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501-0986

TSD

New comments on endangerment

TSD

Section 1

Introduction and Background

The purpose of this document is to provide scientific and technical support for an endangerment analysis regarding greenhouse gas (GHG) emissions under the Clean Air Act. This is a final internal EPA draft which has undergone initial EPA review as well as federal expert review (authors and reviewers are listed under Acknowledgments).

1(a) Scope and Approach of this Document

The primary GHGs of concern that are directly emitted by human activities in general are those reported in EPA's annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks* and include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). The primary effect of these gases is their influence on the climate system by trapping heat in the atmosphere that would otherwise escape to space. This heating effect (referred to as radiative forcing) is very likely to be the cause of most of the observed global warming over the last 50 years. Global warming and climate change, in turn, can affect health, society and the environment. There also are some cases where these gases have other non-climate effects, some of which are direct while others are indirect. For example, elevated concentrations of CO_2 can increase ocean acidification and stimulate terrestrial plant growth, and CH_4 emissions can contribute to background levels of tropospheric ozone, a criteria pollutant. These effects may in turn be influenced by climate change in certain cases. Carbon dioxide and other GHGs can also have direct health effects but at concentrations far in excess of current or projected future ambient concentrations.

This document reviews a wide range of specific and quantifiable vulnerabilities, risks and impacts due to both effects induced by climate change and effects caused directly by the GHGs. Any known or expected benefits of elevated atmospheric concentrations of GHGs or of climate change are documented as well (i.e., impacts can mean either positive or negative consequences). The extent to which observed climate change can be attributed to anthropogenic GHG emissions is assessed. The term "climate change" in this document generally refers to climate change induced by human activities, including activities that emit GHGs. Future projections of climate change, based primarily on future scenarios of anthropogenic GHG emissions, are shown for the global and national scale.

The focus of the vulnerability, risk and impact assessment is primarily within the U.S. However, given the global nature of climate change, there is a brief review of potential international impacts. Greenhouse gases, once emitted, become well mixed in the atmosphere, meaning U.S. emissions can affect not only the U.S. population and environment but other regions of the world as well; likewise, emissions in other countries can affect the U.S. Furthermore, impacts in other regions of the world may have consequences that transcend national boundaries that raise concerns for the U.S.

The timeframe over which vulnerabilities, risks and impacts are considered is consistent with the timeframe over which GHGs, once emitted, have an effect on climate, which is decades to centuries for the primary GHGs of concern. Therefore, in addition to reviewing recent observations, this document generally considers the next several decades, the time period out to around 2100, and for certain impacts the time period beyond 2100.

Comment [A19]: Why 2100? Do we have data and models to support this?

Adaptation to climate change is a key focus area of the climate change research community. This document, however, does not focus on adaptation because adaptation is essentially a response to any known and/or perceived risks due to climate change. Likewise, mitigation measures to reduce GHGs, the U.S., high temperatures and ozone exposure, however, can significantly limit the direct stimulatory CO_2 response (see also Section 8 on Air Quality and Section 9 on Food Production and Agriculture).

Comment [A20]: Can we put a % impact on it? Unclear what is meant

Elevated CO_2 has raised an issue about forage quality for livestock. Elevated CO_2 can increase the carbon to nitrogen ratio in forages and thus reduce the nutritional value of those grasses and thus affect animal weight and performance. The decline under elevated CO_2 of C4 grasses, however, which are less nutritious than C3 grasses, may compensate for the reduced protein. Yet the opposite is expected under associated temperature increases.

At much higher ambient CO_2 concentrations, such those areas exposed to natural CO_2 outgassing due to volcanic activity, the main characteristic of long-term elevated CO_2 zones at the surface is the lack of vegetation (IPCC, 2005). New CO_2 releases into vegetated areas cause noticeable die-off. In those areas where significant impacts to vegetation have occurred, CO_2 makes up about 20–95% of the soil gas, whereas normal soil gas usually contains about 0.2–4% CO_2. Carbon dioxide concentrations above 5% may be dangerous for vegetation and as concentration approach 20%, CO_2 becomes phytotoxic. Carbon dioxide can cause death of plants through 'root anoxia', together with low oxygen concentration (IPCC, 2005).

Regarding oceanic ecosystems, according to IPCC (Fischlin et al., 2007), ocean acidification due to the direct effects of elevated CO_2 concentrations will impair a wide range of planktonic and other marine organisms that use aragonite to make their shells or skeletons. These impacts could result in potentially severe ecological changes to tropical and coldwater marine ecosystems where carbonate-based phytoplankton and corals are the foundation for the trophic system (Schneider et al., 2007). These CO_2 effects will also interact with the effects of temperature change (see Section 14 on Ecosystems and Wildlife).

3(b) Methane (CH_4)

Methane is flammable or explosive at concentrations of 5% to 15% by volume (50,000 to 150,000 ppm) of air (NIOSH, 1994; NRC, 2000). At high enough concentrations, CH_4 is also a simple asphyxiant, capable of displacing enough oxygen to cause death by suffocation. Threshold limit values are not specified because the limiting factor is the available oxygen (NRC, 2000). Atmospheres with oxygen concentrations below 19.5 percent can have adverse physiological effects, and atmospheres with less than 16 percent oxygen can become life threatening (MSHA, 2007). Methane displaces oxygen to 18% in air when present at 14% (140,000 ppm).

When oxygen is readily available, CH_4 has little toxic effect (NRC, 2000). In assessing emergency exposure limits for CH_4, the NRC (2000) determined that an exposure limit that presents an explosion hazard cannot be recommended, even if it is well below a concentration that would produce toxicity. As such, it recommended an exposure limit of 5000 ppm for methane (NRC, 2000). The National Institute for Occupational Health Safety (NIOSH, 1994) established a threshold limit value (TLV) for methane at 1,000 ppm.

The current atmospheric concentration of CH_4 is 1.77 ppm. The projected CH_4 concentration in 2100 ranges from 1.46 ppm to 3.39 ppm by 2100, well below any recommended exposure limits (Meehl et al., 2007).

3(c) Nitrous Oxide (N_2O)

Nitrous oxide is an asphyxiant at high concentrations. At lower concentrations, exposure causes central nervous system, cardiovascular, hepatic (pertaining to the liver), hematopoietic (pertaining to the formation of blood or blood cells), and reproductive effects in humans (Hathaway et al., 1991). At a (versus decades to centuries for the well-mixed GHGs). Tropospheric ozone is also a criteria air pollutant under the U.S. Clean Air Act.

Anthropogenic emissions of aerosols contribute to both positive and negative radiative forcing. Aerosols are non-gaseous substances that are suspended in the atmosphere, and are either solid particles or liquid droplets. Most aerosols, such as sulfates (which are mainly the result of SO_2 emissions), exert a negative forcing or cooling effect, as they reflect and scatter incoming solar radiation. Some aerosols, such as black carbon, cause a positive forcing by absorbing incoming solar radiation. IPCC (2007d) estimated that the net effect of all aerosols (primarily sulfate, organic carbon, black carbon, nitrate and dust) produce a cooling effect, with a total direct radiative forcing of –0.5 (–0.9 to –0.1) W/m^2 and an additional indirect cloud albedo (i.e., enhanced reflectivity)[13] forcing of –0.7 (–1.8 to –0.3) W/m^2. These forcings are now better understood than at the time of the IPCC Third Assessment Report (2001), but nevertheless remain the dominant uncertainty in radiative forcing (IPCC, 2007d). Black carbon aerosols cause yet another forcing effect by decreasing the surface albedo of snow and ice (+0.1 (0.0 to +0.2) W/m^2).

The radiative forcing from increases in stratospheric water vapor due to oxidation of CH_4 is estimated to be +0.07 ± 0.05 W/m^2 (Solomon et al., 2007). The level of scientific understanding is low because the contribution of CH_4 to the corresponding vertical structure of the water vapor change near the tropopause is uncertain.

Changes in surface albedo due to human-induced land cover changes exert a forcing of –0.2 (–0.4 to 0.0) W/m^2. Changes in solar irradiance since 1750 are estimated to cause a radiative forcing of +0.12 (+0.06 to +0.30) W/m^2.

Although water vapor is the most abundant naturally occurring greenhouse gas, direct emissions of water vapor due to human activities make a negligible contribution to radiative forcing (hence its absence in Figure 3.1). However, as temperatures increase, tropospheric water vapor concentrations increase representing a key feedback but not a forcing of climate change (Solomon et al., 2007). Feedbacks are defined as processes in the climate system (such as a change in water vapor concentrations) that can either amplify or dampen the system's initial response to radiative forcing changes (NRC, 2003).

4(b) Global Changes in Temperature

Comment [A21]: The emphasis on global eclipses the minimal discussion on US impacts—suggest revising throughout

Multiple lines of evidence lead to the robust conclusion that the climate system is warming. The IPCC (2007d) stated in its Fourth Assessment Report:

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

Air temperature is a main property of climate and the most easily measured, directly observable, and geographically consistent indicator of climate change. The extent to which observed changes in global

[13] In addition to directly reflecting solar radiation, aerosols cause an additional, indirect negative forcing effect by enhancing cloud albedo (a measure of reflectivity or brightness). This occurs because aerosols act as particles around which cloud droplets can form; an increase in the number of aerosol particles leads to a greater number of smaller cloud droplets, which leads to enhanced cloud albedo. Aerosols also influence cloud lifetime and precipitation but no central estimates of these indirect forcing effects are estimated by IPCC.

- Very little confidence can be assigned to statements concerning the hemispheric mean or global mean surface temperature prior to about A.D. 900 because of sparse data coverage and because the uncertainties associated with proxy data and the methods used to analyze and combine them are larger than during more recent time periods.

Considering this study and additional research, the IPCC (2007d) concluded: "Paleoclimatic information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1,300 years."

4(c) U.S. changes in temperatures

Like global mean temperatures, U.S. temperatures also warmed during the 20th and into the 21st century. According to the National Oceanic and Atmospheric Administration (NOAA, 2007):[17]

- U.S. temperatures are now approximately 1.0°F warmer than at the start of the 20th century, with an increased rate of warming over the past 30 years.

- The 2006 average annual temperature for the contiguous U.S. was the 2nd warmest on record and within 0.1°F of the record set in 1998.

- The past nine years have all been among the 25 warmest years on record for the contiguous U.S.

- The last eight 5-year periods (2002-2006, 2001-2005, 2000-2004, 1999-2003, 1998-2002, 1997-2001, 1996-2000, 1995-1999), were the warmest 5-year periods (i.e. pentads) in the last 112 years of national records, illustrating the anomalous warmth of the last decade.

Comment [A22]: Does this belong on line 18? Or perhaps both values should be presented equally on line 18- or is the NOAA value more scientifically valid?

Comment [A23]: Is this daily or monthly or yearly average?

Deleted: , a streak which is unprecedented in the historical record

[17] U.S. temperature data analyzed by National Aeronautics and Space Administration (NASA) show similar trends over the past 100 years although, due to differences in datasets, processing and analysis, it finds 1934 was the warmest on record for the contiguous U.S., followed by 1998 and 1921. 2006 was the fourth warmest year on record in its analysis. For more information on NASA's temperature data, see: http://data.giss.nasa.gov/gistemp/

biological systems and species (e.g., geographic shift of species) which are shown to change as a result of recent warming.

This section includes the observed changes in physical and biological systems in North America and in other parts of the world.

Comment [A27]: As focus is not US, suggest adding sentence regarding the uncertainty in extrapolating these changes to the US.

The IPCC (2007b) concluded that, "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases." Furthermore, the IPCC states that, "A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems." As detailed above in Section 5(a), recent warming of the last 50 years is very likely the result of the accumulation of anthropogenic GHGs in the atmosphere.

Climate variability and non-climate drivers (e.g., land-use change, habitat fragmentation) need to be considered in order to make robust conclusions about the role of anthropogenic climate change in affecting biological and physical systems. IPCC (Rosenzweig et al. 2007) reviewed a number of joint attribution studies that linked responses in some physical and biological systems directly to anthropogenic climate change using climate, process, and statistical models. The conclusion of these studies is that "the consistency of observed significant changes in physical and biological systems and observed significant warming across the globe likely cannot be explained entirely due to natural variability or other confounding non-climate factors (Rosenzweig et al. 2007)."

The physical systems undergoing significant change include the cryosphere (snow and ice systems), hydrological systems, water resources, coastal zones and the oceans. These effects (reported with high confidence by IPCC (Rosenzweig et al. 2007)) include ground instability in mountain and permafrost regions, shorter travel season for vehicles over frozen roads in the Arctic, enlargement and increase of glacial lakes in mountain regions and destabilization of moraines damming these lakes, changes in Arctic flora and fauna including the sea-ice biomes and predators higher in the food chain, limitations on mountain sports in lower-elevation alpine areas, and changes in indigenous livelihoods in the Arctic.

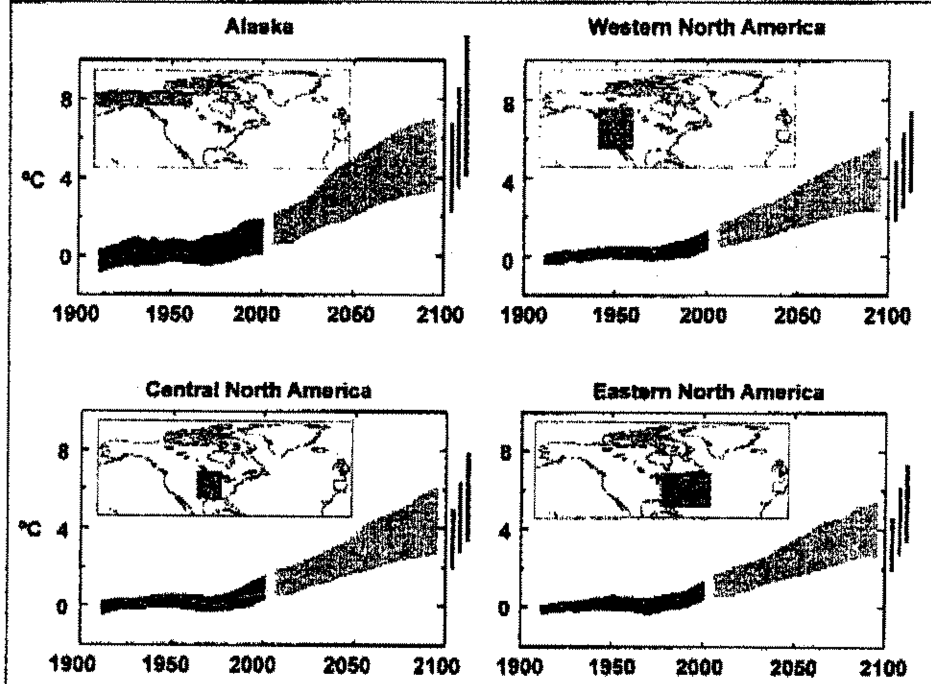
Regarding biological systems, the IPCC (Rosenzweig et al. 2007) reports with very high confidence that the overwhelming majority of studies of regional climate effects on terrestrial species reveal trends consistent with warming, including poleward and elevational range shifts of flora and fauna, the earlier onset of spring events, migration, and lengthening of the growing season, changes in abundance of certain species, including limited evidence of a few local disappearances, and changes in community composition.

Human system responses to climate change are more difficult to identify and isolate due to the larger role that non-climate factors play (e.g., management practices in agriculture and forestry, and adaptation responses to protect human health against adverse climatic conditions).

According to the IPCC, all of North America is very likely to warm during this century as shown in Figures in 6.9 and 6.10, and warm more than the global mean warming in most areas (Christensen et al., 2007). For scenario A1B (moderate emissions growth), the largest warming is projected to occur in winter over northern parts of Alaska, reaching 10°C (18°F) in the northernmost parts as shown in Figure 5.12, due to the positive feedback from a shorter season of snow cover. In western, central and eastern regions of North America, the projected warming has less seasonal variation and is not as large, especially near the coast, consistent with less warming over the oceans. The average warming in the U.S. is projected by nearly all the models used in the IPCC assessment to exceed 2°C (3.6°F), with 5 out of 21 models projecting average warming in excess of 4°C (7.2°F).

Comment [A28]: What did the other 16 models project?

Figure 6.9: Temperature anomalies with respect to 1901 to 1950 for four North American land regions



Source: Christensen et al. (2007). Temperature anomalies with respect to 1901 to 1950 for four North American land regions for 1906 to 2005 (black line) and as simulated (red envelope) by multi-model dataset (MMD) models incorporating known forcings; and as projected for 2001 to 2100 by MMD models for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100 for the B1 scenario (blue), the A1B scenario (orange) and the A2 scenario (red). The black line is dashed where observations are present for less than 50% of the area in the decade concerned.

tropics, with a tendency towards more extreme wind events and higher ocean waves in several regions associated with these deepened cyclones (Meehl et al., 2007).

Possible implications of extreme precipitation events in the U.S. for health are described in Chapter 7, for food production and agriculture in Section 9, for water resources in Section 11, for coastal areas in Section 12, and for ecosystems and wildlife in Section 14.

6(f) Abrupt Climate Change

Abrupt climate change refers to sudden (on the order of decades), large changes in some major component of the climate system, with rapid, widespread effects. Abrupt climate changes are an important consideration because, if triggered, they could occur so quickly and unexpectedly that human or natural systems would have difficulty adapting to them (NRC, 2002). Potential abrupt climate change implications in the U.S. are not discussed in the sections 7 through 14 (the U.S. sectoral impacts) because they cannot be predicted with confidence, particularly for specific regions. This section therefore focuses on the general risks of abrupt climate change globally, with some discussion of potential regional implications where information is available.

Comment [A29]: If referring to changes that take decades, one would think that human systems could adapt. Not sure what this is referring to.

According to the National Research Council (2002): "Technically, an abrupt climate change occurs when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause." Crossing systemic thresholds may lead to large and widespread consequences (Schneider et al., 2007[37]). The triggers for abrupt climate change can be forces that are external and/or internal to the climate system including (NRC, 2002):

- changes in the Earth's orbit[38]
- a brightening or dimming of the sun
- melting or surging ice sheets
- strengthening or weakening of ocean currents
- emissions of climate-altering gases and particles into the atmosphere

More than one of these triggers can operate simultaneously, since all components of the climate system are linked.

Scientific data show that abrupt changes in the climate at the regional scale have occurred throughout history and are characteristic of the Earth's climate system (NRC, 2002). During the last glacial period, abrupt regional warmings (likely up to 16°C within decades over Greenland) and coolings occurred repeatedly over the North Atlantic region (Jansen et al., 2007[39]). These warmings likely had some large-scale effects such as major shifts in tropical rainfall patterns and redistribution of heat within the climate system but it is unlikely that they were associated with large changes in global mean surface temperature.

The National Research Council concluded that anthropogenic forcing may increase the risk of abrupt climate change (NRC, 2002):

Comment [A30]: This seems to track better with the quote

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[37] Schneider et al., 2007 citation refers to Chapter 19, "Assessing key vulnerabilities and the risk from climate change" in IPCC's 2007 Fourth Assessment Report, Working Group II.

[38] According to the National Research Council (2002), changes in the Earth's orbit occur too slowly to be prime movers of abrupt change but might determine the timing of events. Abrupt climate changes of the past were especially prominent when orbital processes were forcing the climate to change during the cooling into and warming out of ice ages (NRC, 2002).

[39] Jansen et al., 2007 refers to Chapter 6, "Palaeoclimate" in IPCC's 2007 Fourth Assessment Report, Working Group I.

Section 7

Human Health

The United States is a highly developed country with a wide range of climates. While there may be fewer cases of illness and death associated with climate change in the U.S. than in the developing world, we nevertheless anticipate increased costs to human health and well being. Greater wealth and a more developed public health system and infrastructure (e.g., water treatment plants, sewers, and drinking water systems; roads, rails and bridges; flood control structures) will continue to enhance our capacity to respond to climate change. Similarly, governments' capacities for disaster planning and emergency response are key assets that should allow the U.S. to adapt to many of the health effects associated with climate change. It is very likely that heat-related morbidity and mortality will increase over the coming decades, however net changes in mortality are difficult to estimate because, in part, much depends on complexities in the relationship between mortality and global change. High temperatures tend to exacerbate chronic health conditions. Studies in temperate areas (which would include large portions of the U.S.) have shown that climate change is projected to bring some benefits, such as fewer deaths from cold exposure. The balance of positive and negative health impacts will vary from one location to another, and will alter over time as temperatures continue to rise.

In its Third Assessment Report, the IPCC produced a number of key findings summarizing the likely climate change health effects in North America (which apply to the U.S.). These effects, which were reaffirmed in the IPCC Fourth Assessment Report, include (Field et al., 2007):

- Increased deaths, injuries, infectious diseases, and stress-related disorders and other adverse effects associated with social disruption and migration from more frequent extreme weather.
- Increased frequency and severity of heatwaves leading to more illness and death, particularly among the young, elderly and frail.
- Expanded ranges of vector-borne and tick-borne diseases in North America but with modulation by public health measures and other factors.

This section describes the literature on the impacts of climate change on human health in four areas: direct temperature effects, extreme events, climate sensitive diseases, and aero-allergens. Non-health related impacts of these areas are discussed in other sections of this document. The health impacts resulting from climate change effects on air quality are discussed in Section 8.

There are few studies which address the interaction effects of multi-sector climate impacts (they may be nonlinear) or of interactions between climate change health impacts and other kinds of local, regional, and global changes (Field et al., 2007). For example, climate change impacts on human health in urban areas may be compounded by aging infrastructure, maladapted urban form and building stock, urban heat islands, air pollution, population growth and an aging population.

7(a) Temperature Effects

Comment [A31]: Language fro the scientific assessment and SPA 4.6 used in place of existing language

Deleted: Warm temperatures and extreme weather already cause and contribute to adverse human health outcomes through heat-related mortality and morbidity, pollution, storm-related fatalities and injuries, and disease. In the absence of effective adaptation, these effects are likely to increase with climate change. Depending on progress in health care, infrastructure, technology and access, climate change could increase the risk of heat wave deaths, respiratory illness through exposure to aero-allergens and ozone (discussed in Section 8), and climate sensitive diseases (Parry et al., 2007[4]).

Comment [A32]: Deletion made because it is world wide and not US focus. Should try to keep focus here on US.

Deleted: Overall it is expected that benefits will be outweighed by the negative health effects of rising temperatures world-wide, especially in developing countries (IPCC, 2007b). The IPCC, which drew this conclusion, did not provide a quantitative assessment of the balance between positive and negative health effects for particular countries.¶

Comment [A33]: The scientific assessment also states: "Climate change is projected to lead to fewer deaths from cold exposure." Please provide this balance. The assessment states that the net effect is unknown—this should be mentioned as well

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According to IPCC (2007d), it is very likely[45] that there were warmer and fewer cold days and nights and warmer and more frequent hot days over most land areas during the late 20th century (see section 4(b)). It is virtually certain that these trends will continue during the 21st century (see Section 6(b)). Net changes in mortality are difficult to estimate because, in part, much depends on complexities in the relationship between mortality and global change.

Comment [A34]: Tracks with language in the scientific assessment

As a result of the projected warming, the IPCC projects increases in heat-related mortality and morbidity globally (including in the U.S.) (IPCC, 2007b). The projected warming is expected to result in fewer deaths due to reduced exposure to the cold.

Increased heat exposure

Heatwaves are associated with marked short-term increases in mortality (Confalonieri et al, 2007). Hot temperatures have also been associated with increased morbidity. Increased hospital admissions for cardiovascular disease and emergency room visits have been documented in parts of North America during heat events (Schwartz et al., 2004 in Field et al., 2007). The populations most vulnerable to hot temperatures are older adults, the chronically sick, the very young and the socially isolated (IPCC, 2007b).

Comment [A35]: Is this comment for US or North America? Please clarify. Has the US been specifically evaluated?

Heat-related morbidity and mortality are projected to increase globally (including in the U.S.) (Confalonieri et al, 2007). Heat exposures vary widely, and current studies do not quantify the years of life lost due to high temperatures. Estimates of heat-related mortality attributable to climate change are reduced but not eliminated when assumptions about acclimatization and adaptation are included in models. There is some indication that populations in the U.S. became less sensitive to high temperatures over the period 1964 to 1988, in part, due to these factors (Davis et al., 2002; Davis et al., 2003; Davis et al., 2004 in Confalonieri et al, 2007). On the other hand, growing numbers of older adults will increase the size of the population at risk because of a decreased ability to thermo-regulate is a normal part of the aging process (Confalonieri et al, 2007). In addition, almost all the growth in population in the next 50 years is expected to occur in cities (Cohen, 2003 in Confalonieri et al, 2007) where temperatures tend to be higher due to the urban heat island[46] effect increasing the total number of people at risk of adverse health outcomes from heat. It is not clear whether increased mortality from heat will be greater or less than decreased cold-related mortality in the U.S. due to climate change.

Comment [A36]: Sentence added to track with sentence in the cold sentence.

Across North America, the population over the age of 65 -- the segment of the population most at-risk of dying from heat waves -- will increase slowly to 2010, and then grow dramatically as the Baby Boomers age (Field et al., 2007). Severe heat waves are projected to intensify in magnitude and duration over the portions of the U.S. where these events already occur (high confidence). The IPCC documents the following U.S. regional projections of increases in heat and/or heat-related effects (Confalonieri et al, 2007; Field et al., 2007):

- By the 2080s, in Los Angeles, number of heat wave days (at or above 32°C or 90°F) increases 4-fold under the B1 emissions scenario (low growth) and 6-8-fold under A1FI emissions scenario (high growth) (Hayhoe, 2004). Annual number of heat-related deaths in Los Angeles increases from about 165 in the 1990s to 319 to 1,182 for a range of emissions scenarios.
- Chicago is projected to experience 25% more frequent heat waves annually by the period spanning 2080-2099 for a business-as-usual (A1B) emissions scenario (Meehl and Tebaldi, 2004).

[45] According to IPCC terminology, "very likely" conveys a 90 to 99% probability of occurrence. See Box 1.3 on page 4 for a full description of IPCC's uncertainty terms.

[46] A heat island refers to urban air and surface temperatures that are higher than nearby rural areas. Many U.S. cities and suburbs have air temperatures up to 10°F (5.6°C) warmer than the surrounding natural land cover.

Reduced cold exposure

Cold waves continue to be a problem in northern latitudes in temperature regions where very low temperatures can be reached in a few hours and extend over long periods (Confalonieri et al, 2007[47]). Accidental cold exposure occurs mainly outdoors, among socially deprived people (alcoholics, the homeless), workers, and the elderly in temperate and cold climates (Ranhoff, 2000 in Confalonieri et al, 2007) but cold waves also affect health in warmer climates (EM-DAT, 2006 in Confalonieri et al, 2007). Living in cold environments in polar regions is associated with a range of chronic conditions in the non-indigenous population (Sorogin, 1993 in Confalonieri et al, 2007) with acute risk from frostbite and hypothermia (Hassi et al., 2005 in Confalonieri et al, 2007). In countries with populations well-adapted to cold conditions, cold waves can still cause substantial increases in mortality if electricity or heating systems fail (Confalonieri et al, 2007).

The IPCC projects reduced human mortality from cold exposure through 2100 (Confalonieri et al, 2007). It is not clear whether reduced mortality from cold will be greater or less than increased heat-related mortality in the U.S. due to climate change. Projections of cold-related deaths, and the potential for decreasing their numbers due to warmer winters, can be overestimated unless they take into account the effects of season as well as influenza, which is not strongly associated with monthly winter temperature (Armstrong et al., 2004 in Confalonieri et al, 2007; McMichael et al, 2001).

IPCC's AR4 does not cite any studies since the TAR which project changes in both heat- and cold-related mortality in the U.S. for different climate scenarios[48]. In the TAR, the IPCC cited several studies that indicate decreases in winter mortality may be greater than increases in summer mortality in some temperate countries under climate change (McMichael et al, 2001). However, it cites one U.S. study (Kalkstein and Greene, 1997) that estimates increases in heat-related deaths will be three times greater than decreases in cold-related deaths. Given the paucity of recent literature on the subject and the challenges in estimating and projecting weather-related mortality, IPCC's AR4 concludes additional research is needed to understand how the balance of heat-and cold-related deaths might change globally under different climate scenarios (Confalonieri et al, 2007).

Comment [A37]: This sentence would be useful in the executive summary and introductory sections as well.

7(b) Extreme Events

In addition to the direct effects of temperature on heat and cold-related mortality, projected trends in climate change-related exposures of importance to human health will increase the number of people (globally, including in the U.S.) suffering from disease and injury due to floods, storms, droughts and fires (high confidence) (Confalonieri et al, 2007). Vulnerability to weather disasters depends on the attributes of the people at risk (including where they live, age, income, education, and disability) and on broader social and environmental factors (level of disaster preparedness, health sector responses, and environmental degradation).

[47] Confalonieri et al., 2007 citation refers to Chapter 8, "Human Health" in IPCC's 2007 Fourth Assessment Report, Working Group II.

[48] Some have raised the issue of the observed trend in migration within the U.S. to the "Sunbelt" (particularly among older adults – for purposes including comfort, recreation and leisure as well as health) and what this implies about potential health benefits as a result of a warmer climate. Average climate warming may indeed provide health benefits in some areas; this point is captured in this section's statement about less cold-related mortality due to climate warming. These potential warming benefits are independent of the potential negative effects of extreme heat events.

Floods and storms

The IPCC projects a very likely increase in heavy precipitation event frequency over most areas as described in Sections 6(b and c). Increases in the frequency of heavy precipitation events are associated with increased risk of deaths and injuries as well as infectious, respiratory and skin diseases (IPCC, 2007b). Floods are low-probability, high-impact events that can overwhelm physical infrastructure, human resilience, and social organization (Confalonieri et al, 2007). Flood health impacts include deaths, injuries, infectious diseases, intoxications and mental health problems (Greenough et al., 2001; Ahern et al., 2005 in Confalonieri et al, 2007). Flooding may also lead to contamination of waters with dangerous chemicals, heavy metals, or other hazardous substances, from storage or from chemicals already in the environment (Confalonieri et al, 2007).

Comment [A38]: What waters? The SDWA and EPA regulations protect our drinking water supply- thus clarification here is needed. See similar language suggested in Exec Sum. Table regarding compliance with NAAQS-can mention compliance costs may rise.

The IPCC (2007d) also projects likely increases in intense tropical cyclone activity as described in Section 6(b). Increases in tropical cyclone intensity are linked to increases in the risk of deaths, injuries, water and foodborne diseases as well as post-traumatic stress disorders (IPCC, 2007b). Drowning by storm surge, heightened by rising sea levels and more intense storms (as projected by IPCC), is the major killer in coastal storms where there are large numbers of deaths (Confalonieri et al, 2007). High-density populations in low-lying coastal regions such as the U.S. Gulf of Mexico experience a high health burden from weather disasters, particularly among lower income groups. In 2005, Hurricane Katrina claimed over 1800 lives in the vicinity of the low-lying U.S. Gulf Coast and lower income groups were most affected (Graumann et al., 2005 in Nicholls et al.[49]; Guidry and Margolis, 2005 in Confalonieri et al., 2007). While Katrina was a Category 3 hurricane and its path was forecast well in advance, there was a secondary failure of the levee system. This illustrates that multiple factors contribute to making a disaster and that adaptation measures may not fully avert adverse consequences. Additional information about U.S. vulnerability to the potential for more intense tropical cyclones can be found in Section 12(b).

Comment [A39]: Is this relevant to the US?

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Droughts

Areas affected by droughts are likely to increase according to IPCC (2007d) as noted in Section 6(e). The health impacts associated with drought tend to most affect semi-arid and arid regions, poor areas and populations, and areas with human-induced water scarcity; hence many of these effects are likely to be experienced in developing countries and not directly in the U.S. Information about the effects of increasing drought on U.S. agriculture can be found in section 9(c).

Forest Fires

In some regions, changes in the mean and variability of temperature and precipitation are projected to increase the frequency and severity of fire events, including in parts of the U.S. (Easterling, W. et al., 2007[50]). Forest and bushfires cause burns, smoke inhalation and other injuries. Large fires are also accompanied by an increased number of patients seeking emergency services for inhalation of smoke and ash (Hoyt and Gerhart, 2004 in Confalonieri et al., 2007). The IPCC (Field et al., 2007) noted a number of observed changes in U.S. wildfire size and frequency. Additional information on the effects of forest fires can be found in Sections 8(b) and 10(b).

7(c) Climate-sensitive diseases

[49] Nicholls et al., 2007 citation refers to Chapter 6, "Coastal Systems and Low-lying Areas" in IPCC's 2007 Fourth Assessment Report, Working Group II.

[50] Easterling et al., 2007 citation refers to Chapter 5, "Food, Fibre and Forest Products" in IPCC's 2007 Fourth Assessment Report, Working Group II.

The IPCC (2007b) notes that many human diseases are sensitive to weather. The incidence of airborne infectious diseases (e.g., coccidioidomycosis) varies seasonally and annually, due partly to climate variations such as drought, which is projected to increase in North America (Kolivras and Comrie, 2003 in Field et al., 2007).

Waterborne disease outbreaks are distinctly seasonal (which suggests potential underlying environmental or weather control), clustered in particular watersheds, and associated with heavy precipitation. The risk of infectious disease following flooding in high-income countries is generally low, although increases in respiratory and diarrheal diseases have been reported after floods (Miettinen et al., 2001; Reacher et al., 2004; Wade et al., 2004 in Confalonieri et al, 2007). For example, after Hurricanes Katrina and Rita in 2005, contamination of water supplies with fecal bacteria led to many cases of diarrheal illness and some deaths (CDC, 2005; Manuel, 2006 in Confalonieri et al, 2007).

Foodborne diseases show some relationship with temperature (e.g., increased temperatures have been associated with increased cases of Salmonellosis) (D'Souza et al., 2004; Kovats et al., 2004; Fleury et al., 2006 in Confalonieri et al, 2007). *Vibrio* spp. infections from shellfish consumption may also be influenced by temperature (Wittmann and Flick, 1995; Tuyet et al., 2002 in Confalonieri et al, 2007). For example, the IPCC (Confalonieri et al, 2007) cited a 2004 outbreak of *V parahaemolyticus* that was linked to atypically high temperatures in Alaskan coastal waters (McLaughlin et al., 2005).

The sensitivity of many zoonotic[51] diseases to climate fluctuations is also highlighted by the IPCC (Field et al., 2007). Above average temperatures in the U.S. during the summers of 2002-2004 were linked to the greatest transmissions of West Nile virus (Reisen et al., 2006 in Field et al., 2007). Saint Louis encephalitis has a tendency to appear during hot, dry La Nina years (Cayan et al., 2003 in Field et al., 2007). Associations between temperature (Ogden et al., 2004) and precipitation (McCabe and Bunnell, 2004) and tick-borne Lyme disease are also noted by IPCC (Field et al., 2007). A study found that the northern range limit of *Ixodes scapularis*, the tick that carries Lyme disease, could shift north by 200 km by the 2020s and 1000 km by the 2080s (Brownstein et al., 2003 in Field et al., 2007).

Although large portions of the U.S. may be at potential risk for diseases such as malaria based on the distribution of competent disease vectors, locally acquired cases have been virtually eliminated, in part due to vector and disease control activities (Confalonieri et al, 2007).

The IPCC concludes that human health risks from climate change will be strongly modulated by changes in health care, infrastructure, technology, and accessibility to health care (UNPD, 2005 in Field et al., 2007). The aging of the population and patterns of immigration and/or emigration will also strongly influence risks (UNPD, 2005 in Field et al., 2007). Infectious diseases could become more prominent if public health systems unravel or if new pathogens arise that are resistant to our current methods of disease control (Barrett et al., 1998 in Confalonieri et al, 2007).

7(d) Aeroallergens

Comment [A40]: CCSP 4.6 seems to conclude that there is not clear evidence. 4.6 only includes the following text. What is the reason for saying something different? Climate change has caused an earlier onset of the spring pollen season for several species in North America (Cassassa *et al.*, 2007). Although data are limited, it is reasonable to infer that allergenic diseases caused by pollen, such as allergic rhinitis, also have experienced concomitant changes in seasonality (Emberlin *et al.*, 2002; Burr *et al.*, 2003). Several laboratory studies suggest that increasing CO_2 concentrations and temperatures could increase ragweed pollen production and prolong the ragweed pollen season (Wan *et al.*, 2002; Wayne *et al.*, 2002; Singer *et al.*, 2005; Ziska *et al.*, 2005; Rogers *et al.*, 2006) and increase some plant metabolites that can affect human health (Ziska *et al.*, 2005; Mohan *et al.*, 2006). Although there are suggestions that the abundance of a few species of airborne pollens has increased due to climate change, it is unclear whether the allergenic content of these pollen types has changed (Huynen and Menne, 2003; Beggs and Bambrick, 2005). The introduction of new invasive species associated with climatic and other changes, such as ragweed and poison ivy, may increase current health risks. There are no projections of the possible impacts of climate change on allergenic diseases.

Exposure to allergens results in allergenic illnesses in approximately 20% of the US population (American Academy of Allergy Asthma & Immunology (AAAAI), 1996-2006). Although there is substantial evidence suggesting a causal relationship between aeroallergens and allergenic illnesses, it remains unclear which aeroallergens are most important for sensitization and subsequent disease development (Nielsen, G. D. et al., 2002). Not only the type, but also the amount of aeroallergen to which an individual is exposed influences the development of an allergenic illness.

[51] A zoonotic disease is any infectious disease that is able to be transmitted from an animal or nonhuman species to humans. The natural reservoir is a nonhuman reservoir.

Climate change, including changes in CO_2 concentrations, could impact the production, distribution, dispersion and allergenicity of aeroallergens and the growth and distribution of weeds, grasses and trees that produce them (McMichael. et al., 2001[52]; Confalonieri et al., 2007). These changes in aeroallergens and subsequent human exposures could affect the prevalence and severity of allergy symptoms. However, the scientific literature does not provide definitive data or conclusions on how climate change might impact aeroallergens and subsequently the prevalence of allergenic illnesses in the U.S. In addition, there are numerous other factors that affect aeroallergen levels and the prevalence of associated allergenic illnesses, such as changes in land use, air pollution, and adaptive responses, many of which are difficult to assess.

It has generally been observed that the presence of elevated CO_2 concentrations and temperatures stimulates plants to increase photosynthesis, biomass, water use efficiency, and reproductive effort. The IPCC concluded that pollens are likely to increase with elevated temperature and CO_2 (Field et al., 2007). Laboratory studies that used a doubling of CO_2 stimulated ragweed-pollen production by over 50% (Wayne et al., 2002 in Field et al., 2007). A U.S.-based field study which used existing temperature/CO_2 concentration differences between urban and rural areas as a proxy for climate change found that ragweed grew faster, flowered earlier, and produced significantly greater aboveground biomass and ragweed pollen at urban locations than at rural locations (Ziska et al., 2003 in Field et al., 2007).

The IPCC (Confalonieri et al, 2007) noted that climate change has caused an earlier onset of the spring pollen season in North America (D'Amato et al., 2002; Weber, 2002; Beggs, 2004) and that there is limited evidence that the length of the pollen season has increased for some species. However, it is unclear whether the allergenic content of these pollens has changed. The IPCC concluded that introductions of new invasive plant species with high allergenic pollen present important health risks, noting that ragweed (*Ambrosia artemisiifolia*) is spreading in several parts of the world (Rybnicek and Jaeger, 2001; Huynen and Menne, 2003; Taramarcaz et al., 2005; Cecchi et al., 2006 in Confalonieri et al, 2007).

[52] McMichael et al., 2001 citation refers to Chapter 4. "Human Health" in IPCC's 2001 Third Assessment Report, Working Group II.

Section 8

Air Quality

The IPCC (2007b) projects with virtual certainty[53] "declining air quality in cities" due to "warmer and fewer cold days and nights and/or warmer/more frequent hot days and nights over most land areas" across all world regions. Furthermore, the IPCC reports with very high confidence that climate change impacts on human health in U.S. cities will be compounded by population growth and an ageing population (Field et al., 2007). Surface air concentrations of air pollutants are highly sensitive to winds, temperature, humidity and precipitation (Denman et al. 2007). Climate change can be expected to influence the concentration and distribution of air pollutants through a variety of direct and indirect processes, including the modification of biogenic emissions, the change of chemical reaction rates, wash out of pollutants by precipitation, and modification of weather patterns that influence pollutant buildup. In summarizing the impact of climate change on ozone and particulate matter (PM), the IPCC (Denman et al., 2007) states that "future climate change may cause significant air quality degradation by changing the dispersion rate of pollutants, the chemical environment for ozone and PM generation and the strength of emissions from the biosphere, fires and dust." The IPCC also states (Denman et al., 2007) that large uncertainties remain for many issues, so that quantitative estimates of the importance of the coupling mechanisms are not always available and, further, regional differences also limit our ability to provide a simple quantitative description of the interactions between biogeochemical processes and climate change.

This section describes how climate change may increase ambient concentrations of ozone and, in some cases, PM with associated impacts on public health and welfare in the U.S.

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8(a) Tropospheric Ozone

Ozone impacts on pubic health and welfare are described in EPA's Air Quality Criteria Document for Ozone (EPA, 2006). Breathing air containing ozone at sufficient concentrations can reduce lung function, thereby aggravating asthma or other respiratory conditions. Ozone exposure has been associated with increases in respiratory infection susceptibility, medicine use by asthmatics, emergency department visits and hospital admissions. Ozone exposure at sufficient concentrations may contribute to premature death, especially in susceptible populations. In contrast to human health effects, which are associated with short-term exposures,, the most significant ozone-induced plant effects (e.g., biomass loss, yield reductions) result from the accumulation of ozone exposures over the growing season, with differentially greater impact resulting from exposures to higher concentrations and/or longer durations.

Comment [A41]: Deletion suggested because text is not consistent with 4.6, but 4.6 is not a quote from IPCC. Since you do not really need this sentence, suggest deleting. Otherwise use text from 4.6 that emphasizes that the increase would occur only if states did not take emissions control measures necessary to meet the current NAAQS.

Deleted: According to the IPCC (Denman et al., 2007), climate change is expected to lead to increases in regional ozone pollution in the U.S. and other countries.

Tropospheric ozone is both naturally occurring and, as the primary constituent of urban smog, a secondary pollutant formed through photochemical reactions involving nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. As described below, climate change can affect ozone by modifying (1) emissions of precursors, (2) atmospheric chemistry, and (3) transport and removal (Denman et al., 2007).

The IPCC (Denman et al., 2007) states that, for all world regions, "climate change affects the sources of ozone precursors through physical response (lightning), biological response (soils, vegetation, and biomass burning) and human response (energy generation, land use, and agriculture)." Nitrogen oxide emissions due to lightning are expected to increase in a warmer climate (Denman et al., 2007). Additionally, studies using general circulation models concur that influx of ozone from the stratosphere to

[53] According to IPCC terminology, "virtually certain" conveys a greater than 99% probability of occurrence. See Box 1.3 on page 4 for a full description of IPCC's uncertainty terms.

the troposphere could increase due to large-scale atmospheric circulation shifts (i.e., the Brewer-Dobson circulation) in response to climate warming (Denman et al., 2007). The sensitivity of microbial activity in soils to temperature also points toward a substantial increase in the nitric oxide emissions (Yienger and Levy 1995; Brasseur et al., 2006). As described below, biogenic VOC emissions increase with increasing temperature.

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Climate induced changes of biogenic VOC emissions alone may be regionally substantial leading to significant increases in ozone concentrations (Hauglustaine et al., 2005; Hogrefe et al., 2004; European Commission, 2003). Sensitivity simulations for the 2050s, relative to the 1990s (under the A2 IPCC scenario) indicate that increased biogenic emissions alone add 1–3 parts per billion (ppb) to summertime average daily maximum 8-hour ozone concentrations in the Midwest and along the eastern seaboard (Hogrefe et al., 2004). The IPCC (Meehl et al., 2007) reports that biogenic emissions are projected to increase by between 27 and 59%, contributing to a 30 to 50% increase in ozone formation over northern continental regions (under the A2 IPCC scenario for the 2090-2100 timeframe, relative to 1990-2000).

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Climate change impacts on temperature and water vapor could affect ozone chemistry significantly (Denman et al., 2007). A number of studies in the U.S. have shown that summer daytime ozone concentrations correlate strongly with temperature. That is, ozone generally increases at higher temperatures. This correlation appears to reflect contributions of comparable magnitude from (1) temperature-dependent biogenic VOC emissions, as mentioned above, (2) thermal decomposition of peroxyacetylnitrate (PAN), which acts as a reservoir for NOx, as described immediately below, and (3) association of high temperatures with regional stagnation, also discussed below (Denman et al., 2007).

Climate change is projected to increase surface layer ozone concentrations in both urban and polluted rural environments (any world region of high emissions) due to decomposition of PAN at higher temperatures (Sillman and Samson, 1995; Liao and Seinfeld, 2006). Warming enhances decomposition of PAN, releasing NOx, an important ozone precursor (Stevenson et al., 2005). Model simulations using increasing temperatures for the year 2100 showed enhanced PAN thermal decomposition caused this species to decrease by up to 50% over source regions and ozone net production to increase (Hauglustaine et al., 2005).

Atmospheric circulation can be expected to change in a warming climate and, thus, modify pollutant transport and removal. If there are more frequent occurrence of stagnant air events in urban or industrial areas could enhance the intensity of air pollution events, although the importance of these effects is not yet well quantified (Denman et al., 2007). The IPCC (2007d) concluded that "extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation, and temperature patterns, continuing the broad pattern of observed trends over the last half-century."

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The IPCC (Denman et al., 2007) cites the Mickley et al. (2004) study for the eastern U.S. which found an increase in the severity and persistence of regional pollution episodes associated with?? the reduced frequency of ventilation by storms tracking across Canada. This study found that surface cyclone activity decreased by approximately 10–20% in a future simulation (for 2050, under the IPCC A1B scenario), which is in general agreement with a number of observational studies over the northern midlatitudes and North America (Zishka and Smith, 1980; Agee, 1991; Key and Chan, 1999; McCabe et al., 2001). Northeast U.S. summer pollution episodes are projected in this study to increase in severity and duration; pollutant concentrations in episodes increase 5-10% and episode durations increase from 2 to 3-4 days.

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Regarding the role water vapor plays in tropospheric ozone formation, the IPCC (Denman et al., 2007) reports that simulations for the 21st century indicate a decrease in the lifetime of tropospheric ozone due to increasing water vapor. The projected increase in water vapor both decelerates the chemical production and accelerates the chemical destruction of ozone (Meehl et al., 2007). Overall, the IPCC states that climate change is expected to decrease background tropospheric ozone due to higher water vapor and to increase regional and urban-scale ozone pollution due to higher temperatures and weaker air circulation (Denman et al., 2007; Confalonieri et al., 2007).

For North America, the IPCC (Field et al., 2007) reports that surface ozone concentration may increase with a warmer climate. Several studies predict increases in ozone concentrations due to climate change in the near future (2020s and 2030s) as well as for 2050 and beyond. The IPCC (Field et al., 2007; Wilbanks et al., 2007) cites Hogrefe et al. (2004) who evaluate the effects of climate change on regional ozone in 15 U.S. cities, finding that average summertime daily 8-hour maximum ozone concentrations could increase by 2.7 ppb in the 2020s and by 4.2 ppb in the 2050s (under the IPCC A2 scenario). For the 2050s (under the IPCC A2 scenario), the IPCC (Field et al., 2007) cites Bell et al. (2007) who report that the projected effects of climate change on ozone in 50 eastern U.S. cities increased the number of summer days exceeding the 8-hour U.S. EPA standard by 68% (Bell et al., 2007).

Mickley et al. (2004) found that significant changes occur at the high end of the pollutant concentration distribution (episodes) in the Midwest and Northeast between 2000 and 2050. Bell and Ellis (2004) also found the largest increases in ozone concentrations occurred near peak values. While summer average daily maximum 8-hour ozone concentrations increase by 2.7, 4.2, and 5.0 ppb in 2020s, 2050s, and 2080s (compared to 1990s), the fourth highest summertime daily maximum 8-hour ozone concentrations increase by 5.0, 6.4, and 8.2 ppb for the 2020s, 2050s, and 2080s, respectively (compared to 1990s) (Hogrefe et al., 2004). These findings raise particular health concerns.

The IPCC (Field et al., 2007) states that, "warming and climate extremes are likely to increase respiratory illness, including exposure to pollen and ozone." And the IPCC further states that "severe heat waves, characterized by stagnant, warm air masses and consecutive nights with high minimum temperatures will intensify in magnitude and duration over the portions of the U.S. and Canada, where they already occur (high confidence) (Field et al., 2007)."

Assuming constant population and dose-response characteristics and no enforcement of the current NAAQS, ozone related deaths from climate change in the U.S. are projected to increase by approximately 4.5% from the 1990s to the 2050s (under the IPCC A2 scenario) (Field et al., 2007; Bell et al., 2007; Knowlton et al., 2004). According to the IPCC (Field et al., 2007), the "large potential population exposed to outdoor air pollution, translates this small relative risk into a substantial attributable health risk." In New York City, health impacts could be further exacerbated by climate change interacting with urban heat island effects (Field et al., 2007).

On the other hand, it is important to recognize that U.S. Environmental Protection Agency administers a well-developed and successful national regulatory program for ozone, PM2.5, and other criteria pollutants. Although many areas of the US remain out of compliance with the ozone and PM2.5 standards, there is evidence for gradual improvements in recent years, and this progress can be expected to continue with more stringent emissions controls going forward in time. Thus, the influence of climate change on air quality will play out against a backdrop of ongoing regulatory control of both ozone and PM2.5 that will shift the baseline concentrations of these two important air pollutants. On the other hand, most of the studies that have examined potential future climate impacts on air quality reviewed below have tried to isolate the climate effect by holding precursor emissions constant over future decades. Thus, the focus has been on examining the sensitivity of ozone concentrations to alternative future climates rather than on attempting to predict actual future ozone concentrations.

Comment [A42]: Paragraph is from CCSP 4.6.

The IPCC reports (Denman et al., 2007) that "the current generation of tropospheric ozone models is generally successful in describing the principal features of the present-day global ozone distribution." The IPCC (Denman et al., 2007) also states that "there are major discrepancies with observed long-term trends in ozone concentrations over the 20th century" and "resolving these discrepancies is needed to establish confidence in the models."

In addition to human health effects, elevated levels of tropospheric ozone has significant adverse effects on crop yields in the U.S. and other world regions, pasture and forest growth and species composition (Easterling et al., 2007; EPA, 2006; Volk et al., 2006; Ashmore, 2005; Vandermeiren, 2005; Loya et al., 2003). Furthermore, the effects of air pollution on plant function may indirectly affect carbon storage; recent research showed that tropospheric ozone resulted in significantly less enhancement of carbon sequestration rates under elevated CO_2 (Loya *et al.*, 2003), due to negative effects of ozone on biomass productivity and changes in litter chemistry (Booker *et al.*, 2005; Liu *et al.*, 2005).

8(b) Particulate Matter

Particulate matter impacts on public health and welfare are described in EPA's Air Quality Criteria Document for Particulate Matter (EPA, 2004). Particulate matter is a complex mixture of anthropogenic, biogenic and natural materials, suspended as aerosol particles in the atmosphere. When inhaled, the smallest of these particles can reach the deepest regions of the lungs. Scientific studies have found an association between exposure to PM and significant health problems, including: aggravated asthma; chronic bronchitis; reduced lung function; irregular heartbeat; heart attack; and premature death in people with heart or lung disease. Particle pollution also is the main cause of visibility impairment in the nation's cities and national parks.

The overall directional impact of climate change on PM levels in the U.S. remains uncertain. The body of literature specifically addressing the potential effects of climate change on PM is limited but there is a substantial body of literature describing how ambient PM responds to a wide range of meteorological conditions. On the basis of this information, broad conclusions can be drawn concerning the behavior of ambient PM concentrations given a set of the meteorological changes anticipated in a warming climate. Those meteorological changes are expected to affect PM concentrations by modifying emissions of (1) primary PM and PM precursor emissions, (2) aerosol photochemistry, and (3) transport and removal, as described below.

Particulate matter and PM precursor emissions are affected by climate change through physical response (wind blown dust), biological response (forest fires and vegetation type/distribution) and human response (energy generation). Most natural aerosol sources are controlled by climatic parameters like wind, moisture and temperature; thus, human induced climate change is expected to affect the natural aerosol burden. Biogenic organic material is both directly emitted into the atmosphere and produced by VOCs. All biogenic VOC emissions are highly sensitive to changes in temperature, and are also highly sensitive to climate-induced changes in plant species composition and biomass distributions. Biogenic emissions rates are predicted to increase, on average across world regions, by 10% per 1°C increase in surface temperature (Denman et al., 2007; Guenther et al. 1993). The response of biogenic secondary organic carbon aerosol production to a temperature change, however, could be considerably lower than the response of biogenic VOC emissions since aerosol yields can decrease with increasing temperature (Denman et al., 2007).

Comment [A43]: Please clarify the proportion of fine vs coarse fraction and the difference in potential implications of differences in speciation between wind blown and fire related PM and energy generation sources of PM and PM precursors.

Particulate matter emissions from forest fires can contribute to acute and chronic illnesses of the respiratory system, particularly in children, including pneumonia, upper respiratory diseases, asthma and chronic obstructive pulmonary diseases (WHO, 2002; Bowman and Johnston, 2005; Moore et al., 2006; Confalonieri et al., 2007). The IPCC (Field et al., 2007) reported with very high confidence that in North America disturbances like wildfire are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons. Pollutants from forest fires can affect air quality for thousands of kilometers (Confalonieri et al., 2007). Westerling et al. (2006; as referenced in IPCC (Field et al., 2007)) found that, in the last three decades, the wildfire season in the western U.S. has increased by 78 days, and burn durations of large fires have increased from 7.5 to 37.1 days, in response to a spring-summer warming of 0.87°C. Earlier spring snowmelt has led to longer growing seasons and drought, especially at higher elevations, where the increase in wildfire activity has been greatest (Westerling et al., 2006). Analysis by the State of California suggests that large wildfires could become up to 55% more frequent in some areas toward the end of the century due to continued global warming (California Climate Change Center, 2006).

Comment [A44]: Identify the current scientific discussion regarding health implications of difference in both the proportion of fine vs coarse fraction and the difference in potential implications of differences in speciation between wind blown and fire related PM and energy generation sources

Particulate matter chemistry is affected by changes in temperature brought about by climate change as follows. Temperature is one of the most important meteorological variables influencing air quality in urban atmospheres because it directly affects gas and heterogeneous chemical reaction rates and gas-to-particle partitioning. The net effect that increased temperature has on airborne particle concentrations is a balance between increased production rates for secondary particulate matter (increases particulate concentrations) and increased equilibrium vapor pressures for semi-volatile particulate compounds (decreases particulate concentrations). Increased temperatures may either increase or decrease the concentration of semi-volatile secondary reaction products such as ammonium nitrate depending on ambient conditions.

The IPCC (Denman et al., 2007) notes that there has been less work on the sensitivity of aerosols to meteorological conditions and cites regional model simulations by Aw and Kleeman (2003). The regional model simulations for Southern California on September 25, 1996 projected decreases in 24-hour average $PM_{2.5}$ concentrations with increasing temperatures for inland portions of the South Coast air basin, and projected increases for coastal regions. Increased temperatures may either increase or decrease the concentration of semi-volatile secondary reaction products such as ammonium nitrate depending on ambient conditions. Regions with relatively hot initial temperatures (>290 K) will likely experience a reduction in particulate ammonium nitrate concentrations as temperature increases, while regions with relatively cool initial temperatures (<290 K) may experience minor reductions or even small increases in particulate ammonium nitrate concentrations as temperature increases. The net effect that increased temperature has on airborne particle concentrations is a balance between increased production rates for secondary PM (increases particulate concentrations) and increased equilibrium vapor pressures for semi-volatile particulate compounds (decreases particulate concentrations).

The transport and removal of PM is highly sensitive to winds and precipitation. Removal of PM from the atmosphere occurs mainly by wet deposition (NAS, 2005). Sulfate lifetime, for example, is estimated to be reduced from 4.7 days to 4.0 days as a result of increased wet deposition (Liao and Seinfeld, 2006). Precipitation also affects soil moisture, with impacts on dust source strength and on stomatal opening/closure of plant leaves, hence affecting biogenic emissions (Denman et al., 2007). Precipitation has generally increased over land north of 30°N over the period 1900 to 2005 and it has become significantly wetter in eastern parts of North America (Trenberth et al., 2007). However, model parameterizations of wet deposition are highly uncertain and not fully realistic in their coupling to the hydrological cycle (NAS, 2005). For models to simulate accurately the seasonally varying pattern of precipitation, they must correctly simulate a number of processes (e.g., evapotranspiration, condensation, transport) that are difficult to evaluate at a global scale (Randall et al., 2007). In 1997, EPA demonstrated that visibility impairment is an important effect on public welfare and that visibility impairment is experienced (though not necessarily attributed to climate change) throughout the U.S., in multi-state

Section 9

Food Production and Agriculture

Food production and the agricultural sector within the U.S. are sensitive to short-term climate variability and long-term climate change. This section addresses how observed and projected climate change may affect U.S. food production and agriculture. Food production and agriculture here include crop yields and production, livestock production (e.g., milk and meat), freshwater fisheries, and key climate-sensitive issues for this sector including drought risk and pests and weeds.

In addition to changes in average temperatures and precipitation patterns, this section also addresses how U.S. food production and agriculture may be affected directly by elevated CO_2 levels, as well as the frequency and severity of extreme events, such as droughts and storms. Climate change-induced effects on tropospheric ozone levels and their impacts on agriculture are discussed in Section 8 on Air Quality.

Vulnerability of the U.S. agricultural sector to climate change is a function of many interacting factors including pre-existing climatic and soil conditions, changes in pest competition, water availability, and the sector's capacity to cope and adapt through management practices, seed and cultivar technology, and changes in economic competition among regions.

The IPCC (2007b) made the following conclusion about food production and agriculture for North America:

> Moderate climate change in the early decades of the century is projected to increase aggregate yields of rainfed agriculture by 5-20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or depend on highly utilized water resources [high confidence].[55]

The CCSP (2008a) report addressing agriculture made the following general conclusions for the U.S.:

Comment [A45]: What is this? Suggest replacing these bullets with those from final SAP 4.3 exec summary for the agricultural sector (pages 6 and 7). These bullets do not represent the balance shown in 4.3. should also mention need for monitoring

- With increased CO_2 and temperature, the life cycle of grain and oilseed crops will likely progress more rapidly. But, as temperature rises, these crops will increasingly begin to experience failure, especially if climate variability increases and precipitation lessens or becomes more variable.
- Climate change is likely to lead to a northern migration of weeds.
- Higher temperatures will very likely reduce livestock production during the summer season, but these losses will very likely be partially offset by warmer temperatures during the winter season.

9(a) Crop yields and productivity

The productivity of most agricultural enterprises has increased dramatically over recent decades due to cumulative effects from technology, fertilizers, innovations in seed stocks and management techniques, and changing climate influences. Given the interaction of these various factors, it is difficult to identify the specific impact from any one factor on specific yield changes. The largest changes are probably due to technological innovations (Hatfield et al.,

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[55] According to IPCC terminology, "high confidence" conveys an 8 out of 10 chance of being correct. See Box 1.3 on page 4 for a full description of IPCC's uncertainty terms.

2008). However, weather events are a major factor in annual crop yield variation.

Comment [A46]: Language from CCSP Scientific Assessment was added

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The IPCC Fourth Assessment conclusion that North American rain-fed agriculture is projected to experience net benefits with moderate climate change, with significant regional variation, generally confirms the previous conclusion from the IPCC Third Assessment Report (2001).[56] Moderate climate change for temperate regions such as the U.S. is described as local increases in temperature of 1-3°C (~2-5°F), which may occur within the next few decades or past mid-century depending on scenario (see Section 6 for temperature projections). Increased average warming leads to an extended growing season, especially for northern regions of the U.S. Further warming, however, is projected to have increasingly negative impacts in all regions (meaning both temperate, including the U.S., and tropical regions of the world) (Easterling et al. 2007).

Observational evidence shows that, over the last century, aggregate yields of major U.S. crops have been increasing (USDA, 2007; Troyer, 2004 as referenced in Field et al., 2007), with significant regional and temporal variation. Multiple factors contribute to these long term trends, including seed technology, use of fertilizers, management practices, and climate change. Weather events are a major factor in annual crop yield variation. The IPCC (Field et al., 2007 and references therein) reviewed a number of studies showing the effects of weather and climate variability on U.S. crop yields:

- Excessive soil moisture reduced the value of the U.S. corn crop by an average of 3% or US$600 million/yr between 1951-1998 (Rosenzweig et al., 2002);
- In California, warmer nights have enhanced the production of high-quality wine grapes, but additional warming may not result in similar increases as wine grapes may already be near climate thresholds;
- For twelve major crops in California, climate fluctuations over the last 20 years have not had large effects on yield, though they have been a positive factor for oranges and walnuts but negative for avocados and cotton.

For projected climate change effects, the IPCC summary conclusion of net beneficial effects in the early decades in the U.S., with significant regional variation, is supported by a number of recent assessments for most major crops. The variable future climate change effects among regions and crops have also been identified. For example, the south-eastern U.S. may be more vulnerable to increases in average temperature than more northern regions due to pre-existing temperatures that are already relatively high. Likewise, certain crops that are currently near climate thresholds (e.g., wine grapes in California) are likely to experience decreases in yields, quality, or both, even under moderate climate change scenarios (Field et al., 2007).

Changes in precipitation patterns will play a large role in determining the net impacts of climate change at the national and sub-national scales, where uncertainties about precipitation changes remain very large. The IPCC (Field et al., 2007) reviewed integrated assessment modeling studies exploring the interacting impacts of climate and economic factors on agriculture, water resources, and biome boundaries in the U.S. and concluded that scenarios with decreased precipitation create important challenges, restricting the availability of water for irrigation and at the same time increasing water demand for irrigated agriculture, as well as urban and ecological uses. The critical importance of specific agro-climatic events, such as last frost, also introduces uncertainty in future projections (Field et al., 2007).

[56] The North America chapter from the IPCC Third Assessment Report (Cohen et al. 2007) concluded: "Food production is projected to benefit from a warmer climate, but there probably will be strong regional effects, with some areas in North America suffering significant loss of comparative advantage to other regions (high confidence)."

There is still debate and uncertainty about the sensitivity of crop yields in the U.S. and other world regions to the direct effects of elevated CO_2 levels. The IPCC (Easterling et al., 2007) concluded that elevated CO_2 levels are expected to contribute to small beneficial impacts on crop yields. The IPCC confirmed the general conclusions from its previous Third Assessment Report in 2001. Experimental research on crop responses to elevated CO_2 through the FACE (Free Air CO_2 Enrichment)[57] experiments indicate that, at ambient CO_2 concentrations of 550 ppm (approximately double the concentration from pre-industrial times), crop yields increase under unstressed conditions by 10-25% for C3 crops, and by 0-10% for C4 crops (medium confidence)[58]. Crop model simulations under elevated CO_2 are consistent with these ranges (high confidence) (Easterling et al., 2007). High temperatures, water and nutrient availability, and ozone exposure, however, can significantly limit the direct stimulatory CO_2 response (see also Section 8 on Air Quality). The CCSP (2008a) report concluded that the benefits of CO_2 rise over the next 30 years will mostly offset the negative effects of temperature for most C3 crops except rice and bean, while the C4 crop yields will be reduced by rising temperatures because they have little response to the CO_2 rise.

9(b) Irrigation requirements

Projected trends have conflicting effects on likely water needs. Increasing temperatures and a lengthening of the growing season will contribute to increased water demand. However, increasing CO2 concentrations will contribute to reduced stomatal conductance (speed of water vapor evaporation from plant pores) and decreased demand (Ainsworth and Long, 2005; Ainsworth and Rogers, 2007).

Comment [A47]: From CCSP Scientific Assessment

The impacts of climate change on irrigation water requirements may be large (Easterling et al., 2007). The IPCC considered this to be a new, robust finding since the Third Assessment Report in 2001. The increase in irrigation demand due to climate change is expected in the majority of world regions including the U.S. due to decreased rainfall in certain regions and/or increased evaporation arising from increased temperatures. In modeling studies of future climate change, additional irrigation is often assumed in order to counterbalance the potential adverse yield effects of significant temperature increases (Easterling et al., 2007).

Comment [A48]: Deletion made because this sentence is not in similar paragraph in CCSP Assessment and is covered by paragraph above.

Deleted: Longer growing seasons may contribute to the increased irrigation demands as well.

9(c) Climate variability and extreme events

In addition to changes in average climatic variables, such as temperature and precipitation, it is important to examine the potential for altered variability in extreme events such as extended heat waves, droughts, and floods. The potential for these events to change in frequency and magnitude introduces a key uncertainty regarding the yield of U.S. agriculture even under modest climate change. On this issue, the IPCC (Easterling et al. 2007) drew the following conclusion: "Recent studies indicate that climate change scenarios that include increased frequency of heat stress, droughts and flooding events reduce crop yields and livestock productivity beyond the impacts due to changes in mean variables alone, creating the possibility for surprises. Climate variability and change also modify the risks of fires, and pest and pathogen outbreaks, with negative consequences for food, fiber and forestry (high confidence)." The adverse effects on crop yields due to droughts and other extreme events may offset the beneficial direct effects of elevated CO_2, moderate temperature increases over the near term, and longer growing seasons.

Comment [A49]: Edit made to track with CCSP Scientific Assessment introduction to this IPCC statement

Deleted: The projected impacts of climate change often consider changes in *average* temperature and precipitation patterns alone, while not reflecting the potential for altered variability in events such as droughts and floods. The potential for these events to change in frequency and magnitude introduces a key uncertainty regarding IPCC's general conclusion that U.S. agriculture, in aggregate, is expected to benefit under modest climate change.

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[57] http://www.bnl.gov/face/

[58] C3 and C4 refer to different carbon fixation pathways in plants during photosynthesis. C3 is the most common pathway, and C3 crops (e.g., wheat, soybeans and rice) are more responsive than C4 crops such as maize.

Drought events are already a frequent occurrence, especially in the western U.S. Vulnerability to extended drought is, according to IPCC (Field et al., 2007), increasing across North America as population growth and economic development increase demands from agricultural, municipal, and industrial uses, resulting in frequent over-allocation of water resources. While often associated with the western United States, the eastern region has also experienced droughts and attendant reductions in water supply, changes in water quality and ecosystem function, and challenges in allocation (Field et al., 2007). Average annual precipitation is projected to decrease in the southwestern U.S. but increase over the rest of North America (Christensen et al., 2007). Some studies project widespread increases in extreme precipitation (Christensen et al., 2007), with greater risks of not only flooding from intense precipitation, but also droughts from greater temporal variability in precipitation.

Comment [A50]: Edit made to track with CCSP Scientific Assessment framing.

Deleted: Though droughts occur more frequently and intensely in the western part of the U.S., the east is not immune from droughts and attendant reductions in water supply, changes in water quality and ecosystem function, and challenges in allocation (Field et al., 2007).¶

9(d) Pests and weeds

Pests and weeds can reduce crop yields, cause economic losses to farmers, and require management control options. How climate change (elevated atmospheric CO2, increased temperatures, altered precipitation patterns, and changes in the frequency and intensity of extreme events) may affect the prevalence of pests and weeds is an issue of concern for food production and the agricultural sector. Recent warming trends in the United States have led to earlier spring activity by insects and proliferation of some species (Easterling et al., 2007). Additionally, research suggests that increased climate extremes may promote plant disease and pest outbreaks (Alig et al., 2004; Gan, 2004).

Comment [A51]: Edit made to track with the CCSP scientific assessment, page 128. Please add appropriate citations to reference list.

In particular, the IPCC review indicated that interactions between CO2, temperature, and precipitation will play an important role in determining plant damage from pests in future decades (Stacey and Fellows, 2002; Chen et al., 2004; Salinari et al., 2006; Zvereva and Kozlov, 2006 in Easterling et al., 2007). However, to date, most studies continue to investigate pest damage as a separate function of either elevated ambient CO2 concentrations or temperature. Pests and weeds are additional factors that, for example, are often omitted when projecting the stimulatory effect of elevated CO2 on crop yields. Research on the combined effects of elevated atmospheric CO2 and climate change on pests, weeds, and disease is still insufficient for U.S. and world agriculture (Easterling et al., 2007)

Deleted: Pests and weeds can reduce crop yields, cause economic losses to farmers, and require management control options. How climate change (elevated CO_2, increased temperatures, altered precipitation patterns, and changes in the frequency and intensity of extreme events) may affect the prevalence of pests and weeds is an issue of concern for food production and the agricultural sector. Recent warming trends in the U.S. have led to earlier insect spring activity and proliferation of some species (Easterling, et al., 2007). Weeds generally respond more positively to increasing CO_2 than most cash crops, particularly C3 invasive weeds; and while there are many weed species that have the C4 photosynthetic pathway and therefore show a smaller response to atmospheric CO_2 relative to C3 crops, in most agronomic situations, crops are in competition with both C3 and C4 weeds (CCSP, 2008a). The IPCC (Easterling et al., 2007) concluded, with high confidence, that climate variability and change modify the risks of fires, and pest and pathogen outbreaks, with negative consequences for food, fiber and forestry across all world regions. ¶
¶
Most studies, however, continue to investigate pest damage as a separate function of either elevated ambient CO_2 concentrations or temperature. Pests and weeds are additional factors that, for example, are often omitted when projecting the direct stimulatory effect of elevated CO_2 on crop yields. Research on the combined effects of elevated CO_2 and climate change on pests, weeds and disease is still insufficient for U.S. and world agriculture (Easterling et al., 2007).¶

9(e) Livestock

Climate change has the potential to influence livestock productivity in a number of ways. Elevated CO_2 concentrations can affect forage quality; thermal stress can directly affect the health of livestock animals; an increase in the frequency or magnitude of extreme events can lead to livestock loss; and climate change may affect the spread of animal diseases. The IPCC has generated a number of new conclusions in this area compared to the Third Assessment Report in 2001. These conclusions, applicable to U.S. and other livestock producing regions, include (Easterling et al., 2007):

- Changes in forage quality: Elevated CO_2 can increase the carbon to nitrogen ratio in forages and thus reduce the nutritional value of those grasses, which in turn affects animal weight and performance. Under elevated CO_2, a decrease of C4 grasses and an increase of C3 grasses (depending upon the plant species that remain) may occur which could potentially reduce or alter the nutritional quality of the forage grasses available to grazing livestock; however the exact effects on both types of grasses and their nutritional quality still needs to be determined.

- Thermal stress reduces productivity, conception rates and is potentially life threatening to livestock. According to one study reviewed in IPCC (Frank et al., 2001), the U.S. percentage decrease in swine, beef and dairy milk production in 2050 averaged 1.2%, 2.0%, and 2.2%, respectively, using one climate model and 0.9%, 0.7%, and 2.1%, respectively, using a different climate model. However, reduced livestock production due to higher temperatures in the summer may be offset due to higher temperatures during the winter (CCSP, 2008a).

- Increased climate variability (including extremes in both heat and cold) and droughts may lead to livestock loss. The impact on animal productivity due to increased variability in weather patterns will likely be far greater than effects associated with the average change in climatic conditions.

Comment [A52]: What is citation for this? Suggest replacing with language from SAP 4.3: "Higher temperatures will very likely reduce livestock production during the summer season, but these losses will very likely be partially offset by warmer temperatures during the winter season. For ruminants, current management systems generally do not provide shelter to buffer the adverse effects of changing climate; such protection is more frequently available for non-ruminants (e.g., swine and poultry)."

9(f) Freshwater and marine fisheries

Freshwater fisheries are sensitive to changes in temperature and water supply, which affect flows of rivers and streams, as well as lake levels. Climate change can interact with other factors that affect the health of fish and productivity of fisheries (e.g., habitat loss, land-use change).

The IPCC (Field et al., 2007 and references therein) reviewed a number of North American studies showing how freshwater fish are sensitive to, or are being affected by, observed changes in climate:

- Cold- and cool-water fisheries, especially salmonids, have been declining as warmer/drier conditions reduce their habitat. The sea-run salmon stocks are in steep decline throughout much of North America;
- Pacific salmon have been appearing in Arctic rivers;[59]
- Salmonid species have been affected by warming in U.S. streams;
- Success of adult spawning and survival of fry brook trout is closely linked to cold groundwater seeps, which provide preferred temperature refuges for lake-dwelling populations. Rates of fish egg development and mortality increase with temperature rise within species-specific tolerance ranges.

Regarding the impacts of future climate change, IPCC concluded, with high confidence for North America, that cold-water fisheries will likely be negatively affected; warm-water fisheries will generally benefit; and the results for cool-water fisheries will be mixed, with gains in the northern and losses in the southern portions of ranges (Field et al., 2007). A number of specific impacts by fish species and region in North America are projected (Field et al., 2007 and references therein):

- Salmonids, which prefer cold water, are likely to experience the most negative impacts;
- Arctic freshwaters will likely be most affected, as they will experience the greatest warming;
- Many warm-water and cool-water species will shift their ranges northward or to higher altitudes;
- In the continental U.S., cold-water species will likely disappear from all but the deeper lakes, cool-water species will be lost mainly from shallow lakes, and warm water species will thrive except in the far south, where temperatures in shallow lakes will exceed survival thresholds.

Climate variability and change can also impact fisheries in coastal and estuarine waters, although non-climatic factors, such as overfishing and habitat loss and degradation, are already responsible for reducing fish stocks (Nichols et al., 2007). Coral reefs, for example, are vulnerable to a range of stresses and for many reefs, thermal stress thresholds will be crossed, resulting in bleaching, with severe adverse consequences for reef-based fisheries (Nichols et al., 2007). Increased storm intensity, temperature and salt water intrusion in coastal water bodies can also adversely impact coastal fisheries production.

[59] Arctic includes large regions of Alaska, and the Alaskan indigenous population makes up largest indigenous population of the Arctic (see ACIA, 2004).

Section 10

Forestry

This section addresses how climate change may affect forestry, including timber yields, wildfires and drought risk, forest composition, and pests in the U.S. For North America, the IPCC (Field et al., 2007) concluded:

- Overall forest growth in North America will likely increase modestly (10-20%) as a result of extended growing seasons and elevated CO_2 over the next century, but with important spatial and temporal variation (medium confidence).[60]

- Disturbances like wildfire and insect outbreaks are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons (very high confidence). Although recent climate trends have increased vegetation growth, continuing increases in disturbances are likely to limit carbon storage, facilitate invasive species, and disrupt ecosystem services. Over the 21st century, pressure for species to shift north and to higher elevations will fundamentally rearrange North American ecosystems. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and ecological connections will alter ecosystem structure, function, and services.

Comment [A53]: What is citation for this? Suggest using language from SAP 4.3 which states: "The combined effects of rising temperatures and CO2, nitrogen deposition, ozone, and forest disturbance on soil processes and soil carbon storage remains unclear."

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The CCSP (2008a) report addressing forestry and land resources made the following general conclusions for the U.S.:

- Climate change has very likely increased the size and number of forest fires, insect outbreaks, and tree mortality in the interior West, the Southwest, and Alaska, and will continue to do so.

- Rising CO_2 will very likely increase photosynthesis for forests, but this increase will likely only enhance wood production in young forests on fertile soils.

- The combined effects of rising temperatures and CO_2, nitrogen deposition, ozone, and forest disturbance on soil processes and soil carbon storage remains unclear.

10(a) Forest Productivity

Climate strongly influences forest productivity and species composition. Research reviewed in the North America IPCC chapter indicates that forest growth appears to have increased slightly in the previous decade (less than 1% per decade) in regions where growth has historically been limited by low temperatures and short growing seasons (Caspersen et al., 2000; McKenzie et al., 2001; Joos et al., 2002; Boisvenue and Running, 2006 in Field et al., 2007). However, as noted by Ryan et al. (2008), it is difficult to separate the role of climate from other potentially influencing factors particularly because these interactions vary by location. Other potentially influential factors include increases in precipitation (observed in the Midwest and Lake States), increases in nitrogen deposition, temperature increases and a lengthened growing season in the northern United States, changing age structure of forests (greater percentage of forests in young age classes), and evolving management practices.

Comment [A54]: Added text from CCSP scientific assessment.

[60] According to IPCC terminology, "medium confidence" conveys a 5 out of 10 chance of being correct. See Box 1.3 on page 4 for a full description of IPCC's uncertainty terms.

Forestry productivity is known to be sensitive to changes in climate variables (e.g. temperature, radiation, precipitation, water vapor pressure in the air, and wind speed), as these affect a number of physical, chemical, and biological processes in forest systems (Easterling, et al., 2007).

For the U.S. as a whole, forest growth and productivity have been observed to change, in part due to observed climate change. Nitrogen deposition and warmer temperatures have very likely increased forest growth where water is not limiting (CCSP, 2008a). The IPCC (Field et al., 2007 and references therein) outlines a number of studies demonstrating the connection between changes in U.S. forest growth and changes in climate variables:

- Forest growth appears to be slowly accelerating (less than 1% per decade) in regions where tree growth has historically been limited by low temperatures and short growing seasons;
- The length of the vegetation growing season has increased an average of 2 days per decade since 1950 in the conterminous U.S., with most of the increase resulting from earlier spring warming;
- Growth is slowing in areas subject to drought;
- On dry south-facing slopes in Alaska, growth of white spruce has decreased over the last 90 years, due to increased drought stress;
- In semi-arid forests of the south-western U.S., growth rates have decreased since 1895, correlated with drought from warming temperatures,
- For a widespread species like lodgepole pine, a 3°C temperature increase would increase growth in the northern part of its range, decrease growth in the middle, and decimate southern forests (Field et al., 2007),
- Mountain forests are increasingly encroached upon from adjacent lowlands, while simultaneously losing high altitude habitats due to warming (Fischlin et al., 2007).
- In Colorado, aspen have advanced into the more cold-tolerant spruce-fir forests over the past 100 years;
- A combination of warmer temperatures and insect infestations has resulted in economically significant losses of forest resource base to spruce bark beetle in Alaska.

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Forest productivity gains may result through: (i) the direct stimulatory CO_2 fertilization effect (although the magnitude of this effect remains uncertain over the long term and can be curtailed by other changing factors); (ii) warming in cold climates, given concomitant precipitation increases to compensate for possibly increasing water vapor pressure deficits; and (iii) precipitation increases under water limited conditions (Fischlin et al., 2007).

New studies suggest that direct CO_2 effects on tree growth may be lower than previously assumed. Additionally, the initial increase in growth increments may be limited by competition, disturbance, air pollutants (primarily tropospheric ozone), nutrient limitations, ecological processes, and other factors, and the response is site- and species-specific (Easterling et al., 2007). Similarly, a CCSP (2008a) report stated that, where nutrients are not limiting, rising CO_2 increases photosynthesis and wood production, but that on infertile soils the extra carbon from increased photosynthesis will be quickly respired.

Productivity gains in one area can occur simultaneously with productivity losses in other areas. Climate change is expected to increase California timber production by the 2020s because of stimulated growth in the standing forest. In the long run (up to 2100), these productivity gains were offset by reductions in productive area for softwoods growth. Risks of losses from Southern pine beetle likely depend on the seasonality of warming, with winter and spring warming leading to the greatest damage (Easterling et al., 2007 and references therein).

Deleted: For a widespread species like lodgepole pine, a 3°C temperature increase would increase growth in the northern part of its range, decrease growth in the middle, and decimate southern forests (Field et al., 2007).

Comment [AS5]: Unclear that this belongs here. Should this be a bullet above?

According to studies reviewed by IPCC (Field et al., 2007), the effects of climate change, in the absence of dramatic increases in disturbance, on the potential for commercial harvest in the 2040s ranged from mixed for a low emissions scenario to positive for a high emissions scenario (see Perez-Garcia et al., 2002). The tendency for North American producers to suffer losses increases if climate change is accompanied by increased disturbance, with simulated losses averaging US$1-2 billion/year, over the 21st century (Sohngen and Sedjo, 2005).

A changing climate will also substantially impact other non-timber goods, such as seeds, nuts, hunting, resins, plants used in pharmaceutical and botanical medicine, and in the cosmetics industry; these impacts will vary significantly across world regions (Easterling et al., 2007).

U.S. forestry, in addition to experiencing direct climate change effects, may be indirectly affected by changing forest productivity in different regions of the world. Sohngen and Sedjo (2005) show two climate change scenarios where North American forests undergo more dieback in general than forests in other regions of the world, and where certain North American forest yields increase but less so compared to other regions. The implication is that forests in other parts of the world (including tropical forests with shorter rotations) could have a competitive advantage within the global forestry sector under a changing climate.

10(b) Wildfire and Drought Risk

While in some cases a changing climate may have positive impacts on the productivity of forest systems, changes in disturbance patterns are expected to have a substantial impact on overall gains or losses. More prevalent forest fire disturbances have recently been observed in the U.S. and other world regions (Fischlin, et al., 2007). Wildfires and droughts, among other extreme events (e.g., hurricanes) that can cause forest damage, pose the largest threats over time to forest ecosystems. The frequency and severity of wildfires and droughts are expected to be altered by climate change, which can also induce stress on trees that indirectly exacerbate disturbances. General climate warming encourages wildfires by extending the summer period that dries fuels, promoting easier ignition and faster spread.

The IPCC (Field et al., 2007 and references therein) noted a number of observed changes to U.S. wildfire size and frequency, often associating these changes with changes in average temperatures:

- Since 1980, an average of about 22,000 km^2/year (13,700 mi^2/year) has burned in wildfires, almost twice the 1920-1980 average of about 13,000 km^2/year (8,080 mi^2/year);
- The forested area burned in the western U.S. from 1987-2003 is 6.7 times the area burned from 1970-1986;
- Human vulnerability to wildfires has increased, with a rising population in the wildland-urban interface;
- In the last three decades, the wildfire season in the western U.S. has increased by 78 days, and burn durations of fires greater than 1,000 ha (2,470 acres) have increased from 7.5 to 37.1 days, in response to a spring/summer warming of 0.87°C (1.4°F);
- Earlier spring snowmelt has led to longer growing seasons and drought, especially at higher elevations, where the increase in wildfire activity has been greatest;
- In the south-western U.S., fire activity is correlated with El Nino Southern Oscillation positive phases, and higher Palmer Drought Severity Indices.[61]

Comment [A56]: Is this part of the scenario below? Should these be presented together?

Deleted: Climate change will also substantially impact other services, such as seeds, nuts, hunting, resins, plants used in pharmaceutical and botanical medicine, and in the cosmetics industry; these impacts will vary significantly across world regions (Easterling et al., 2007).

Comment [A57]: Please provide citation for this

Comment [A58]: Citation?

[61] The Palmer Drought Severity Index is used by NOAA and uses a formula that includes temperature and rainfall to determine dryness. It is most effective in determining long-term drought.

20% tree mortality. Also following recent warming in Alaska, spruce budworm has reproduced farther north reaching problematic numbers (Anisimov et al., 2007).

Climate change may indirectly affect insect outbreaks by affecting the overall health and productivity of trees. For example, susceptibility of trees to insects is increased when multi-year droughts degrade the trees' ability to generate defensive chemicals (Field, et al., 2007). Warmer temperatures have already enhanced the opportunities for insect spread across the landscape in the U.S. and other world regions (Easterling et al., 2007).

The IPCC (Easterling et al., 2007) stated that modeling of future climate change impacts on insect and pathogen outbreaks remains limited. Nevertheless, the IPCC (Field et al., 2007) states with high confidence that, across North America, impacts of climate change on commercial forestry potential are likely to be sensitive to changes in disturbances from insects and diseases, as well as wildfires. Climate change can shift the current boundaries of insects and pathogens and modify tree physiology and tree defense (Easterling, et al., 2007). An increase in climate extremes may also promote plant disease and pest outbreaks.

Comment [A59]: Who made this finding? Please provide citation.

Section 11

Water Resources

This section covers climate change effects on U.S. water supply, water quality, extreme events affecting water resources, and water uses. Information about observed trends as well as projected impacts is provided.

For North America, IPCC concluded:

- Climate change will constrain North America's over-allocated water resources, increasing competition among agricultural, municipal, industrial, and ecological uses (very high confidence)[63] (Field et al., 2007). Rising temperatures will diminish snowpack and increase evaporation, affecting seasonal availability of water. Higher demand from economic development, agriculture and population growth will further limit surface and groundwater availability. In the Great Lakes and major river systems, lower levels are likely to exacerbate challenges relating to water quality, navigation, recreation, hydropower generation, water transfers, and bi-national relationships.

11(a) Water Supply and Snowpack

Surface Water and Snowpack

Surface water availability and precipitation differ greatly across the United States. Generally, conditions become increasingly dry from east to west. However, conditions in the upslope areas of the Cascade and coastal mountain ranges, especially in the Pacific Northwest, are much more humid (Lettenmaier et al., 2008). The driest climates occur in the Intermountain West and the Southwest. Precipitation variability follows similar trends with less variability in the humid areas (eastern United States and Pacific Northwest) and the greatest variability in the arid and semiarid West (Lettenmaier et al., 2008). The IPCC (Kundzewicz et al., 2007) concluded with high confidence that semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater.

IPCC reviewed a number of studies showing trends in U.S. precipitation patterns, surface water supply, and snowpack, and how climate change may be contributing to some of these trends (Field et al., 2007):

- Annual precipitation has increased throughout most of North America.
- Streamflow in the eastern U.S. has increased 25% in the last 60 years, but has decreased by about 2% per decade in the central Rocky Mountain region over the last century.
- Since 1950, stream discharge in both the Colorado and Columbia river basins has decreased.
- In regions with winter snow, warming has shifted the magnitude and timing of hydrologic events. The fraction of annual precipitation falling as rain (rather than snow) increased at 74% of the weather stations studied in the western mountains of the U.S. from 1949-2004.
- Spring and summer snow cover has also decreased in the U.S. West. April snow water equivalents have declined 15-30% since 1950 in the western mountains of North America, particularly at lower

Comment [A60]: Suggest replacing this with broader opening statement. Scientific Assessment has this suggested paragraph: "The IPCC (Kundzewicz et al., 2007) found that climate change is one of many factors exerting pressure on existing freshwater systems. Other factors include water pollution, damming of rivers, wetland drainage, reduction in streamflow, and lowering of the groundwater table (e.g., due to irrigation). The authors conclude that while climate-related changes have been small compared to these other pressures to date, climate change is expected to result in increasing effects in the future. Ultimately, each of these factors influences the availability of and access to freshwater. In this section, we review effects of global change on water supply, water quality, and extreme events, and explore the implications for water use."

Comment [A61]: From scientific assessment

[63] According to IPCC terminology, "very high confidence" conveys a 9 out of 10 chance of being correct. See Box 1.3 on page 4 for a full description of IPCC's uncertainty terms.

elevations, due primarily to warming temperatures rather than changes in precipitation (See Figure 14.1).
- Break-up of river and lake ice across North America advanced by 0.2 – 12.9 days over the last 100 years.

In the Arctic, precipitation has increased by about 8% on average over the past century. Much of the increase has fallen as rain, with the largest increases occurring in autumn and winter. Later freeze-up and earlier break-up of river and lake ice have combined to reduce the ice season by one to three weeks in some areas. Glaciers throughout North America are melting, and the particularly rapid retreat of Alaskan glaciers represents about half of the estimated loss of glacial mass worldwide (ACIA, 2004). Permafrost plays a large role in the hydrology of lakes and ponds. The spatial pattern of lake disappearance strongly suggests that permafrost thawing is driving the changes. These changes to Arctic precipitation, ice extent, and glacial abundance will affect key regional bio-physical systems, act as climatic feedbacks (primarily by changing surface albedo), and have socio-economic impacts (high confidence) (Anisimov et al., 2007). The vulnerability of freshwater resources in the U.S. to climate change varies from region to region. In regions including the Colorado River, Columbia River, and Ogallala Aquifer, surface and/or groundwater resources are intensively used and subject to competition from agricultural, municipal, industrial, and ecological needs. This increases the potential vulnerability to future changes in timing and availability of water (Field et al., 2007).

Projections for the western mountains of the U.S. suggest that warming, and changes in the form, timing, and amount of precipitation will very likely lead to earlier melting and significant reductions in snowpack by the middle of the 21st century (IPCC: high confidence). In mountainous snowmelt-dominated watersheds, projections suggest advances in the timing of snowmelt runoff, increases in winter and early spring flows (raising flooding potential), and substantially decreased summer flows. Heavily-utilized water systems of the western U.S. that rely on capturing snowmelt runoff, such as the Columbia River system, will be especially vulnerable (Field et al., 2007). Reduced snowpack has been identified as a major concern for the State of California (California Energy Commission, 2006).

Globally, current water management practices are very likely to be inadequate to reduce the negative impacts of climate change on water supply reliability, flood risk, and aquatic ecosystems (very high confidence) (Kundzewicz et al., 2007[64]). Less reliable supplies of water are likely to create challenges for managing urban water systems as well as for industries that depend on large volumes of water. U.S. water managers currently anticipate local, regional, or state-wide water shortages over the next ten years. Threats to reliable supply are complicated by high population growth rates in western states where many resources are at or approaching full utilization. Potential increases in heavy precipitation, with expanding impervious surfaces, could increase urban flood risks and create additional design challenges and costs for stormwater management (Field et al., 2007). The IPCC (Field et al., 2007 and references therein) reviewed several regional-level studies on climate change impacts to U.S. water management which showed:

Comment [A62]: Why global focus, when scientific assessment has so much US information. Suggest revision.

- In the Great Lakes – St. Lawrence Basin, many, but not all, assessments project lower net basin supplies and lake water levels. Lower water levels are likely to influence many sectors, with multiple, interacting impacts (IPCC: high confidence). Atmosphere-lake interactions contribute to the uncertainty in assessing these impacts though.
- Urban water supply systems in North America often draw water from considerable distances, so climate impacts need not be local to affect cities. By the 2020s, 41% of the water supply to southern

[64] The Kundzewicz et al. citation refers to Chapter 3, "Freshwater Resources and their Management" in IPCC's 2007 Fourth Assessment Report, Working Group II.

California is likely to be vulnerable due to snowpack loss in the Sierra Nevadas and Colorado River basin.

- The New York area will likely experience greater water supply variability. New York City's system can likely adapt to future changes, but the region's smaller systems may be vulnerable, leading to a need for enhanced regional water distribution plans.

In the Arctic, river discharge to the ocean has increased during the past few decades, and peak flows in the spring are occurring earlier. These changes are projected to accelerate with future climate change. Snow cover extent in Alaska is projected to decrease by 10-20% by the 2070s, with greatest declines in spring (ACIA, 2004 and reference therein).

The IPCC concluded with high confidence that under most climate change scenarios, water resources in small islands around the globe are likely to be seriously compromised (Mimura et al., 2007). Most small islands have a limited water supply, and water resources in these islands are especially vulnerable to future changes and distribution of rainfall. Reduced rainfall typically leads to decreased surface water supply and slower recharge rates of the freshwater lens[65], which can result in prolonged drought impacts. Many islands in the Caribbean (which include U.S. territories of Puerto Rico and U.S. Virgin Islands) are likely to experience increased water stress as a result of climate change. Under all SRES scenarios, reduced rainfall in summer is projected for the Caribbean, making it unlikely that the demand for water resources will be met. Increased rainfall in winter is unlikely to compensate for these water deficits due to lack of storage capacity (Mimura et al., 2007[66]).

Groundwater

The available research suggests that groundwater systems generally respond more slowly to climate change than surface water systems. In general, groundwater levels correlate most strongly with precipitation, but temperature becomes more important for shallow aquifers, especially during warm periods. With climate change, availability of groundwater is expected to be influenced by changes in withdrawals (reflecting development, human and agricultural demand, and availability of other sources) and recharge (determined by temperature, timing, and amount of precipitation, and surface water interactions) (medium confidence) (Kundzewicz et al., 2007). In general, simulated aquifer levels respond to changes in temperature, precipitation, and the level of withdrawal.

Comment [A63]: Tracks with the scientific assessment

Deleted: Groundwater systems generally respond more slowly to climate change than surface water systems. Limited data on existing supplies of groundwater makes it difficult to understand and measure climate effects. In general, groundwater levels correlate most strongly with precipitation, but temperature becomes more important for shallow aquifers, especially during warm periods. In semi-arid and arid areas, groundwater resources are particularly vulnerable because precipitation and streamflow are concentrated over a few months, year-to-year variability is high, and deep groundwater wells or reservoirs generally do not exist (Kundzewicz et al., 2007).

With climate change, availability of groundwater is likely to be influenced by changes in withdrawals (reflecting development, demand, and availability of other sources) and recharge (determined by temperature, timing, and amount of precipitation, and surface water interactions) (medium confidence). In general, simulated aquifer levels respond to changes in temperature, precipitation, and the level of withdrawal. According to IPCC, base flows were found to decrease in scenarios that are drier or have higher pumping rates, and increase in wetter scenarios on average across world regions (Kundzewicz et al., 2007).

Projections suggest that efforts to offset declining surface water availability by increasing groundwater withdrawals will be hampered by decreases in groundwater recharge in some water-stressed regions, such as the southwest US. Vulnerability in these areas is also often exacerbated by the rapid increase of population and water demand (high confidence) (Kundzewicz et al., 2007). Projections for the Ogallala

[65] Freshwater lens is defined as a relatively thin layer of freshwater within island aquifer systems that floats on an underlying mass of denser seawater. Numerous factors control the shape and thickness of the lens, including the rate of recharge from precipitation, island geometry, and geologic features such as the permeability of soil layers.
[66] Mimura et al., 2007 refers to Chapter 16, "Small Islands" in IPCC's 2007 Fourth Assessment Report, Working Group II.

aquifer region suggest that natural groundwater recharge decreases more than 20% in all simulations with different climate models and future warming scenarios of 2.5°C or greater (Field et al., 2007 and reference therein).

In addition, sea level rise will extend areas of salinization of groundwater and estuaries, resulting in a decrease in freshwater availability for humans and ecosystems in coastal areas. For a discussion of these impacts, please see Section 12.

Deleted: Groundwater resources can also be adversely impacted in coastal areas by sea level rise induced saltwater intrusion

11(b) Water Quality

The IPCC concluded with high confidence that higher water temperatures, increased precipitation intensity, and longer periods of low flows exacerbate many forms of water pollution and can impact ecosystems, human health, and water system reliability and operating costs. A CCSP (2008a) report also acknowledges that water quality is sensitive to both increased water temperatures and changes in precipitation; however, most water quality changes observed so far in the U.S. are likely attributable to causes other than climate change.

Pollutants of concern in this case include sediment, nutrients, organic matter, pathogens, pesticides, salt, and thermal pollution (Kundzewicz et al., 2007). IPCC (Kundzewicz et al., 2007) reviewed several studies discussing the impacts of climate change on water quality that showed:

- In lakes and reservoirs, climate change effects are primarily caused by water temperature variations. These variations can be caused by climate change or indirectly through increases in thermal pollution as a result of higher demand for cooling water in the energy sector. This affects, for the U.S. and all world regions, dissolved oxygen regimes, redox potentials[67], lake stratification, mixing rates, and the development of aquatic biota, as they all depend on water temperature. Increasing water temperature affects the self-purification capacity of rivers by reducing the amount of dissolved oxygen available for biodegradation.

- Water pollution problems are exacerbated during low flow conditions where small water quantities result in less dilution and greater concentrations of pollutants.

- Heavy precipitation frequencies in the U.S. were at a minimum in the 1920s and 1930s, and have increased through the 1990s (Field, et al., 2007). Increases in intense rain events result in the introduction of more sediment, nutrients, pathogens, and toxics into water bodies from non-point sources.

Comment [A64]: Not clear where this comes from. Suggest instead adding the paragraph from CCSP scientific assessment which says: "Lettenmaier et al. (2008) found that two main factors that influence water quality are temperature and water quantity. Higher temperatures enhance rates of biogeochemical transformation and physiological processes of aquatic plants and animals. As temperatures increase, the ability of water to hold dissolved oxygen declines, with potential negative impacts on aquatic organisms.
High nutrient loads can also contribute to anoxic conditions. Increased streamflow can dilute nutrient concentrations and thus diminish excessive biological production. However, higher flows can flush excess nutrients from sources of origin in a stream. The overall balance of these competing effects in a changing climate is not yet known."

North American simulations of future surface and bottom water temperatures of lakes, reservoirs, rivers, and estuaries consistently increase, with summer surface temperatures exceeding 30°C in midwestern and southern lakes and reservoirs. IPCC projects that warming is likely to extend and intensify summer thermal stratification in surface waters, further contributing to oxygen depletion (Field et al., 2007 and references therein).

Higher water temperature and variations in runoff are likely to produce adverse changes in water quality affecting human health, ecosystems, and water uses. Elevated surface water temperatures will promote algal blooms and increases in bacteria and fungi levels. Warmer waters also transfer volatile and semi-volatile compounds (ammonia, mercury, PCBs, dioxins, pesticides) from surface water bodies to the

[67] Redox potential is defined as the tendency of a chemical species to acquire electrons and therefore be reduced.

atmosphere more rapidly (Kundzewicz et al., 2007). Although this transfer will improve water quality, air quality will be negatively impacted.

Lowering of the water levels in rivers and lakes can lead to re-suspension of bottom sediments and liberating compounds, with negative effects on water supplies (Field et al., 2007 and references therein). These impacts may lead to a bad odor and taste in chlorinated drinking water and greater occurrence of toxins. More intense rainfall will lead to increases in suspended solids (turbidity) and pollutant levels in water bodies due to soil erosion (Kundzewicz et al., 2007). Moreover, even with enhanced phosphorus removal in wastewater treatment plants, algal growth in water bodies may increase with warming over the long term. Increasing nutrient and sediment loads due to more intense runoff events will negatively affect water quality, possibly rendering a source unusable unless special treatment is introduced.

Comment [A65]: Unusable for what? IF you are talking about drinking water we have a regulatory structure to protect us. Please clarify.

Climate change is likely to make it more difficult to achieve existing water quality goals for sediment (IPCC: high confidence) because hydrologic changes affect many geomorphic processes including soil erosion, slope stability, channel erosion, and sediment transport (Field et al., 2007). IPCC reviewed a number of region-specific studies on U.S. water quality and projected that:

- Changes in precipitation may increase nitrogen loads from rivers in the Chesapeake and Delaware Bay regions by up to 50% by 2030 (Kundzewicz et al., 2007 and reference therein).

- Decreases in snowcover and increases in winter rain on bare soil will likely lengthen the erosion season and enhance erosion intensity. This will increase the potential for sediment related water quality impacts in agricultural areas (Field et al., 2007 and reference therein). All studies on soil erosion suggest that increased rainfall amounts and intensities will lead to greater rates of erosion, within the U.S. and in other regions, unless protection measures are taken (Kundzewicz et al., 2007). Soil management practices (e.g., crop residue, no-till) in some regions (e.g., the Cornbelt) may not provide sufficient erosion protection against future intense precipitation and associated runoff (Field et al., 2007).

11(c) Extreme Events

There are a number of climatic and non-climatic drivers influencing flood and drought impacts. Whether risks are realized depends on several factors. Floods can be caused by intense and/or long-lasting precipitation events, rapid snowmelt, dam failure, or reduced conveyance due to ice jams or landslides. Flood magnitude and spatial extent depend on the intensity, volume, and time of precipitation, and the antecedent conditions of rivers and their drainage basins (e.g., presence of snow and ice, soil composition, level of human development, existence of dikes, dams, and reservoirs, etc.) (Kundzewicz et al., 2007).

Precipitation intensity will increase across the U.S., but particularly at mid and high latitudes where mean precipitation also increases. This will affect the risk of flash flooding and urban flooding (Kundzewicz et al., 2007). Some studies project widespread increases in extreme precipitation with greater risks of not only flooding from intense precipitation, but also droughts from greater temporal variability in precipitation. In general, projected changes in precipitation extremes are larger than changes in mean precipitation (Field et al., 2007).

The socio-economic impacts of droughts arise from the interaction between climate, natural conditions, and human factors such as changes in land use. In dry areas, excessive water withdrawals from surface and groundwater sources can exacerbate the impacts of drought (Kundzewicz et al., 2007). Although drought has been more frequent and intense in the western part of the U.S., the East is also vulnerable to

Deleted: not immune from

droughts and attendant reductions in water supply, changes in water quality and ecosystem function, and challenges in allocation (Field et al., 2007).

In addition to the effects on water supply, extreme events, such as floods and droughts, will likely reduce water quality. Increased erosion and runoff rates during flood events will wash pollutants (e.g., organic matter, fertilizers, pesticides, heavy metals) from soils into water bodies, with subsequent impacts to species and ecosystems. During drought events, the lack of precipitation and subsequent low flow conditions will impair water quality by reducing the amount of water available to dilute pollutants. These effects from floods and droughts will make it more difficult to achieve pollutant discharge limits and water quality goals (Kundzewicz et al., 2007).

Comment [A66]: Are you referring to drinking water? Please clarify-we have a regulatory structure in place to ensure quality.

Lettenmaier et al. (2008) found that U.S. consumptive use of water per capita has declined over the last two decades, primarily as a result of various improvements in water use efficiency related both to legal mandates and to water pricing, as well as some changes in water laws that have facilitated reallocation of water, particularly in the western United States and during droughts. Trends toward increased water use efficiency seem likely to continue in the coming decades. Pressures for reallocation of water will be greatest in areas of highest population growth, such as the Southwest. Declining water consumption, if it continues, will help mitigate the impacts of climate change on water resources.

Comment [A67]: From CCSP Scientific assessment

11(d) Implications for Water Uses

There are many competing water uses in the U.S. that will be adversely impacted by climate change impacts to water supply and quality. The IPCC reviewed a number of studies describing the impacts of climate change on water uses in the U.S. which showed:

- Decreased water supply and lower water levels are likely to exacerbate challenges relating to navigation in the U.S. (Field et al., 2007). Some studies have found that low flow conditions may restrict ship loading in shallow ports and harbors (Kundzewicz et al., 2007). However, navigational benefits from climate change exist as well. For example, the navigation season for the North Sea Route is projected to increase from the current 20-30 days per year to 90-100 days by 2080 (ACIA, 2004 and references therein).
- Climate change impacts to water supply and quality will affect agricultural practices, including the increase of irrigation demand in dry regions and the aggravation of non-point source water pollution problems in areas susceptible to intense rainfall events and flooding (Field et al., 2007). For more information on climate change impacts to agriculture, please see Section 9.
- The U.S. energy sector, which relies heavily on water for generation (hydropower) and cooling capacity, will be adversely impacted by changes to water supply and quality in reservoirs and other water bodies (Wilbanks et al., 2007). For more information on climate change impacts to the energy sector, please see Section 13.
- Climate-induced environmental changes (e.g., loss of glaciers, reduced river discharge, reduced snow-fall in winter) will affect park tourism, winter sport activities, inland water sports (e.g., fishing, rafting, boating), and other recreational uses dependent upon precipitation (Field et al., 2007). While the North American tourism industry acknowledges the important influence of climate, its impacts have not been analyzed comprehensively.

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Comment [A68]: Not clear why this bullet is even in this section. Can we talk about a longer warm season and the positive impacts on watersports as well to balance? This should be added.

Comment [A69]: From scientific assessment

- Recent winters with less ice in the Great Lakes and Gulf of St. Lawrence have increased coastal exposure to damage from winter storms (Field et al., 2007).
- Recent severe tropical and extra-tropical storms demonstrate that North American urban centers with assumed high adaptive capacity remain vulnerable to extreme events (Field et al., 2007).

Demand for waterfront property and building land in the U.S. continues to grow, increasing the value of property at risk. Of the $19 trillion value of all insured residential and commercial property in the US states exposed to North Atlantic hurricanes, $7.2 trillion (41%) is located in coastal counties. This economic value includes 79% of the property in Florida, 63% of property in New York, and 61% of the property in Connecticut (AIR, 2002 in Field et al., 2007). The devastating effects of hurricanes Ivan in 2004 and Katrina, Rita and Wilma in 2005 illustrate the vulnerability of North American infrastructure and urban systems that were not designed or not maintained to adequate safety margins. When protective systems fail, impacts can be widespread and multi-dimensional (Field et al., 2007). While the North American tourism industry acknowledges the important influence of climate, its impacts have not been analyzed comprehensively.

Section 13

Energy, Infrastructure and Settlements

According to IPCC (Wilbanks et al., 2007), "[i]ndustries, settlements and human society are accustomed to variability in environmental conditions, and in many ways they have become resilient to it when it is a part of their normal experience. Environmental changes that are more extreme or persistent than that experience, however, can lead to vulnerabilities, especially if the changes are not foreseen and/or if capacities for adaptation are limited."

Climate change is likely[73] to affect U.S. energy use and energy production; physical infrastructures; institutional infrastructures; and will likely interact with and possibly exacerbate ongoing environmental change and environmental pressures in settlements (Wilbanks et al., 2007), particularly in Alaska where indigenous communities are facing major environmental and cultural impacts on their historical lifestlyes (ACIA, 2004). As noted in SAP 4.5, overall research is relatively clear that climate warming will mean reductions in total U.S. heating requirements and increases in total cooling requirements for buildings (Wilbanks et al., 2007b). Changes will vary by region and season and will affect household and business energy demands and cost. In general, the changes imply increased demands for electricity, which supplies virtually all cooling energy services but only some heating services. Natural gas is the most common heating fuel, fuel oil is commonly used in the Northeast, while in parts of the country with relatively short, mild winters and/or inexpensive electricity, electricity is commonly used for heating.

Comment [A70]: Unclear what this means, thus added language

Comment [A71]: Suggested intro text from the CCSP assessment

With climate warming, less heating is required for industrial, commercial, and residential buildings in the United States. A review of the relevant literature in SAP 4.5 (Scott and Huang, 2007) found that projected reductions varied across studies depending on the amount of temperature change in the climate scenario, the calculated sensitivity of the building stock to warming, and the adjustments allowed in the building stock over time.

13(a) Heating and Cooling Requirements

With climate warming, less heating is required for industrial, commercial, and residential buildings in the U.S., but more cooling is required, with changes varying by region and by season. Net energy demand at a national scale will be influenced by the structure of the energy supply. The main source of energy for cooling is electricity, while coal, oil, gas, biomass, and electricity are used for space heating. Regions with substantial requirements for both cooling and heating could find that net annual electricity demands increase while demands for other heating energy sources decline. Critical factors for the U.S. are the relative efficiency of space cooling in summer compared to space heating in winter, and the relative distribution of populations in colder northern or warmer southern regions. Seasonal variation in total demand is also important. In some cases, due to infrastructure limitations, peak demand could go beyond the maximum capacity of the electricity transmission system (Wilbanks et al., 2007).

Recent North American studies generally confirm earlier work showing a small net change (increase or decrease, depending on methods, scenarios, and location) in net demand for energy in buildings but a significant increase in demand for electricity for space cooling, with further increases caused by additional market penetration of air conditioning (high confidence) (Field et al., 2007). Generally speaking, the net effects of climate change in the U.S. on total energy demand are projected to amount to

[73] According to IPCC terminology, "likely" conveys a 66 to 90% probability of occurrence. See Box 1.3 on page 4 for a full description of IPCC's uncertainty terms.

between perhaps a 5% increase and decrease in demand per 1°C in warming in buildings. Existing studies do not agree on whether there would be a net increase or decrease in energy consumption with changed climate because a variety of methodologies have been used (CCSP, 2007a).

In California, if temperatures rise according to a high scenario range (8-10.5°F; ~4.5-5.6°C), annual electricity demand for air conditioning could increase by as much as 20% by the end of the century (assuming population remains unchanged and limited implementation of efficiency measures) (California Energy Commission, 2006)[74]. In Alaska, there will be savings on heating costs: modeling has predicted a 15% decline in the demand for heating energy in the populated parts of the Arctic and sub-Arctic and up to one month decrease in the duration of a period when heating is needed (Anisimov et al., 2007).

Overall, both net delivered energy and net primary energy consumption increase or decrease only a few percent with a 1°C or 2°C warming; however, there is a robust result that, in the absence of an energy efficiency policy directed at space cooling, climate change would cause a significant increase in the demand for electricity in the U.S., which would require the building of additional electricity generation capacity (and probably transmission facilities) worth many billions of dollars (CCSP, 2007a).

Beyond the general changes described above, general temperature increases can mean changes in energy consumption in key climate-sensitive sectors of the economy, such as transportation, construction, agriculture, and others. Furthermore, there may be increases in energy used to supply other resources for climate-sensitive processes, such as pumping water for irrigated agriculture and municipal uses (CENR, 2008).

Comment [A72]: Is this a final document? Publically available?

13(b) Energy Production

Climate change could affect U.S. energy production and supply (a) if extreme weather events become more intense, (b) where regions dependent on water supplies for hydropower and/or thermal power plant cooling face reductions in water supplies, (c) where changed conditions affect facility siting decisions, and (d) where climatic conditions change (positively or negatively) for biomass, wind power, or solar energy production (Wilbanks et al., 2007).

Comment [A73]: What about the converse—increases in hydropower due to increased precipitation?

Significant uncertainty exists about the potential impacts of climate change on energy production and distribution, in part because the timing and magnitude of climate impacts are uncertain. Nonetheless, every existing source of energy in the U.S. has some vulnerability to climate variability. Renewable energy sources tend to be more sensitive to climate variables; but fossil energy production can also be adversely effected by air and water temperatures, and the thermoelectric cooling process that is critical to maintaining high electrical generation efficiencies also applies to nuclear energy. In addition, extreme weather events have adverse effects on energy production, distribution, and fuel transportation (CCSP, 2007a).

Fossil and Nuclear Energy

Climate change impacts on U.S. electricity generation at fossil and nuclear power plants are likely to be similar. The most direct climate impacts are related to power plant cooling and water availability. As currently designed, power plants require significant amounts of water, and they will be vulnerable to fluctuations in water supply. Regional scale changes would likely mean that some areas would see significant increases in water availability while other regions would see significant decreases. In those areas seeing a decline, the impact on power plant availability or even siting of new capacity could be

[74] Temperature projections for the State of California are based on IPCC global emission scenarios as discussed in Section 6(a).