This report briefly reviews extreme event attribution methodologies in practice (Ch. 3: Detection and Attribution) and provides a number of examples within the chapters on various climate phenomena (especially relating to the United States in Chapters 6–9).

Extreme Heat and Cold

The frequency of multiday heat waves and extreme high temperatures at both daytime and nighttime hours is increasing over many of the global land areas (IPCC 2013). There are increasing areas of land throughout our planet experiencing an excess number of daily highs above given thresholds (for example, the 90th percentile), with an approximate doubling of the world's land area since 1998 with 30 extreme heat days per year (Seneviratne et al. 2014). At the same time, frequencies of cold waves and extremely low temperatures are decreasing over the United States and much of the earth. In the United States, the number of record daily high temperatures has been about double the number of record daily low temperatures in the 2000s (Meehl et al. 2009), and much of the United States has experienced decreases of 5%–20% per decade in cold wave frequency (IPCC 2013; Easterling et al. 2016).

The enhanced radiative forcing caused by greenhouse gases has a direct influence on heat extremes by shifting distributions of daily temperature (Min et al. 2013). Recent work indicates changes in atmospheric circulation may also play a significant role (see Ch. 5: Circulation and Variability). For example, a recent study found that increasing anticyclonic circulations partially explain observed trends in heat events over North America and Eurasia, among other effects (Horton et al. 2015). Observed changes in circulation may also be the result of human influences on climate, though this is still an area of active research.

Extreme Precipitation

A robust consequence of a warming climate is an increase in atmospheric water vapor, which exacerbates precipitation events under similar meteorological conditions, meaning that when rainfall occurs, the amount of rain falling in that event tends to be greater. As a result, what in the past have been considered to be extreme precipitation events are becoming more frequent (IPCC 2013; Asadieh and Krakauer 2015; Kunkel and Frankson 2015; Donat et al. 2016). On a global scale, the observational annual-maximum daily precipitation has increased by 8.5% over the last 110 years; global climate models also derive an increase in extreme precipitation globally but tend to underestimate the rate of the observed increase (Asadieh and Krakauer 2015; Donat et al. 2016; Fischer and Knutti 2016). Extreme precipitation events are increasing globally in frequency over both wet and dry regions (Donat et al. 2016). Although more spatially heterogeneous than heat extremes, numerous studies have found increases in precipitation extremes on many regions using a variety of methods and threshold definitions (Kunkel et al. 2013), and those increases can be attributed to human-caused changes to the atmosphere (Min et al. 2011; Zhang et al. 2013). Finally, extreme precipitation associated with tropical cyclones

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(TCs) is expected to increase in the future (Knutson et al. 2015), but current trends are not clear (Kunkel et al. 2013).

The impact of extreme precipitation trends on flooding globally is complex because additional factors like soil moisture and changes in land cover are important (Berghuijs et al. 2016). Globally, due to limited data, there is low confidence for any significant current trends in river-flooding associated with climate change (Kundzewicz et al. 2014), but the magnitude and intensity of river flooding is projected to increase in the future (Arnell and Gosling 2016). More on flooding trends in the United States is in Chapter 8: Droughts, Floods, and Wildfires.

Tornadoes and Thunderstorms

Increasing air temperature and moisture increase the risk of extreme convection, and there is evidence for a global increase in severe thunderstorm conditions (Sander et al. 2013). Strong convection, along with wind shear, represents favorable conditions for tornadoes. Thus, there is reason to expect increased tornado frequency and intensity in a warming climate (Diffenbaugh et al. 2013). Inferring current changes in tornado activity is hampered by changes in reporting standards, and trends remain highly uncertain (Kunkel et al. 2013) (see Ch. 9: Extreme Storms).

Winter Storms

Winter storm tracks have shifted slightly northward (by about 0.4 degrees) in recent decades over the Northern Hemisphere (Bender et al. 2012). More generally, extratropical cyclone activity is projected to change in complex ways under future climate scenarios, with increases in some regions and seasons and decreases in others. There are large model-to-model differences among CMIP5 climate models, with some models underestimating the current cyclone track density (Colle et al. 2013; Chang 2013).

Enhanced Arctic warming (arctic amplification), due in part to sea ice loss, reduces lower tropospheric meridional temperature gradients, diminishing baroclinicity (a measure of how misaligned the gradient of pressure is from the gradient of air density)—an important energy source for extratropical cyclones. At the same time, upper-level meridional temperature gradients will increase due to a warming tropical upper troposphere and a cooling high-latitude lower stratosphere. While these two effects counteract each other with respect to a projected change in midlatitude storm tracks, the simulations indicate that the magnitude of Arctic amplification may modulate some aspects (e.g., jet position, wave extent, and blocking frequency) of the circulation in the North Atlantic region in some seasons (Barnes and Polvani 2015).

Tropical Cyclones

Detection and attribution of trends in past tropical cyclone (TC) activity is hampered by uncertainties in the data collected prior to the satellite era and by uncertainty in the relative contributions of natural variability and anthropogenic influences. Theoretical arguments and

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numerical modeling simulations support an expectation that radiative forcing by greenhouse gases and anthropogenic aerosols can affect tropical cyclone activity in a variety of ways, but robust formal detection and attribution for past observed changes has not yet been realized. Since the IPCC AR5 (2013), there is new evidence that the locations where tropical cyclones reach their peak intensity have migrated poleward in both the Northern and Southern Hemispheres, in concert with the independently measured expansion of the tropics (Kossin et al. 2014). In the western North Pacific, this migration has substantially changed the tropical cyclone hazard exposure patterns in the region and appears to have occurred outside of the historically measured modes of regional natural variability (Kossin et al. 2016).

Whether global trends in high-intensity tropical cyclones are already observable is a topic of active debate. Some research suggests positive trends (Elsner et al. 2008; Kossin et al. 2013), but significant uncertainties remain (Kossin et al. 2013; see Ch. 9: Extreme Storms). Other studies have suggested that aerosol pollution has masked the increase in TC intensity expected otherwise from enhanced greenhouse warming (Wang et al. 2014; Sobel et al. 2016).

TC intensities are expected to increase with warming, both on average and at the high end of the scale, as the range of achievable intensities expands, so that the most intense storms will exceed the intensity of any in the historical record (Sobel et al. 2016). Some studies have projected an overall increase in tropical cyclone activity (Emanuel 2013). However, studies with high-resolution models are giving a different result. For example, a high-resolution dynamical downscaling study of global TC activity under the RCP4.5 scenario projects an increased occurrence of the highest-intensity tropical cyclones (Saffir-Simpson Categories 4 and 5), along with a reduced overall tropical cyclone frequency, though there are considerable basin-to-basin differences (Knutson et al. 2015). Chapter 9: Extreme Storms covers more on extreme storms affecting the United States.

1.6. Global Changes in Land Processes

Changes in regional land cover have had important effects on climate, while climate change also has important effects on land cover (IPCC 2013; also see Ch. 10: Land Cover). In some cases, there are changes in land cover that are both consequences of and influences on global climate change (e.g., declines in land ice and snow cover, thawing permafrost, and insect damage to forests).

Northern Hemisphere snow cover extent has decreased, especially in spring, primarily due to earlier spring snowmelt (by about 0.2 million square miles [0.5 million square km]; NSIDC 2017; Kunkel et al. 2016), and this decrease since the 1970s is at least partially driven by anthropogenic influences (Rupp et al. 2013). Snow cover reductions, especially in the Arctic region in summer, have led to reduced seasonal albedo (Callaghan et al. 2011).

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While global-scale trends in drought are uncertain due to insufficient observations, regional trends indicate increased frequency and intensity of drought and aridification on land cover in the Mediterranean (Sousa et al. 2011; Hoerling et al. 2013) and West Africa (Sheffield et al. 2012; Dai 2013) and decreased frequency and intensity of droughts in central North America (Peterson et al. 2013) and northwestern Australia (Jones et al. 2009; Sheffield et al. 2012; Dai 2013).

Anthropogenic land-use changes, such as deforestation and growing cropland extent, have increased the global land surface albedo, resulting in a small cooling effect. Effects of other land-use changes, including modifications of surface roughness, latent heat flux, river runoff, and irrigation, are difficult to quantify, but may offset the direct land-use albedo changes (Bonan 2008; de Noblet-Ducoudré et al. 2012).

Globally, land-use change since 1750 has been typified by deforestation, driven by the growth in intensive farming and urban development. Global land-use change is estimated to have released 190 ± 65 GtC (gigatonnes of carbon) through 2015 (Le Quéré et al. 2015, 2016). Over the same period, cumulative fossil fuel and industrial emissions are estimated to have been 410 ± 20 GtC, yielding total anthropogenic emissions of 600 ± 70 GtC, of which cumulative land-use change emissions were about 32% (Le Quéré et al. 2015, 2016). Tropical deforestation is the dominant driver of land-use change emissions, estimated at 0.1–1.7 GtC per year, primarily from biomass burning. Global deforestation emissions of about 3 GtC per year are compensated by around 2 GtC per year of forest regrowth in some regions, mainly from abandoned agricultural land (Houghton et al. 2012; Pan et al. 2011).

Natural terrestrial ecosystems are gaining carbon through uptake of CO_2 by enhanced photosynthesis due to higher CO_2 levels, increased nitrogen deposition, and longer growing seasons in mid- and high latitudes. Anthropogenic atmospheric CO_2 absorbed by land ecosystems is stored as organic matter in live biomass (leaves, stems, and roots), dead biomass (litter and woody debris), and soil carbon.

Many studies have documented a lengthening growing season, primarily due to the changing climate (Myneni et al. 1997; Menzel et al. 2006; Schwartz et al. 2006; Kim et al. 2012), and elevated CO_2 is expected to further lengthen the growing season in places where the length is water limited (Reyes-Fox et al. 2014). In addition, a recent study has shown an overall increase in greening of the Earth in vegetated regions (Zhu et al. 2016), while another has demonstrated evidence that the greening of Northern Hemisphere extratropical vegetation is attributable to anthropogenic forcings, particularly rising atmospheric greenhouse gas levels (Mao et al. 2016). However, observations (Finzi et al. 2006; Palmroth et al. 2006; Norby et al. 2010) and models (Sokolov et al. 2008; Thornton et al. 2009; Zaehle and Friend 2010) indicate that nutrient limitations and land availability will constrain future land carbon sinks.

Modifications to the water, carbon, and biogeochemical cycles on land result in both positive and negative feedbacks to temperature increases (Betts et al. 2007; Bonan 2008; Bernier et al. 2011).

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Snow and ice albedo feedbacks are positive, leading to increased temperatures with loss of snow and ice extent. While land ecosystems are expected to have a net positive feedback due to reduced natural sinks of CO_2 in a warmer world, anthropogenically increased nitrogen deposition may reduce the magnitude of the net feedback (Churkina et al. 2009; Zaehle et al. 2010; Thornton et al. 2009). Increased temperature and reduced precipitation increase wildfire risk and susceptibility of terrestrial ecosystems to pests and disease, with resulting feedbacks on carbon storage. Increased temperature and precipitation, particularly at high latitudes, drives up soil decomposition, which leads to increased CO_2 and CH_4 (methane) emissions (Page et al. 2002; Ciais et al. 2005; Chambers et al. 2007; Kurz et al. 2008; Clark et al. 2010; van der Werf et al. 2010; Lewis et al. 2011). While some of these feedbacks are well known, others are not so well quantified and yet others remain unknown; the potential for surprise is discussed further in Chapter 15: Potential Surprises.

1.7. Global Changes in Sea Ice, Glaciers, and Land Ice

Since NCA3 (Melillo et al. 2014), there have been significant advances in the understanding of changes in the cryosphere. Observations continue to show declines in Arctic sea ice extent and thickness, Northern Hemisphere snow cover, and the volume of mountain glaciers and continental ice sheets (Derksen and Brown 2012; IPCC 2013; Stroeve et al. 2014a,b; Comiso and Hall 2014; Derksen et al. 2015). Evidence suggests in many cases that the net loss of mass from the global cryosphere is accelerating indicating significant climate feedbacks and societal consequences (Rignot et al. 2011, 2014; Williams et al. 2014; Zemp et al. 2015; Seo et al. 2015; Harig and Simons 2016).

Arctic sea ice areal extent, thickness, and volume have declined since 1979 (IPCC 2013; Stroeve et al. 2014a,b; Comiso and Hall 2014; Perovich et al. 2015). Annually-averaged Arctic sea ice extent has decreased by 3.5%–4.1% per decade since 1979 with much larger reductions in summer and fall (IPCC 2013; Stroeve et al. 2012b; Stroeve et al. 2014a; Comiso and Hall 2014). For example, September sea ice extent decreased by 13.3% per decade between 1979 and 2016. At the same time, September multi-year sea ice has melted faster than perennial sea ice (13.5% ± 2.5% and 11.5% ± 2.1% per decade, respectively, relative to the 1979–2012 average) corresponding to 4–7.5 feet (1.3–2.3 meter) declines in winter sea ice thickness (IPCC 2013; Perovich et al. 2015). October 2016 serves as a recent example of the observed lengthening of the Arctic sea ice melt season marking the slowest recorded Arctic sea ice growth rate for that month (Stroeve et al. 2014a; Parkinson 2014; NSIDC 2016). While current generation climate models project a nearly ice-free Arctic Ocean in late summer by mid-century, they still simulate weaker reductions in volume and extent than observed, suggesting that projected changes are too conservative (IPCC 2013; Stroeve et al. 2012a; Stroeve et al. 2014b; Zhang and Knutson 2013). See Chapter 11: Arctic Changes for further discussion of the implications of changes in the Arctic.

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In contrast to the Arctic, sea ice extent around Antarctica has increased since 1979 by 1.2% to 1.8% per decade (IPCC 2013). Strong regional differences in the sea ice growth rates are found around Antarctica but most regions (about 75%) show increases over the last 30 years (Zunz et al. 2013). The gain in Antarctic sea ice is much smaller than the decrease in Arctic sea ice. Changes in wind patterns, ice–ocean feedbacks, and freshwater flux have contributed to Antarctic sea ice growth (Zunz et al. 2013; Eisenman et al. 2014; Pauling et al. 2016; Meehl et al. 2016b).

Since the NCA3 (Mellilo et al. 2014), the Gravity Recovery and Climate Experiment (GRACE) constellation (e.g., Velicogna and Wahr 2013) has provided a record of gravimetric land ice measurements, advancing knowledge of recent mass loss from the global cryosphere. These measurements indicate that mass loss from the Antarctic Ice Sheet, Greenland Ice Sheet, and mountain glaciers around the world continues accelerating in some cases (Rignot et al. 2014; Joughin et al. 2014; Williams et al. 2014; Harig and Simons 2015; Seo et al. 2015; Harig and Simons 2016). The annually averaged ice mass from 37 global reference glaciers has decreased every year since 1984, a decline expected to continue even if climate were to stabilize (IPCC 2013; Pelto 2015; Zemp et al. 2015; Mengel et al. 2016).

Observed rapid mass loss from West Antarctica is attributed to increased glacial discharge rates due to diminishing ice shelves from the surrounding ocean becoming warmer (Jenkins et al. 2010; Feldmann and Levermann 2015). Recent evidence suggests that the Amundsen Sea sector is expected to disintegrate entirely (Rignot et al. 2014; Joughin et al. 2014; Feldmann and Levermann 2015) raising sea level by at least 1.2 meters (about 4 feet) and potentially an additional foot or more on top of current sea level rise projections during this century (DeConto and Pollard 2016; see Section 1.2.7 and Ch. 12: Sea Level Rise for further details). The potential for unanticipated rapid ice sheet melt and/or disintegration is discussed further in Chapter 15: Potential Surprises.

Over the last decade, the Greenland Ice Sheet mass loss has accelerated, losing 244 ± 6 Gt per year on average between January 2003 and May 2013 (Harig and Simons 2012; Jacob et al. 2012; IPCC 2013; Harig and Simons 2016). The portion of the Greenland Ice Sheet experiencing annual melt has increased since 1980 including significant events (Tedesco et al. 2011; Fettweis et al. 2011; IPCC 2013; Tedesco et al. 2015). A recent example, an unprecedented 98.6% of the Greenland Ice Sheet surface experienced melt on a single day in July 2012 (Nghiem et al. 2012; Tedesco et al. 2013). Encompassing this event, GRACE data indicate that Greenland lost 562 Gt of mass between April 2012 and April 2013—more than double the average annual mass loss.

In addition, permafrost temperatures and active layer thicknesses have increased across much of the Arctic (Shiklomanov et al. 2012; IPCC 2013; Romanovsky et al. 2015; also see Ch. 11: Arctic Changes). Rising permafrost temperatures causing permafrost to thaw and become more discontinuous raises concerns about potential emissions of carbon dioxide and methane (IPCC 2013). The potentially large contribution of carbon and methane emissions from permafrost and

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the continental shelf in the Arctic to overall warming is discussed further in Chapter 15: Potential Surprises).

1.8. Global Changes in Sea Level

Statistical analyses of tide gauge data indicate that global mean sea level has risen about 8–9 inches (20–23 cm) since 1880, with a rise rate of approximately 0.5–0.6 inches/decade from 1901 to1990 (about 12–15 mm/decade; Church and White 2011; Hay et al. 2015; also see Ch. 12: Sea Level Rise). However, since the early 1990s, both tide gauges and satellite altimeters have recorded a faster rate of sea level rise of about 1.2 inches/decade (approximately 3 cm/decade; Church and White 2011; Nerem et al. 2010; Hay et al. 2015), resulting in about 3 inches (about 8 cm) of the global rise since the early 1990s. Nearly two-thirds of the sea level rise measured since 2005 has resulted from increases in ocean mass, primarily from land-based ice melt; the remaining one-third of the rise is in response to changes in density from increasing ocean temperatures (Merrifield et al. 2015).

Global sea level rise and its regional variability forced by climatic and ocean circulation patterns are contributing to significant increases in annual tidal-flood frequencies, which are measured by NOAA tide gauges and associated with minor infrastructure impacts to date; along some portions of the U.S. coast, frequency of the impacts from such events appears to be accelerating (Ezer and Atkinson 2014; Sweet and Park 2014; also see Ch. 12: Sea-Level Rise).

Future projections show that by 2100, global mean sea level is *very likely* to rise by 1.6–4.3 feet (0.5–1.3 m) under RCP8.5, 1.1–3.1 feet (0.35–0.95 m) under RCP4.5, and 0.8–2.6 feet (0.24–0.79 m) under RCP2.6 (see Ch. 4: Projections for a description of the scenarios) (Kopp et al. 2014). Sea level will not rise uniformly around the coasts of the United States and its oversea territories. Local sea level rise is *likely* to be greater than the global average along the U.S. Atlantic and Gulf Coasts and less than the global average in most of the Pacific Northwest. Emerging science suggests these projections may be underestimates, particularly for higher scenarios; a global mean sea level rise exceeding 8 feet (2.4 m) by 2100 cannot be excluded (see Ch. 12: Sea Level Rise), and even higher amounts are possible as a result of marine ice sheet instability (see Ch. 15: Potential Surprises). We have updated the global sea level rise scenarios for 2100 of Parris et al. (2012) accordingly (Sweet et al. 2017), and also extended to year 2200 in Chapter 12: Sea Level Rise. The scenarios are regionalized to better match the decision context needed for local risk framing purposes.

1.9. Recent Global Changes Relative to Paleoclimates

Paleoclimate records demonstrate long-term natural variability in the climate and overlap the records of the last two millennia, referred to here as the "Common Era". Before the emissions of greenhouse gases from fossil fuels and other human-related activities became a major factor over the last few centuries, the strongest drivers of climate during the last few thousand years had

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been volcanoes and land-use change (which has both albedo and greenhouse gas emissions effects) (Schmidt et al. 2011). Based on a number of proxies for temperature (for example, from tree rings, fossil pollen, corals, ocean and lake sediments, and ice cores), temperature records are available for the last 2,000 years on hemispherical and continental scales (Figures 1.8 and 1.9) (Mann et al. 2008; PAGES 2K Consortium 2013). High-resolution temperature records for North America extend back less than half of this period, with temperatures in the early parts of the Common Era inferred from analyses of pollen and other archives. For this era, there is a general cooling trend, with a relatively rapid increase in temperature over the last 150–200 years (Figure 1.9, PAGES 2k Consortium 2013). For context, global annual-averaged temperatures for 1986–2015 are likely much higher, and appear to have risen at a more rapid rate during the last 3 decades, than any similar period possibly over the past 2,000 years or longer (IPCC [2013] makes a similar statement, but for the last 1,400 years because of data quality issues before that time).

[INSERT FIGURES 1.8 AND 1.9 HERE]

Global temperatures of the magnitude observed recently (and projected for the rest of this century) are related to very different forcings than past climates, but studies of past climates suggest that such global temperatures were *likely* last observed during the Eemian period—the last interglacial—125,000 years ago; at that time, global temperatures were, at their peak, about 1.8°F–3.6°F (1°C–2°C) warmer than preindustrial temperatures (Turney and Jones 2010). Coincident with these higher temperatures, sea levels during that period were about 16–30 feet (6–9 meters) higher than modern levels (Kopp et al. 2009; Dutton and Lambeck 2012) (for further discussion on sea levels in the past, see Ch. 12: Sea Level Rise).

Modeling studies suggest that the Eemian period warming can be explained in part by the hemispheric changes in solar insolation from orbital forcing as a result of cyclic changes in the shape of Earth's orbit around the sun (e.g., Kaspar et al. 2005), even though greenhouse gas concentrations were similar to preindustrial levels. Equilibrium climate with modern greenhouse gas concentrations (about 400 ppm CO_2) most recently occurred 3 million years ago during the Pliocene. During the warmest parts of this period, global temperatures were 5.4°F–7.2°F (3°C–4°C) higher than today, and sea levels were about 82 feet (25 meters) higher (Haywood et al. 2013).

----- **START BOX 1.2 HERE** -----

Box 1.2: Advances Since NCA3

This assessment reflects both advances in scientific understanding and approach since NCA3, as well as global policy developments. Highlights of what aspects are either especially strengthened or are emerging in the findings include

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- *Spatial downscaling*: Projections of climate changes are downscaled to a finer resolution than the original global climate models using the Localized Constructed Analogs (LOCA) empirical statistical downscaling model. The downscaling generates temperature and precipitation on a 1/16th degree latitude/longitude grid for the contiguous United States. LOCA, one of the best statistical downscaling approaches, produces downscaled estimates using a multi-scale spatial matching scheme to pick appropriate analog days from observations (Chapters 4,6,7).

- *Risk-based framing*: Highlighting aspects of climate science most relevant to assessment of key societal risks are included more here than in prior national climate assessments. This approach allows for emphasis of possible outcomes that, while relatively unlikely to occur or characterized by high uncertainty, would be particularly consequential, and thus associated with large risks (Chapters 6,7,8,9,12,15).

- *Detection and attribution*: Significant advances have been made in the attribution of the human influence for individual climate and weather extreme events since NCA3. This assessment contains extensive discussion of new and emerging findings in this area (Chapters 3,6,7,8).

- *Atmospheric circulation and extreme events:* The extent to which atmospheric circulation in the midlatitudes is changing or is projected to change, possibly in ways not captured by current climate models, is a new important area of research. While still in its formative stages, this research is critically important because of the implications of such changes for climate extremes including extended cold air outbreaks, long-duration heat waves, and changes in storms and drought patterns (Chapters 5,6,7).

- *Increased understanding of specific types of extreme events:* How climate change may affect specific types of extreme events in the United States is another key area where scientific understanding has advanced. For example, this report highlights how intense flooding associated with atmospheric rivers could increase dramatically as the atmosphere and oceans warm or how tornadoes could be concentrated into a smaller number of high-impact days over the average severe weather season (Chapter 9).

- *Model weighting*: For the first time, maps and plots of climate projections will not show a straight average of all available climate models. Rather, each model is given a weight based on their 1) historical performance relative to observations and 2) independence relative to other models. Although this is a more accurate way of representing model output, it does not significantly alter the results: the weighting produces very similar trends and spatial patterns to the equal-weighting-of-models approach used in prior assessments (Chapters 4,6,7).

- *High-resolution global climate model simulations*: As computing resources have grown, multidecadal simulations of global climate models are now being conducted at horizontal resolutions on the order of 15 miles (25 km) that provide more realistic characterization of intense weather systems, including hurricanes. Even the limited number of high-resolution models currently available have increased confidence in projections of extreme weather (Chapter 9).

- *The so-called "global warming hiatus"*: Since NCA3, many studies have investigated causes for the reported slowdown in the rate of increase in near-surface global mean temperature from roughly 2000 through 2013. The slowdown, which ended with the record warmth in 2014–2016, is understood to have been caused by a combination of internal variability, mostly in the heat exchange between the ocean and the atmosphere, and short-term variations in external forcing factors, both human and natural. On longer time scales, relevant to human-induced climate change, there is no hiatus and the planet continues to warm at a steady pace as predicted by basic atmospheric physics and the well-documented increase in heat-trapping gases (Chapter 1).

- *Oceans and coastal waters*: Concern over ocean acidification, warming, and oxygen loss is increasing as scientific understanding of the severity of their impacts grows. Both oxygen loss and acidification may be magnified in some U.S. coastal waters relative to the global average, raising the risk of serious ecological and economic consequences. There is some evidence, still highly uncertain, that the Atlantic Meridional Circulation (AMOC), sometimes referred to as the ocean's conveyor belt, may be slowing down (Chapters 2, 13).

- *Local sea level change projections*: For the first time in the NCA process, sea level rise projections incorporate geographic variation based on factors such as local land subsidence, ocean currents, and changes in Earth's gravitational field (Chapter 12).

- *Accelerated ice-sheet loss and irreversibility*: New observations from many different sources confirm that ice-sheet loss is accelerating. Combining observations with simultaneous advances in the physical understanding of ice sheets, scientists are now concluding that up to 8.5 feet of global sea level rise is possible by 2100 under a high emissions scenario, up from 6.6 feet in NCA3 (Chapter 12).

- *Slower Arctic sea-ice area extent regrowth in fall and winter 2016-2017*: The annual Arctic sea ice extent minimum for 2016 relative to the long-term record was the second lowest on record; since 1981, the sea ice minimum has decreased by 13.3% per decade, more than 46% over the 35 years. In fall and winter 2016–2017, record-setting slow ice regrowth was the lowest since observations began in 1981 (Chapter 11).

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- *Potential surprises*: Both large-scale state shifts in the climate system (sometimes called "tipping points") and compound extremes have the potential to generate unanticipated surprises. The further the Earth system departs from historical climate forcings, and the more the climate changes, the greater the potential for these surprises. For the first time in the NCA process we include an extended discussion of these potential surprises (Chapter 15).

- *The Paris Agreement*: The Paris Agreement, which entered into force November 4, 2016, provides a new framework for its parties for the mitigation of and adaptation to climate change, and to periodically update and revisit their respective domestic commitments. This report discusses some important aspects of climate science that are relevant to meeting the objectives of the Agreement (Chapters 4, 14).

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TRACEABLE ACCOUNTS

Key Finding 1

The global climate continues to change rapidly compared to the pace of the natural variations in climate that have occurred throughout Earth's history. Trends in globally averaged temperature, sea level rise, upper-ocean heat content, land-based ice melt, Arctic sea ice, depth of seasonal permafrost thaw, and other climate variables provide consistent evidence of a warming planet. These observed trends are robust and have been confirmed by multiple independent research groups around the world.

Description of evidence base

The Key Finding and supporting text summarize extensive evidence documented in the climate science literature. Similar to statements made in previous national (NCA3; Melillo et al. 2014) and international (IPCC 2013) assessments.

Evidence for changes in global climate arises from multiple analyses of data from in-situ, satellite, and other records undertaken by many groups over several decades. These observational datasets are used throughout this chapter and are discussed further in Appendix 1 (e.g., updates of prior uses of these datasets by Vose et al. 2012; Karl et al. 2015). Changes in the mean state have been accompanied by changes in the frequency and nature of extreme events (e.g., Kunkel and Frankson 2015; Donat et al. 2016). A substantial body of analysis comparing the observed changes to a broad range of climate simulations consistently points to the necessity of invoking human-caused changes to adequately explain the observed climate system behavior. The influence of human impacts on the climate system has also been observed in a number of individual climate variables (attribution studies are discussed in Ch. 3: Detection and Attribution and in other chapters).

Major uncertainties

Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to observe these changes at sufficient resolution and to simulate and attribute such changes using climate models. Innovative new approaches to instigation and maintenance of reference quality observation networks such as the U.S. Climate Reference Network (http://www.ncei.noaa.gov/crn/), enhanced climate observational and data analysis capabilities, and continued improvements in climate modeling all have the potential to reduce uncertainties.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

There is *very high confidence* that global climate is changing and this change is apparent across a wide range of observations, given the evidence base and remaining uncertainties. All

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observational evidence is consistent with a warming climate since the late 1800s. There is *very high confidence* that the global climate change of the past 50 years is primarily due to human activities, given the evidence base and remaining uncertainties (IPCC 2013). Recent changes have been consistently attributed in large part to human factors across a very broad range of climate system characteristics.

Summary sentence or paragraph that integrates the above information

The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. The trends described in NCA3 have continued and our understanding of the observations related to climate and the ability to evaluate the many facets of the climate system have increased substantially.

Key Finding 2

The frequency and intensity of extreme heat and heavy precipitation events are increasing in most continental regions of the world (*very high confidence*). These trends are consistent with expected physical responses to a warming climate. Climate model studies are also consistent with these trends, although models tend to underestimate the observed trends, especially for the increase in extreme precipitation events (*very high confidence* for temperature, *high confidence* for extreme precipitation). The frequency and intensity of extreme temperature events are *virtually certain* to increase in the future as global temperature increases (*high confidence*). Extreme precipitation events will *very likely* continue to increase in frequency and intensity throughout most of the world (*high confidence*). Observed and projected trends for some other types of extreme events, such as floods, droughts, and severe storms, have more variable regional characteristics.

Description of evidence base

The Key Finding and supporting text summarizes extensive evidence documented in the climate science literature and are similar to statements made in previous national (NCA3; Melillo et al., 2014) and international (IPCC 2013) assessments. The analyses of past trends and future projections in extreme events and the fact that models tend to underestimate the observed trends are also well substantiated through more recent peer-reviewed literature as well (Seneviratne et al. 2014; Arnell and Gosling 2016; Wuebbles et al. 2014; Kunkel and Frankson 2015; Easterling et al. 2016; Donat et al. 2016; Berghuijs et al. 2016; Fischer and Knutti 2016).

Major uncertainties

Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to simulate and attribute such changes using climate models. Innovative new approaches to climate data analysis,

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continued improvements in climate modeling, and instigation and maintenance of reference quality observation networks such as the U.S. Climate Reference Network (http://www.ncei.noaa.gov/crn/) all have the potential to reduce uncertainties.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

There is *very high confidence* for the statements about past extreme changes in temperature and precipitation and *high confidence* for future projections, based on the observational evidence and physical understanding, that there are major trends in extreme events and significant projected changes for the future.

Summary sentence or paragraph that integrates the above information

The Key Finding and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. The trends for extreme events that were described in the NCA3 and IPCC assessments have continued and our understanding of the data and ability to evaluate the many facets of the climate system have increased substantially.

Key Finding 3

Many lines of evidence demonstrate that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. Formal detection and attribution studies for the period 1951 to 2010 find that the observed global mean surface temperature warming lies in the middle of the range of likely human contributions to warming over that same period. We find no convincing evidence that natural variability can account for the amount of global warming observed over the industrial era. For the period extending over the last century, there are no convincing alternative explanations supported by the extent of the observational evidence. Solar output changes and internal variability can only contribute marginally to the observed changes in climate over the last century, and we find no convincing evidence for natural cycles in the observational record that could explain the observed changes in climate. (*Very high confidence*)

Description of evidence base

The Key Finding and supporting text summarizes extensive evidence documented in the climate science literature and are similar to statements made in previous national (NCA3; Melillo et al. 2014) and international (IPCC 2013) assessments. The human effects on climate have been well documented through many papers in the peer reviewed scientific literature (e.g., see Ch. 2: Physical Drivers of Climate Change and Ch. 3: Detection and Attribution for more discussion of supporting evidence).

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Major uncertainties

Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to simulate and attribute such changes using climate models. The exact effects from land use changes relative to the effects from greenhouse gas emissions needs to be better understood.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

There is *very high confidence* for a major human influence on climate.

Summary sentence or paragraph that integrates the above information

The key message and supporting text summarizes extensive evidence documented in the climate science peer reviewed literature. The analyses described in the NCA3 and IPCC assessments support our findings and new observations and modeling studies have further substantiated these conclusions.

Key Finding 4

Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse (heat-trapping) gases emitted globally and on the remaining uncertainty in the sensitivity of Earth's climate to those emissions (very *high confidence)*. With significant reductions in the emissions of greenhouse gases, the global annually averaged temperature rise could be limited to 3.6°F (2°C) or less. Without major reductions in these emissions, the increase in annual average global temperatures relative to preindustrial times could reach 9°F (5°C) or more by the end of this century (*high confidence*).

Description of evidence base

The Key Finding and supporting text summarizes extensive evidence documented in the climate science literature and are similar to statements made in previous national (NCA3; Melillo et al. 2014) and international (IPCC 2013) assessments. The projections for future climate have been well documented through many papers in the peer-reviewed scientific literature (e.g., see Ch. 4: Projections for descriptions of the scenarios and the models used).

Major uncertainties

Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to simulate and attribute such changes using climate models. Of particular importance are remaining

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uncertainties in the understanding of feedbacks in the climate system, especially in ice-albedo and cloud cover feedbacks. Continued improvements in climate modeling to represent the physical processes affecting Earth's climate system are aimed at reducing uncertainties. Monitoring and observation programs also can help improve the understanding needed to reduce uncertainties.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

There is *very high confidence* for continued changes in climate and *high confidence* for the levels shown in the Key Finding.

Summary sentence or paragraph that integrates the above information

The Key Finding and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. The projections that were described in the NCA3 and IPCC assessments support our findings and new modeling studies have further substantiated these conclusions.

Key Finding 5

Natural variability, including El Niño events and other recurring patterns of ocean–atmosphere interactions, impact temperature and precipitation, especially regionally, over months to years. The global influence of natural variability, however, is limited to a small fraction of observed climate trends over decades.

Description of evidence base

The Key Finding and supporting text summarizes extensive evidence documented in the climate science literature and are similar to statements made in previous national (NCA3; Melillo et al. 2014) and international (IPCC 2013) assessments. The role of natural variability in climate trends has been extensively discussed in the peer-reviewed literature (e.g., Karl et al. 2015; Rahmstorf et al. 2015; Lewandowsky et al. 2016; Mears and Wentz 2016; Trenberth et al. 2014; Santer et al. 2017a,b).

Major uncertainties

Uncertainties still exist in the precise magnitude and nature of the full effects of individual ocean cycles and other aspects of natural variability on the climate system. Increased emphasis on monitoring should reduce this uncertainty significantly over the next few decades.

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Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

There is *very high confidence*, affected to some degree by limitations in the observational record, that the role of natural variability on future climate change is limited.

Summary sentence or paragraph that integrates the above information

The Key Finding and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. There has been an extensive increase in the understanding of the role of natural variability on the climate system over the last few decades, including a number of new findings since NCA3.

Key Finding 6

Longer-term climate records over past centuries and millennia indicate that average temperatures in recent decades over much of the world have been much higher, and have risen faster during this time period, than at any time in the past 1,700 years or more, the time period for which the global distribution of surface temperatures can be reconstructed.

Description of evidence base

The Key Finding and supporting text summarizes extensive evidence documented in the climate science literature and are similar to statements made in previous national (NCA3; Melillo et al., 2014) and international (IPCC 2013) assessments. There are many recent studies of the paleoclimate leading to this conclusion including those cited in the report (e.g., Mann et al. 2008; PAGE 2K Consortium 2013).

Major uncertainties

Despite the extensive increase in knowledge in the last few decades, there are still many uncertainties in understanding the hemispheric and global changes in climate over the Earth's history, including that of the last few millennia. Additional research efforts in this direction can help reduce those uncertainties.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

There is *high confidence* for current temperatures to be higher than they have been in at least 1,700 years and perhaps much longer.

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Summary sentence or paragraph that integrates the above information

The Key Finding and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. There has been an extensive increase in the understanding of past climates on our planet, including a number of new findings since NCA3.

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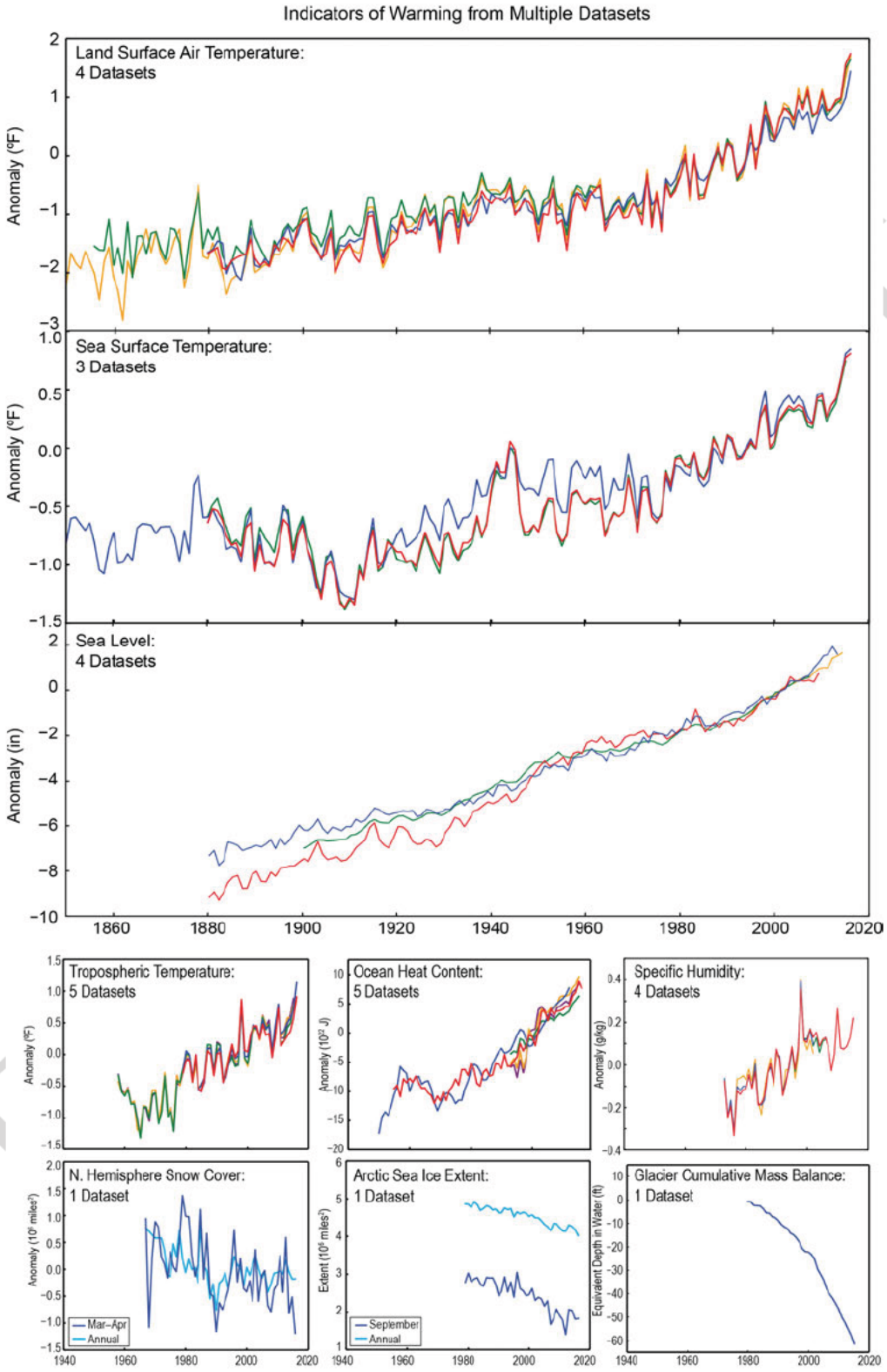
1 **FIGURES**


Indicators of Warming from Multiple Datasets
Land Surface Air Temperature:
4 Datasets
Anomaly (°F)
Sea Surface Temperature:
3 Datasets
Anomaly (°F)
Sea Level:
4 Datasets
Anomaly (in)
1860
1880
1900
1920
1940
1960
1980
2000
2020
Tropospheric Temperature:
5 Datasets
Anomaly (°C)
Ocean Heat Content:
5 Datasets
Anomaly (10²² J)
Specific Humidity:
4 Datasets
Anomaly (g/kg)
N. Hemisphere Snow Cover:
1 Dataset
Anomaly (10⁶ miles²)
Mar–Apr
Annual
Arctic Sea Ice Extent:
1 Dataset
Extent (10⁶ miles²)
September
Annual
Glacier Cumulative Mass Balance:
1 Dataset
Equivalent Depth in Water (ft)

2

Figure 1.1. This image shows observations globally from nine different variables that are key indicators of a warming climate. The indicators (listed below) all show long-term trends that are consistent with global warming. In parentheses are the number of datasets shown in each graph, the length of time covered by the combined datasets and their anomaly reference period (where applicable), and the direction of the trend: land surface air temperature (4 datasets, 1850–2016 relative to 1976–2005, increase); sea surface temperature (3 datasets, 1850–2016 relative to 1976–2005, increase); sea level (4 datasets, 1880–2014 relative to 1996–2005, increase); tropospheric temperature (5 datasets, 1958–2016 relative to 1981–2005, increase); ocean heat content, upper 700m (5 datasets, 1950–2016 relative to 1996–2005, increase); specific humidity (4 datasets, 1973–2015 relative to 1986–2000, increase); Northern Hemisphere snow cover, March–April and annual (1 dataset, 1967–2016 relative to 1976–2005, decrease); Arctic sea ice extent, September and annual (1 dataset, 1979–2016, decrease); glacier cumulative mass balance (1 dataset, 1980–2015, decrease). More information on the datasets can be found in the accompanying metadata. (Figure source: NOAA NCEI/CICS-NC, updated from Melillo et al. 2014; Blunden and Arndt 2016).

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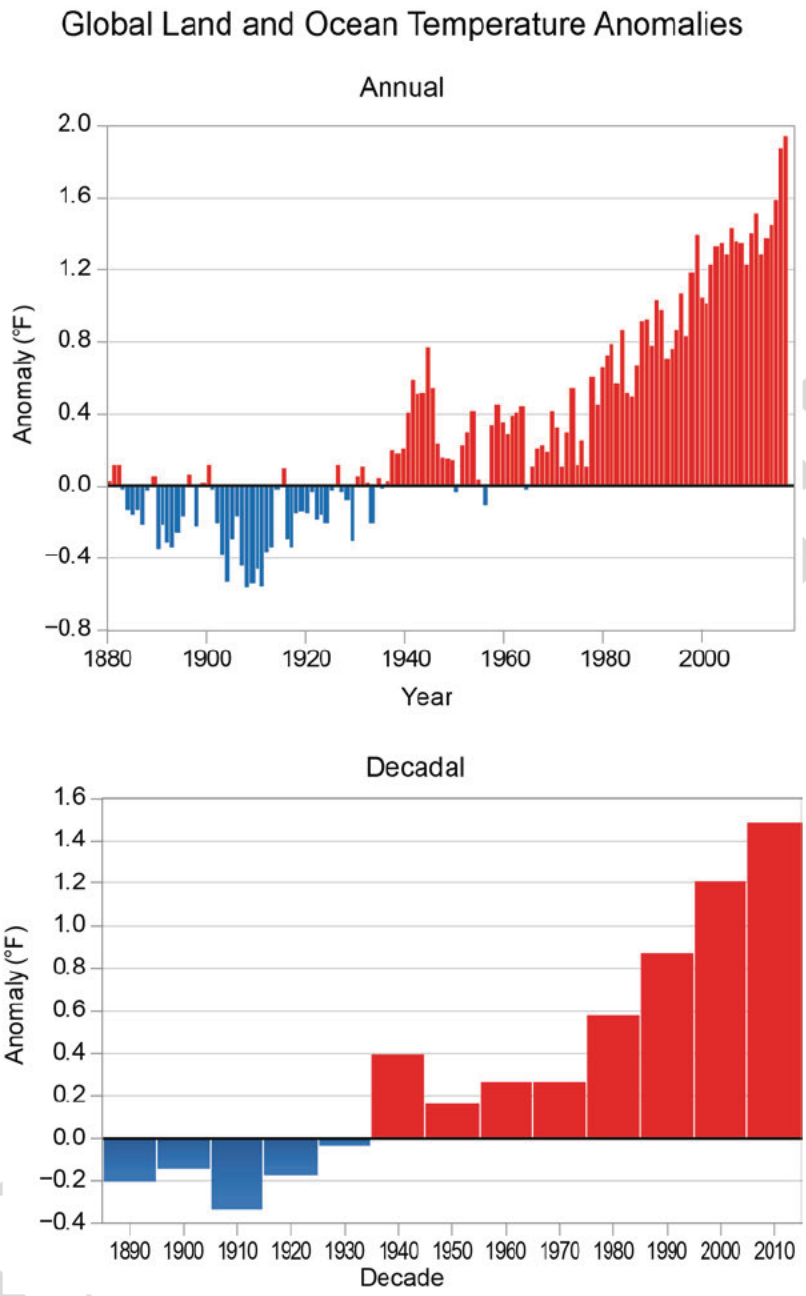

Figure 1.2. Top: Global annual average temperatures (as measured over both land and oceans) for 1880–2016 relative to the reference period of 1901–1960; red bars indicate temperatures above the average over 1901–1960, and blue bars indicate temperatures below the average. Global annual average temperature has increased by more than 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960. While there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are mainly due to natural sources of variability, such as the effects of El Niños, La Niñas, and volcanic eruptions. Based on the NCEI (NOAAGlobalTemp) dataset (updated from Vose et al. 2012). Bottom:

Global average temperature averaged over decadal periods (1886–1895, 1896–1905, …, 1996–2005, except for the 11 years in the last period, 2006–2016). Horizontal label indicates mid-point year of decadal period. Every decade since 1966–1975 has been warmer than the previous decade. (Figure source: [top] adapted from NCEI 2016, [bottom] NOAA NCEI / CICS-NC).

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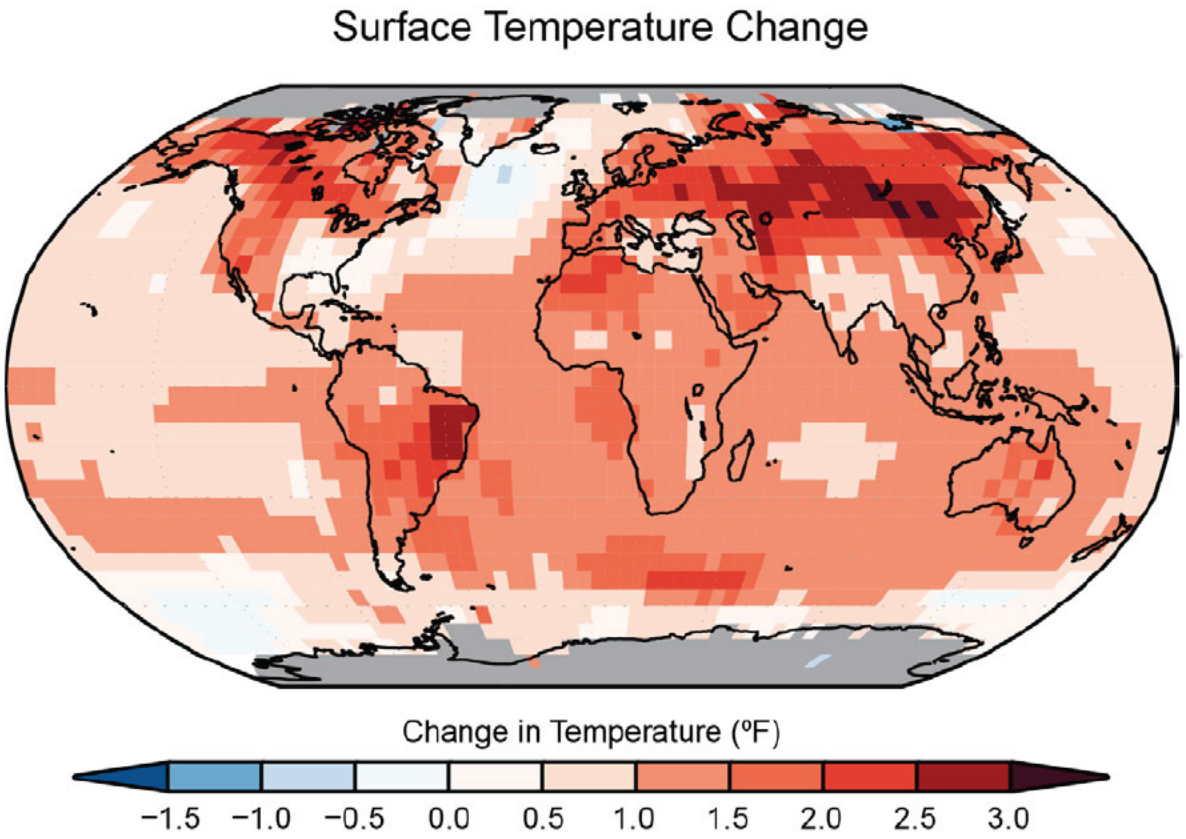

Figure 1.3. Surface temperature change (in °F) for the period 1986–2015 relative to 1901–1960 from the NOAA National Centers for Environmental Information's (NCEI) surface temperature product. For visual clarity, statistical significance is not depicted on this map. Changes are generally significant (at the 90% level) over most land and ocean areas. Changes are not significant in parts of the North Atlantic Ocean, the South Pacific Ocean, and the southeastern United States. There is insufficient data in the Arctic Ocean and Antarctica for computing long-term changes (those sections are shown in grey because no trend can be derived). The relatively coarse resolution (5.0° × 5.0°) of these maps does not capture the finer details associated with mountains, coastlines, and other small-scale effects (see Ch. 6: Temperature Changes for a focus on the United States). (Figure source: updated from Vose et al. 2012).

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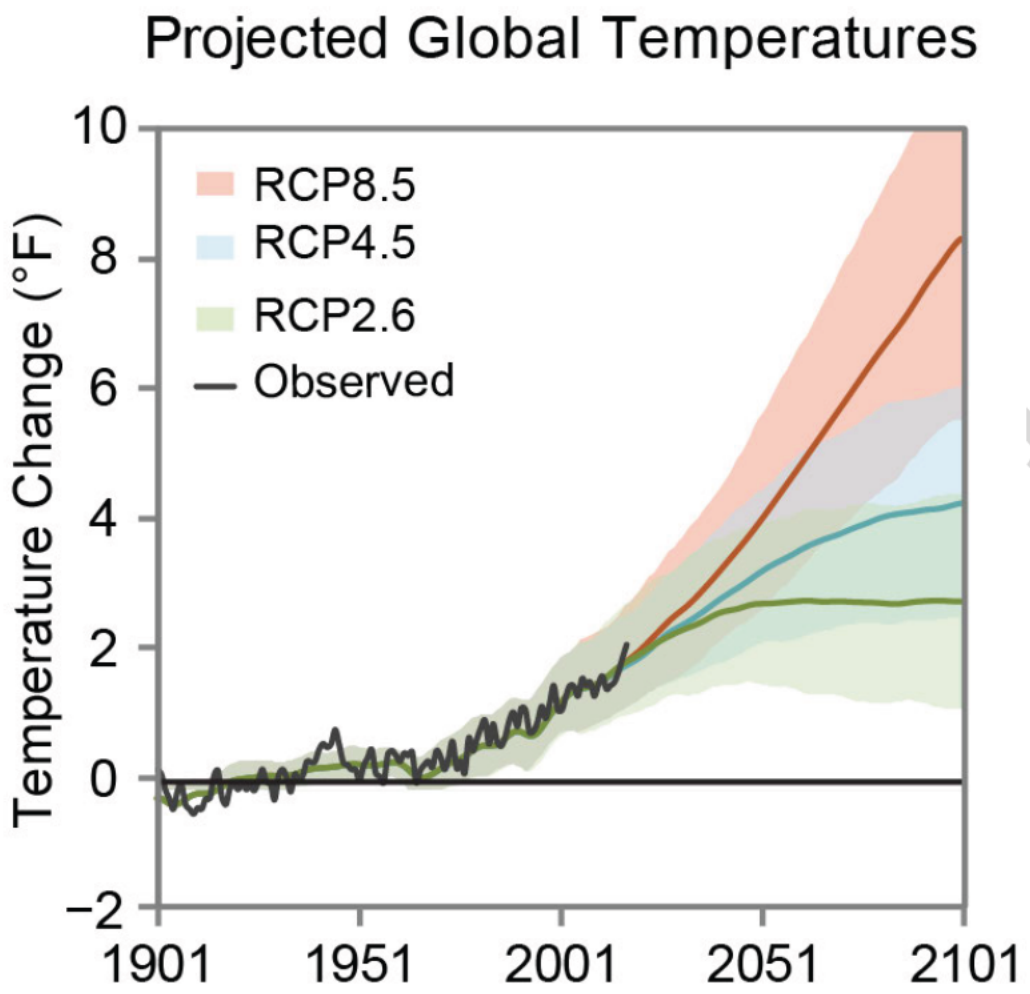

Figure 1.4. Multimodel simulated time series from 1900 to 2100 for the change in global annual mean surface temperature relative to 1901–1960 for a range of the Representative Concentration Pathways (RCPs; see Ch. 4: Projections for more information). These scenarios account for the uncertainty in future emissions from human activities (as analyzed with the 20+ models from around the world used in the most recent international assessment [IPCC 2013]). The mean (solid lines) and associated uncertainties (shading, showing ±2 standard deviations [5%–95%] across the distribution of individual models based on the average over 2081–2100) are given for all of the RCP scenarios as colored vertical bars. The numbers of models used to calculate the multimodel means are indicated. (Figure source: adapted from Walsh et al. 2014).

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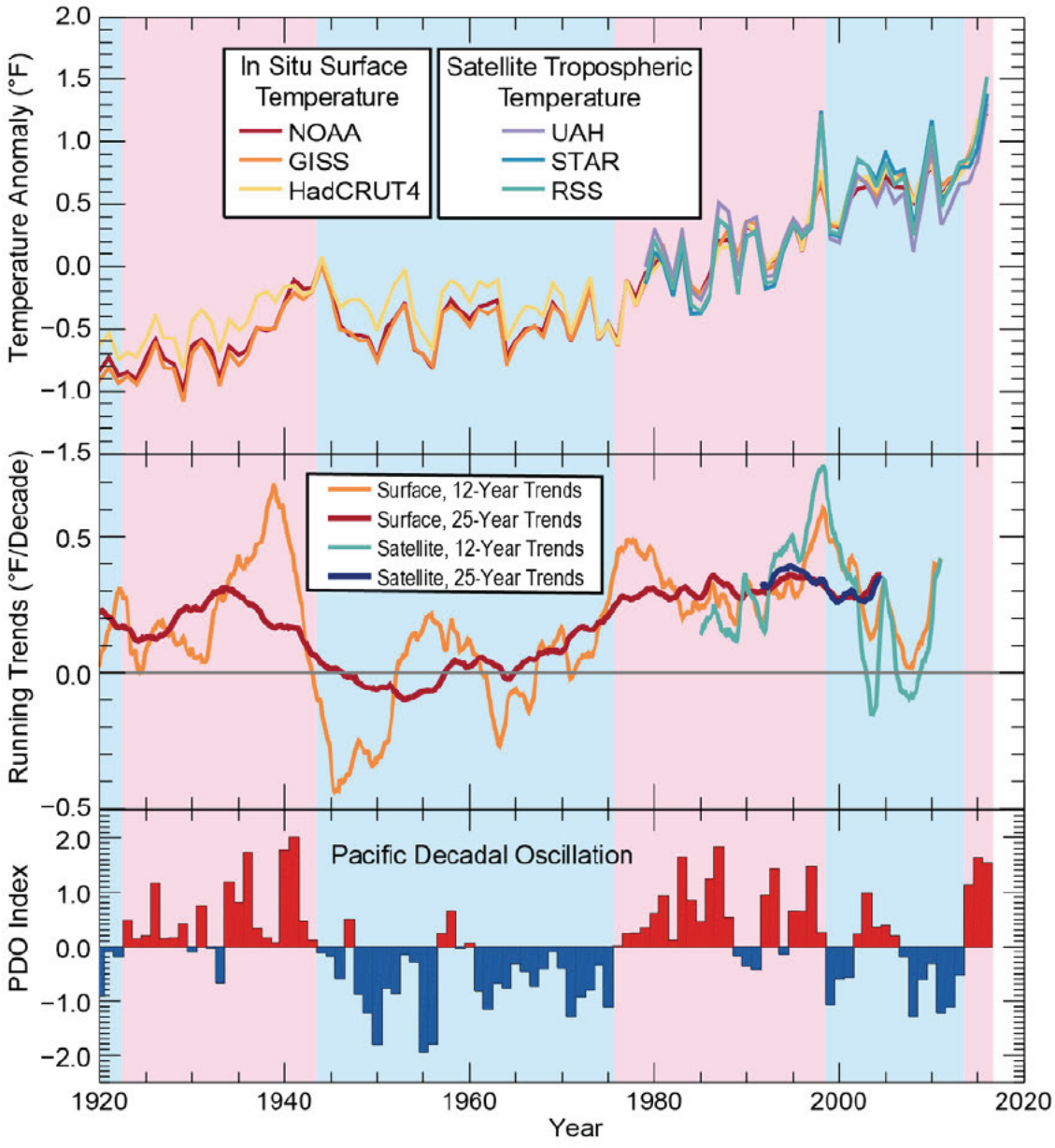

Figure 1.5. Panel A shows the annual mean temperature anomalies relative to a 1901–1960 baseline for global mean surface temperature and global mean tropospheric temperature. Short-term variability is superposed on a long-term warming signal, particularly since the 1960s. Panel B shows the linear trend of short (12-year) and longer (25-year) overlapping periods plotted at the time of the center of the trend period. For the longer period, trends are positive and nearly constant since about 1975. Panel C shows the annual mean Pacific Decadal Oscillation (PDO) index. Short-term temperature trends show a marked tendency to be lower during periods of generally negative PDO index, shown by the blue shading. (Figure source: adapted and updated from Trenberth 2015 and Santer et al. 2017a; Panel B, © American Meteorological Society. Used with permission.)

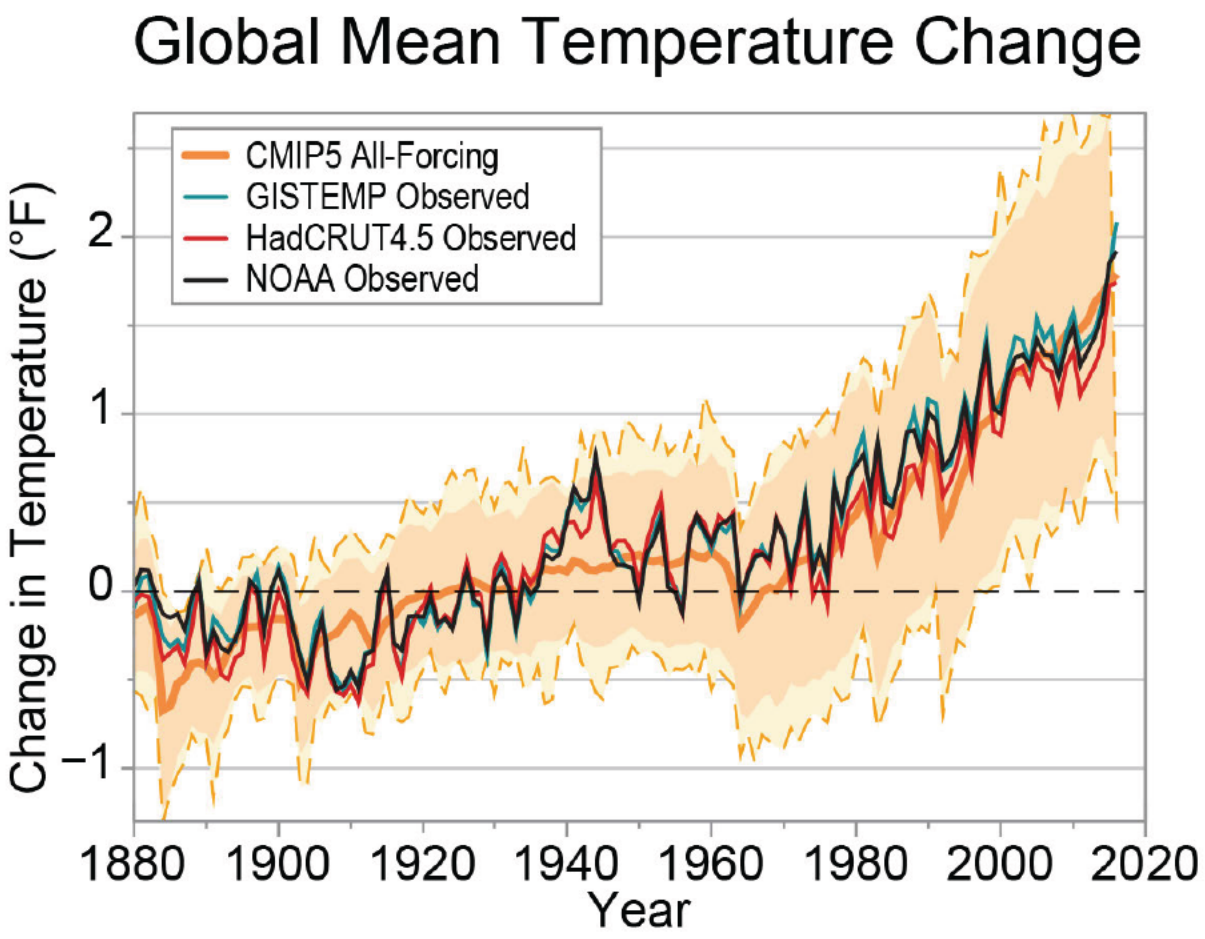

Figure 1.6. Comparison of global mean temperature anomalies (°F) from observations (through 2016) and the CMIP5 multimodel ensemble (through 2016), using the reference period 1901-1960. The CMIP5 multimodel ensemble (black) is constructed from blended surface temperature (ocean regions) and surface air temperature (land regions) data from the models, masked where observations are not available in the GISTEMP dataset (Knutson et al. 2016). The importance of using blended model data is shown in Richardson et al. (2016). The thick solid orange curve is the model ensemble mean, formed from the ensemble across 36 models of the individual model ensemble means. The shaded region shows the +/- two standard deviation range of the individual ensemble member annual means from the 36 CMIP5 models. The dashed lines show the range from maximum to minimum values for each year among these ensemble members. The sources for the three observational indices are: HadCRUT4.5 (brown): http://www.metoffice.gov.uk/hadobs/hadcrut4/data/current/download.html; NOAA (black): https://www.ncdc.noaa.gov/monitoring-references/faq/anomalies.php; and GISTEMP (green): https://data.giss.nasa.gov/pub/gistemp/gistemp1200_ERSSTv4.nc. (NOAA and HadCRUT4 downloaded on Feb. 15, 2017; GISTEMP downloaded on Feb. 10, 2017). (Figure source: adapted from Knutson et al. 2016)

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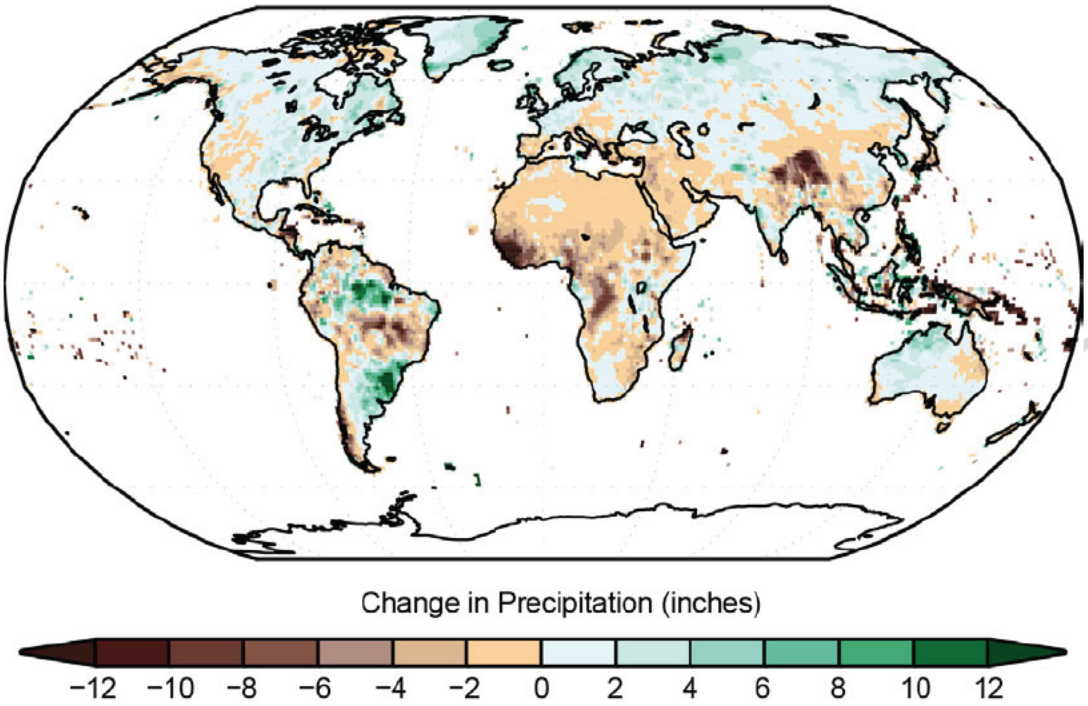

Figure 1.7. Surface annually averaged precipitation change (in inches) for the period 1986–2015 relative to 1901–1960. The data is from long-term stations, so precipitation changes over the ocean and Antarctica cannot be evaluated. The trends are not considered to be statistically significant because of a lack of data coverage early in the record. The relatively coarse resolution (0.5° × 0.5°) of these maps does not capture the finer details associated with mountains, coastlines, and other small-scale effects. (Figure source: NOAA NCEI / CICS-NC).

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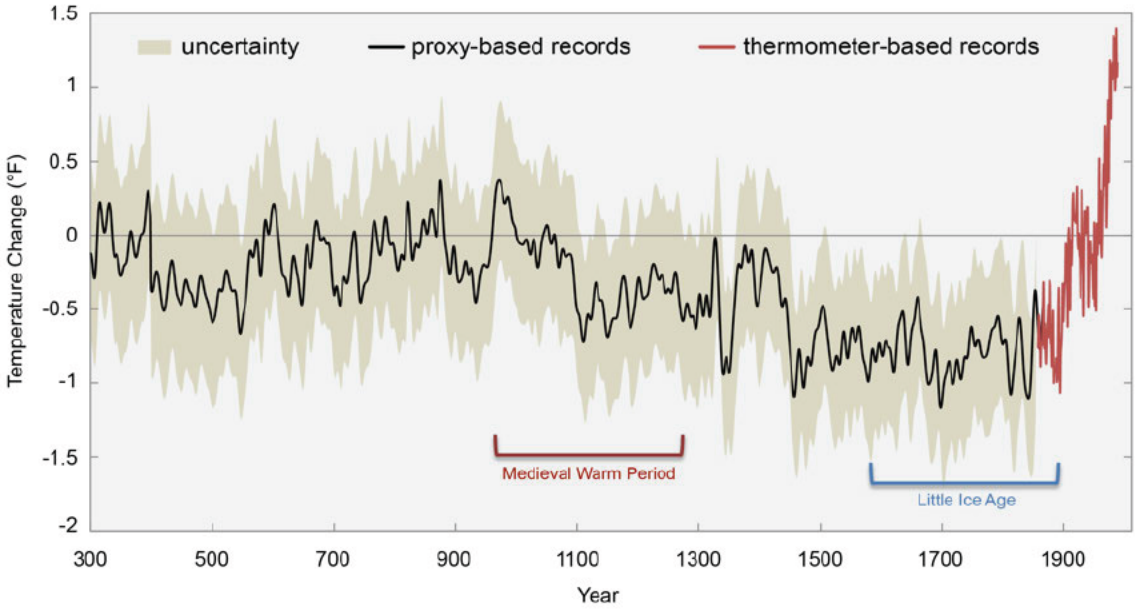

Figure 1.8. Changes in the temperature of the northern hemisphere from surface observations (in red) and from proxies (in black; uncertainty range represented by shading) relative to 1961–1990 average temperature. If this graph were plotted relative to 1901–1960 instead of 1961–1990, the temperature changes would be 0.47°F (0.26°C) higher. These analyses suggest that current temperatures are higher than seen in the Northern Hemisphere, and likely globally, in at least the last 1,700 years, and that the last decade (2006–2015) was the warmest decade on record. (Figure source: adapted from Mann et al. 2008).

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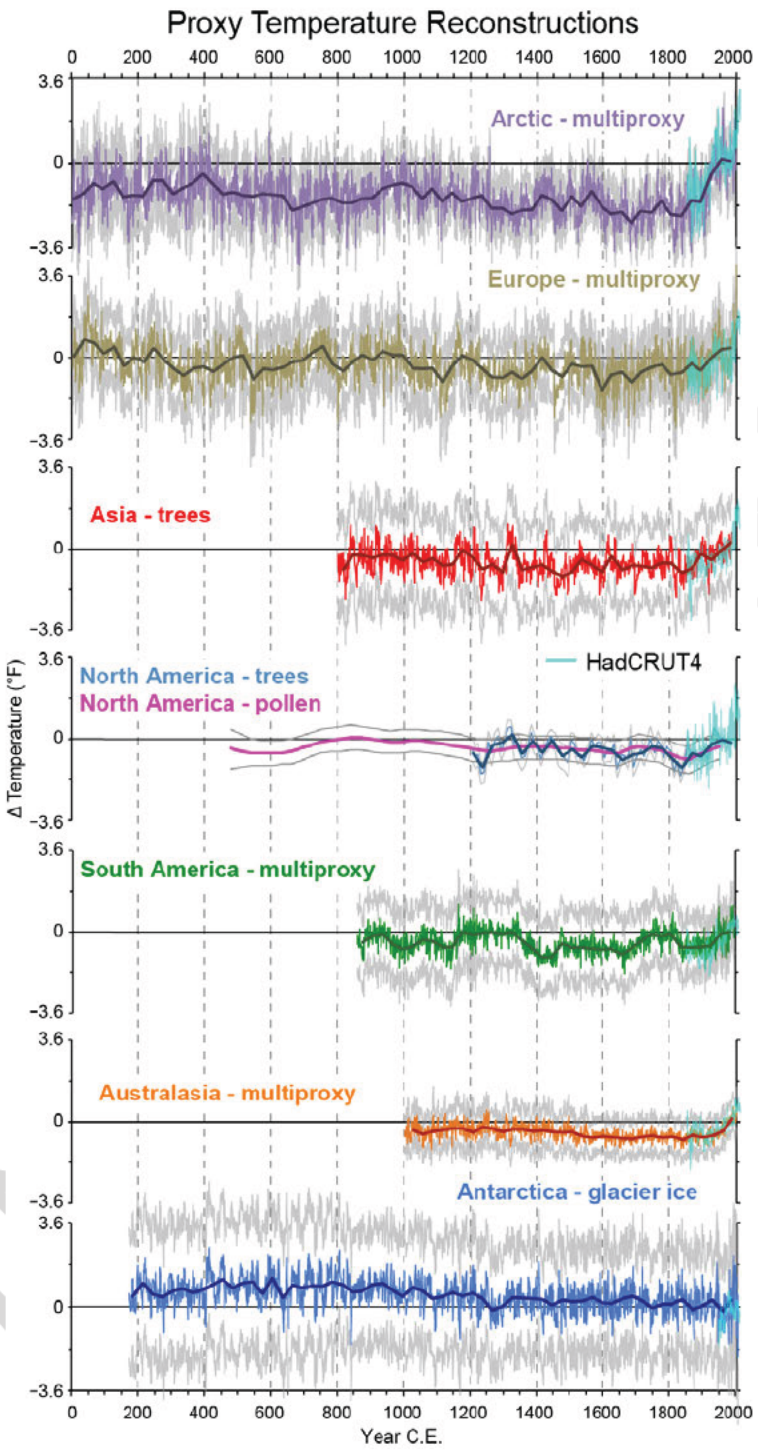

Figure 1.9. Proxy temperatures reconstructions for the seven regions of the PAGES 2K Network. Temperature anomalies are relative to the 1961–1990 reference period. If this graph were plotted relative to 1901–1960 instead of 1961–1990, the temperature changes would 0.47°F (0.26°C) higher. Grey lines around expected-value estimates indicate uncertainty ranges as defined by each regional group (see PAGE 2K Consortium 2013 and related Supplementary Information). Note that the changes in temperature over the last century tend to occur at a much

faster rate than found in the previous time periods. The teal values are from the HadCRUT4 surface observation record for land and ocean for the 1800s to 2000 (Jones et al. 2012). (Figure source: adapted from PAGES 2k Consortium 2013).

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REFERENCES

Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P.-P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin, and E. Nelkin, 2003: The version-2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (1979–present). *Journal of Hydrometeorology,* **4,** 1147-1167. http://dx.doi.org/10.1175/1525-7541(2003)004<1147:TVGPCP>2.0.CO;2

Alexander, L.V., X. Zhang, T.C. Peterson, J. Caesar, B. Gleason, A.M.G. Klein Tank, M. Haylock, D. Collins, B. Trewin, F. Rahimzadeh, A. Tagipour, K. Rupa Kumar, J. Revadekar, G. Griffiths, L. Vincent, D.B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci, and J.L. Vazquez-Aguirre, 2006: Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research,* **111,** 22. http://dx.doi.org/10.1029/2005JD006290

Allen, M.R. and W.J. Ingram, 2002: Constraints on future changes in climate and the hydrologic cycle. *Nature,* **419,** 224-232. http://dx.doi.org/10.1038/nature01092

Anderson, B.T., J.R. Knight, M.A. Ringer, J.-H. Yoon, and A. Cherchi, 2012: Testing for the possible influence of unknown climate forcings upon global temperature increases from 1950 to 2000. *Journal of Climate,* **25,** 7163-7172. http://dx.doi.org/10.1175/jcli-d-11-00645.1

Arnell, N.W. and S.N. Gosling, 2016: The impacts of climate change on river flood risk at the global scale. *Climatic Change,* **134,** 387-401. http://dx.doi.org/10.1007/s10584-014-1084-5

Asadieh, B. and N.Y. Krakauer, 2015: Global trends in extreme precipitation: climate models versus observations. *Hydrology and Earth System Sciences,* **19,** 877-891. http://dx.doi.org/10.5194/hess-19-877-2015

Balmaseda, M.A., K.E. Trenberth, and E. Källén, 2013: Distinctive climate signals in reanalysis of global ocean heat content. *Geophysical Research Letters,* **40,** 1754-1759. http://dx.doi.org/10.1002/grl.50382

Barnes, E.A. and L.M. Polvani, 2015: CMIP5 projections of arctic amplification, of the North American/North Atlantic circulation, and of their relationship. *Journal of Climate,* **28,** 5254-5271. http://dx.doi.org/10.1175/JCLI-D-14-00589.1

Becker, A., P. Finger, A. Meyer-Christoffer, B. Rudolf, K. Schamm, U. Schneider, and M. Ziese, 2013: A description of the global land-surface precipitation data products of the Global Precipitation Climatology Centre with sample applications including centennial (trend) analysis from 1901–present. *Earth System Science Data,* **5,** 71-99. http://dx.doi.org/10.5194/essd-5-71-2013

FINAL DRAFT

Bender, F.A.-M., V. Ramanathan, and G. Tselioudis, 2012: Changes in extratropical storm track cloudiness 1983–2008: Observational support for a poleward shift. *Climate Dynamics,* **38,** 2037-2053. http://dx.doi.org/10.1007/s00382-011-1065-6

Benestad, R.E., 2017: A mental picture of the greenhouse effect. *Theoretical and Applied Climatology,* **128,** 679-688. http://dx.doi.org/10.1007/s00704-016-1732-y

Berghuijs, W.R., R.A. Woods, C.J. Hutton, and M. Sivapalan, 2016: Dominant flood generating mechanisms across the United States. *Geophysical Research Letters,* **43,** 4382-4390. http://dx.doi.org/10.1002/2016GL068070

Bernier, P.Y., R.L. Desjardins, Y. Karimi-Zindashty, D. Worth, A. Beaudoin, Y. Luo, and S. Wang, 2011: Boreal lichen woodlands: A possible negative feedback to climate change in eastern North America. *Agricultural and Forest Meteorology,* **151,** 521-528. http://dx.doi.org/10.1016/j.agrformet.2010.12.013

Betts, R.A., O. Boucher, M. Collins, P.M. Cox, P.D. Falloon, N. Gedney, D.L. Hemming, C. Huntingford, C.D. Jones, D.M.H. Sexton, and M.J. Webb, 2007: Projected increase in continental runoff due to plant responses to increasing carbon dioxide. *Nature,* **448,** 1037-1041. http://dx.doi.org/10.1038/nature06045

Bindoff, N.L., P.A. Stott, K.M. AchutaRao, M.R. Allen, N. Gillett, D. Gutzler, K. Hansingo, G. Hegerl, Y. Hu, S. Jain, I.I. Mokhov, J. Overland, J. Perlwitz, R. Sebbari, and X. Zhang, 2013: Detection and attribution of climate change: From global to regional. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 867–952. http://www.climatechange2013.org/report/full-report/

Blunden, J. and D.S. Arndt, 2016: State of the climate in 2015. *Bulletin of the American Meteorological Society,* **97,** Si-S275. http://dx.doi.org/10.1175/2016BAMSStateoftheClimate.1

Bonan, G.B., 2008: Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science,* **320,** 1444-1449. http://dx.doi.org/10.1126/science.1155121

Callaghan, T.V., M. Johansson, R.D. Brown, P.Y. Groisman, N. Labba, V. Radionov, R.S. Bradley, S. Blangy, O.N. Bulygina, T.R. Christensen, J.E. Colman, R.L.H. Essery, B.C. Forbes, M.C. Forchhammer, V.N. Golubev, R.E. Honrath, G.P. Juday, A.V. Meshcherskaya, G.K. Phoenix, J. Pomeroy, A. Rautio, D.A. Robinson, N.M. Schmidt, M.C. Serreze, V.P. Shevchenko, A.I. Shiklomanov, A.B. Shmakin, P. Sköld, M. Sturm, M.-k. Woo, and E.F.

FINAL DRAFT

Wood, 2011: Multiple effects of changes in Arctic snow cover. *Ambio,* **40,** 32-45. http://dx.doi.org/10.1007/s13280-011-0213-x

Chambers, J.Q., J.I. Fisher, H. Zeng, E.L. Chapman, D.B. Baker, and G.C. Hurtt, 2007: Hurricane Katrina's carbon footprint on U.S. Gulf Coast forests. *Science,* **318,** 1107-1107. http://dx.doi.org/10.1126/science.1148913

Chang, E.K.M., 2013: CMIP5 projection of significant reduction in extratropical cyclone activity over North America. *Journal of Climate,* **26,** 9903-9922. http://dx.doi.org/10.1175/JCLI-D-13-00209.1

Chen, X. and K.-K. Tung, 2014: Varying planetary heat sink led to global-warming slowdown and acceleration. *Science,* **345,** 897-903. http://dx.doi.org/10.1126/science.1254937

Church, J.A. and N.J. White, 2011: Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics,* **32,** 585-602. http://dx.doi.org/10.1007/s10712-011-9119-1

Church, J.A., N.J. White, L.F. Konikow, C.M. Domingues, J.G. Cogley, E. Rignot, J.M. Gregory, M.R. van den Broeke, A.J. Monaghan, and I. Velicogna, 2011: Revisiting the Earth's sea-level and energy budgets from 1961 to 2008. *Geophysical Research Letters,* **38,** L18601. http://dx.doi.org/10.1029/2011GL048794

Churkina, G., V. Brovkin, W. von Bloh, K. Trusilova, M. Jung, and F. Dentener, 2009: Synergy of rising nitrogen depositions and atmospheric CO2 on land carbon uptake moderately offsets global warming. *Global Biogeochemical Cycles,* **23,** n/a-n/a. http://dx.doi.org/10.1029/2008GB003291

Ciais, P., M. Reichstein, N. Viovy, A. Granier, J. Ogee, V. Allard, M. Aubinet, N. Buchmann, C. Bernhofer, A. Carrara, F. Chevallier, N. De Noblet, A.D. Friend, P. Friedlingstein, T. Grunwald, B. Heinesch, P. Keronen, A. Knohl, G. Krinner, D. Loustau, G. Manca, G. Matteucci, F. Miglietta, J.M. Ourcival, D. Papale, K. Pilegaard, S. Rambal, G. Seufert, J.F. Soussana, M.J. Sanz, E.D. Schulze, T. Vesala, and R. Valentini, 2005: Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature,* **437,** 529-533. http://dx.doi.org/10.1038/nature03972

Clark, D.B., D.A. Clark, and S.F. Oberbauer, 2010: Annual wood production in a tropical rain forest in NE Costa Rica linked to climatic variation but not to increasing CO2. *Global Change Biology,* **16,** 747-759. http://dx.doi.org/10.1111/j.1365-2486.2009.02004.x

Colle, B.A., Z. Zhang, K.A. Lombardo, E. Chang, P. Liu, and M. Zhang, 2013: Historical evaluation and future prediction of eastern North American and western Atlantic extratropical cyclones in the CMIP5 models during the cool season. *Journal of Climate,* **26,** 6882-6903. http://dx.doi.org/10.1175/JCLI-D-12-00498.1

FINAL DRAFT

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver, and M. Wehner, 2013: Long-term climate change: Projections, commitments and irreversibility. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1029–1136. http://www.climatechange2013.org/report/full-report/

Comiso, J.C. and D.K. Hall, 2014: Climate trends in the Arctic as observed from space. *Wiley Interdisciplinary Reviews: Climate Change,* **5,** 389-409. http://dx.doi.org/10.1002/wcc.277

Dai, A., 2013: Increasing drought under global warming in observations and models. *Nature Climate Change,* **3,** 52-58. http://dx.doi.org/10.1038/nclimate1633

Davy, R., I. Esau, A. Chernokulsky, S. Outten, and S. Zilitinkevich, 2016: Diurnal asymmetry to the observed global warming. *International Journal of Climatology,* **37,** 79-93. http://dx.doi.org/10.1002/joc.4688

de Noblet-Ducoudré, N., J.-P. Boisier, A. Pitman, G.B. Bonan, V. Brovkin, F. Cruz, C. Delire, V. Gayler, B.J.J.M.v.d. Hurk, P.J. Lawrence, M.K.v.d. Molen, C. Müller, C.H. Reick, B.J. Strengers, and A. Voldoire, 2012: Determining robust impacts of land-use-induced land cover changes on surface climate over North America and Eurasia: Results from the first set of LUCID experiments. *Journal of Climate,* **25,** 3261-3281. http://dx.doi.org/10.1175/JCLI-D-11-00338.1

DeConto, R.M. and D. Pollard, 2016: Contribution of Antarctica to past and future sea-level rise. *Nature,* **531,** 591-597. http://dx.doi.org/10.1038/nature17145

Delworth, T.L. and T.R. Knutson, 2000: Simulation of early 20th century global warming. *Science,* **287,** 2246-2250. http://dx.doi.org/10.1126/science.287.5461.2246

Derksen, C. and R. Brown, 2012: Spring snow cover extent reductions in the 2008–2012 period exceeding climate model projections. *Geophysical Research Letters,* **39,** L19504. http://dx.doi.org/10.1029/2012gl053387

Derksen, D., R. Brown, L. Mudryk, and K. Loujus, 2015: [The Arctic] Terrestrial snow cover [in "State of the Climate in 2014"]. *Bulletin of the American Meteorological Society,* **96 (12),** S133-S135. http://dx.doi.org/10.1175/2015BAMSStateoftheClimate.1

Deser, C., R. Knutti, S. Solomon, and A.S. Phillips, 2012: Communication of the role of natural variability in future North American climate. *Nature Climate Change,* **2,** 775-779. http://dx.doi.org/10.1038/nclimate1562

FINAL DRAFT

Diffenbaugh, N.S., M. Scherer, and R.J. Trapp, 2013: Robust increases in severe thunderstorm environments in response to greenhouse forcing. *Proceedings of the National Academy of Sciences,* **110,** 16361-16366. http://dx.doi.org/10.1073/pnas.1307758110

Donat, M.G., A.L. Lowry, L.V. Alexander, P.A. Ogorman, and N. Maher, 2016: More extreme precipitation in the world's dry and wet regions. *Nature Climate Change,* **6,** 508-513. http://dx.doi.org/10.1038/nclimate2941

Dutton, A. and K. Lambeck, 2012: Ice volume and sea level during the Last Interglacial. *Science,* **337,** 216-219. http://dx.doi.org/10.1126/science.1205749

Easterling, D.R. and M.F. Wehner, 2009: Is the climate warming or cooling? *Geophysical Research Letters,* **36,** 3. http://dx.doi.org/10.1029/2009GL037810

Easterling, D.R., K.E. Kunkel, M.F. Wehner, and L. Sun, 2016: Detection and attribution of climate extremes in the observed record. *Weather and Climate Extremes,* **11,** 17-27. http://dx.doi.org/10.1016/j.wace.2016.01.001

Eisenman, I., W.N. Meier, and J.R. Norris, 2014: A spurious jump in the satellite record: Has Antarctic sea ice expansion been overestimated? *The Cryosphere,* **8,** 1289-1296. http://dx.doi.org/10.5194/tc-8-1289-2014

Elsner, J.B., J.P. Kossin, and T.H. Jagger, 2008: The increasing intensity of the strongest tropical cyclones. *Nature,* **455,** 92-95. http://dx.doi.org/10.1038/nature07234

Emanuel, K.A., 2013: Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. *Proceedings of the National Academy of Sciences,* **110,** 12219-12224. http://dx.doi.org/10.1073/pnas.1301293110

England, M.H., S. McGregor, P. Spence, G.A. Meehl, A. Timmermann, W. Cai, A.S. Gupta, M.J. McPhaden, A. Purich, and A. Santoso, 2014: Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus. *Nature Climate Change,* **4,** 222-227. http://dx.doi.org/10.1038/nclimate2106

EPA, 2016: Climate change indicators in the United States, 2016. U.S. Environmental Protection Agency, 92 pp.

Ezer, T. and L.P. Atkinson, 2014: Accelerated flooding along the U.S. East Coast: On the impact of sea-level rise, tides, storms, the Gulf Stream, and the North Atlantic Oscillations. *Earth's Future,* **2,** 362-382. http://dx.doi.org/10.1002/2014EF000252

Feldmann, J. and A. Levermann, 2015: Collapse of the West Antarctic Ice Sheet after local destabilization of the Amundsen Basin. *Proceedings of the National Academy of Sciences,* **112,** 14191-14196. http://dx.doi.org/10.1073/pnas.1512482112

FINAL DRAFT

Fettweis, X., M. Tedesco, M. van den Broeke, and J. Ettema, 2011: Melting trends over the Greenland ice sheet (1958–2009) from spaceborne microwave data and regional climate models. *The Cryosphere,* **5,** 359-375. http://dx.doi.org/10.5194/tc-5-359-2011

Finzi, A.C., D.J.P. Moore, E.H. DeLucia, J. Lichter, K.S. Hofmockel, R.B. Jackson, H.-S. Kim, R. Matamala, H.R. McCarthy, R. Oren, J.S. Pippen, and W.H. Schlesinger, 2006: Progressive nitrogen limitation of ecosystem processes under elevated CO2 in a warm-temperate forest. *Ecology,* **87,** 15-25. http://dx.doi.org/10.1890/04-1748

Fischer, E.M., and R. Knutti, 2016: Observed heavy precipitation increase confirms theory and early models. *Nature Climate Change*, **6**, 986-992

Fyfe, J.C., G.A. Meehl, M.H. England, M.E. Mann, B.D. Santer, G.M. Flato, E. Hawkins, N.P. Gillett, S.-P. Xie, Y. Kosaka, and N.C. Swart, 2016: Making sense of the early-2000s warming slowdown. *Nature Climate Change,* **6,** 224-228. http://dx.doi.org/10.1038/nclimate2938

Greve, P., B. Orlowsky, B. Mueller, J. Sheffield, M. Reichstein, and S.I. Seneviratne, 2014: Global assessment of trends in wetting and drying over land. *Nature Geoscience,* **7,** 716-721. http://dx.doi.org/10.1038/ngeo2247

Harig, C. and F.J. Simons, 2012: Mapping Greenland's mass loss in space and time. *Proceedings of the National Academy of Sciences,* **109,** 19934-19937. http://dx.doi.org/10.1073/pnas.1206785109

Harig, C. and F.J. Simons, 2015: Accelerated West Antarctic ice mass loss continues to outpace East Antarctic gains. *Earth and Planetary Science Letters,* **415,** 134-141. http://dx.doi.org/10.1016/j.epsl.2015.01.029

Harig, C. and F.J. Simons, 2016: Ice mass loss in Greenland, the Gulf of Alaska, and the Canadian Archipelago: Seasonal cycles and decadal trends. *Geophysical Research Letters,* **43,** 3150-3159. http://dx.doi.org/10.1002/2016GL067759

Hausfather, Z., K. Cowtan, D.C. Clarke, P. Jacobs, M. Richardson, and R. Rohde, 2017: Assessing recent warming using instrumentally homogeneous sea surface temperature records. *Science Advances,* **3**. http://dx.doi.org/10.1126/sciadv.1601207

Hay, C.C., E. Morrow, R.E. Kopp, and J.X. Mitrovica, 2015: Probabilistic reanalysis of twentieth-century sea-level rise. *Nature,* **517,** 481-484. http://dx.doi.org/10.1038/nature14093

Haywood, A.M., D.J. Hill, A.M. Dolan, B.L. Otto-Bliesner, F. Bragg, W.L. Chan, M.A. Chandler, C. Contoux, H.J. Dowsett, A. Jost, Y. Kamae, G. Lohmann, D.J. Lunt, A. Abe-Ouchi, S.J. Pickering, G. Ramstein, N.A. Rosenbloom, U. Salzmann, L. Sohl, C. Stepanek, H. Ueda, Q. Yan, and Z. Zhang, 2013: Large-scale features of Pliocene climate: Results from

FINAL DRAFT

the Pliocene Model Intercomparison Project. *Climate of the Past,* **9,** 191-209. http://dx.doi.org/10.5194/cp-9-191-2013

Held, I.M. and B.J. Soden, 2006: Robust responses of the hydrological cycle to global warming. *Journal of Climate,* **19,** 5686-5699. http://dx.doi.org/10.1175/jcli3990.1

Hoegh-Guldberg, O., R. Cai, E.S. Poloczanska, P.G. Brewer, S. Sundby, K. Hilmi, V.J. Fabry, and S. Jung, 2014: The Ocean. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change*. Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1655-1731. http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap30_FINAL.pdf

Hoerling, M., M. Chen, R. Dole, J. Eischeid, A. Kumar, J.W. Nielsen-Gammon, P. Pegion, J. Perlwitz, X.-W. Quan, and T. Zhang, 2013: Anatomy of an extreme event. *Journal of Climate,* **26,** 2811–2832. http://dx.doi.org/10.1175/JCLI-D-12-00270.1

Horton, D.E., N.C. Johnson, D. Singh, D.L. Swain, B. Rajaratnam, and N.S. Diffenbaugh, 2015: Contribution of changes in atmospheric circulation patterns to extreme temperature trends. *Nature,* **522,** 465-469. http://dx.doi.org/10.1038/nature14550

Houghton, R.A., J.I. House, J. Pongratz, G.R. van der Werf, R.S. DeFries, M.C. Hansen, C. Le Quéré, and N. Ramankutty, 2012: Carbon emissions from land use and land-cover change. *Biogeosciences,* **9,** 5125-5142. http://dx.doi.org/10.5194/bg-9-5125-2012

Huber, M. and R. Knutti, 2014: Natural variability, radiative forcing and climate response in the recent hiatus reconciled. *Nature Geoscience,* **7,** 651-656. http://dx.doi.org/10.1038/ngeo2228

Hulme, M., 2014: Attributing weather extremes to 'climate change'. *Progress in Physical Geography,* **38,** 499-511. http://dx.doi.org/10.1177/0309133314538644

Hurrell, J.W. and C. Deser, 2009: North Atlantic climate variability: The role of the North Atlantic oscillation. *Journal of Marine Systems,* **78,** 28-41. http://dx.doi.org/10.1016/j.jmarsys.2008.11.026

IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, 1535 pp. http://www.climatechange2013.org/report/

FINAL DRAFT

Jacob, T., J. Wahr, W.T. Pfeffer, and S. Swenson, 2012: Recent contributions of glaciers and ice caps to sea level rise. *Nature,* **482,** 514-518. http://dx.doi.org/10.1038/nature10847

Jenkins, A., P. Dutrieux, S.S. Jacobs, S.D. McPhail, J.R. Perrett, A.T. Webb, and D. White, 2010: Observations beneath Pine Island Glacier in West Antarctica and implications for its retreat. *Nature Geoscience,* **3,** 468-472. http://dx.doi.org/10.1038/ngeo890

Johnson, G.C., J.M. Lyman, J. Antonov, N. Bindoff, T. Boyer, C.M. Domingues, S.A. Good, M. Ishii, and J.K. Willis, 2015: [Global Oceans] Ocean Heat Content [in "State of the Climate in 2014"]. Bulletin of the American Meteorological Society (BAMS), **96** (7), S64-S66

Jones, D.A., W. Wang, and R. Fawcett, 2009: High-quality spatial climate data-sets for Australia. *Australian Meteorological and Oceanographic Journal,* **58,** 233-248. http://dx.doi.org/10.22499/2.5804.003

Jones, P.D., D.H. Lister, T.J. Osborn, C. Harpham, M. Salmon, and C.P. Morice, 2012: Hemispheric and large-scale land surface air temperature variations: An extensive revision and an update to 2010. *Journal of Geophysical Research,* **117**. http://dx.doi.org/10.1029/2011JD017139

Joughin, I., B.E. Smith, and B. Medley, 2014: Marine ice sheet collapse potentially under way for the Thwaites Glacier Basin, West Antarctica. *Science,* **344,** 735-738. http://dx.doi.org/10.1126/science.1249055

Karl, T.R., A. Arguez, B. Huang, J.H. Lawrimore, J.R. McMahon, M.J. Menne, T.C. Peterson, R.S. Vose, and H.-M. Zhang, 2015: Possible artifacts of data biases in the recent global surface warming hiatus. *Science,* **348,** 1469-1472. http://dx.doi.org/10.1126/science.aaa5632

Kaspar, F., N. Kühl, U. Cubasch, and T. Litt, 2005: A model-data comparison of European temperatures in the Eemian interglacial. *Geophysical Research Letters,* **32,** n/a-n/a. http://dx.doi.org/10.1029/2005GL022456

Katz, R.W. and B.G. Brown, 1992: Extreme events in a changing climate: Variability is more important than averages. *Climatic Change,* **21,** 289-302. http://dx.doi.org/10.1007/bf00139728

Kim, Y., J.S. Kimball, K. Zhang, and K.C. McDonald, 2012: Satellite detection of increasing Northern Hemisphere non-frozen seasons from 1979 to 2008: Implications for regional vegetation growth. *Remote Sensing of Environment,* **121,** 472-487. http://dx.doi.org/10.1016/j.rse.2012.02.014

Knutson, T.R., J.J. Sirutis, M. Zhao, R.E. Tuleya, M. Bender, G.A. Vecchi, G. Villarini, and D. Chavas, 2015: Global projections of intense tropical cyclone activity for the late twenty-first

FINAL DRAFT

century from dynamical downscaling of CMIP5/RCP4.5 scenarios. *Journal of Climate,* **28,** 7203-7224. http://dx.doi.org/10.1175/JCLI-D-15-0129.1

Knutson, T.R., R. Zhang, and L.W. Horowitz, 2016: Prospects for a prolonged slowdown in global warming in the early 21st century. *Nature Communcations,* **7,** 13676. http://dx.doi.org/10.1038/ncomms13676

Kopp, R.E., F.J. Simons, J.X. Mitrovica, A.C. Maloof, and M. Oppenheimer, 2009: Probabilistic assessment of sea level during the last interglacial stage. *Nature,* **462,** 863-867. http://dx.doi.org/10.1038/nature08686

Kopp, R.E., R.M. Horton, C.M. Little, J.X. Mitrovica, M. Oppenheimer, D.J. Rasmussen, B.H. Strauss, and C. Tebaldi, 2014: Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future,* **2,** 383-406. http://dx.doi.org/10.1002/2014EF000239

Kosaka, Y. and S.-P. Xie, 2013: Recent global-warming hiatus tied to equatorial Pacific surface cooling. *Nature,* **501,** 403-407. http://dx.doi.org/10.1038/nature12534

Kossin, J.P., T.L. Olander, and K.R. Knapp, 2013: Trend analysis with a new global record of tropical cyclone intensity. *Journal of Climate,* **26,** 9960-9976. http://dx.doi.org/10.1175/JCLI-D-13-00262.1

Kossin, J.P., K.A. Emanuel, and G.A. Vecchi, 2014: The poleward migration of the location of tropical cyclone maximum intensity. *Nature,* **509,** 349-352. http://dx.doi.org/10.1038/nature13278

Kossin, J.P., K.A. Emanuel, and S.J. Camargo, 2016: Past and projected changes in western North Pacific tropical cyclone exposure. *Journal of Climate,* **29,** 5725-5739. http://dx.doi.org/10.1175/JCLI-D-16-0076.1

Kundzewicz, Z.W., S. Kanae, S.I. Seneviratne, J. Handmer, N. Nicholls, P. Peduzzi, R. Mechler, L.M. Bouwer, N. Arnell, K. Mach, R. Muir-Wood, G.R. Brakenridge, W. Kron, G. Benito, Y. Honda, K. Takahashi, and B. Sherstyukov, 2014: Flood risk and climate change: Global and regional perspectives. *Hydrological Sciences Journal,* **59,** 1-28. http://dx.doi.org/10.1080/02626667.2013.857411

Kunkel, K.E. and R.M. Frankson, 2015: Global land surface extremes of precipitation: Data limitations and trends. *Journal of Extreme Events,* **02,** 1550004. http://dx.doi.org/10.1142/S2345737615500049

Kunkel, K.E., T.R. Karl, H. Brooks, J. Kossin, J. Lawrimore, D. Arndt, L. Bosart, D. Changnon, S.L. Cutter, N. Doesken, K. Emanuel, P.Y. Groisman, R.W. Katz, T. Knutson, J. O'Brien, C.J. Paciorek, T.C. Peterson, K. Redmond, D. Robinson, J. Trapp, R. Vose, S. Weaver, M.

FINAL DRAFT

Wehner, K. Wolter, and D. Wuebbles, 2013: Monitoring and understanding trends in extreme storms: State of knowledge. *Bulletin of the American Meteorological Society,* **94**. http://dx.doi.org/10.1175/BAMS-D-11-00262.1

Kunkel, K.E., D.A. Robinson, S. Champion, X. Yin, T. Estilow, and R.M. Frankson, 2016: Trends and extremes in Northern Hemisphere snow characteristics. *Current Climate Change Reports,* **2,** 65-73. http://dx.doi.org/10.1007/s40641-016-0036-8

Kurz, W.A., G. Stinson, G.J. Rampley, C.C. Dymond, and E.T. Neilson, 2008: Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. *Proceedings of the National Academy of Sciences,* **105,** 1551-1555. http://dx.doi.org/10.1073/pnas.0708133105

Le Quéré, C., R. Moriarty, R.M. Andrew, J.G. Canadell, S. Sitch, J.I. Korsbakken, P. Friedlingstein, G.P. Peters, R.J. Andres, T.A. Boden, R.A. Houghton, J.I. House, R.F. Keeling, P. Tans, A. Arneth, D.C.E. Bakker, L. Barbero, L. Bopp, J. Chang, F. Chevallier, L.P. Chini, P. Ciais, M. Fader, R.A. Feely, T. Gkritzalis, I. Harris, J. Hauck, T. Ilyina, A.K. Jain, E. Kato, V. Kitidis, K. Klein Goldewijk, C. Koven, P. Landschützer, S.K. Lauvset, N. Lefèvre, A. Lenton, I.D. Lima, N. Metzl, F. Millero, D.R. Munro, A. Murata, J.E.M.S. Nabel, S. Nakaoka, Y. Nojiri, K. O'Brien, A. Olsen, T. Ono, F.F. Pérez, B. Pfeil, D. Pierrot, B. Poulter, G. Rehder, C. Rödenbeck, S. Saito, U. Schuster, J. Schwinger, R. Séférian, T. Steinhoff, B.D. Stocker, A.J. Sutton, T. Takahashi, B. Tilbrook, I.T. van der Laan-Luijkx, G.R. van der Werf, S. van Heuven, D. Vandemark, N. Viovy, A. Wiltshire, S. Zaehle, and N. Zeng, 2015: Global carbon budget 2015. *Earth System Science Data,* **7,** 349-396. http://dx.doi.org/10.5194/essd-7-349-2015

Le Quéré, C., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., Peters, G. P., Manning, A. C., Boden, T. A., Tans, P. P., Houghton, R. A., Keeling, R. F., Alin, S., Andrews, O. D., Anthoni, P., Barbero, L., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Currie, K., Delire, C., Doney, S. C., Friedlingstein, P., Gkritzalis, T., Harris, I., Hauck, J., Haverd, V., Hoppema, M., Klein Goldewijk, K., Jain, A. K., Kato, E., Körtzinger, A., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Melton, J. R., Metzl, N., Millero, F., Monteiro, P. M. S., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., O'Brien, K., Olsen, A., Omar, A. M., Ono, T., Pierrot, D., Poulter, B., Rödenbeck, C., Salisbury, J., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Stocker, B. D., Sutton, A. J., Takahashi, T., Tian, H., Tilbrook, B., van der Laan-Luijkx, I. T., van der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J., and Zaehle, S., 2016: Global Carbon Budget 2016, *Earth Syst. Sci. Data*, 8, 605-649, doi:10.5194/essd-8-605-2016.

Lewandowsky, S., J.S. Risbey, and N. Oreskes, 2016: The "pause" in global warming: Turning a routine fluctuation into a problem for science. *Bulletin of the American Meteorological Society,* **97,** 723-733. http://dx.doi.org/10.1175/BAMS-D-14-00106.1

UNDER DRAFT

Lewis, S.L., P.M. Brando, O.L. Phillips, G.M.F. van der Heijden, and D. Nepstad, 2011: The 2010 Amazon drought. *Science,* **331,** 554-554. http://dx.doi.org/10.1126/science.1200807

Mann, M.E., Z. Zhang, M.K. Hughes, R.S. Bradley, S.K. Miller, S. Rutherford, and F. Ni, 2008: Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences,* **105,** 13252-13257. http://dx.doi.org/10.1073/pnas.0805721105

Mao, J., A. Ribes, B. Yan, X. Shi, P.E. Thornton, R. Seferian, P. Ciais, R.B. Myneni, H. Douville, S. Piao, Z. Zhu, R.E. Dickinson, Y. Dai, D.M. Ricciuto, M. Jin, F.M. Hoffman, B. Wang, M. Huang, and X. Lian, 2016: Human-induced greening of the northern extratropical land surface. *Nature Climate Change,* **6,** 959-963. http://dx.doi.org/10.1038/nclimate3056

Marcott, S.A., J.D. Shakun, P.U. Clark, and A.C. Mix, 2013: A reconstruction of regional and global temperature for the past 11,300 years. *Science,* **339,** 1198-1201. http://dx.doi.org/10.1126/science.1228026

Marvel, K. and C. Bonfils, 2013: Identifying external influences on global precipitation. *Proceedings of the National Academy of Sciences,* **110,** 19301-19306. http://dx.doi.org/10.1073/pnas.1314382110

Mears, C.A. and F.J. Wentz, 2016: Sensitivity of satellite-derived tropospheric temperature trends to the diurnal cycle adjustment. *Journal of Climate,* **29,** 3629-3646. http://dx.doi.org/10.1175/JCLI-D-15-0744.1

Meehl, G.A., C. Tebaldi, G. Walton, D. Easterling, and L. McDaniel, 2009: Relative increase of record high maximum temperatures compared to record low minimum temperatures in the US. *Geophysical Research Letters,* **36,** L23701. http://dx.doi.org/10.1029/2009GL040736

Meehl, G.A., J.M. Arblaster, J.T. Fasullo, A. Hu, and K.E. Trenberth, 2011: Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods. *Nature Climate Change,* **1,** 360-364. http://dx.doi.org/10.1038/nclimate1229

Meehl, G.A., A. Hu, B.D. Santer, and S.-P. Xie, 2016a: Contribution of the Interdecadal Pacific Oscillation to twentieth-century global surface temperature trends. *Nature Climate Change,* **6,** 1005-1008. http://dx.doi.org/10.1038/nclimate3107

Meehl, G.A., J.M. Arblaster, C.M. Bitz, C.T.Y. Chung, and H. Teng, 2016b: Antarctic sea-ice expansion between 2000 and 2014 driven by tropical Pacific decadal climate variability. *Nature Geoscience,* **9,** 590-595. http://dx.doi.org/10.1038/ngeo2751

Melillo, J.M., T.C. Richmond, and G.W. Yohe, eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program: Washington, D.C., 842 pp. http://dx.doi.org/10.7930/J0Z31WJ2

FINAL DRAFT

Mengel, M., A. Levermann, K. Frieler, A. Robinson, B. Marzeion, and R. Winkelmann, 2016: Future sea level rise constrained by observations and long-term commitment. *Proceedings of the National Academy of Sciences,* **113,** 2597-2602. http://dx.doi.org/10.1073/pnas.1500515113

Menzel, A., T.H. Sparks, N. Estrella, E. Koch, A. Aasa, R. Ahas, K. Alm-Kübler, P. Bissolli, O.G. Braslavská, A. Briede, F.M. Chmielewski, Z. Crepinsek, Y. Curnel, Å. Dahl, C. Defila, A. Donnelly, Y. Filella, K. Jatczak, F. Måge, A. Mestre, Ø. Nordli, J. Peñuelas, P. Pirinen, V. Remišvá, H. Scheifinger, M. Striz, A. Susnik, A.J.H. Van Vliet, F.-E. Wielgolaski, S. Zach, and A.N.A. Zust, 2006: European phenological response to climate change matches the warming pattern. *Global Change Biology,* **12,** 1969-1976. http://dx.doi.org/10.1111/j.1365-2486.2006.01193.x

Merrifield, M.A., P. Thompson, E. Leuliette, G.T. Mitchum, D.P. Chambers, S. Jevrejeva, R.S. Nerem, M. Menéndez, W. Sweet, B. Hamlington, and J.J. Marra, 2015: [Global Oceans] Sea level variability and change [in "State of the Climate in 2014"]. *Bulletin of the American Meteorological Society,* **96 (12),** S82-S85. http://dx.doi.org/10.1175/2015BAMSStateoftheClimate.1

Min, S.-K., X. Zhang, and F. Zwiers, 2008: Human-induced Arctic moistening. *Science,* **320,** 518-520. http://dx.doi.org/10.1126/science.1153468

Min, S.K., X. Zhang, F.W. Zwiers, and G.C. Hegerl, 2011: Human contribution to more-intense precipitation extremes. *Nature,* **470,** 378-381. http://dx.doi.org/10.1038/nature09763

Min, S.-K., X. Zhang, F. Zwiers, H. Shiogama, Y.-S. Tung, and M. Wehner, 2013: Multimodel detection and attribution of extreme temperature changes. *Journal of Climate,* **26,** 7430-7451. http://dx.doi.org/10.1175/JCLI-D-12-00551.1

Mountain Research Initiative, 2015: Elevation-dependent warming in mountain regions of the world. *Nature Climate Change,* **5,** 424-430. http://dx.doi.org/10.1038/nclimate2563

Myneni, R.B., C.D. Keeling, C.J. Tucker, G. Asrar, and R.R. Nemani, 1997: Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature,* **386,** 698-702. http://dx.doi.org/10.1038/386698a0

NAS, 2016: *Attribution of Extreme Weather Events in the Context of Climate Change*. The National Academies Press, Washington, DC, 186 pp. http://dx.doi.org/10.17226/21852

NCEI, 2016: Climate at a Glance: Global Temperature Anomalies. http://www.ncdc.noaa.gov/cag/time-series/global/globe/land_ocean/ytd/12/1880-2015

FINAL DRAFT

Nerem, R.S., D.P. Chambers, C. Choe, and G.T. Mitchum, 2010: Estimating mean sea level change from the TOPEX and Jason altimeter missions. *Marine Geodesy,* **33,** 435-446. http://dx.doi.org/10.1080/01490419.2010.491031

Nghiem, S.V., D.K. Hall, T.L. Mote, M. Tedesco, M.R. Albert, K. Keegan, C.A. Shuman, N.E. DiGirolamo, and G. Neumann, 2012: The extreme melt across the Greenland ice sheet in 2012. *Geophysical Research Letters,* **39,** L20502. http://dx.doi.org/10.1029/2012GL053611

Nieves, V., J.K. Willis, and W.C. Patzert, 2015: Recent hiatus caused by decadal shift in Indo-Pacific heating. *Science,* **349,** 532-535. http://dx.doi.org/10.1126/science.aaa4521

Norby, R.J., J.M. Warren, C.M. Iversen, B.E. Medlyn, and R.E. McMurtrie, 2010: CO2 enhancement of forest productivity constrained by limited nitrogen availability. *Proceedings of the National Academy of Sciences,* **107,** 19368-19373. http://dx.doi.org/10.1073/pnas.1006463107

NSIDC, 2016: Sluggish Ice Growth in the Arctic. Arctic Sea Ice News and Analysis, National Snow and Ice Data Center. http://nsidc.org/arcticseaicenews/2016/11/sluggish-ice-growth-in-the-arctic/

NSIDC, 2017: SOTC (State of the Cryosphere): Northern Hemisphere Snow. National Snow and Ice Data Center. https://nsidc.org/cryosphere/sotc/snow_extent.html

Page, S.E., F. Siegert, J.O. Rieley, H.-D.V. Boehm, A. Jaya, and S. Limin, 2002: The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature,* **420,** 61-65. http://dx.doi.org/10.1038/nature01131

PAGES 2K Consortium, 2013: Continental-scale temperature variability during the past two millennia. *Nature Geoscience,* **6,** 339-346. http://dx.doi.org/10.1038/ngeo1797

Palmroth, S., R. Oren, H.R. McCarthy, K.H. Johnsen, A.C. Finzi, J.R. Butnor, M.G. Ryan, and W.H. Schlesinger, 2006: Aboveground sink strength in forests controls the allocation of carbon below ground and its [CO2]-induced enhancement. *Proceedings of the National Academy of Sciences,* **103,** 19362-19367. http://dx.doi.org/10.1073/pnas.0609492103

Pan, Y., R.A. Birdsey, J. Fang, R. Houghton, P.E. Kauppi, W.A. Kurz, O.L. Phillips, A. Shvidenko, S.L. Lewis, J.G. Canadell, P. Ciais, R.B. Jackson, S.W. Pacala, A.D. McGuire, S. Piao, A. Rautiainen, S. Sitch, and D. Hayes, 2011: A large and persistent carbon sink in the world's forests. *Science,* **333,** 988-93. http://dx.doi.org/10.1126/science.1201609

Parkinson, C.L., 2014: Spatially mapped reductions in the length of the Arctic sea ice season. *Geophysical Research Letters,* **41,** 4316-4322. http://dx.doi.org/10.1002/2014GL060434

FINAL DRAFT

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss, 2012: Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Tech Memo OAR CPO-1. National Oceanic and Atmospheric Administration, Silver Spring, MD. 37 pp. http://scenarios.globalchange.gov/sites/default/files/NOAA_SLR_r3_0.pdf

Pauling, A.G., C.M. Bitz, I.J. Smith, and P.J. Langhorne, 2016: The response of the Southern Ocean and Antarctic sea ice to freshwater from ice shelves in an Earth system model. *Journal of Climate,* **29,** 1655-1672. http://dx.doi.org/10.1175/JCLI-D-15-0501.1

Pelto, M.S., 2015: [Global Climate] Alpine glaciers [in "State of the Climate in 2014"]. *Bulletin of the American Meteorological Society,* **96 (12),** S19-S20. http://dx.doi.org/10.1175/2015BAMSStateoftheClimate.1

Perovich, D., S. Gerlnad, S. Hendricks, W. Meier, M. Nicolaus, and M. Tschudi, 2015: [The Arctic] Sea ice cover [in "State of the Climate in 2014"]. *Bulletin of the American Meteorological Society,* **96 (12),** S145-S146. http://dx.doi.org/10.1175/2015BAMSStateoftheClimate.1

Peterson, T.C., R.R. Heim, R. Hirsch, D.P. Kaiser, H. Brooks, N.S. Diffenbaugh, R.M. Dole, J.P. Giovannettone, K. Guirguis, T.R. Karl, R.W. Katz, K. Kunkel, D. Lettenmaier, G.J. McCabe, C.J. Paciorek, K.R. Ryberg, S. Schubert, V.B.S. Silva, B.C. Stewart, A.V. Vecchia, G. Villarini, R.S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C.A. Woodhouse, and D. Wuebbles, 2013: Monitoring and understanding changes in heat waves, cold waves, floods and droughts in the United States: State of knowledge. *Bulletin of the American Meteorological Society,* **94,** 821-834. http://dx.doi.org/10.1175/BAMS-D-12-00066.1

Ramsayer, K., 2014: Antarctic sea ice reaches new record maximum. https://www.nasa.gov/content/goddard/antarctic-sea-ice-reaches-new-record-maximum

Rahmstorf, S., J.E. Box, G. Feulner, M.E. Mann, A. Robinson, S. Rutherford, and E.J. Schaffernicht, 2015: Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Climate Change,* **5,** 475-480. http://dx.doi.org/10.1038/nclimate2554

Reyes-Fox, M., H. Steltzer, M.J. Trlica, G.S. McMaster, A.A. Andales, D.R. LeCain, and J.A. Morgan, 2014: Elevated CO2 further lengthens growing season under warming conditions. *Nature,* **510,** 259-262. http://dx.doi.org/10.1038/nature13207

Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley, and F. Wang, 2013: Observations: Ocean. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A.

FINAL DRAFT

Nauels, Y. Xia, V. Bex, and P.M. Midgley, Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 255–316. http://www.climatechange2013.org/report/full-report/

Richardson, M., K. Cowtan, E. Hawkins, and M.B. Stolpe, 2016: Reconciled climate response estimates from climate models and the energy budget of Earth. *Nature Climate Change,* **6,** 931-935. http://dx.doi.org/10.1038/nclimate3066

Ridley, D.A., S. Solomon, J.E. Barnes, V.D. Burlakov, T. Deshler, S.I. Dolgii, A.B. Herber, T. Nagai, R.R. Neely, A.V. Nevzorov, C. Ritter, T. Sakai, B.D. Santer, M. Sato, A. Schmidt, O. Uchino, and J.P. Vernier, 2014: Total volcanic stratospheric aerosol optical depths and implications for global climate change. *Geophysical Research Letters,* **41,** 7763-7769. http://dx.doi.org/10.1002/2014GL061541

Rignot, E., I. Velicogna, M.R. van den Broeke, A. Monaghan, and J.T.M. Lenaerts, 2011: Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters,* **38,** L05503. http://dx.doi.org/10.1029/2011GL046583

Rignot, E., J. Mouginot, M. Morlighem, H. Seroussi, and B. Scheuchl, 2014: Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler Glaciers, West Antarctica, from 1992 to 2011. *Geophysical Research Letters,* **41,** 3502-3509. http://dx.doi.org/10.1002/2014GL060140

Romanovsky, V.E., S.L. Smith, H.H. Christiansen, N.I. Shiklomanov, D.A. Streletskiy, D.S. Drozdov, G.V. Malkova, N.G. Oberman, A.L. Kholodov, and S.S. Marchenko, 2015: [The Arctic] Terrestrial permafrost [in "State of the Climate in 2014"]. *Bulletin of the American Meteorological Society,* **96 (12),** S139-S141. http://dx.doi.org/10.1175/2015BAMSStateoftheClimate.1

Rupp, D.E., P.W. Mote, N.L. Bindoff, P.A. Stott, and D.A. Robinson, 2013: Detection and attribution of observed changes in Northern Hemisphere spring snow cover. *Journal of Climate,* **26,** 6904-6914. http://dx.doi.org/10.1175/JCLI-D-12-00563.1

Sander, J., J.F. Eichner, E. Faust, and M. Steuer, 2013: Rising variability in thunderstorm-related U.S. losses as a reflection of changes in large-scale thunderstorm forcing. *Weather, Climate, and Society,* **5,** 317-331. http://dx.doi.org/10.1175/WCAS-D-12-00023.1

Santer, B.D., C. Mears, F.J. Wentz, K.E. Taylor, P.J. Gleckler, T.M.L. Wigley, T.P. Barnett, J.S. Boyle, W. Brüggemann, N.P. Gillett, S.A. Klein, G.A. Meehl, T. Nozawa, D.W. Pierce, P.A. Stott, W.M. Washington, and M.F. Wehner, 2007: Identification of human-induced changes in atmospheric moisture content. *Proceedings of the National Academy of Sciences,* **104,** 15248-15253. http://dx.doi.org/10.1073/pnas.0702872104

FINAL DRAFT

Santer, B.D., C. Bonfils, J.F. Painter, M.D. Zelinka, C. Mears, S. Solomon, G.A. Schmidt, J.C. Fyfe, J.N.S. Cole, L. Nazarenko, K.E. Taylor, and F.J. Wentz, 2014: Volcanic contribution to decadal changes in tropospheric temperature. *Nature Geoscience,* **7,** 185-189. http://dx.doi.org/10.1038/ngeo2098

Santer, B.D., S. Solomon, G. Pallotta, C. Mears, S. Po-Chedley, Q. Fu, F. Wentz, C.-Z. Zou, J. Painter, I. Cvijanovic, and C. Bonfils, 2017a: Comparing tropospheric warming in climate models and satellite data. *Journal of Climate,* **30,** 373-392. http://dx.doi.org/10.1175/JCLI-D-16-0333.1

Santer, B.D., S. Soloman, F.J. Wentz, Q. Fu, S. Po-Chedley, C. Mears, J.F. Painter, and C. Bonfils, 2017b: Tropospheric Warming Over The Past Two Decades. *Scientific Reports*, in press.

Sardeshmukh, P.D., G.P. Compo, and C. Penland, 2015: Need for caution in interpreting extreme weather statistics. *Journal of Climate,* **28,** 9166-9187. http://dx.doi.org/10.1175/JCLI-D-15-0020.1

Schmidt, G.A., J.H. Jungclaus, C.M. Ammann, E. Bard, P. Braconnot, T.J. Crowley, G. Delaygue, F. Joos, N.A. Krivova, R. Muscheler, B.L. Otto-Bliesner, J. Pongratz, D.T. Shindell, S.K. Solanki, F. Steinhilber, and L.E.A. Vieira, 2011: Climate forcing reconstructions for use in PMIP simulations of the last millennium (v1.0). *Geoscientific Model Development,* **4,** 33-45. http://dx.doi.org/10.5194/gmd-4-33-2011

Schmidt, G.A., D.T. Shindell, and K. Tsigaridis, 2014: Reconciling warming trends. *Nature Geoscience,* **7,** 158-160. http://dx.doi.org/10.1038/ngeo2105

Schwartz, M.D., R. Ahas, and A. Aasa, 2006: Onset of spring starting earlier across the Northern Hemisphere. *Global Change Biology,* **12,** 343-351. http://dx.doi.org/10.1111/j.1365-2486.2005.01097.x

Seneviratne, S.I., M.G. Donat, B. Mueller, and L.V. Alexander, 2014: No pause in the increase of hot temperature extremes. *Nature Climate Change,* **4,** 161-163. http://dx.doi.org/10.1038/nclimate2145

Seo, K.-W., C.R. Wilson, T. Scambos, B.-M. Kim, D.E. Waliser, B. Tian, B.-H. Kim, and J. Eom, 2015: Surface mass balance contributions to acceleration of Antarctic ice mass loss during 2003–2013. *Journal of Geophysical Research: Solid Earth,* **120,** 3617-3627. http://dx.doi.org/10.1002/2014JB011755

Sheffield, J., E.F. Wood, and M.L. Roderick, 2012: Little change in global drought over the past 60 years. *Nature,* **491,** 435-438. http://dx.doi.org/10.1038/nature11575

FINAL DRAFT

Shiklomanov, N.E., D.A. Streletskiy, and F.E. Nelson, 2012: Northern Hemisphere component of the global Circumpolar Active Layer Monitory (CALM) program. In *Proceedings of the 10th International Conference on Permafrost,* Salekhard, Russia. Kane, D.L. and K.M. Hinkel, Eds., 377-382. http://research.iarc.uaf.edu/NICOP/proceedings/10th/TICOP_vol1.pdf

Sobel, A.H., S.J. Camargo, T.M. Hall, C.-Y. Lee, M.K. Tippett, and A.A. Wing, 2016: Human influence on tropical cyclone intensity. *Science,* **353,** 242-246. http://dx.doi.org/10.1126/science.aaf6574

Sokolov, A.P., D.W. Kicklighter, J.M. Melillo, B.S. Felzer, C.A. Schlosser, and T.W. Cronin, 2008: Consequences of considering carbon–nitrogen interactions on the feedbacks between climate and the terrestrial carbon cycle. *Journal of Climate,* **21,** 3776-3796. http://dx.doi.org/10.1175/2008JCLI2038.1

Solomon, S., K.H. Rosenlof, R.W. Portmann, J.S. Daniel, S.M. Davis, T.J. Sanford, and G.-K. Plattner, 2010: Contributions of stratospheric water vapor to decadal changes in the rate of global warming. *Science,* **327,** 1219-1223. http://dx.doi.org/10.1126/science.1182488

Sousa, P.M., R.M. Trigo, P. Aizpurua, R. Nieto, L. Gimeno, and R. Garcia-Herrera, 2011: Trends and extremes of drought indices throughout the 20th century in the Mediterranean. *Natural Hazards and Earth System Sciences,* **11,** 33-51. http://dx.doi.org/10.5194/nhess-11-33-2011

Steinman, B.A., M.B. Abbott, M.E. Mann, N.D. Stansell, and B.P. Finney, 2012: 1,500 year quantitative reconstruction of winter precipitation in the Pacific Northwest. *Proceedings of the National Academy of Sciences,* **109,** 11619-11623. http://dx.doi.org/10.1073/pnas.1201083109

Stott, P., 2016: How climate change affects extreme weather events. *Science,* **352,** 1517-1518. http://dx.doi.org/10.1126/science.aaf7271

Stroeve, J.C., V. Kattsov, A. Barrett, M. Serreze, T. Pavlova, M. Holland, and W.N. Meier, 2012a: Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations. *Geophysical Research Letters,* **39,** L16502. http://dx.doi.org/10.1029/2012GL052676

Stroeve, J.C., M.C. Serreze, M.M. Holland, J.E. Kay, J. Malanik, and A.P. Barrett, 2012b: The Arctic's rapidly shrinking sea ice cover: A research synthesis. *Climatic Change,* **110,** 1005-1027. http://dx.doi.org/10.1007/s10584-011-0101-1

Stroeve, J., A. Barrett, M. Serreze, and A. Schweiger, 2014a: Using records from submarine, aircraft and satellites to evaluate climate model simulations of Arctic sea ice thickness. *The Cryosphere,* **8,** 1839-1854. http://dx.doi.org/10.5194/tc-8-1839-2014

FINAL DRAFT

Stroeve, J.C., T. Markus, L. Boisvert, J. Miller, and A. Barrett, 2014b: Changes in Arctic melt season and implications for sea ice loss. *Geophysical Research Letters,* **41,** 1216-1225. http://dx.doi.org/10.1002/2013GL058951

Sweet, W.V., and J. Park, 2014: From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. *Earth's Future,* **2**, 579-600. http://dx.doi.org/10.1002/2014EF000272

Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas, 2017: Global and Regional Sea Level Rise Scenarios for the United States. NOAA Tech. Rep. NOS CO-OPS 083. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD. 75 pp. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

Tedesco, M., X. Fettweis, M.R.v.d. Broeke, R.S.W.v.d. Wal, C.J.P.P. Smeets, W.J.v.d. Berg, M.C. Serreze, and J.E. Box, 2011: The role of albedo and accumulation in the 2010 melting record in Greenland. *Environmental Research Letters,* **6,** 014005. http://dx.doi.org/10.1088/1748-9326/6/1/014005

Tedesco, M., X. Fettweis, T. Mote, J. Wahr, P. Alexander, J.E. Box, and B. Wouters, 2013: Evidence and analysis of 2012 Greenland records from spaceborne observations, a regional climate model and reanalysis data. *The Cryosphere,* **7,** 615-630. http://dx.doi.org/10.5194/tc-7-615-2013

Tedesco, M., E. Box, J. Cappelen, R.S. Fausto, X. Fettweis, K. Hansen, T. Mote, C.J.P.P. Smeets, D.V. As, R.S.W.V.d. Wal, and J. Wahr, 2015: [The Arctic] Greenland ice sheet [in "State of the Climate in 2014"]. *Bulletin of the American Meteorological Society,* **96 (12),** S137-S139. http://dx.doi.org/10.1175/2015BAMSStateoftheClimate.1

Thornton, P.E., S.C. Doney, K. Lindsay, J.K. Moore, N. Mahowald, J.T. Randerson, I. Fung, J.F. Lamarque, J.J. Feddema, and Y.H. Lee, 2009: Carbon-nitrogen interactions regulate climate-carbon cycle feedbacks: Results from an atmosphere-ocean general circulation model. *Biogeosciences,* **6,** 2099-2120. http://dx.doi.org/10.5194/bg-6-2099-2009

Trenberth, K.E., 2015: Has there been a hiatus? *Science,* **349,** 691-692. http://dx.doi.org/10.1126/science.aac9225

Trenberth, K.E., A. Dai, G. van der Schrier, P.D. Jones, J. Barichivich, K.R. Briffa, and J. Sheffield, 2014: Global warming and changes in drought. *Nature Climate Change,* **4,** 17-22. http://dx.doi.org/10.1038/nclimate2067

FINAL DRAFT

Turney, C.S.M. and R.T. Jones, 2010: Does the Agulhas Current amplify global temperatures during super-interglacials? *Journal of Quaternary Science,* **25,** 839-843. http://dx.doi.org/10.1002/jqs.1423

USGCRP, 2017: [National Climate Assessment] Indicators. U.S. Global Change Research Program. http://www.globalchange.gov/browse/indicators

van der Werf, G.R., J.T. Randerson, L. Giglio, G.J. Collatz, M. Mu, P.S. Kasibhatla, D.C. Morton, R.S. DeFries, Y. Jin, and T.T. van Leeuwen, 2010: Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmospheric Chemistry and Physics,* **10,** 11707-11735. http://dx.doi.org/10.5194/acp-10-11707-2010

Velicogna, I. and J. Wahr, 2013: Time-variable gravity observations of ice sheet mass balance: Precision and limitations of the GRACE satellite data. *Geophysical Research Letters,* **40,** 3055-3063. http://dx.doi.org/10.1002/grl.50527

Vihma, T., J. Screen, M. Tjernström, B. Newton, X. Zhang, V. Popova, C. Deser, M. Holland, and T. Prowse, 2016: The atmospheric role in the Arctic water cycle: A review on processes, past and future changes, and their impacts. *Journal of Geophysical Research: Biogeosciences,* **121,** 586-620. http://dx.doi.org/10.1002/2015JG003132

Vose, R.S., D. Arndt, V.F. Banzon, D.R. Easterling, B. Gleason, B. Huang, E. Kearns, J.H. Lawrimore, M.J. Menne, T.C. Peterson, R.W. Reynolds, T.M. Smith, C.N. Williams, and D.L. Wuertz, 2012: NOAA's merged land-ocean surface temperature analysis. *Bulletin of the American Meteorological Society,* **93,** 1677-1685. http://dx.doi.org/10.1175/BAMS-D-11-00241.1

Walsh, J.E., J.E. Overland, P.Y. Groisman, and B. Rudolf, 2011: Ongoing climate change in the Arctic. *Ambio,* **40,** 6-16. http://dx.doi.org/10.1007/s13280-011-0211-z

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014: Ch. 2: Our changing climate. *Climate Change Impacts in the United States: The Third National Climate Assessment*. Melillo, J.M., T.C. Richmond, and G.W. Yohe, Eds. U.S. Global Change Research Program, Washington, D.C., 19-67. http://dx.doi.org/10.7930/J0KW5CXT

Wang, C., L. Zhang, S.-K. Lee, L. Wu, and C.R. Mechoso, 2014: A global perspective on CMIP5 climate model biases. *Nature Climate Change,* **4,** 201-205. http://dx.doi.org/10.1038/nclimate2118

Willett, K.M., D.J. Philip, W.T. Peter, and P.G. Nathan, 2010: A comparison of large scale changes in surface humidity over land in observations and CMIP3 general circulation

FINAL DRAFT

models. *Environmental Research Letters,* **5,** 025210. http://dx.doi.org/10.1088/1748-9326/5/2/025210

Williams, S.D.P., P. Moore, M.A. King, and P.L. Whitehouse, 2014: Revisiting GRACE Antarctic ice mass trends and accelerations considering autocorrelation. *Earth and Planetary Science Letters,* **385,** 12-21. http://dx.doi.org/10.1016/j.epsl.2013.10.016

Wuebbles, D., G. Meehl, K. Hayhoe, T.R. Karl, K. Kunkel, B. Santer, M. Wehner, B. Colle, E.M. Fischer, R. Fu, A. Goodman, E. Janssen, V. Kharin, H. Lee, W. Li, L.N. Long, S.C. Olsen, Z. Pan, A. Seth, J. Sheffield, and L. Sun, 2014: CMIP5 climate model analyses: Climate extremes in the United States. *Bulletin of the American Meteorological Society,* **95,** 571-583. http://dx.doi.org/10.1175/BAMS-D-12-00172.1

Zaehle, S., P. Friedlingstein, and A.D. Friend, 2010: Terrestrial nitrogen feedbacks may accelerate future climate change. *Geophysical Research Letters,* **37,** L01401. http://dx.doi.org/10.1029/2009GL041345

Zaehle, S. and A.D. Friend, 2010: Carbon and nitrogen cycle dynamics in the O-CN land surface model: 1. Model description, site-scale evaluation, and sensitivity to parameter estimates. *Global Biogeochemical Cycles,* **24,** n/a-n/a. http://dx.doi.org/10.1029/2009GB003521

Zemp, M., H. Frey, I. Gärtner-Roer, S.U. Nussbaumer, M. Hoelzle, F. Paul, W. Haeberli, F. Denzinger, A.P. Ahlstrøm, B. Anderson, S. Bajracharya, C. Baroni, L.N. Braun, B.E. Cáceres, G. Casassa, G. Cobos, L.R. Dávila, H. Delgado Granados, M.N. Demuth, L. Espizua, A. Fischer, K. Fujita, B. Gadek, A. Ghazanfar, J.O. Hagen, P. Holmlund, N. Karimi, Z. Li, M. Pelto, P. Pitte, V.V. Popovnin, C.A. Portocarrero, R. Prinz, C.V. Sangewar, I. Severskiy, O. Sigurðsson, A. Soruco, R. Usubaliev, and C. Vincent, 2015: Historically unprecedented global glacier decline in the early 21st century. *Journal of Glaciology,* **61,** 745-762. http://dx.doi.org/10.3189/2015JoG15J017

Zhang, R. and T.R. Knutson, 2013: The role of global climate change in the extreme low summer Arctic sea ice extent in 2012 [in "Explaining Extreme Events of 2012 from a Climate Perspective"]. *Bulletin of the American Meteorological Society,* **94 (9),** S23-S26. http://dx.doi.org/10.1175/BAMS-D-13-00085.1

Zhang, X., F.W. Zwiers, G.C. Hegerl, F.H. Lambert, N.P. Gillett, S. Solomon, P.A. Stott, and T. Nozawa, 2007: Detection of human influence on twentieth-century precipitation trends. *Nature,* **448,** 461-465. http://dx.doi.org/10.1038/nature06025

Zhang, X., H. Wan, F.W. Zwiers, G.C. Hegerl, and S.-K. Min, 2013: Attributing intensification of precipitation extremes to human influence. *Geophysical Research Letters,* **40,** 5252-5257. http://dx.doi.org/10.1002/grl.51010

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