Case No. 18-36082

IN THE UNITED STATES COURT OF APPEALS
FOR THE NINTH CIRCUIT

KELSEY CASCADIA ROSE JULIANA, *et al*.,
Plaintiffs-Appellees,
v.
UNITED STATES OF AMERICA, *et al*.,
Defendants-Appellants.

On Interlocutory Appeal Pursuant to 28 U.S.C. § 1292(b)

DECLARATION OF KEVIN E. TRENBERTH IN SUPPORT OF PLAINTIFFS' URGENT MOTION UNDER CIRCUIT RULE 27-3(b) FOR PRELIMINARY INJUNCTION

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I, Dr. Kevin E. Trenberth, hereby declare and if called upon would testify as follows:

1. I am a Senior Scientist at the National Center for Atmospheric Research. My office is located in Boulder, Colorado.
2. I have been retained as an expert on behalf of Plaintiffs in this litigation before the United States District Court for the District of Oregon ("District Court").
3. I have prepared an expert report for this litigation ("Expert Report"), which forms part of the record in the District Court (D. Ct. Doc. 267-1). On September 14, 2018, Plaintiffs' counsel served on Defendants a supplemental version of my Expert Report. A true and correct copy of my Supplemental Expert Report is attached hereto as **Exhibit 1**. Additional information regarding my professional and educational background can be found in my curriculum vitae, attached to this declaration as **Exhibit A** to **Exhibit 1**.
4. I submit this declaration in support of Plaintiffs' Motion for Preliminary Injunction, in order to inform the Court of recent scientific findings which show that the ocean is warming at a greater pace than previously anticipated and the warming is accelerating. This evidence once again confirms the urgency of rapid greenhouse gas emission reductions and abatement in order to prevent increasing irreparable harm to these young Plaintiffs. A true and correct copy of the study, which was published in the January 11, 2019 edition

of the eminent peer-reviewed journal *Science*,[1] is attached hereto as **Exhibit 2**.

Expert Qualifications and Experience

5. I have authored over 550 publications in the area of climate science and given hundreds of talks on the subject. I am among the most highly-cited researchers in all of geophysics. I have extensively investigated global-scale climate dynamics, the observations, processes and modeling of climate changes from interannual to centennial time scales. I have particular expertise in El Niño, the hydrological and energy cycles, hurricanes and storms, and climate change. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards.

6. I have been involved in global warming science and extensively involved in the Intergovernmental Panel on Climate Change ("IPCC") scientific assessment activity as a lead author of individual chapters, the Technical Summary, and Summary for Policy Makers of Working Group I for the Second, Third and Fourth Assessment Reports (SAR, TAR and AR4). I was a Coordinating Lead Author for the SAR and AR4; in the latter I led Chapter 3 that dealt with observations of surface and atmospheric climate change. I

[1] Cheng, L. et al., *How fast are the oceans warming?*, 363 Science 128, 129 (2019).

was a Review Editor of the Fifth IPCC Assessment Report (AR5) in 2013. Accordingly, I shared the Nobel Peace Prize in 2007 that went to the IPCC and Al Gore. In 2017 I was awarded the prestigious Roger Revelle Medal by the American Geophysical Union.

The Oceans are Warming Faster than Previously Projected

7. On January 11, 2019, the study *How fast are the oceans warming?* was published in volume 363, issue 6423 of the peer-reviewed journal *Science*. The study was authored by me, alongside three co-authors.[2]

8. The study reviews and synthesizes recent peer-reviewed observational studies of the change in ocean heat content ("OHC") that have been published since the publication of the IPCC's AR5. Drawing on multiple lines of evidence – including improved reconstructions of OHC records; improved methods of measuring OHC and better accounting for spatial and temporal gaps of OHC measurements, and records from improved and more recently-deployed OHC-measuring instruments – we were able to provide a robust conclusion that our oceans are warming faster than previously indicated.[3]

9. As I noted in my Supplemental Expert Report, one of the weaknesses inherent in the IPCC's periodic assessment reports is that the lengthy timeline and

[2] Lijing Cheng of the Chinese Academy of Sciences was the lead author of the study.
[3] Ex. 2 at 128.

review-process for producing an IPCC report means that many of the findings lag behind the current state of the literature.[4] Our study has now shown that assessments of rates of ocean warming are another area in which IPCC findings and projections have been overly-conservative compared to the most-recent, real-world observations and peer-reviewed literature. Indeed, our study largely accounts for what was previously a supposed anomaly between the IPCC's "observed" ocean warming, and that projected by IPCC climate models.[5]

10. The implications of our study's finding that the oceans are warming faster than previously thought are staggering. The rate of warming in the upper levels of the ocean since 1991 has been approximately five-times greater than the rate of warming through the 1970s and 1980s (see Figure below).[6] The amount of energy absorbed by the oceans alone in 2018 – 9.1 zettajoules (1 zettajoule = 10^{21} joules).[6] This is equivalent to 680 times the total electricity energy consumption in the United States in 2017.[7]

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[4] See Ex. 1 at 15 note 5.
[5] Ex. 2 at 128-129.
[6] Cheng, L., et al., *2018 continues record global ocean warming*, 36(3) Adv. Atmos. Sci. 249 (2019), https://doi.org/10.1007/s00376-019-8276-x.
[7] U.S. Energy Information Administration, *Electric power annual 2015* (2016), https://www.eia.gov/electricity/annual/html/epa_01_02.html.

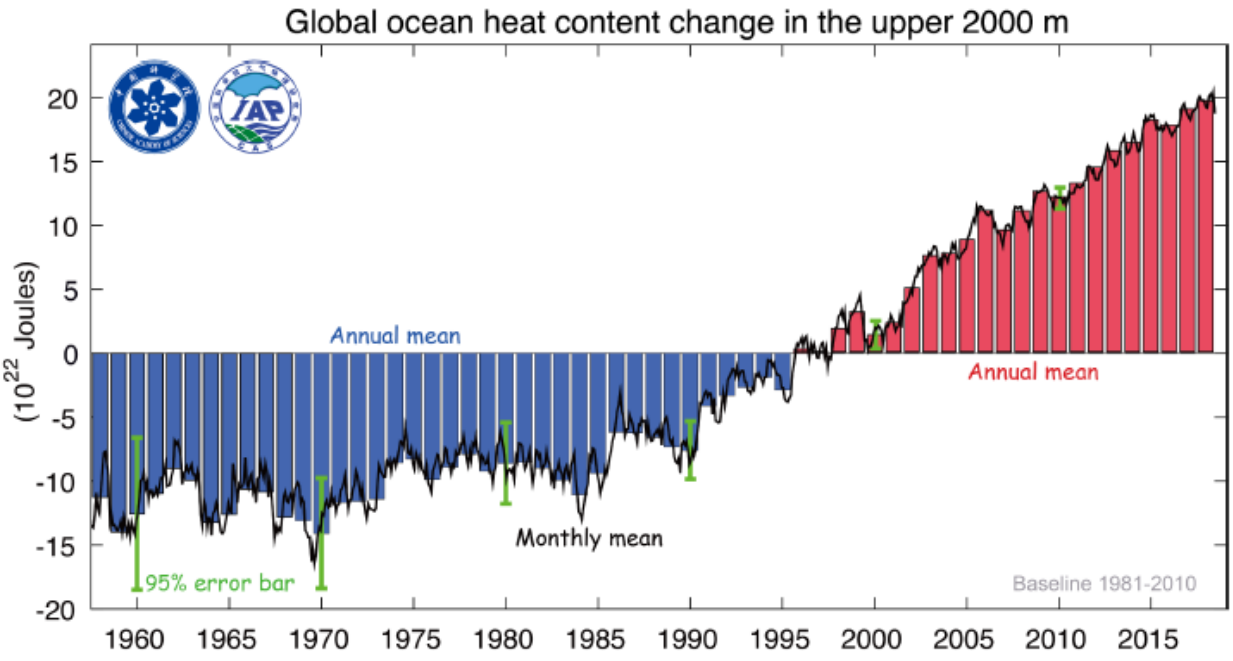

Figure: Change in 0–2000 m OHC from 1958 to 2018. Each bar shows the annual mean relative to a 1981–2010 baseline (positive in red and negative in blue). The green error bar indicates the 95% confidence interval, and the black line is the monthly time series.

11. The principle driver of this warming has been the accumulation of anthropogenic greenhouse gases, and the resulting deepening of the energy imbalance in Earth's climate system.[8] Both global and U.S. emissions are currently increasing,[9] meaning that, until emissions begin to decline, oceans will continue to warm even more rapidly, with devastating consequences.

[8] Ex. 2 at 128.

[9] Carrington, Damian, 'Brutal news': global carbon emissions jump to all-time high in 2018, *The Guardian*, Dec. 5, 2018, https://www.theguardian.com/environment/2018/dec/05/brutal-news-global-carbon-emissions-jump-to-all-time-high-in-2018; Holden, Emily, Carbon emissions up as Trump agenda rolls back climate change work, *The Guardian*, Jan. 8, 2019, https://www.theguardian.com/environment/2019/jan/08/carbon-emissions-trump-agenda-climate-change; Rhodium Group, *Preliminary US Emissions Estimates for 2018* (January 8, 2018), https://rhg.com/research/preliminary-us-emissions-estimates-for-2018/

12. These findings of our recent study thus underline and emphasize the opinions expressed in my Supplemental Expert Report, as well as the opinions of other experts retained by Plaintiffs. As I noted in my Supplemental Expert Report, the record-breaking hurricanes, super storms and extreme flooding that the Earth has experienced in the last decade – including Super Typhoon Haiyan/Yolanda, Superstorm Sandy, Hurricanes Harvey and Irma, and the 2016 Louisiana Floods – were driven by increased ocean heat content and resulting high sea surface temperatures. These warmer ocean temperatures in turn increased atmospheric moisture content, storm size, and precipitation, causing greater damage to property and loss of lives.[10]

13. It should also be noted that more and higher rates of ocean warming will have dire implications for marine ecosystems and will contribute significantly to sea level rise through thermal expansion of the oceans. As our study concluded, the only way to slow or stop these impacts is to slow or stop the warming of our climate, which requires immediate reductions in greenhouse gas emissions.[11] Given what we now know about the acceleration of the warming of the oceans, I believe that efforts by the present administration to expand fossil fuel production and continue authorizing the extraction of coal on federal lands are extremely reckless.

[10] Ex. 1 at 18-20.
[11] Ex. 2 at 129.

14. To climate scientists, ongoing high levels of greenhouse gas emissions and ocean warming have created a state of emergency. The inherent latency and slow response-times built in to both our infrastructure and climate systems means that, absent rapid actions to reduce emissions, we are already approaching an existential crisis where the very continuation of life on the planet in anything like the current state becomes less likely after mid-century.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct. Executed on February 3, 2019.

Respectfully submitted,

Kevin E. Trenberth, Sc.D.

Exhibit 1

SUPPLEMENTAL EXPERT REPORT
OF
KEVIN E. TRENBERTH, Sc.D.

Distinguished Senior Scientist, National Center for Atmospheric Research,
Head, Climate Analysis Section

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,
through his Guardian Tamara Roske-Martinez; et al.,
Plaintiffs,

v.

The United States of America; Donald Trump,
in his official capacity as President of the United States; et al.,
Defendants.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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TABLE OF ACRONYMS AND ABBREVIATIONS

ACE:	Accumulated Cyclone Energy
GMST:	Global mean surface temperature
IPCC:	Intergovernmental Panel on Climate Change
NASA:	National Aeronautics and Space Administration
NCAR:	National Center for Atmospheric Research
NOAA:	National Oceanic and Atmospheric Administration
OHC:	Ocean Heat Content
SST:	Sea surface temperature
UNEP:	United Nations Environment Programme
USGCRP:	U.S. Global Change Research Program
WMO:	World Meteorological Organization

INTRODUCTION

I, Kevin Trenberth, have been retained by Plaintiffs in the above-captioned matter to provide expert testimony regarding the impacts of human-caused greenhouse gas emissions and climate change on the water cycle and extreme weather events. Below I also discuss the role of the atmosphere and oceans, and their interactions.

EXECUTIVE SUMMARY

The climate system consists of the atmosphere, oceans, land and cryosphere. The atmosphere is the most volatile component while both atmosphere and oceans are fluids and couple together to produce the predominant patterns of variability in the water cycle. We live on land, where availability of water depends on rainfall, snow-melt, lakes and rivers, while ice is important where it occurs. Weather and climate extremes happen all of the time, even in an unchanging climate. Yet these extremes are becoming more frequent and more severe, and the primary driver is human-induced climate change. Indeed, the main way in which climate change is already affecting, and is likely to continue to affect, human societies around the world, is through changes in extreme weather events. Here I summarize the way to think about the relationship between our oceans and atmosphere, weather and climate change. I provide my expert opinion on how climate change is increasing many extremes, with major consequences for human society, including these plaintiffs, and the environment.

Activities on Earth are adjusted to our current climate, which has been relatively stable throughout the past 2,000 years, coinciding with much of the development of human civilization. Natural changes in the past have occurred from small variations in the sun and effects of volcanic eruptions, and on geological time scales from changes in the Earth's orbit around the sun. Now changes in atmospheric composition from human activities, primarily the burning of fossil fuels and deforestation, are the main cause of anthropogenic climate change by enhancing the greenhouse effect. Globally, on a day-to-day basis, the effects from these human activities are responsible for 1 to 2% of the flow of natural energy through the climate system. However, because anthropogenic global warming is always heating the planet, excess energy accumulates, and those cumulative effects create a much bigger impact. Importantly, all weather events are now occurring in an environment which has changed in significant ways, as compared to 50 years ago. The main way this is manifested, the "memory" of these changes, is through the accumulated warming of the oceans and the loss of Arctic sea ice. Owing to anthropogenic global warming, sea surface temperatures have warmed by over 1°F since the 1970s, and over the oceans this has led to 5 to 10% more water vapor in the atmosphere. The warmer and moister atmosphere in turn has likely led to at least a 5 to 20% effect on storms that is greatly exaggerated for extreme weather events. When climate change's increased effect on storms is compounded with natural variations, such as an El Niño event, the effects are much larger, and more destructive.

Up until recently, scientists claimed we could not attribute any single weather event to global warming (climate change) even though the event was consistent with expectations. The reason scientists were reluctant to attribute a single event to global warming is that weather

events cannot be predicted more than about 2 weeks in advance, at best. But climate change clearly increases the odds of such events occurring. In reality, ***all*** weather-related events have both natural and anthropogenic components in this era of climate change. When anthropogenic climate change and natural climate patterns work synergistically, thresholds are crossed, records are broken and it can be said that such extreme events would have been very unlikely to occur without global warming. In my expert opinion, if business-as-usual greenhouse gas emissions continue, the security and lives of young people and future generations are and will be increasingly threatened by ever more extreme weather events than those already being experienced. Several of the youth plaintiffs in this case live in regions of the United States that have already experienced extreme events compounded by climate change, and are very likely to suffer ongoing and increasingly severe extreme events which are made worse by climate change.

QUALIFICATIONS AND COMPENSATION

This report contains my opinions, conclusions, and the reasons therefore. The opinions expressed in this report are my own and are based on the data and facts available to me at the time of writing. All opinions expressed herein are to a reasonable degree of scientific certainty, unless otherwise specifically stated. Should additional relevant or pertinent information become available, I reserve the right to supplement the discussion and findings in this expert report in this action.

My curriculum vitae is attached as **Exhibit A** to my expert report in this action. A list of publications I authored within the last ten years is shown in **Exhibit B** to my expert report in this action. A statement of my previous testimony within the preceding four years as an expert at trial or by deposition is contained in **Exhibit C** to my expert report in this action. My report contains citations to the principal documents that I have used or considered in forming my opinions, listed in **Exhibit D**.

I have authored over 550 publications in the area of climate, and given hundreds of talks on the subject. I am among the most highly cited researchers in all of geophysics. I have extensively investigated global-scale climate dynamics, the observations, processes and modeling of climate changes from interannual to centennial time scales. I have particular expertise in El Niño, the hydrological and energy cycles, hurricanes and storms, and climate change. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards. I co-chaired the international Climate Variability and Predictability (CLIVAR) Scientific Steering Group of the World Climate Research Programme (WCRP) from 1996 to 1999 and I have served as a member and officer of the Joint Scientific Committee that oversees the WCRP as a whole from 1998 to 2006. I chaired the WCRP Observations and Assimilation Panel from 2004 to 2010 and from 2010 to 2014 I chaired the Scientific Steering Group of GEWEX: the Global Energy and Water Cycle Experiment of WCRP. I remain involved in CLIVAR committees. I have been involved in global warming science and extensively involved in the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activity as a lead author of individual chapters, the Technical Summary, and Summary for Policy Makers (SPM) of Working Group (WG) I for the Second, Third and Fourth Assessment Reports (SAR, TAR and AR4; IPCC 1996, 2001, 2007). I was a Coordinating Lead Author for the SAR and AR4; in the latter I led Chapter 3 that dealt with observations of surface and atmospheric climate change. I was a Review Editor of the Fifth IPCC Assessment Report (AR5) in 2013. Accordingly, I shared the Nobel Peace Prize in 2007 that went to the IPCC and Al Gore. In 2017 I was awarded the prestigious Roger Revelle Medal by the American Geophysical Union.

In preparing my expert report and testifying at trial, I am deferring my expert witness fees to the charged Plaintiffs given the financial circumstances of these young Plaintiffs. If a party seeks discovery under Federal Rule 26(b), I will charge my reasonable fee of $200 per hour for the time spent in addressing that party's discovery.

EXPERT OPINION

1. The climate is changing

Humans have released carbon dioxide and other heat-trapping "greenhouse" gases in sufficient quantity to change the composition of the atmosphere, resulting in an accumulation of heat in the Earth's system, commonly referred to as "global warming." The Earth's climate has responded through higher temperatures in the atmosphere, land and ocean, ice melting, rising sea level, and increases in extreme weather events (heat waves, wildfires, heavy rains and flooding). The calendar year 2016 is by far the warmest on record for the global mean surface temperatures (GMSTs) (**Figure 1**). It easily beat out 2015, which in turn beat out the previous record holder 2014. Global sea level continues to rise at a rate of over a foot per century (**Figure 2**). Calendar year 2017 continued the record-breaking trend by being the warmest on record for the global oceans down to 2,000 m depth (**Figure 3**) and thus for the planet as a whole, and it was third warmest in GMST. Every year since 1997 has been warmer than average in the United States. A 2018 NOAA report found that the five hottest years in 123 years of record-keeping in the United States have all been in the past decade. Also, according to NOAA, five states had their warmest years on record, including Arizona, Georgia, New Mexico, North Carolina and South Carolina. Alaska had its warmest December ever, with temperatures 15.7°F above its historic average, for a statewide average of 19.4°F. There is no doubt whatsoever that the planet is warming and it has major consequences for other aspects of our climate. However, there is also a lot of natural variability manifested in the GMST record; the biggest fluctuations from year to year are associated with El Niño events.

The USGCRP Climate Science Special Report of 2017 (which I helped the National Academy of Sciences peer review), projects with high confidence between 1.6°C and 6.6°C (2.8–11.9°F) of warming this century, depending on low or high emissions scenarios, with record-setting years becoming the norm and much larger temperature increases by late century. The U.S. government has very high confidence that the number of days below freezing will continue to decline and the number of days over 90°F will increase.

The overall warming is caused by human activities, mostly through the changes in composition of the atmosphere through burning of fossil fuels (industry, electricity generation, driving cars, flying airplanes, space heating, etc.), and deforestation. Carbon dioxide concentrations in the atmosphere have increased by well over 40% since pre-industrial times (see **Figure 1**) and a key reason is that carbon dioxide has a lifetime of centuries. Air pollution in the form of aerosol particulates also plays an important role, but because the particles are washed out by rainfall, their average lifetime is on the order of a week. Hence their effects are not global but rather regional, and their production has to continue for their effects to be present. Their effects are also complex because some reflect the sun and cause cooling, some (carbonaceous) are dark and absorb the sun's rays, and many become involved in clouds and affect the brightness, lifetime and disposition of clouds; in general, they cause a cooling effect. In contrast, even if we stopped emitting carbon dioxide into the atmosphere today, the elevated concentrations already established would persist for some time, thus underscoring the need for urgent reductions in carbon dioxide emissions. Hence, changes in atmospheric composition, and particularly the increase in carbon dioxide concentrations, enhance the greenhouse effect, although with important regional effects from aerosol particulates. As discussed further below, scientists at the National Center for Atmospheric Research (NCAR), as well as other scientists around the world,

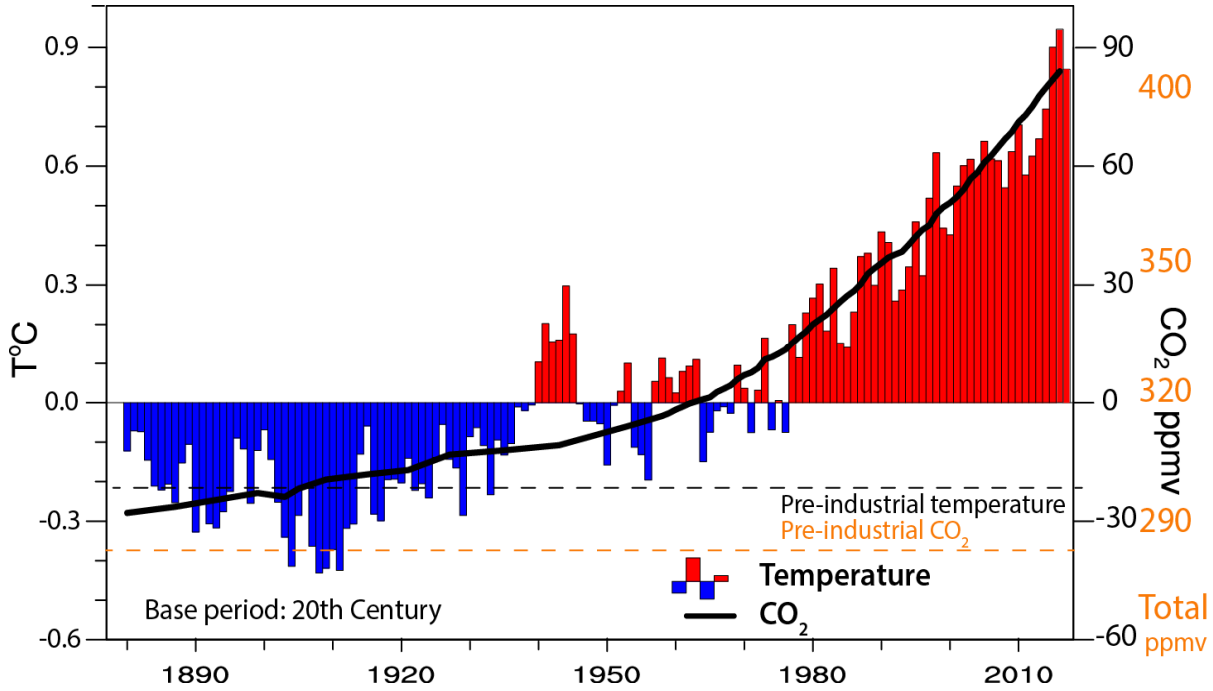

Figure 1. Global mean annual surface temperatures (from NOAA) relative to the Twentieth Century average, along with the carbon dioxide concentrations (values at right) in parts per million by volume (from NOAA) based on the Mauna Loa record after 1958 and ice core bubbles of air prior to then. Estimates of the pre-industrial values for each are also given (Updated through 2017 from Trenberth, K. E., and J. T. Fasullo, 2013: An apparent hiatus in global warming? *Earth's Future*. 1, 19-32. Doi: 10.002/2013EF000165).

have proven that the global warming is driven primarily from the rise in carbon dioxide by using comprehensive climate models, which enable us to also make projections into the future.

The increased heat-trapping gases in the atmosphere lead to an energy imbalance at the top of the atmosphere, and that excess energy is the cause of the warming. Globally on a day-to-day basis these increased greenhouse gases produce an extra 1 to 2% of the flow of natural energy through the climate system. However, because global warming is always heating the planet, there is a much bigger impact from the cumulative effects of this added energy. Hence, all weather events are now occurring in an environment which has changed in significant ways as compared to even 50 years ago. Most of the energy imbalance as excess heat, over 91%, ends up in the ocean. Hence, the oceans are warmer, Arctic sea ice is melting, and land glaciers and ice sheets, such as Greenland, are also melting. The largest temperature rises are occurring in the Arctic, where bright reflective snow and ice are melting to reveal dark ocean and land. This darkened surface reflects less sunshine, compounding the warming that is causing the melting in the first instance. The combination of a warmer ocean that expands, and extra melt-water in the oceans means that sea level is rising at a rate of well over a foot per century (**Figure 2**). **Figure 2** shows that sea level is clearly rising as the planet warms. The main fluctuations are associated with El Niño when there is more rain over the Pacific Ocean while dips occur in La Niña events (such as 2011) when more rain and snow occur over land.

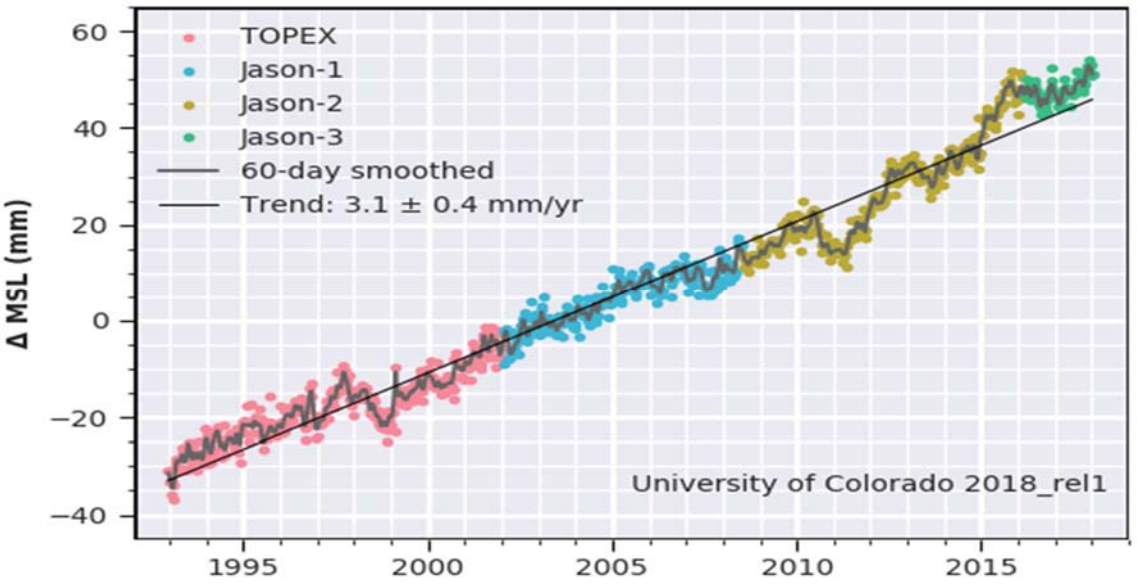

Figure 2. Global sea level rise based upon altimeter measurements from space since late 1992, with the annual cycle removed. Nerem, R. S., D. Chambers, C. Choe, and G. T. Mitchum. Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions. *Marine Geodesy* 33, no. 1 supp 1 (2010): 435. http://sealevel.colorado.edu/

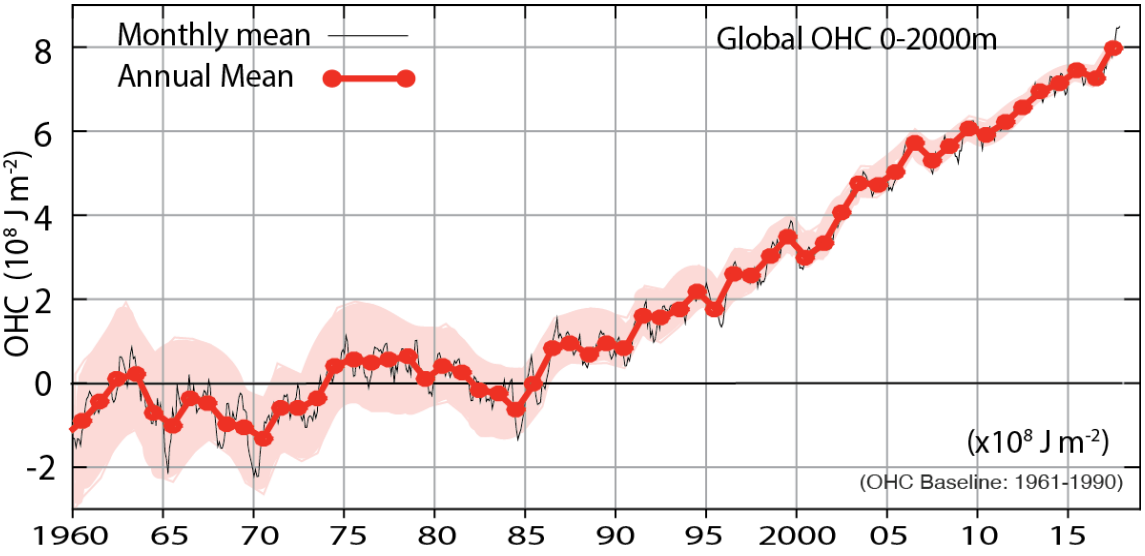

Figure 3. Global Ocean Heat Content (OHC) for the top 2000 m of the global ocean, updated from the analysis of Cheng et al. (2017). The baseline (zero) is the 1961–90 mean; the monthly values are indicated in the thin black line, annual values by the red dots with uncertainty indicated in pink. Cheng, L., K. Trenberth, J. Fasullo, T. Boyer, J. Abraham, and J. Zhu, 2017: Improved estimates of ocean heat content from 1960-2015. *Sci. Adv.* **3**, 3, e1601545, Doi:10.1126/sciadv.1601545. http://advances.sciencemag.org/content/3/3/e1601545

2. How global warming affects extreme events

As well as the overall heating of the planet mainly from human changes in the atmospheric composition, which leads to general temperature increases in the atmosphere and oceans, and melting ice, there are substantial impacts on extreme events. Indeed, the biggest impacts of climate change on society and the environment arise from changes in extremes. (**Figure 4**). These are realized through the daily weather systems, which naturally produce tremendous variability on all time scales and over many different spatial scales. Hence just by chance, extreme values of temperatures, precipitation, or wind, and so forth, occur from vigorous weather systems. With global warming, some of these extremes are pushed higher and beyond previous values, creating new records. Moreover, global warming often pushes values over various thresholds used for design purposes: whether for heat, rain, wind, or sea level, and accordingly things break. This also means that the events and the new records are episodic.

There is not a continuous level of high values, rather the values fluctuate substantially as they have always done with natural weather patterns. It also means that in one month records are broken at one location, while in the next month records break somewhere else, and then somewhere else again. The fact that the extremes occur in different places over time, means that the public often does not connect them to climate change, and their accumulated effects have been greatly underestimated by many. It also means that because of the natural climate variability from year to year, it is often difficult to conclusively detect the climate change influences—an issue of signal-to-noise, as discussed later.

However, 2017 saw many episodic events setting off-the-charts records with extreme wildfires in the western U.S., hurricanes in the southeastern U.S. and the Caribbean, and the deadly monsoon flooding in India, Nepal and Bangladesh, all made worse by climate change.

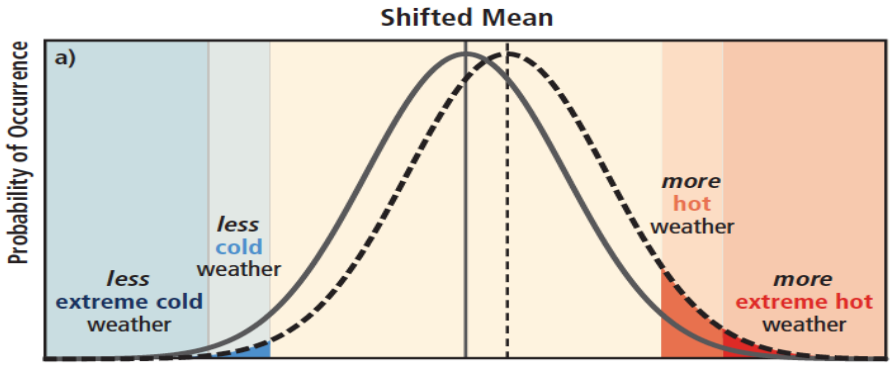

Figure 4. The effect of changes in the mean temperature on extremes: without (solid) and with (dashed) climate change. From IPCC (2012).

a. Heat waves

The most obvious expectation is for an increase in short-duration heat waves and their impacts as overall temperatures rise.[1] With global warming, often these increasing short-duration heat waves result in temperature rises beyond anything previously experienced in

[1] Defendants agree that anthropogenic climate change in the United States has produced warmer summers and that prolonged heat events in recent years have been the most extreme on record and that climate change has contributed to these events (Fed. Answer ¶ 221, 227). They also acknowledge that "[h]eat waves would then [if BAU continues] increase in frequency, severity, and duration" (Fed. Answer ¶ 247).

recorded history. This has been borne out in many studies, as documented by Intergovernmental Panel on Climate Change (IPCC) reports and other assessments.

Heat waves nearly always occur in association with a strong slow-moving anticyclone. The major European heat wave in the summer of 2003, was one of the first to be well documented both in terms of its detection as extremely unusual, and in terms of attribution to anthropogenic climate change using climate models. There were major consequences in terms of wildfires, and loss of life. A more recent example is the extreme Russian heat wave of 2010, again with widespread wildfires, smoke, agricultural losses, and loss of life. Some confusion and debate has occurred in the scientific literature about this event over the cause and rarity of the weather situation, versus the role of human-induced warming. As discussed in the next section on attribution, this confusion arises because the weather events (strong anticyclones) tend to occur naturally; while it is the global warming that pushes what would have been an extreme event anyway into one that goes well outside previous bounds and causes major strife. After analyzing the highest annual temperatures for approximately 9,000 stations globally, we found a global increase of 0.19°C per decade over the past 50 years (through 2015), which accelerated to 0.25°C per decade during the last 30 years, a faster increase than in the mean annual temperature. Short-term heat waves are increasingly worse with climate change. Other studies have also shown that human-caused climate change has increased the severity and probability of the hottest days and month of the year by >80%.

High temperatures can result in detrimental health, economic, and social impacts. The European 2003 and the Russian 2010 heat waves caused, respectively, almost 70,000 and 55,000 deaths, while an average of 658 deaths were reported annually during 1999–2009 in the United States alone due to excessive heat. Extreme high temperatures cause human casualties in large cities and have profound impacts on farms due to reduced crop productivity and adverse effects on animals, including mortality. Temperature extremes stress infrastructure, transportation, water supply, and electricity demand; severely affect ecosystems and forests, and increase wildfire activity. Heat strokes—the most lethal condition of hyperthermia—can be caused by exposure to high ambient environmental temperatures. More frequent, more intense, and longer lasting heat waves are robustly projected in the 21st Century as a result of human-induced global warming.

b. Drought and wildfire

In the United States, and indeed in mid-latitude continental areas around the world, there is a strong negative correlation between monthly-mean temperatures and precipitation in the summer half-year, as there is year-round in the tropics. Heat waves, especially ones of longer duration, often occur in association with drought. The anticyclonic conditions that persist in a drought situation make for dry settled weather, with little or no precipitation. Under these circumstances, the land and vegetation dry out, and the modest extra heat from global warming exacerbates the dry conditions. Evaporative cooling ceases as plants wilt, wildfire risk increases, and the heat intensifies. That in turn increases the atmospheric demand for moisture, further drying out the vegetation in a vicious cycle.

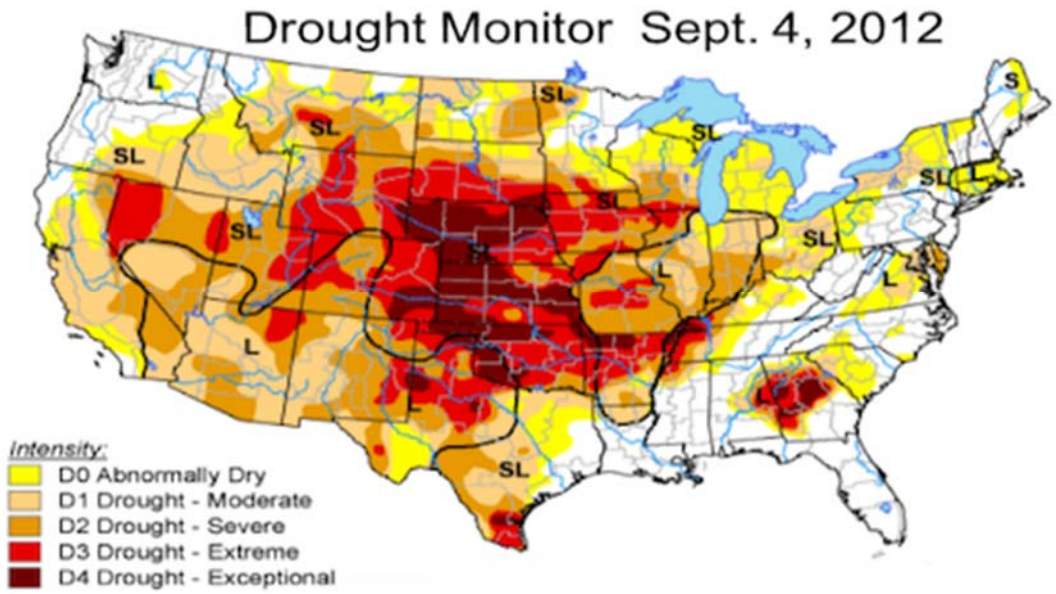

Figure 5. NOAA's drought monitor for September 4, 2012

The warmest year on record for the United States as a whole was 2012 when there was a widespread drought in association with persistent anticyclonic conditions over much of the country. Extreme drought was estimated to cover 39% of the country at its peak in September 2012, rivaling the Dust Bowl years in the early 1930s. According to the Sept. 4, 2012 drought monitor, 64% of the country was in moderate to extreme drought. Wildfires became endemic in many places, and firefighting costs soared. As a result of these events and the agricultural and livestock losses, the net cost has been estimated as over $75 billion, although a partial accounting by NOAA lists it as $32 billion. *Wildfire Today* reports the fire-fighting costs alone in 2012 were $2 billion.

Perhaps the best example of how climate change can lead to an increase in drought conditions is in the West, particularly California. A record-setting drought began in 2012 and persisted until 2016 in spite of the big El Niño event (which favors more storms coming into the West Coast). It included the lowest annual precipitation on record, the highest annual temperature, as well as the most extreme drought indicators ever recorded in California. Along with widespread water shortages, the drought brought prolonged and costly wildfires. Indeed, wildfires were rampant throughout the West, especially in the summer of 2015, with wildfires widespread in Alaska, western Canada, Washington, Oregon and California. In May 2016, a major wildfire broke out in Fort McMurray, Alberta following 5 to 8 months of prolonged (El Niño related) drought. Major wildfires continued again in August 2016 and July and December 2017 in California, and the consensus has become that the wildfire season in California is now almost continuous.

Certain bugs and diseases flourish under these warmer and dryer conditions, such as the bark beetle, which is decimating forests across the West. Increased carbon dioxide is not good for plants!

c. Storms and precipitation

Perhaps less obvious, but even more dangerous than heat, are the effects of a warming planet on the water cycle in which the oceans play a key role (**Figure 6**). The atmosphere holds about 4% more moisture per 1°F (or 7% per 1°C) increase in temperature, which leads to increased water vapor in the atmosphere, and this provides the biggest influence on precipitation. It is undisputed that water vapor is a powerful greenhouse gas, and hence this amplifies the original warming substantially. In addition, sea surface temperatures have warmed by more than 1°F since the 1970s, and over the oceans this has led to 5 to 10% more water vapor in the atmosphere.

Storms, whether individual thunderstorms, extratropical rain or snow storms, or tropical cyclones and hurricanes, supplied by increased moisture, produce more intense precipitation events, even in places where total precipitation is decreasing. The increased moisture and related latent heat release can intensify storms, including hurricanes (next section), and perhaps double[2] the original change so that the precipitation increases 5 to 20%. This leads to much stronger and more intense rains, and snows, and it increases risk of flooding that exceeds previous bounds for extreme weather events. At the same time, dry spells in between such events also increase. Indeed, in places where it is not raining, the extra heat dries things out, exacerbating heat waves as the evaporative cooling is lost. Hence, droughts set in quicker and become more intense, increasing risk of wildfire. This is especially a dangerous problem in the U.S. West, as noted above.

Examples are discussed in more detail below. However, in Colorado, the unprecedented widespread flooding along the Front Range in September 2013 is a case in point. The moisture sources came from very warm ocean regions to the south (the Gulf of Mexico and especially from west of Mexico) that undoubtedly had a global warming component. More recently, widespread flooding occurred in Missouri (Nov.–Dec. 2015), in Houston in April 2016, in Louisiana in August 2016, and in the Carolinas from hurricane Matthew in October 2016. The major winter storm "Jonas" that "bombed" Washington D.C. with feet of snow in January 2016 is another example of such an extreme event.

In early 2017, in association with unusually high sea temperatures in the subtropical North Pacific, the drought in California was abated with heavy rains and snows, leading to flooding in many areas. This was a short-lived boon in terms of snowpack to the Sierra Nevadas and Rocky Mountains. Meanwhile torrential rains, flooding, mud slides, and loss of life occurred in South America: in northern Chile in late February 2017, in Peru in March, and Colombia in early April in association with a coastal El Niño that led to very high sea temperatures off the Pacific coast in combination with global warming.

Without climate change, many of these events would have been properly labeled as "1000-year events." However, because of climate change and its effects on the environment, they are no longer 1 in 1000-year events, and instead, they are now more likely 1 in 50-year or 100-year events. They are still uncommon, but not unlikely. The increased flooding from climate

[2] The effect on the storm depends on where the precipitation and released heat occurs relative to the storm center. For hurricanes, the effect is direct and the result can be doubled or more. For extratropical storms the effects are more complicated and the effect is a factor of 1 to 2. It varies from storm to storm.

change exposes people in the U.S. to trillions of dollars of damage this century and significant human suffering from loss of property and life.

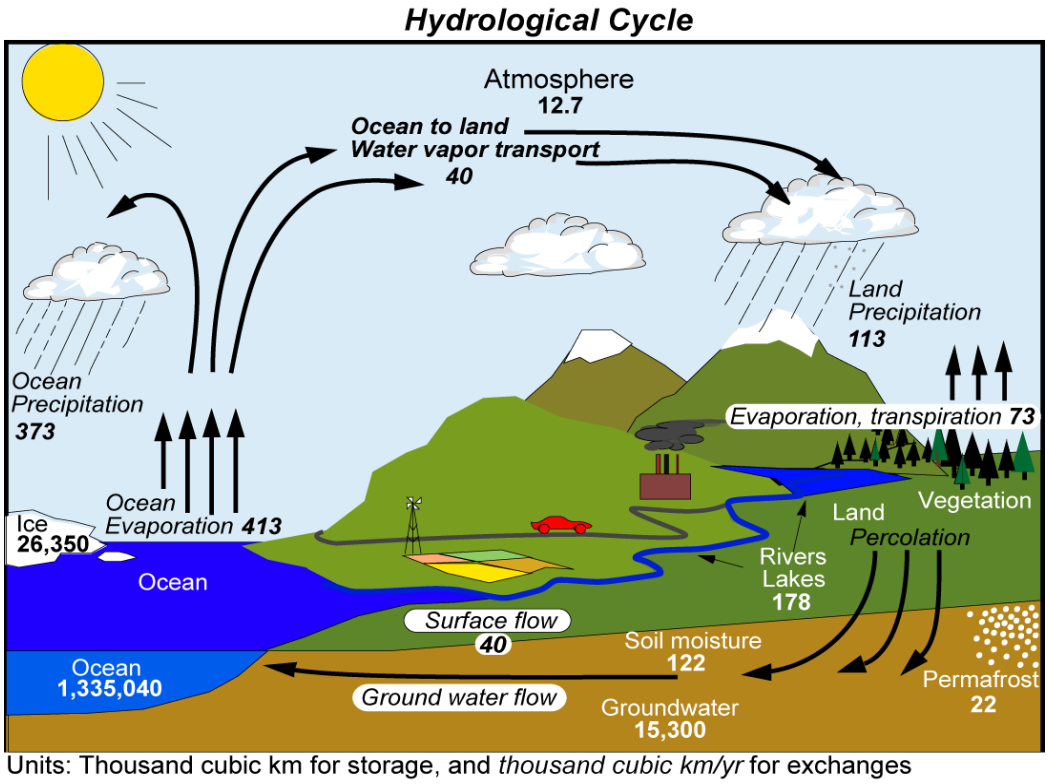

Figure 6. The global water cycle, showing the amount in each reservoir in thousand cubic km, and the flows between reservoirs in thousand cubic km per year. From Trenberth, K. E., L. Smith, T. Qian, A. Dai and J. Fasullo, 2007: Estimates of the global water budget and its annual cycle using observational and model data. *J. Hydrometeor*, **8**, 758-769.

d. Tropical storms and hurricanes

Tropical storms and hurricanes/typhoons mostly occur in the deep tropics in summer in association with high sea surface temperatures (SSTs) over 27°C. In turn these reflect high ocean heat content (OHC) below the surface and it is this heat energy that is transferred into the atmosphere through evaporation, moistening the atmosphere, while evaporative cooling occurs in the ocean. The fuel for tropical storms and hurricanes comes from the release of the latent heat in heavy rainfall as the moisture is gathered into the storm and condensed. (**Figure 7**).

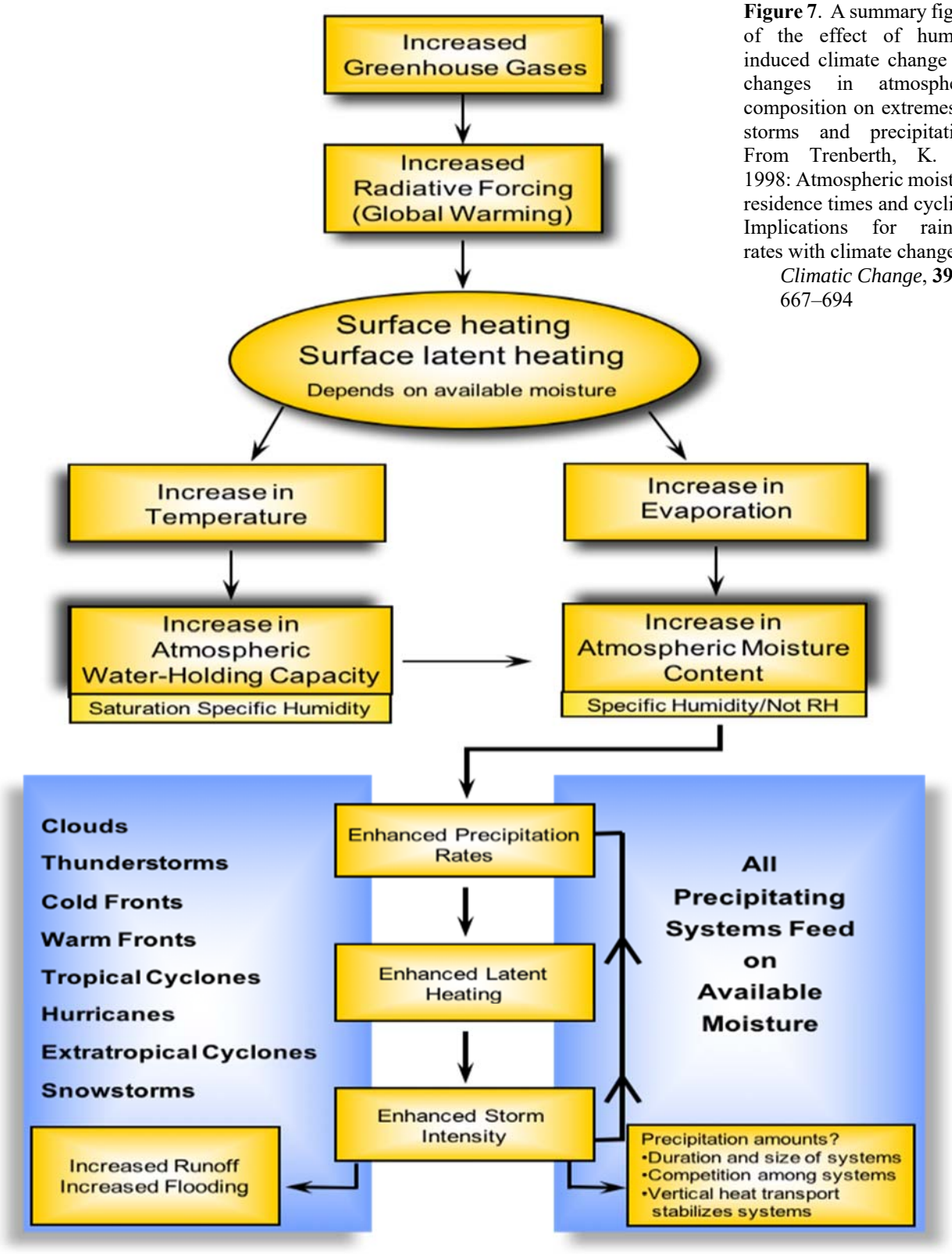

Figure 7. A summary figure of the effect of human-induced climate change via changes in atmospheric composition on extremes of storms and precipitation. From Trenberth, K. E., 1998: Atmospheric moisture residence times and cycling: Implications for rainfall rates with climate change. *Climatic Change*, **39**, 667–694

One harmful aspect of hurricanes is the fierce winds that cause destruction to people's homes and other buildings and infrastructure. However, hurricanes are also responsible for huge storm surges in coastal regions that can be very damaging and are expected to become much worse due to both stronger winds and higher sea levels. The most widespread damage, though, is actually the flooding from torrential rains that can extend hundreds of miles from the coast.

One major source of variability in tropical SSTs is the El Niño phenomenon that produces a warming in the central and eastern Pacific with a corresponding shift in tropical storm activity into that region at the expense of other regions. Hurricanes become more frequent in the eastern North Pacific but decrease in the Atlantic, for example. Indeed, there is always a competition throughout the tropics for where the main activity occurs, and high SSTs are the main factor. Once activity is underway in one region of the tropics, it tends to suppress activity elsewhere by creating a large overturning circulation in the atmosphere that creates subsiding stable air elsewhere and wind-shear in in-between regions (where the low-level winds and upper level winds in the troposphere at jet stream level are indifferent directions and/or speeds), and this tends to blow a developing vortex apart. Accordingly, tropical storms are clustered and cannot occur everywhere at once.

In general, climate warming invigorates tropical storm activity[3] by adding energy to the storms, but it can be manifested in several ways. With climate change, it is expected that hurricanes will become more intense and possibly larger in size and longer lived, but fewer in number, as one big storm essentially replaces the effects of several smaller weaker storms in terms of the heat energy pulled out of the ocean. Owing to the large natural climate variability from year-to-year and unreliable records prior to the satellite era (~1980), it is difficult to clearly detect climate change influences on tropical storm activity. "Detection" relies on a climate signal that is larger than the noise of natural variability, confounded also in this case by unreliable data. So, it is not that there is no signal, but rather that the noise is large. Indeed, there is very compelling evidence that there is a climate signal to increased tropical storm activity.

Examples of increased activity are the record-breaking exceptionally large number and strength of storms in the Atlantic in 2005, super storm Sandy on the East Coast in 2012, the strongest land-falling typhoon on record: Haiyan in 2013 that went through the Philippines, and the very strong storms recorded in several regions in 2015 and 2016 (strongest in the southern Hemisphere—Winston in 2016 that went through Fiji). The year 2015 is the most active year globally for hurricanes/typhoons ever. The latter is in part because it was an El Niño year, but it highlights the fact that high sea surface temperatures for whatever reason produce bigger and stronger storms. At the same time, there are quiet years, that highlight the large variability.

[3] Because a warmer atmosphere holds more moisture, there will be an increase in heavy precipitation, and related flooding, from tropical storms and hurricanes. Moreover, because tropical storms and hurricanes are now occurring in the context of sea level rise, the storm surges are greater and more destructive than they were when sea levels were lower (see discussion of Super Storm Sandy in Section 3(b) below). For example, Defendants agree that rising relative sea levels have caused increased flooding in many communities (Fed. Answer ¶ 218). Defendants in this case also agree, for instance, that climate change is associated with increases in hurricane intensity, increased frequency of intense storms and heavy precipitation, and that the number of very heavy precipitation events has been significantly above average since 1991 (Fed. Answer ¶ 220).

In the Atlantic, following the record-breaking active years of 2004 and 2005, the tropical storms were less active, until 2017. Hurricanes Harvey, Irma, and Maria were very strong, huge and long-lived and did well over $250 billion in damage to Texas, Florida, Puerto Rico and many Caribbean Islands. Atlantic hurricanes are normal events in summer, with an average of 12 named storms and 6 hurricanes in the Atlantic. However, in 2017 there were 17 named storms and 10 hurricanes, 6 of which were categorized as "Major." According to National Oceanic and Atmospheric Administration (NOAA), the Accumulated Cyclone Energy (ACE) was 225% of normal. Harvey's record-shattering rainfall featured several locations with over 60 inches (1,500 mm) and a study has shown how the probability of exceptionally high rainfalls in Harvey-like storms has increased because of climate change. Another study used an extreme value analysis to show that climate change had increased Harvey precipitation over land by about 37.7%, as a best estimate. The extremely high rainfalls have been linked to the record high ocean heat content in the Gulf prior to the storm.

Our oceans serve as the memory of the accumulated human-induced global warming (**Figure 3**). The higher ocean heat content and sea surface temperatures invigorate tropical cyclones to make them bigger, more intense and longer lasting, leading to more destructive rains and flooding. Hurricanes cool tropical oceans through their strong winds and increased evaporation. The evidence strongly suggests that these 2017 storms would not have happened with as much rainfall and intensity, and resulting damage, without climate change. Michel-Kergan and Kunreuther (2011) discuss the costs of flooding and conclude that hurricanes Katrina, Rita and Wilma in 2005 cost over $180 billion (2011 prices); and they also assign costs to several other events.

e. Snowfall and snow cover

In winter over the northern hemisphere land, the snow season is getting shorter at each end as more precipitation arrives as rain.[4] Generally, the biggest snowfall occurs with temperatures just below freezing, and hence in mid-winter, the prospects, as observed, are for bigger snowfalls and larger snow pack from November through January. With climate change, it is no longer "too cold to snow" very often. In contrast, snow pack is observed to be much reduced across the northern hemisphere from March through August 1966 to 2014. Due to global warming, snow melt starts sooner, runoff occurs sooner in the spring, and the risk of drought and water shortages are greater in summer, along with wildfire, and insect pest infestations.

3. Attribution

Scientists are working to attribute causes to weather and climate events, which is often challenging from a physical standpoint. Owing to the chaotic nature of the atmospheric circulation (often depicted by the flap of a butterfly's wings changing the future weather), the detailed day-to-day weather cannot be forecast more than about two weeks into the future. Many repeated computer runs with small perturbations in initial states (forming ensembles) are used to bring out the robust features in future predictions versus those that depend on unknown details. This is done even for 2-week weather forecasts and is essential for climate simulations and

[4] Defendants have acknowledged that "[b]y 2050, snowmelt is projected to shift three to four weeks earlier than the 20th century average." (Fed. Answer ¶ 249).

predictions. In dealing with climate predictions, then, the goal is not to predict the detailed evolution but the general patterns of weather, such as those that occur from one season to the next. Hence the reason scientists are reluctant to *attribute* a single event to global warming is that weather events cannot be predicted more than about 2 weeks, but climate change may change the odds of such events occurring.

The climate science community has responded to the demand for timely information by attempting to perform attribution of climate extremes. The dissemination of attribution has been partly through the IPCC[5] reports, but also through annual reports offering closer to real-time assessments and posing the question of whether the likelihood or strength of the event was affected by anthropogenic climate change. Increasingly, some reports are issued in near real time, but often with compromises as to what can be done.

More generally, there are perhaps two main kinds of attribution analyses performed, what I call the conventional approach and the conditional approach. The first relates the particular extreme event to the associated weather and weather patterns with statements such as 'the drought was caused by a blocking anticyclone'; 'the outbreak of tornadoes was caused by a displaced and active storm track and jet stream.' Although useful, these phenomena are really a description of the event, not a cause. Importantly, this approach does not ask the questions: 'Why did that weather phenomenon behave the way it did?' In particular, 'What influences external to the atmosphere were playing a role, and what climate factors were in play?'

The second kind of attribution study, the conditional approach, relates to the objective of assessing the role of human activities, and especially of human-induced climate change, in the event. Results depend, however, upon how the questions are framed.

The conventional approach assesses how the weather system might have changed from climate change influences; it requires many climate model runs with and without climate change present to sort out how unusual the weather event was and how the odds were changed by climate change. Because of the infinite natural variety of weather and the often-uncertain nature of the human influences, such changes are mostly very small and lost in the noise. The huge computational demand precludes the near real-time commentary required by the media. Instead,

[5] The IPCC is a body of scientists from around the world convened by the United Nations jointly under the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) and initiated in 1988 under the leadership of the United States. Its mandate is to provide policy makers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate and the effects of human activities on climate in particular. Major assessments were made in 1990, 1995, 2001, 2007, and 2013. Each new IPCC report reviews all the published literature over the previous 5 to 7 years, and assesses the state of knowledge, while trying to reconcile disparate claims and resolve discrepancies, and document uncertainties. The IPCC perhaps represents the scientific consensus, but precisely because it is a consensus assessment among very disparate scientists from many countries with varying expertise, it is extremely conservative and lags behind the state-of-the-art scientific understanding. The IPCC format has always created certain difficulties because of the huge numbers of scientists involved whose contributions are voluntary. The many chapters are written by teams in parallel, and the three Working Groups mostly work in parallel. The timeline for a report is several years and, because it is thoroughly reviewed, it is not current at time of publication. This has led to calls for a more operational and timely assessment process.

it is more useful to regard the extreme circulation regime or weather event as being secondary—it is the means whereby the event happens—and instead focus on the effects of the well-established changes in the environment from global warming on the impacts of the particular event. The conventional attribution framework struggles with dynamically-driven extremes where the weather system itself plays a major role because the natural variability of weather is so large, and hence there are small signal-to-noise ratios. Moreover, the expected changes in weather systems (from climate models) are often highly uncertain. It is better to examine whether known changes in the climate system's thermodynamic state (i.e. temperature related) affected the impact of the particular event. Because the water-holding capacity of the atmosphere depends strongly on temperature – it increases 7% per °C—there is also a direct relationship with humidity and precipitation. The National Academy of Sciences *"Attribution of Extreme Weather Events in the Context of Climate Change*" in March 2016, presented both approaches as two aspects of the same spectrum, virtually without comment. But the message was that the strongly conditioned approach is completely acceptable, and moreover that the traditional approach will be limited by adequacy of the modeling tools available. In particular, as the consideration turns from extremes such as heat waves to extreme precipitation and storms, useful statements are much more likely from the strongly conditioned approach.

In the past, the conventional way of approaching attribution tried to deal with all aspects of the problem. But the changes in weather phenomena and weather systems, where they go, and so forth have infinite variety (called weather) and any climate change signal is small (except in the case of the ozone hole). This has confounded the results. In particular, the conventional approach to attribution of climate events is to characterize the event and ask (i) whether the likelihood or strength of such events has changed in the observational record, and (ii) whether this change is consistent with the anthropogenic influence as found in one or more climate models. This approach has had considerable success with extremes that are strongly governed by thermodynamic aspects of climate change, especially those related to temperature, each finding providing another independent line of evidence that anthropogenic climate change is affecting climate extremes.

The conventional approach, however, is severely challenged when evaluating climate extremes that are strongly governed by atmospheric circulation, including local aspects of precipitation. It is inherently conservative and prone to false negatives, which underestimate the true likelihood of the human influence. This is all the more reason why the more recently developed "conditional" approach provides more insight and illumination as to what is truly going on and the role of climate change.

a. More fruitful scientific questions: the conditional approach

Because of the infinite variety of weather systems and how rapidly they develop and respond to small perturbations, the atmospheric circulation (dynamics) aspects of climate change are much less predictable than those associated with heat and temperature (thermodynamics). Hence separating out the thermodynamic from dynamic effects in extreme events, i.e., the conditional approach, is a new fruitful way forward in evaluating attribution and results in a different set of questions to be addressed than in the past (prior to 2015):

- Given the weather pattern, how were the temperatures, precipitation and associated impacts influenced by climate change?

- Given a drought, how was the drying (evapotranspiration) enhanced by climate change, and how did that influence the moisture deficits and dryness of soils, and the wildfire risk? Did it lead to a more intense and perhaps longer-lasting drought, as is likely?
- Given a flood, where did the moisture come from? Was it enhanced by high ocean temperatures that might have had a climate change component?
- Given a heat wave, how was that influenced by drought, changes in precipitation (absence of evaporative cooling from dry land) and extra heat from global warming?
- Given extreme snow, where did the moisture come from? Was it related to higher than normal SSTs off the coast or farther afield?
- Given an extreme storm, how was it influenced by anomalous SSTs and OHC, anomalous moisture transports into the storm, and associated rainfall and latent heating? Was the storm surge worse because of high sea levels?

In other words, given the change in atmospheric circulation that brought about the event, how did climate change alter its impacts?

Therefore, a fruitful and robust approach to climate extreme-event attribution is to regard the circulation regime or weather event as a conditional state (whose change in likelihood is not assessed), and ask whether the impact of the particular event was affected by known changes in the climate system's thermodynamic state (for example sea level, sea surface temperature or atmospheric moisture content), concerning which there is a reasonably high level of confidence.

The consequences of climate change are that things dry out quicker (stronger longer droughts) —as the atmosphere demands more evaporative moisture—and the extra moisture means heavier rains and greater risk of flooding elsewhere, so that ironically, the risk of both extremes of the hydrological cycle are substantially increased.

This is confusing to many people, but of course the floods and droughts occur at different times or even different years, and different places at the same time. Those studies that have sought to understand this through changes in the weather patterns have generally failed and concluded that natural variability rules. But, as explained above, the weather patterns occur in a different environment, one that is warmer and moister and thus one where the atmosphere demands more moisture and causes drying where it is not raining, but one that provides much more moisture to storms with resulting much heavier rains, or even snows, where it is precipitating.

Of course, there are some observed changes in weather patterns, most notably in the southern hemisphere in association with the ozone hole, and small changes elsewhere are projected in the future. In addition, some changes have apparently occurred in association with decadal variability (e.g., related to the pause in the rise of GMST from 2000 to 2013) to further confound results. The main data available to study circulation changes begin in 1979, and the strong Pacific Decadal Oscillation pattern in its negative phase from 1999 through 2013, associated with the slow-down in the rise in GMST, has led to published claims of such changes, but they are flawed as the signal is not that of climate change. This confusion has also been apparent in IPCC reports and national assessments. Below I provide some examples where the thermodynamic aspects are emphasized to bring out the human influence.

b. Examples

Super Typhoon Haiyan/Yolanda, November 2013: the strongest recorded storm ever to reach land. (**Figure 8**). The OHC and sea level in the Philippines' region had both increased a great deal since 1993 and especially since 1998. Consequently, as Typhoon Haiyan approached the Philippines, it was riding on very high SSTs with very deep support through the high OHC. The strong winds and resulting ocean mixing did not cause as much cooling as would normally be experienced, helping the storm to maintain its tremendous strength.

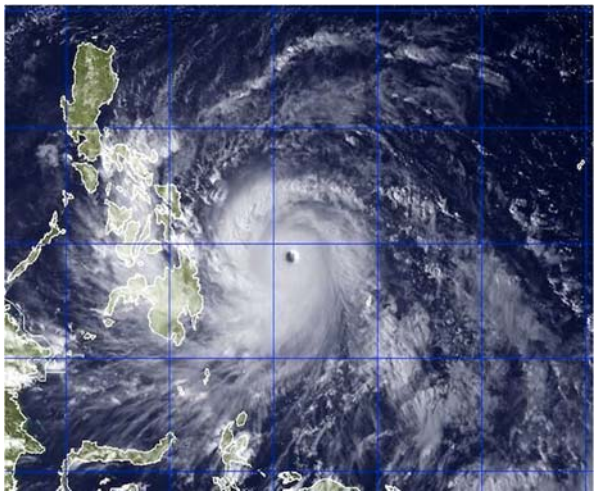

Figure 8. Typhoon Haiyan from NEXSAT satellite, Thursday Nov. 7, 2013 at 2:30 a.m. EDT. Courtesy U.S. Naval Research Lab.

Moreover, the storm surge was undoubtedly exacerbated considerably by the sea levels, which were some 30 cm (1 foot) above 1993 values. Although natural variability played an important role, increased OHC from the Earth's energy imbalance (climate change) made the typhoon more intense and bigger.

Super storm Sandy. Super storm Sandy (**Figure 9**) struck the Northeast in late October 2012 and devastated the Jersey Shore and parts of New York City, including flooding the subway and tunnels to Brooklyn and New Jersey, and 233 lives were lost. Munich Re puts the cost of the storm surge at US $68.4 billion although other estimates are higher. Because the storm was very well predicted a week ahead of time by sophisticated numerical weather prediction models, it was possible to run many computer-based forecasts with observed SSTs versus those with climatological conditions, that showed almost no effects on the track of the storm, but large and significant effects for intensity, wind strength and size. Hence Sandy was undoubtedly larger and stronger as a result of climate change, and the storm surge was much greater owing to high sea levels and stronger winds. It is quite likely that the subways and tunnels in and around New York would not have flooded without the warming-induced increases in sea level and in storm intensity and size.

Figure 9. GOES satellite image of super storm Sandy at 1740 UTC October 28, 2012, off the east coast in the Atlantic Ocean. Courtesy NASA.

This is an excellent example of thresholds being crossed with highly nonlinear consequences. Relatively small increases in water from the climate change component caused billions of dollars in damage. For example, on 14 Nov. 2012 the New York Times editorial "*Money to rebuild after Sandy*" reported that "New York, New Jersey and Connecticut — the states hit hardest by Hurricane Sandy — will need tens of billions of federal dollars to repair bridges, tunnels, subway and commuter rail lines, rebuild schools, power stations and homes, and pay off staggering amounts of overtime" and noted the request from Mr. Cuomo (the Governor) for $30 billion.

Hurricane Harvey. August 2017. (**Figure 10**). When hurricane Harvey made landfall in Texas, it produced record amounts of rainfall, over 60 inches in some spots, causing an estimated $125 billion in damage. In the weeks prior to Harvey, OHC was at a record high levels in the Gulf of Mexico. This ocean heat sharply declined with Harvey via evaporative cooling and was realized in the atmosphere as moisture. Climate change contributed to the record high OHC and sea surface temperatures and likely increased Harvey's precipitation by 37.7%, or as much as 15 inches in places. Harvey was the wettest tropical cyclone on record in the United States to date.

Figure 10. Hurricane Harvey 28 Aug 2017, Courtesy NASA

California drought, 2013–16. (**Figure 11**). One study of the recent California drought that focused on atmospheric circulation effects found no significant trends in winter precipitation in recent decades while another pointed out the critical role of the record high annual mean temperatures in combination with record low annual precipitation for 2013, which led to increased evapotranspiration and more intense drought. Another study suggested between 8 and 27% of the warming contributing to the drought was anthropogenic, but even this is likely an underestimate as it used inadequate models and did not account for the changing snowpack. The combination of the weather pattern and climate change had impacts on water shortages, vegetation and agriculture, and increased wildfire risk.

Figure 11. The drought monitor for January 2014 for California. Courtesy NOAA.

The odds of this combination of events have increased with human-induced climate change and anthropogenic warming causing increased risk of drought and heat waves. Again, several studies are consistent with the view that the atmospheric circulation changes are not the dominant factor, as they arise mostly from natural reasons, while climate change greatly increases heat and drying under favorable conditions and thus increases the impacts.

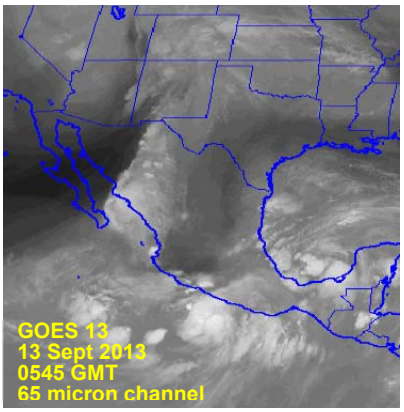

Figure 12. The satellite imagery from the water vapor channel for 13 September 2013, showing the atmospheric river into Colorado. Courtesy NOAA.

Colorado Floods, September 2013. (**Figure 12**). In Colorado, the unprecedented heavy rains (over 9 inches in 24 hours, over 17 inches in several locations from 9 to 15 September) led to widespread flooding along the Front Range caused widespread devastation, with 345 homes lost and over 550 more damaged. The unusual tropical moisture sources came from very warm ocean regions to the south (the Gulf of Mexico and especially from west of Mexico), where twin hurricanes Manuel and Ingrid formed as soon as the moisture flow to the north was cut off and the double strike in Mexico led to 192 deaths and

nearly $6 billion in damage. The exceptionally high SSTs at the time of the Colorado floods in the absence of an El Niño undoubtedly had a global warming component.

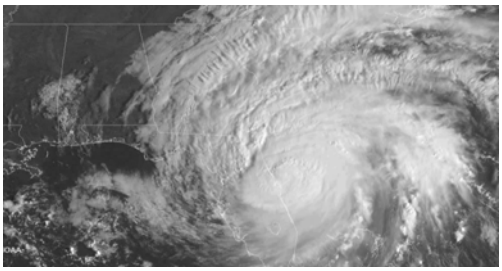

Figure 13. Hurricane Matthew making landfall in Florida on Oct 7, 2016. Image courtesy NOAA. To the north of the eye, strong easterly winds bought moisture ashore from over the subtropical North Atlantic.

Southeast flooding in 2016 from both Louisiana floods (August) and hurricane Matthew (October) (**Figure 13**). In both cases, record high values of atmospheric moisture were measured (by instrumented radio-sonde balloons) in association with very high SSTs in the Gulf of Mexico and in the subtropical North Atlantic. The moisture was transported into the region of the flooding by the storms and resulted in unprecedented rains and flooding. By one very credible estimate, climate change increased the chance of the 3-day torrential rains in south Louisiana by over 40 percent. The impacts were profound.

These events highlight that it is the combination of natural variability (weather, El Niño etc.) and climate change, when they go in the same direction that causes records to be broken. Hence there are more extreme climate events of all sorts. The result is huge both in terms of economic loss and human suffering.

c. Harm and risks to the youth plaintiffs

Several of the youth Plaintiffs have been harmed by the extreme weather events I mention above. Extreme events like those described above will increasingly threaten these youth, and indeed all of the next generation.

a. ***Plaintiff Jayden*** lives in Rayne (just west of Lafayette), Louisiana, outside of what was determined to be the floodplain. However, during the extreme storms and flooding in August 2016 and again in May 2017, Jayden's home experienced flooding. The August flooding destroyed much of Jayden's home, her room included, and she had been forced to sleep with her siblings in their living room. Just two months before the May floods Jayden had moved back into her room for the first time. While the May floods were not as destructive, it did cause cracks in the foundation of Jayden's house and flooding in the hallways. As noted above, these "Louisiana floods" resulted from record-breaking amounts of water vapor gathered by the storms and dumped on the region. The magnitude of the rainfalls and the extent of the flooding near Jayden's home would not have occurred without the human-induced climate change. (**Figure 14**).

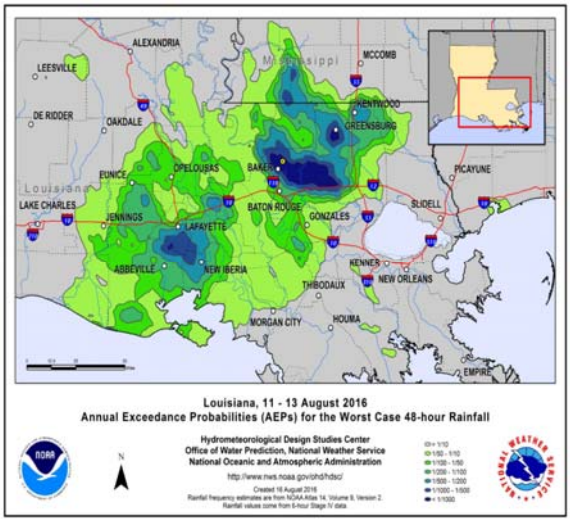

Figure 14. Rainfall analysis for the Louisiana floods of 11-13 August 2016, from NOAA.

b. ***Plaintiff Levi*** was forced to evacuate his home and his island when Hurricane Matthew threatened and eventually struck the east coast in October 2016 and again when Hurricane Irma struck Florida in October 2017. While Levi was away from his home in 2016, it was flooded with around 1 inch of water and a neighbor's home had burned to the ground when a downed powerline started a fire. The Hurricane caused significant erosion and accumulation of debris on the beaches Levi visits. Once again, record-breaking amounts of water vapor were gathered by the storms and the magnitude of the rainfalls and the extent of the flooding near Levi's home would not have occurred without the human-induced climate change. **(Figure 13)**.

Figure 15. An example of the devastation in Boulder, CO, on 12 September, 2013.

c. ***Plaintiff Xiuhtezcatl,*** in Boulder CO, lived through the Colorado floods in September 2013, as my family did. Several people were killed. Record breaking rain amounts occurred over several days. The damage was widespread and recovery is still underway. As explained above, human-induced climate change played a role in enhancing the rains and flooding. **(Figure 15).**

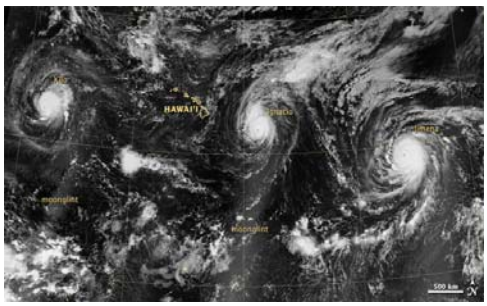

Figure 16. 31 August 2015, satellite imagery of three hurricanes/typhoons that threatened Hawaii. Courtesy NASA.

d. ***Plaintiff Journey*** in Kauai is threatened by extreme storm events. In 2015 an unprecedented (at that time) number of hurricanes threatened the Hawaiian Islands, again enhanced by human-induced climate change. **(Figure 16).** In 2018, two hurricanes threatened the Hawaiian Islands and caused major flooding.

Figure 17. Super storm Sandy devastated the Jersey Shore and the Atlantic City Boardwalk (shown here) on 29 October 2012.

e. ***Plaintiff Victoria,*** White Plains, NY lived through Super storm Sandy in New York. Many people died and many were evacuated for over a week (including my wife and daughter and family who were in Hoboken, NJ), with great cost and human suffering. ***Super storm Sandy*** was bigger and stronger, and impacts were much worse because of human-induced climate change. **(Figure 17).**

f. ***Plantiff Jacob,*** Roseburg, Oregon, lives on a farm and enjoys the outdoors. He has become very concerned and influenced by the ***expanding wildfire season***, especially in 2015, and now in 2018, when smoke degraded the air quality on many days. The wildfire season has become longer and more intense due to human-induced climate change. **(Figure 18).**

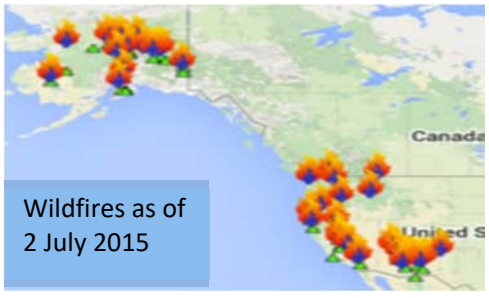

Figure 18. Excerpt from the map of wildfires on 2 July, 2015; from NOAA.

g. ***Plaintiff Jaime*** from Cameron, AZ, has experienced water shortages related to increasing significant drought, wildfires and heat waves. Wildfires, drought and heatwaves have increased in the area of Jaime's home and reservation because of human-induced climate change. **(Figure 18).**

h. ***Plaintiff Zealand*** lives in Eugene, OR and has had to be evacuated from the backcountry due to wildfire. In the fall of 2017 Zealand suffered another loss when his grandmother's trailer park in Santa Rosa burned to the ground during one of the wildfires that blazed through California (as part of what is known as the extremely destructive Tubbs fire). Global warming directly contributes to increased risk of wildfire. **(Figures 18 and 19).**

i. ***Plaintiff Nathan*** has experienced thawing permafrost and wildfires around his home in Fairbanks, Alaska, especially in 2015. Thawing permafrost is uneven and more likely on sunlight slopes, and has led to tilted and broken buildings and frost heaves in roads. Wildfires were widespread in Alaska in the summer of 2015. These harms are made worse by human-induced climate change. **(Figure 20).**

Figure 19. Santa Rosa, CA, before (top) and after (bottom) the wildfire on Oct 13, 2017.

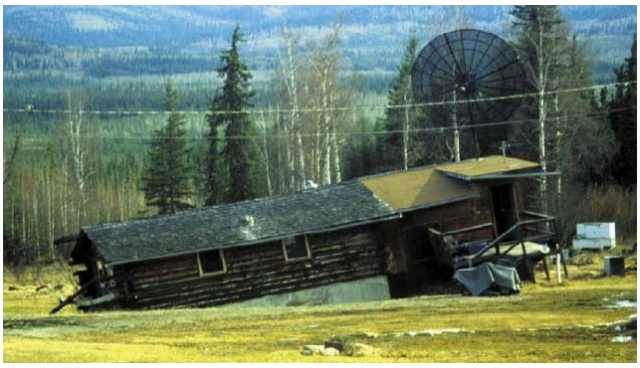

Figure 20. Leaning buildings are a characteristic of thawing permafrost in Fairbanks, Alaska.

4. Conclusions and Recommendations

Based on over 40 years of experience, it is my expert opinion that Plaintiffs including Jayden, Levi, Xiuhtezcatl, Victoria, Jaime, Journey, Zealand, and Nathan are already experiencing extreme weather events that have been exacerbated due to anthropogenic climate change.

Furthermore, based on the regions where they live, it is my expert opinion that they are likely to experience even greater impacts from extreme weather events in the coming decades.

A summary of the way human influences affect storms and precipitation is given in **Figure 7**.

There are increasing numbers of billion dollar disasters in the U.S. and around the world. In the U.S. in the past 20 years there has been on average over $42 billion in weather-related disaster costs, according to NOAA. **Figure 21** shows numbers worldwide from Munich Re for 1980 through 2016 (based on data downloaded 4 July 2017) along with the contributions from weather and climate-related events in billions of U.S. $. A lot of this depends on where the disaster happens and how much infrastructure is present, and it does not measure the human factors, such as strife and loss of life, especially in developing countries.

Of course, extreme weather has always happened, but now thresholds are being crossed, records broken, and so at least a portion of these losses can be ascribed to climate change. There is no precise tool for how much should be ascribed to human influences. On the one hand, records can be broken even without climate change. At the very least, the storm, precipitation and weather-related events are

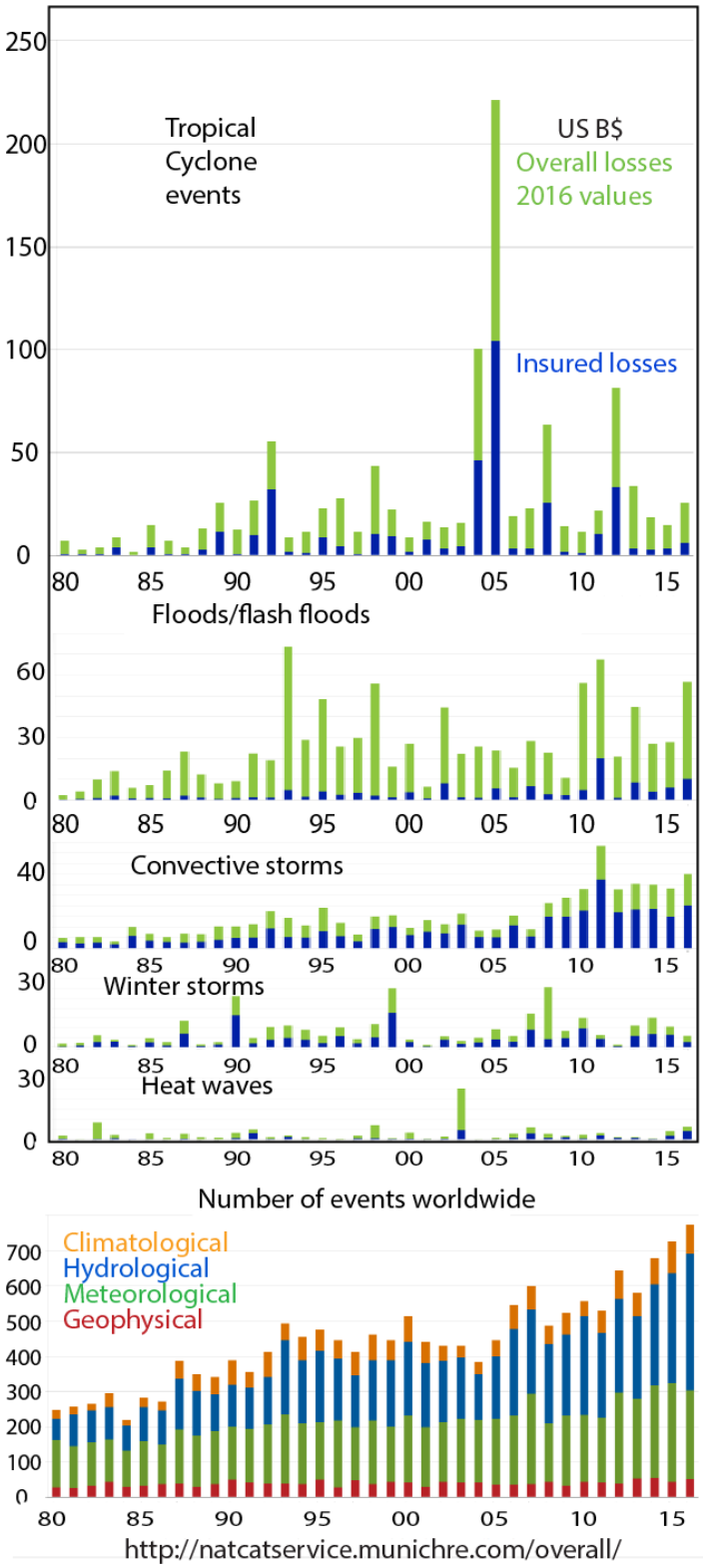

Figure 21. Overall (insured plus uninsured) losses as estimated by Munich Re for 1980 to 2016 in 2016 values, for tropical cyclones, floods, convective storms, winter storms and heatwaves.

amplified by water vapor increases of 5 to 10% since 1970, and these lead to 5 to 30% increases in precipitation intensity, or more. But it is not appropriate to then assign only 5 to 30% of the cost of the disaster to human-induced climate change because the damage is highly nonlinear. Once thresholds are crossed, things break, burn or die!

In my expert opinion, it is generally accurate to say that extreme events, which break records and cross thresholds, would not have happened without global warming, because otherwise the event would have been well within previous experience. Thus, thresholds are crossed and records are broken because of anthropogenic climate change. Moreover, every event is different. Events occur in different places and evolve very differently, whether floods, wildfires, or heat waves, but they all have one aspect in common, they would not have been as severe without the human influence. In light of this, one could argue that the whole cost might be assigned to climate change. Certainly, a very good case can be made that damages due to climate change are likely already well over $10 billion per year.

Hence the increased ocean temperatures and the increased water vapor in the atmosphere have led to changes in extremes, which have huge impacts on society and on ecosystems and the environment. Thus, climate extremes exacerbated by human-induced climate change already pose a serious risk of harm to people's lives, personal security, and property in new ways. The causes of the global warming are clear and future projections are for more of the same but with increasing magnitude. What are extreme and unusual events now, boosted by the right kind of circumstances (weather system), will become commonplace in a decade or two. Without immediate reductions in fossil fuel emissions, farming may become difficult unless major evolution occurs (different crops), and by mid-century many trees and ecosystems will no longer be viable where they currently stand.

The atmosphere is global; we share these problems with other nations, although when considering cumulative emissions, the U.S. has been the biggest contributor by far. As scientists, we can lay out the facts and evidence, and the prospects, but fully addressing climate change requires government leadership.

The costs of the increased frequency and destructiveness of extreme weather events are not borne by those who cause the problem. There is still time to manage the problem and avoid the worst possible outcomes, and there can be major economic advantages as well greater energy efficiency when transitioning off fossil fuels. It does not have to cost more if done in the right way.

These youth Plaintiffs and future generations will continue to live with even more extreme weather events, which will threaten their personal security, property, and lives. However, swift action to reduce emissions and transition off of fossil fuels can slow and eventually stop further damage to the climate system and water cycle. Therefore, in my expert opinion, the federal defendants in this action should be required to swiftly decarbonize the U.S. energy system, as an essential step to protect children and future generations from the real dangers posed by human-induced climate change. We are all together on this spaceship Earth. What the U.S. government does with our national energy system and emissions matters immensely to our ability to preserve a livable climate for our posterity.

Signed this 14th day of September, 2018 in Boulder, Colorado.

Kevin E. Trenberth, Sc.D.

EXHIBIT A: CURRICULUM VITAE

KEVIN E. TRENBERTH

March, 2018

ADDRESS: National Center for Atmospheric Research
P. O. Box 3000
Boulder, Colorado 80307

DATE AND PLACE OF BIRTH: 8 November 1944, Christchurch, New Zealand

EDUCATION:
B.Sc. (HONS First Class): 1966, University of Canterbury, Christchurch, New Zealand
Sc.D.: 1972, Massachusetts Institute of Technology, Cambridge, Massachusetts

PROFESSIONAL EXPERIENCE:

New Zealand Meteorological Service:	
Meteorologist	1966–1977
Junior forecaster, research	1966–1968
M.I.T. graduate student	1968–1972
Research meteorologist	1972–1977
Superintendent -dynamic meteorology	1977
University of Illinois	1977 –1984
Associate Professor of Meteorology	1977–1982
Professor of Meteorology	1982–1984
Adjunct Professor	1984–1989
Editor, Monthly Weather Review	1981–1987
Associate Editor, Monthly Weather Review	1986–1988
Associate Editor, J. Climate	1987–1995
Editor, Earth Interactions	1996–1998
National Center for Atmospheric Research	
Scientist III	1984–1986
Senior Scientist	1986–
Leader, Empirical Studies Group	1987
Leader, TOGA/CLIVAR activities	1986–2008
Head, Climate Analysis Section	1987–2011
Deputy Director, CGD	1991–1995

PROFESSIONAL SOCIETIES:

American Association for the Advancement of Science	1978–
Council Delegate, Section on Atmospheric and Hydrospheric Sciences	1993–1996
Member at Large, Section on Atmospheric and Hydrospheric Sciences	2009–2013
American Meteorological Society	1969–
Royal Society of New Zealand	1972–1977
Meteorological Society of New Zealand	1980–
American Geophysical Union	1998–
The New York Academy of Sciences	1979–1981

LISTED IN:

Who's Who in America
Who's Who in American Men and Women of Science
Who's Who in Technology Today
Who's Who in Technology
Who's Who in Frontier Science and Technology
Who's Who in the West
Who's Who of Emerging Leaders in America
Who's Who in Science and Engineering
New Zealand Who's Who
Who's Who in Australasia Pacific Nations
The International Directory of Distinguished Leadership
Men of Achievement
International Leaders in Achievement
5,000 Personalities of the World
American Men and Women of Science
Dictionary of International Biography
Honored member Strathmore's Who's Who Registry
2000 Outstanding Scientists of the 20th Century
The Twentieth Century Award for Achievement
Featured as one of the top ten climate scientists, compiled by the Financial Times of London, 22 Nov 2009.
http://www.ft.com/cms/s/2/f1d9f856-d4ad-11de-a935-00144feabdc0.html

AWARDS:

New Zealand Research Fellowship	1968–1972
NSF research grants	1978–1988
NOAA research grants	1986–
NASA research grants	1989–
Fellow American Meteorological Society	1985–
Fellow American Association for the Advancement of Science	1994–
Honorary Fellow Royal Society of New Zealand	1995–
NCAR Best Publication Award Nominee	1988, 1989, 1992, 1993, 1994, 2008, 2012
NCAR Outstanding Education Performance Award Nominee	1996
NCAR Distinguished Achievement Award	2003
NCAR Education and Outreach award nominee	2007, 2008
Keuhnast annual lecture, Univ. Minnesota, 15 Oct.	1998
American Meteorological Society Editors Award (J. Climate)	1989
Jule G. Charney award, American Meteorological Society,	2000
Highly Cited Researcher (top 25 Geosciences), ISI.	2002-15
Symons Lecture, Royal Meteorological Society, London, 21 May	2004
Fellow American Geophysical Union	2006
American Geophysical Union Editor's citation for excellence in reviewing,	2007
Massachusetts Marine Educators award of Certificate of Appreciation	2007
Shared Nobel Peace Prize that went to the IPCC 2007	2007
Atmospheric Science Librarians International 2007 ASLI CHOICE award for the 2007 IPCC WG I assessment volume.	2007
Yoshi Ogura lecture, Univ. Illinois at Champaign-Urbana, 30 Apr.	2008
Honorary fellow of the Institute of Green Professionals, 15 Oct.	2008

Prince Sultan Bin Abdulaziz International Prize for Water: Surface water prize (joint award with Aiguo Dai for $133,000), Riyadh, Saudi Arabia, January 2013.
AGU's 2013 Climate Communication Prize ($25,000) December 2013
Honorable mention, 2014 Colorado Governor's Award for High-Impact Research in the Sustainability category for the Global Energy and Water Exchanges (GEWEX) Project. Oct 2014.
Bownocker medal and lecture, The Ohio State University November 2017
AGU's Roger Revelle Medal for 2017 December 2017
Honorary member New Zealand Meteorological Society December 2017
Ludwick lecture, Old Dominion University, Norfolk, Va April 2018

PROFESSIONAL ACTIVITIES:

1. Principal committees or panels

University of Illinois Senate, 1979–1984.

NCAR panel on NCAR Community Climate Model, 1980

NOAA-EPOCS (Equatorial Pacific Ocean Climate Studies) Advisory Panel, 1980–83.

NOAA-EPOCS council member, 1983–1985.

TOGA (NOAA, NSF) ad hoc proposal review panel, 6–8 February 1985

Science review of the Air Resources Laboratory of NOAA, 18–20 March 1987.

Member "NOAA Panel on Climate and Global Change", 1987–2006
Member Executive Council 1991–2006.
Renamed "NOAA Climate and Global Change Working Group" 2003–2005
Renamed "NOAA Climate Working Group" 2005–2006.

Member "Climate Trends Panel", National Climate Program Office, September 1988–1990.

Member "NOAA Panel on Climate and Global Change Working Group on Data Management" 1989–90.

Visiting lecturer; appointed to Graduate School, University of Colorado (May 1990).
Member Ph.D. committees, 1990–1992; 1994–2000.

Member Appointments Review Group, NCAR, January 1992–95.

Member Technical Advisory Committee "Reporters' Guide to Science of Global and Climate Change", October 1992–1994

Council Delegate American Association for the Advancement of Science, Section on Atmospheric and Hydrospheric Sciences. (Elected) 1993–96

Member review panel, Mission to the Planet Earth (MTPE), NASA. June 15-18, 1993, Washington D.C.

Member Climate Modeling Analysis and Prediction (CMAP) Science Advisory Council. 1993–98.

Member Climate System Modeling Advisory Board, UCAR/NSF. 1998–2000.

UCAR Office for Interdisciplinary Earth Studies (OIES) Steering Committee, 1993–94.

Member Center for Ocean-Land-Atmosphere Studies (COLA) Scientific Advisory Committee, 1994–99. Chair 1995, 1998-99.

Member of drafting group to define the International Research Institute for seasonal to interannual climate prediction Network Consultative Group (INCG). 1997.

Member NOAA Council on Long-term Monitoring, 1998–2003; reconstituted new name NOAA Climate Monitoring Working Group 2003–05.

Member review panel for NCEP Climate Prediction Center. 1997–98.

Member Scientific Steering Committee for 20th anniversary of the US-China bilateral workshop and symposium. 1999.

Member NOAA Climate Observing System Council. 1999–

Earth and Sky Radio Science advisor, 1999– .

Member NOAA Science Advisory Board Panel on Strategies for Climate Monitoring, 2000–01.

Member NOAA Science Advisory Panel for the Climate Change Data Detection (CCDD) program. 2001–05.

Member Research Advisory Executive Committee for *The Climate Report*. Maryam Golnaraghi Editor. June 2001–03.

Lead author, with Tom Spence, on "Climate Observing System" for the Presidential Climate Change Research Initiative, August 2001.

Member committee to decide awardee of Latsis Prize (Europe). 2001.

Chairman, Byrd Polar Research Center External Review Team, 31 October, 1 November 2002, Columbus Ohio.

Member ad hoc UCAR panel workshop on "Integrated Earth System Observations", Smithsonian Inst. Washington D.C. 12-15 Aug, 2003.

Member organizing committee for the Workshop on Ongoing Analysis of the Climate System, 18-20 August 2003, Boulder, CO.

Member Climate Change Science Program reanalysis implementation plan working group 2004.

Member ad hoc NOAA working group on paleoclimate, 2003.

Member External Advisory Committee for Atmospheric Technology Division, NCAR 2004-05.

Member US Interagency Committee on Global Earth Observing System of Systems (GEOSS) 2004

Member NASA CERES Climate Model and Analysis Advisory Group 2003–

Member American Geophysical Union Roger Revelle Medal Selection Committee. 2006-08.

Chair, panel to review of NOAA's Climate Observations and Analysis Program, April 11-13, 2007. "*Report on the Climate Working Group review of NOAA's Climate Observations and Analysis Program*, April 11-13, 2007" 35 pp.

Member AGU panel on AGU position statement on data preservation and availability. 2008-2009

Member NASA MERRA Advisory Board 2007–2009

Member at Large, American Association for the Advancement of Science, Section on Atmospheric and Hydrospheric Sciences. (Elected) 2009–2013

Member AGU Climate Communication Prize committee 2015-2018

Member Protect Our Winter Science Alliance. 2014-

Member AGU College of Fellows Sub-Committee on AGU Centennial, 2017-

International

Committee to report on possible effects of halomethanes on the ozone layer (New Zealand), 1975.

Program committee of Australasian conference on Climate and Climatic Change. Monash University, Clayton, Victoria, Australia, 7–12 Dec. 1975.

Member for New Zealand on the working group of the Global Data Processing Systems of the Commission for Basic Systems of the World Meteorological Organization, 1976–77.

Member, Committee on Space Research (COSPAR) "Integrated Earth System Science Roadmap" Study Group; July 2013-16.

Member ISSI Working group on "Consistency of Integrated Observing Systems monitoring the energy flows in the Earth System" International Space Science Institute, Bern Switzerland, 2014-15.

Intergovernmental Panel on Climate Change (IPCC):

Scientific Assessment of Climate Change, WMO/UNEP),
1990, 1992: contributor, reviewer multiple chapters and volumes
1995: WG I Convening Lead Author Chapter 1, Lead Author Technical Summary;

2001: WG I Lead Author Chapter 7, Lead Author Technical Summary, Lead Author Summary for Policy Makers;
2001 Synthesis Report: Lead Author;
2007: WG I Coordinating Lead Author Chapter 3; contributor Technical Summary, Summary for Policy Makers.
2007: WG II contributor and reviewer
2013: WG I Review Editor (chapter 14).

World Climate Research Programme (WCRP):

TOGA: Member International Tropical Oceans Global Atmosphere Scientific Steering Group (SSG) 1989–94.
CLIVAR: International Climate Variability and Predictability (CLIVAR) Member SSG 1995–2004.
Member CLIVAR 2004 International Scientific Conference committee, 2002-04.
Member organizing committee for International CLIVAR workshop on Ocean Reanalysis 2004.
Co-chair CLIVAR SSG 1996–1999.
Co-chair "Consistency between planetary energy balance and ocean heat storage (CONCEPT-HEAT)" working group, 2014-
Executive Committee member CLIVAR Open Science Conference 2015-16
CLIVAR/PAGES/IPCC Workshop "A multi-millennia perspective on drought and implications for the future", Tucson, AZ November 18-21, 2003. Co-convener with Jon Overpeck.
JSC: Member Joint Scientific Committee 1999–2006. Officer (member Exec. Committee) 2003–2006.
WOAP: Chair WCRP Observation and Assimilation Panel (WOAP) 2004–2010.
Member Third International Reanalysis Conference organizing committee. 2006-08. Tokyo, Japan.
Member Fourth International Reanalysis Conference organizing committee. 2010-12. Maryland, USA.
WCRP Modeling Panel: Member 2004–09.
COPES: Member Task Force on Coordinated Observation and Prediction of the Earth System (COPES) 2003-04
GEWEX: Member Global Energy and Water Cycle Experiment/Global Energy and Water Exchanges (GEWEX) Scientific Steering Group 2007– 2014; Chair GEWEX SSG 2010–13; Co-chair Seventh International Scientific Conference on the Global Water and Energy Cycle, The Hague, The Netherlands, July 2014.
WCRP Open Science Conference committee member, 2009-2011 (held Denver October 2011).

Global Climate Observing System (GCOS):

Member Atmospheric Observation Panel for Climate of the Global Climate Observing System. 1994–99.
Lead Author and Member of team of experts to write
The Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC. 2002-2003; (GCOS 82)
Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, 2003-2004 (GCOS 92)
Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004-2008, (GCOS-129)
Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, 2010 update (GCOS 138)
Member Scientific Committee Inter-American Meteorological Congress, Brasilia, 20–24 October 1986.
Member ECMWF ReAnalysis (ERA) Project Advisory Group. February 1993–2004.

American Meteorological Society

AMS Committee on Southern Hemisphere Meteorology, 1981–1986.
Member of program committee of First International Conference on Southern Hemisphere Meteorology, San Jose dos Campos, Brazil; 31 July–6 August 1983.
Program chairman Second International Conference on Southern Hemisphere Meteorology, 1984–1986.
Chairman, AMS Committee on the Southern Hemisphere, 1985–1987.
Member Program Committee of Third International Conference on Southern Hemisphere Meteorology and Oceanography, Buenos Aires, Argentina 13–17 November 1989.
Member Program Committee AMS Special Session on Climate Variations, Anaheim, CA 7–9 February 1990.

Member AMS Committee on Climate Variations, January 1991–1994.

Member AMS Committee on Atmospheric Research Awards Committee. 2001–2004.

Member, AMS Board on Global Strategies, Commission on the Weather and Climate Enterprise, August 2013-2018

Member, AMS Centennial Committee, 2015-

National Academy of Sciences

Member of Committee on Earth Sciences of the Space Science Board, 1982–1985. [Co-author of: *A Strategy for Earth Science from Space in the 1980's and 1990's Part II: Atmosphere and Interactions with the Solid Earth, Oceans, and Biota*. National Academy Press, 1985, 149pp.]

Member TOGA Advisory Panel, Board on Atmospheric Sciences and Climate, 1984–1987. [Co-author of *U.S. Participation in the TOGA Program. A Research Strategy*. National Academy Press, 1986, 24pp.]

Member Polar Research Board 1986–1990.

Member Climate Research Committee, Board on Atmospheric Sciences and Climate, 1987–1990.

Member Global Ocean Atmosphere Land System (GOALS) Panel, 1994–98.

Corresponding member Panel on Climate Observing System Status, Board on Atmospheric Sciences and Climate, 1998–99.

Member Climate Research Committee Panel on Reconciling Temperature Observations. Board on Atmospheric Sciences and Climate, 1999–2000.

Member Committee on Global Change Research, Division of Earth and Life Sciences. 1999–2002.

Member NRC Panel on "Evaluation of climate change indicators for EPA". Washington D.C. 2004.

Member writing team "*Climate Change: Evidence and Causes*", 33pp. National Academy Press http://nas-sites.org/americasclimatechoices/events/a-discussion-on-climate-change-evidence-and-causes/ and http://royalsociety.org.

2. Invited participation in workshops or conferences

Principal lecturer, Colloquium, summer 1978, NCAR. The General Circulation: Theory, modeling and observations.

Member of working group on SPOCS (South Pacific Ocean Climate Studies) Workshop, University of Washington, March 1980.

Member of National Academy of Sciences, Climate Board, panel to formulate the Southern Oscillation Program, July 1981.

National Academy of Sciences, Climate Board, workshop on Southern Oscillation, Boulder, CO, 14–16 Sept. 1981.

National Academy of Sciences, Board on Atmospheric Sciences and Climate, workshop on Southern Oscillation–El Niño, Princeton, NJ, 11–15 Oct. 1982. Group leader. [*El Niño and the Southern Oscillation: A scientific plan.* National Academy Press, 1983, 72pp.]

Invited speaker and chairman of session IAMAP Third Scientific Assembly, Hamburg, F.R. Germany, 17–28 August 1981.

WMO–CAS/JSC Expert study meeting on long-range forecasting, GFDL, Princeton, NJ, December 1982.

National Academy of Sciences, Board on Atmospheric Sciences and Climate, TOGA/Pacific Drafting workshop 11–18 May 1983, Miami, FL.

National Academy of Sciences, Polar Research Board, workshop on Potential CO_2–induced changes in the environment of West Antarctica, 5–7 July 1983, Madison, WI.

Invited Speaker and chairman of session First International Conference on Southern Hemisphere Meteorology, San Jose dos Campos, Brazil, 31 July–6 August 1983.

Session chairman National Academy of Sciences, Board on Atmospheric Sciences and Climate, El Niño–Southern Oscillation workshop, Miami, FL, 3–4 Nov. 1983.

Invited speaker, and workshop chairman National Center for Atmospheric Research, workshop on climate variations and research, NCAR, Boulder, CO, 28 Nov.–2 Dec. 1983.

Invited speaker TOGA Indian Ocean–Monsoon Climate Program Workshop, 14–16 Feb. 1984, Scripps Institution of Oceanography, La Jolla, CA.

Invited speaker FGGE Workshop, 9–20 July 1984, National Academy of Sciences Study Center, Woods Hole, MA. [FGGE advisory panel of U.S. Committee for GARP, Board on Atmospheric Sciences and Climate, N.A.S.].

Invited speaker and chairman of session "Scientific seminar on global diagnostic studies based on data collected during the Global Weather Experiment", Helsinki, Finland, 28–31 August 1984. Chairman of session to write summary document.

WMO–ICSU International Conference on the International Variability of the Tropical Oceans and Global Atmosphere (TOGA), Paris, 17–22 Sept. 1984. Represented U.S. TOGA Panel. Participated in drafting International TOGA *Plan for the TOGA Scientific Programme*.

AMS Third Conference on Climate Variations and Symposium on Contemporary Climate: 1850–2100. Los Angeles, CA, 8–11 January 1985. Session chairman, and wrote part of summary report for BAMS.

JIMAR (NOAA) review participant (January 1985).

TOGA/WOCE Data Management Panel meeting, invited participant 5–6 June 1985, Boulder, CO.

Invited speaker IAMAP/IAPSO Joint Assembly 5–16 August 1986, Honolulu, Hawaii.

TOGA Circulation Workshop. 16–18 October 1985, Boulder, CO. Discussion leader.

Invited speaker and chair of session Second International Conference on Southern Hemisphere Meteorology, Wellington, New Zealand, 1–5 December 1986.

U.S. Environmental Protection Agency Workshop on CO_2. Invited participant. Boulder, CO, 25–26 February 1987.

Invited speaker Fourth Conference on Climate Variations: Climate Dynamics Update. Baltimore, MD. 10–13 March 1987.

Invited speaker NCAR Summer Colloquium 1987: Dynamics of low-frequency phenomena in the atmosphere. 7–24 July 1987.

Invited speaker IUGG XIX General Assembly, Vancouver, Canada, 9–22 August 1987. Union 15 Symposium.

Invited speaker Symposium on ozone depletion, greenhouse gases and climate change. NAS Board on Atmospheric Science and Climate, 23 March 1988, Washington, D.C.

UCAR Annual Members Meeting, Boulder, 12–13 October 1988. Science briefing.

Invited speaker Joint BASC, NCPO, Resources of the Future: Strategic Planning Seminar on "The Drought of 1988 and Beyond", 18 October 1988, Washington, D.C.

Invited speaker Fall AGU meeting, 5–9 December 1988, San Francisco.

Invited speaker UCAR/OIES Climate Systems Modeling Initiative, 25–27 January 1989, Boulder.

Invited speaker EPOCS Advisory Council Meeting, Miami, FL 7–10 February 1989.

Fourth International Meeting on Statistical Climatology, Rotorua, New Zealand, 27–31 March 1989. Session chairman.

Invited paper and chair of Working Gp I: Observations at DOE Workshop, Amherst, MA, 7–12 May 1989.

Invited paper Fifth Scientific Assembly of the International Association of Meteorology and Applied Physics (IAMAP). 31 July–12 August 1989, Univ. Reading, United Kingdom.

Colloquium speaker on “The 1988 North American Drought” at NASA Goddard Space Flight Center, Greenbelt, MD, 4 October 1989.

Invited paper, OCEANS '89, Seattle, Washington, 19–21 September 1989.

Invited speaker, Workshop on “Climatic variability and its environmental impact”. Buenos Aires, Argentina, 6–10 November 1989.

Invited paper and session chair, Third International Conference on Southern Hemisphere Meteorology and Oceanography. Buenos Aires, Argentina, 13–17 November 1989.

Invited speaker and chair of two sessions, AMS Symp. Global Change Systems, 5–6 February 1990, and AMS special session on climate variations, joint session on hydrology and climate variations, 7–9 February 1990, Anaheim, CA.

Invited plenary lecture on global warming, American Association for Advancement of Science (AAAS). Annual meeting in New Orleans 15–20 February 1990.

Invited speaker “Discussion of Greenhouse Warming Science Controversies”, COSEPUP, NAS meeting 24 January 1990.

Invited plenary speaker on meteorological aspects of climate variations, Canadian Meteorological and Oceanographic Society annual meeting, 28 May–1 June 1990, Victoria, B.C., Canada.

Invited lead speaker at Workshop on 1988 North American Drought, University of Maryland, 30 April–2 May 1990, Washington, D.C.

Colloquium speaker on “Global warming and recent climate change: Observation and modeling”, Johns Hopkins University, 5 October 1990.

Invited speaker National Research Council colloquium “Managing water resources under conditions of climate uncertainty”, Phoenix, AZ 14–16 November 1990.

Invited speaker at international global change workshop on “Earth system response to global change: Northern and southern hemisphere contrasts”, La Serena, Chile 2–4 December 1990.

Invited speaker, NMC/NCAR Reanalysis workshop, Washington, 25-26 April 1991.

Invited participant, CSMP workshop, Boulder, 20–21 May 1991.

Invited speaker, Co-organizer of, and writer of text for Coupled Climate System Modeling: Summer Workshop. U. Wisconsin–Madison 14–27 July 1991.

Chair of session at IAMAP symposium, IUGG, Vienna, Austria, 11-24 August 1991.

Invited speaker and session chair, Fifth Conference on Climate Variations, Denver, 14–18 October 1991.

Invited speaker, workshop on Long-term Monitoring of Global Climate Forcings and Feedbacks. GISS, New York, 2–4 February 1992.

Invited speaker, Interdecadal Variability Workshop, CCCO, Honolulu, 18–20 February 1992.

Invited lead speaker, Twelfth Conference on Probability and Statistics in the Atmospheric Sciences, Toronto, Canada, 22-26 June 1992.

Invited speaker, Workshop on Decade to century timescales of climate variability. National Academy of Sciences, Irvine, CA., Sept. 21–24, 1992.

Invited lead speaker, International symposium on Climate change and Northern Fish populations, Victoria, B.C., Canada. October 13–16, 1992.

Invited speaker and student mentor. Workshop on Coupled Climate System Modelling: A Southern Hemisphere perspective, Macquarie University, Sydney, Australia, 6–19 February, 1993.

Invited speaker at Global Ocean Atmosphere Land System (GOALS) workshop, National Academy of Sciences, Honolulu, Hawaii, 28 February–3 March 1993.

Invited lead speaker, Fourth International Conference on Southern Hemisphere Meteorology and Oceanography, Hobart, Tasmania, Australia, 29 March–2 April 1993.

Invited speaker CLIVAR SSG-1 meeting, Lamont Doherty Earth Observatory, 6-9 July 1993.

Invited panel member, Climate Diagnostics Workshop, 4 November 1993.

Member of Panel discussion “Issues relating to the Midwest flood of 1993”. Climate Diagnostics Workshop. 4 Nov. 1993.

Invited Distinguished Lecturer, Center for Ocean-Land-Atmosphere Studies, Washington D.C., 1 Feb. 1994.

Invited speaker Workshop on Data Sets for Terrestrial Biosphere Modeling, Boulder, CO, 9–11 May 1994.

Invited speaker NOAA/UCAR Summer Institute on Climate and Global Change, Steamboat Springs, CO, 13–17 June 1994.

Invited lecturer NCAR Summer Colloquium on Applications of Statistics to Modeling the Earth's Climate System, Boulder CO, 6–19 July 1994.

Invited speaker, breakout group chairman at meeting on Long-term Climate Monitoring for GCOS. Asheville, NC, 9–11 January 1995.

Invited speaker, Intl. TOGA Conf., Melbourne, Australia, 3-7 April 1995.

Invited speaker, IUGG XXI General Assembly, Boulder CO, 14 July 1995.

Invited speaker, WCRP Workshop on air-sea flux fields for forcing ocean models and validating GCMs, ECMWF, Reading, U.K., 24-27 October 1995.

Invited speaker, Climate prediction & Insurance Risk Conference. Bermuda, 1-4 November 1995.

Invited participant: International forum on Forecasting El Niño: Launching an International Research Institute. Washington D.C. 6-8 November 1995.

Invited speaker, Seventh Symposium on Global Change Studies. Atlanta, (2 talks) 28 January-2 February 1996.

Invited speaker, Symposium on Global Ocean-Atmosphere-Land System (GOALS). Atlanta, 28 January-2 February 1996.

Invited speaker, Symposium on Climate Change: The second Assessment Report of the IPCC. AAAS Annual meeting, Baltimore MD, February 10, 1996.

Keynote address, 1996 annual meeting NOAA Climate Monitoring and Diagnostics Laboratory, Boulder, March 6-7 1996.

Invited speaker, JCESS/CLIVAR Workshop on Decadal Climate Variability, Columbia MD, 22-24 April 1996.

Invited speaker, Intl. wkshp Ocean Climate Variations from Seasons to Decades with Special Emphasis on Pacific Ocean Buoy Network. Mutsu City, Japan, 29-31 May 1996.

Invited lecturer, Monsoon workshop, Trieste, Italy 15-26 July 1996.

Invited lecturer, Aspen Global Change Institute, Aspen CO 30 July-8 August 1996.

Invited lecturer, CLIVAR/PAGES workshop on Annual Records of Tropical Systems (ARTS) Kauai, HI. 27 Sept-1 Oct 1996.

Invited speaker, van Loon symposium, NCAR Boulder CO. 21-22 October 1996.

Invited speaker, Joint Scientific and Technological Committee (JSTC) for GCOS meeting, Victoria BC. 30-31 Oct. 1996.

Invited speaker, Global water vapor Project (GVaP) meeting, Geneva.12-15 November 1996.

Invited speaker, Thirteenth Conf. on Hydrology. Amer. Meteor. Soc., Long Beach CA. 2-7 Feb 1997.

Invited speaker, three papers, Eighth Symp. on Global Change Studies. Amer. Meteor. Soc., Long Beach CA. 2-7 Feb 1997.

Invited speaker, First symposium on Integrated Observing Systems Amer. Meteor. Soc., Long Beach CA. 2-7 Feb 1997.

Invited speaker, Chair breakout group in Workshop on Indices and Indicators for Climate Extremes, Asheville, NC. 3-6 June 1997.

Invited speaker, Seminar on International Information Network Contributions to Global Change Research. “GOIN” (Global Observation Information Network) 23 June 1997.

Invited speaker, IAMAS/IAPSO 1997 Joint Assembly, Melbourne, Australia. 1-9 July 1997.

Invited speaker, NCAR Advanced Study Program summer colloquium on El Niño systems. Boulder, 20 July–1 August 1997.

Invited keynote speaker and session chair, Fifth Symposium on the Biogeochemistry of Wetlands, Royal Holloway College, Univ. London, 16-19 Sept, 1997.

Invited plenary speaker, Science Summit on Climate Change. Washington D.C. Sept. 30, 1997.

Invited speaker, Scientific Colloquium at NASA/Goddard, Washington D.C. October 10, 1997.

Program committee, chair of session chair of panel discussion at First Intl. Conference on Reanalysis. 27-31 Oct. 1997, Silver Spring, Maryland.

Invited participant, Second Annual NOAA strategic planning workshop. Washington D.C. Feb 11 1998.

Invited participant, IPCC workshop on Rapid nonlinear Climate Change, Noordwijkerout, Netherlands, 31 Mar–2 Apr 1998.

Invited participant/speaker, U.S. Global Change Research Project retreat Airlie Center, Warrenton VA. 20-21 May 1998.

Invited lecturer, Third NOAA Climate and Global Change Summer Institute, Steamboat Springs, CO. 15-18 June 1998.

Invited speaker, COARE 98 conference, Boulder CO. 7-14 July 1998.

Invited participant and discussant, A review of the causes and consequences of cold events: A La Niña Summit. Boulder CO. 15-17 July 1998.

Invited speaker, Geophysical Statistics Project Summer Colloquium “Statistics for understanding atmosphere and ocean”. 18-24 July 1998.

Invited speaker, Intl. Symp. Triangle '98, Kyoto, Japan, Sept 29-Oct 2, 1998.

Invited participant, workshop on Global Change Science Requirements for Long-term Archives and Data Continuity. Boulder CO, 28-30 Oct. 1998.

Keynote invited talk “The evolution of CLIVAR Science”, International CLIVAR Conference, UNESCO, Paris, France, 2-4 Dec. 1998

Invited participant and speaker, PAGES/CLIVAR Data Workshop January 15-17, 1999, Boulder.

Invited speaker, Tenth Symposium on Global Change Studies. 11-15 Jan. 1999. Dallas TX.

Invited speaker, Second Hayes Symposium on seasonal to interannual climate variability – The 1997/98 ENSO cycle. 12-15 Jan. 1999. Dallas TX.

Invited speaker, UNISPACE-III Forum on "Climate Variability and Global Change." 19-30 July, 1999. Vienna, Austria.

Invited speaker, Second International Conference on Reanalyses, 23-27 August 1999, Reading, U.K.

Invited speaker, Symposium on climate, environmental change and regional impacts. September 21-24, 1999, Beijing, China.

Invited speaker, Chapman Conference on Water Vapor, 12-15 October 1999, Potomac, MD.

Invited participant and speaker, PAGES/CLIVAR Workshop, 8-12 Nov 1999, Venice, Italy.

Invited speaker, NCAR ASP Colloquium, 17-28 July 2000, Boulder CO. “Decadal variability in the atmosphere over the Pacific: observations”, and Chair Panel on “ENSO and global warming”.

Invited keynote speaker, Commission on Climatology International Symposium, Climate Change and Variability, and their Impacts. Aug 9-13, 2000, Seoul, Korea.

Invited speaker, NRC/NAS workshop on “Predictability and Limit-of-prediction for hydrological systems”, Committee on Hydrological Sciences, Boulder, CO. 21-22 Sept, 2000.

Speaker and organizer of NCAR workshop on Precipitation Processes in the Climate System, 26 September, 2000, FL. “Why and how does precipitation change”

Invited speaker Sino–US Workshop on Climate Change and Modeling. 15-16 January 2001, Shanghai, China.

Invited speaker, WCRP/SCOR Workshop on Intercomparison and Validation of Ocean–Atmosphere flux fields, 21-25 May 2001. Washington D.C.

Invited speaker, International Association for Meteorology and Atmospheric Science conference, Innsbruck, Austria, 10-18 July 2001.

Invited speaker, Woods Hole Oceanographic Institute summer colloquium, Woods Hole, 1-3 August 2001.

Invited speaker, Climate and Ozone Programme Conference. Programme Board of the Committee for Research on Change of Climate and the Ozone Layer of the Norwegian Research Council. Bergen, Norway, 27-29 November 2001.

Invited speaker, Fifth NOAA Summer Institute for the Postdoctoral program in Climate and Global Change. 1 7-21 June, 2002, Steamboat Springs, CO. "New estimates of fresh water discharge from land into the ocean, and issues of how to get that right in models." Also leader of session debate on "How can the science community most effectively communicate with governments and the private sector to supply sound research results as an input to policy-making."

Invited lecturer in course at Colorado University "Global climate change and society". R. Pielke Jr. 27 June 2002, 1.5 hours.

Invited distinguished lecturer, Woods Hole Oceanographic Institute. 24 September, 2002.

Invited keynote speaker and panelist for Climate Change Science Program planning workshop for scientists and stakeholders, 3-5 December, 2002, Washington D.C. Keynote address: *Interactions between data, observations and modeling*, panelist: *Resolution of disparities in tropospheric temperature records*.

Invited speaker, 7th International Conference on Southern Hemisphere Meteorology and Oceanography, Wellington, New Zealand. "Heat budgets and poleward atmospheric energy transports". 24 March 2003.

Invited distinguished Vetlesen lecturer, University of Rhode Island, "The global hydrological cycle and new estimates of freshwater discharge from land into the ocean" 22 May 2003.

Invited speaker, workshop on "Integrated Earth System Observations", Smithsonian Inst. Washington D.C. 12-15 Aug, 2003.

Invited keynote speaker, chair of working group, workshop on Ongoing Analysis of the Climate System, 18-20 August 2003, Boulder, CO.

Invited talks at IPCC scoping meeting, September 1-4, 2003, Potsdam Germany

- "Scope for Chapter 3: Observations: Atmospheric, land and marine climate change." WGI
- "Technology Issues in WGI: Climate data records from observations" Cross cutting theme on Technology (all WGs)
- "The global hydrological cycle: How should precipitation change as climate changes?" Cross cutting theme on Water. All WGs.

Invited talk "Report on workshop on "Ongoing Analysis of the Climate System", Boulder, August 2003", NOAA Climate Monitoring Working Group (CMWG), September 17-19, 2003, Chicago, IL.

Invited talk "The need for a new network of high quality radiosondes", NOAA Climate Monitoring Working Group (CMWG), September 17-19, 2003, Chicago, IL.

Invited lead speaker, CLIVAR/PAGES/IPCC Workshop "A multi-millennia perspective on drought and implications for the future", Tucson, AZ November 18-21, 2003.

Invited presentation "Long-Lived Data Collections Workshop", National Science Board, March 23, 2004, Washington D.C.

Invited speaker at Office of Climate Observation Annual System Review workshop, "IPCC (2007) AR4 the next assessment WGI, Relevance for ocean observations", Washington DC. April 13-14, 2004.

Symons lecture, “The flow of energy through the Earth's climate system”, Royal Meteorological Society, London, England, 19 May 2004.

Keynote talk “Monitoring and prediction of the Earth’s Climate: A future perspective” at the International CLIVAR Science Conference, Baltimore, MD 21-25 June, 2004,

Invited talk “Anticipated and observed trends in the global hydrological cycle”. Aspen Global Change Inst. workshop on “Aerosols and the hydrological cycle” July 11-17, 2004, Aspen, CO.

Invited participant in NRC Workshop on Earth Observations and Applications from Space: A Community Assessment and Strategy for the Future, Woods Hole, 23-25 Aug, 2004.

Keynote address, CAHMDA II workshop on “The Terrestrial Water Cycle: Modeling and Data Assimilation Across Catchment Scales.” Princeton University, Princeton, 27-29 October, 2004.

Invited talk at IGWCO/GEWEX/UNESCO workshop on global trends in water cycle variables and their relevance for IPCC assessments. Paris, France, Nov. 3-5, 2004.

Invited talk, CLIVAR Ocean Reanalysis Workshop on “COPES and the WGOA”, NCAR Boulder CO, 8-10 Nov, 2004

Invited talk, CLIVAR Global Synthesis and Observation Panel (GSOP) meeting, on “COPES and the WGOA”, Boulder CO, 10-12 Nov, 2004

Invited panelist AMS “Living with a Limited Water Supply” symposium, panel on “Water in the 21st Century: Outstanding issues and research challenges.” San Diego, 10 Jan 2005.

Invited talk at AMS 16th Symposium on Global Change and Climate Variations, session on "Climate Change Assessment Activities of the IPCC and the CCSP" “The CLIVAR/PAGES/IPCC workshop on a multi-millennia perspective on drought and implications for the future” San Diego, 11 Jan 2005.

Invited talk at AMS Lorenz Symposium “The general circulation revisited”. San Diego. 13 Jan 2005.

Invited keynote speaker, Chapman Conference on Tropical-Extratropical Climatic Teleconnections, A Long-Term Perspective. “The Role of the Tropics in the Global Energy and Water Cycles and Implications for Teleconnections”. Honolulu, Hawaii.8-11 February 2005.

Invited plenary talk 5th International Scientific Conference on the Global Energy and Water Cycle (GEWEX) “Estimates of the global water budget and its changes using observational and model data”. 20-24 June 2005, Costa Mesa CA.

Invited talk to U.S. CLIVAR meeting 15-17 August 2005, Keystone, CO, on WCRP COPES.

Invited seminar, Aeronomy Lab, NOAA (and CDC and CMDL) 14 September, 2005 “Anticipated and observed trends in the global hydrological cycle”.

Invited keynote lead talk “WCRP perspective on reanalysis and reprocessing for climate”, Workshop on “The development of Improved Observational Datasets for Reanalysis”, 28-30 September, 2005, Washington DC.

Invited presentation to Climate Research Committee, National Research Council, 4 October, 2005. “Observations and their analysis for WCRP/COPES”. Washington, DC.

Invited speaker at the Bob Dickinson symposium, “Hurricanes and global warming” 17-18 October 2005, Atlanta, GA.

Invited speaker and participant at the National Science Board hurricane workshop, 7 February, 2006. “Issues in hurricane research”

Invited speaker Western Coalition of Arid States meeting, 21-24 February 2006, Denver, “Observations of global climate change and drought”.

Invited seminar, Centre for Atmospheric Research, University of Canterbury, Christchurch, New Zealand, 24 March, 2006.

Invited seminar, School of Earth Sciences, Victoria University, Wellington, New Zealand, “Changes in hurricanes and storms with climate change” 27 March, 2006.

Invited presenter and participant in meeting with New Zealand government senior officials, politicians and policy experts, organized by the Royal Society of New Zealand, the Wellington Club, Wellington, New Zealand, 30 March 2006.

Invited speaker Center for Health and the Global Environment, Harvard Medical School, Course for Congressional Staff "Environmental Change: The Science and Human Health Impacts" April 18-19, 2006, Cosmos Club, Washington, D.C.

Invited speaker, 8th International Conference on Southern Hemisphere Meteorology and Oceanography. Foz do Iguaçu, Brazil, 24-28 April, 2006. Chaired session.

Invited speaker, "The role of hurricanes in the climate system". IMAGe Theme of the Year Workshop on "*Multi-scale processes for low frequency variability, climate, and climate change response*". May 15-19, 2006; Boulder CO.

Invited speaker, "Achieving Satellite Instrument Calibration for Climate Change (ASIC^3) Workshop". May 16-18, 2006, National Conference Center, Washington, DC.

Invited speaker, Global Climate Observing System "Workshop on "Reference Upper Air Observations for the Global Climate Observing System: Potential Technologies and Networks", May 22-24, 2006, Seattle, Washington.

Seminar, Univ. Washington, "Hurricanes and climate change", 24 May 2006, Seattle Washington.

Invited talk, WCRP reanalysis conference, "Observations and their analysis for WCRP/COPES." ECMWF, Reading, U.K. 19-22 June, 2006.

Invited talk, "What is the role of hurricanes in global climate". David Anderson, retirement seminar, ECMWF, Reading U.K., 23 June 2006.

Talk on status of comments on Chapter 3, IPCC AR4 Plenary meeting, Bergen, Norway, 25-28 June 2006.

Invited talk, "The role of hurricanes in climate" NOAA Postdoc retreat, Steamboat Springs, 9-13 July, 2006.

Invited talk "Attribution of Recent Increases in Atlantic Hurricane Activity". 31st Annual Climate Diagnostics Workshop, Boulder, CO, 23-27 October, 2006, and participation in Forum of Panel of Experts on outstanding attribution questions.

Invited talk on WOAP activities at WCRP Modeling Panel meeting, 23-24 October 2006, Boulder, CO.

Invited plenary talk at Earth System Science Partnership Open Science Conference on Global Environmental Change: Regional Challenges, "Relation to International Environmental Assessments and Conventions". Beijing, China, 9-12 November, 2006.

Invited distinguished lecture, Univ. Utah, "The role of tropical storms in climate and climate change", Salt Lake City, 28 November, 2006.

Invited keynote talk, "Progress Toward Integrated Earth System Analysis**"** *11th Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans and Land Surface (IOAS-AOLS),* "Toward an Integrated Earth System Analysis" *14-18 January 2007* at the American Meteorological Society Annual Meeting in San Antonio, Texas.

Invited talk, "The atmospheric hydrological cycle: Advances facilitated by Gene Rasmusson**",** *Rasmusson symposium, 18 January 2007* at the American Meteorological Society Annual Meeting in San Antonio, Texas.

Plenary talk on climate observations and the IPCC at the IPCC AR4 WG I meeting in Paris, 29 Jan to 1 February 2007.

Talk to NCAR Director's Committee mtg, 15 February, 2007 on IPCC findings.

Invited talk, "*Global water budget estimates and uncertainties*" Workshop on Satellite Observations of the Global Water Cycle, Beckman Center of the National Academies, Irvine, CA, March 7-9, 2007.

Invited seminar *"Hurricanes and global warming"* University of Wisconsin, Madison. 23 April 2007.

Invited talk, "*Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering"* AGU conference, Acapulco, Mexico, 21-25 May, 2007.

Invited talk, "*The water and energy budgets of hurricanes and implications for climate change***"** First International summit on hurricanes and climate change, May 27-June 1, 2007, Crete, Greece.

Invited talk, "*IPCC Fourth Assessment report- Ocean observations"* NOAA Climate Observations mtg 5-7 June 2007, Washington, DC.

Invited talk "*Hurricanes and global climate change*" Select Committee Congressional staff of Committee on energy independence and global warming, visit to NCAR 20 August 2007.

Invited talk "*Report on the Climate Observations and Analysis Review*" to NOAA Science Advisory Board, Mystic, CT, 24 August 2007.

Invited seminar, Yale University, "*Hurricanes and climate change*". New Haven, CT, 12 September 2007.

Invited talk, "*Issues from IPCC AR4 WG 1, Atmospheric modeling and observations*", GCOS/WCRP/IBGP IPCC workshop on *Learning from the IPCC Fourth Assessment* October 4-6, 2007, Sydney, Australia.

Invited talk, *An imperative: Building a climate information system to enable adaptation to regional climate change.* National Research Council workshop on Future priorities for the U.S. CCSP, Committee on Strategic Advice on the U.S. CCSP. Oct. 15-17, 2007, Washington DC.

Invited speaker, *An imperative: Building a climate information system to enable adaptation to regional climate change.* COSMIC-Formosat conference, Boulder CO 22-24 October, 2007.

Invited speaker, *Observations of climate.* American Statistical Association conference on "A statistical consensus on global warming". Boulder, CO. 26-27 October 2007.

Invited speaker, *A comparison of vertically-integrated water and energy cycle diagnostics from several reanalyses.* Third WCRP International Conference on Reanalyses, Tokyo, Japan, 28 Jan- 1 Feb 2008.

Invited talk, *Extremes in climate models*. GEWEX SSG meeting, Buenos Aires, Argentina, 4-9 February, 2008.

Invited talk, *WCRP Observations and Assimilation Panel.* GEWEX SSG meeting, Buenos Aires, Argentina, 4-9 February, 2008.

Invited talk, "Weather and climate in the 21st century: what do we know? And what don't we know?" Amer. Meteor. Soc. Policy Forum: "What about water? A reality check for the 21st century". Washington, DC, 26-27 Mar, 2008.

Invited keynote talk at the QUEST Hydrological Cycle meeting, on "*How may the spatial and temporal characteristics of precipitation change under global warming, and what are the fundamental processes that will constrain those changes?"* Totnes, Devon, U.K. as telecon. 21 April 2008.

Invited talk, World Climate Modelling Summit for Climate Prediction, "*Exploiting and evaluating models with observations*", Reading, U.K., 6-9 May 2008.

Invited keynote speaker in the American Geophysical Union's 2008 spring meeting in the Union session on "Understanding and Predicting Water and Energy Cycle Changes", on "*Earth's changing energy and water cycles*". Fort Lauderdale, FL, 28 May 2008.

Invited keynote speaker, "*The flow of energy through the Earth's climate system*", workshop on "Variability of the Global Atmospheric Circulation During the Past 100 Years" 15-20 June 2008, Monte Verità, Switzerland.

Invited discussant, NOAA Climate Working Group retreat on the NOAA strategic Plan for a National Climate Service. Vail, CO, June 23-26 2008.

Invited lecturer, European Space Agency summer school, Frascati (Rome), Italy, 4-14 August 2008:
3 lectures: *1) The flow of energy through the Earth's climate system.*
2) The global water cycle and its changes.
3) Climate change and an imperative: building a climate information system to enable adaptation to regional climate change.

Invited speaker, two talks, *"Storage and movement f heat in the ocean", "User requirements and applications: IPCC";* NOAA Climate Observation Division 6th Annual System Review, Washington, DC, 3-5 September 2008.

Invited speaker, Global Climate Observing System Steering Committee meeting XVI, Geneva, 14-17 October, 2008.

Invited speaker, "*The importance and challenges of closing the water budget*" U.S.-Canada GEO bilateral workshop on ice and water. 28-30 October 2008, Arlington, VA.

Invited speaker, "*Climate and weather forecasting using numerical models*". Chevron Fellows METamorphosis conference, Galveston, TX, 5 Nov. 2008.

Invited distinguished Climate Center Lecturer, Columbia University: 3 lectures 1) *The flow of energy through the climate system,* Lamont-Doherty Earth Observatory 17 November, 2) *The flow of energy through the climate system: observations and model performance,* NASA/Goddard Institute for Space Studies in New York City, 19 November; 3) *The global water cycle and its changes,* The International Research Institute for Climate and Society, 20 November 2008.

Invited speaker "*Climate change: Updated scientific assessment relevant to security",* Military Advisory Board for the CNA. National Renewable Energy Lab., Golden, 8 January 2009.

Invited speaker, "*Climate change: Updated scientific assessment relevant to health*." Institute of Medicine of the National Academies, Roundtable on Environmental Health Sciences, Research and Medicine, Washington, D.C. 15-16 January 2009.

Invited speaker, "*Attributing climate variations events: The role of energy*", and "*Attributing climate variations as part of a climate information system*" NCAR First international meeting on Attribution of Climate Events. NCAR, Boulder, 26 Jan 2009.

Invited speaker, "*WOAP perspective on GCOS*", Expert meeting on updating the GCOS IP. Geneva, Switzerland, 2-5 February, 2009

Invited talk "*Climate research and NCAR and climate change*" Civil Applications Committee, NCAR, 14 May 2009

Invited talk and panel member, *Impact of anthropogenic CO2 and other greenhouse gases on climate since 1940*. American Association of Petroleum Geologists annual meeting special session on Global Climate Change: the science behind CO2 and temperature, Denver, CO 9 June 2009

Invited talk to NCAR Undergraduate Leadership Workshop "*Climate change and the IPCC*", 15 June 2009, Boulder.

Invited talk "*Global climate change, an update*" to the 101st annual conference of the Association of American State Geologists, Park City, UT. 22 June 2009

Invited plenary talk "An observational perspective on changes in the global hydrological cycle" 2009 Royal Meteorological Society conference, Reading, U.K. 27 June-2 July 2009.

Invited talk "*A dry land and water cocktail: shaken not stirred*", 2009 Royal Meteorological Society conference, Reading, U.K. 27 June-2 July 2009.

Invited talk "*Changes in precipitation and runoff in a changing climate*" to Gordon Research Conference on Radiation, New London, NH, 4-9 July 2009.

Invited talk NCAR symposium on Health and Climate "*Climate change; Updated scientific assessment relevant to health*" 13 July 2009, Boulder. (given by John Fasullo)

Invited lecturer for NCAR ASP summer colloquium on Marine Ecosystems and climate: modeling and analysis of observed variability. "*The Earth's climate system: variability and change*" 3 Aug 2009, Boulder.

Invited talk at the GEWEX/iLEAPS international conference "Water in a changing climate", "*Aspects of a climate observing system: energy and water*", 24-28 August 2009, Melbourne, Australia.

Invited plenary lecture "*IPCC and Attribution and Prediction of Climate*" OceanObs'09 conference, Venice, Italy, 21 September, 2009.

Invited seminar "*The flow of energy through the climate system: Observations and model performance.*" Jet Propulsion Laboratory, Pasadena, CA, 7 Oct, 2009

Invited seminar "*Changes in climate extremes*" Univ. of Calgary, Calgary, Canada, 26 Oct 2009.

Invited talk, "*Tracking Earth's global energy*", Amer. Geophys. Union, San Francisco, Dec 16, 2009

Invited lead talk at National Academy of Sciences workshop on *The global Change and Extreme Hydrology: Testing conventional wisdom*, "*Understanding changes in precipitation and runoff with a changing climate.*" 5-6 January 2010, Washington, DC.

Invited lead talk at The third Kaplan symposium-Challenges of the global water shortage. "*Potential impacts of climate change on precipitation*". 11-13 April, 2010, Ma'agan, Israel.

Invited keynote talk "*The Earth's climate system: Variability and change*", International symposium on "Climate Change Effects on Fish and Fisheries", Sendai, Japan, 26-29 April 2010 (via DVD and Skype)

Invited talk to NCAR ASP Summer Colloquium on "Forecast Verification in the atmospheric sciences", "*Analyses and reanalyses for climate*" 8 June 2010, NCAR.

Invited talk to NCAR Journalism Fellowship Agenda "*Climate change*" 14 June 2010, and Invited participant in Round Table discussion (2 hours), 16 June, 2010

Invited talk to the 2010 Undergraduate Leadership workshop, "*Climate change*", NCAR, June 14, 2010

Invited panelist 35th annual Natural Hazards Research and Applications Workshop, session on "Translating climate predictions into adaptation decisions", Broomfield, CO., July 13, 2010

Invited talk to NCAR ASP Summer Colloquium on "Asia in the 21st century" "*Changes in precipitation with climate change*", 5 August, 2010, NCAR.

Rapporteur report for WG I, Attribution workshop, Broomfield, CO 17-18 Aug 2010

Leader of breakout working group, CLIVAR workshop *Decadal Variability, Predictability, and Prediction: Understanding the Role of the Ocean*, NCAR, Boulder 20-23 Sept 2010.

Invited keynote opening talk at the WCRP-UNESCO (GEWEX/CLIVAR/IHP) Workshop on "*Metrics and methodologies of estimation of extreme climate events"* (Paris, UNESCO headquarters, 27-29 September 2010).

Discussion leader for 90 minutes in plenary at WCRP-UNESCO (GEWEX/CLIVAR/IHP) Workshop on "*Metrics and methodologies of estimation of extreme climate events"* (Paris, UNESCO headquarters, 27-29 September 2010).

Invited keynote talk "*The scientific evidence for global climate change and ramifications for society."* "Asphalt Rubber –Engineering, Environment and Economy" conference, 11-12 October, 2010, Oporto, Portugal.

Invited talk "*GEWEX matters including the pan-GEWEX meeting*." WGNE meeting, Tokyo, Japan 18-22 October, (by Skype, for 50 minutes)

Invited talk "*Ocean observations and the IPCC*", NOAA Ocean Climate Observations (OCO) Annual System Review and Climate Observing System Council (COSC) meeting, Silver Spring, MD Oct 27-29, 2010.

Invited opening talk "*An overview of atmospheric reanalyses*" Workshop on Evaluation of Reanalyses-Developing and Integrated Earth System Analysis (IESA) Capability. Baltimore, MD. Nov. 1-3, 2010.

Invited talk "*Building a Climate Information System*", Third Atmospheric Circulation Reconstructions over the Earth (ACRE) workshop, Baltimore MD, Nov 3-5, 2010.

Invited talk: "*Evolution of GEWEX*", NCAR Water System Program Retreat, Boulder, 7 Dec, 2010.

Invited talks (2) ISSI workshop "Observing and modeling Earth's energy flows", Bern, Switzerland, 10-14 January 2011. (i) *The flow of energy through the climate system and its replication in climate models;(ii) Closing the Earth's energy budget.*

Invited 90 minute lectures (3) to ERCA, European Research Course on the Atmospheres, 17-18 January 2011, Grenoble, France. (i) *Impact of climate changes on precipitation; (ii) The flow of energy through the climate system and changes with global warming; (iii)Analyses and reanalyses for climate*

Invited speaker, AMS special session on WCRP Projects, Conf. Climate Variability and Change, AMS 91st Annual mtg, "*The New GEWEX",* 25 January 2011, Seattle, WA.

Speaker, AMS 23rd Conf. Climate Variability and Change "*Promoting climate information and communication of climate change*" AMS 91st Annual Meeting, 23-27 January 2011 Seattle, WA.

Invited speaker GEOSS-IPCC workshop: *A workshop on the data needs of the climate impacts, adaptation and vulnerability research community,* WMO, Geneva, 1 – 4 February 2011 (i) *Data needs and priorities of the research community (ii) Managing data to support assessments: continuity of measurements.*

Invited speaker Simon Fraser University: *The role of the ocean in climate*. 15 March 2011.Vancouver, BC, Canada.

Invited speaker WOAP Workshop on Evaluation of Satellite-Related Global Climate Datasets, *Diagnostic studies and data issues.* 18-20 April 2011.Frascati (Rome), Italy.

Invited speaker NRC Committee on A National Strategy for Advancing Climate Modeling, *Observing systems: Evaluating and Improving Models*. 27-28 April 2011, NCAR, Boulder, CO.

Invited speaker, Tokio Marine's 2011 Summit on Global Warming and Climate Change, *The climate extremes of 2010-11 and their attribution.* 29 April 2011, Atlanta, GA

Invited talk: *Developments in GEWEX*. CLIVAR SSG, Paris 1-5 May 2011.

Invited lecturer NCAR Advanced Study Program colloquium on "Statistical assessment of extreme weather phenomena under climate change. *Physical understanding of changes in extremes in precipitation with climate change.* 6 June, 2011 (90 minutes). NCAR, Boulder.

Invited lecture: *Drought and floods*. NCAR Journalism Fellowship meeting, 7 June 2011. (1 hour). NCAR Boulder.

Seminar: *The Russian Heat Wave and other Climate Extremes of 2010;* Australian Bureau of Meteorology, 28 June 2011, Melbourne, Australia

Seminar: *Tracking Earth's energy: From El Niño to global warming.* NIWA, Wellington, New Zealand, 14 July 2011.

Invited talk: Climate variability and water: Today and future prospects. American Chemistry Society annual meeting, symposium on "A sustainable future: Interface of energy, food, water and climate sustainability", Denver, 30 Aug 2011.

Invited keynote talk "*Tracking Earth Energy: from El Niño to global warming*". SORCE Science Meeting "Decadal cycles in the sun, sun-like stars, and Earth's climate system", Sedona, AZ 13-16 Sept 2011.

Invited lead speaker "*The Russian heat wave and other climate extremes of 2010*", Geological Society of America annual meeting, session on "Extreme climate and weather events: Past, present and future" Minneapolis, MN, 11 Oct 2011.

Invited keynote address "*Challenges of a sustained climate observing system*", World Climate Research Programme Open Science Conference, Denver, CO, 24-28 October 2011.

Invited speaker, "*Climate change and extremes in 2010 and 2011*". 23rd Annual Steamboat Weather Summit. Steamboat Springs, CO, 15-20 January 2012.

Invited speaker, "*Role of the southern ocean in climate change*", Climate Reality Project, on board ***National Geographic Explorer***, in Antarctica, Jan 28-Feb 6, 2012.

Invited speaker, "*Challenges for observing and modeling the global water cycle",* ISSI. Workshop on *The Earth's Hydrological Cycle*, International Space Science Institute (ISSI) in Bern Switzerland, 6-10 February 2012.

Invited speaker, "*Challenges for observing and modeling the global water cycle"* AGU Chapman Conference on Remote Sensing of the Terrestrial Water Cycle, Kona, Hawaii, 19 –22 February 2012

Invited speaker, "*Grand Scientific Challenges in GEWEX*" CliC SSG meeting, Innsbruck, Austria, by Skype 12 March, 2012.

Invited speaker, "*Changing water availability in the presence of climate change*" In "Water: Integrated assessment, governance and management in changing conditions at global, regional and transboundary levels" session of the GEC Conference "Planet under Pressure: New Knowledge towards Solutions", 26-29 March 2012, London, UK

Invited speaker, "*An evaluation of reanalysis transports between ocean and land*", Fourth Intl Reanalysis Conf., 7-11 May 2012, Silver Spring, MD.
Invited speaker, "Climate change and extreme weather". Morss Colloquium "The Ocean and Earth's Changing Water Cycle", May 16-18, 2012. Woods Hole Oceanographic Institute, Woods Hole, MA.
Invited panelist on 2 panels, Aspen Environment Institute June 23-25, 2012, Aspen, CO.
Invited speaker, "*Climate change and extremes of the hydrological cycle*", NERC Research Programmes "Changing water cycle" workshop, U. Reading, Reading, U.K. 26-28 June 2012.
Invited speaker, International Finance Corporation (IFC) climate change course, *Changing precipitation and water availability in the presence of climate change.* NCAR 11-12 July 2012.
Invited speaker Summer School on Dynamical Core Model Intercomparison Project (DCMIP), 7/30/2012-8/10/2012, NCAR, FL2 Boulder, CO.
Invited speaker, "*Changing precipitation and water availability in the presence of climate change"*. SIESD Summer School, National Center for Earth-surface Dynamics (NCED), University of Minneapolis, Minnesota, 9-10 August 2012.
Invited speaker, "*Climate Change: What We Know and Implications for the Future?* " American Sociology Association meeting, Thematic session "Global Warming and the Prospects for Real Utopias", 17 Aug 2012, Denver, CO.
Invited speaker, "*GEWEX*", pan-GASS workshop, NCAR, Boulder, CO, 10 Sept 2012
Invited speaker, "*Observations for the evaluation of the multi-scale aspects of the water cycle in models*", DOE workshop on "Observations for the evaluation of the multi-scale aspects of the water cycle in models", Washington DC, 24-26 Sept. 2012.
Invited speaker, "*Regional energy and water cycles: Transports from Ocean to Land*", AGU, San Francisco, 3-7 December, 2012
Keynote invited talk: "*Estimating the effects of climate change on the global hydrological cycle with a clear explanation of the global water budget"* 5th International Conf. on Water Resources and Arid Environments. Riyadh, Saudi Arabia, 7-9 Jan 2013
Invited talk, *Introduction to climate science*, CU Scripps Fellows, 8 Feb 2013.
Invited talk, *Challenges of a sustained climate observing system***,** NRC Committee on Earth Science and Applications from Space, mtg in Washington DC, by webinar, 7 Mar 2013
Invited talk, "*Global warming, coming ready or not*", Colorado University, Program on Atmospheric and Ocean Sciences 14 March 2013
Invited talk to NRDC visitors, "Global warming, coming ready or not!", 5 Apr, 2013.NCAR
Invited speaker, "Extreme weather and climate change", EPA Region 8 2013 Climate Change Speaker Series, Denver, CO. April 8, 2013.
Invited speaker, *GEWEX and the need for new water-cycle observations*. Water cycle Missions for the Next Decade meeting, NASA, 29-30 April 2013, Baltimore, Md.
Invited speaker, *GEWEX Report*. CLIVAR SSG meeting, Kiel, Germany 6-9 May 2013
Invited speaker, *GEWEX Report*. WCRP JSC meeting, Brasilia, Brazil, 26-31 May 2013.
Invited speaker, *GEWEX Report*. GEWEX wkshop on Water Resources, Saskatoon, Canada 5-7 June 2013
Invited speaker, *GEWEX Report*. GEWEX workshop on Precipitation, Fort Collins, CO 24-26 June 2013
Invited speaker and Panelist, "*Challenges of a sustained observing system*", Third workshop on "Understanding climate change from data", Northwestern University, Evanston, IL, 15-16 Aug. 2013.
Invited speaker, *The GEWEX Science Conference*. Joint GDAP/GHP meeting, Rio de Janeiro, Brazil.
Invited keynote speaker, "*Requirements for an End-to-end Climate Observing System*", Occultations for Probing Atmosphere and Climate – International Radio Occultation Working Group Workshop (OPAC-IROWG 2013), Seggau Castle, Leibnitz, Austria, 5-11 Sept, 2013.
Invited speaker, "*Earth's energy imbalance*" Workshop on the Role of Oceans in Multi-decadal Climate Variability" Beijing, China, Sep. 21-22 2013.
Invited speaker, "*Earth's energy imbalance: The apparent hiatus in warming?*" Beijing Symposium on Global Change-2013, Beijing, China, Sep. 23-25, 2013.

Invited keynote speaker, "*Earth's energy imbalance and implications for ocean heat content*." Ocean surface topography science team meeting, Oct. 10, 2013, Boulder, CO.
Invited talk GLASS meeting in Exeter, UK 16 Oct 2013. "*GEWEX Grand Science Questions, WCRP Grand Challenges, and the GEWEX Science Conference*". 1 hour by webex.
Invited Seminar, "*Earth's energy imbalance*", Wichita State University, Wichita, KS, 14 Nov 2013.
Invited speaker, "*Ocean heat uptake, the apparent hiatus in global warming, and climate sensitivity*", Workshop "Uncertainty in climate change: A conversation with climate scientists and economists", Yale University, 21 Nov. 2013.
Invited keynote talk: "*Climate change and water from the globe to Utah*", 2014 Spring Runoff Conference, Utah State University, Logan UT. 1-2 April, 2014.
Invited "Frontiers in Global Change Research" Seminar Speaker, "*Seasonal aspects of the hiatus in global warming*", Pacific Northwest National Laboratory, Richland WA, 22 April, 2014.
Invited speaker, Harvard University, "*The hiatus in global temperature rise*" Cambridge, MA, May 2-3, 2014.
Invited speaker, "*Earth's energy imbalance*". Working Group on Energy imbalance in the climate system, International Space Science Institute, Bern, Switzerland, 11-13 June, 2014.
Invited speaker, "*Climate change: It's about the data isn't it?*" Fourth Workshop on understanding climate change from data. NCAR, Boulder, CO, 30 June-2 July 2014.
Invited speaker, "*Where is global warming*?" Tokio Marine's Ninth Summit on Global Warming and Climate Change. Atlanta, GA; 8 Aug. 2014.
Invited colloquium speaker: *Earth's energy balance revisited.* Michigan State University, East Lansing MI, 18 Sept, 2014.
Invited speaker, "*Seasonal aspects of the recent hiatus is surface warming*", Session 1 "Clouds, Circulation and Climate Sensitivity", "The Climate Symposium 2014" Darmstadt, Germany. 13-17 Oct. 2014.
Invited speaker, "*The changing water cycle: A GEWEX Perspective*", Session 2 "The Changing Water Cycle", "The Climate Symposium 2014" Darmstadt, Germany. 13-17 Oct. 2014.
Invited talk, "*Challenges in Large-Scale Water Availability Changes*" American Geophysical Union, Observed and Projected Climate Change Impacts on Water Resources and Agriculture I session, San Francisco, 15 Dec. 2014.
Invited talk, "*How Does Drought Change With Climate Change*" American Geophysical Union, Drought and Its Impacts on Terrestrial Ecosystems: Current Understanding and Future Prospects I session, San Francisco, 16 Dec. 2014.
Invited speaker, "*The cost of CMIP-6*" CMIP-6 workshop, Univ. Maryland, MD, 9-10 Feb. 2015.
Invited speaker, *"Reanalyses continue to get better and are useful for diagnosing feedbacks: A case study of radiation vs temperatures." Shukla Symposium on Predictability in the Midst of Chaos*. 23-24 April 2015, Rockville, MD.
Invited speaker, "*Earth's energy imbalance*", Dept. Environmental Sci., Rutgers University, NJ. 1 May 2015.
Invited talk "*Earth's energy imbalance*", International Space Science Institute, Bern, Switzerland, 18-19 June, 2015
Invited talk, "*Attribution of extreme climate events*" IUGG, Prague, Czechoslovakia, 23 June-2 July 2015.
Invited talk, "*Climate feedbacks and relationships between TOA radiation and temperatures on Earth*" IUGG, Prague, Czechoslovakia, 23 June-2 July 2015.
Invited speaker, "*Climate Feedbacks and Relationships Between Top-of-Atmosphere Radiation and Temperatures on Earth*"; Radiation & Climate Gordon Research Conference, *Towards Understanding the Interactions Between Radiation, Clouds, Aerosol, Precipitation and Climate;* Bates College, Lewiston, ME. July 26-31, 2015.
Invited speaker, "*Sun and Earth's climate*" HAO: Past, Present and Future: A celebration of 75 years of solar science excellence. Boulder CO.1-3 Sept., 2015.

Invited keynote speaker, "*Approaches to addressing the Earth's energy imbalance*". CLIVAR CONCEPT-HEAT Workshop on energy flow through the climate system; MetOffice, Exeter, UK; 29 September - 1 October 2015.

Invited speaker, "*Attribution of climate extreme events*", 2 hour webinar to National Research Council Committee on Extreme Weather Events and Climate Change Attribution. 14 October, 2015.

Overview talk "*Co-variability of top-of-atmosphere radiation, temperature and precipitation: observations and models*." Earth Observation for Water Cycle Science 2015 conference, European Space Agency, Frascati, Italy, 20-23 October 2015.

Invited speaker and panelist, "*Future of the IPCC*", GFDL's 60th Anniversary Symposium. 2-3 November, 2015, Princeton, NJ.

Invited speaker, "*The intersection of El Niño and climate change*." El Niño 2015 conference, International Research Institute for Climate and Society, Columbia university, Lamont Doherty Earth Observatory, Palisades, NY, 17-18 Nov. 2015.

Invited talk, "*Relationships Among Top-of-atmosphere Radiation and Atmospheric State Variables in Observations and CESM"* American Geophysical Union, Improved Understanding of the Surface Energy Balance and the Spatiotemporal Variation of Its Components I session, San Francisco, 15 Dec. 2015.

Invited talk and member of Panel, "*Was there a hiatus in the rise of global mean surface temperatures and is it over?"* American Geophysical Union, US CLIVAR Session on the Global Energy Balance, Ocean Heat Content, and the Warming Hiatus; 17 Dec. 2015.

Invited talk: "*Attribution of extreme climate events*", International Detection and Attribution Group (IDAG) meeting, NCAR, Boulder, CO. Feb 1-3, 2016.

Invited keynote plenary talk, "*Insights into Earth's Energy Imbalance from multiple sources"*, 50th Canadian Meteorological and Oceanographic Society Congress, Fredericton, New Brunswick, 29 May-2 June, 2016.

Invited talk, "*Attribution of extreme climate events*", 50th Canadian Meteorological and Oceanographic Society Congress, Fredericton, New Brunswick, 29 May-2 June, 2016.

Invited keynote talk, "*Insights into Earth's Energy Imbalance from multiple sources"*, Eric Wood Symposium, Princeton University, Princeton, NJ, 1-2 June, 2016.

Invited talk, "*Weather and Climate Extremes: Attribution and Risk"* NCAR, Boulder, CO, 30 June 2016, http://scied.ucar.edu/events/Climate2016

Invited speaker NASA/Goddard Space Flight Center Scientific Colloquium, Greenbelt, MD, *Implications of Earth's energy imbalance for surface fluxes and especially ocean heat transports.* 12 Oct, 2016.

Invited speaker, University of Toronto, *Insights into Earth's Energy Imbalance from multiple sources,* Toronto, Canada. 20 Oct. 2016.

Invited speaker, University of Delaware, *Insights into Earth's Energy Imbalance from multiple sources,* Newark, DE, 31 Oct. 2016.

Invited seminar U. Reading *Insights into Earth's Energy Imbalance from multiple sources.* 21 Nov, 2016, Reading, U.K.

Invited seminar U. Oxford *"Intermittency in precipitation: duration, frequency, intensity and amounts using hourly data"* 22 Nov 2016, Oxford, U.K.

Invited talk Royal Society meeting "Storylines as an alternative way of representing uncertainty in climate change". "*Availability of water: too much or too little"*. Chichester Hall, UK. 22-24 Nov. 2016.

Invited participant US Army War College symposium "*Climate impact on national security*" in Carlisle, PA Nov 27-Dec 1, 2016.

Invited talk, AGU, "*A new estimate of surface fluxes and implications, especially for ocean heat transports"* San Francisco, CA. 14 Dec, 2016.

Invited keynote talk NCAR Water Cycle Retreat, *"Intermittency in precipitation: duration, frequency, intensity and amounts using hourly data"* 17 Jan 2017, Boulder CO

Invited talk AMS "*The vital need for a climate information system"*, Weather water and Climate Enterprise, 25 Jan 2017, Seattle, WA

Invited talk and panelist, The University of Alabama and the National Water Center, 2nd Annual Water Policy Summit April 6 & 7, 2017. '*Climate Change: Hydrologic Extremes*', Tuscaloosa, AL

Invited panelist for the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) 31 May-1 June 2017, Bonn, Germany.

Invited seminar, "*The flow of energy through the climate system*", Texas A&M University, 13 September 2017, College Station TX.

Invited seminar, "*Challenges of a sustained climate information system*", NOAA, Boulder, CO., 19 Oct. 2017.

Invited speaker/panelist "*Turning observations into climate information*". Global Environmental Monitoring and Measurement session of The Optical Society (OSA) and The International Photonics Coalition. NCAR (Center Green), Boulder, CO 7 Nov 2017.

Invited talk, Station Scientist session AMS annual meeting "*Are recent hurricane (Harvey, Irma, Maria) disasters natural?* Austin, TX. 10 Jan. 2018.

Invited talk, Environmental Defense Fund meeting of lawyers, "*Extreme weather and the changing climate"*. Hotel Boulderado, Boulder, CO, 27 Feb. 2018.

Invited keynote talk, "*Changes in Hydrological Extremes with Climate Change, including Atlantic hurricanes in 2017"* Extremes 2018, Hannover Herrenhausen, Hannover, Germany, 5-9 March 2018.

3. Invited general or public lectures

Invited speaker on global warming CISM/CGU (Canadian Geophysical Union) '90 Congress 22–25 May 1990, Ottawa, Canada.

LASERS (Learning about Science Easily and Readily Series) talks *"Children of the Tropics: El Niño and La Niña"*. NCAR, 2 and 9 December 1993

Invited speaker, Press conference Summit of Eight: G-8 scorecard on global warming. Denver CO, 21 June 1997.

Invited featured speaker, Town Meeting on Global Warming. New Orleans, LA. Oct 3, 1997.

Invited participant, The White House Conf. on Climate Change: The challenge of Global Warming. Washington D.C., Oct 6. 1997.

Invited participant, Workshop on *"Is there a causal link between decline of amphibian populations and global climate change."* Colorado Univ., Boulder CO. 8 May 1998.

Invited speaker (Capitol Hill Briefing), Hart Senate Office Building. Washington DC. 3 June 1998.

Invited lecturer, Project LEARN. Boulder CO. 8 June 1998.

Invited presentation to The Forum for Environmental Law, Science, Engineering and Finance (a.k.a. F.E.L.S.E.F. or "FailSafe"(TM)) *"The latest scientific evidence about climate change and the latest economic impact analyses about Kyoto"*, 1450 G Street, N.W., Washington D.C. 13 October 1998.

Invited 6th Annual Kuehnast Lecture, University of Minnesota, 15 October, 1998.

Invited speaker, SOLAR '98 - *"Creating the Right Climate"*, Proc. 36th Annual Conf. of the Australian and New Zealand Solar Energy Society. Christchurch, New Zealand 25-27 Nov 1998. By video conf.

Invited speaker, Denver/Boulder chapter of the Amer. Meteor. Soc: *"Assessment of recent climate variations"* Dec. 16 1998.

Invited lecture, Smithsonian Institution, March 31, 1999, Washington D.C.

Invited speaker, Special session on Global Warming, at 1999 American Nuclear Society winter meeting, 16 Nov. 1999, Long Beach CA.

Invited speaker, Human Health and Global Environmental Change course, Harvard Medical School, October 12, 2000. *"The Science of Global Climate Change"*

Invited speaker, USGCRP seminar, *"The Earth's Surface Temperature in the 20th Century: Coming to Grips with Satellite and Surface-Based Records of Temperature"* Wednesday, May 17, 2000, Dirksen Senate Office Bldg, Washington D.C.

Invited speaker, The Scripps Howard Institute on the Environment, May 22-27 2000, Boulder. *"Mysteries of climate variability"*.

Invited speaker, PLAN - Boulder County luncheon, June 2, 2000, University Club, Boulder *"Global warming is happening"*

Invited speaker, Korean Meteorological Administration ceremony on opening new Climate Change Information Center, Aug 10, 2000, Seoul, Korea.

Lecturer, Course through Denver University "*Global warming and the American Economy*", December 11-15, 2000. 4 Lectures and several discussion groups.

Invited speaker Royal Society of New Zealand, 21 Feb 2001. *"Global climate change and the IPCC"*. Wellington, New Zealand.

Invited keynote speaker, "Swiss Global Change Day" April 5, 2001, Bern, Switzerland. "*How should rainfall change as climate changes: Prospects for increases in extremes?*"

Invited talk/campus wide public lecture: Albrecht/Earth Day lecture "*Global warming is happening*". April 23, 2001, Univ. Missouri, Columbia.

Distinguished lecturer, Ford Research Lab, (50th Anniversary), Dearborn MI, May 7, 2001.

Invited speaker, Symposium on "Energy and Climate Change", hosted by the Denver World Affairs Council, August 28th, 2001, Denver.

Invited speaker, Prince of Wales' Business & the Environment Programme. Racine, Wisconsin from 29 October to 2 November 2001.

Invited presentation at First Annual NCAR Climate and Global Change Workshop (for teachers); 29 July 2002. *"El Niño and La Niña - An example of a coupled air-sea process that affects global change."*

Invited speaker, 52nd Pugwash Conference on 'Science-Sustainability-Security', University of California, La Jolla, CA. August 10-14 2002.

Invited speaker and panelist, The 13th Annual South Platte Forum. Oct 23-24, 2002, Longmont, CO.

Invited talk, local chapter of the Amer. Met. Soc. *Drought and Global Climate Change: Is 2002 a glimpse of the future?* 20 Nov. 2002, Boulder CO.

Invited public talk, Te Papa, Wellington, New Zealand, evening 24 March, 2003 *"The importance of water in climate variability and climate change"*.

Invited keynote address, International Council for Local Environmental Initiatives (ICLEI) Cities for Climate Protection workshop, May 28-31, 2003, Denver, CO. *"The science of global climate change"*.

Invited JPL-wide public lecture, part of Earth and Space Science Colloquium series, *"The flow of energy through the Earth's climate system"*, April 23, 2004, Pasadena, CA.

Invited distinguished lecturer (Public lecture), University of Oklahoma *"Manifestations of global climate change on accelerating the hydrological cycle: Prospects for increases in extremes."* Norman OK, January 26, 2005.

Panel member and speaker "*Katrina: a hurricane of issues.*" Present Tense Films and Discussion, Boulder Theatre, 11 September, 2005 (Public event about 300 present).

Invited public seminar on Capitol Hill: American Meteorological Society's Environmental Science Seminar Series, *Hurricanes: Are They Changing and Are We Adequately Prepared for the Future?* Dirksen Senate Office Building, Room G-50**,** Washington D.C., Oct. 25, 2005.

Invited speaker at the Peter Schroeder Colloquium, Michigan State University, 3 November, 2005 *"The flow of energy through the Earth's climate system and implications for climate change."*

Public lecture, Michigan State University. 2 November, 2005. *"Changes in hurricanes and storms with climate change"*.

Invited public lecture, University of Canterbury, Christchurch, New Zealand, "Science Prestige lecture" *"The Science of global climate change and human influences"*, 24 March 2006.

Invited presenter Public Forum event, *"Hurricanes and climate change"* Wellington, New Zealand, sponsored by School of Earth Science, Victoria University and ICLEI-A/NZ. 27 March 2006.

Invited speaker, Climate Change and Governance Conference, Te Papa, Wellington, New Zealand, 28-29 March, 2006, "*Observed changes to the climate and their causes*" and participant in Panel Discussion.

Invited speaker at Public climate seminar led by ABC TV Channel 7 (Mike Nelson). "*Climate change and water in the West*". April 12, 2006, Omni, Broomfield CO.

Invited public seminar, Northwest Fisheries Science Center, "*Global climate change and drought in the West*" 25 May 2006, Seattle, Washington.

Invited talk "*The Earth's climate system: variability and change*." NCAR summer colloquium on Climate and Health. 16-21 July 2006. Boulder, CO.

Invited talk, "*Science of climate change*". .Joint Inter-American Institute (IAI) - NCAR Advanced Study Program (ASP) Colloquium "Policy Planning and Decision Making Involving Climate Change and Variability", September 11 – 22, 2006. Boulder CO.

Invited talk, "*Global warming and climate changes: The scientific evidence and the possible ramifications upon our resources and future lifestyle*." 2006 Special District Association of Colorado Annual Conference, Keystone, CO. Sept. 21, 2006. (90 minutes).

Invited talk, "*Global climate change and water in the West*". National Wildlife Federation. Golden CO. Sept. 27, 2006.

Invited public lecture, University of Utah, "*Observed changes in climate, their causes, and what it means*". Salt Lake City, 29 November, 2006.

Invited keynote address, "*Le Réchauffement Global L'analyse du GIEC*" (Global warming, the analyses of the Group of Inter-agency Experts on Climate Development = IPCC). Colloque: Changement Climatique: La Caraïbe en danger! Martinique, 11-13 December, 2006

Invited talk "*Global warming is unequivocal*" to VIVA! (Vibrant, Intellectually Vigorous Adults). VIVA! is a self-directed, lifelong learning institute of the University College, University of Denver. Denver CO, 19 February 2007 (90 minutes).

Invited lecture 1.25 hours at Colorado University in course "*Discovering Climate Change*" Russ Monson, Department of Ecol & Evol Biol. 22 February 2007.

Invited talk to Coast Guard Academy, New London, CT. "*Global warming is unequivocal*" 26 Feb. 2007.

Invited Public lecture, "*Global warming is unequivocal*" Harriot College of Arts and Sciences Lecture, East Carolina University. 19 April 2007.

Invited Public lecture, "*Global warming is unequivocal*" University of Wisconsin, Madison. 23 April 2007.

Invited Public lecture, "*Global warming is unequivocal*" Hochstein School of Music, Rochester, New York. 25 April 2007.

Invited keynote address (1 hour) "*Climate and weather forecasting: Issues and prospects for prediction of climate on multiple time scales*" at 27th Annual International Symposium on Forecasting (ISF) in New York City, 26 June 2007.

Invited keynote plenary talk, "*Global warming is unequivocal*", *Transport–The next 50 years* conference, Christchurch, New Zealand, 25-27 July, 2007.

Invited talk, "*My career and climate change research*", Linwood College, Christchurch, New Zealand, July 31, 2007.

Invited keynote talk (1 hour) "*Global warming is unequivocal*" to 22nd International Conference on Amorphous and Nanocrystalline Semiconductors. Breckenridge, CO 21 August 2007.

Invited Colloquium lecture, Yale University, "*Global warming is unequivocal*". New Haven, CT, 12 September 2007.

Invited Public lecture "*Global warming affects us all: What must be done?"* Ecoarts event; Energy & Environmental Security Initiative, 24 September, 2007, Boulder, CO.

Invited Public ESSL/NCAR lecture, "*Global warming, coming ready or not.*" NCAR, Boulder, 18 October 2007.

Invited public lecture "*Global warming is unequivocal*". Embry-Riddle Aeronautic University, Daytona Beach, FL. 5 November, 2007.

Invited public lecture "*The latest update on climate change and the 4th IPCC assessment*." Channel 7 (Mike Nelson) Wild Weather Seminar 2007; The Wildlife Experience IMAX Theater, Parker, CO. 13 Nov. 2007.

Invited public lecture, "*Global warming, coming ready or not.*" University of Alabama, Tuscaloosa, AL, 6 Dec. 2007.

Invited public lecture "*Global warming is unequivocal*". Seagate, Longmont, CO, 10 Jan 2008.

Invited lecture, "*Global warming, coming ready or not.*" Denver University College of Law, Denver. 17 Jan 2008.

Invited lecture "*Global warming is unequivocal*". IEEE Aerospace conference, Big Sky, MT, 5 March 2008.

Invited public lecture "*Global warming, coming ready or not.*" Sustainable Mountain Living, Estes Park, CO. 1 April 2008. (2 hours)

Invited public lecture "*Global warming: The physical science basis*" Measuring Up conference, UCAR, Boulder, CO. 10 April 2008.

Invited participation in Public Forum: "*How serious is climate change? How serious are we about addressing it?*" Three person panel at Colorado University moderated by Richard Brenne, 2 hours. 17 April 2008.

Invited speaker, 2008 EDUCAUSE Center for Applied Research (ECAR) Summer Symposium, "*Global warming affects us all; What must be done*", St. Julien Hotel, Boulder, CO, 10 June 2008.

Keynote address, "*Climate change and extreme weather events*", Catastrophe Modeling Forum, New York, NY., 11-12 June 2008.

Invited talk, "*Climate change, coming ready or not*", AIG Investments, New York, NY, 13 June 2008.

Panelist, "*Facts about our changing climate*" AMS Broadcast Meteorologist Conference, Denver, CO 28 June 2008.

Invited speaker/panelist "*Global warming*", Democratic National Convention, Denver, CO 27 August, 2008.

Invited keynote speaker, *"Global warming: Coming ready or not",* North American Powertrain Executive Management meeting (about 200),. Chicago, Il, 3 September 2008.

Panelist (one of four) for teleconference briefing for Broadcast Meteorologists on "U.S. Climate Science Program Report Updates" focused on changing extremes in climate. Oct. 7, 2008; Q and A for 85 minutes.

Invited public lecture, "*Global warming, coming ready or not!*", Washington, DC, sponsored by District of Columbia Chapter of the American Meteorological Society, 29 October, 2008.

Invited public lecture, "*Global warming, coming ready or not!*", University of Houston, Houston, 4 November 2008.

Invited lecture "*Global warming is unequivocal*", to "Elk Resources" geologists at NCAR, 21 Nov. 2008. Paul E. Belanger, Ph.D., Geologist; Elk Resources, LLC; 1401 17th St., Ste 700; Denver, CO 80202

Invited keynote speaker, "*The flow of energy through the climate system and changes with global warming*", Annual meeting of the American Physical Society (evening lecture), Pittsburgh, PA 16 March 2009.

Invited panelist (one of 4) on climate change to Offshore Technology Conference, 6 May 2009, Houston, TX. [Over 300 in audience for 2.5 hour panel discussion and presentation.]

Invited public lecture University of Otago, Dunedin, New Zealand. "*The flow of energy through the Earth's climate system: observations and model performance in the Southern Hemisphere*". 31 Aug, 2009.

Invited talk "*Global warming: Coming ready or not"* to Global General Gathering of the Triple Nine Society (GGG999) (whose members are all above the 99.9 percentile in intelligence), 7 Sept 2009, Denver, CO.

Invited panelist in public forum: "*Preserving our planet: Climate and Energy. A call to action"* as the second Chautauqua Grant Convergence. Sept, 12, 2009, Boulder, CO.

Invited talk, Rocky Mountain Chapter Explorer's Club, "*Global Warming: Coming Ready or Not*", 8 October 2009, Boulder, CO.

Invited public lecture, "*Global Warming: Coming Ready or Not!*", Sponsored by the Institute for Pure and Applied Mathematics (IPAM), UCLA, May 5, 2010, Los Angeles, CA.

Invited public "Visher lecture", "*The scientific evidence for global climate change and ramifications for society."* Indiana University, 17 September 2010, Bloomington, IN. http://themester.indiana.edu/events/trenberth.shtml

Invited keynote public lecture at Sate University of New York at Albany "*The scientific evidence for global climate change and ramifications for society."* 3 October, 2010, on the occasion of the celebration of the 50th anniversary of the Dept of Atmospheric Science, Albany, NY.

Invited public lecture to AIChE Rocky Mountain Section (American Institute of Chemical Engineers) "*Global Warming – Coming Ready or Not*", Univ. Colorado, Boulder, CO on March 15th 2011.

Invited public lecture: *The Russian Heat Wave and other Climate Extremes of 2010,* In assoc. with The University of Victoria, Wellington, New Zealand , 15 Jul 2011.

Invited public lecture: "*Global warming: Coming Ready or Not!*" Osher Lifelong Learning Institute (OLLI) at the University of Denver; Jefferson Unitarian Church. Golden, CO. 27 Sept, 2011.

Invited public lecture, *Global warming: Coming Ready or Not!*" Metro State University, Denver, 7 March, 2012.

Invited lecture "*Perspectives on climate issues*" in Science and Public Policy at CU-Boulder (Physics 3000); Michael Ritzwoller, 1.25 hours. 13 March 2012.

Invited lecture and panelist, "*Climate change and extreme weather*". Drought or Deluge? The Ocean and the Earth's Changing Water Cycle". Redfield Auditorium, Woods Hole, 17 May 2012. 2 hours. http://www.livestream.com/whoitv/video?clipId=pla_0da58105-4459-4224-8d93-387e72bc0eea&utm_source=lslibrary&utm_medium=ui-thumb

Invited Public lecture, "*Global warming, coming ready or not!*", Ridgefield Public Library, New Jersey, 31 Aug, 2012. (2.5 hours with many questions)

Invited public lecture, "*Climate extremes and climate change: The Russian heat wave and other recent extremes"* Stanford University, San Francisco, CA, 4 Oct, 2012.

Invited public lecture "*Climate extremes and climate change*", University of New South Wales, Sydney, Australia, 16 October, 2012.

Invited banquet speaker, "*The new normal*", NOAA 37th Climate Diagnostics and Prediction Workshop, Fort Collins, 22-25 Oct 2012.

Invited speaker, "Climate change and extremes", Boulder City Council, Broadcast live on Channel 8, 2 April, 2013. Available on line: http://vimeo.com/63349024

*Telepress Conference; Webex: Climate Change & Ocean Warming***:** 11:00AM EST, April 11; Kevin Trenberth and Josh Willis**;** 1 hour, setup by Climate Nexus**.**

Invited public lecture, (TED talk), Seattle Science Festival, Seattle on Saturday 15 June 2013 in the www.seattlesciencefestival.org, I am on about beginning minute 34. http://www.youtube.com/watch?v=beKLrwCvkO0&feature=youtu.be&t=2m14s

Invited Presentation *"Global warming, coming ready or not!"* to the Sonoran Institute Board, 1.5 hours, 29 June 2013, Boulder, CO.

Keynote talk, ggg999 meeting, Denver 30 Aug 2013 **"** Look Out the Window, Global Warming Signs Are Here**"** http://www.youtube.com/watch?v=L_LTM_e7Mfc&list=PLc-WD36KUoif0urxlPvhrd0T26_QI0lVA&index=9

Invited speaker, "*How human-induced climate change affects weather extremes*." University of Rio de Janeiro, Rio de Janeiro, Brazil, 2 September, 2013.

Invited panelist, Performing Arts Center (PAC), Naropa University Graduate Theater program, following "*Moons of Jupiter*" play and discussion of global environmental issues. Boulder, 18 October 2013.

Invited keynote speaker, "*Earth's energy imbalance*", American Physical Society, Four Corners Section, conference, University of Denver, Denver, CO, 18-19 October 2013.

Invited after dinner speaker, "*Climate change and weather extremes in Colorado*", Colorado Mountain Club, annual meeting Boulder Group, Boulder, CO., 9 Nov 2013.

Invited speaker and panelist at Conference on World Affairs, Colorado University, "*Climate Change: It's the Data, not the Politics*" 11 April 2014, Boulder CO.

Webinar: *Extreme Weather: Climate Change Impact, Adaptation and Mitigation*; Presenters Kevin Trenberth and Paty Romero-Lankao. Climate Webinars for Educators: Massive Open Online Course; CIRES Outreach and Education, Colorado University, and UCAR. 16 April 2014; 90 minutes live. 350 signed up. http://new.livestream.com/lmac/extremeweathermitigation

Invited public lecture (Peter Schroder lecture): *Climate change: It's about the data isn't it?* Michigan State University, East Lansing MI, 18 Sept, 2014.

Invited lecture: *Climate change: It's about the data isn't it?* Fourth International Workshop on Climate Informatics (CI 2014), NCAR, Boulder, CO., 25 Sept, 2014.

Invited lead panelist: "*What are the possibilities for creating a sustainable water supply in the future*", UN Day 2014, Colorado University, 26 October, 2014. [2 hour event, 3 panelists].

Invited public lecture: "*Climate change: Coming ready or not!"* Colorado Foothills World Affairs Council meeting, Mount Vernon Country Club, Nov. 18, 2014. https://www.youtube.com/watch?v=_RKUlhgjU8Y

Invited lecture, IPCC Chapter 14: Climate Phenomena and their Relevance for Future Regional Climate Change. Reading the IPCC Report - A CIRES-ATOC Seminar Series. Colorado University, Boulder, CO. 9 Dec., 2014.

Invited public lecture, "*Climate disruption in the wild west region*" 2015 Wild West Citizen's Climate Lobby Regional conference, Jefferson Unitarian Church, Golden, CO. 7 Feb., 2015

Invited talk and panelist, "*Climate disruption in the U.S.!*" 2015 Solar Power Colorado conference, Broomfield, CO, 23-25 February 2015.

Invited public lecture "*Climate disruption in the U.S.: The fifty shades of climate change*" North Jersey Public Policy lecture March 26, 2015 Ramapo College of NJ, Mahwah, NJ 07480.

Invited student lecture, "*Fifty shades of climate change*", Research Experiences Undergraduate program, Colorado School of Mines, Golden, CO, 10 July 2015.

Invited lecture, "*How human induced climate change affects us all*", Rubberized Asphalt conference, RAR2015 Keynote lecture, Las Vegas, NV, 5 October, 2015.

Invited talk and panelist, "*Attribution of climate extreme events*" Tokio Marine's Tenth Summit on Global Warming and Climate Change, Fairmont Mayakoba, Playa del Carmen, Mexico 8-9 October 2015.

Invited speaker, "*Fifty shades of climate change*" Envirofest 2015, October 15, 4:30-9:30 at the Lakewood Cultural Center, Lakewood, CO.

Invited speaker NCAR Explorer Series public Lecture; 20 and 23 Jan 2016. "*What's going on with El Niño?*" Mesa Lab. NCAR, Boulder CO. https://ncar.ucar.edu/diversity-education-outreach/kevin-trenberth http://video.ucar.edu/mms/ncar/explorer_series_kevin_trenberth.mp4. Available also: UCARConnect's YouTube channel. A version with American Sign Language interpretation.

https://www.youtube.com/watch?v=fSDdkRFdtTQ ;http://ucar.us4.list-manage1.com/track/click?u=289033ba2718c3aa3d2b2e76f&id=d55014f82e&e=518491ab42

Invited speaker, "*Global Warming is Alive and Well (not that this is a good thing)",* The Audubon Society of Greater Denver and the Sierra Club 2016 Legislative Forum, First Plymouth Congregational Church, Englewood, CO, February 27, 2016

Invited panelist and speaker, MIT Alumni "View from the Top" event, Denver Museum of Nature and Science, Denver, CO 6 April 2016

Invited keynote talk to 2016 Boulder Climate Leaders Workshop, "*Global Warming is Alive and Well (not that this is a good thing)",* Downtown Boulder, CO, 28 April 2016

Invited public talk: *"El Niño 101",* SilverSneakers, YMCA of Boulder Valley, Boulder, CO, 26 May 2016.

Invited keynote lecture: *Weather and Climate Extremes: Attribution and Risk.* Climate Change 2016 workshop Broadcast via UCARLive at http://ucarconnect.ucar.edu/live. NCAR, Boulder, CO., 29 June, 2016.

Invited presenter at a global webinar: "El Niño's impact on human geography: What we thought, what we learned". "*2015-16 manifestations of El Niño*" World Wide Human Geography Data, http://wwhgd.org. 3 Aug., 2016

Invited keynote speaker, *Weather and Climate Extremes: Risks, Resilience, and Attribution* June 30th - July 2nd, 2016, NCAR, Boulder, CO.

Invited public lecture, "*Global Warming is Alive and Well (not that this is a good thing)",* 30 Oct, 2016; Beth Evergreen Synagogue, Evergreen, CO.

Discussion panel, "*The climate crisis and its solutions"* 2.5 hours, with Al Gore and Henry Pollack, Climate Reality Project training at Colorado Convention Center, over 1000 in attendance. 3 March 2017. https://www.climaterealityproject.org/

Invited public lecture and panel, "*Global Warming is Alive and Well (not that this is a good thing)",* Vail Symposium, 9 March 2017, Vail CO. Vail Symposium - Convening Locally, Thinking Globally

Invited lecture to over 400 high school students at Ridgewood High School, "*What's with the weird weather?*" March 28, 2017, Ridgewood, NJ, 07450.

Invited Public Lecture, NCAR Explorer Series, Denver Public Library, "*What's with the weird weather*", Denver, CO, 20 April 2017.

Invited public lecture, "*Global Warming is Alive and Well (not that this is a good thing)",* Community Activism for Progress and Equity (C.A.P.E.) meeting, Mercury Café, Denver, CO, 21 April 2017.

Invited keynote talk (lunch speaker), *'The Fifty Shades of Climate Change'*, Rocky Mountain Chapter ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Technical Conference, Denver West Sheraton Hotel, Lakewood, CO. 28 Apr. 2017.

Invited public lecture, "*Climate Change: Prospects for how water issues will shape the world in which we live*", Temple Sinai, Denver, CO, 25 Oct. 2017.

Invited public lecture (and panelist) "*The science of climate change*". Fort Lewis College Climate Symposium, Durango, CO, 9 Nov. 2017.

Invited public lecture to TV Broadcasters, "*Extreme weather and the changing climate"*. Steamboat Springs, CO, 25 Jan. 2018.

Invited talk, Charney-Lorenz centennial symposium, "*Ed Lorenz was no Tarzan, but he loved the outdoors, and he had Jane.* MIT, 1-2 February 2018.

Invited Lecture at Denver University, Global Climate Change Law & Policy Seminar at DU Sturm College of Law, *"Extreme weather and the changing climate",* 2 hours, 9 Feb. 2018.

Invited public talk and panel: "Climate extremes and climate change" Vail Symposium, 15 March 2018, Vail CO. Vail Symposium - Convening Locally, Thinking Globally

OTHER PROFESSIONAL ACTIVITIES:

Participation in many other conferences and workshops.

Reviewer of papers for:

AAAS book Detection CO_2 Induced Climate Change
American Chemical Society
American Geophysical Union Monograph
American Meteorological Society Monographs
Annals Association for American Geographers
Atmosphere Ocean
The Atmosphere–Ocean System
Bulletin of the American Meteorological Society
Cambridge University Press
Climatic Change
Climate Dynamics
Climate Research
D. C. Heath, Canada Ltd book
Dynamics of Atmospheres and Ocean
Environmental Science & Technology
Estuarine coastal and shelf science
Environmental Research Letters
Environmental Science & Technology
Environmental Science & Policy
Geophysical Research Letters
IAMAP Symposium Series
International Space Science Institute
Intergovernmental Panel on Climate Change
International J. Climatology
J. Advances in Modeling Earth Systems
J. Applied Meteorology
J. Atmospheric Sciences
J. Climate and Applied Meteorology
J. Climate
J. Climatology
J. Geophysical Research
J. Hydrometeorology
J. Meteor. Soc. Japan
J. Royal Statistical Society
J. Tech.
Monthly Weather Review
National Academy of Sciences
National Geographic
National Research Council
Nature
Nature climate change
Nature Geosciences
New Zealand Consumer Magazine
New Zealand J. Science
New Zealand Meteor. Service Technical Reports
NOAA Professional Paper Series
O. Acta
PNAS
Procedia Environmental Sciences
Quarterly J. Royal Meteorological Society
Quarterly J. Royal Society of New Zealand
Reidel book chapter
Reports to the Nation series, NOAA.
Second World Climate Conference
Science
Science for Fourth to Eighth graders
Surveys in Geophysics
Surveys in Geophys. and Space Sci.
Tellus
Theoretical and Applied Climate
Weather and Forecasting
WIREs climate change
World Meteorological Organization

Reviewer of proposals for:

Atmospheric Environmental Service, Canada.
Calspace
Cambridge University Press book proposals
Global Climate Observing System
Hadley Centre
National Environmental Research Council (UK)
German Science Foundation
University of Illinois Research Board
National Research Council
National Science Foundation
National Climate Assessment
NASA
NCAR
New Zealand Research Council
New Zealand Marsden Fund
NOAA
NCPO
TOGA, GOALS, CLIVAR, GEWEX
World Bank

Delivered seminars:

Within New Zealand Meteorological Service	1972–1977	6
Outside of New Zealand Meteorological Service	1972–1977	13
Within University of Illinois	1977–1984	12
Outside of University of Illinois	1977–1984	12

Public Service and Other Activities:

Participation on radio talkback shows, radio programs, and local television news
Appearances on national TV News: CBS Evening News 1/3/89; CBS Morning Program 1/4/89; NBC Today Show 1/26/89, 3/16/93, NBC Nightly News 4/7/97, NBC Dateline 4/29/97, ABC Evening News 7/2/97, Lehrer News Hour (8 minutes) 12/4/1997, CBS Evening News 1/9/98, NBC Nightly News 10/21/99, MSNBC 12/28/99, NBC Nightly News and MSNBC 4/1/2000, CNN 24-25 August 2000. CNN 16 October 2000, CNN: "America's Best" profile of Dr Lonnie Thompson, August 01; ABC News with Peter Jennings, Ned Potter, 13 May 2002; ABC News with Peter Jennings, May 2004. CNN Science show, Camille Feanny:24 and 25 July 2004; interview and commentary on heat waves in Europe 2003. ABC 20/20, 23 September 2005 "Hurricanes and global warming". May 2006 HBO "Too Hot Not to Handle". Dozens in January – February 2007 (post IPCC). Lou Dobbs, CNN 12 May 2008. Many others.

Also many appearances on local TV.
Featured on TV shows:
Beyond Tomorrow 1988,
Program on 1993 US flooding,
NHK/Japan Broadcasting Corp. Sept 1993.
Australian ABC TV *Four Corners* 1997,
El Niño BBC and Discover Channel Nov 1997– Feb 1998.
Earth in the Hot Seat, AE 8/16/99;
Understanding Weather, The Learning Channel 11/14/99 and several other times, also Channel 4, U.K.;
Assignment TV New Zealand, 19 April 2000;
What's up with the weather. Frontline/NOVA PBS special 4/18/00;
Planet Earth 2000. ABC News special, 22 April 2000;
TV New Zealand, *Good Morning* (live) 21 Feb 2001.
Globus on German Public Television/NDR, First Channel. Christine Gerberding. April 12, 2002.
Asahi TV, *"Spaceship the Earth"*, July 9, 2003. Mika Yamamoto.
Stonehaven Production Services documentary, *"The End of Eden"* on PBS (February 2005), October 7, 2003. Michael Taylor.
NHK TV Japan, July and November 2005.
KBDI *Global Agenda* half-hour discussion program on climate change, Oct. 26, 2005. Alison Hill producer.
PBS nationwide: *Global Warming: The Signs and The Science*, a one-hour documentary, South Carolina ETV and Stonehaven Productions. Nov 2, 2005 (and other broadcasts).
NBC Nightly News *"Hurricanes and climate"* 7 September 2008.
PBS NewsHour, live interview for about 6 minutes with Judy Wooruff: 2 July 2012 http://www.pbs.org/newshour/bb/weather/july-dec12/climate_07-02.html;
CBS Evening News, Chip Reed. 3 July 2012: Lead story http://www.cbsnews.com/8301-18563_162-57466244/heat-wave-raises-warning-signs-for-climate-change-scientists/
NBC Nightly News, Oct, 30, 2012: Sandy, http://video.msnbc.msn.com/nightly-news/49616092/#49616092
CNN 1 hour documentary *"The coming storms":* 5 Jan 2013.
Documentary: 1.5 hours, "*Greedy Lying Bastards*", opened 8 March 2013.
BBC TV *Tornado Earth Juice*; 5/30/13; 4 minute interview. http://www.youtube.com/watch?v=8VU-YxBvuFk
NBC Nightly News**,** Jan 8 2014; Anne Thompson interview. http://www.nbcnews.com/video/nightly-news/54016372/#54016372
ABC News (national) 6 March 2014; Interview on the Return of El Nino. Clayton Sandell. 1:23 http://abcnews.go.com/WNT/video/return-el-nino-22811597
NBC News May 22, 2014; Global Warming Linked to Frigid U.S. Winter, Scientist Says
By John Roach; http://www.nbcnews.com/science/environment/global-warming-linked-frigid-u-s-winter-scientist-says-n111676

ABC News, 13 August 2014; Clayton Sandell via World News; http://abcnews.go.com/US/heavy-downpours-increasing-due-global-warming-scientists/story?id=24965926
Australia ABC News documentary; 16 Oct 2014 air time; The global warming pause http://www.abc.net.au/catalyst/stories/4107264.htm
NBC News,19 Nov, 2014; Freezing on East Coast? Blame a Super Typhoon and Maybe Global Warming. By Miguel Llanos; http://www.nbcnews.com/science/environment/freezing-east-coast-blame-super-typhoon-maybe-global-warming-n252111

Many interviews on National Public Radio, and other radio programs.

Numerous quotes and work featured in major newspaper and magazine articles.
Major (2 page) newspaper article in "The Press" New Zealand, 28 December 1976
Interviews featured in: N.Y. Times, TIME, U.S. News and World Report, Science, Earth, Science News, Nature, Scientific American, Playboy, Forbes. Mother Jones,
Contributor to many issues of National Geographic (May 1998, March 1999, Oct 2000, Feb. 2001, Sep. 2004, special report April 2008 "*Changing Climate*")
Talks to Rotary Clubs
Speaker at conventions, meetings etc. ("after dinner speaker")
Judge at Illinois Junior Academy of Science Expositions
Judge at Boulder Schools' Science Fair
Briefings on climate change for Congressional staff, Washington D.C., 24 Jun 1996, 20 Oct 1997.
Briefings on global climate change for members of State Dept, EPA, USGCRP 11 Jan 1998.
Briefing for NSF, NOAA and NASA program managers on CLIVAR Status.11 Jan 1998.
Featured interview "Engineering Earth with Kevin Trenberth" and Megan Sever in *Geotimes*, December 2007 pp 38-40.
UNEP's online interactive feature *Ask Today's Expert* from 7 to 8 September 2008.
Yale Forum on climate Change and the Media Rutgers' Francis and NCAR's Trenberth; June, 2013. Two Expert -- and Diverging – Views on Arctic's Impact on Weather 'Whiplash' Video interview.
http://www.yaleclimatemediaforum.org/2013/06/video-of-two-expert-and-diverging-views-on-arctics-impact-on-weather-whiplash-francis-trenberth/
NPR; The 'Consensus' View: Kevin Trenberth's Take On Climate Change by Richard Harris Aug. 23, 2013 5:47 PM http://www.npr.org/2013/08/23/214198814/the-consensus-view-kevin-trenberths-take-on-climate-change
"*Inquiring Minds*". Feb 21, 2014; 1 hour interview host Chris Mooney and guests Kevin Trenberth and Jennifer Francis. https://itunes.apple.com/us/podcast/inquiring-minds/id711675943?mt=2
Webinar *Extreme Weather: Climate Change Impact, Adaptation and Mitigation*; 16 April 2014; 90 minutes live. Presenters Kevin Trenberth and Paty Romero-Lankao; Climate Webinars for Educators: Massive Open Online Course; CIRES Outreach and Education, Colorado University, and UCAR http://new.livestream.com/lmac/extremeweathermitigation

Testimony
Colorado Legislature/Water Conservation Board "Water Forum", 14 July 1988, Colorado Capitol, Denver
Western Interstate Energy Board, 1 December 1988, Tempe, Arizona
The role of clouds in climate change, U.S. Senate Committee on Commerce, Science and Transportation, Washington, D.C., 7 October 1991.
Climate change and temperatures. The U. S. Senate Committee on Commerce, Science, and Transportation, The United States Senate, May 17, 2000.
The 2001 Assessment of Climate Change. The U. S. Senate Committee on Environment and Public Works, The United States Senate, Room 628 of the Dirksen Senate Building, 9:30 a.m., May 2, 2001.

Observations of climate change: *The 2007 IPCC Assessment.* Committee on Science and Technology, United States House of Representatives, Room 2318 of the Rayburn House Office Building, 10:00 a.m., February 8, 2007.

Observations of climate change: *The 2007 IPCC Assessment.* The U. S. Senate Committee on Environment and Public Works, The United States Senate, Dirksen Senate Building, 1:30 p.m. May 2, 2007.

Observations of climate change: *The 2007 IPCC Assessment.* Committee on Energy and Commerce, United States House of Representatives, Rayburn House Office Building, 9:00 a.m., February 9, 2007.

Colorado General Assembly, Hearing on House Bill 08-1164, Capitol Building, Denver, 8 April, 2008.

CO Public Utilities Commission Docket No. 07A-447E, 28 April, 2008 15 pp.

An update on human-induced climate change. The U. S. Senate Committee on Environment and Public Works, The United States Senate, Room 406 of the Dirksen Senate Building, 10:00 a.m., July 22, 2008.

An update on human-induced climate change to the Colorado Air Quality Commission hearings, 17 Sept. 2009, Denver CO.

University of Illinois Teaching experience:

ATMOS 222	Weather Processes
ATMOS 406	Dynamical Weather Prediction
ATMOS 441	Dynamics of Climate and Climate Change
ATMOS 497	Geophysical Fluid Dynamics
ATMOS 397	Statistical Methods in Meteorology
ATMOS 491	Seminar in Atmospheric Sciences
ATMOS 499	Thesis Research

University committees:

Graduate College Engineering and Physical Sciences area Subcommittee 1979–81.
University of Illinois Senate 1979–84.
Committee on Educational Policy 1980–84.
Chairman subcommittee A (Engineering and Physical Sciences) 1981–82.

Departmental committees:

Chairman Graduate Studies Committee 1978–82.
Chairman miscellaneous ad hoc committees.
Participant in many other committees.

Students supervised:

M.S. degree
Daniel A. Paolino, Jr., May 1980
Gary Swanson, September 1980
Won-Tae K. Shin, August 1983
John R. Christy, May 1984

Ph.D. degree
Shyh-Chin Chen, October 1986
John R. Christy, July 1987

Other:
Graduate faculty member 1979–
Supervisor of graduate students
Supervisor of undergraduate (Independent Plan of Study) student (who received honorable mention AMS Undergraduate Scholarships 1984, Gerald Bell).
Special graduate faculty seminar participant (September 1981)

PROFESSIONAL ACTIVITIES

Research grants and contracts

Title: Predictability of Short-Term Climate Fluctuations
Sponsor: National Science Foundation
Period: 1 November 1978 – 30 April 1980
Amount: $32,600
Capacity: Principal Investigator

Title: Predictability of Short-Term Climate Fluctuations
Sponsor: National Center for Atmospheric Research
Period: 1978 – 1982
Amount: $20K CRU
Capacity: Principal Investigator

Title: Interannual Variability of the Atmospheric Circulation in the Southern Hemisphere
Sponsor: National Science Foundation
Period: 1 November 1979 – 30 April 1983
Amount: $142,000
Capacity: Principal Investigator

Title: The Global and Southern Hemisphere Atmospheric General Circulation
Sponsor: National Science Foundation
Period: 1 November 1982 – 30 April 1986
Amount: $175,460
Capacity: Principal Investigator, 3rd year Co-P.I. with Dr. Mankin Mak

Title: Southern Hemisphere General Circulation Studies
Sponsor: National Center for Atmospheric Research
Period: 1982 – 1985
Amount: $20K CRU + 8 GAU
Capacity: Principal Investigator

Title: The Global Atmospheric General Circulation
Sponsor: National Science Foundation
Period: 1 November 1985 – 30 April 1988
Amount: $97,400
Capacity: Principal Investigator, Dr. Mankin Mak Co-PI.

Title: Interannual Variability of the Global Atmospheric Circulation
Sponsor: TOGA Project Office (NOAA)
Period: 19 May 1986 – May 1989
Amount: $304,800
Capacity: Principal Investigator

Title: Interannual Variability of the Global Atmospheric Circulation
Sponsor: TOGA Project Office (NOAA)
Period: May 19, 1989 – May 1992
Amount: $318,000
Capacity: Principal Investigator

Title: Case study of the drought of 1988 on regional and global scale
Sponsor: NASA
Period: 1 July 1989 – 31 March 1993
Amount: $90,000 (180K), 120,000, 60,000 = $450,000
Capacity: Co-Investigator (R. Dickinson P.I.), NCAR leader 1990–93

Title: NCAR project to interface modeling on global and regional scales with Earth Observing System (Eos) observations
Sponsor: NASA (Eos Interdisciplinary proposal)
Period: 1 July 1989 – 1999
Amount: $1,097,000 1992
Capacity: Co-Investigator

Title: Interannual Variability of the Global Atmospheric Circulation
Sponsor: TOGA Project Office (NOAA)
Period: May 19, 1992 – May 1995
Amount: $330,000
Capacity: Principal Investigator

Title: Interannual Variability of the Global Atmospheric Circulation
Sponsor: GOALS/Climate and Global Change Program (NOAA)
Period: April 1995 – March 1999
Amount: $570,100
Capacity: Principal Investigator

Title: Global climate datasets for model validation and diagnostic studies
Sponsor: Climate and Global Change Program (NOAA) and NASA
Period: April 1997 – March 2000
Amount: $324,700
Capacity: Principal Investigator

Title: Interannual Variability of the Global Atmospheric Circulation
Sponsor: Climate and Global Change Program (NOAA)
Period: May 1999 – February 2003
Amount: $580,300
Capacity: Principal Investigator

Title: Global climate datasets for model validation and diagnostic studies
Sponsor: Climate and Global Change Program (NOAA) and NASA
Period: September 2000– August 2003
Amount: $380,000
Capacity: Principal Investigator

Title: Interannual Variability of the Global Atmospheric Circulation
Sponsor: Climate and Global Change Program (NOAA)
Period: March 2003 – February 2006
Amount: $425,050
Capacity: Principal Investigator

Title: Quantifying fresh water fluxes, runoff and precipitation in the global water cycle and applying them to evaluate the CCSM.
Sponsor: National Science Foundation Water Cycle Research
Period: Feb 2003 - February 2006
Amount: $386,064
Capacity: Co-Principal Investigator with Aiguo Dai.

Title: Evaluation of ERA-40 reanalyses and the vertical structure of the atmosphere.
Sponsor: Climate and Global Change Program (NOAA)
Period: April 2004– March 2007
Amount: $427,500
Capacity: Principal Investigator

Title: The flow of energy through the coupled ocean-atmosphere system.
Sponsor: Climate and Global Change Program (NOAA)
Period: June 2006– May 2010
Amount: $527,100
Capacity: Principal Investigator

Title: Diagnostics in support of MERRA.
Sponsor: NASA
Period: January 2006– December 2006
Amount: $25,000
Capacity: Principal Investigator
Title: Evaluation of new reanalyses and the vertical structure of the atmosphere.
Sponsor: Climate and Global Change Program (NOAA)
Period: August 2007– July 2010
Amount: $390,044
Capacity: Principal Investigator

Title: Diagnostics in support of MERRA: The Flow of Moisture and Energy through the Coupled Climate System (08-MAP-14)
Sponsor: NASA MAP
Period: June 2009-May 2013
Amount: $133,184, $182,944, $220,331, $225,197
Capacity: Principal Investigator

Title: Diagnostics of the water and energy cycles.
Sponsor: NASA
Period May 2011-Apr. 2014
Amount: $420,649
Capacity: Principal Investigator

Title: An Informed Guide to Climate Data Sets with Relevance to Earth System Model Evaluation
Sponsor: NSF EASM
Period: Mar. 2011-Feb. 2014
Amount: $899,973
Capacity: Co-PI

Title: Collaborative Research to Narrow Uncertainties in Precipitation and the Hydrological Cycle in Climate Models
Sponsor: DOE: Office of Biological & Environmental Research within Office of Science
Period: 08/15/2014 to 08/14/2018
Amount: $507,012
Capacity: Principal Investigator

LIST OF PUBLICATIONS

The total (Mar 2018) is 65 books or book chapters, 268 journal articles published, 23 Tech. Notes, 117 proceedings or preprints, and 81 other articles, plus four videos, for a total of 554 publications plus 4 videos, and many blogs. On the Web of Science, there are over 33,400 citations and an H index of 84 (84 publications have 84 or more citations). On Google Scholar, there are > 85,700 citations and an ***H index of 110*** (or 73 since 2013).

Videos

Guillemot C. J., and K. E. Trenberth, 1992: ENSO: SST monthly mean anomalies Pacific Sector. Jan. 1982–July 1992, 8 minutes (long version) and 5 minutes (short version), plus handout.

Guillemot C. J., and K. E. Trenberth, 1995: ENSO: SST monthly mean anomalies Pacific Sector. Jan. 1982–1994, 4 minutes 20 seconds, plus handout.

Henson, R. and K. E. Trenberth, 1998: Children of the Tropics: El Niño and La Niña. Learning about Science Easily and Readily Series (LASERS), NCAR, Online paper with movie clips:
http://www.ucar.edu/communications/lasers/elnino/

Books

Trenberth, K. E., 1988: "Global temperature trends." In *Ozone Depletion, Greenhouse Gases, and Climate Change*, National Academy Press, Washington, D.C., 85–97.

Trenberth, K. E., 1989: TOGA and atmospheric processes. *Understanding Climate Change*, Proc. of IUGG Symp. 15, Geophys. Monogr. No. 52, IUGG Vol. 7. A. Berger, R. E. Dickinson, and J. W. Kidson (Eds). Amer. Geophys. Union, Washington, D.C. 117–125.

Trenberth, K. E., and J. G. Olson, 1991: Representativeness of a 63-station network for depicting climate changes. DOE Workshop, 8–12 May 1989, Amherst, Mass. *Greenhouse-Gas-Induced Climate Change: A Critical Appraisal of Simulations and Observations*, Elsevier, M. Schlesinger, Ed., 615 pp., 249–260.

Trenberth, K. E., 1991: Recent climate changes in the Northern Hemisphere. DOE Workshop, 8–12 May 1989, Amherst, Mass. In *Greenhouse-Gas-Induced Climate Change: A Critical Appraisal of Simulations and Observations*, Elsevier, M. Schlesinger, Ed., 615 pp., 377–390.

Trenberth, K. E., et al., 1991: Observations. Report by Working Group I: DOE Workshop, 8–12 May 1989, Amherst, Mass. In *Greenhouse-Gas-Induced Climate Change: A Critical Appraisal of Simulations and Observations*, Elsevier, M. Schlesinger, Ed., 615 pp., 571–582.

Trenberth, K. E., 1991: General characteristics of El Niño–Southern Oscillation. Chapter 2 of *ENSO Teleconnections Linking Worldwide Climate Anomalies: Scientific Basis and Societal Impact*. M. H. Glantz, R. W. Katz, and N. Nicholls, Editors, Cambridge University Press, 13–42.

Trenberth, K. E., 1991: The science of climate change and climate variability II: The climate record. Proc. of colloquium on *Managing water resources under conditions of climate uncertainty*, 14–16 November 1990. Water Science and Technology Board, NAS. National Academy Press, 47–70.

Trenberth, K. E., Editor, 1992: *Climate System Modeling*. Cambridge University Press, 788pp.

Trenberth, K. E., 1993: Northern hemisphere climate change: Physical processes and observed changes. Chapter 3 of *Earth system responses to global change: Contrasts between North and South America*. Ed. H. A. Mooney, E. R. Fuentes and B. I. Kronberg. Academic Press, 35–59.

Trenberth, K. E., 1993: North-south comparisons: Climate controls. Chapter 5 of *Earth system responses to global change: Contrasts between North and South America.* Ed. H. A. Mooney, E. R. Fuentes and B. I. Kronberg. Academic Press, 71–72.

Trenberth, K. E., and J. W. Hurrell, 1995: Decadal climate variations in the Pacific. *Natural Climate Variability on Decade-to-Century Time Scales.* National Research Council, D. G. Martinson, K. Bryan, M. Ghil, M. M. Hall, T. R. Karl, E. S. Sarachik, S. Sorooshian, and L.D. Talley, Eds. National Academy Press, Washington, D.C., 472–482.

Trenberth, K. E., 2009: An imperative for adapting to climate change: Tracking Earth's global energy. *Current Opinion in Environmental Sustainability*, **1**, 19-27. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B985C-4WXB58T-1&_user=4845034&_coverDate=10%2F31%2F2009&_rdoc=6&_fmt=high&_orig=browse&_srch=doc-info(%23toc%2359095%232009%23999989998%231488174%23FLA%23display%23Volume)&_cdi=59095&_sort=d&_docanchor=&_ct=18&_acct=C000000593&_version=1&_urlVersion=0&_userid=4845034&md5=7865599530a7520fc983d9fcc874cd86

Trenberth, K. E., 1996: Coupled climate system modelling, Chapter 3 of: *Climate Change, Developing Southern Hemisphere Perspectives* Editors: T. Giambelluca and A. Henderson-Sellers. John Wiley & Sons Ltd. 475pp, 63–88.

Trenberth, K. E., 1996: El Niño – Southern Oscillation, Chapter 6 of: *Climate Change, Developing Southern Hemisphere Perspectives* Editors: T. Giambelluca and A. Henderson-Sellers. John Wiley & Sons Ltd. 475pp, 145–173.

Trenberth, K. E., 1996: What is happening to El Niño? *1997 Yearbook of Science and the Future*. Encyclopaedia Britannica, 88–99.

Trenberth, K. E., 1996: What's happening to El Niño? 1996 *Book of the Year* Encyclopaedia Britannica, p 164.

Trenberth, K. E., J. T. Houghton, and L. G. Meira Filho, 1996: The climate system: An overview. Chapter 1 of *Climate Change 1995. The science of Climate Change*. Contribution of WG 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. J.T. Houghton, L.G. Meira Filho, B. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds). Cambridge University Press. 51–64.

Trenberth, K. E. et al., 1996: Technical summary of *Climate Change 1995. The science of Climate Change*. Contribution of WG 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. J.T. Houghton, L.G. Meira Filho, B. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds). Cambridge University Press. 9–49.

Trenberth, K. E., et al. 1997: *CLIVAR. A research programme on climate variability and predictability for the 21st century*. Intl. CLIVAR Proj. Office Rep. 101, WCRP/TD No. 853. 48 pp.

Trenberth, K. E., et al. 1997: Common questions about climate change. WMO, UNEP. 24 pp.

Trenberth, K. E., and C. J. Guillemot, 1998: Estimating evaporation-minus-precipitation as a residual of the atmospheric water budget. Chapter 7.1 of *Global energy and water cycles*. K. Browning and R. Gurney (Eds.), Cambridge University Press. 236–246.

Trenberth, K. E., et al. 1998: *The CLIVAR Initial Implementation Plan*. WCRP 103, WMO/TD 869, ICPO 14, 356 pp.

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EXHIBIT B: LIST OF PUBLICATIONS IN LAST TEN YEARS

As of March 2018, my total publications include 64 books or book chapters, 268 journal articles published, 23 Tech. Notes, 117 proceedings or preprints, and 81 other articles, plus four videos, for a total of 554 publications plus 4 videos, and many blogs. On the Web of Science, I am cited over 33,400 times with an H index of 84 (84 publications have 84 or more citations). On Google Scholar, I am cited > 85,700 times with an ***H index of 110*** (or 73 since 2013).

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"Climate change and wildfires – how do we know if there is a link?"
The Conversation, US Edition 10 August 2018
http://theconversation.com/climate-change-and-wildfires-how-do-we-know-if-there-is-a-link-101304

EXHIBIT C: PREVIOUS TESTIMONY IN PRECEDING FOUR YEARS

November, 2016: I submitted an Amicus Curiae Declaration in support of the *Greenpeace v. Exxon* Petition to The Commission on Human Rights of the Philippines requesting for investigation of the responsibility of the Carbon Majors for human rights violations or threats of violations resulting from the impacts of climate change, Case No.: CHR-NI-2016-0001.

EXHIBIT D: CITATIONS, REFERENCES AND BIBLIOGRAPHY

Data

Some datasets used in our research include:

OHC data are available at http://159.226.119.60/cheng/.

NOAA High Resolution SST data are provided from https://www.esrl.noaa.gov/psd/ by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA.

We use monthly TOA Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Ed. 4.0 radiation on (*Loeb, et al.,* 2009) http://ceres.larc.nasa.gov/order_data.php.

The atmospheric data are the global reanalyses from ECMWF Interim Re-Analysis (ERA-I) (*Dee et al.* 2011) http://data-portal.ecmwf.int/data/d/interim_daily/.

The rainfall data are from GPCP version 1DD (1 degree daily) V1.3. available at https://www.ncei.noaa.gov/data/global-precipitation- climatology-project-gpcp-daily/access/ .

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Exhibit 2

CLIMATE CHANGE

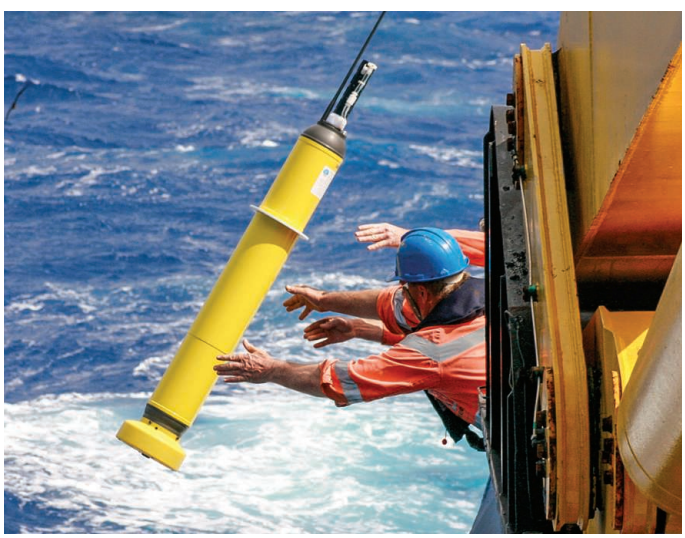
How fast are the oceans warming?

Observational records of ocean heat content show that ocean warming is accelerating

By **Lijing Cheng[1], John Abraham[2], Zeke Hausfather[3], Kevin E. Trenberth[4]**

Climate change from human activities mainly results from the energy imbalance in Earth's climate system caused by rising concentrations of heat-trapping gases. About 93% of the energy imbalance accumulates in the ocean as increased ocean heat content (OHC). The ocean record of this imbalance is much less affected by internal variability and is thus better suited for detecting and attributing human influences (*1*) than more commonly used surface temperature records. Recent observation-based estimates show rapid warming of Earth's oceans over the past few decades (see the figure) (*1*, *2*). This warming has contributed to increases in rainfall intensity, rising sea levels, the destruction of coral reefs, declining ocean oxygen levels, and declines in ice sheets; glaciers; and ice caps in the polar regions (*3*, *4*). Recent estimates of observed warming resemble those seen in models, indicating that models reliably project changes in OHC.

The Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5), published in 2013 (*4*), featured five different time series of historical global OHC for the upper 700 m of the ocean. These time series are based on different choices for data processing (see the supplementary materials). Interpretation of the results is complicated by the fact that there are large differences among the series. Furthermore, the OHC changes that they showed were smaller than those projected by most climate models in the Coupled Model Intercomparison Project 5 (CMIP5) (*5*) over the period from 1971 to 2010 (see the figure).



Scientists deploy an Argo float. For over a decade, more than 3000 floats have provided near-global data coverage for the upper 2000 m of the ocean.

Since then, the research community has made substantial progress in improving long-term OHC records and has identified several sources of uncertainty in prior measurements and analyses (*2*, *6*–*8*). In AR5, all OHC time series were corrected for biases in expendable bathythermograph (XBT) data that had not been accounted for in the previous report (AR4). But these correction methods relied on very different assumptions of the error sources and led to substantial differences among correction schemes. Since AR5, the main factors influencing the errors have been identified (*2*), helping to better account for systematic errors in XBT data and their analysis.

Several studies have attempted to improve the methods used to account for spatial and temporal gaps in ocean temperature measurements. Many traditional gap-filling strategies introduced a conservative bias toward low-magnitude changes (*9*). To reduce this bias, Domingues *et al.* (*10*) used satellite altimeter observations to complement the sparseness of in situ ocean observations and update their global OHC time series since 1970 for the upper 700 m. Cheng *et al.* (*2*) proposed a new gap-filling method that used multimodel simulations to provide an improved prior estimate and error covariance. This method allowed propagation of information from data-rich regions to the data gaps (data are available for the upper 2000 m since 1940). Ishii *et al.* (*6*) completed a major revision of their estimate in 2017 to account for the previous underestimation and also extended the analysis down to 2000 m and back to 1955. Resplandy *et al.* (*11*) used ocean warming outgassing of O_2 and CO_2, which can be isolated from the direct effects of anthropogenic emissions and CO_2 sinks, to independently estimate changes in OHC over time after 1991.

These recent observation-based OHC estimates show highly consistent changes since the late 1950s (see the figure). The warming is larger over the 1971–2010 period than reported in AR5. The OHC trend for the upper 2000 m in AR5 ranged from 0.20 to 0.32 W m^{-2} during this period (*4*). The three more contemporary estimates that cover the same time period suggest a warming rate of 0.36 ± 0.05 (*6*), 0.37 ± 0.04 (*10*), and 0.39 ± 0.09 (*2*) W m^{-2}. [Note that the analysis in Domingues *et al.* (*10*) is combined with that in Levitus *et al.* (*12*) for 700 to 2000 m to produce a 0 to 2000 m time series.] All four recent studies (*2*, *6*, *10*, *11*) show that the rate of ocean warming for the upper 2000 m has accelerated in the decades after 1991 to 0.55 to 0.68 W m^{-2} (calculations provided in the supplementary materials).

Multiple lines of evidence from four independent groups thus now suggest a stronger observed OHC warming. Although climate model results (see the supplementary materials) have been criticized during debates about a "hiatus" or "slowdown" of global mean surface temperature, it is increasingly clear that the pause in surface warming was at least in part due to the redistribution of heat within the climate system from Earth surface into the ocean interiors (*13*). The recent OHC warming estimates (*2*, *6*, *10*, *11*) are quite similar to the average of CMIP5 models, both for the late 1950s until present and during the 1971–2010 period highlighted in AR5 (see the figure). The ensemble average of the models has a linear ocean warming trend of 0.39 ± 0.07 W m^{-2} for the upper 2000 m

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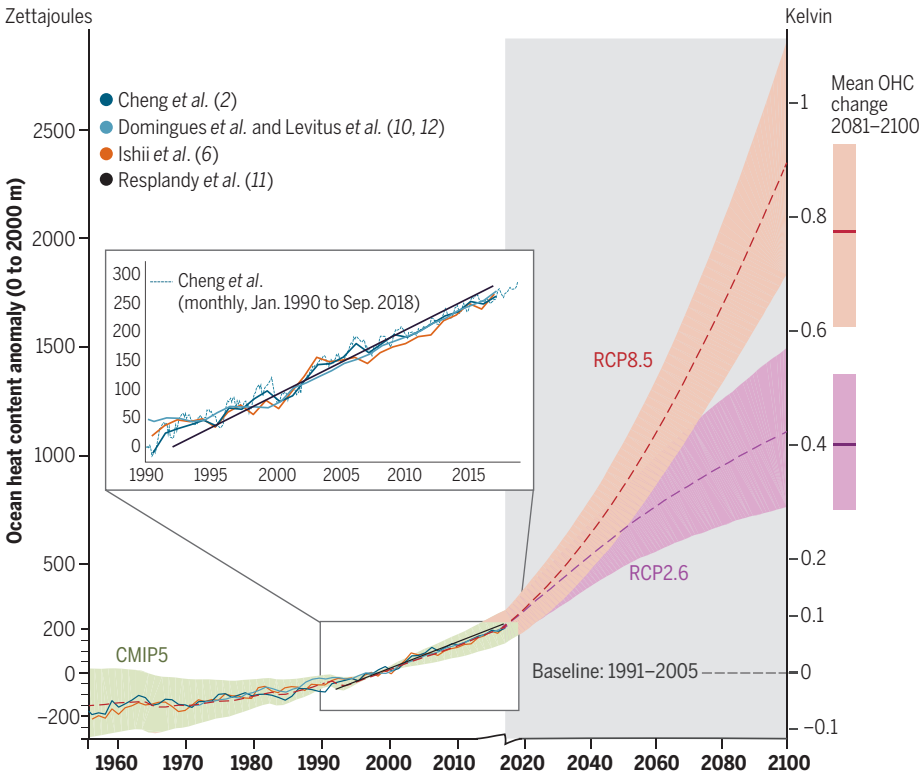
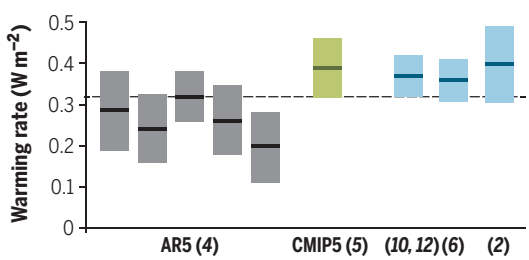
Past and future ocean heat content changes

Annual observational OHC changes are consistent with each other and consistent with the ensemble means of the CMIP5 models for historical simulations pre-2005 and projections from 2005–2017, giving confidence in future projections to 2100 (RCP2.6 and RCP8.5) (see the supplementary materials). The mean projected OHC changes and their 90% confidence intervals between 2081 and 2100 are shown in bars at the right. The inset depicts the detailed OHC changes after January 1990, using the monthly OHC changes updated to September 2018 [Cheng *et al*. (*2*)], along with the other annual observed values superposed.





Updated OHC estimates compared with AR5. The three most recent observation-based OHC analyses give ocean warming rates (depths from 0 to 2000 m) for 1971 to 2010 that are closer to model results than those reported in AR5. This increases confidence in the model projections (see the supplementary materials for more detail). The error bars are 90% confidence intervals.

from 1971–2010 compared with recent observations ranging from 0.36 to 0.39 W m^{-2} (see the figure).

The relatively short period after the deployment of the Argo network (see the photo) in the early 2000s has resulted in superior observational coverage and reduced uncertainties compared to earlier times. Over this period (2005–2017) for the top 2000 m, the linear warming rate for the ensemble mean of the CMIP5 models is 0.68 ± 0.02 W m^{-2}, whereas observations give rates of 0.54 ± 0.02 (*2*), 0.64 ± 0.02 (*10*), and 0.68 ± 0.60 (*11*) W m^{-2}. These new estimates suggest that models as a whole are reliably projecting OHC changes.

However, some uncertainties remain, particularly for deep and coastal ocean regions and in the period before the deployment of the Argo network. It is important to establish a deep ocean observation system to monitor changes below 2000 m (*14*). It is also essential to improve the historical record, for example, by recovering undigitized OHC observations.

Simulations of future climate use a set of scenarios or plausible radiative forcing pathways based on assumptions about demographic and socioeconomic development and technological changes (*5*). Two scenarios shown in the figure project a substantial warming in the 21st century. For the Representative Concentration Pathways (RCP) 2.6 scenario, the models project an ocean warming (0 to 2000 m) of 1037 zettajoules (ZJ) (~0.40 K) at the end of the 21st century (mean of 2081–2100 relative to 1991–2005); this pathway is close to the Paris Agreement goal of limiting global warming to well below 2°C. For the RCP8.5 scenario, a business-as-usual scenario with high greenhouse gas emissions, the models project a warming of 2020 ZJ (~0.78 K). This level of warming would have major impacts on ocean ecosystems and sea level rise through thermal expansion; 0.78 K warming at 2100 is roughly equal to a sea level rise of 30 cm. This is in addition to increased sea level rise caused by land ice melt.

The fairly steady rise in OHC shows that the planet is clearly warming. The prospects for much higher OHC, sea level, and sea-surface temperatures should be of concerngiven the abundant evidence of effects on storms, hurricanes, and the hydrological cycle, including extreme precipitation events (*3*, *15*). There is a clear need to continue to improve the ocean observation and analysis system to provide better estimates of OHC, because it will enable more refined regional projections of the future. In addition, the need to slow or stop the rates of climate change and prepare for the expected impacts is increasingly evident. ■

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SUPPLEMENTARY MATERIALS

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Science

How fast are the oceans warming?

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