Springtime solar heating and reduced snow cover from carbonaceous particles

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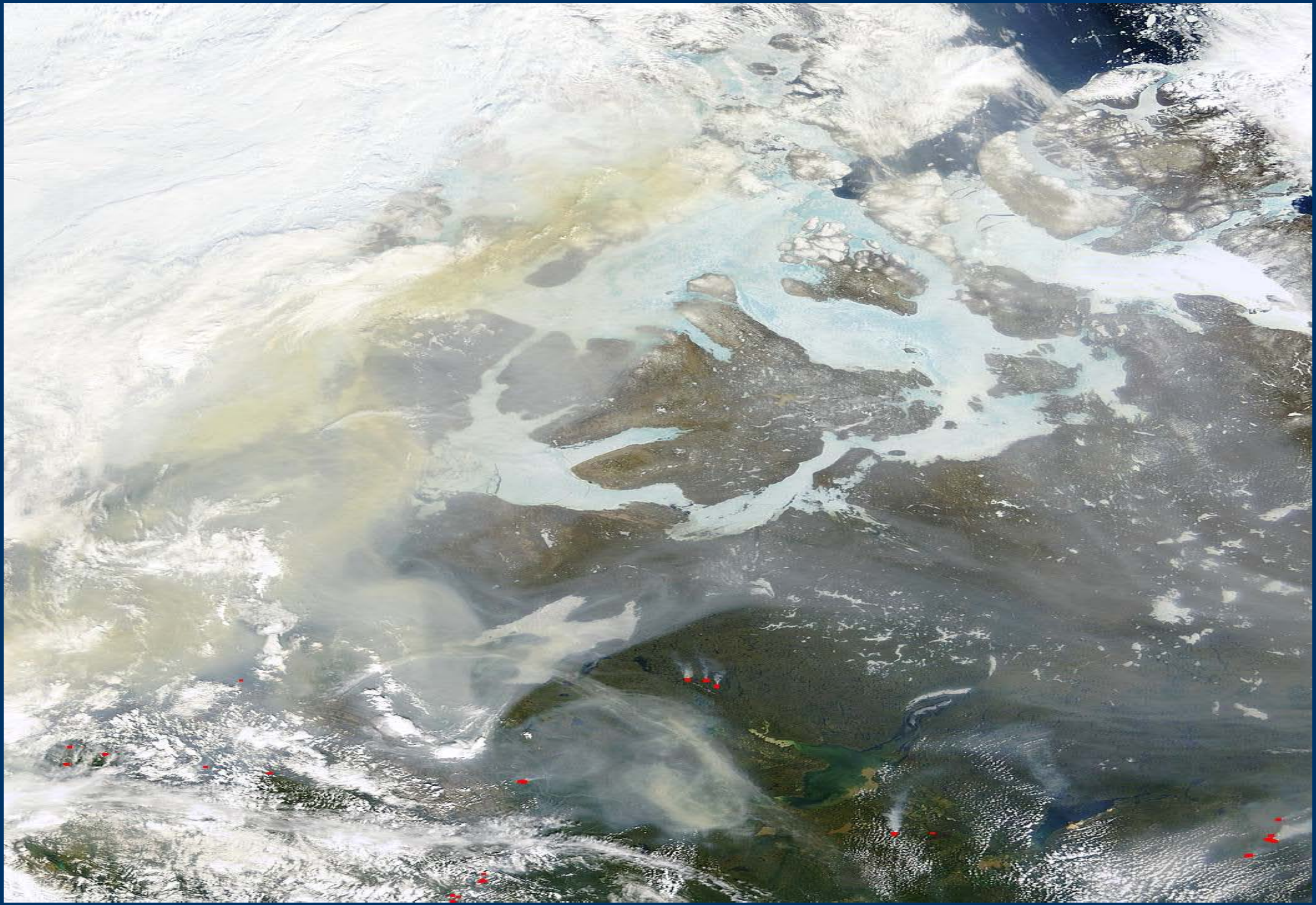
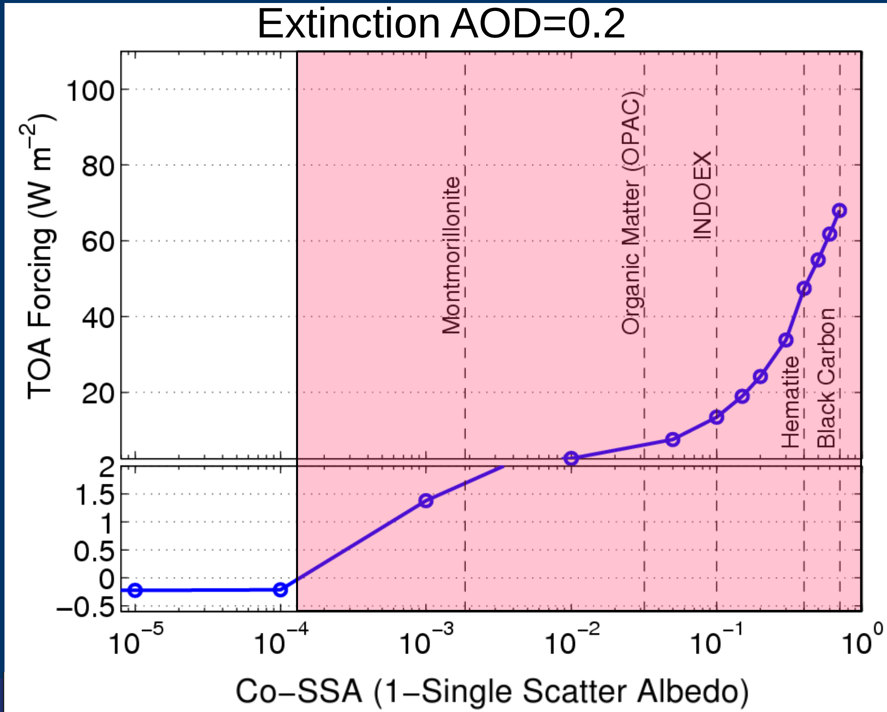
Carbonaceous particles: Positive radiative forcing over snow



Smoke over the Canadian Arctic



Less absorptive

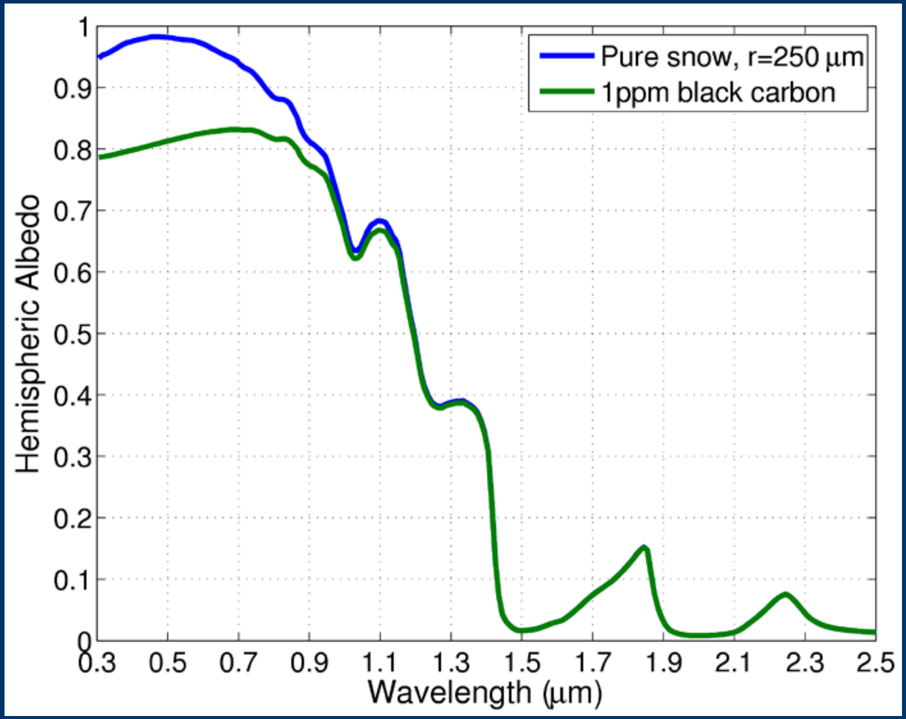
More absorptive

Atmospheric aerosol forcing over pure snow

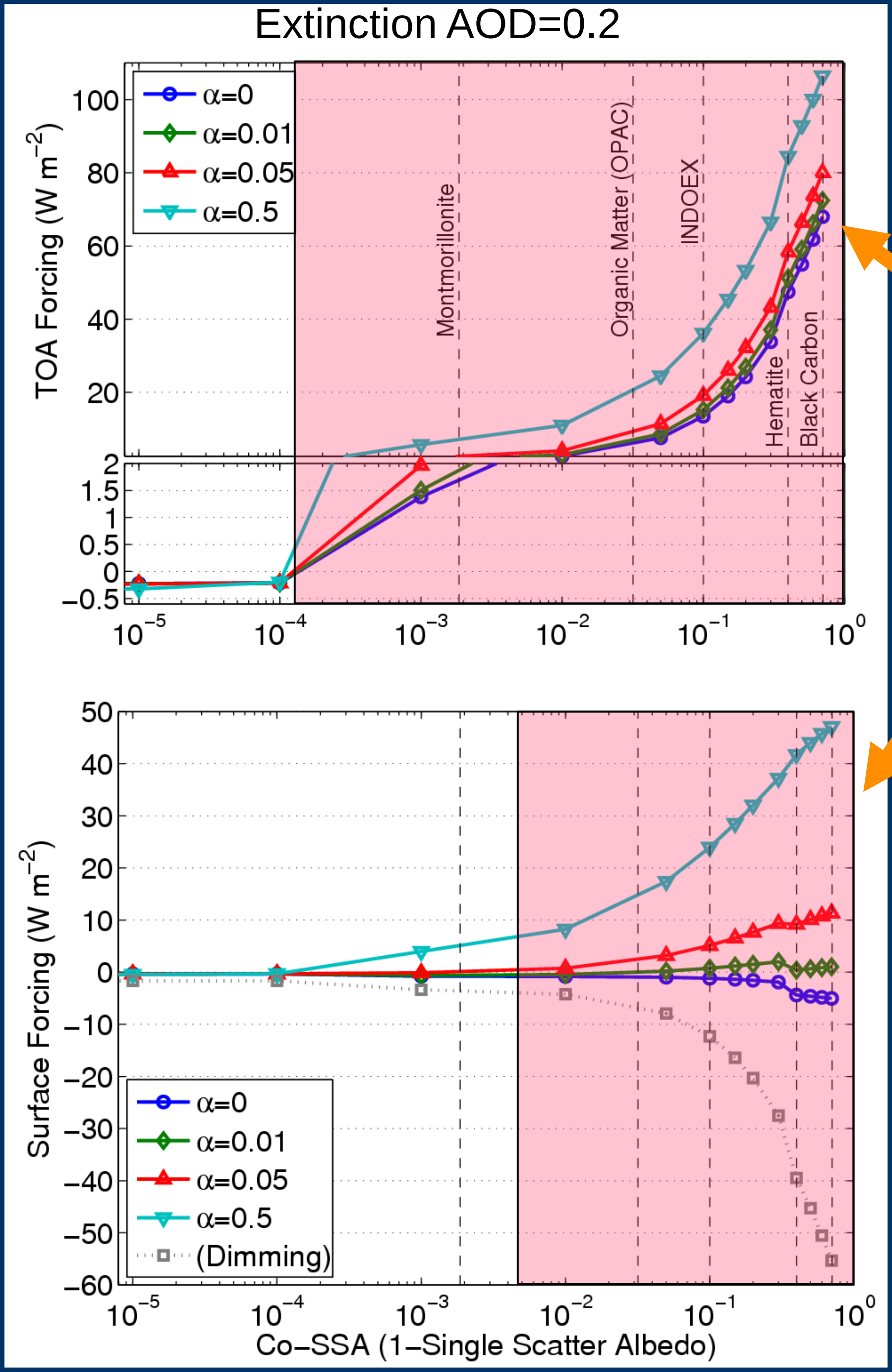
- Top-of-atmosphere
  - Mixtures with SSA<0.9999 (λ=500nm) produce warming
  - Small cooling from sulfate
  - Warming from organic matter
- Surface
  - Large "dimming" from absorbing aerosols, but only a slight cooling effect because of snow's high reflectance
  - Multiple scattering between snow and clouds/aerosols

Flanner et. al. (2009), *Atmos. Chem. Phys.*

Snow albedo perturbation by black carbon



- BC absorptivity is ~5 orders of magnitude > ice
- Flux is highly actinic at snow surface
  - Typical green photon undergoes ~1000 scattering events before emerging from top of snowpack. Large path-length.
- Longer persistence in near-surface snow than atmosphere. Springtime surface accumulation.



Less absorptive

More absorptive

Atmospheric aerosol forcing over dirty snow

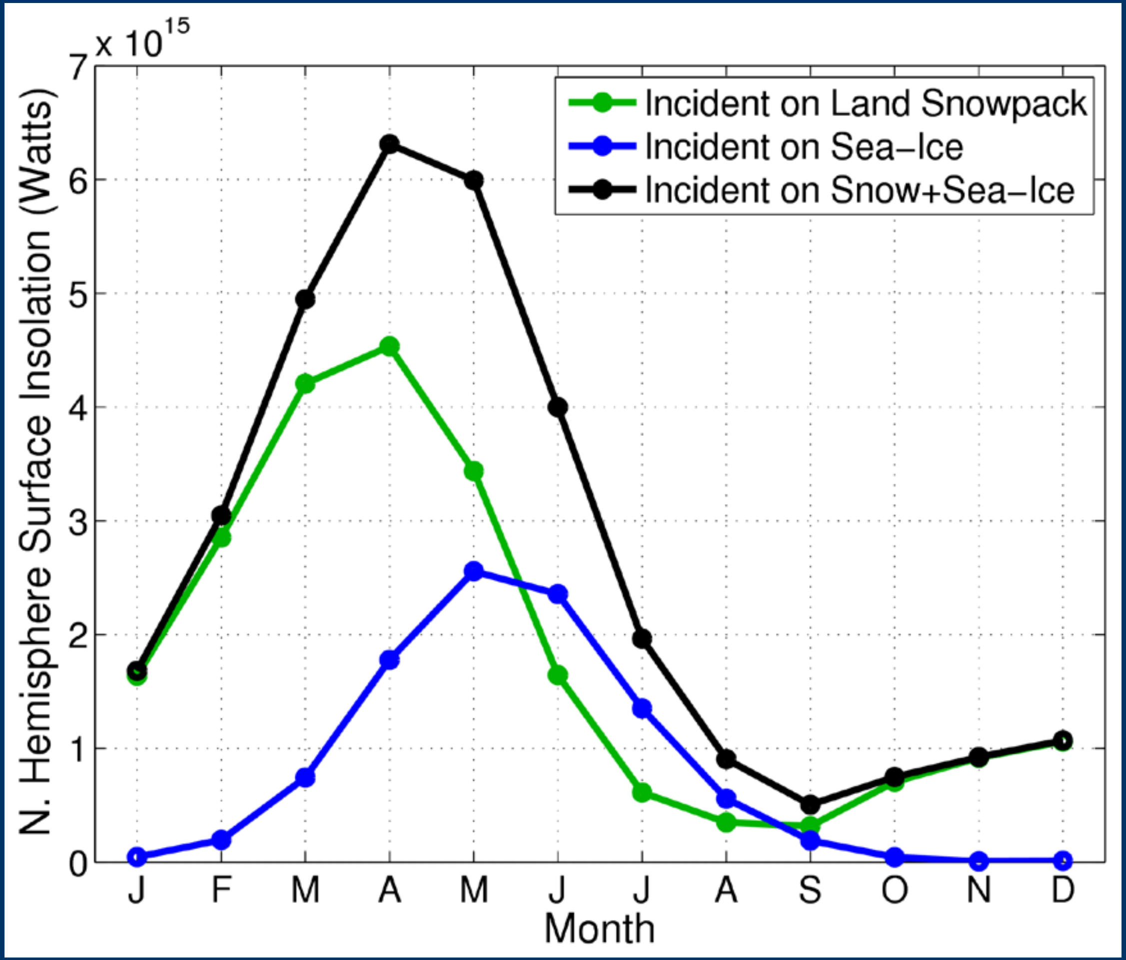
- Snow darkening
  - Increases TOA forcing
  - **Reverses the sign of surface forcing**
    - **(darkening > dimming)**
- α: snow/atmosphere column burden ratio
  - Controlled by
    - Deposition efficiency
    - Meltwater removal removal from snow
    - Mean estimate is 0.07
- Over global snow: ***darkening 6x > dimming***

Flanner et. al. (2009), *Atmos. Chem. Phys.*

Springtime susceptibility to snow changes

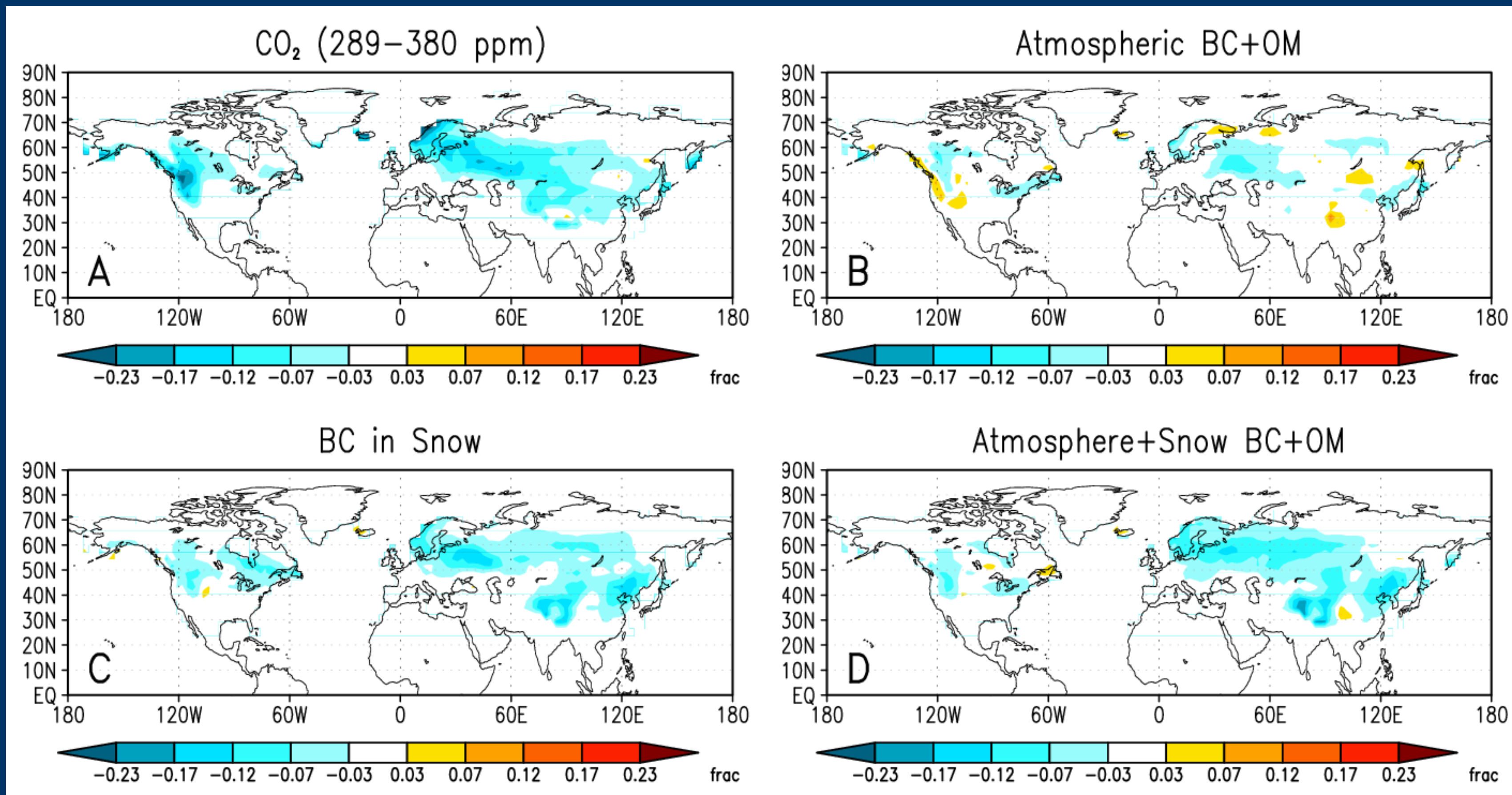
- Hemispheric solar energy incident on land snowpack peaks in March-May
  - Time of maximum albedo feedback (*Hall and Qu*, 2006)
- Incident flux on sea-ice peaks in May-June

How do different forcing agents influence spring snow cover?



Equilibrium changes in spring snow cover

- NCAR Community Atmosphere Model 3.1
  - BC+OM emissions from *Bond et al.* (2004)



- Eurasian springtime snow loss from BC+OM is comparable to that from CO_2
- Large snow losses simulated with BC in snow, but not with BC+OM exclusively in atmosphere

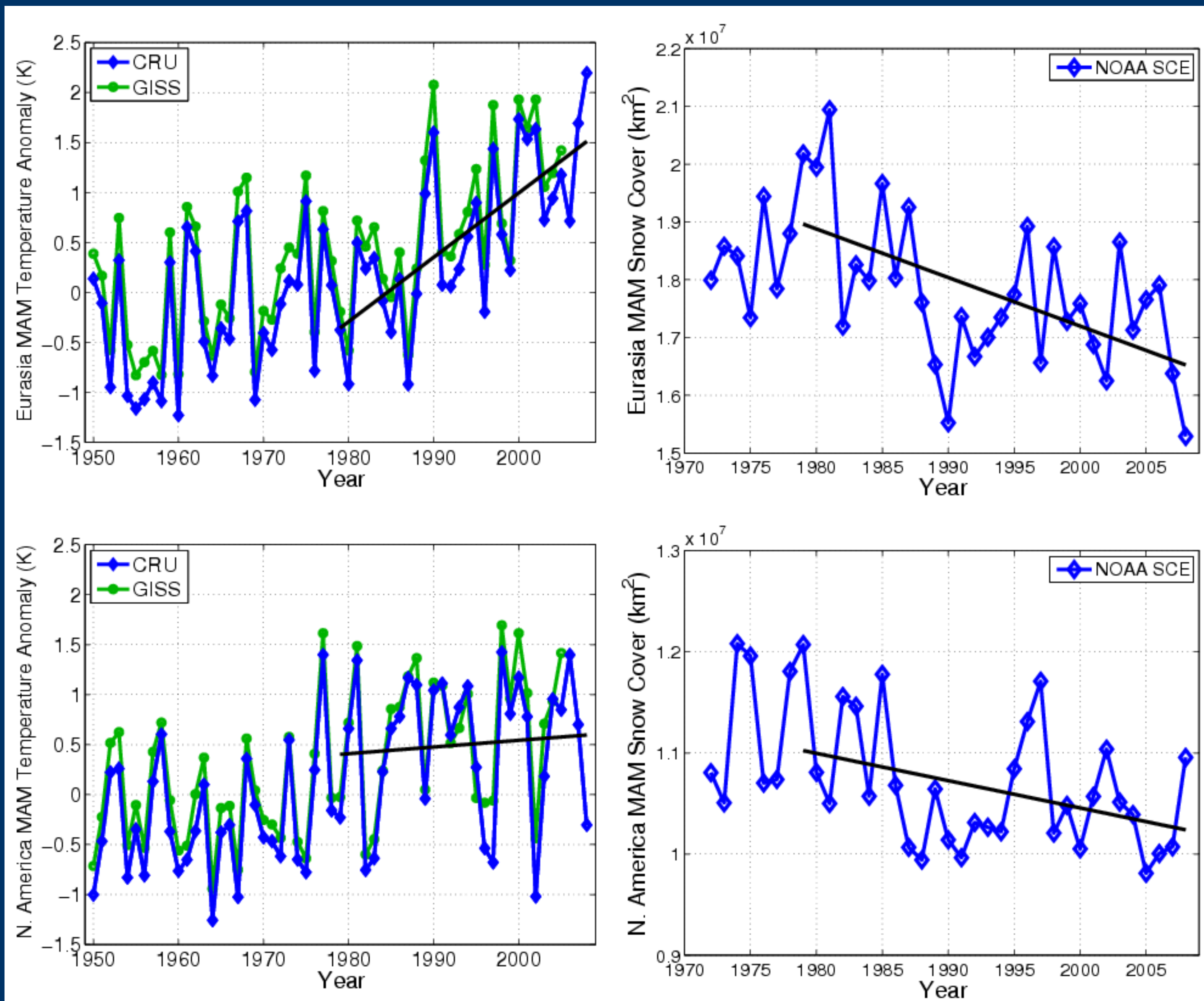
Observed springtime climate trends

Temperature

Snow cover

Eurasia

North America



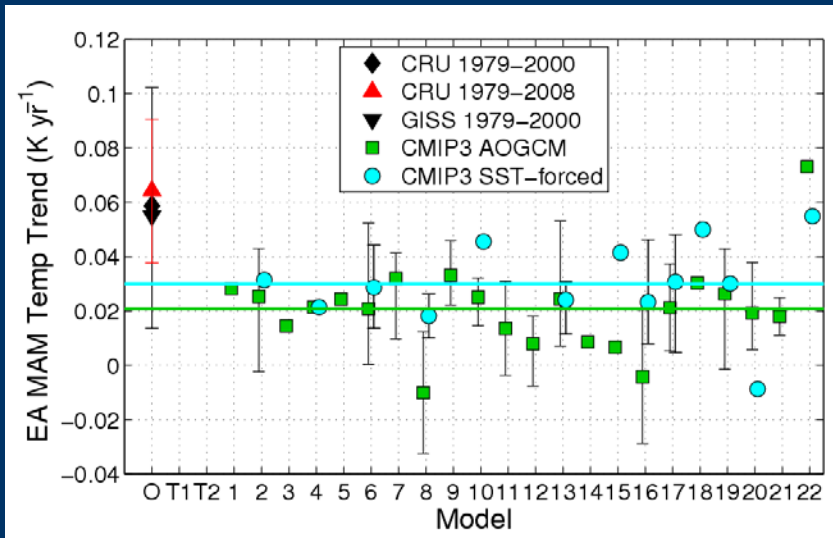
- 1979-2008 warming rate over springtime Eurasia is +0.64°C/decade, much smaller over N. America
- Spring snow cover losses:
  - Eurasia: 14%
  - North America: 7%

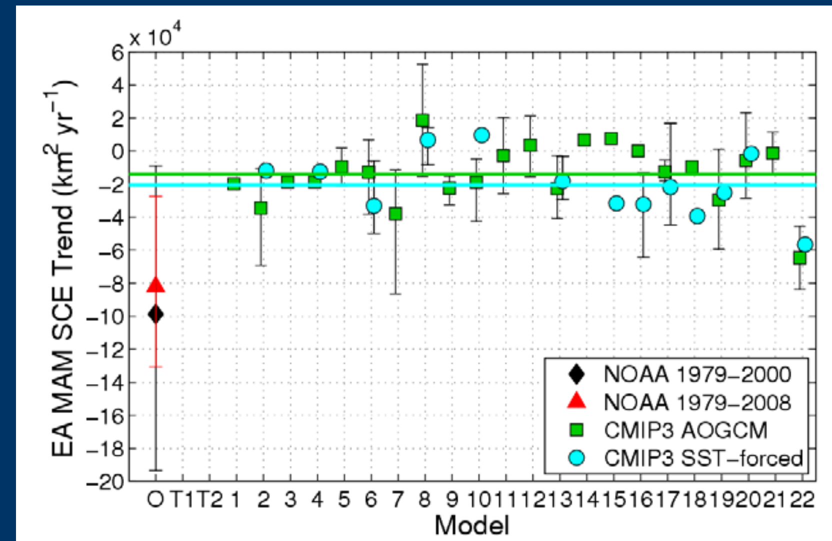
1979-2000 springtime hindcasts from CMIP3

Temperature trends

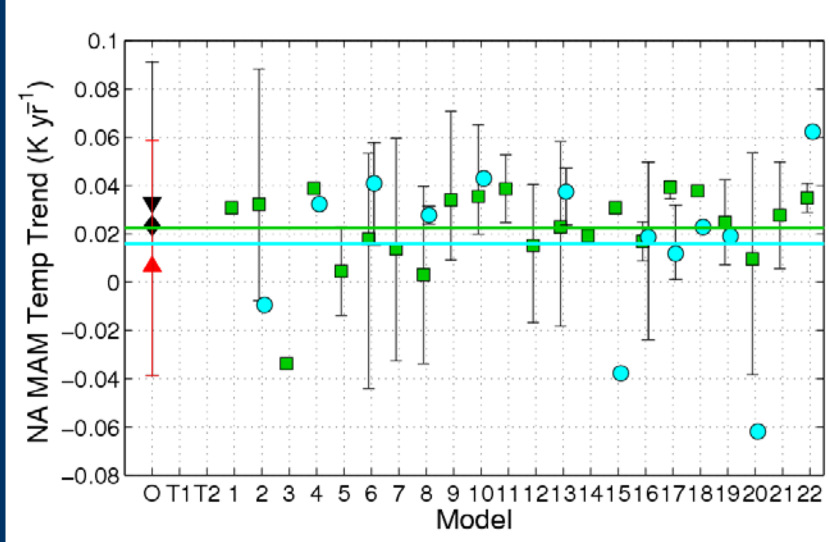
Snow cover trends

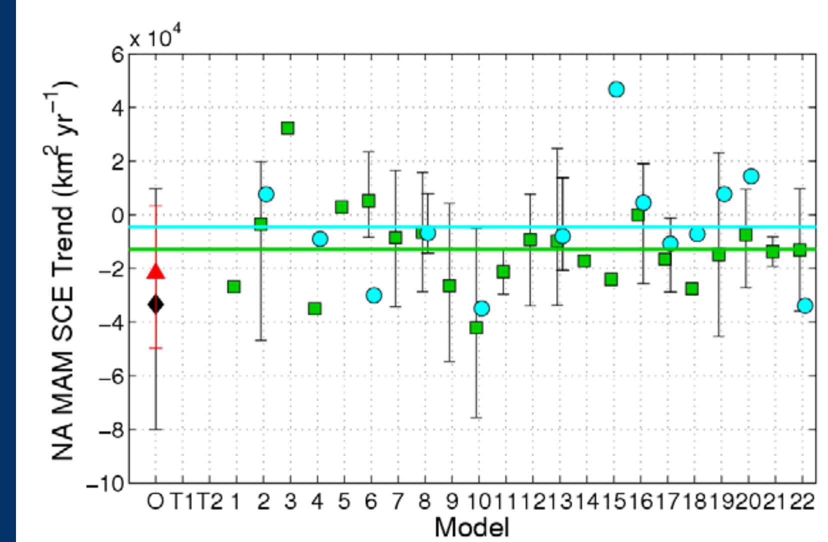
Eurasia





North America

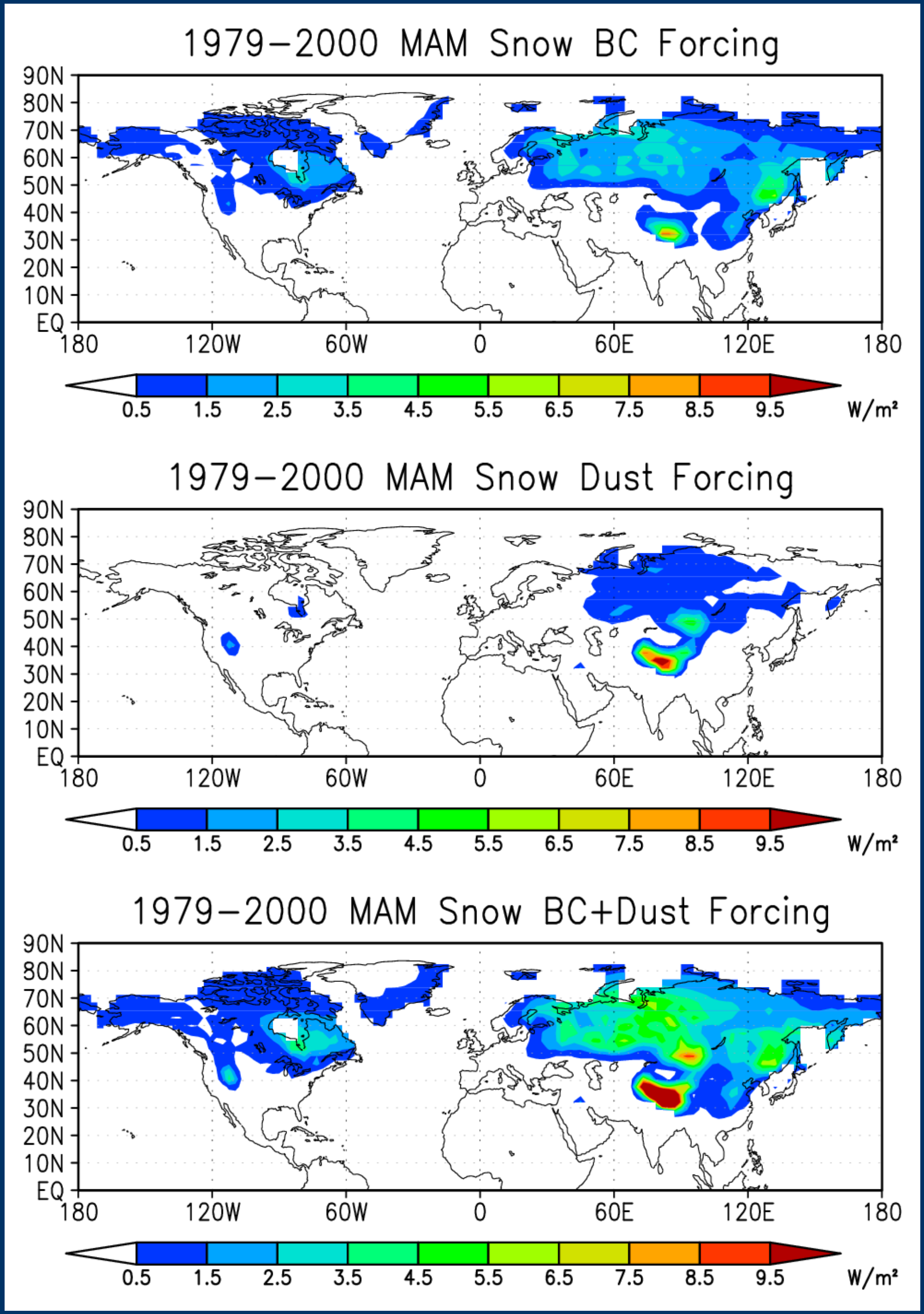




Green: CMIP3 coupled atmosphere-ocean simulations
Light blue: CMIP3 forced-SST (AMIP) simulations

Springtime forcing from BC and dust

- Snow-averaged surface forcings:
  - Eurasia: +3.9 W/m^2
  - North America: +1.2 W/m^2
  - Not included in IPCC simulations
- BC emissions from Asia increased from ~1.6-2.6 Tg/yr during 1980-2000 (*Bond et al.*, 2007)



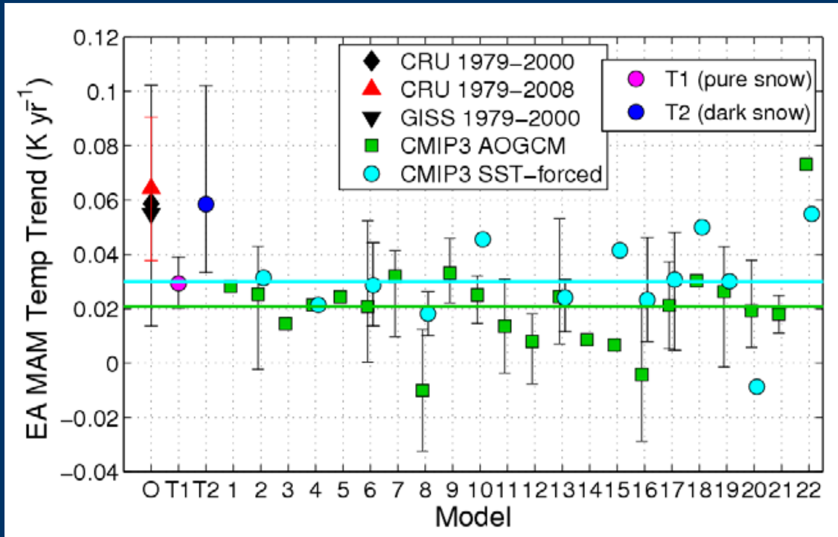
NCAR CAM model coupled with SNICAR

Flanner et. al. (2009), *Atmos. Chem. Phys.*

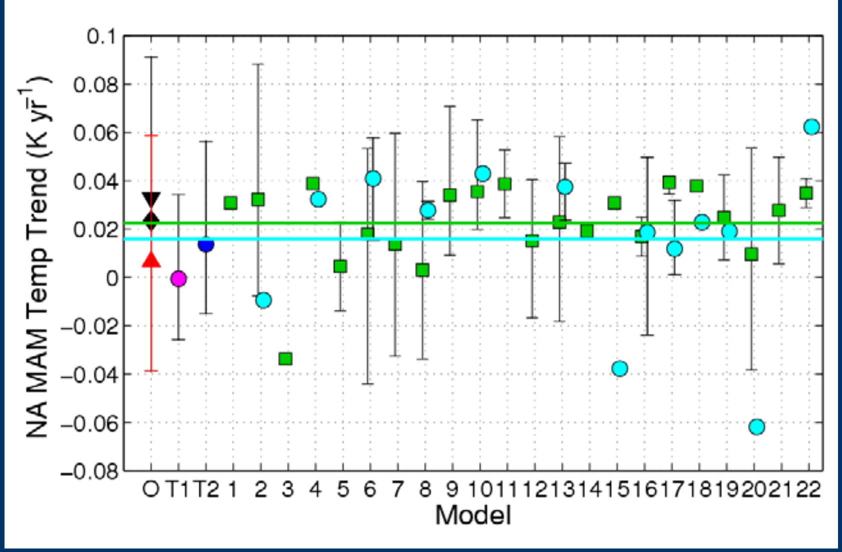
1979-2000 springtime hindcasts from CMIP3

Temperature trends

Eurasia

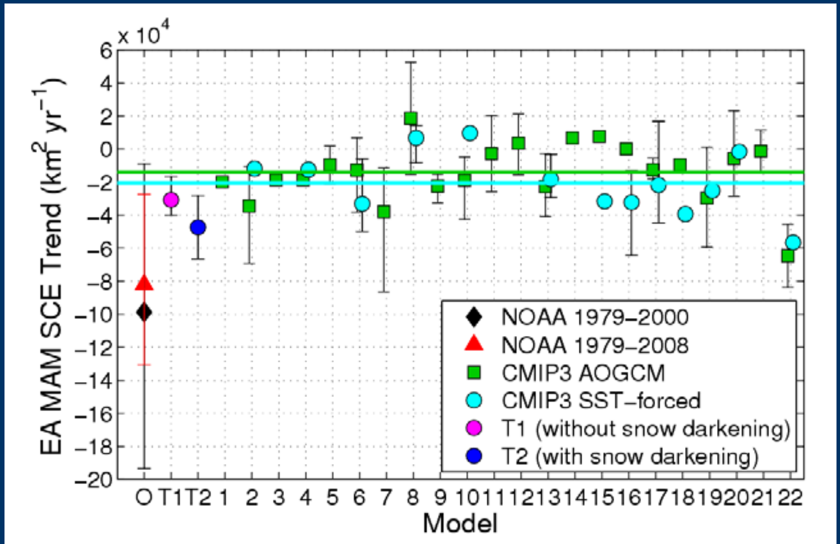


North America

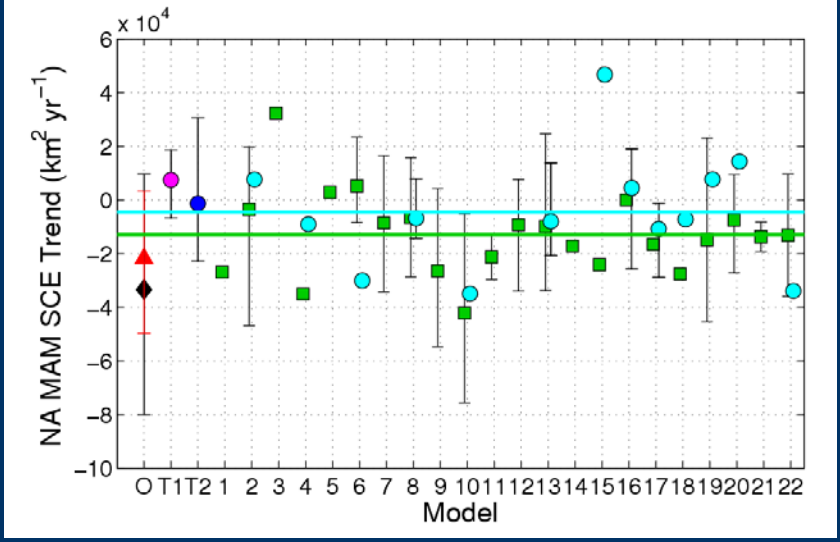


Snow cover trends

Eurasia

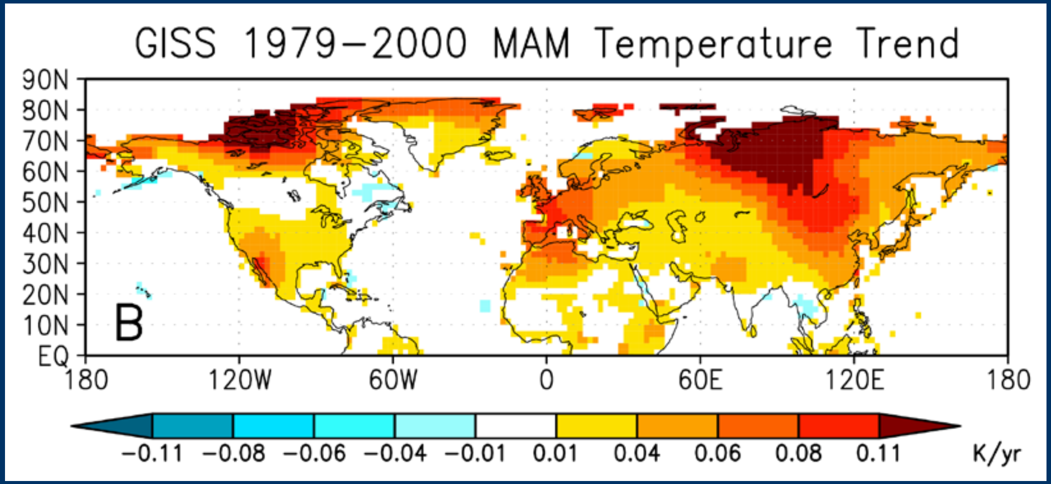


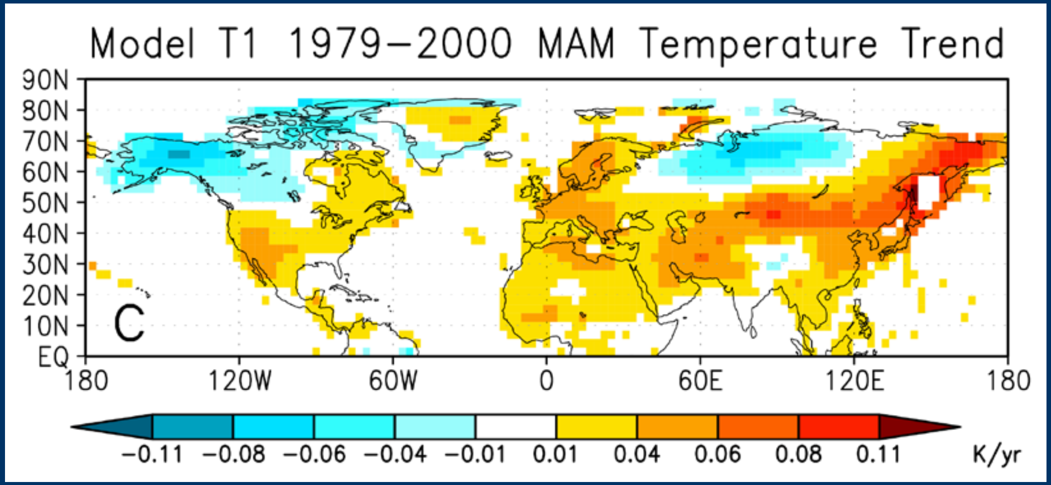
North America

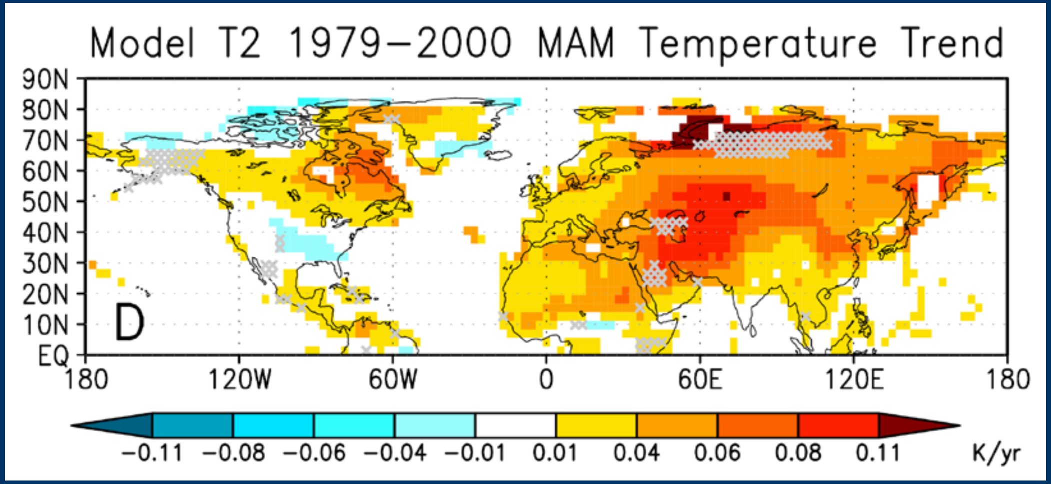


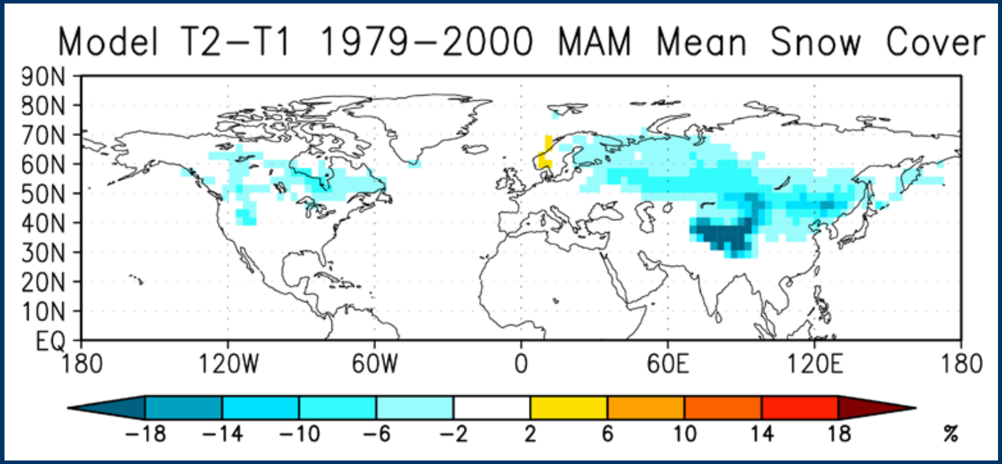
Green: CMIP3 coupled atmosphere-ocean simulations
Light blue: CMIP3 forced-SST (AMIP) simulations
Purple: CAM/SNICAR without snow darkening
Dark Blue: CAM/SNICAR with snow darkening

Spatial patterns of temperature trends









Conclusions

- Nearly all aerosol mixtures exert a positive TOA radiative forcing over snow and ice
- "Darkening" from modest amounts of deposited particles outweighs "dimming" from suspended particles: Net positive surface forcing
- Springtime climate is uniquely susceptible to feedback: Maximum snow+insolation
- Eurasian spring snow cover responds as strongly to current BC+OM emissions as to 90 ppm ΔCO_2
- Transient snow darkening may explain some of model-observation discrepancy in Eurasian land warming trends
  - Biases in snow cover trend persist