## Aerosol properties

By using a smaller aerosol size (about 30% less than Pinatubo), there is about half the heating of the lower tropical stratosphere as compared to the equivalent loading using a Pinatubo size aerosol.

We injected it at about the same altitude as Pinatubo but if the sulfate was closer to the tropopause and larger in size it would warm the tropopause cold point and let a lot more water vapor into the stratosphere, and this could cause additional problems that would have to be considered.


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# Latitudes and Altitudes

**Tropical:** We put $SO_2$ into the lower stratosphere (16-22 km) over the Equator at a daily rate equal to
5 Mt/yr (1 Pinatubo every 4 years) or
10 Mt/yr (1 Pinatubo every 2 years) for 20 years,
and then continue to run for another 20 years to see how fast the system warms afterwards.

**Arctic:** We put $SO_2$ into the lower stratosphere (10-15 km) at 68°N at a daily rate equal to 3 Mt/yr for 20 years, and then continue to run for another 20 years to see how fast the system warms afterwards.


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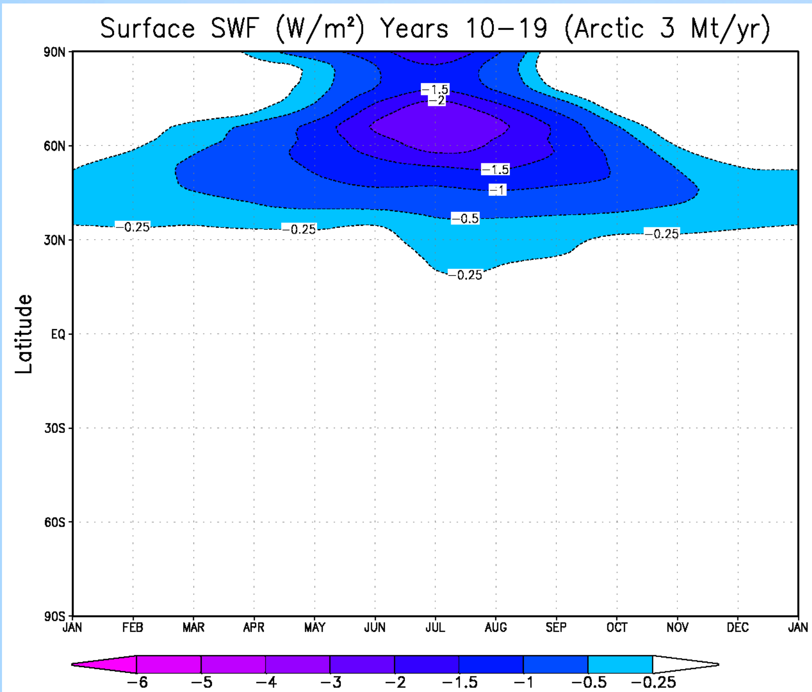
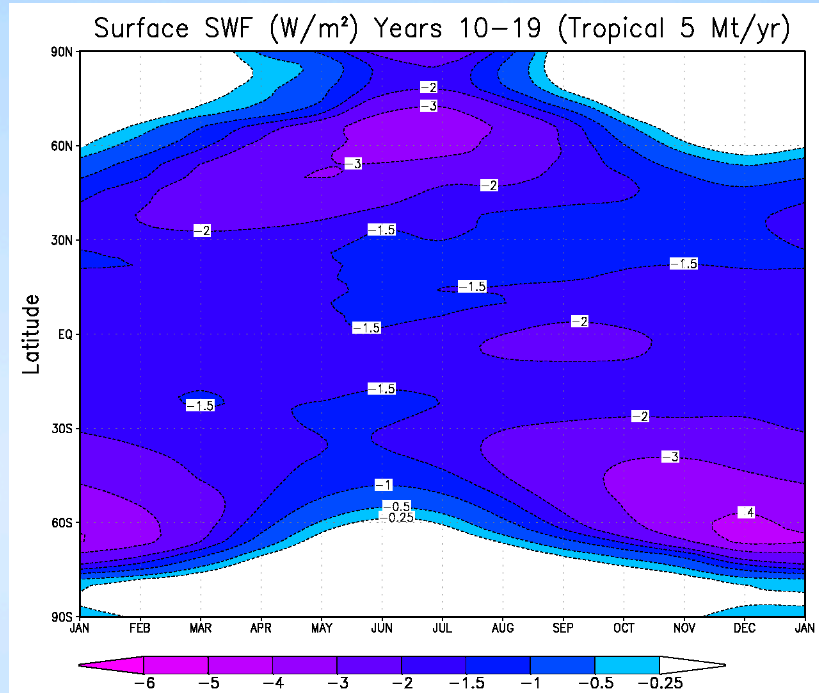
# Change in downward solar radiation at Earth's surface




Arctic emission at 68°N leaks into the subtropics

Tropical emission spreads to cover the planet



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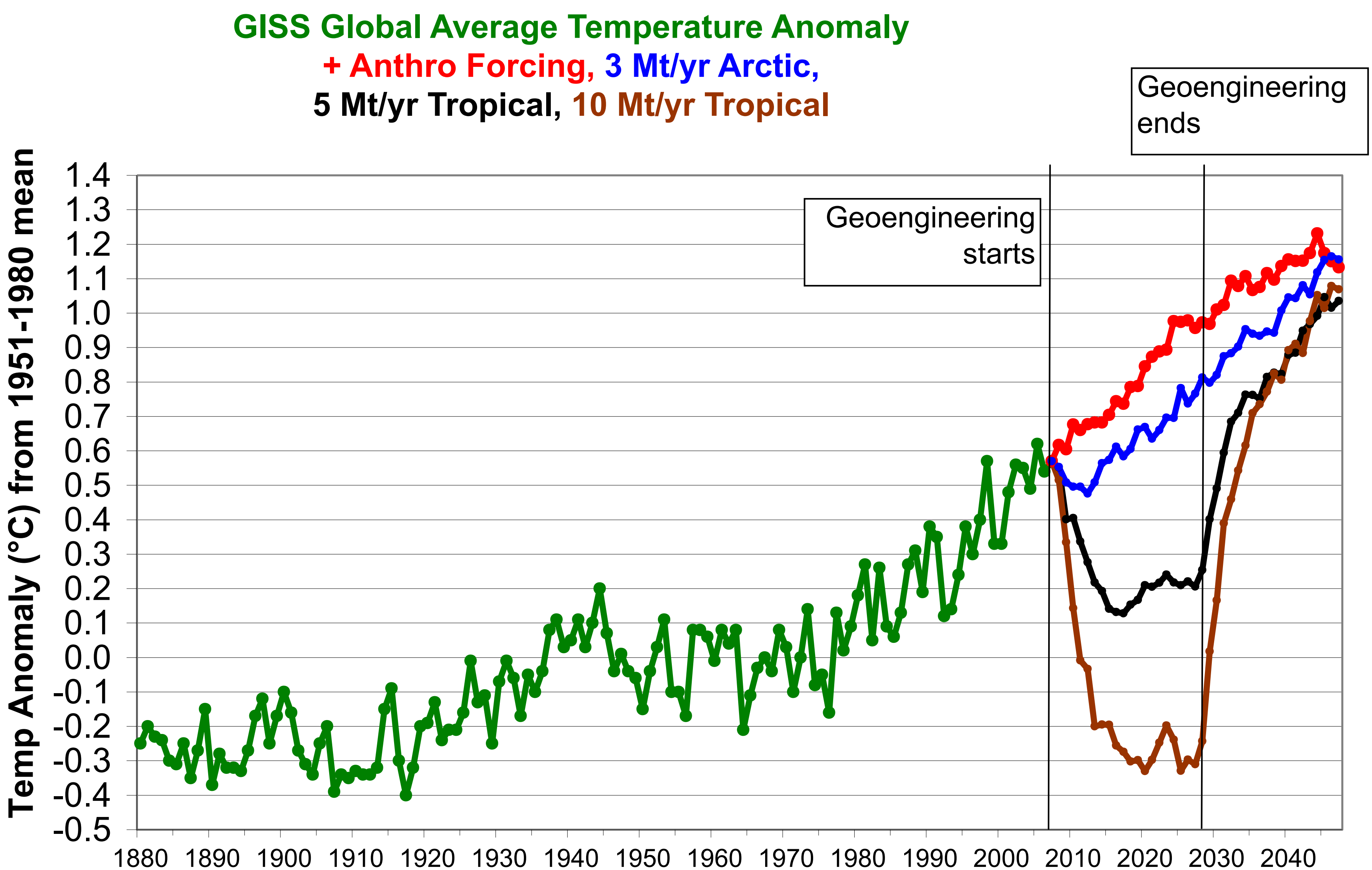
Department of Environmental Sciences



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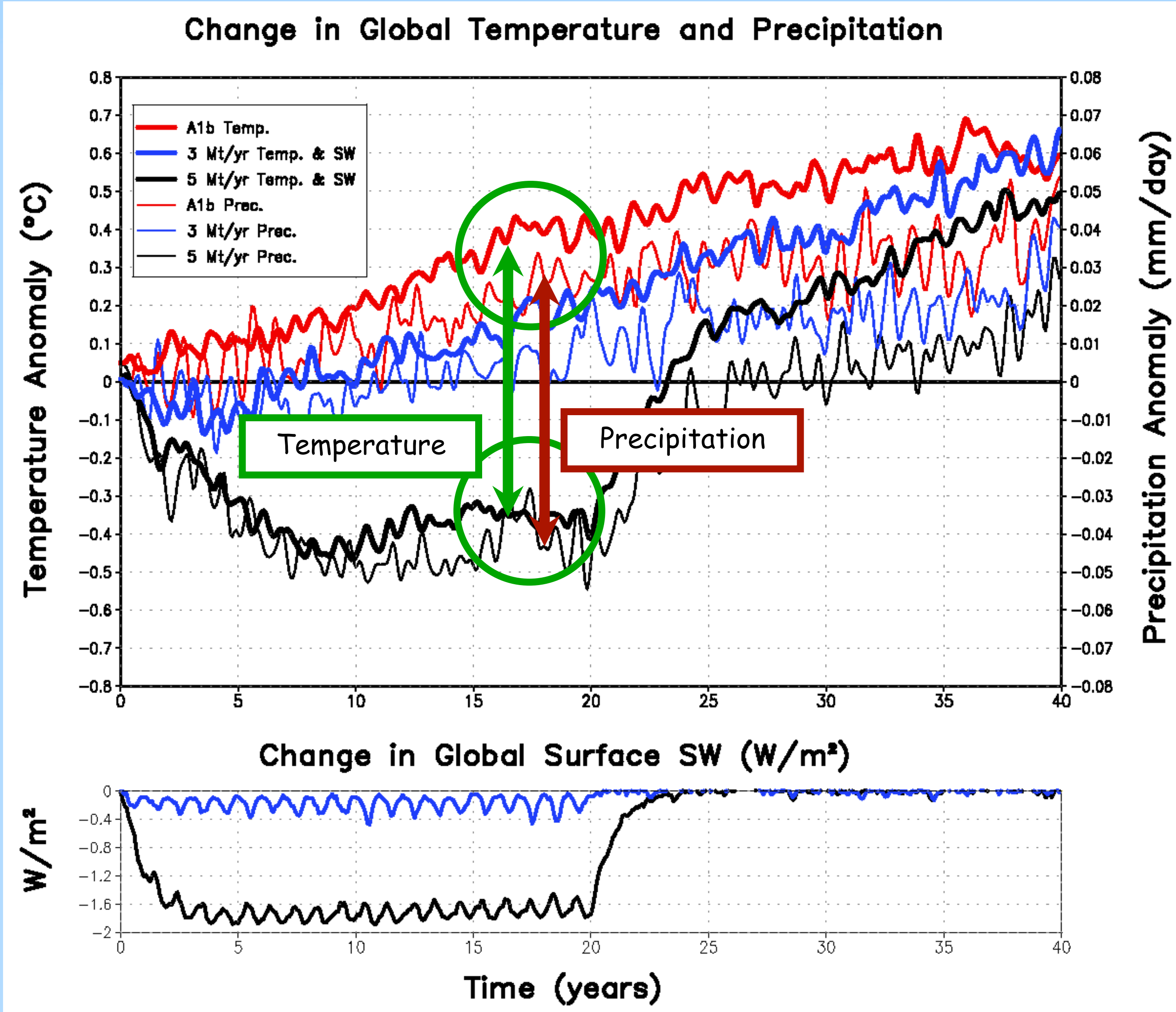
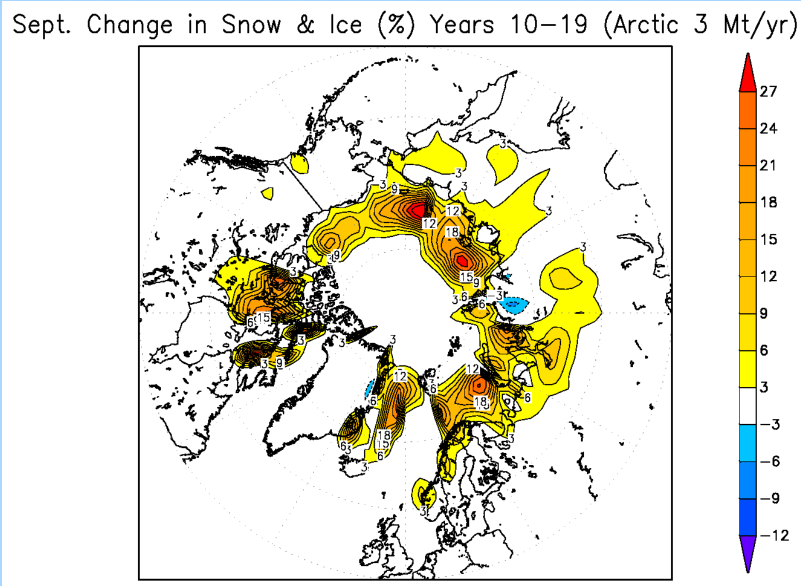
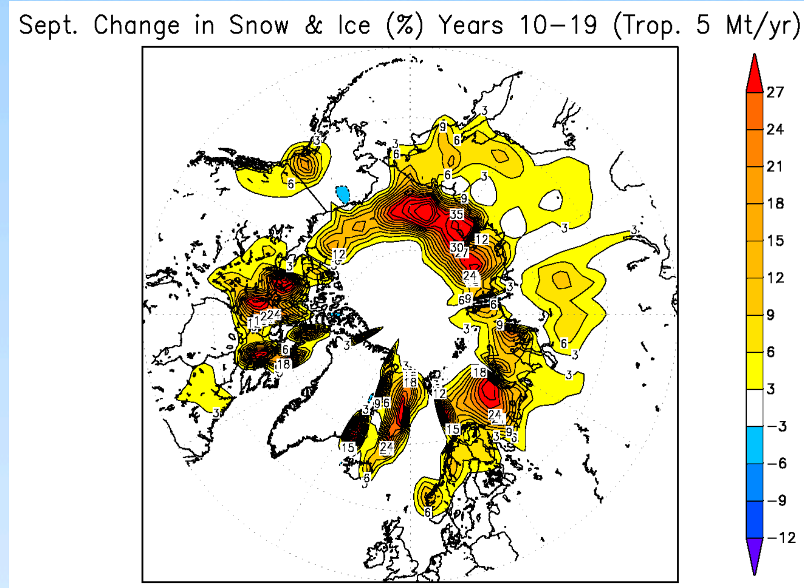
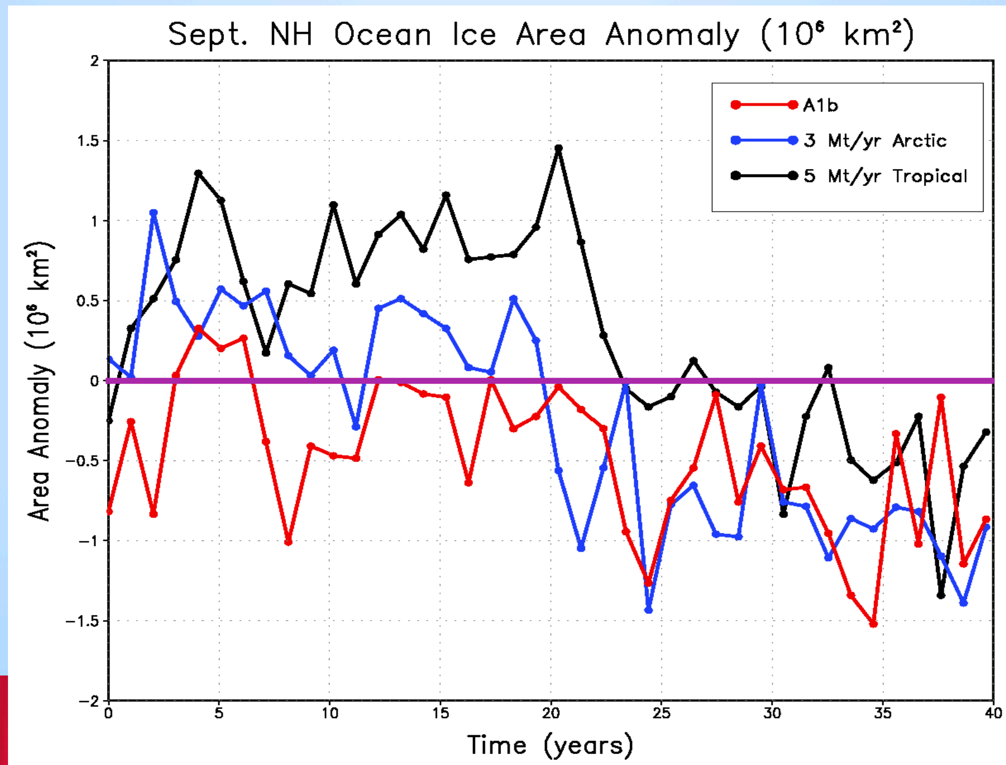



Global average changes in temperature, precipitation, and downward shortwave radiation for A1B, Arctic 3 Mt/yr and Tropical 5 Mt/yr geoengineering runs.

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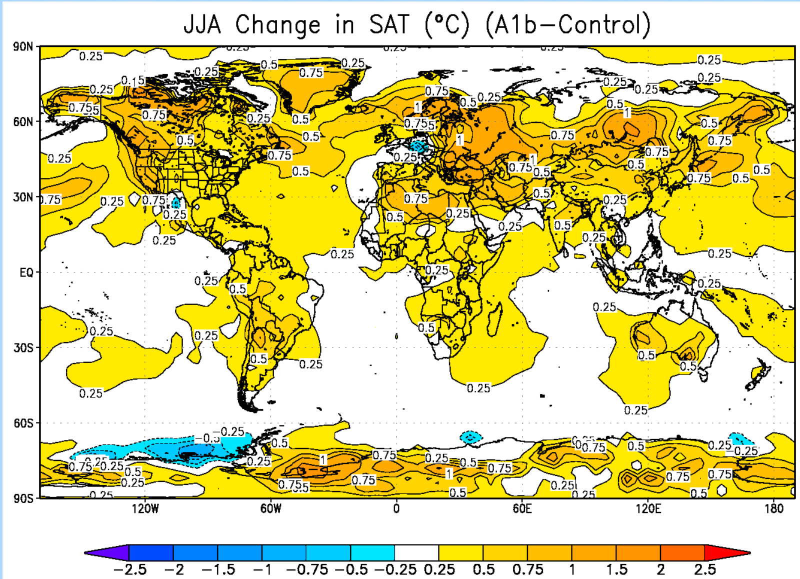
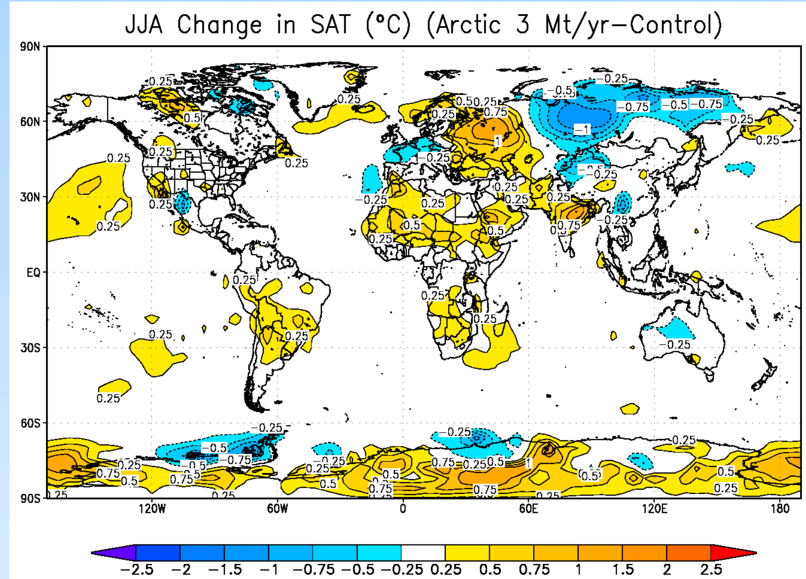
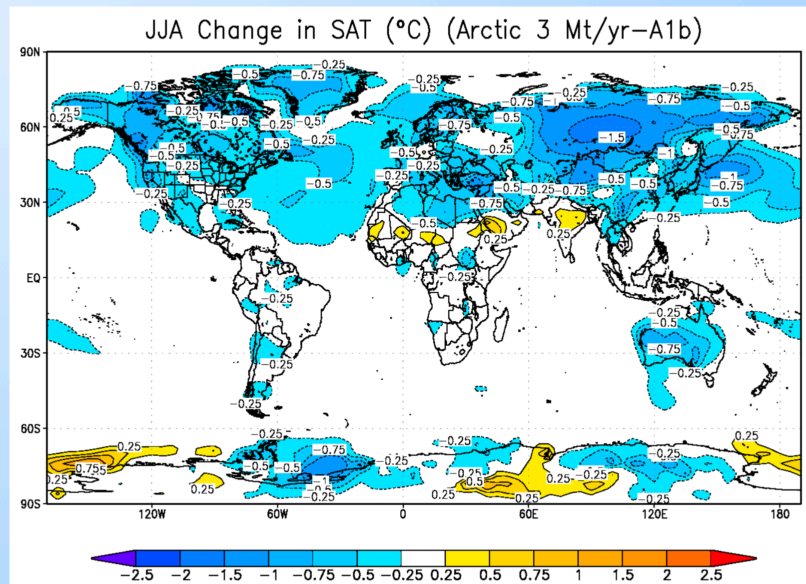



Mean response for second decade of aerosol injection for IPCC A1B + Arctic 3 Mt/yr case for NH summer surface air temperature

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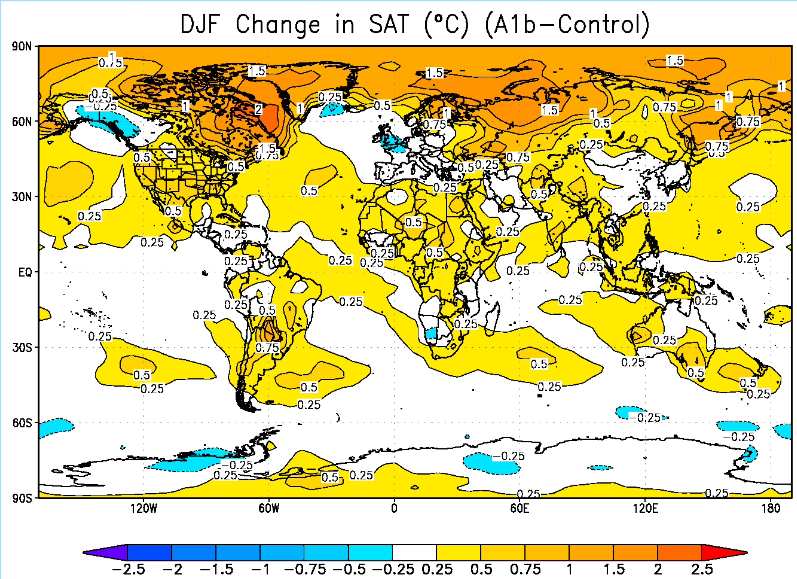
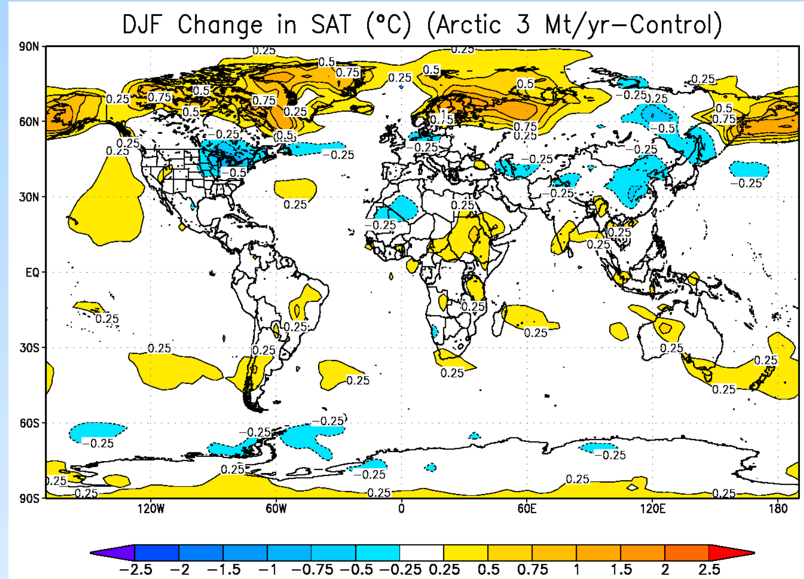
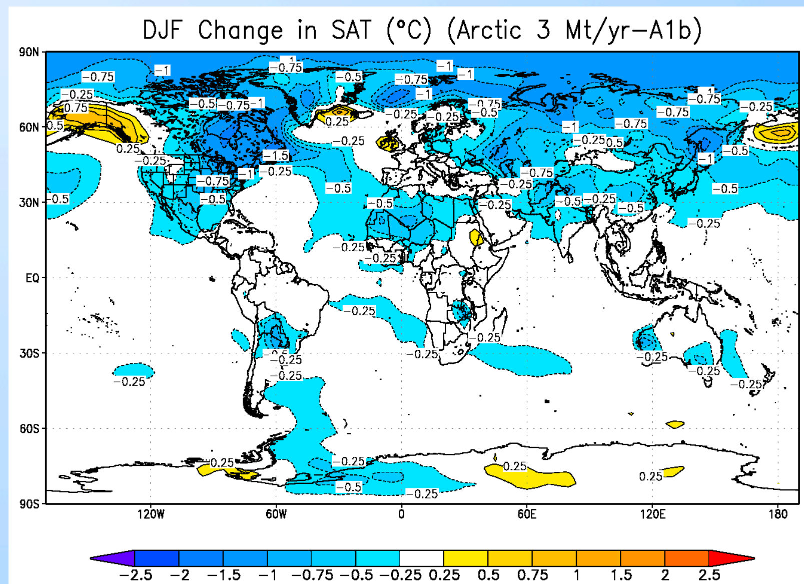



Mean response for second decade of aerosol injection for IPCC A1B + Arctic 3 Mt/yr case for NH winter surface air temperature

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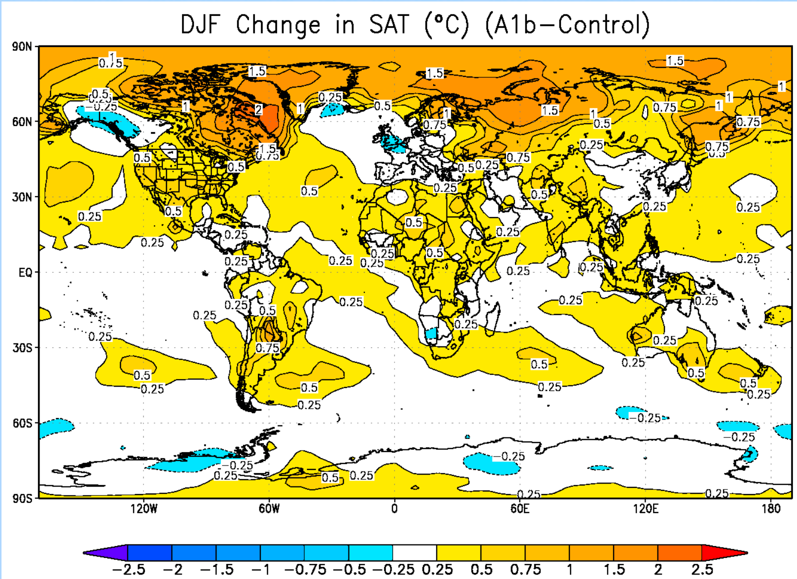
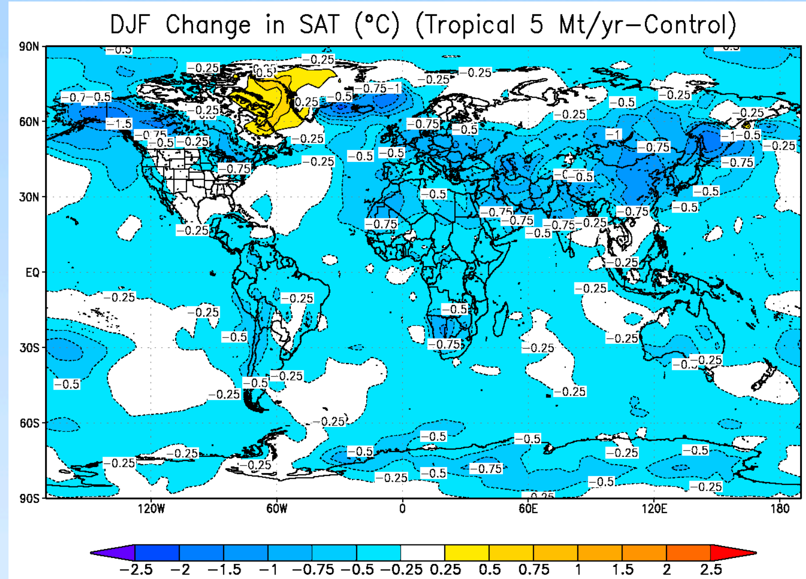
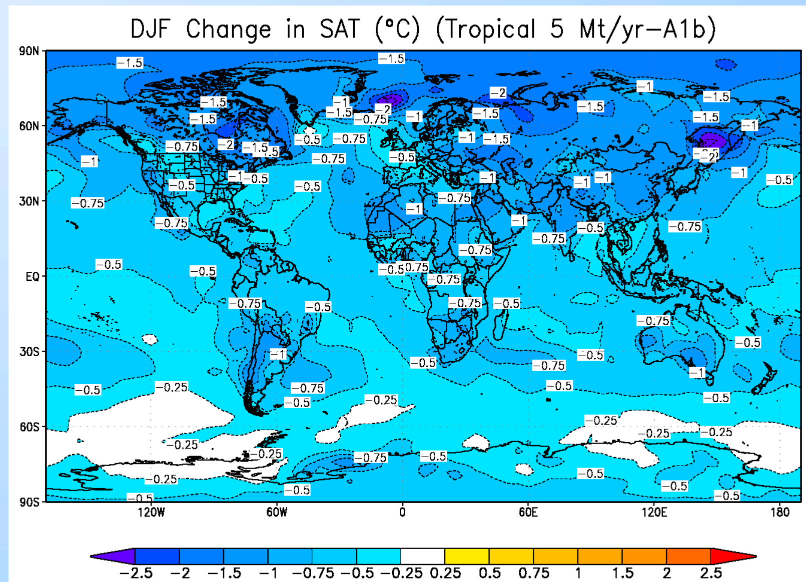
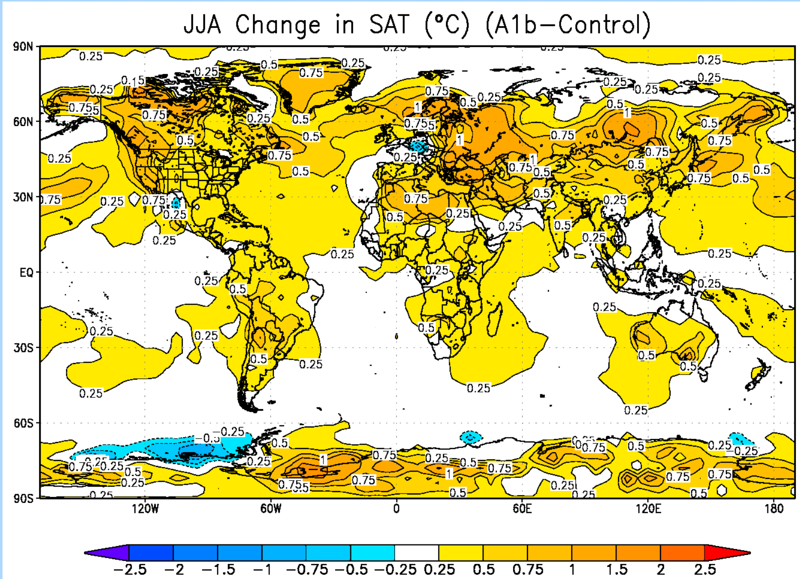
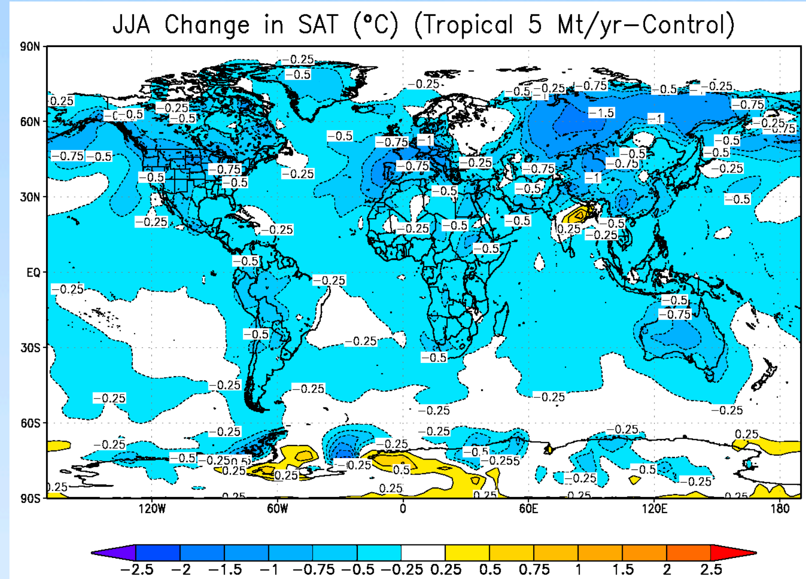


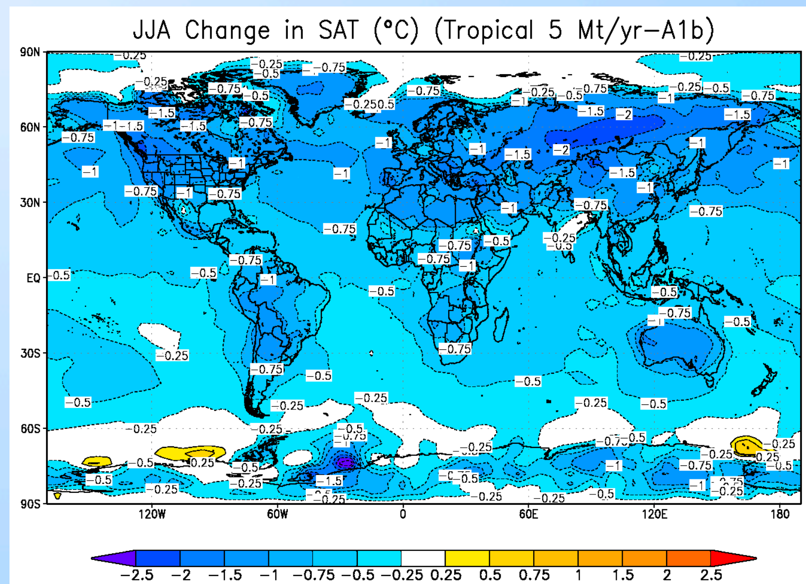

Mean response for second decade of aerosol injection for IPCC A1B + Tropical 5 Mt/yr case for NH winter surface air temperature






Mean response for second decade of aerosol injection for IPCC A1B + Tropical 5 Mt/yr case for <u>NH summer</u> surface air temperature

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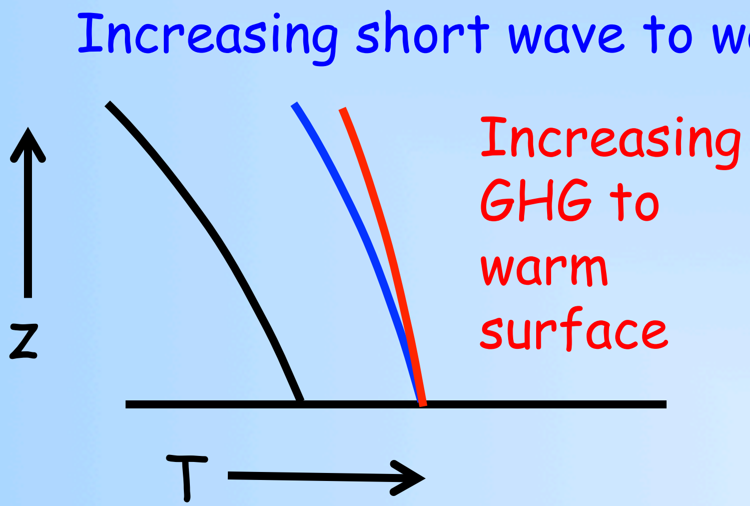
## Reducing solar radiation to keep temperature constant **reduces precipitation**



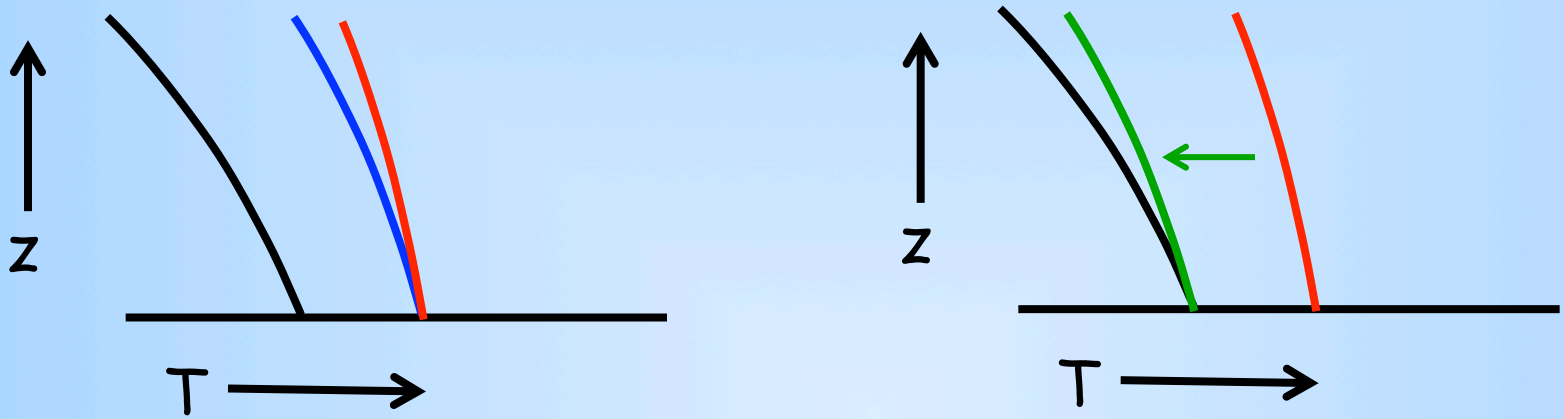

If we compensate for the increased downward longwave radiation from greenhouse gases by reducing solar radiation by the same amount, we can produce a net radiation balance at the surface so temperature will not change.

However, this will result in a reduction of precipitation, since changing solar radiation has a larger impact on precipitation than changing longwave radiation.

This will produce warming from drier surfaces requiring even more solar reduction and more drying.

# Reducing solar radiation to keep temperature constant **reduces precipitation**

Decreasing short wave to cool surface

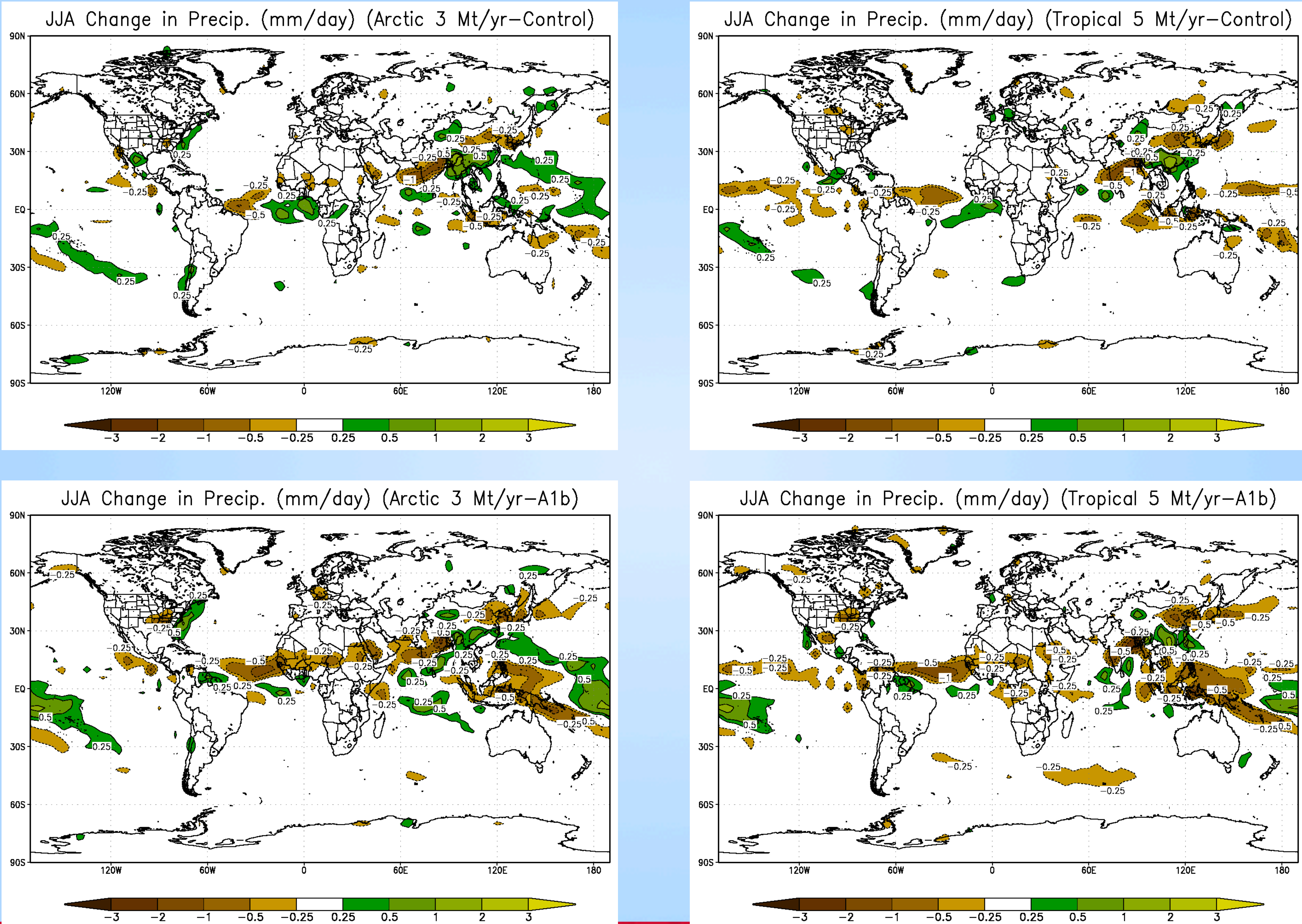



If we compensate for the increased downward longwave radiation from greenhouse gases by reducing solar radiation by the same amount, we can produce a net radiation balance at the surface so temperature will not change.

However, this will result in a reduction of precipitation, since changing solar radiation has a larger impact on precipitation than changing longwave radiation.

This will produce warming from drier surfaces requiring even more solar reduction and more drying.

# Arctic 3 Mt/yr NH summer precipitation Tropical 5 Mt/yr

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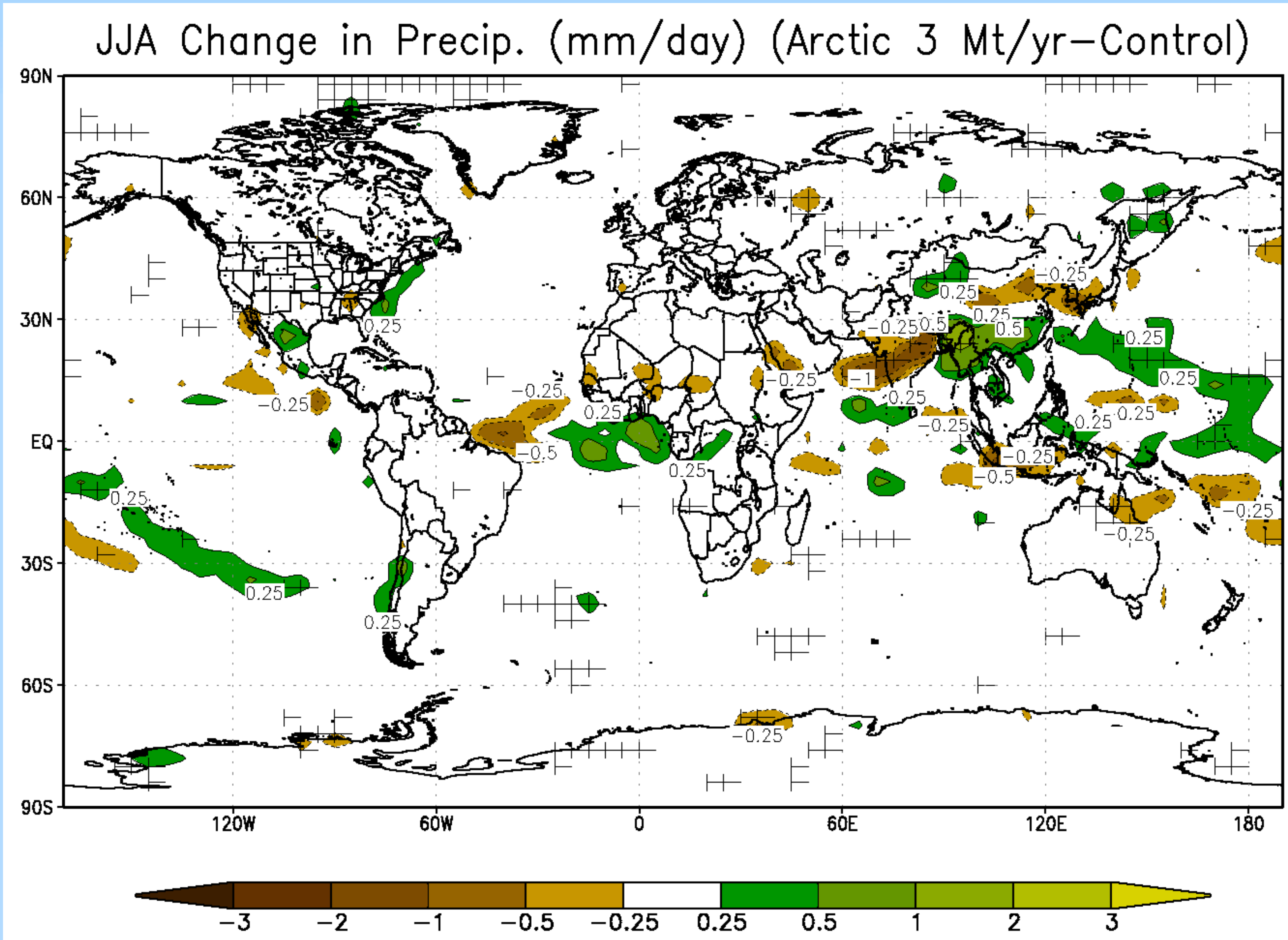


= significant at the 95% level

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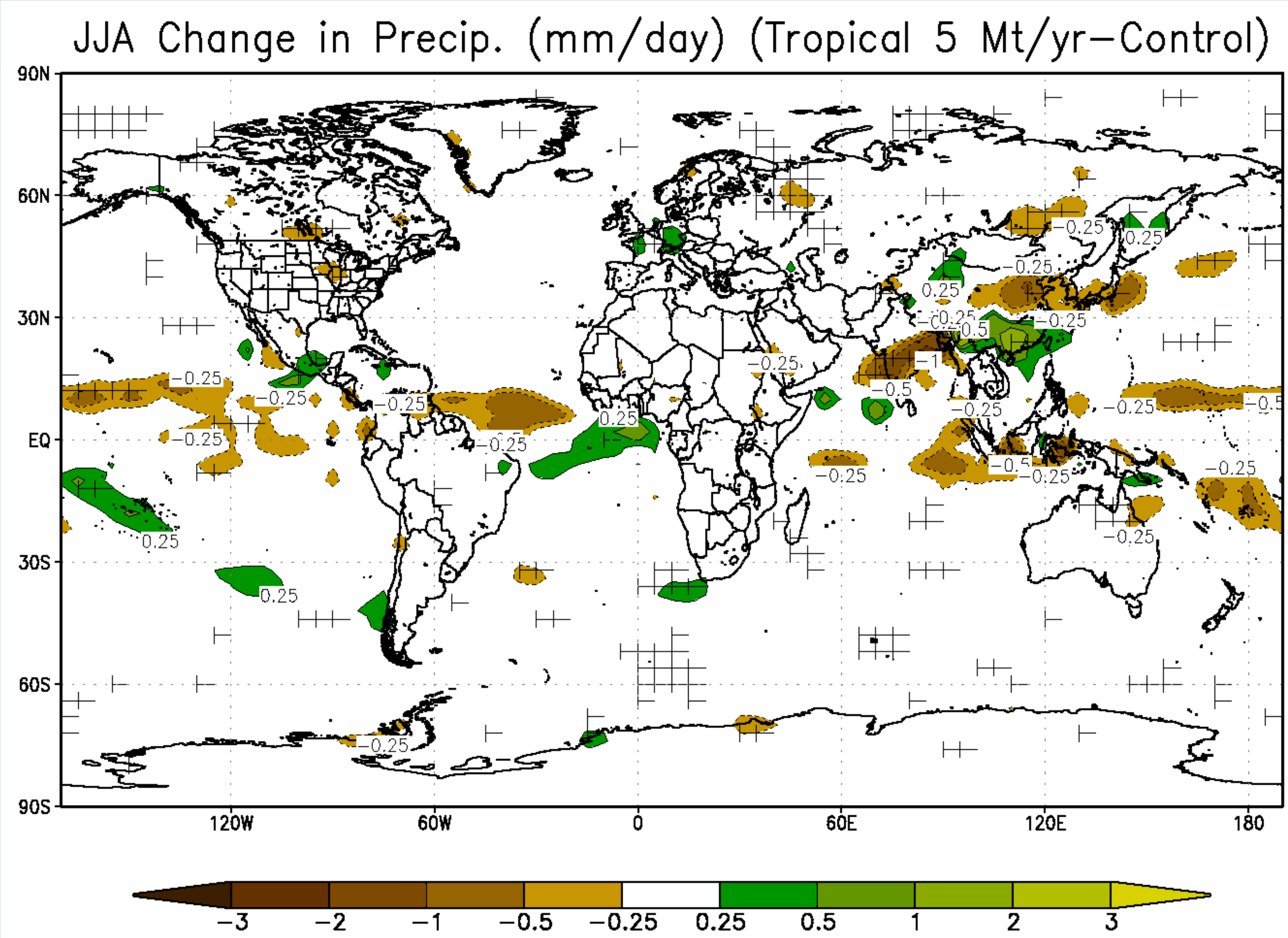


= significant at the 95% level

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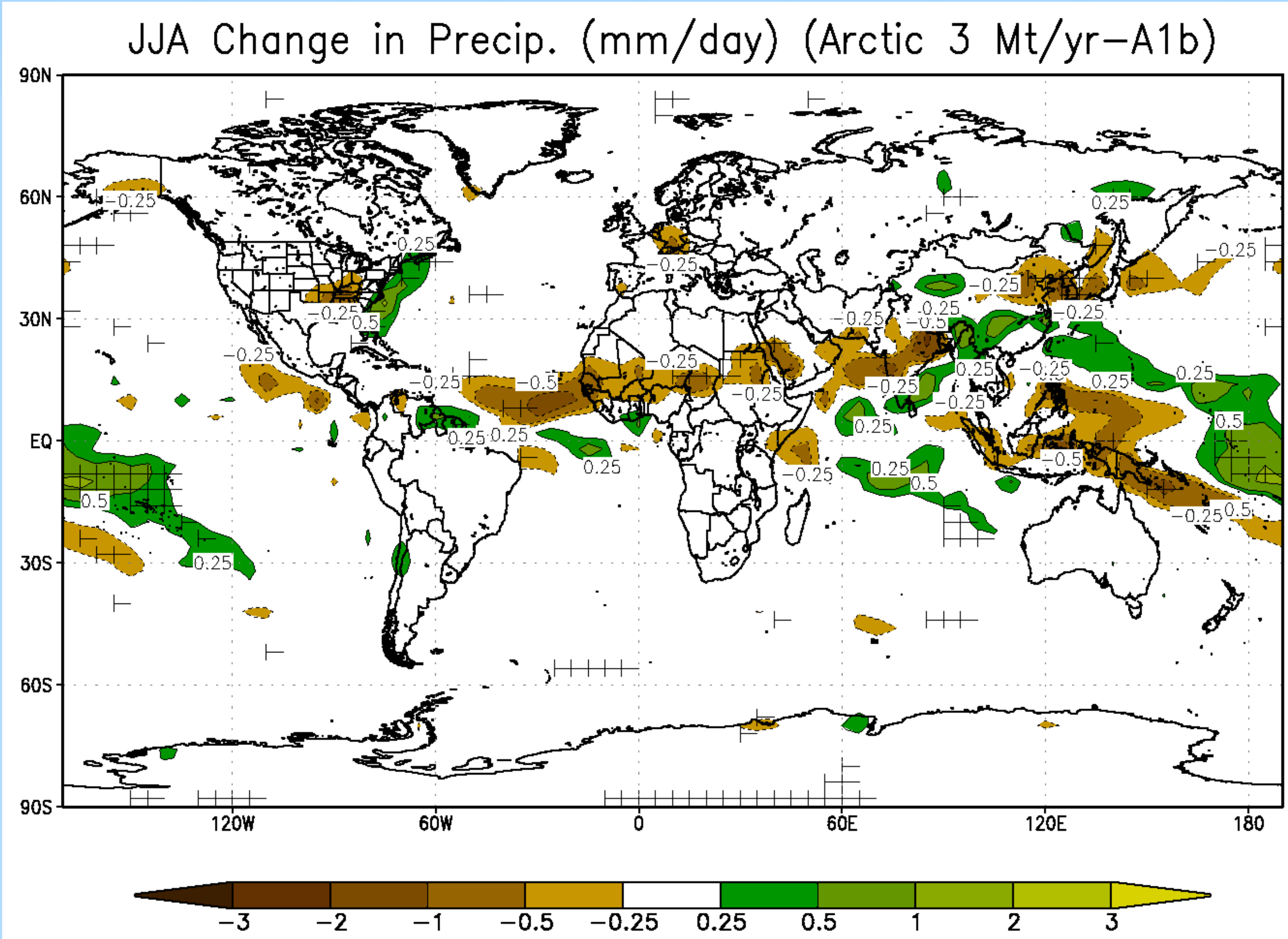
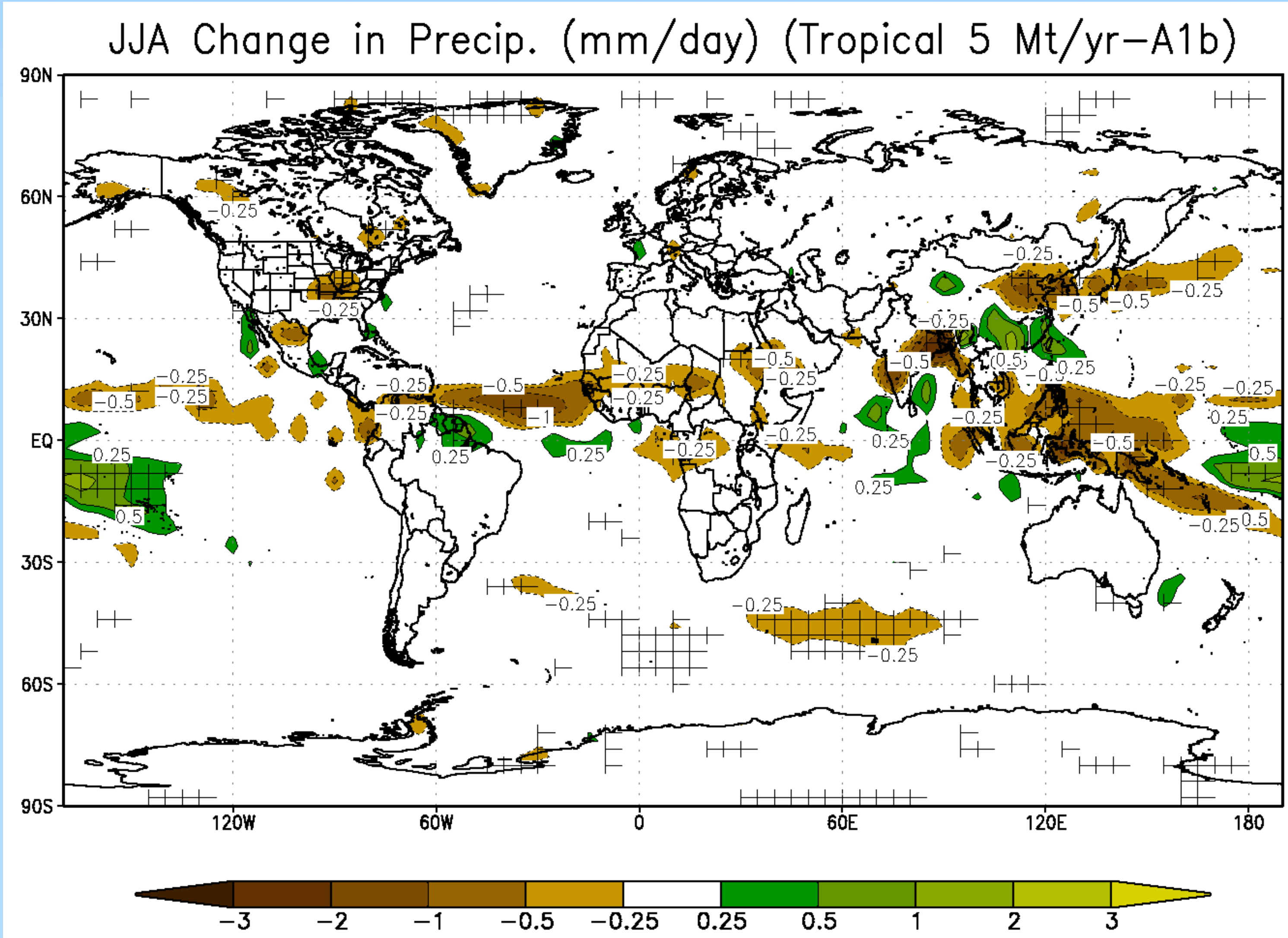



= significant at the 95% level

Robock, Alan, Luke Oman, and Georgiy Stenchikov, 2008: Regional climate responses to geoengineering with tropical and Arctic $SO_2$ injections. *J. Geophys. Res.*, in press.




= significant at the 95% level

Robock, Alan, Luke Oman, and Georgiy Stenchikov, 2008: Regional climate responses to geoengineering with tropical and Arctic $SO_2$ injections. *J. Geophys. Res.*, in press.

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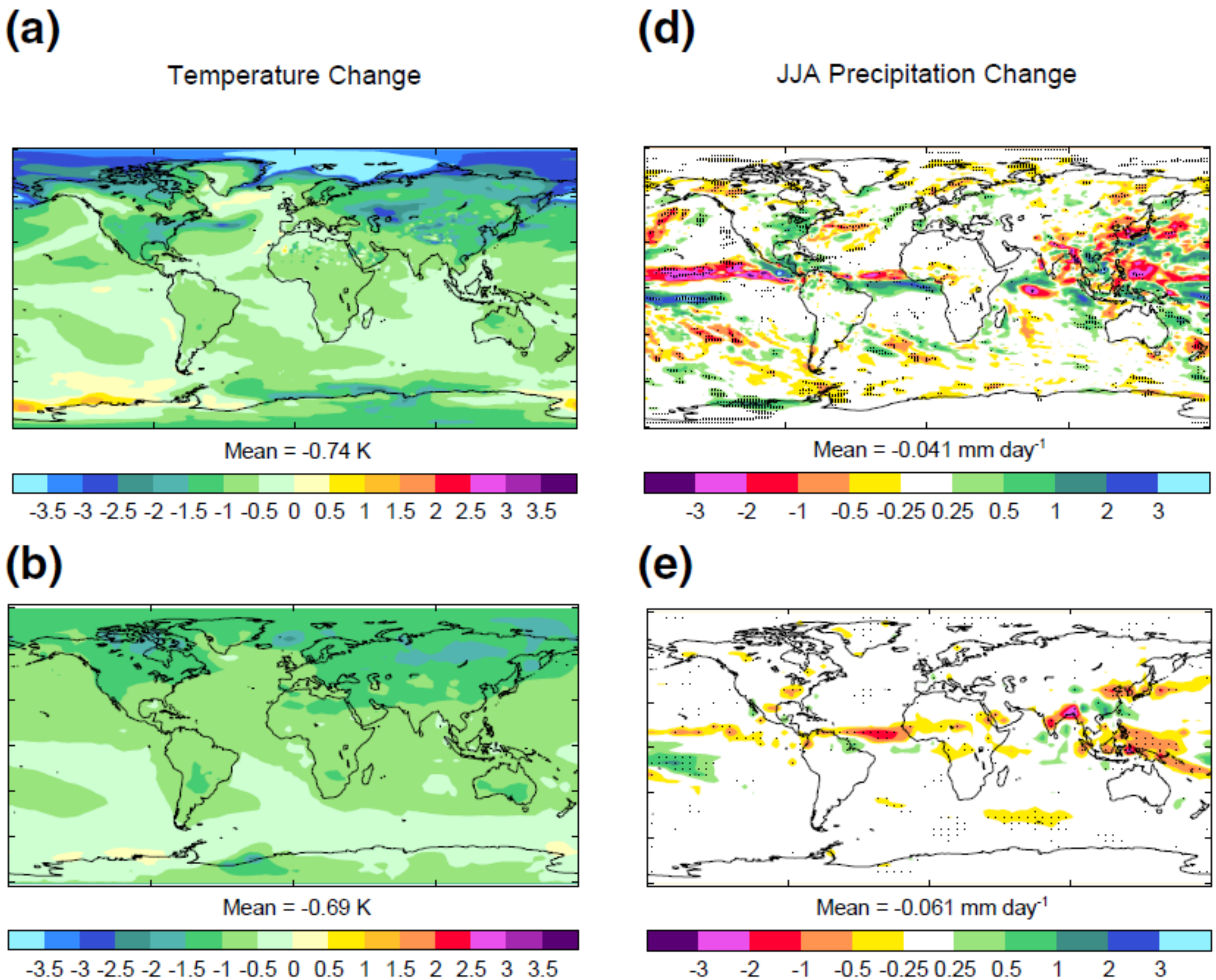


Met Office, Hadley Centre

5Mt/yr – A1b

ModelE

5Mt/yr – A1b

Jones, Andy, Jim Haywood, Olivier Boucher, Ben Kravitz, and Alan Robock, 2010: Geoengineering by stratospheric $SO_2$ injection: Results from the Met Office HadGEM2 climate model and comparison with the Goddard Institute for Space Studies ModelE. *Atmos. Chem. Phys.*, **10**, 5999-6006.

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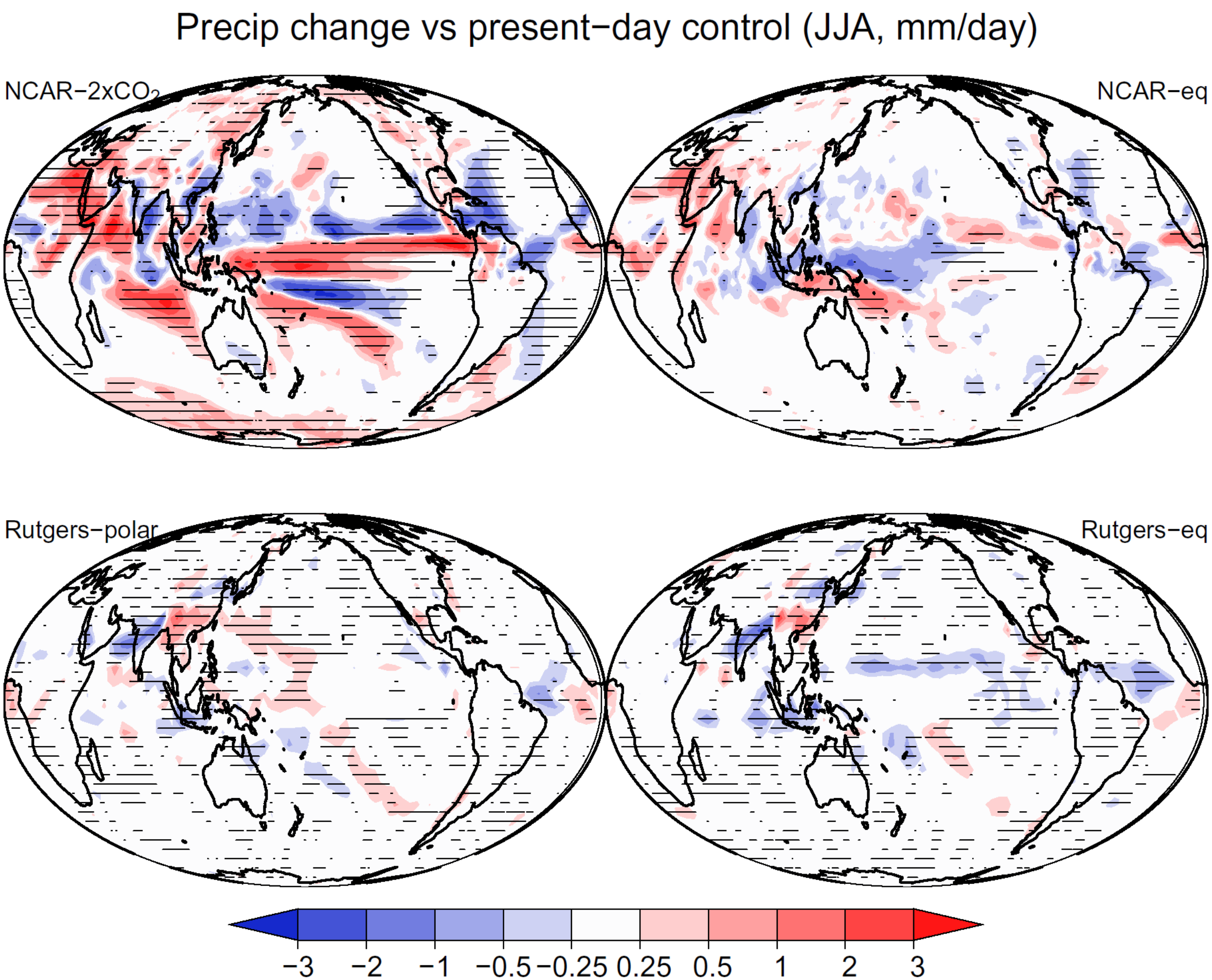


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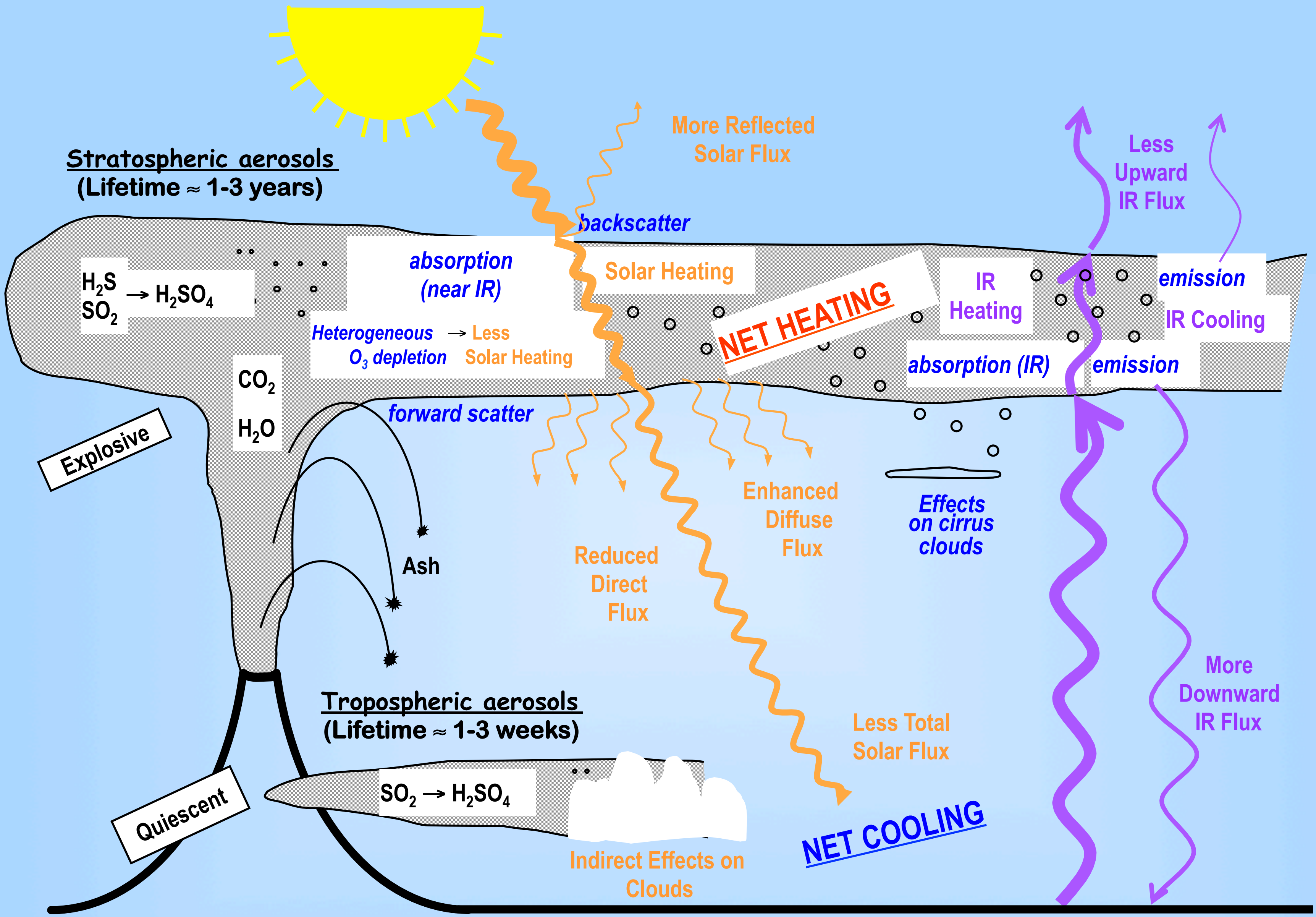
Rasch, Philip J., Simone Tilmes, Richard P. Turco, Alan Robock, Luke Oman, Chih-Chieh (Jack) Chen, Georgiy L. Stenchikov, and Rolando R. Garcia, 2008: An overview of geoengineering of climate using stratospheric sulphate aerosols. *Phil. Trans. Royal Soc. A.*, **366**, 4007-4037, doi:10.1098/rsta.2008.0131.

# Conclusions

1. If there were a way to continuously inject $SO_2$ into the lower stratosphere, it would produce global cooling.
2. Tropical $SO_2$ injection would produce sustained cooling over most of the world, with more cooling over continents.
3. Arctic $SO_2$ injection would not just cool the Arctic.
4. Solar radiation reduction produces larger precipitation response than temperature, as compared to greenhouse gases.
5. Both tropical and Arctic $SO_2$ injection might disrupt the Asian and African summer monsoons, reducing precipitation to the food supply for billions of people.



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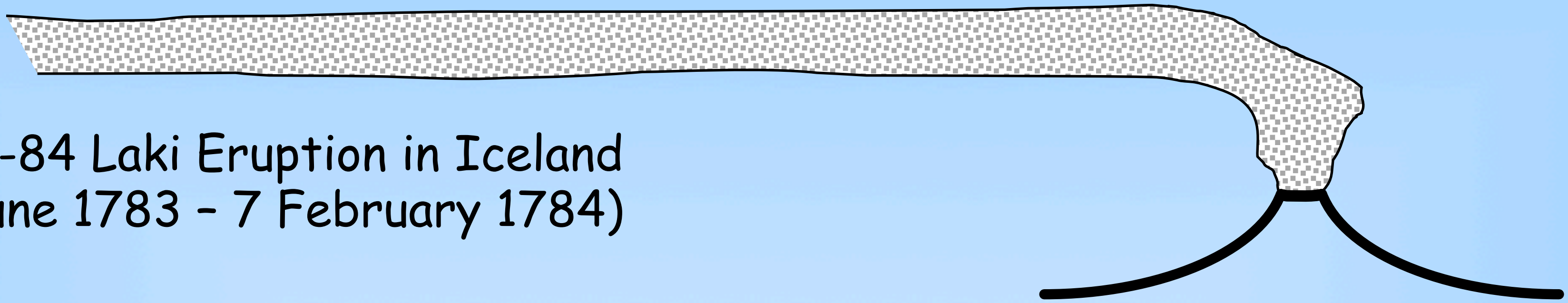
# 1783-84, Lakagígar (Laki), Iceland



1783-84 Laki Eruption in Iceland
(8 June 1783 – 7 February 1784)

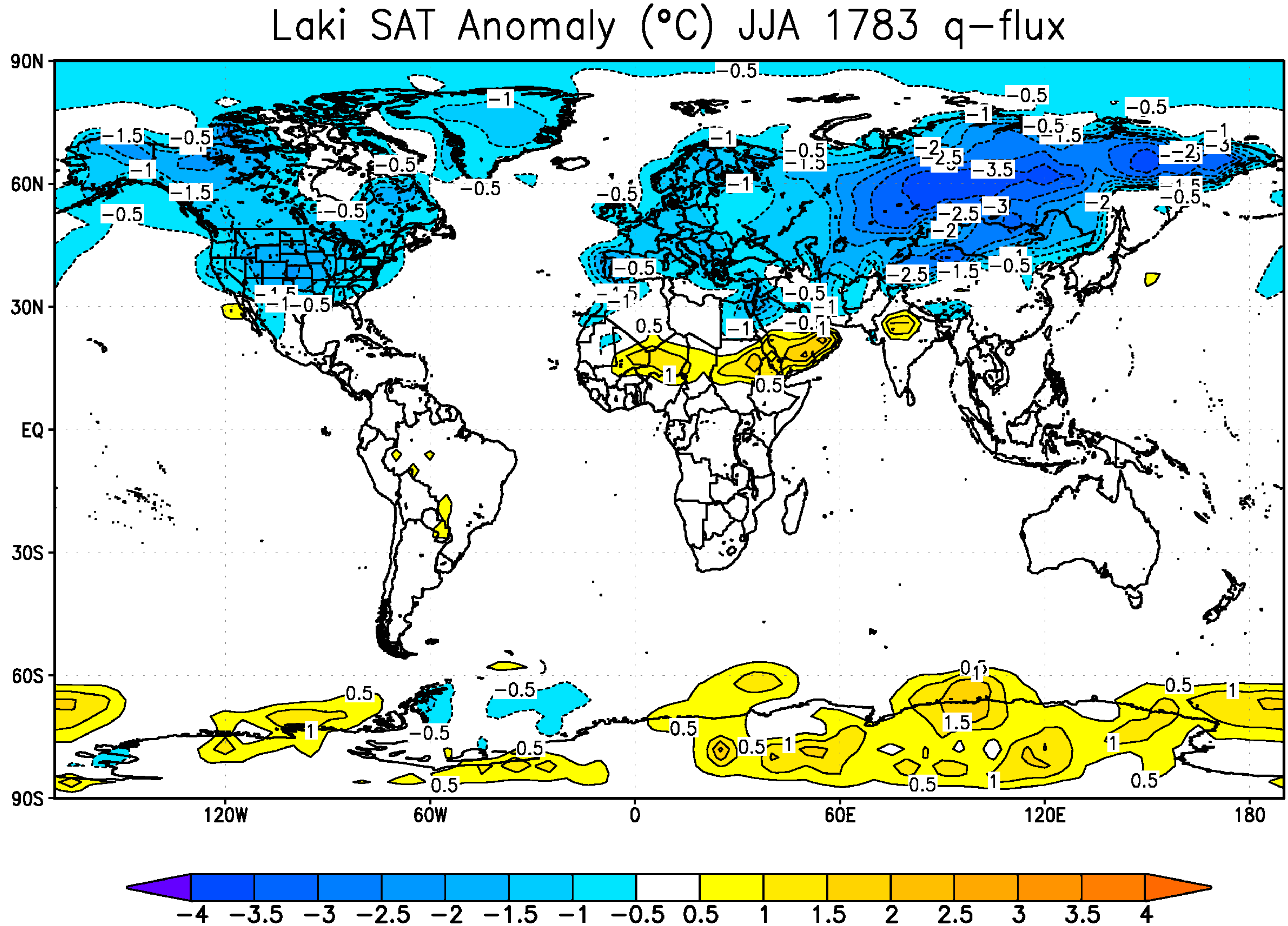
Second largest flood lava eruption in historical time

Iceland's biggest natural disaster

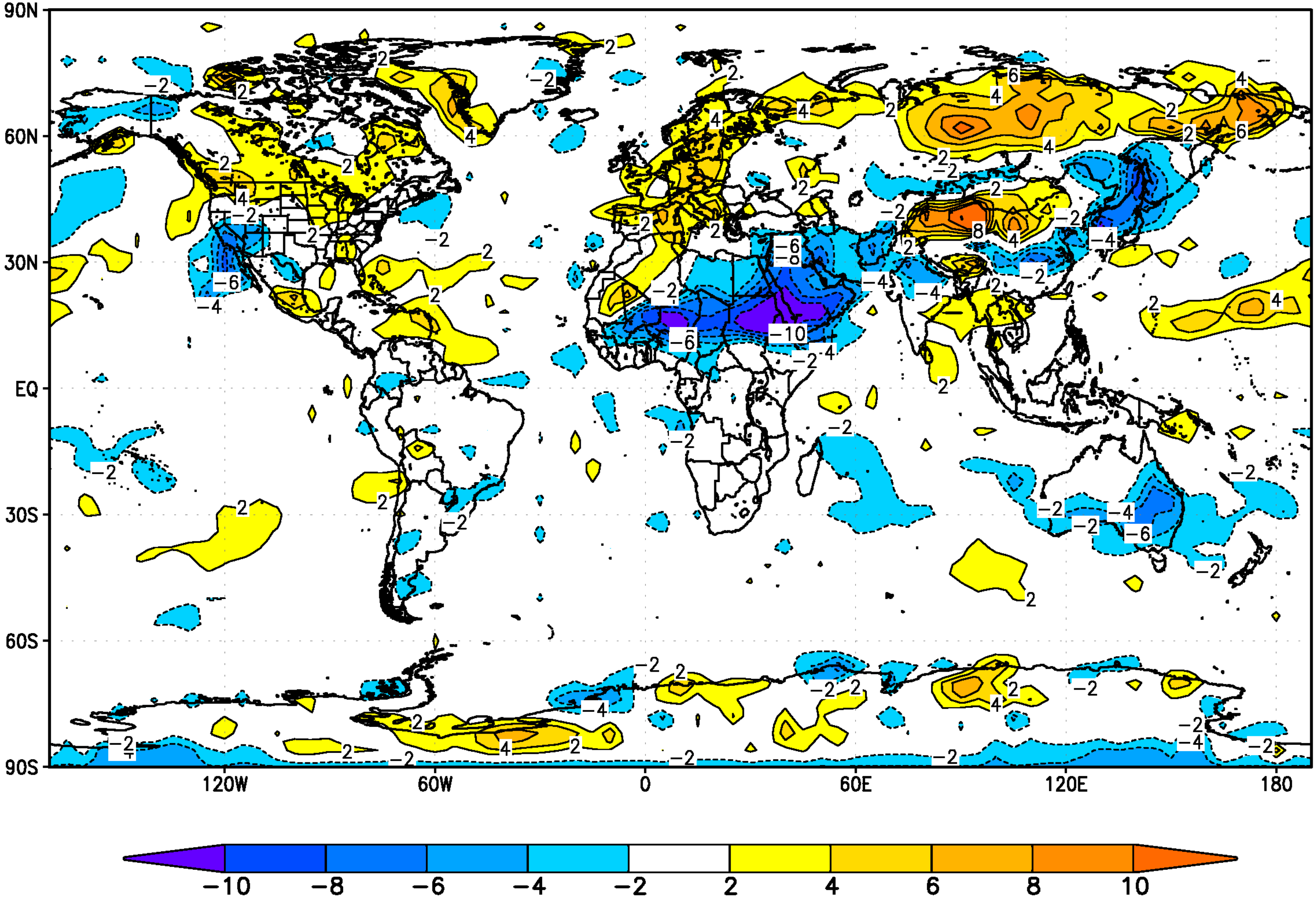
Lava = 14.7 $km^3$
Tephra = 0.4 $km^3$

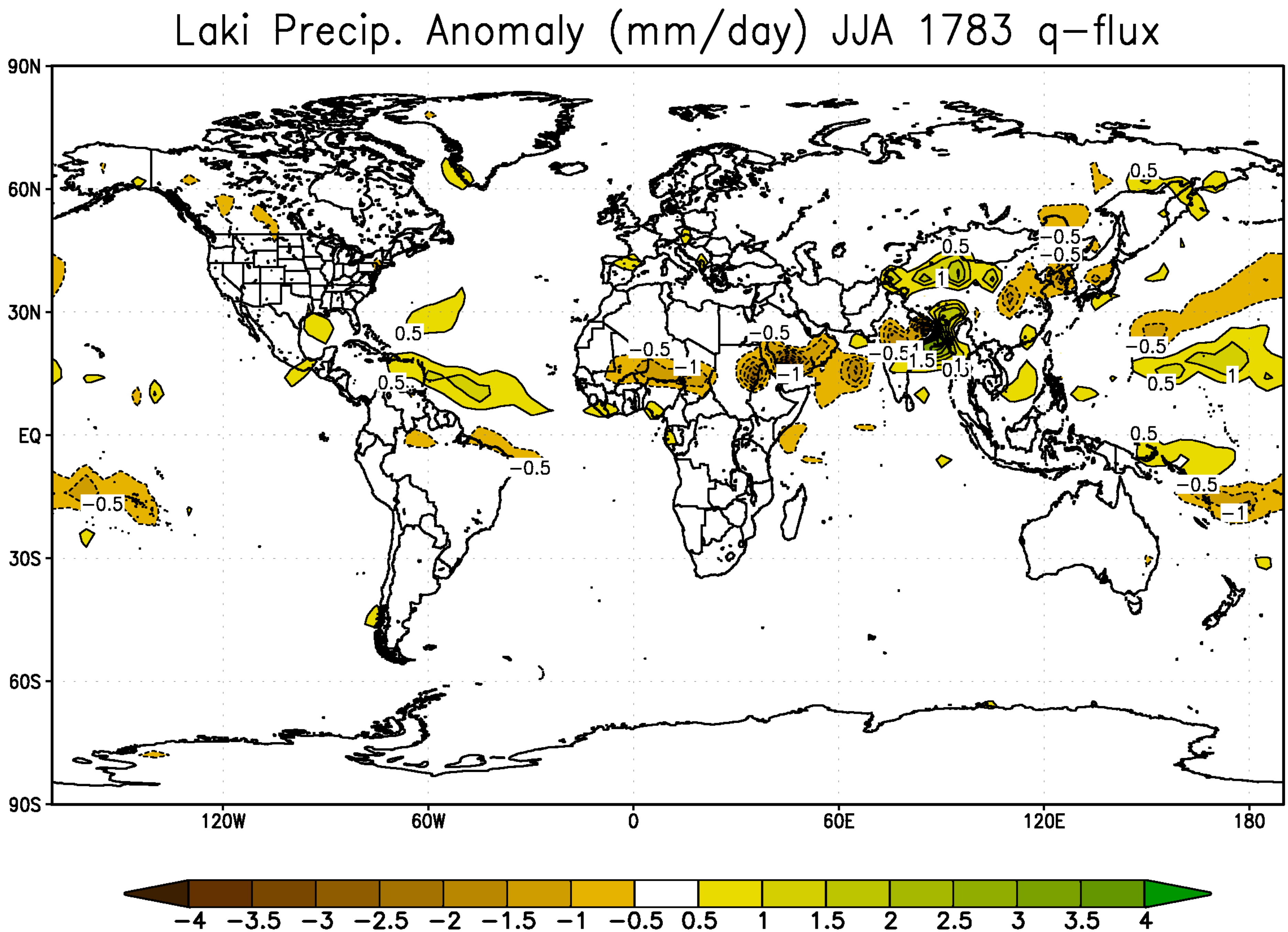
WVZ, EVZ, NVZ are Western, Eastern and Northern Volcanic Zones


Fig. 1 from Thordarson and Self (2003)


Laki SAT Anomaly (°C) JJA 1783 q–flux
90N
60N
30N
EQ
30S
60S
90S
120W
60W
0
60E
120E
180
–4
–3.5
–3
–2.5
–2
–1.5
–1
–0.5
0.5
1
1.5
2
2.5
3
3.5
4

# Laki Cloud Cover Anomaly (%) JJA 1783 q−flux





Laki Precip. Anomaly (mm/day) JJA 1783 q-flux
90N
60N
30N
EQ
30S
60S
90S
120W
60W
0
60E
120E
180
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3
3.5
4

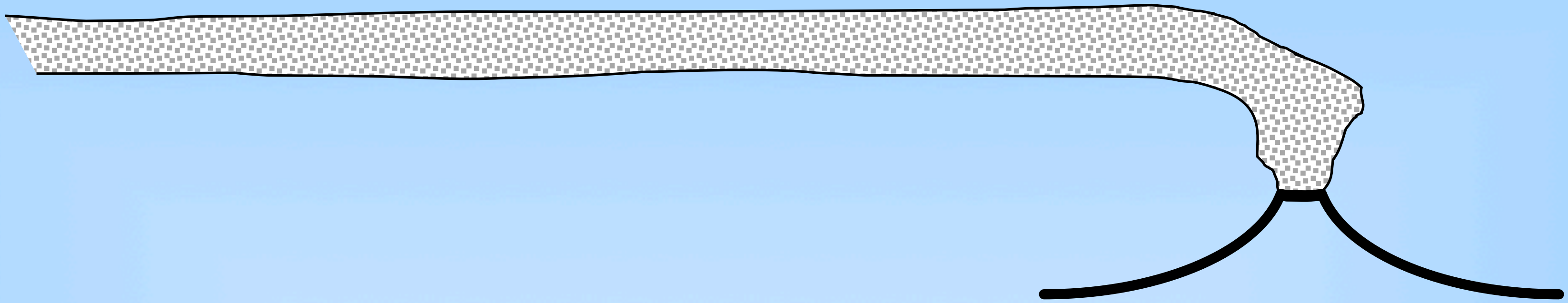
Constantin-François de Chasseboeuf,
**Comte de Volney**
*Travels through Syria and Egypt, in the years 1783, 1784, and 1785, Vol. I*
Dublin, 258 pp. (1788)

"The inundation of 1783 was not sufficient, great part of the lands therefore could not be sown for want of being watered, and another part was in the same predicament for want of seed. In 1784, the Nile again did not rise to the favorable height, and the dearth immediately became excessive. Soon after the end of November, the famine carried off, at Cairo, nearly as many as the plague; the streets, which before were full of beggars, now afforded not a single one: all had perished or deserted the city."

By January 1785, 1/6 of the population of Egypt had either died or left the country in the previous two years.



http://www.academie-francaise.fr/images/immortels/portraits/volney.jpg



# FAMINE IN INDIA AND CHINA IN 1783

The Chalisa Famine devastated India as the monsoon failed in the summer of 1783.

There was also the Great Tenmei Famine in Japan in 1783-1787, which was locally exacerbated by the Mount Asama eruption of 1783.

# What about other high latitude eruptions?

There have been three major high latitude eruptions in the past 2000 years:

939 Eldgjá, Iceland - Tropospheric and stratospheric

1783-84 Lakagígar (Laki), Iceland - Same as Eldgjá

1912 Novarupta (Katmai), Alaska - Stratospheric only

Photo by George C. Martin

KATMAI VILLAGE, LOOKING NORTH TOWARD KATMAI VOLCANO, WHICH IS CONCEALED IN THE CLOUD BEYOND THE HILLS
AUGUST 13, 1912

The eruption of Katmai Volcano, though one of the most violent explosions recorded, did not cause the loss of a single life, owing to the sparse settlement of the neighborhood. The town of Katmai was deserted at the time of the eruption, most of the inhabitants being away, engaged in the summer fishing.

Katmai village, buried by ash from the June 6, 1912 eruption
Katmai volcano in background covered by cloud

Simulations showed same reduction in African summer precipitation.



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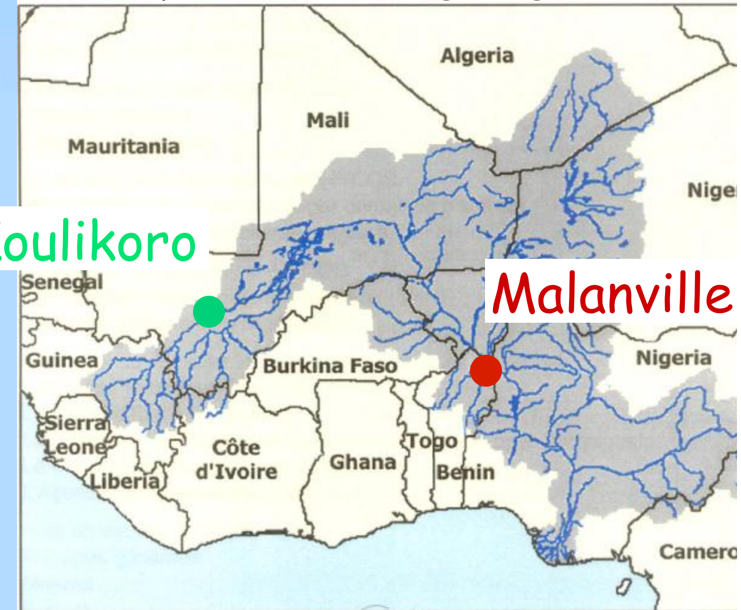
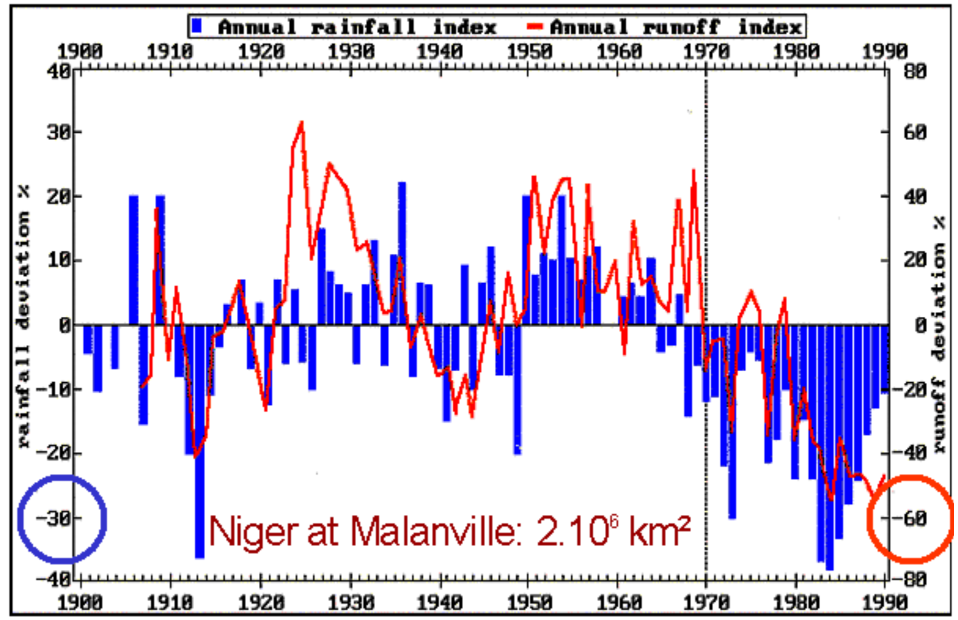
Department of Environmental Sciences

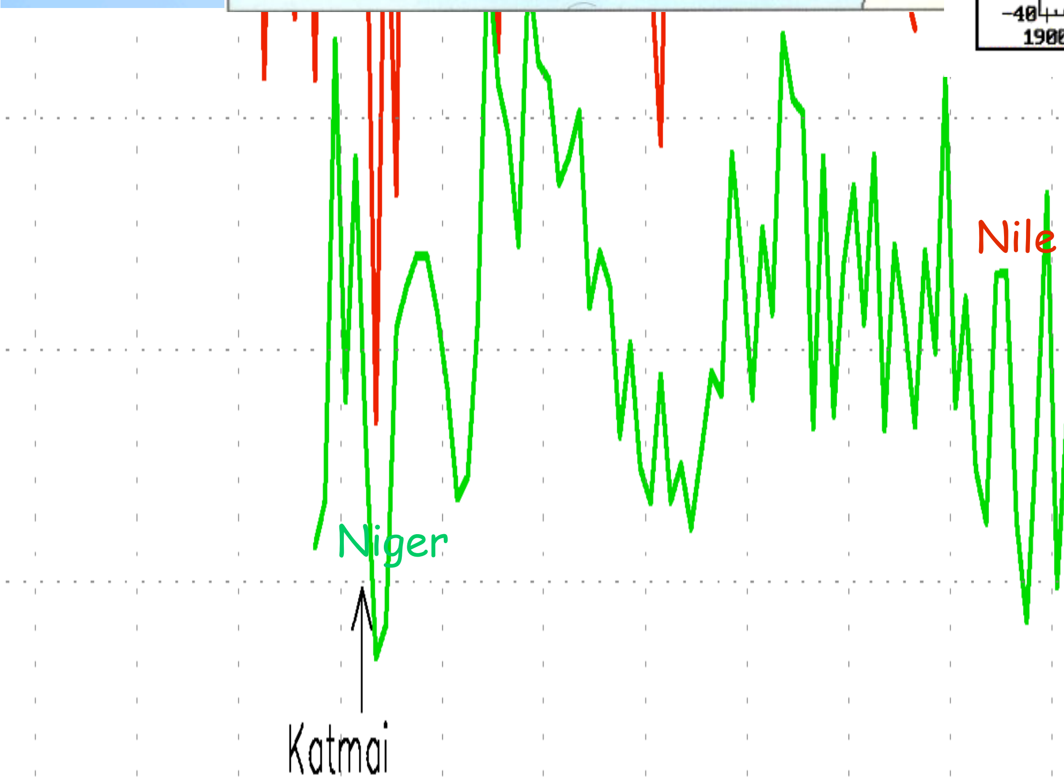
Niger Basin

http://www.festivalsegou.org




Annual rainfall & runoff deficit for the Niger river





http://www.isiimm.agropolis.org

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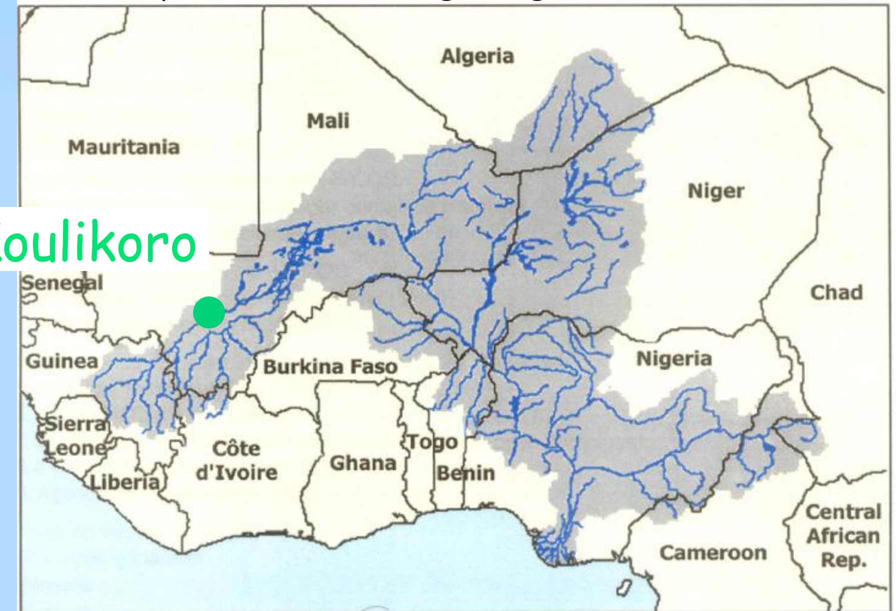
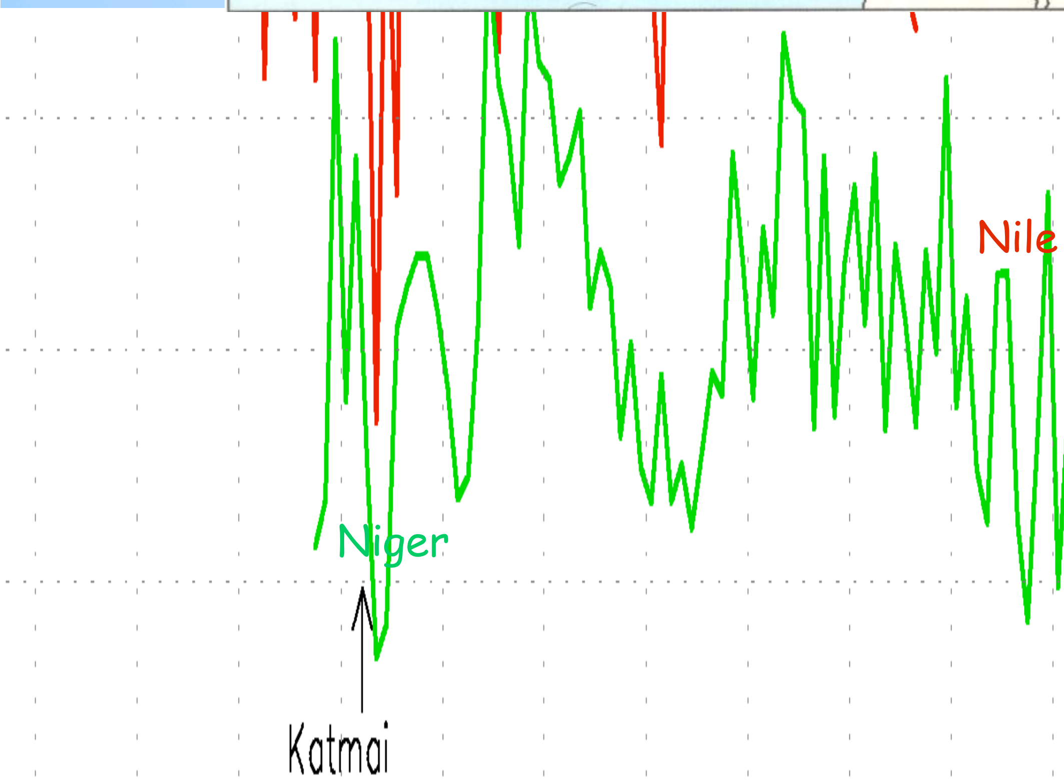
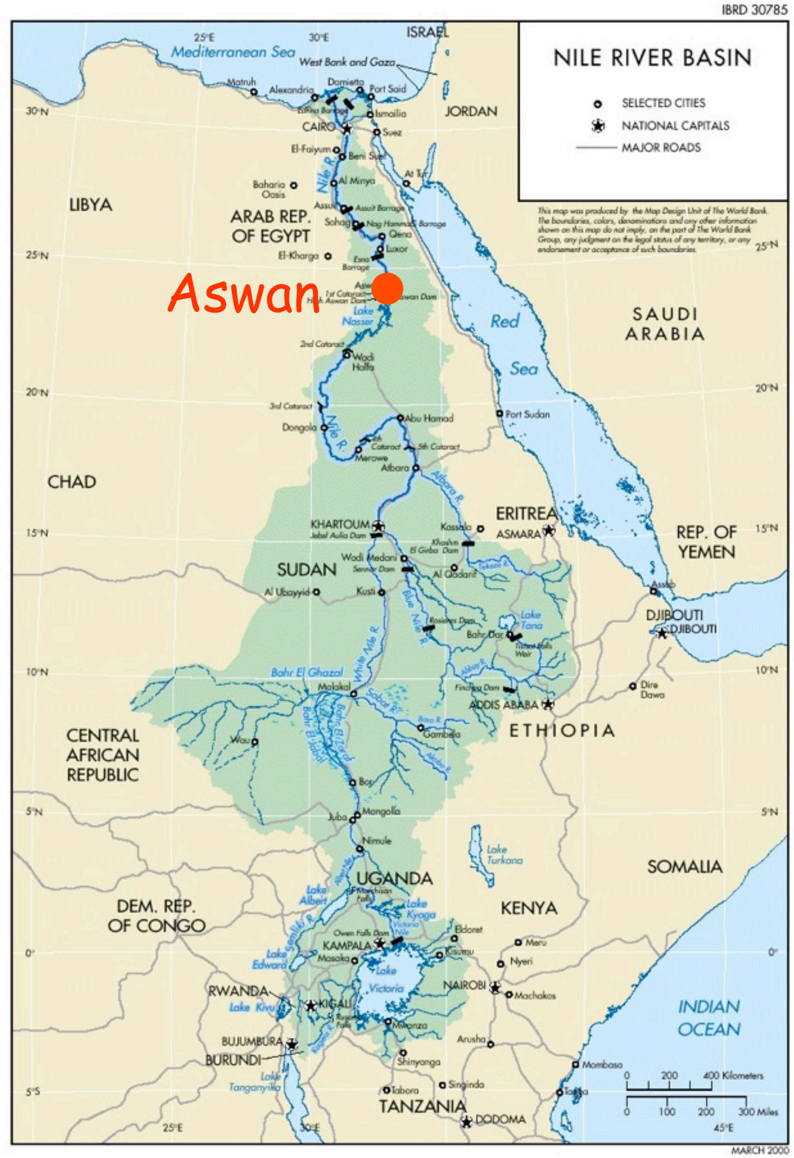
Niger Basin

http://www.festivalsegou.org




http://www.isiimm.agropolis.org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## High-latitude Eruptions and the Nile River Level

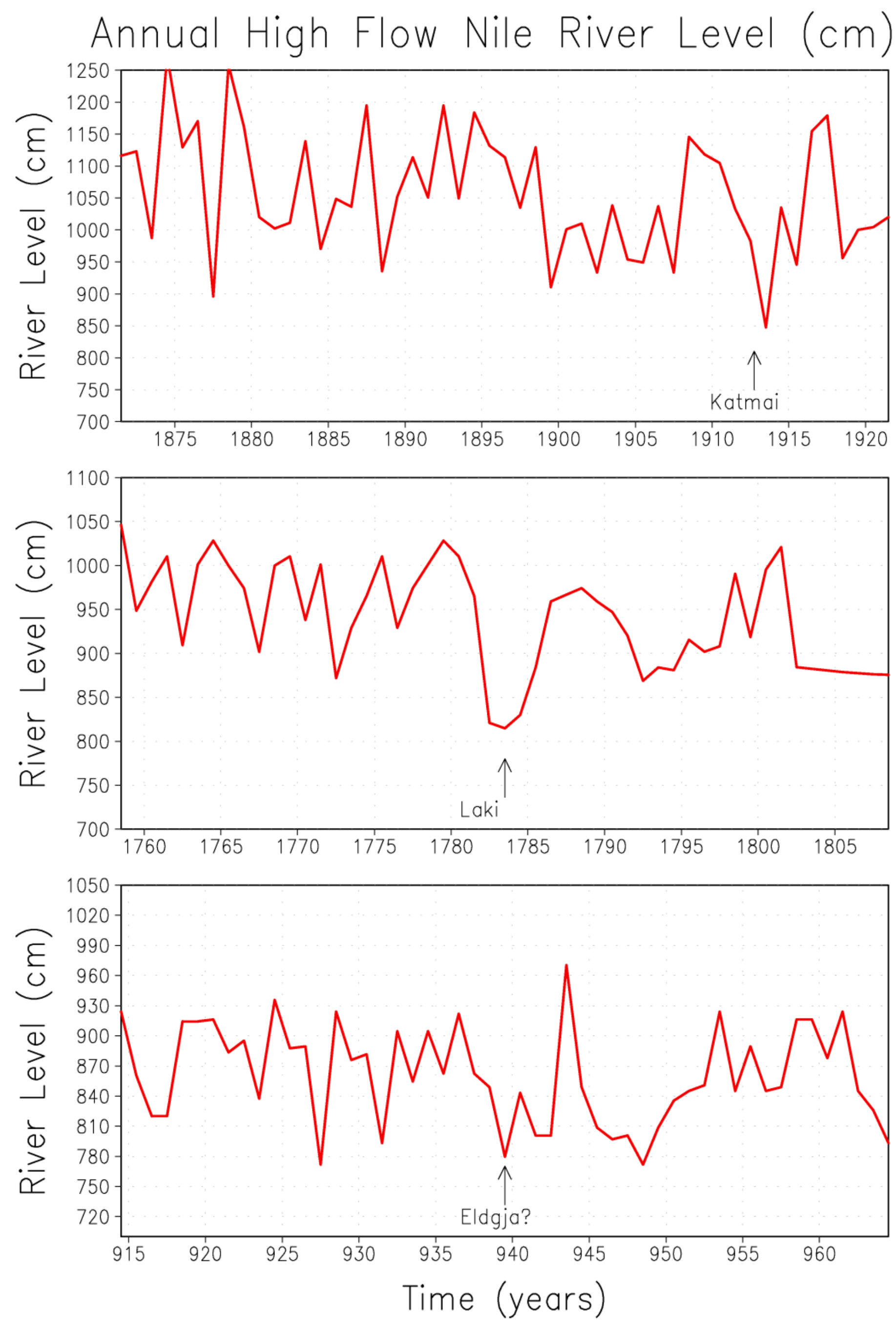
The exact dating of Eldgjá is not known but it is thought to have occurred between 933 and 941 A.D.

Several points suggest 939:

Astronomical observations in Irish Annals (McCarthy and Breen, 1997)

GISP2 ice core has peak acidity in 938 ±4 years (Zielinski, 1995)

Winter of 939-940 was very severe over Europe and similar to 1783-1784 after Laki.

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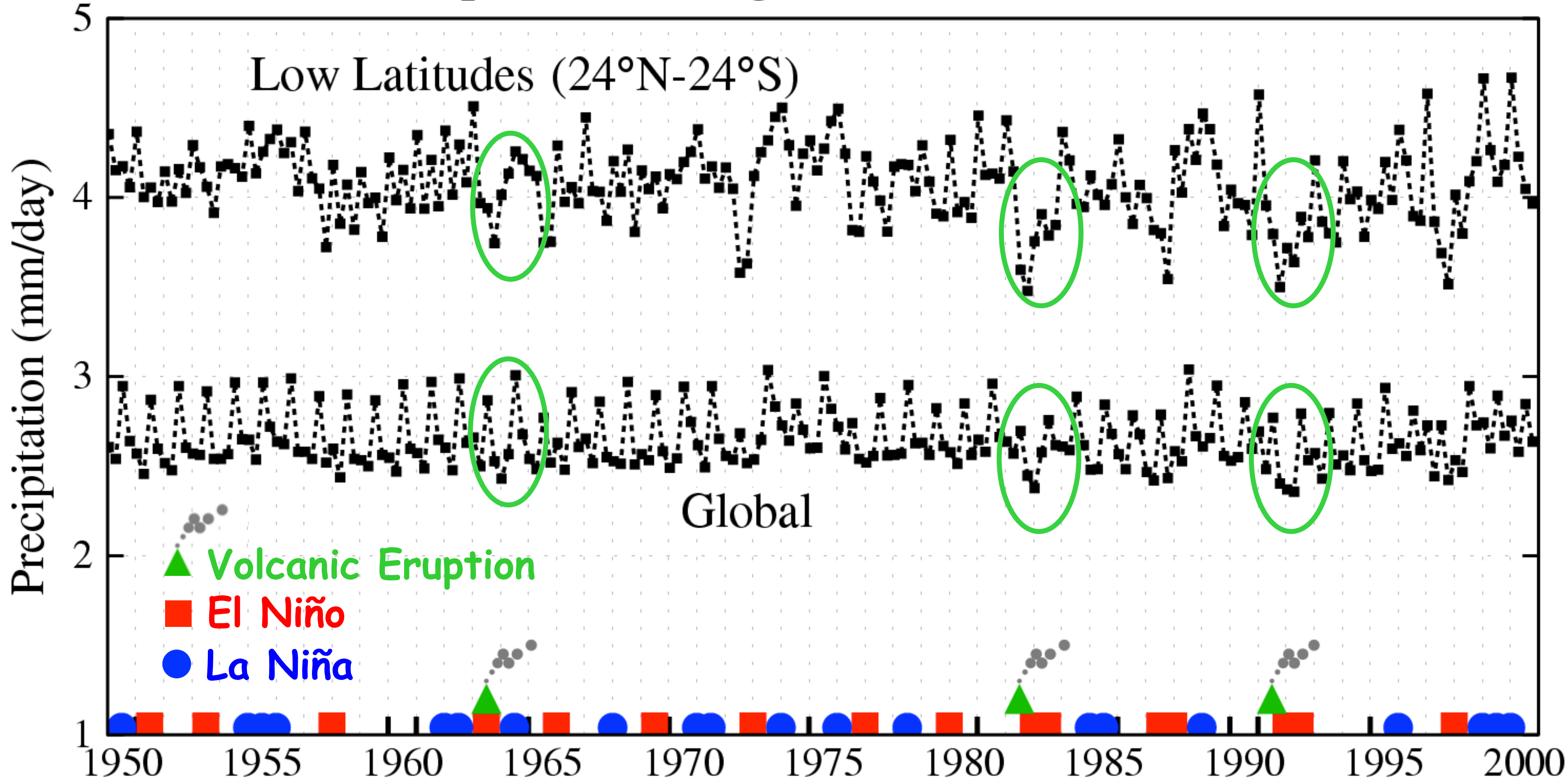
## Precipitation Change at Seasonal Resolution




Drawn by Makiko Sato (NASA GISS)
using CRU TS 2.0 data

Trenberth and Dai (2007)

Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering

*Geophys. Res. Lett.*

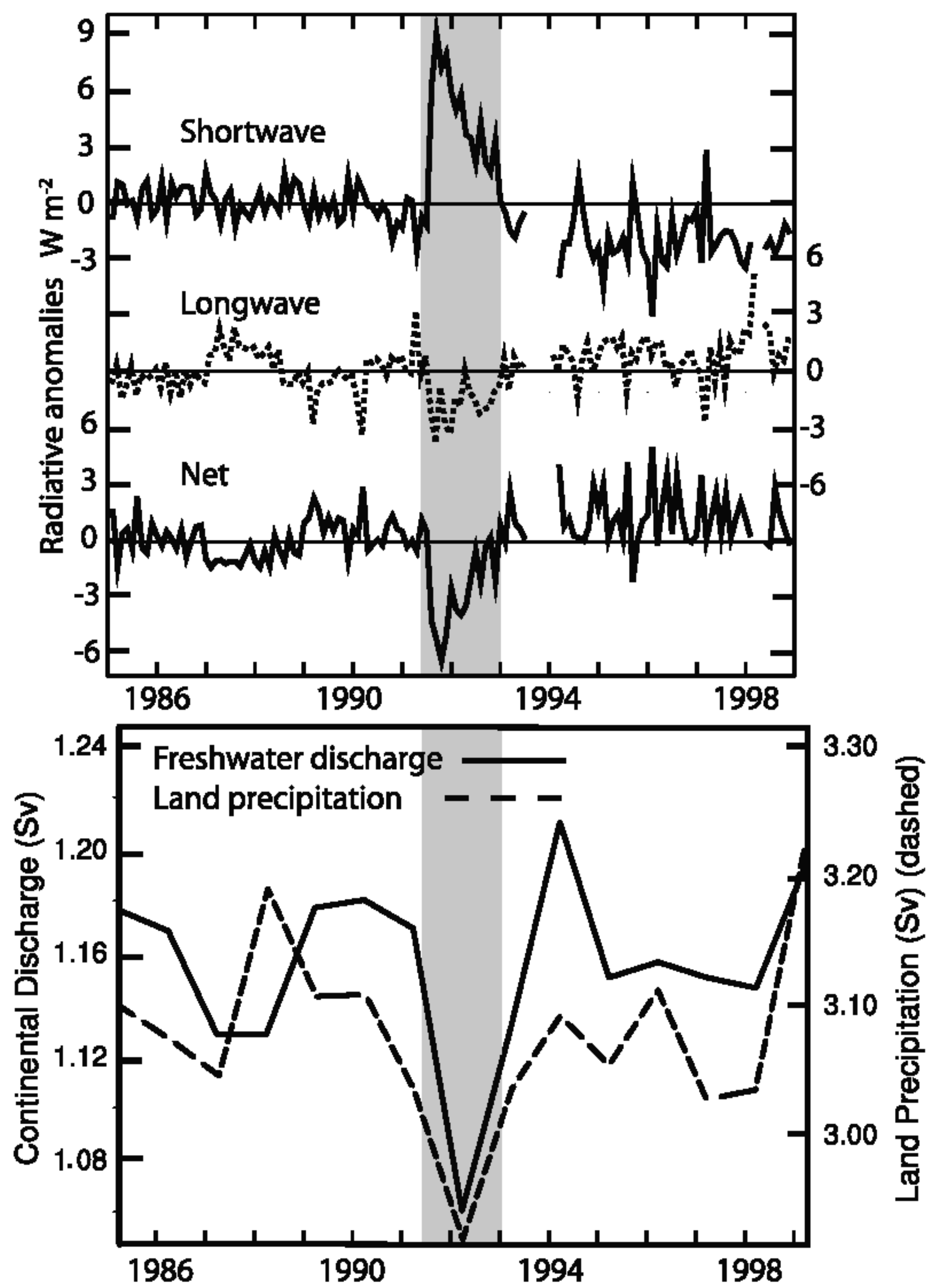



**Figure 2.** (top) Adapted time series of 20°N to 20°S ERBS non-scanner wide-field-of-view broadband shortwave, longwave, and net radiation anomalies from 1985 to 1999 [*Wielicki et al.*, 2002a, 2002b] where the anomalies are defined with respect to the 1985 to 1989 period with Edition 3_Rev 1 data [*Wong et al.*, 2006]. (bottom) Time series of the annual water year (Oct. to Sep.); note slight offset of points plotted vs. tick marks indicating January continental freshwater discharge and land precipitation (from Figure 1) for the 1985 to 1999 period. The period clearly influenced by the Mount Pinatubo eruption is indicated by grey shading.

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Trenberth and Dai (2007)

Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering

*Geophys. Res. Lett.*



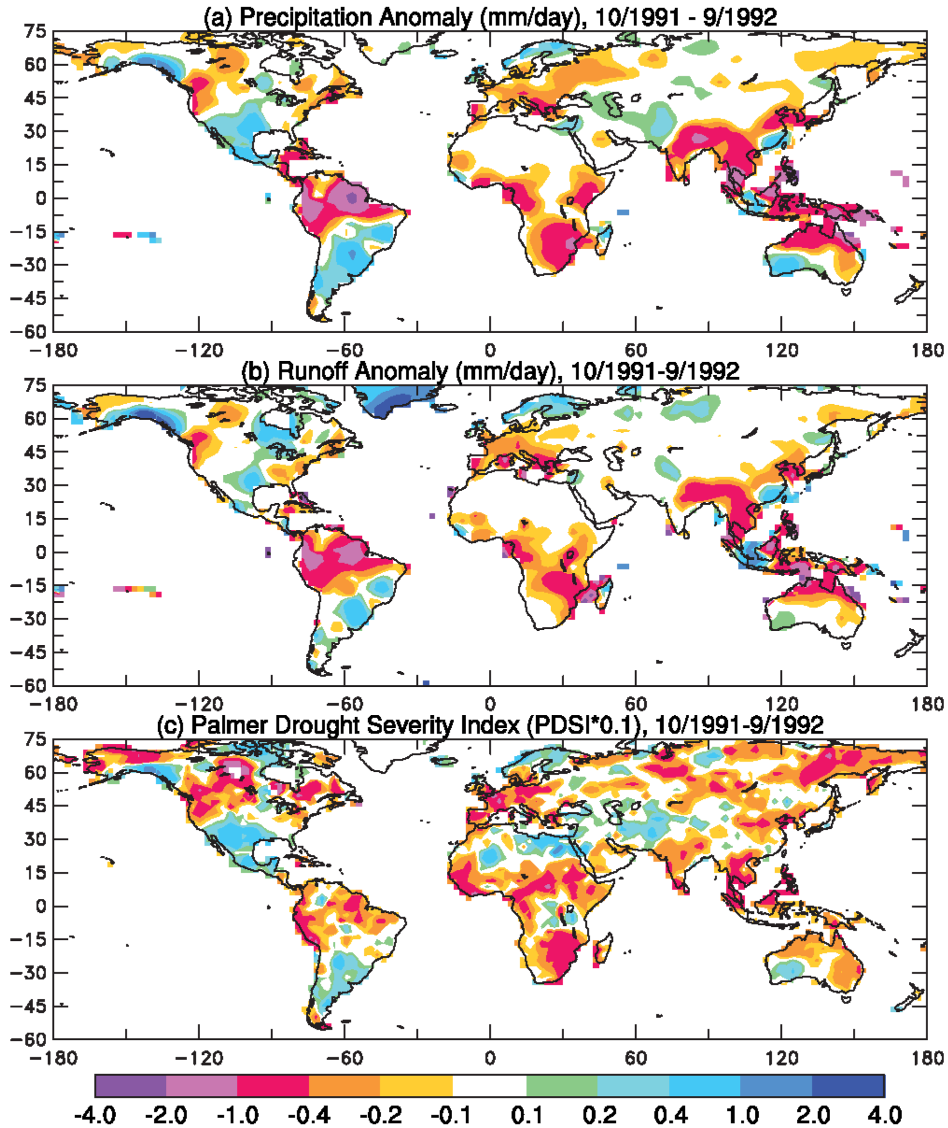


**Figure 3.** (a) Observed precipitation anomalies (relative to 1950–2004 mean) in mm/day during October 1991–September 1992 over land. Warm colors indicate below normal precipitation. (b) As for Figure 3a but for the simulated runoff [*Qian et al.*, 2006] using a comprehensive land surface model forced with observed precipitation and other atmospheric forcing in mm/day. (c) Palmer Drought Severity Index (PDSI, multiplied by 0.1) for October 1991–September 1992 [*Dai et al.*, 2004]. Warm colors indicate drying. Values less than −2 (0.2 on scale) indicate moderate drought, and those less than −3 indicate severe drought.

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# Summer monsoon drought index pattern using tree rings for 750 years

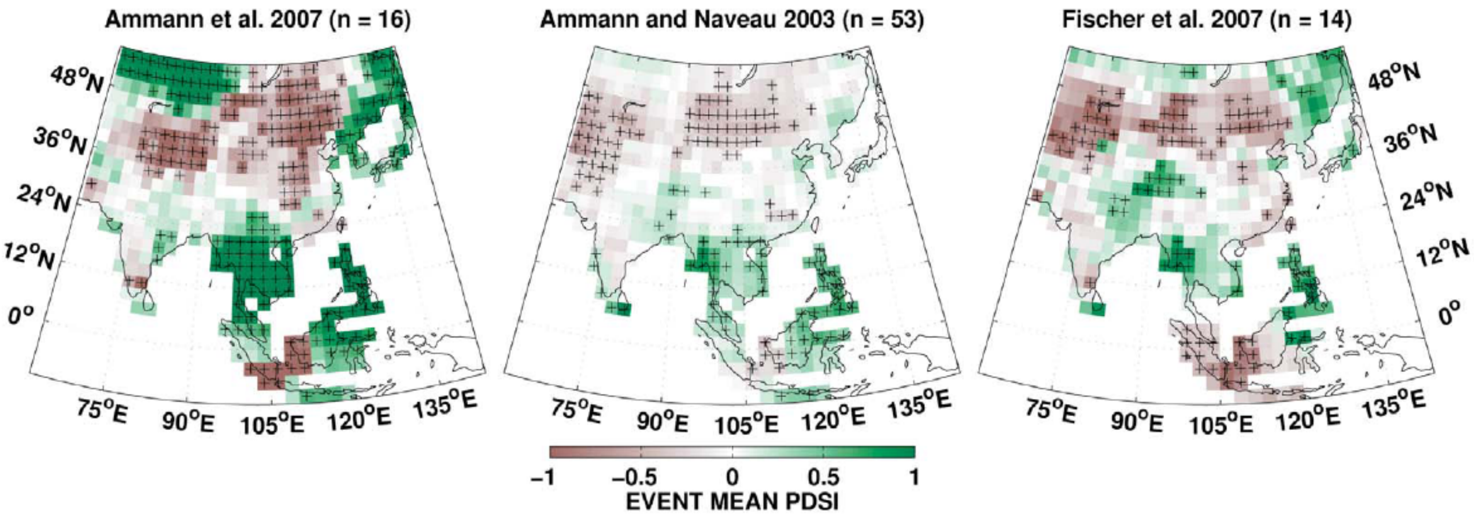
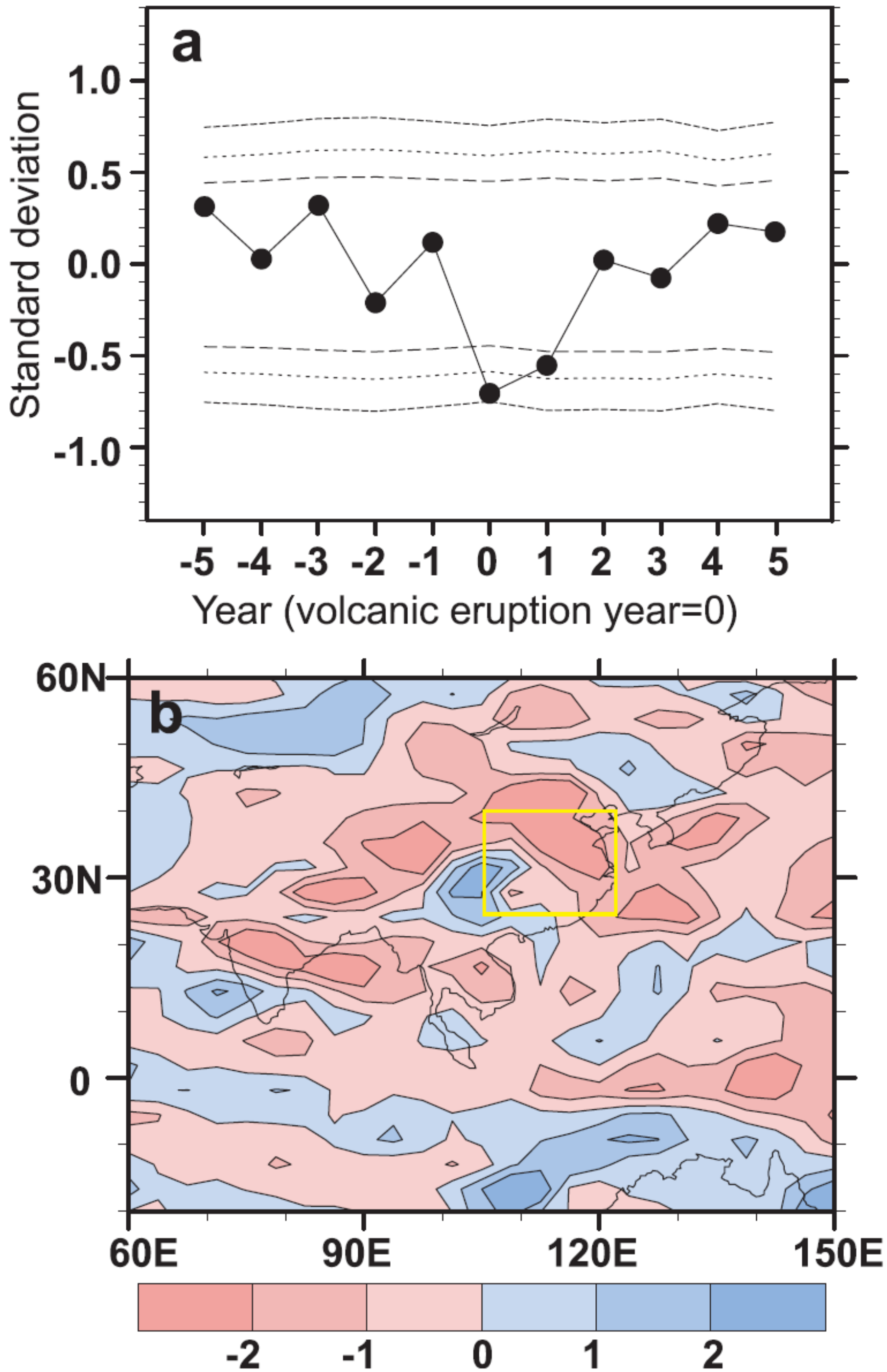



**Figure 2.** Superposed epoch analysis using the reconstructed PDSI values from the Monsoon Asia Drought Atlas (MADA) [*Cook et al.*, 2010] and the sets of events years shown in Table 1. Statistically significant (90% one-tailed) epochal anomalies based on Monte Carlo resampling (n = 10,000) are indicated by crosses.

Anchukaitis et al. (2010), Influence of volcanic eruptions on the climate of the Asian monsoon region. *Geophys. Res. Lett.*, *37*, L22703, doi:10.1029/2010GL044843



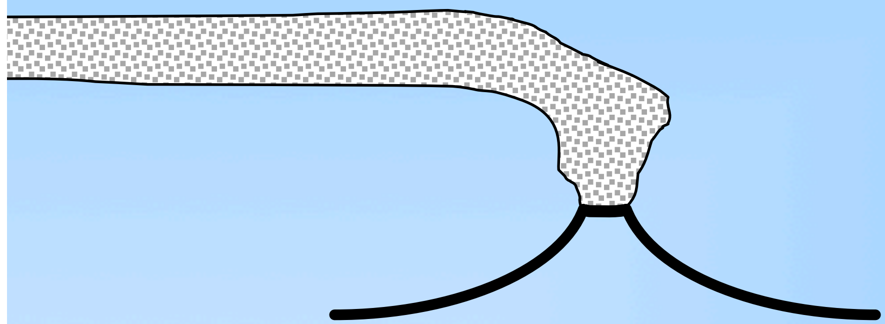



FIG. 1. (a) Results of superposed epoch analysis of modeled summer precipitation for 18 cases of large volcanic eruption showing the response of summer precipitation over eastern China. Bootstrapping procedures are used to assess the statistical significance of summer precipitation above and below the mean. The dashed and dotted lines represent confidence intervals of 90%, 95%, and 99% derived from 1000 Monte Carlo simulations. (b) Spatial pattern of composite anomalies of summer precipitation over East Asia and tropical oceans during the volcanic eruption year for 18 cases of large volcanic eruption; yellow box shows our study area.

# NCAR CCSM 2.0.1 simulation for past 1000 years

Peng, Youbing, Caiming Shen, Wei-chyung Wang, and Ying Xu, 2010: Response of summer precipitation over Eastern China to large volcanic eruptions. *J. Climate*, **23**, 818-825.

# GeoMIP

We are carrying out standard experiments with the new GCMs being run as part of CMIP5 using identical global warming and geoengineering scenarios, to see whether our results are robust.

For example, how will the hydrological cycle respond to stratospheric geoengineering? Will there be a significant reduction of Asian monsoon precipitation? How will ozone and UV change?

Kravitz, Ben, Alan Robock, Olivier Boucher, Hauke Schmidt, Karl Taylor, Georgiy Stenchikov, and Michael Schulz, 2011: The Geoengineering Model Intercomparison Project (GeoMIP). *Atmospheric Science Letters*, **12**, 162-167, doi:10.1002/asl.316.

WCRP World Climate Research Programme

# GeoMIP

GeoMIP is a CMIP Coordinated Experiment, as part of the Climate Model Intercomparison Project 5 (CMIP5).

GeoMIP is also a SPARC CCMVal Geoengineering Model Intercomparison Project.

GeoMIP is led by Ben Kravitz (Stanford University), Alan Robock (Rutgers University), and Olivier Boucher (Laboratoire de Météorologie Dynamique).

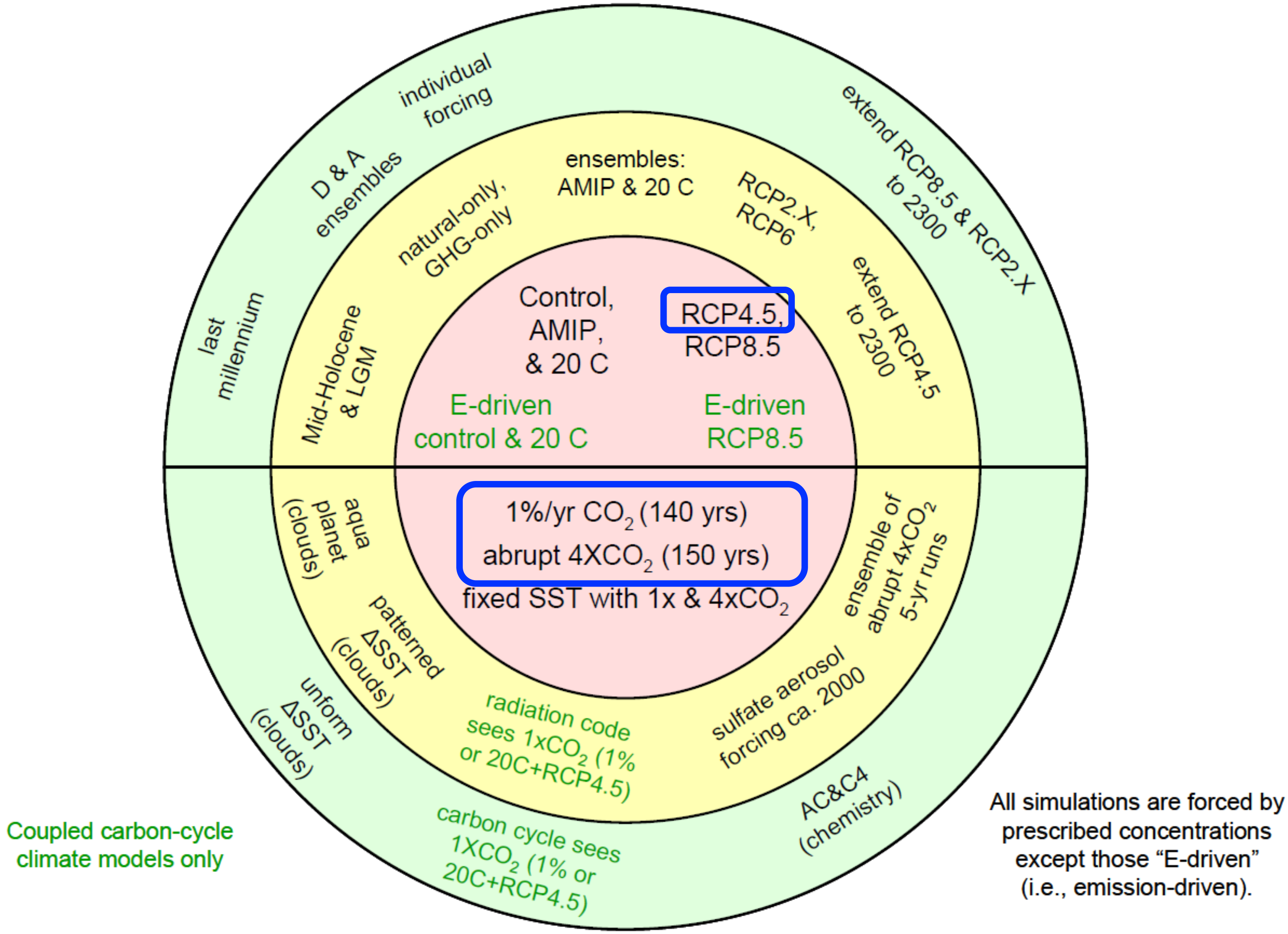
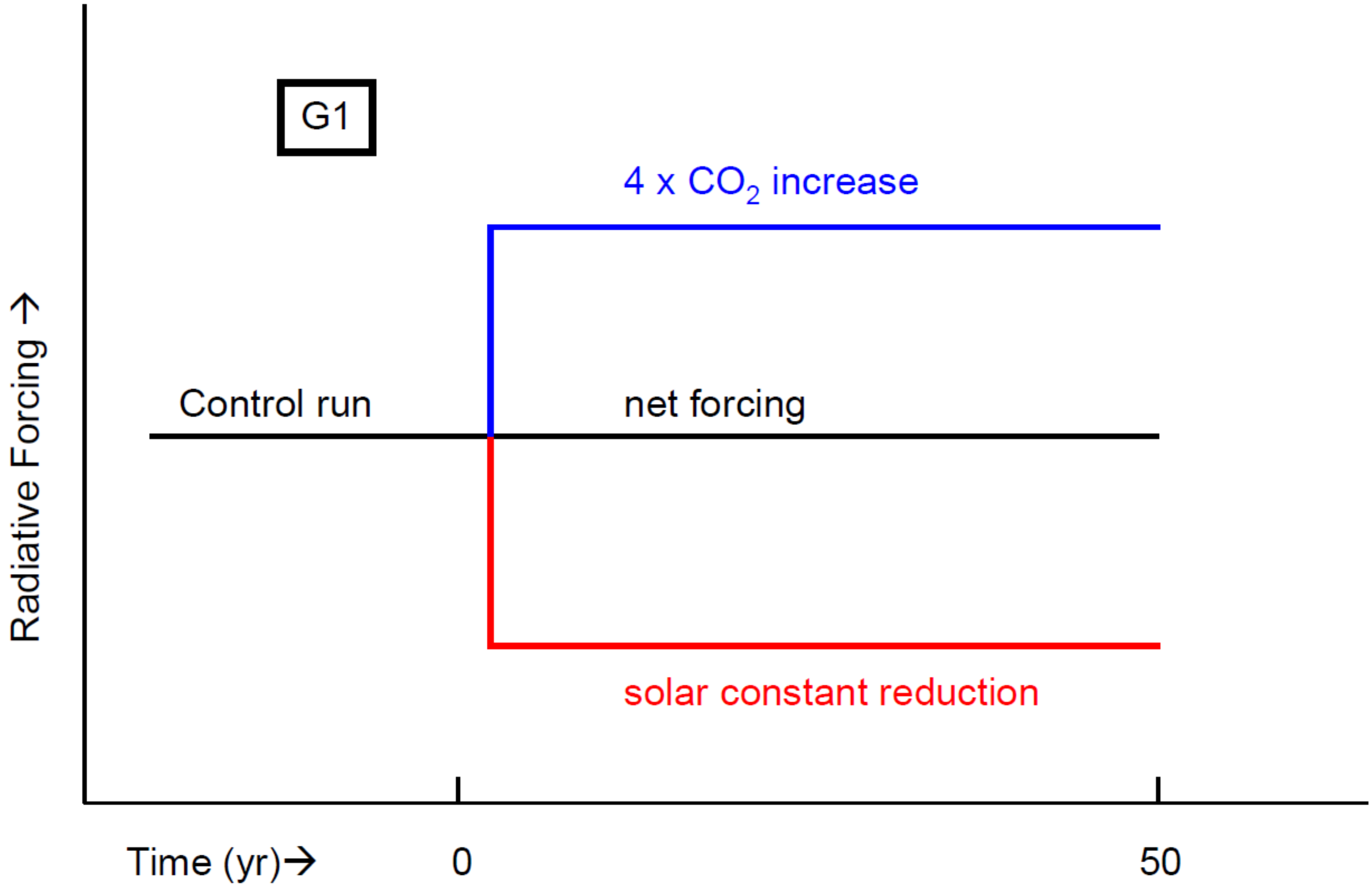
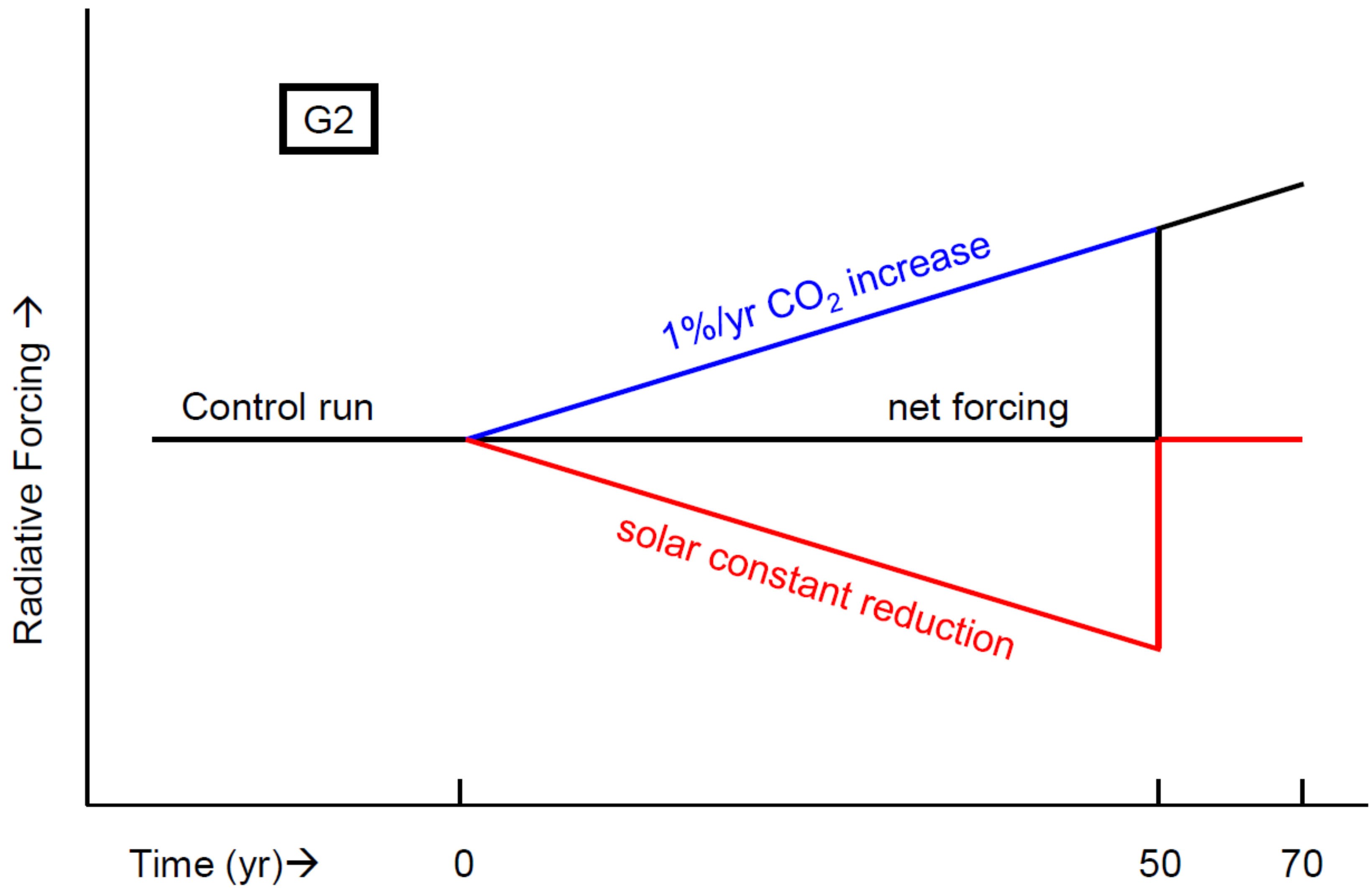



Figure 3: Schematic summary of CMIP5 long-term experiments.

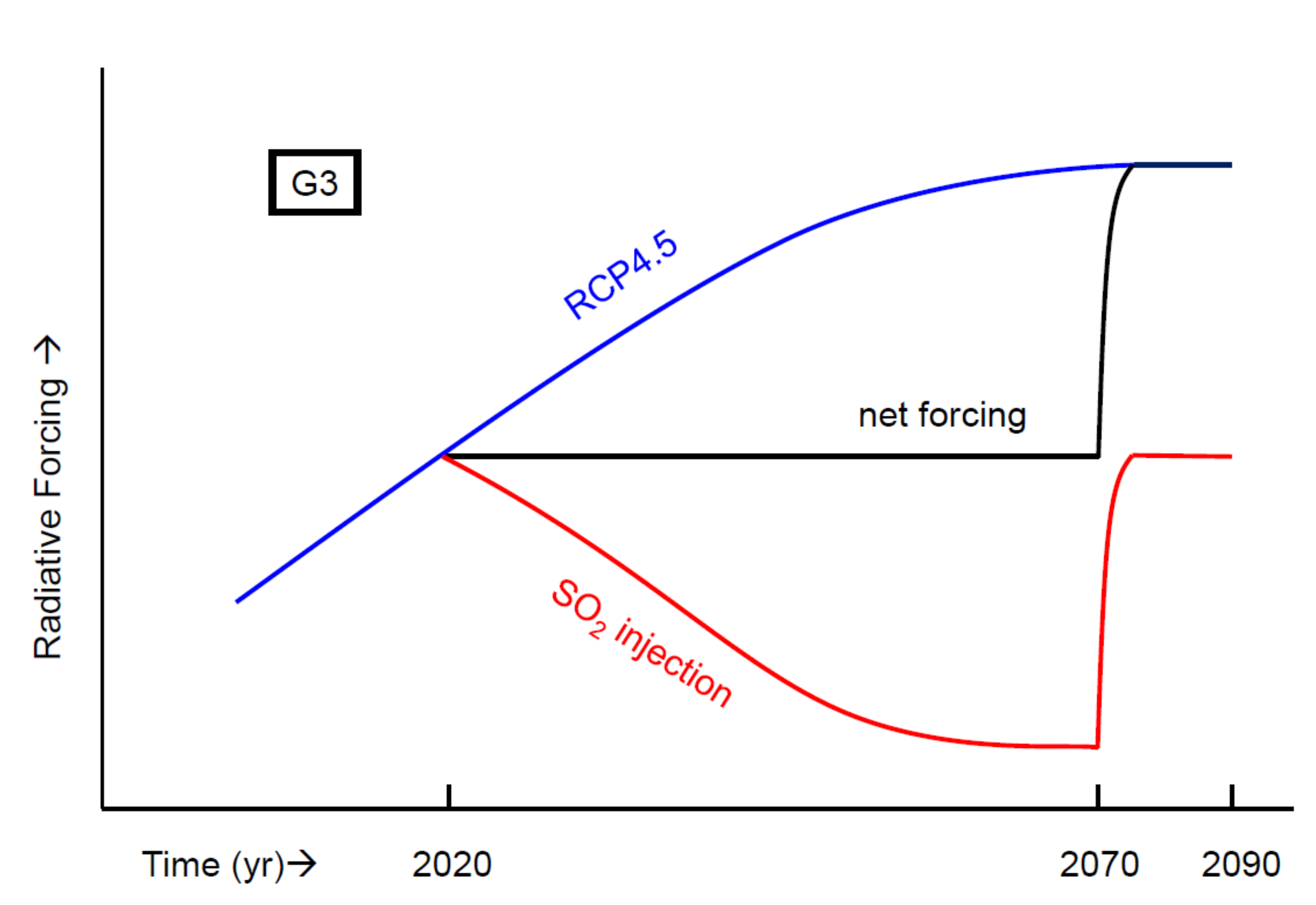
Taylor et al. (*BAMS*, 2012)



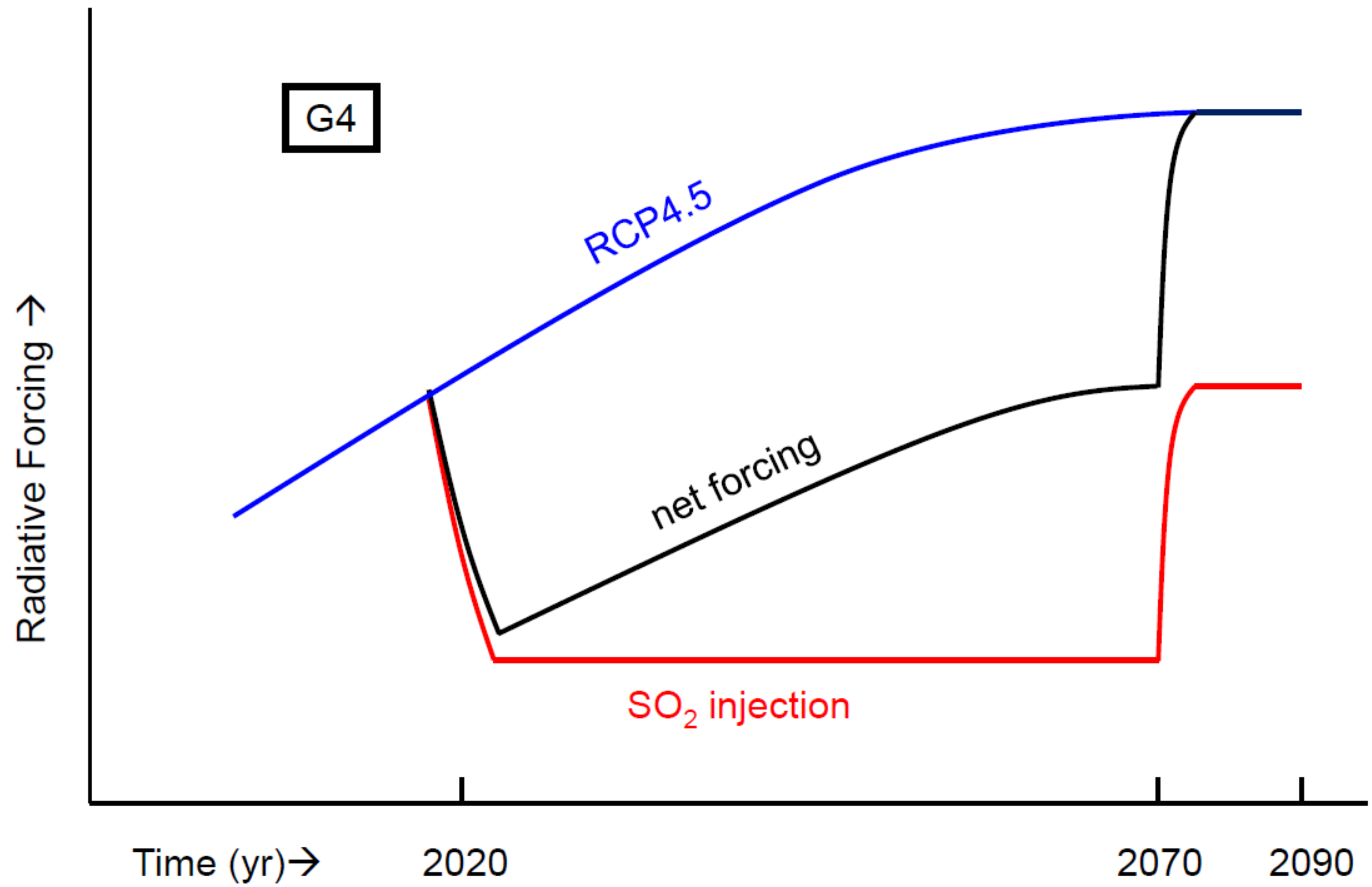

G1: Instantaneously quadruple $CO_2$ concentrations (as measured from preindustrial levels) while simultaneously reducing the solar constant to counteract this forcing.




G2: In combination with 1% $CO_2$ increase per year, gradually reduce the solar constant to balance the changing radiative forcing.



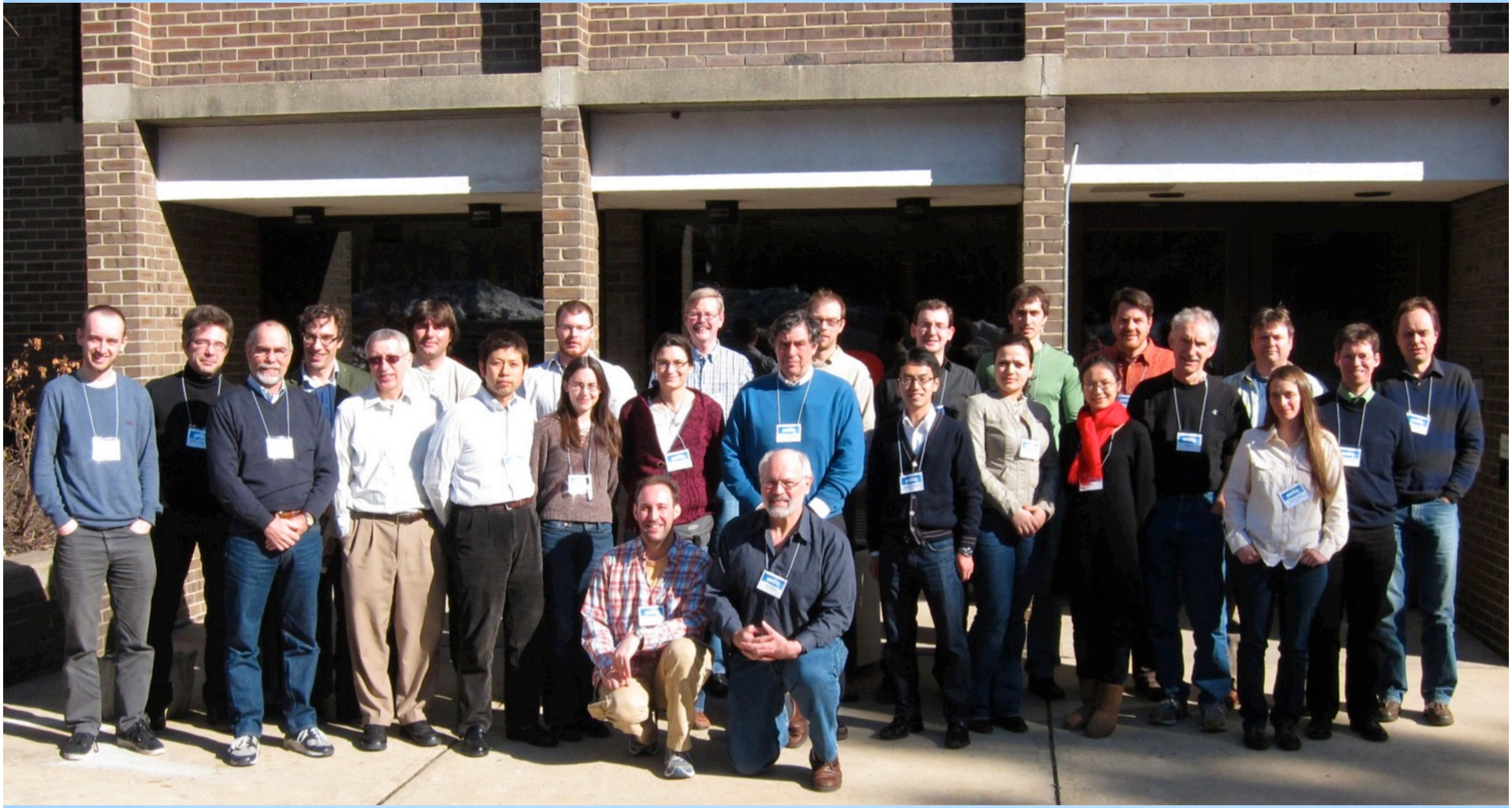

G3: In combination with RCP4.5 forcing, starting in 2020, gradual ramp-up the amount of $SO_2$ or sulfate aerosol injected, with the purpose of keeping global average temperature nearly constant. Injection will be done at one point on the Equator or uniformly globally.




G4: (optional) In combination with RCP4.5 forcing, starting in 2020, daily injections of a constant amount of $SO_2$ at a rate of 5 Tg $SO_2$ per year at one point on the Equator through the lower stratosphere (approximately 16-25 km in altitude).

# First GeoMIP Workshop, Rutgers University, February 10-12, 2011

http://climate.envsci.rutgers.edu/GeoMIP/events/rutgersfeb2011.html



Workshop was sponsored by the United Kingdom embassy in the United States.

Robock, Alan, Ben Kravitz, and Olivier Boucher, 2011: Standardizing Experiments in Geoengineering; GeoMIP Stratospheric Aerosol Geoengineering Workshop; New Brunswick, New Jersey, 10-12 February 2011, *EOS*, **92**, 197, doi:10.1029/ 2011ES003424.

# Second GeoMIP Workshop, University of Exeter, March 30-31, 2012

http://climate.envsci.rutgers.edu/GeoMIP/events/exetermarch2012.html

Workshop was sponsored by the Integrated Assessment of Geoengineering Proposals project.

Kravitz, Ben, Alan Robock, and James Haywood, 2012: Progress in climate model simulations of geoengineering: 2nd GeoMIP Stratospheric Aerosol Geoengineering Workshop; Exeter, UK, 30-31 March 2012, *EOS*, **93**, 340, doi:10.1029/2012ES003871.

# Third GeoMIP Workshop, Institute for Advanced Sustainability Studies (IASS), Potsdam, Germany, April 15-16, 2013

Workshop was sponsored by NSF and IASS.

Kravitz, Ben, Alan Robock, and James Haywood, 2012: Progress in climate model simulations of geoengineering: 2nd GeoMIP Stratospheric Aerosol Geoengineering Workshop; Exeter, UK, 30-31 March 2012, *EOS*, **93**, 340, doi:10.1029/2012ES003871.

# GeoMIP Participants

Status as of November 2012

| | | | | | | | # of ensemble members (* in progress) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model (CMIP5 or CCMVal participant) | Contact | Atmospheric Model Resolution | Atmospheric Model Top | Oceanic Model Resolution | Stratospheric Aerosols | Ozone | G1 | G2 | G3 | G3 solar | G4 |
| BNU-ESM | John Moore, Duoying Ji | 2.8° lat x 2.8° lon L26 | 42 km | 200 km lat x 360 km lon | Prescribed | Prescribed | 1 | 3 | 1 | | 1 |
| MPI-ESM -LR (ECHAM6) | Hauke Schmidt, Ulrike Niemeier | T63L47 | 0.01 mb | 1.5° lat X 1.5° lon L40 | Prescribed AOD and surface area | Prescribed | 1 | 1 | 3 | | |
| IPSLCM5A | Michael Schulz, Diana Karam, Olivier Boucher | 2.5° lat x 3.75° lon L39 | 0.1 mb (80 km) | 2° lat X 2° lon | Prescribed AOD | Calculated | 1 | 1 | * | | |
| GISS ModelE2 | Ben Kravitz | 2° lat X 2.5° lon L40 | 0.1 mb (80 km) | 1° lat X 1.25° lon L32 | Generated from $SO_2$ injection (Koch scheme) | Calculated | 3 | 3 | 3 | | 3 |
| NorESM1-M | Jón Egill Kristjánsson, Kari Alterskjær | 1.9° lat x 2.5° lon | 42 km | ~0.5° lat x ~1° lon, 1.125 degrees along the equator | Prescribed | Prescribed | 1 | 1 | | | |
| CESM-CAM5.1-FV | Phil Rasch, Jin-Ho Yoon | 1.9° lat x 2.5° lon L30 | 3.5 mb | gx1v6 (displaced pole) | Prescribed | Prescribed | 1 | 1 | * | | |
| CCSM4 (CESM-CAM4) | Simone Tilmes, Jean-Francois Lamarque | 0.9° lat x 1.25° lon | 42 km | ~1° lat x ~1° lon | Prescribed | Prescribed | 2 | 3 | | 3 | |
| CESM-CAM4 Chem (G3 solar, G3, G4) | Simone Tilmes, Jean-Francois Lamarque | 1.9° lat x 2.5° lon | 42 km | ~1° lat x ~1° lon | Generated from $SO_2$ injection (bulk aerosol scheme) | Calculated | | | | * | |
| CESM-WACCM4 | Michael Mills | 1.9° lat x 2.5° lon | 5.9603E-6 hPa (~145 km) | ~1° lat x ~1° lon | Prescribed from SAGE, prognostic PSC growth | Calculated | | | | | |
| MIROC-ESM | Michio Kawamiya, Shingo Watanabe | 2.8° x 2.8° (T42) | ~85 km (80 levels) | 0.56° ~1.4° lat x ~1.4° lon (44 levels) | Prescribed AOD | Prescribed | 1 | 1 | | | 1 |
| MIROC-ESM-CHEM | Michio Kawamiya, Shingo Watanabe | 2.8° x 2.8° (T42) | ~85 km (80 levels) | 0.56° ~1.4° lat x ~1.4° lon (44 levels) | Prescribed AOD --> sulfate SAD | Calculated | | | | | 4 |
| HadGEM2-ES | Andy Jones | 1.25° lat x 1.875° lon | 39.3 km | 30°N-S: 1/3°, 30°-90°N/S: 1°x1° | Generated from $SO_2$ injection | Prescribed | 1 | 3 | 3 | 3 | 3 |
| CanESM2 | Jason Cole, Charles Curry | ~ 2.81° x 2.81° (T63) | ~1 hPa (35 layers) | 0.94° lat x 1.4° lon | Prescribed | Prescribed | 3 | 3 | 3 | | 3 |
| CMCC-CMS | Chiara Cagnazzo | ~1.8° x 1.8° (T63) | 0.01 hPa (95 levels) | 2° lat X 2° lon (31 levels) | Prescribed $SO_2$ or AOD | Prescribed | | | | | |
| UMUKCA (future HadGEM3-ES) | Peter Braesicke, Luke Abraham | 2.5° lat x 3.75° lon (N48) L60 | ~84 km (60 levels) | ~2° L31 | Prescribed | Calculated | * | * | | | |
| CCSRNIES / MIROC3.2 | Hideharu Akiyoshi | T42 | 0.012 mb | | Prescribed | Calculated | | | | | 1 |
| EMAC2 (DLR) | Martin Dameris, Patrick Jöckel, Veronika Eyring | T42L90MA | 0.01 mb | | Prescribed | Calculated | | | | | |
| LMDzrepro | Bekki/Marchand | 2.5° lat x 3.75° lon) | 0.07 mb | | Prescribed | Calculated | | | | | |
| SOCOL | Eugene Rozanov | T30 | 0.01 mb | | Prescribed | Calculated | | | | | |
| ULAQ | Pitari | R6/11.5° lat x 22.5° lon | 0.04 mb | | Prescribed | Calculated | | | | | |
| UMSLIMCAT | Martin Chipperfield | 2.5° lat x 3.75° lon | 0.01 mb | | Prescribed | Calculated | | | | | |
| EMAC (ECHAM5/MESSy) | Mark Lawrence | ca. 2.8° X 2.8° (T42) | ~80 km (1 Pa), 90 levels | | Generated from $SO_2$ injection | Calculated | | | | | |
| HadCM3 | Peter Irvine | 2.5° lat X 3.75° lon L19 | 5 mb (28 km) | 1.25° lat X 1.875° Lon L20 | Prescribed $SO_2$ or AOD | Fixed | 3 | 3 | | | |
| HadCM3 [27-member perturbed physics ensemble] | Peter Irvine | 2.5° lat X 3.75° lon L19 | 5 mb (28 km) | 1.25° lat X 1.875° Lon L20 | Prescribed $SO_2$ or AOD | Fixed | * | * | | | |
| IAPRASCM | Alexander Chernokulsky | 4.5° lat X 6° lon L8 | 80 km | 4.5° lat X 6° lon L3 | Prescribed lifetime | Prescribed | | | | | |
| GCCESM | John Moore | 2.8° x 2.8° (T42) | 42 km | 200 lat x 360 lon, 30°-90°N/S: 1°x1° | Prescribed | Prescribed | | | | | |
| CSIRO Mk3L | Andrew Lenton | 5.6° x 3.2° (R21) | 36 km (18 levels) | 1.6° lat x 2.8° lon (21 levels) | Prescribed | Prescribed | | | | | |

# Current GeoMIP participants

AOGCM groups, who are participants in CMIP5:

NASA Goddard Institute for Space Studies ModelE
National Center for Atmospheric Research (NCAR; 3 versions:
CESM-CAM5, CESM-CAM4, CESM-WACCM4)
UK Met Office Hadley Centre (HadGEM2-ES)
Max Planck Institute for Meteorology (MPI-ESM/ECHAM6)
Laboratoire des Sciences du Climat et l'Environnement (LSCE;
IPSLCM5A)
Japan Agency for Marine-Earth Science and Technology (MIROC-ESM)?
Norwegian Met Office (NORESM)

Additional groups, who are not participants in CMIP5:

Max Planck Institute for Chemistry (EMAC/ECHAM5)?
University of Bristol (HadCM3, perturbed physics ensemble)
Cambridge University (UMUKCA)?
Russian Institute of Atmospheric Physics (IAPRASCM)


Alan Robock
Department of Environmental Sciences

## Possible GeoMIP publications:

Workshop report – EOS

Overview – model results and summary of gross features – Boucher et al.

What does GeoMIP tell us about how robust models need to be for geoengineering? –Rasch et al.

Fast responses – Forster et al.

Volcanic diagnosis of CMIP5 models to interpret GeoMIP results – Driscoll et al.

Precipitation, hydrology (e.g., monsoon response) G1, G2 – Kravitz, Robock, ...

Precipitation, hydrology (e.g., monsoon response) G3, G4 – Kravitz, Robock, ...

Radiation/energy budget – Schmidt et al.

Stratospheric dynamical responses – Tilmes et al.

Chemistry and ozone (stratospheric / tropospheric responses) – Tilmes et al.



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## Possible GeoMIP publications:

Snow cover /sea ice – Kravitz et al.
Diurnal cycle – Taylor et al.
Regional focus (e.g., Mediterranean, Asia)
Benefits and risks of geoengineering (including regional differences) – Irvine et al.
Agricultural responses – Xia et al.
Natural vegetation (ecosystem) responses to temperature, precipitation, diffuse/direct radiation – Foster et al.
Ocean circulation response – Stenchikov et al.
Aerosol microphysics (G3, G4) – Mann et al.
Volcanic eruptions (observations) as analogs for geoengineering – Haywood et al.
UTLS / tropopause response – Braesicke et al.
Cryosphere / sea level response – Irvine et al.



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CCM Validation Activity for SPARC
CCMVal
http://www.pa.op.dlr.de/CCMVal

The Chemistry-Climate Model Validation Activity (**CCMVal**) is part of Stratospheric Processes and their Role in Climate (**SPARC**), which was created in 1992 by the World Climate Research Programme (**WCRP**).
Led by Veronika Eyring, they have expressed interest in participating in GeoMIP.

http://www.pa.op.dlr.de/CCMVal/

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Alan Robock
Department of Environmental Sciences

# CCMVal-3: Participating Models (preliminary)

| | Model | PI/Rep | TropChem | ACCMIP | ACC-MIP Meeting | Hind-cast | Help Define | GeoMIP runs | RCP runs |
|---|---|---|---|---|---|---|---|---|---|
| 1 | AMTRAC3 | Austin | | | | | | | |
| 2 | CAM3.5 | Lamarque | Y | Y | Lamarque | Y | Y | Y | Y |
| 3 | CCSRNIES / MIROC3.2 | Akiyoshi | Maybe | N | N | N | N | Y | Y |
| 4 | CMAM | Plummer | Y | N | Y | Some | Y | N | maybe |
| 5 | CNRM-ACM | Michou | in ~ 1 year | N | Y | N | Y | | Y |
| 6 | EMAC(DLR) | Jöckel | Y | Y | Eyring | Y | Y | maybe | Y |
| 7 | GEOSCCM | Douglass | Y | Maybe | Y | Some | Y | | |
| 8 | LMDzrepro | Bekki/Marchand | maybe | Y | Y | Some | Y | maybe | |
| 9 | HadGEM | Collins | Y (no stratchem) | Y (no stratchem) | Y | Some | Y | Y (no stratchem) | Y (no stratchem) |
| 10 | MRI | Shibata | Y | Y | Y | N | N | TBD | N |
| 11 | NIWA-SOCOL | Smale | N | | | | | | |
| 12 | SOCOL | Rozanov | Y | Some | TBD | Some | Y | Y | |
| 13 | ULAQ | Pitari | Y | Some | N | Some | N | Y | Y |
| 14 | UMSLIMCAT | Chipperfield | Y | N | Chipperfield | Y | Y | Y | N |
| 15 | UMUKCA | Braesicke/ Morgenstern | Y | Some | Y | Some | Y | maybe | maybe |
| 16 | WACCM | Kinnison | Y | Maybe | Lamarque | Some | Y | Y | Y |

# GeoMIP participation thus far

20 models participating from 12 countries

Experiment G1: 13 models
Experiment G2: 13 models
Experiment G3: 7 models
Experiment G4: 7 models



Alan Robock
Department of Environmental Sciences

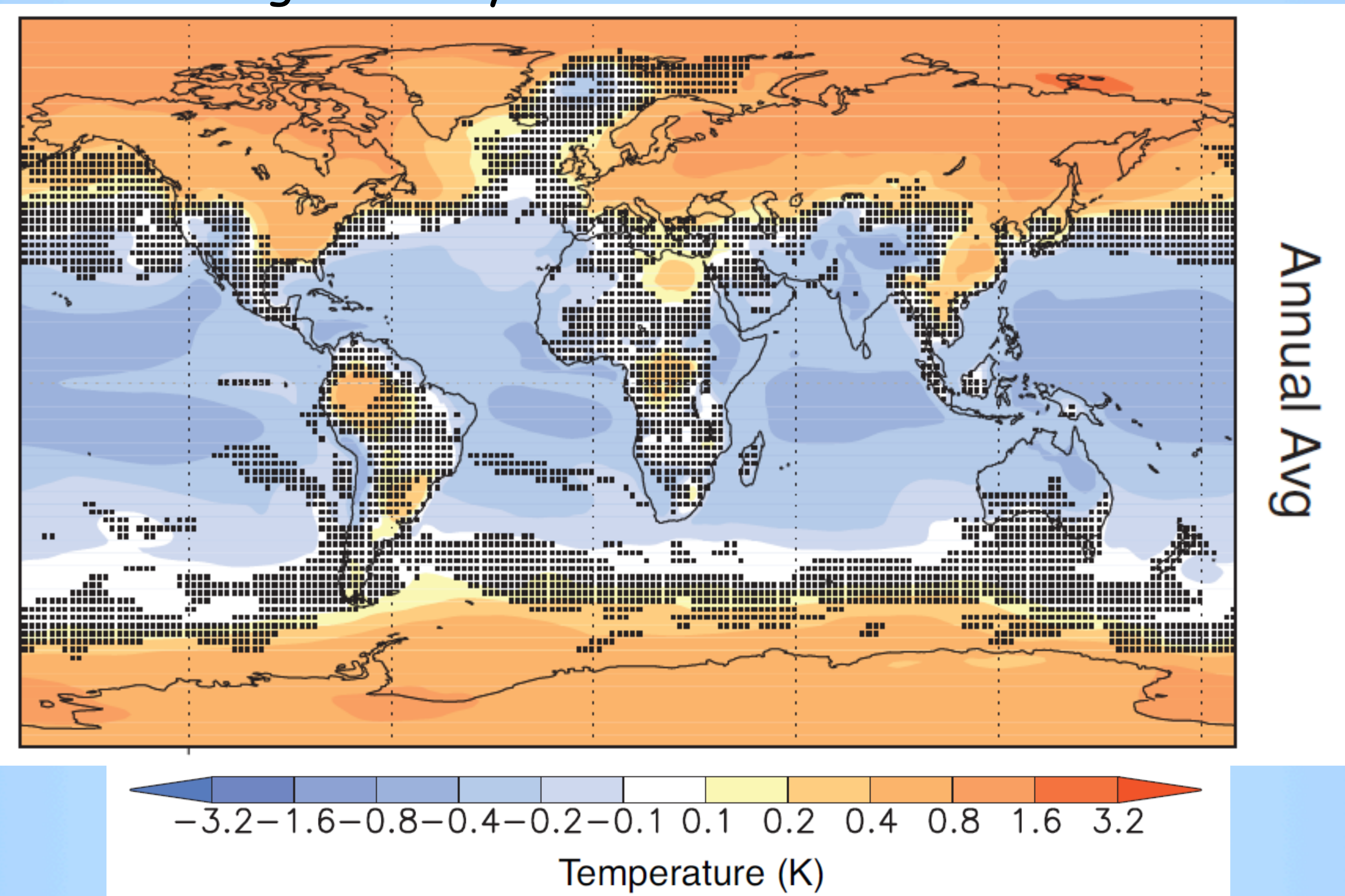
**Here are preliminary results from G1 experiments by 12 climate models.**

**This is a very artificial experiment, with large forcing so as to get large response.**

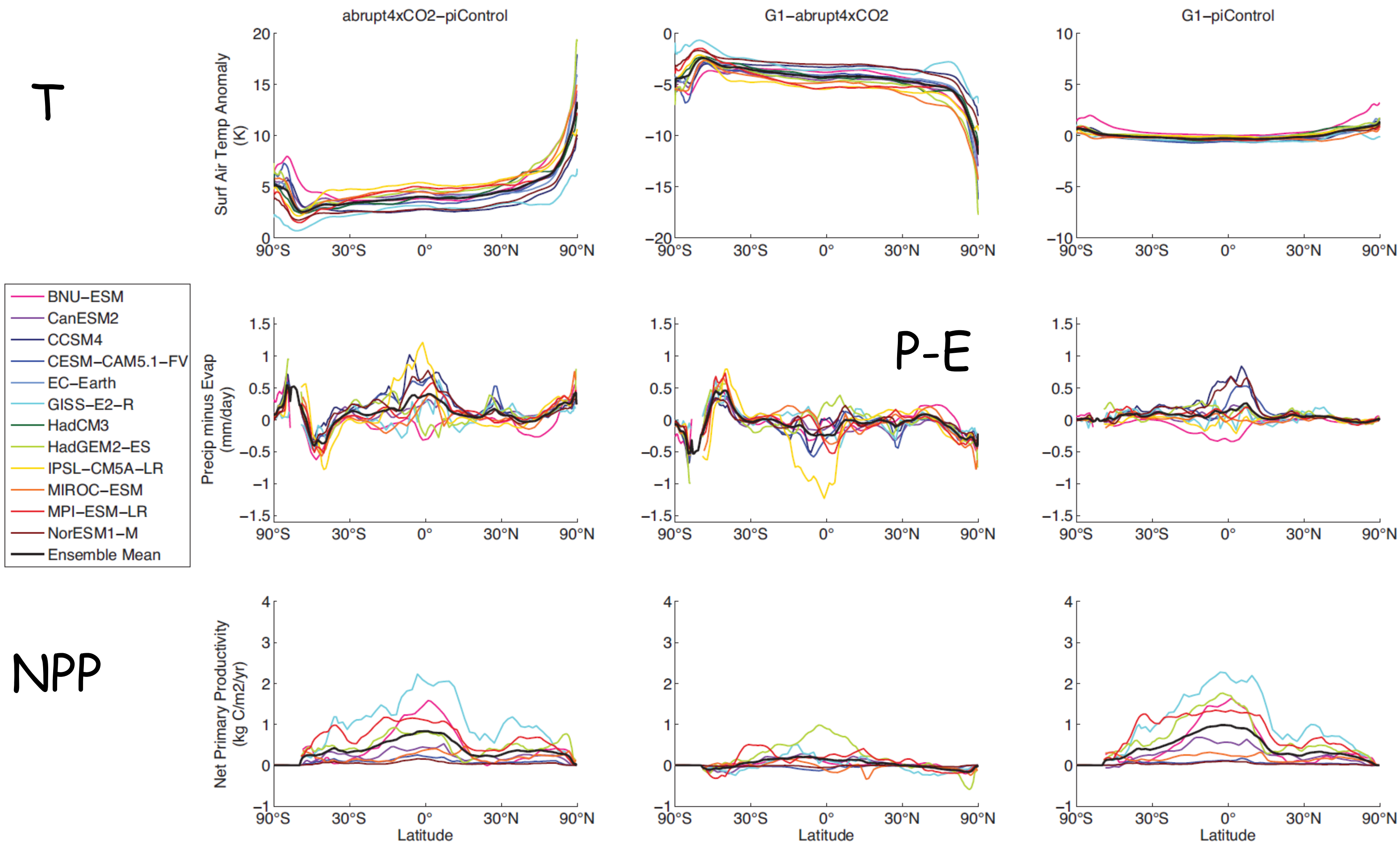
Shown are averages from years 11-50 of the simulations, balancing $4xCO_2$ with solar radiation reduction to achieve global average radiation balance.

Kravitz et al. (2013)
submitted to *Journal of Geophysical Research*

# Surface air temperature differences (*G1–piControl*), averaged over years 11-50 of the simulation.




No stippling denotes agreement on the sign of the response in at least 75% of models.




# Zonal average over years 11-50 of simulation



Alan Robock
Department of Environmental Sciences

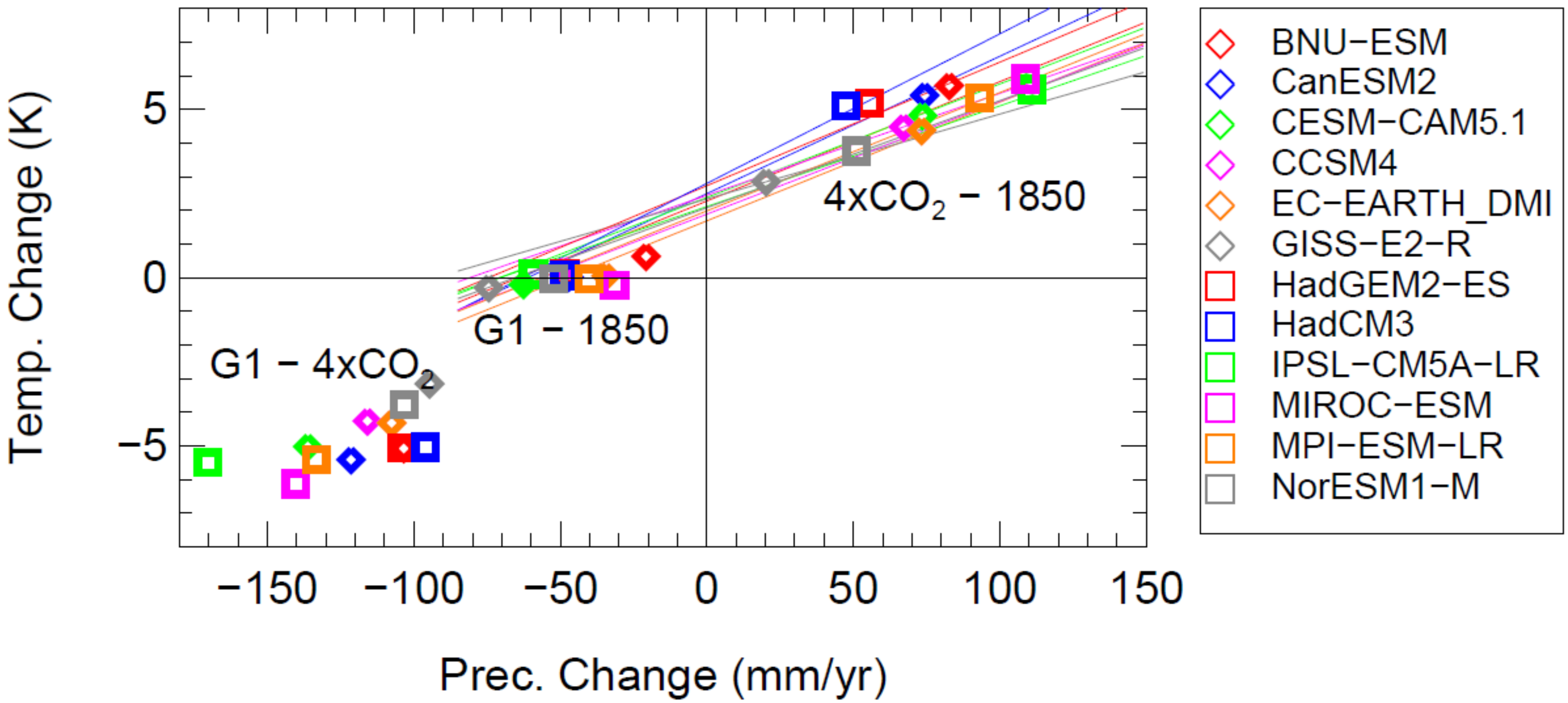
**Here are preliminary results from G1 experiments by 12 climate models.**

**This is a very artificial experiment, with large forcing so as to get large response.**

Shown are averages from years 11-50 of the simulations, balancing $4xCO_2$ with solar radiation reduction to achieve global average radiation balance.

Tilmes et al. (2013)
submitted to *Journal of Geophysical Research*

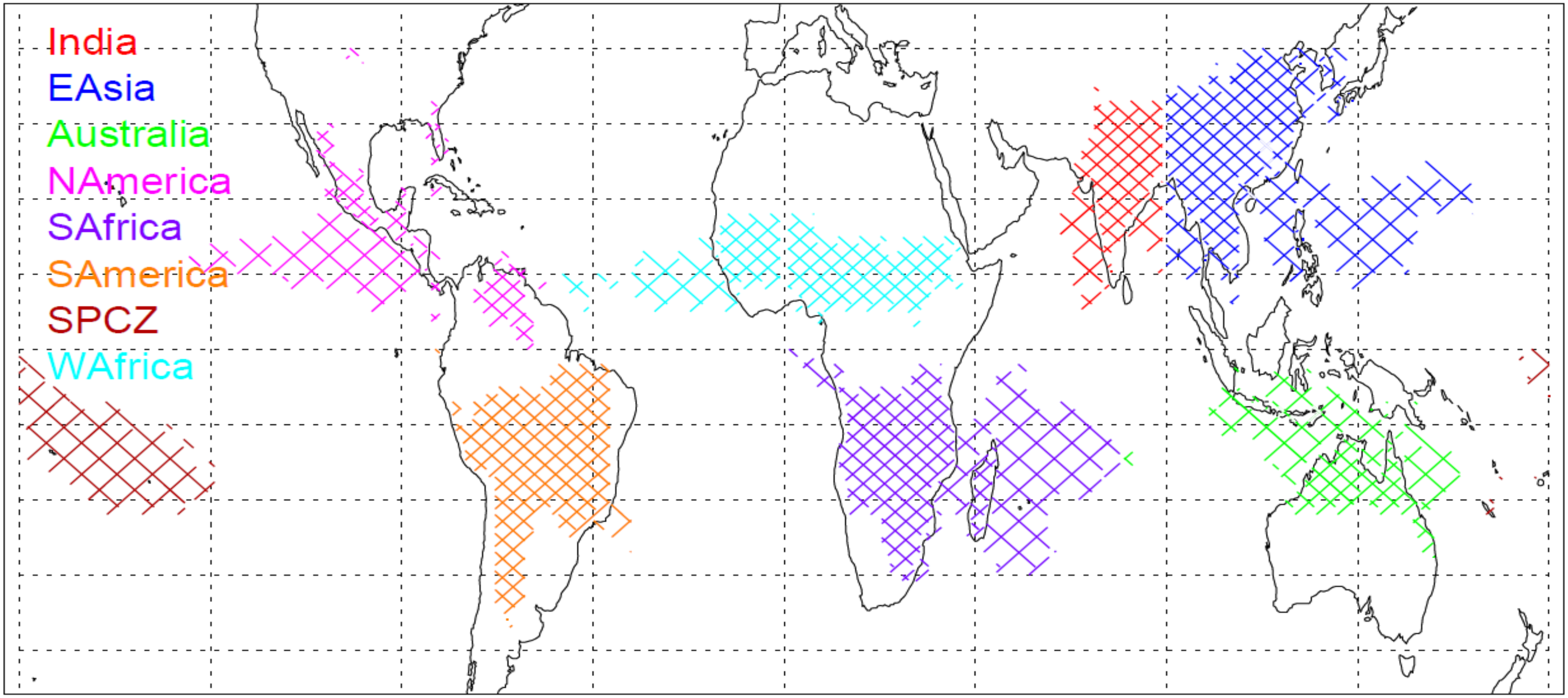
# Global average results for all years for G1 and for years 11-50 of simulation for $4xCO_2$

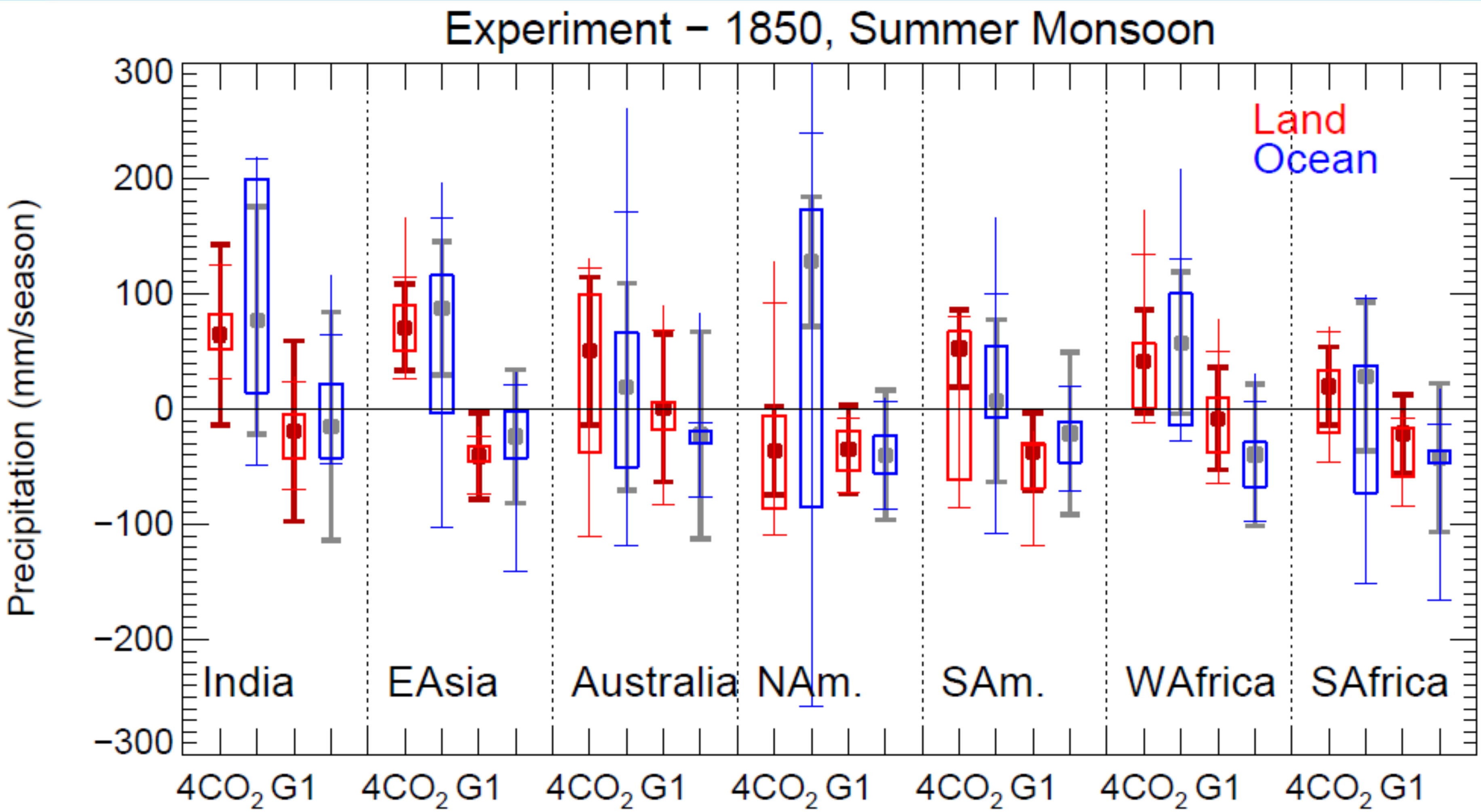





Alan Robock
Department of Environmental Sciences

# Monsoon regions






Years 11-50

RUTGERS
Alan Robock
Department of Environmental Sciences

**Here are preliminary results from G2 experiments by 12 climate models.**

**This is a 1%/year increase of $CO_2$ balanced by a reduction of insolation.**

Shown are averages from years 11-50.

Jones et al. (2013)
submitted to *Journal of Geophysical Research*.



Alan Robock
Department of Environmental Sciences