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THE STATE UNIVERSITY
OF NEW JERSEY

Climate Change: Past, Present, and Future

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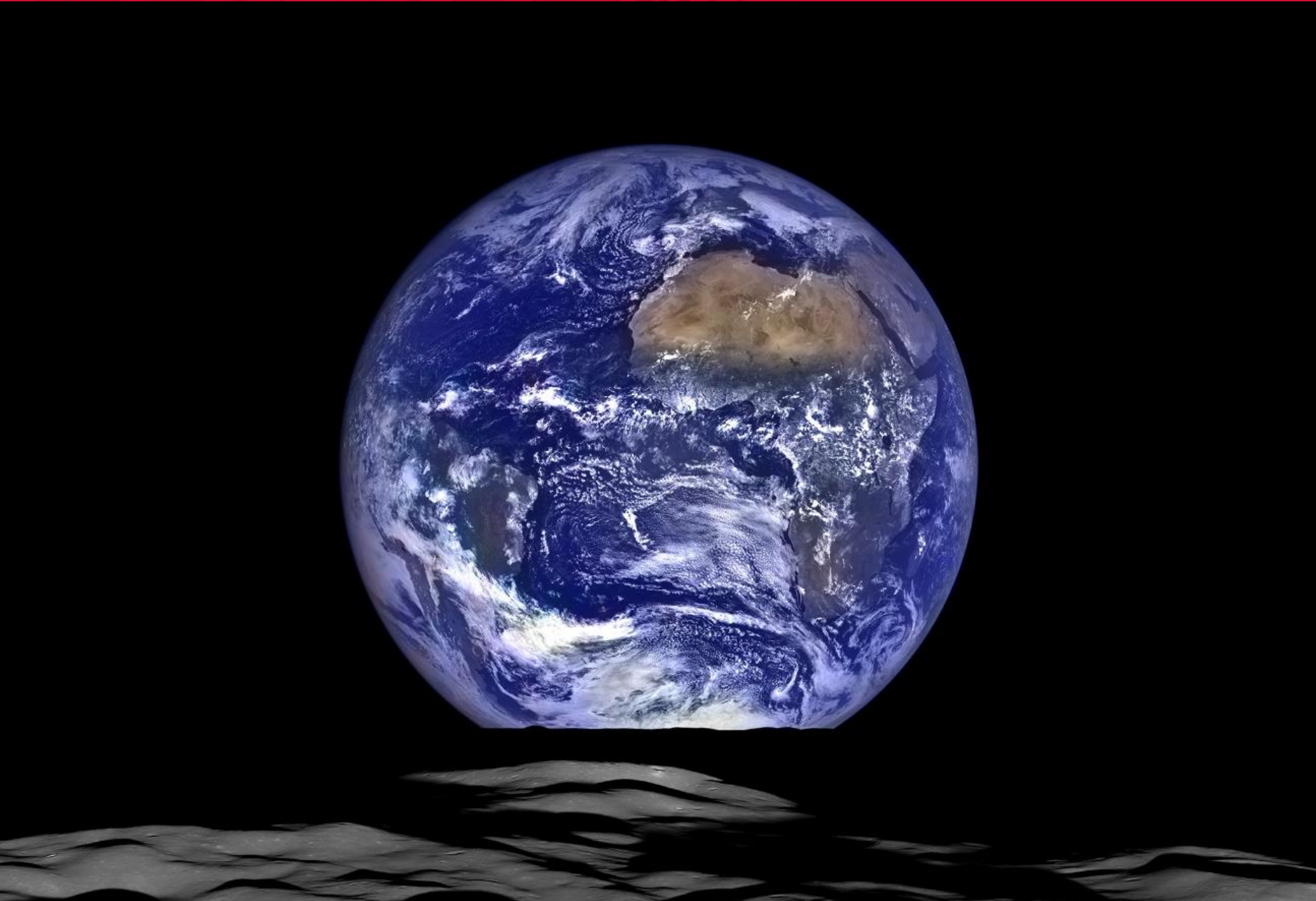
Bowman’s Hill Wildflower Preserve
New Hope, PA
January 27, 2019



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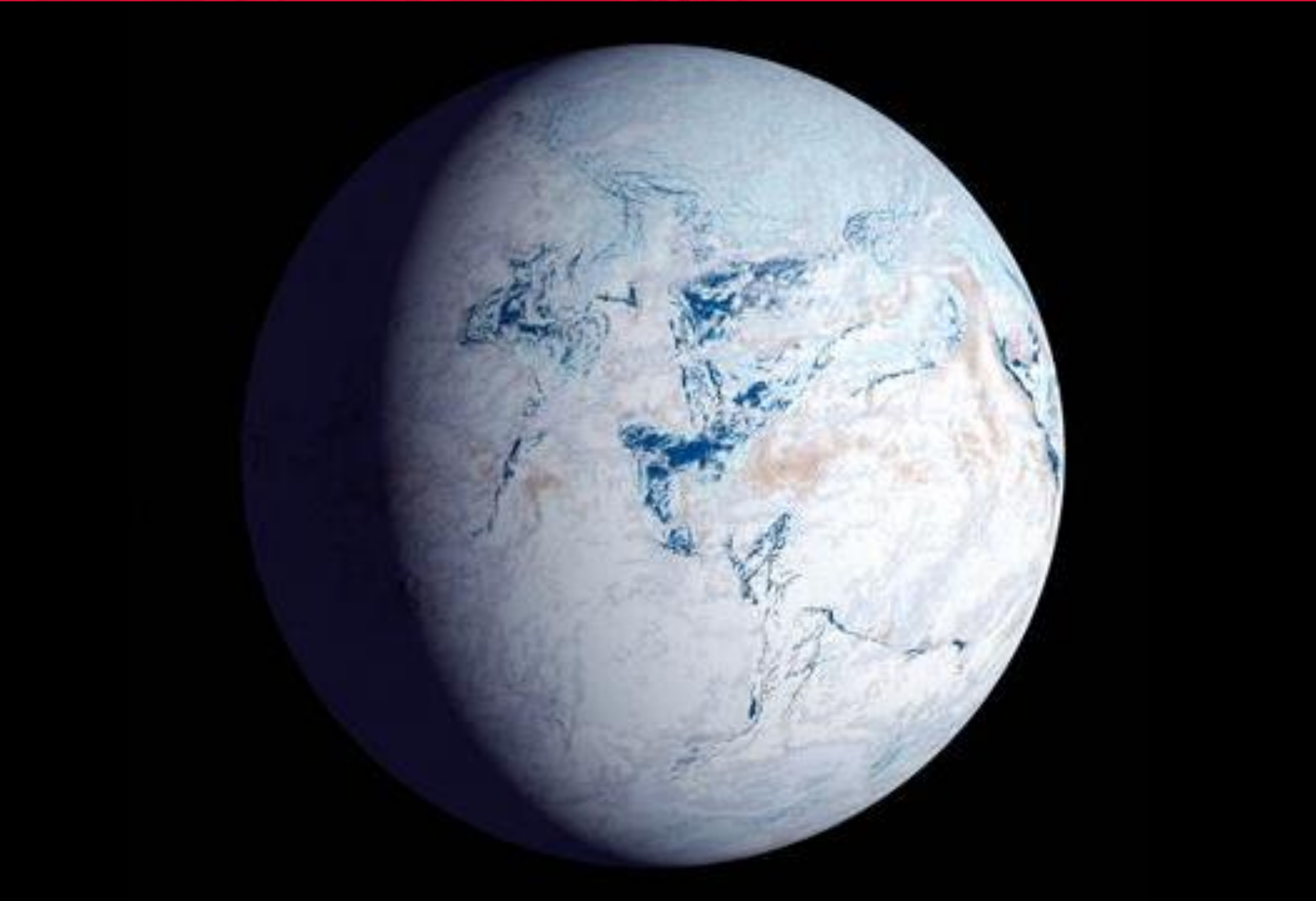
Outline of today's talk

- Climates of the distant past
- Recent changes in climate and their causes
- What does the future hold?
- What can we do?

Climates of the distant past



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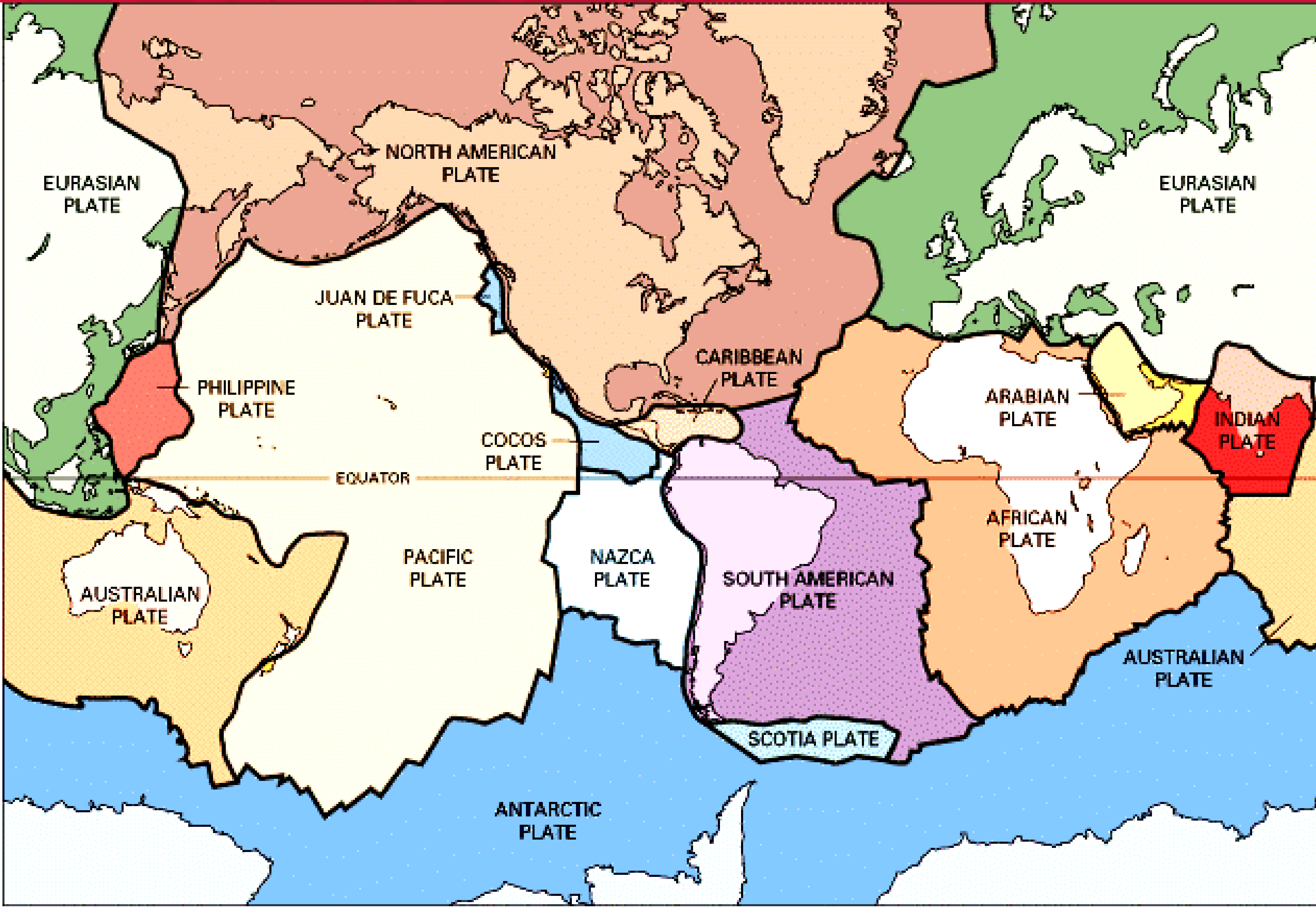
NORTH AMERICAN PLATE
EURASIAN PLATE
EURASIAN PLATE
JUAN DE FUCA PLATE
PHILIPPINE PLATE
CARIBBEAN PLATE
ARABIAN PLATE
INDIAN PLATE
COCOS PLATE
EQUATOR
AFRICAN PLATE
PACIFIC PLATE
NAZCA PLATE
AUSTRALIAN PLATE
SOUTH AMERICAN PLATE
AUSTRALIAN PLATE
SCOTIA PLATE
ANTARCTIC PLATE

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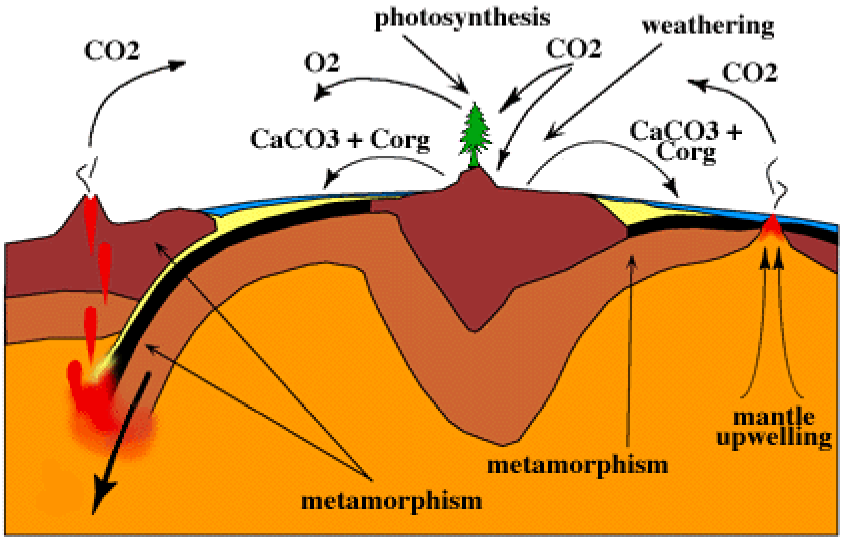
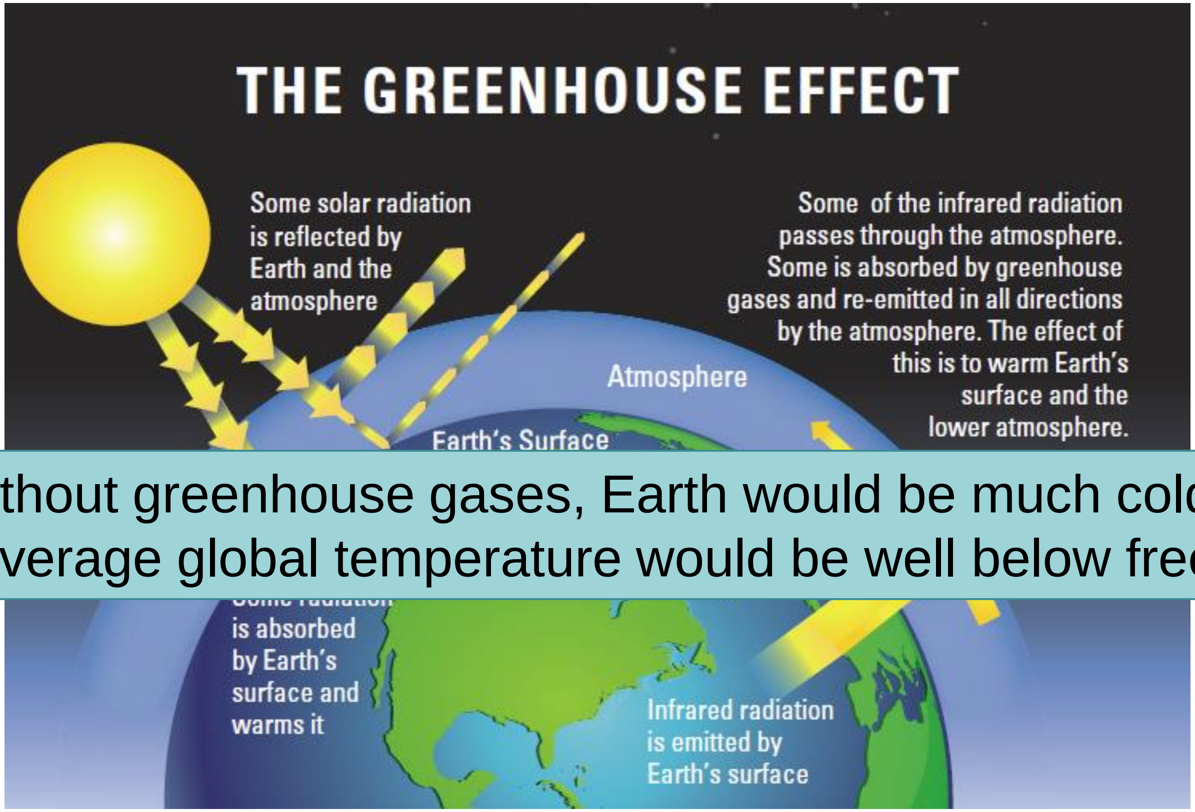
The natural carbon cycle

- Prior to human influences on the carbon cycle, the amount of carbon dioxide in the atmosphere was determined by the balance between outgassing from the solid earth (molten rock and gases originating in subduction zones and spreading ridges) and consumption by weathering and photosynthesis.



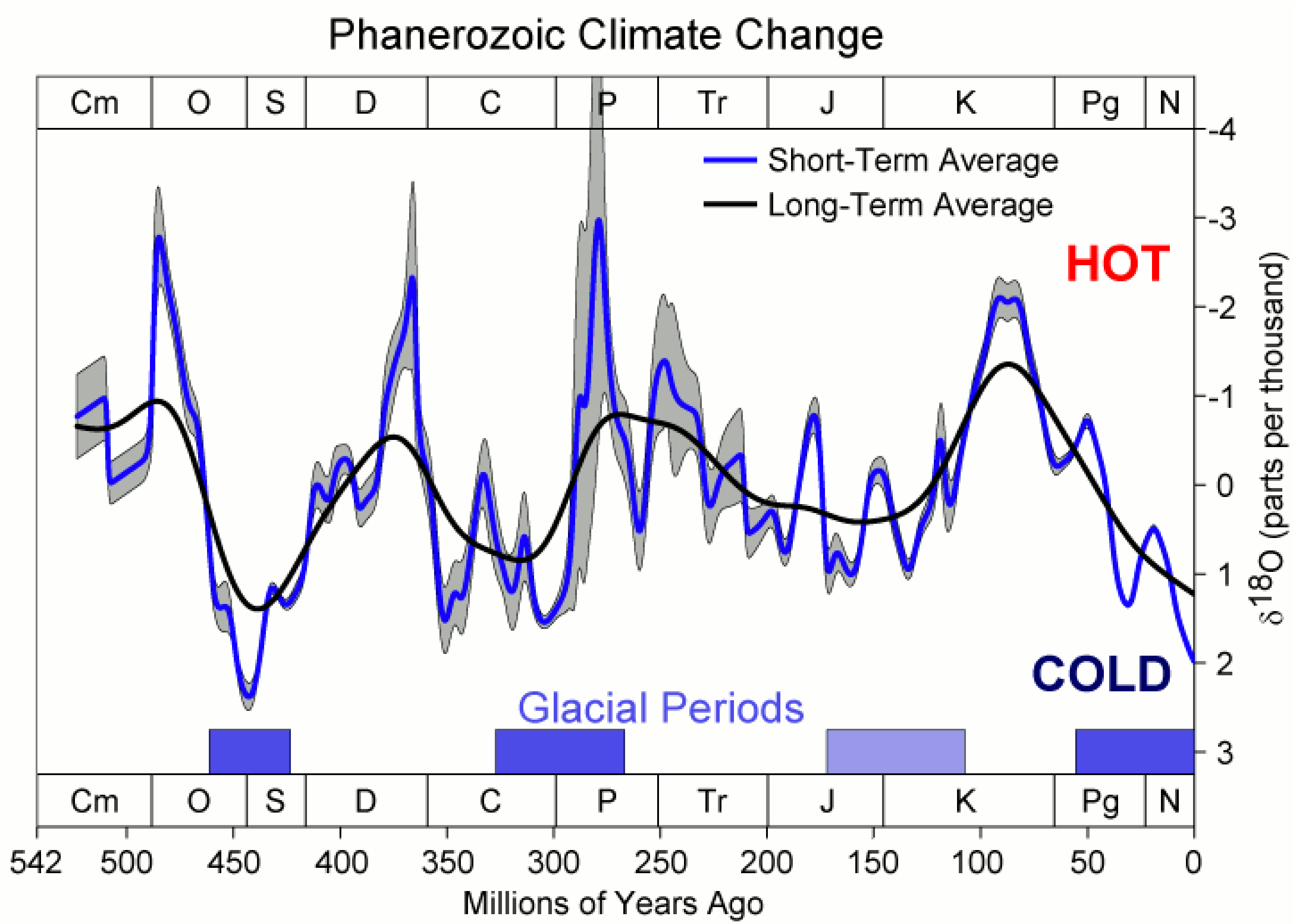
Why is carbon dioxide important?

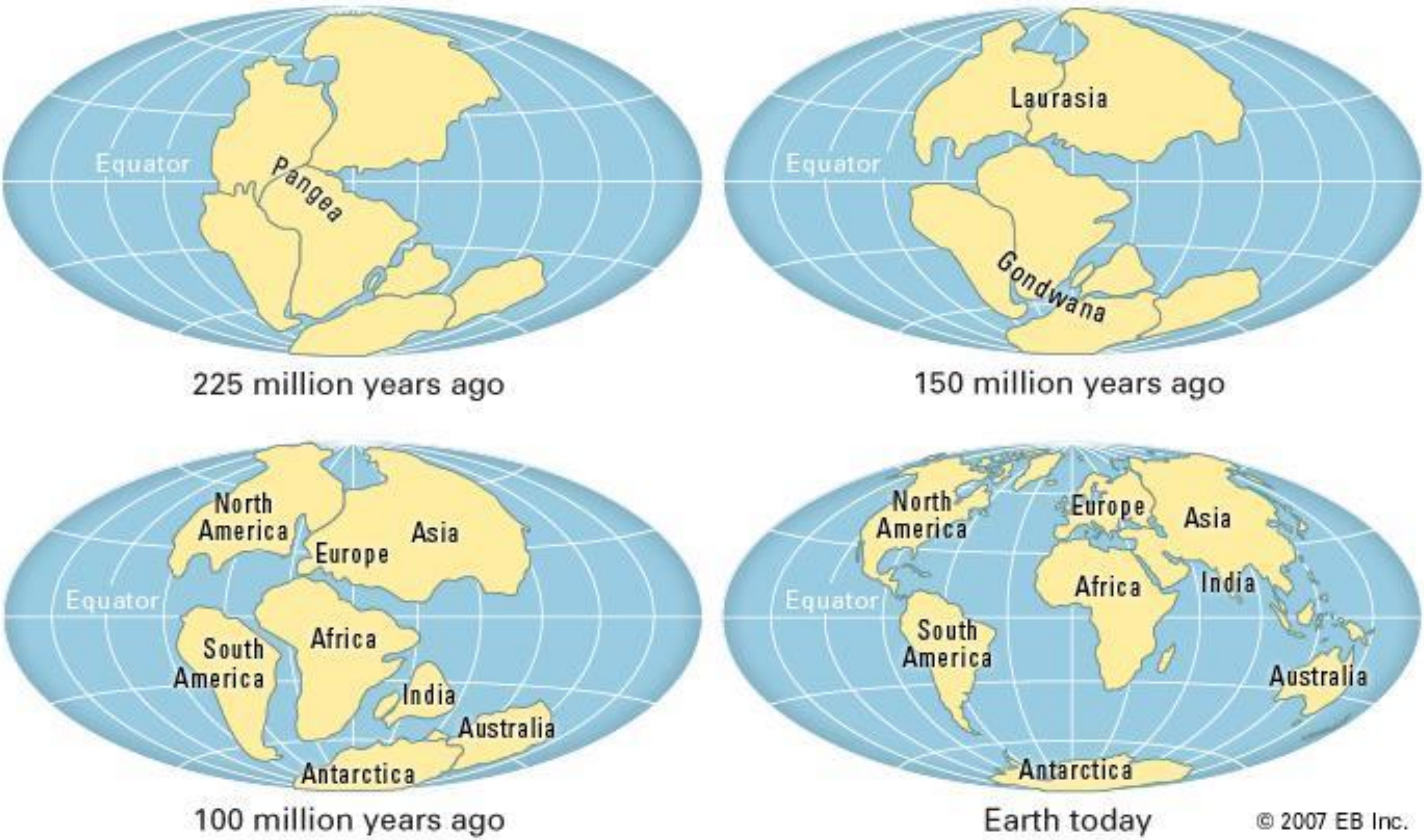
- Carbon dioxide (CO_2) is a “greenhouse gas” that absorbs infrared light, making it more difficult for heat energy from Earth’s surface to escape into space.



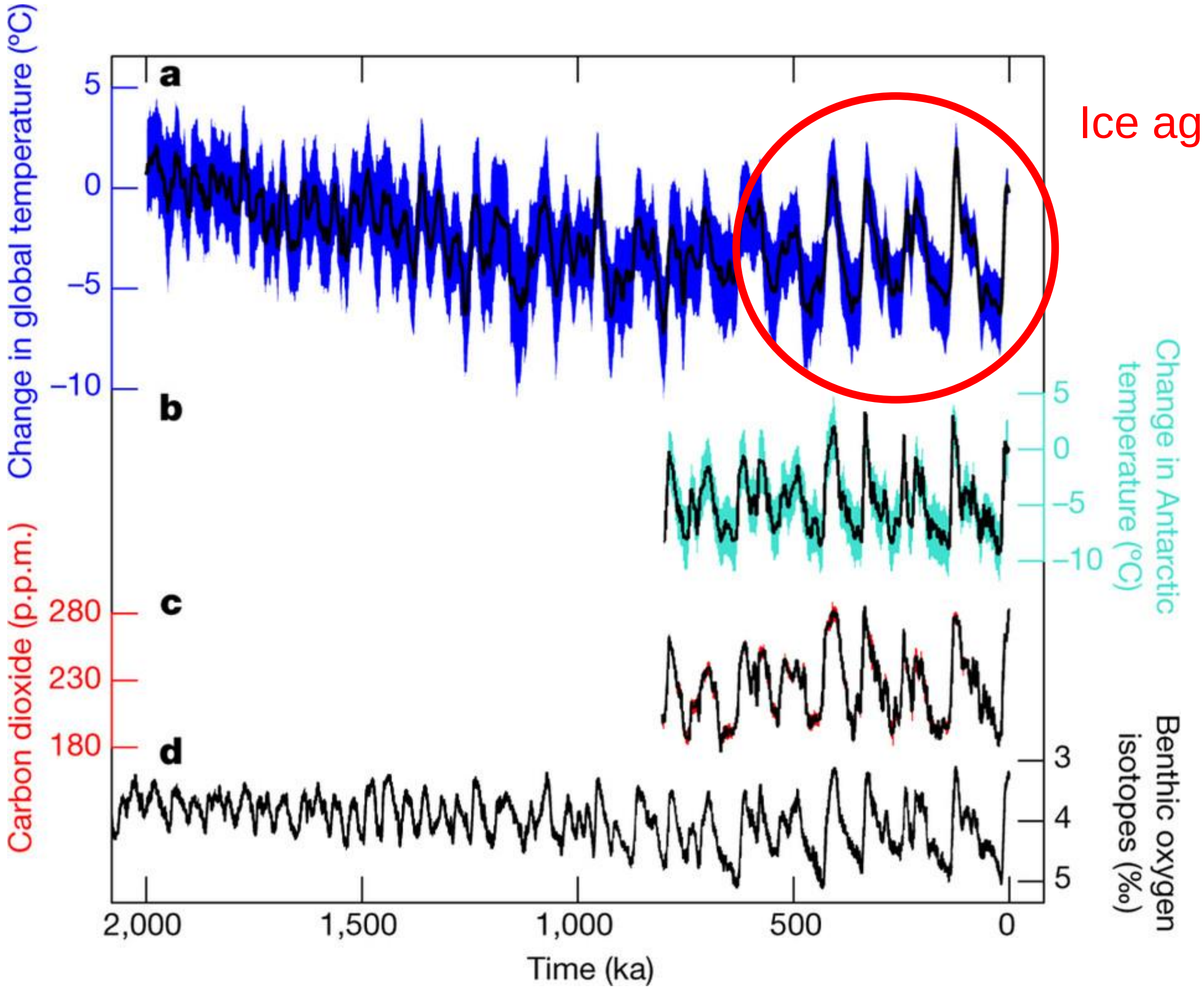
Without greenhouse gases, Earth would be much colder.
The average global temperature would be well below freezing).

500,000,000 years of Earth's "temperature"

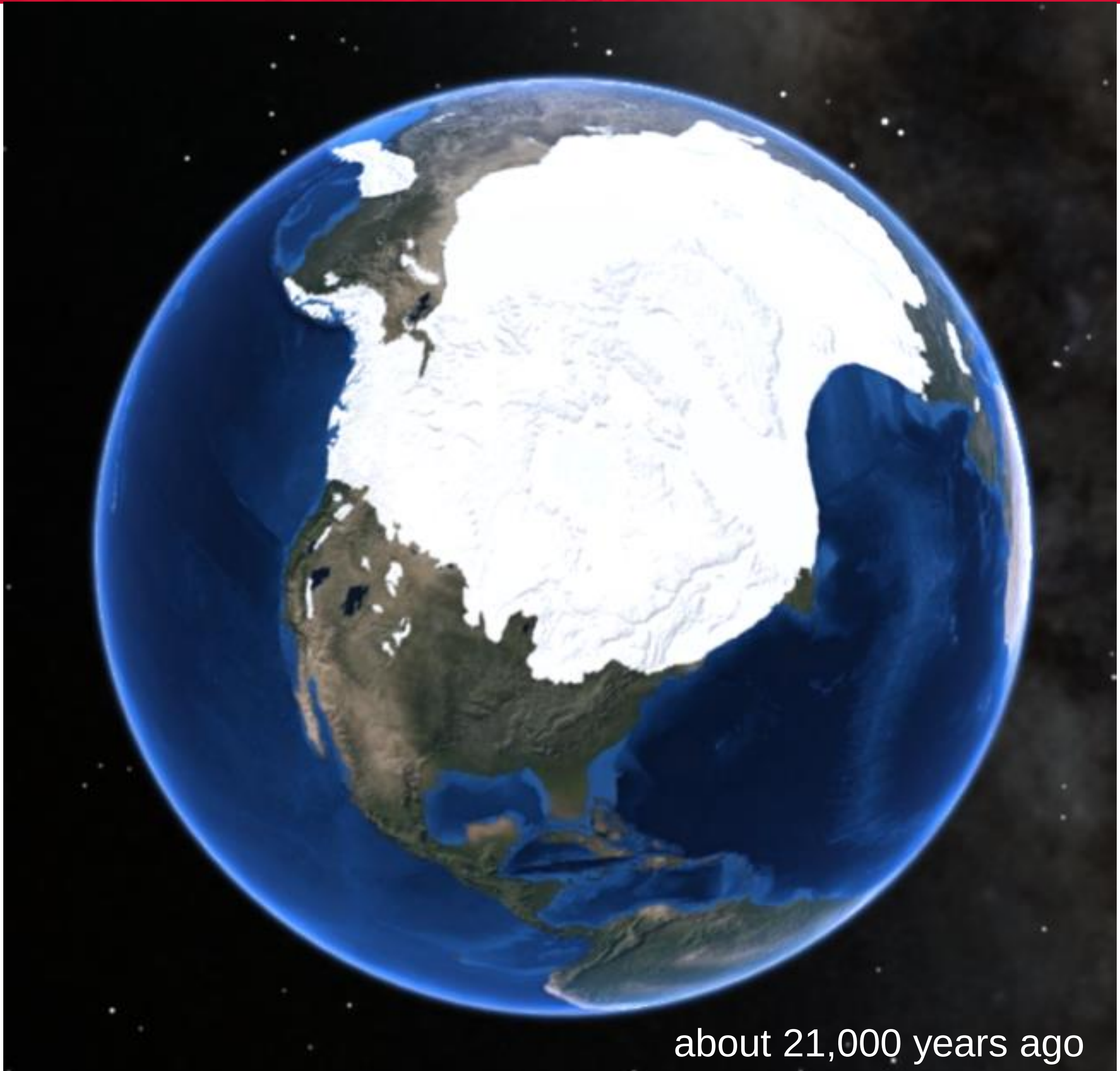



Equator
Pangea
225 million years ago
Laurasia
Equator
Gondwana
150 million years ago
North America
Europe
Asia
Equator
South America
Africa
India
Australia
Antarctica
100 million years ago
North America
Europe
Asia
Equator
Africa
India
South America
Australia
Antarctica
Earth today
© 2007 EB Inc.

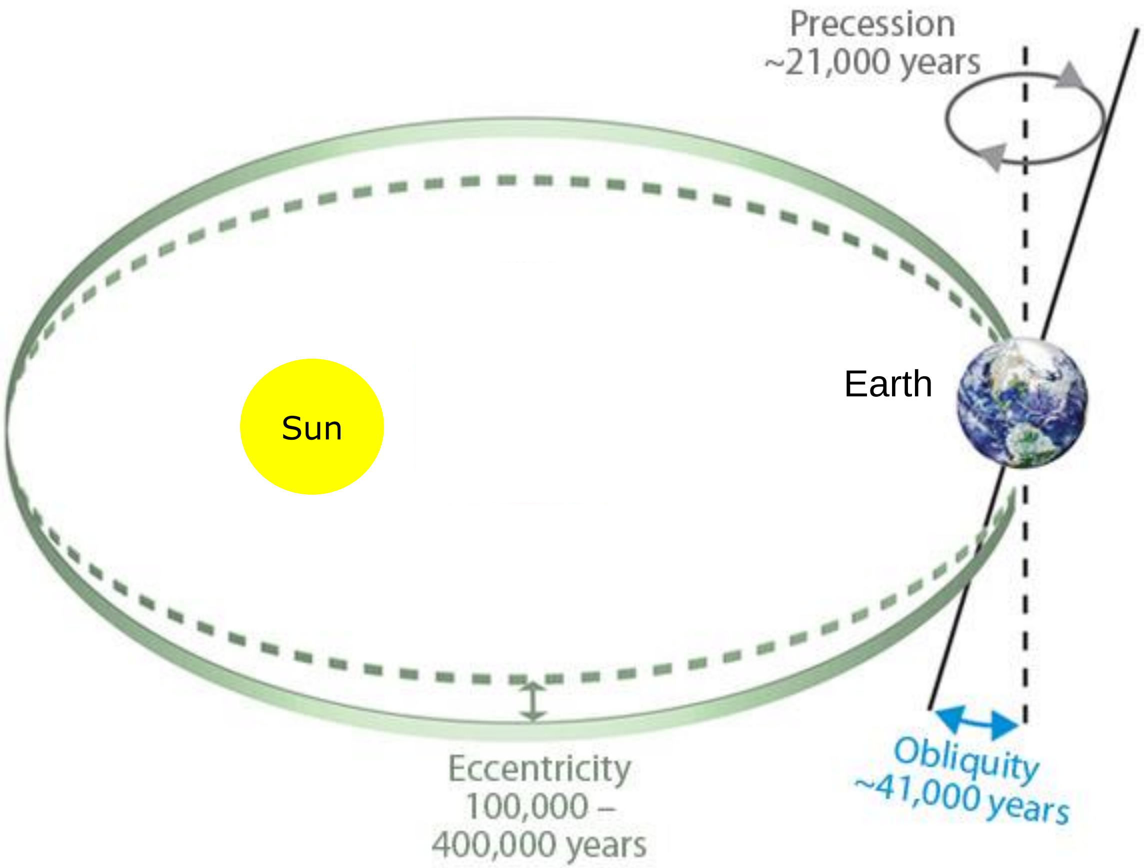
2,000,000 years of Earth's temperature



Source: Snyder (2016), *Nature*


about 21,000 years ago

Earth’s changing orbit



Earth’s Energy Balance: Regulator of Global Climate

- Earth is heated by the sunlight that is absorbed by its surface and atmosphere.
- Without a cooling mechanism, Earth’s temperature would steadily increase.
- Earth’s cooling mechanism is the emission of energy in the form of infrared radiation.
- These two processes form Earth’s energy balance, which determines its temperature.

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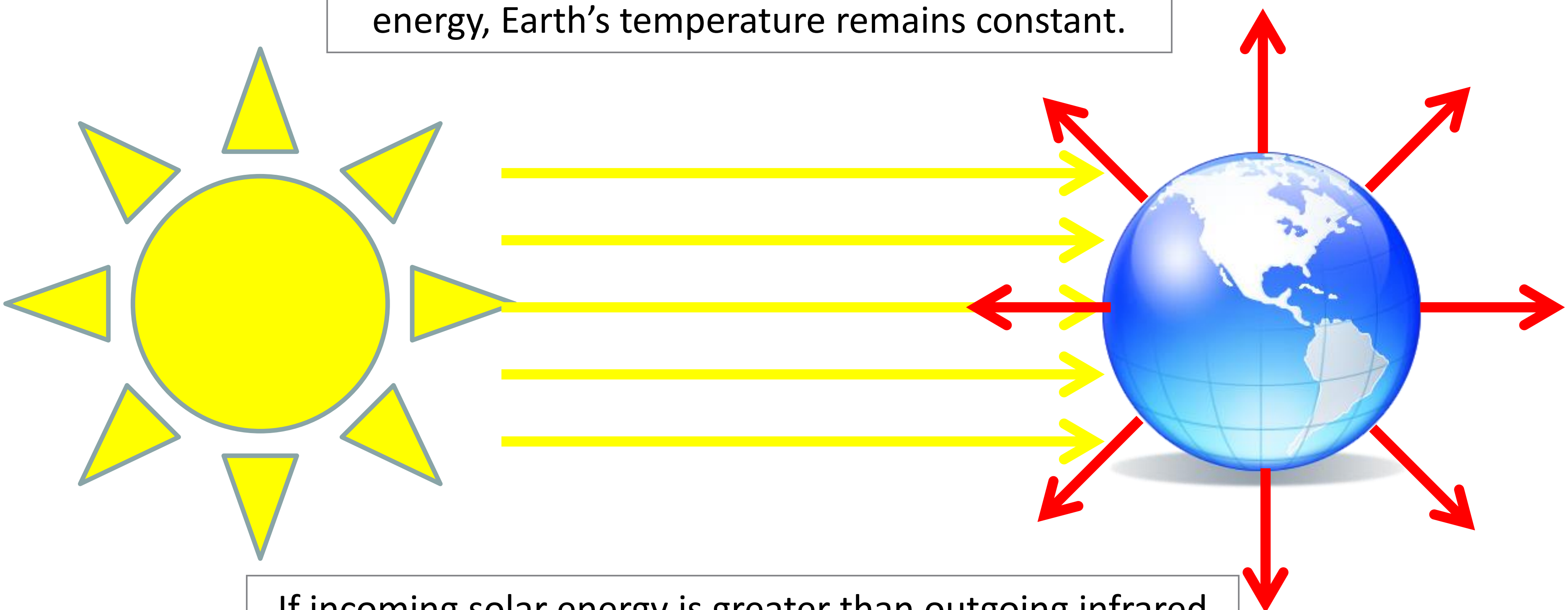
Earth's Energy Balance

If incoming solar energy equals outgoing infrared energy, Earth's temperature remains constant.



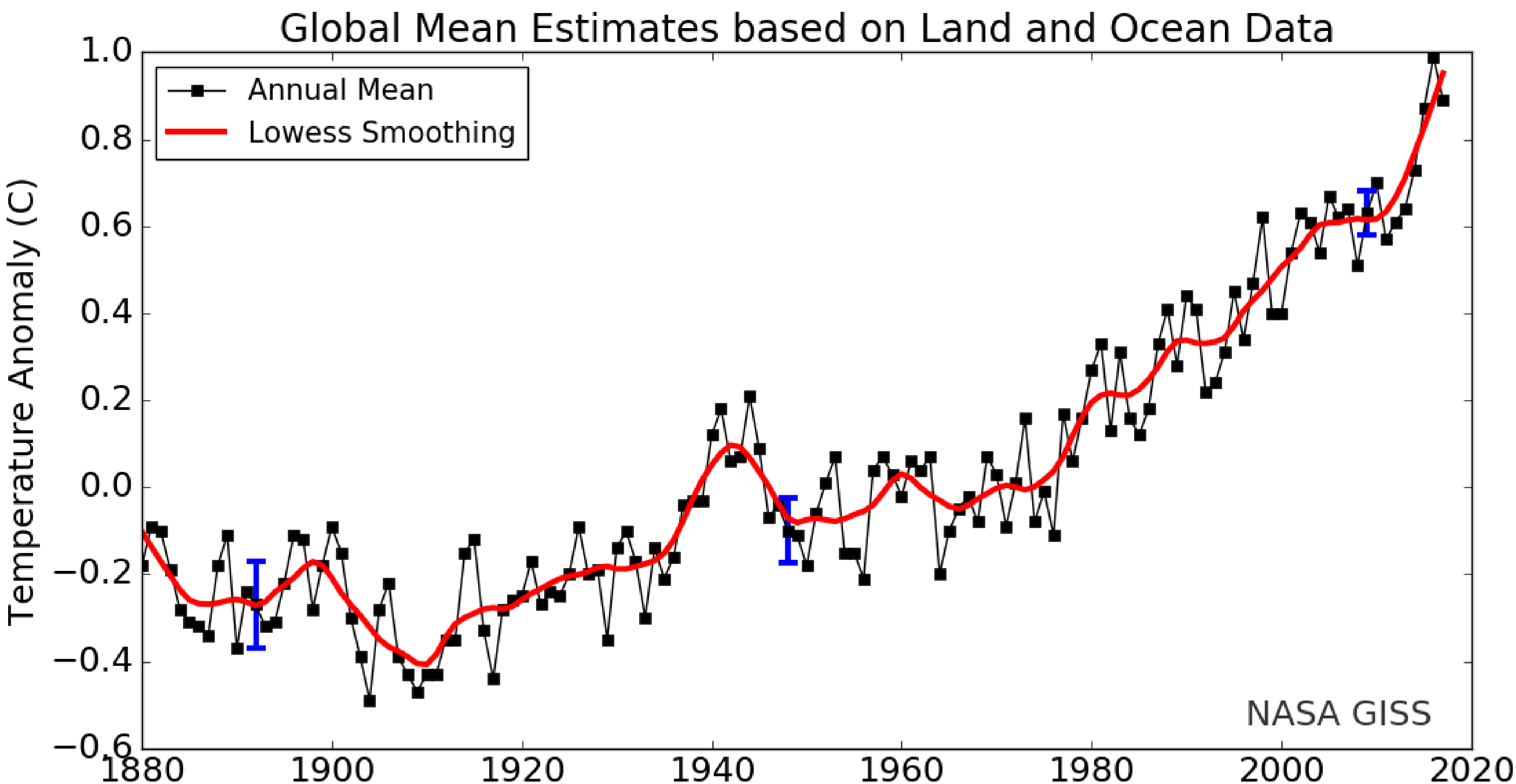
If incoming solar energy is greater than outgoing infrared energy, Earth's temperature will increase.

If incoming solar energy is less than outgoing infrared energy, Earth's temperature will decrease.

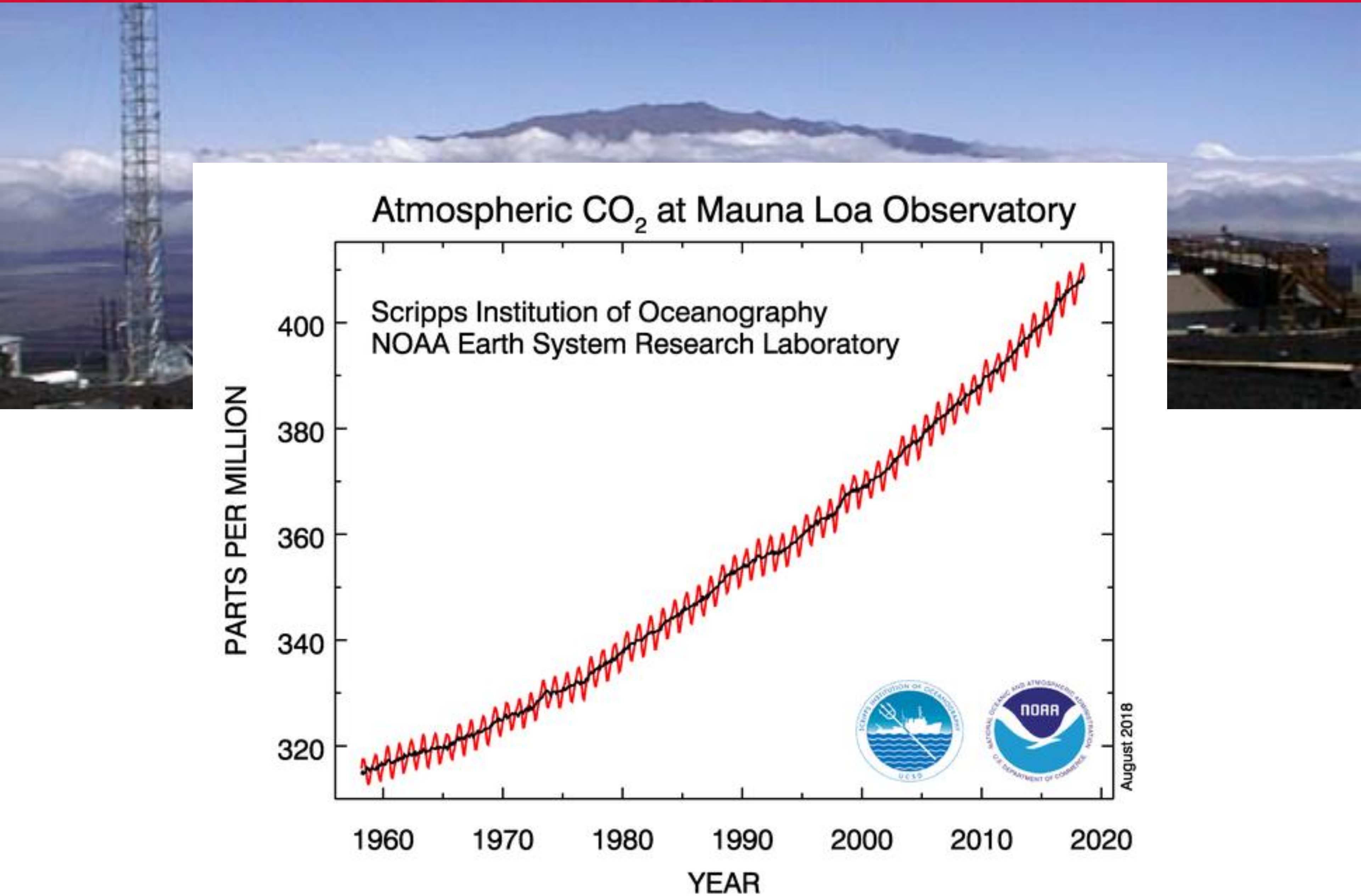
Take-home messages:

- The climate system is sensitive to changes in the global energy balance.
- Anything the alters the global energy balance (e.g., changes in solar brightness, changing greenhouse gas concentrations, shape of Earth's orbit or tilt of its axis) will have effects on global climate.

Recent changes in climate and their causes



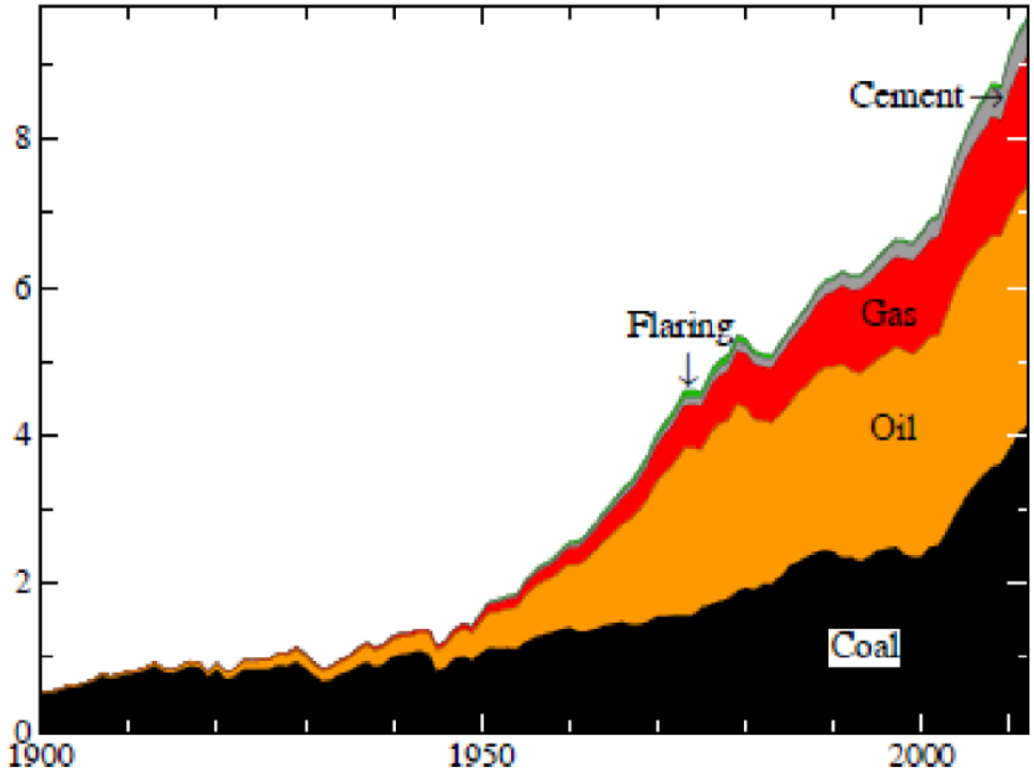
Source: NASA/Goddard Institute for Space Studies


Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
320
340
360
380
400
1960
1970
1980
1990
2000
2010
2020
YEAR
August 2018
NOAA

Fossil fuels and CO_2

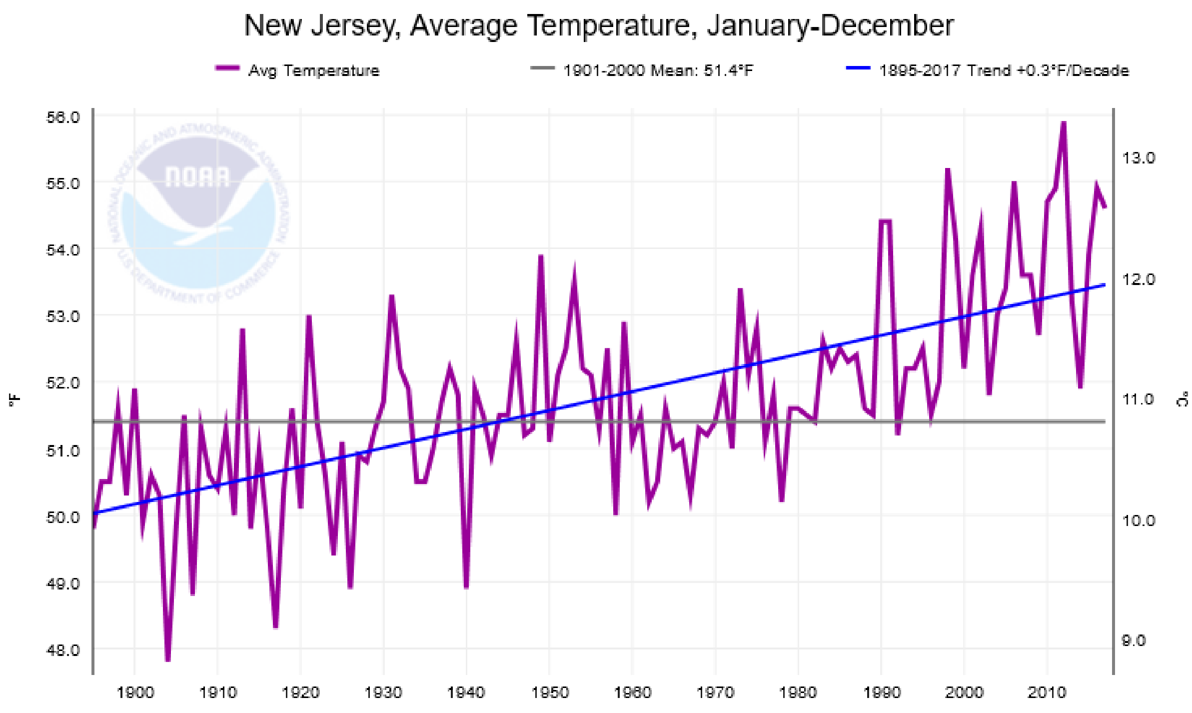
- Fossil fuels (coal, petroleum, natural gas) are formed from ancient organic matter (mainly plants) that is buried in Earth's crust and transformed under pressure and heat.
- Combustion of fossil fuels releases CO_2 as carbon is oxidized.
- How much CO_2 is emitted from fossil fuel energy?
  - Coal: 88-98 kg/GJ
  - Petroleum: 68-69 kg/GJ
  - Natural gas: 50 kg/GJ
- Annual global CO_2 emissions from fossil fuel combustion and cement production are about 32.5 gigatons of CO_2 (about 8.9 GtC); deforestation adds another 3.5 gigatons of CO_2 (about 1 GtC).

Annual Emissions of CO_2 from Fossil Fuels



Source: James Hansen, Columbia University

Trends in annual mean New Jersey temperature



Long-term upward trend of 2.8°F per 100 years

More rapid warming since 1980

The seven warmest years have occurred since 1998

2012 was the warmest year on record

Source: National Centers for Environmental Information

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Unusually warm and cold months in New Jersey

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Jan																			
Feb																			
Mar																			
Apr																			
May																			
Jun																			
Jul																			
Aug																			
Sep																			
Oct																			
Nov																			
Dec																			

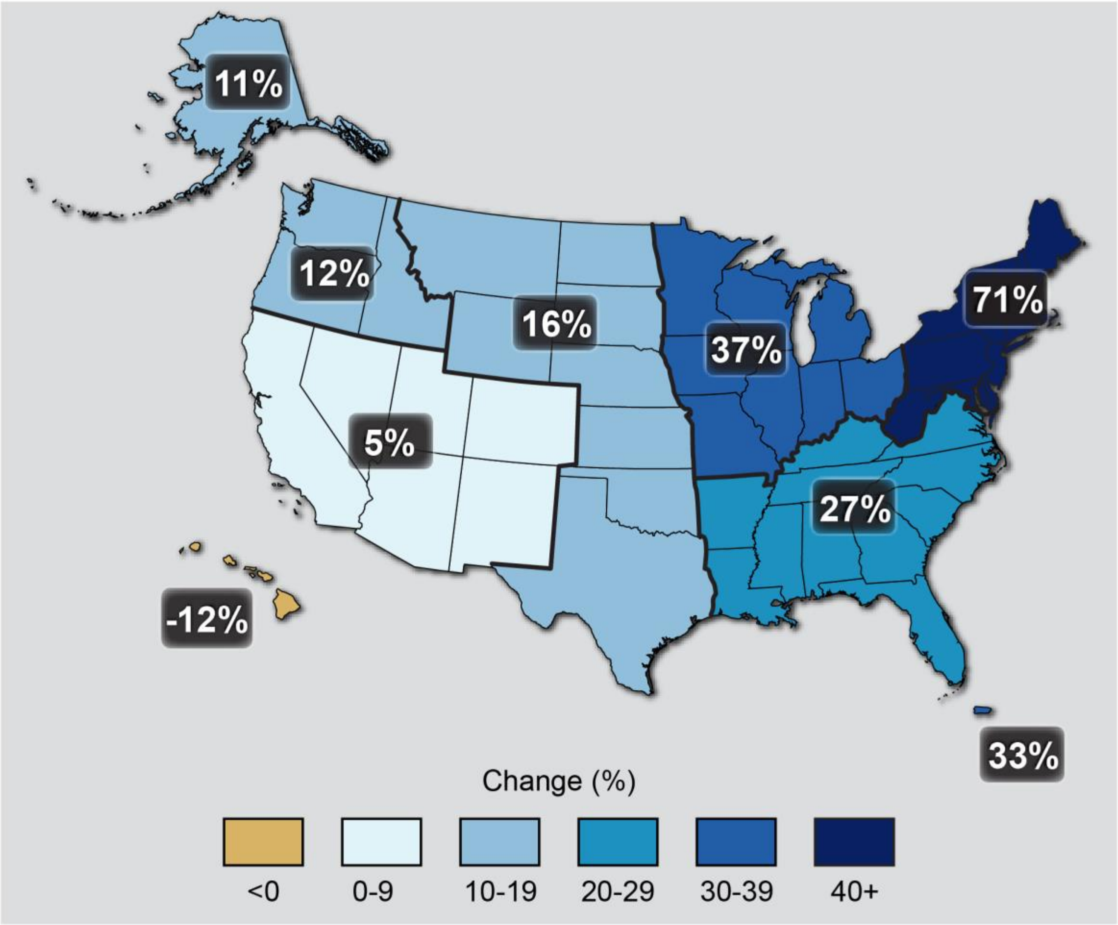
Unusually warm and cold months in New Jersey

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Jan							3												
Feb			5										4					1	2
Mar													1				4		
Apr			5								2	5						1	
May					2								4			1			4
Jun									3		1								
Jul											4	1	5	5					
Aug			4			3											1		1
Sep						4										2	5		3
Oct								2										1	
Nov							1			3		4				1			
Dec		3					2					5	4			1			

- Unusually warm and cold months are defined as the five warmest and coldest for each calendar month (total of 60 warm and 60 cold plus ties)
- Since 2000, there have been 40 unusually warm months and 0 unusually cold months

Source: National Centers for Environmental Information

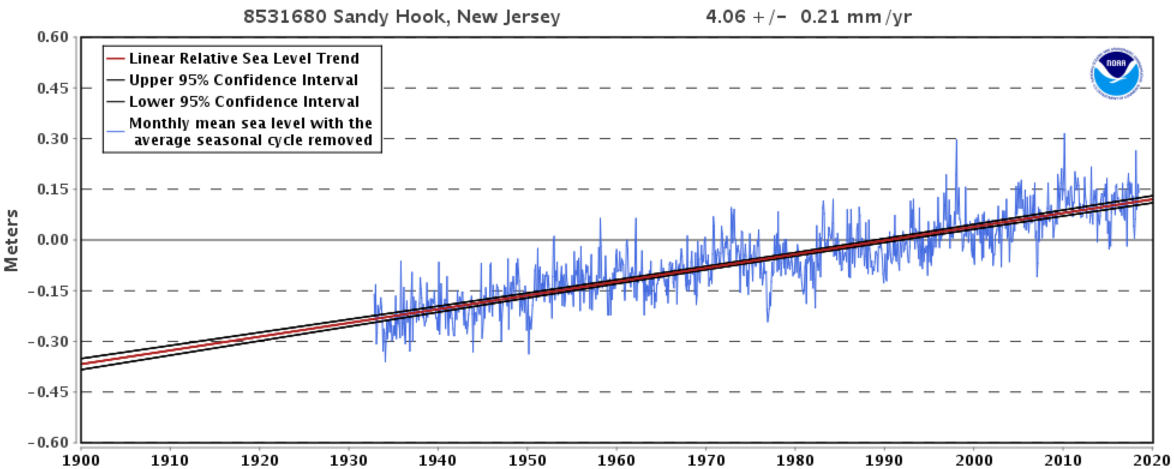
Change in amount of precipitation from very heavy events

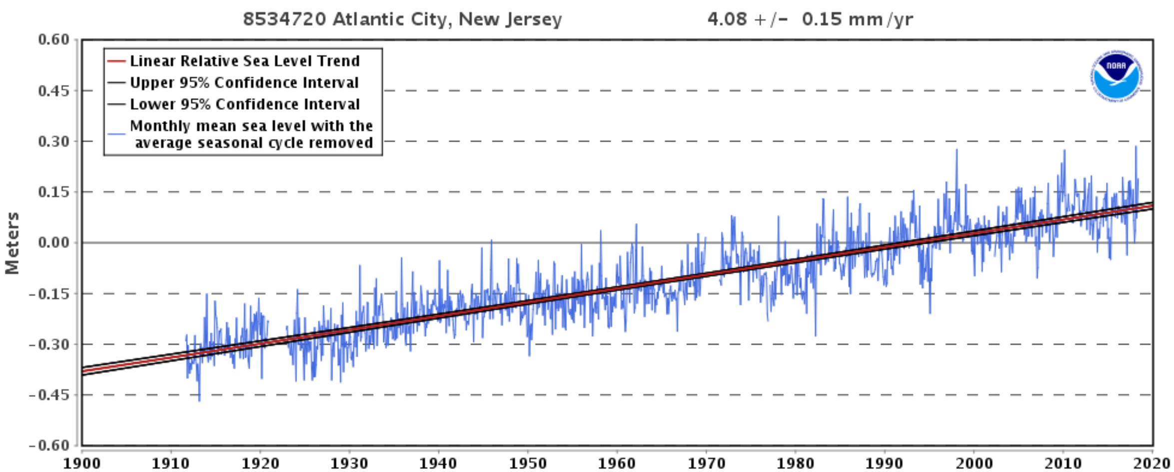


- Period: 1958 to 2011
- Very heavy = the heaviest 1% of precipitation events
- A similar analysis indicates that recent decades have are also higher than the first half of the 20^{th} century

Source: National Climate Assessment (2014)

New Jersey sea level trends





- Century-scale global sea level rise has been 1.7±0.3 mm/yr
- Local sea level rise along the NJ coast has been more rapid than the global rise due to land subsidence (combination of post-glacial movement of earth's crust and compaction of coastal plain sediments)

Take-home messages:

- Greenhouse gases, the most important of which is carbon dioxide, have been increasing as a result of human activities.
- Increasing greenhouse gas concentrations in the atmosphere are altering Earth's energy balance.
- Changes in climate and sea level are already happening, both globally and locally.

What does the future hold?

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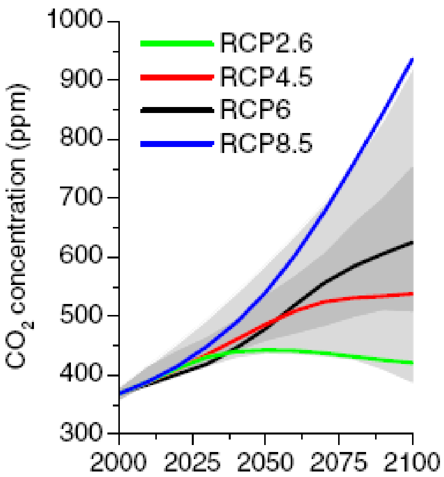
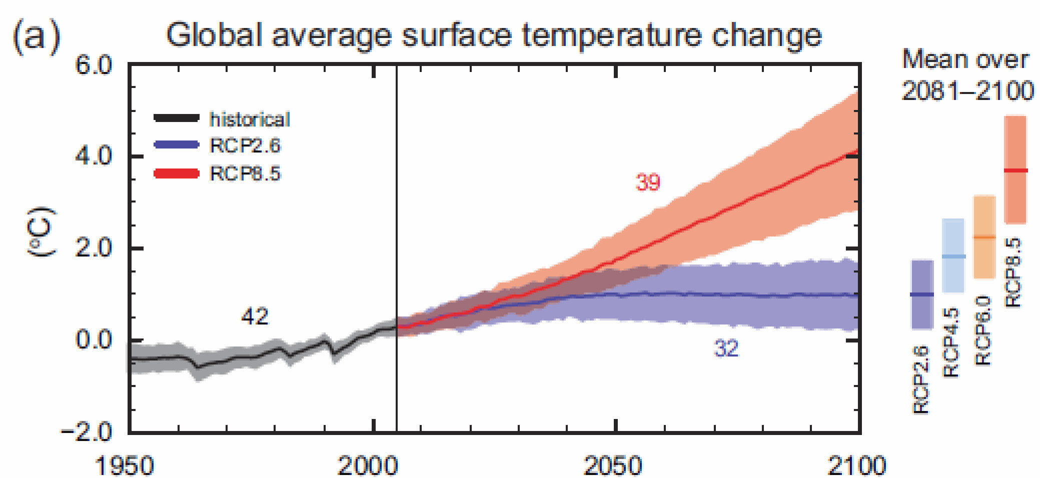
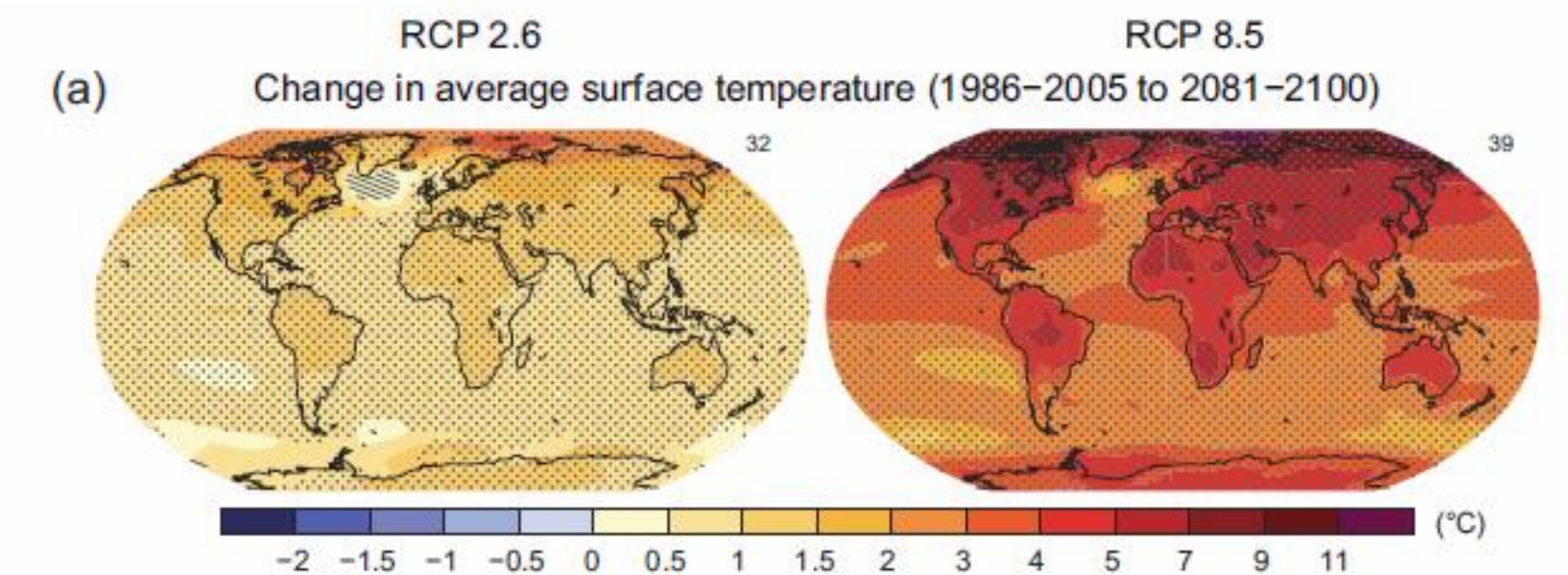
Future projections: Temperature

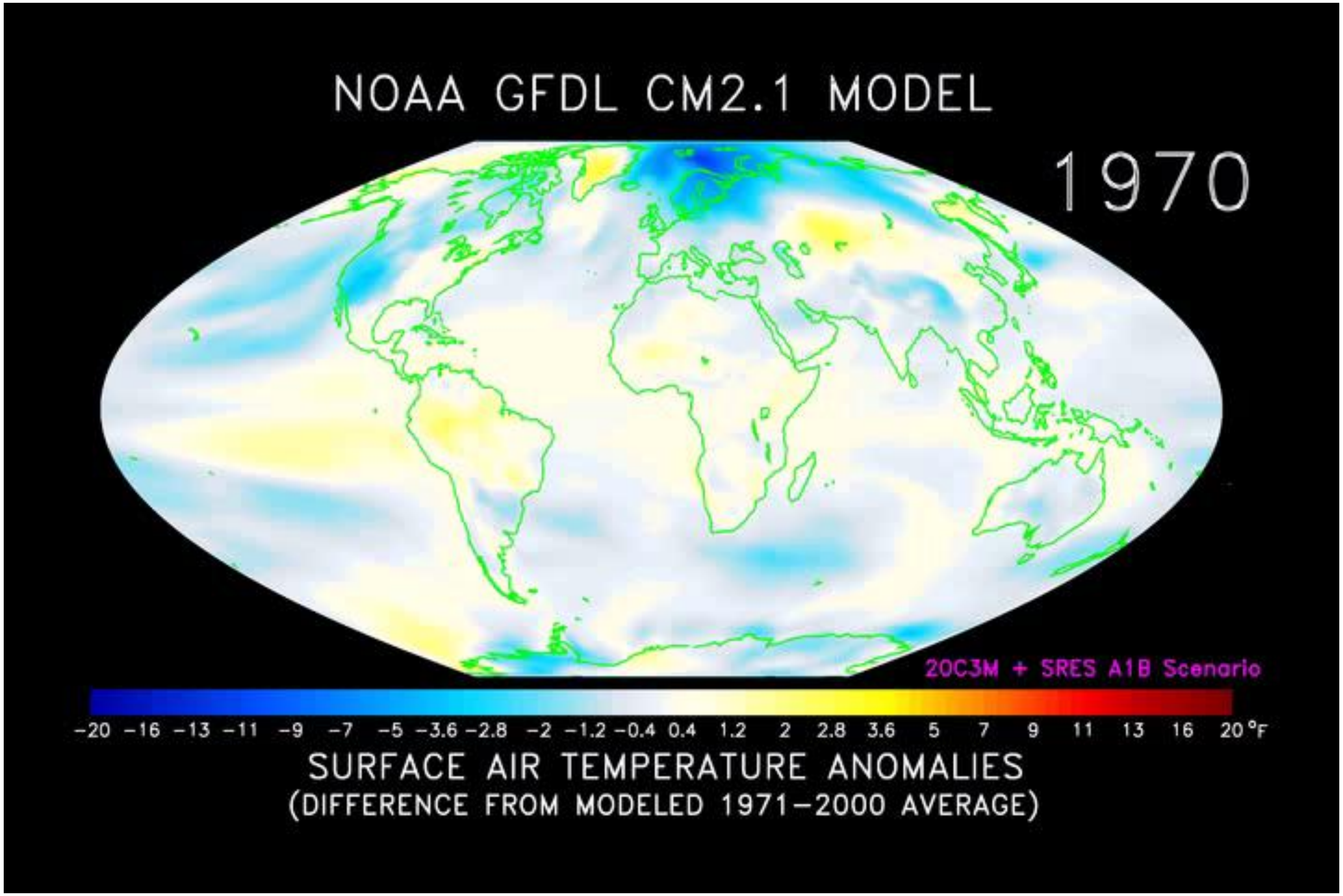






Source: Intergovernmental Panel on Climate Change

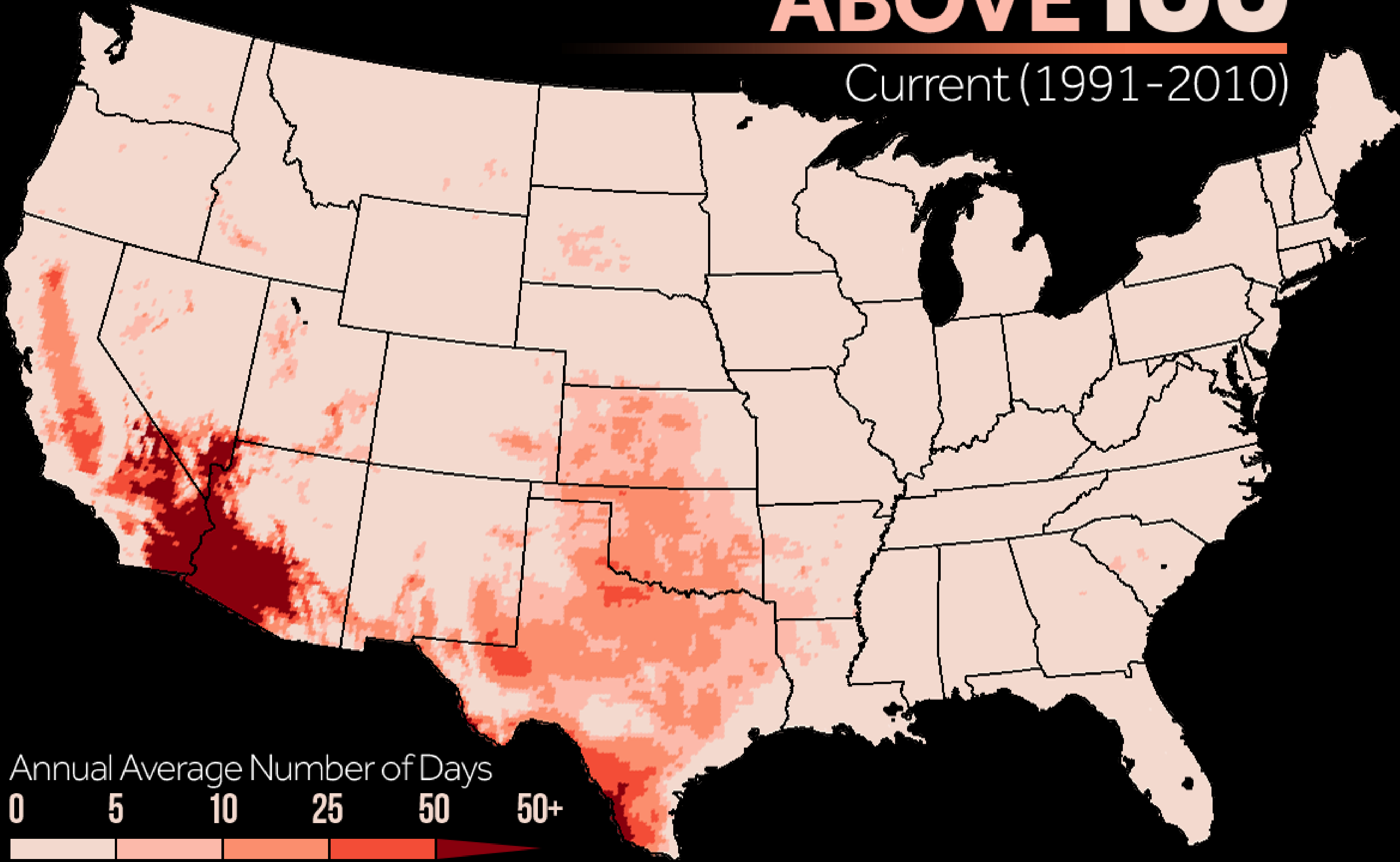
Simulating Future Climate Change



Source: NOAA Geophysical Fluid Dynamics Laboratory

DAYS ABOVE 100°

Current (1991-2010)

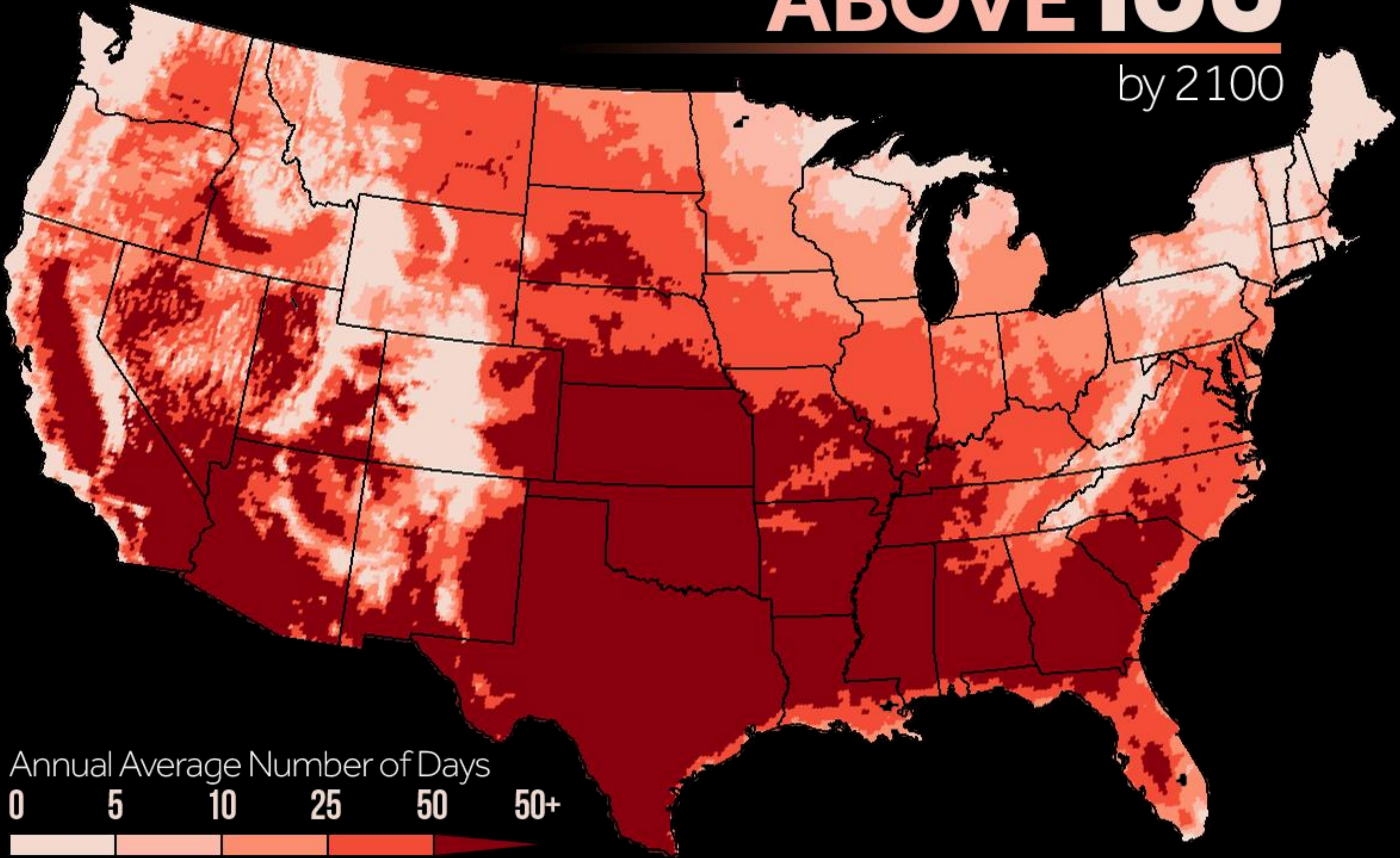


Source: Maurer et al. (2002), Santa Clara University

CLIMATE CENTRAL

DAYS ABOVE 100°

by 2100

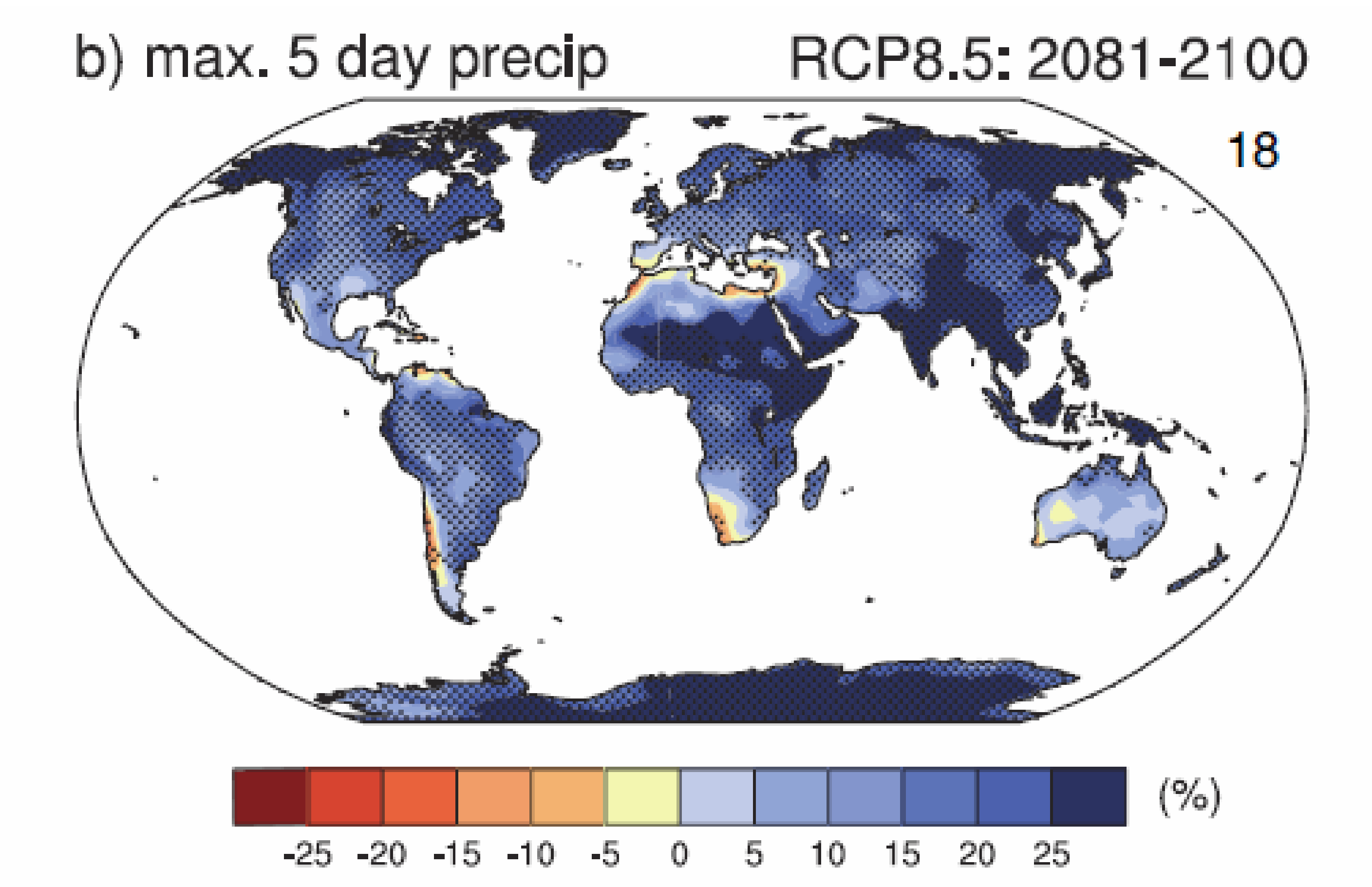


Source: CMIP5 model projections of daily maximum temperature averaged over 20 year periods.

CLIMATE CENTRAL


STOP
4-WAY

Heavy rains may become heavier



Source: Intergovernmental Panel on Climate Change

New Jersey sea level projections

- Sea level in New Jersey is rising more rapidly than the global average because the land is sinking.
- Projected changes in ocean currents are also expected to add to the rate of sea level rise on the New Jersey coast.
- A recent analysis by a Rutgers-led team of scientists projects that by 2030, sea level on the NJ coast will likely rise by 0.6-1.0 feet (relative to 2000), with a central estimate of 0.8 feet.
- In 2050, the range is 1.0-1.8 feet with a central estimate of 1.4 feet.
- By 2100, the range is 1.7-3.1 feet (best estimate of 2.3 feet) for a lower emissions scenario and 2.4-4.5 feet (best estimate 3.4 feet) for a higher emission scenario.

Source: Kopp, R. E. et al., 2016: *Assessing New Jersey's Exposure to Sea-Level Rise and Coastal Storms: Report of the New Jersey Climate Adaptation Alliance Science and Technical Advisory Panel.*

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Take-home messages:

- Without drastic reductions in greenhouse gas emissions, climate change will continue and sea level rise will accelerate.

- Consequences of climate change will include more frequent and intense heat waves, heavier precipitation events, and increased coastal flooding from sea level rise.

- Reducing emissions of greenhouse gases can reduce the amount of future climate change.

What can we do?

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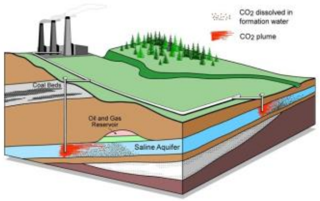
Options for dealing with climate change

- Mitigation—Efforts to reduce or prevent the emission of greenhouse gases
- Adaptation—Planning for the changes in climate that are expected to occur, particularly by taking actions to avoid the adverse impacts
- Geoengineering—Deliberate large-scale manipulation of the planetary environment to counteract human-caused climate change

Examples of emissions reduction strategies

- Energy efficiency
- Fuel switching
- Carbon capture and storage
- Nuclear electricity
- Solar electricity
- Wind electricity
- Biofuels
- Natural sinks



Source: Carbon Mitigation Initiative, Princeton University

Examples of adaptation strategies

- Warning systems to reduce exposure to extreme heat, including cooling stations for people without air conditioning
- Expanding flood zones and increasing the capacity of storm water drainage systems
- Making building roofs more reflective
- Raising outflows of wastewater treatment plants
- Raising residential buildings in coastal areas

Examples of geoengineering

- Carbon dioxide removal
  - Enhancing uptake and storage by terrestrial biosphere
  - Enhancing uptake and storage by oceanic organisms
  - Using engineered systems
- Solar radiation management
  - Modifying land or ocean reflectivity
  - Modifying cloud properties
  - Altering upper-atmospheric composition (sulfate aerosols)
  - Space-based reflectors

Source: The Royal Society, *Geoengineering the Climate*, Sep. 2009