

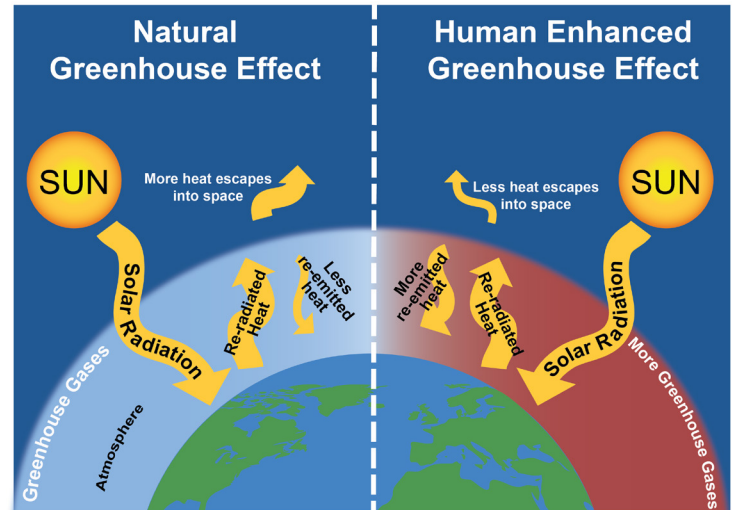
# Climate Change: Science and Impacts

## The Earth's Climate

Climate change is altering temperature, precipitation, and sea levels, and will adversely impact humans and natural systems, including water resources, human health, human settlements, ecosystems, and biodiversity. The unprecedented acceleration of climate change over the last 50 years and the increasing confidence in global climate models add to the compelling evidence that climate is being affected by greenhouse gas (GHG) emissions from human activities.<sup>2</sup>

Changes in climate should not be confused with changes in weather. Weather is observed at a particular location on a time scale of hours or days, and exhibits a high degree of variability, whereas climate is the long-term average of short-term weather patterns, such as the annual average temperature or rainfall at a given location. Under a stable climate, there is an energy balance between incoming solar radiation (short wave) and outgoing infrared radiation (long wave). Solar radiation passes through the atmosphere and most is absorbed by the Earth's surface. The surface then re-emits some energy as infrared radiation, a portion of which radiates into space. Increases in the concentrations of greenhouse gases in the atmosphere reduce the efficiency with which the Earth's surface radiates energy to space, thus warming the planet.<sup>3</sup>

The Earth's Greenhouse Effect<sup>1</sup>



## Climate Forcings

- Any disturbance of the Earth's balance of incoming and outgoing energy is referred to as a positive or a negative climate forcing. Positive forcings, such as GHGs, exert a warming influence on the Earth, while negative forcings, such as sulfate aerosols, exert a cooling influence.<sup>4</sup>
- Increased concentrations of GHGs from anthropogenic sources have increased the absorption and emission of infrared radiation, enhancing the natural greenhouse effect. Methane and other GHGs are more potent, but CO<sub>2</sub> contributes most to warming because of its prevalence.<sup>4</sup>
- Anthropogenic GHG emissions, to date, amount to a climate forcing roughly equal to 1% of the net incoming solar energy, or the energy equivalent of burning 13 million barrels of oil every minute.<sup>5</sup>

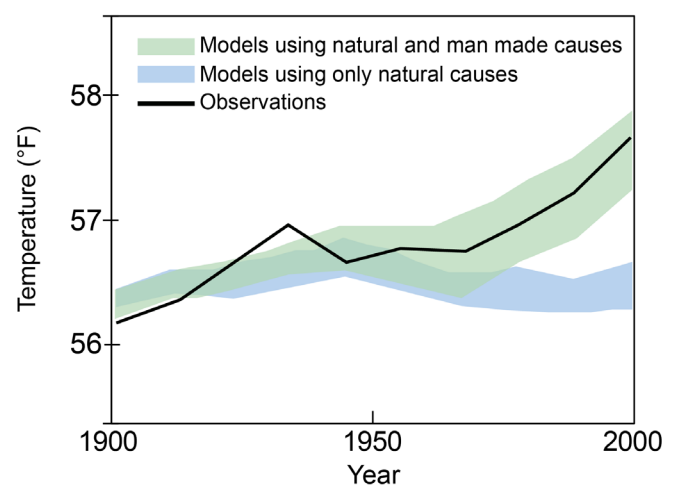
## Climate Feedbacks and Inertia

- Climate change is also affected by the Earth's responses to forcings, known as climate feedbacks. For example, the increase in water vapor that occurs with warming increases the climate's sensitivity to CO<sub>2</sub> by a factor of two.<sup>6</sup>
- The depth of the ocean creates a large thermal inertia that slows the response of climate change to forcings; energy balance changes result in delayed climate response with high momentum.<sup>7</sup>
- As polar ice melts, less sunlight is reflected and the oceans absorb even more heat.<sup>6</sup>
- Due to global warming, large reserves of organic matter frozen in subarctic permafrost will thaw and decay, releasing additional CO<sub>2</sub> and methane to the atmosphere.<sup>8</sup>
- If GHG emissions were completely eliminated today, climate change impacts would still continue for centuries.<sup>9</sup> The Earth's temperature requires 25 to 50 years to reach 60% of its equilibrium response.<sup>10</sup>
- Today's emissions will affect future generations; CO<sub>2</sub> persists in the atmosphere for hundreds of years.<sup>11</sup>

## Human Influence on Climate

- Separately, neither natural forcings (i.e., volcanic activity and solar variation) nor anthropogenic forcings (i.e., GHGs and aerosols) can fully explain the warming experienced since 1850.<sup>4</sup>
- Climate models most closely match the observed temperature trend only when the effects of natural and anthropogenic forcings are considered together.<sup>4</sup>
- In 2013, the Intergovernmental Panel on Climate Change (IPCC) concluded that: "It is extremely likely (>95 % certainty) that human influence has been the dominant cause of the observed warming since the mid-20<sup>th</sup> century."<sup>6</sup>

Modeled and Observed Temperatures<sup>12</sup>



# Observed Impacts

## Physical Systems

- Average surface temperatures have risen at least 0.78°C (1.4°F) since the mid 1800s.<sup>6</sup>
- 2016 was the warmest year on record since records began in 1880 and marks the 40<sup>th</sup> consecutive year that annual global temperatures were above average. 2016 global average ocean temperatures also experienced a record high.<sup>13</sup>
- During the 20<sup>th</sup> century, winter temperatures in Alaska and western Canada increased by 3-4°C (5.4-7.2°F), and Arctic sea-ice thickness declined by about 40% during the late summer and early autumn in the last three decades.<sup>14</sup> In 2016, the annual Arctic sea ice extent averaged 800,000 square miles below the 1981-2010 average, making this the second smallest annual ice extent on record.<sup>15</sup>
- U.S. average annual precipitation has increased by 5% over the past 50 years. Most of the increase has come in the form of fewer, more extreme precipitation events, with 20% more rainfall in the heaviest events.<sup>2</sup>
- In the 20<sup>th</sup> century, global mean sea level rose between 17 and 21 cm, after having been quite stable over the previous several thousand years.<sup>6</sup>
- Snow cover has noticeably decreased in the Northern Hemisphere. From 1967-2012, snow cover extent very likely decreased by 53% in June, and around 7% in March and April.<sup>6</sup>

Northwestern Glacier melt, Alaska, 1940-2005<sup>16</sup>



## Biological Systems

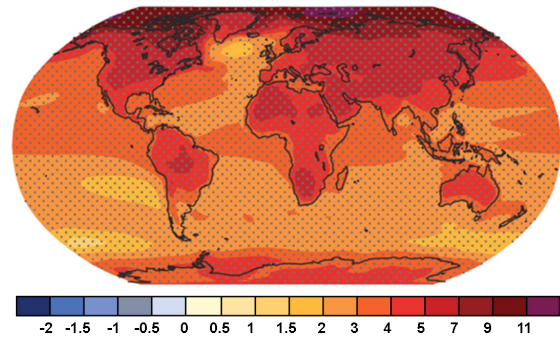
- Warming that has already occurred is affecting the biological timing (phenology) and geographic range of plant and animal communities.<sup>17</sup> Relationships such as predator-prey interactions are affected by these shifts, especially when changes do not occur evenly among species.<sup>18</sup>
- Since the start of the 20<sup>th</sup> century, the average growing season in the U.S. has lengthened by nearly two weeks.<sup>19</sup>

# Predicted Changes

## Increased Temperature

- Between now and 2035, the IPCC predicts that the temperature will rise between 0.3-0.7°C (0.5-1.3°F). In the long term, global mean surface temperatures are predicted to rise 0.4-2.6°C (0.7-4.7°F) from 2045-2065 and 0.3-4.8°C (0.5-8.6°F) from 2081-2100, relative to the reference period of 1986-2005. In the past, a change of 5°C (9°F) most often occurred over thousands of years.<sup>6</sup>
- A warming planet does not simply result in higher average daytime temperatures. The frequency of very hot days increases, while the frequency of very cold days decreases.<sup>6</sup>

Predicted Annual Mean Change in Temperature (°C)  
2081-2100 relative to 1986-2005<sup>6</sup>



## Ocean Impacts

- By 2100, the average sea level is anticipated to rise between 26 and 82 cm. The rise will be a result of thermal expansion from warming oceans and additional water added to the oceans by melting glaciers and ice sheets.<sup>6</sup>
- The oceans absorb about 27% of anthropogenic CO<sub>2</sub> emissions, resulting in increased acidity. Even under conservative projections, coral reefs will be severely impacted.<sup>20</sup>

# Implications for Human and Natural Systems

- Impacts of climate change will vary regionally but are very likely to impose costs which will increase as global temperatures increase.<sup>9</sup>
- This century, an unprecedented combination of climate change, associated disturbances, and other global change drivers will likely exceed many ecosystems' capacities for resilience.<sup>21</sup> Species extinction, food insecurity, human activity constraints, and limited adaptability are risks associated with warming at or above predicted temperatures for the year 2100 (4°C or 7°F above pre-industrial levels).<sup>9</sup>
- With an increase in average global temperatures of 2°C, nearly every summer would be warmer than the hottest 5% of recent summers.<sup>22</sup>
- A 2-foot rise in sea level would cause relative increases of 2.3 feet in New York City and 3.5 feet in Galveston, TX.<sup>2</sup>
- Increased temperatures and changes in precipitation and climate variability would alter the geographic ranges and seasonality of diseases spread by organisms like mosquitoes.<sup>22</sup>
- Although higher CO<sub>2</sub> concentrations and slight temperature increases can boost crop yields, the negative effects of warming on plant health and soil moisture lead to lower yields at higher temperatures. Intensified soil and water resource degradation resulting from changes in temperature and precipitation will further stress agriculture in certain regions.<sup>22</sup>

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16. Photo courtesy of the National Snow and Ice Data Center/World Data Center for Glaciology.

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