ATM 265, Spring 2019
Lecture 14
Modern Earth System Modeling
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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 (large-eddy simulations, chemical master mechanism, …)

Slides by J.F. Lamarque

Importance of Atmospheric Models

- Atmospheric models allow us to test our understanding of the physical system against observations.
- Atmospheric models are our primary tool for making predictions on the future climate of Earth (10-100 year simulations).
- Atmospheric models can be thought of as scientific instruments that allow us to experiment with the Earth system (which would be impossible in practice).

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Design of Earth-System Models

Earth-system models consist of dozens of interwoven parts, incorporating the vast base of knowledge we have developed around the Earth system:

- Different dynamical cores (solve the primitive equations for quantities resolved on the grid scale)
- Sub-grid-scale dynamical parameterizations (turbulence closures, gravity wave drag for unresolved atmospheric motions)
- Moist physics parameterizations (microphysics, macrophysics, precipitation, clouds)
- Chemistry (greenhouse gases, aerosols)
- Ocean, ice and land components

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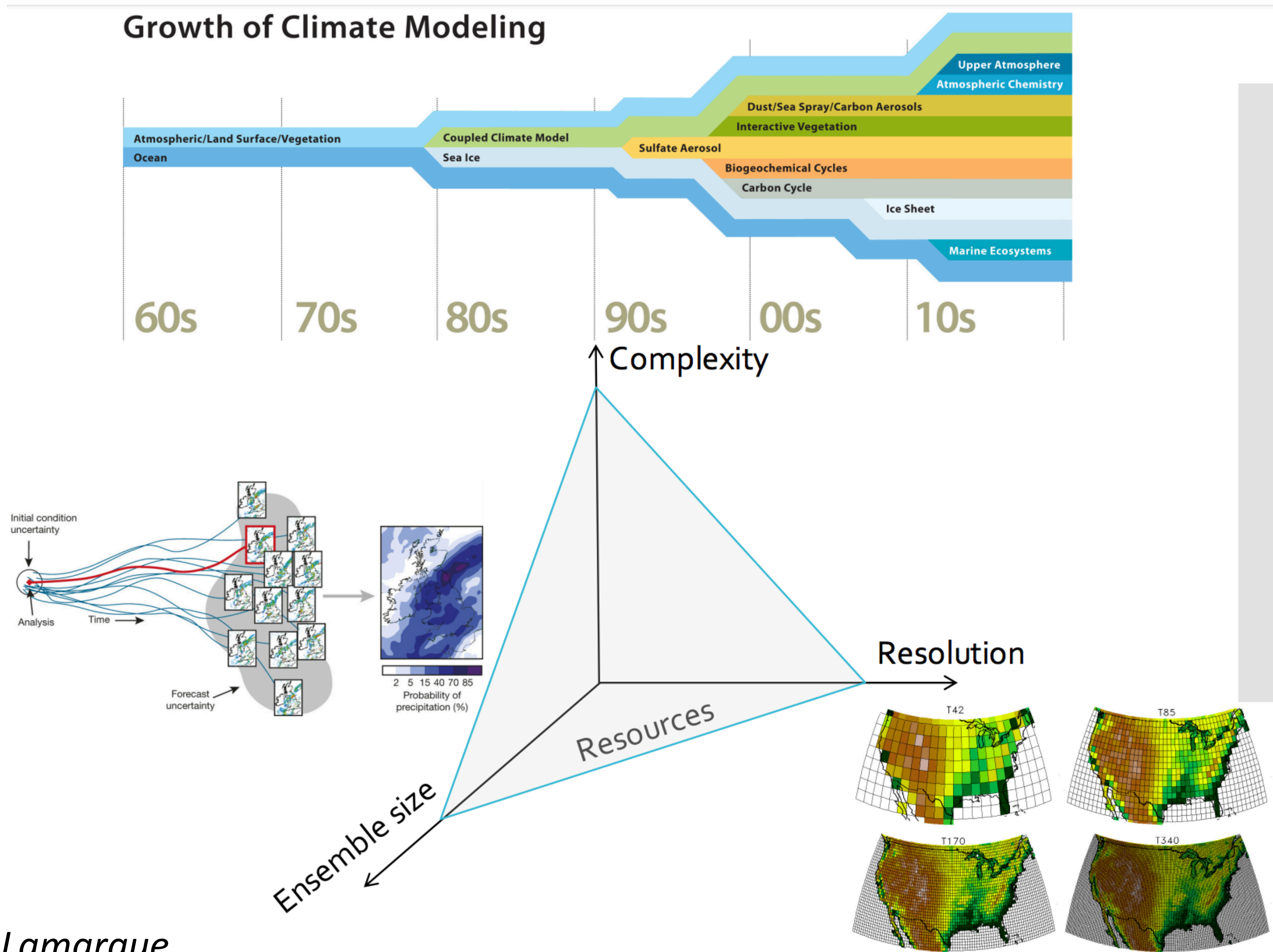
Outlook: Balancing with Constrained Resources



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Outlook: Large Ensemble (LENS)

The CESM Large Ensemble (LENS) consists of:

- A 40-member ensemble of fully coupled CESM1 simulations over the historical plus future period 1920-2100 under RCP8.5.
- Differences arise from a slightly different initial state (initial condition ensemble)

- A similar ensemble is presently being constructed using E3SM.

http://www.cesm.ucar.edu/projects/community-projects/LENS/

Outlook: Big Data

Big Data Problems

The success of climate modeling has driven a "big data" problem. Storage and analysis of climate data is increasingly time consuming and costly.

	CMIP1	CMIP2	CMIP3	CMIP5	CMIP6
Year	1996	1997	2005	2010	2016
# Models	19	24	21	45	TBD
# Runs	19	48	211	841	TBD
Volume	1 GB	500 GB	36 TB	3.3 PB	~90 PB

Solutions

Analyze and transform Big Data before transfer to end user

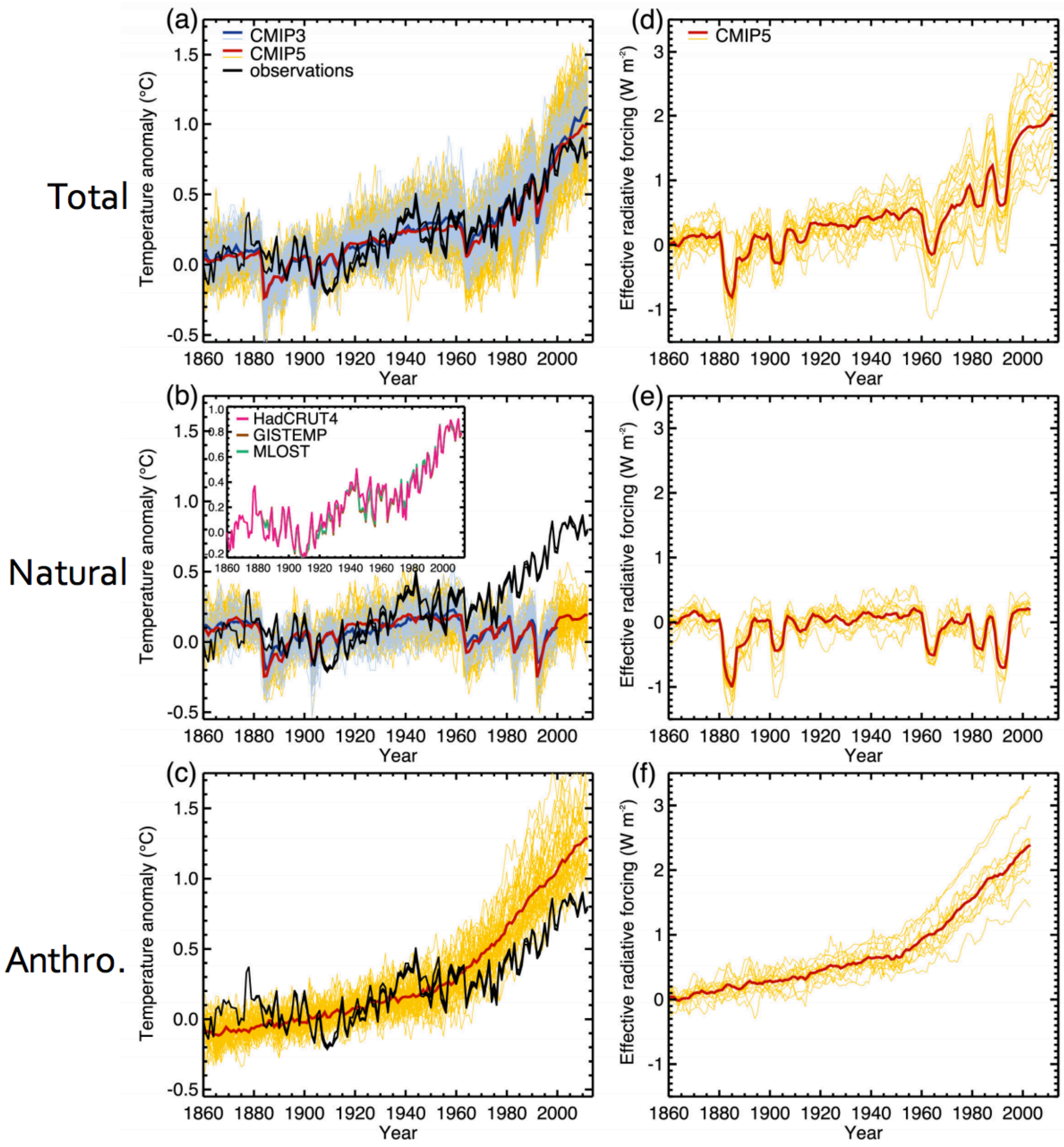
Reduce the need for large data downloads

Capture expertise as automated processing

Improve usability for applications & non-specialists

Slides by S. McGinnis

Natural vs. Anthropogenic Surface Temp. Change



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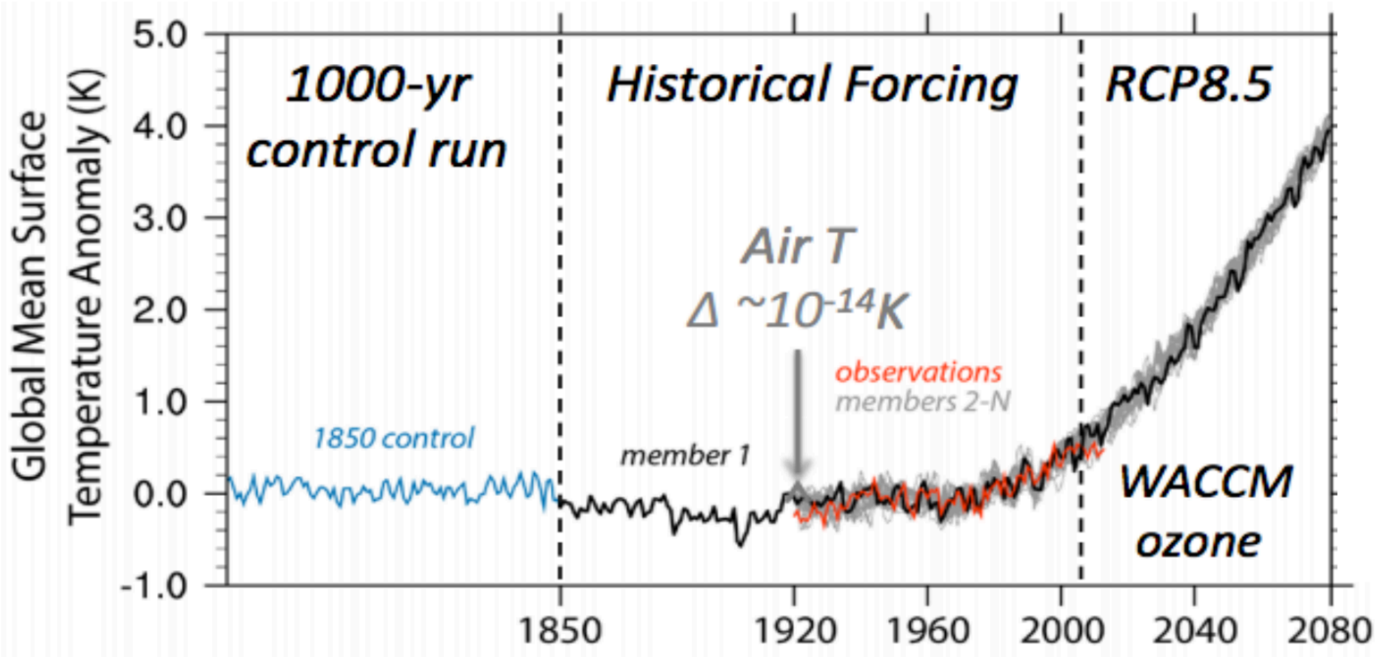
Internal Variability and Ensembles



40 runs (NCAR/U. Toronto)

1920-2100

Same forcing

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

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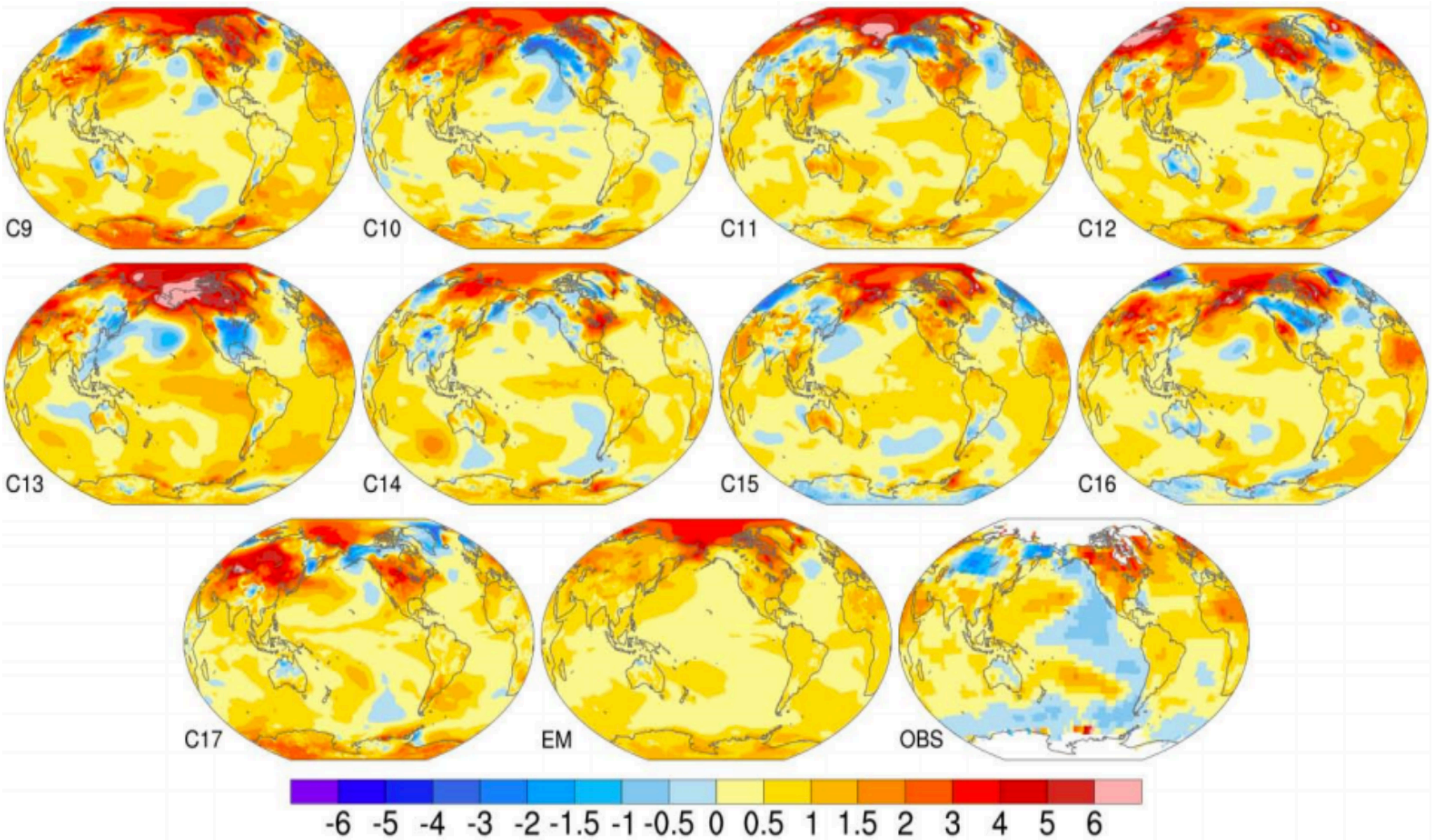
Internal Variability and Ensembles



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

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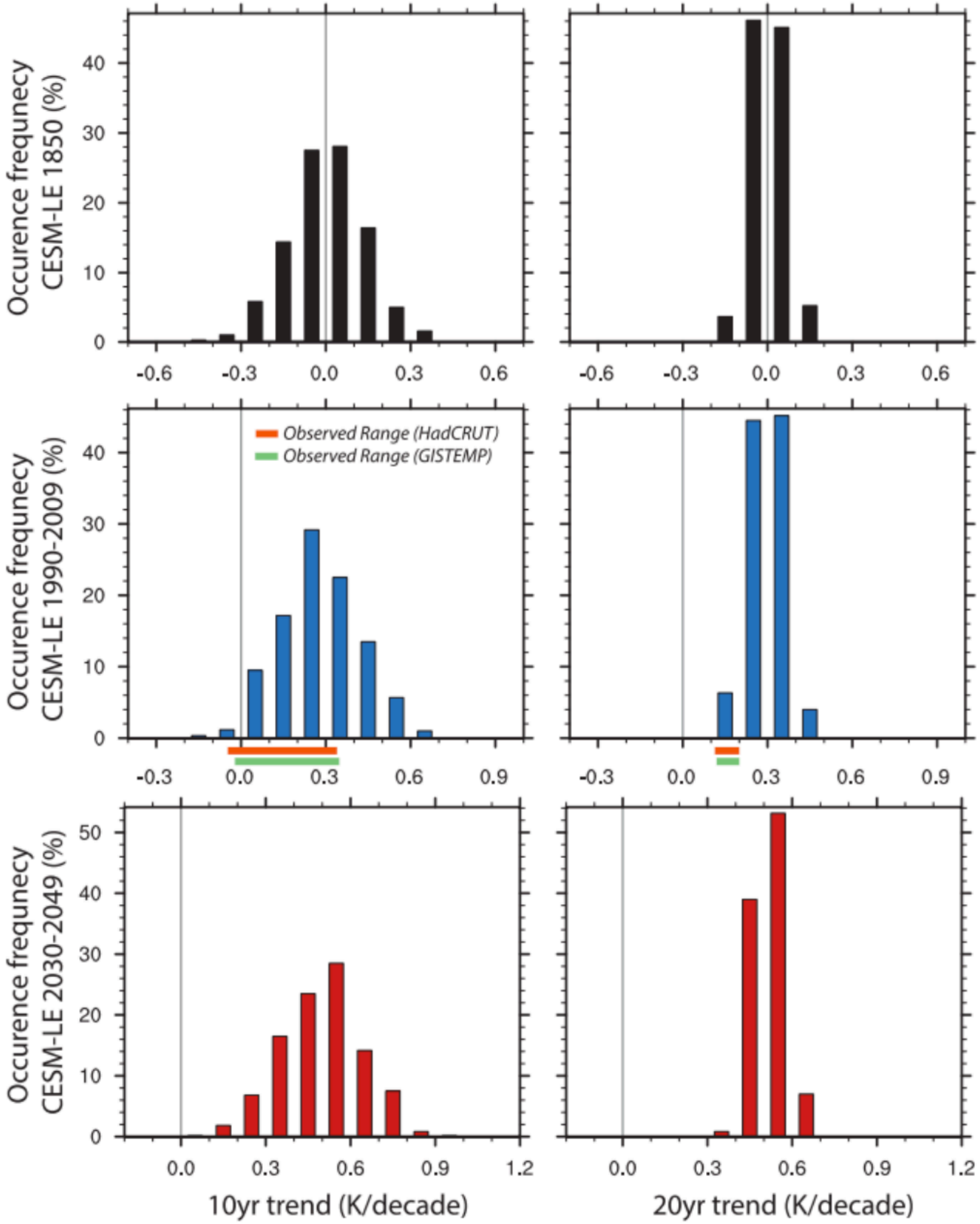
Internal Variability and Ensembles

(Kay et al., 2015)



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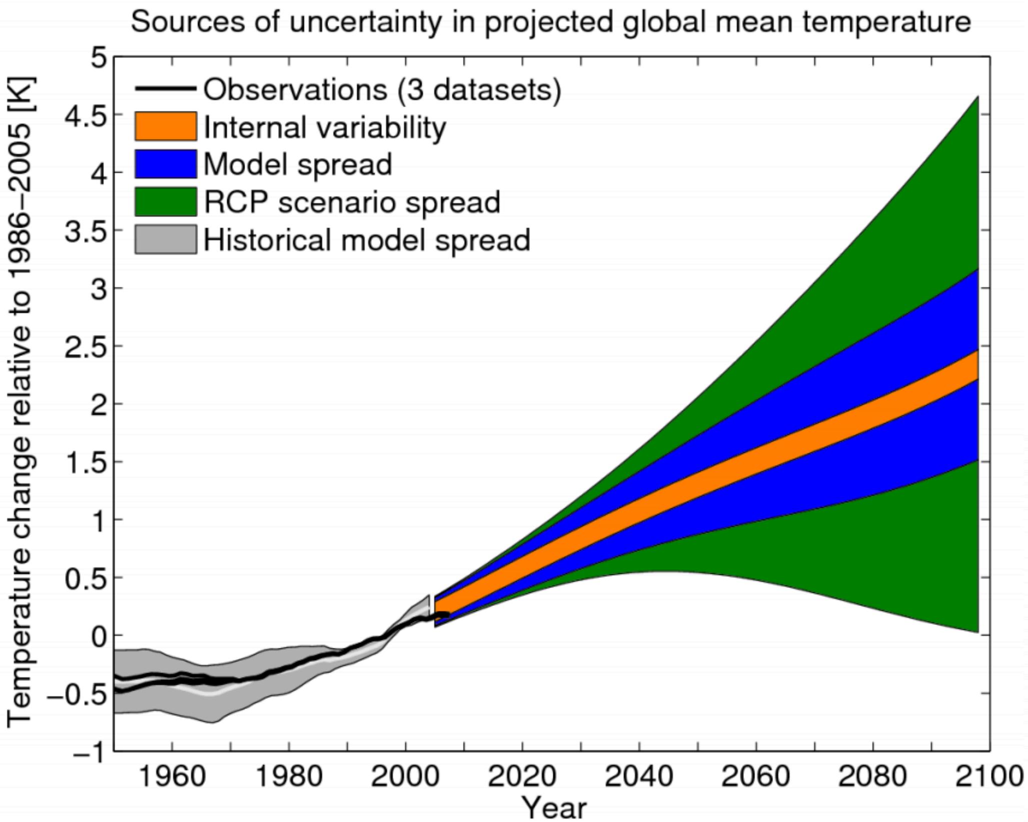
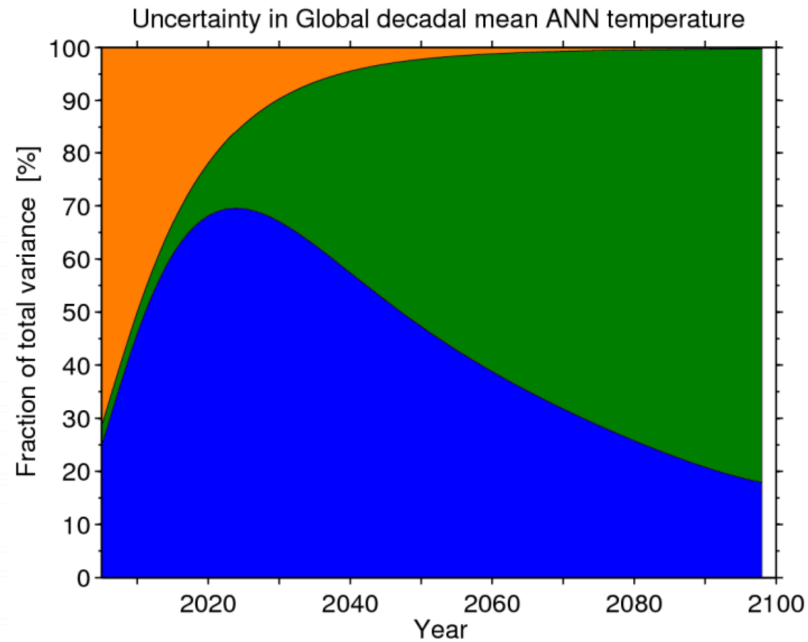
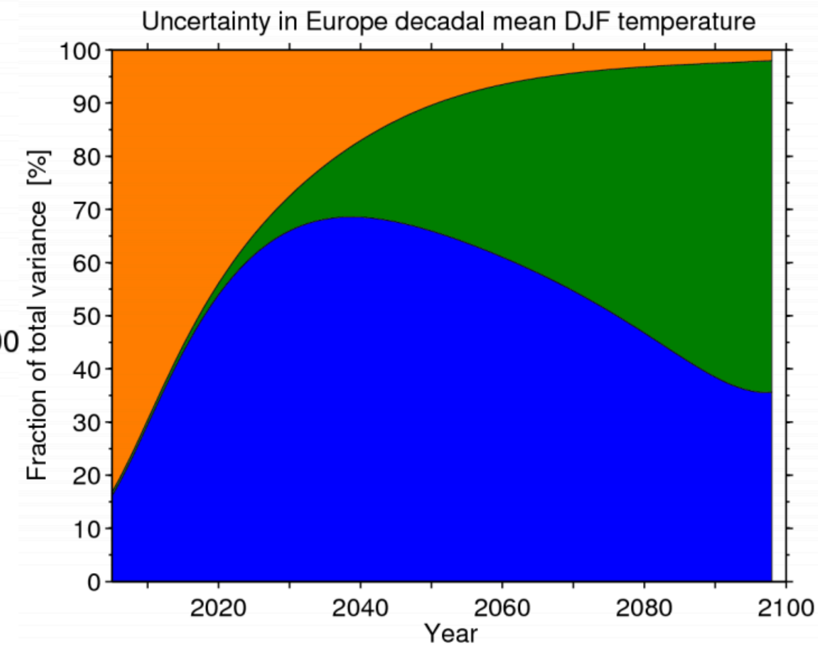
Sources of Uncertainty







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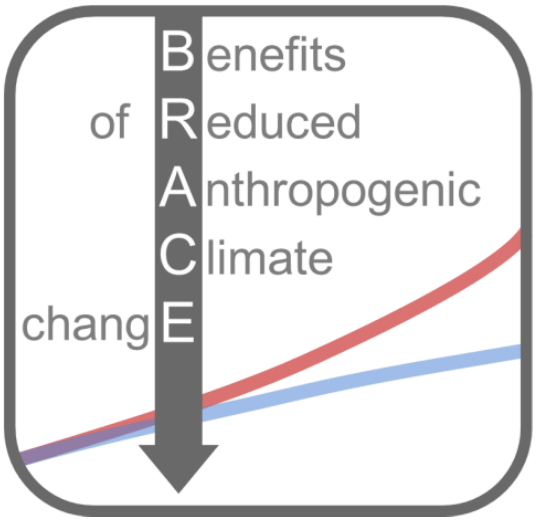
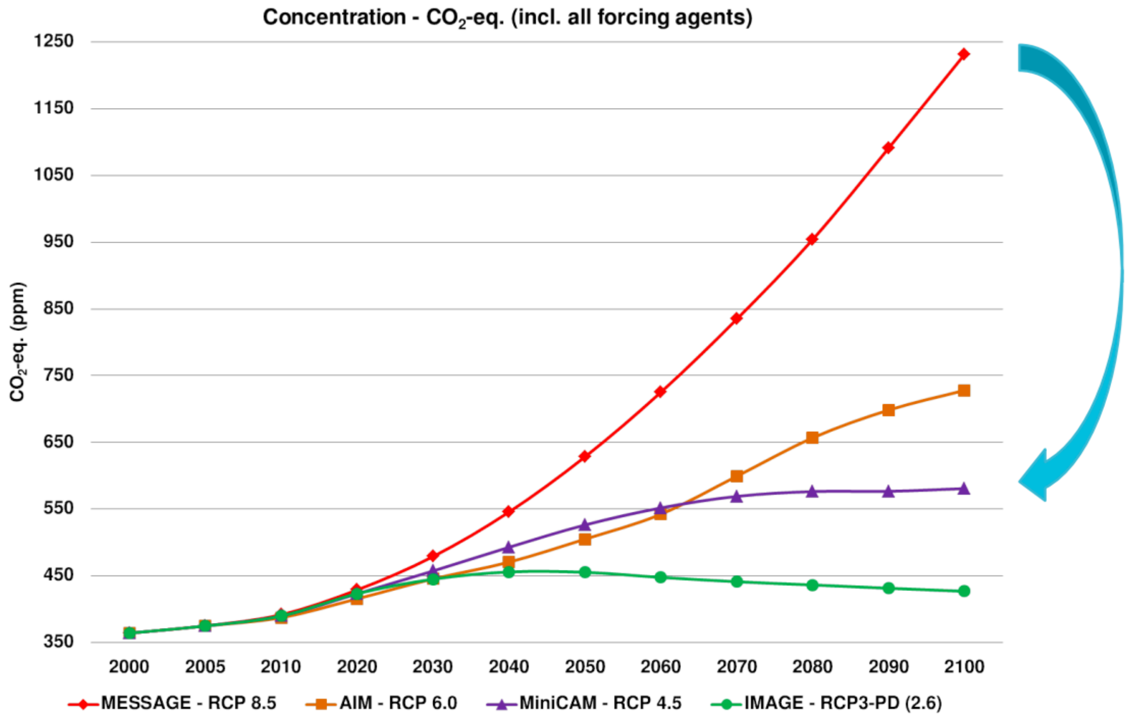
BRACE

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





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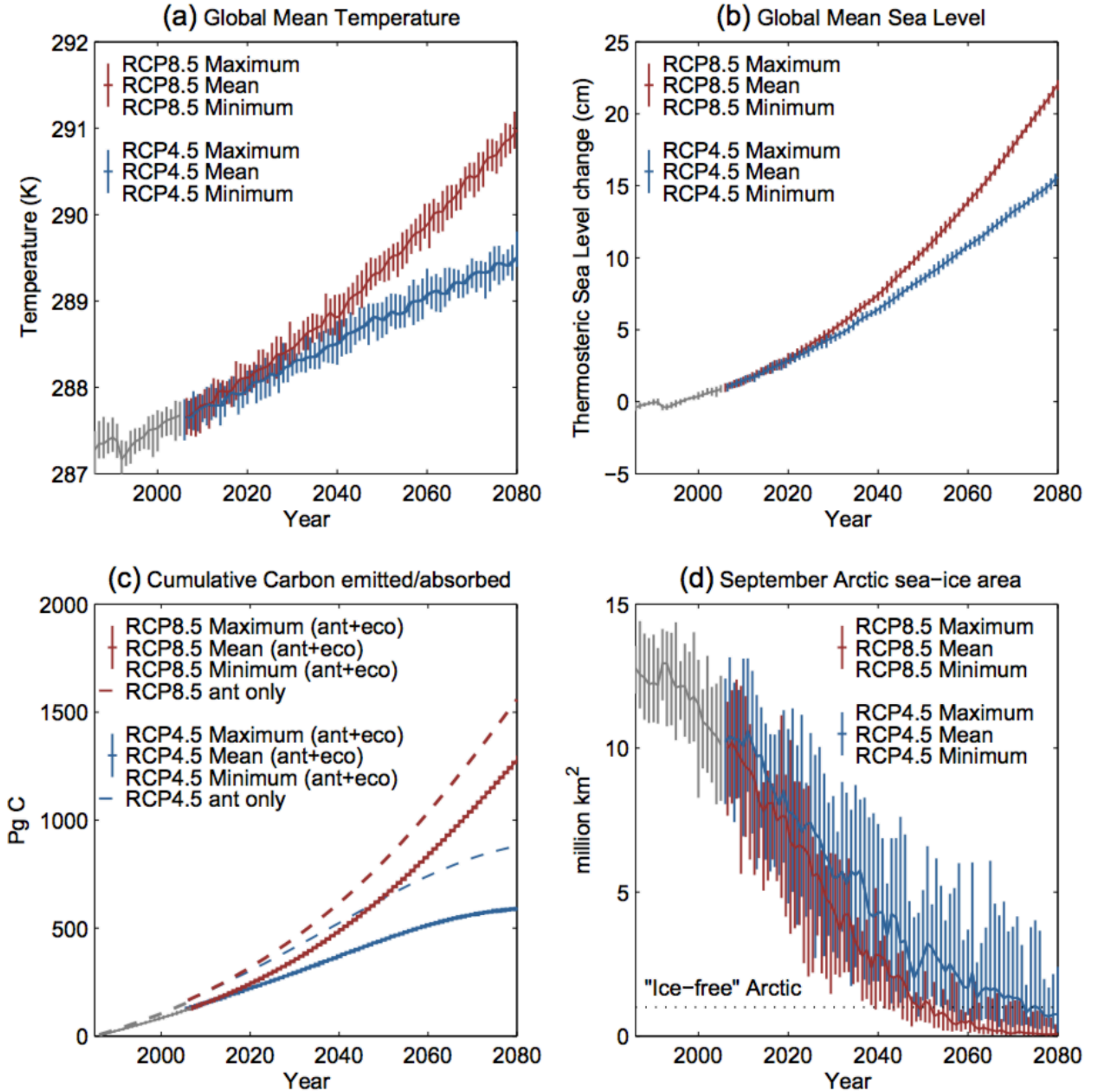
Large scale comparison of RCP8.5 and RCP4.5



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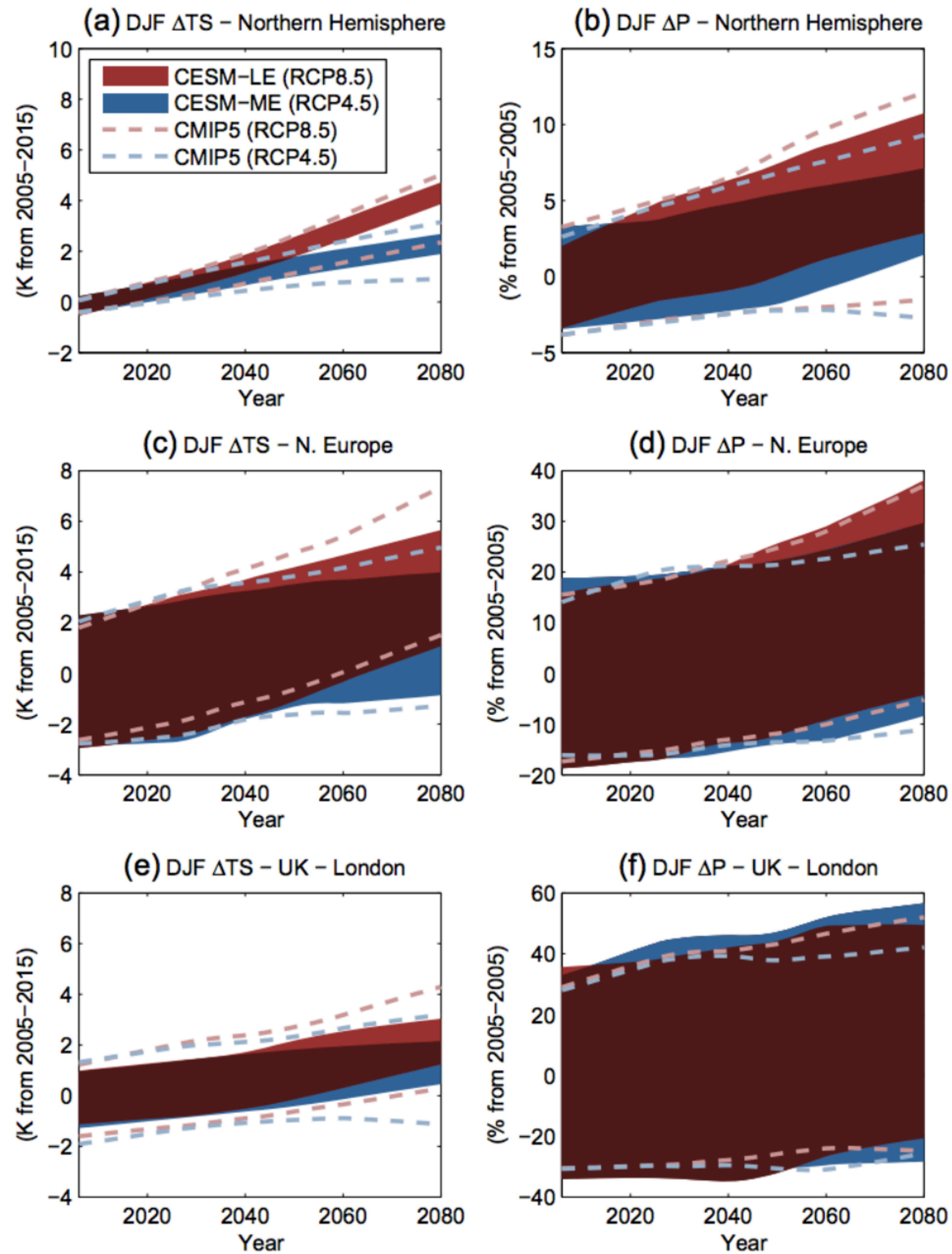
Regional trends: LE and CMIP5



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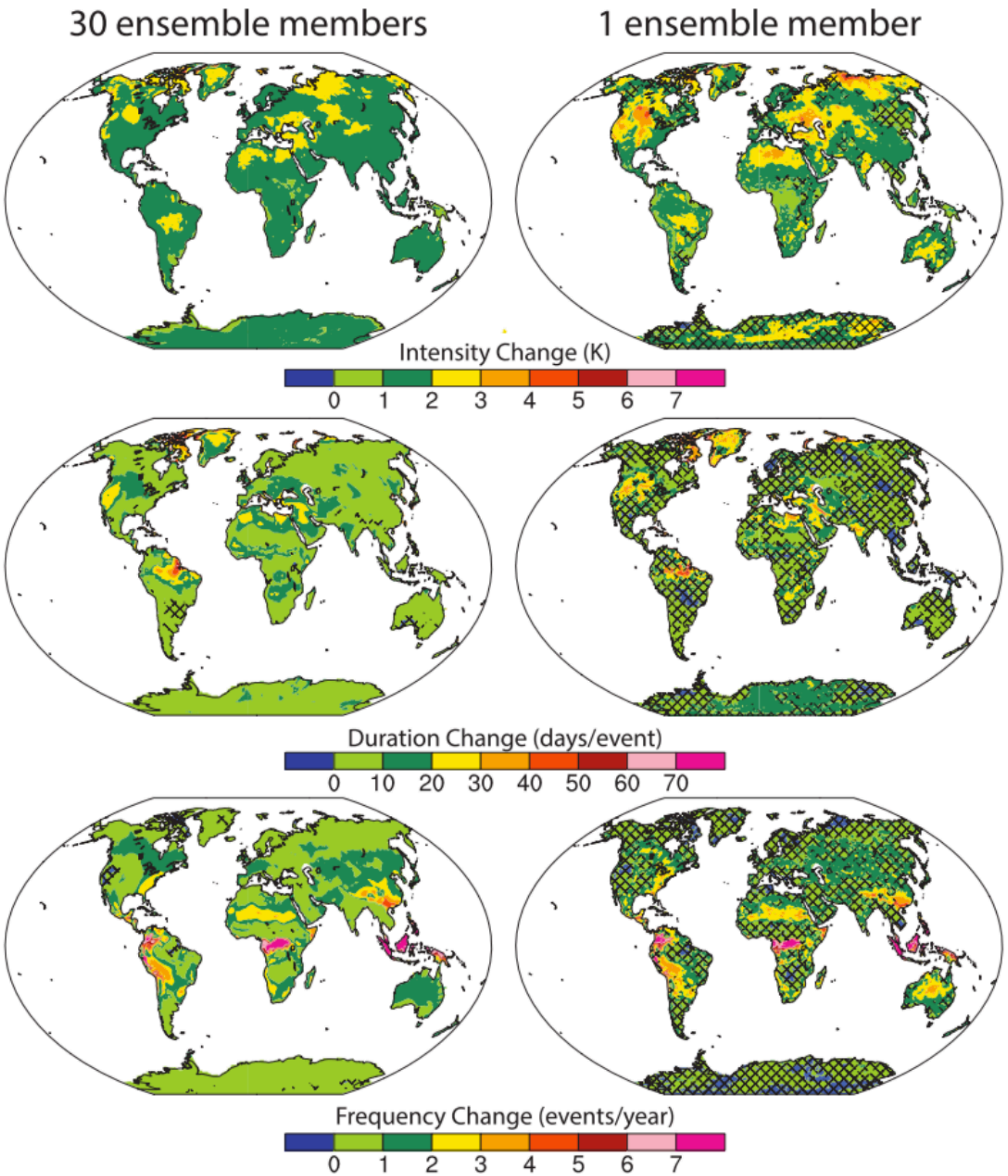
Heat waves and ensemble size

2040s -2010s change in heat wave intensity, duration, and frequency. Hatching indicates differences insignificant at the 95% level using a Student's t – test

Kay et al., 2015



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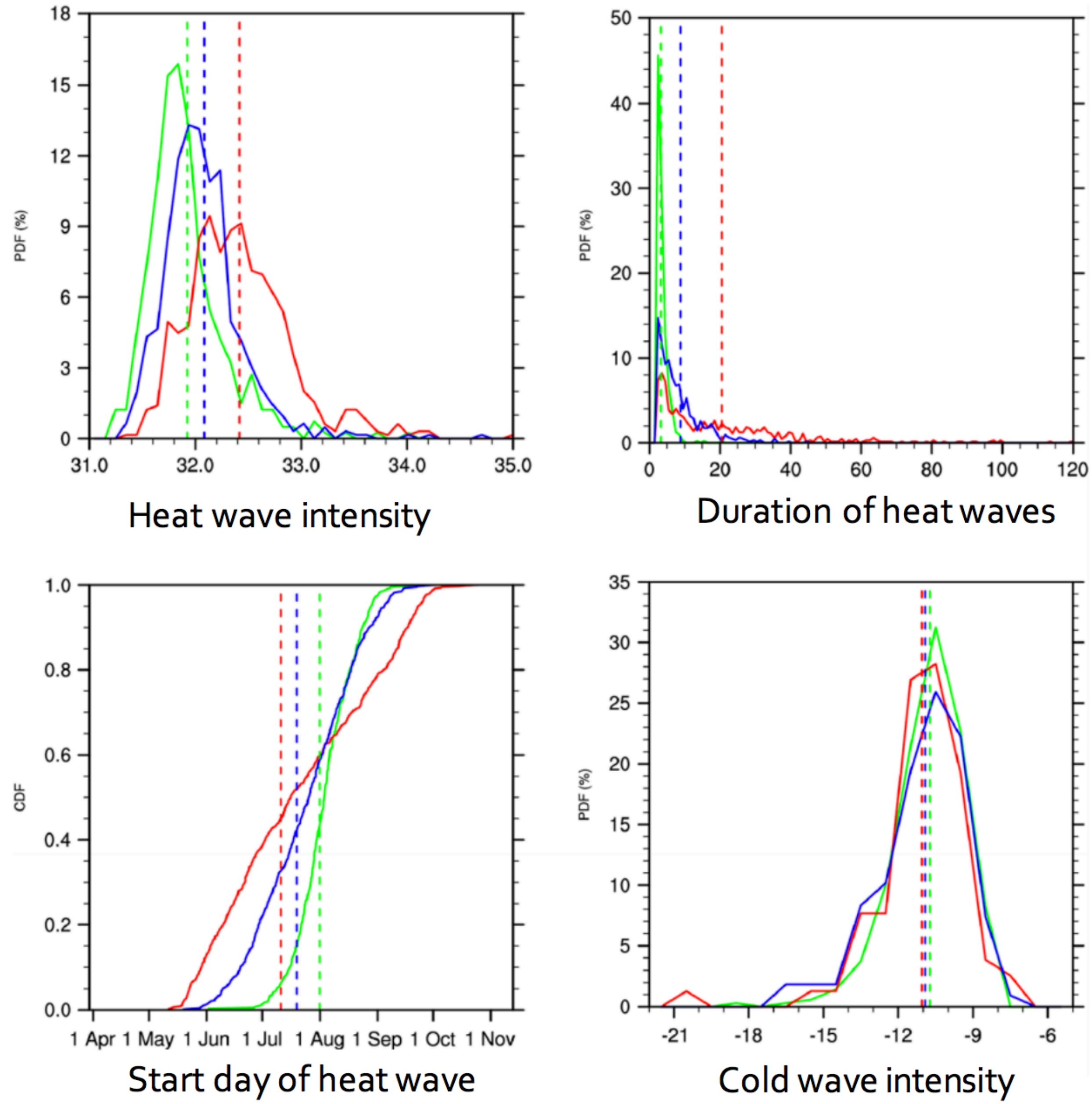
Focusing on extremes in urban areas (Oleson et al., 2016)



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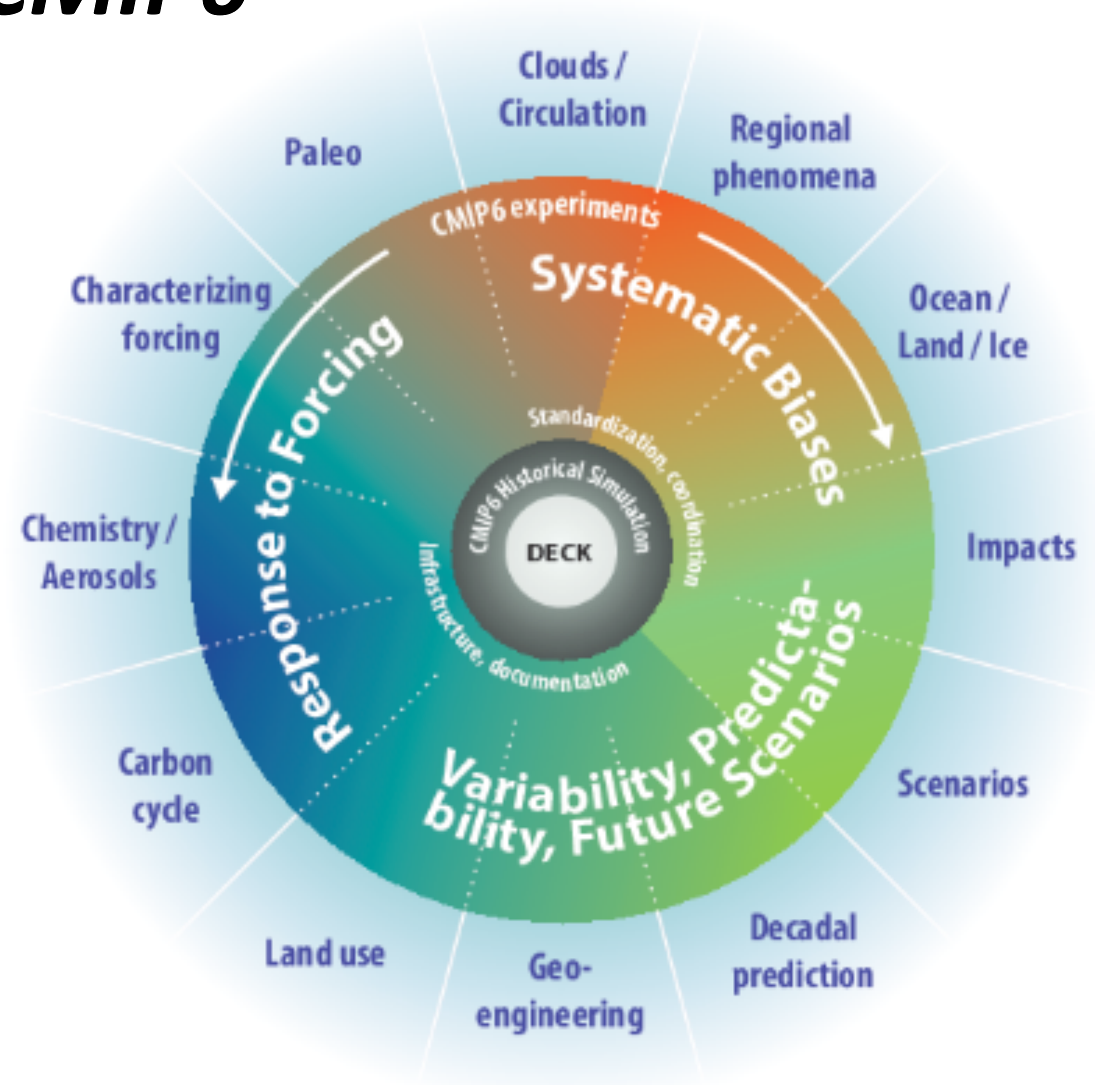
CMIP6


CMIP
The World Climate Research Programme's
Coupled Model Intercomparison Project

CMIP6



Three questions:

- How does the Earth system respond to forcing?
- What are the origins and consequences of systematic model biases?
- How can we assess future climate changes given internal climate variability, predictability, and uncertainties in scenarios?

https://www.geosci-model-dev.net/9/1937/2016/gmd-9-1937-2016.pdf

CMIP6 DECK and Historical

DECK consists of four baseline experiments:

- A historical Atmospheric Model Intercomparison Project (AMIP) simulation
- A pre-industrial control simulation (piControl)
- A simulation forced by an abrupt quadrupling of CO_2 (abrupt-4xCO_2)
- A simulation forced by a 1%/yr CO_2 increase (1pct CO_2)

Historical consists of the period from 1850 to present.

https://www.geosci-model-dev.net/9/1937/2016/gmd-9-1937-2016.pdf

CMIP6 Endorsed MIPs

AerChemMIP	Aerosols and Chemistry Model Intercomparison Project
C4MIP	Coupled Climate Carbon Cycle Model Intercomparison Project
CDRMIP	The Carbon Dioxide Removal Model Intercomparison Project
CFMIP	Cloud Feedback Model Intercomparison Project
DAMIP	Detection and Attribution Model Intercomparison Project
DCPP	Decadal Climate Prediction Project
FAFMIP	Flux-Anomaly-Forced Model Intercomparison Project
GeoMIP	Geoengineering Model Intercomparison Project
GMMIP	Global Monsoons Model Intercomparison Project
HighResMIP	**High-Resolution Model Intercomparison Project**
ISMIP6	Ice Sheet Model Intercomparison Project for CMIP6
LS3MIP	Land Surface, Snow and Soil Moisture
LUMIP	Land-Use Model Intercomparison Project
OMIP	Ocean Model Intercomparison Project
PAMIP	Polar Amplification Model Intercomparison Project
PMIP	Palaeoclimate Modelling Intercomparison Project
RFMIP	Radiative Forcing Model Intercomparison Project
ScenarioMIP	**Scenario Model Intercomparison Project**
VolMIP	Volcanic Forcings Model Intercomparison Project
CORDEX	**Coordinated Regional Climate Downscaling Experiment**
DynVarMIP	Dynamics and Variability Model Intercomparison Project
SIMIP	Sea Ice Model Intercomparison Project
VIACS AB	Vulnerability, Impacts, Adaptation and Climate Services Advisory Board