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LAS GLOBAL STUDIES

Nuclear Winter

Nuclear Winter Responses to Nuclear War Between the United States and Russia in the Whole Atmosphere Community Climate Model Version 4 and the Goddard Institute for Space Studies ModelE

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ACDIS program in arms control & domestic and international security

Physics/Global Studies 280: Final

- The **final exam** will take place on

- **Thursday May 14th from 8-11 am**
- Final prep sessions on Tuesday 10am to noon
- and Wednesday from 3-5pm

- **Scope of exam:**
- 75 multi-choice problems (70%), cumulative

- 1 Essay question (30%)

- 50% of the multiple-choice questions will be taken from the final exams of the last 3 years (available from the course web-page)

- Uses CBTF-remote, you will be contacted with instructions by CTBF staff

Suggestions for Final Prep

(1) Study old final exams and use slides + posted reading assignments to verify your answers.

(2) Review all news discussed in class

(3) Bring questions to review sessions Tuesday, May 12th , 10-noon and Wednesday, May 13rh, 3-5 pm.

(4) Review course slides on Top Hat or on course web-page.

(5) Review reading materials.

Outline

- Background of Nuclear Winter
- How would it affect humanity?
- Current problems with assessing consequences of nuclear winter

Background

- In August, 1945, the Japanese cities, Hiroshima and Nagasaki, were hit with air burst nuclear explosions.
- Fireball temperatures of a nuclear explosion reach those in the interior of the sun,~100 million degrees Celsius, and produce a massive fireball.
- On the ground, material surfaces can reach 1000 degrees Celsius after the explosion.
- Combustible materials to burst into flames.
- The atomic bombs dropped on Hiroshima and Nagasaki started fires that burned more than 5 square miles in the two cities.

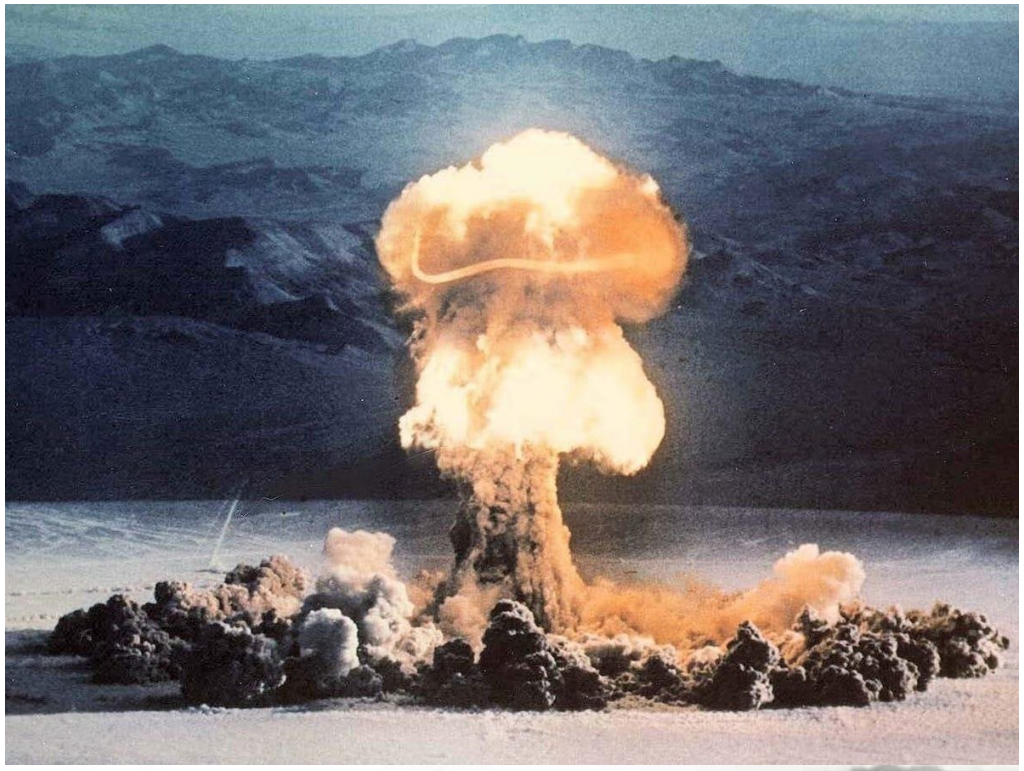
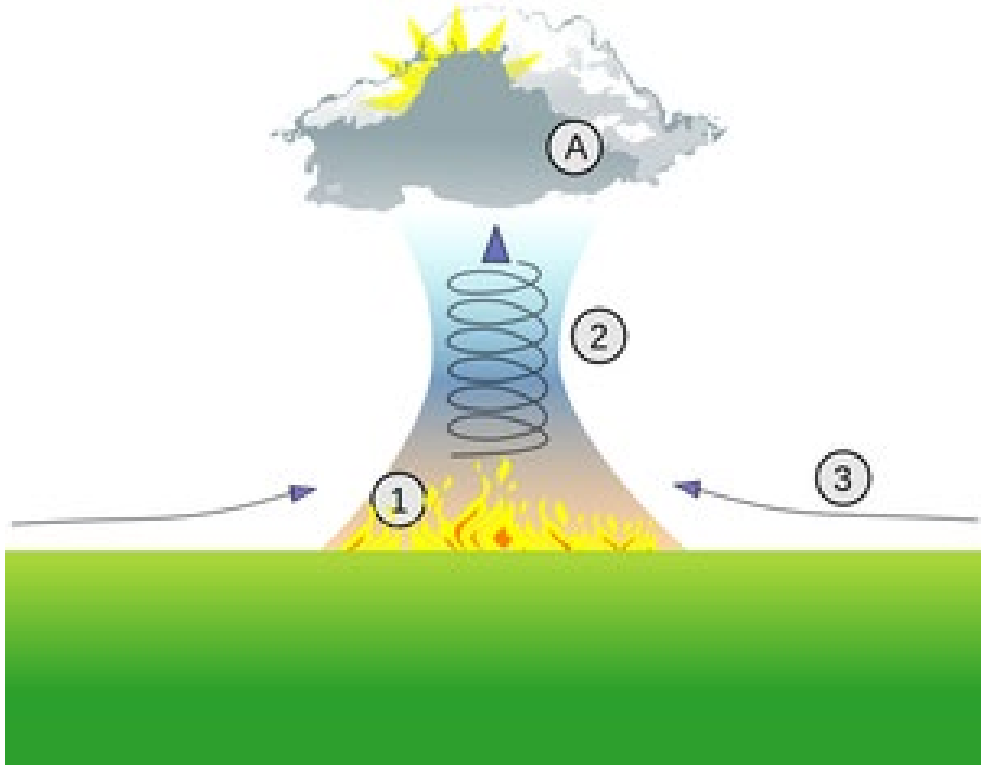


Photo at top: A 37-kiloton blast known as "Priscilla" explodes during an Operation Plumbbob nuclear test at the Nevada Test Site on June 24, 1957.

Photo at bottom: Hiroshima – 1945 after the nuclear bombing

Firestorm

1. Fires from ground zero.
2. Superheated air rises, forming hurricane-force winds.
3. Strong winds blow towards the fires near the bottom and funnel up
4. Black clouds formed by the smoke.



- This generates massive fires for hundreds of square miles.
- Observations of reduced solar irradiance might support the hypothesis that smoke was injected into the stratosphere by the city fires during WWII.

Photo: A bushfire burns in the Tallaganda national park, east of Braidwood in New South Wales on Nov. 30 2019

Questions

What is nuclear winter?

- Nuclear winter theory says that smoke from burning cities attacked with nuclear weapons will rise into the upper atmosphere and spread around the world, absorbing sunlight and cooling the surface.

What are the consequences of nuclear winter?

- Less incoming solar radiation (sunlight blocked out by smoke)
- Global surface cooling
- Crop failure (growing season reduced) and famine
- Precipitation reductions (weak summer monsoon)
- Ozone depletion (human health problems)

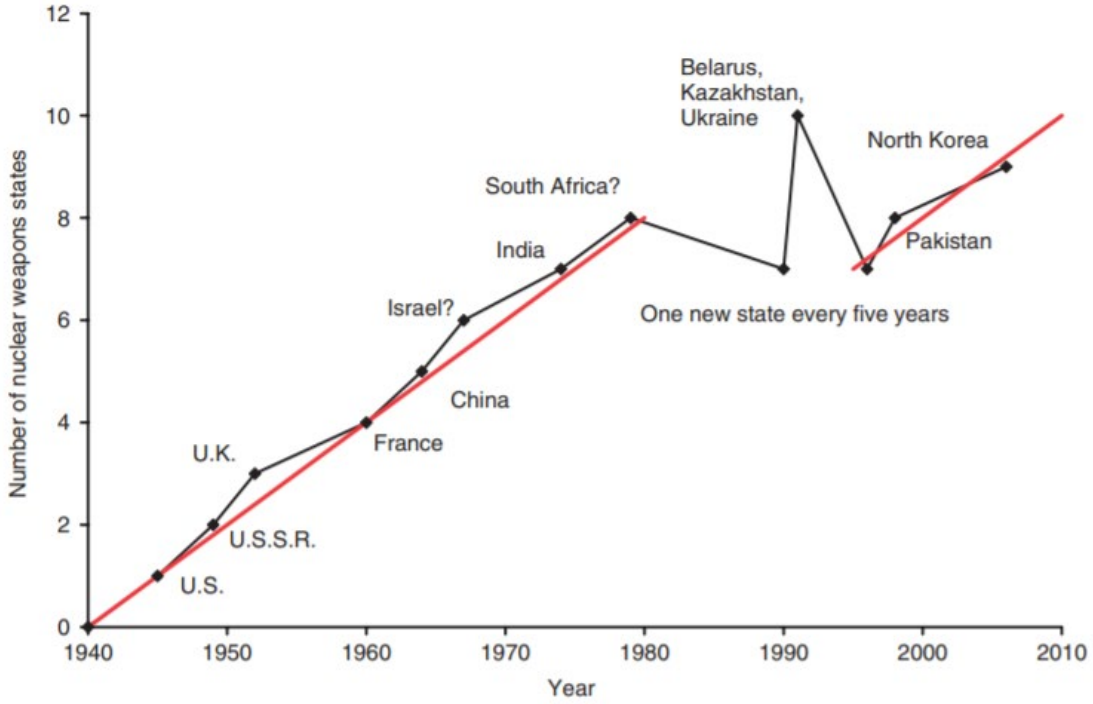
Nuclear Winter

Global Cooling

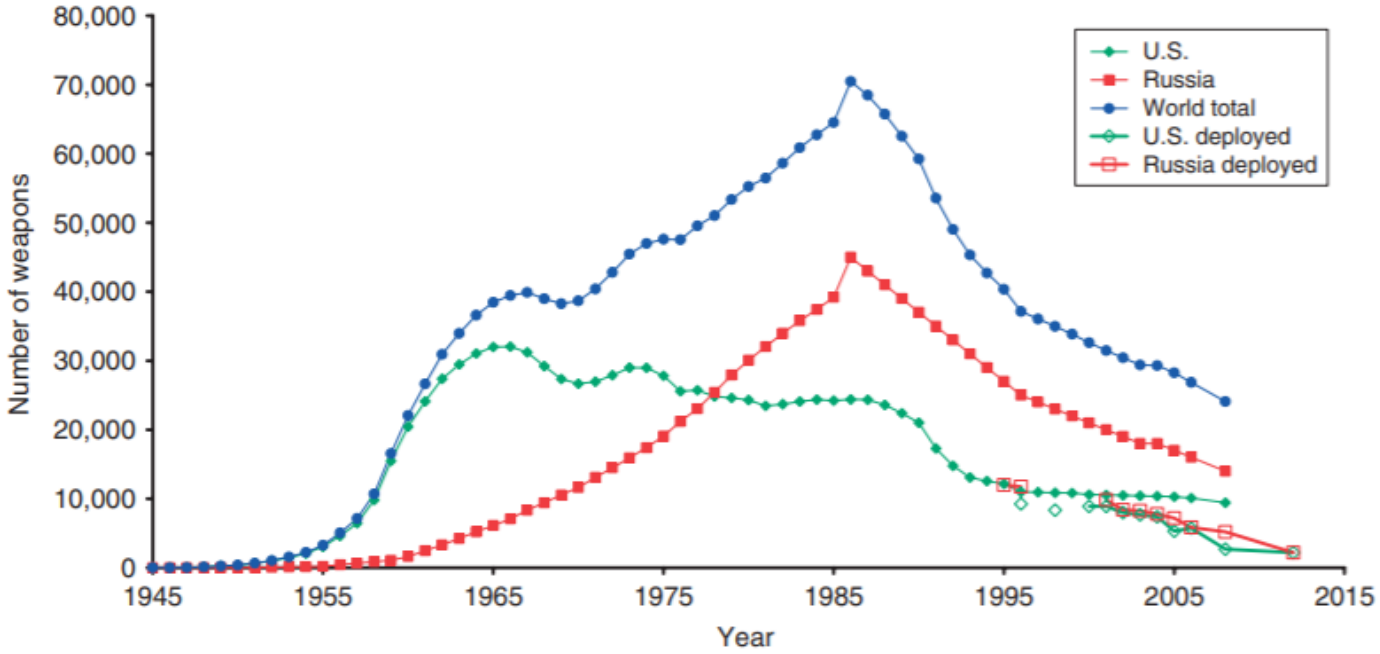
- Studies showed that the average global surface temperature will drop as much as 9-10 degree Celsius in the 2 years following a nuclear war between Russia and USA (Robock et al. 2007).

- The received global surface radiative power received will be reduced by 100-120 W/m^2 compared to normal 1000 W/m^2

Global nuclear weapons stockpiles



New nuclear states have steadily appeared since the invention of nuclear weapons

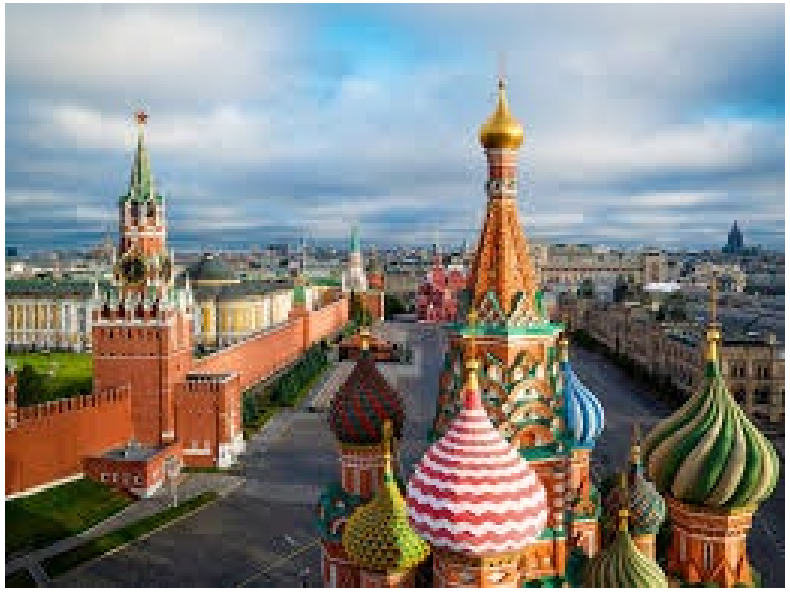


Number of nuclear warheads in Russia (formerly USSR), the US, and the total for all the nuclear weapons states.

Approximate Number of Nuclear Weapons in the Arsenals of Different Countries As of January 2006 and 2017

Country	Number of Weapons	
	Year 2006	Year 2017
Russia	10,000	4300
United States	10,000	4000
France	350	300
China	200	270
Britain	200	215
Israel	75– 200	80
India	40– 50	130
Pakistan	<50	140
North Korea	<15	<15

From Norris and Kristensen [2006]. The totals for the United States and Russia do not include warheads awaiting dismantlement. For 2017 data adapted from https://thebulletin.org/nuclear-notebook-multimedia/



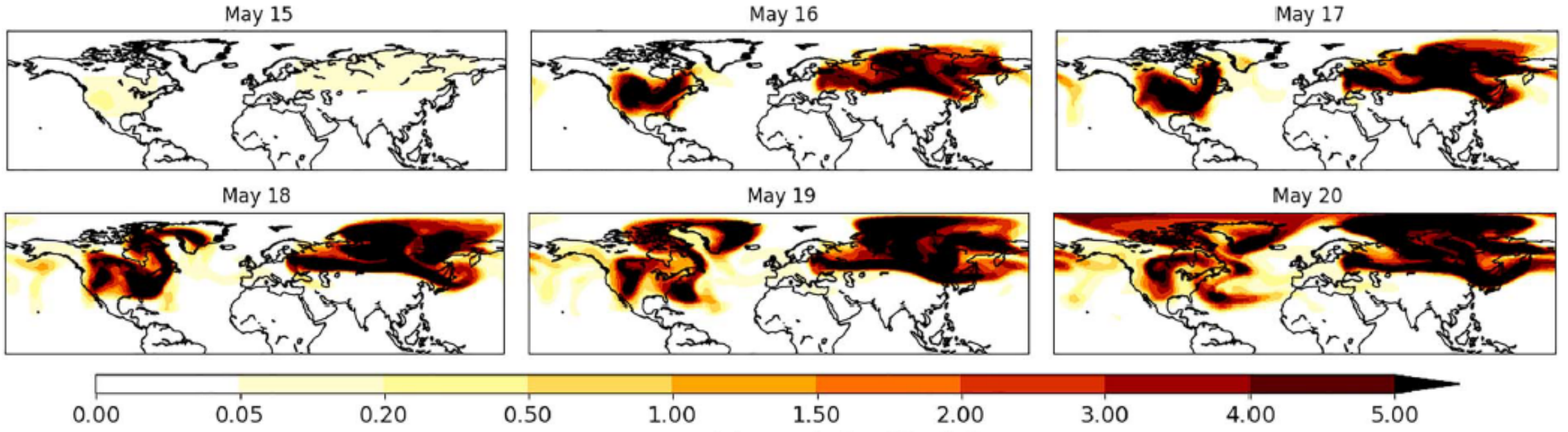
Nuclear Winter (Case Study 1: US vs. Russia)

Total explosive yield of warheads	5000 Mt -- 95% of the world arsenal at 2006
Targeting	Main population centers attacked
Population density	U.S. ~ 36 persons/km^2 (2019) Russia ~ 8.4 persons/km^2 (2019) New York ~ 10,194 persons/km^2 Moscow ~ 8,537.2 persons/km^2
Smoke emission	150 million metric tons

Roughly 150 million tons of smoke would be emitted after the use of the full US and Russian nuclear arsenals, with about 5000 Mt explosive power.

Black Carbon Emissions

11 km above Ground Zero Soot Mass Mixing Ratio (10^{-7}kg/kg)



Soot Mass Mixing Ratio (10^{-7}kg/kg)

Figure 1 Coupe et al. 2019

Black carbon concentration in kg per kg of air near where the air pressure is 0.25 times the surface pressure. (0.25 atmospheres is the pressure near the "tropopause," which bottom of the stratosphere.)

Black carbon is injected near the tropopause (~ 12 miles up)

- Self lofting due to solar heating lifts well into the stratosphere
- During the first week, it spreads out over the targeted countries, Russia and the United States.
- After about 2 weeks some of the soot starts dispersing into the Southern Hemisphere.

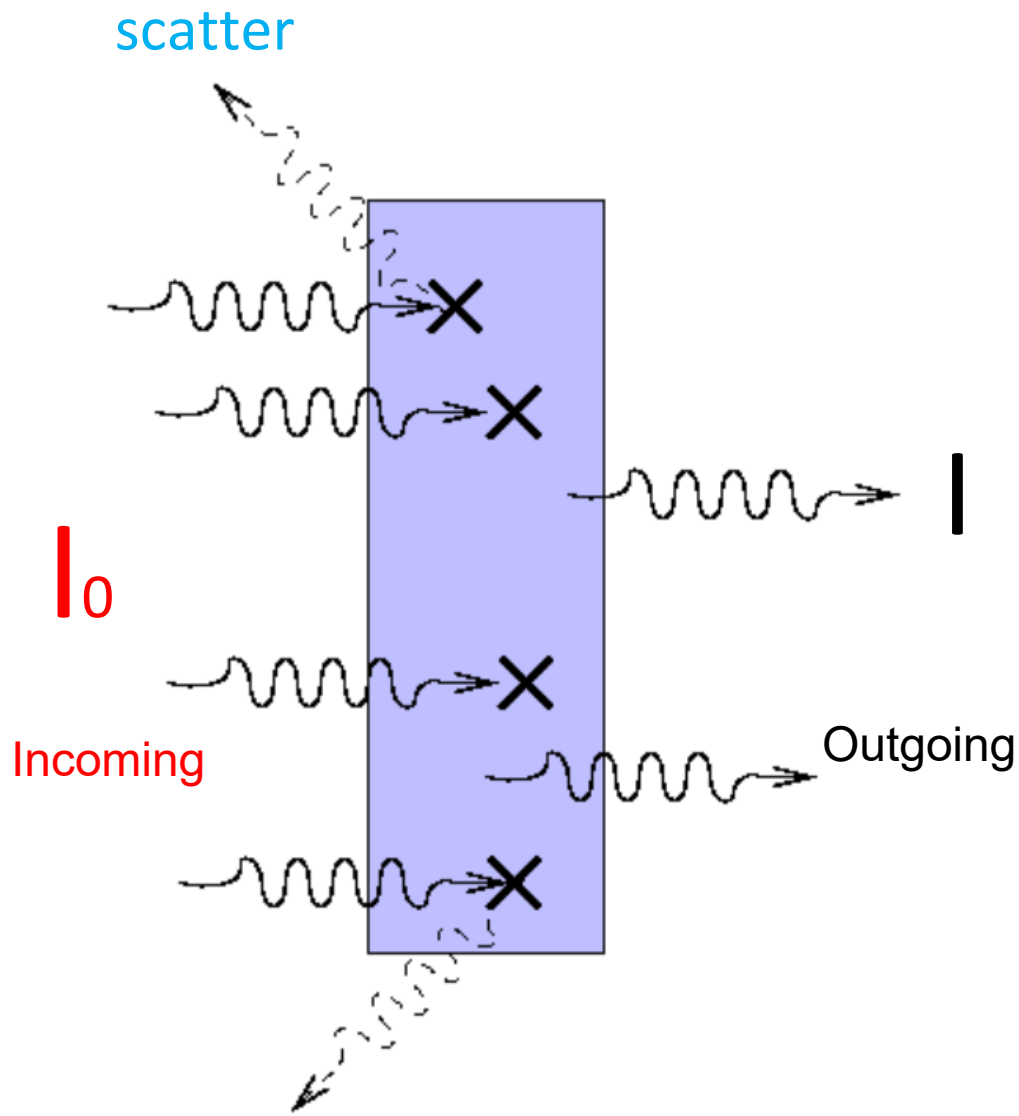
Smoke Particles Absorb and Re-scatter Light

$$\frac{I}{I_0} = e^{-\tau}$$

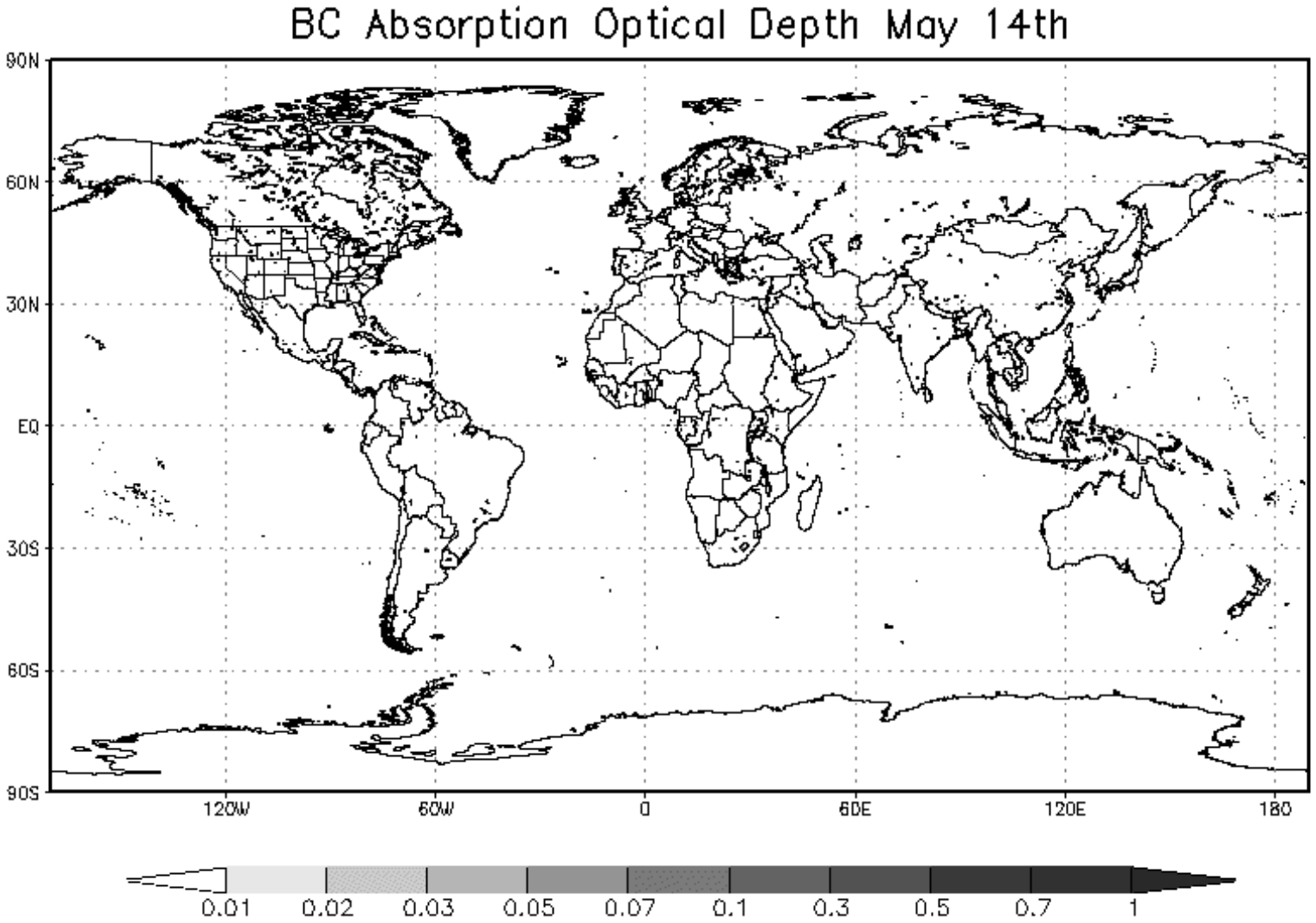
,where τ is called the **optical depth**

Optical depth of 0.1 ➔ only 90% of radiation reaches earth's surface.

Optical depth T measures the ability an object block the sunlight.



Smoke Distribution after US vs. Russian Nuclear War



150 million tonne of smoke from a nuclear war between Russia and U.S. using the entire current arsenal from Robock et al., 2007b

- Left is an animation of the smoke distribution as it is spread around the world by the winds.
- The smoke is heated by absorbing sunlight, lofted into the upper stratosphere, and blown into the Southern Hemisphere.

Photo credit: **Luke Oman**

Changes in visible optical depth

How Does Nuclear Winter Work?

Simple "Black Body" Model Estimation

$$E_{BB} = \sigma T^4$$

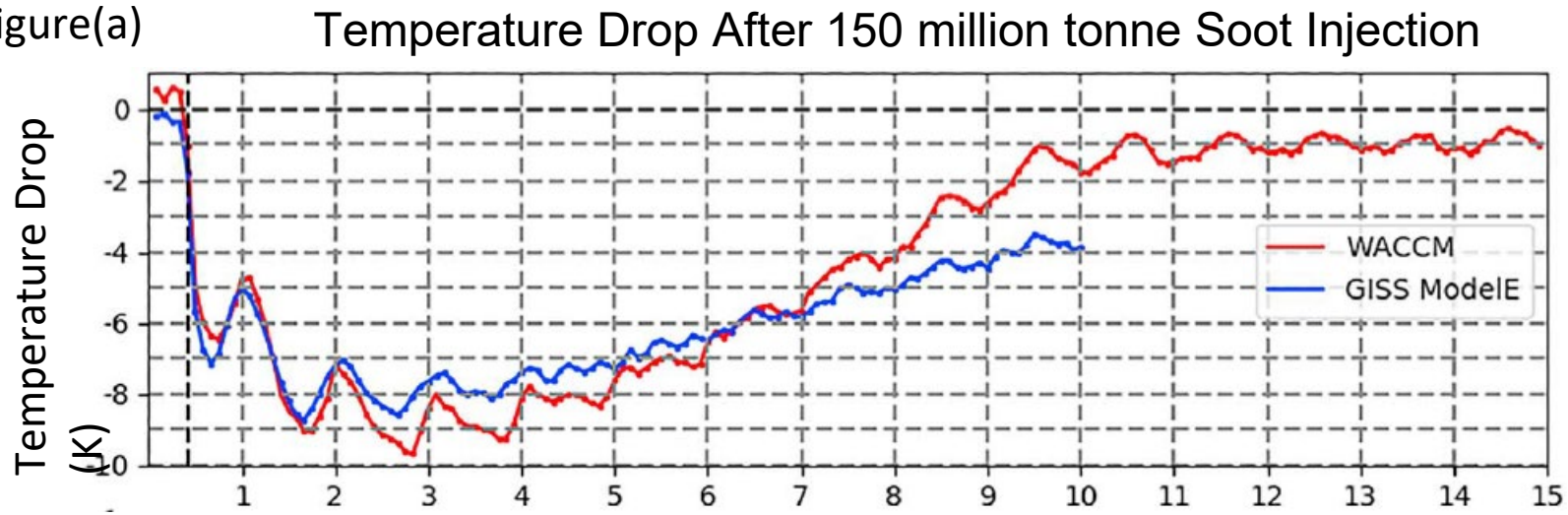
- Where σ = 5.67 ×10^{-8} $Wm^{-2}K^{-4}$ is Stefan-Boltzmann constant.
- % temperature reduction in degrees Kelvin (°K) is about ¼ of the % W/m^2 reduction
- Average earth temperature is nearly 300 °K
- 10% W/m^2 reduction give temperature reduction of (10%/4)x300 °K =7.5 °K
- a 7.5 °K reduction is a reduction by 13.5 °F.

In the Whole Atmosphere Community Climate Model (WACCM)
and Model E from the Goddard Institute for Space Studies (GISS)
there is additional temperature drop due to feedback effects:

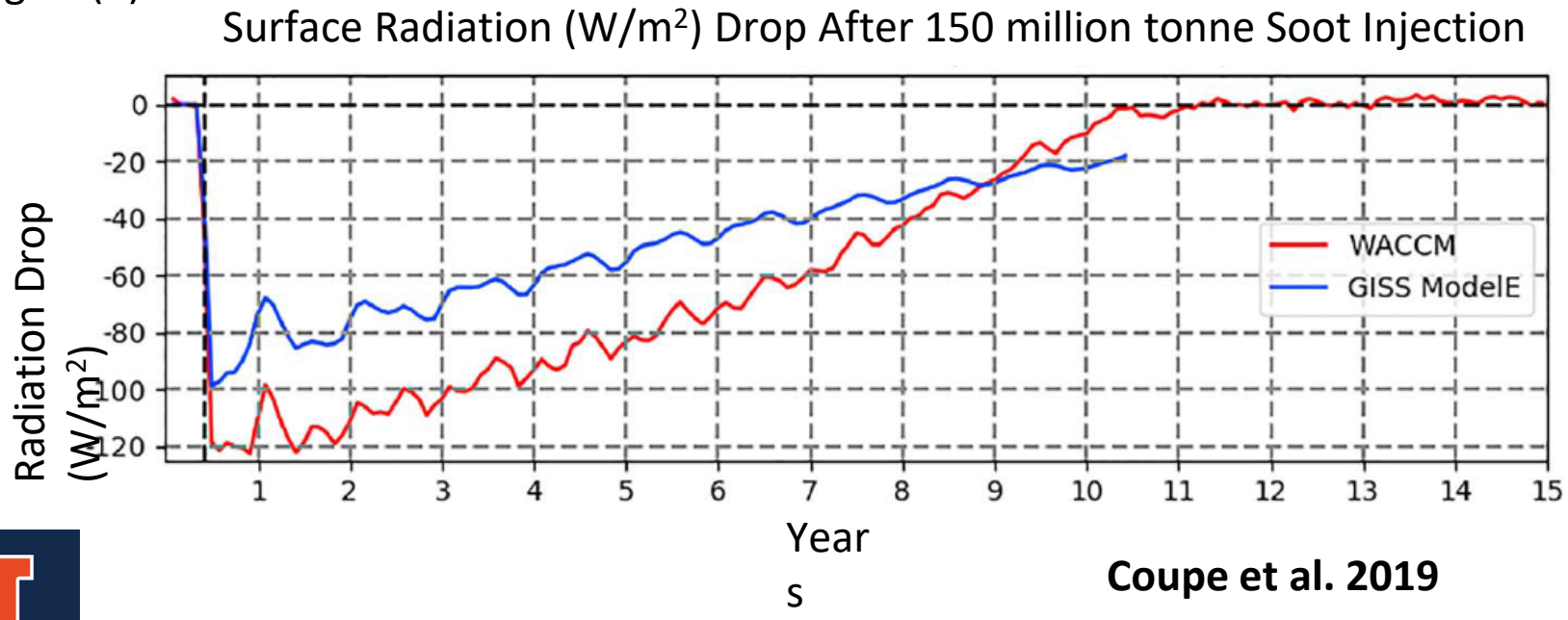
- Lower temperature → More snow and ice → Reflects more sunlight
- Lower temperature → Less atmospheric water vapor, which is a greenhouse gas

Nuclear Winter (US vs. Russia)

Figure(a)



Figure(b)



Coupe et al. 2019

- **Global surface average temperature will drop as much as 9-10 degree Celsius.**
- Reductions of up to 120 W/m^2 during the first year, the average .

Monthly global mean
(a) surface temperature drop in (^{o}K),
(b) surface radiation drop in (W/m^2).
Soot particles gradually aggregate and fall to earth.

Effects on Agriculture

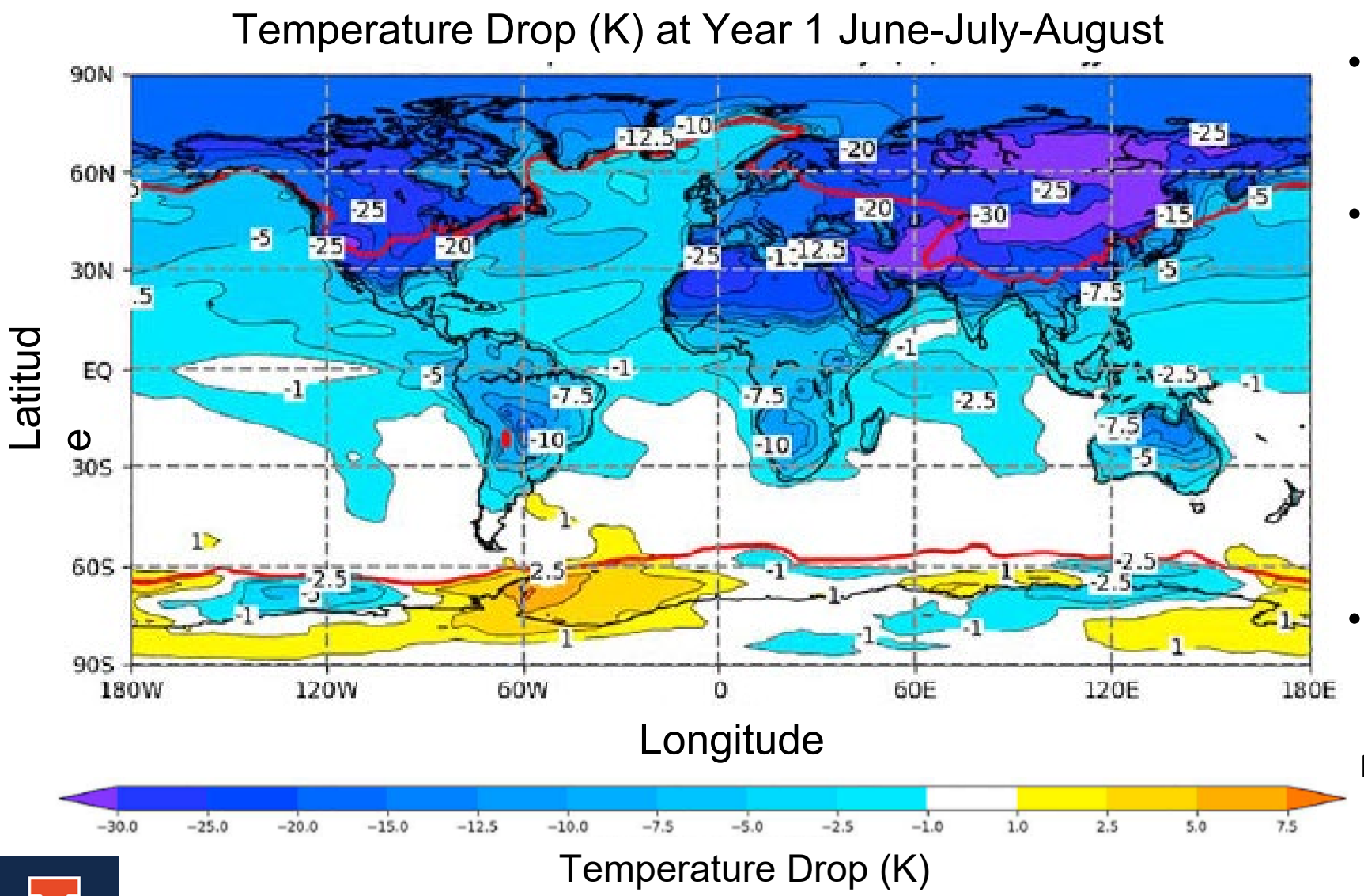
Lower temperature → Shorter growing season

(Could be years of freezing temperatures all summer in most of USA & China)

Less radiative heating of oceans → Less precipitation

(Less cooled subtropical regions can have weaker monsoons)

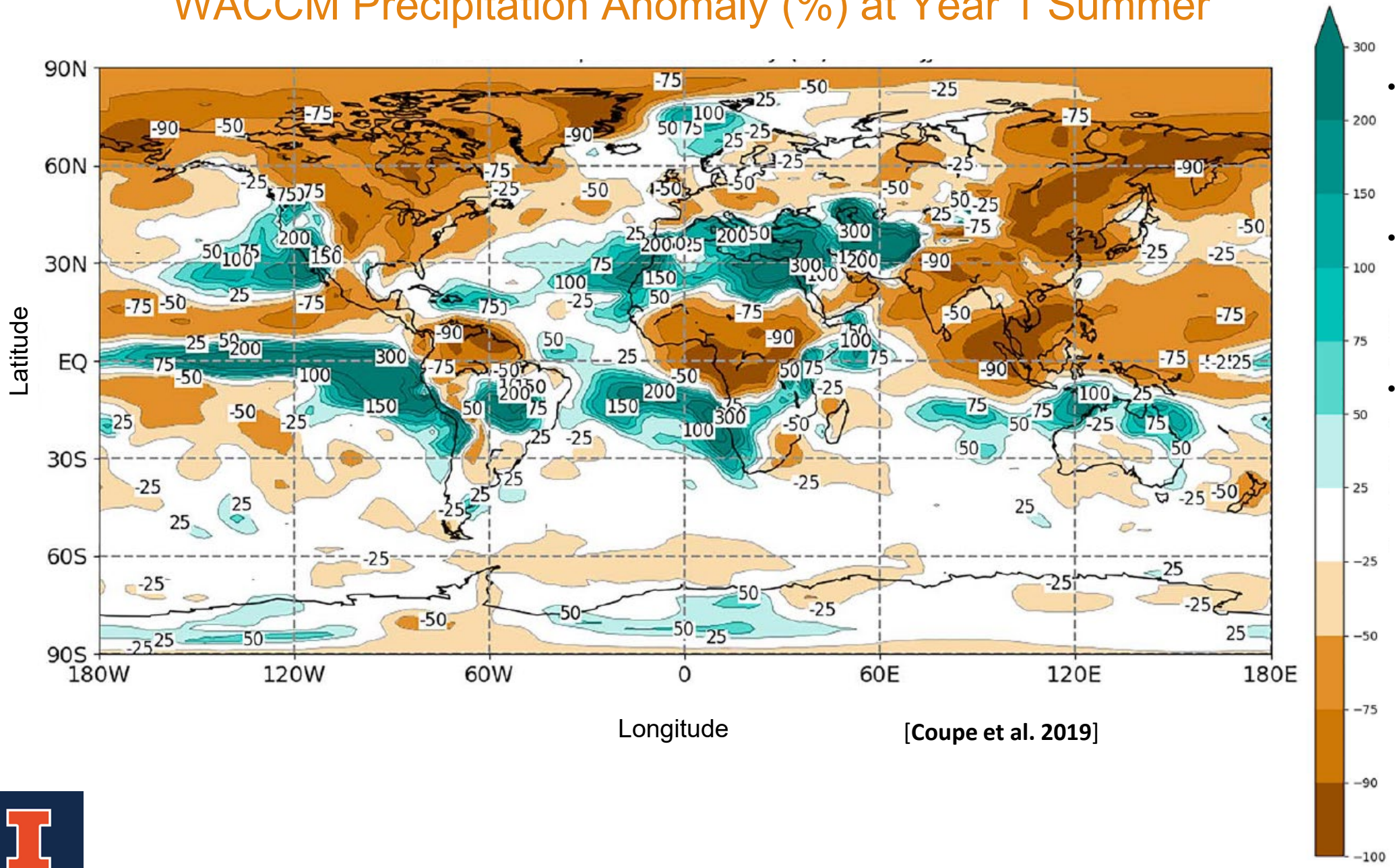
Nuclear Winter: Temperature Drop



- Temperatures drop below freezing over much of the north hemisphere during summer.
- The red contour represents the boarder above which, poleward, the temperature is below 0 °C during the following summer
  - shows a shift as far south as northern Texas, Arkansas, and Missouri in the United States
- Cooling is less significant in the Southern Ocean.

[**Coupe et al. 2019**]

WACCM Precipitation Anomaly (%) at Year 1 Summer

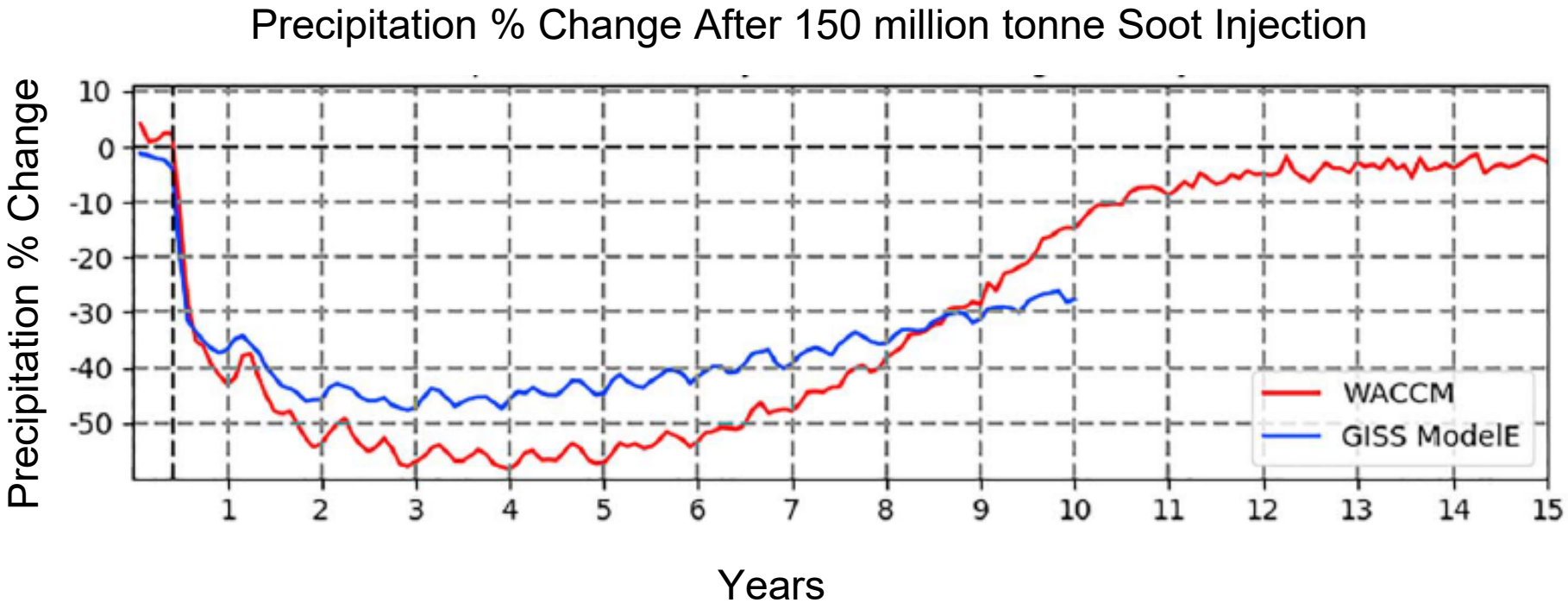


[**Coupe et al. 2019**]

- Across much of the continental areas in the high latitudes, the precipitation reduced much.
- However, in the eastern equatorial Pacific Ocean, there is 100% and greater increase in precipitation.
- Across the entire eastern portion of the Asian continent, cold and dry air settles down causing anomalously high pressure drive consistent surface wind blowing from continents to ocean.

Nuclear Winter

Global Average Precipitation % Change



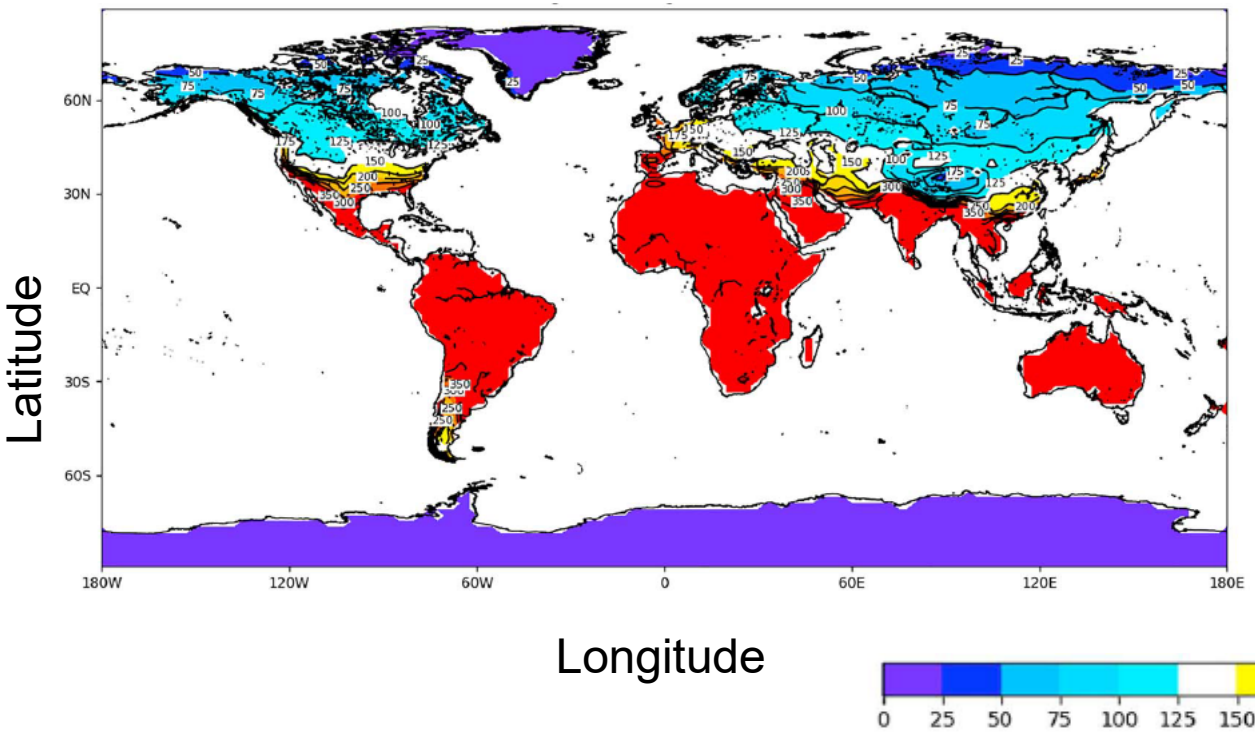
- 30% decline in global precipitation through the first few months of the soot injection.
- Persistent El Niño for more than 7 years after the injection of soot
- Southern Asia suffers from a collapse of the summer monsoon,and does not return for at least 7 years. [**Coupe et al. 2019**]

Note: Starting with the second June after the May injection.

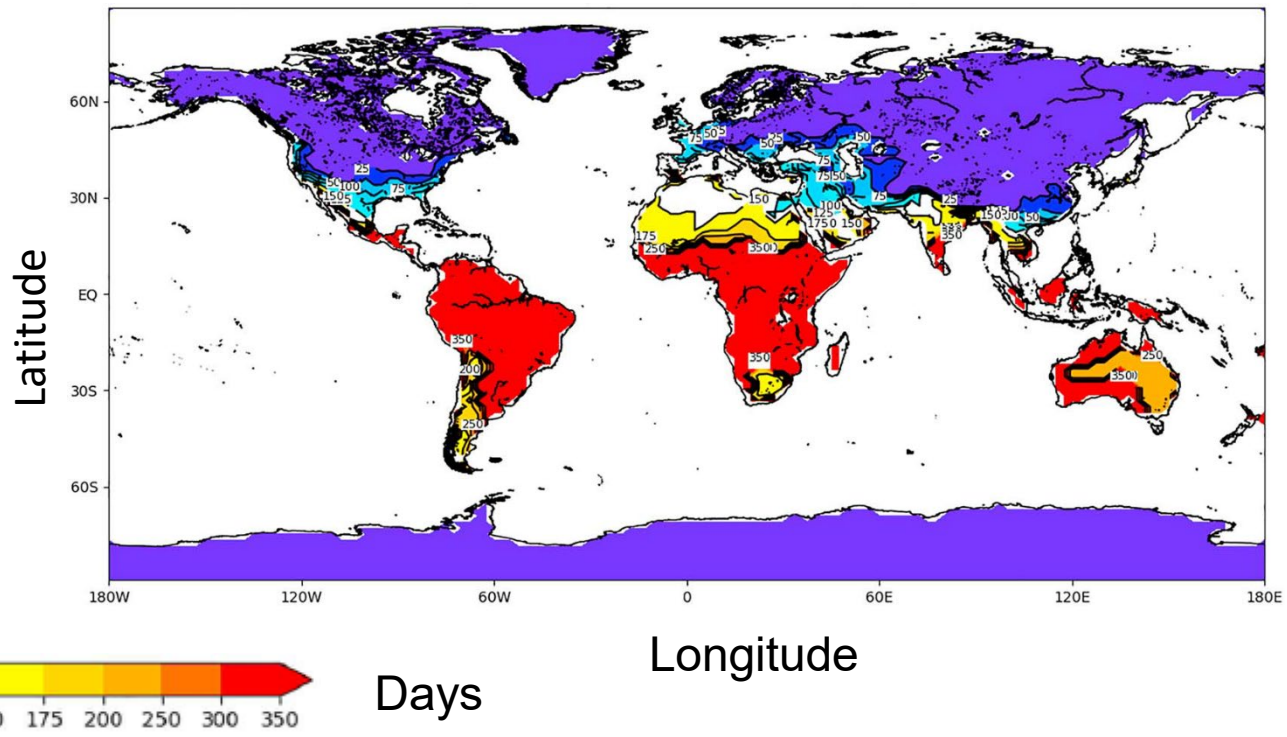
Nuclear Winter

Crop Failure

Growing Season Length (Without Nuclear Attack)



Growing Season Length Year 0-1 (With Nuclear Attack)



- The length of the growing season drops below 50 days across most United States.
- Most of Eastern Europe's growing season is reduced below 50 days, and all parts of Russia have their growing season reduced below 25 days. [**Coupe et al. 2019**]

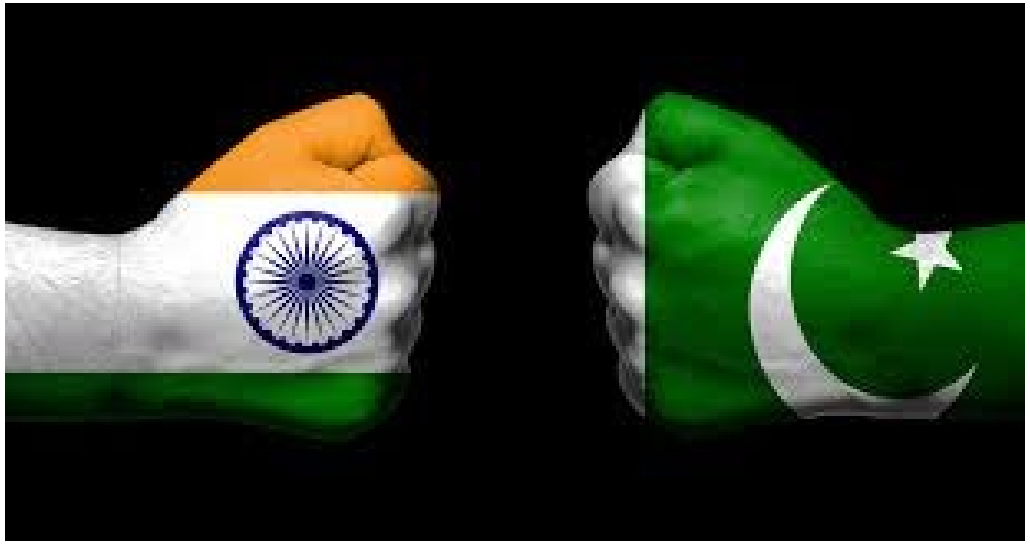
Regional Assured Destruction Nuclear War

Russian and US nuclear battle strategies use many high yield weapons (up to 300 kilo tonne) on rural military targets for ground bursts.

Lower yield weapons (~20 kilo tonne) are used to target population centers for regional mutual assured destruction. This is predicted to produce 100 times as much stratospheric soot per nuclear weapon kt.

Continuing growth of regional nuclear arsenals (e.g. in Pakistan and possibly India) leads to additional possibilities for impacts on global agriculture.

Nuclear Winter (Case Study 2: India vs. Pakistan)

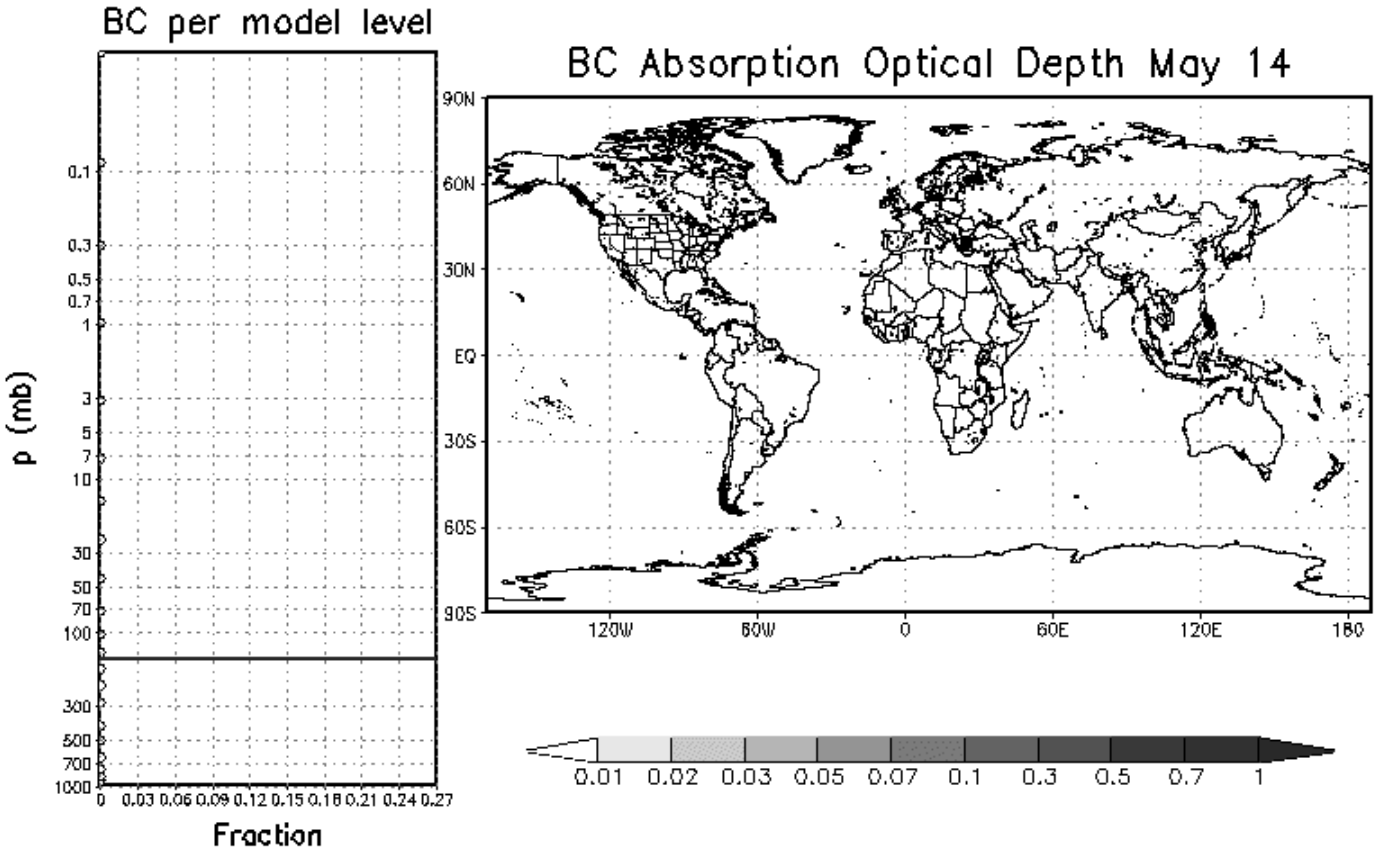


Geographic region	India vs. Pakistan
Number of warheads	100 at 15 kt each ("Hiroshima size")--only 0.03% of the total world arsenal (2006)
Targeting	Main population centers attacked
Burnt area per bomb	13 km^2 (same as in Hiroshima)
Population density	20 000 persons km^{-2}
Fuel loading	11 tons $person^{-1}$
Average soot emission factor	0.016 g(soot) $(g(fuel))^{-1}$
Diameter of soot particles	100 nm, 200 nm

Stenke et al. 2013

Smoke Distribution after India vs. Pakistan Nuclear War

5 million tons of smoke



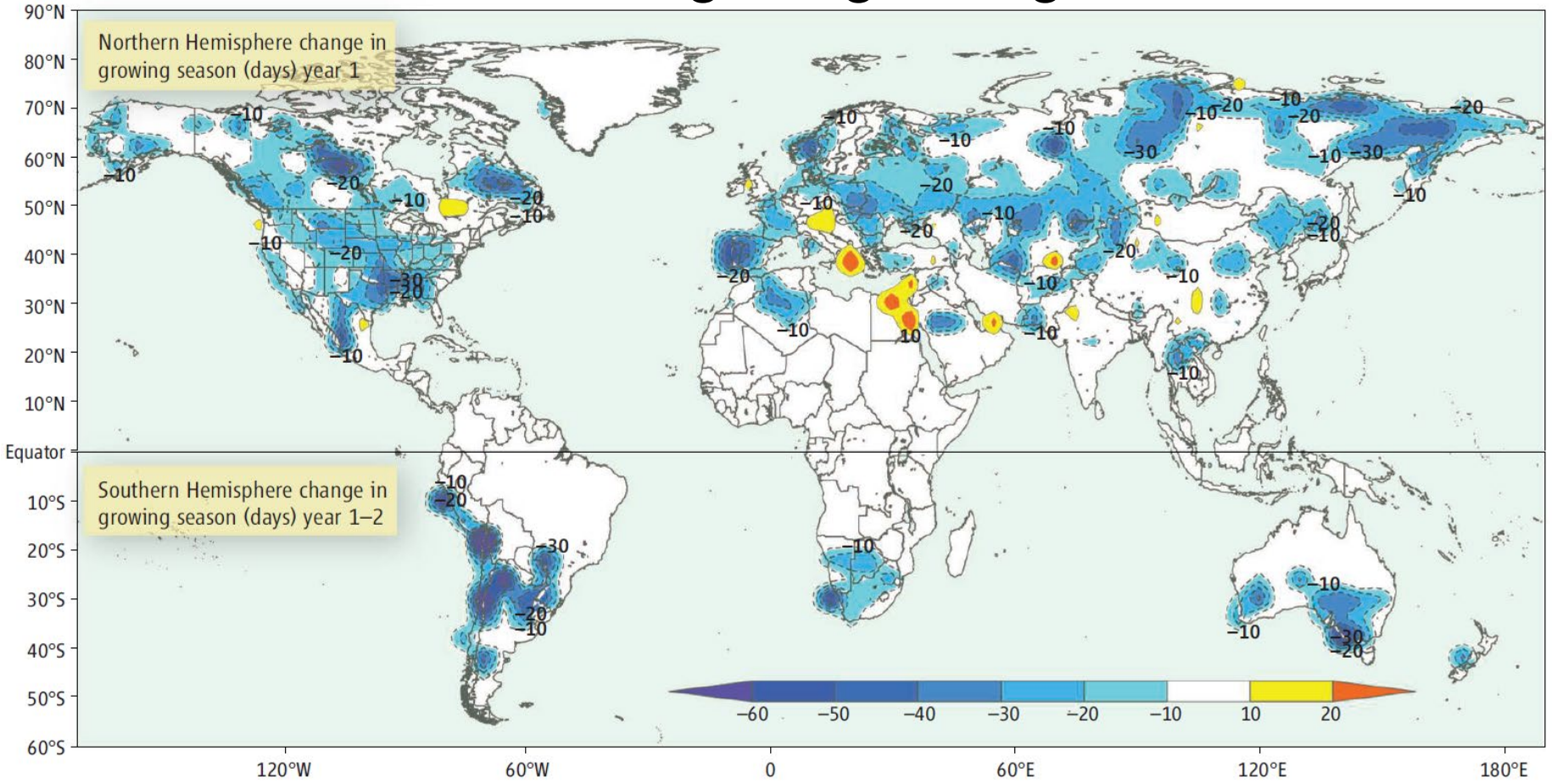
- Within the first week, the smoke in the troposphere is lofted or washed out by rain, and the remaining smoke is lofted well into the stratosphere, where it can remain for years.
- The black horizontal line at about 150 mb marks the boundary between the troposphere and stratosphere, at about 12 km (7 miles). The top of the stratosphere (at 50 km or 30 miles) has a pressure of about 1 mb.

The globally smoke distribution and vertical distribution of the smoke during the first 8 weeks

From Robock et al., 2007a, animation drawn by Luke Oman.

Nuclear Winter (Case Study 2: India vs. Pakistan)

Change in growing season



Latitude

Longitude

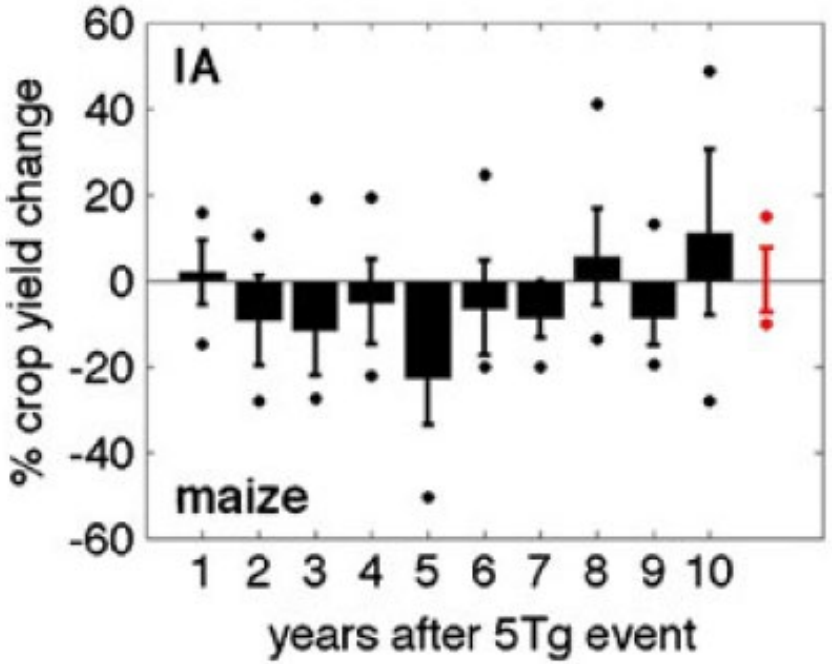
Change in growing season (period with freeze-free days) in the first year after smoke release from 100 15-kilo tonne nuclear explosions. [**Toon et al. 2007**]

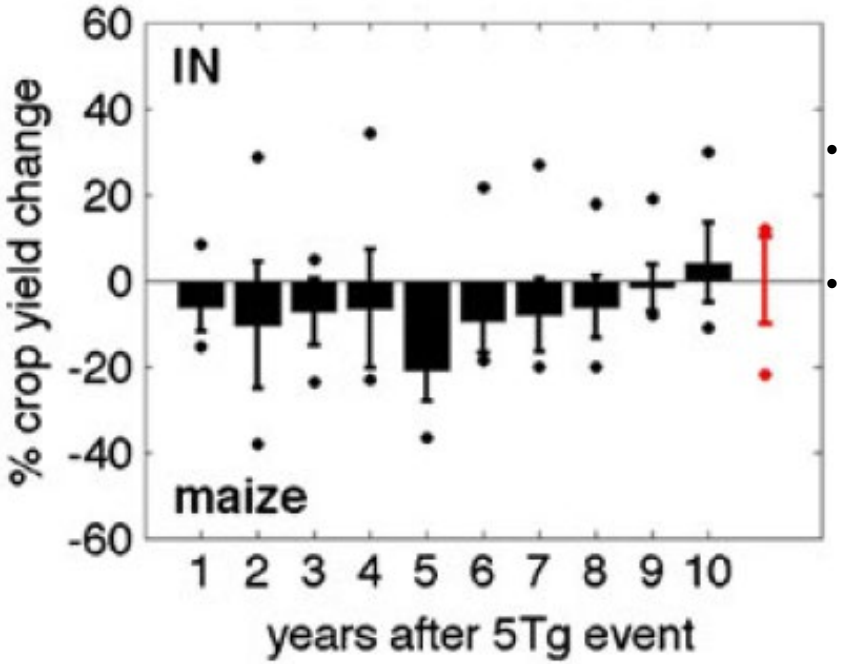
Freeze free period is the number of consecutive days where the air temperature does not fall below 28 °F or -2 °C.

Growing Season - Growing Season is the number of consecutive days where the temperature has not gone below an index temperature for specific vegetation.

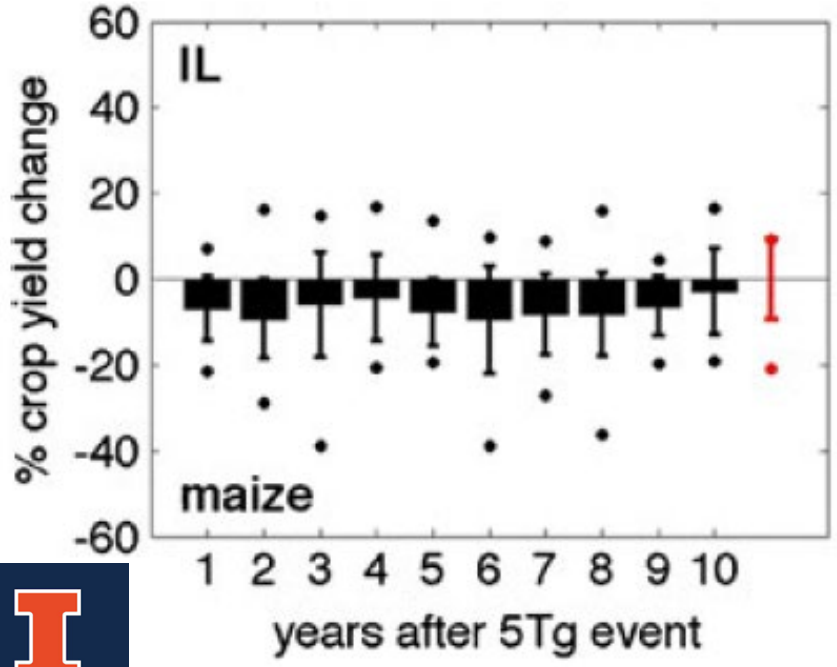
For rice to grow, the temperature must be at least 20 degrees Celsius (68 degrees Fahrenheit). Wheat, however, will sprout at just 5 C (40 F).

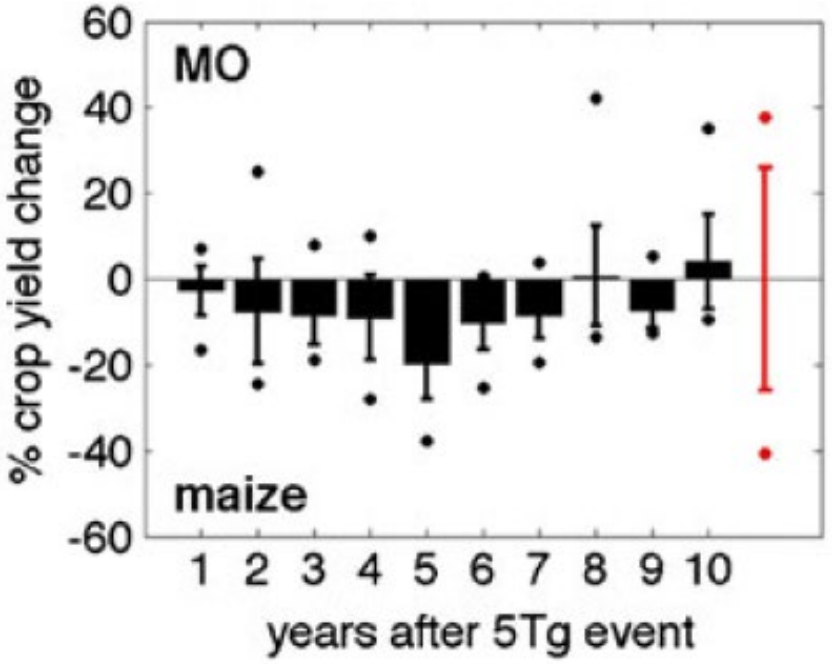
Crops	Temperature	Growing days	Precipitation (mm/total growing period)	Global Consumption 2018
Rice	68 ° F - 80.6 ° F	90 - 150	450-700	490 million tons
Wheat	Spring: 54 ° F - 77 ° F Winter: 37 ° F - 59 °F	Spring wheat: 120 Winter wheat: 210	300 - 400	602 million tons
Maize	Best 77 ° F - 91 ° F Minimum 60.8 ° F	80 -110	500 - 800	602 million tons
Soybeans	Daytime best 85° F Minimum 46.4 - 48.2 °F	90 - 150 days	450 - 700	346 million tons



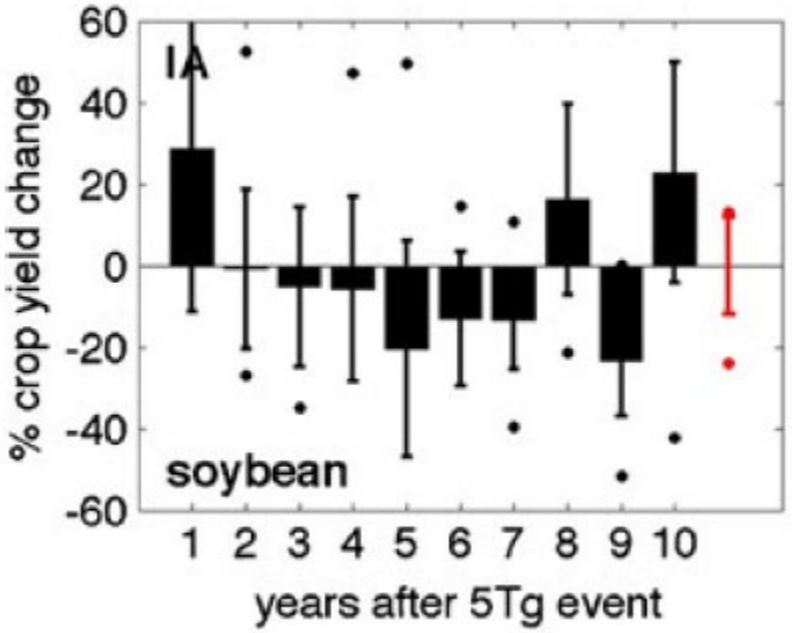


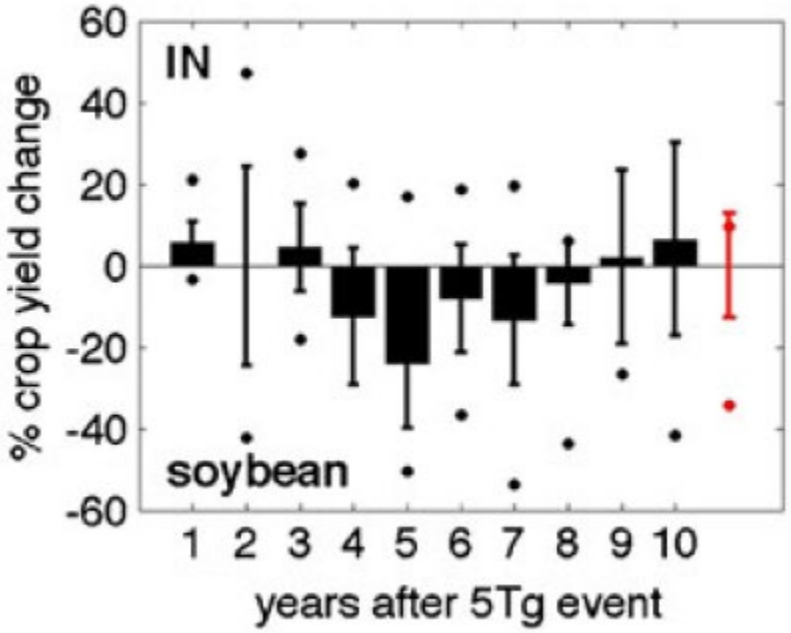
- Corn yield in Midwest reduced by 5-20% in first 5 years with later recovery.
- Typical decline in IL is 5-10%.

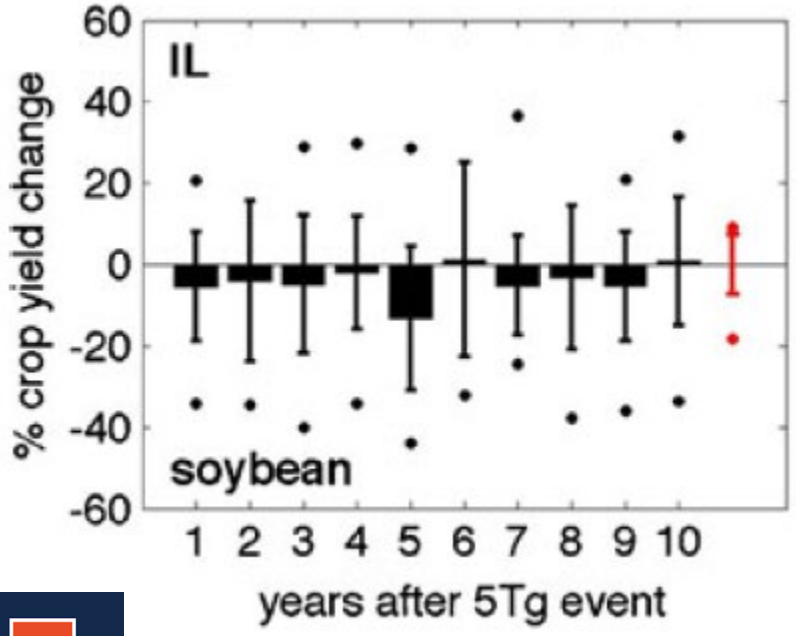


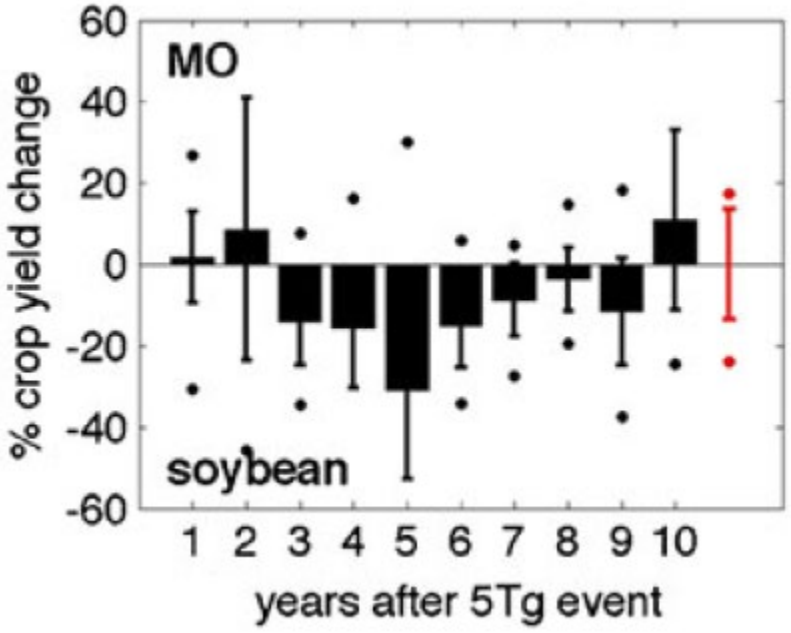


Mutlu Özdoğan & Alan Robock 2013



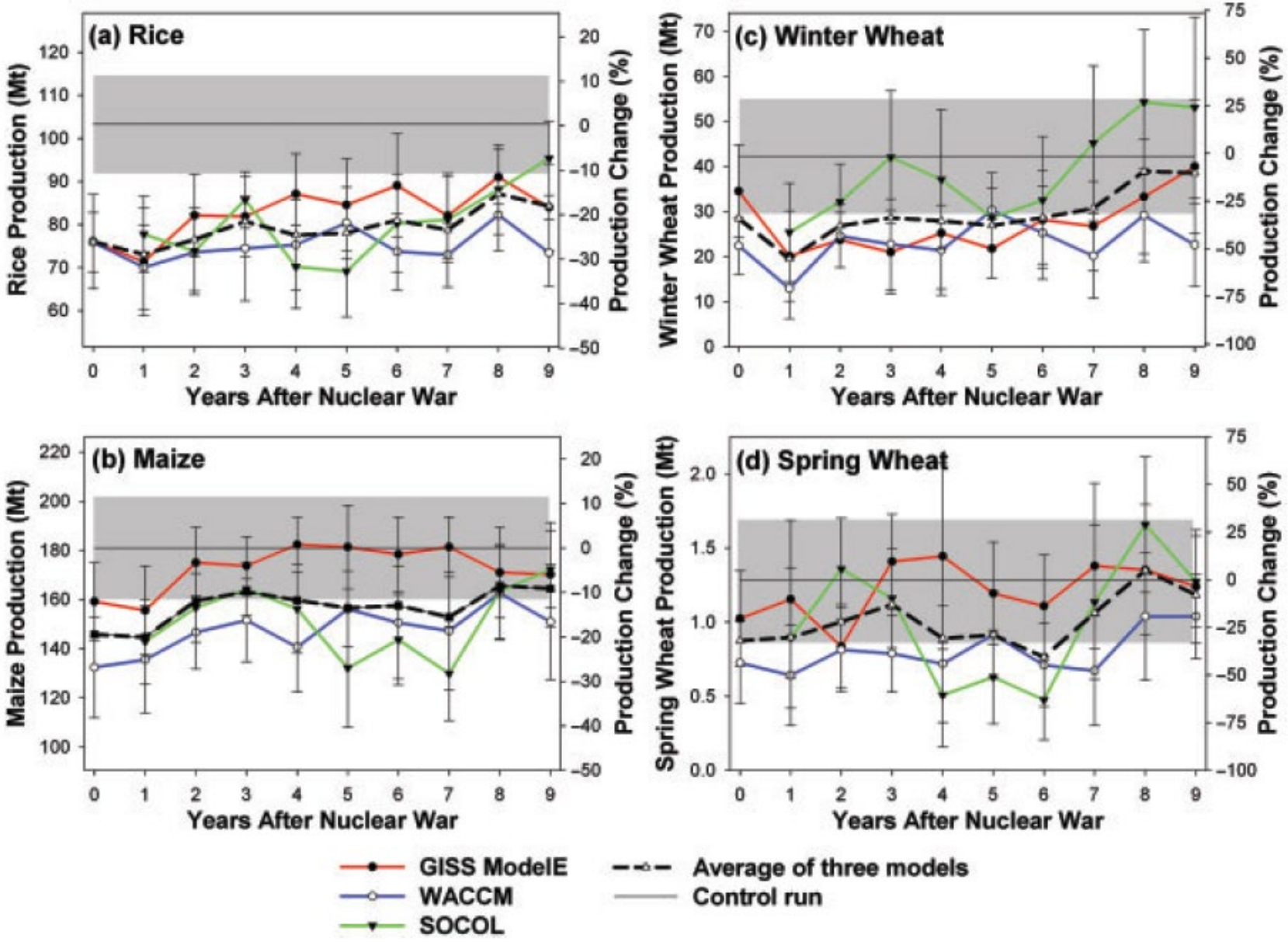






- Soybean yields show similar trends but with greater variation.

Mutlu Özdoğan & Alan Robock 2013

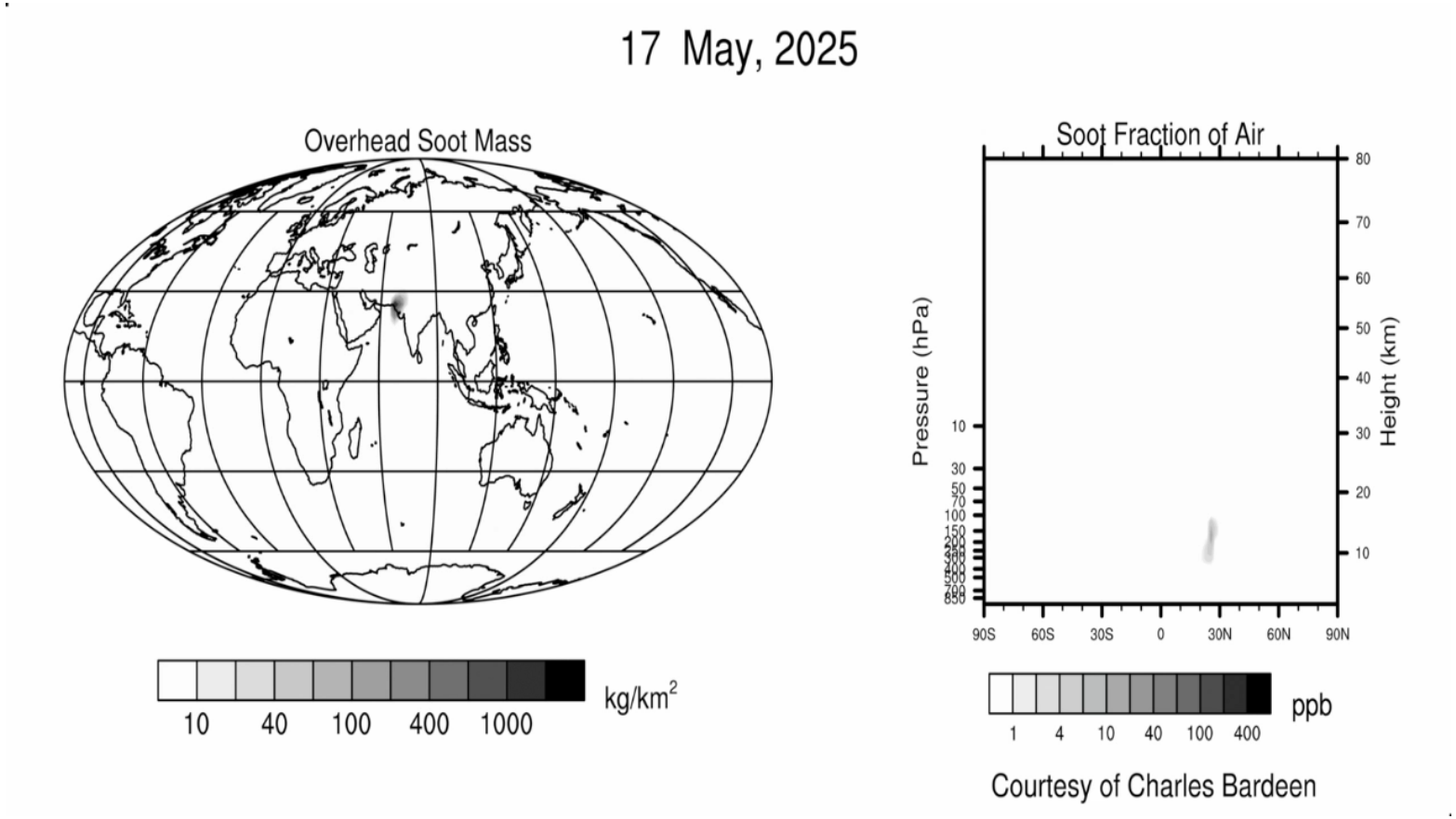


- In year 1, rice production is reduced by 30 megatons (Mt) (29%)
- The strongest maize reduction is in year 1 with a value of 36 Mt (20%) of the average of three climate models.
- Winter wheat production reduces by 50% in year 1.
- Spring wheat production reduces by 40% in year 6.

Xia, L., A. Robock, M. Mills, A. Stenke, and I. Helfand (2015)

Smoke Distribution after India vs. Pakistan Nuclear War

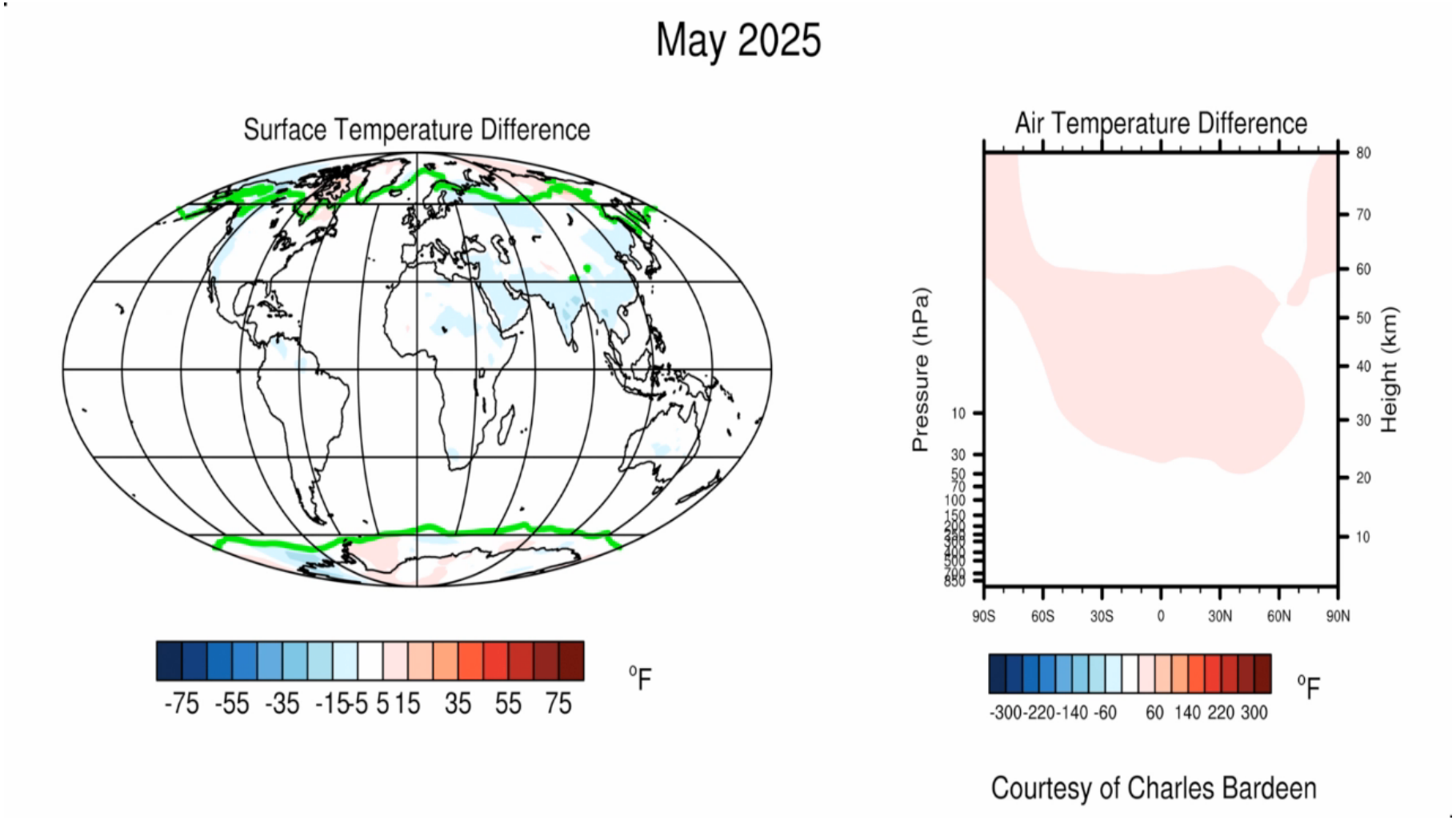
27 million tons of smoke



From Toon et al., 2019

Temperature changes after India vs. Pakistan

27 million tons of smoke



From Toon et al., 2019