New investigations into human and environmental impacts from nuclear war using WACCM

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WACCM Working Group Meeting
February 20, 2019

Open Philanthropy Project

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FAS Federation of American Scientists

“Climate Effects and Human Impacts from Nuclear War”

- PIs: Alan Robock (Rutgers) & Brian Toon (CU)
- Funded by the Open Philanthropy Project (http://www.openphilanthropy.org)
- Goal: Use improved information, models, and techniques to better evaluate the environmental and human impacts of nuclear war.
- All results presented here are preliminary.

<u>Approach</u>

1. Develop plausible scenarios for initiation and escalation of nuclear war
2. Determine the weapons to be used and their individual targets
3. Estimate the combustible fuel at each target site
4. Simulate the smoke production for nuclear weapon triggered fires (WRF-Fire)
5. Simulate the climate response to these smoke emissions (WACCM)
6. Evaluate environmental and human impacts from this climate change

Step 1: Develop war scenarios

- Where, how, and why would a nuclear war start?
- How might this escalate into attacks on urban areas?

- Meeting with experts in 2018
  - Bruce Blair (Princeton), Ian Foster (Argonne), Ira Helfland (PSR), Feroz Khan (NPS), Ted Postol (MIT), Daniel Elsberg , Hans Kristensen (FAS), Matthew McKenzie (NRDC), …
- Progress
  - Outlined scenarios for:
    - Hacking/Terrorist Incident
    - North Korea
    - India/Pakistan
    - US/China
    - US/Russia

Step 2: Determine weapons and targets

- What would be targeted by nuclear weapons?
- What type of weapons would be used for each target?

- Population Based
  - Toon (CU), Bardeen (CU)
  - Update for increased population and latest weapons stockpiles
- Target Based
  - Kristensen (FAS), McKenzie (NRDC)
  - Identify specific weapons and targets
    - latitude, longitude
    - yield, burst height
- Progress
  - Updated population based estimates for India/Pakistan
  - Details of target based approach soon

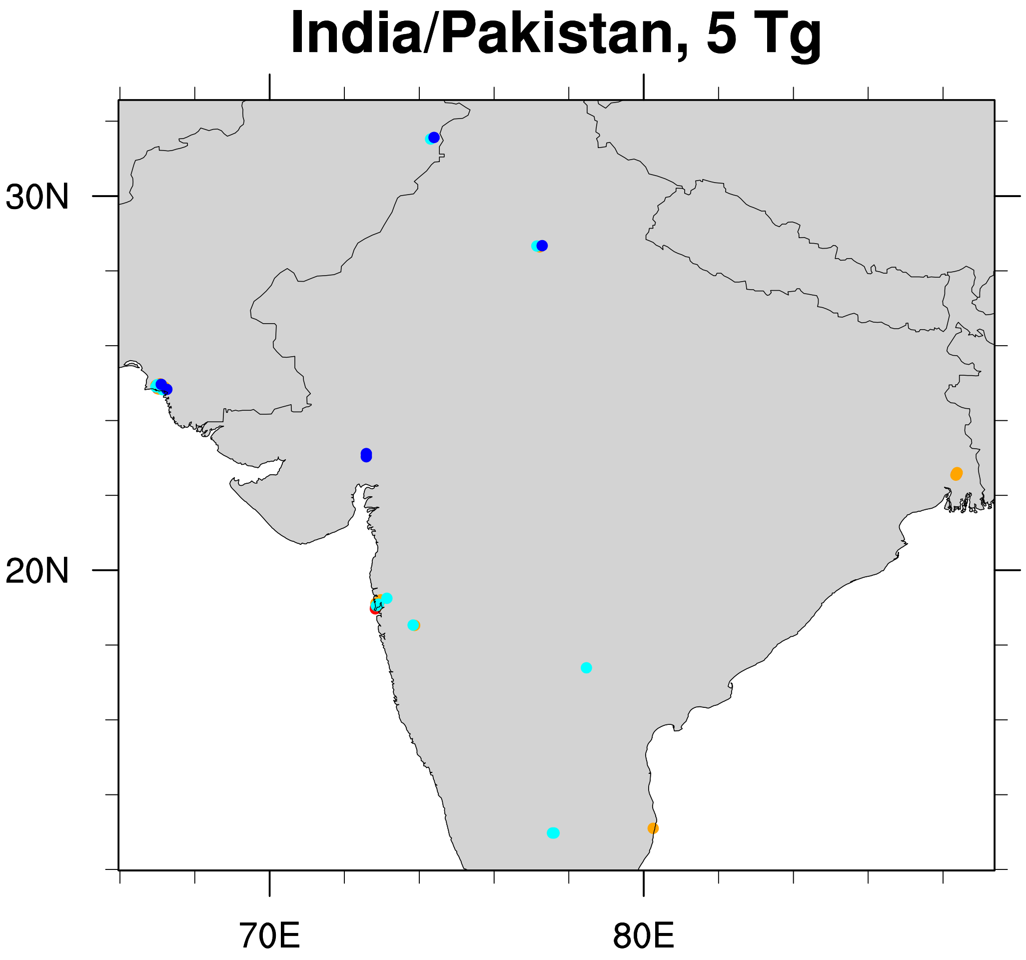
Targets for India/Pakistan from LandScan2016

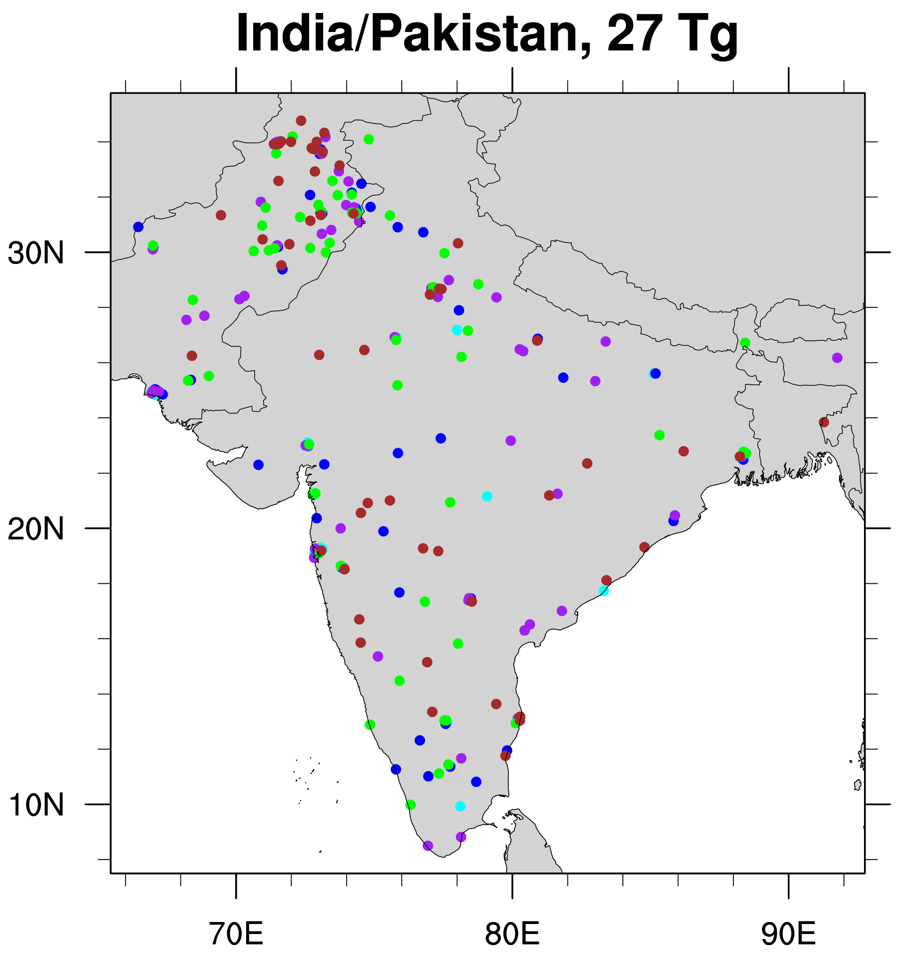
5 Tg

- Matches Robock (2007)
  - 15 kt
  - 50 India
  - 50 Pakistan
- Weapons
  - 15 kt
  - 22 India
  - 22 Pakistan

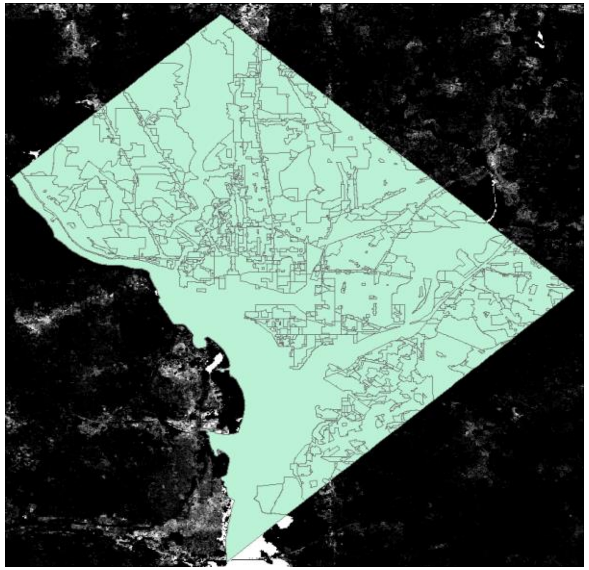
27 Tg

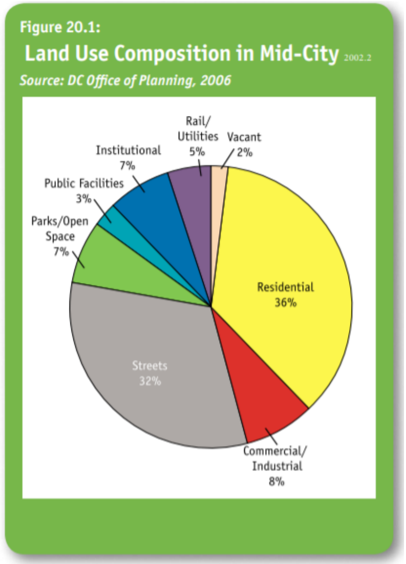
- New Arsenals
- Weapons
  - 50 kt
  - 100 India
  - 150 Pakistan





Step 3: Estimate combustible fuel at targets





- How much combustible material is at the target sites?
- What types of material are present?

- Population Based
  - Toon (CU), Bardeen (CU)
  - fuel load = P * Mf
    - P – population density (Landscan)
    - Mf – fuel load (1.1×10^7 g/person)
  - Lumped, No Categories
- Map/Inventory Based
  - Xi (CU), Frishcosy (CU), Wang (CU)
  - Using Washington D.C. as test case
  - Gridded building information from Wang and DCZoneMaps
  - Fuel Types: lumber, primary petroleum, secondary petroleum, plastics, asphalt, vegetation
- Progress
  - Updated population based estimates for India/Pakistan using Landscan2016
  - Map/inventory based approach coming soon for D.C.

Step 4: Simulate smoke production

Urban Fire Scenarios
- Winds
- Stability
- Moisture
- Fuel Load
- Tropopause Height

WRF-Fire Simulations
- Smoke Distributions as a function of height

- How much smoke is produced?
- Where does the smoke go?
- How is this affected by meteorology and fuel loads?

- Population Based
  - Toon (CU), Bardeen (CU)
  - soot = M * R * Fi
    - M - fuel load
    - R – rainout (0.2)
    - Fi – emission factor (0.02 g soot / g)
  - Emission at 150 to 300 hPa
- WRF-Fire Simulations
  - Lundquist (CU), Redfern (CU)
  - Simulations of urban mass fires under a variety of fuel loads and meteorological conditions.
  - Generalize results into a lookup table for smoke emissions.
- Progress
  - Updated population based estimates for India/Pakistan using Landscan2016
  - WRF-Fire simulations in progress

Types of Mass Fire

Fire Storm

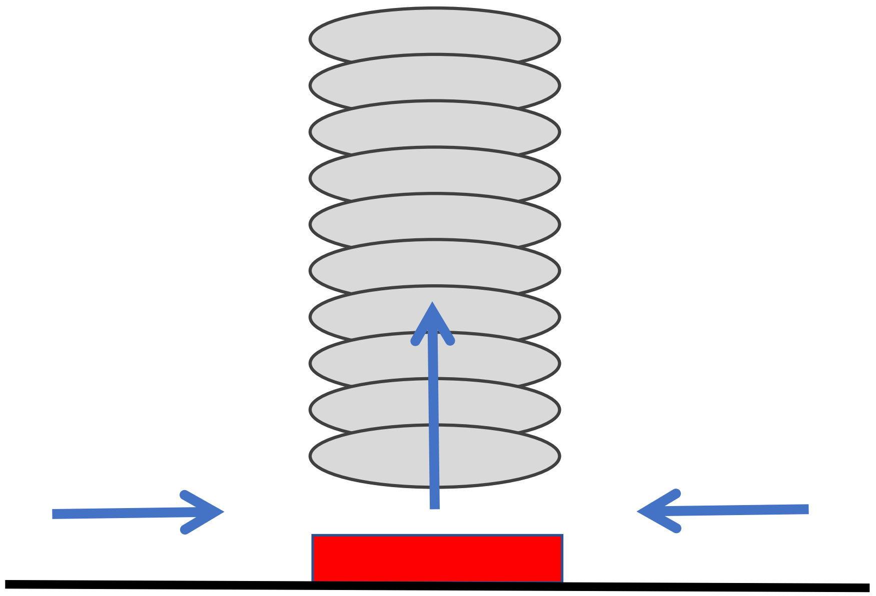
Constraints (Rodden et al., 1965) :
Winds < 8 mph
Fuel Load > 8 lb. / sq. ft.
Fire Area > 0.5 sq. mi.
50% of structures on fire

Conflagration

Constraints:
Winds > 8 mph ?

Types of Mass Fire

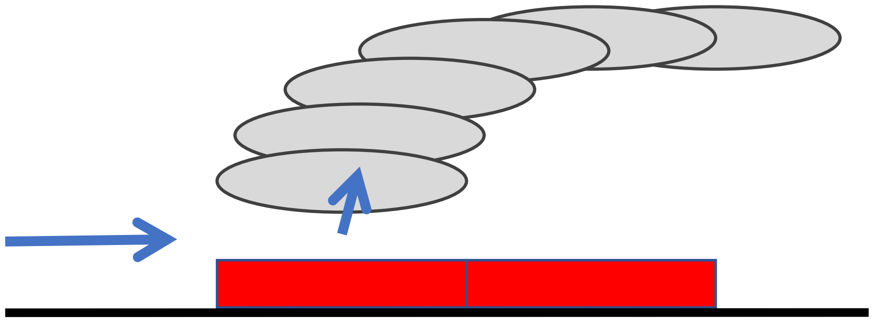
Fire Storm



100% fuel burned, no fire spread

Example:
Incendiary bombing
Hamburg, July 1943
Calm winds

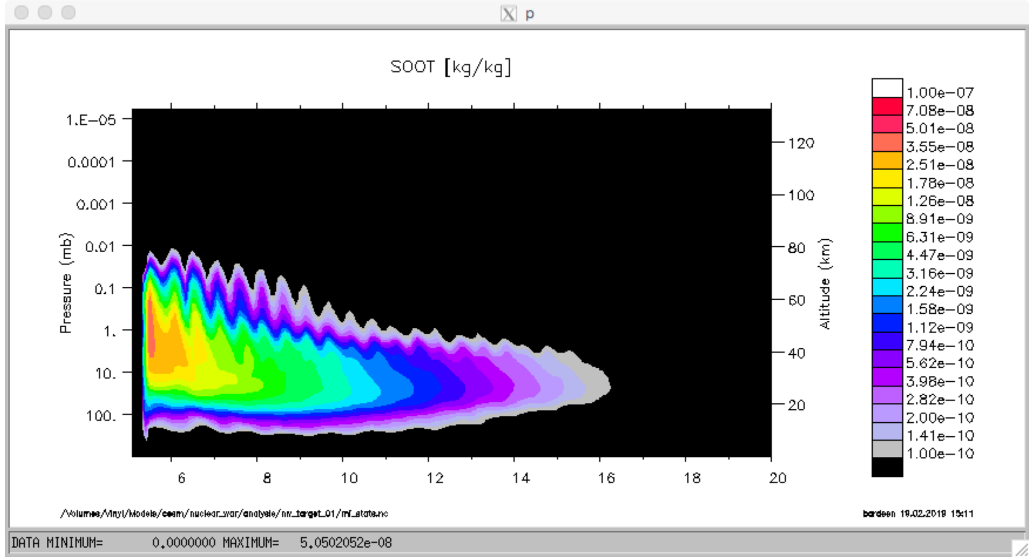
Conflagration



50% fuel burned, fire spreads downwind

Example:
Incendiary bombing
Tokyo, March 1945
20+ mph winds

Step 5: Simulate climate response to smoke



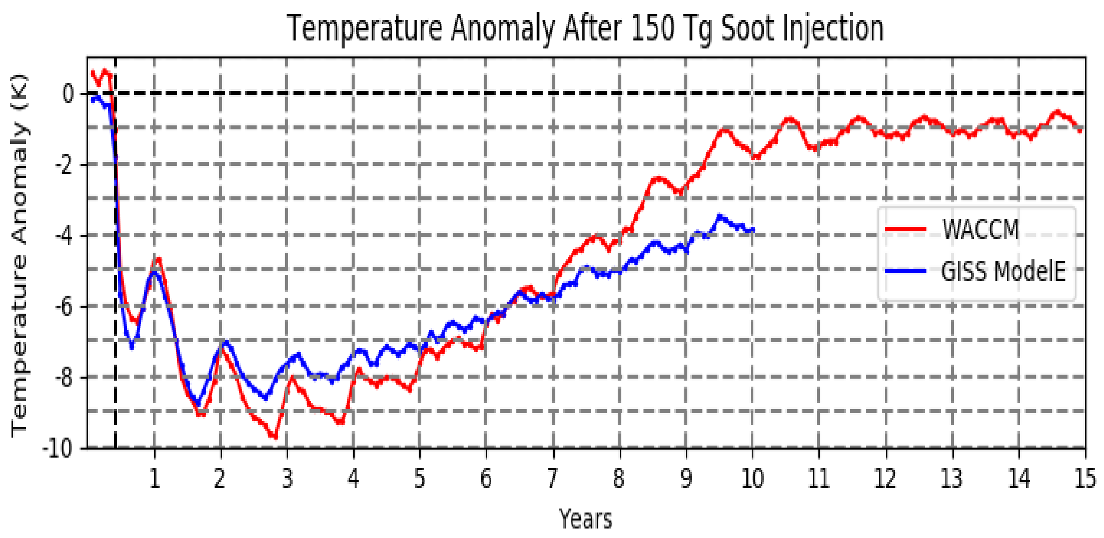
- What are the climatic effects from nuclear war smoke?
- What are the sensitivities of the model to input assumptions and model parameterizations?

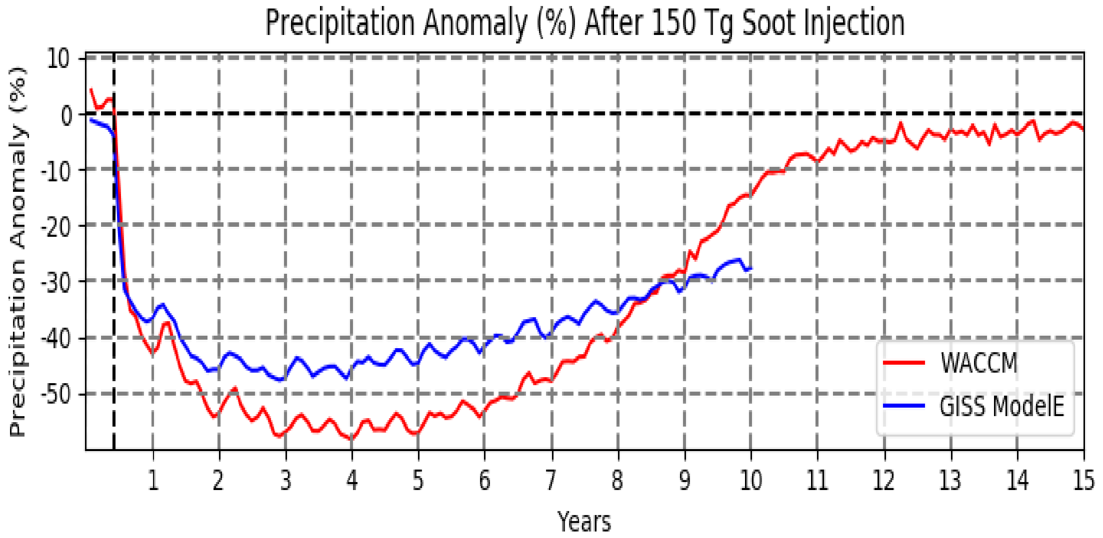
- WACCM Model
  - Bardeen (CU), Yu (NOAA), Coupe (Rutgers)
  - WACCM4/CARMA
  - 1.9˚x2.5˚ resolution
  - Fractal soot
  - Includes biogeochemistry for land and ocean
  - Target based emissions
- Progress
  - Reproduced simulations of US/Russia and India/Pakistan
  - Created ensembles for Control and India/Pakistan
  - Exploring sensitivities to fire type, emission amount, and aerosol representation
  - Emissions profile based upon wind speed

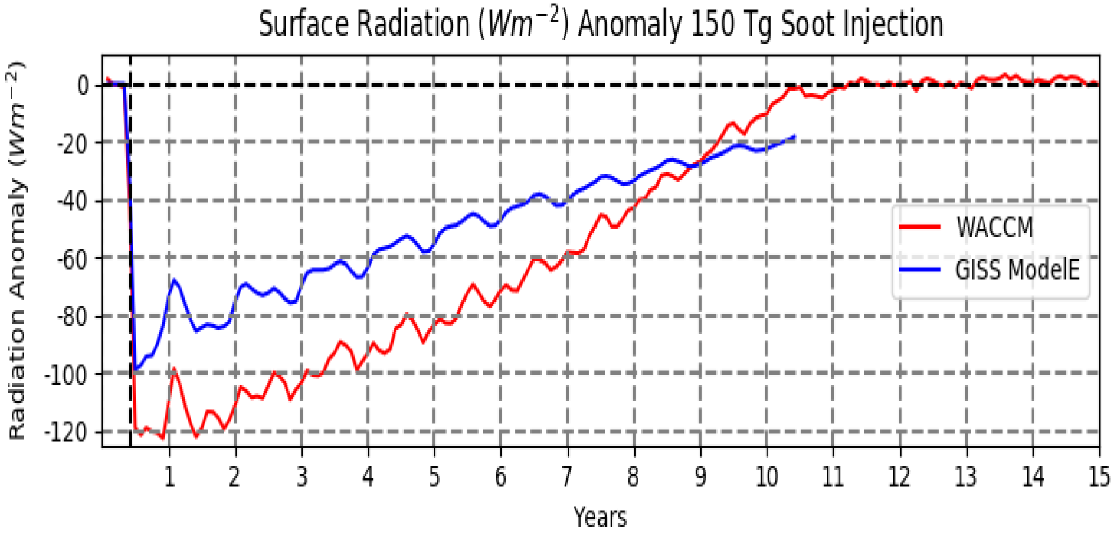
Prior Work

Study	Model	Region	Smoke (Tg)	Additions
Robock et al. 2007	GISS Model E	India/Pakistan	5	
Robock et al. 2007	GISS Model E	US/Russia	50, 150	
Mills et al. 2008, 2014	WACCM	India/Pakistan	1, 5	improved ocean, chemistry
Pausata et al. 2016	Nor-ESM1-M	India/Pakistan	5	improved aerosols, organic coating
Reisner et al. 2018	WACCM	India/Pakistan	3.7, 5	improved emissions (fire model)
This Project Coupe et al., …	WACCM	US/Russia	150	improved ocean, aerosols, chemistry, biogeochemistry
This Project Bardeen et al., …	WACCM	India/Pakistan	5, 16, 27, 37, 47	improved emissions, aerosols, chemistry, biogeochemistry

US/Russia response in WACCM similar to ModelE







New WACCM simulation has:

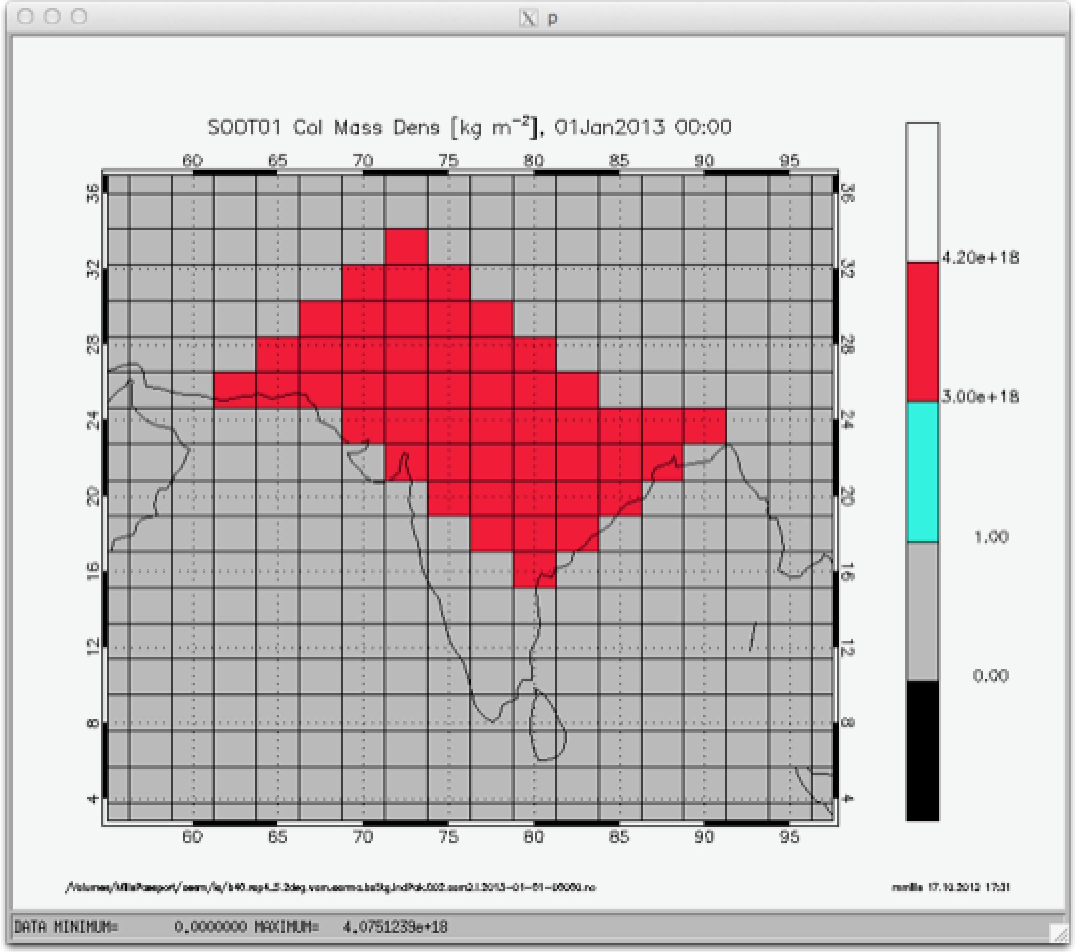
- Same emissions as Robock et al. 2007
- Higher resolution
- Higher model top
- Fractal soot with coagulation
- Full ocean
- Biogeochemistry

Coupe et al., (in prep)

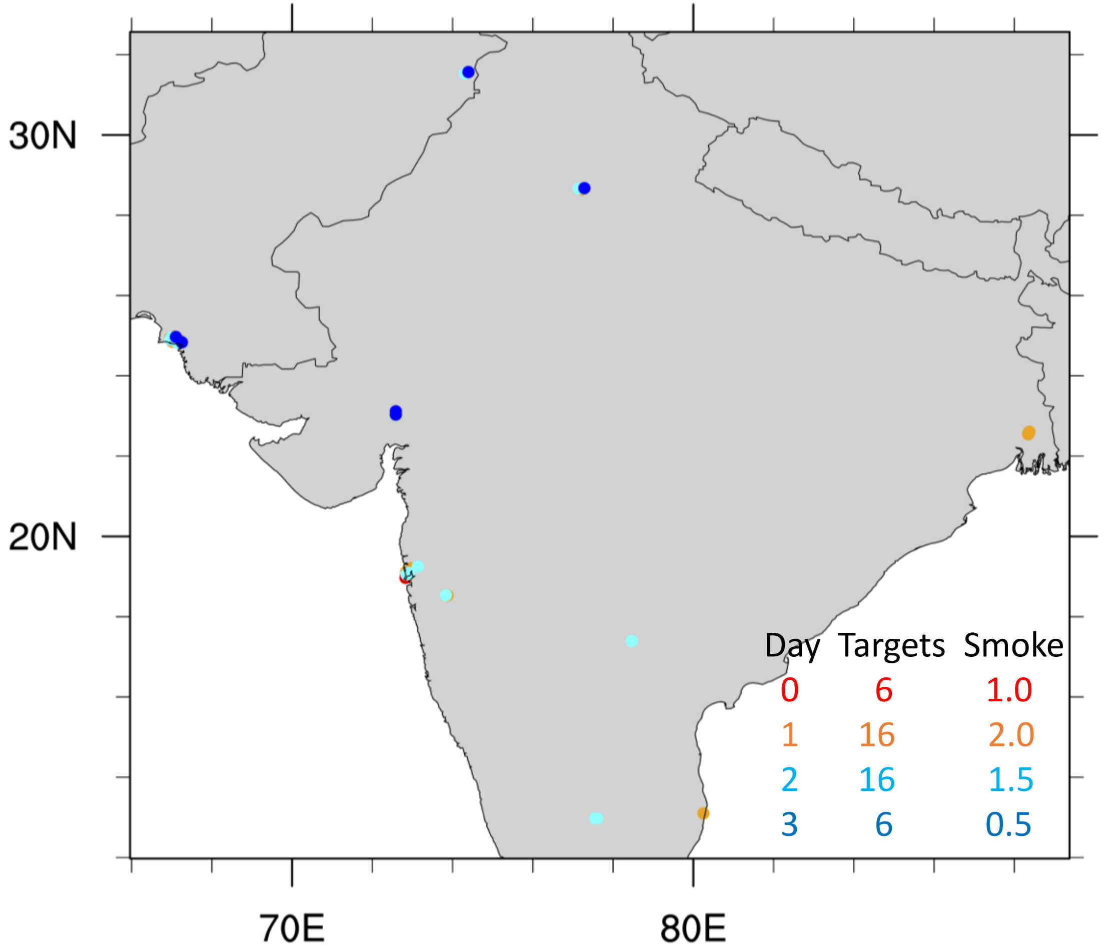
Changing Paradigm for Smoke Emissions

India/Pakistan 5 Tg

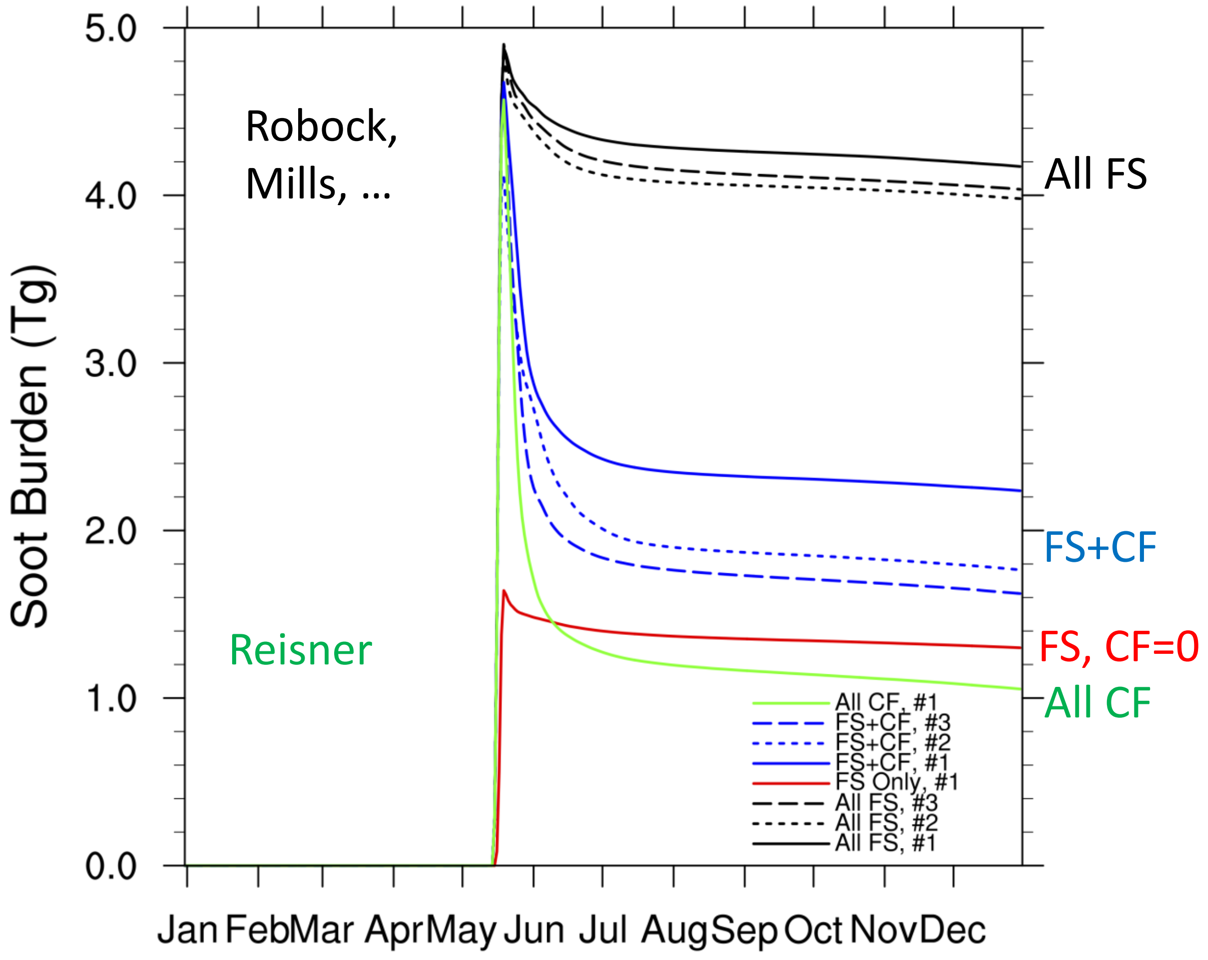
Mills et al. [2008, 2014]

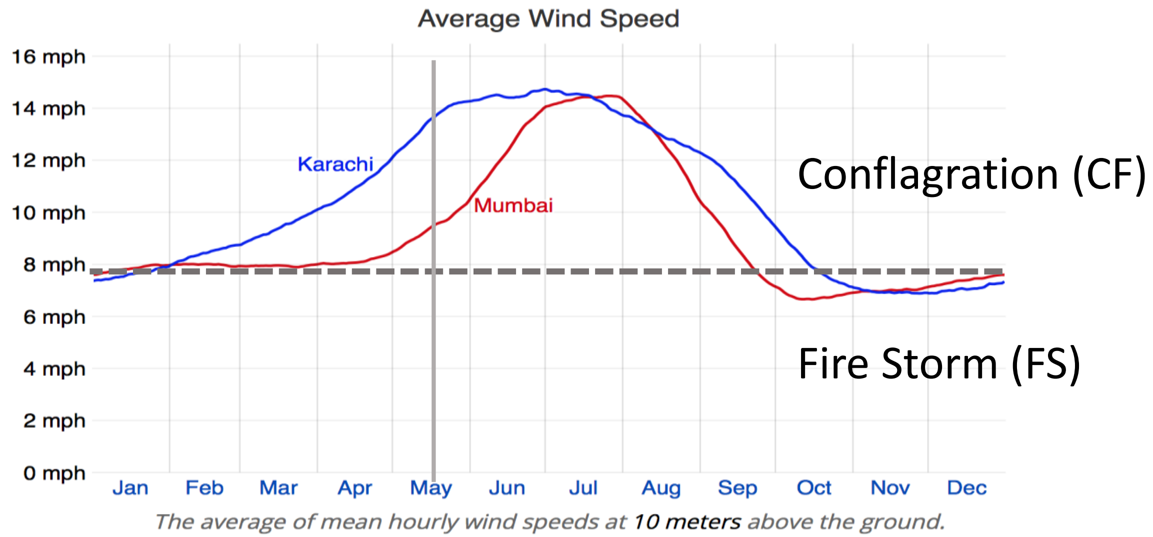


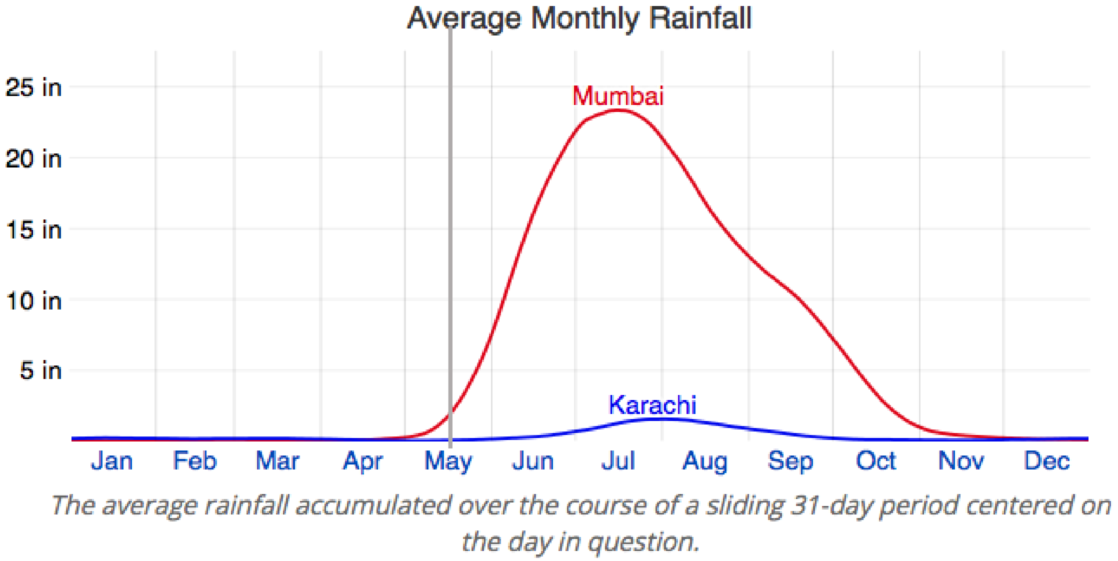
New



How much does fire type affect smoke?



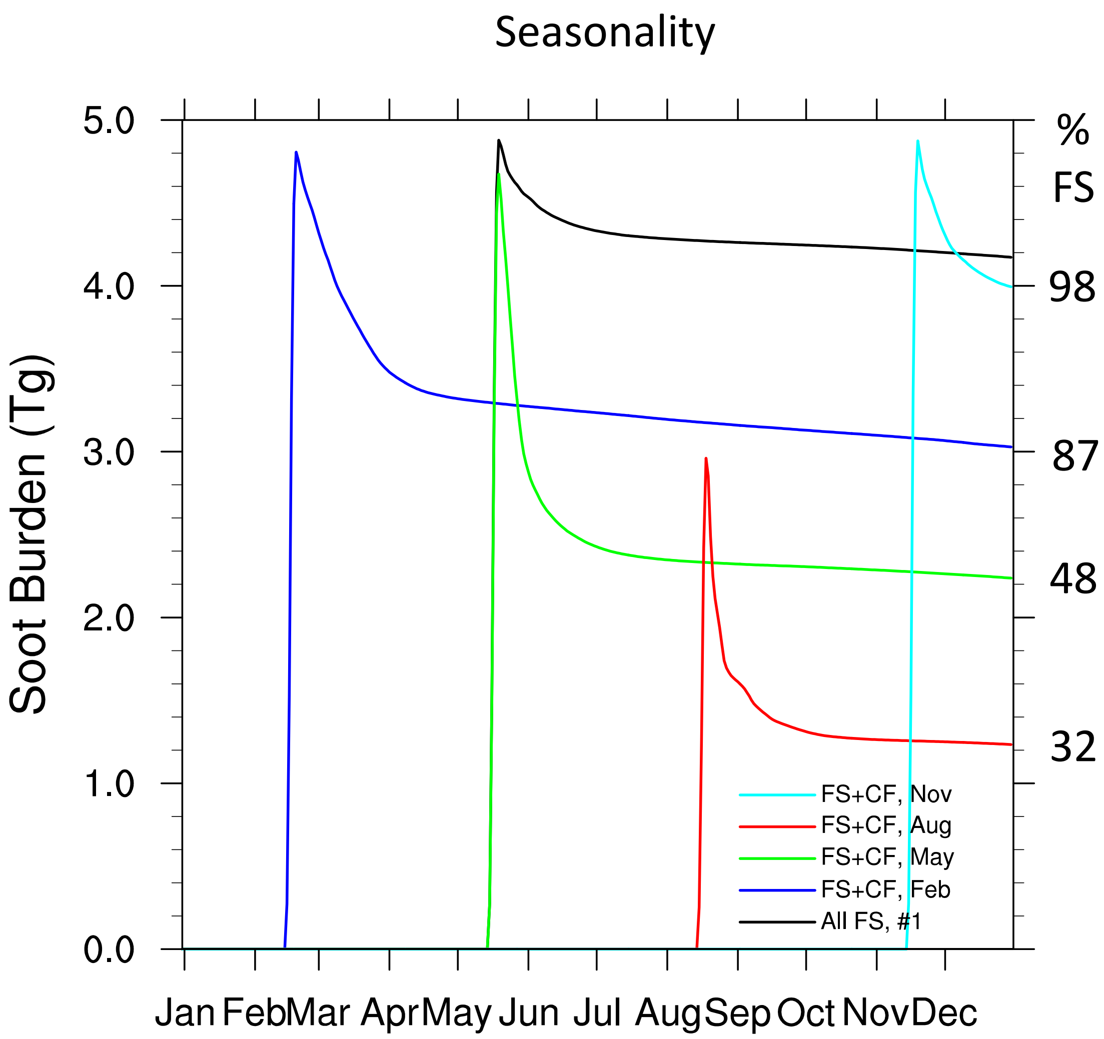


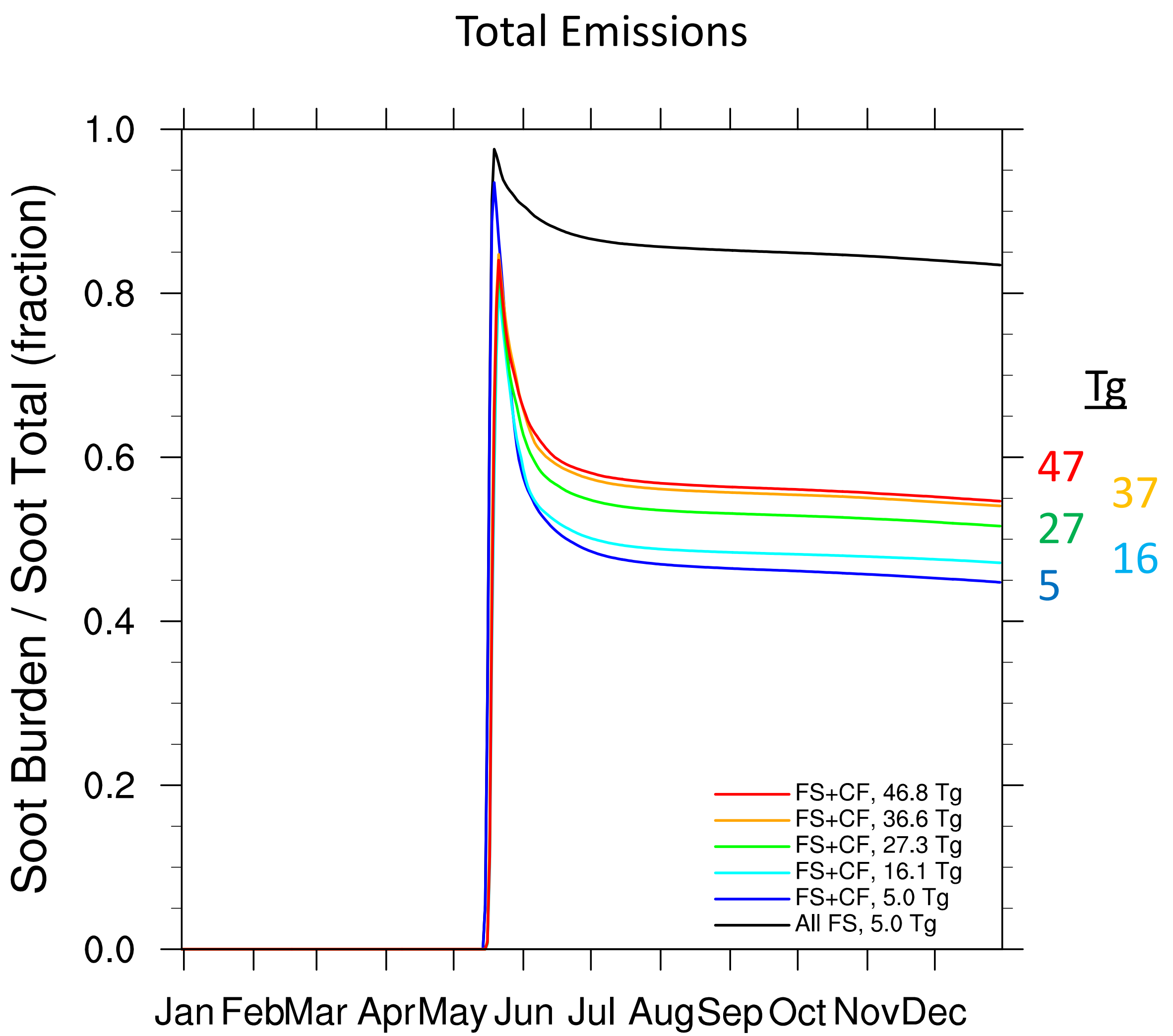


FS – Assume emission between 150-300 hPa

CF – Assume emission profile from Reisner et al., 2018

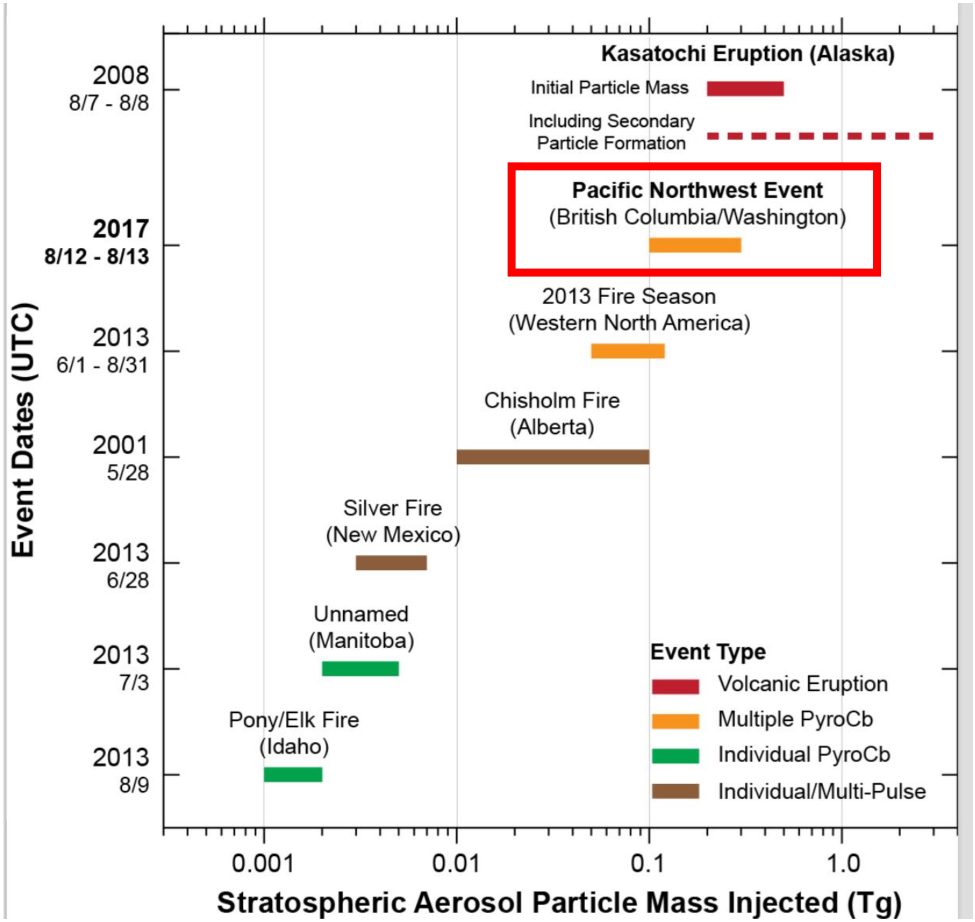
How much do season and size affect smoke?





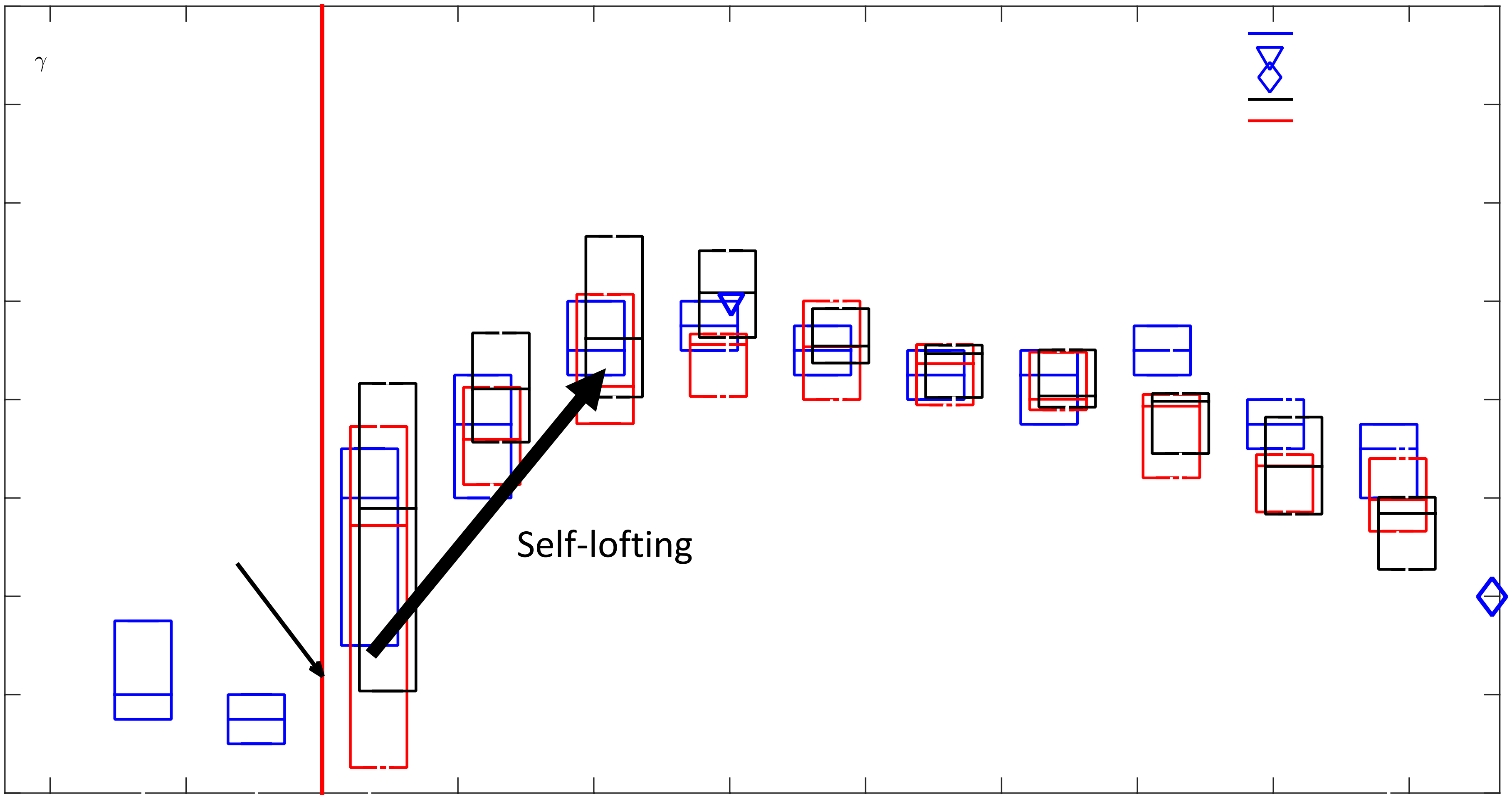
Soot Aerosols - Using PyroCb as a NW Smoke Proxy

- Large Boreal wildfire put 0.1-0.3 Tg of smoke into the stratosphere
- Observed by satellites for 8 months
- Modeled by Yu et al. (in prep) using CAM-Chem/CARMA
  - aerosols
    - pure sulfate
    - mixed OC, BC, sulfate, organics
    - pure OC
    - assume fractal BC coated with organics
  - initial injection at 12 km
- Demonstrates self-lofting
- Determine OC/BC ratio and oxidation rate



[Peterson et al., 2018]

Soot Aerosols - Using PyroCb as a NW Smoke Proxy



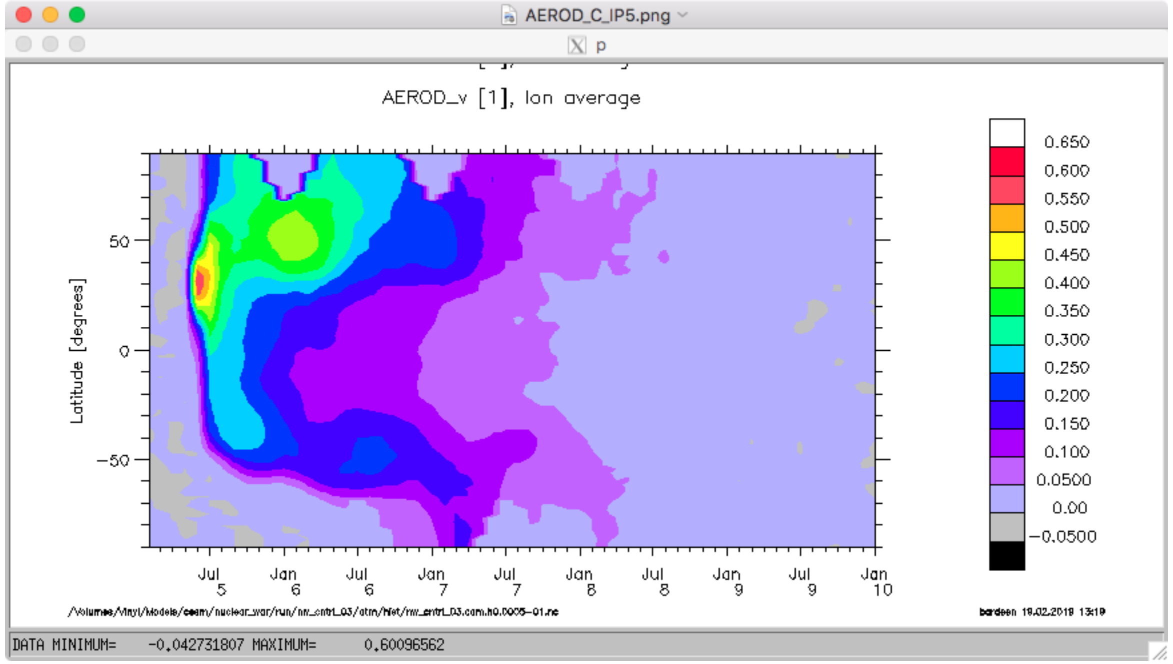
0.3 Tg Smoke with 2% BC, γ=1e-6

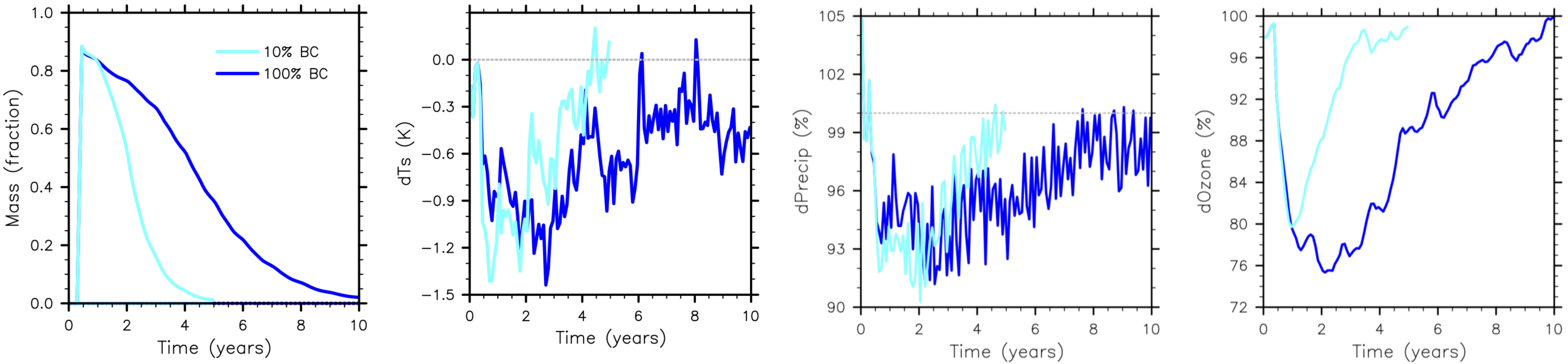
[Yu et al., (in prep)]

India/Pakistan, 5 Tg of BC

Pure = 100% BC
Mix = 10% BC

AOD, Mix - Pure

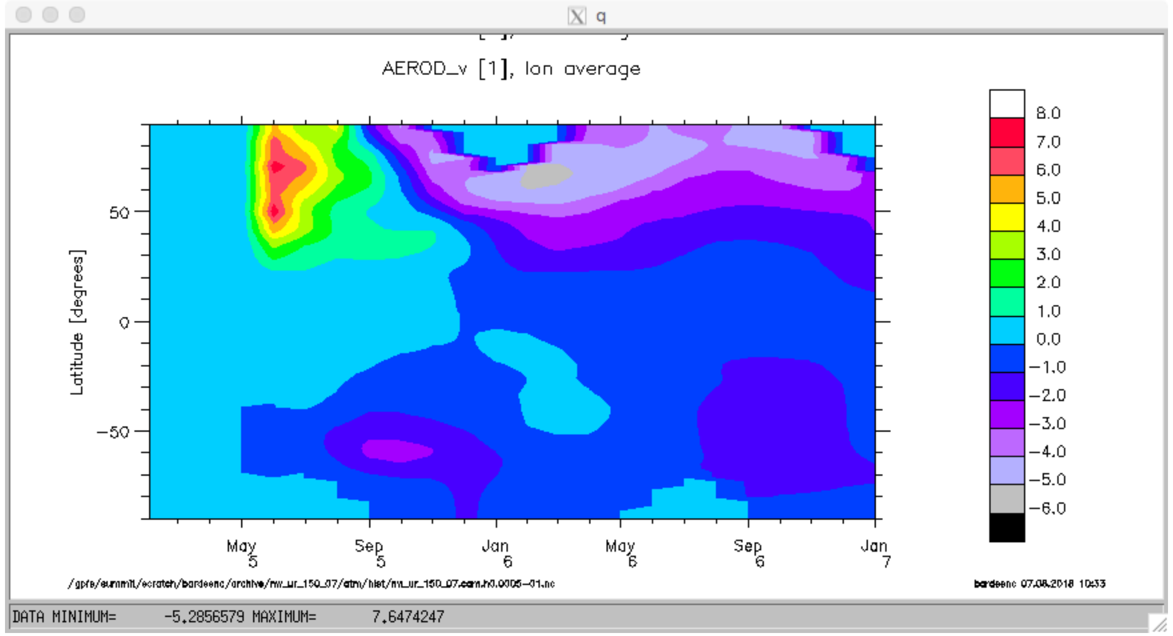


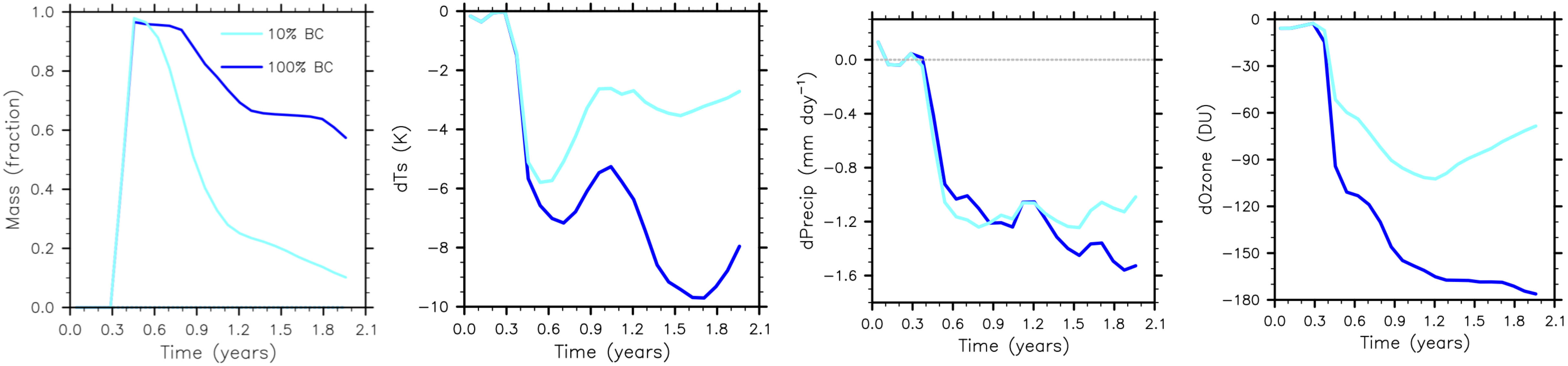


US/Russia, 150 Tg of BC

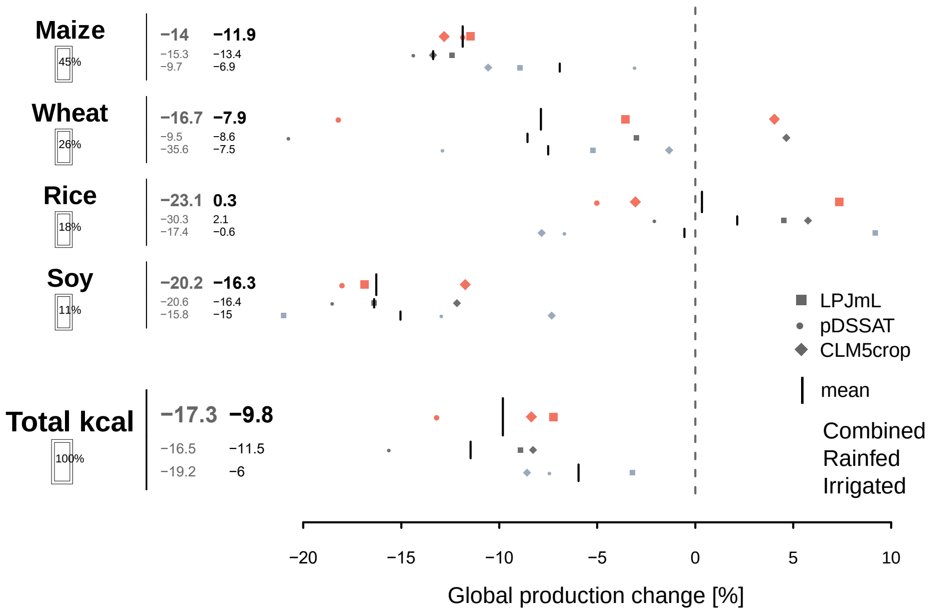
Pure = 100% BC
Mix = 10% BC

AOD, Mix - Pure





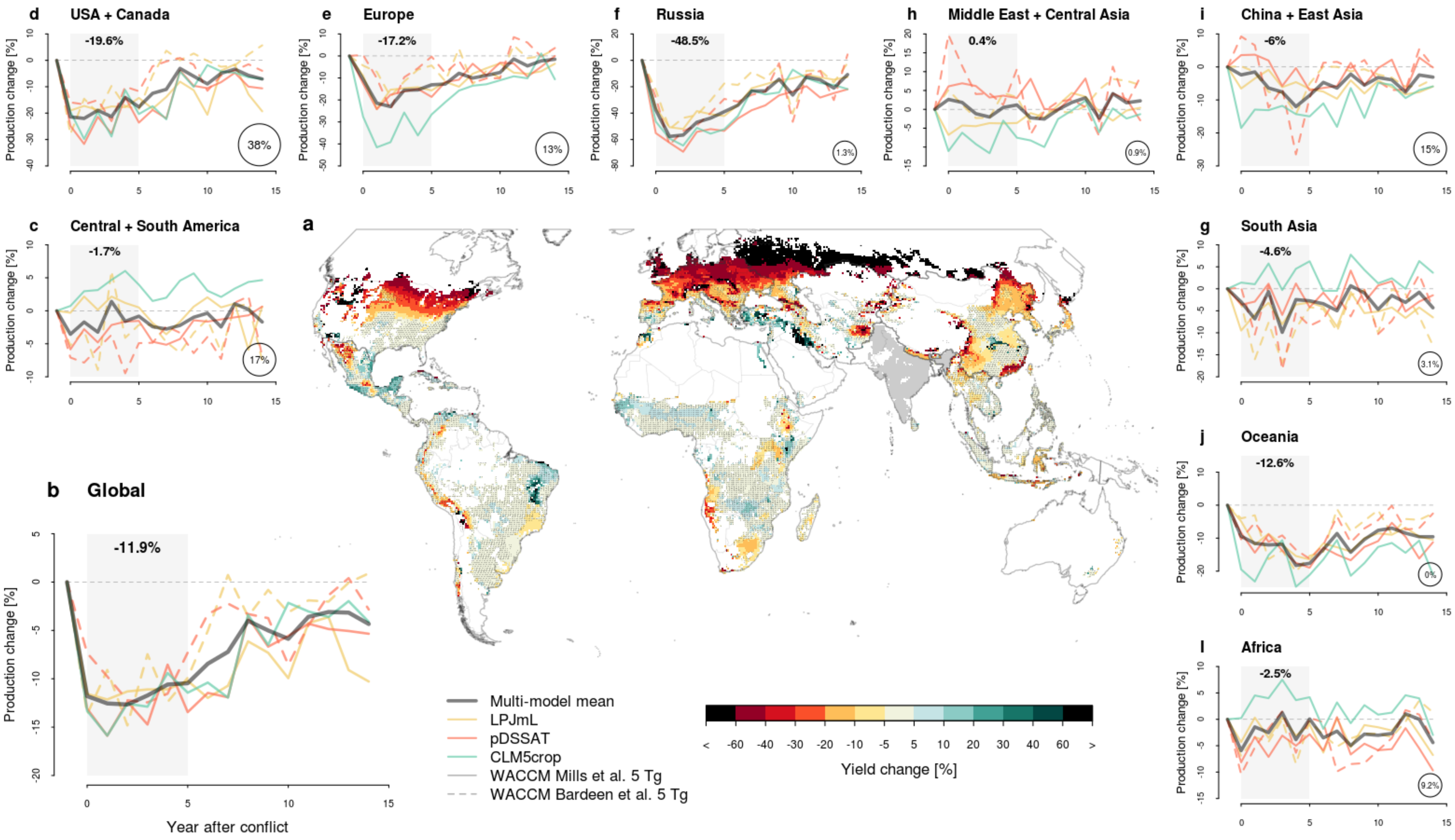
Step 6: Evaluate human impacts from changes



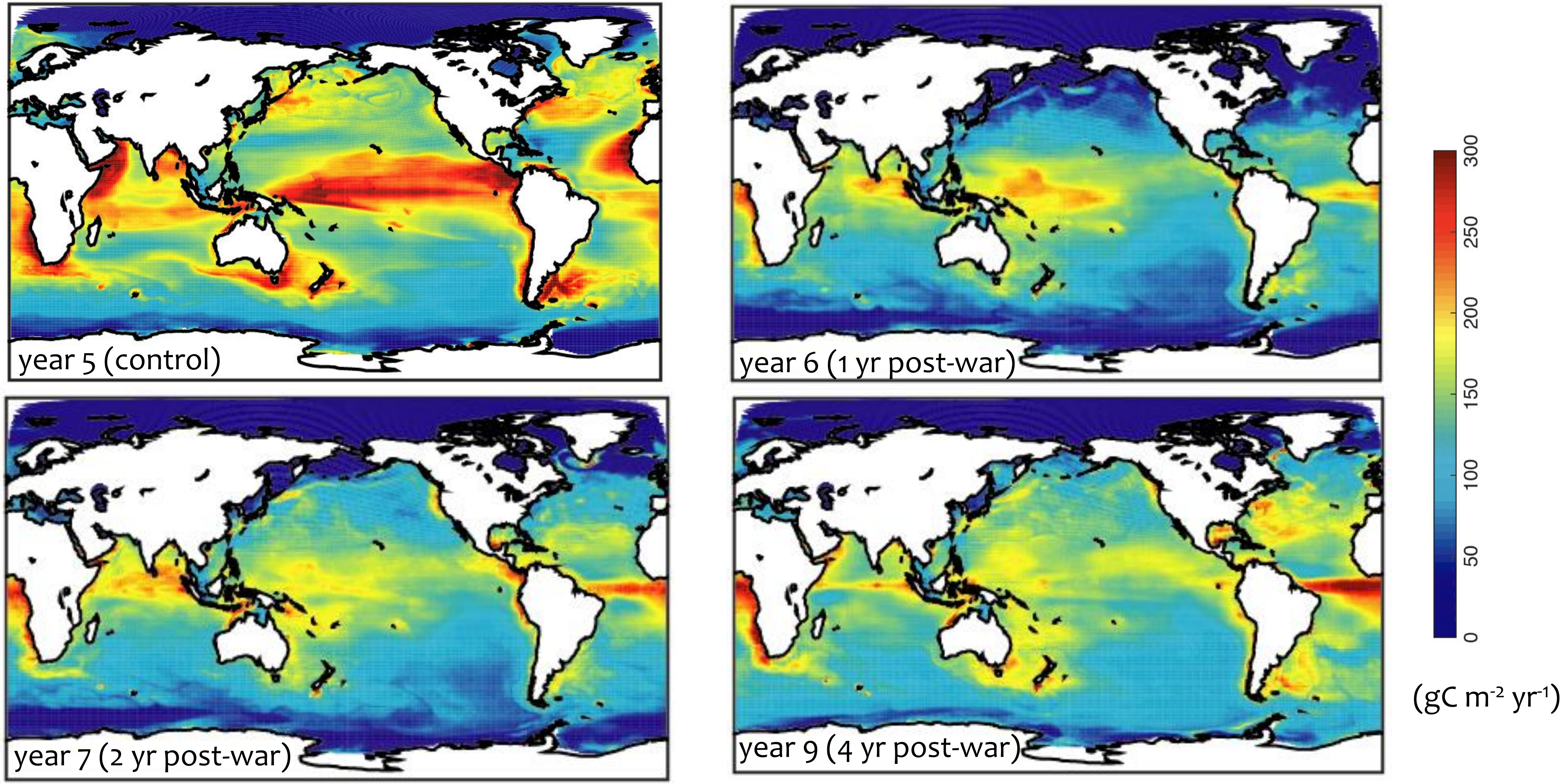
- How is agriculture affected?
- How are fisheries affected?
- How do these changes affect trade and the global economy?

- Land
  - Xia (Rutgers), Jagermeyr (NASA)
  - Participation in GGCMI (global gridded crop model intercomparison project)
    - Uses AgMERRA delta-correction approach
    - GGCMI crop models include (LPJmL, pDSSAT, GEPIC, PEPIC, LPJ-GUESS, PROMET, CLM5crop)
  - Also using coupler output directly with CLM5
- Ocean
  - Lovenduski (CU), Harrison (CU), Coupe(Rutgers), Stevenson (UCSB), Rohr(MIT)
  - Analyzing ocean physical and biogeochemical responses
  - Developing fishery metrics
- Economy
  - Hochman (Rutgers)
  - Analyze economic impacts of agricultural and fishery changes
- Progress
  - Included Mills et al. [2014] and our India/Pakistan cases in GGCMI
  - Preparing to run CLM5 for all cases
  - Analyzing ocean physical and biogeochemical response for US/Russia case
  - Evaluating economic effects of India/Pakistan cases

Implications for temperate maize cultivation last for at least a decade



Phytoplankton Net Primary Production



Summary … so far …

- We are making progress on many fronts to better understand the environmental and human impact of nuclear war.
- Observations of the 2017 pyroCb show evidence for self-lofting, mixed BC/OC smoke, and oxidation of the OC coating that are quantified by modeling studies.
- Effects of mixed BC/OC for the India/Pakistan case show greater impact initially, but a shorter lifetime consistent with Pausata et al. (2016). For larger emissions in the US/Russia case, there is no global increase, only a decreased lifetime relative to the pure BC case.
- Smoke emissions at the target site rather than as a uniform amount spread over a broad area allow for consideration of effects of local meteorology on emissions.
- For the India/Pakistan case, emissions with a mix of fire storms and conflagrations show burdens after 6 months that are twice the value reported by Reisner et al. (2018) and half the values assumed by Robock et al. (2007) and Mills et al. (2008, 2014).
- Including target sites and meteorological effects on emissions introduces a sensitivity to seasonal changes in winds and precipitation not present in earlier simulations.

This work utilized the RMACC Summit supercomputer, which is supported by the National Science Foundation (awards ACI-1532235 and ACI-1532236), the University of Colorado Boulder, and Colorado State University. The Summit supercomputer is a joint effort of the University of Colorado Boulder and Colorado State University.