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Geoengineering Stratospheric Aerosols: Lessons from Volcanic and PyroCb Injections

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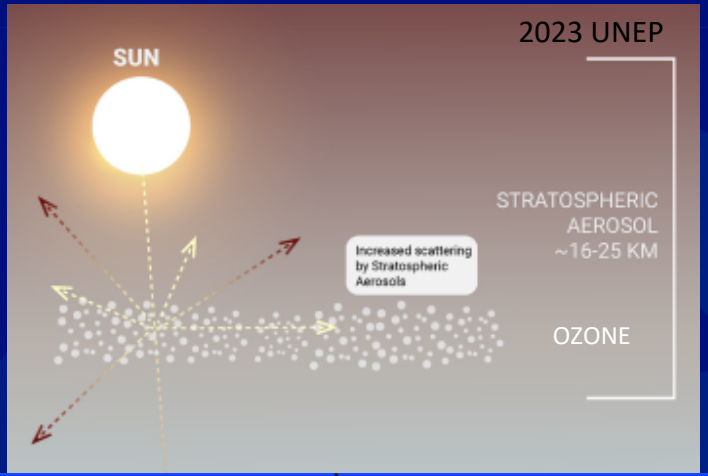
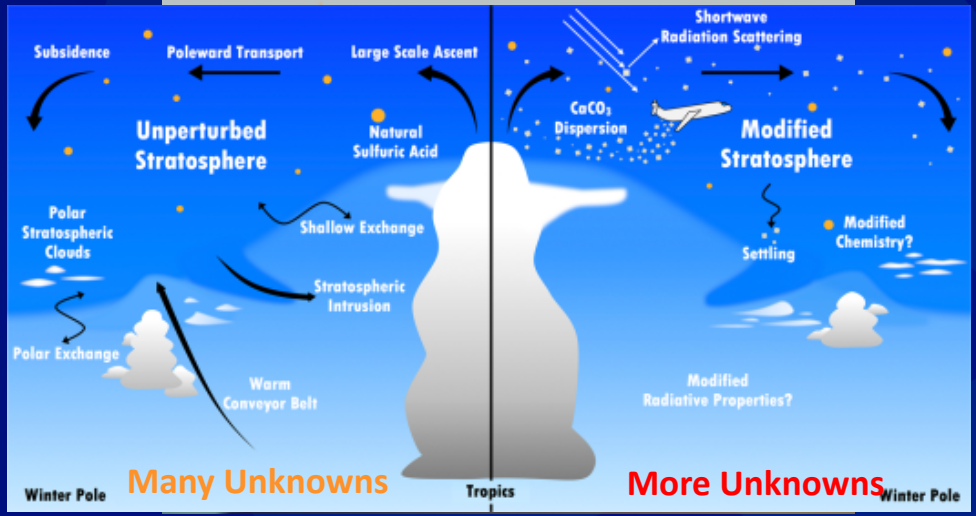
X. Sun and P. Chylek

Battelle Innovations in Climate Resilience

Columbus, OH 3/29/2023

LA-UR-23-23043

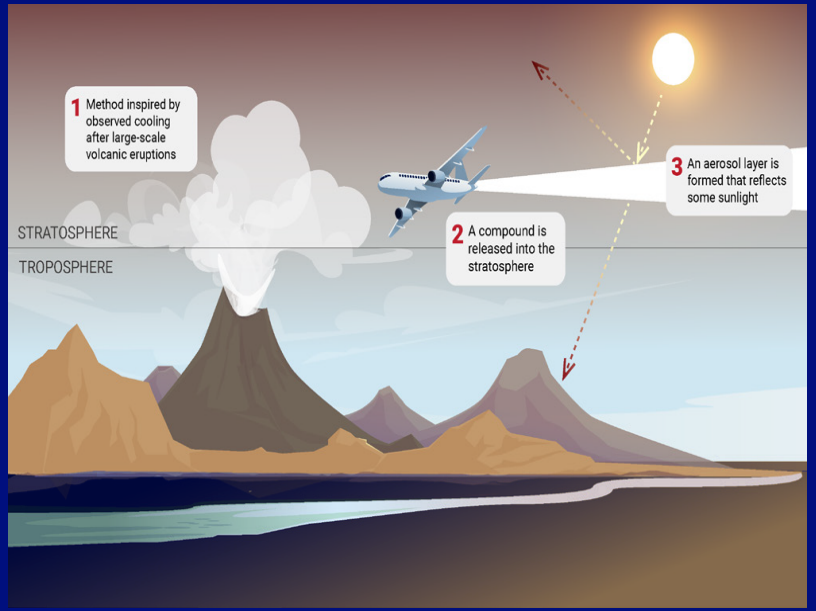




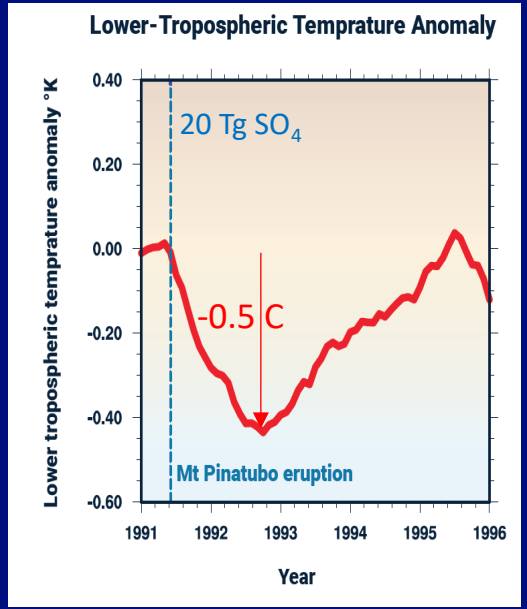
Czisco Sc. Rep 2019

Solar Geoengineering Concept and Rational

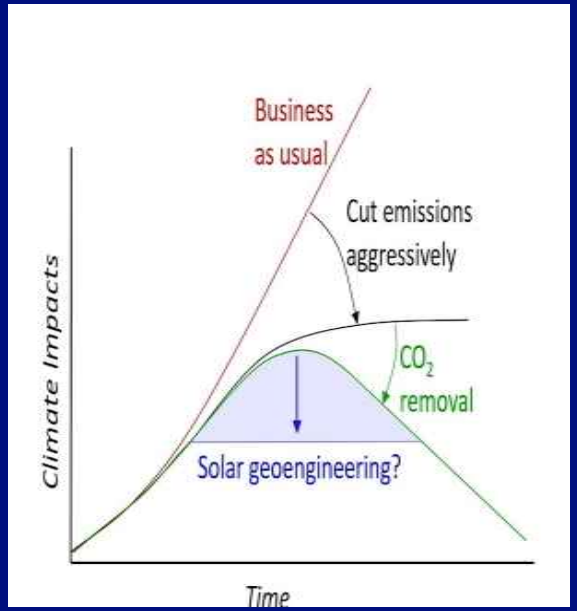
Raise Stratospheric Aerosols to Reflect More Sunlight and Cool the Surface



Global Post Pinatubo Cooling



Fast response, needs steady injection, risks unknown

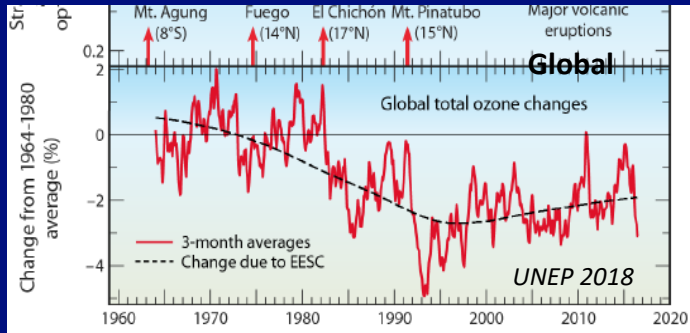


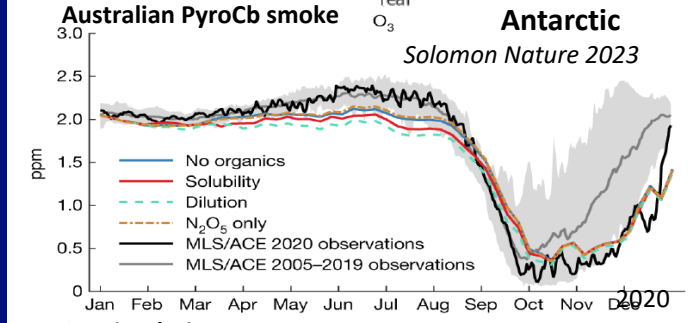
https://www.unep.org/resources/report/Solar-Radiation-Modification-research-deployment

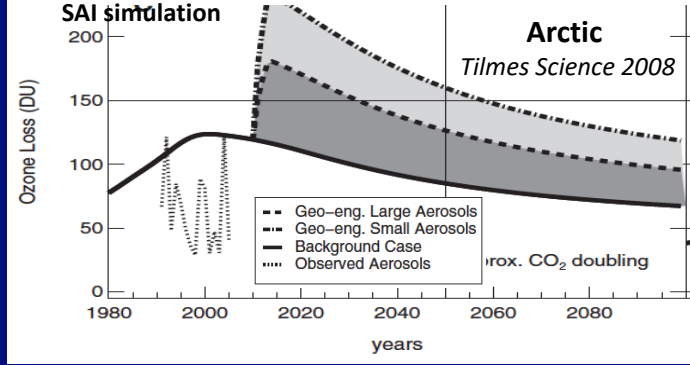
SAI Risks: Known and Unknowns

- Human Engineered Model Simulations
  - Sulfate, Smoke, $CaCO_3$
- Use Natural Analogues to **evaluate model skill**
  - Volcanic Sulfate
  - PyroCb smoke/soot
- Knowledge Gaps and Heterogeneous Impacts
  - Cools to slow global warming: Low costs at scale
  - **Stratospheric ozone depletion/warming**
  - Regional Cooling/Warming or Drying/Wetting
  - Global circulation and cloud (cirrus) feedbacks
  - Surface deposition and air quality
  - No Governance, Risk Unilateral Action
  - Slows decarbonization pace, Ocean acidifies
  - Emergency response to extreme thresholds

O_3 loss after Volc./PyroCb & SAI scenario







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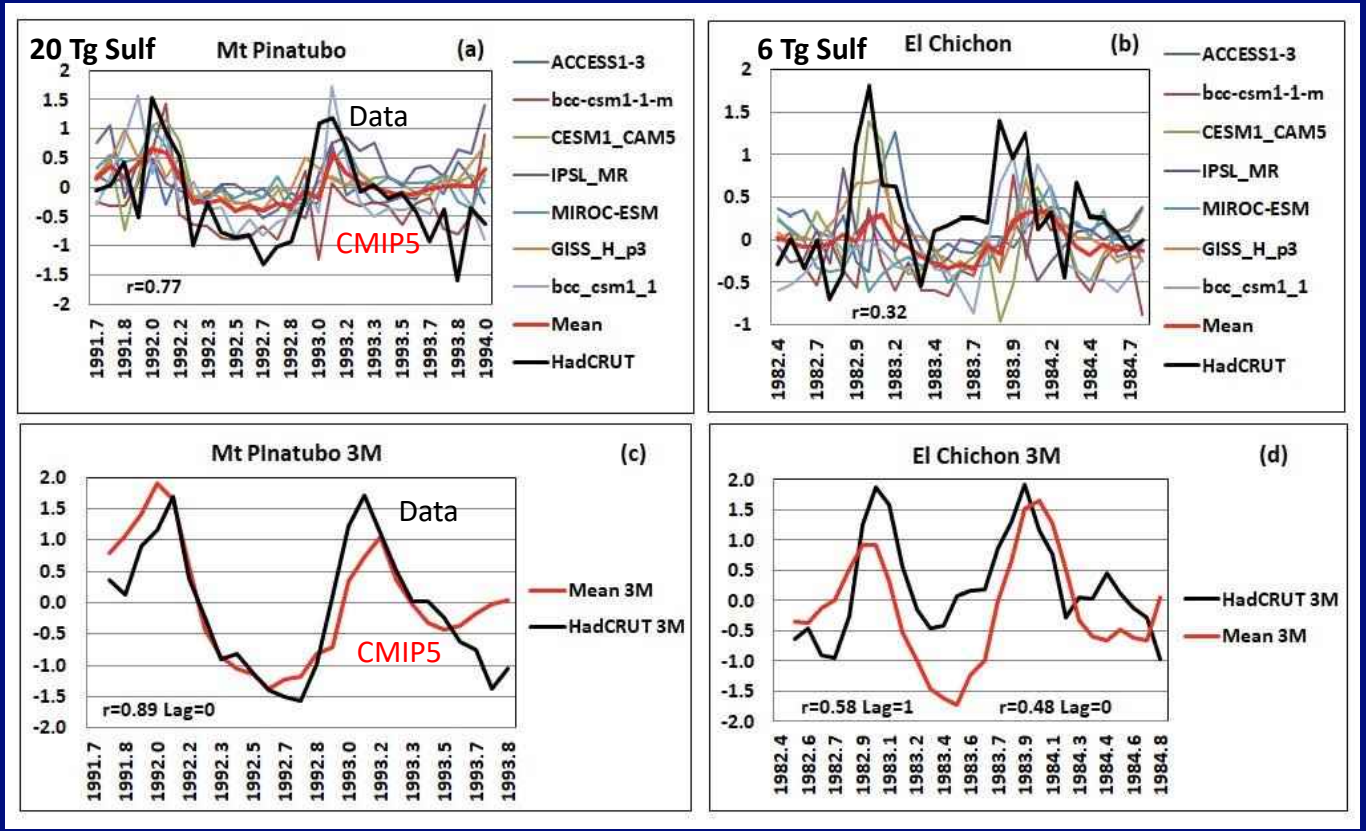
CMIP5: 50-75° Winter Warming after Volcanoes captured by 7/30 Models

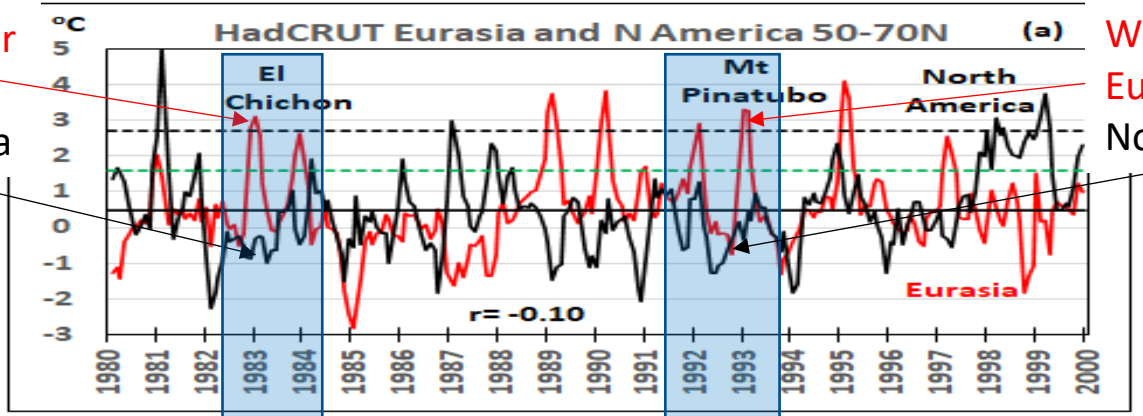
Chylek GRL 2020

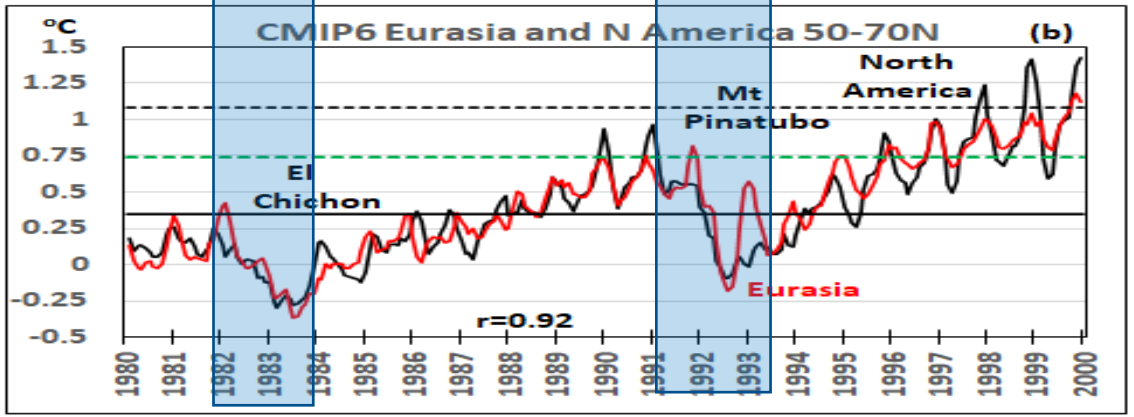


Post Volcanic Winter Warming over Eurasia for 2 years

Winter Warming over Eurasia (2 yr)

None over N America





Winter Warming over Eurasia (2 yr)

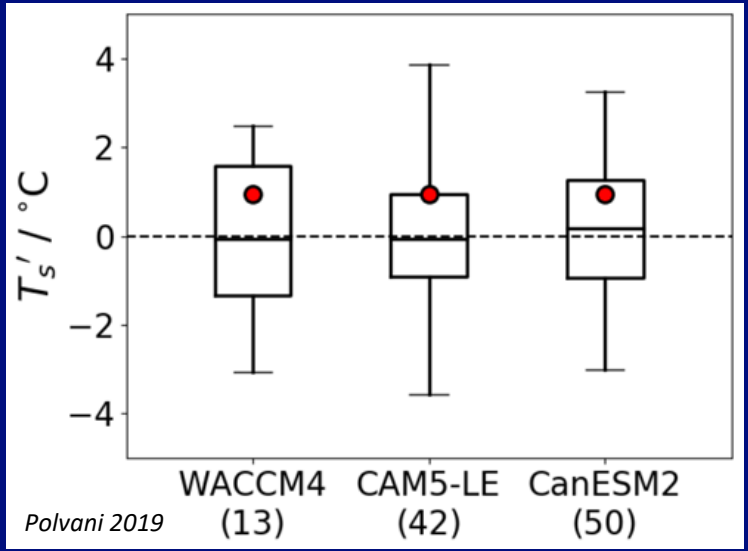
None over N America

Dynamics + chemistry

CMIP6 models reproduce winter warmings after Pinatubo but not El Chichon

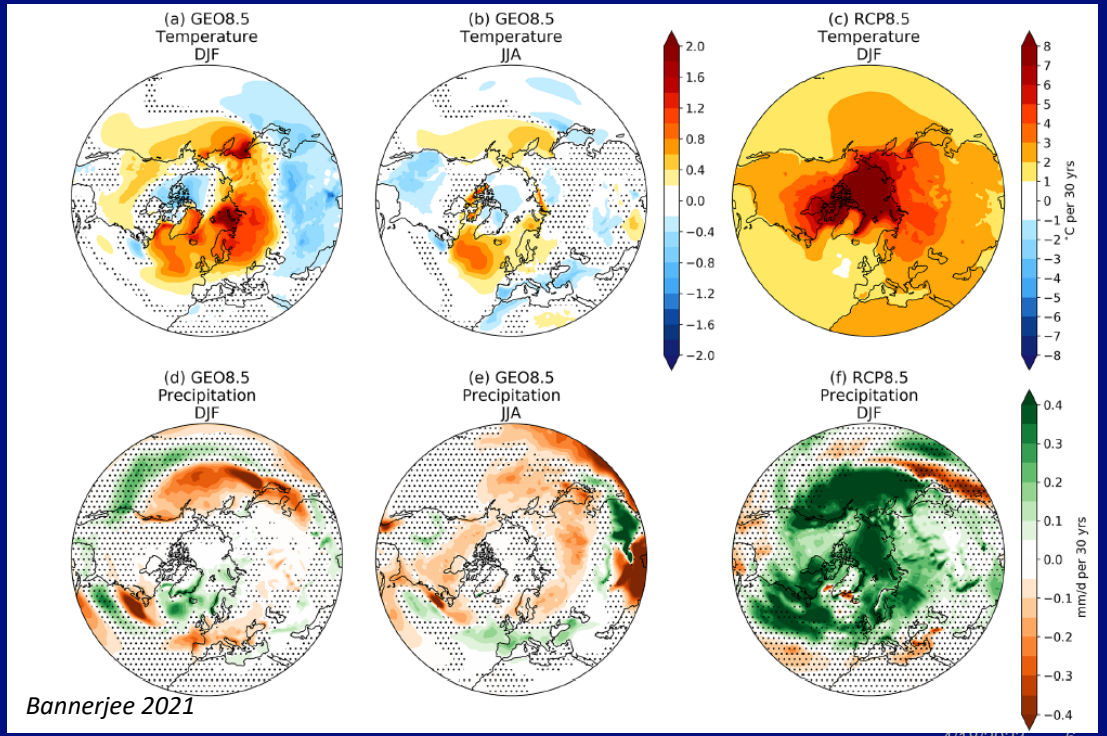
Winter warming via stratospheric dynamics (positive Northern Annular Mode excitation and positive North Atlantic Oscillation)

Pinatubo NH Winter 91/92 Warming



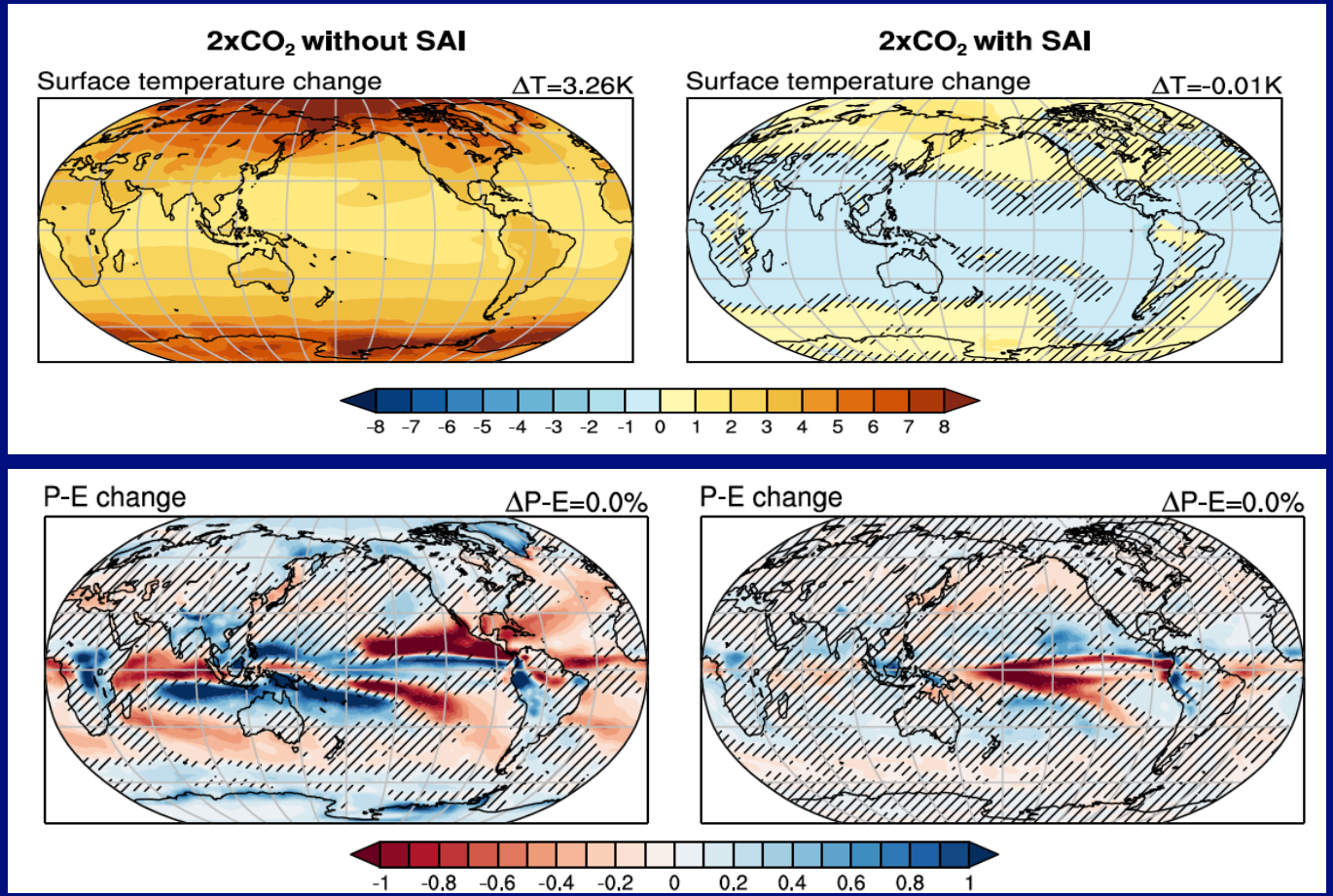
Polvani 2019

Geoengineering: Eurasian Winter Warming 2020-2095

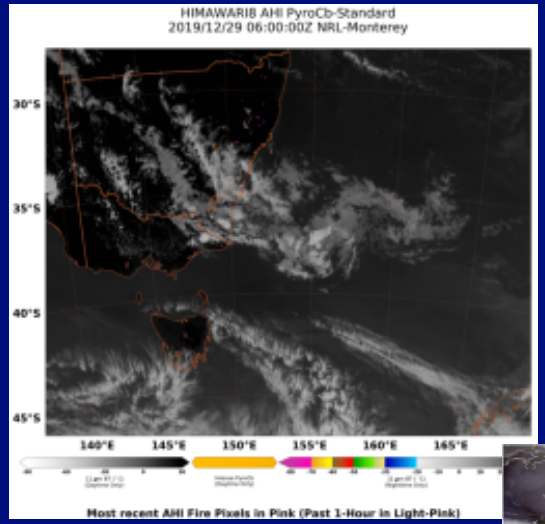


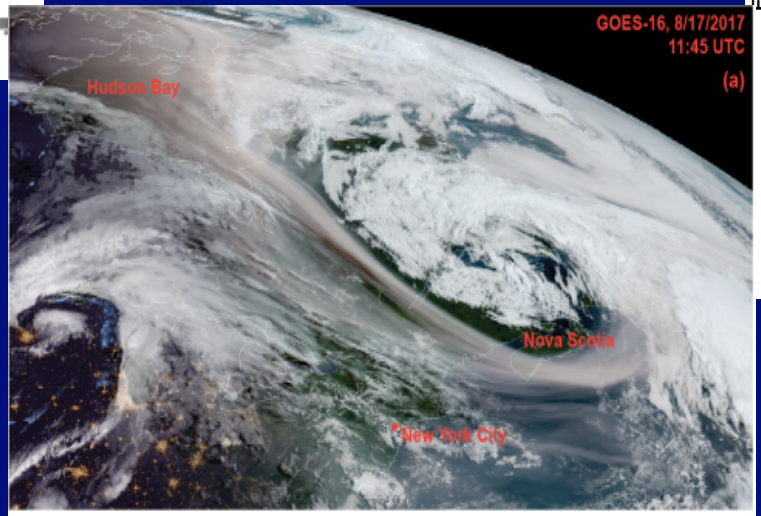
Bannerjee 2021

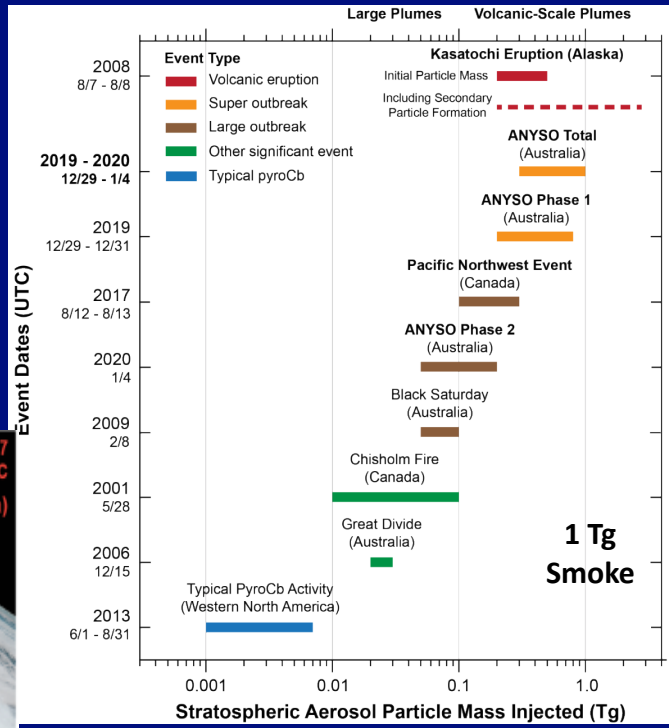
Temperature vs Hydrological Cycle (P-E)



PyroCb Stratospheric Smoke: British Columbia & Australia

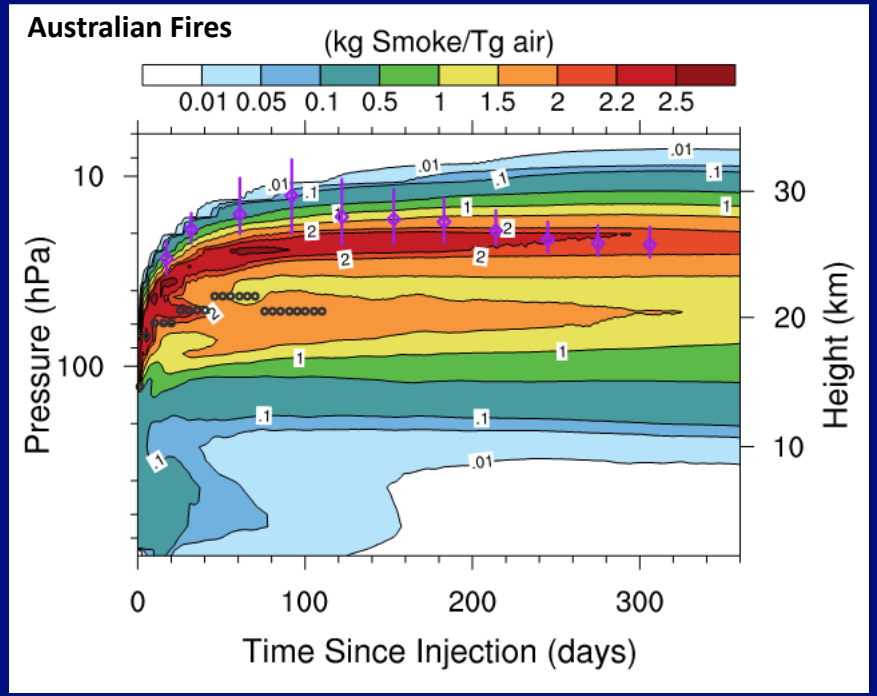


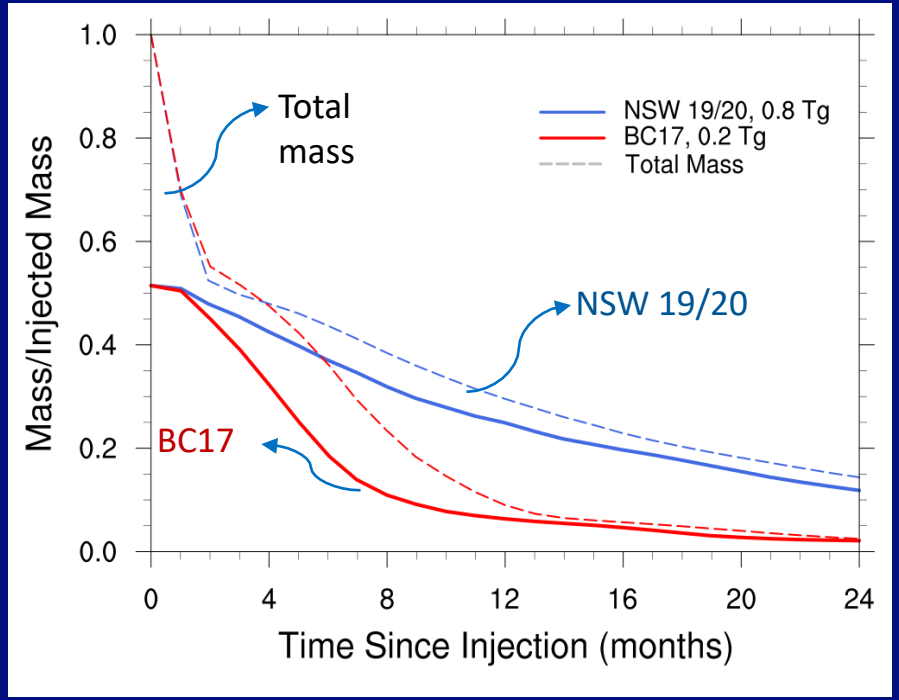




PyroCb Smoke Mass & Lifetime Captured by LES + CESM

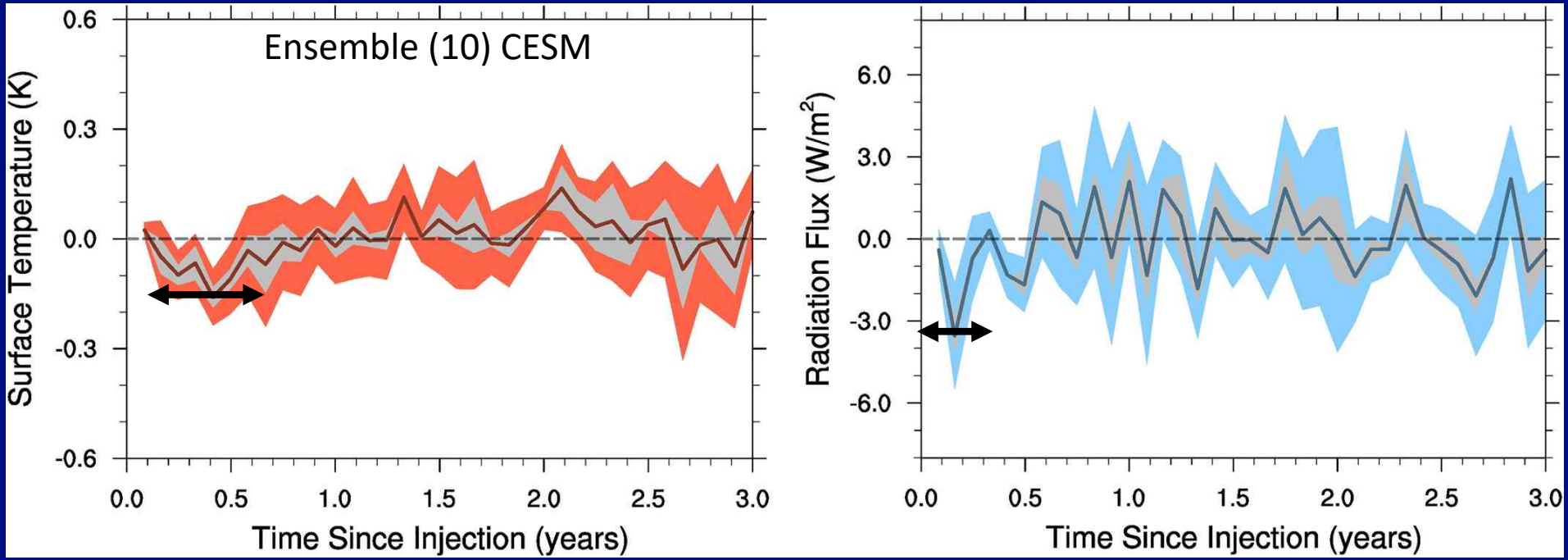
D'Angelo JGR 2022, Reisner JGR 2023





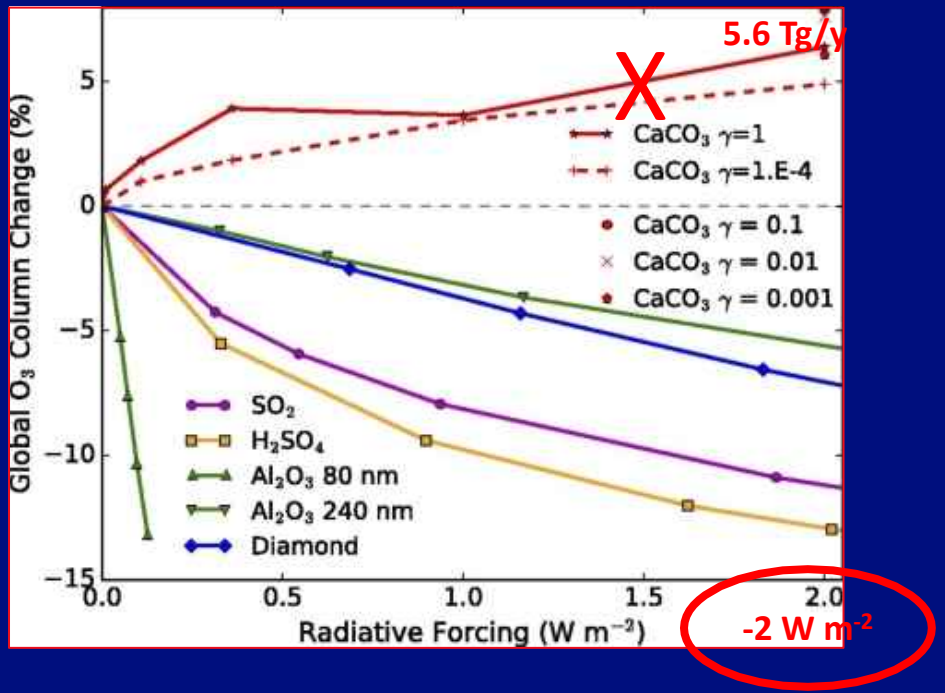
Australian Fires injected 0.8 Tg smoke: Small 0.1-0.2 C cooling (20-60S), -3 W/m^2 sunlight reduction for <6 months

D'Angelo JGR 2022

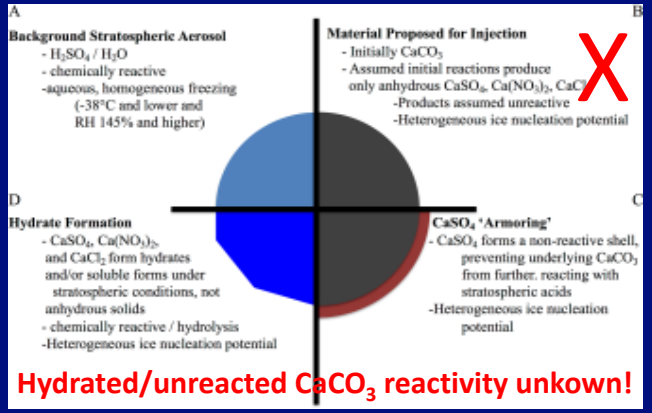


Engineered $CaCO_3$: Chemistry/Ice-Nucleation Gaps

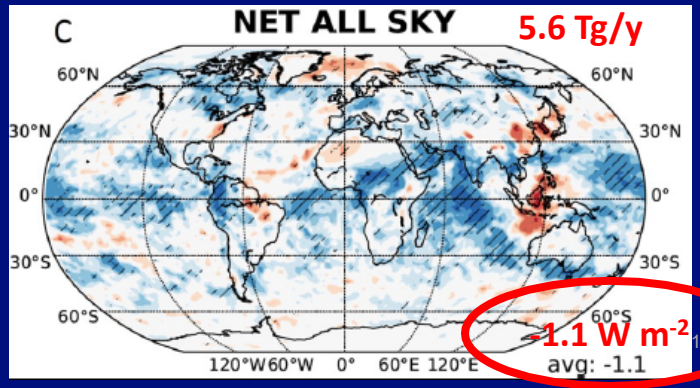
Model: SAI without O_3 loss *(Keith PNAS 2016)*



Gaps: O_3 loss by hydrates *(Czisco, Sci. Rep. 2019)*



Cloud Shielding: Less-cooling & Ice Nuclei?



Incomplete knowledge of natural aerosol perturbations that is worse for engineered aerosols is the limiting factor

1. Cooling of 0.5 C from 20 Tg Pinatubo SO_4 & 0.1 C from 1 Tg Australian fire smoke.
2. Stratospheric O_3 loss/warming observed after natural pulses, also predicted for SAI.
3. Dynamical (tropics-pole) changes cause Eurasian winter warming after volcanoes.
4. Model $CaCO_3$ chemistry is incomplete and cirrus cloud feedbacks unknown.
5. Cloud shielding reduces the efficacy of SAI cooling by ~50%.
6. Historically models have lagged observations in capturing the chemical-dynamical complexities: Research, caution and carefully managed expectations are critical.
7. Unilateral action, heterogeneous impacts & no governance are security concerns.
8. Fundamental aerosol-climate-chemistry research on impacts of pollution, volcanoes, fires, nuclear exchange, and **SAI** need to be coherently integrated.