ESM Science Questions that Require Coupling and/or Inputs from IAM/IAV

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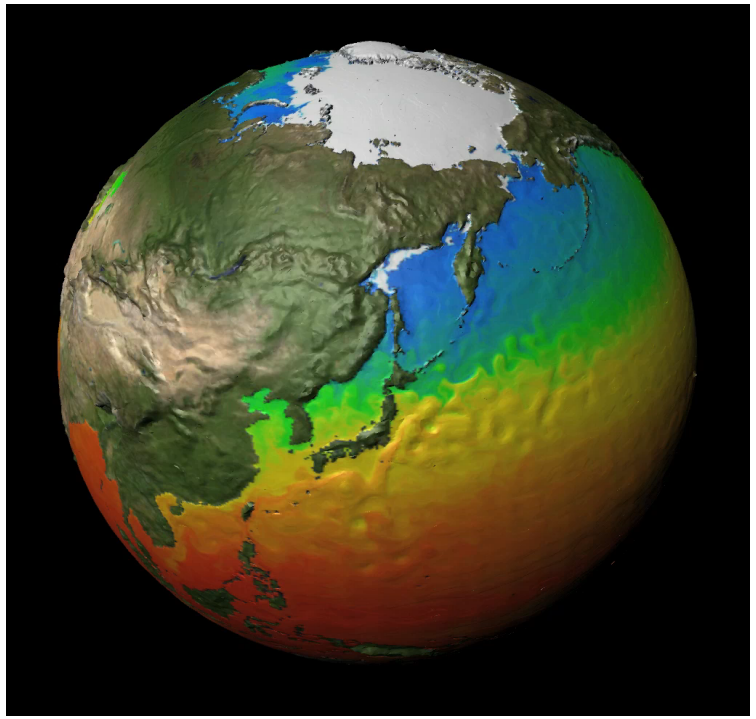
Purpose of Earth System Modeling

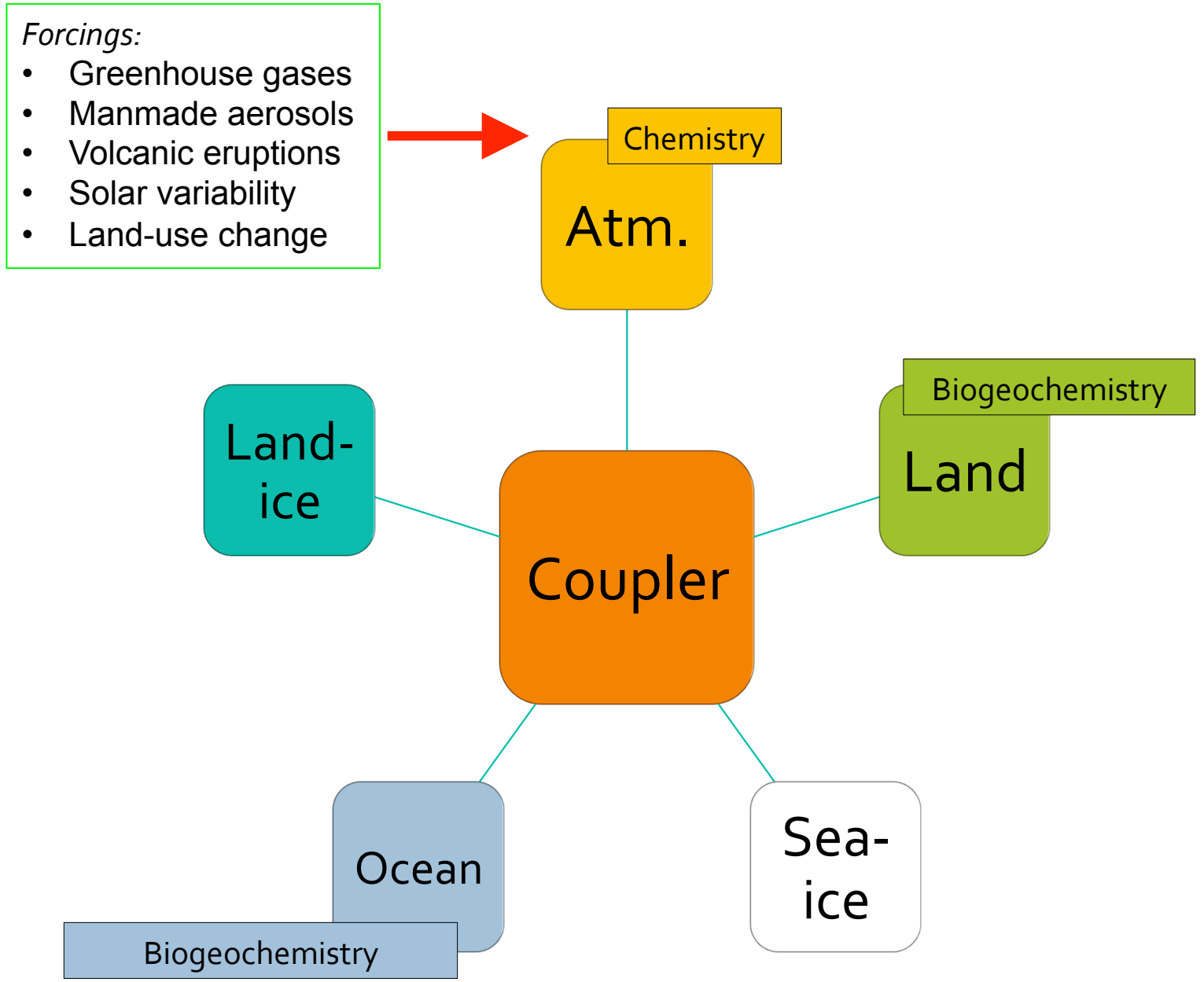
- **To provide scientific understanding of observed climate change (historical, paleo)**
- **To simulate future climate change and its impacts**
- **Builds on our process understanding from observations and highly-detailed models**

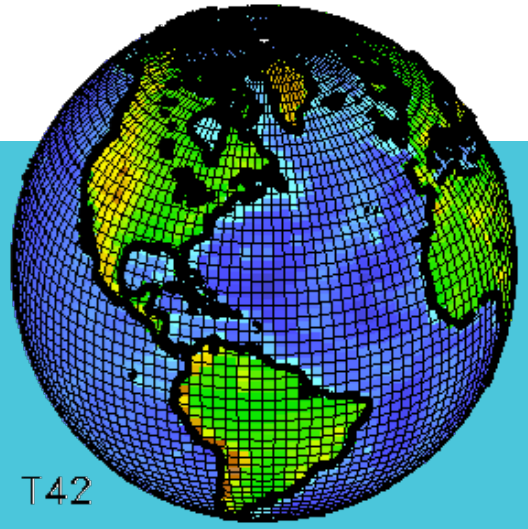


High-resolution (25 km atmosphere, 0.1^{o} ocean) coupled simulation captures short-term variability (hurricanes) and seasonal variations (sea-ice)

From J. Small

Components to an Earth System Model

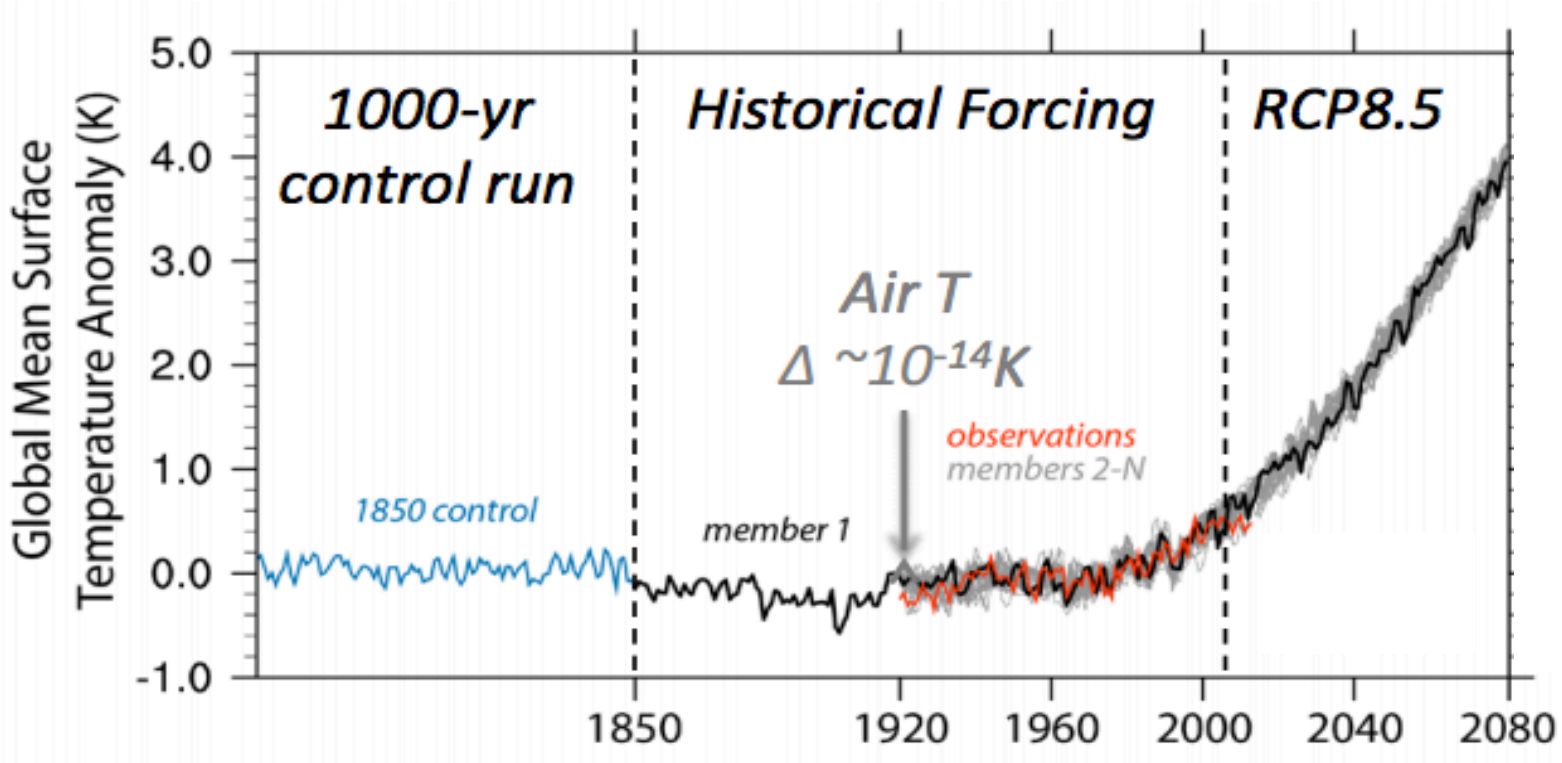




Some facts about the Community Earth System Model (CESM)

- 0.25°, 1° , 2° resolutions, regional-refinement
- 30 minute time step (for 1° and 2°)
- 32 atmosphere levels (72 for WACCM)
- 60 ocean levels (0.1° or 1°)
- 25 ground layers
- ~5 million grid boxes at 1° resolution
- >1.5 million lines of computer code
- Approximately 20 simulated years per day (1°, 32 L)
- Data archived (monthly, daily, hourly) for hundreds of geophysical fields

Internal variability and ensembles



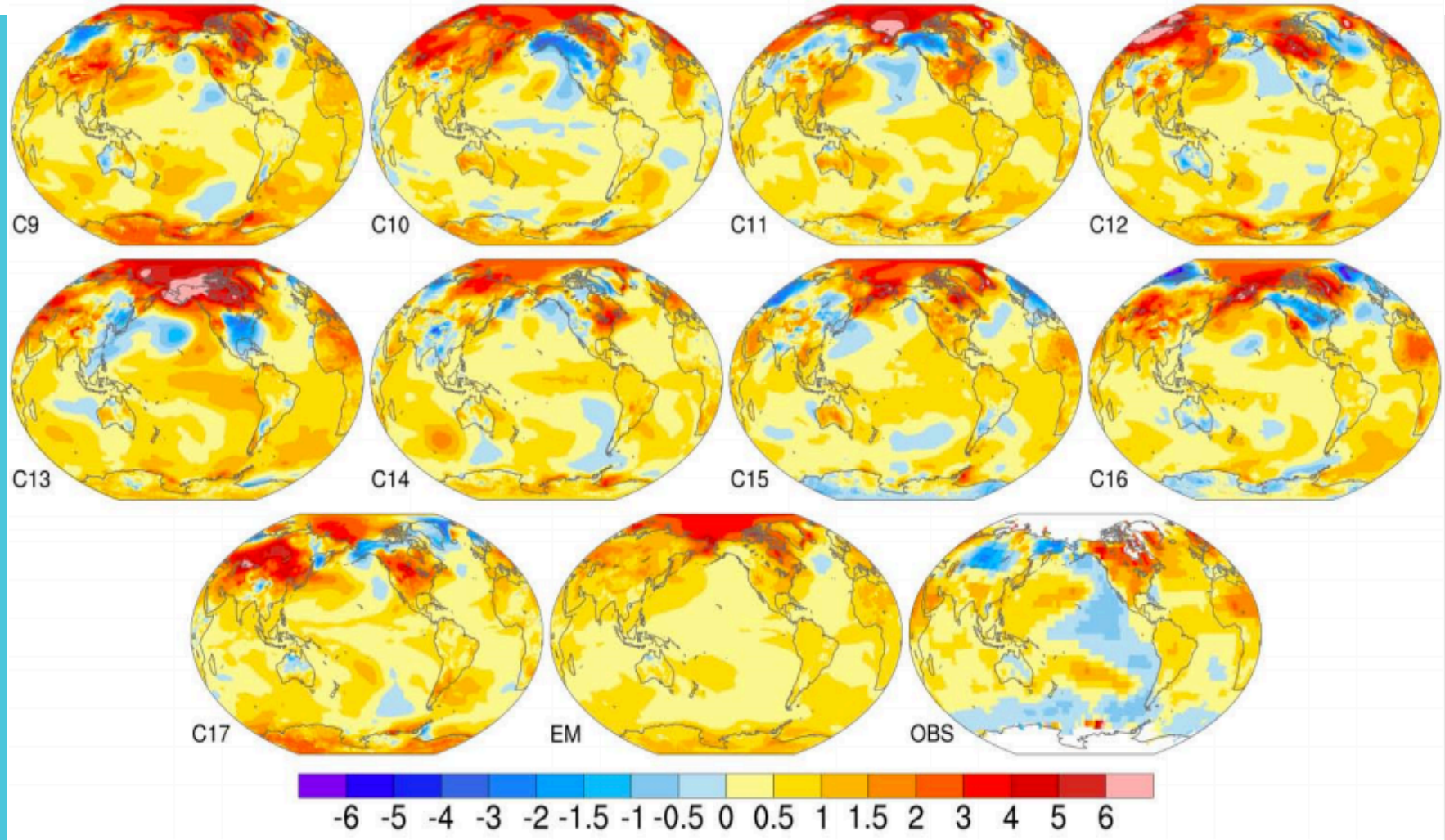
40 runs (NCAR/U. Toronto)

1920-2100

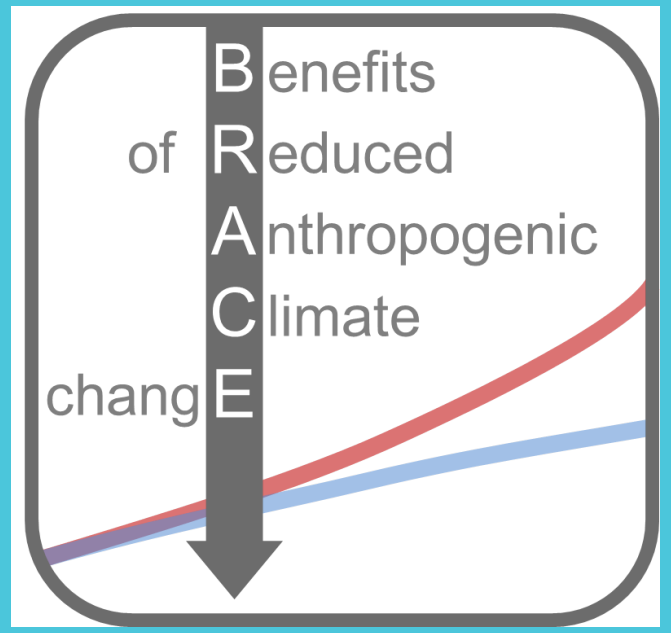
Same forcing

Same initial conditions except for round-off perturbation to initial air temperature

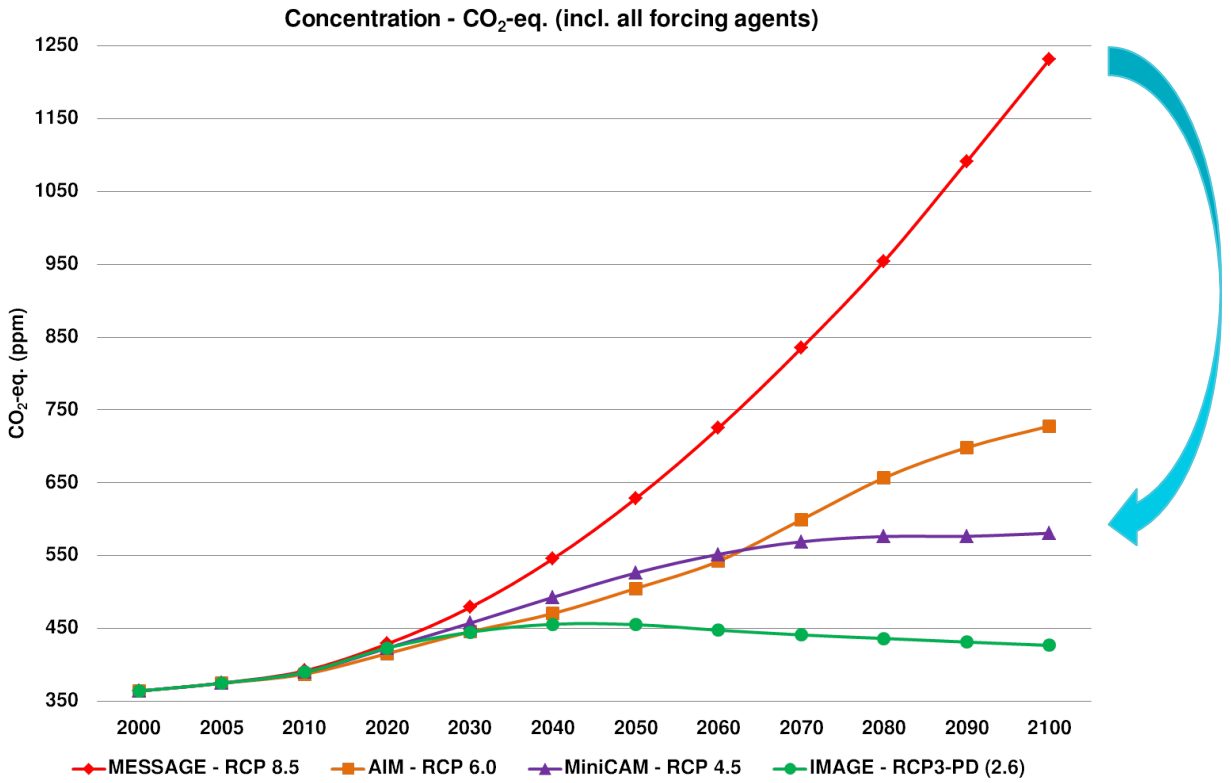
Internal variability and ensembles



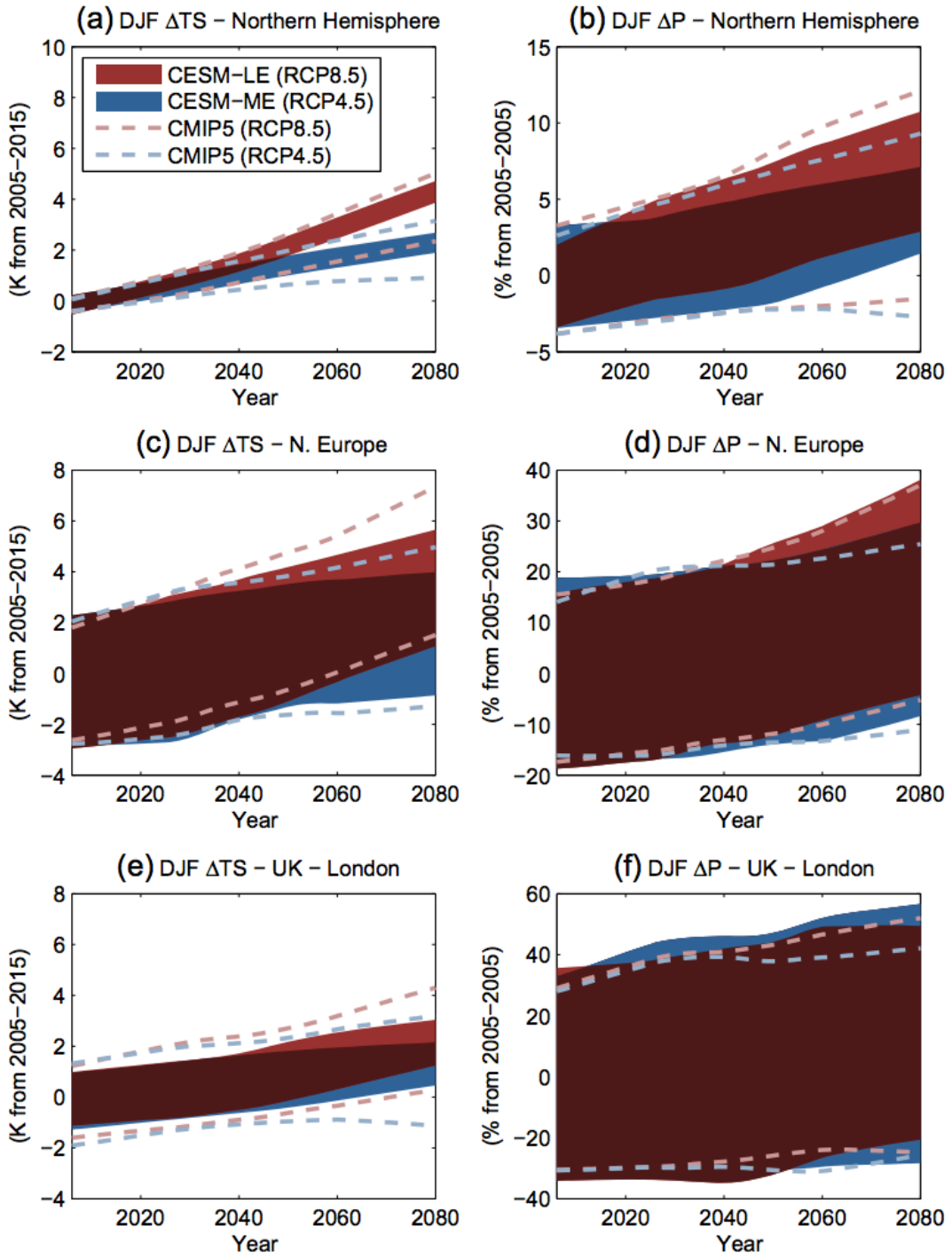
Panels show 1979-2012 DJF surface temperature trends for 9 ensemble members, the ensemble mean, and observations.



What are the benefits of mitigating from a high-emission scenario (RCP8.5) to a medium-emission scenario (RCP4.5)?

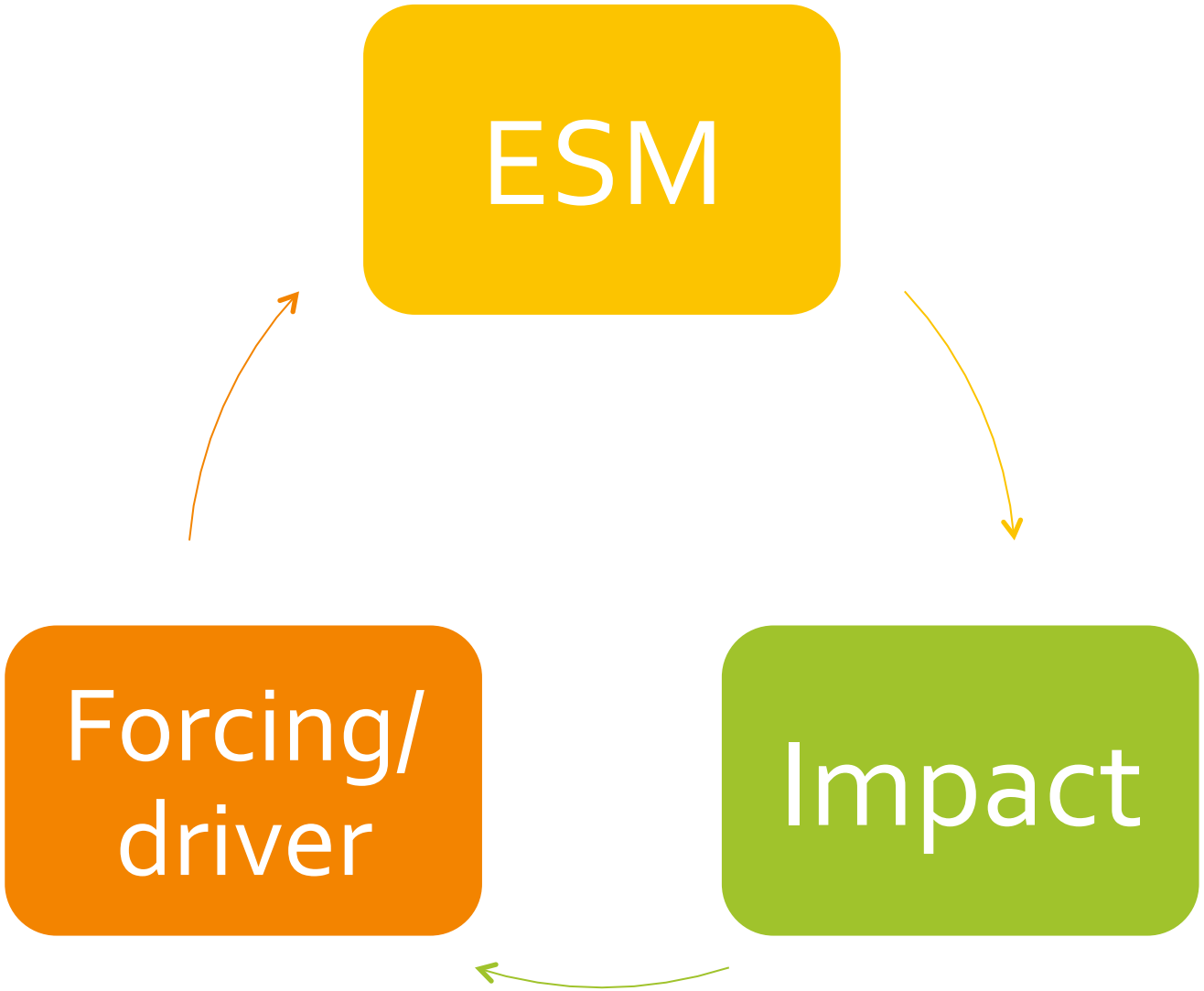


Regional trends: LE and CMIP5



Sanderson et al., 2015

Coupling ESM & IAM/IAV: online or offline

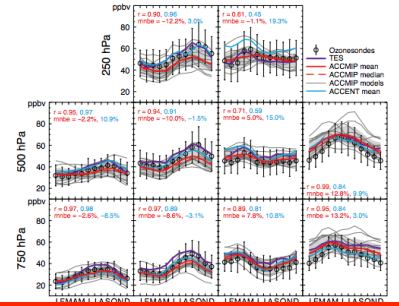


Some topics that require coupling between ESM and IAM/IAV

- air quality & health
- ozone/crop & vegetation yields
- water availability and energy production
- droughts & floods
- sea-level rise and population
- carbon cycle/land-based mitigation

Pollution

Surface concentration of hourly/8h ozone



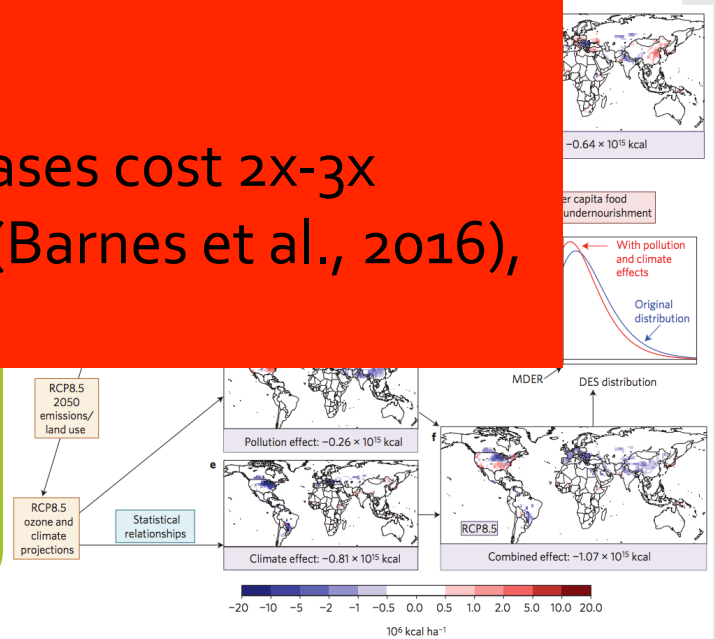
Young et al., 2013

Main issues:

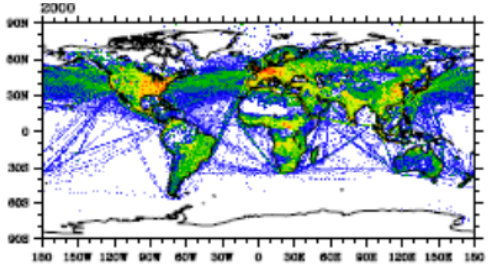
1) Resolution: chemistry is highly nonlinear
2) Cost: adding chemistry to atmosphere model increases cost 2x-3x
3) Meteorological variability affects chemistry trends (Barnes et al., 2016), but strong forcing from emissions

Change in pollutant emissions (population/controls)

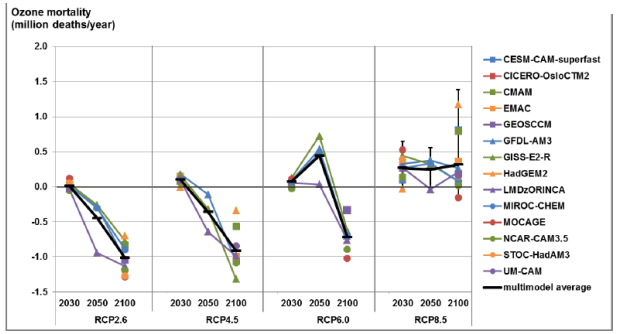
Mortality and decrease in plant yield



Tai et al., 2014



Lamarque et al., 2010



Silva et al., 2016

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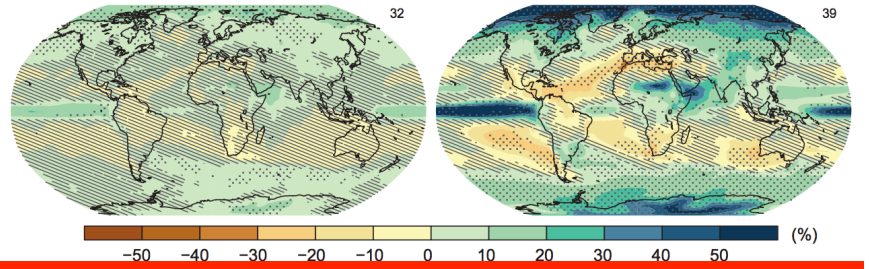
Water

Precipitation -> river flow

(b) Change in average precipitation (1986–2005 to 2081–2100)

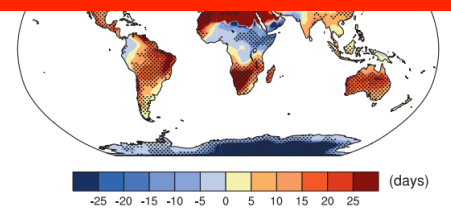


IPCC AR5

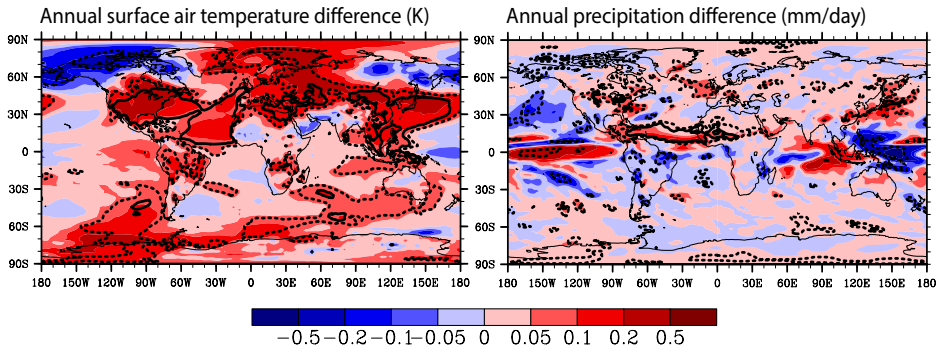
Main issues:

1) Precip. change is very noisy signal: hard to extract signal from noise
2) Resolution: orography key in getting amount/phase/flow
3) Bias: limited skill/robustness in getting agreement in large-scale change
4) Extremes might be more important than the mean

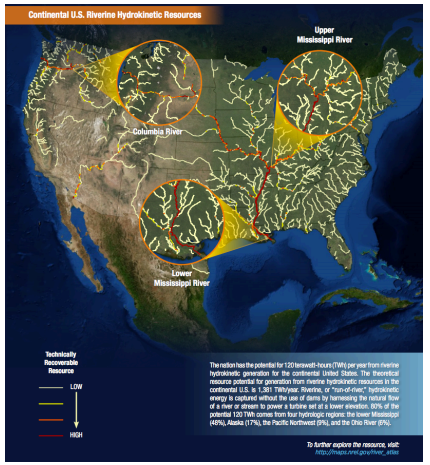
Power generation

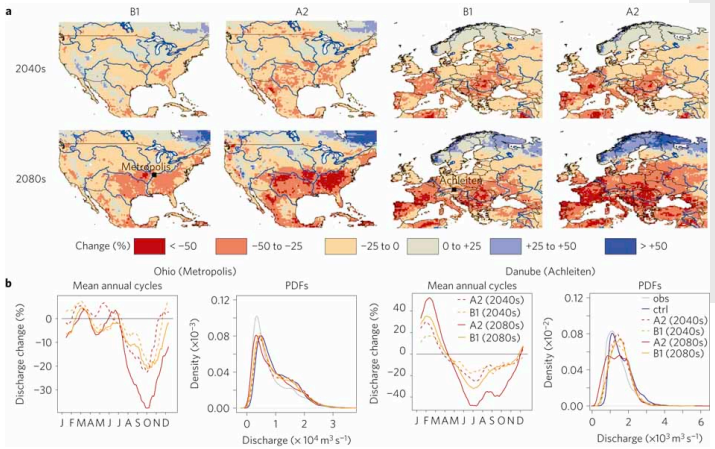


Van Vliet et al., 2012



Annual mean difference in surface air temperature (in K, left) and precipitation (in mm.day^{-1}, right) associated with the removal of SO_2 emissions over the United States.





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Sea-level rise

Sea-level rise projection

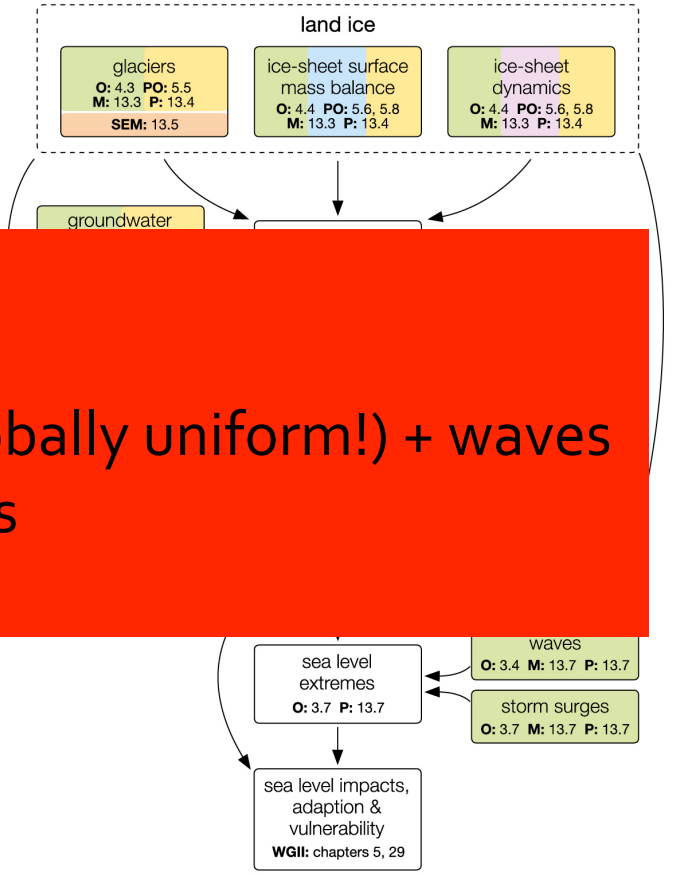
demography

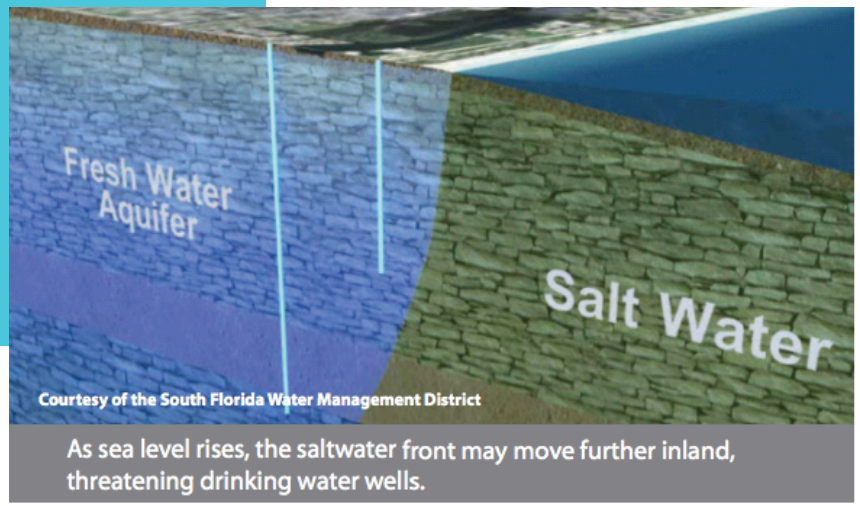
population

Main issues:

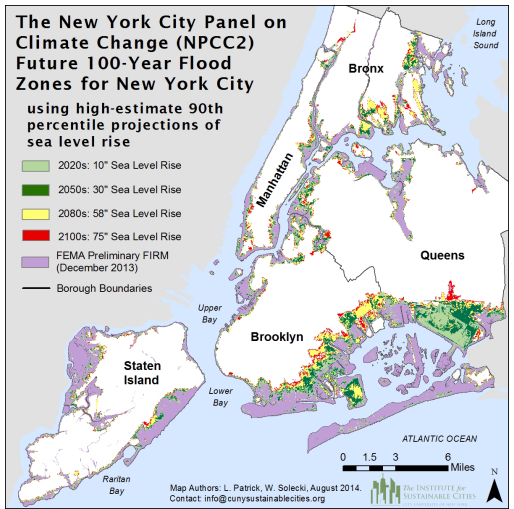
1) Resolution: getting glacier physics right
2) Resolution: regional patterns of sea-level rise (not globally uniform!) + waves
3) Underground water (usually) not represented in ESMs
4) Basic processes are not fully understood

IPCC AR5





As sea level rises, the saltwater front may move further inland, threatening drinking water wells.



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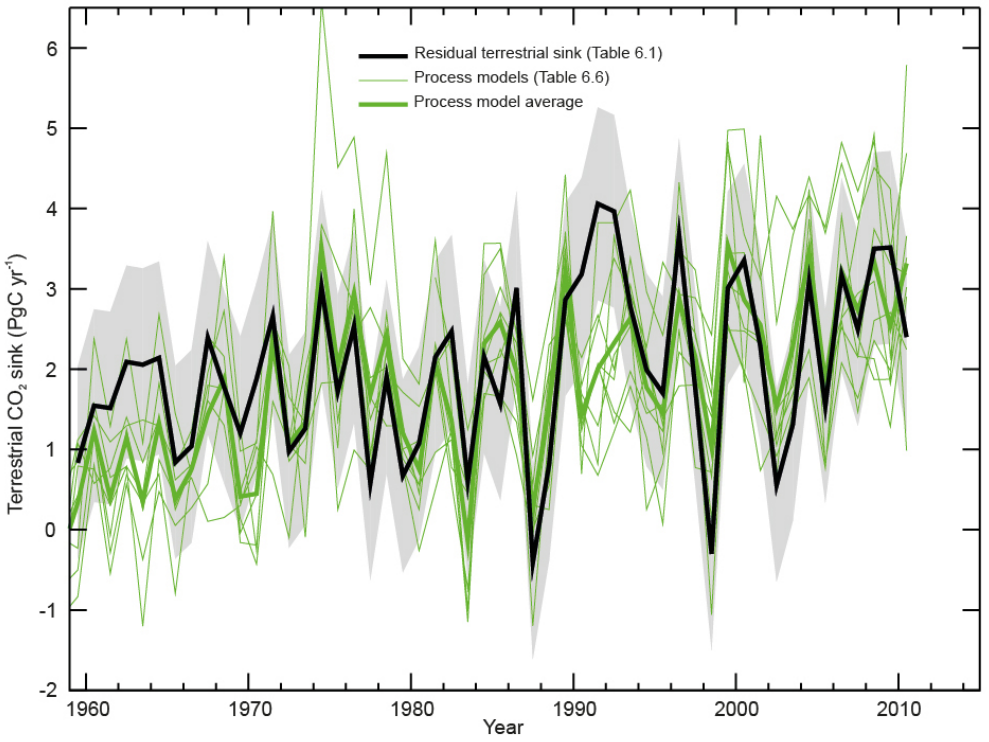
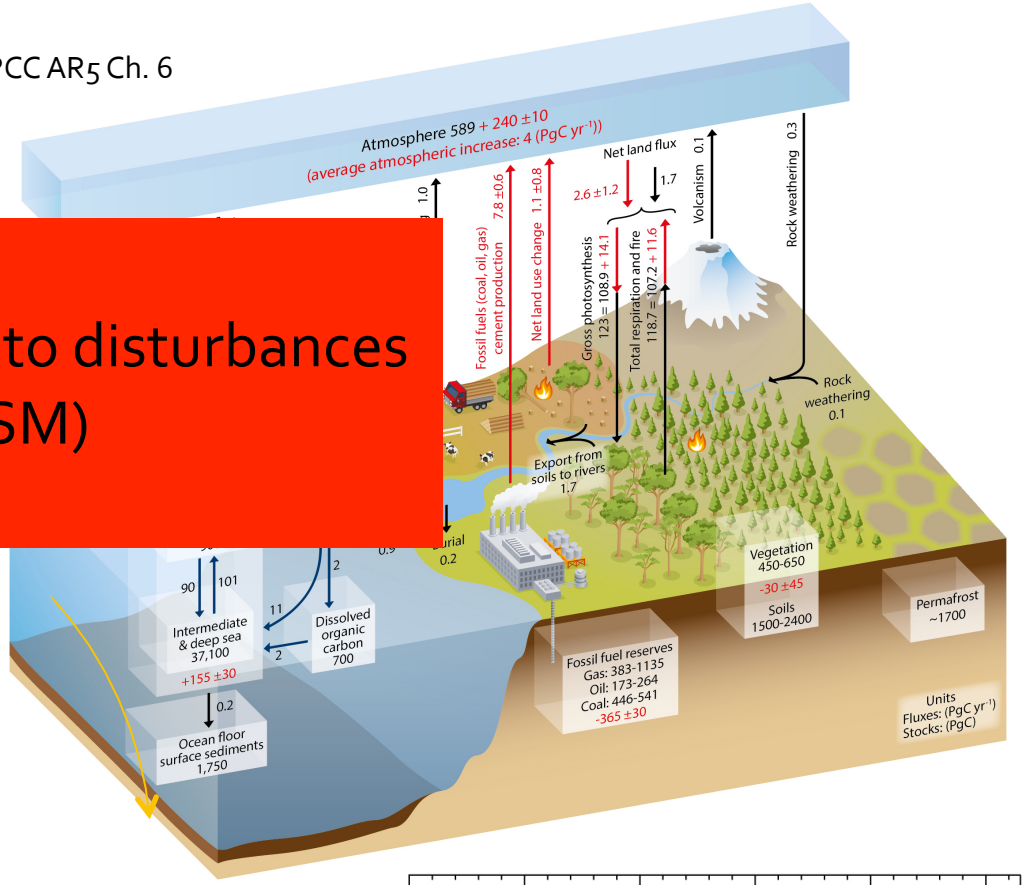
Main issues:

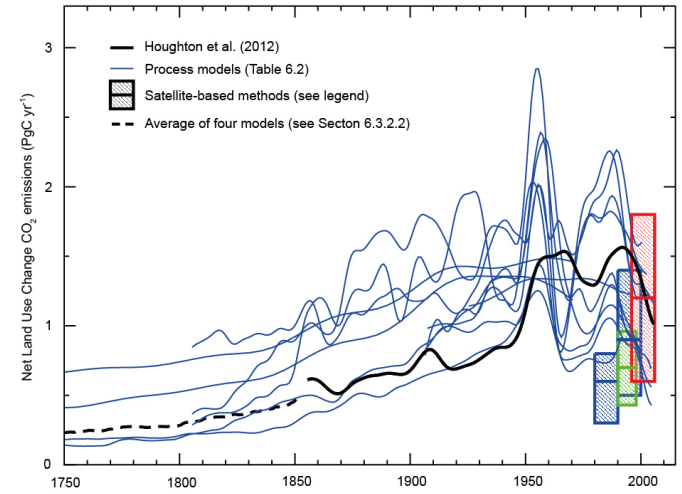
1) Incomplete knowledge of vegetation response to disturbances
2) Translation of land-use into ESM quantities (iESM)
3) Large interannual variability



IPCC AR5 Ch. 6

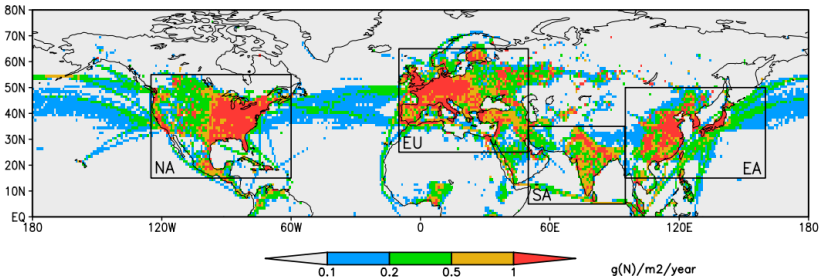


Local and global climate impacts, food security



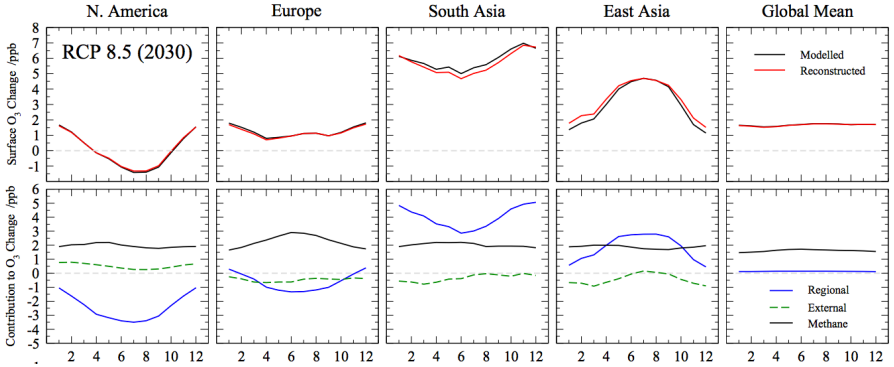
Questions?

Emulators: mean *versus* extremes



Source-receptor regions

Wild et al., 2012



Surface ozone