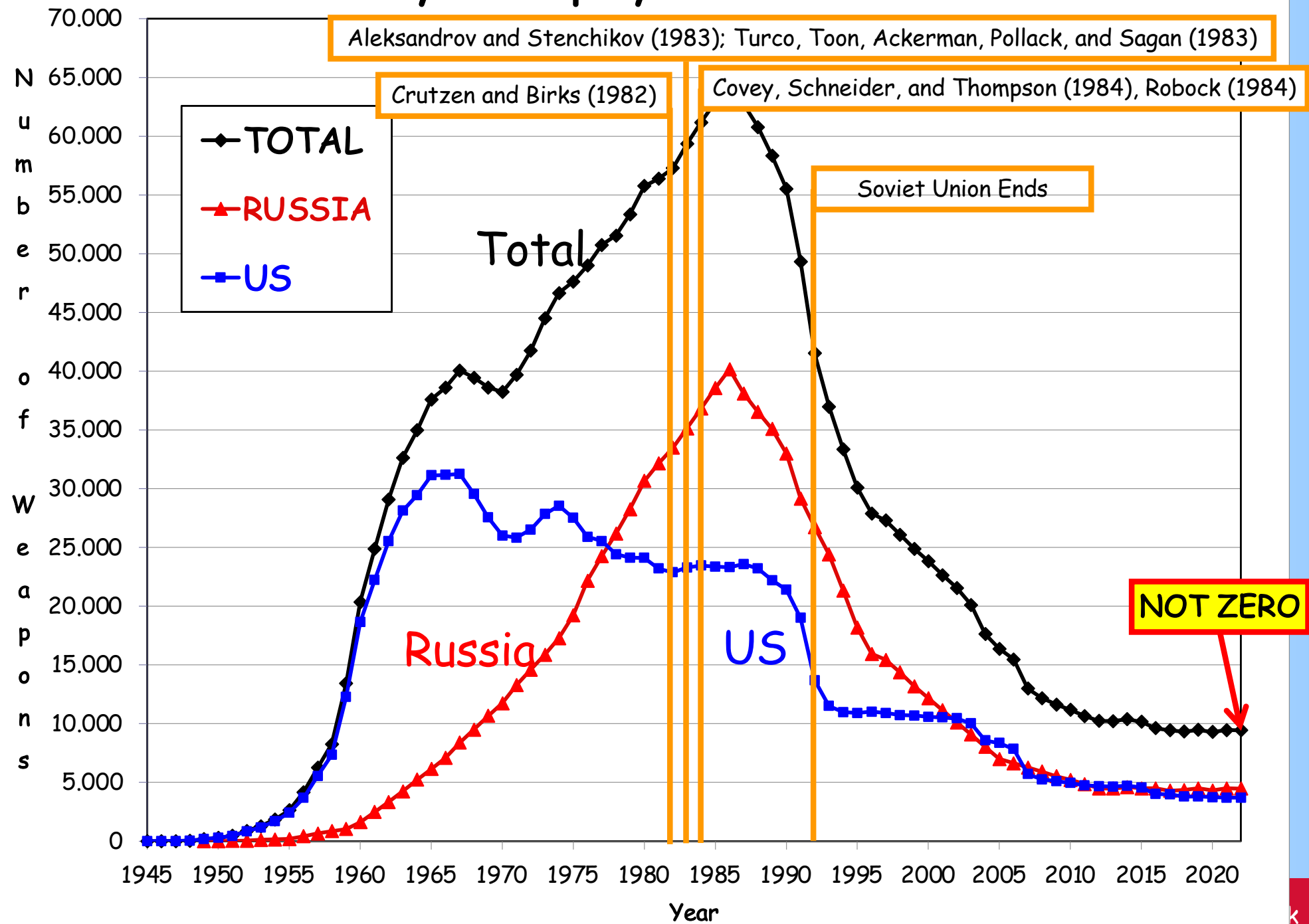
A JOURNAL OF THE HUMAN ENVIRONMENT

Nuclear War: The Aftermath

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.

History of Deployed Nuclear Warheads



Aleksandrov and Stenchikov (1983); Turco, Toon, Ackerman, Pollack, and Sagan (1983)

Crutzen and Birks (1982)

Covey, Schneider, and Thompson (1984), Robock (1984)

Soviet Union Ends

NOT ZERO

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 ..."

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."

Forty years after the threat of nuclear winter was discovered, we now ask:

1. Although the Cold War and its associated nuclear arms race are over, could remaining nuclear arsenals still produce nuclear winter?
2. What would be the consequences of the use of a much smaller number of nuclear weapons in a regional nuclear conflict?

Forty years after the threat of nuclear winter was discovered, we now ask:

1. Although the Cold War and its associated nuclear arms race are over, could remaining nuclear arsenals still produce nuclear winter? **YES, AND IT WOULD LAST FOR HALF A DECADE KILLING MOST OF HUMANITY.**
2. What would be the consequences of the use of a much smaller number of nuclear weapons in a regional nuclear conflict?

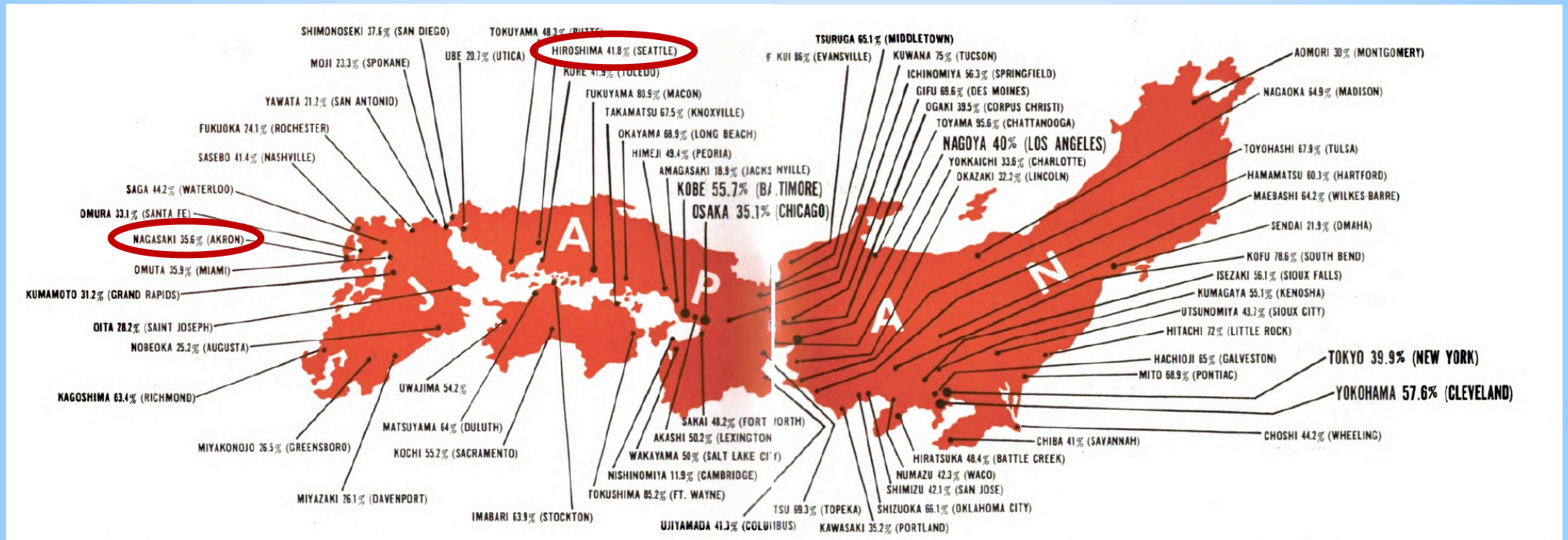
Forty years after the threat of nuclear winter was discovered, we now ask:

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2. What would be the consequences of the use of a much smaller number of nuclear weapons in a regional nuclear conflict? **NOT NUCLEAR WINTER, BUT MILLIONS DEAD FROM BLAST, RADIOACTIVITY AND FIRES, AND BILLIONS STARVING.**

Scenes from the 1992 Gulf War



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.

Hiroshima

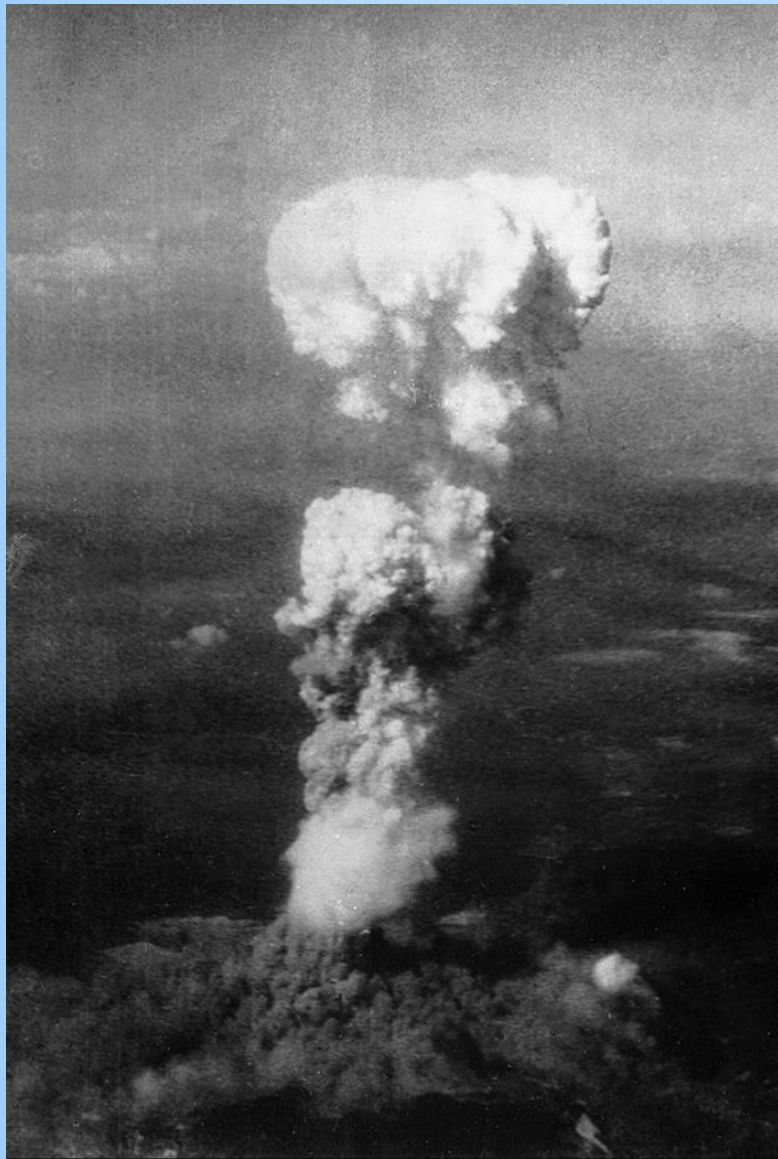
August 6, 1945

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.

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



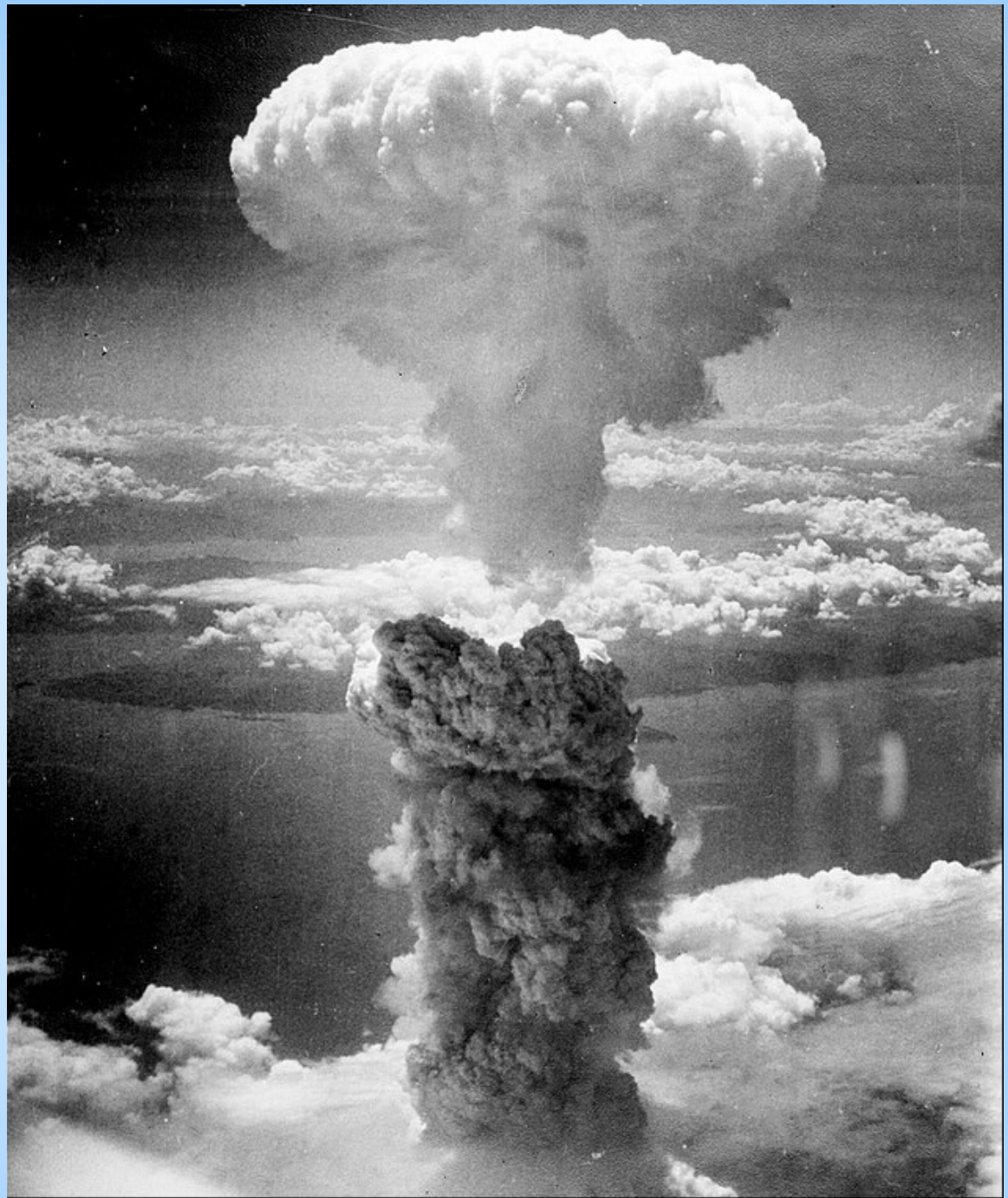




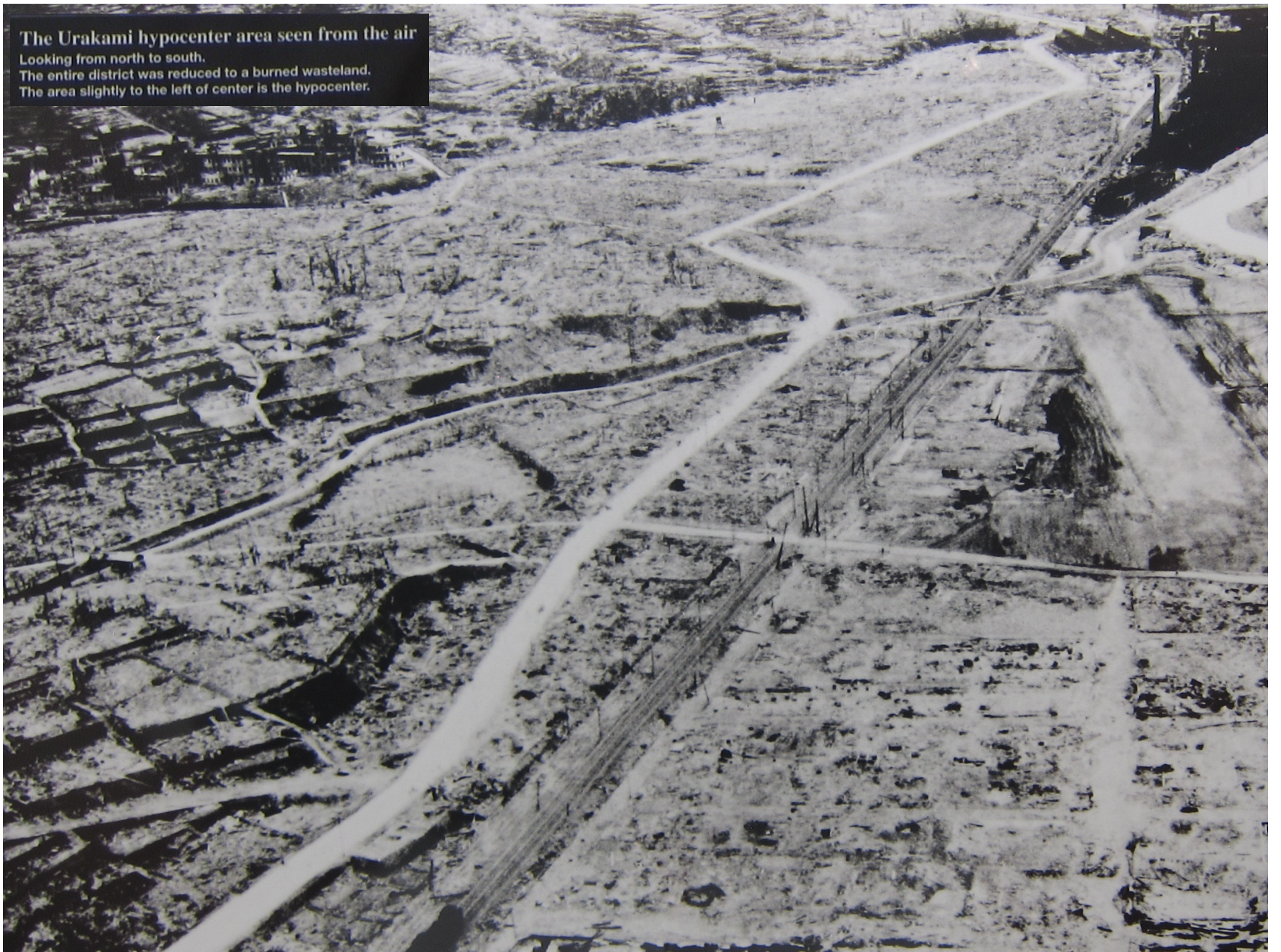
0665



Nagasaki
Aug. 9, 1945
11:02 am



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.



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)

The World's Nuclear Warheads Count June 2022

Russia 5,975

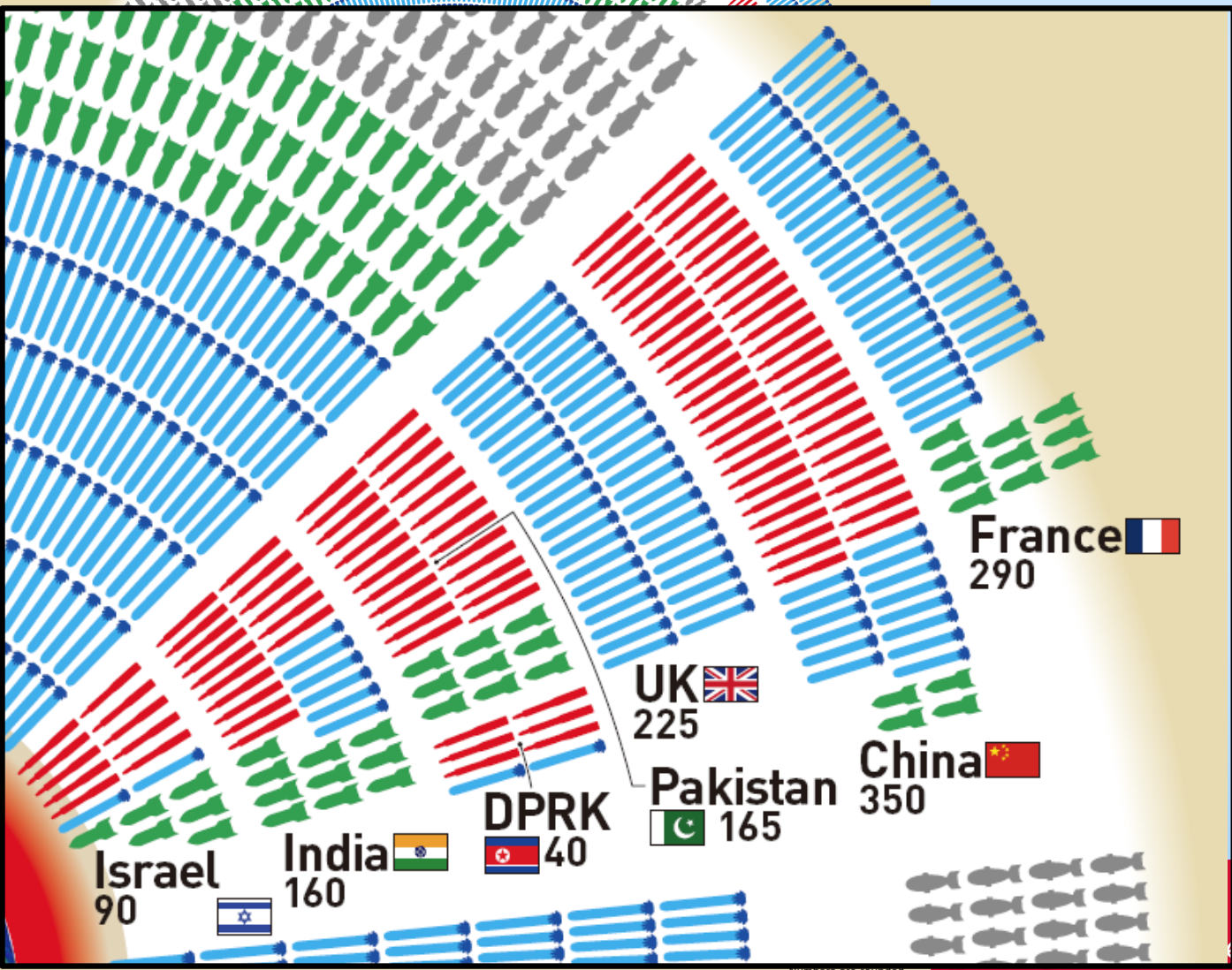
Carried by land-based missiles including ICBM	1,660
Deployed at sea including SLBM	1,735
Carried by aircraft	1,080
Retired or to be dismantled, etc.	1,500

US 5,425

Carried by land-based missiles including ICBM	800
Deployed at sea including SLBM	1,920
Carried by aircraft	988
Retired or to be dismantled, etc.	1,717

■ Carried by land-based missiles including ICBM
■ Deployed at sea including SLBM
■ Carried by aircraft
■ Retired or to be dismantled, etc.

×5



China 350

Carried by land-based missiles including ICBM	258
Deployed at sea including SLBM	72
Carried by aircraft	20

France 290

Deployed at sea including SLBM	240
Carried by aircraft	50

UK 225

Deployed at sea including SLBM	225
--------------------------------	-----

Pakistan 165

Carried by land-based missiles including ICBM	124
Carried by aircraft	41

India 160

Carried by land-based missiles including ICBM	84
Deployed at sea including SLBM	28
Carried by aircraft	48

Israel 90

Carried by land-based missiles including ICBM	50
Deployed at sea including SLBM	10
Carried by aircraft	30

DPRK 40

Carried by land-based missiles including ICBM	?
Deployed at sea including SLBM	?

Numbers are rounded.



What if India and Pakistan had a nuclear war? Imagine a skirmish in Kashmir escalating, due to poor communication, misunderstanding, panic, and fear.

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.

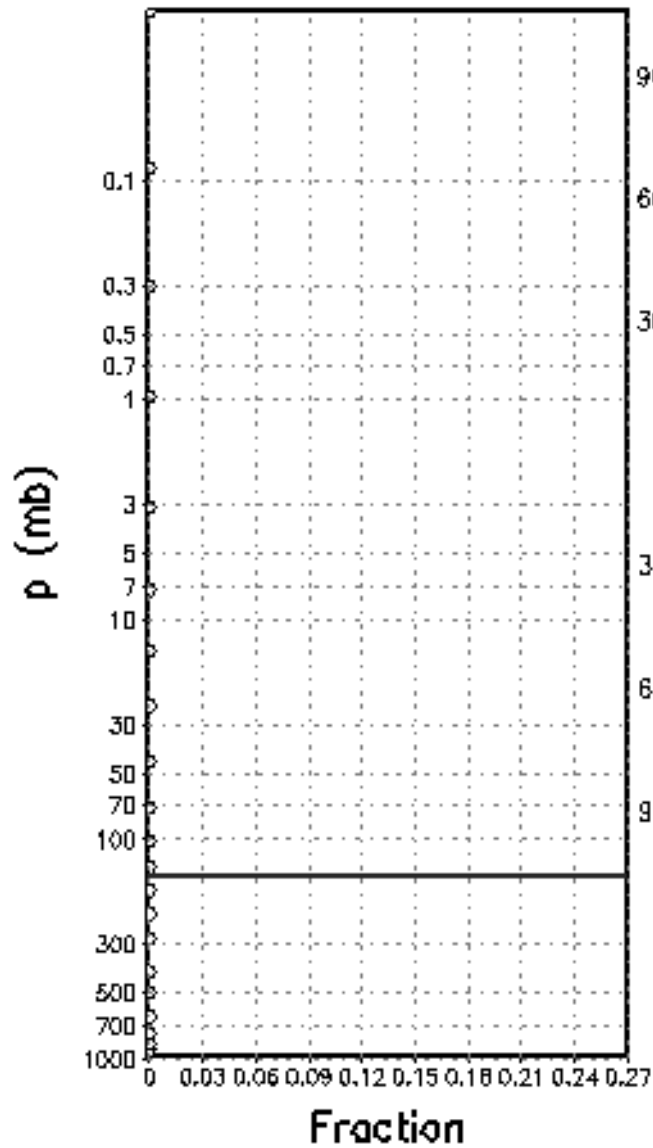
5 million tons of smoke injected into the upper atmosphere, accounting for fuel loading, emission factors and rainout.

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

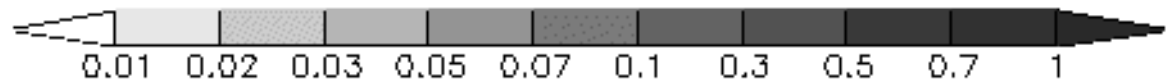
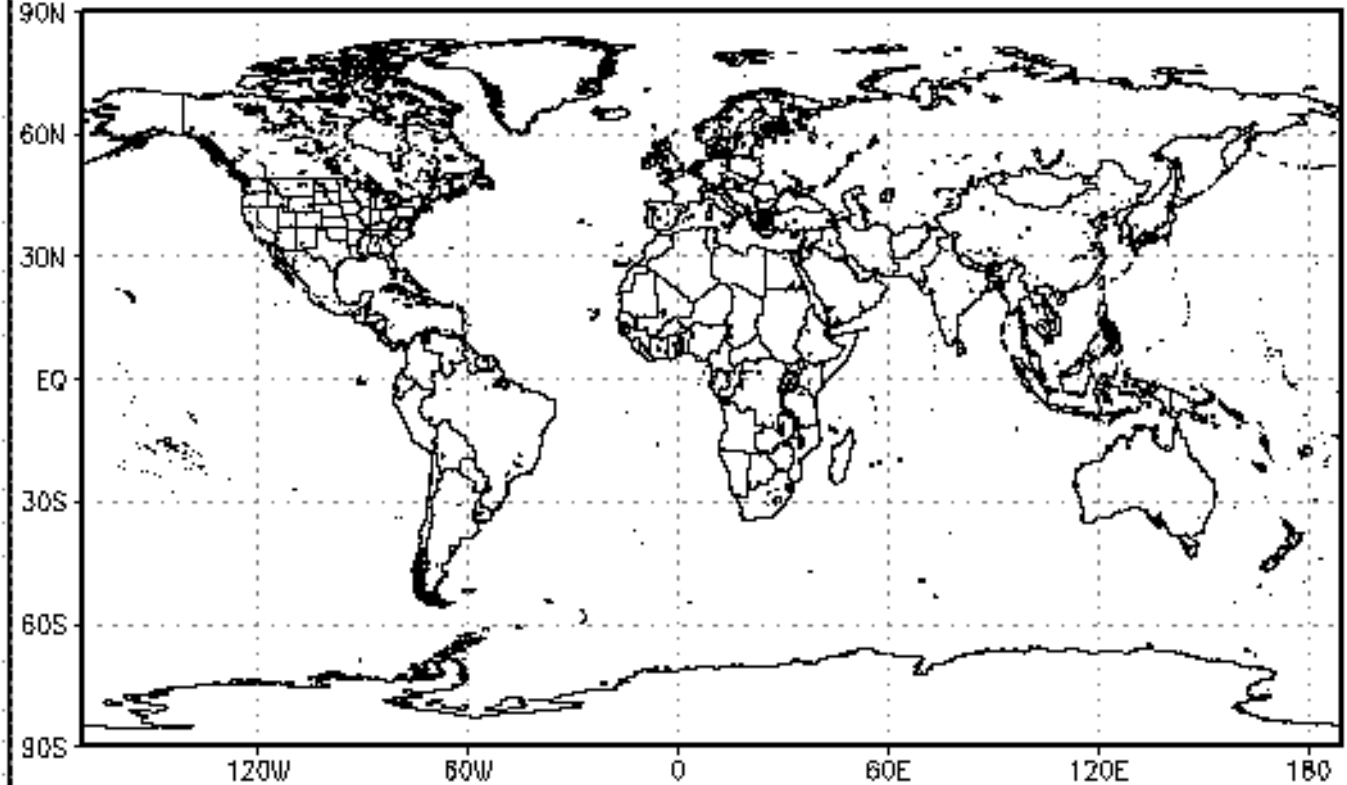
We use the NASA GISS ModelE atmosphere-ocean general circulation model.

- 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

BC per model level



BC Absorption Optical Depth May 14

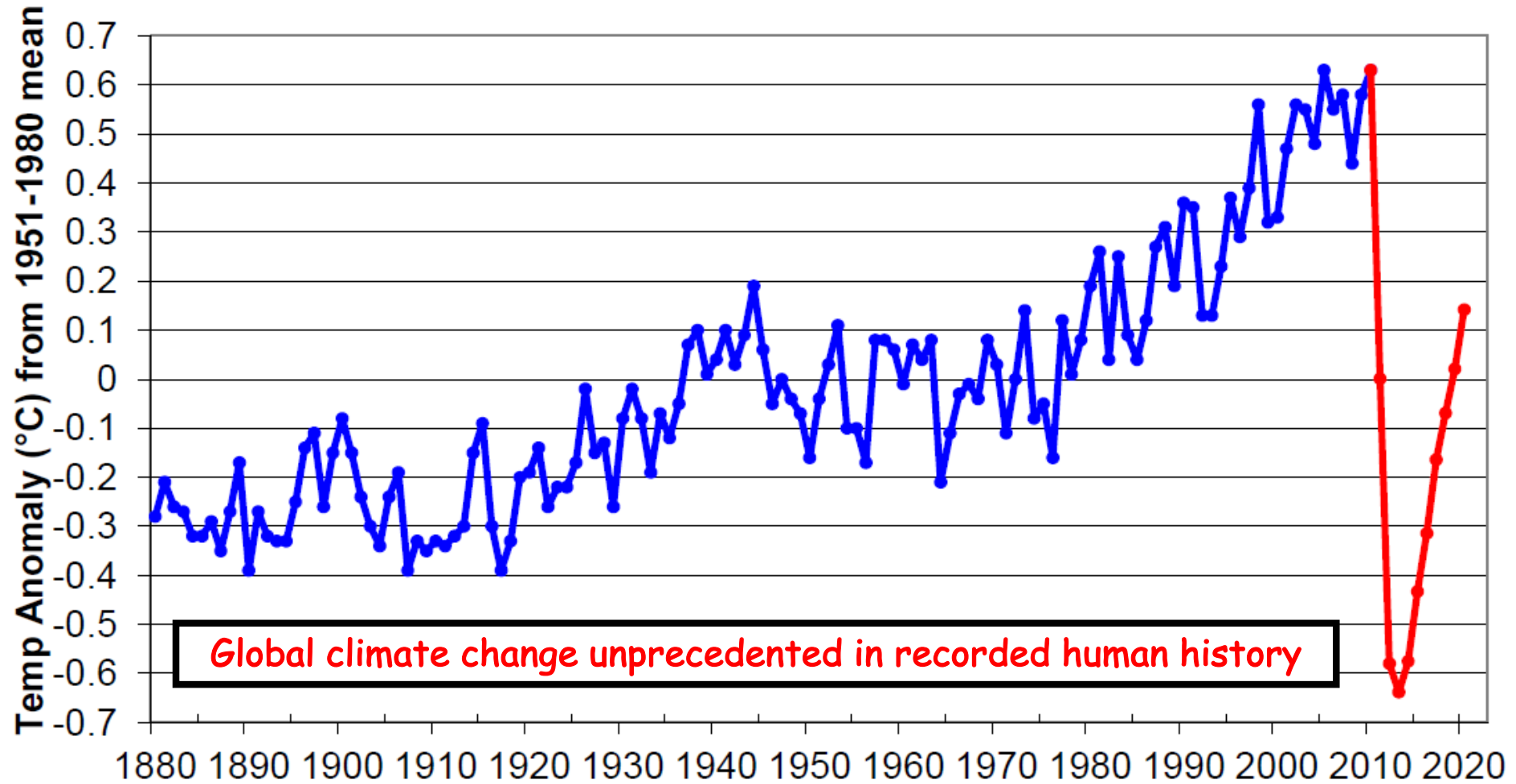


Robock et al., 2007a

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

GISS Global Average Temperature Anomaly

+ 5 Tg smoke in 2011



Robock et al., 2007a

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

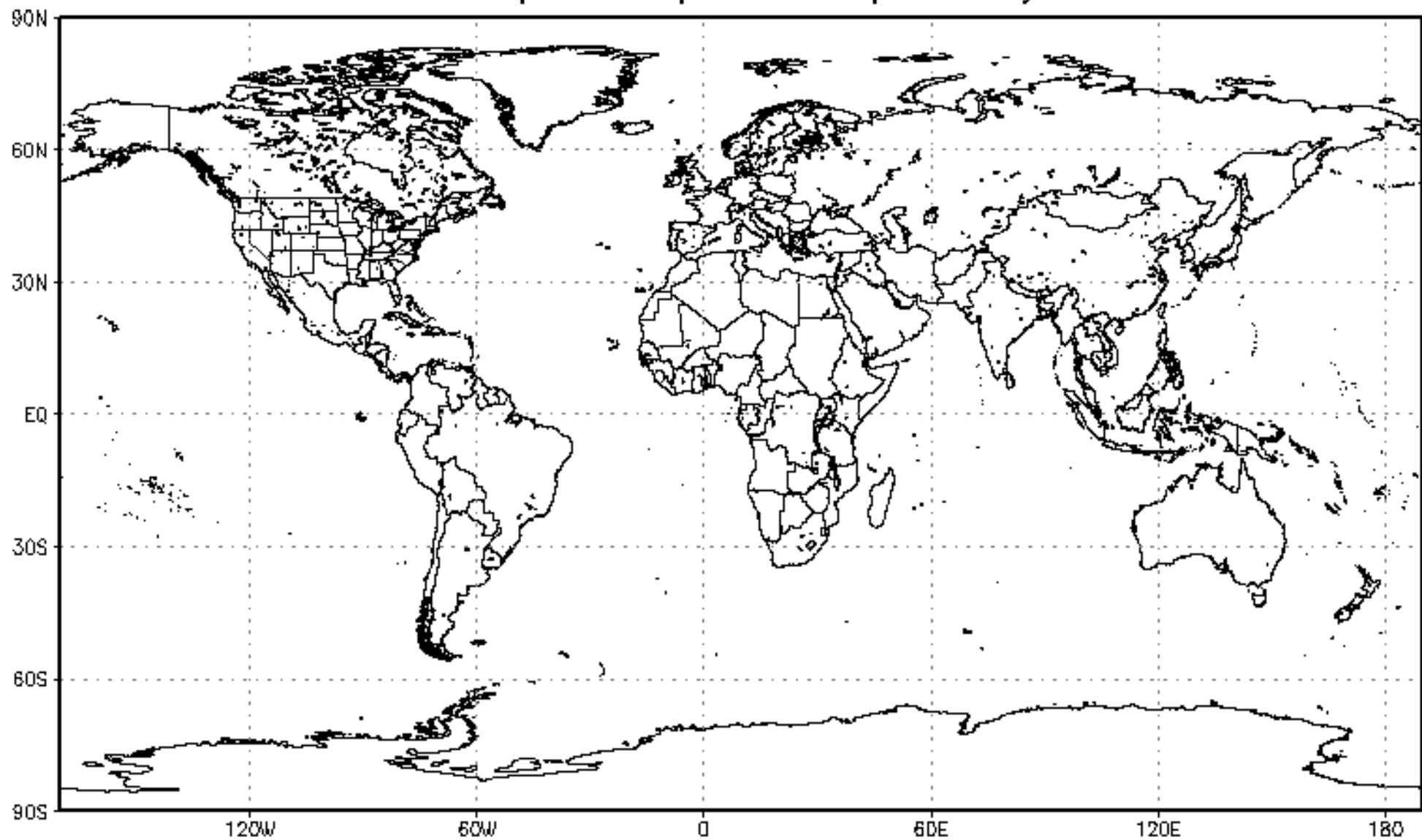
We use the NASA GISS ModelE atmosphere-ocean general circulation model.

- 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)

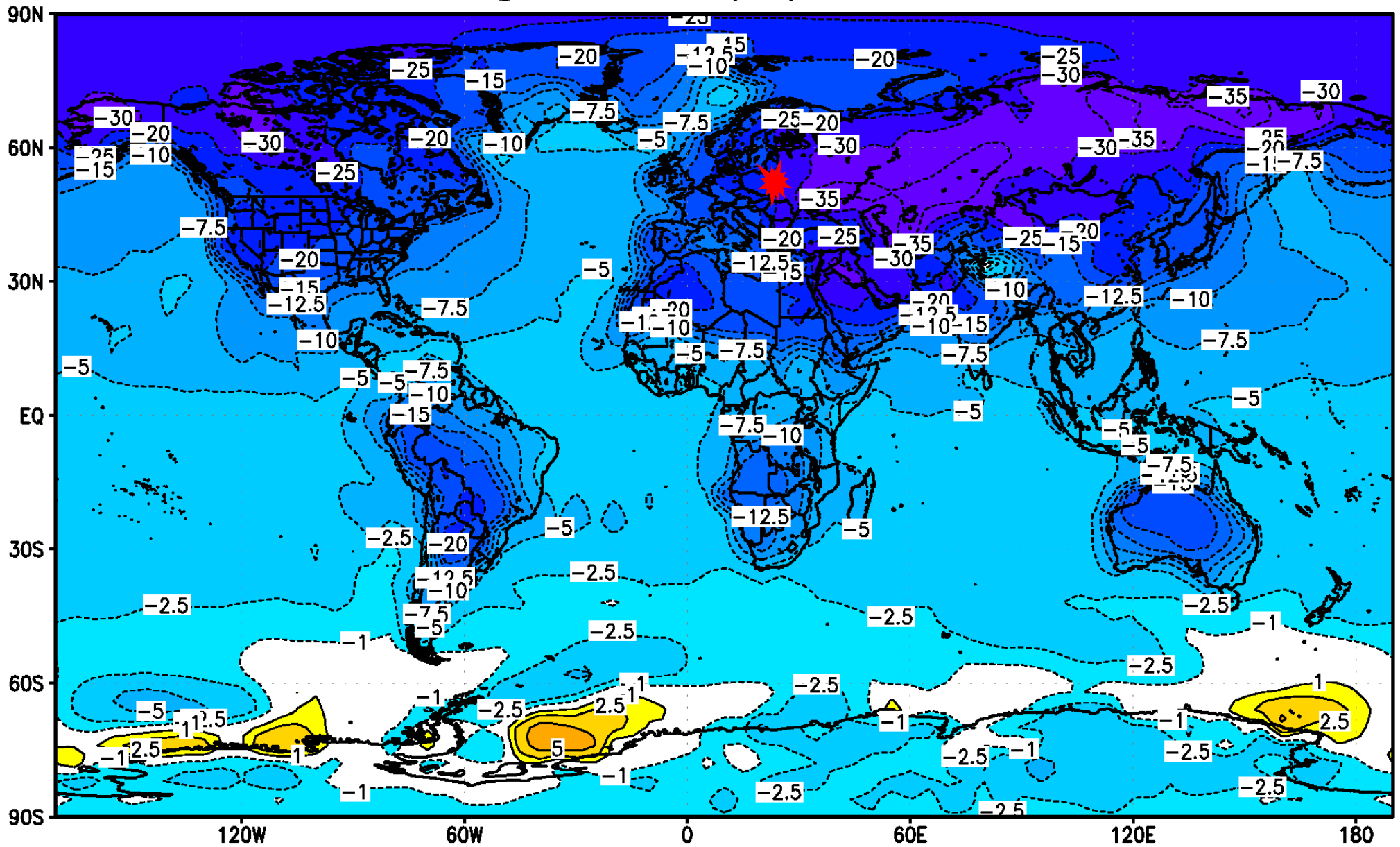
BC Absorption Optical Depth May 14th



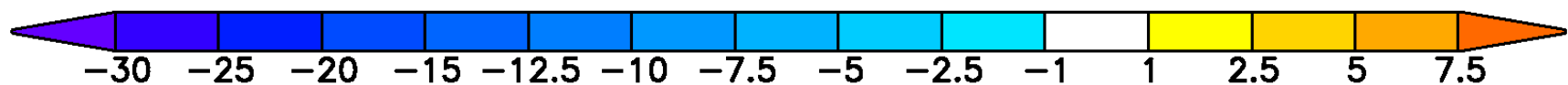
Robock et al., 2007a



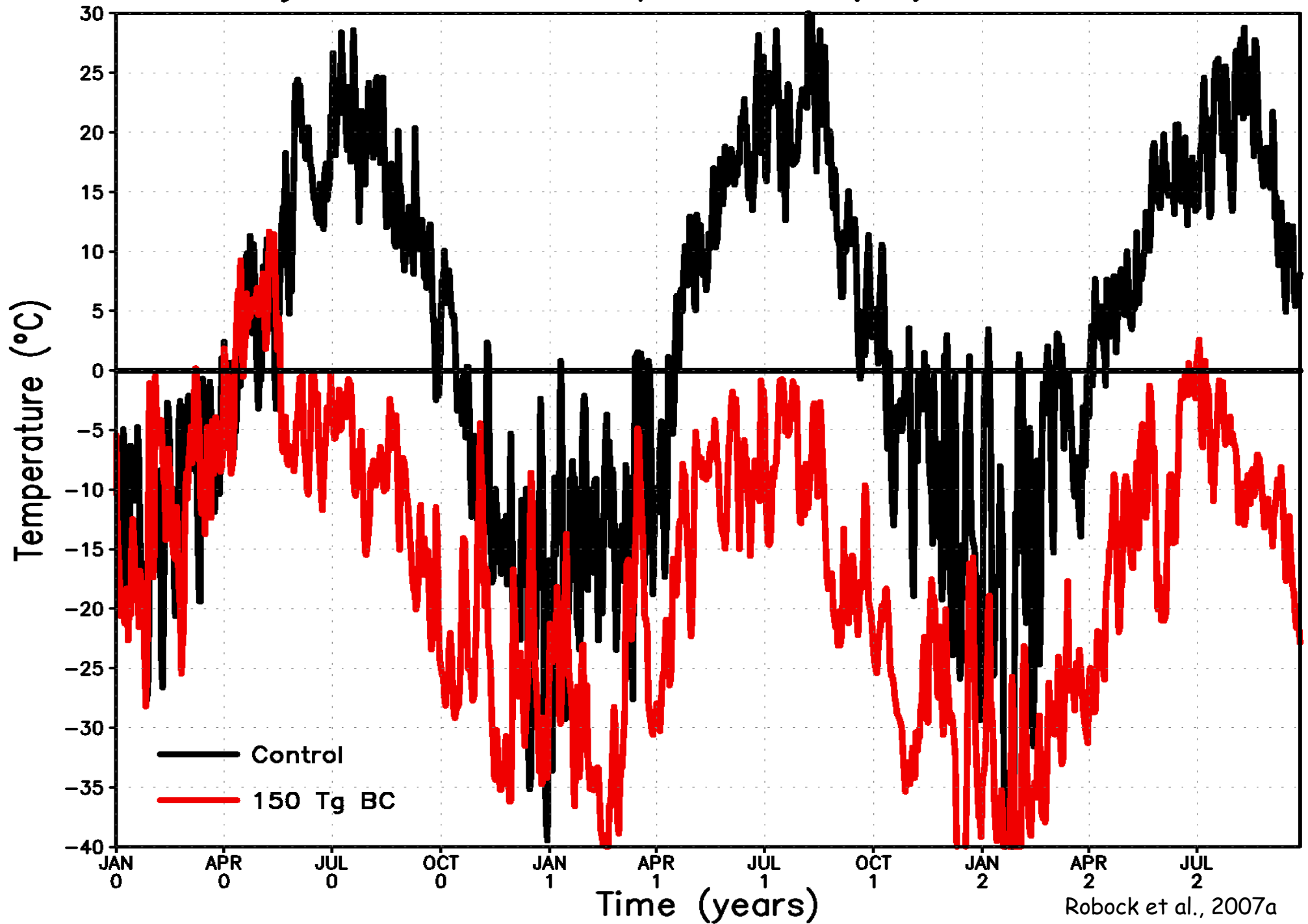
Change in SAT (°C) JJA Year 1



Robock et al., 2007a



Daily Minimum Temperature ($^{\circ}\text{C}$) 50°N 30°E



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

- horizontal resolution of $1.9^\circ \times 2.5^\circ$ (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.

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