Northwest **Power** and **Conservation** Council

June 4, 2019

MEMORANDUM

TO: **Power Committee**

FROM: **Massoud Jourabchi, Manager Economic Analysis**

SUBJECT: **Background on Climate Change Models**

BACKGROUND:

Presenter: Dr. David Rupp (Oregon State University)

Summary: In this presentation Dr. Rupp will provide a background on what are Global General Circulation Models (GCM). He will discuss genesis of these models, as well as their projections for regional temperature and precipitation over the next few decades. Although all GCMs project increase in temperature and changes in timing of precipitation, degree of change varies across models. The decadal projections for daily minimum and maximum temperatures as well as change in precipitation across the Northwest will used to evaluate impact on loads and hydro generation. This is a high-level summary of a more extended presentation Dr. Rupp has made at Council's recent workshop on impact of climate change on resource planning.

Relevance: Climate change is anticipated to have both direct (temperature and precipitation) and indirect impacts on the regional use and generation of electricity in the next 20 years.

Workplan: A.3.1. Develop Base Load Forecast: Price Effects & Frozen Efficiency Forecast for 2021 Power Plan

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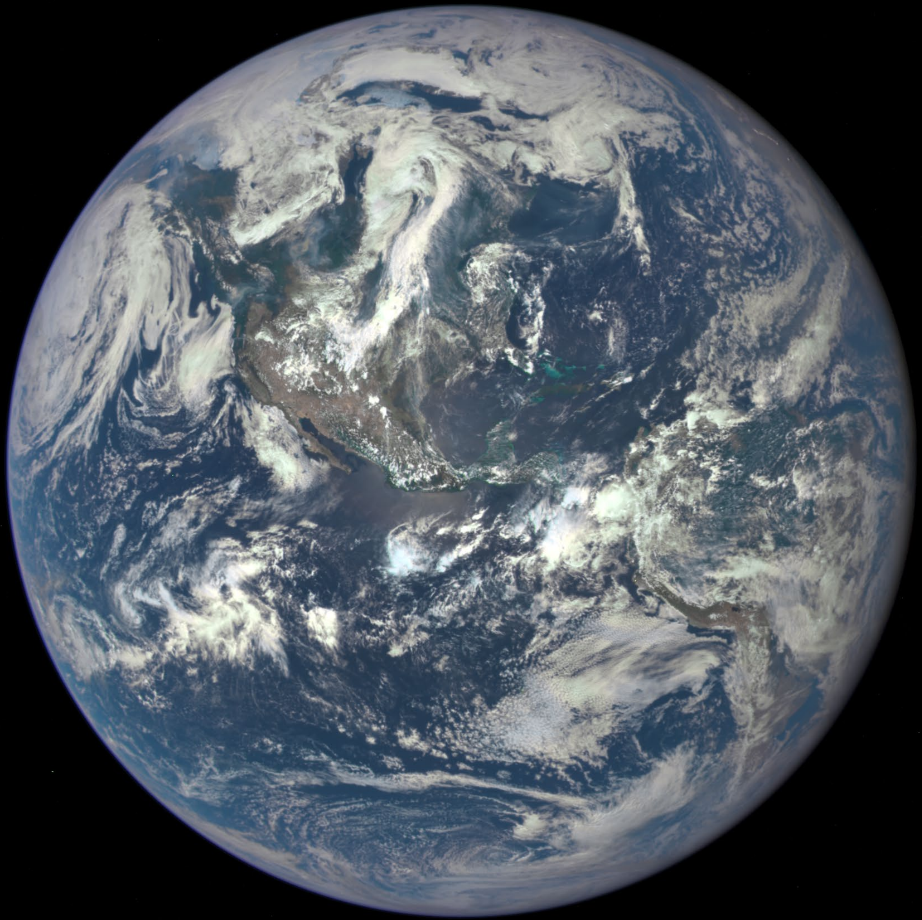
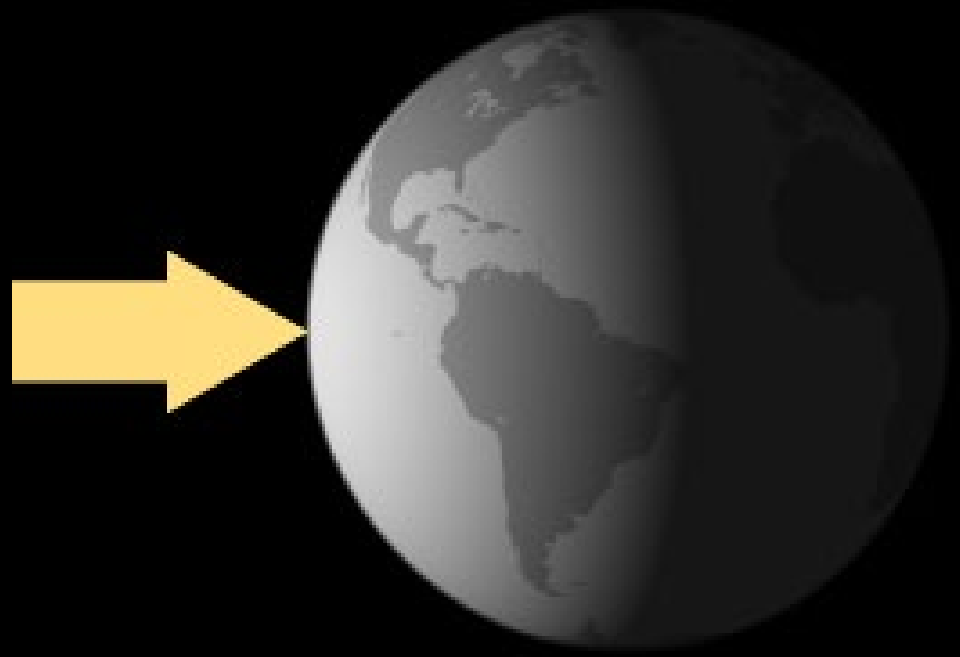
Global Climate Models



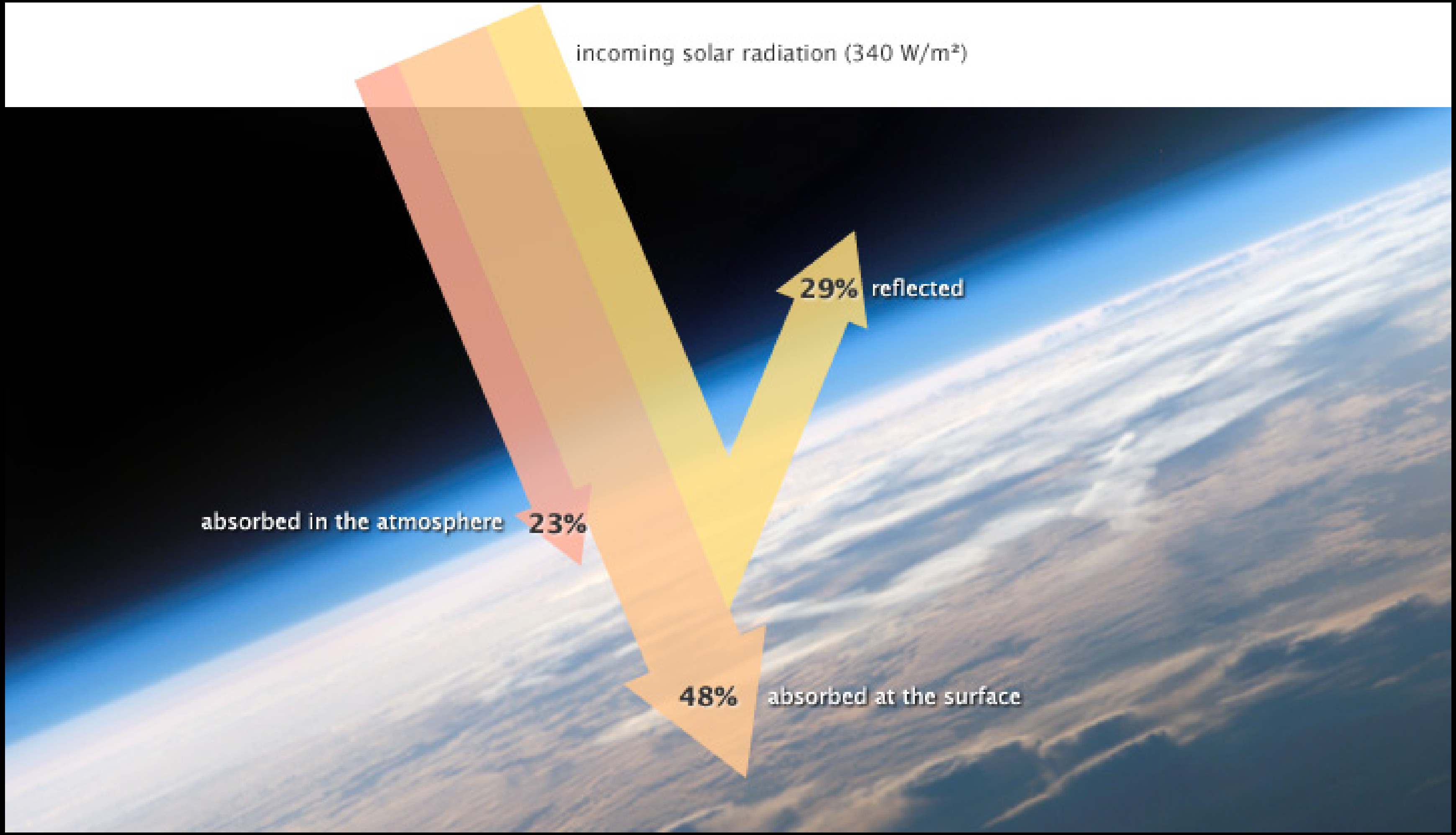
NASA

A Very Simple Global Climate Model

Incoming sunlight (shortwave [SW] radiation)



NASA illustrations by Robert Simmon.



Absorbed Solar Radiation

= (1 - Albedo) x Incoming Solar Radiation

NASA illustrations by Robert Simmon. Astronaut photograph ISS013-E-8948.

Outgoing heat (longwave [LW] or IR radiation)

NASA illustrations by Robert Simmon.

“Blackbody” emission [Stephan-Boltzmann’s Law]:

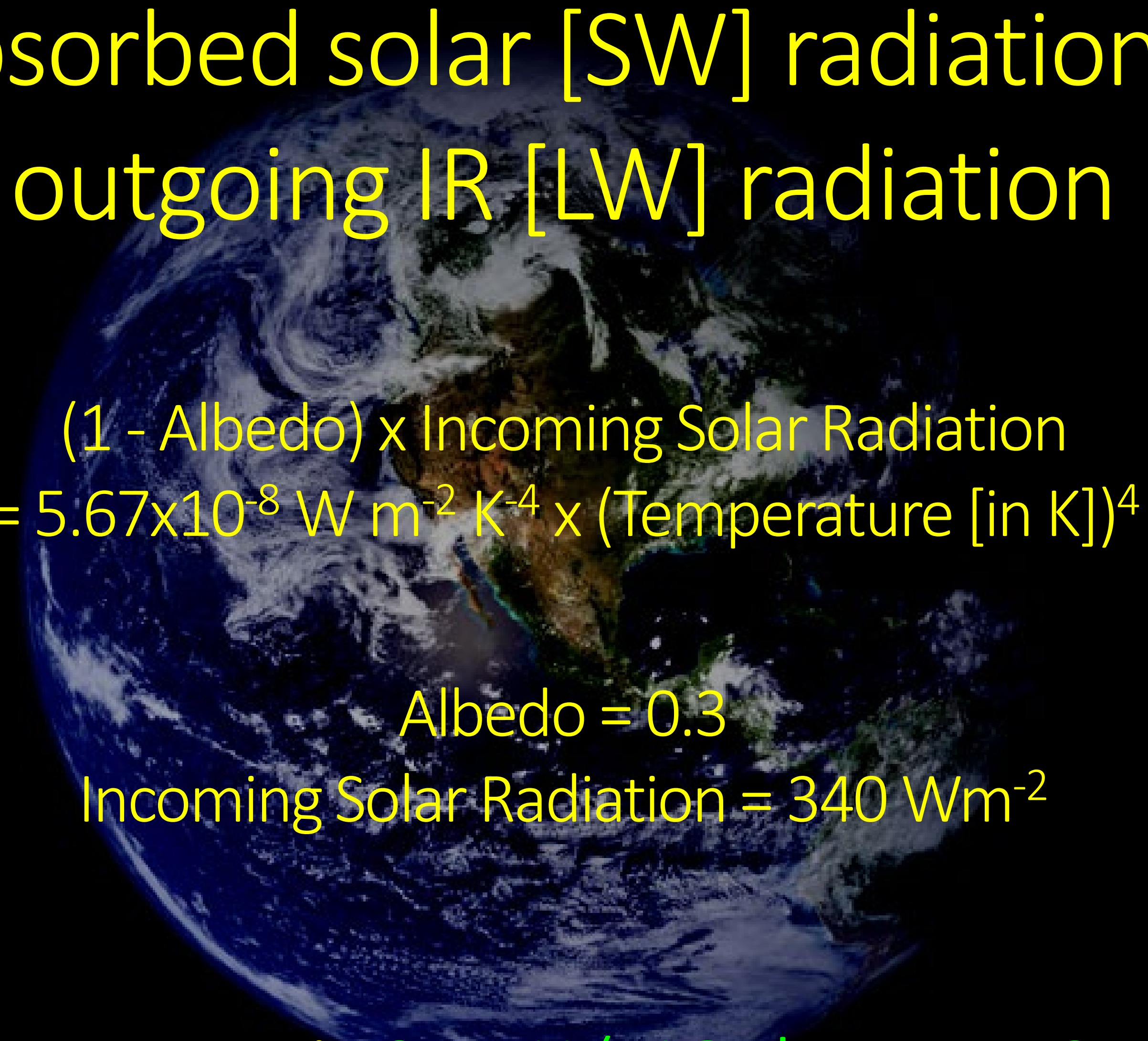
Outgoing IR Radiation=

$5.67x10^{-8}\ Wm^{-2}K^{-4}$ x (Temperature [in K])^4

The greater the temperature, the greater the emitted radiation

Karen Shell

Absorbed solar [SW] radiation = outgoing IR [LW] radiation

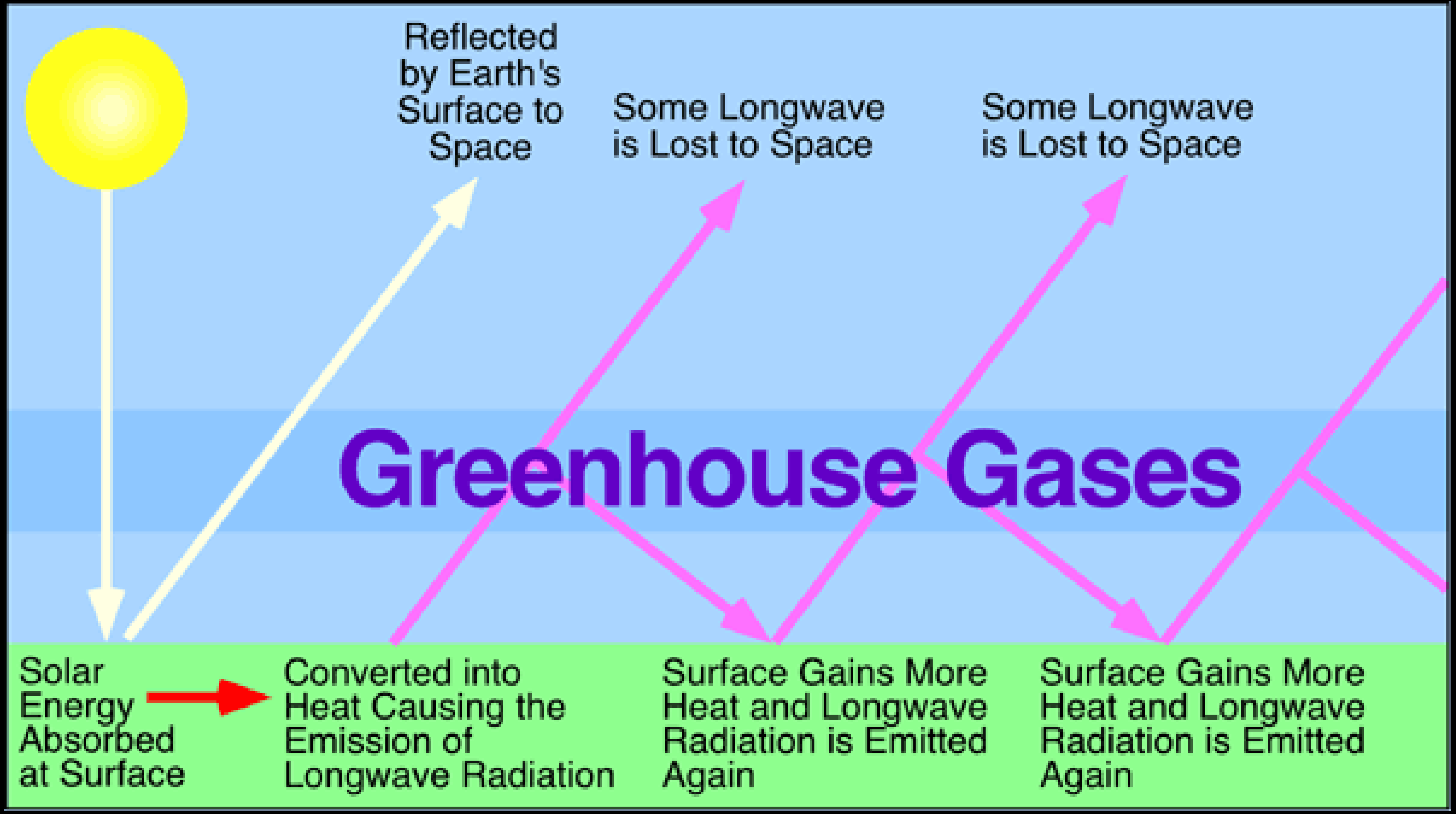


(1 - Albedo) x Incoming Solar Radiation
= 5.67×10^{-8} W m^{-2} K^{-4} x (Temperature [in K])^4

Albedo = 0.3
Incoming Solar Radiation = 340 Wm^{-2}

$\Rightarrow$ Earth's temperature is 255 K (-18 degrees C, -0.4 degrees F)

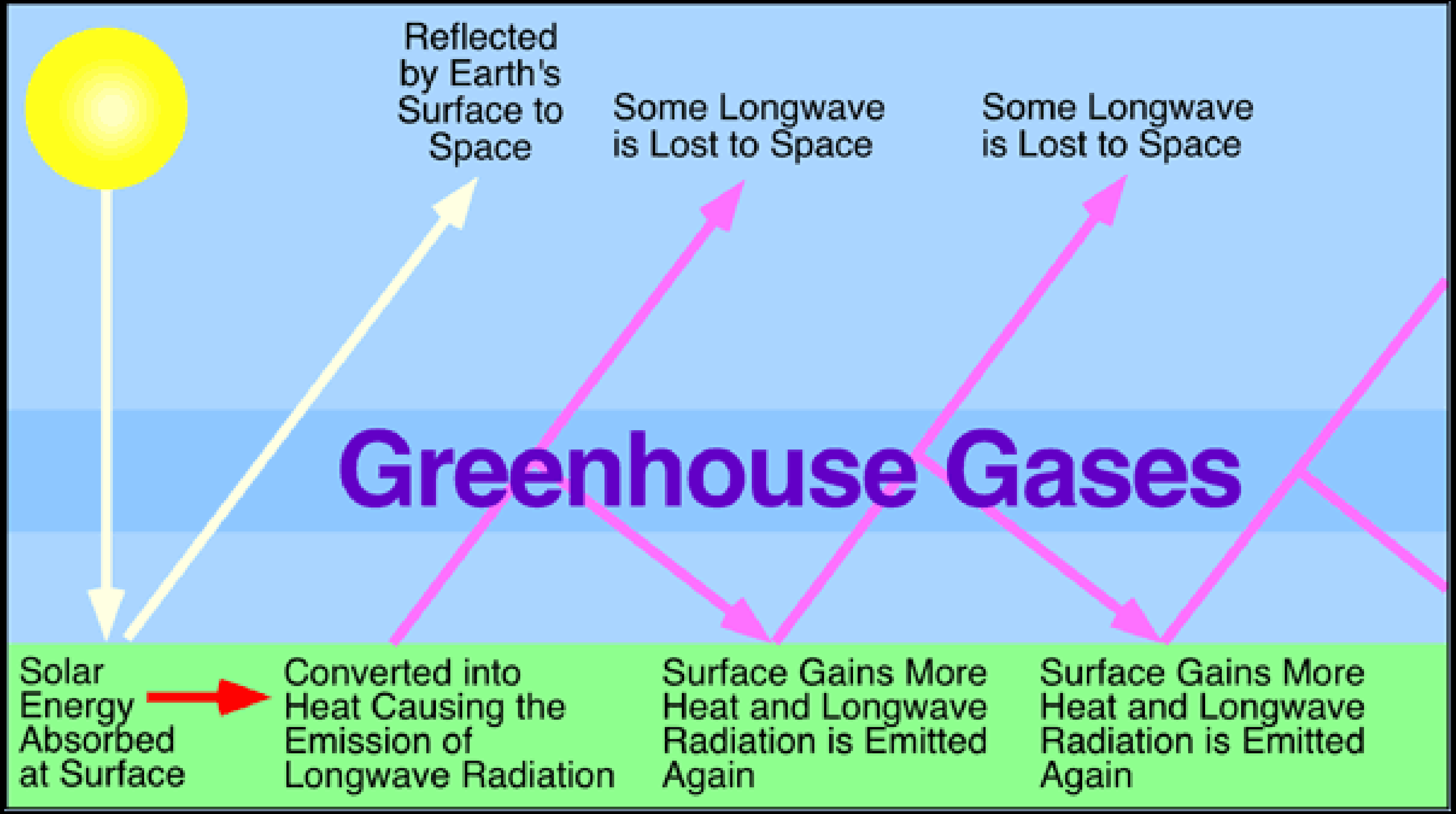
Karen Shell



$\Rightarrow$Earth's temperature is 288 K (15 degrees C, 59 degrees F)

This is the Greenhouse Effect

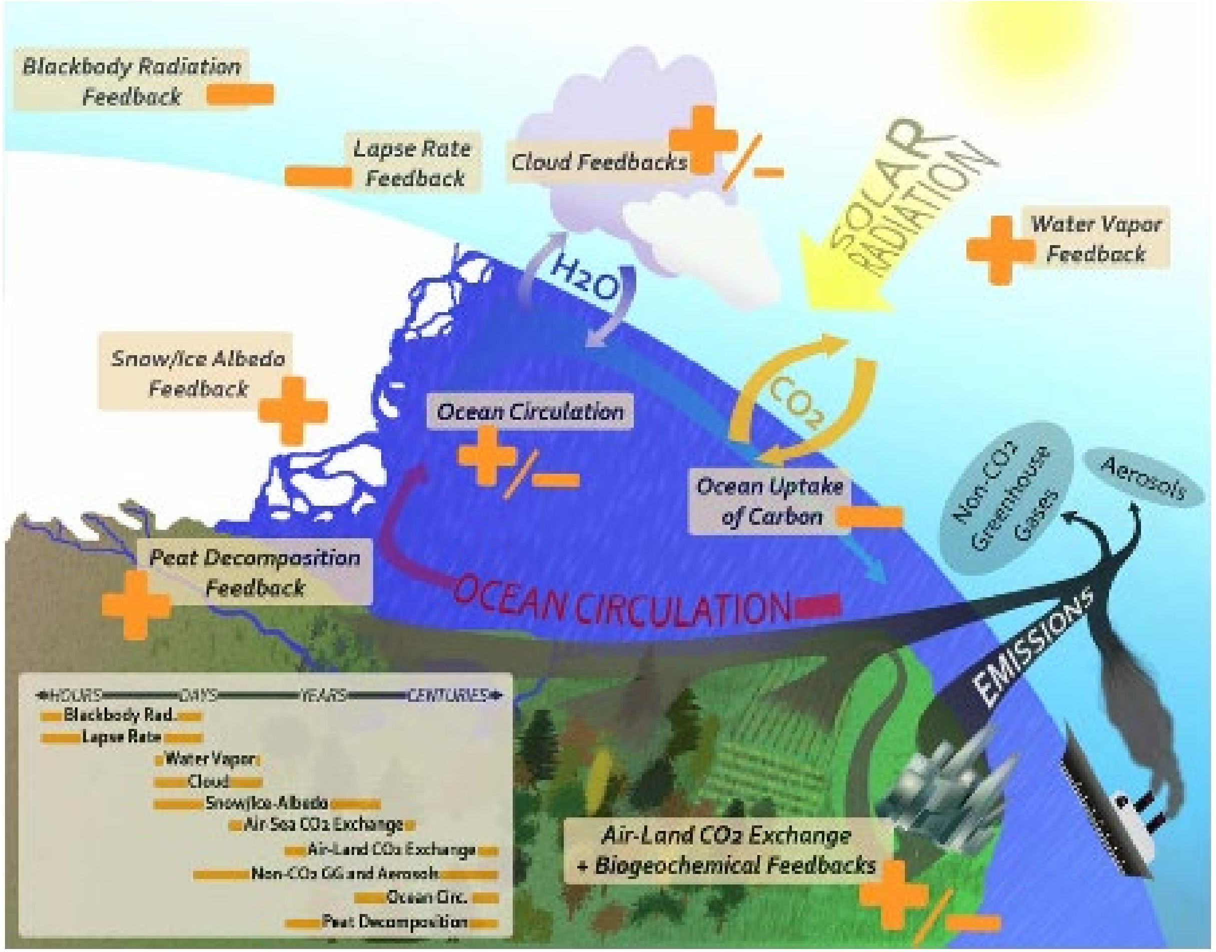
Pidwirny, M. (2006). http://www.physicalgeography.net



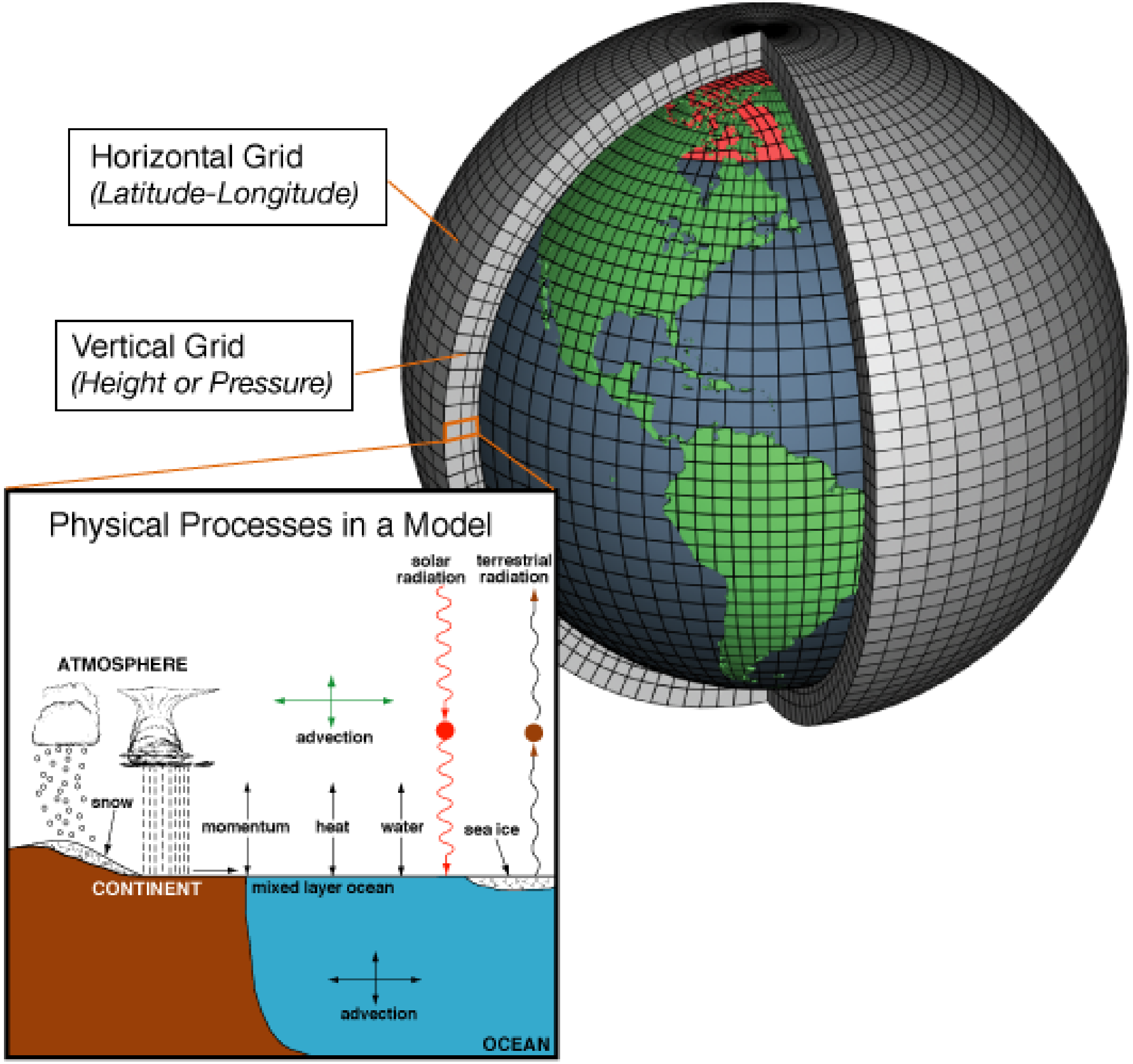
Emitting more greenhouse gases creates an energy ***imbalance***.
This imbalance is called ***radiative forcing***.

The hard part…

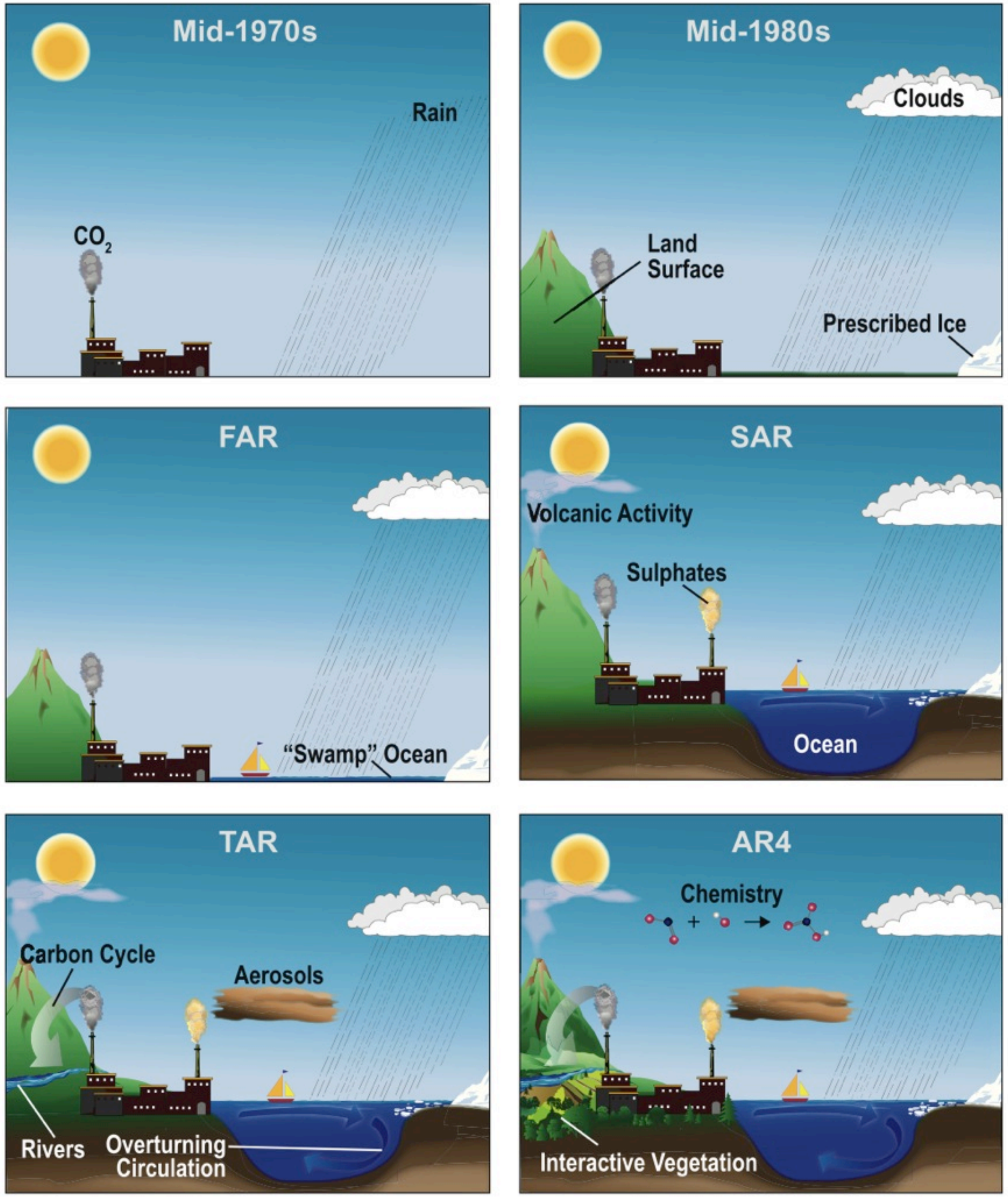
Quantifying the climate ***feedbacks*** to changing greenhouse gas concentrations



Global climate model building blocks



The World in Global Climate Models



Atmospheric General Circulation Model (AGCM)

↓

Ocean General Circulation Model (OGCM)

↓

Coupled General Circulation Model (AOGCM)

↓

Earth System Model (ESM)

Why is there a wide range in climate projections?

Radiative forcing

+

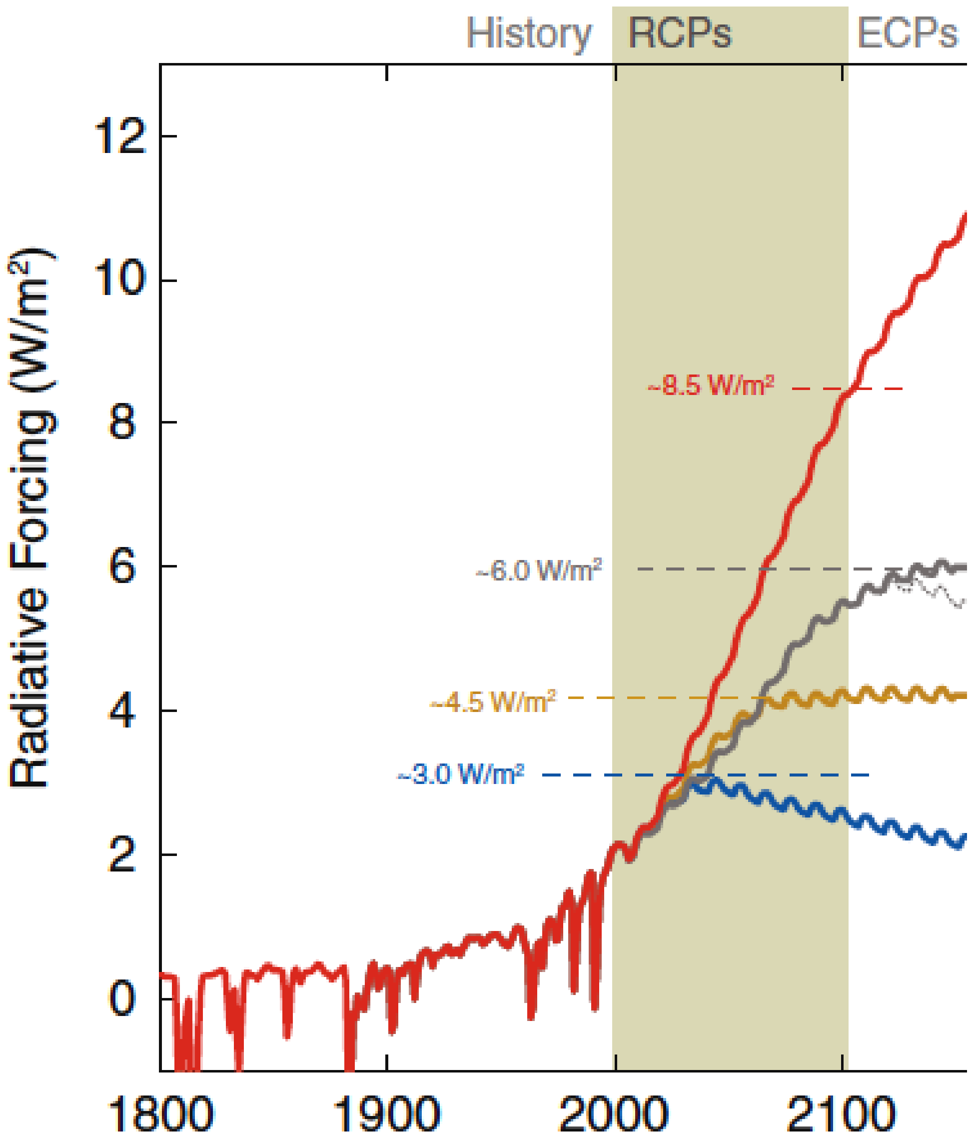
Climate sensitivity

+

Natural variability

Emissions Scenarios

4 Representative Concentration Pathways (RCPs)



Meinshausen et al. 2011

RCP8.5: reaches ~8.5 w/m² by 2100

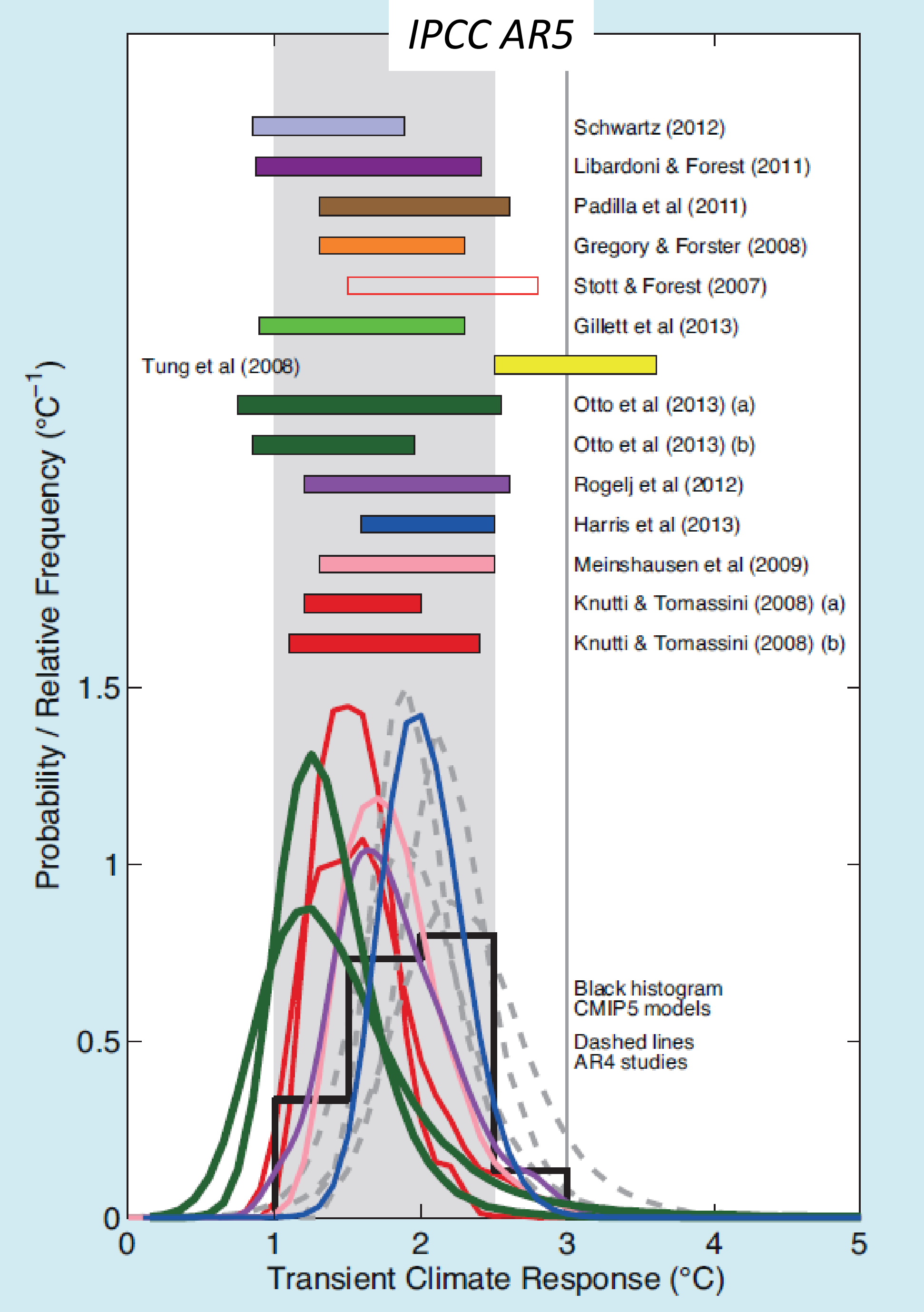
RCP6.0: stabilizes at ~6.0 w/m² by 2150

RCP4.5: stabilizes at ~4.5 w/m² by 2100

RCP2.6: peaks at ~3.0 w/m² in ~2040, declines to ~2.6 w/m² by 2100

GCMs show different climate *sensitivities*

"Transient climate response is likely in the range 1°C to 2.5°C"
– *IPCC AR5*



Transient climate response = temperature increase at time of doubling CO_2 while increasing CO_2 by 1% per year

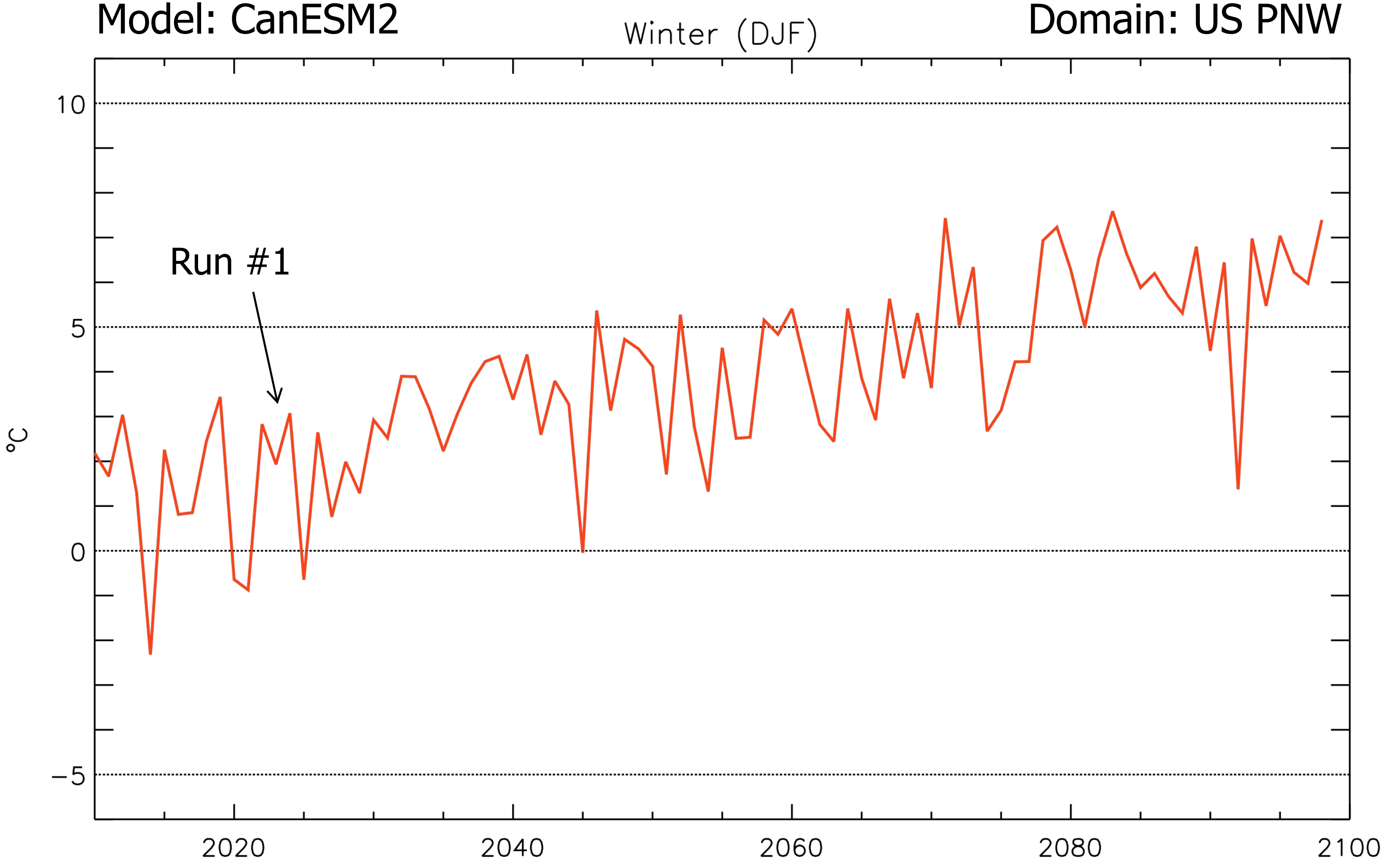
The butterfly effect: initial conditions and internal variability

National Geographic

Initial conditions and internal variability

Model: CanESM2

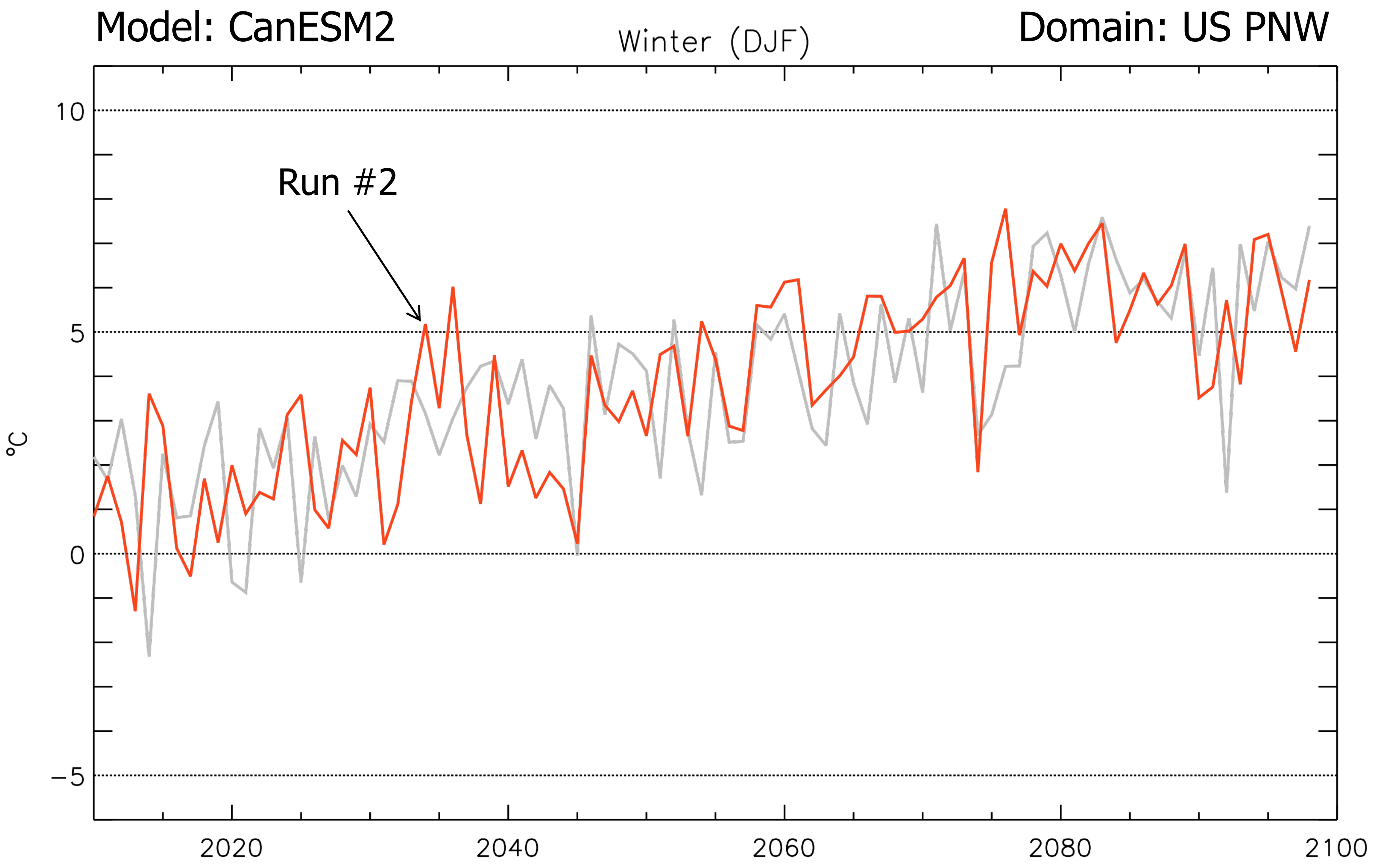
Domain: US PNW



Modeled changes relative to 1950-1999 baseline.

RCP8.5

Initial conditions and internal variability



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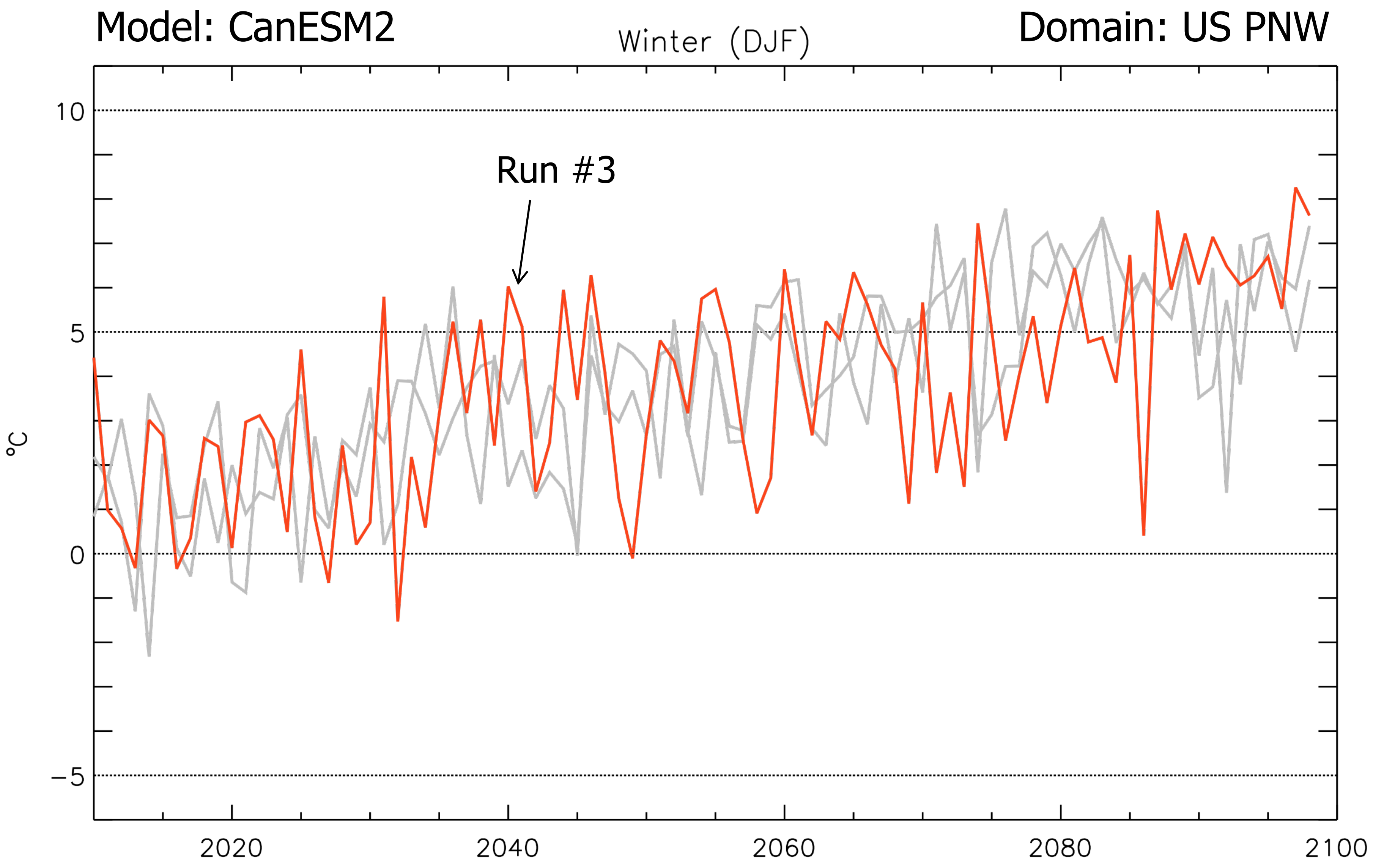

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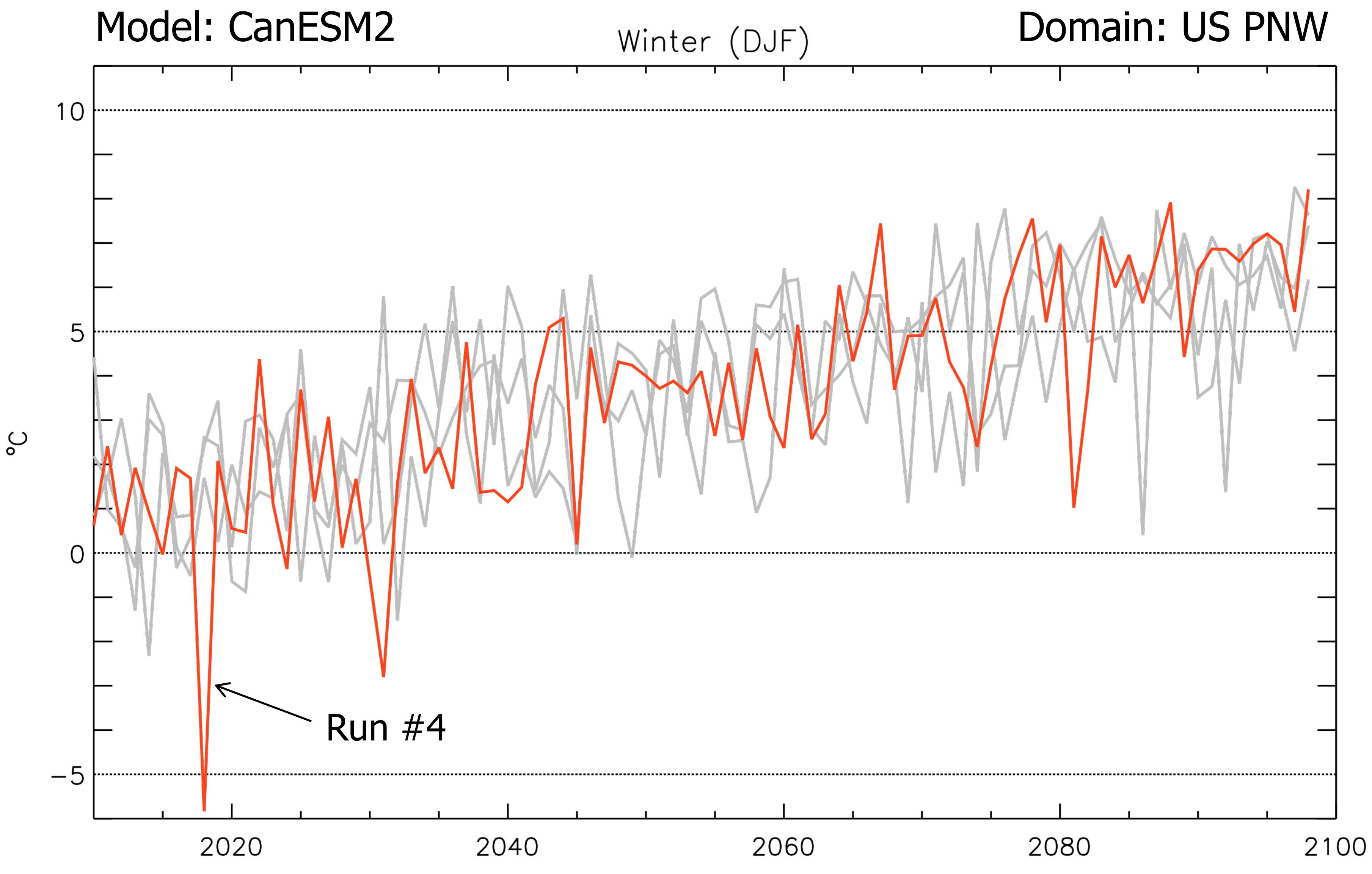

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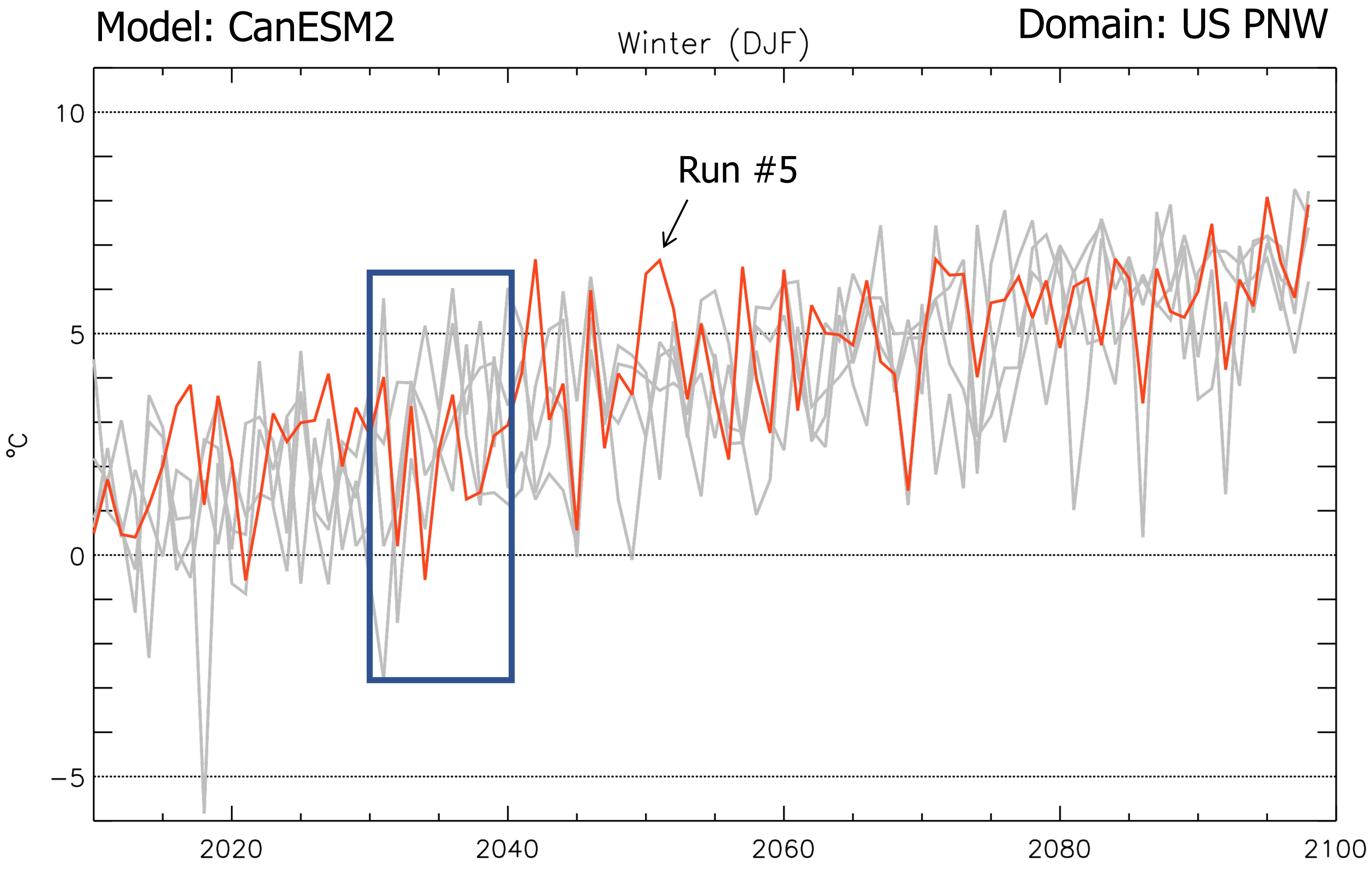


Modeled changes relative to 1950-1999 baseline.

RCP8.5

Earth System Models

Developed to account for all the major processes that effect the climate

Increasing in complexity

Despite improvements, slow to converge towards a common *climate sensitivity*

An overview of the Representative Concentration Pathways

The four Representative Concentration Pathways (RCPs):

8.5, 6.0, 4.5, & 2.6

The four Representative Concentration Pathways (RCPs):

8.5, 6.0, 4.5, & 2.6

What do these numbers mean?

“8.5” = 8.5 Watts per square meter

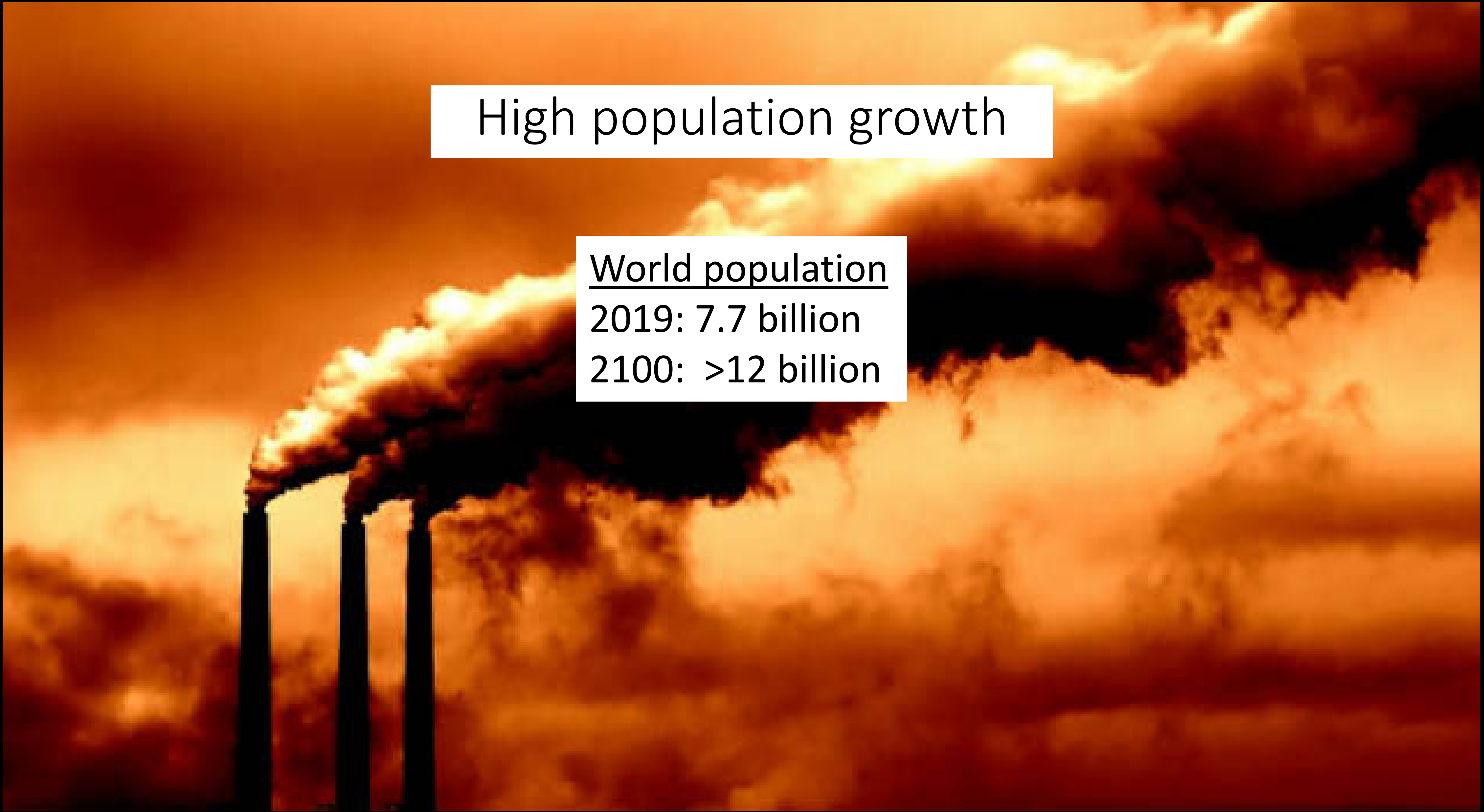
RCP 8.5

A heterogeneous world

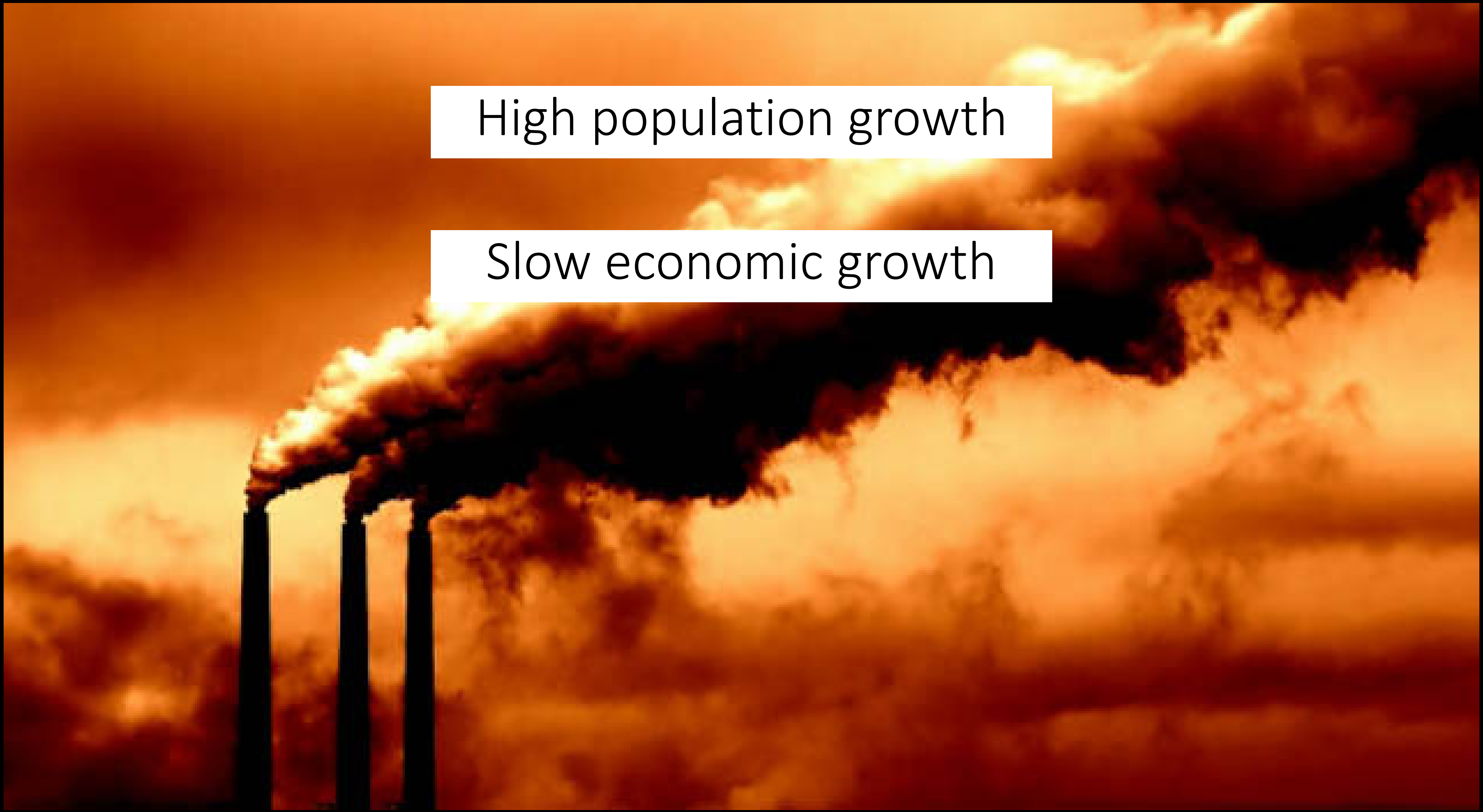
NASA

High population growth

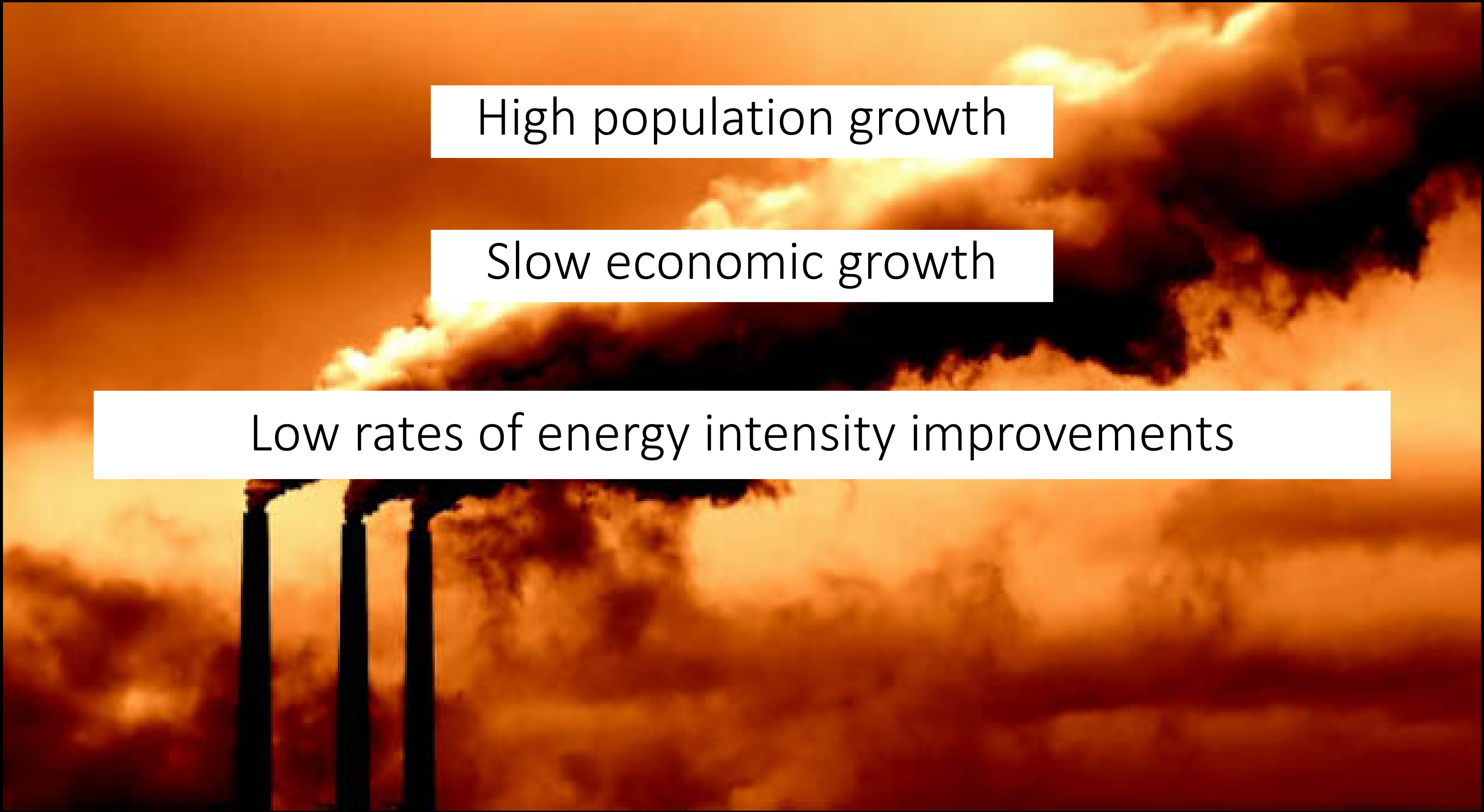
<u>World population</u>
2019: 7.7 billion
2100: >12 billion



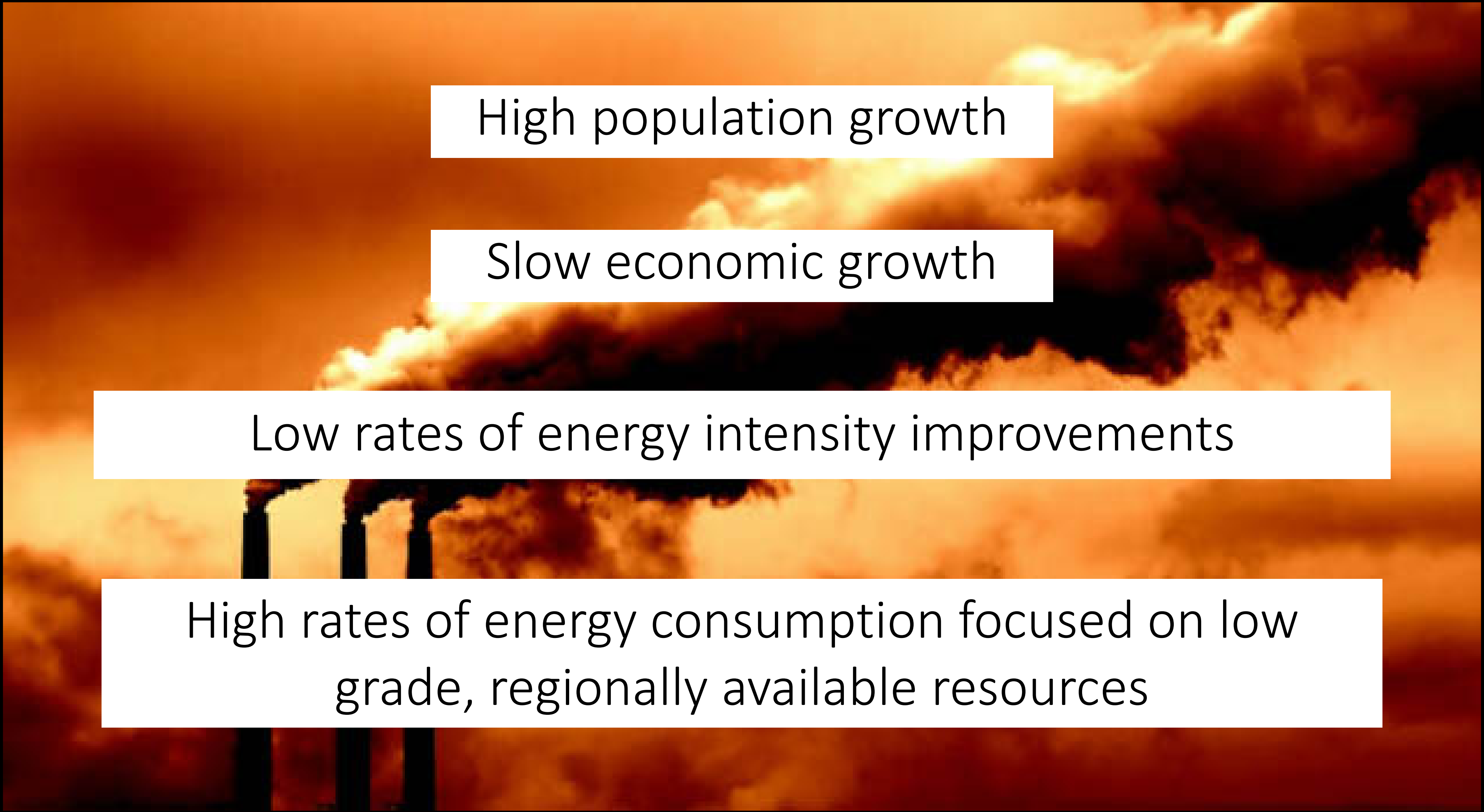
NASA



NASA


High population growth
Slow economic growth
Low rates of energy intensity improvements

NASA



High population growth

Slow economic growth

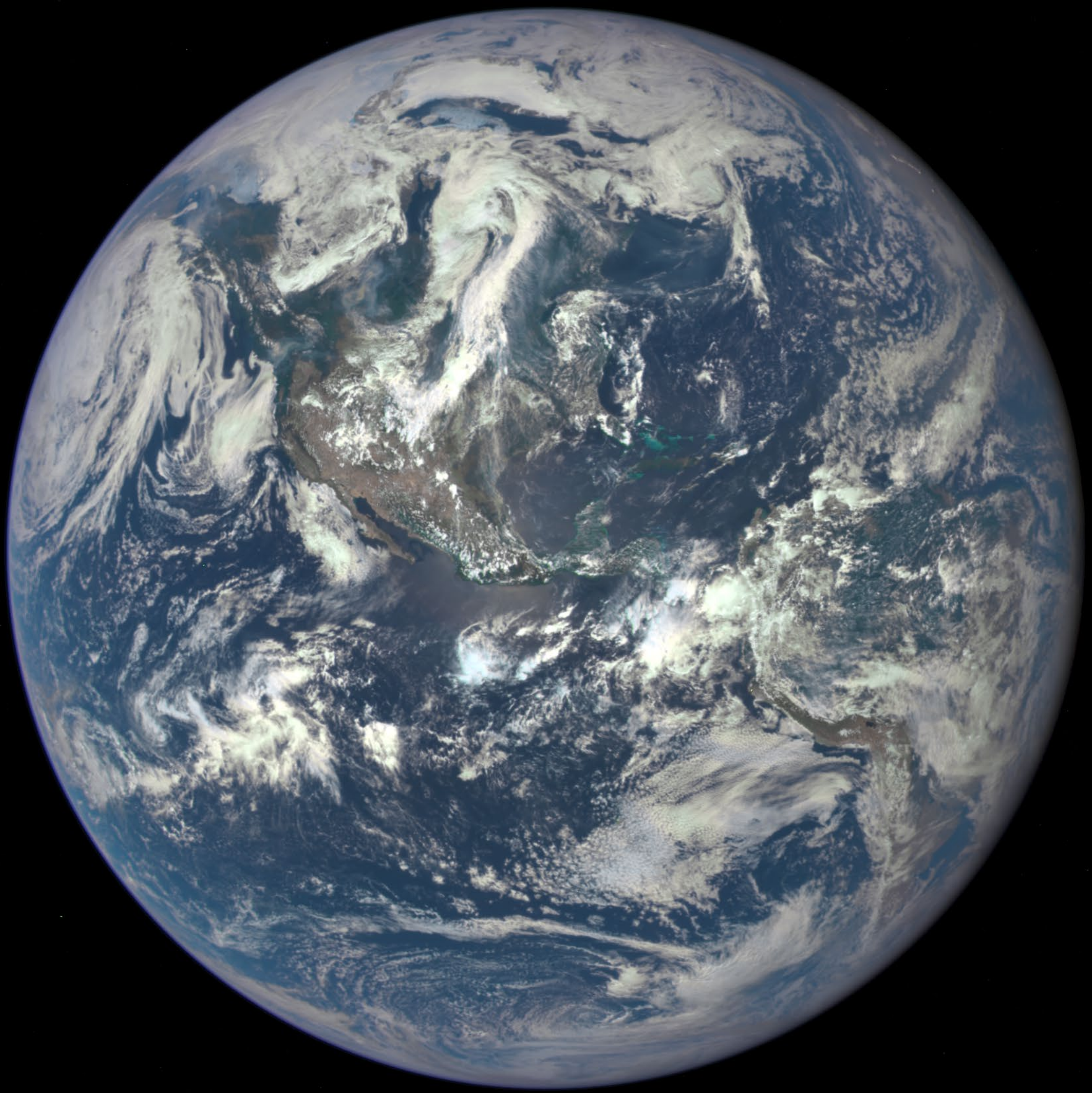
Low rates of energy intensity improvements

High rates of energy consumption focused on low grade, regionally available resources

NASA

RCP 2.6

Limiting global warming to 2°C



NASA

Is it technologically feasible to limit warming to 2 degrees C?

NASA

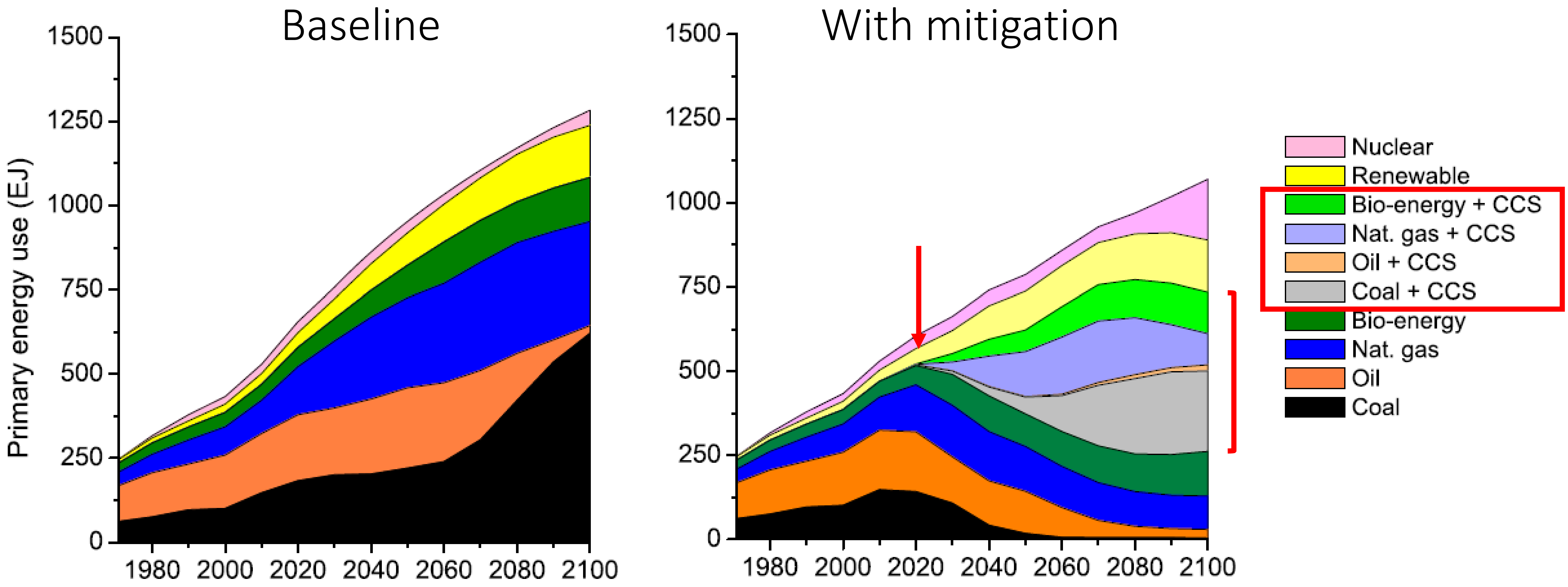
Is it technologically feasible to limit warming to 2 degrees C?

Assumptions: medium economic growth, moderate rates of energy intensity improvements, geopolitical landscape not characterized by conflict and lack of international agreements

NASA

RCP2.6

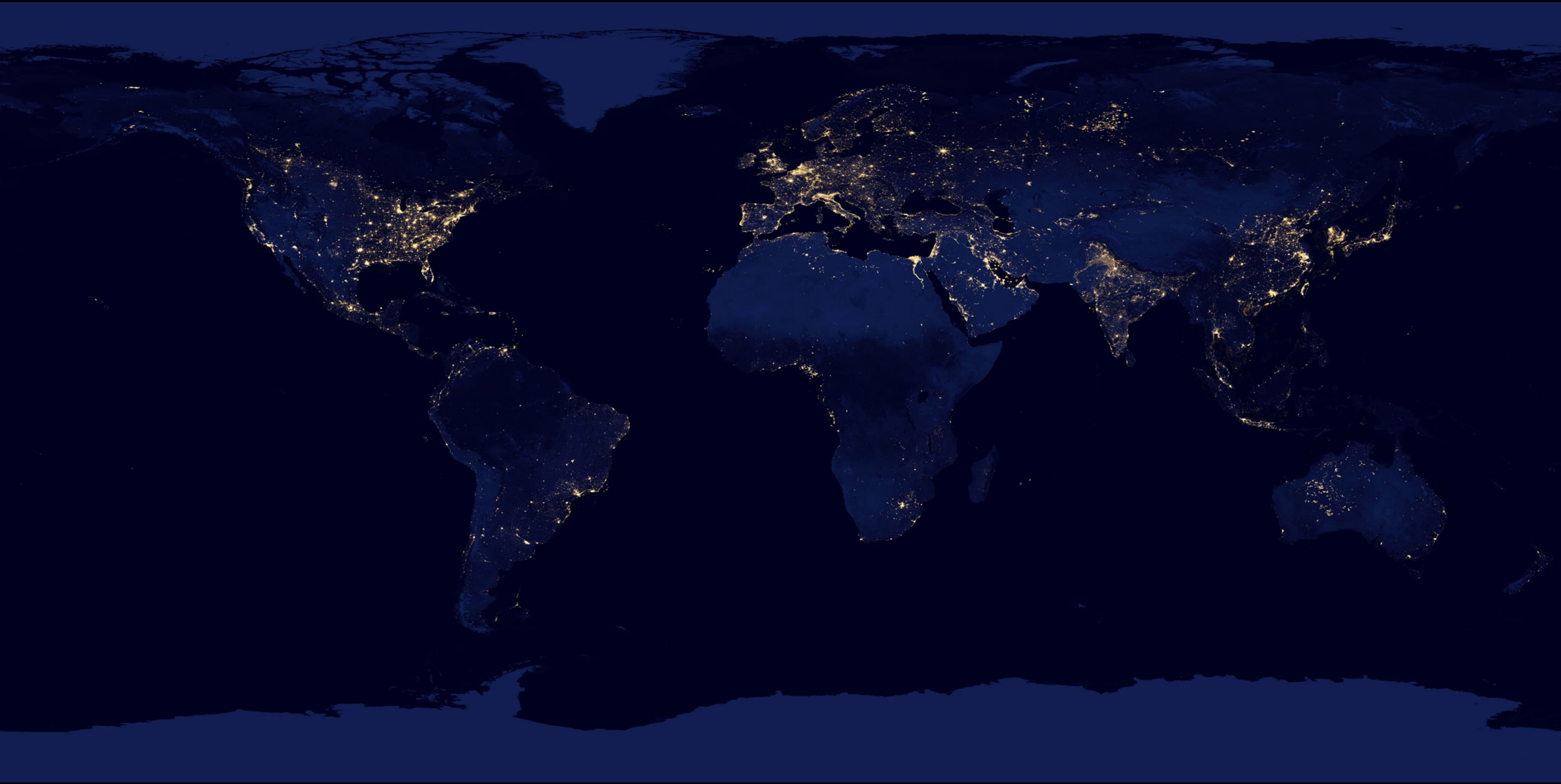
Primary mitigation measure: carbon capture and storage (CCS)



Van Vuuren et al., 2011

RCP 4.5

A cost-minimizing pathway to stabilization



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Common global pricing on emissions

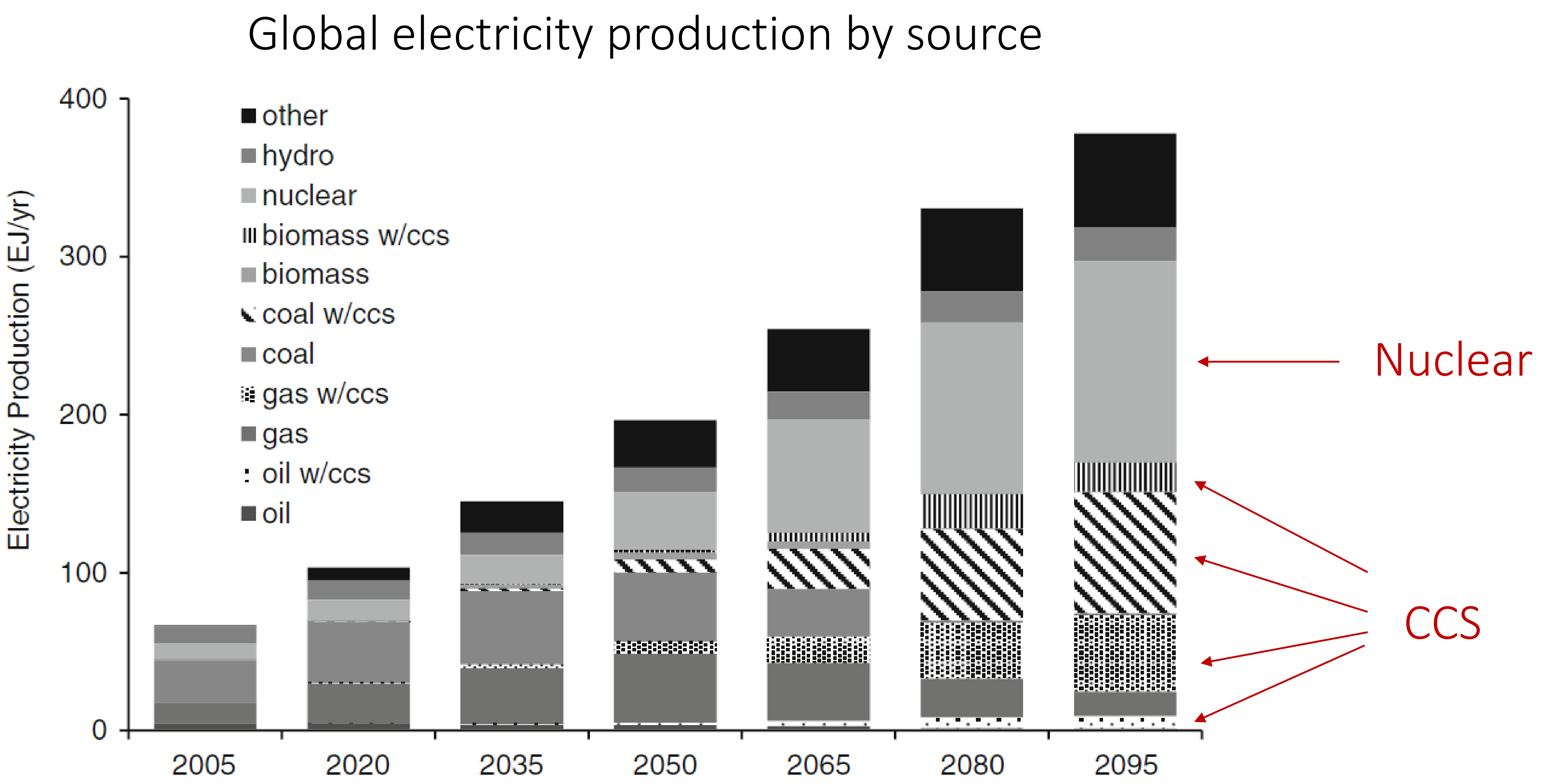
All nations participate

All sectors included

All available technology options used to minimize cost

NASA

RCP4.5



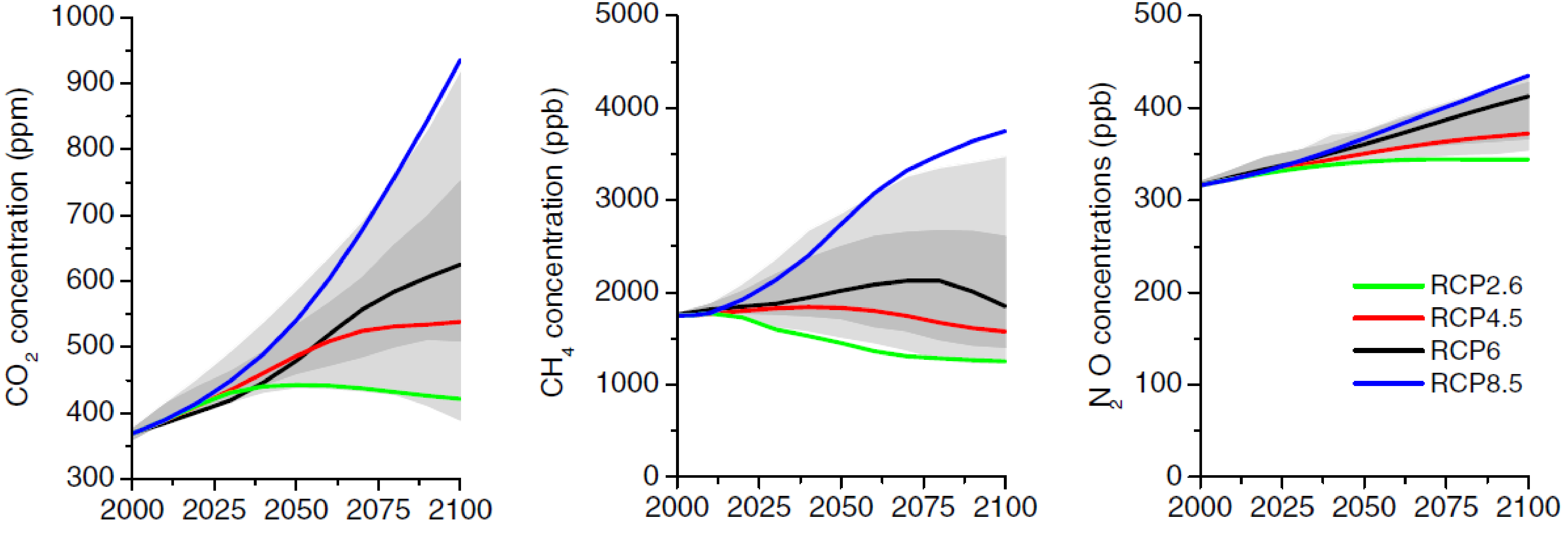
Thompson et al., 2011

RCPs: Greenhouse gas concentrations

Carbon dioxide

Methane

Nitrous oxide



Van Vuuren et al., 2011

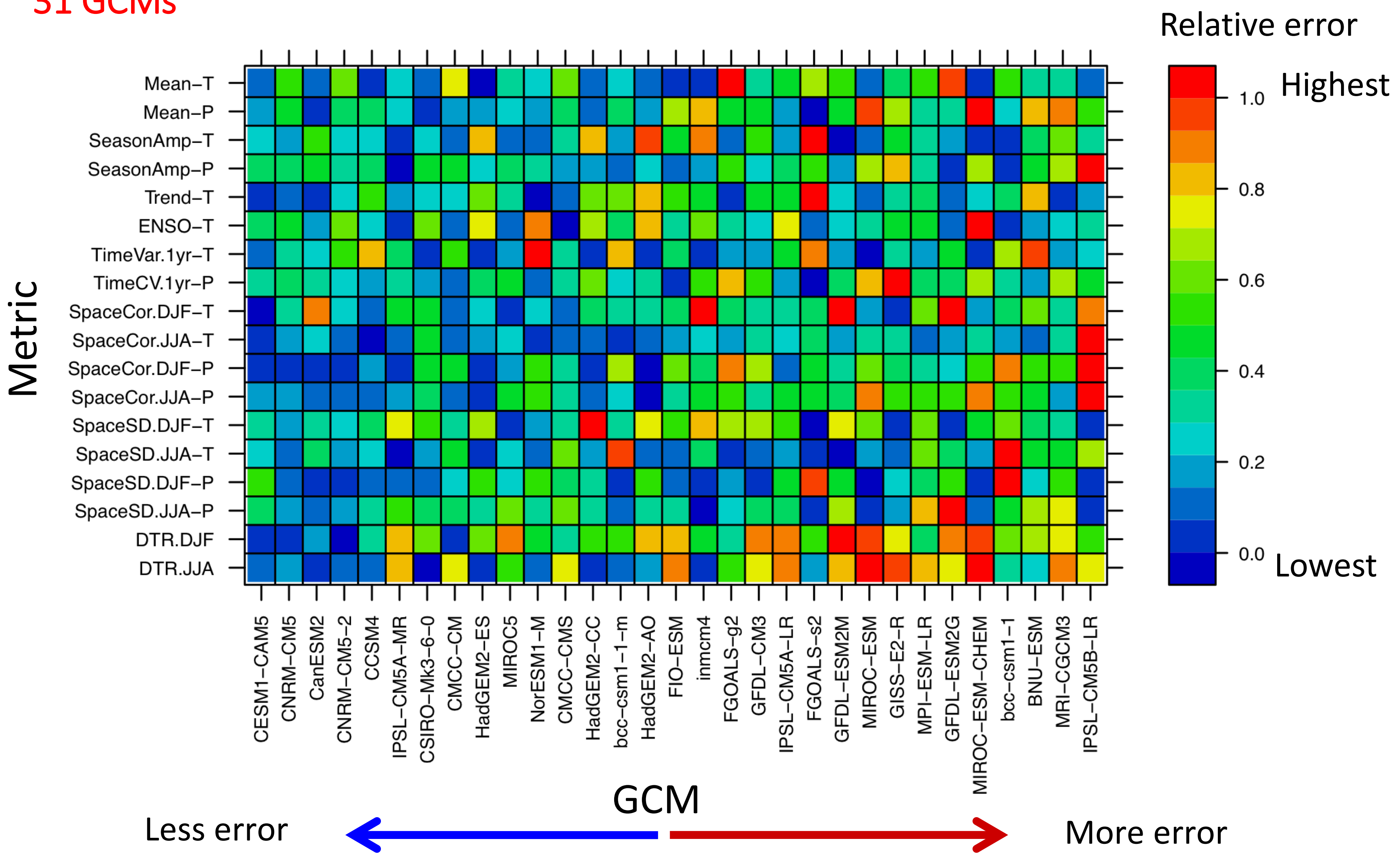
Climate model/scenario selection for the northwest US

Climate model/scenario selection: a 2-part process

1. Historical performance
2. Future projections

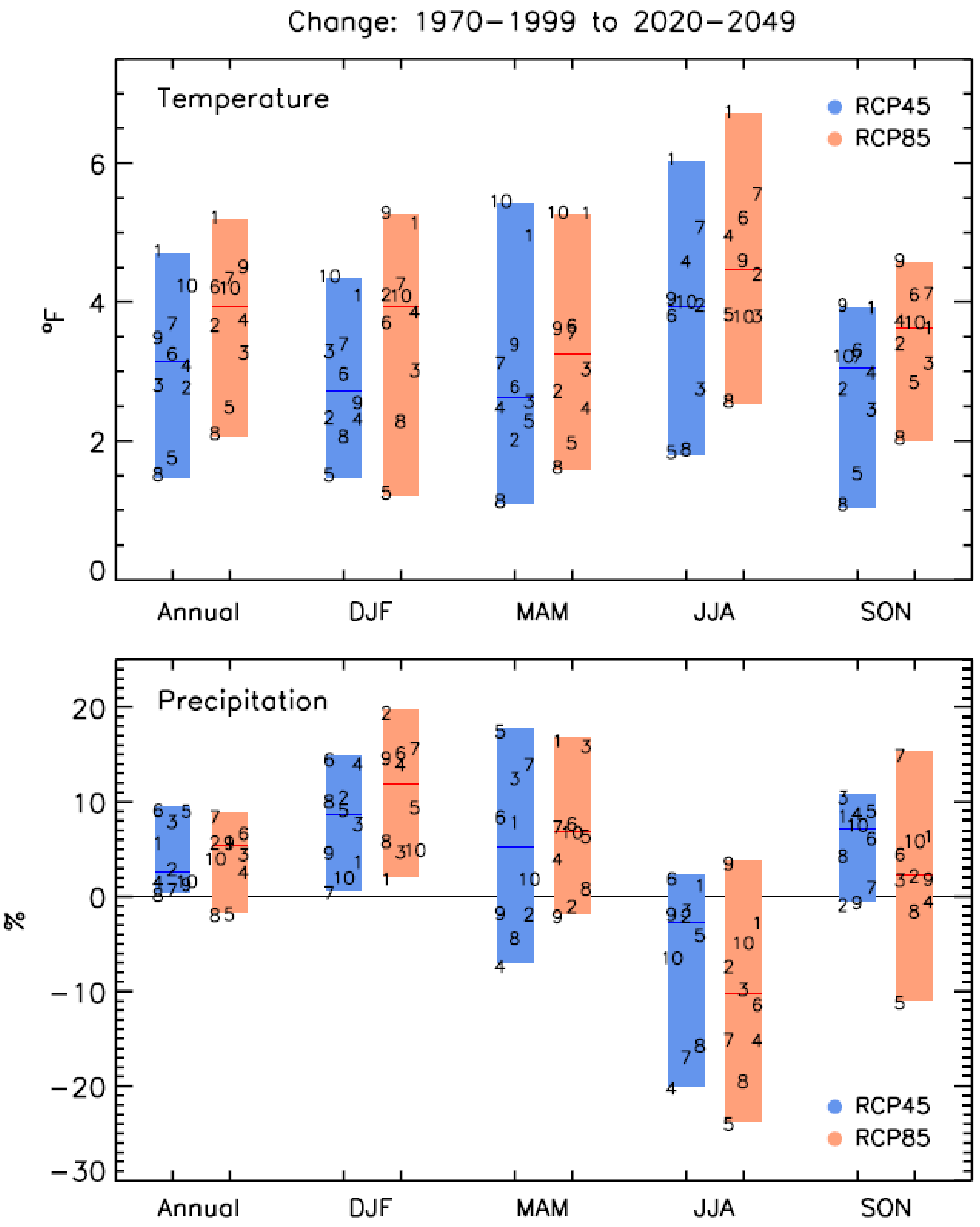
GCM Performance Quilt

18 Metrics
31 GCMs



2030s climate projections for the Columbia River Basin**

Increased precipitation = more intense precipitation, not more frequent precipitation

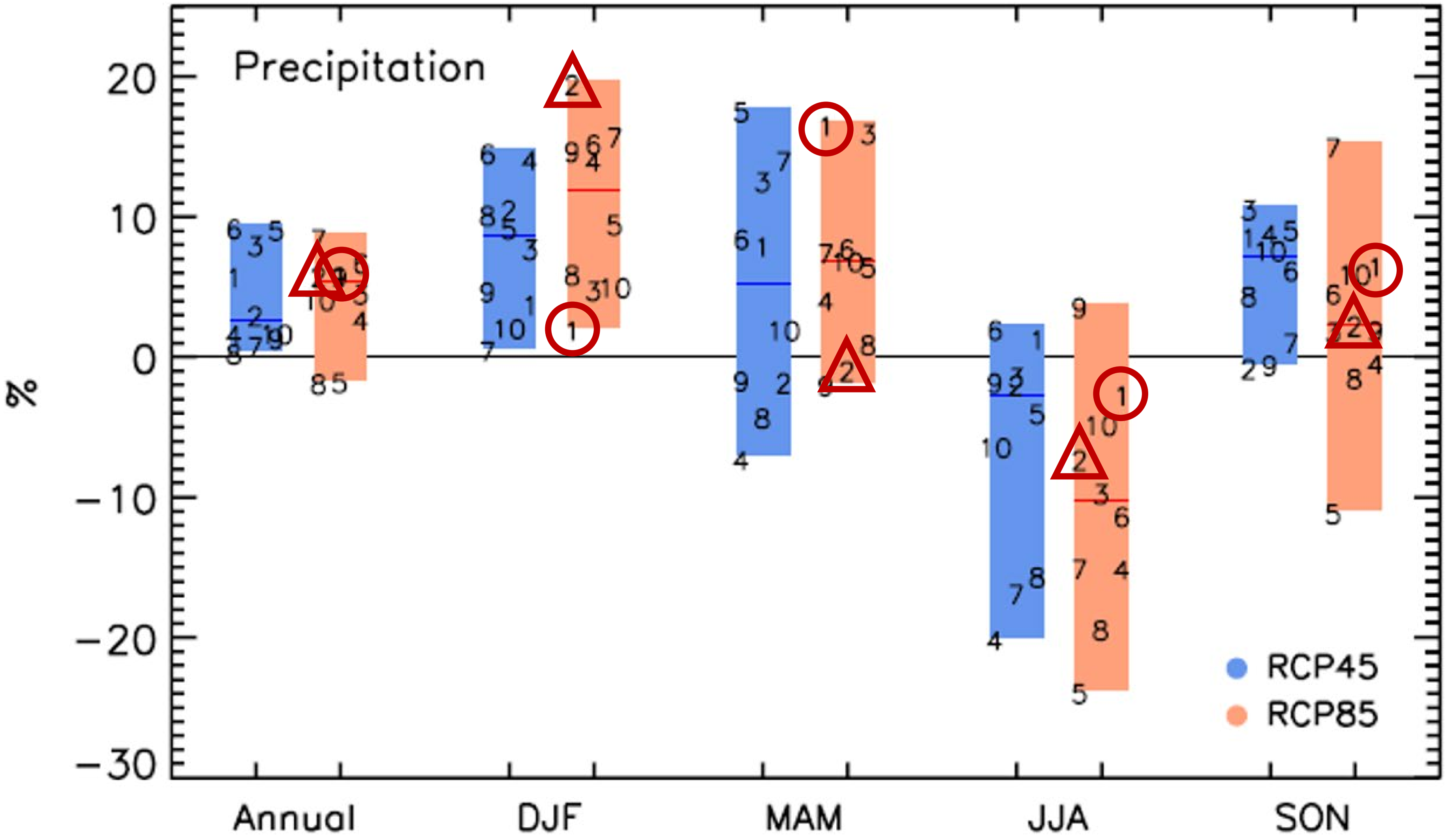


The RMJOC-II "10"

1. **CanESM2**
2. CCSM4
3. **CNRM-CM5**
4. CSIRO-Mk3-6-0
5. GFDL-EMS2M
6. **HadGEM2-CC**
7. **HadGEM2-ES**
8. inmcm4
9. IPSL-CM5A-MR
10. MIROC5

**Above The Dalles

2030s precipitation projections for the Columbia River Basin**



The RMJOC-II "10"

1. **CanESM2**
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3. **CNRM-CM5**
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6. **HadGEM2-CC**
7. **HadGEM2-ES**
8. inmcm4
9. IPSL-CM5A-MR
10. MIROC5

**Above The Dalles

Extra slides

Climate change impacts on fish and wildlife

Fish habitat is expected to degrade due to increasing peak flows, earlier streamflow timing, reduced summer low flows, and warming summer stream temperatures that could shift preferred habitats, alter the timing of life history stages, and exacerbate current stressors for the Pacific Northwest's salmon and steelhead (Oncorhynchus spp.) and other aquatic wildlife.

3rd Oregon Climate Assessment Report (2017)

Climate change impacts on fish

Warmer temperatures, shift from snow to rain, and higher rainfall intensities increase risk of:

- Lethal stream temperatures
- Scouring of shallow-buried eggs from heavier winter streamflow
- Downstream migration timing of smolts desynchronized with spring freshet
- Upstream migration in summer/fall delayed by lower summer flow

	Historical relative performance by evaluation criteria				Ranking change in temperature, 1970-1999 to 2020-2049, RCP8.5					Ranking by change in precipitation, 1970-1999 to 2020-2049, RCP8.5				
	Rupp et al. (2013)	Atmospheric rivers	1-5 year drought	Global precipitation	Temperature, annual	Temperature, winter	Temperature, spring	Temperature, summer	Temperature, fall	Precipitation, annual	Precipitation, winter	Precipitation, spring	Precipitation, summer	Precipitation, fall
1. CanESM2	A	A	A+	A	1	2	2	1	6	4	10	1	2	2
2. CCSM4	A	A	*	C	7	4	7	6	7	3	1	9	4	5
3. CNRM-CM5	A	A	A	A	8	8	6	8	8	6	9	2	5	7
4. CSIRO-Mk3-6-0	B	C	B	B	6	6	8	4	4	8	5	7	8	8
5. GFDL-EMS2M	C	B	B	C	9	10	9	7	9	9	6	6	10	10
6. HadGEM2-CC	A	A	A	A	4	7	3	3	3	2	3	3	6	4
7. HadGEM2-ES	A	*	A+	A	3	3	5	2	2	1	2	4	7	1
8. inmcm4	C	B	B	B	10	9	10	10	10	10	7	8	9	9
9. IPSL-CM5A-MR	A	A	A	B	2	1	4	5	1	5	4	10	1	6
10. MIROC5	B	B	C	B	5	5	1	9	5	7	8	5	3	3

Performance		Relative change in temperature	Relative change in precipitation	Relative change in precipitation
A	Better	High warming	High increase	High decrease
B	Medium	Near-mean warming	Medium high increase	Medium high decrease
C	Poorer	Medium-low warming	Near-mean increase	Near-mean decrease
		Low warming	Medium-low increase	Medium low decrease
			Low increase	Low decrease