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


WACCM Working Group Meeting
February 20, 2019
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.

Approach
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

- 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 = \( P \times Mf \)
    - \( P \) – population density (Landscan)
    - \( Mf \) – fuel load (1.1x10^7 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

- 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
- 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

- **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

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

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

Seasonality

Total Emissions
• 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, $\gamma=1e^{-6}$

[Yu et al., (in prep)]
India/Pakistan, 5 Tg of BC

Pure = 100% BC
Mix = 10% BC
US/Russia, 150 Tg of BC

Pure = 100% BC  
Mix   = 10% BC
Step 6: Evaluate human impacts from changes

- **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, GEPIAC, 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

- **How is agriculture affected?**
- **How are fisheries affected?**
- **How do these changes affect trade and the global economy?**
Implications for temperate maize cultivation last for at least a decade.
Phytoplankton Net Primary Production

year 5 (control)

year 6 (1 yr post-war)

year 7 (2 yr post-war)

year 9 (4 yr post-war)

(gC m\(^{-2}\) yr\(^{-1}\))
• 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.

Summary ... so far ...
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.