February 13, 2007

John Kim, Esq.,
Hearing Officer
Illinois EPA
1021 N. Grand Ave, E.,
Springfield, IL 62794-9276

Re: Christian County Generation, LLC PSD Permit
Application No. 05040027

Dear Mr. Kim:

Please find enclosed comments filed on behalf of the Sierra Club and its 28,000 Illinois members regarding the above-referenced draft construction permit. Thank you for the opportunity to comment on the draft permit. Please do not hesitate to contact me if you have any questions about our comments.

Sincerely,
/s/
Bruce Nilles
Attorney for Sierra Club

Cc: Stephen Rothblatt / EPA Region 5 (email)
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SIERRA CLUB COMMENTS
Christian County Generation, LLC
Draft Prevention of Significant Deterioration Permit
Application No. 05040027

1. A Decision To Grant This Permit Must Consider Global Warming Impacts

The international scientific consensus has indicated that the earth's climate is changing and that human activity is a major factor. International Panel on Climate Change, *Climate Change 2007: The Physical Science Basis, Summary for Policy Makers*, hereinafter IPCC 2007 (attached and available at www.ipcc.ch). The 2007 IPCC report goes on to note that:

- The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 279 ppm in 2005.
- The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years (180-300 ppm) as determined from ice cores.
- The annual carbon dioxide concentration rate was larger during the last ten yerrs (1995-2005 average: 1.9 ppm) than it has since the beginning of continuous direct atmospheric measurements (1960 – 2005 average: 1.4 ppm per year). IPCC 2007.

Fossil fuel burning is the primary contributor to increasing concentrations of CO2 (IPCC 2007).

"Warming of the climate system is now unequivocal." IPCC 2007. Eleven of the past twelve years (1995 – 2006) rank among the 12 warmest years in the instrumental record of global surface temperatures (since 1850). Id.

There can be no doubt that accelerating global warming will pose a serious danger to humans and the environment. Emissions of global warming pollutants have already doubled the risk of extreme heat waves, according to a team of scientists led by Peter Stott at the British Met Office.[1] As the scientific journal *Nature* reported, global warming pollution is linked to the European heat wave of 2003 that killed more than 15,000 people. Similarly, the U.S. EPA concludes that "[a] few degrees of warming increases the chances of more frequent and severe heat waves, which can cause more heat-related death and illness,"[2] as well as "more frequent droughts, ... greater rainfall,

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[1] Stott, *et al.*, Human Contribution to the European Heatwave of 2003, *Nature* (432:610), Dec. 2, 2004.

[2] U.S. Environmental Protection Agency, climate change web site, last updated on April 6, 2001, http://www.epa.gov/globalwarming/faq/fundamentals.html.

and possibl[e] change[s in] the strength of storms."[3] These are only a few of the threats posed by global warming. The IPCC identified the following impacts as either "likely" or "very likely" to occur as CO2 concentrations in the atmosphere increase:

- Higher maximum temperatures over most land areas;
- Higher maximum temperatures and more hot days over nearly all land areas;
- Higher minimum temperatures and fewer cold days and frost days over nearly all land areas;
- Reduced diurnal temperature range over most land areas;
- More intense precipitation events over many areas; and
- Increased summer dry conditions and associated risk of drought over most mid-latitude continents.

TAR: The Scientific Basis, 15. The NAS and EPA make similar predictions. *Climate Change Science*; *CAR*, 106. The IPCC quantifies these predictions as between 66 and 99% probable, depending on the specific environmental impact. *TAR: The Scientific Basis*, 2. By any measure, global warming will cause serious negative impacts for humans and the environment.

The extent of negative global warming impacts will depend on the amount of CO2 emitted into the atmosphere. The NAS similarly found that the "risk [to human welfare and ecosystems] increases with increases in both the rate and the magnitude of climate change." *CAR*, 254. Simply put, the more CO2 humans release into the atmosphere, the more serious the impacts on the environment.

In 2001, the US Global Change Research Program released *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*,[4] (*National Assessment*) predicting effects of climate change for each region in the U.S. According to the National Assessment, effects on Illinois are expected to be significant and severe. Increased average temperatures and increased evaporation are expected—leading to net soil moisture declines, particularly in the southern part of the region. In other words, drought conditions in Southern Illinois are expected to worsen.

These types of weather conditions, which will increase as global warming worsens, have already caused serious health, welfare, and economic problems in the region. For example, "[a] short-term heat wave in July 1995 caused the death of over 4,000 feedlot cattle in Missouri. The severe drought from Fall 1995 through Summer 1996 in the agricultural regions of the southern Great Plains resulted in about $5 billion in damages." *Id.* at 61.

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[3] U.S. Environmental Protection Agency, climate change web site, last updated on April 6, 2001, http://www.epa.gov/globalwarming/faq/moredetail.html.

[4] National Assessment Synthesis Team, Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, US Global Change Research Program, Washington DC, 2000 (National Assessment Overview).

The *National Assessment* also predicts that "a reduced risk of life-threatening cold and an increased risk of life-threatening heat are likely to accompany warming." *National Assessment Overview*, 55. With the increased heat, air pollution is also likely to worsen. *TAR: Impacts*, 764. "Without strict attention to regional emissions of air pollutants, the undesirable combination of extreme heat and unhealthy air quality is likely to result." *National Assessment Overview*, 55. In other words, bad air quality will accompany the droughts predicted for Illinois as a result of global warming. Additionally, increases in global temperature may also cause flooding, which poses a direct threat to human health. *TAR: Impacts*, 762. Such floods pose a danger due to rising flood waters, but also due to the health threat posed by the agricultural and other non-point source pollution washed into surface water and groundwater supplied during floods. *National Assessment Overview*, 54.

Illinois agriculture is particularly sensitive to the degree of warming because of the existing threats of heat waves, flooding and drought. Unless releases of global warming pollution are curbed and then significantly decreased, global warming pollution will pose significant threats to the health, welfare, and economy of Illinois.

The IEPA must do its part to prevent these dire health and environmental threats by prohibiting, or at a minimum mitigating, the 3-4,000,000 tons of CO_2 pollution that would result from the proposed project annually. Said another way, this project would add the carbon emissions from adding approximately 500,000 cars per year for each of the next fifty years.[5]

There are at least four ways in which IEPA must consider the global warming impacts associated with this proposed project: (1) as part of the endangered species act consultation process; (2) as a non-regulated criteria pollutant in the BACT analysis, (3) as a public nuisance under the State Implementation Plan; (4) and in the alternatives analysis under CAA Section 165.

a. The ESA Consultation Must Consider Global Warming Impacts

The federal Endangered Species Act, 16 U.S.C. § 1531 et seq., was enacted, in part, to provide a means whereby ecosystems upon which endangered species and threatened species depend may be conserved ...[and] a program for the conservation of such endangered species and threatened species ..." 16 U.S.C. § 1531(b). The ESA is the most comprehensive legislation for the preservation of species ever enacted by any nation." *Tennessee Valley Authority v. Hill*, 437 U.S. 153, 180 (1978). The Supreme Court's review of the ESA's language, history, and structure" convinced the Court "beyond a doubt" that "Congress intended endangered species to be afforded the highest of priorities." Id. at 174. "[T]he plain intent of Congress in enacting this statute was to halt and reverse the trend toward species extinction, whatever the cost." *Id.* at 184.

[5] See EPA Office of Air and Radiation. Factsheet EPA420-F-00-013 "Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks: Emission Facts

Section 2(c) of the ESA establishes that it is "the policy of Congress that all Federal departments and agencies shall seek to conserve endangered species and threatened species and shall utilize their authorities in furtherance of the purposes of the Act." 16 U.S.C. § 1531(c)(1). The term "conservation" is defined to mean "the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to the Act are no longer necessary.'" 16 U.S.C. § 1532(3).

Section 7 consultation is required for "any action [that] may affect listed species or critical habitat." 50 C.F.R. § 402.14. "Agency "action" is defined in the implementing regulations to include:

> all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies in the United States or upon the high seas. Examples, include, but are not limited to: (a) actions intended to conserve listed species or their habitat; (b) the promulgation of regulations; (c) the granting of licenses, contracts, leases, easements, rights-of-way, permits or grants-in-aid; or (d) action directly or indirectly causing modifications to the land, water, or air.

50 C.F.R. § 402.02.

The most significant environmental issue associated with IEPA's decision to grant or deny the proposed project and that may affect listed species is the enormous amount of global warming pollution that this project would, if approved, release annually. In short, the action of granting this permit will cause directly and indirectly the emissions of 3-4,000,000 tons of carbon dioxide per year for the foreseeable future. According to the Oak Ridge National Laboratory there are over seventy (70) countries that emit, in total, less carbon dioxide annually than would be emitted from this proposed project. Countries that emit less than 4 million tons of carbon dioxide annually include Iceland, Georgia, Democratic Republic of Congo Tibet, Cameroon, and Nicaragua.[6]

Global warming emissions are already having direct and indirect impact on numerous listed species and the additional pollution associated with this project will further exacerbate this problem. Therefore, the global warming pollution associated with the proposed project "may affect" multiple listed species, and thereby triggering the consultation requirement. While virtually every listed species is likely to be affected to some degree by global warming, these comments focus on two listed coral species, the elkhorn and staghorn corals, as the final listing rule for these species specifically discussed the impacts of global warming and global warming emissions on the species. *See* 71 Fed. Reg. 26,852. As such, EPA/IEPA cannot claim they are outside of the "action area" or that such impacts are unforeseen. Other species that could be reasonably

[6] http://cdiac.ornl.gov/trends/emis/top2003.tot

affected by global warming include all listed species that rely on the prairie potholes in the Dakotas, and cold-water dependant species in the Upper Midwest.

Coral reefs are among the first ecosystems to show significant adverse impacts of global warming. An estimated 30 percent are already severely degraded and as much as sixty percent may be lost by 2030. The primary cause of coral reef degradation is the bleaching associated with the expulsion of symbiotic algal zooxanthellae from coral due to elevated sea temperatures. As the authors of the journal *Science* put it:

> The link between increased greenhouse gases, climate change, and regional-scale bleaching of corals, considered dubious by many reef researchers only 10 to 20 years ago, is now incontrovertible. Moreover, future changes in ocean chemistry due to higher atmospheric carbon dioxide may cause weakening of coral skeletons and reduce the accretion of reefs, especially in higher latitudes. The frequency and intensity of hurricanes (tropical cyclones, typhoons) may also increase in some regions, leading to a shorter time for recovery between recurrences. The most pressing impact of climate changes, however, is episodes in coral bleaching and disease that have already increased greatly in frequency and magnitude over the past 30 years.

Hughes et al. (2003).

Elkhorn and staghorn coral were as recently as thirty years ago the dominant reef building corals in the Caribbean and Gulf of Mexico (Precht and Aronson, 2004). They have subsequently declined by upwards of 90 percent. *Id.* The primary drivers of the decline have been disease and temperature-induced bleaching. 71 Fed. Reg. 26,852; (Pandofi et al, 2005). The coral diseases impacting the species have also been linked to elevated water temperatures. (Harvell et al. 2002). As the National Marine Fisheries Service stated: "The major threats to these species' persistence (i.e. disease, elevated sea surface temperatures, and hurricanes) are severe, unpredictable, have increased over the past 3 decades, and at current levels of knowledge, the threats are unmanageable." 71 Fed. Reg. at 26,858. Each of these threats is directly linked to global warming pollution.

Carbon dioxide emissions are also causing ocean acidification, and further inhibiting coral growth:

> Along with elevated sea temperatures, atmospheric carbon dioxide levels have increased in the past century, and there is no apparent evidence the trend will not continue. As atmospheric carbon dioxide is dissolved in surface seawater, seawater becomes more acidic, shifting the balance of inorganic carbon away from carbon dioxide and carbonate to bicarbonate. This shift reduces the ability of the corals to calcify because corals are thought to use carbonate, not bicarbonate, to build their aragonite skeletons. Experiments have shown a reduction or coral calcification in response to elevated carbon dioxide levels; therefore, increased carbon

dioxide levels in seawater may be contributing to the status of the two species.

71 Fed. Reg. at 26,858-9. The impacts of global warming pollution and global warming on the elkhorn and staghorn corals are well established. USEPA/IEPA cannot ignore these impacts and abrogate their ESA responsibilities.

There are numerous opportunities for mitigating the carbon dioxide emissions associated with the proposed project. First, the project could be designed to expeditiously capture and attempt to store underground in geologic formations a significant portion of the project's proposed CO2 emissions. The current proposal to have the project "capture ready" does nothing to advance the critical question facing the entire coal industry – whether coal can have a future in a carbon-constrained world.

Second, this new source of carbon dioxide could be conditioned on the closure of existing sources of carbon dioxide, similar to the recent Springfield settlement. Third, the project's efficiency (and reduce the need for fossil fuels generally) could be improved by co-locating an industry that could utilize the waste heat/steam, such as a new ethanol or bio-diesel plant.

b. Carbon Dioxide Must Be Considered In the BACT Collateral Impacts Analysis

Even in the absence of USEPA regulating carbon dioxide, IEPA must still consider carbon dioxide as a non-regulated pollutant in the BACT analysis. This "collateral impacts" analysis is intended to target pollutants that are otherwise unregulated under the PSD provisions.

i. A Stringent Output-Based Standard Would Minimize CO2 Emissions

Carbon dioxide emissions are directly related to the amount of coal burned. The more coal (or syngas) burned to produce a megawatt of electricity, the more carbon dioxide emitted. Similarly, the less coal burned the lower the emissions of regulated pollutants.

In the top-down BACT analysis for each regulated pollutant IEPA must consider output based limits.

As part of the new NSPS standards USEPA adopted output-based standards as a step towards minimizing inefficient and unnecessarily polluting boilers. In the analysis for the new NSPS standards USEPA identified that boiler efficiency can vary enormously. See Memo from Christian Fellner USEPA to Utility, Industrial and Commercial NSPS File, *Gross Efficiency of New Units* (February 2005). The following table from that same memo and identified as Table 2 describes the range of efficiencies:

Table 2: EIA 2003 Annual Efficiency Values

Percent of Units Operating at or Above Gross Efficiency	**Net Efficiency**
Top 10%	35.0%
Top 20%	34.0%
Top 25%	33.6%
Top 33%	33.2%
Top 50%	32.0%

USEPA further explained that the highest efficiency subbituminous, bituminous, and lignite facilities are 43, 38, 37 percent respectively.

In a paper presented by three USEPA combustion experts at the 2005 Pittsburgh Coal Conference they detailed the enormous difference in the efficiency (i.e. the CO2 emissions per ton of coal burned) between sub-critical, super-critical, ultra-supercritical and IGCC coal plants. See Sikander Khan et al, *Environmental Impact Comparisons IGCC vs. PC Plants* (Sept. 2005) (attached). Following is Table 2 from that paper:

TABLE 2

THERMAL PERFORMANCE COMPARISONS, IGCC VS. PC PLANTS

Plant Configuration	IGCC Bit Coal	IGCC Sub-Bit Coal	IGCC Lignite	PC Sub-Crit. Bit Coal	PC Sub-Crit. Sub-Bit Coal	PC Sub-Crit. Lignite	PC Sup-Crit. Bit Coal	PC Sup-Crit. Sub-Bit Coal	PC Sup-Crit. Lignite	PC Ultra Sup-Crit. Bit Coal	PC Ultra Sup-Crit. Sub-Bit Coal	PC Ultra Sup-Crit. Lignite
Net Thermal Efficiency, % HHV	41.8	40.0	38.4	35.9	34.8	33.1	38.3	37.9	35.8	42.7	42.1	37.9
Heat Rate, Btu/kWh (HHV)	8,167	8,520	8,897	9,500	9,800	10,300	8,900	9,000	9,500	8,000	8,100	9000
Gross Power, MWe	564	575	591	540	541	544	540	541	544	543	543	546
Internal Power, MWe	64	75	91	40	41	44	40	41	44	43	43	46
Fuel required, lb/h	349,744	484,089	741,063	407,143	587,331	857,954	381,418	539,384	791,288	342,863	485,445	749,624
Net Power, MWe	500	500	500	500	500	500	500	500	500	500	500	500

Legends:

	IGCC	Integrated gasification combined cycle
	PC:	Pulverized coal
	Bit Coal:	Bituminous Coal
	Sub-Bit. Coal:	Sub-bituminous Coal
	Sub-Crit.	Sub-critical boiler
	Sup-Crit.	Supercritical boiler
	Ultra Sup-Crit.	Ultra-supercritical boiler
	HHV	Higher heating value of coal

To minimize the emissions of carbon dioxide IEPA should insert a permit provision requiring the project proponent to maintain a net thermal efficiency at or above 41 percent. Such a term would minimize both the emissions of regulated pollutants and the collateral emissions of carbon dioxide.

ii. Clean Fuels Can Reduce Regulated Pollutants and CO2

Contrary to the plain language of the Act, the agency has not considered clean fuels in its BACT analysis. For some inexplicable reason the agency sets two BACT limits, one for syngas and one for natural gas. If the proposed facility can burn natural gas then it must be considered an available clean fuel in a top-down BACT analysis and may only rejected in favor of syngas in accordance with the procedures detailed in the 1990 NSR Manual. Similarly, there is no discussion of the feasibility of blending biomass into the fuel mix as a way to mitigate the emissions of criteria pollutants and "non-regulated pollutants," such as carbon dioxide. Every increment of additional natural gas or biomass that displaces syngas means less regulated pollutant emissions associated with the burning of syngas and less carbon dioxide emissions. Governor Blagojevich has committed to moving the state forward with investments in bio-fuels.

> Last summer, I unveiled an ambitious plan to meet our energy needs by investing in clean, homegrown energy sources that will cut our greenhouse gas emissions. My plan calls for investing in pollution-free wind power and cleaner burning renewable fuels made from crops like corn and soybeans. It also calls for a significant increase in energy saving technologies that will reduce greenhouse gases while cutting utility bills for families and businesses.[7]

IEPA must require a lawful top-down BACT analysis for each regulated pollutant, including SO2, NOx, PM and SAM, that considers the use of cleaner fuels (natural gas and gasified biomass) as a way to minimize emissions of regulated pollutants and the collateral benefits associated with reducing overall CO2 emissions as well.

c. IEPA May Not Increase Emissions of Global Warming

IEPA is prohibited from granting this permit without mitigating the global warming impacts because it would allow the project proponent to emit carbon dioxide (and other greenhouse gases such as nitrous oxide) in such quantities that would cause or tend to cause air pollution. The State Implementation Plan states: "[N]o person shall cause or threaten or allow the discharge or emission of any contaminant into the environment in any State so as, either alone or in combination with other sources, to cause or tend to cause air pollution in Illinois." 35 Ill. Admin. Code § 201.141.

The term "air pollution" is further defined to mean "the presence in the atmosphere of one or more air contaminants in sufficient quantities and of such characteristics and duration as to be injurious to human, plant, or animal life, to health …." 35 Ill. Admin. Code § 201.102.

Governor Blagojevich has recognized that global warming is a serious threat to Illinois and its residents.[8]

[7] http://www.illinois.gov/PressReleases/ShowPressRelease.cfm?SubjectID=3&RecNum=5697
[8] http://www.illinois.gov/PressReleases/ShowPressRelease.cfm?SubjectID=3&RecNum=5697

... we can cut greenhouse gases that contribute to global warming, rising sea levels, and deadly storms like Hurricane Katrina, while also conserving energy and preserving the environment for our children and all future generations. I urge the President and Congress to follow the lead of states like ours by acting on the latest global warming report and taking aggressive steps to curb this looming problem.

Based on the discussion above and the actions of the state of Illinois, carbon dioxide constitutes air pollution and adding more global warming pollution will accelerate global warming and cause further harm human, plant and animal life. IEPA may not issue a permit that will cause additional injury to human health and the health of animal and plant life.

As demonstrated in the recent Springfield settlement, it is possible to approve the construction of a new source of carbon dioxide conditioned on achieving overall carbon reductions through strategic investments in the retiring of existing sources, adding large amounts of clean wind power and boosting spending on energy efficiency measures.

d. IEPA Must Consider Global Warming Under the Alternatives Analysis

CAA Section 165(a)(2) provides that a PSD permit may be issued only after an opportunity for a public hearing at which the public can appear and provide comment on the proposed source, including "alternatives thereto" and "other appropriate considerations." 42 U.S.C. § 7475(a)(2).

There are numerous options to building a new coal plant. As the City of Springfield has demonstrated, it is possible to build new coal and through a combination of closing old, inefficient boilers, large investments in wind power and energy efficiency, curb overall carbon dioxide emissions.

If IEPA does elect to issue this permit, we urge the agency to condition approval of the proposed permit on agreement by the project proponent to curb overall CO_2 emissions associated with providing electricity to its customers by 25 percent below 2005 levels by 2012 (i.e. meet the Kyoto Protocol reductions). This approach is consistent with the Governor's stated goal for his new Global Warming Task Force: Identify strategies to curb global warming emissions to 1990 levels by 2020 and 60 percent by 2050.

2. Particulate Matter BACT

The draft permit proposes a PM filterable limit of 0.0090 lb/MMBtu and a total PM limit of 0.022 lb/MMBtu, both limits based on a 3-hour block average. The proposed filterable PM limit is identical to the filterable PM limit in the final PSD permit for the EKPC Spurlock 4 CFB unit in Kentucky. The proposed total PM limit is higher than the total PM limit for that same Kentucky facility (0.012 lb/MMBtu). IEPA does indicate that the proposed input-based PM limits for the proposed project cannot be compared to the limits for other coal boilers (project summary at 8), but does not explain why.

a. Cleaner Fuels

There are at least two fuels that are cleaner than synfuel that must be considered in the top-down BACT determination for each of the regulated pollutants, including particulate matter. The draft permit sets PM limits for when the facility is burning natural gas (0.007 lb/MMBtu filterable and 0.011 lb/MMBtu for total PM). These proposed PM limits when the project is firing natural gas are lower than the PM limits for firing synfuel. Therefore, the top-down BACT analysis must consider the use of cleaner fuels, including natural gas, as available clean fuels. Since the facility is specifically designed to be able to fire natural gas, alone or in combination with syngas, there is no argument that burning gas would "redefine the source."

Similarly, by burning a mix of natural gas with syngas, the source could lower both the pound-per-MMBtu emission rate and the hourly emission rate for each of the regulated pollutants, including PM. While natural-gas fired generation must be considered, as noted above, a BACT analysis must also consider mixing natural gas with syngas. If the cost effectiveness of combusting gas, or a combination of gas and syngas, is within the range generally accepted as cost-effective for similar sources (i.e., under $10,000 per ton of pollutant removed), the BACT limit for PM must be established based on a BACT analysis that factors in natural gas.

Another available clean fuel that has received no discussion in the agency's top-down BACT analysis is biomass. There are numerous examples of coal plants co-firing biomass that should be considered in the top-down BACT analysis. For example, the St. Paul heating plant burns approximately sixty percent biomass and forty percent coal.[9] The biomass is primarily waste wood from tree trimmings in the Twin Cities and other industrial activities. The Xcel Bay Point power plant in Ashland, Wisconsin, also burns large amounts of wood waste, consisting primarily of saw dust. This is also consistent with Governor Blagojevich's recent commitment to expanding the use of locally-grown bio-fuels.

The U.S. Department of Energy has urged federal facility managers to consider co-firing up to 20 percent biomass in existing coal-fired boilers.[10] In the Netherlands, the four electricity generation companies (EPON, EPZ, EZH and UNA) have all developed plans to modify their conventional coal fired installations to accommodate woody biomass as a co-fuel.[11] The types of available biomass include wood wastes, agricultural waste, switchgrass and prairie grasses.[12]

[9] http://www.districtenergy.com/
[10] http://www1.eere.energy.gov/biomass/pdfs/33811.pdf
[11] http://www.eeci.net/archive/biobase/B10252.html
[12] http://www.nsf.gov/news/news_summ.jsp?cntn_id=108206

The PM BACT analysis must consider the burning of biomass, natural gas, and syngas.

b. Post-Combustion Controls

IEPA rejected consideration of post combustion PM controls for this proposed project, including an electrostatic precipitator or filtration, on the grounds that their use in combination with pre-combustion controls would be "a theoretical approach to emission control that should not be attempted at the proposed plant." Project Summary at 8. This is not a legitimate basis for rejecting post-combustion controls. Electrostatic precipitators and baghouses are widely used as post-combustion controls on new and existing coal plants. IEPA has not identified any technical reason why such controls could not be used on an IGCC plant. The PM BACT analysis must be redone with, at a minimum, a consideration of an ESP and/or baghouse. IEPA may only reject post-combustion controls if does so in accordance with a legitimate top-down BACT analysis.

c. PM CEMS

In 2004, EPA promulgated final performance specifications, PS-11, for installation, operation, maintenance, and quality assurance of continuous particulate matter emission monitoring systems (PM-CEMS). Since the PSD program is supposed to be technology forcing, requiring a PM-CEMS to ensure compliance with the PM permit limits would be consistent with that goal. Moreover, utilities can emit large amounts of particulate matter when pollution sources and/or control devices are not function properly and PM-CEMS can help identify such compliance issues. *See* USEPA Region 7 Sunflower PSD Comments.

Kentucky recently required the use of a PM CEMS in the PSD permit for the EKPC Spurlock 4 CFB project. There is extensive experience of PM CEMS on coal plants as a result of numerous NSR settlements around the country, including in Illinois. We urge IEPA to require the use of a PM CEMS and that a PM CEMS is required for determining compliance with the permit's PM filterable limit.

d. Bulk Handling, Storage, Processing and Loadout Operations

For some inexplicable reason IEPA failed to set BACT limits for each of the bulk handling facilities. In fact, the bulk handling provisions of this permit are really odd and look nothing like the bulk storage requirements IEPA has established in other coal plant PSD permits, including the permits for Indeck, Prairie State and the City of Springfield. This section of the permit needs significant work. In short, IEPA needs to identify each of the emission units (coal handling, coal storage, etc) and establish through a lawful top-down BACT analysis appropriate BACT limits for each unit.

The problems with the draft permit are extensive. For example, the draft permit establishes the following coal handling requirements: "For receiving and storage of coal, for which total enclosure is not practicable, measures must be used to very effectively reduce the generation of emissions." Draft Permit at 43. This is unenforceable language and cannot represent BACT.

The top-down BACT analysis must start with the limits IEPA has required in other permits, including the limit of no greater than 0.005 grains/dry standard cubic foot and no visible emissions, based on the permit IEPA issued for the proposed Indeck-Elwood facility. See Indeck Permit at 27. The top-down analysis must also include enclosure as a viable control option as was required in Indeck and other PSD permits.

IEPA also needs to set BACT limits for bulk materials other than coal, including for slag handling. In its project summary IEPA states that given the size of the plant property and location in an agricultural area "the BACT determination need not require storage of bulk dry materials in building or silos." Project Summary at 15. In contrast, the draft permit states "bulk materials other than coal or slag that have the potential for PM emissions shall be stored in silos, bins, and building, without storage of such materials in outdoor piles except on a temporary basis." Draft Permit at 45. Neither requirement constitutes BACT.

e. Cooling Towers

The Draft Permit establishes a limit that requires the cooling tower to "utilize 0.0005% Drift Eliminators." Draft Permit, at 54. This is not BACT, and it is not an enforceable emission limit. First, a drift efficiency control rate, by itself, does not correspond to a PM emission rates. PM is formed by dissolved solids in the circulating water. The drift is emitted from the cooling towers, the water is evaporated, leaving the solids that become particulate matter. The percent of the circulating water that is emitted (drift rate), by itself, is not a measure of particulate emissions.

Second, an emission rate, calculated from the drift fraction, TDS, and circulating water flow rate should be established as the permit limit for the cooling tower, based on a top-down BACT analysis. The draft permit sets a drift rate and requires that TDS be measured, but it falls short as it does not set an emission rate or maximum TDS level in the circulating water flow. Absent a limit on the dissolved solids in the circulating water, a 0.0005% drift efficiency rate does not limit total PM emissions. If IEPA relies on cooling tower drift eliminators to establish BACT, the Permit must include a limit on the dissolved solids and circulating water flow rate based on the lowest concentration achievable.

Third, the permit does not require any emissions testing. Draft Permit at 55. The permit must require monitoring of dissolved solids and an initial test and periodic testing of drift rates.

Fourth, a cooling tower with drift eliminators is not the least polluting technology, and does not constitute BACT. Use of an air cooled condenser ("ACC"), an alternative method, system or technique of cooling within the definition of BACT, is available and has lower PM emissions than a cooling tower with drift eliminators. ACCs have been used on large coal-fired power plants for over 25 years. The 330 MW Wyodak coal-fired power plant in Wyoming has successfully operated with an ACC for over 25 years. The largest ACC-equipped coal fired power plant in the world, the 4,000 MW Matimba facility in South Africa, has been operating successfully for over 10 years. Two coal-fired units in Australia with condenser heat rejection rates nearly identical to that proposed for Weston Unit 4 have been operational since 2002. A number of new coal-fired power plants have been proposed in New Mexico over the last three years. In all cases the project proponents have voluntarily incorporated ACC into the plant design to minimize plant water use. A 36 MW pulverized coal unit in Iowa, Cedar Falls Utilities Streeter Station Unit 7, was retrofit with dry cooling in 1995 due to highway safety concerns caused by the wet tower plume in winter. The use of dry cooling is well established.

The application of an AAC would eliminate nearly all of the PM emissions from the cooling process. Therefore, unless AAC can be rejected in a top-down BACT analysis, based on site-specific collateral impacts, it must be used to establish BACT. AAC cannot be eliminated based on cost, especially because it must be compared to the total cost of a cooling tower, including the towers, raw water clarification system, and intake structures. Moreover, use of AAC has additional environmental benefits, including no water withdrawals for cooling, no brine discharge to river, no aesthetic issues related to visible vapor plumes, no cooling tower drift emissions or particulate deposition.

Other potential options to reduce PM/PM10 emissions from the cooling process include a plume abated tower and a wet/dry system. Like ACC, these alternative processes result in lower emissions and, therefore, must be considered in a top-down BACT analysis. The applicant's analysis fails to identify, much less consider these options for reducing PM/PM10 emissions. A revised BACT analysis must be conducted for the cooling process.

3. Nitrogen Oxide BACT

a. No BACT For Natural Gas

The draft permit does not limit the use of natural gas as a fuel. As explained elsewhere, BACT requires the consideration of natural gas as an available clean fuel control measure in the top-down BACT determination for each regulated pollutant. Given that the applicant can use natural gas exclusively – and BACT may require as much – the NOx BACT determination must also include consideration of low-NOx combustion controls. In its project summary IEPA rejects the use of low-NOx combustion controls on the basis that such controls are allegedly only effective when burning natural gas and natural gas will only be used as a back up fuel. However, because there is no permit limit restricting the use of natural gas IEPA cannot simply allege that natural gas will be used as a back-up fuel and fail to conduct a top-down BACT analysis that considers low-NOx combustion controls in combination with natural gas.

b. The NOx Limit Does Not Protect NAAQS & Increments

The permit sets a NOx BACT limit for syngas at 0.034 lb/MMBtu and for natural gas at 0.025 lb/MMBtu, both based on a 24-hour average. NOx is a precursor for ozone and the current ozone NAAQS is 0.08 ppm based on an 8-hour averaging time. The permit does not explain how the proposed 24-hour NOx limits adequately ensure that the proposed project does not cause a violation of the 8-hour ozone standard. It must.

4. Sulfur Dioxide BACT for Combustion Turbines

The permit limits the use of fuel to syngas that has been processed by the syngas cleanup system. Draft permit at 25. However, the only limitation on the sulfur content of the syngas is the requirement that it meet a SO2 limit of 10ppm by volume. Draft Permit at 26. There does not appear to be any clean fuel consideration applied to this standard. For example, as described above in the PM BACT discussion, there does not appear to have been any consideration of the use of natural gas and/or biomass either in whole or in part as a clean fuel control method to minimize the emissions of criteria pollutants, including sulfur dioxide. The SO2 top-down BACT determination for the CTs must include consideration of natural gas and gasified biomass. The use of natural gas is consistent with Draft Permit Condition 4.2.2.a.i that lists natural gas as a control technology to limit emissions of SO2 and PM.

5. Sulfuric Acid Mist BACT

The Draft Permit contains a SAM limit of 0.0035 lb/MMBtu on a three-hour block average. Draft Permit at 26. This purports to be a BACT limit, but appears high given the related SO2 emission rate. In 2002 the AES Puerto Rico permit for a coal-fired CFB plant had a SAM emission limit of 0.0024 lb/MMBtu.

We urge IEPA to consider a lower SAM limit and the use of a Wet Electrostatic Precipitator in a top-down BACT determination. The use of WESPs are now common on new coal plants burning high-sulfur coal (see e.g. Prairie State) and we are not aware of any obvious technical reasons why a WESP could not be used on an IGCC plant as well.

6. Visible Emission (Opacity)

The permit contains an opacity limit of 20%, except that a maximum of twenty-seven percent for not more than 1 six-minute per hour. Draft Permit at 27. This emissions limit is based on the NSPS standard, and not on BACT level control. See Draft Permit at 27. The Draft Permit is therefore deficient. The permit must contain a visible emission limit for regulated pollutants (i.e., PM and SAM)[13] that is based on the maximum degree of reduction achievable with the best pollution control option for the proposed facility.

A PSD permit must require BACT for all regulated pollutants. BACT is defined as an "emissions limitation, including a visible emission standard..." 42 U.S.C. § 7479(3); 40 C.F.R. § 52.21(b)(12). Although a BACT limit for PM or SAM typically includes an

[13] A visible emission standard is a limit on "light scattering particles," which include both fine particulate matter ("PM") and sulfuric acid mist ("SAM") aerosols. Both PM and SAM are regulated under PSD and, therefore, a complete PSD permit must contain a BACT limit which includes a visible emission limit based on BACT for PM and SAM.

emission rate limit (i.e., pounds per hour or pounds per million Btu heat input), a BACT limit must nevertheless also "includ[e] a visible emission standard." Id. Other recent coal plant permits include visible emission as part of the BACT limits for those facilities. For example, the Springerville facility in Arizona has a BACT limit of 15% opacity, and the Mid-America facility in Council Bluffs has an opacity limit of 5 percent. See Iowa DNR Permit No. 03-A-425-P, §10a (Permit available online at http://aq48.dnraq.state.ia.us:8080/psd/7801026/PSD_PN_02-258/03-A-425-P-Final.pdf, last visited October 28, 2005). The Wisconsin Department of Natural Resources set a 10% opacity limit as BACT for the Fort Howard (Fort James) Paper Company's 500 MW CFB boiler. The Minnesota Pollution Control Board also considered the issue and determined that a 5% opacity limit should be established based on BACT. The maximum achievable visible emission reduction for a combustion turbine, however, is much lower than 20% opacity. For example, the JEA Northside CFB in Jacksonville, Florida, conducted a compliance test during the summer of 2002, while burning high-sulfur coal, and measured opacity of less than 2%. William Goodrich, et al., Summary of Air Emissions from the First Year Operation of JEA's Northside Generating Station, Presented at ICAC Forum '03, p. 16. Testing done by Black & Veatch for the Department of Energy showed visible emissions at the JEA facility of 1.1% and 1.0% opacity. See Black & Veatch, Fuel Capability Demonstration Test Report 1 for the JEA Large-Scale CFB Combustion Demonstration Project, DOE Issue Rev. 1 p. 12 (Sept. 3, 2004). Also, the City of Springfield agreed to a lower opacity limit.

The final permit must contain BACT limits that include a visible emission standard for the combustion turbines. The BACT limits for PM and SAM must include a visible emission limit of no more than 2% opacity based on the results of testing at the JEA Northside facility. See Goodrich, *supra*, p. 16. In other words, if opacity at a CFB plant can be limited to less than 2 percent opacity, the project applicant must explain why it cannot meet such a limit when firing syngas, a fuel with lower particulate matter emissions than solid coal.

7. Start up and shutdown BACT

   a. Sulfur Recovery Unit.

The draft permit sets a startup, shutdown and malfunction limit of 201 lbs of SO2/hour for the sulfur recovery unit. Draft Permit at 13. This is problematic. First, IEPA cannot set a limit for periods of malfunction. The project proponent has an obligation at all times to minimize the time and degree of any malfunction. IEPA cannot create a blanket amnesty for a certain degree and period of malfunction. Second, there are no obvious reasons why the permit could not require the use of natural gas during periods of startup and shutdown of the sulfur recovery unit and thereby avoid the firing of high-sulfur syngas during these periods. In Condition 4.1.2.1.c.iii the draft permit does require the use of natural gas during periods of gasifier startup. Accordingly, the use of natural gas must be considered in setting a top-down SO2 BACT limits for the sulfur recovery unit during periods of start up and shutdown. The existing limit does not constitute BACT.

b. Combustion Turbines Lack Startup & Shutdown Limits

The draft permit does not appear to have any meaningful start up or shutdown limits for the combustion turbines for any pollutants, except SO2. Proposed Condition 4.2.2 exempts periods of start up and shutdown from any input-based limits for PM (both filterable and total), NOx, CO and sulfuric acid mist. The only other applicable limits to these pollutants appear to be the annual limits in Table 1 of Attachment 1. Annual limits are not sufficient to meet the requirement that a PSD permit include BACT startup and shutdown limits for each regulated pollutant and protect air quality standards. In setting lawful startup and shutdown BACT limits IEPA must consider the use of cleaner fuels, *i.e.* other than syngas, such as natural gas and/or gasified biomass. If IEPA issues a new permit with startup and shutdown BACT limits for each regulated pollutant -- as we believe it must -- the agency should explain why the public should not get an opportunity to comment on such new limits prior to being finalized.

c. Terms Should Be Defined

The term "startup" should be defined as "the period beginning with ignition and lasting until the equipment has reached a continuous operating level and operating permit limits." The term "shutdown" should be defined as the period beginning with the lowering of equipment from base load and lasting until fuel is no longer added to the combustion turbine and combustion has ceased."

8. Timing of the ESA Consultation.

The federal Endangered Species Act applies to this permit proceeding. The Environmental Appeals Board has warned that it expects that "ESA consultation would ordinarily be completed, at the very latest, prior to the issuance of the permit and, optimally, prior to the comment period on the permit, where the flexibility to address ESA concerns is the greatest." *See Indeck* (EAB, 2006). The Board cautioned IEPA not to wait until after the permit is issued because it would "tolerate an ESA violation whenever an appeal is not taken." *Id.* Despite this admonition from the Board, IEPA is now proposing to issue the second PSD permit post-*Indeck* without providing any of these procedural safeguards and without finalizing the ESA Consultation prior to the issuance of the draft permit. We urge IEPA to allow EPA to finalize the ESA consultation process and provide an additional period for public review of the consultation findings before closing the comment period on this draft permit.

As described above, the ESA consultation must consider the global warming impacts associated with building a large new source of carbon dioxide and further accelerating global warming.

9. Commencement of Construction

The draft permit provides that should the applicant fail to commence construction within 18 months of receipt of the final permit that IEPA may extend the expiration timeline.

We urge that IEPA clarify that if the permit applicant does not commence construction within 18 months that the permit is automatically void. The only exception to this hard rule is if the applicant submits a timely extension request to IEPA that includes an updated BACT and modeling analysis and that there be an opportunity for public (and USEPA) review and comment prior to IEPA acting on the extension request. This is consistent with the practice in other states, including North Dakota. In a November 9, 2006 Letter from USEPA Region 7 to Kansas Department of Health & Environment regarding the proposed PSD permit for the Sunflower coal plant proposal in West Kansas the agency wrote:

> "[A]ny … permit extension … should benefit from public and EPA peer review. Therefore, we recommend that KDHE add this additional clarification.
>
> Lastly, if Sunflower does not commence construction on one or more of the units and does not provide the analysis required by the permit in a time frame prior to the close of the 18 months period, KDHE should make clear that authorization to construct any subsequent units automatically becomes void. It is essential that Sunflower submit the reanalysis in a timely fashion or they must begin a new PSD permitting review. Again, KDHE may provide any clarification in a permit, or associated record, so there is no confusion later on.

10. New Mercury Standard Must Be Included

IEPA does not explain how the state's new landmark mercury rule would apply to this facility. We urge it to do so.

11. Permit Must Include A PM2.5 BACT Limit

The Draft Permit does not include a BACT limit for PM2.5 emissions. Nor does it appear that IEPA even considered such a limit. This is unlawful and must be corrected before a PSD permit can issue. The federal PSD program requires a BACT limit "for each pollutant subject to regulation under the Act that it would have the potential to emit in significant amounts." 40 C.F.R. § 52.21(j)(2). PM2.5 is "a pollutant subject to regulation under the Act" because EPA established a NAAQS for PM2.5 in 1997. 62 Fed. Reg. 38711; 40 C.F.R. § 50.7. Moreover, PM2.5 will be emitted from this facility in a "significant" amount because it will be emitted at "any emission rate." 40 C.F.R. § 52.21(b)(23)(ii). For these reasons a BACT limit for PM2.5 is required. 42 U.S.C. § 7475(a)(4); 40 C.F.R. § 52.21(j). Nevertheless, the Draft Permit does not contain a BACT limit for PM2.5 emissions. This is a deficiency that must be corrected before a final PSD permit can issue.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Climate Change 2007: The Physical Science Basis

Summary for Policymakers

Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

This Summary for Policymakers was formally approved at the 10th Session of Working Group I of the IPCC, Paris, February 2007.

Note:
Text, tables and figures given here are final but subject to copy-editing.

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INTRODUCTION

The Working Group I contribution to the IPCC Fourth Assessment Report describes progress in understanding of the human and natural drivers of climate change[1], observed climate change, climate processes and attribution, and estimates of projected future climate change. It builds upon past IPCC assessments and incorporates new findings from the past six years of research. Scientific progress since the TAR is based upon large amounts of new and more comprehensive data, more sophisticated analyses of data, improvements in understanding of processes and their simulation in models, and more extensive exploration of uncertainty ranges.

The basis for substantive paragraphs in this Summary for Policymakers can be found in the chapter sections specified in curly brackets.

HUMAN AND NATURAL DRIVERS OF CLIMATE CHANGE

Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties alter the energy balance of the climate system. These changes are expressed in terms of radiative forcing[2], which is used to compare how a range of human and natural factors drive warming or cooling influences on global climate. Since the Third Assessment Report (TAR), new observations and related modelling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols have led to improvements in the quantitative estimates of radiative forcing.

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (see Figure SPM-1). The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture. {2.3, 6.4, 7.3}

- Carbon dioxide is the most important anthropogenic greenhouse gas (see Figure SPM-2). The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm[3] in 2005. The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years (180 to 300 ppm) as determined from ice cores. The annual carbon dioxide concentration growth-rate was larger during the last 10 years (1995 – 2005 average: 1.9 ppm per year), than it has been since the beginning of continuous direct atmospheric measurements (1960 – 2005 average: 1.4 ppm per year) although there is year-to-year variability in growth rates. {2.3, 7.3}
- The primary source of the increased atmospheric concentration of carbon dioxide since the pre-industrial period results from fossil fuel use, with land use change providing another significant but smaller contribution. Annual fossil carbon dioxide emissions[4] increased from an average of 6.4 [6.0 to 6.8][5] GtC

[1] *Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

[2] *Radiative forcing* is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface while negative forcing tends to cool it. In this report radiative forcing values are for 2005 relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre ($W\ m^{-2}$). See Glossary and Section 2.2 for further details.

[3] ppm (parts per million) or ppb (parts per billion, 1 billion = 1,000 million) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air. For example: 300 ppm means 300 molecules of a greenhouse gas per million molecules of dry air.

[4] Fossil carbon dioxide emissions include those from the production, distribution and consumption of fossil fuels and as a by-product from cement production. An emission of 1 GtC corresponds to 3.67 $GtCO_2$.

[5] In general, uncertainty ranges for results given in this Summary for Policymakers are 90% uncertainty intervals unless stated otherwise, i.e., there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Best estimates are given where available. Assessed uncertainty intervals are not always symmetric about the corresponding best estimate. Note that a number of uncertainty ranges in the Working Group I TAR corresponded to 2-sigma (95%), often using expert judgement.

(23.5 [22.0 to 25.0] $GtCO_2$) per year in the 1990s, to 7.2 [6.9 to 7.5] GtC (26.4 [25.3 to 27.5] $GtCO_2$) per year in 2000–2005 (2004 and 2005 data are interim estimates). Carbon dioxide emissions associated with land-use change are estimated to be 1.6 [0.5 to 2.7] GtC (5.9 [1.8 to 9.9] $GtCO_2$) per year over the 1990s, although these estimates have a large uncertainty. {7.3}

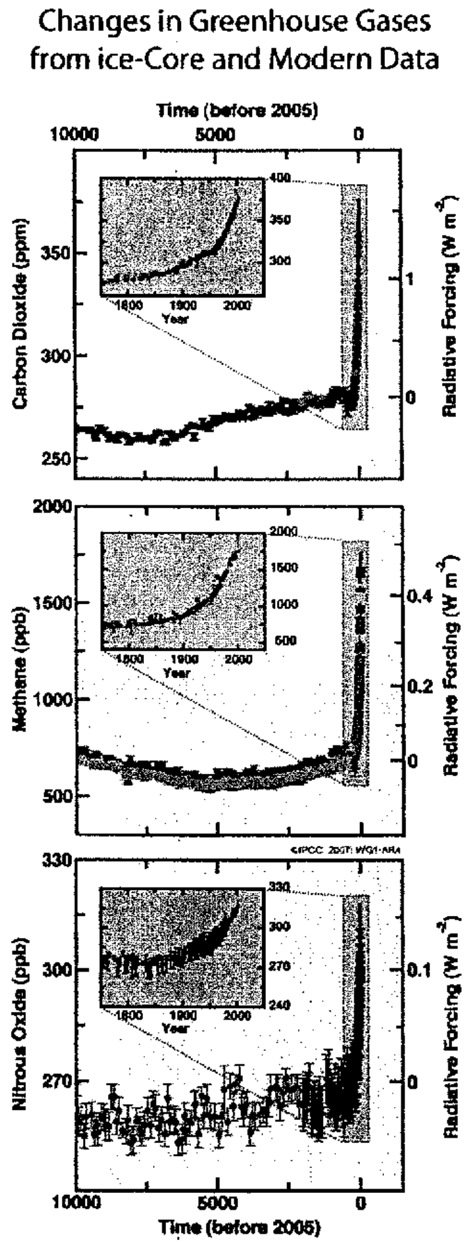

FIGURE SPM-1. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. {Figure 6.4}

- The global atmospheric concentration of methane has increased from a pre-industrial value of about 715 ppb to 1732 ppb in the early 1990s, and is 1774 ppb in 2005. The atmospheric concentration of methane in 2005 exceeds by far the natural range of the last 650,000 years (320 to 790 ppb) as determined from ice cores. Growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. It is *very likely*[6] that the observed increase in methane concentration is due to anthropogenic activities, predominantly agriculture and fossil fuel use, but relative contributions from different source types are not well determined. {2.3, 7.4}
- The global atmospheric nitrous oxide concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. The growth rate has been approximately constant since 1980. More than a third of all nitrous oxide emissions are anthropogenic and are primarily due to agriculture. {2.3, 7.4}

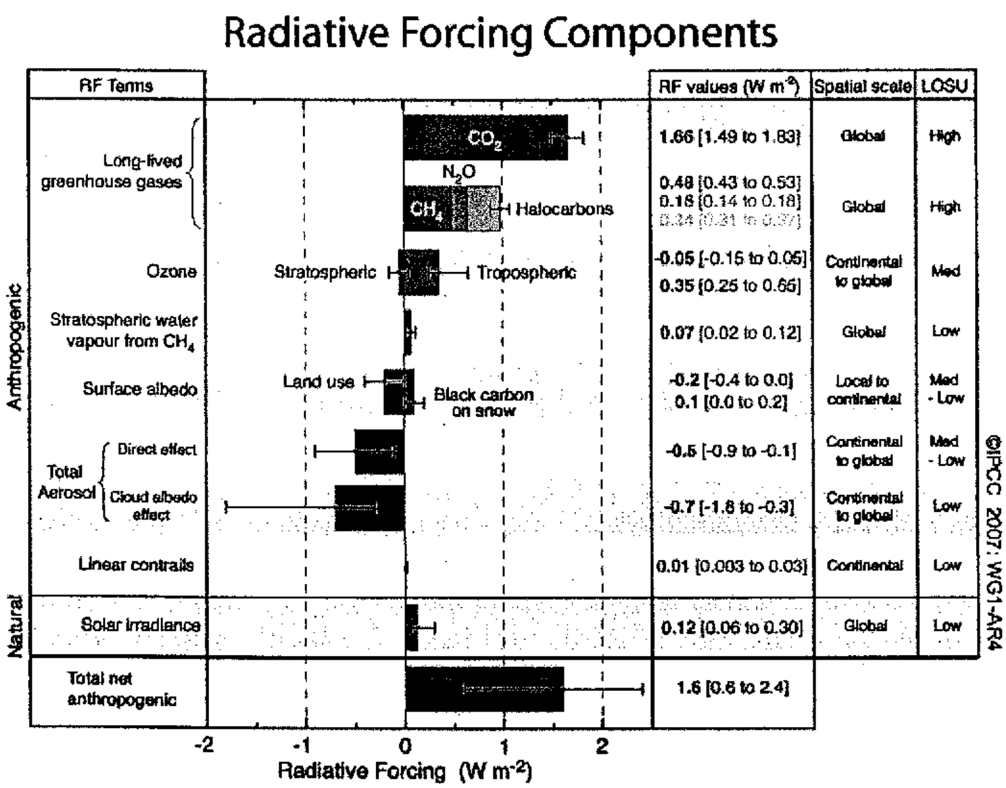

FIGURE SPM-2. Global-average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. Range for linear contrails does not include other possible effects of aviation on cloudiness. {2.9, Figure 2.20}

[6] In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%. (See Box TS.1.1 for more details).

The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to *very high confidence*[7] that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W m^{-2}. (see Figure SPM-2). {2.3. 6.5, 2.9}

- The combined radiative forcing due to increases in carbon dioxide, methane, and nitrous oxide is +2.30 [+2.07 to +2.53] W m^{-2}, and its rate of increase during the industrial era is *very likely* to have been unprecedented in more than 10,000 years (see Figures SPM-1 and SPM-2). The carbon dioxide radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years. {2.3, 6.4}
- Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of -0.5 [-0.9 to -0.1] W m^{-2} and an indirect cloud albedo forcing of -0.7 [-1.8 to -0.3] W m^{-2}. These forcings are now better understood than at the time of the TAR due to improved *in situ*, satellite and ground-based measurements and more comprehensive modelling, but remain the dominant uncertainty in radiative forcing. Aerosols also influence cloud lifetime and precipitation. {2.4, 2.9, 7.5}
- Significant anthropogenic contributions to radiative forcing come from several other sources. Tropospheric ozone changes due to emissions of ozone-forming chemicals (nitrogen oxides, carbon monoxide, and hydrocarbons) contribute +0.35 [+0.25 to +0.65] W m^{-2}. The direct radiative forcing due to changes in halocarbons[8] is +0.34 [+0.31 to +0.37] W m^{-2}. Changes in surface albedo, due to land-cover changes and deposition of black carbon aerosols on snow, exert respective forcings of -0.2 [-0.4 to 0.0] and +0.1 [0.0 to +0.2] W m^{-2}. Additional terms smaller than ±0.1 W m^{-2} are shown in Figure SPM-2. {2.3, 2.5, 7.2}
- Changes in solar irradiance since 1750 are estimated to cause a radiative forcing of +0.12 [+0.06 to +0.30] W m^{-2}, which is less than half the estimate given in the TAR. {2.7}

DIRECT OBSERVATIONS OF RECENT CLIMATE CHANGE

Since the TAR, progress in understanding how climate is changing in space and in time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade. However, data coverage remains limited in some regions.

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 (see Figure SPM-3). {3.2, 4.2, 5.5}

- Eleven of the last twelve years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature[9] (since 1850). The updated 100-year linear trend (1906–2005) of 0.74 [0.56 to 0.92]°C is therefore larger than the corresponding trend for 1901-2000 given in the TAR of 0.6 [0.4 to 0.8]°C. The linear warming trend over the last 50 years (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the last 100 years. The total temperature increase from 1850 – 1899 to 2001 – 2005 is 0.76 [0.57 to 0.95]°C. Urban heat island effects are real but local, and have a negligible influence (less than 0.006°C per decade over land and zero over the oceans) on these values. {3.2}

[7] In this Summary for Policymakers the following levels of confidence have been used to express expert judgments on the correctness of the underlying science: *very high confidence* at least a 9 out of 10 chance of being correct; *high confidence* about an 8 out of 10 chance of being correct. (See Box TS.1.1)

[8] Halocarbon radiative forcing has been recently assessed in detail in IPCC's Special Report on Safeguarding the Ozone Layer and the Global Climate System (2005).

[9] The average of near surface air temperature over land, and sea surface temperature.

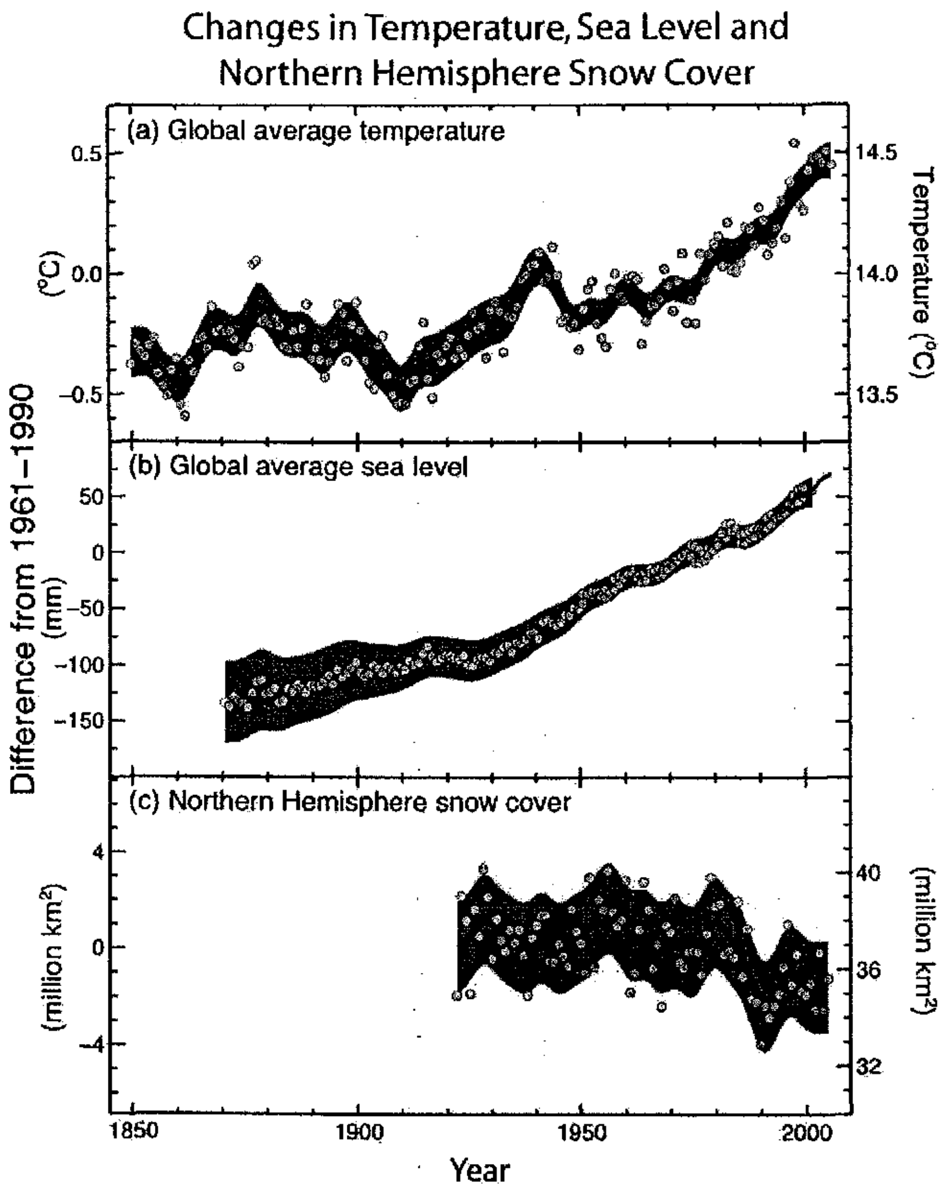

FIGURE SPM-3. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {FAQ 3.1, Figure 1, Figure 4.2 and Figure 5.13}

- New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR. {3.2, 3.4}

- The average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere. The increase is broadly consistent with the extra water vapour that warmer air can hold. {3.4}
- Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea level rise (see Table SPM-1). {5.2, 5.5}

Table SPM-1. Observed rate of sea level rise and estimated contributions from different sources. {5.5, Table 5.3}

	Rate of sea level rise (mm per year)	
Source of sea level rise	**1961 – 2003**	**1993 – 2003**
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland ice sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5[a]	3.1 ± 0.7[a]
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

Table note:
[a] Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry.

- Mountain glaciers and snow cover have declined on average in both hemispheres. Widespread decreases in glaciers and ice caps have contributed to sea level rise (ice caps do not include contributions from the Greenland and Antarctic ice sheets). (See Table SPM-1.) {4.6, 4.7, 4.8, 5.5}
- New data since the TAR now show that losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea level rise over 1993 to 2003 (see Table SPM-1). Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. Such dynamical ice loss is sufficient to explain most of the Antarctic net mass loss and approximately half of the Greenland net mass loss. The remainder of the ice loss from Greenland has occurred because losses due to melting have exceeded accumulation due to snowfall. {4.6, 4.8, 5.5}
- Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm per year. Whether the faster rate for 1993 to 2003 reflects decadal variability or an increase in the longer-term trend is unclear. There is *high confidence* that the rate of observed sea level rise increased from the 19th to the 20th century. The total 20th century rise is estimated to be 0.17 [0.12 to 0.22] m. {5.5}
- For 1993-2003, the sum of the climate contributions is consistent within uncertainties with the total sea level rise that is directly observed (see Table SPM-1). These estimates are based on improved satellite and *in-situ* data now available. For the period of 1961 to 2003, the sum of climate contributions is estimated to be smaller than the observed sea level rise. The TAR reported a similar discrepancy for 1910 to 1990. {5.5}

At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones[10]. {3.2, 3.3, 3.4, 3.5, 3.6, 5.2}

- Average Arctic temperatures increased at almost twice the global average rate in the past 100 years. Arctic temperatures have high decadal variability, and a warm period was also observed from 1925 to 1945. {3.2}
- Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. These values are consistent with those reported in the TAR. {4.4}
- Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic (by up to 3°C). The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with a decrease in spring of up to 15%. {4.7}
- Long-term trends from 1900 to 2005 have been observed in precipitation amount over many large regions[11]. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally, and data are limited in some regions. Long-term trends have not been observed for the other large regions assessed[11]. {3.3, 3.9}
- Changes in precipitation and evaporation over the oceans are suggested by freshening of mid and high latitude waters together with increased salinity in low latitude waters. {5.2}
- Mid-latitude westerly winds have strengthened in both hemispheres since the 1960s. {3.5}
- More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying linked with higher temperatures and decreased precipitation have contributed to changes in drought. Changes in sea surface temperatures (SST), wind patterns, and decreased snowpack and snow cover have also been linked to droughts. {3.3}
- The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour. {3.8, 3.9}
- Widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent (see Table SPM-2). {3.8}
- There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual numbers of tropical cyclones. {3.8}

[10] Tropical cyclones include hurricanes and typhoons.

[11] The assessed regions are those considered in the regional projections Chapter of the TAR and in Chapter 11 of this Report.

Table SPM-2. Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f, h]	*Likely*[i]

Table notes:

[a] See Table 3.7 for further details regarding definitions.

[b] See Table TS-4, Box TS.3.4 and Table 9.4.

[c] Decreased frequency of cold days and nights (coldest 10%).

[d] Warming of the most extreme days and nights each year.

[e] Increased frequency of hot days and nights (hottest 10%).

[f] Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgement rather than formal attribution studies.

[g] Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

[h] Changes in observed extreme high sea level closely follow the changes in average sea level {5.5.2.6}. It is *very likely* that anthropogenic activity contributed to a rise in average sea level. {9.5.2}

[i] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period {10.6}. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Some aspects of climate have not been observed to change. {3.2, 3.8, 4.4, 5.3}

- A decrease in diurnal temperature range (DTR) was reported in the TAR, but the data available then extended only from 1950 to 1993. Updated observations reveal that DTR has not changed from 1979 to 2004 as both day- and night-time temperature have risen at about the same rate. The trends are highly variable from one region to another. {3.2}
- Antarctic sea ice extent continues to show inter-annual variability and localized changes but no statistically significant average trends, consistent with the lack of warming reflected in atmospheric temperatures averaged across the region. {3.2, 4.4}

- There is insufficient evidence to determine whether trends exist in the meridional overturning circulation of the global ocean or in small scale phenomena such as tornadoes, hail, lightning and dust-storms. {3.8, 5.3}

A Paleoclimatic Perspective

Paleoclimatic studies use changes in climatically sensitive indicators to infer past changes in global climate on time scales ranging from decades to millions of years. Such proxy data (e.g., tree ring width) may be influenced by both local temperature and other factors such as precipitation, and are often representative of particular seasons rather than full years. Studies since the TAR draw increased confidence from additional data showing coherent behaviour across multiple indicators in different parts of the world. However, uncertainties generally increase with time into the past due to increasingly limited spatial coverage.

Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise. {6.4, 6.6}

- Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. Some recent studies indicate greater variability in Northern Hemisphere temperatures than suggested in the TAR, particularly finding that cooler periods existed in the 12 to 14th, 17th, and 19th centuries. Warmer periods prior to the 20th century are within the uncertainty range given in the TAR. {6.6}
- Global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 4 to 6 m higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 3 to 5°C higher than present, because of differences in the Earth's orbit. The Greenland ice sheet and other Arctic ice fields *likely* contributed no more than 4 m of the observed sea level rise. There may also have been a contribution from Antarctica. {6.4}

Understanding and Attributing Climate Change

This Assessment considers longer and improved records, an expanded range of observations, and improvements in the simulation of many aspects of climate and its variability based on studies since the TAR. It also considers the results of new attribution studies that have evaluated whether observed changes are quantitatively consistent with the expected response to external forcings and inconsistent with alternative physically plausible explanations.

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations[12]. This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns (see Figure SPM-4 and Table SPM-2). {9.4, 9.5}

- It is *likely* that increases in greenhouse gas concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. {2.9, 7.5, 9.4}
- The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* that global climate change of the past fifty years can be explained without external forcing, and *very likely* that it is not due to known natural causes alone. {4.8, 5.2, 9.4, 9.5, 9.7}

[12] Consideration of remaining uncertainty is based on current methodologies.

- Warming of the climate system has been detected in changes of surface and atmospheric temperatures, temperatures in the upper several hundred metres of the ocean and in contributions to sea level rise. Attribution studies have established anthropogenic contributions to all of these changes. The observed pattern of tropospheric warming and stratospheric cooling is *very likely* due to the combined influences of greenhouse gas increases and stratospheric ozone depletion. {3.2, 3.4, 9.4, 9.5}

- It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica (see Figure SPM-4). The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing. The ability of coupled climate models to simulate the observed temperature evolution on each of six continents provides stronger evidence of human influence on climate than was available in the TAR. {3.2, 9.4}

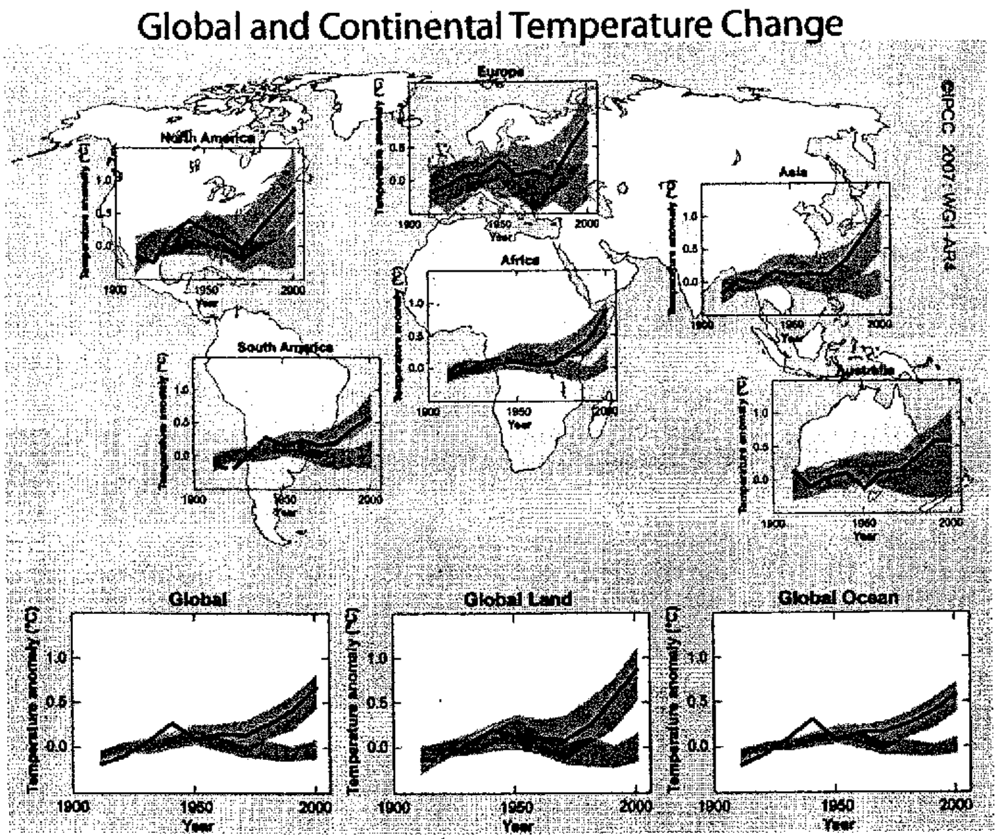

FIGURE SPM-4. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906–2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {FAQ 9.2, Figure 1}

- Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings and feedbacks also make it difficult to estimate the contribution of greenhouse gas increases to observed small-scale temperature changes. {8.3, 9.4}
- Anthropogenic forcing is *likely* to have contributed to changes in wind patterns[13], affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated in response to 20th century forcing change. {3.5, 3.6, 9.5, 10.3}
- Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves (see Table SPM-2). {9.4}

Analysis of climate models together with constraints from observations enables an assessed *likely* range to be given for climate sensitivity for the first time and provides increased confidence in the understanding of the climate system response to radiative forcing. {6.6, 8.6, 9.6, Box 10.2}

- The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations. It is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. Water vapour changes represent the largest feedback affecting climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty. {8.6, 9.6, Box 10.2}
- It is *very unlikely* that climate changes of at least the seven centuries prior to 1950 were due to variability generated within the climate system alone. A significant fraction of the reconstructed Northern Hemisphere interdecadal temperature variability over those centuries is *very likely* attributable to volcanic eruptions and changes in solar irradiance, and it is *likely* that anthropogenic forcing contributed to the early 20th century warming evident in these records. {2.7, 2.8, 6.6, 9.3}

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

A major advance of this assessment of climate change projections compared with the TAR is the large number of simulations available from a broader range of models. Taken together with additional information from observations, these provide a quantitative basis for estimating likelihoods for many aspects of future climate change. Model simulations cover a range of possible futures including idealised emission or concentration assumptions. These include SRES[14] illustrative marker scenarios for the 2000–2100 period and model experiments with greenhouse gases and aerosol concentrations held constant after year 2000 or 2100.

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. {10.3, 10.7}

[13] In particular, the Southern and Northern Annular Modes and related changes in the North Atlantic Oscillation. {3.6, 9.5, Box TS.3.1}

[14] SRES refers to the IPCC Special Report on Emission Scenarios (2000). The SRES scenario families and illustrative cases, which did not include additional climate initiatives, are summarized in a box at the end of this Summary for Policymakers. Approximate CO_2 equivalent concentrations corresponding to the computed radiative forcing due to anthropogenic greenhouse gases and aerosols in 2100 (see p. 823 of the TAR) for the SRES B1, A1T, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550 ppm respectively. Scenarios B1, A1B, and A2 have been the focus of model inter-comparison studies and many of those results are assessed in this report.

- Since IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade for 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. {1.2, 3.2}
- Model experiments show that even if all radiative forcing agents are held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans. About twice as much warming (0.2°C per decade) would be expected if emissions are within the range of the SRES scenarios. Best-estimate projections from models indicate that decadal-average warming over each inhabited continent by 2030 is insensitive to the choice among SRES scenarios and is *very likely* to be at least twice as large as the corresponding model-estimated natural variability during the 20th century. {9.4, 10.3, 10.5, 11.2–11.7, Figure TS-29}

Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. {10.3}

- Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emission scenarios. Results for different emission scenarios are provided explicitly in this report to avoid loss of this policy-relevant information. Projected globally-averaged surface warmings for the end of the 21st century (2090–2099) relative to 1980–1999 are shown in Table SPM-3. These illustrate the differences between lower to higher SRES emission scenarios and the projected warming uncertainty associated with these scenarios. {10.5}
- Best estimates and *likely* ranges for globally average surface air warming for six SRES emissions marker scenarios are given in this assessment and are shown in Table SPM-3. For example, the best estimate for the low scenario (B1) is 1.8°C (*likely* range is 1.1°C to 2.9°C), and the best estimate for the high scenario (A1FI) is 4.0°C (*likely* range is 2.4°C to 6.4°C). Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8°C), they are not directly comparable (see Figure SPM-5). The AR4 is more advanced as it provides best estimates and an assessed likelihood range for each of the marker scenarios. The new assessment of the *likely* ranges now relies on a larger number of climate models of increasing complexity and realism, as well as new information regarding the nature of feedbacks from the carbon cycle and constraints on climate response from observations. {10.5}

Table SPM-3. Projected globally averaged surface warming and sea level rise at the end of the 21st century. {10.5, 10.6, Table 10.7}

	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Table notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulaion Models (AOGCMs).

[b] Year 2000 constant composition is derived from AOGCMs only.

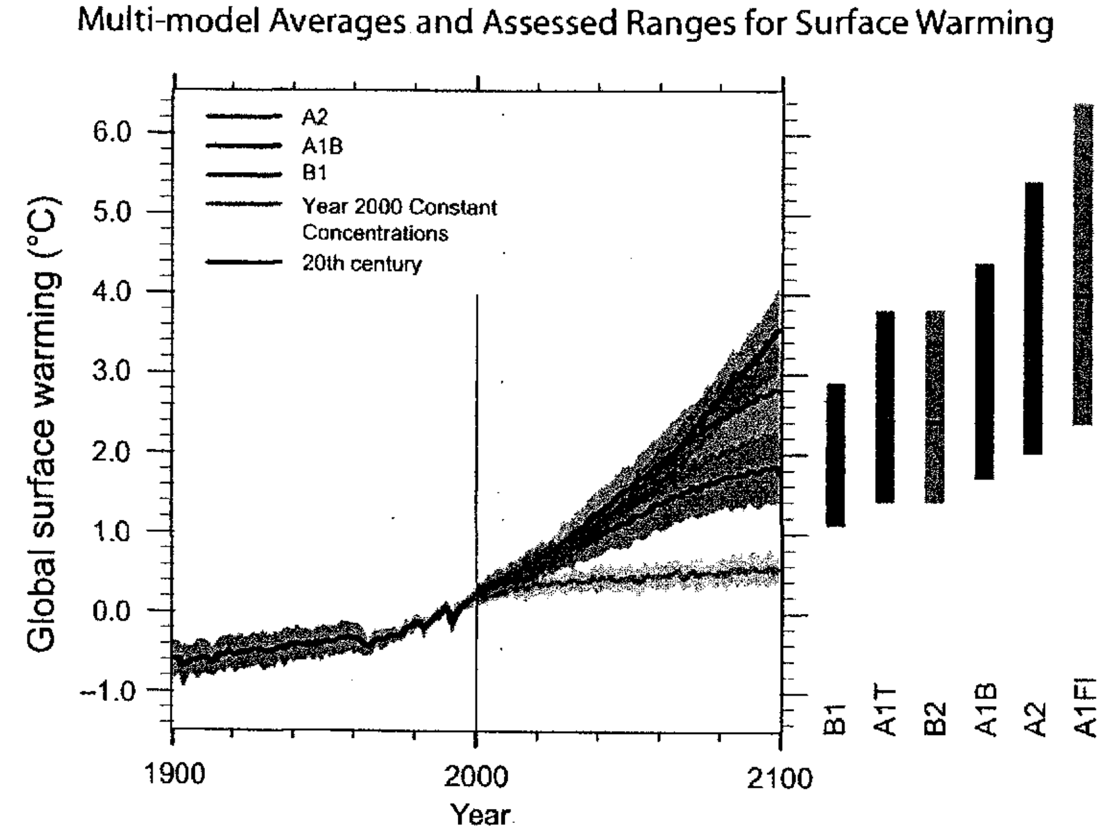

FIGURE SPM-5. Solid lines are multi-model global averages of surface warming (relative to 1980-99) for the scenarios A2, A1B and B1, shown as continuations of the 20[th] century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The gray bars at right indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios. The assessment of the best estimate and *likely* ranges in the gray bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}

- Warming tends to reduce land and ocean uptake of atmospheric carbon dioxide, increasing the fraction of anthropogenic emissions that remains in the atmosphere. For the A2 scenario, for example, the climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1°C. Assessed upper ranges for temperature projections are larger than in the TAR (see Table SPM-3) mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. {7.3, 10.5}

- Model-based projections of global average sea level rise at the end of the 21[st] century (2090-2099) are shown in Table SPM-3. For each scenario, the midpoint of the range in Table SPM-3 is within 10% of the TAR model average for 2090-2099. The ranges are narrower than in the TAR mainly because of improved information about some uncertainties in the projected contributions[15]. {10.6}

- Models used to date do not include uncertainties in climate-carbon cycle feedback nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. For example, if this contribution were to grow

[15] TAR projections were made for 2100, whereas projections in this Report are for 2090-2099. The TAR would have had similar ranges to those in Table SPM-2 if it had treated the uncertainties in the same way.

linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table SPM-3 would increase by 0.1 m to 0.2 m. Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise. {10.6}

- Increasing atmospheric carbon dioxide concentrations leads to increasing acidification of the ocean. Projections based on SRES scenarios give reductions in average global surface ocean pH[16] of between 0.14 and 0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial times. {5.4, Box 7.3, 10.4}

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice. {8.2, 8.3, 8.4, 8.5, 9.4, 9.5, 10.3, 11.1}

- Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic ocean (see Figure SPM-6). {10.3}

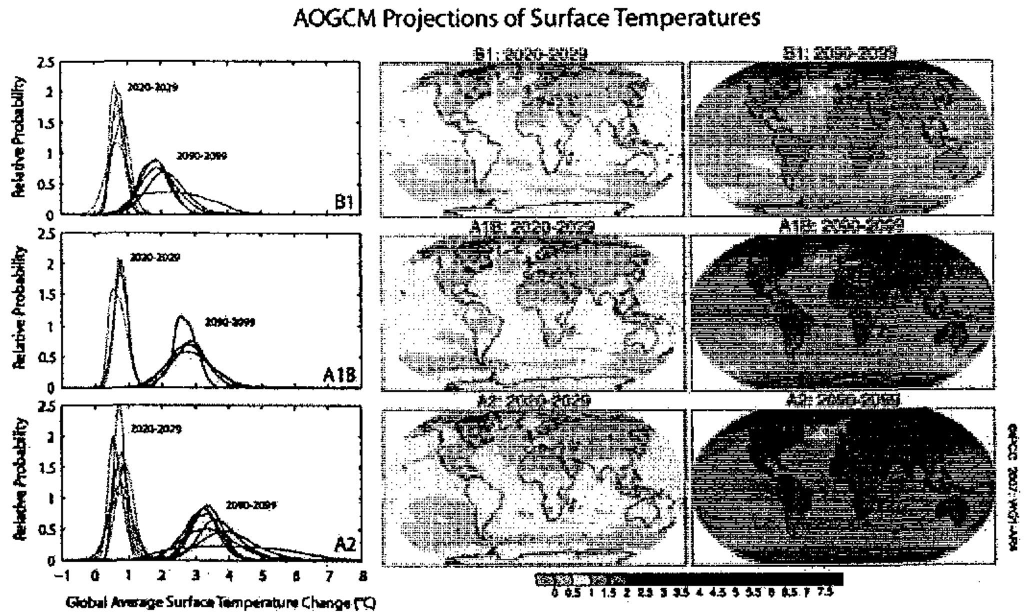

FIGURE SPM-6. Projected surface temperature changes for the early and late 21st century relative to the period 1980–1999. The central and right panels show the Atmosphere-Ocean General Circulation multi-Model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over decades 2020–2029 (center) and 2090–2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming from several different AOGCM and EMICs studies for the same periods. Some studies present results only for a subset of the SRES scenarios, or for various model versions. Therefore the difference in the number of curves, shown in the left-hand panels, is due only to differences in the availability of results. {Figures 10.8 and 10.28}

[16] Decreases in pH correspond to increases in acidity of a solution. See Glossary for further details.

- Snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. {10.3, 10.6}
- Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century. {10.3}
- It is *very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. {10.3}
- Based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SSTs. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period. {9.5, 10.3, 3.8}
- 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. {3.6, 10.3}
- Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are *likely* in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100, see Figure SPM-7), continuing observed patterns in recent trends. {3.3, 8.3, 9.5, 10.3, 11.2 to 11.9}
- Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century. The multi-model average reduction by 2100 is 25% (range from zero to about 50%) for SRES emission scenario A1B. Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases of greenhouse gases. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. {10.3, 10.7}

Projected Patterns of Precipitation Changes

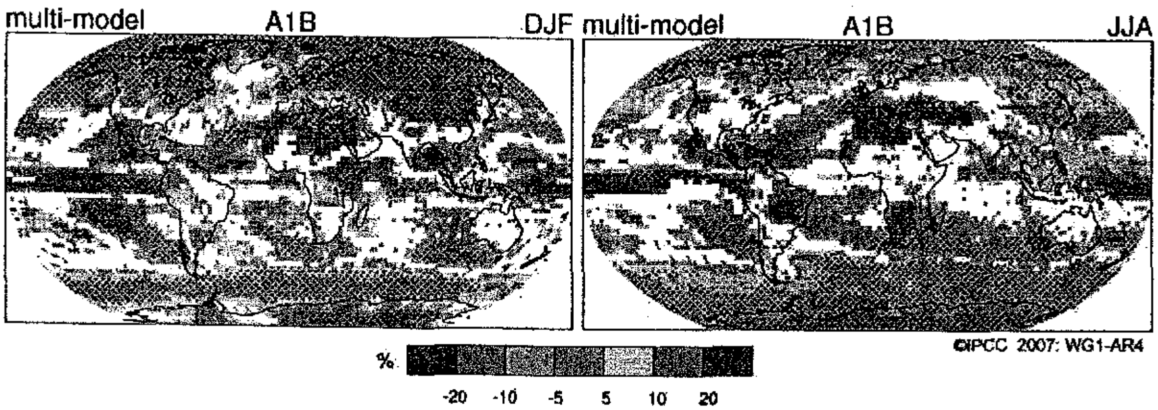

FIGURE SPM-7. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized. {10.4, 10.5, 10.7}

- Climate carbon cycle coupling is expected to add carbon dioxide to the atmosphere as the climate system warms, but the magnitude of this feedback is uncertain. This increases the uncertainty in the trajectory of carbon dioxide emissions required to achieve a particular stabilisation level of atmospheric carbon dioxide concentration. Based on current understanding of climate carbon cycle feedback, model studies suggest that to stabilise at 450 ppm carbon dioxide, could require that cumulative emissions over the 21st century be reduced from an average of approximately 670 [630 to 710] GtC (2460 [2310 to 2600] $GtCO_2$) to approximately 490 [375 to 600] GtC (1800 [1370 to 2200] $GtCO_2$). Similarly, to stabilise at 1000 ppm this feedback could require that cumulative emissions be reduced from a model average of approximately 1415 [1340 to 1490] GtC (5190 [4910 to 5460] $GtCO_2$) to approximately 1100 [980 to 1250] GtC (4030 [3590 to 4580] $GtCO_2$). {7.3, 10.4}
- If radiative forcing were to be stabilized in 2100 at B1 or A1B levels[11] a further increase in global average temperature of about 0.5°C would still be expected, mostly by 2200. {10.7}
- If radiative forcing were to be stabilized in 2100 at A1B levels[11], thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300 (relative to 1980–1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean. {10.7}
- Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to precipitation and that the surface mass balance becomes negative at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m. The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when paleoclimatic information suggests reductions of polar land ice extent and 4 to 6 m of sea level rise. {6.4, 10.7}
- Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude. {4.6, 10.7}
- Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. {10.7}
- Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the timescales required for removal of this gas from the atmosphere. {7.3, 10.3}

The Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)[17]

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

[17] Emission scenarios are not assessed in this Working Group One report of the IPCC. This box summarizing the SRES scenarios is taken from the TAR and has been subject to prior line by line approval by the Panel.