The large scale climate responses to the Chicxulub Impact

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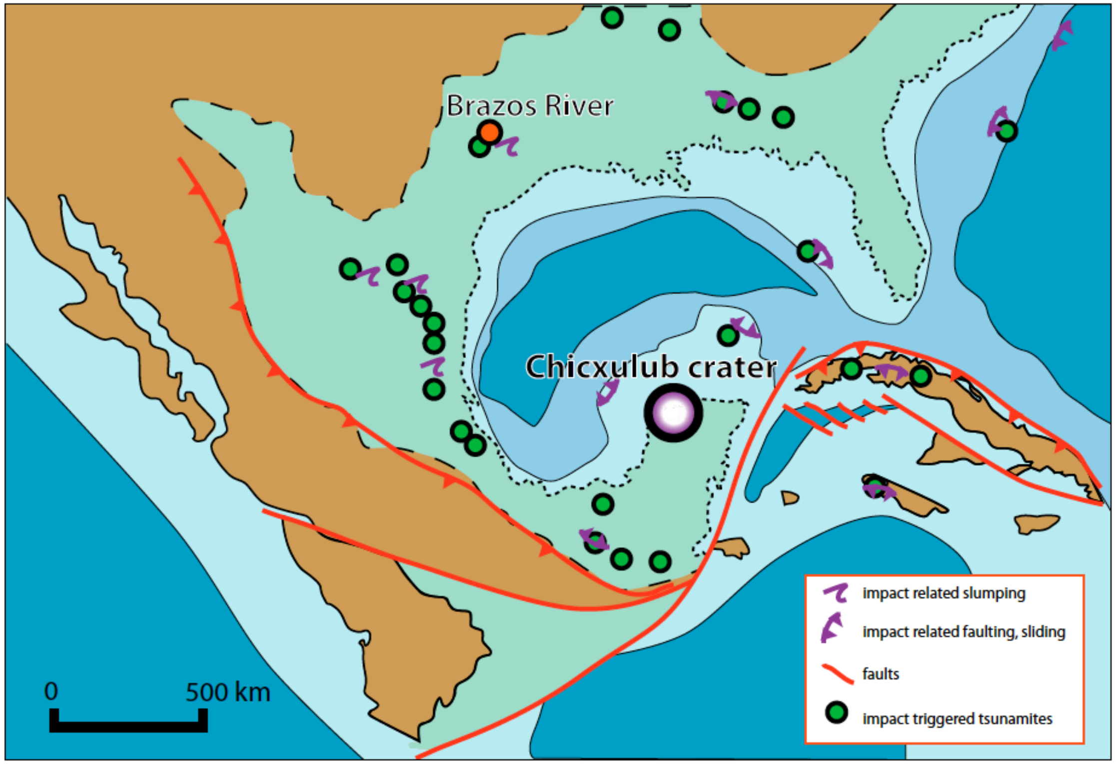
Illustration: Donald E. Davis, 1994

Background: Chicxulub Impact

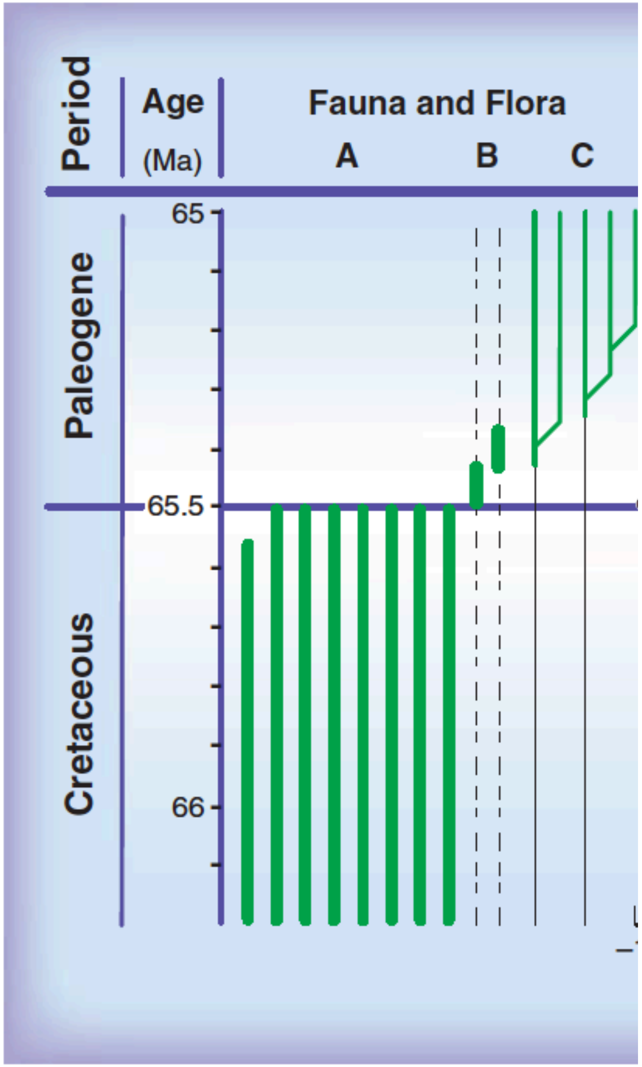
- **Time**: 66 Ma
- **Size**: 10 km
- **Crater:** 180 km
- **Where**: Yucatan Peninsula



Vellekoop et al. (2014)

Background: Effects

- Huge blast
- Heat and fire due to ejecta
- Mega tsunamis
- Triggering of earthquakes
- Emissions of soot, dust, GHGs, etc..
  - Blocking of sunlight
  - Destruction of O_3
- Mass extinction

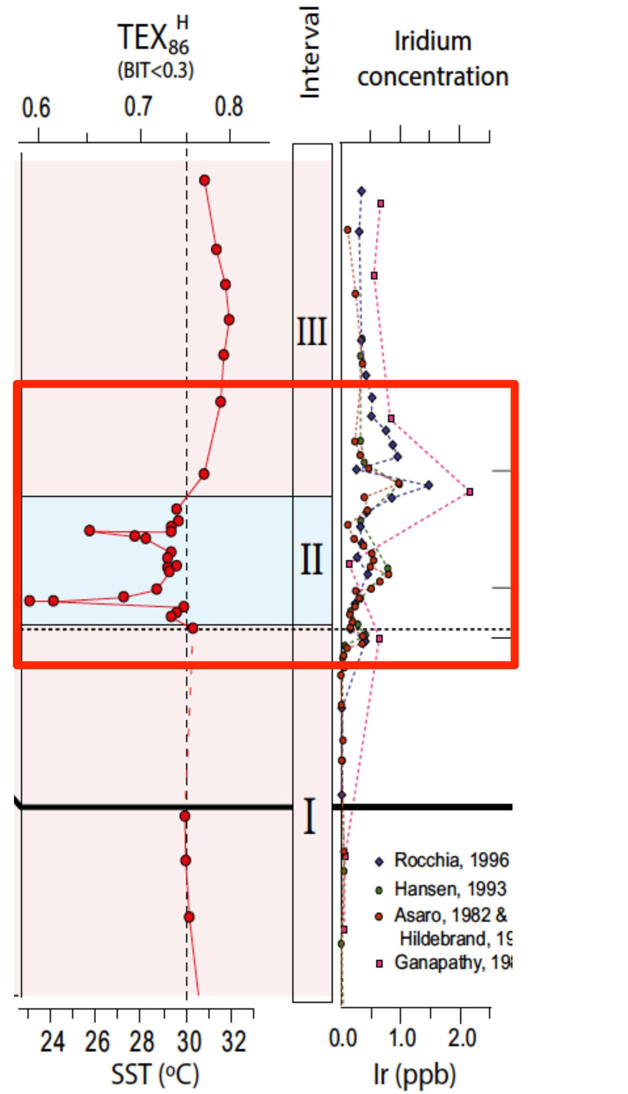


Toon et al. (1998)

Schulte et al. (2010)

Background: Temp / CO_2 Records

- Potential for rapid cooling >7°C (Vellekoop et al. (2014)
- Possible CO_2 increase from 500->2,300 ppm (Beerling et al., 2002)
  - Vaporized carbonate and organic matter burning



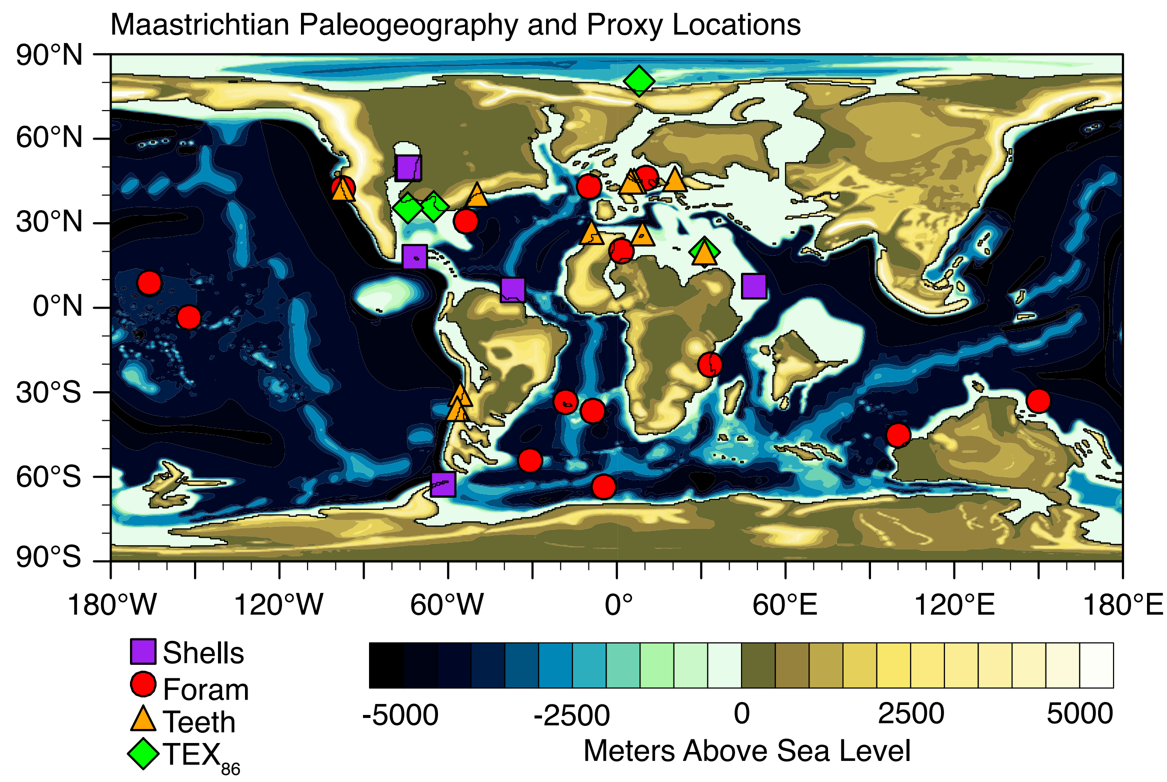
Vellekoop et al. (2014)

Previous Work

- Present-day climate response to 1 km and 10 km impacts with WACCM4
  - Focus on soot forcing
  - *Climatic Effects of Medium-Sized Asteroid Impacts on Land* (Bardeen et al., 2015)
  - *Abrupt Climate Change Caused by Global Fires from a Large Meteor Impact* (Toon et al., 2015)

Setup: Model Spin-up

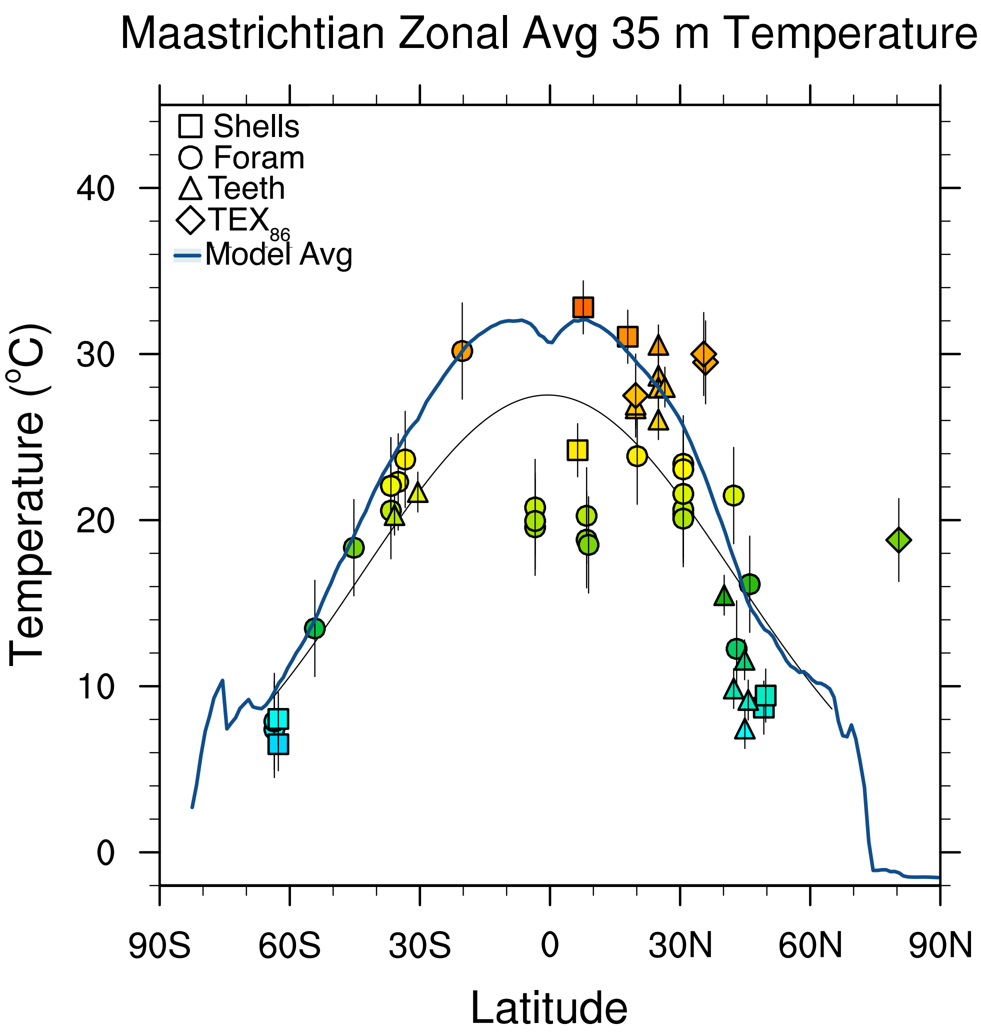
- **Models:**
  - CCSM4–CAM4, POP2, CLM4, CICE4
    - 1.9°x2.5° / ~1°
- **Configuration:**
  - Maastichtian (72-66 Ma) paleogeography
  - 560 ppm CO_2
  - Adjusted solar constants
  - 2,200 years run



Markwick Getech Plc.

Setup: Equilibrium Cretaceous

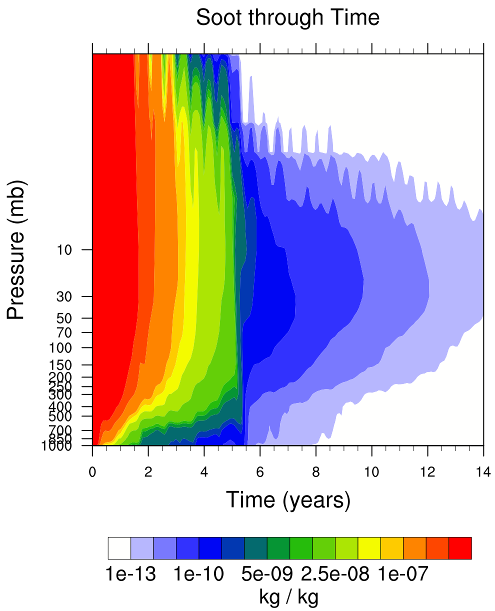
- Climate:
  - Global surface temp: 22.3°C
  - Some sea ice
  - South Pacific deep water formation
- General agreement between model and SST proxies

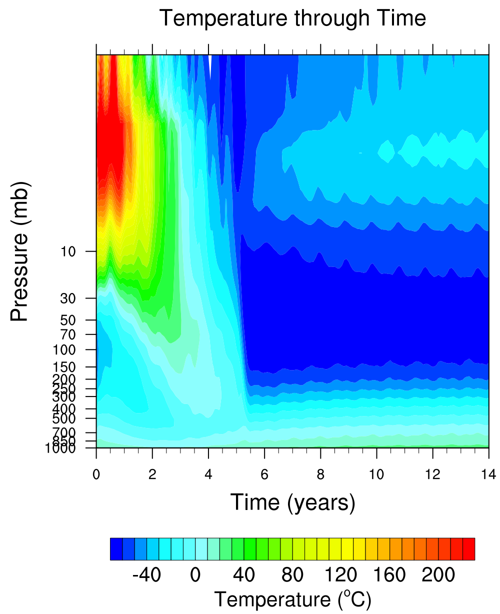


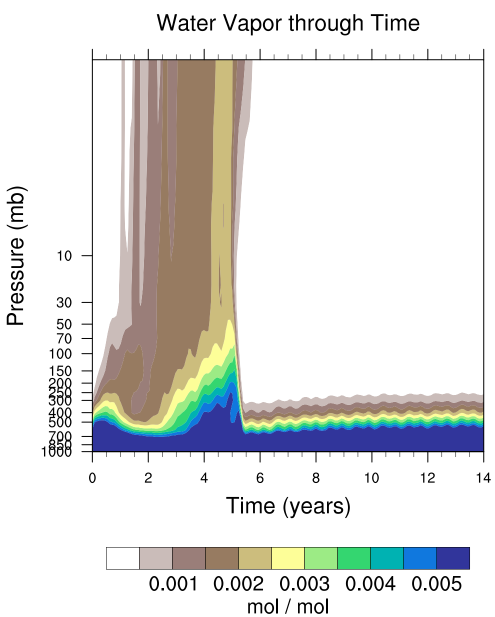
Setup: Perturbation Experiment

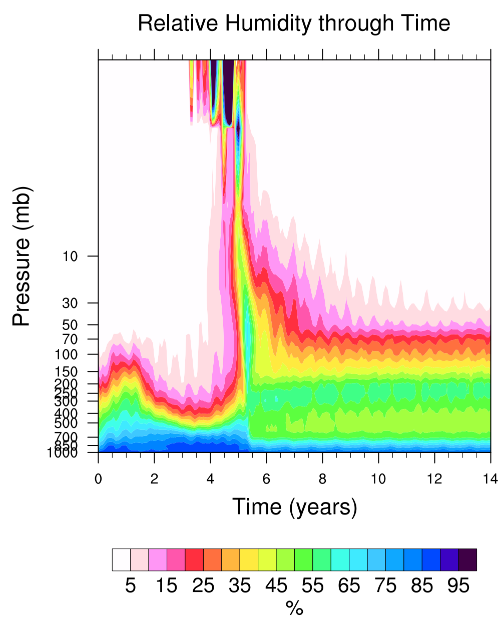
- **Models:**
  - WACCM4
    - Coupled chemistry
    - 26 levels -> 66 levels
    - Community Aerosol and Radiation Model for Atmospheres for impact soot aerosols (Bardeen et al., 2016, *in prep*)
- **Configuration:**
  - Pre-impact: 15-year run
    - CCSM4 restarts
  - Post-impact: 15-year run
    - 70,000 Tg global soot release in 1 day (Wolback et al. 1988; Toon et al;, 2016, ACP-D)
    - CO_2 increase to 2,000 ppm

Soot Response



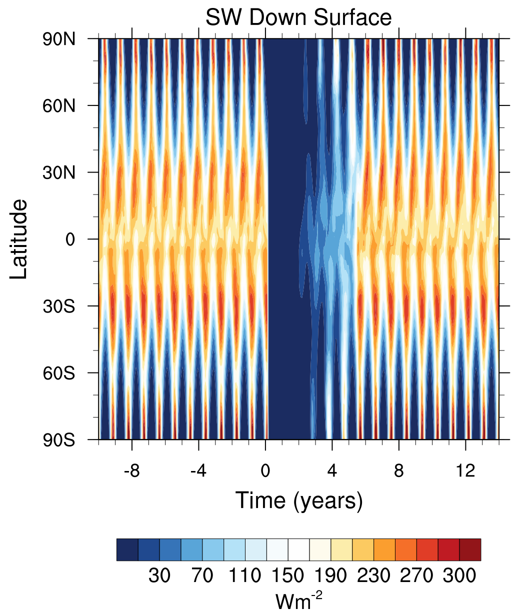




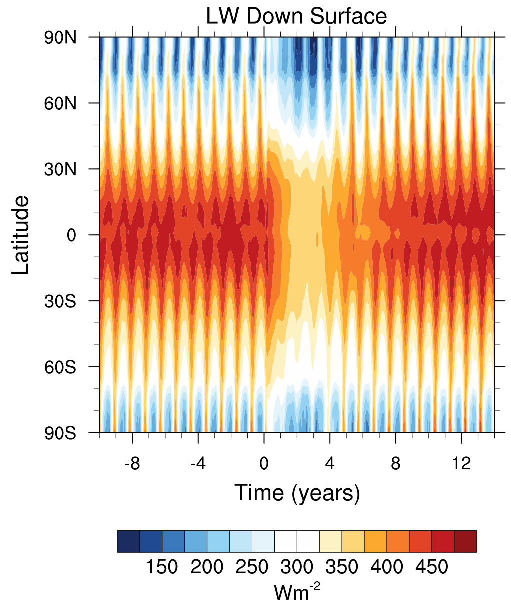


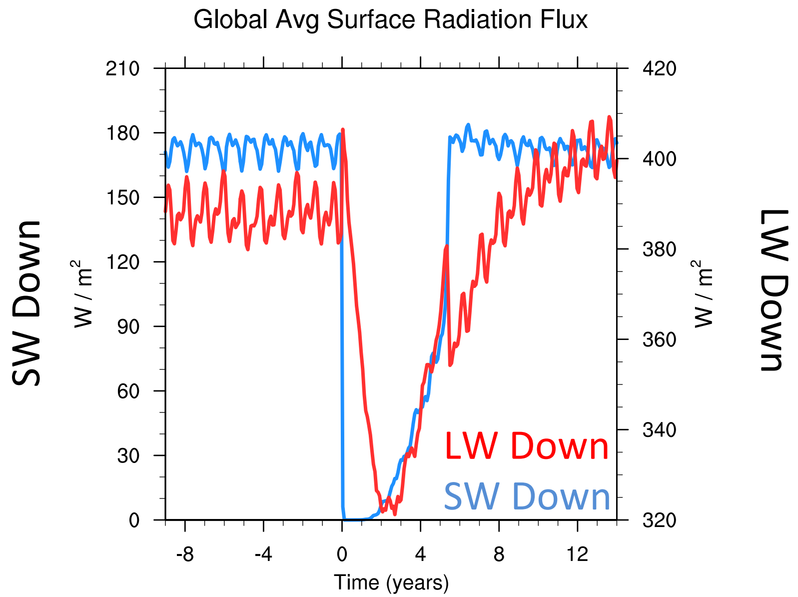
- Soot fills the atmosphere
- Upper atmosphere warms and inversions break down
- Large increase in upper atmosphere water vapor
- Cooling causes condensation and wet removal

Radiation Response

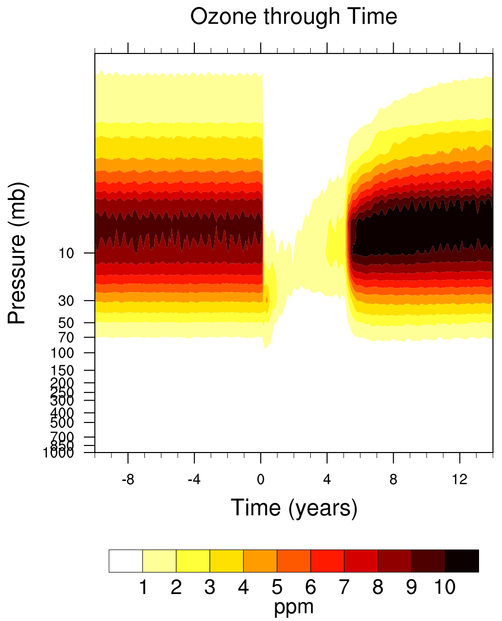


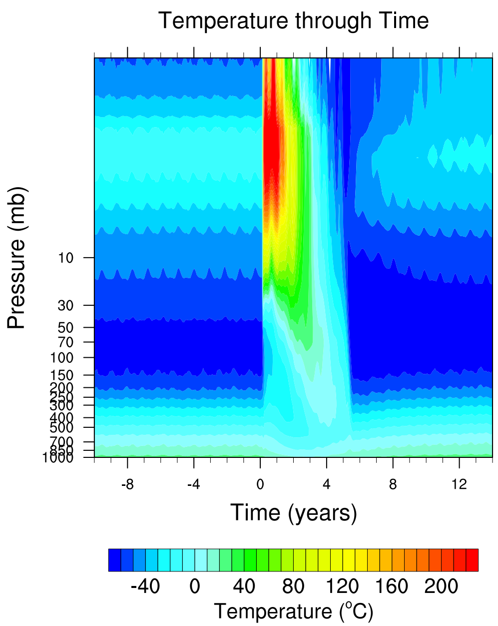
- Soot blocks SW from reaching the surface for 2 years
- Soot blocks escape of LW
  - Reduces amount of cooling





Ozone Response

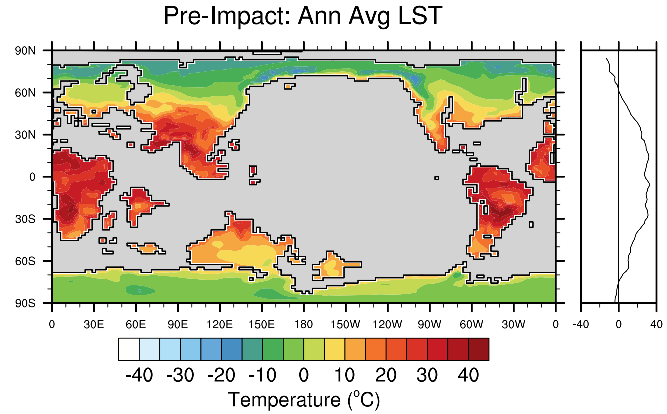


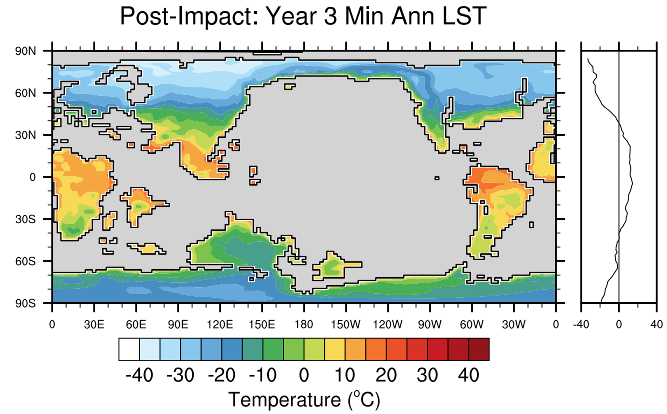


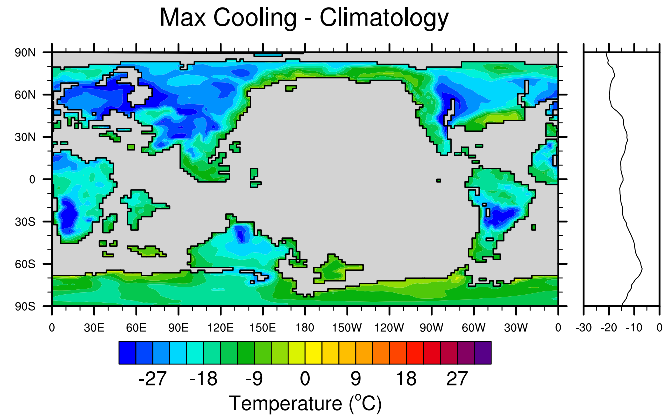
- Soot and water vapor in upper atmosphere destroy O_3 layer
- Soot also blocks most UV radiation
- Rapid recovery of O_3 after soot removal
- Additional CO_2 cools the upper atmosphere, leading to more O_3 formation

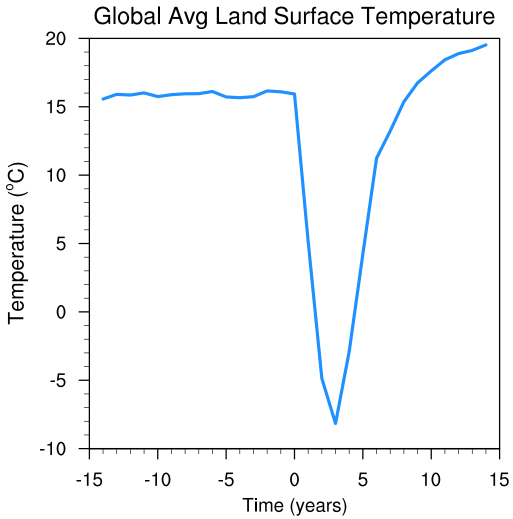
Temperature Response

- Land surface responds rapidly
  - Minimum in year 3
    - ~25°C of total cooling
  - Pre-impact levels by year 8



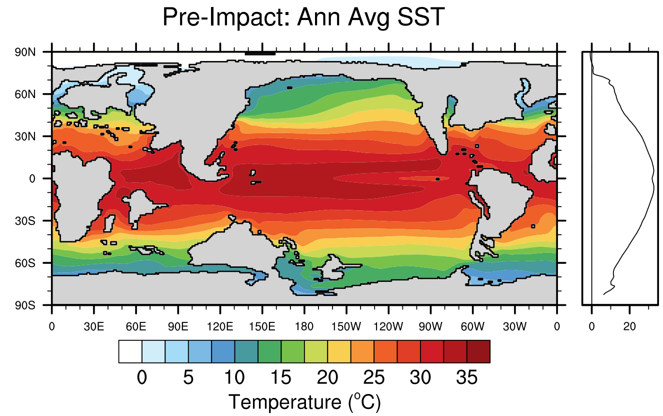


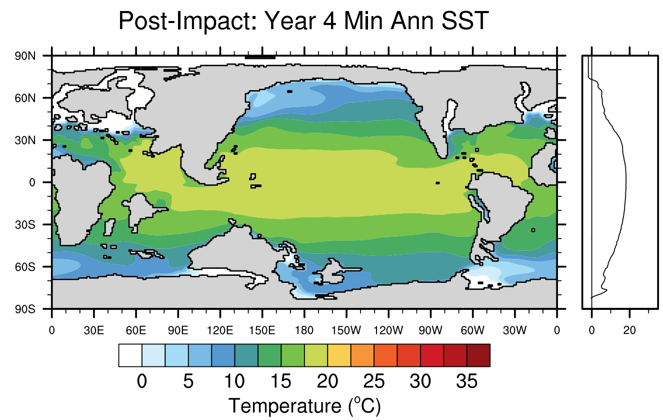


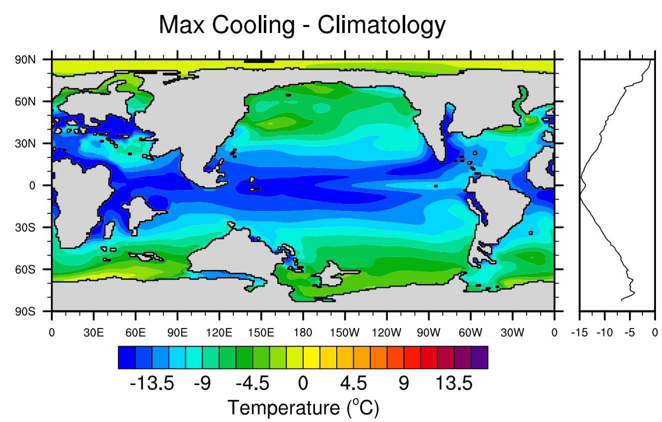


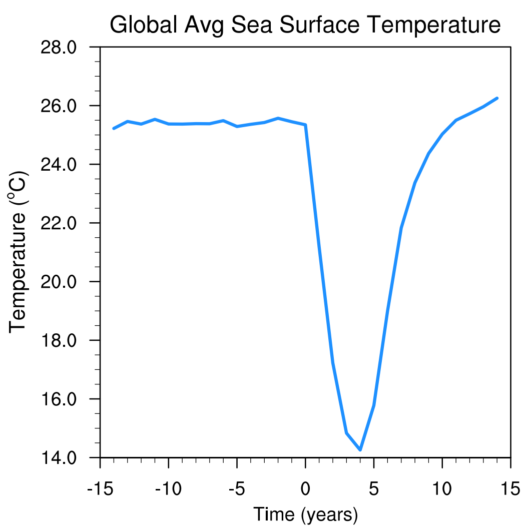
Temperature Response

- Ocean surface responds less
  - Minimum in year 4
    - ~11°C of total cooling
  - Pre-impact levels by year 11

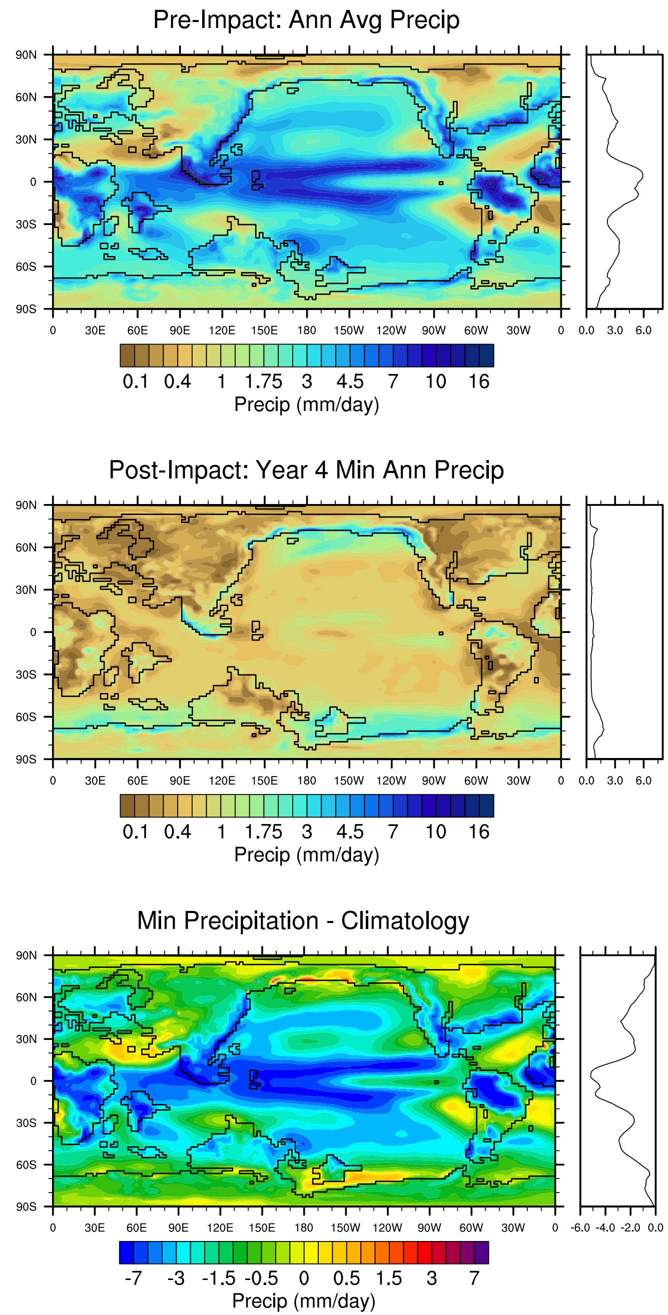




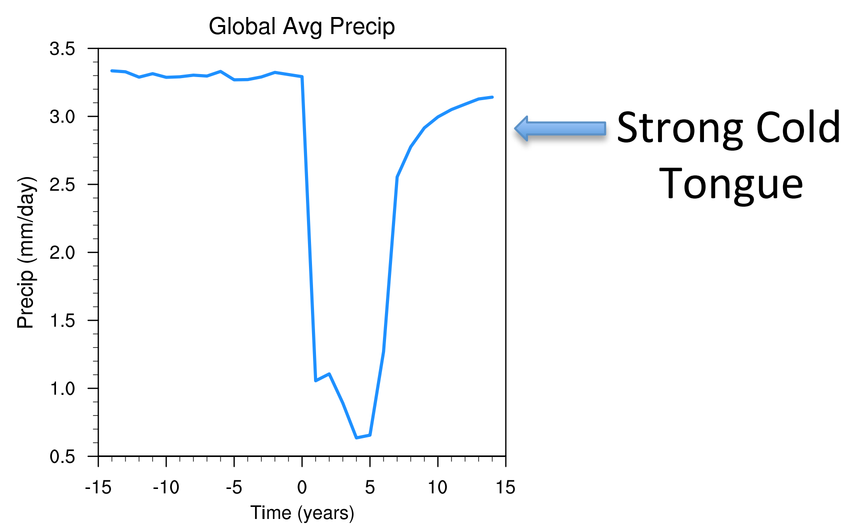


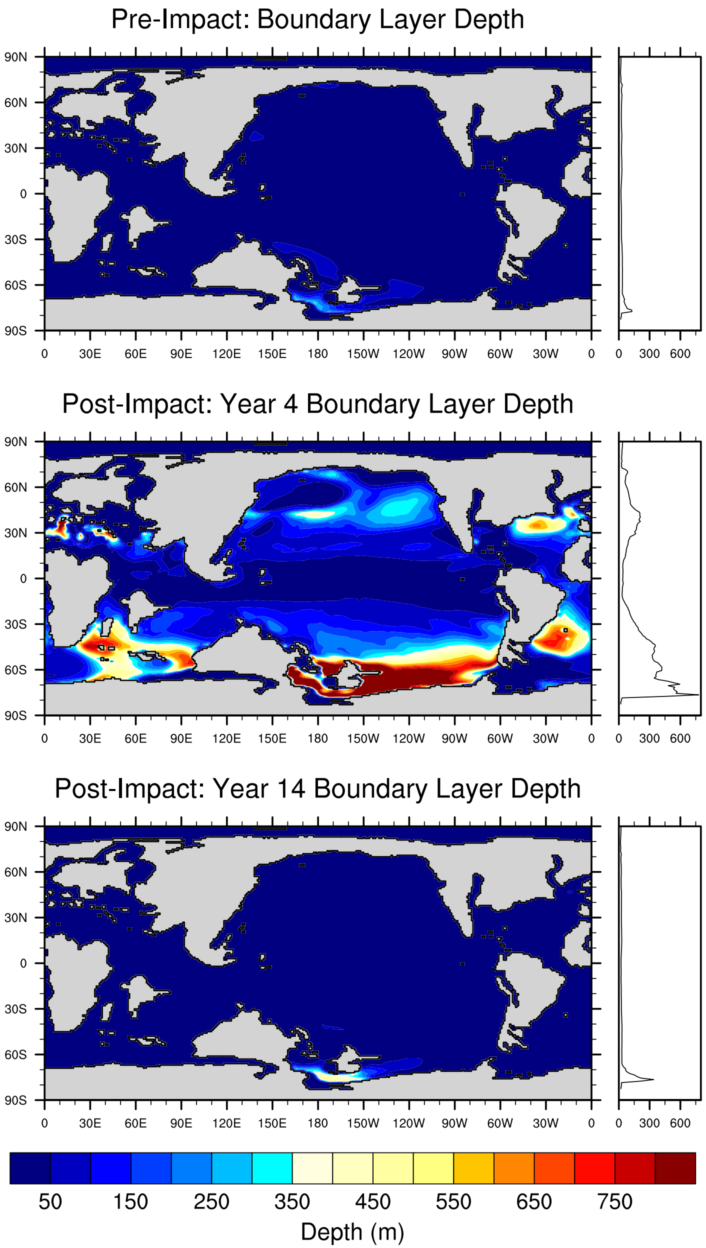


Precipitation Response



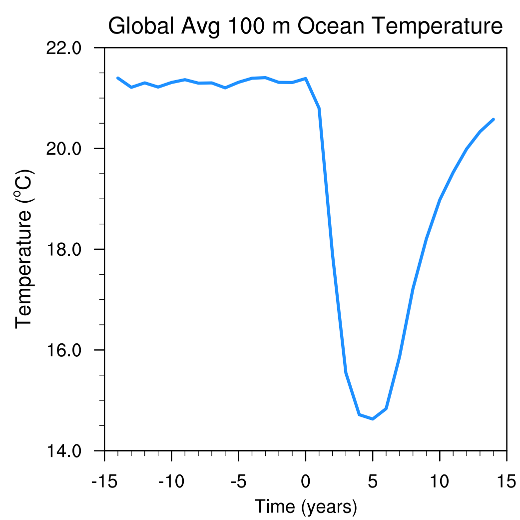
- Stability increases post-impact
- Convective precip slows down
- Slight precip increase where SST cooling muted



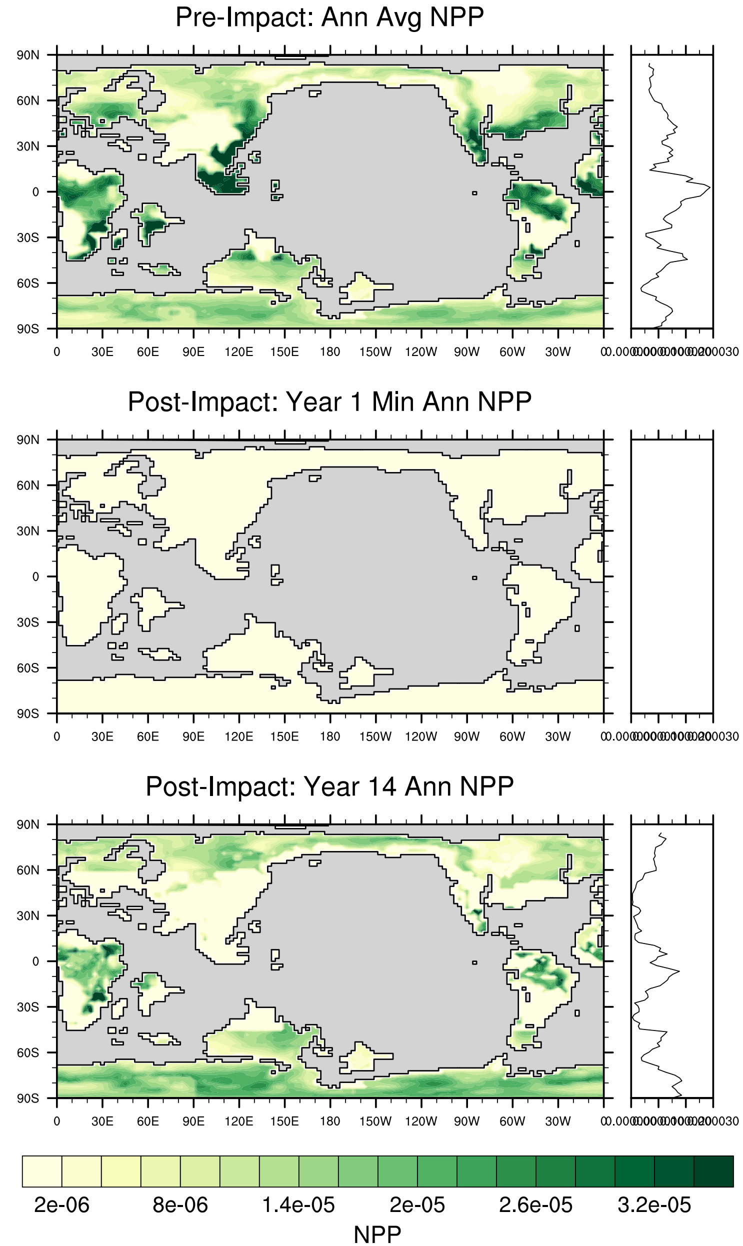


Ocean Overturning

- Extreme increase in deep-water formation
- Rapid cooling followed by rapid warming increases stratification



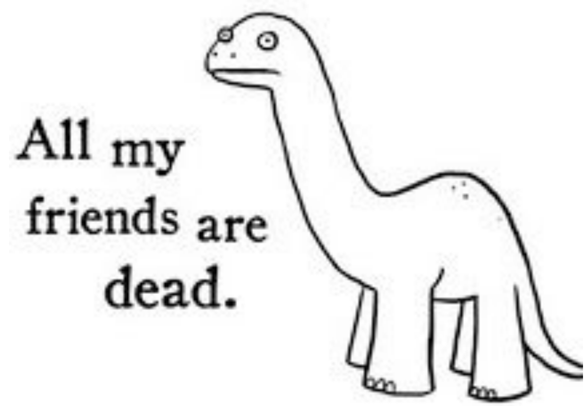
Vegetation



- Lack of sunlight stops net primary productivity for several years
- Low latitude vegetation does not recover after 15 years
- High latitude vegetation increases due to warm /wet temperatures after 15 years

Conclusions

- Killers:
  - Blocked SW
  - Cold temperatures
  - Low precipitation
  - O_3 destruction
- Saviors:
  - Trapped LW
  - High relative humidity
  - Blocked UV



Future Work

- Test other potential emissions:
  - Dust
  - Water Vapor
  - Sulfur Oxides
  - Halogens
- Improve vegetation response
- Turn on BGC model?
- Run for 1000+ years

Thanks for Listening!
Questions?

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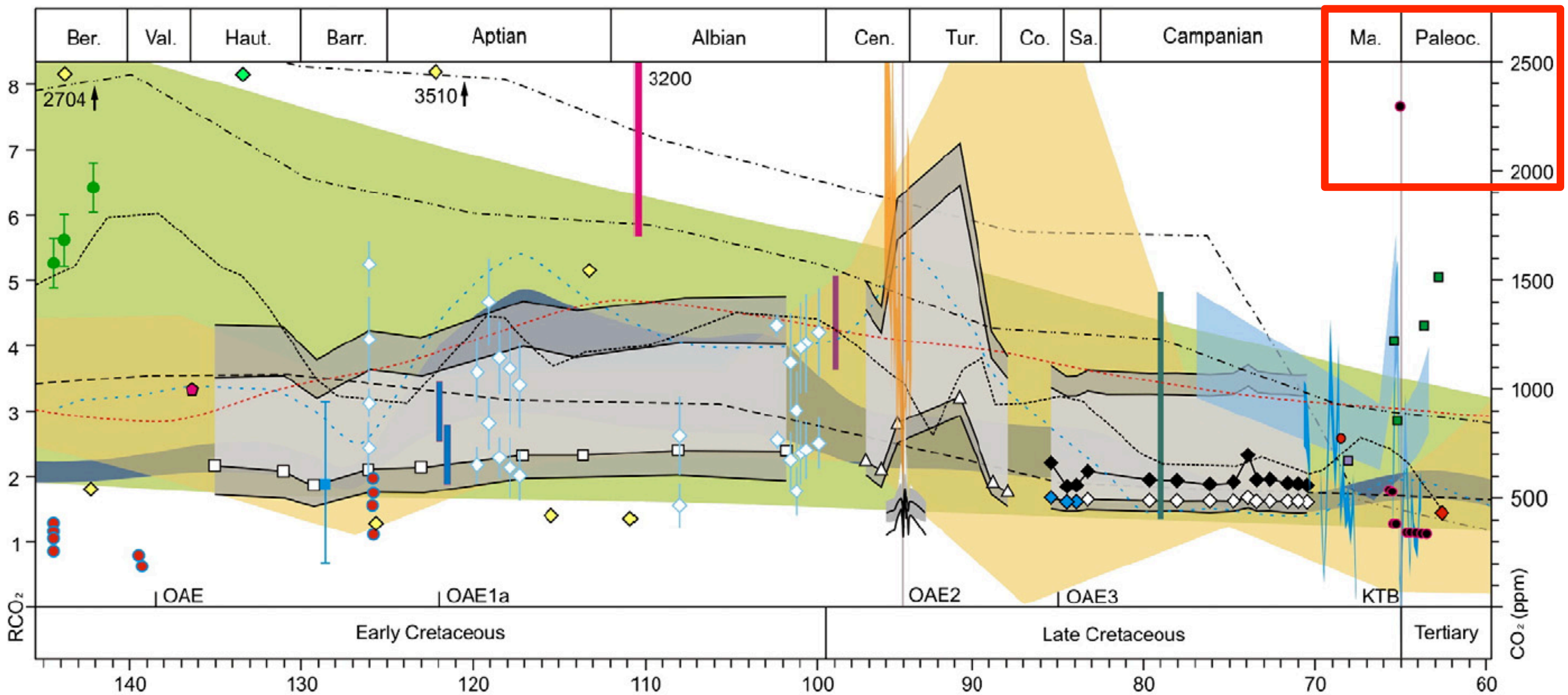
Background: CO_2 Record

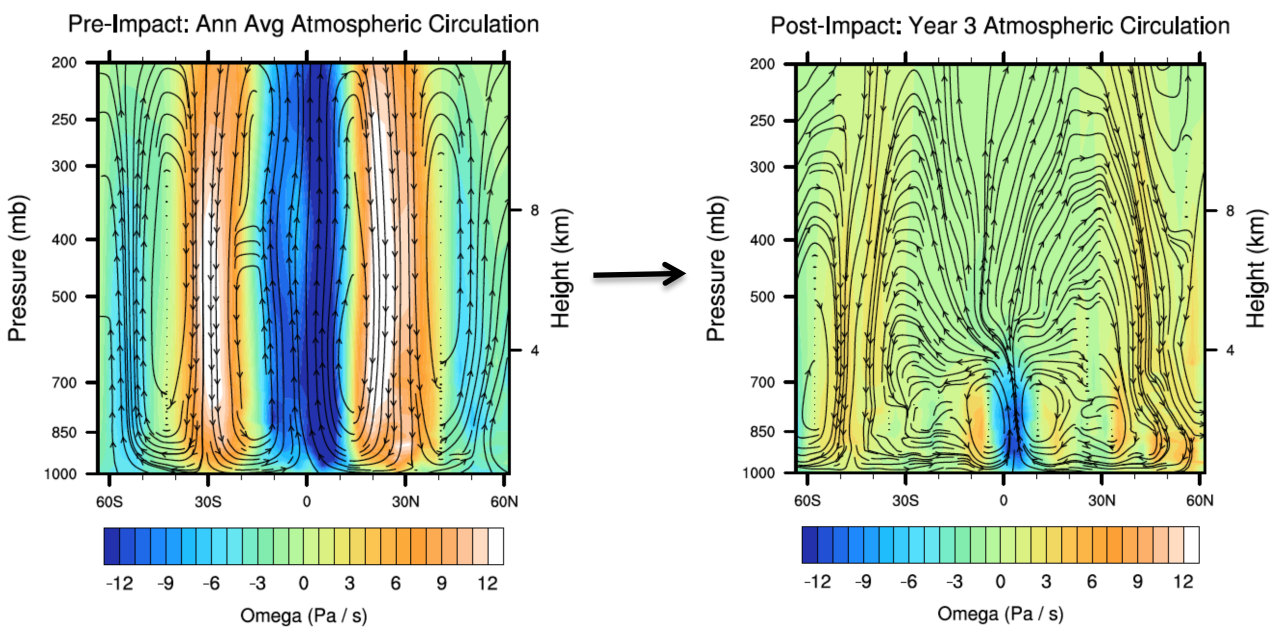
- Vaporized carbonate and organic matter burning could release CO_2



Wang et al. (2014)

Atmospheric Circulation

- Hadley Cells becomes weak and merges with the Ferrel Cells
- Weak uplift near the equator
- Weak subsidence at ~15°N/S and ~50°N/S



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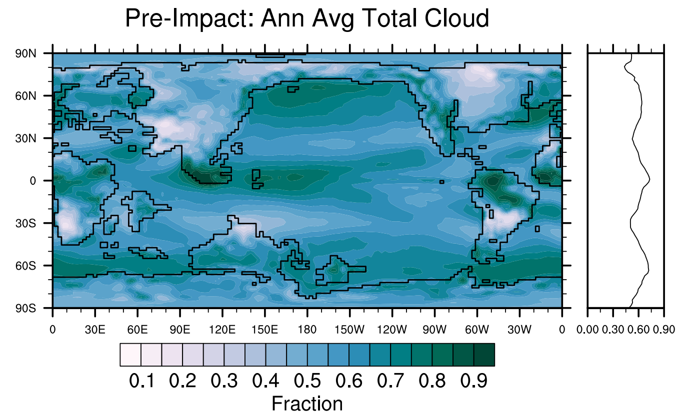
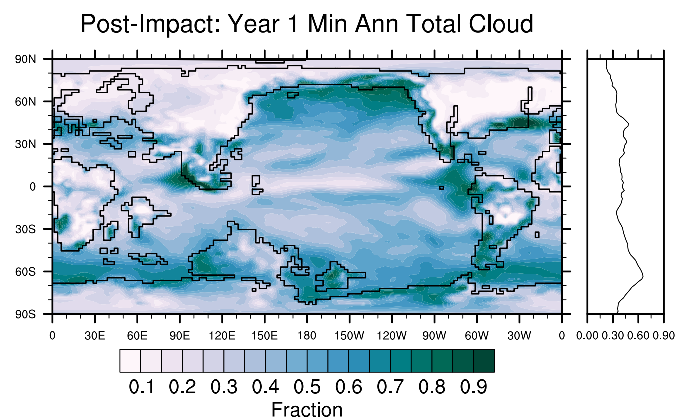
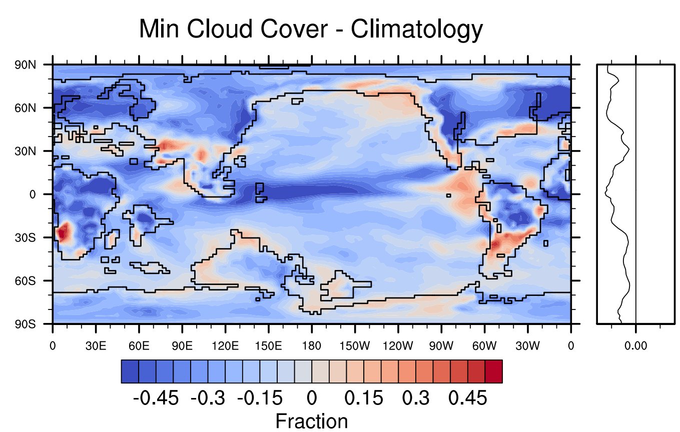
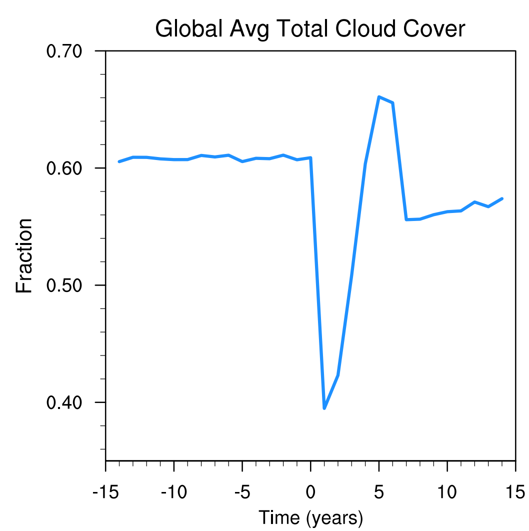
Cloud Response

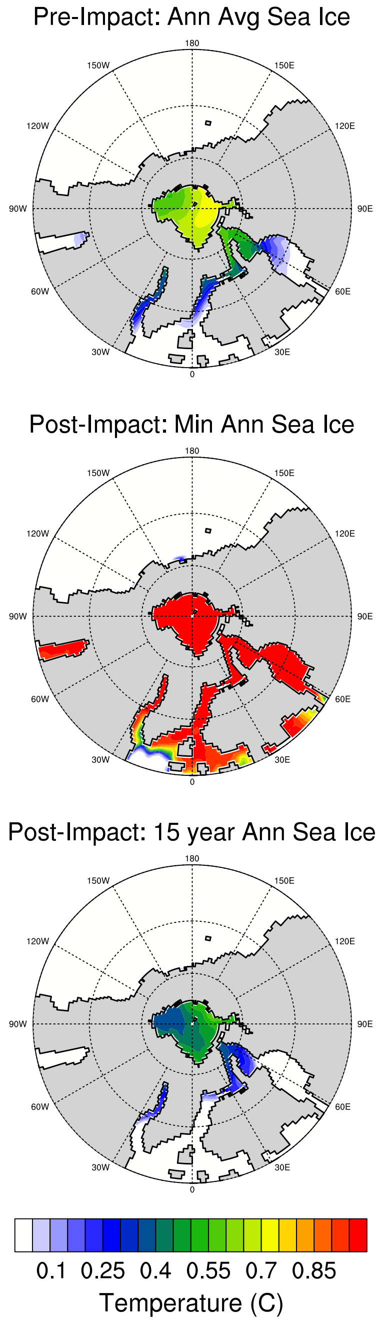
- Initial loss of cloud cover
- Rapid Response – overshoot
  - Formation of high level clouds











Sea Ice Response

- Significant increase in perennial sea ice where circulation is poor and seas are shallow
  - Expansion to mid-latitudes!
- In open ocean, increased poleward heat transport prevents additional sea ice formation

Moisture Response

- Cooling and low light results in high relative humidity and little surface evaporation
- Soil moisture does not change significantly