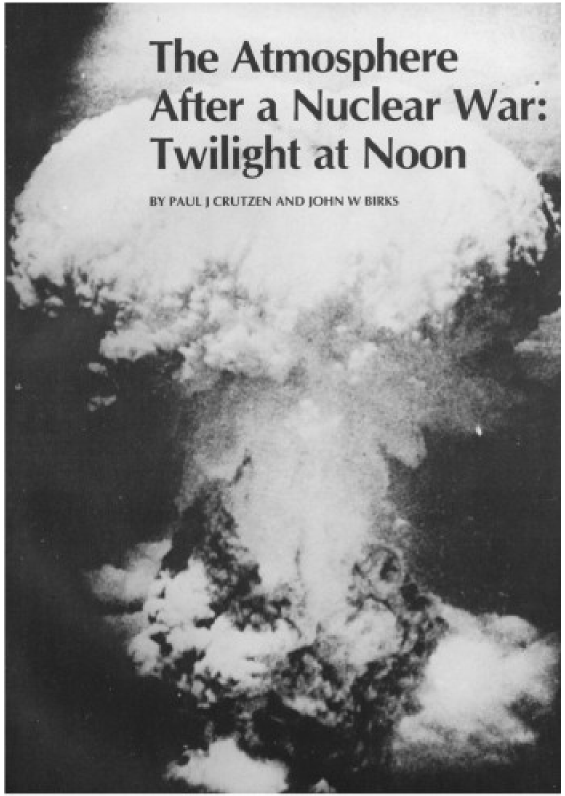
Climate consequences of a - limited - nuclear exchange

1982 : Original paper by Paul J. Crutzen (co-laureate 1995 Nobel Prize in Chemistry for his work on stratospheric ozone), and John W. Birks, in the Swedish environmental journal Ambio

- Monstrous fires in burning cities would lead to huge emission of dust and soot that could absorb Sun’s radiation for years resulting in catastrophic reduction of agricultural production throughout the Northern hemisphere.

- stimulated further scenario studies on collateral effects of nuclear explosions



Nuclear winter basics

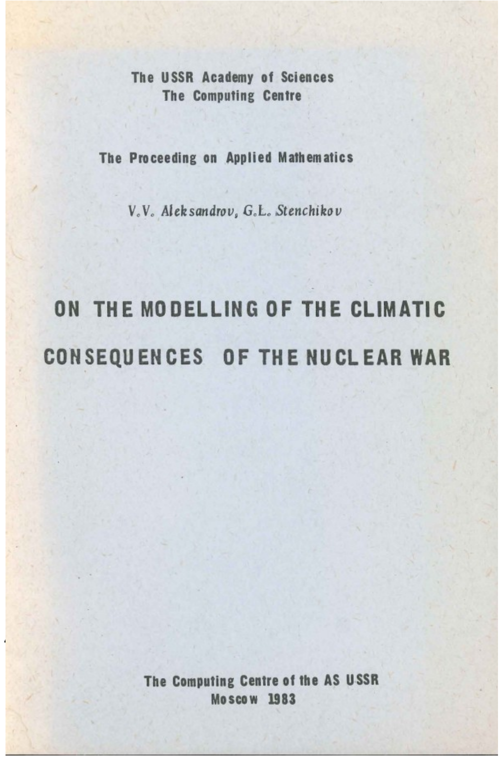
- NW exploded on cities produce fires, with massive amount of smoke rising up in the atmosphere.
- Soot disperses globally once it has reached upper atmosphere.
- Smoke blocks sunlight, earth surface becomes cold and dry, stratosphere is heated, destroying ozone and increasing UV radiation
- Sea ice extension

Use a 3D GCM with coarse resolution *:*

« Strong temperature drop over the surface of continents of the Northern hemisphere, the warm up of large mountains, the crucial change of the hydrological cycle and of the mechanism of the global circulation of the atmosphere »

1D radiative convective model, low computer power, no dynamical response, no spatial distribution

« For many simulated exchanges of several thousand megatons in which dust and smoke are generated and encircle the earth with 1 to 2 weeks […] land temperature can reach -15 to -25 °C […] Large horizontal and vertical temperature gradients caused by absorption of sunlight in smoke and dust clouds may greatly accelerate transport of particles and radioactivity from the Northern hemisphere to the Southern Hemisphere. When combined with the prompt destruction from nuclear blast, fires, and fallout and the later enhancement of solar ultraviolet radiation due to ozone depletion, long-term exposure to cold, dark, and radioactivity could pose a serious threat to human survivors and to other species » ***« Nuclear winter »***

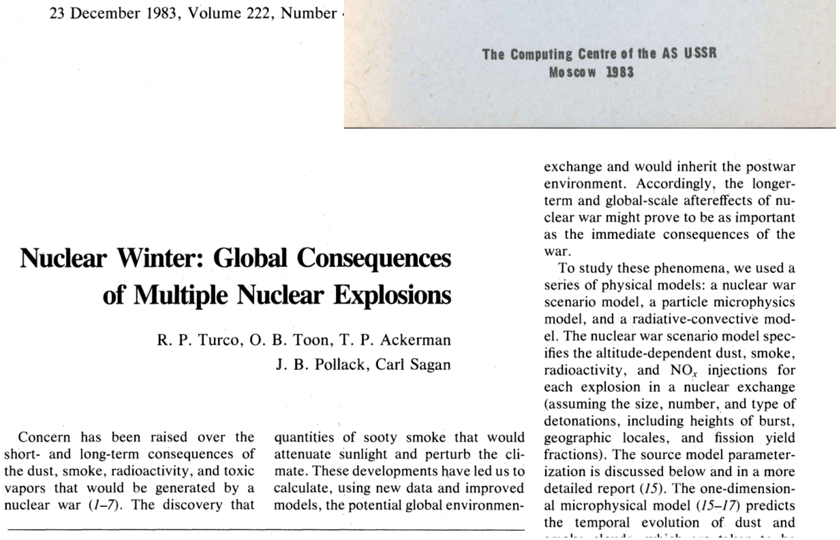

The USSR Academy of Sciences
The Computing Centre

The Proceeding on Applied Mathematics

V. V. Aleksandrov, G. L. Stenchikov

ON THE MODELLING OF THE CLIMATIC CONSEQUENCES OF THE NUCLEAR WAR

The Computing Centre of the AS USSR
Moscow 1983


23 December 1983, Volume 222, Number

Nuclear Winter: Global Consequences of Multiple Nuclear Explosions

R. P. Turco, O. B. Toon, T. P. Ackerman
J. B. Pollack, Carl Sagan

Concern has been raised over the short- and long-term consequences of the dust, smoke, radioactivity, and toxic vapors that would be generated by a nuclear war (*1–7*). The discovery that quantities of sooty smoke that would attenuate sunlight and perturb the climate. These developments have led us to calculate, using new data and improved models, the potential global environmen- exchange and would inherit the postwar environment. Accordingly, the longer-term and global-scale aftereffects of nuclear war might prove to be as important as the immediate consequences of the war.

To study these phenomena, we used a series of physical models: a nuclear war scenario model, a particle microphysics model, and a radiative-convective model. The nuclear war scenario model specifies the altitude-dependent dust, smoke, radioactivity, and NO_x injections for each explosion in a nuclear exchange (assuming the size, number, and type of detonations, including heights of burst, geographic locales, and fission yield fractions). The source model parameterization is discussed below and in a more detailed report (*15*). The one-dimensional microphysical model (*15–17*) predicts the temporal evolution of dust and

12 February 1985, Ronald Reagan *:* nuclear winter is the reason why US and USSR should reduce nuclear stockpiles

« Or now, as 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 »

Mikhail Gorbachev *:* "great stimulus" to act and reverse the arms race

« 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. »

- 12,500 NW, 1/4 operational
- New NWS : North Korea (30), Israël (80), India (160), Pakistan (165) (Sipri, 2023)
- Climate models : more computer power, models more accurate

2007 : Toon, Robock, Turco *et al : Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences*

- atmospheric model coupled with ocean general circulation model.

- simulating a realistic atmosphere up to 80 km (23 layers)

- models the ocean thermal inertia at different depths and oceanic circulation changes : can compute the ocean response, surface and deep layers (13 layers)

- sea ice model

- module to compute the transport and removal of aerosol particles

- resolution : 4 X 5 °

- 10 years simulation : longer time scale for the climate response and removal of aerosols

- calibration of models : satellite observations, volcanic eruptions, forest fires, oil-well fires (Gulf war)

---> smoke particles heated by the Sun rising in the upper atmosphere would remain for many more years : climatic effects last longer / 1983 studies

- 2 x 10 years simulations with 150 Tg (total current stockpile) and 50 Tg (1/3 stockpile) smoke injected in upper troposphere on one week starting 15 May.
- Black carbon particles are heated by Sun radiation and lofted in upper stratosphere
- Aerosols quickly spread globally and produce long lasting climate forcing
- Cooling larger on land
- Last ice age, 18000 years ago, T : -5°C / present
- Main uncertainties : amount of smoke

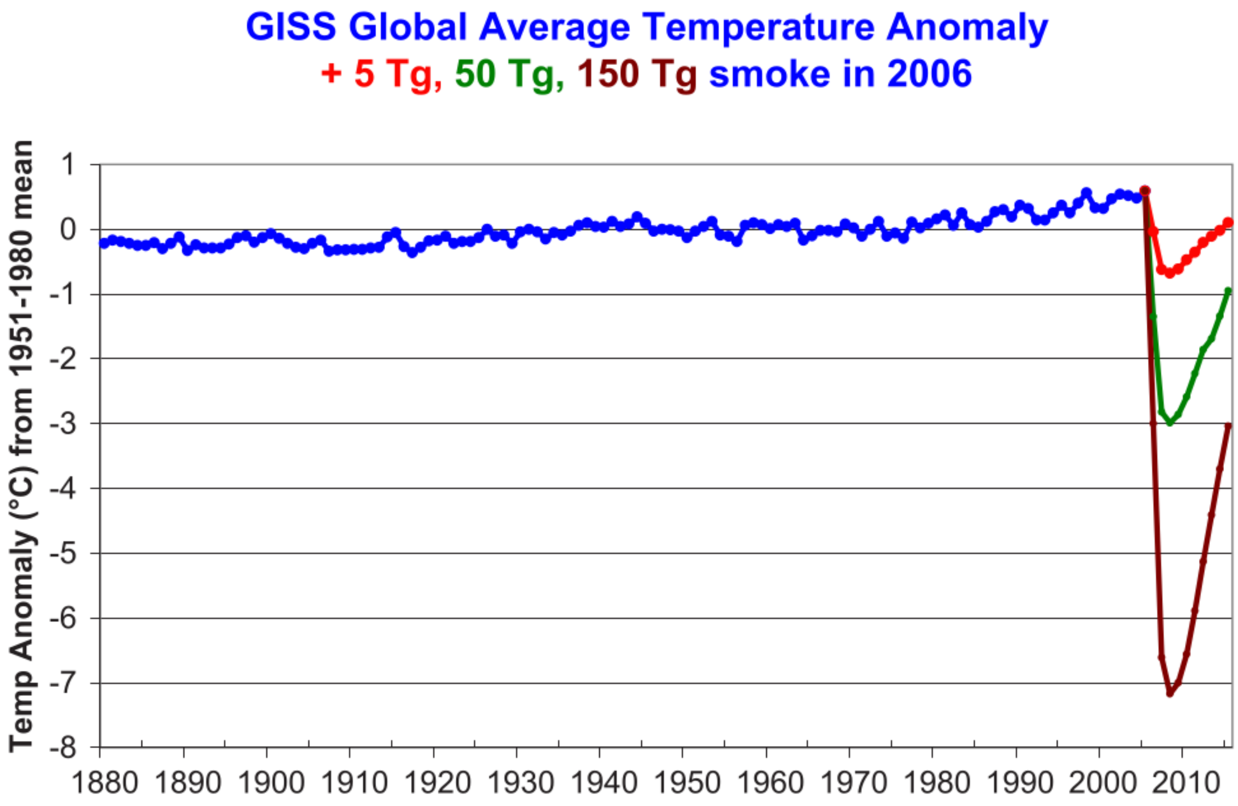
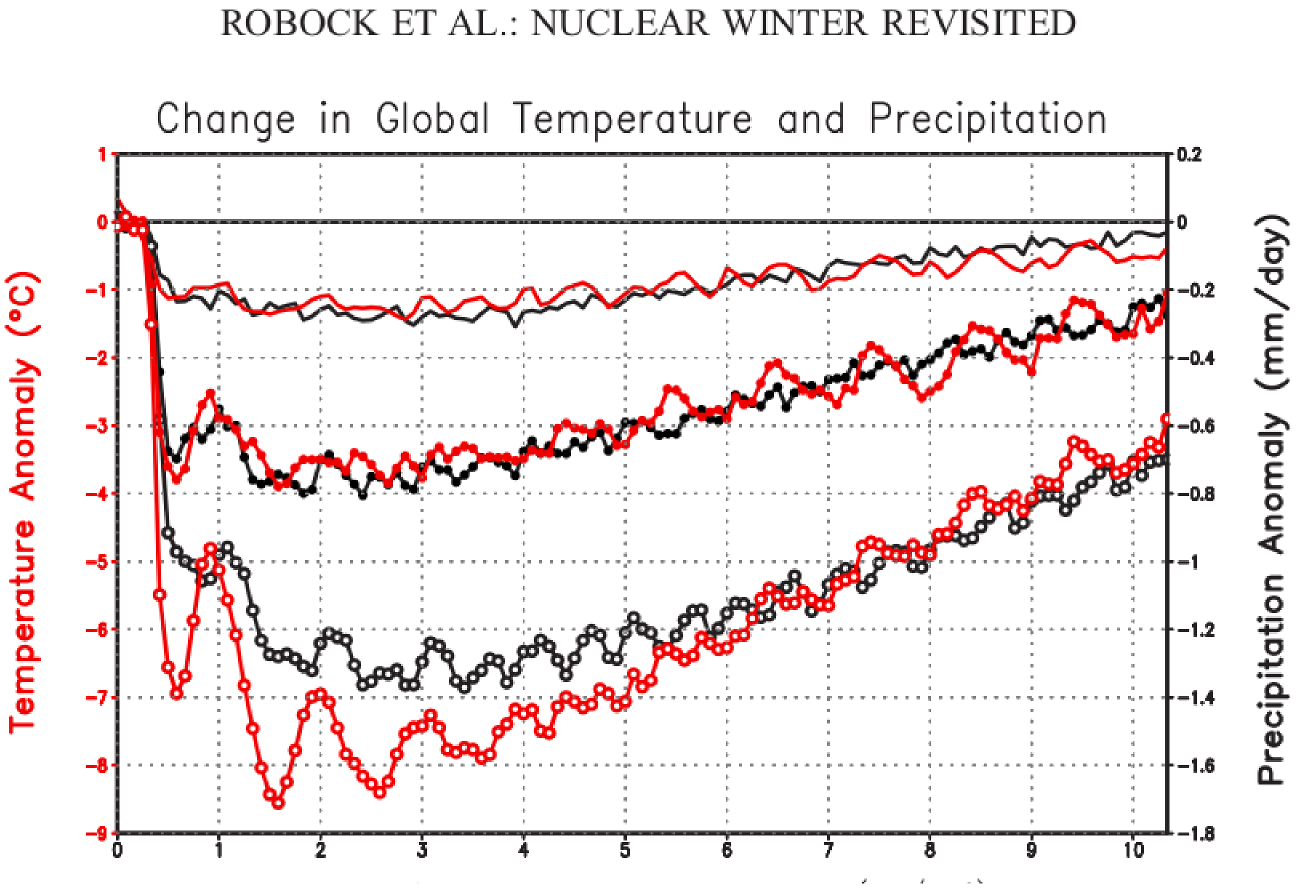
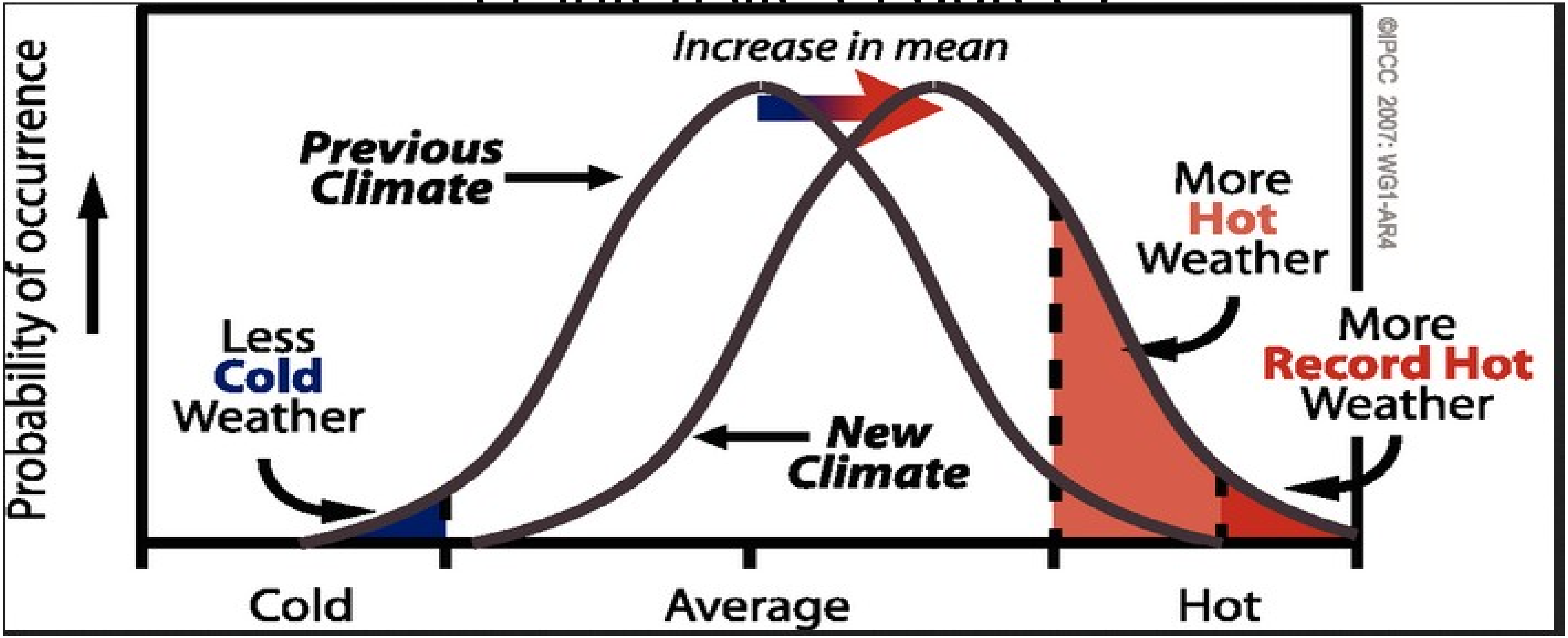


Figure 8. Global average surface air temperature change from the 5 Tg (red), 50 Tg (green), and 150 Tg (brown) cases in the context of the climate change of the past 125 years. Observations are from the National Aeronautics and Space Administration Goddard Institute for Space Studies analysis [*Hansen et al.*, 2001, updated at http://data.giss.nasa.gov/gistemp/2005/].


ROBOCK ET AL.: NUCLEAR WINTER REVISITED
Change in Global Temperature and Precipitation
Temperature Anomaly (°C)
Precipitation Anomaly (mm/day)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
−1.8
0 1 2 3 4 5 6 7 8 9 10

Déplacement de la moyenne et fréquence des extrêmes

(+ intensité et durée)



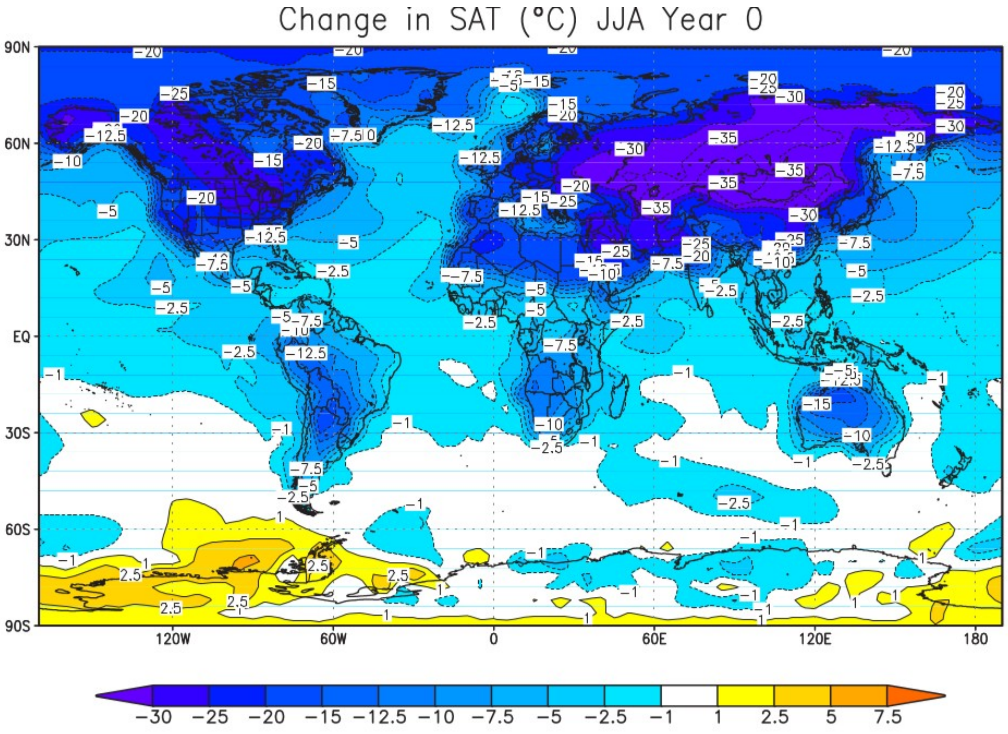


Figure 4. Surface air temperature changes for the 150 Tg case averaged for June, July, and August of the year of smoke injection and the next year. Effects are largest over land, but there is substantial cooling over oceans, too. The warming over Antarctica in year 0 is for a small area, is part of normal winter interannual variability, and is not significant. Also shown as red circles are two locations in Iowa and Ukraine, for which time series of temperature and precipitation are shown in Figures 5 and 7.

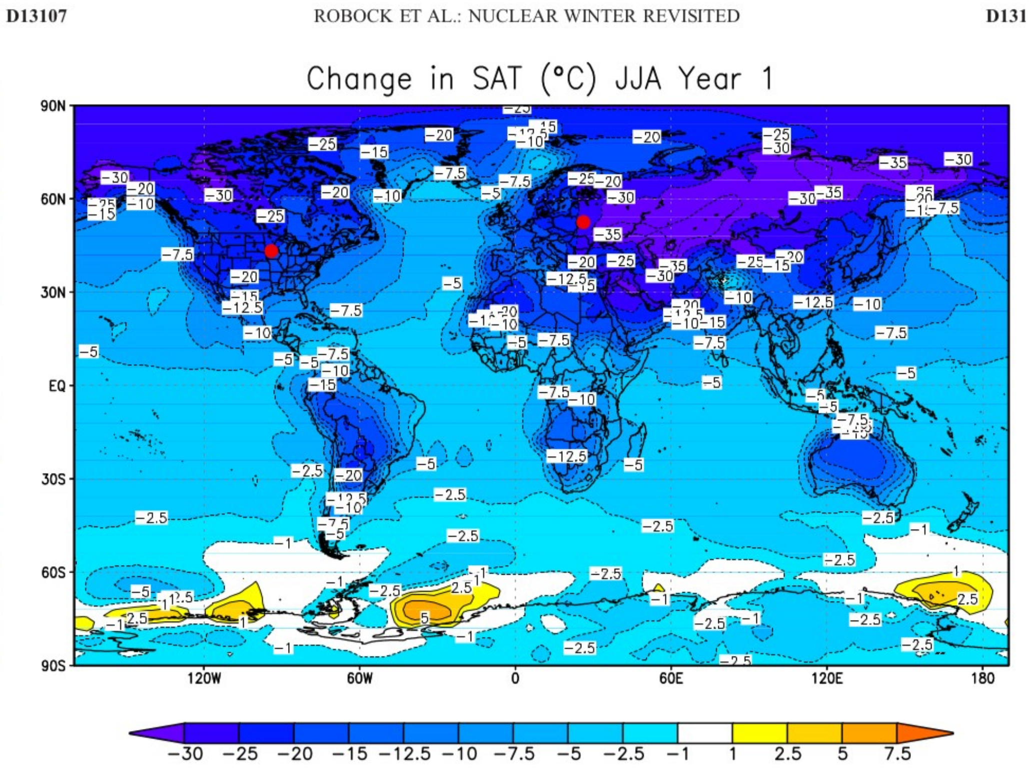


Figure 4. (continued)

- Cooling →evapo-transpiration / convection / precipitation are reduced

  → global hydrological cycle is weakened
- Summer monsoon collapse
- Global precipitation : - 45 % (150 Tg).

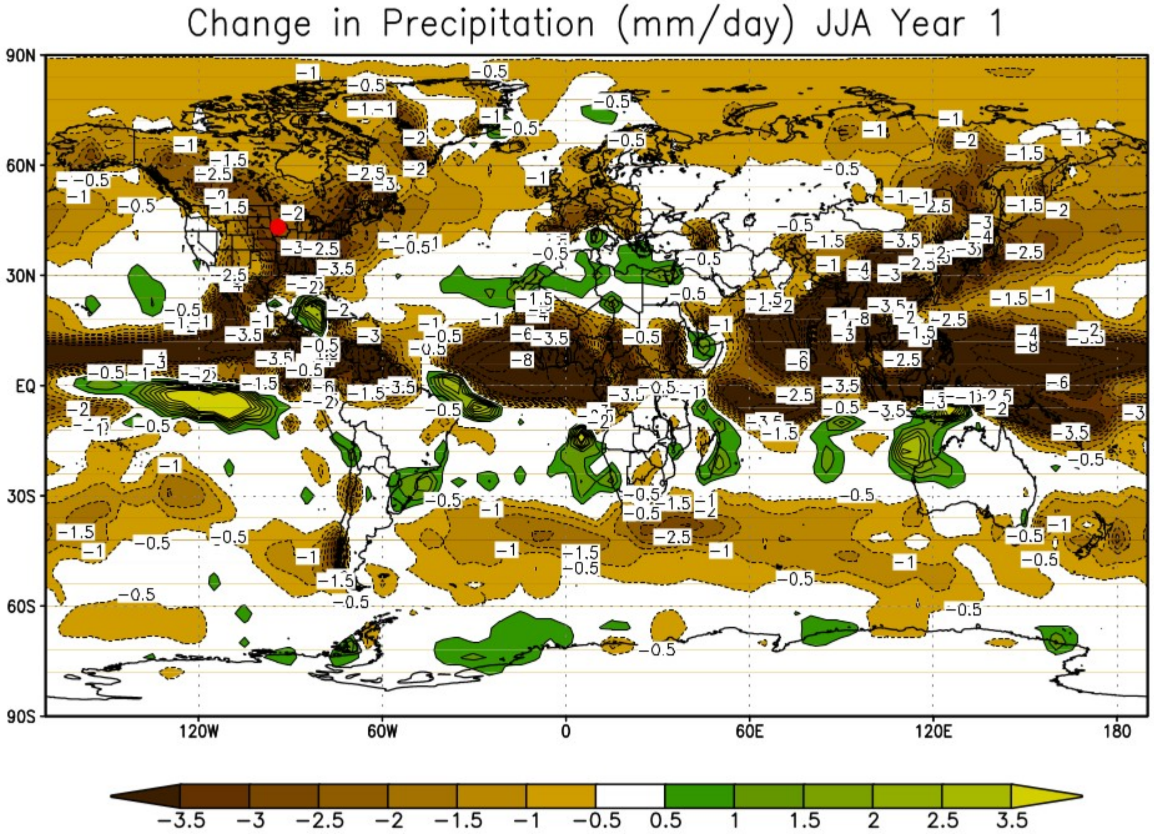


Figure 6. Precipitation changes (mm/day) in response to the 150 Tg case averaged for June, July, and August of the first year following the smoke injection. There are large reductions over large regions, especially those affected by the North American, Asian, and African summer monsoons. The small areas of increased precipitation are in the subtropics in response to a severely weakened Hadley Cell. Also shown as a red circle is the location in Iowa for which time series of precipitation are shown in Figure 7.

Results for 50 Tg

- climate response is identical to 150 Tg, but with 50 % amplitude : saturation effect : once solar radiation is blocked, additional soot has smaller effect.
- Identical timescale of response : aerosols have same stratospheric residence time / 150 Tg : for lower soot amount, solar radiation can affect larger proportion of soot and it is lofted higher.

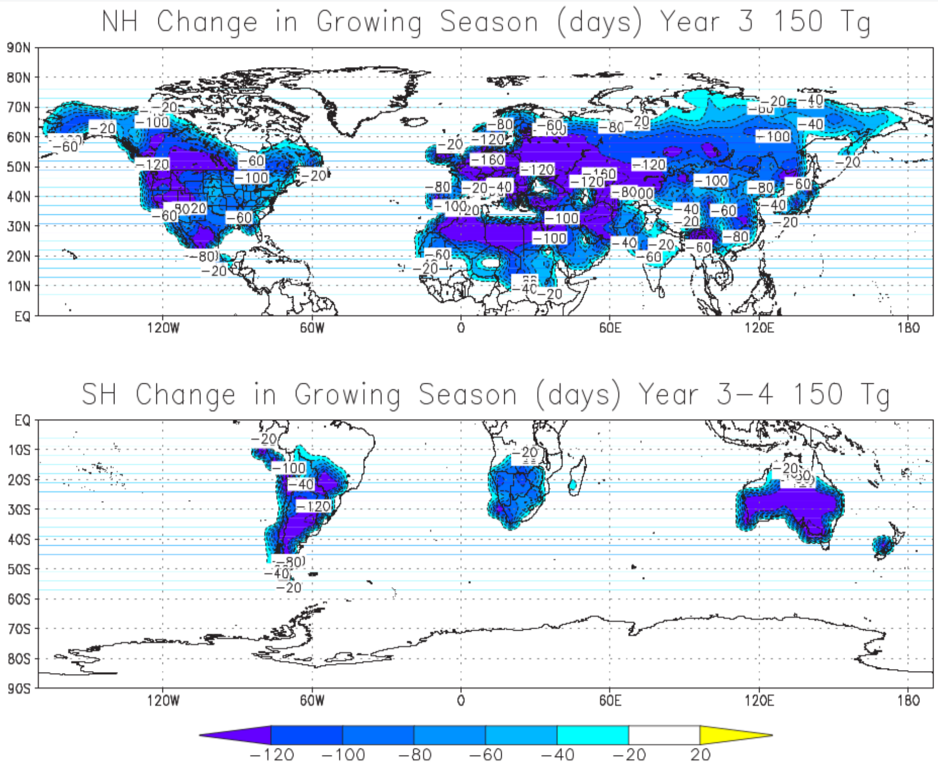


Figure 10. Change in growing season (period with freeze-free days) in the third year following the smoke injection for the 150 Tg and 50 Tg cases.

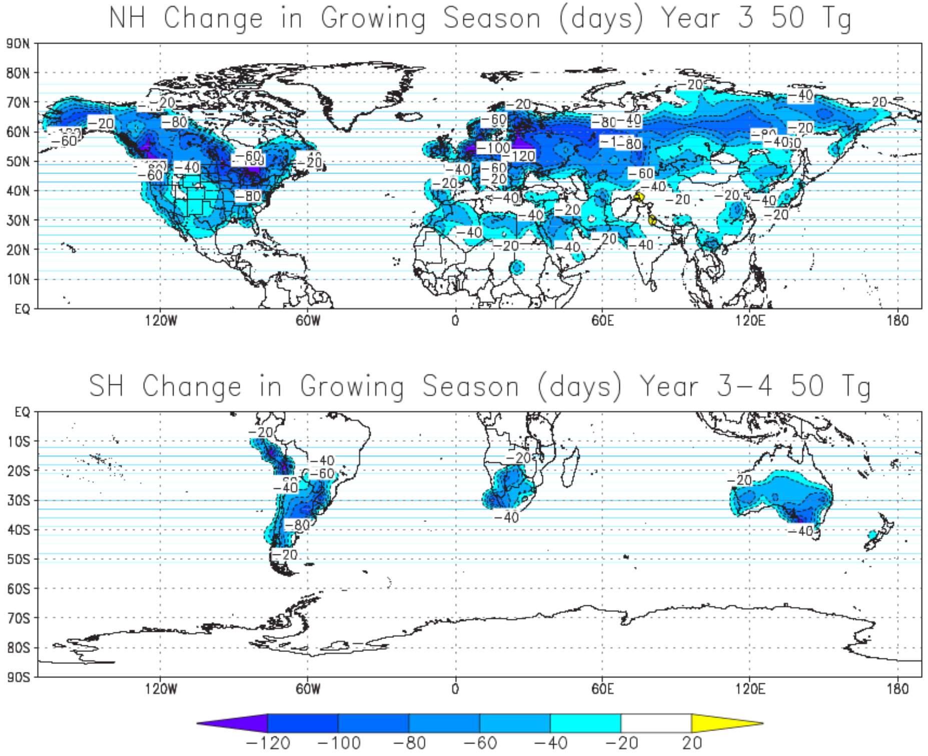
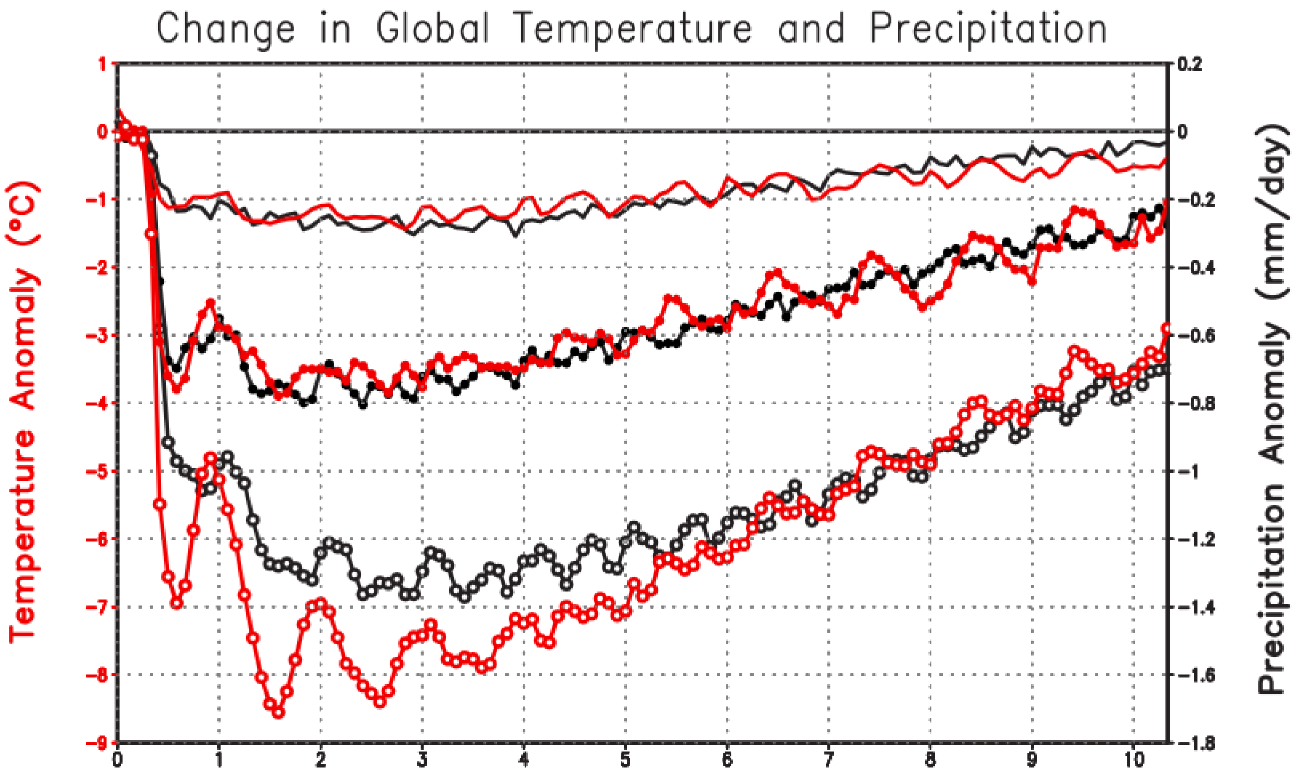


Figure 10. (continued)

2007 : Climatic consequences of regional nuclear conflicts

- Same model
- Scenario : India/ Pakistan : 50 + 50 15 kt NW (0,03 % / 2007 explosive yield) on biggest cities
- 1-5 Tg of black carbon aerosols.
- - 1.25 °C after 3 years, - 0.5 °C after 10 years, T changes larger over land, large T drop over grain growing regions
- Global precipitation : - 10 %
- Large effects in regions far from conflict zone

ROBOCK ET AL.: NUCLEAR WINTER REVISITED



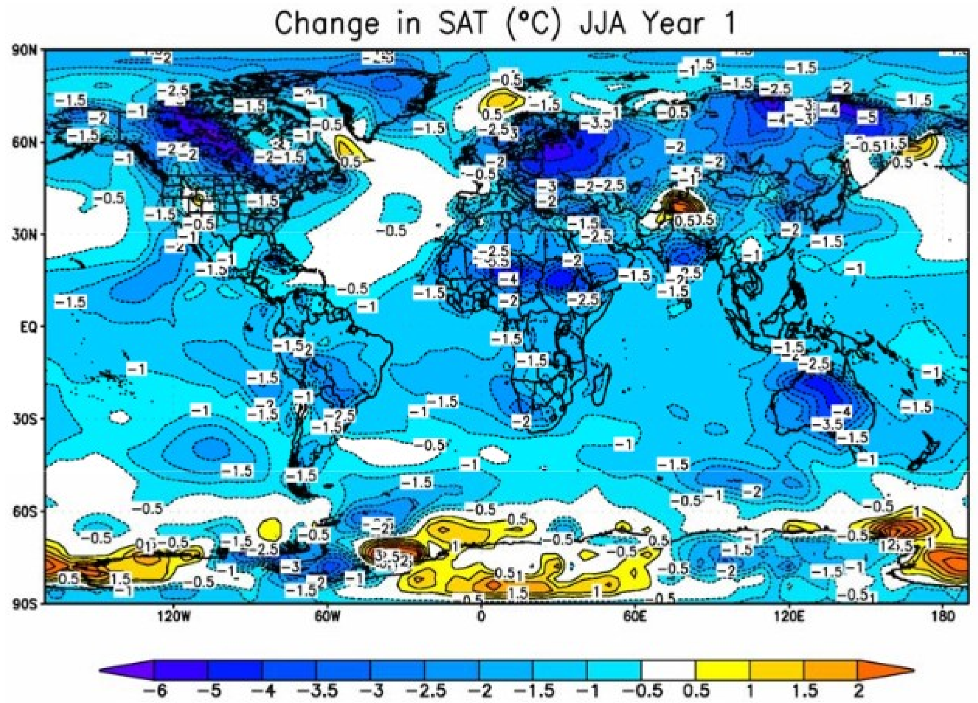


Fig. 5. Surface air temperature changes for the 5 Tg standard case averaged for June, July, and August of the first year following the smoke injection. Effects are largest over land, but there is substantial cooling over tropical oceans, too. The warming over Antarctica is for a small area, is part of normal winter interannual variability, and is not significant.

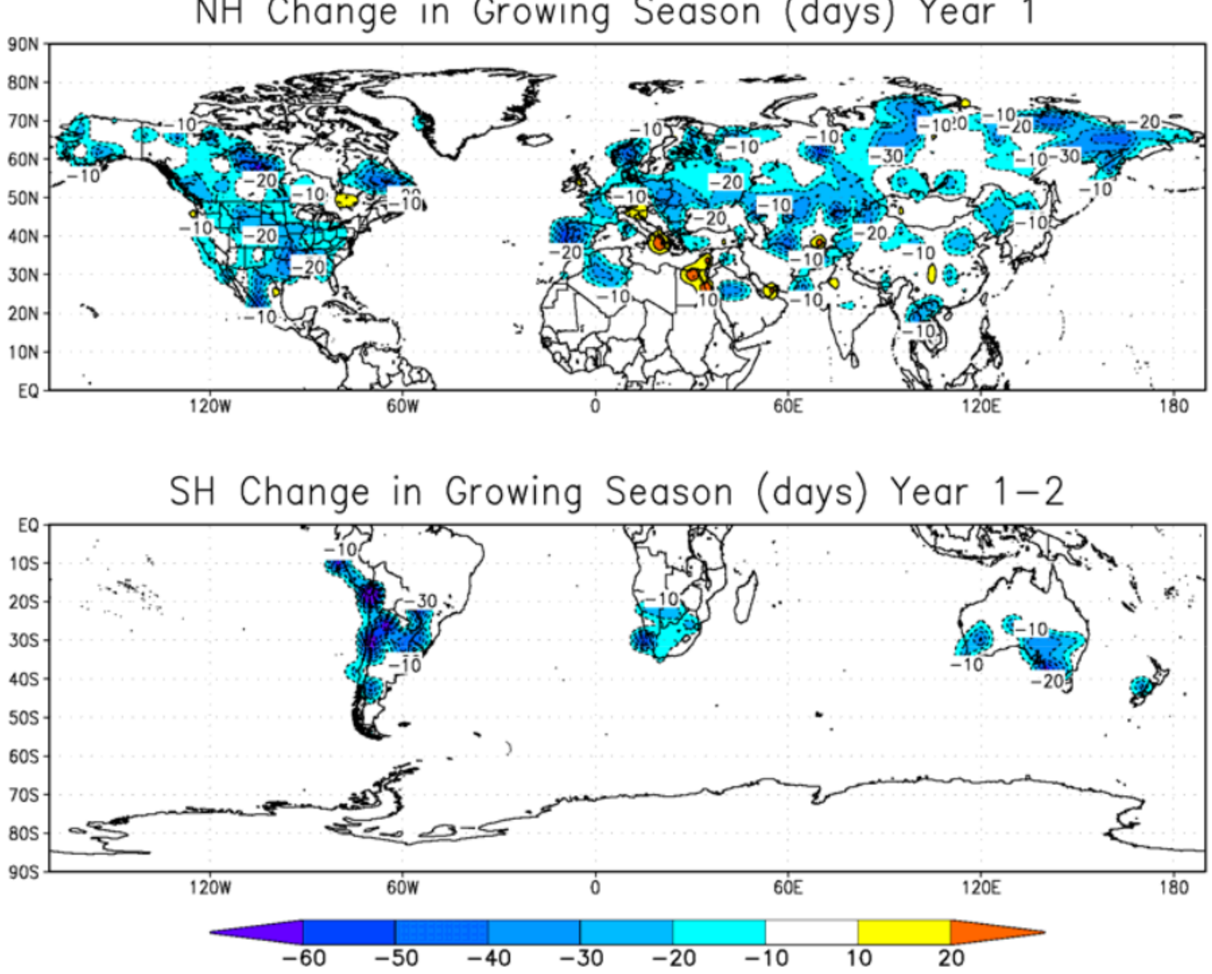


Fig. 11. Change in growing season (period with freeze-free days) in the first year following the 5 Tg standard case smoke injection.

2019 : Rapidly expanding nuclear arsenals in Pakistan and India portend regional and global catastrophe

- work resumed in 2017 / Open Philanthropy Project

- India and Pakistan have > 160 nw in 2023. Crisis prone region. Missile (tactical and ballistic) and airborne capacities allow them to strike most of the main cities of the other country.

- increased yields : 12 kt, 50, 100 (to several hundreds?)

- / 2007 : urban population increasing (up to 37 to 80 000 hab/km2 in India)

- several scenarios (advice from military and policy experts)

- main determinants : uncertainties : nb of NW used, yields,

targets, ignition processes, smoke composition, lofting.

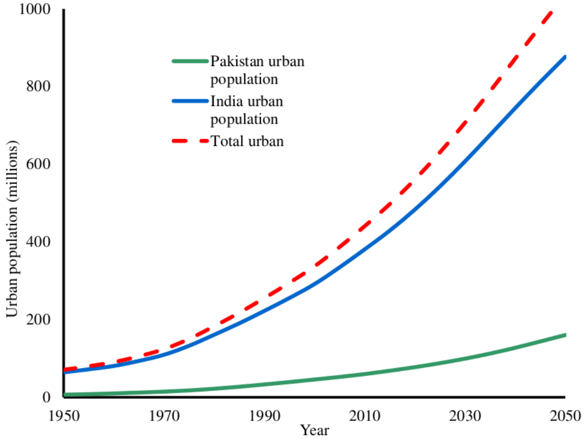
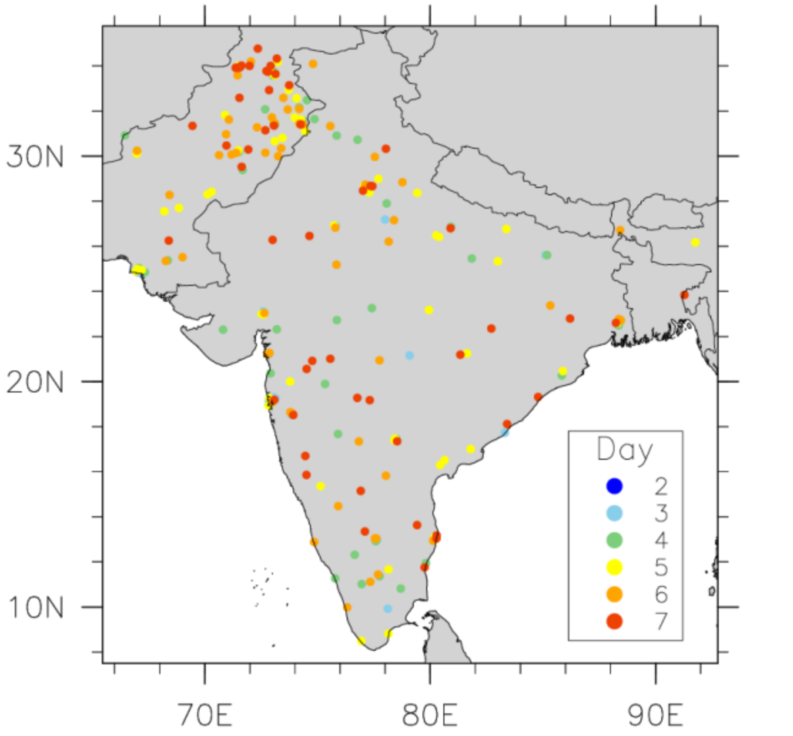


Fig. S4. Estimated urban populations of India, Pakistan, and total for both nations (*19*).

Table 1 | Number of weapons on urban targets, yields, direct fatalities from the bomb blasts and resulting number of people in danger of death due to famine for the different scenarios we studied

Soot (Tg)	Number of weapons	Yield (kt)	Number of direct fatalities
5	100	15	27,000,000
16	250	15	52,000,000
27	250	50	97,000,000
37	250	100	127,000,000
47	500	100	164,000,000
150	4,400	100	360,000,000
150	4,400	100	360,000,000



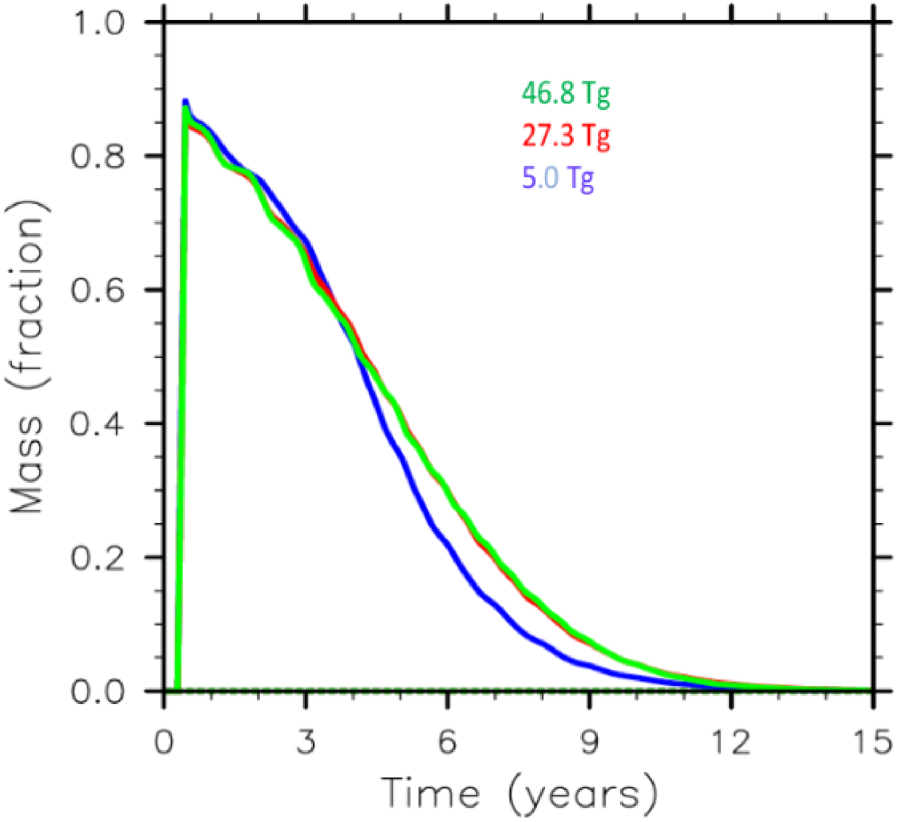


Fig. S5. Fraction of the injected smoke remaining in the atmosphere as a function of time.

- scenario 2 : 100 NW / India, 150 NW / Pakistan. 15 kt. Only towns are targeted. War last one week.

- 52 millions fatalities

- 16,1 Mt of black carbon in the atmosphere after 20 % removed by black rain

- T average over land = - 4 °C

- precipitation reduced = - 15 %

- ocean thermal inertia and sea ice extension : effect max 3 y after conflict, last 4 y, preconflict after 12 y

- large decrease of precipitation in India, central China, some regions of the US (North East and Midwest) could loose 50 %.

- 926 million people starving to death after two years

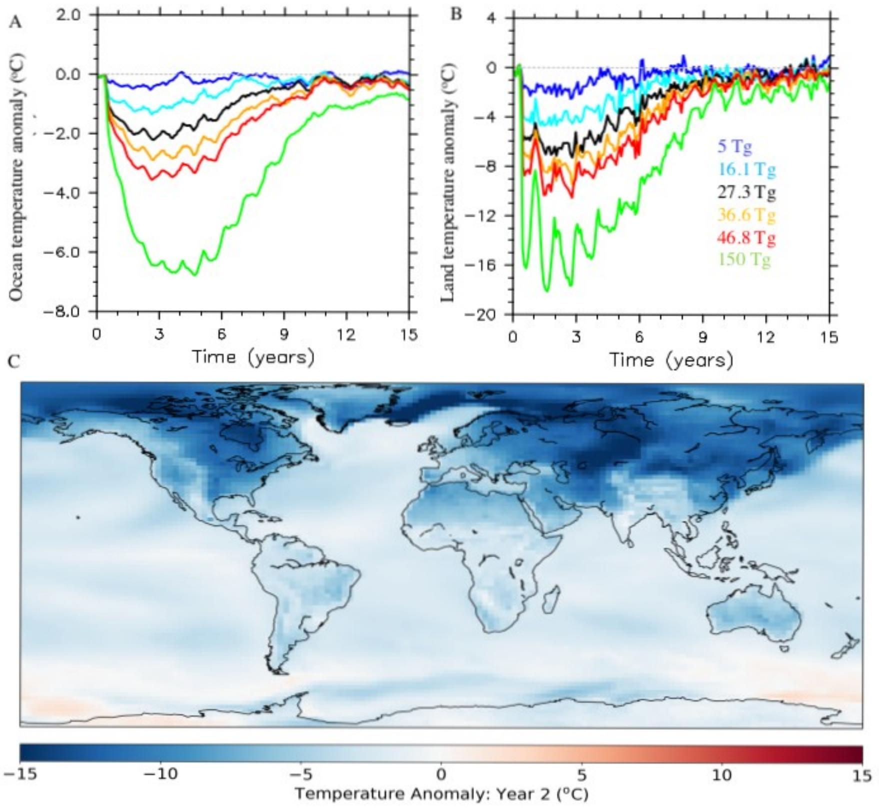


Fig. S6. Decline in ocean surface temperature (A) and land surface temperature (B) as a function of time. Color-coding designates the assumed black carbon (BC) injections. The ocean surface temperatures apply to a layer that can deepen over time to a few hundred meters as the heat deficit propagates downward. Panel C illustrates the global distribution of changes in ocean and land surface temperatures averaged over the second year following a conflict beginning in May of year one for the scenario with 50 kt weapons and a 27.3 Tg injection of BC.

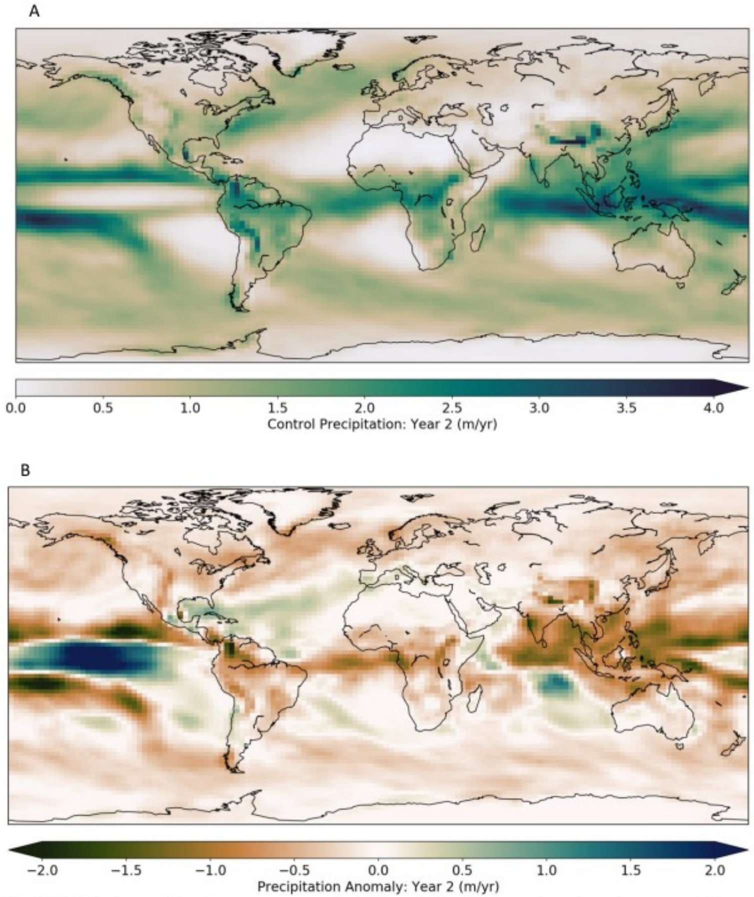


Fig. S7. Global precipitation patterns and changes following a regional nuclear war. (A) Global pattern of precipitation averaged over the second year of a control run with the climate model. (B) Change in precipitation averaged over the second year following a conflict beginning in May of year one for the scenario with 50 kt weapons and a 27.3 Tg injection of BC. Note the large declines in precipitation throughout Southeast Asia and Indonesia, tropical South America and Africa, as well as in the Midwestern U.S.

2020 : A regional nuclear conflict would compromise global food security

- Before simplified single crop, localized
- Global scale assessment model, with 6 crop models
- Scenario : 5 Tg black carbon
- T < 1.8 °C, precip < 8 % for > 5 years
- Gradual recovery in years 10-15

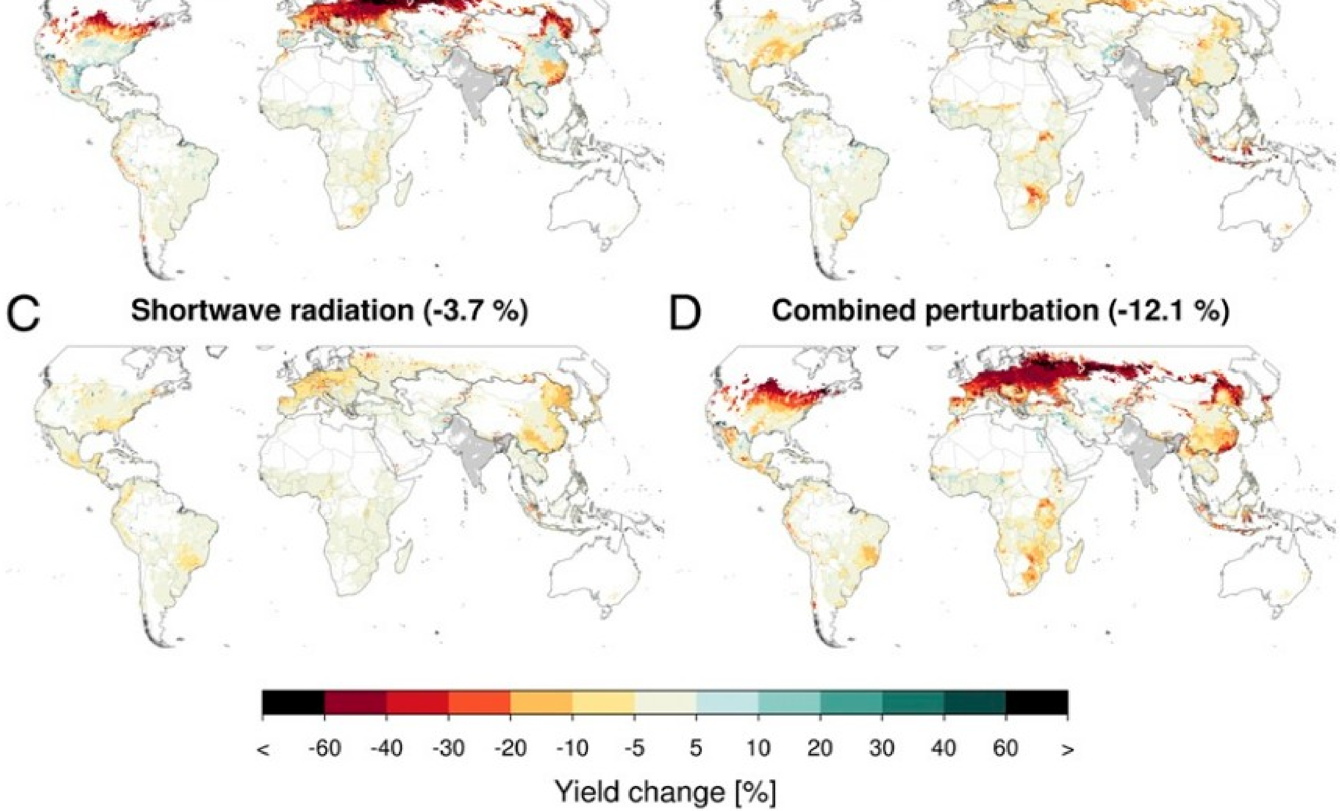
Global cereal production losses over 5 years

Maize (35% of total global prod/trade) - 12.6 (±1.2) %

Ice and snow feedback, cold damage, fail to reach maturity
-> higher losses at high latitudes = main food producers

Canada and US (40% prod) : - 17.5 (±2.4) %
China and East Asia (18% prod) : - 6.3 (±1.2) %
Europe (15% prod) : - 16.7 (±5.5) %
Russia (1.8% prod) : - 48.2 (±4.5) %

- **Wheat** (24 % cereal prod) : - 11 (± 8 %) %
- **Rice** (21 % cereal prod) : - 3 (± 5 %) %
- **Soybean** (10 % cereal prod) : - 17 (± 2 %) %



. 5. Maize yield and production sensitivity to individually perturbed climate drivers. Changes in simulated maize yield (%) for climate input variables rturbed one at a time: (*A*) air temperature, (*B*) precipitation, and (*C*) surface incoming shortwave solar radiation, filled in with control AgMERRA climate. The combined perturbation has all four drivers perturbed collectively. Percentage numbers at the top of each plot indicate the respective global caloric oduction change. This sensitivity study is performed for climate model simulation $CF1_a$ and by the crop models EPIC-BOKU, GEPIC, LPJmL, pDSSAT, and PIC. Data are shown as the mean across crop models, post conflict years 1 to 5, 29 y of historical climatology, and rainfed and irrigated systems. India and kistan are excluded.

- Domestic reserves and global trade could provide food for the first year

- repercussions on international food trade → shock worldwide

→ constrain food availability in food insecure countries

- after 5 years, maize / wheat

> -10 % in countries / 3.7 billion hab

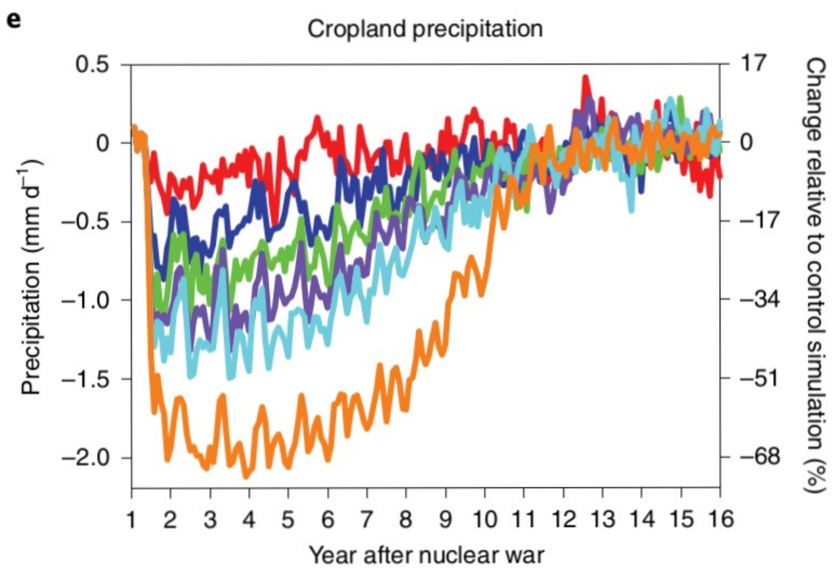
> - 20 % in 71 countries / 1.3 billion hab

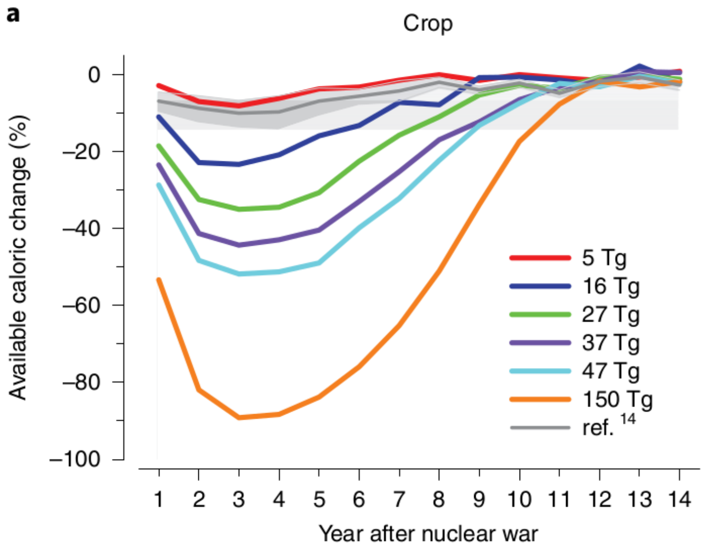
- Climate response is proportional to BC mass

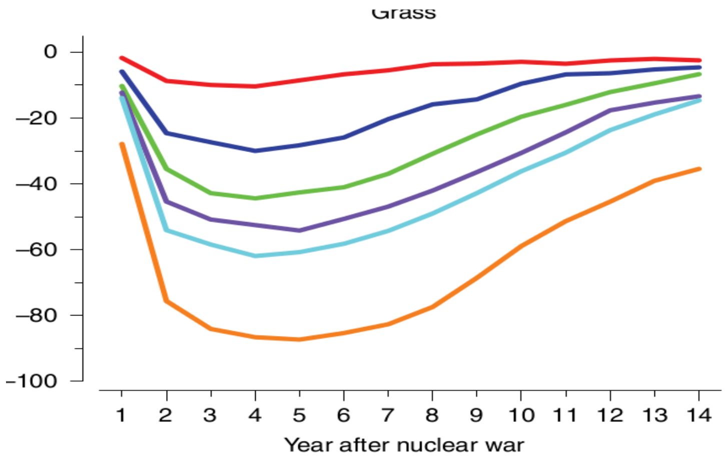
→ Linear crop decline -1.5 °C to -4°C

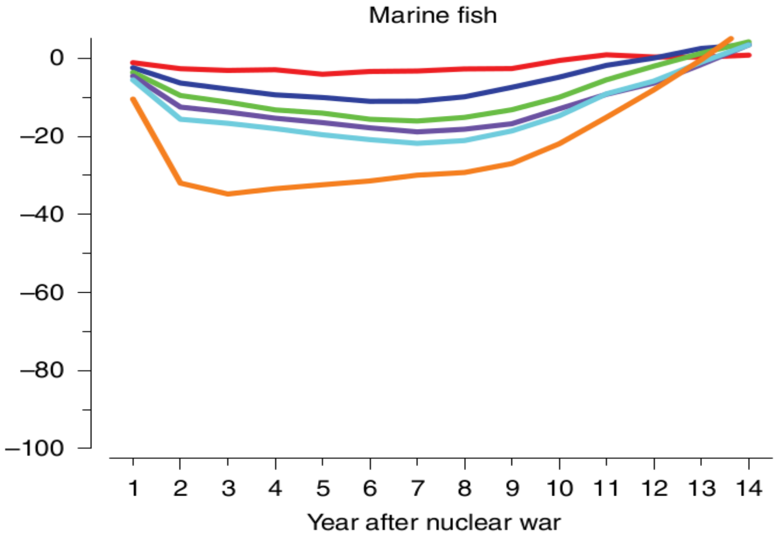
2022 : Global food insecurity and famine from reduced crop, marine fishery and livestock production due to climate disruption from nuclear war soot injection

- simulations of major crops and marine fish → assess global calorie supply.
- crops : 5 (47) Tg : - 7 (50) % year 1-5
- fish : T decrease is less in oceans


e
Cropland precipitation
0.5
0
−0.5
−1.0
−1.5
−2.0
17
0
−17
−34
−51
−68
Precipitation (mm d−1)
Change relative to control simulation (%)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Year after nuclear war


a
Crop
0
−20
−40
−60
−80
−100
Available caloric change (%)
5 Tg
16 Tg
27 Tg
37 Tg
47 Tg
150 Tg
ref. 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Year after nuclear war


Grass
0
−20
−40
−60
−80
−100
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Year after nuclear war


Marine fish
0
−20
−40
−60
−80
−100
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Year after nuclear war

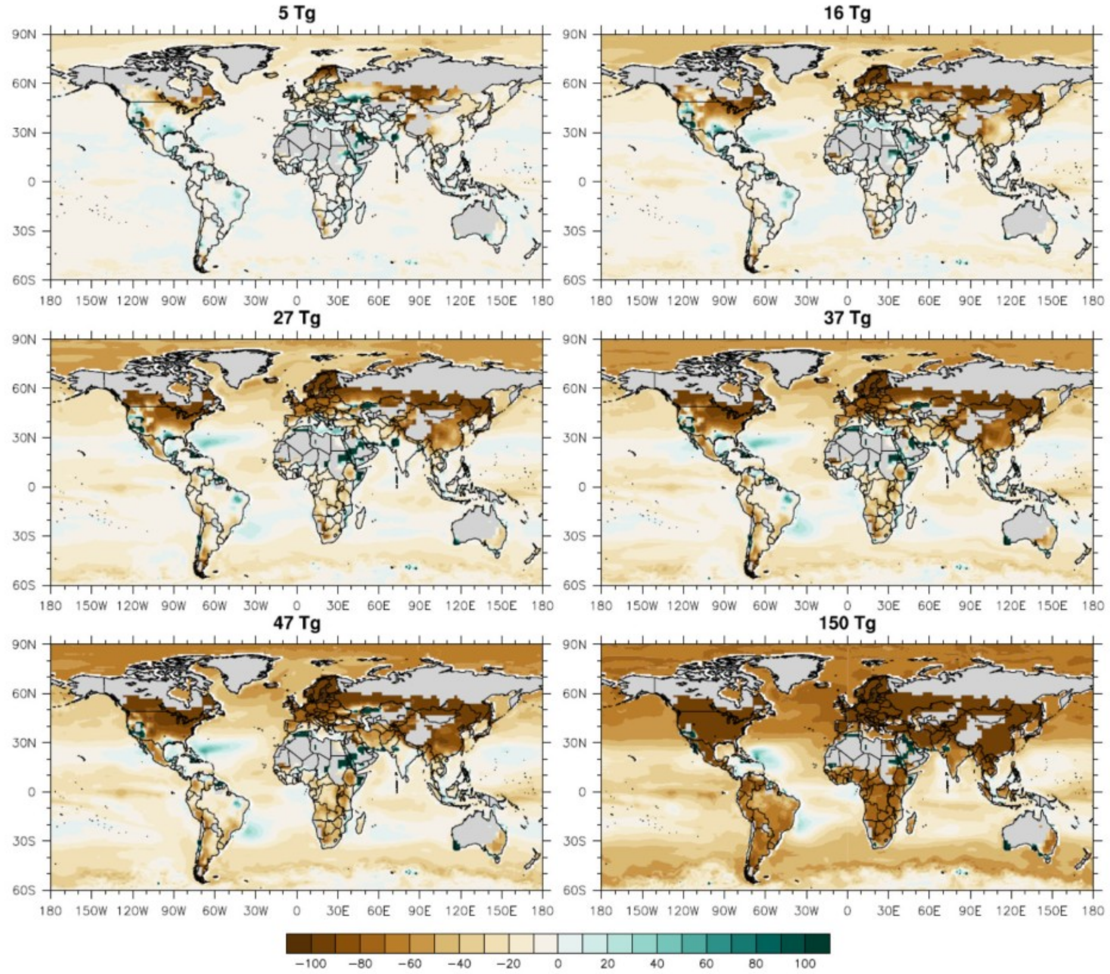


Figure S4. Change in calorie production (%) for the explicitly simulated agricultural crops and

Impacts on calories intake

- FAO (2010) : global calorie 51% cereals, 31% vegetables, fruit, roots, tubers and nuts,18% from animal and related products (of which fish : 7%)
- many crops (maize and soybean) are used mainly for non-food uses (livestock feed)
- international food trade suspended
- food distributed equally inside nations
- 5 Tg : most nations show < calorie intake /2010 but still sufficient to maintain weight

Food intake in year 2

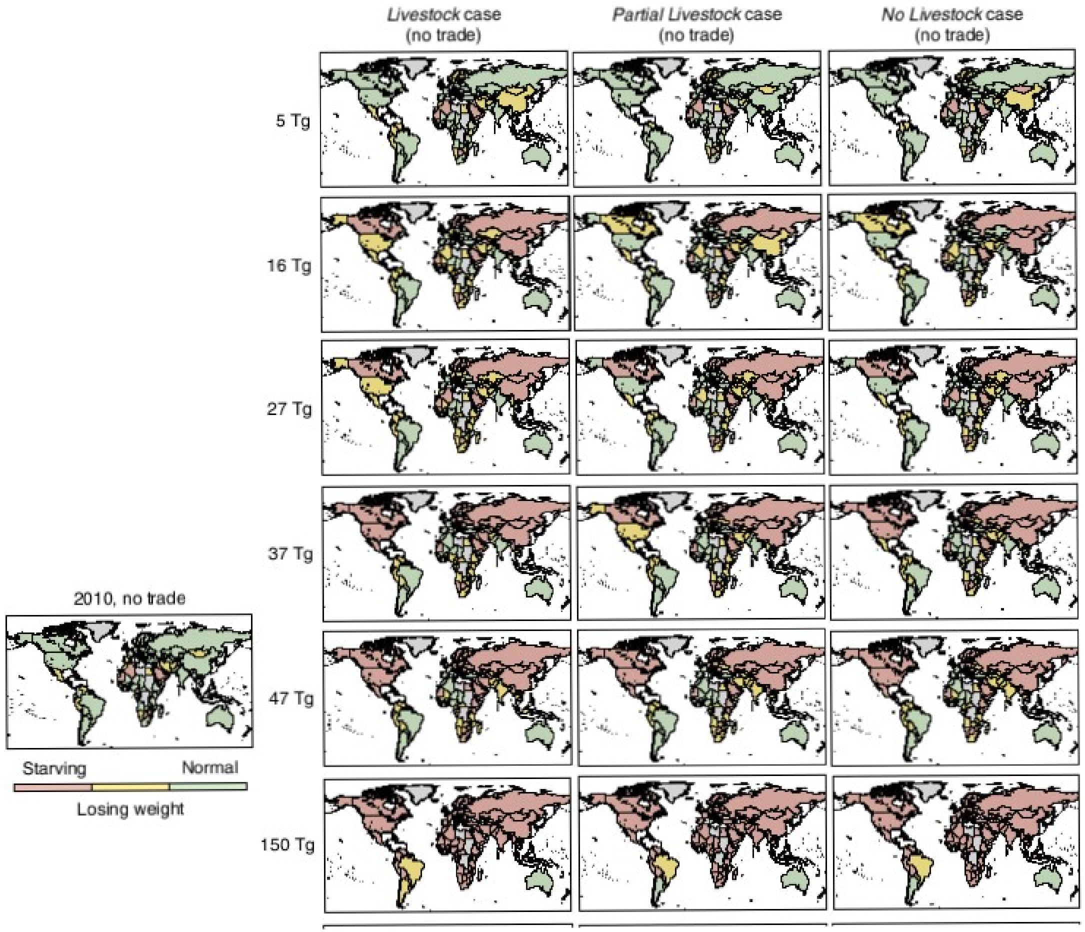


Table 1 | Number of weapons on urban targets, yields, direct fatalities from the bomb blasts and resulting number of people in danger of death due to famine for the different scenarios we studied

Soot (Tg)	Number of weapons	Yield (kt)	Number of direct fatalities	Number of people without food at the end of Year 2
5	100	15	27,000,000	255,000,000
16	250	15	52,000,000	926,000,000
27	250	50	97,000,000	1,426,000,000
37	250	100	127,000,000	2,081,000,000
47	500	100	164,000,000	2,512,000,000
150	4,400	100	360,000,000	5,341,000,000
150	4,400	100	360,000,000	[a]5,081,000,000

Some conclusions

- An exchange involving about 1 % of current NW stockpile of nuclear weapons would have global climate consequences of a nature and magnitude never before known.
- The indirect effects, impacting also populations outside the conflict zone, would be far greater than the direct effects.
- Indiscriminate killing / no possible protection, even in case of a limited exchange : however adaptation of the doctrines makes the NW use more likely.
- Upon learning of the findings of the 2007 study, Gorbachev said:

  "*I am convinced that nuclear weapons must be abolished. Their use in a military conflict is unthinkable; using them to achieve political objectives is immoral. Over 25 years ago, President Ronald Reagan and I ended our summit meeting in Geneva with a joint statement that 'Nuclear war cannot be won and must never be fought,' and this new study underscores in stunning and disturbing detail why this is the case*."

Main Sources

- **Climatic consequences of regional nuclear conflicts**, A. Robock , L. Oman, G. L. Stenchikov, O. B. Toon, C. Bardeen, and R. P. Turco,Atmos. Chem. Phys., 7, 2003–2012, **2007,**
- **Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences,** Robock, A., Oman, L., and Stenchikov, G. L. (July **2007**), JOURNAL OF GEOPHYSICAL RESEARCH, 112.
- **Rapidly expanding nuclear arsenals in Pakistan and India portend regional and global catastrophe**, Owen B. Toon, et al, . Sci. Adv. **2019**.
- **A regional nuclear conflict would compromise global food security,** Jonas Jägermeyr et al, PNAS, March 31, **2020 |** vol. 117 **|** no. 13 **|** 7071–7081
- **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, Nature Food **|** VOL 3 **|** August **2022**.

2 billion people could die from a regional war

Uncertainties :

* Effect of reduced population

* Farm management adaptation

* Alternative food sources (sea weeds, ..)