Climate outcome of combined mitigation and geoengineering scenarios between 2040 and 2200

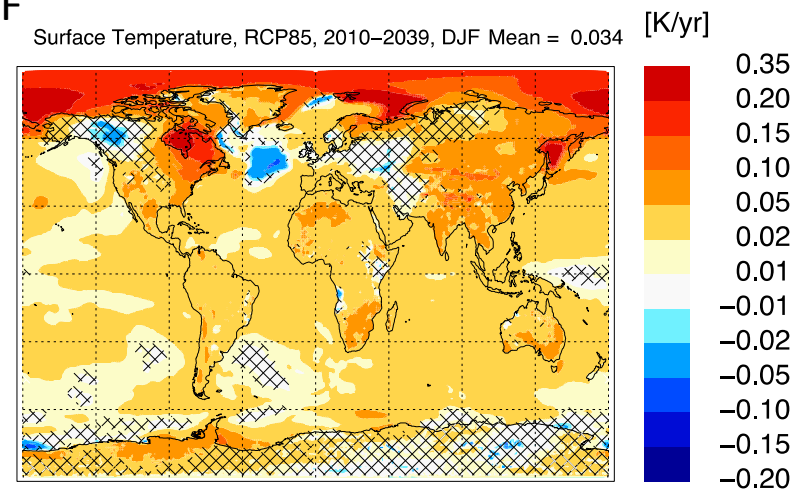
Simone Tilmes, Ben Sanderson, Brian O'Neill

Scenario: Business as usual until 2040.

What is required to stabilize the climate starting in 2040?

DJF

2010-2039



2040-2079

Surface temperature trends in RCP8.5 are strongly increasing after 2040

Model Experiments

RCP8.5
Overshoot
RPC4.5
RCP2.6

Integrated Science Assessment Model (ISAM)

- Derived concentrations for overshoot scenario
- Includes maximum decarbonization

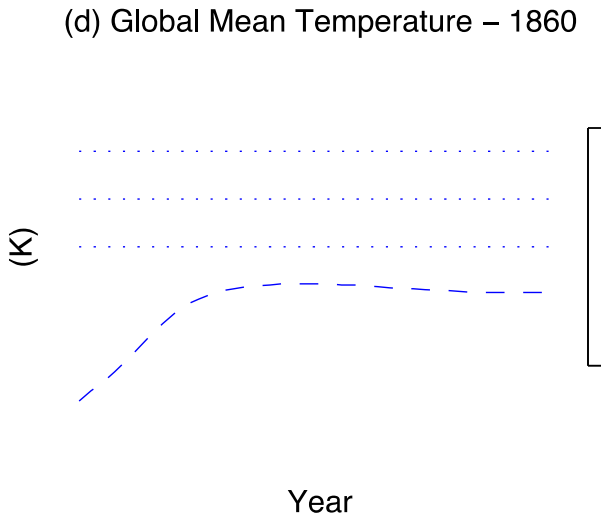
CESM1.2

- LE CESM1.2 model tag, 1deg horizontal resolution
- Branch run from 1st LE RCP8.5
- Apply new lower boundary conditions
- Include sulfate aerosol forcing file for solar dimming experiments

Simulations:

Years 2040-2200, 2 ensemble members each

- Overshoot (OS)
- Overshoot plus sulfate aerosol layer to reduce temperature to about 2.5deg above pre-industrial (Geo2.5)
- Overshoot plus sulfate aerosol forcing to reduce temperature to about 2.0deg above pre-industrial (Geo2.0) -> comparable to RCP2.6 scenario



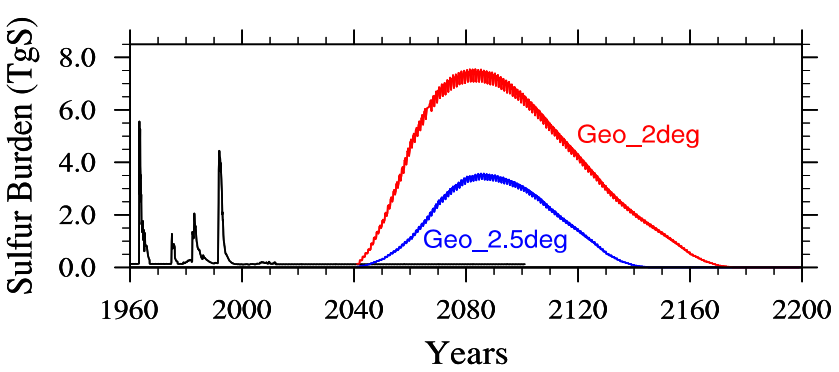
Stratospheric Aerosol Distribution

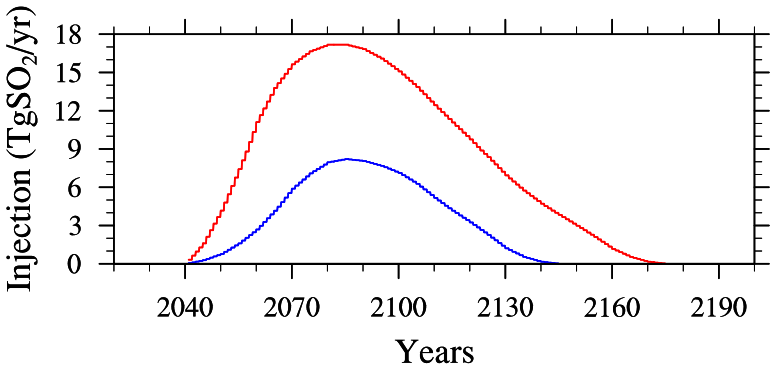
Stratospheric aerosol distribution derived from ECHAM model, injection is 8 $TgSO_2$/yr, produces a radiative forcing of about 1. W/m2.

Tilmes et al., 2015

Calculation of the radiative response to different fractions of the aerosol distribution, using a double radiation call in CESM

-> Scaling of the aerosol distribution to the required RF from the ISAM





Uncertainty of these values may lay around a factor of 2, other models show more effective impact of aerosols on RF -> less injection required.

CESM Results

Global Mean Surface Temperature

RCP8.5
Overshoot
Geo 2.5
Geo 2.0
RPC2.6

- Overshoot scenario was designed to achieve the goal of reaching maximum 3deg warming
- Geo 2.5 dimming was correctly calculated to stay at 2.5degree warming
- Geo 2.0 was slightly cooler than anticipated, however, very close to RCP 2.6!

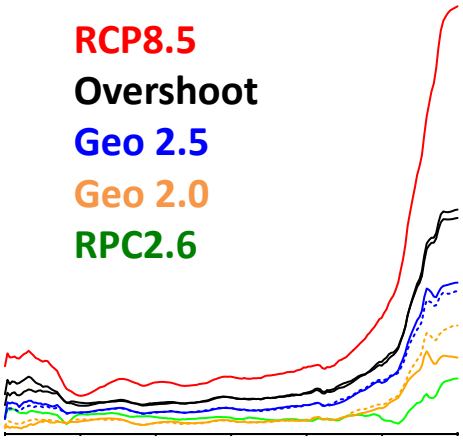
-> Combined strong mitigation, CDR, and SRM can result in keeping temperatures from going over certain limits

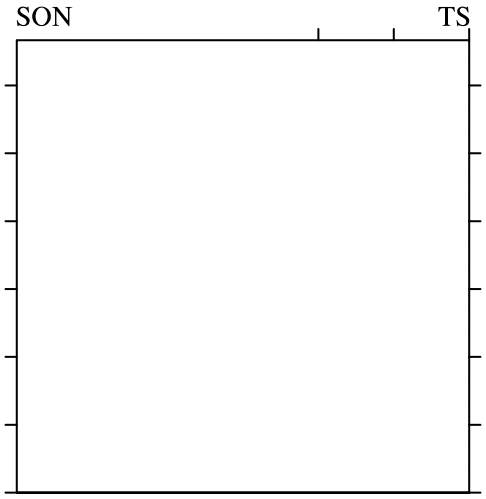
- Warmer peak in the OS case will result in slower reduction to the 2degree target in 2200

Climate for the 3 cases similar in 2200.
How different is the impact of different pathways?
How different is RCP2.6 ad Geo2.0?

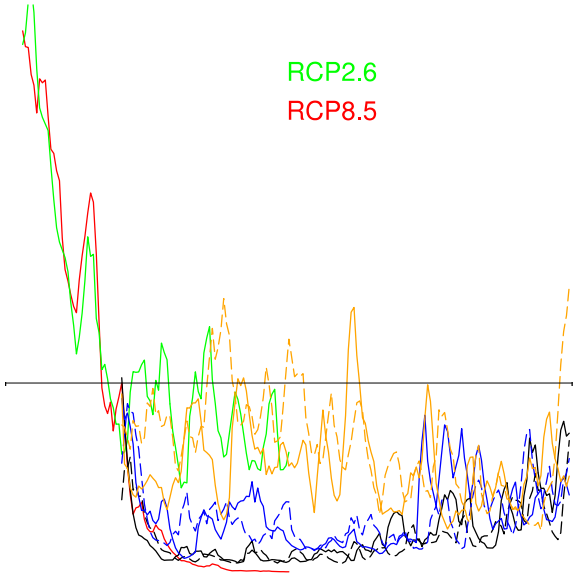
Surface Temperature Changes, Zonal Average

2070-2099 minus 2010-2039





Evolution of NH Sept. Sea-Ice



- **Sept. Sea-Ice in Geo2.0 similar to RCP2.6**
- **Outcome in 2200 very similar for all scenarios**

CESM Results

Global Mean Surface Temperature

Global Mean Precipitation

RCP2.6 vs. Geo2.0: Similar temperatures, differences in precipitation

-> Differences in short-wave radiation and atmospheric CO_2 (evapotranspiration)

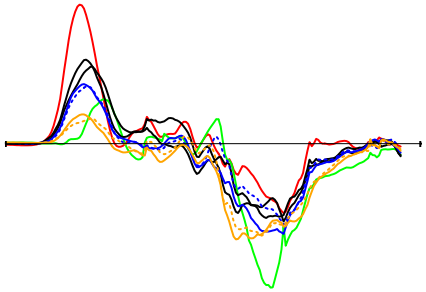
-> **RCP2.6**: less CO_2, more SW, **Geo2.0**: more CO_2, less SW

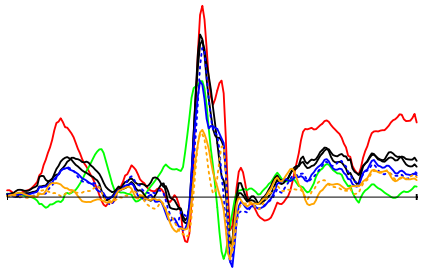
-> Hydrological cycle changes vary largest in Geo2.0, adaptation more difficult?

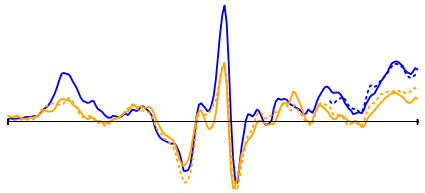
AOD and Precipitation Changes, Zonal Average

2070-2099 minus 2010-2039

RCP8.5
Overshoot
Geo 2.5
Geo 2.0
RPC2.6

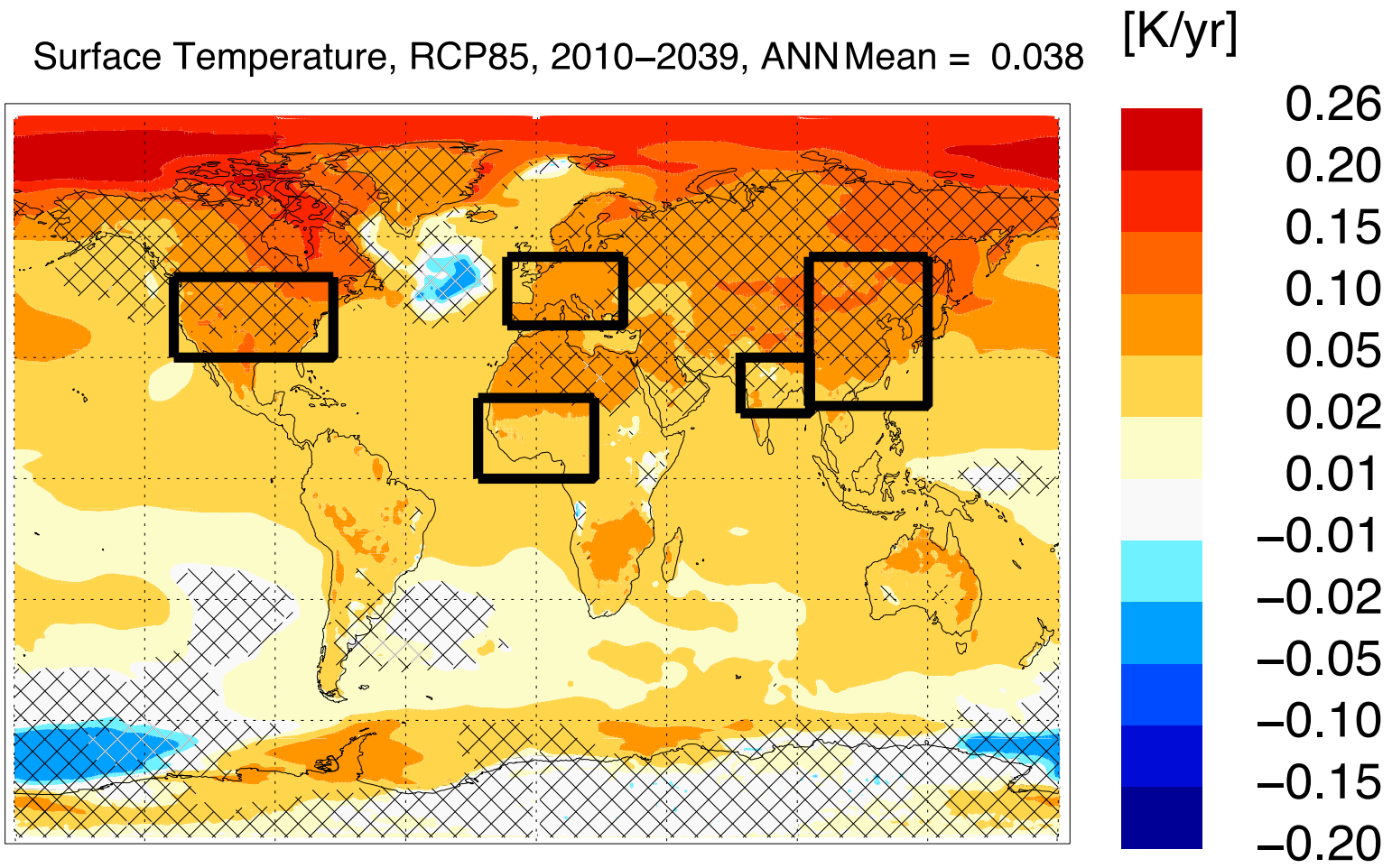




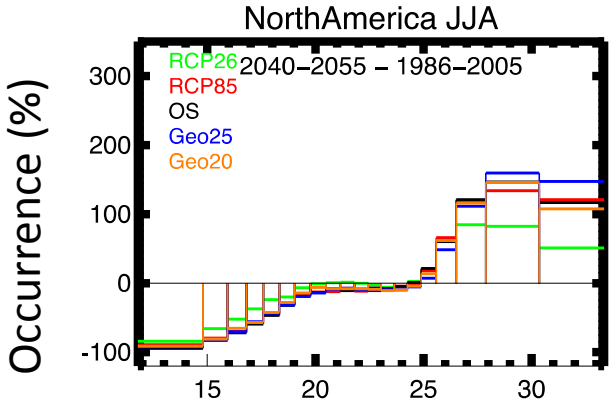


- AOD is globally reduced, but also shows a latitudinal gradient for all experiments
- Shift of the ITCZ, and regional changes possible due to changes in tropospheric aerosol
- Changes in precipitation pattern expected for all pathways

Identify changes in surface temperature and precipitation for specific regions



Frequency of surface temperature occurrence over land



380

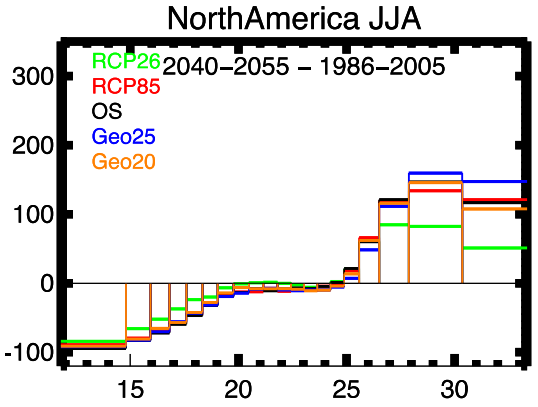
Surface Temperature (deg C)

Start in 2040

Maximum Temperature; solar dimming

Climate by 2200

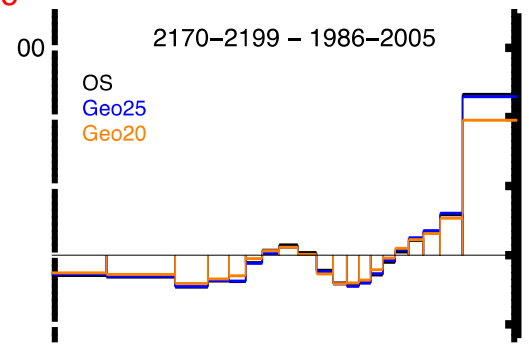
Frequency of surface temperature occurrence over land



380

460

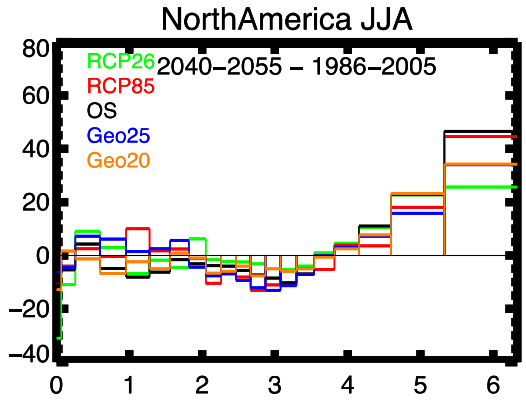
390 600



Occurrence (%)

Surface Temperature (deg C)

Frequency of precipitation occurrence over land



Occurrence (%)

Precipitation (mm/day)

Conclusions

Delayed action by 2040 to stabilize the climate by 2200, in comparison to mitigation following RCP2.6

Maximizing decarbonization including mitigation and active carbon dioxide removal -> **3K warming**, but not enough to reach 2degree target

- Large SRM around 1Mt Pinatubo a year -> **2.5K or 2.0K** (costs, risks, and strategies very uncertain)

What do we gain from combined effort after 2040:

- Global temperature stabilization possible, regional improvement of extreme heat
- Loss of summer sea-ice prevented, but still large reductions
- Combined strategy causes up and down in the strength of the hydrological cycle
- Regional precipitation changes somewhat improved compared to RCP8.5 in most regions. Adaptation to changes required no matter what.

Costs are uncertain for different scenarios.

Early action would prevent large costs, risks, and additional side effects from geoengineering later on.

Global Surface Energy Budget

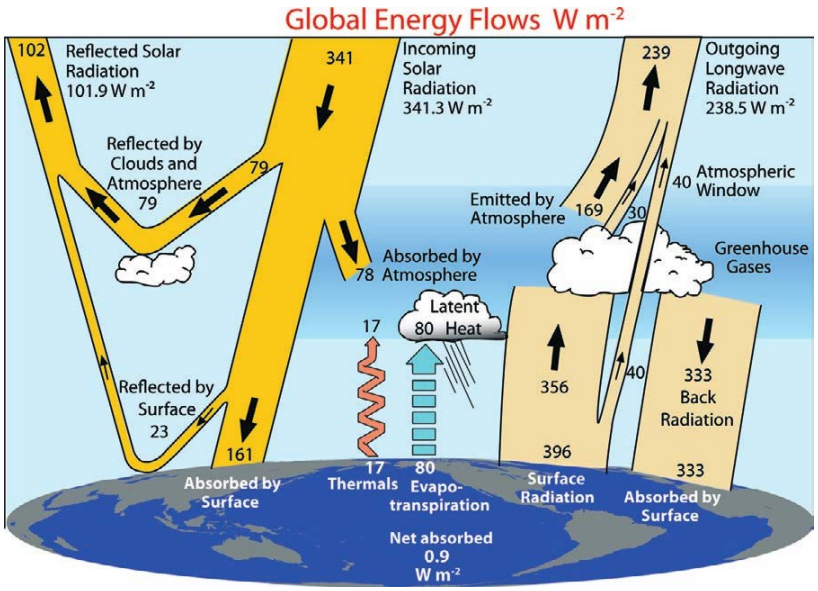
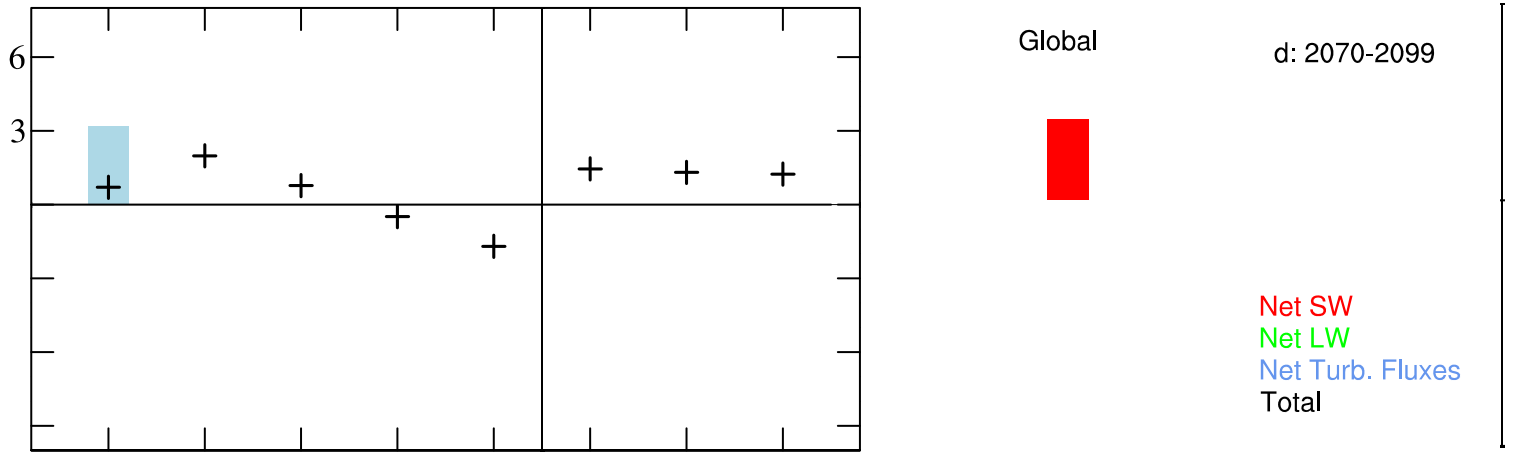


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.



Fluxes are positive downward