Lecture 3: Climate Change Review

Climate Change Ecology
Geography 404
Jeff Hicke

Radiation budget of Earth

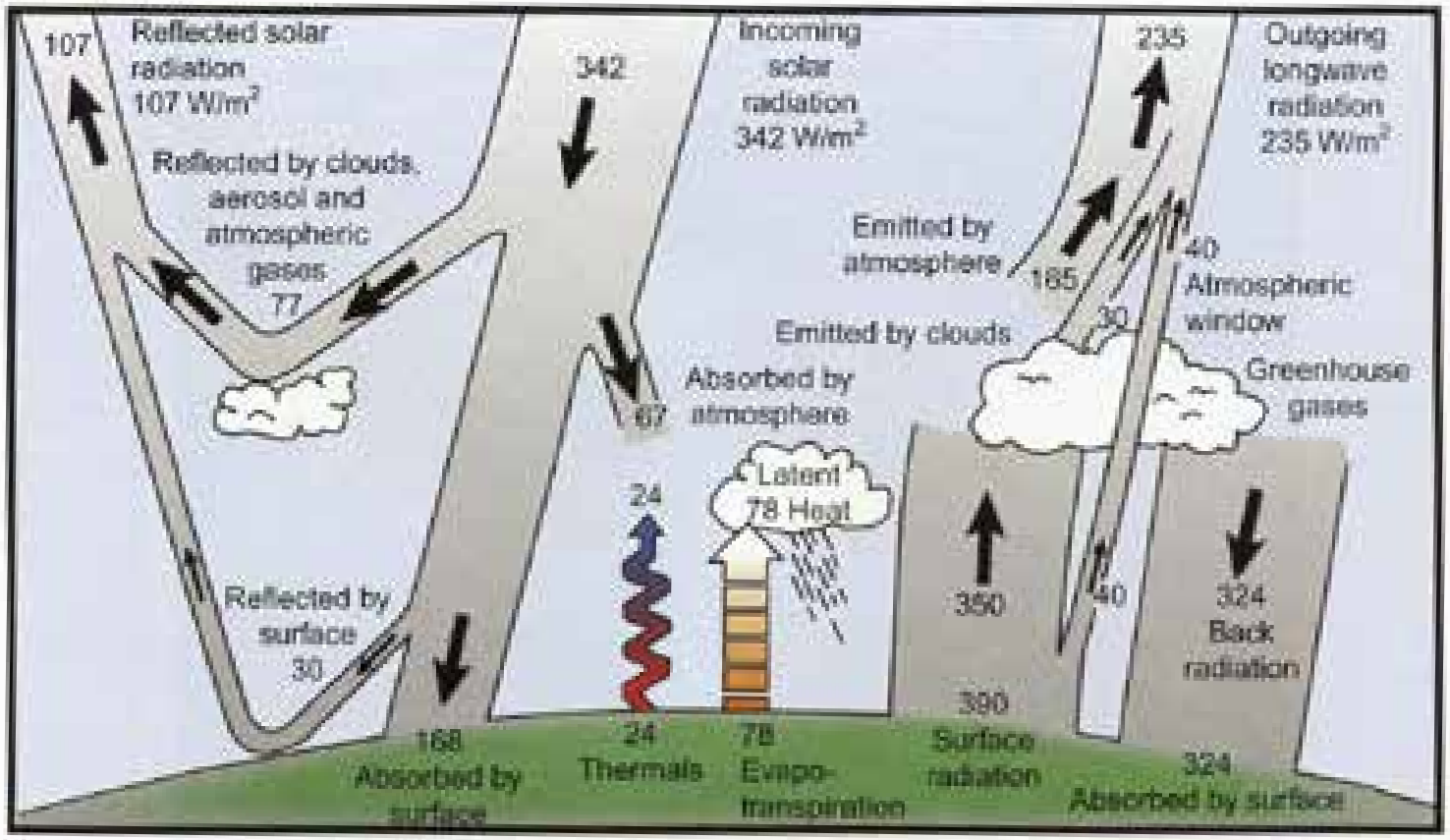

FIGURE 2.9 **Earth's Radiation Balance.**
Approximately 342 W/m² of solar energy reaches the Earth's surface. 107 W/m² is reflected into space, whereas 235 W/m² is emitted from the Earth as long-wave radiation. *From* Climate Change 2007: The Physical Science Basis. *Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.*

Hannah, *Climate Change Biology*, 2011

Global temperature has changed substantially over hundreds of millions of years

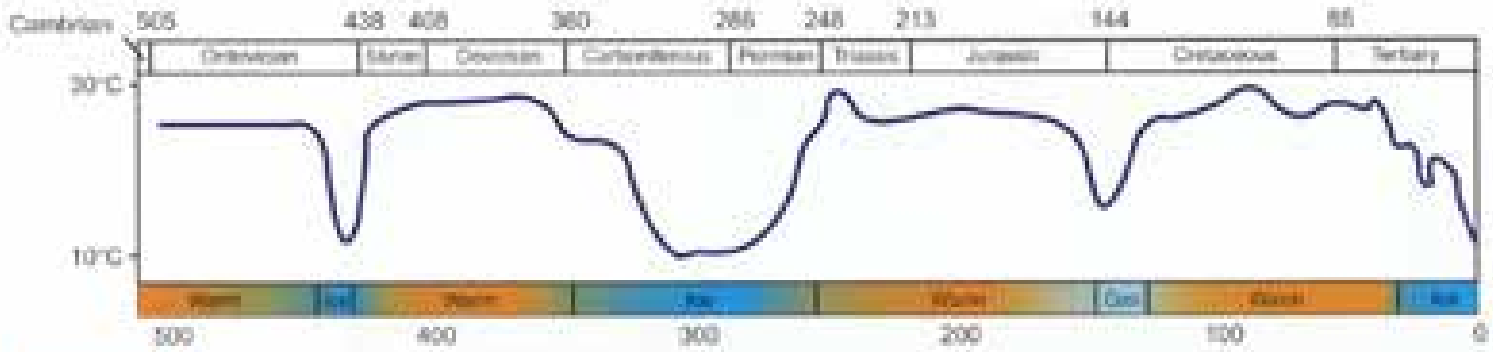

FIGURE 2.5 Global Temperature During the Past 500 Million Years.
Global mean temperature has fluctuated between icehouse and hothouse conditions during the past billion years. Four major hothouse periods have seen a largely ice-free planet, whereas four major icehouse periods have had major polar or continental ice sheets. Current climate is in a warm phase within an icehouse period. *Reproduced with permission from Christopher R. Scotese.*

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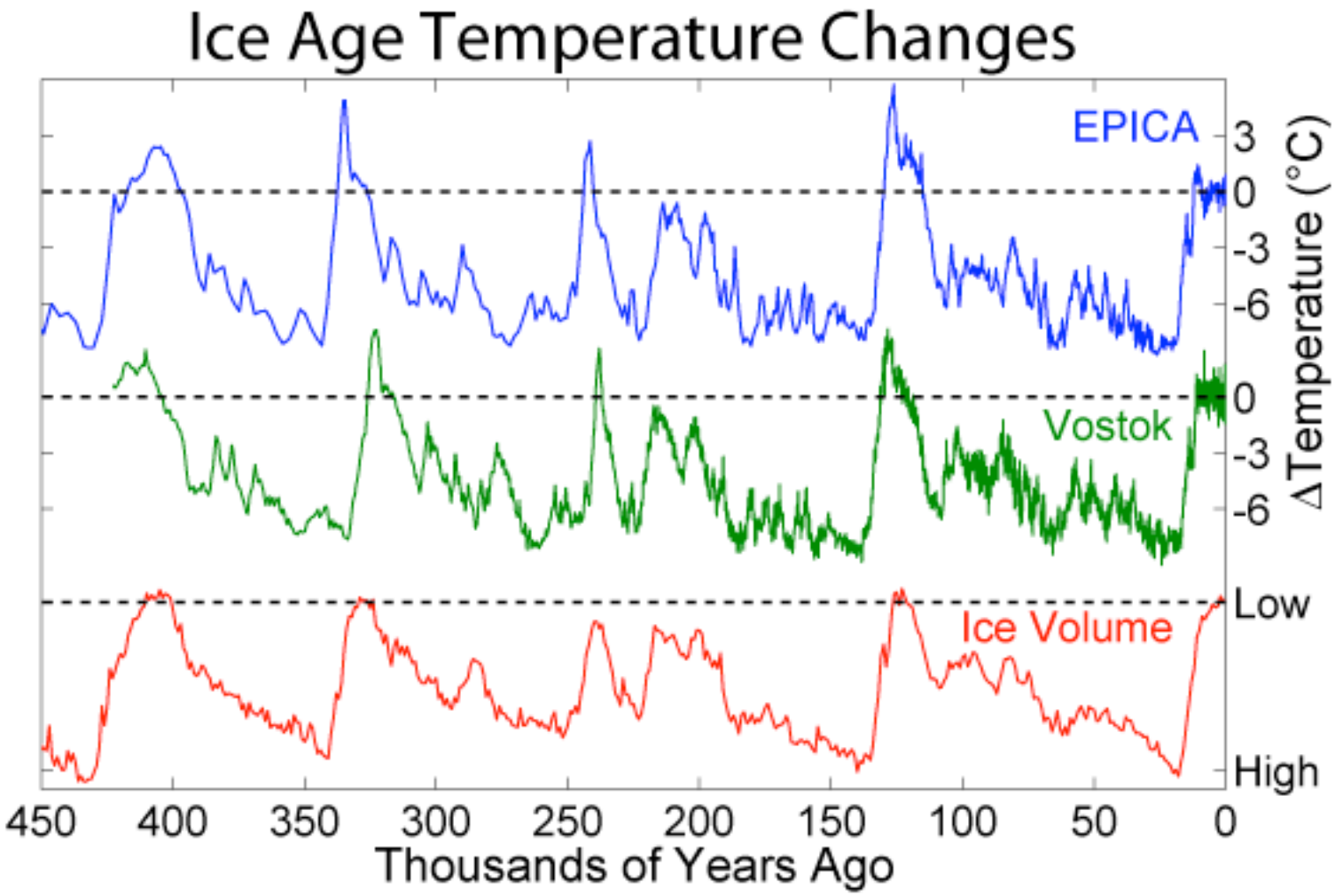
Global temperature has changed substantially over hundreds of thousands of years



globalwarmingart.com

Atmospheric circulation patterns on Earth

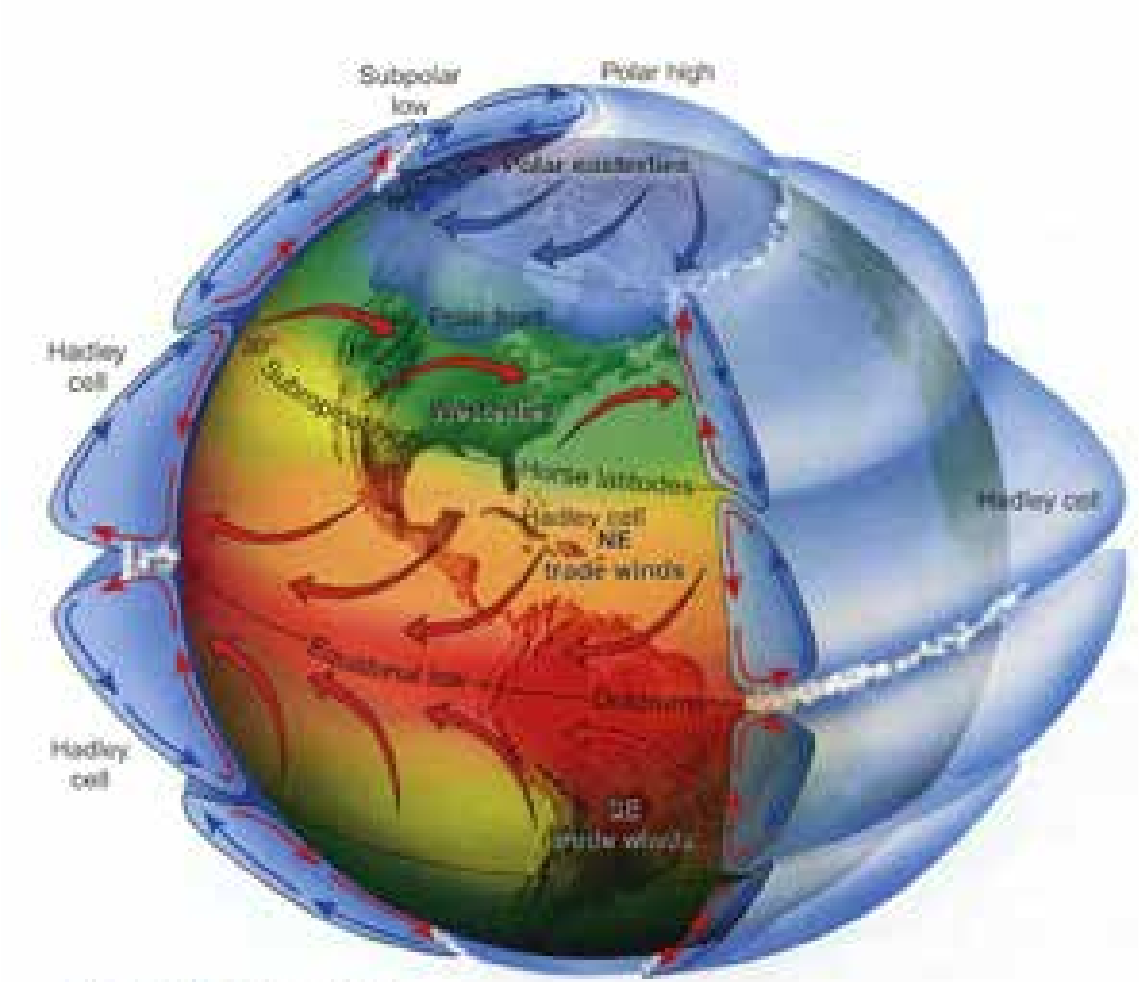


FIGURE 2.11 Hadley Cells.
Warm air rises in the atmosphere, cools, and descends. This phenomenon results in the formation of major vertical circulation features in the atmosphere known as Hadley cells. *Reproduced with permission from Pearson Publishers.*

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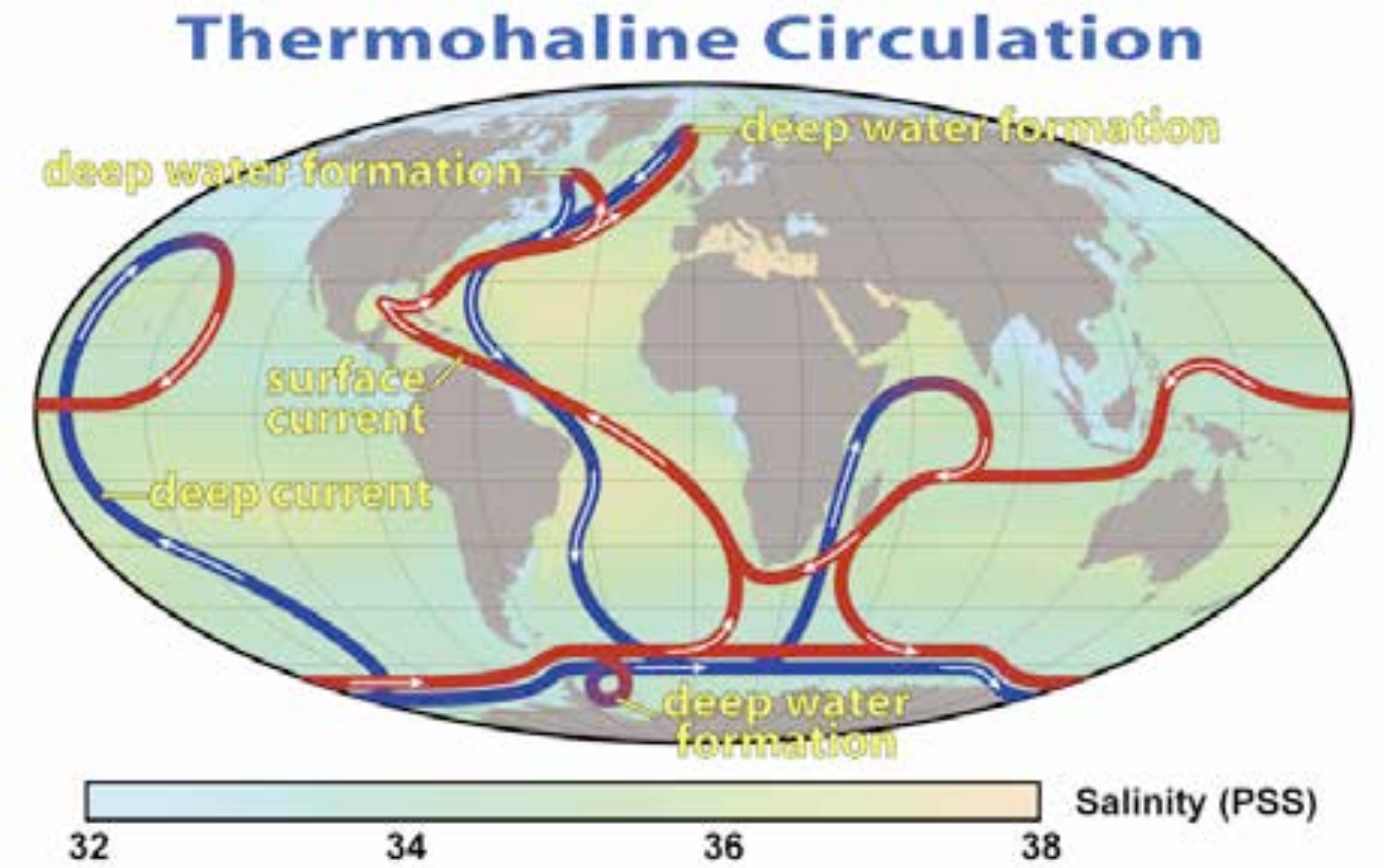

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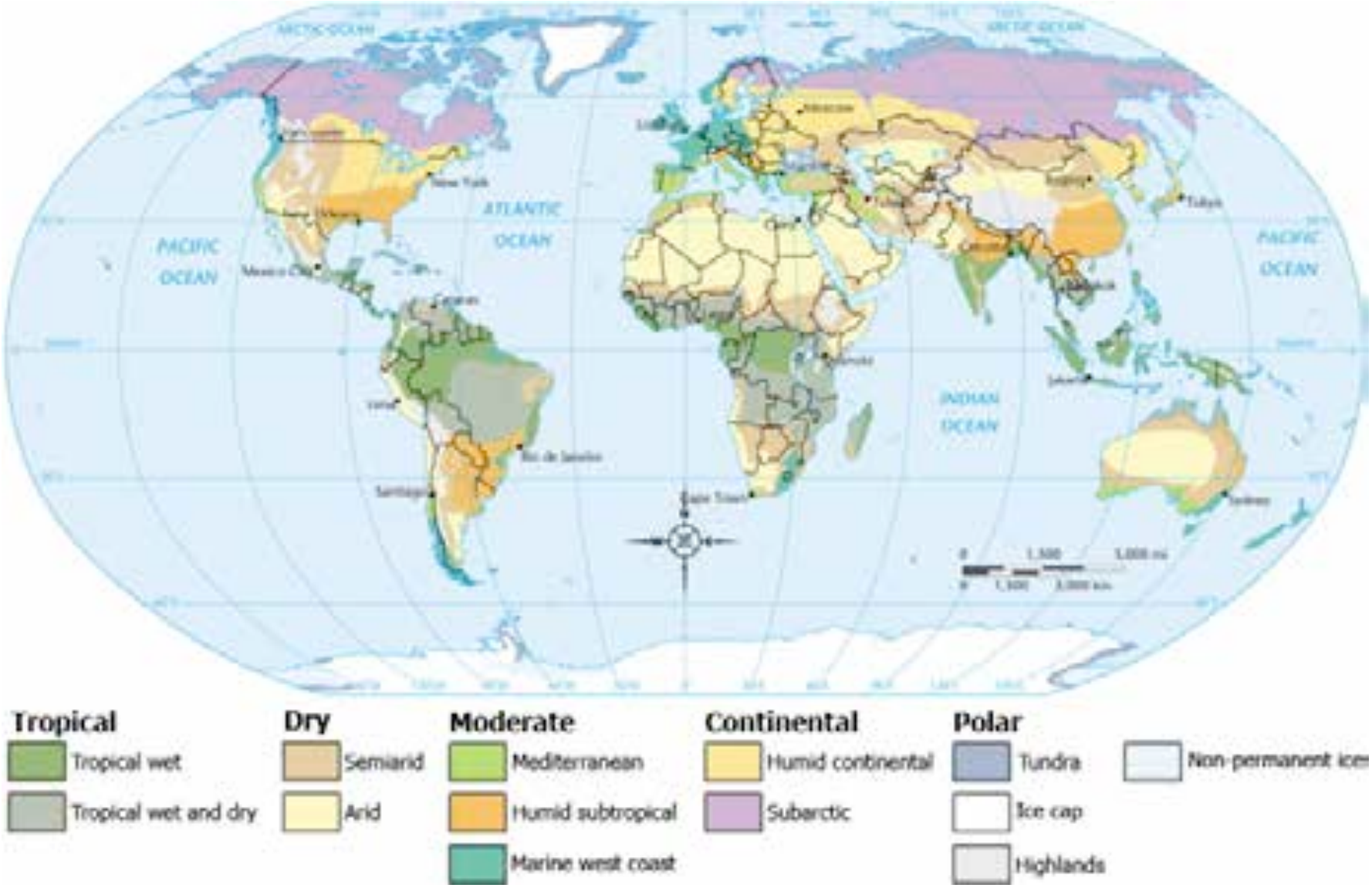
Climates on Earth



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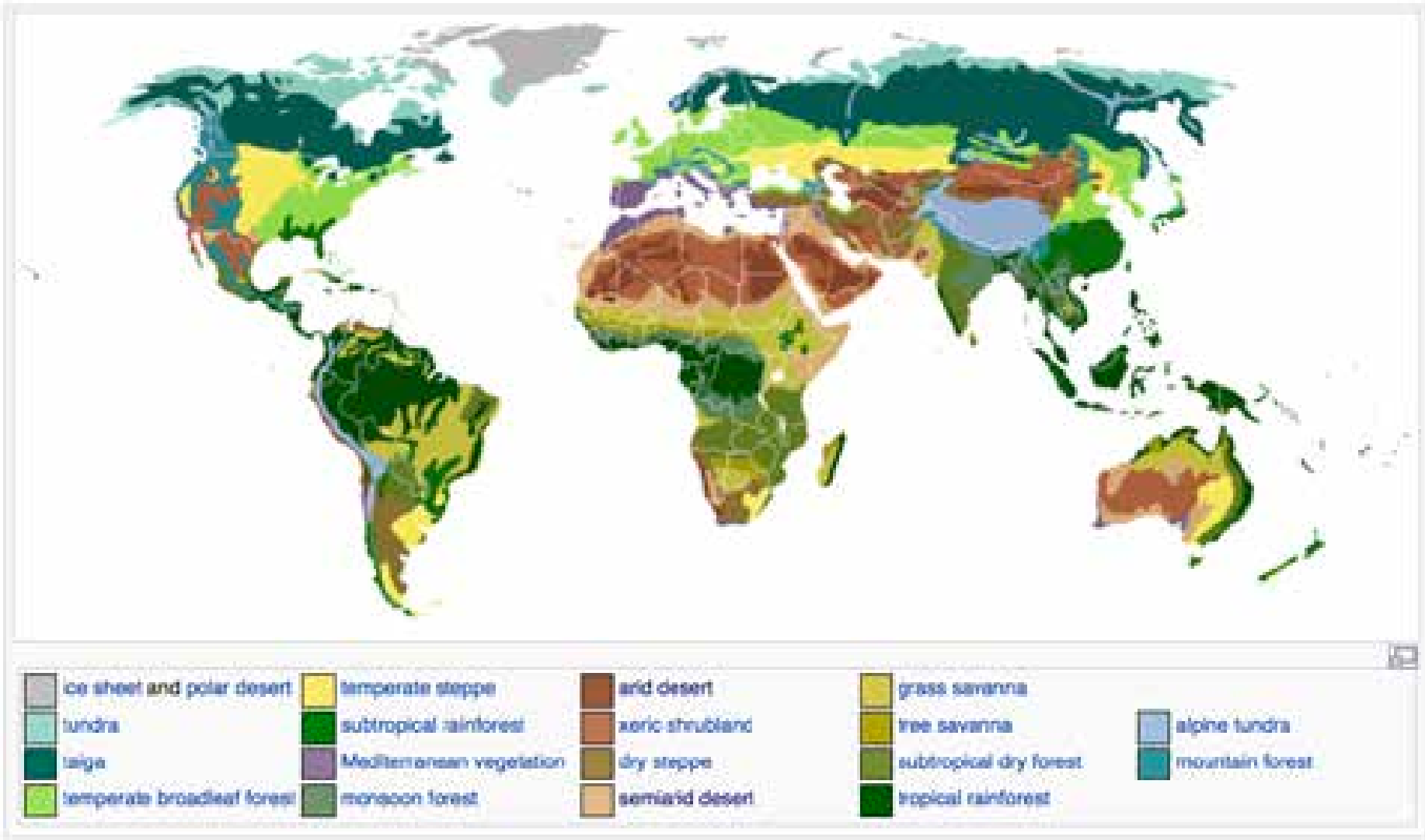
Biomes



wikipedia.org

Changes in the climate system

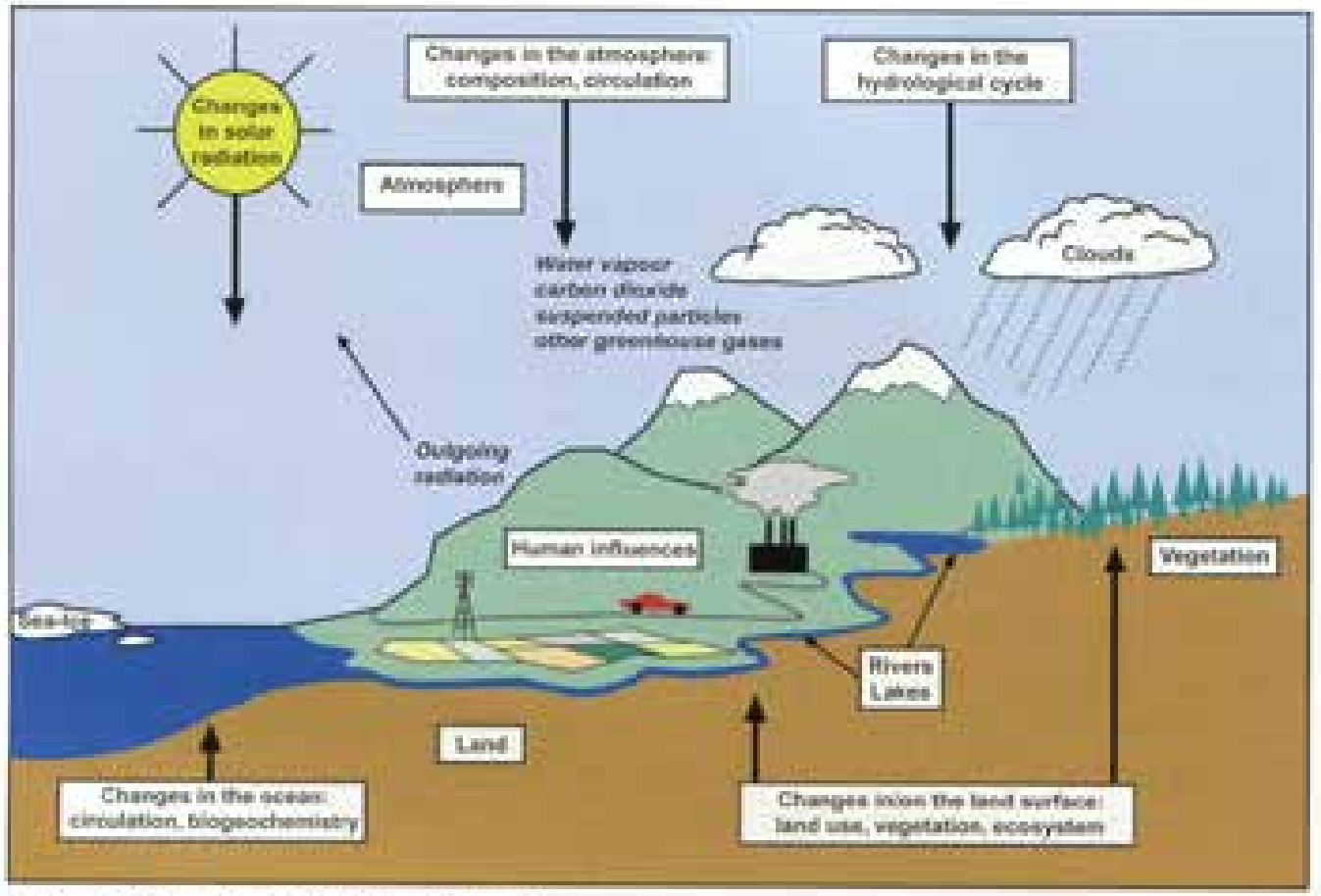


FIGURE 2.1 Climate System Elements.

The land surface, oceans, and atmosphere are the major elements of the climate system. Human-driven change in the climate system acts largely through additions of greenhouse gases to the atmosphere. *From Trenberth, K. E., et al. 1996.* The climate system: An overview. *Contribution of WG 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.*

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Changes in global temperature since 1850

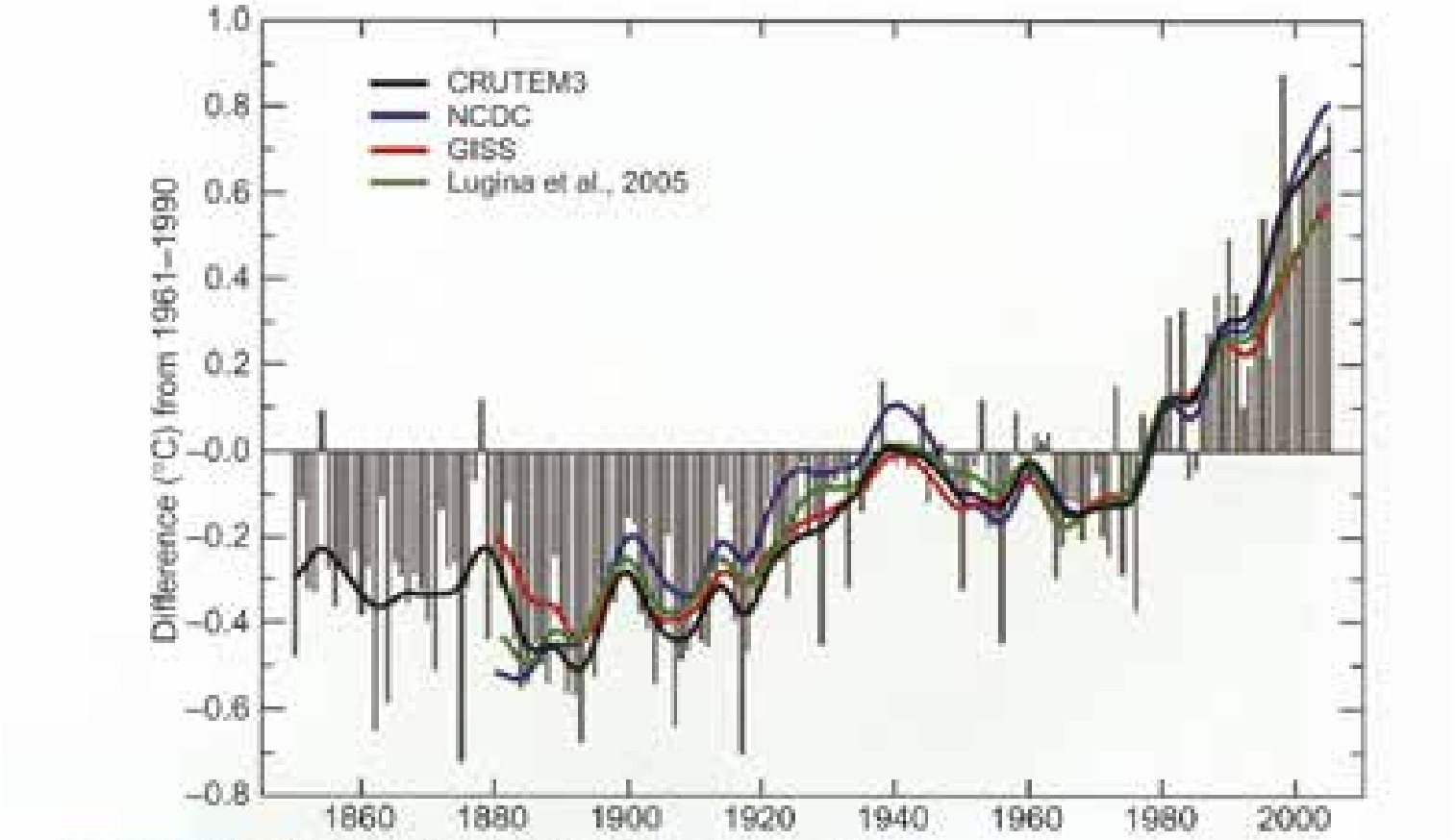

FIGURE 2.19 Historic Rise in Global Mean Temperature.
Units are deviation in degrees Celsius from the reference year 1980. Colored lines represent temperature reconstructions using different methods. Bars indicate values from the instrumental record. *From* Climate Change 2007: The Physical Science Basis. *Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.*

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Unprecedented melt on surface of Greenland Ice Sheet

FIGURE 2.32 Recent Greenland Ice Melting.
Red indicates areas of ice melt. Melt zones increased with warming in the latter half of the 20th century. Greenland melt increases sea level rise, in contrast to the melting of sea ice (e.g., in Antarctica), which does not increase sea level because the ice is already displacing seawater. Continued acceleration of melting could result in shutdown of thermohaline circulation. *Source: Arctic Climate Impact Assessment*

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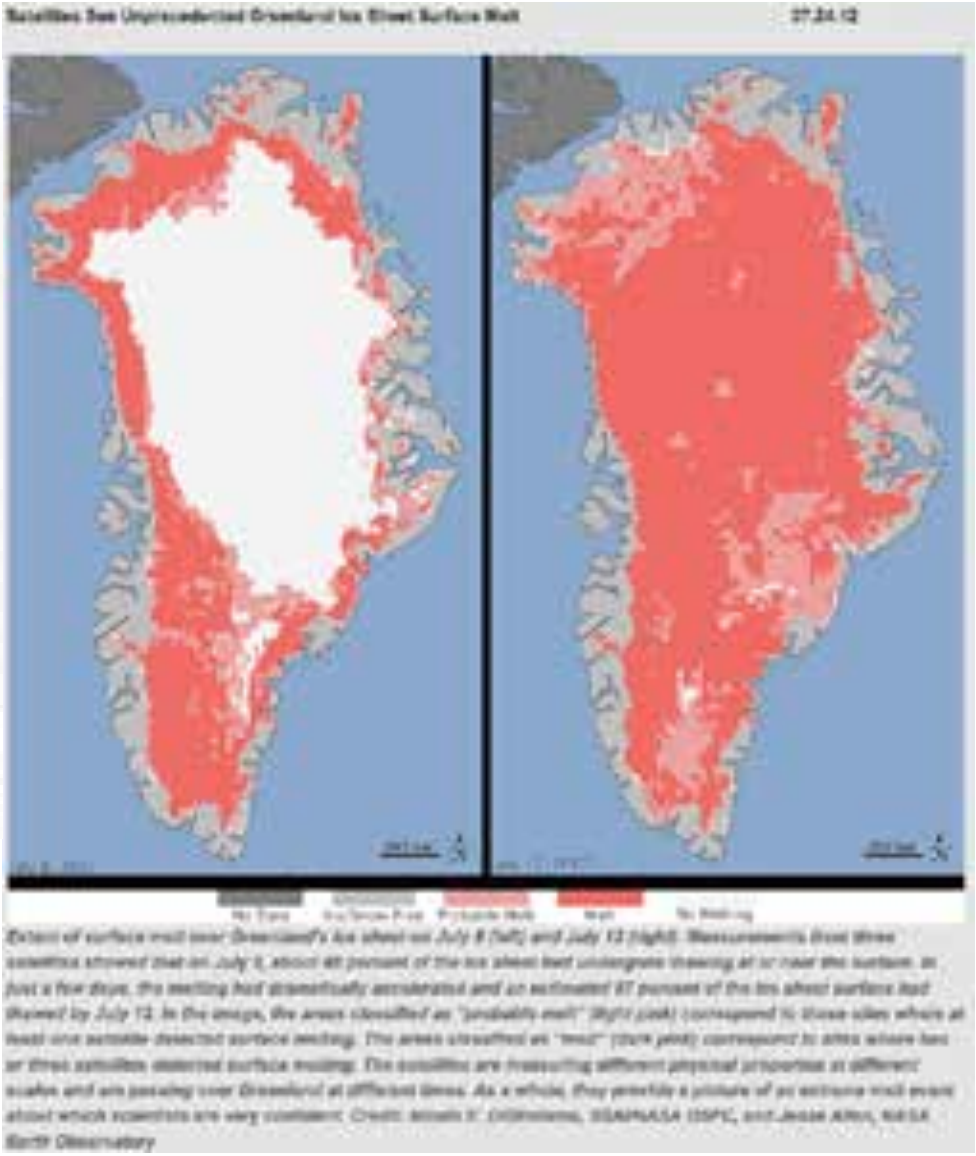

http://www.nasa.gov/topics/earth/features/greenland-melt.html

Changes in atmospheric carbon dioxide

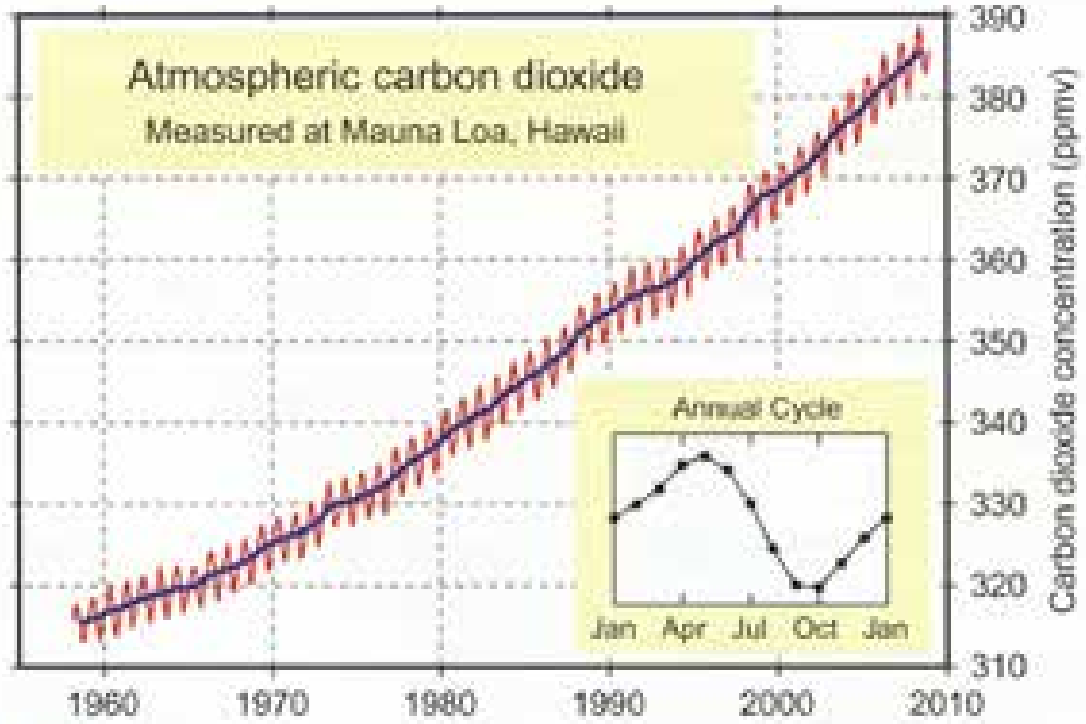

FIGURE 2.16 **Mauna Loa CO_2 Record.**

The CO_2 record from Mauna Loa clearly shows strongly rising atmospheric CO_2 concentrations during approximately the past 50 years. Superimposed on a multiyear increase is a much smaller "sawtooth" annual cycle, which results from the release and uptake of CO_2 from vegetation. *From* Climate Change 2007: The Physical Science Basis. *Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.*

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Recent climate change and attribution to humans

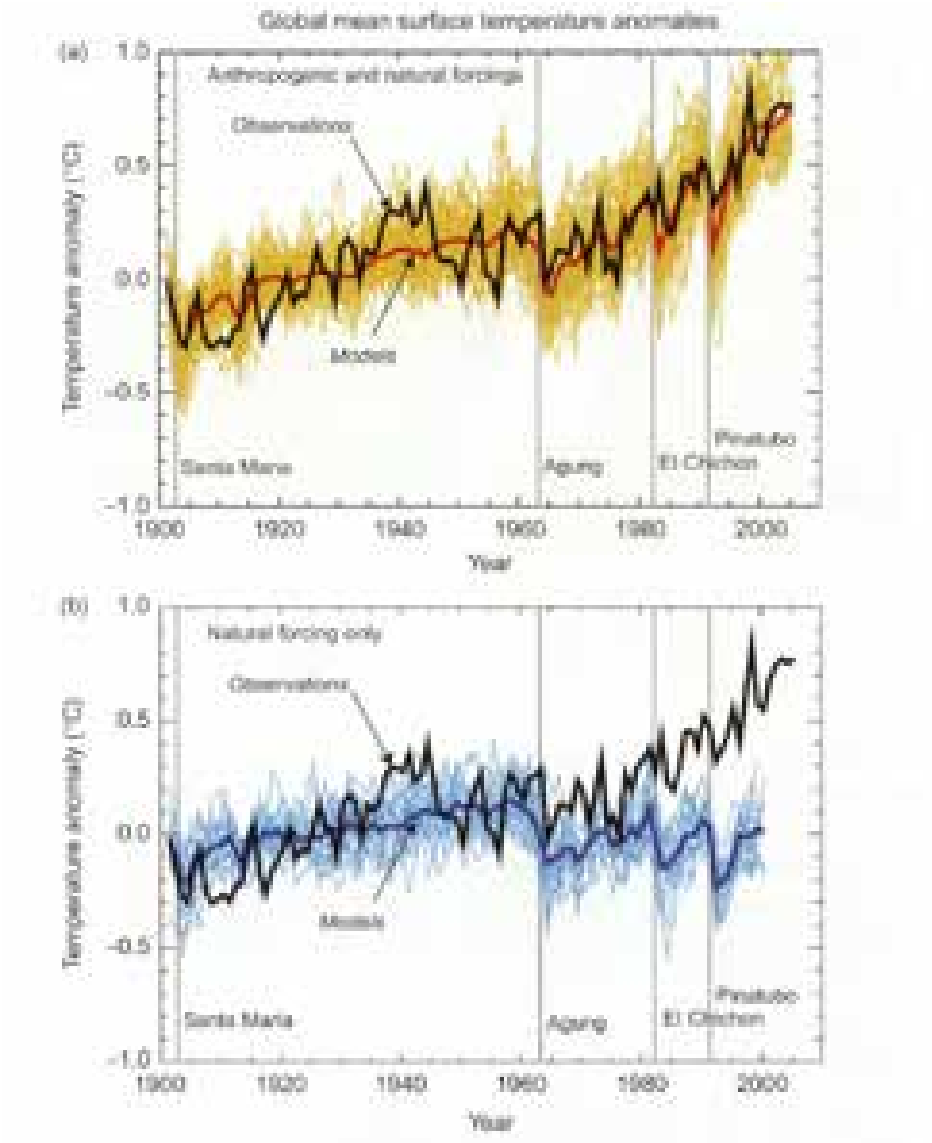

FIGURE 2.8 Global Temperature Change.
Global temperature cooled measurably in the years immediately after the Mount Pinatubo eruption (bold line). The global temperature trace indicates major volcanic events that drove decreases in global temperatures. It is coupled with mean temperature projections from global climate model (GCM) computer simulations (colored lines) showing that the actual temperature record can only be fully reproduced when human forcings, primarily burning of fossil fuels and deforestation, are included in the GCM simulations. *From Climate Change 2001: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure TS.23.* Cambridge University Press.

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Attribution of recent climate change to humans

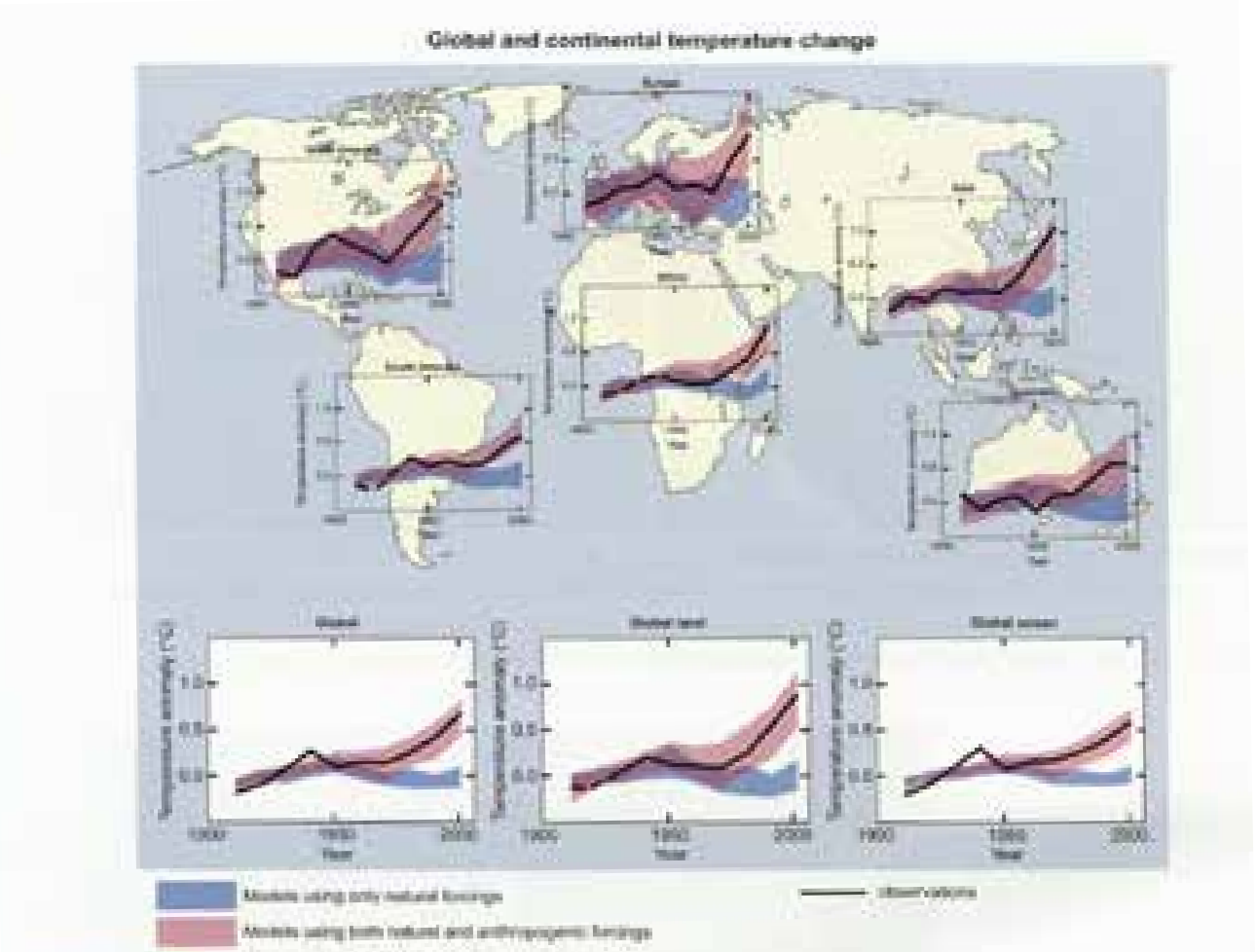

FIGURE 2.20 Rise in Mean Temperature by Continent.
Bold lines indicate historical record. Pink shading indicates the range of values from GCM simulations using both human and natural forcings on climate. Blue shading indicates range of values from GCMs forced with only natural (no human greenhouse gases) forcings. *From Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.*

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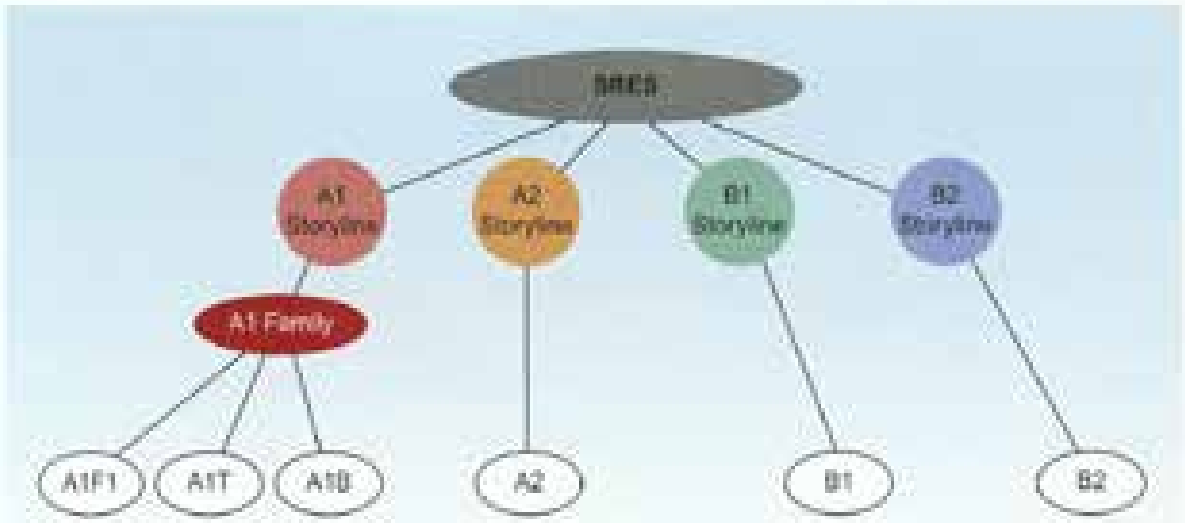
Climate modeling: CO2 emissions scenarios

Old way: SRES

New way: RCPs



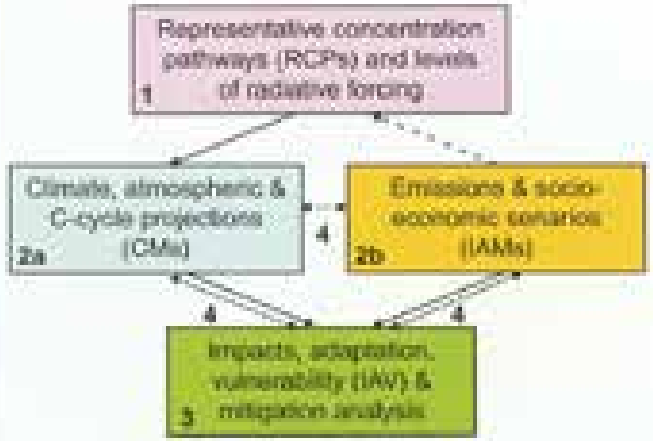


FIGURE 2.28 IPCC Emissions Scenarios.

IPCC emissions scenarios are described by the Special Report on Emissions Scenarios (SRES), and divided into several "families." Each family of scenarios is defined by a logically consistent storyline about how the world may develop. For instance, in an "A" storyline, globalization is advanced, whereas in a "B" storyline there is more regionalization. Within a storyline with globalization, a high-technology pathway may be logically consistent, whereas it would not be consistent with a more regional world in which technology exchange is limited. *From IPCC, 2000. Special Report on Emissions Scenarios. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Figure SPM-1. Cambridge University Press (left side only).*

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Projections of future global temperature

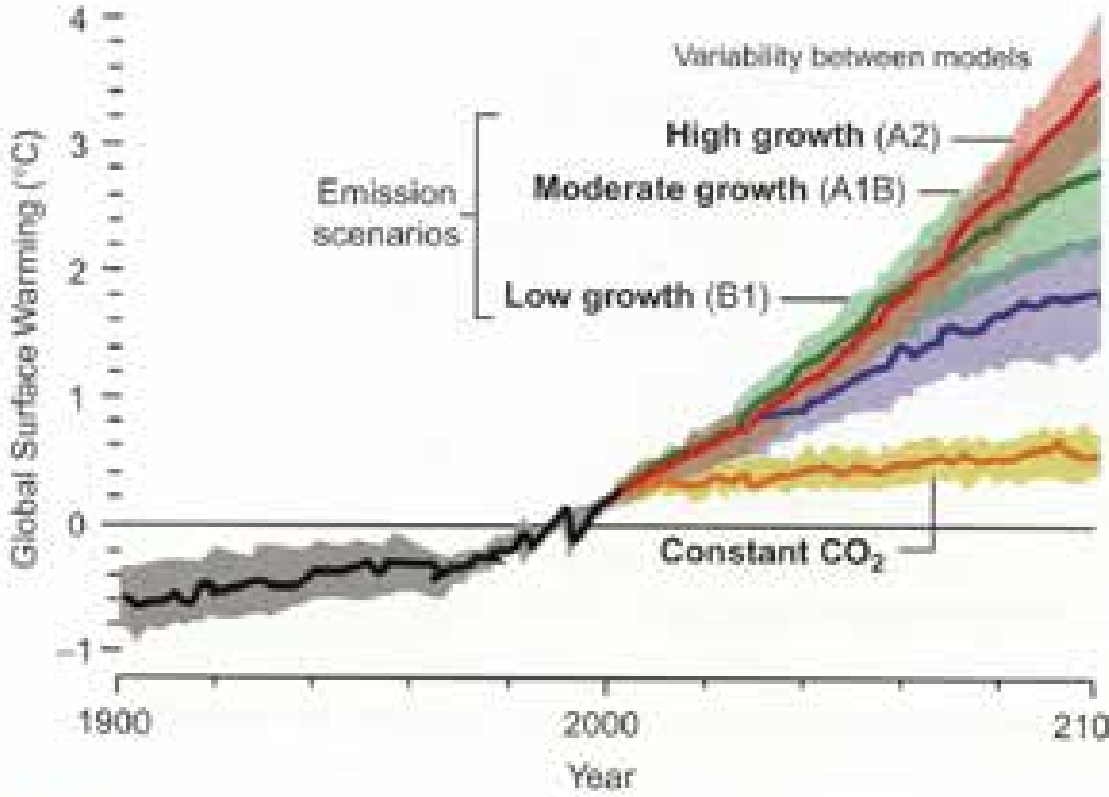

FIGURE 2.29 Global Mean Temperature Estimated from GCMs.
Using IPCC emissions scenarios, GCMs simulate global climate change. One summary statistic from these simulations is global mean temperature, shown here as it varies with emissions scenario (colored lines) and GCM (variation around colored lines). *From* Climate Change 2007: The Physical Science Basis. *Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.*

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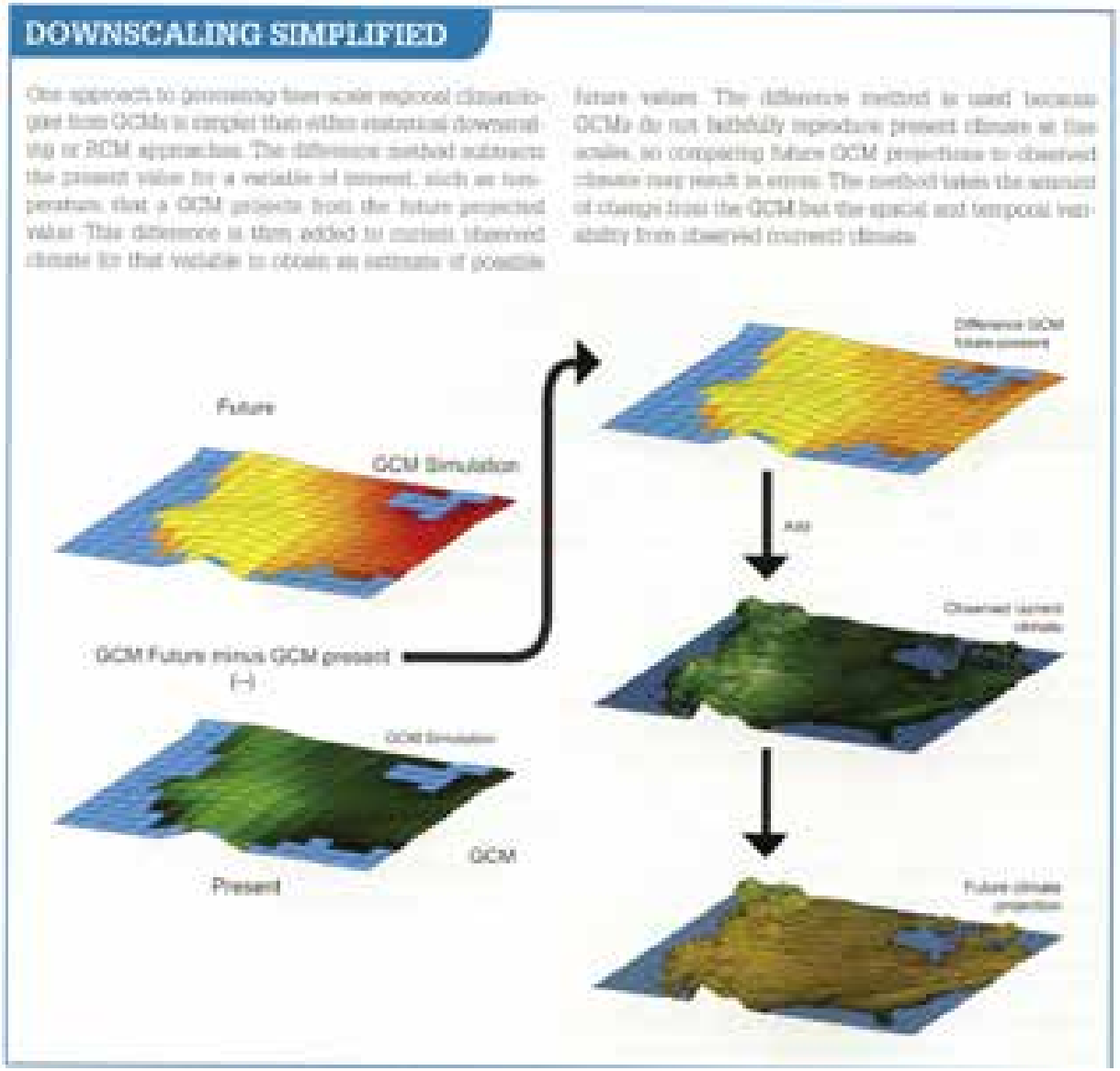
Finer resolution => better studies of impacts



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Climate modeling: spatial resolution

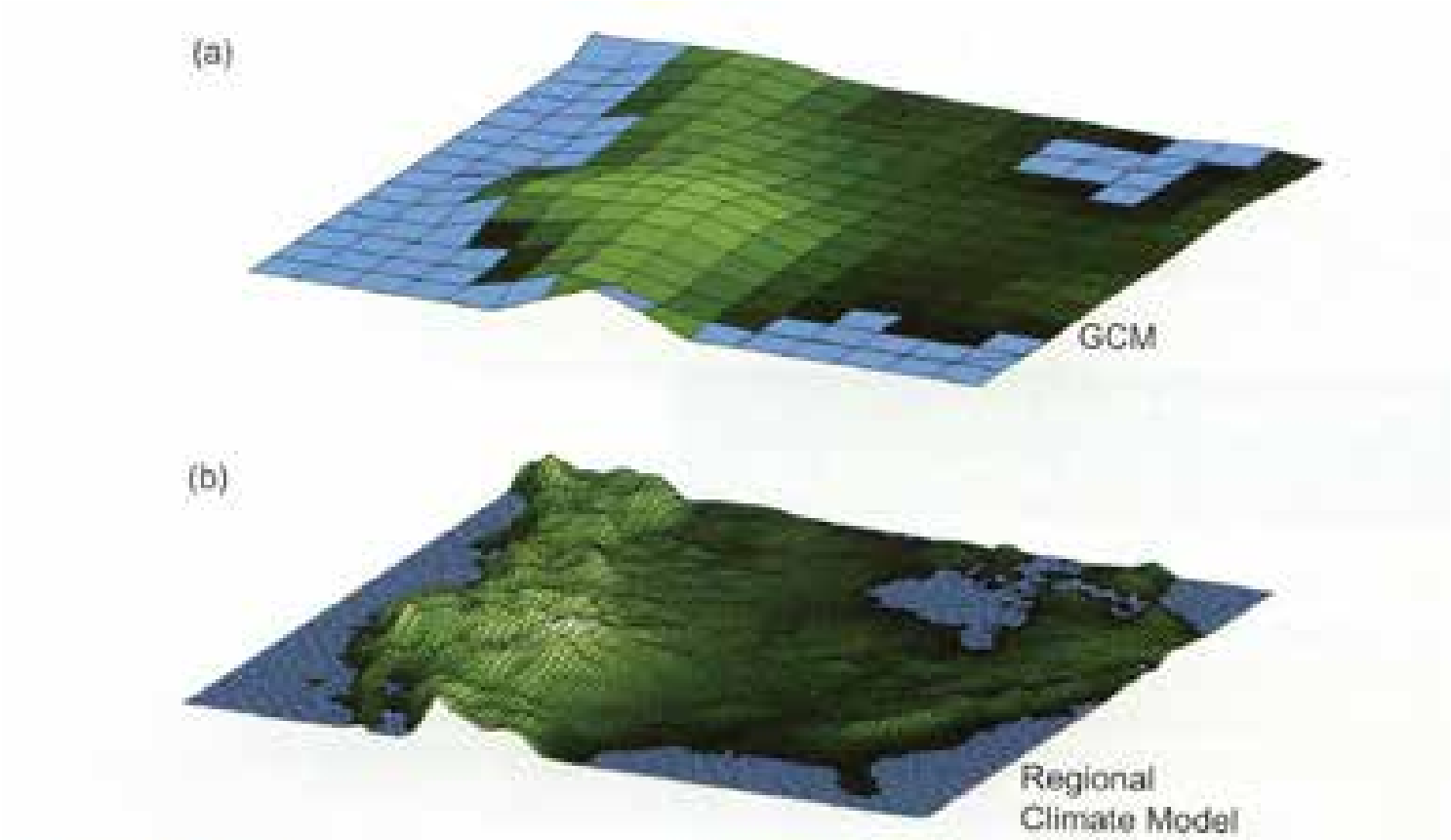

FIGURE 2.27 RCM Resolution.
An RCM can resolve features such as mountain ranges that have important influence on climate. In this example from North America, all mountains from the Sierras of California to the Rocky Mountains are represented as a single "hump" at the horizontal resolution of a GCM, whereas they are better resolved at the resolution of the RCM. *Reproduced with permission from Yale University Press.*

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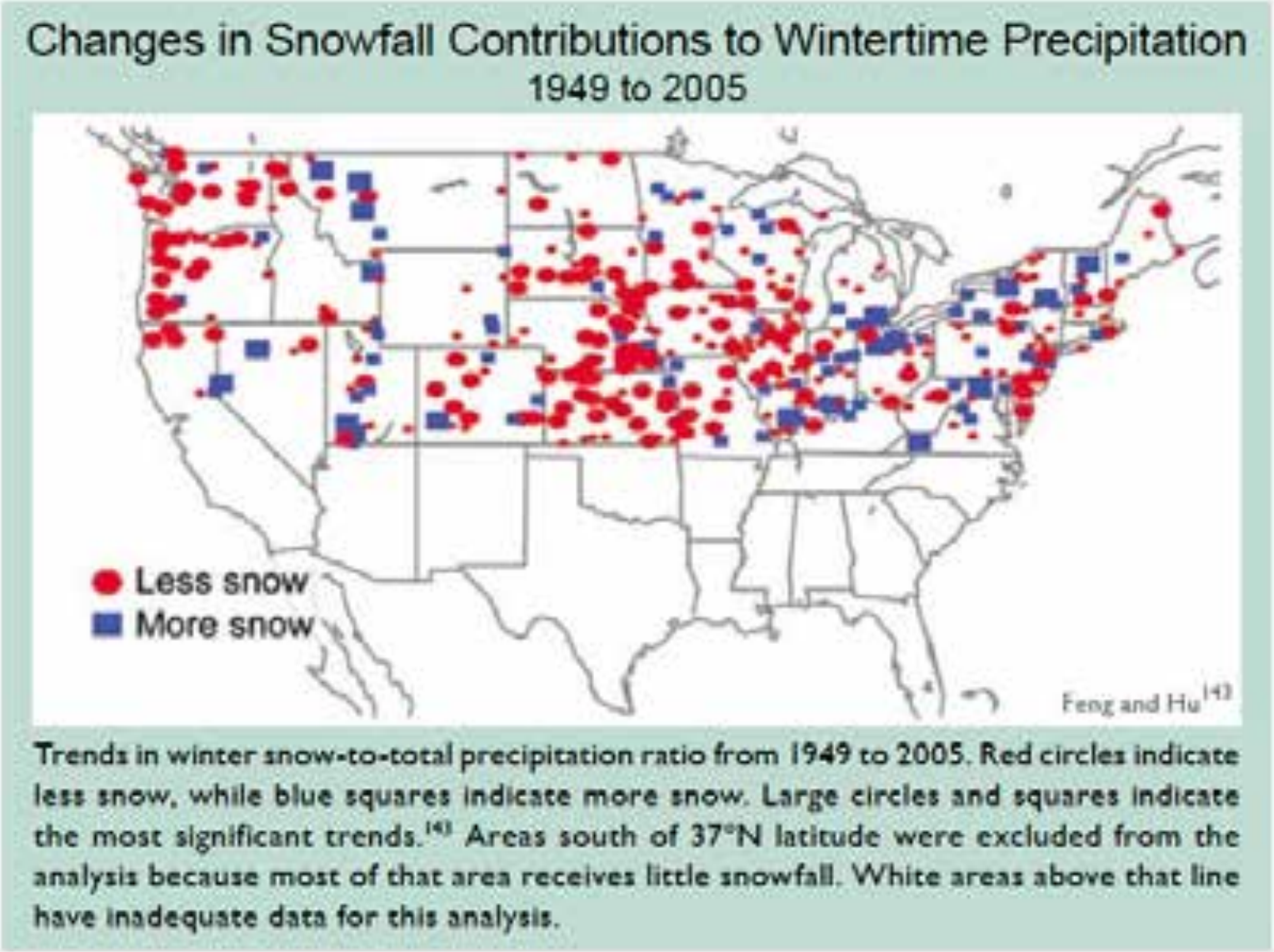
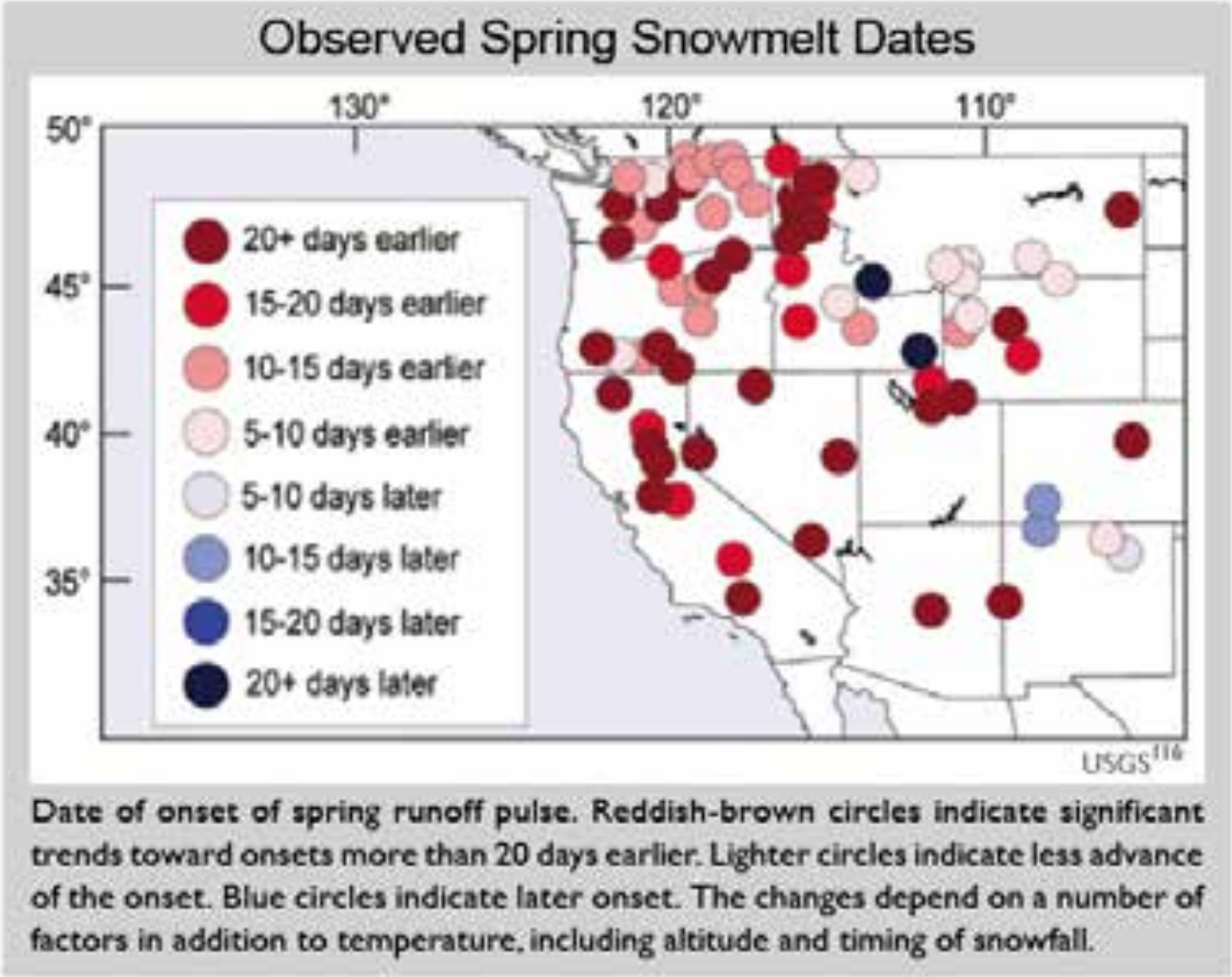
Impacts to physical climate system important to biology



Trends in winter snow-to-total precipitation ratio from 1949 to 2005. Red circles indicate less snow, while blue squares indicate more snow. Large circles and squares indicate the most significant trends.[43] Areas south of 37°N latitude were excluded from the analysis because most of that area receives little snowfall. White areas above that line have inadequate data for this analysis.

USGCRP, *Global Climate Change Impacts in the United States*, 2009

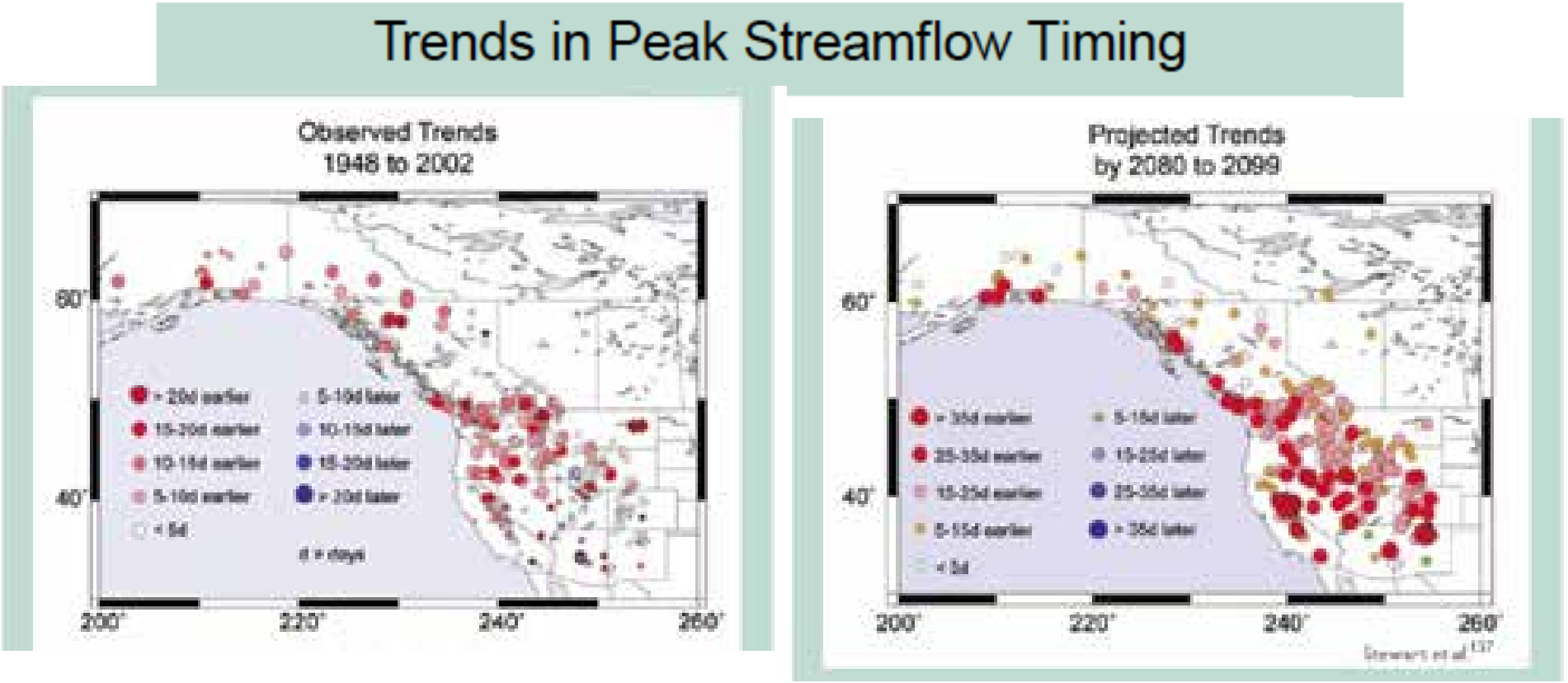
Impacts to physical climate system important to biology



Date of onset of spring runoff pulse. Reddish-brown circles indicate significant trends toward onsets more than 20 days earlier. Lighter circles indicate less advance of the onset. Blue circles indicate later onset. The changes depend on a number of factors in addition to temperature, including altitude and timing of snowfall.

USGCRP, *Global Climate Change Impacts in the United States*, 2009

Impacts to physical climate system important to biology



USGCRP, *Global Climate Change Impacts in the United States*, 2009

Impacts to physical climate system important to biology

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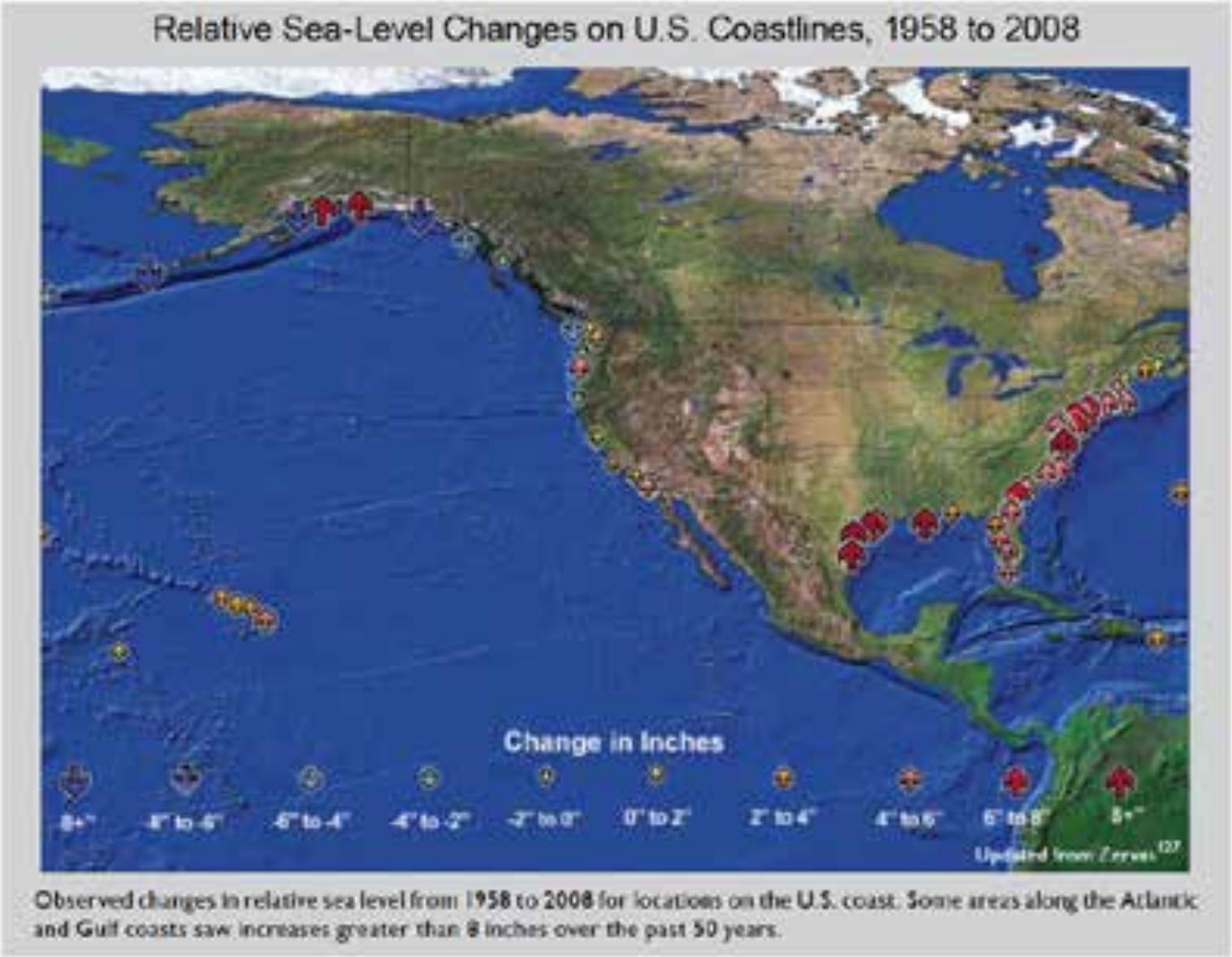
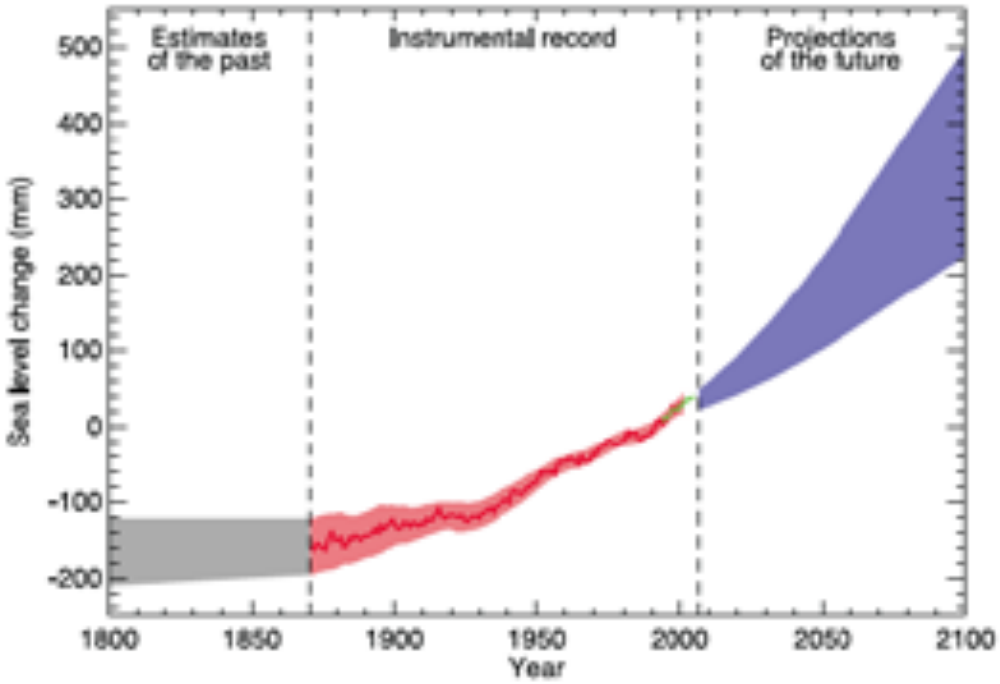


Observed changes in relative sea level from 1958 to 2008 for locations on the U.S. coast. Some areas along the Atlantic and Gulf coasts saw increases greater than 8 inches over the past 50 years.

USGCRP, *Global Climate Change Impacts in the United States*, 2009

Impacts to physical climate system important to biology

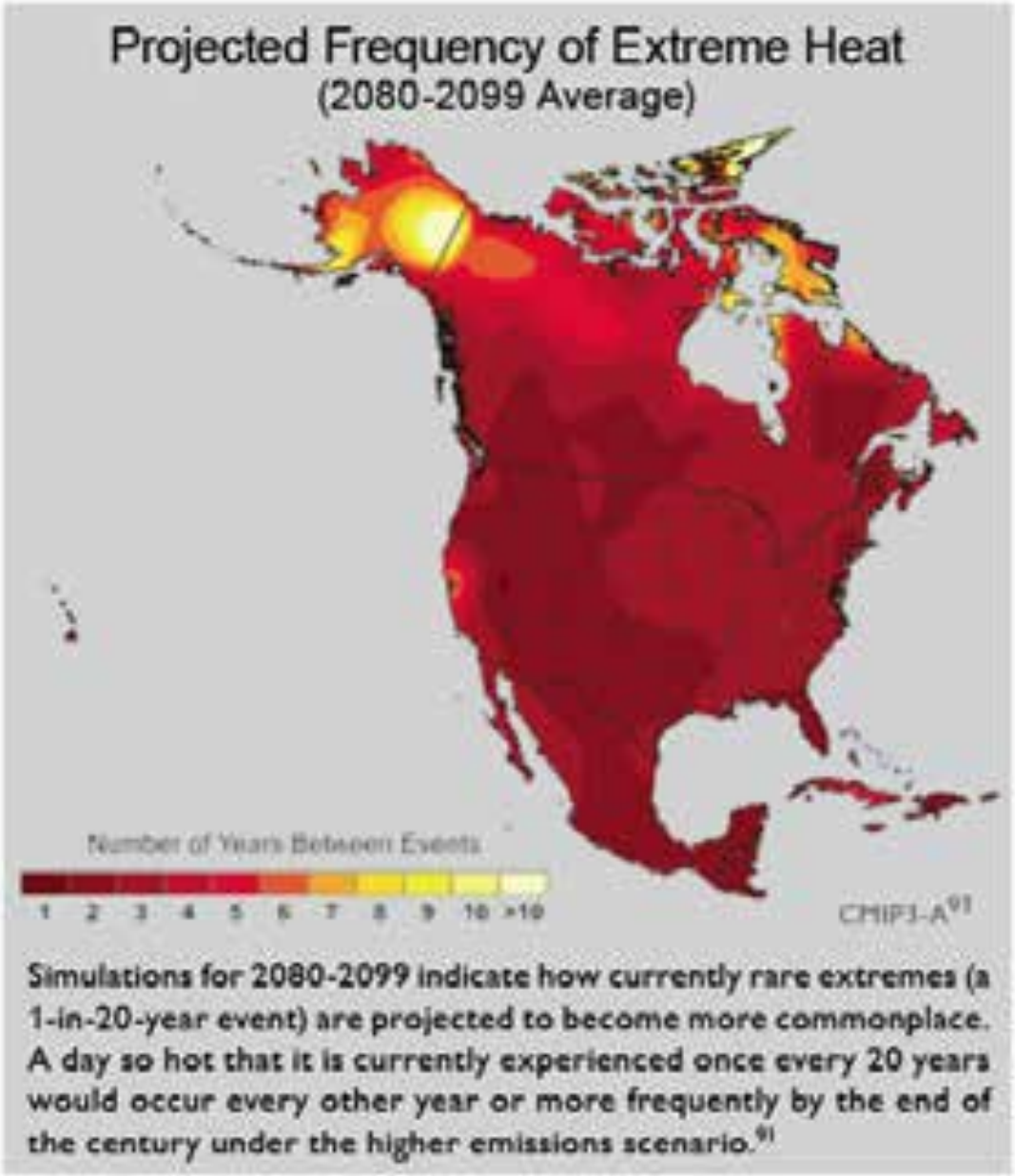


FAQ 5.1, Figure 1. *Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before 1870, global measurements of sea level are not available. The grey shading shows the uncertainty in the estimated long-term rate of sea level change (Section 6.4.3). The red line is a reconstruction of global mean sea level from tide gauges (Section 5.5.2.1), and the red shading denotes the range of variations from a smooth curve. The green line shows global mean sea level observed from satellite altimetry. The blue shading represents the range of model projections for the SRES A1B scenario for the 21st century, relative to the 1980 to 1999 mean, and has been calculated independently from the observations. Beyond 2100, the projections are increasingly dependent on the emissions scenario (see Chapter 10 for a discussion of sea level rise projections for other scenarios considered in this report). Over many centuries or millennia, sea level could rise by several metres (Section 10.7.4).*

Past and projected sea level rise

IPCC Working Group I, 2007

Impacts to physical climate system important to biology



USGCRP, *Global Climate Change Impacts in the United States*, 2009

Changes in biologically relevant temperatures

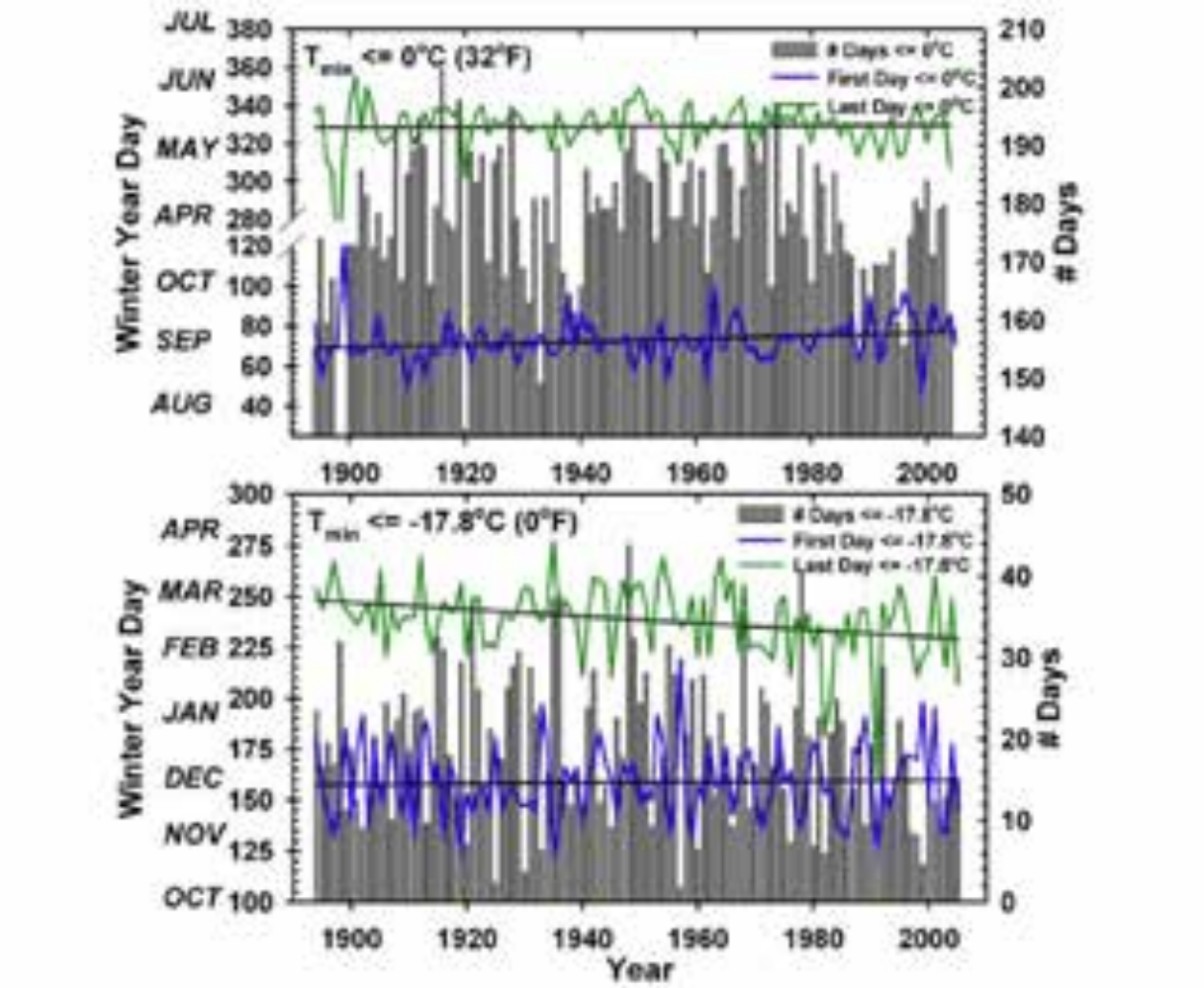


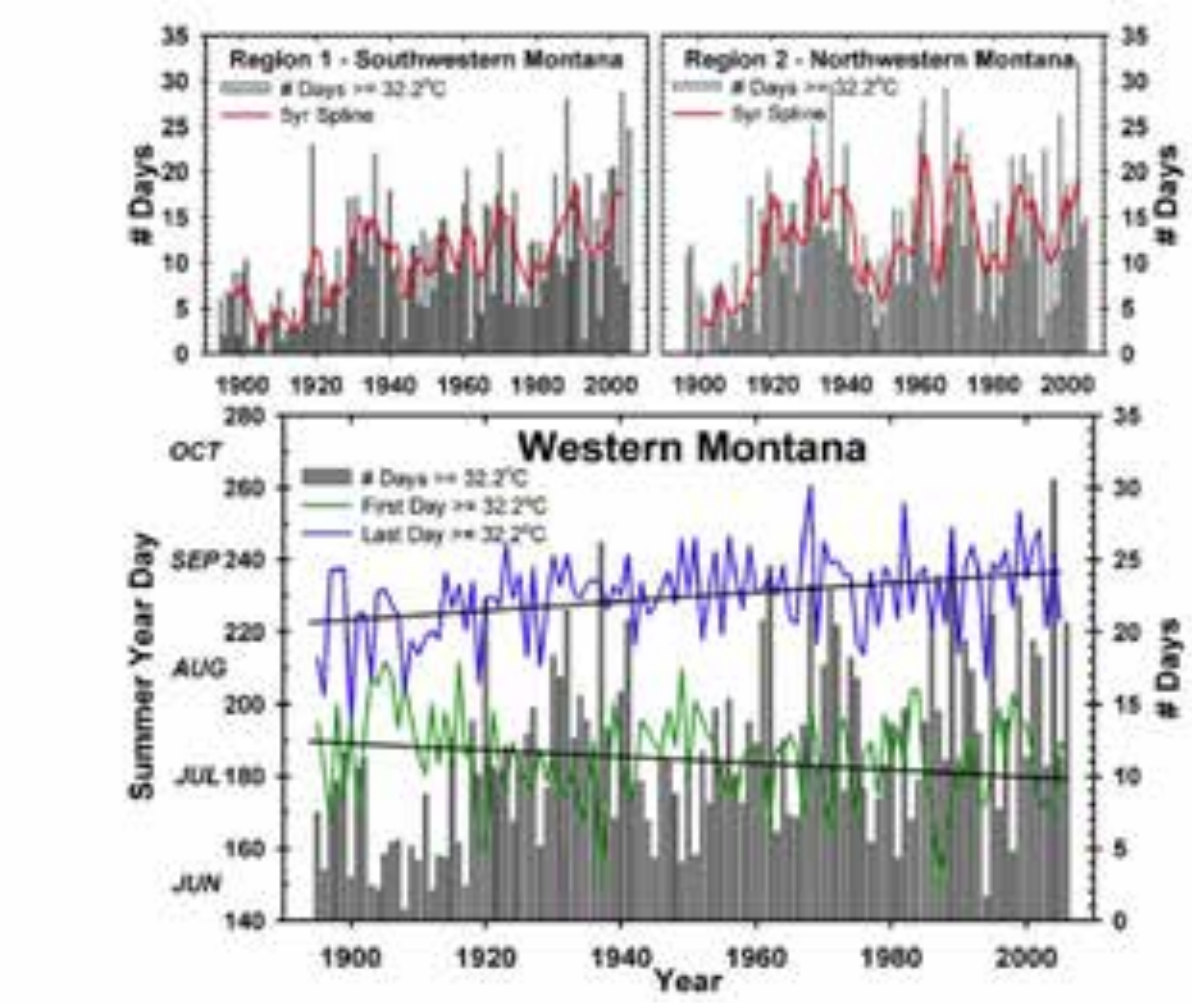
Fig. 5 Average number of frost/freeze days (#days $^{3}T_{min} \leq 0.0°C$ (32.0°F)) or extremely cold days (#days $^{3}T_{min} \leq -17.8°C$ (0.0°F)) per winter year in Western Montana (*gray bars*). Graphs also depict the first day of fall (*blue line*) and last day of spring (*green line*) temperature equaled or exceeded the defined threshold

#days when
T > 32ºF

first and last day
when T > 32ºF

Pederson et al., *Climatic Change*, 2010

Changes in biologically relevant temperatures



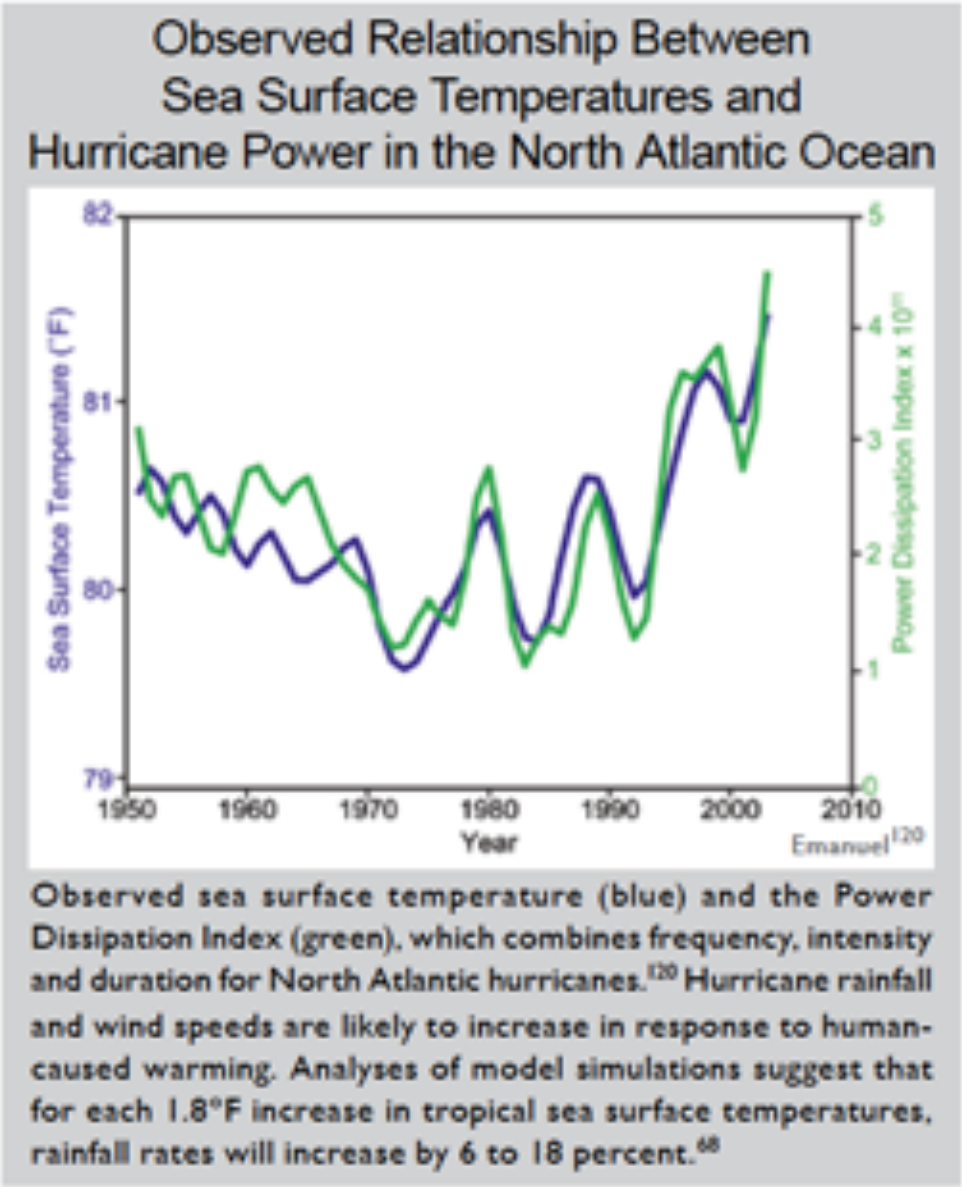
#days when T > 90ºF

first and last day when T > 90ºF

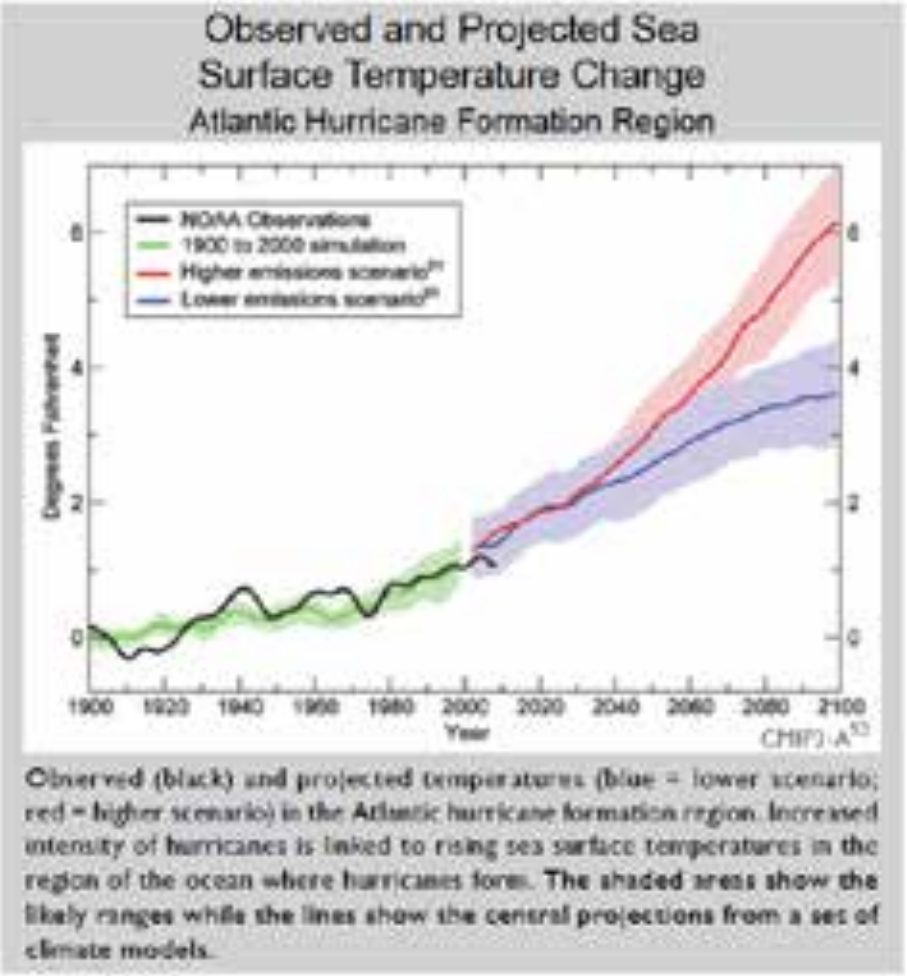
Fig. 4 *Top*: Graphs showing the different rates of change in number of days with $T_{MAX} \geq 32.2°C$ (*gray bars*) for southwestern (*left*) and northwestern Montana (*right*) from 1895–2006. A 5-year moving average (*red line*) highlights trends and variability in #days with $T \geq 32.2°C$. *Bottom*: Trends in number of days (*gray bars*), and the first (*green line*) and last (*blue line*) day of every summer, that temperature in western Montana equaled or exceeded 32.2°C

Pederson et al., *Climatic Change*, 2010

Hurricanes and warming



Observed sea surface temperature (blue) and the Power Dissipation Index (green), which combines frequency, intensity and duration for North Atlantic hurricanes.[120] Hurricane rainfall and wind speeds are likely to increase in response to human-caused warming. Analyses of model simulations suggest that for each 1.8°F increase in tropical sea surface temperatures, rainfall rates will increase by 6 to 18 percent.[68]



Observed (black) and projected temperatures (blue = lower scenario; red = higher scenario) in the Atlantic hurricane formation region. Increased intensity of hurricanes is linked to rising sea surface temperatures in the region of the ocean where hurricanes form. The shaded areas show the likely ranges while the lines show the central projections from a set of climate models.

USGCRP, *Global Climate Change Impacts in the United States*, 2009