I. STATEMENT OF RELIANCE ON THREE LINES OF EVIDENCE

The three "lines of evidence" in support of EPA's professed confidence that anthropogenic GHGs are the primary cause of warming are: **(i)** its "basic physical understanding" of the climate system; **(ii)** the output of computer climate models; and **(iii)** recent temperatures that EPA contends are "unusual" in climate history. 74 Fed. Reg. 66,523 [JA29].

> The **first** line of evidence arises from our basic physical understanding of the effects of changing concentrations of greenhouse gases, natural factors, and other human impacts on the climate system. Greenhouse gas concentrations have indisputably increased and their radiative properties are well established. The **second** line of evidence arises from indirect, historical estimates of past climate changes that suggest that the changes in global surface temperature over the last several decades are unusual. The **third** line of evidence arises from the use of computer-based climate models to simulate the likely patterns of response of the climate system to different forcing mechanisms (both natural and anthropogenic). These models are unable to replicate the observed warming unless anthropogenic emissions of greenhouse gases are included in the simulations. Natural forcing alone cannot explain the observed warming. In fact, the assessment literature [27] indicates the sum of solar and volcanic forcing in the past half century would likely have produced cooling, not warming. Please see the relevant volume of the Response to Comments for more detailed responses.

From JA024:

> The attribution of observed climate change to anthropogenic activities is based on multiple lines of evidence. The **first** line of evidence arises from our basic physical understanding of the effects of changing concentrations of greenhouse gases, natural factors, and other human impacts on the climate system. The **second** line of evidence arises from indirect, historical estimates of past climate changes that suggest that the changes in global

surface temperature over the last several decades are unusual.[23] The **third** line of evidence arises from the use of computer-based climate models to simulate the likely patterns of response of the climate system to different forcing mechanisms (both natural and anthropogenic).

TSD p. 47.

II. PHYSICAL UNDERDSTANDING

From TSD, ES-2: JA03343

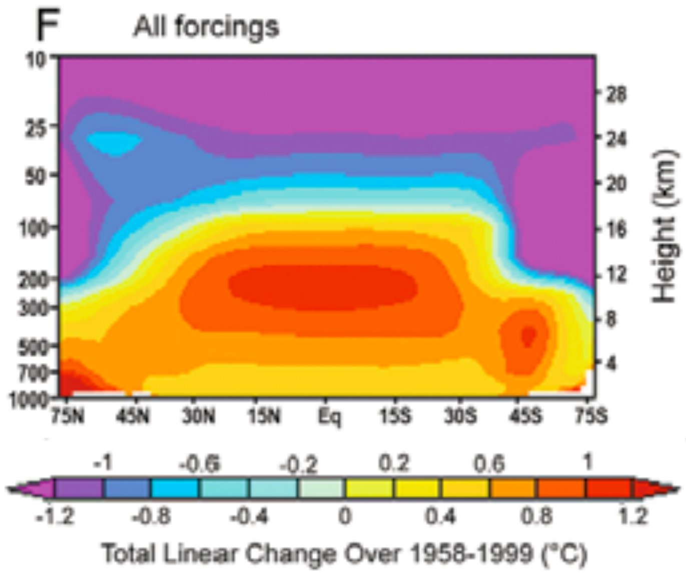
> **The global average net effect of the increase in atmospheric GHG concentrations, plus other human activities (e.g., land-use change and aerosol emissions), on the global energy balance since 1750 has been one of warming.** This total net heating effect, referred to as forcing, is estimated to be +1.6 (+0.6 to +2.4) watts per square meter (W/m^2), with much of the range surrounding this estimate due to uncertainties about the cooling and warming effects of aerosols. However, as aerosol forcing has more regional variability than the well-mixed, long-lived GHGs, the global average might not capture some regional effects. The combined radiative forcing due to the cumulative (i.e., 1750 to 2005) increase in atmospheric concentrations of CO_2, CH_4, and N_2O is estimated to be +2.30 (+2.07 to +2.53) W/m^2. The rate of increase in positive radiative forcing due to these three GHGs during the industrial era is very likely to have been unprecedented in more than 10,000 years.

From EF, JA00029, col. 2:

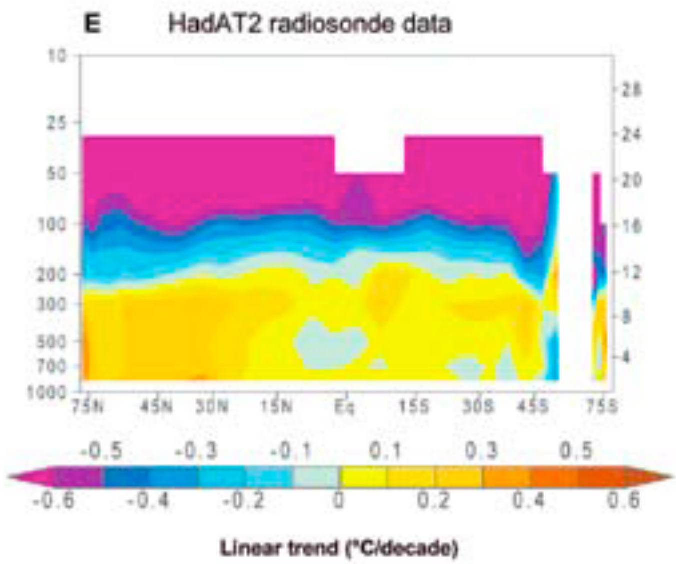
> The first line of evidence arises from our basic physical understanding of the effects of changing concentrations of greenhouse gases, natural factors, and other human impacts on the climate system. Greenhouse gas concentrations have indisputably increased and their radiative properties are well established. (Emphasis in original).

See Docket 0004 pp. 18-19 for a description of the assumptions behind the fingerprint. (Discussed in more detail below).

Docket 0004, p. 25, Figure 1.3(F). *See* also IPCC AR4 WG1 Fig 9.1(f). Predicted upper tropospheric tropical warming "fingerprint:"



Docket 0004 p. 116, Fig. 5.7(E), Observations showing no "fingerprint."



The history of the hot spot controversy is recounted in *Tropospheric Temperature Trends: History Of An Ongoing Controversy*, by Thorne and others from the Department of Commerce, January 1, 2011, http://onlinelibrary.wiley.com/doi/10.1002/wcc.80/full. The first simulation of the hot spot was in early modeling work by Manabe and Wetherald in papers published in 1967 and 1975.[1]

Searching for references to Manabe in the Endangerment Record, we find the fundamental theoretical clam set forth in one of the CCSP Reports that is included in the Joint Appendix at Vol XI, JA05106-7, which is CCSP SAP 1.1, Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences, § 1.1, The Thermal Structure of the Atmosphere, pp. 17-19.

This discussion starts with a an explanation of the dry adiabatic temperature lapse rate with altitude, and an explanation that the lapse rate is lower with moist air:

> The lapse rate for a dry atmosphere, when there are no moist processes and the air is rising quickly enough to be unaffected by other heating/cooling sources, is close to 10ºC/km. However, because of moist convection, there is condensation of moisture, formation of clouds and release of latent heat as the air parcels rise, causing the lapse-rate to be much less, as low as 4ºC/km in very humid atmospheres (Houghton, 1977).

Id. at p. 18. After discussing additional and immense complexities in the vertical temperature profile in the tropics, the basic theoretical proposition is given as follows:

> The sense of the radiative-convective-dynamical balance above, together with the requirement of radiative balance at the top-of-the atmosphere (namely, equilibrium conditions wherein the net solar energy absorbed by the Earth's climate system must be balanced by the infrared radiation emitted

[1] The 1975 paper, *The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model*, http://journals.ametsoc.org/doi/pdf/10.1175/1520-0469%281975%29032%3C0003%3ATEODTC%3E2.0.CO%3B2, It says:

> It should be noted that in low and middle latitudes, the warming is greater in the upper troposphere (~336 mb) than near the surface. This is due to the fact that the moist convective processes in the model tend to adjust temperatures in a column toward the moist adiabatic lapse rate. Since this lapse rate is more stable in a warmer atmosphere than in a colder atmosphere, the greatest difference in temperature will be found near the top of the moist convective layer. Therefore, the area of maximum tropospheric warming occurs in the upper troposphere instead of near the earth's surface.

The Manabe and Wetherald 1967 paper is *Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity*, http://journals.ametsoc.org/doi/pdf/10.1175/1520-0469%281967%29024%3C0241%3ATEOTAW%3E2.0.CO%3B2.

by the Earth), can help illustrate the significance of long-lived infrared absorbing gases in the global atmosphere. The presence of such greenhouse gases (e.g., carbon dioxide, methane, nitrous oxide, halocarbons) increases the radiative heating of the surface and troposphere. As specific humidity is strongly related to temperature, it is expected to rise with surface warming (IPCC, 1990), The increased moisture content of the atmosphere amplifies the initial radiative heating due to the greenhouse gas increases (**Manabe and Wetherald,** 1967; Ramanathan, 1981). The re-establishment of a new thermal equilibrium in the climate system involves the communication of the added heat input to the troposphere and surface, leading to surface warming (Goody and Yung, 1989; IPCC, 1990; Lindzen and Emanuel, 2002). **From the preceding discussions, the lapse rate can be expected to decrease with the resultant increase in humidity**, and also to depend on the resultant changes in atmospheric circulation. **In general, the lapse rate can be expected to decrease with warming such that temperature changes aloft exceed those at the surface.** As a consequence, the characteristic infrared emission level of the planet is shifted to a higher altitude in the atmosphere.

(Emphasis added).

A simpler statement of this point was made by Lindzen in testimony to the House of Commons, on February 12, 2012. He shows the model predictions of the hot spot and says: "The response [to a doubling of CO_2] is characterized by the so-called hot spot (ie, the response in the tropical upper troposphere is from 2-3 times larger than the surface response). We know that the models are correct in this respect since the hot spot is simply a consequence of the fact that tropical temperatures approximately follow what is known as the moist adiabat. This is simply a consequence of the dominant role of moist convection in the tropics."

III. TEMPERATURE RECORDS

From TSD ES-2-3, JA03343-4.

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. Global mean surface temperatures have risen by 1.3 ± 0.32°F (0.74°C ± 0.18°C) over the last 100 years. Eight of the 10 warmest years on record have occurred since 2001. Global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period during the preceding four centuries.

Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. Climate model simulations suggest natural forcing alone (i.e., changes in solar irradiance) cannot explain the observed warming.

U.S. temperatures also warmed during the 20th and into the 21st century; temperatures are now approximately 1.3°F (0.7°C) warmer than at the start of the 20th century, with an increased rate of warming over the past 30 years. Both the IPCC and the CCSP reports attributed recent North American warming to elevated GHG concentrations. In the CCSP (2008g) report, the authors find that for North America, "more than half of this warming [for the period 1951-2006] is likely the result of human-caused greenhouse gas forcing of climate change."

Observations show that changes are occurring in the amount, intensity, frequency and type of precipitation. Over the contiguous United States, total annual precipitation increased by 6.1% from 1901 to 2008. It is likely that there have been increases in the number of heavy precipitation events within many land regions, even in those where there has been a reduction in total precipitation amount, consistent with a warming climate.

There is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate. It is not clear whether the increasing rate of sea level rise is a reflection of short-term variability or an increase in the longer-term trend. Nearly all of the Atlantic Ocean shows sea level rise during the last 50 years with the rate of rise reaching a maximum (over 2 millimeters [mm] per year) in a band along the U.S. east coast running east-northeast.

Satellite data since 1979 show that annual average Arctic sea ice extent has shrunk by 4.1% per decade. The size and speed of recent Arctic summer sea ice loss is highly anomalous relative to the previous few thousands of years.

Widespread changes in extreme temperatures have been observed in the last 50 years across all world regions, including the United States. Cold days, cold nights, and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent.

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. However, directly attributing specific regional changes in climate to emissions of GHGs from human activities is difficult, especially for precipitation.

Ocean CO2 uptake has lowered the average ocean pH (increased acidity) level by approximately 0.1 since 1750. Consequences for marine ecosystems can include reduced calcification by shell-forming organisms, and in the longer term, the dissolution of carbonate sediments.

Observations show that climate change is currently affecting U.S. physical and biological systems in significant ways. The consistency of these observed changes in physical and biological systems and the observed significant warming likely cannot be explained entirely due to natural variability or other confounding non-climate factors.

IV. MODELING

From Endangerment Finding, p. 127, JA00024

As noted in the TSD, the observed warming can only be reproduced with models that contain both natural and anthropogenic forcings, and the warming of the past half century has taken place at a time when known natural forcing factors alone (solar activity and volcanoes) would likely have produced cooling, not warming.

From EF, p. 155: JA00029, col. 2

> The third line of evidence arises from the use of computer-based climate models to simulate the likely patterns of response of the climate system to different forcing mechanisms (both natural and anthropogenic). These models are unable to replicate the observed warming unless anthropogenic emissions of greenhouse gases are included in the simulations. Natural forcing alone cannot explain the observed warming.

From TSD, p. 47: JA03395

> Confidence in these models comes from their foundation in accepted physical principles and from their ability to reproduce observed features of current climate and past climate changes (IPCC, 2007a). For additional discussion on the strengths and limitations of models, see Section 6(b). Attribution studies evaluate whether observed changes are consistent with quantitative responses to different forcings (from GHGs, aerosols, and natural forcings such as changes solar intensity) represented in well-tested models and are not consistent with alternative physically plausible explanations.

From TSD p. 49: JA03397

> Climate model simulations by the IPCC, shown in Figure 5.1, suggest natural forcings alone cannot explain the observed warming (for the globe, the global land and global ocean). The observed warming can only be reproduced with models that contain both natural and anthropogenic forcings.

TSD p. 50 on Hot Spot Controversy: JA03398

> However, an important inconsistency may have been identified in the tropics. In the tropics, most observational data sets show more warming at the surface than in the troposphere, while almost all model simulations have larger warming aloft than at the surface (Karl et al., 2006). Karl et al. (2009) state that when uncertainties in models and observations are properly accounted for, newer observational data sets are in agreement with climate model results.

TSD p. 63: JA03411

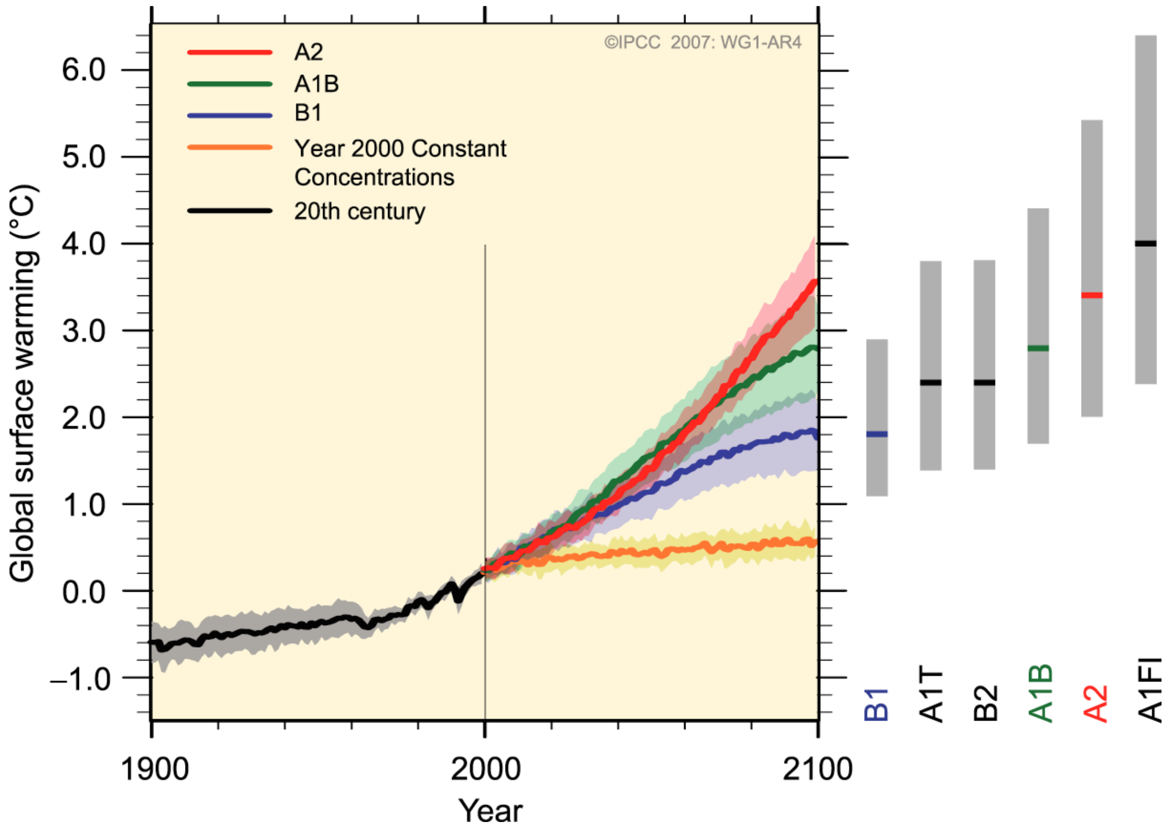
Using the emissions scenarios described in Section 6(a), computer models project future changes in temperature, precipitation, and sea level at global and regional scales. According to the IPCC (Meehl at al., 2007):

TSD p. 64: JA03412

The latest IPCC assessment uses a larger number of simulations available from a broader range of models to project future climate relative to earlier assessments (IPCC, 2007d). All of the simulations performed by the IPCC project warming for the full range of emissions scenarios. For the next two decades, a warming of about 0.4°F (0.2°C) per decade is projected for a range of SRES emissions scenarios (IPCC, 2007d). Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels (see the "Year 2000 Constant Concentrations" scenario in Figure 6.7), a further warming of about 0.2°F (0.1°C) per decade would be expected because of the time it takes for the climate system, particularly the oceans, to reach equilibrium (with year 2000 GHG levels). Through about 2030, the warming rate is mostly insensitive to choices between the SRES A2, A1B, or B1 scenarios and is consistent with that observed for the past few decades.

TSD p. 65: JA03413

Figure 6.7: Multi-Model Averages and Assessed Ranges for Surface Warming



Source: IPCC (2007d). Solid lines are multi-model global averages of surface warming (relative to 1980– 1999) for the scenarios A2, A1B, and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at 2000 values. The grey 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 grey bars includes the AOGCMs in the left the figure, as well as results from a hierarchy of independent models and observational constraints.

V. EXTREME EVENTS

A. <u>ENDANGERMENT FINDING</u>

EF p. 10-11 -

> The Administrator has considered how elevated concentrations of the well-mixed greenhouse gases and associated climate change affect public health by evaluating the risks associated with changes in air quality, increases in temperatures, changes in extreme weather events, increases in food- and water-borne pathogens, and changes in aeroallergens. …

> The evidence concerning how human-induced climate change may alter extreme weather events also clearly supports a finding of endangerment, given the serious adverse impacts that can result from such events and the increase in risk, even if small, of the occurrence and intensity of events such as hurricanes and floods. Additionally, public health is expected to be adversely affected by an increase in the severity of coastal storm events due to rising sea levels.

EF p. 157:

> First, the Administrator finds the scientific evidence linking human emissions and resulting elevated atmospheric concentrations of the six well-mixed greenhouse gases **to observed global and regional temperature increases** and other climate changes to be sufficiently robust and compelling.

p. 163:

> The Administrator finds that the well-mixed greenhouse gas air pollution is reasonably anticipated to endanger public health, for both current and future generations. The Administrator finds that the public health of current generations is endangered and that the threat to public health for both current and future generations will likely mount over time as greenhouse gases continue to accumulate in the atmosphere **and result in ever greater rates of climate change.**

p. 163:

> In making this public health finding, the Administrator considered **direct temperature effects**, air quality effects, the potential for changes in vector-borne diseases, and the **potential for changes in the severity and frequency of extreme weather events.**

p. 167:

> In addition to the direct effects of temperature on heat- and cold-related mortality, the Administrator considers the potential for increased deaths, injuries, infectious diseases, and stress-related disorders and other adverse effects associated with

social disruption and migration from more frequent extreme weather.

p. 168

The IPCC finds the following with regard to extreme events and human health: Increases in the frequency of heavy precipitation events …

Increases in tropical cyclone intensity …

p. 171:

The evidence concerning how human-induced climate change may alter extreme weather events also clearly supports a finding of endangerment, given the serious adverse impacts that can result from such events and the increase in risk, even if small, of the occurrence and intensity of events such as hurricanes and floods. Additionally, public health is expected to be adversely affected by an increase in the severity of coastal storm events due to rising sea levels.

B. TSD CAUSAL CHAIN TO EXTREME EVENTS

p. 23 – Emissions increase radiative forcing:

IPCC (2007d) concluded that the understanding of anthropogenic warming and cooling influences on climate has improved since the IPCC *Third Assessment Report*, leading to *very high confidence*[24] that the global average 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.

p. 26:

Multiple lines of evidence lead to the robust conclusion that the climate system is warming.

This is followed by a discussion of GAST, both instrumental and proxy records

p. 43:

Climate is defined not simply as average temperature and precipitation but also by the type, frequency, and intensity of extreme events. The

IPCC documents observed changes in climate extremes related to temperature, precipitation, tropical cyclones, and sea level.

Temps –

"Widespread changes in extreme temperatures have been observed in the last 50 years. Cold"

Heavy Precip and Drought, citing IPCC:

> • 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 has contributed to changes in drought. The regions where droughts have occurred seem to be determined largely by changes in sea surface temperatures (SSTs), especially in the tropics, through associated changes in the atmospheric circulation and precipitation. Decreased snowpack and snow cover have also been linked to droughts.
>
> • It is likely that there have been increases in the number of heavy precipitation events[38] within many land regions, even in those where there has been a reduction in total precipitation amount, consistent with a warming climate and observed significant increasing amounts of water vapor in the atmosphere. Increases have also been reported for rarer precipitation events (1-in-50-year return period), but only a few regions have sufficient data to assess such trends reliably (Trenberth et al., 2007).

Storms

Trenberth et al (2007) find there has *likely* been a net increase in frequency and intensity of strong low pressure systems (also known as mid-latitude storms and/or extra tropical cyclones) over Northern Hemisphere land areas, as well as a poleward shift in track since about 1950. They caution, however, that detection of long-term changes in cyclone measures is hampered by incomplete and changing observing systems. They

> also note longer records for the northeastern Atlantic suggest that the recent extreme period may be similar in level to that of the late 19th century.
>
> The CCSP (2008i) report on extreme events, in its section on tropical cyclones (i.e., tropical storms and hurricanes), states that there have been spatially inhomogeneous increases in the power dissipation index, a measure of potential tropical cyclone destructiveness, over the last few decades (Kunkel et al., 2008). However, there remain reliability issues with historical data. Kunkel et al. (2008) refer to a study that was not able to corroborate the presence of upward intensity trends over the last two decades in ocean basins other than the North Atlantic. The report cautions that quantifying tropical cyclone variability is limited, sometimes seriously, by a large suite of problems with the historical record of tropical cyclone activity. Correspondingly, there is no clear trend in the annual numbers of tropical cyclones (IPCC, 2007d). The IPCC (2007a; Trenberth et al., 2007) concluded there is insufficient evidence to determine whether trends exist in small-scale phenomena such as thunderstorms, tornadoes, hail, lightning and dust-storms.

This is followed by a detailed discussion of trends in US Extremes at pp. 44-46.

p. 51:

> "Temperature extremes have also likely been influenced by anthropogenic forcing. Many indicators of climate extremes, including the annual numbers of frost days, warm and cold days, and warm and cold nights, show changes that are consistent with warming (Hegerl et al., 2007). An anthropogenic influence has been detected in some of these indices, and there is evidence that anthropogenic forcing may have substantially increased the risk of extremely warm summer conditions regionally, such as the 2003 European heat wave (Hegerl et al., 2007). Karl et al. (2008) conclude the increase in human-induced emissions of GHGs is estimated to have substantially increased the risk of a very hot year in the United States, such as that experienced in 2006. They add that other aspects of observed increases in temperature

extremes, such as changes in warm nights and frost days, have been linked to human influences

p. 73 – model projections of extreme events

> Models suggest that human-induced climate change is expected to alter the prevalence and severity of many extreme events such as heat waves, cold waves, storms, floods, and droughts. This section describes CCSP (2008i) and IPCC's projections for extreme events focusing on North America and the United States. Sections 7 to 14 summarize some of the sectoral impacts of extreme events for the United States.

There follows a discussions of model projections for temperature, precipitation and drought, and storms,

C. CCSP ON CAUSATION

TSD Cites and Relies on CCSP SAP 3.3, Weather and Climate Extremes in a Changing Climate, available here: http://www.climatescience.gov/Library/sap/sap3-3/final-report/.

Synopsis, p. vii:

> It is well established through formal attribution studies that the global warming of the past 50 years is due primarily to human-induced increases in heat-trapping gases. Such studies have only recently been used to determine the causes of some changes in extremes at the scale of a continent. Certain aspects of observed increases in temperature extremes **have been linked** to human influences. The increase in heavy precipitation events **is associated with an increase in water vapor, and the latter has been attributed to human-induced warming.** No formal attribution studies for changes in drought severity in North America have been attempted. There is **evidence suggesting** a **human contribution** to recent changes in hurricane activity as well as in storms outside the tropics, though a confident assessment will require further study.

This is very weak sauce.

While EPA does not have a thorough discussion of causation of extreme events in the Endangerment Finding or the TSD (check comments), the CCSP SAP 3.3

does in Chapter 3. At p. 81-82, it says they are caused by GHG-induced warmer GAST and ocean heat content:

> Changes in some weather and climate extremes are attributable to human-induced emissions of greenhouse gases. Human-induced warming has likely caused much of the average temperature increase • in North America over the past 50 years. This affects changes in temperature extremes.
>
> • Heavy precipitation events averaged over North America have increased over the past 50 years, consistent with the observed increases in atmospheric water vapor, which have been associated with human-induced increases in greenhouse gases.
>
> • It is very likely that the human-induced increase in greenhouse gases has contributed to the increase in sea surface temperatures in the hurricane formation regions. Over the past 50 years there has been a strong statistical connection between tropical Atlantic sea surface temperatures and Atlantic hurricane activity as measured by the Power Dissipation Index (which combines storm intensity, duration, and frequency). This evidence suggests a human contribution to recent hurricane activity. However, a confident assessment of human influence on hurricanes will require further studies using models and observations, with emphasis on distinguishing natural from human-induced changes in hurricane activity through their influence on factors such as historical sea surface temperatures, wind shear, and atmospheric vertical stability
>
> **Projected Changes**
>
> • Future changes in extreme temperatures will generally follow changes in average temperature:
>
> ◦ Abnormally hot days and nights and heat waves are very likely to become more frequent.
>
> ◦ Cold days and cold nights are very likely to become much less frequent.
>
> ◦ The number of days with frost is very likely to decrease.

• Droughts are likely to become more frequent and severe in some regions as higher air temperatures increase the potential for evaporation.

• Over most regions, precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase.

• For North Atlantic and North Pacific hurricanes and typhoons:

◦ It is likely that hurricane/typhoon wind speeds and core rainfall rates will increase in response to human-caused warming. Analyses of model simulations suggest that for each 1°C increase in tropical sea surface temperatures, hurricane surface wind speeds will increase by 1 to 8% and core rainfall rates by 6 to 18%.

◦ Frequency changes are currently too uncertain for confident projections.

◦ The spatial distribution of hurricanes / typhoons will likely change.

◦ Storm surge levels are likely to increase due to projected sea level rise, though the degree of projected increase has not been adequately studied.

There are likely to be more frequent deep low-pressure systems (strong storms) outside the tropics, with stronger winds and more extreme wave heights.

D. DETECTION AND ATTRIBUTION OF TRENDS IN EXTREME EVENTS, CCSP SAP 3.3

Explaining mechanics of attribution analysis for extreme events. P. 83:

Detection of climatic changes in extremes involves demonstrating statistically significant changes in properties of extremes over time. Attribution further links those changes with variations in climate forcings, such as changes in greenhouse gases (GHGs), solar radiation, or volcanic eruptions. Attribution is a necessary step toward identifying the physical causes of changes in extremes. Attribution often uses quantitative

> comparison between climate-model simulations and observations, comparing expected changes due to physical understanding integrated in the models with those that have been observed.

There follows a long and detailed discussion of the attribution analysis.

P. 85. GHG induced warming increases moisture content of atmosphere, leading to increase in precipitation and heavy precipitation events, consistent with observations.

Level of detail in CCSP report - 36 pages of dual column print and figures, need not be repeated here.