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8   UNITED STATES DISTRICT COURT

9   NORTHERN DISTRICT OF CALIFORNIA

10   SAN FRANCISCO DIVISION

11

12	THE PEOPLE OF THE STATE OF CALIFORNIA,	Case No. C 17-06011 WHA Case No. C 17-06012 WHA
13		
14	Plaintiff,	Hearing Date: March 21, 2018 at 8:00 a.m.
15	v.	**ADMINISTRATIVE MOTION OF WILLIAM HAPPER, STEVEN E. KOONIN, AND RICHARD S. LINDZEN FOR LEAVE TO SUBMIT PRESENTATION IN RESPONSE TO THE COURT'S TUTORIAL QUESTIONS**
16	B.P. P.L.C., *et al.*,	
17	Defendants.	
18		The Honorable William H. Alsup

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1   The Court has invited a tutorial on global warming and climate change, which is set to occur

2 March 21, 2018. The Court also identified specific questions to be addressed at the tutorial. Pursuant

3 to Civil L.R. 7-11, Professors William Happer, Steven E. Koonin, and Richard S. Lindzen respectfully

4 ask the Court to accept their presentation (attached to this motion as Exhibit A) in response to the

5 Court's questions. The professors would be honored to participate directly in the tutorial if the Court

6 desires.

7   A.   Identity of the Filing Parties

8   The professors are accomplished and well-credentialed scientists. William Happer is the Cyrus

9 Fogg Bracket Professor of Physics Emeritus at Princeton University. Dr. Happer also has extensive

10 experience advising the government on energy research and policy, having served President George

11 H.W. Bush's administration as the director of energy research in the Department of Energy. Steven E.

12 Koonin is the founding director of New York University's Center for Urban Science and Progress. Dr.

13 Koonin previously served as the second Under Secretary for Science at the U.S. Department of Energy

14 in President Barack Obama's administration. In this role, Dr. Koonin oversaw science, energy, and

15 security activities. Richard S. Lindzen is a Professor Emeritus in the Department of Earth,

16 Atmospheric, and Planetary Sciences at the Massachusetts Institute of Technology. Dr. Lindzen's

17 research involves studies of the role of the tropics in mid-latitude weather and global heat transport,

18 the moisture budget and its role in global change, the origins of ice ages, seasonal effects in atmospheric

19 transport, stratospheric waves, and the observational determination of climate sensitivity. Each of the

20 professors has been elected to the prestigious National Academy of Sciences, a highly selective non-

21 profit organization recognizing the country's most distinguished researchers. Biographies for the

22 professors appear at the end of Exhibit A to this motion.

23   B.   The Presentation Would Provide Unique Information and Perspective

24   District courts have the inherent authority to accept amicus curiae materials. *See In re Bayshore*

25 *Ford Truck Sales, Inc.*, 471 F.3d 1233, 1249 n. 34 (11th Cir. 2006). District courts "frequently welcome

26 amicus submissions from non-parties concerning legal issues that have potential ramifications beyond

27 the parties directly involved or if the amicus has unique information or perspective that can help the

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2   ADMIN. MOTION FOR LEAVE TO
SUBMIT TUTORIAL PRESENTATION
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Case No.: C 17-06012-WHA

court beyond the help the lawyers for the parties are able to provide." *NGV Gaming, Ltd. v. Upstream Point Molate, LLC*, 355 F.Supp.2d 1061, 1067 (N.D. Cal. 2005) (internal quotation omitted). Here, the results of this case could be far-reaching—with potential national impact.   As active and longstanding members of the scientific community, the professors are particularly well qualified to assist the Court and address the concerns the Court has raised in its Notice of the Tutorial.

The Court has asked for information on: (1) the history of scientific study of climate change, and (2) the best science now available on global warming, glacier melt, sea rise, and coastal flooding. *See* Notice re Tutorial, Dkt. 135. The Court also identified nine specific areas of inquiry: (1) the cause of the various ice ages and the resulting rise in sea level; (2) the molecular difference by which CO_2 absorbs infrared radiation but oxygen and nitrogen do not; (3) the mechanism by which infrared radiation trapped by CO_2 in the atmosphere is turned into heat and finds its way back to sea level; (4) whether CO_2 in the atmosphere reflects sunlight back into space; (5) the effect of the collective heat from tail pipe exhausts, engine radiators, and other heat from the combustion of fossil fuels; (6) the relationship between human respiration and the buildup of CO_2 and whether plant life absorbs the CO_2 humans emit; (7) the main sources of CO_2 that account for the incremental buildup of CO_2 in the atmosphere; (8) the main sources of heat that account for the incremental rise in temperature on Earth; and (9) the GCC and GCSCT presentations referred to in the Complaint. *See* Some Questions for the Tutorial, Dkt. 138.

The Court's specified questions include topics that have been the subject of the professors' study and analysis for decades. These men have been thought and policy leaders in the scientific community and in the administrations of two different U.S. Presidents. They have extensive research experience with the specific issues the Court identified. As such, they offer a valuable perspective on these issues.

The attached presentation contains three sections: (1) an overview; (2) responses to the Court's questions; and (3) biographies of the professors. The short overview section makes the following points: (1) the climate is always changing; changes like those of the past half-century are common in the geologic record, driven by powerful natural phenomena; (2) human influences on the climate are a

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ADMIN. MOTION FOR LEAVE TO
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Case No.: C 17-06011-WHA
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1 small (1%) perturbation to natural energy flows; (3) it is not possible to tell how much of the modest

2 recent warming can be ascribed to human influences; and (4) there have been no detrimental changes

3 observed in most salient climate variables and projections of future changes are highly uncertain. The

4 second section carefully goes through each of the questions the Court has raised.

5   Accordingly, Professors William Happer, Steven E. Koonin, and Richard S. Lindzen

6 respectfully request that the Court accept for consideration their attached presentation. They also are

7 available to participate in the tutorial if the Court desires.

8

9 DATED: March 19, 2018   ILLOVSKY LAW OFFICE
                                           EUGENE ILLOVSKY
10

11   By: /s/   *Eugene Illovsky*
                                               Eugene Illovsky
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13   Attorneys for *Amicus Curiae*
                                           William Happer, Steven E. Koonin,
14   and Richard S. Lindzen

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4   ADMIN. MOTION FOR LEAVE TO
                     SUBMIT TUTORIAL PRESENTATION
                                Case No.: C 17-06011-WHA
                                Case No.: C 17-06012-WHA

EXHIBIT A

March 19, 2018

The Honorable Judge William H. Alsup
United States District Court
Northern District of California

Your Honor:

We write to offer a presentation in response to your request for a tutorial on the best science available on global warming and climate change. We appreciate your willingness to dig more deeply into technical issues, since wise societal decisions require an understanding of this complex and nuanced subject.

As independent senior scientists and educators long involved in climate matters, we are well-positioned to offer a clear and informed perspective on what is known, and unknown, about the earth's changing climate. During our individual careers, we have provided scientific advice on diverse complex decisions, always striving to be dispassionate and "call it like we see it." That ethos not only best informs decisions, which must consider the science in the context of many other factors, but also preserves the integrity of science, preventing its degradation by bias or agenda.

Upon hearing of your request for a tutorial, we three came together spontaneously with the goal of providing such advice. You will find that our presentation, while crafted for this purpose, is consistent with our past publications. None of us has received any compensation for the considerable effort expended in its preparation.

Our brief consists of three sections. Section I is a tutorial overview of climate science, covering the most essential concepts and results and highlighting fundamental problems with the claimed scientific "consensus." Section II provides detailed answers to the eight specific questions you asked that the tutorial cover; we appreciate that these questions focus attention on the underlying basics, an essential foundation for evaluating derivative claims. Finally, Section III contains our biographical sketches.

We appreciate your willingness to consider our input, and we would, of course, be happy to provide any further information you might find useful.

Respectfully,

Dr. William Happer   Dr. Steven E. Koonin   Dr. Richard S. Lindzen
Princeton University   New York University   Massachusetts Institute
                                                                     of Technology

## Section I: Climate science overview

Our overview of climate science is framed through four statements:

1. **The climate is always changing; changes like those of the past half-century are common in the geologic record, driven by powerful natural phenomena**
2. **Human influences on the climate are a small (1%) perturbation to natural energy flows**
3. **It is not possible to tell how much of the modest recent warming can be ascribed to human influences**
4. **There have been no detrimental changes observed in the most salient climate variables and today's projections of future changes are highly uncertain**

We offer supporting evidence for each of these statements drawn almost exclusively from the Climate Science Special Report (CSSR) issued by the US government in November, 2017 or from the Fifth Assessment Report (AR5) issued in 2013-14 by the UN's Intergovernmental Panel on Climate Change or from the refereed primary literature.

1. The climate is always changing; changes like those of the past half-century are common in the geologic record, driven by powerful natural phenomena

The graph below (CSSR Figure ES.1) shows the globe's warming during the past 130 years as measured directly by surface instruments.   The left panel shows changes in the anomaly of the global surface temperature. The annual average temperature anomaly has increased by more than 1.6° F (0.9 C) for the period 1986–2015 relative to 1901–1960. [Red bars show temperatures that were above the 1901–1960 average, and blue bars indicate temperatures below the average.]
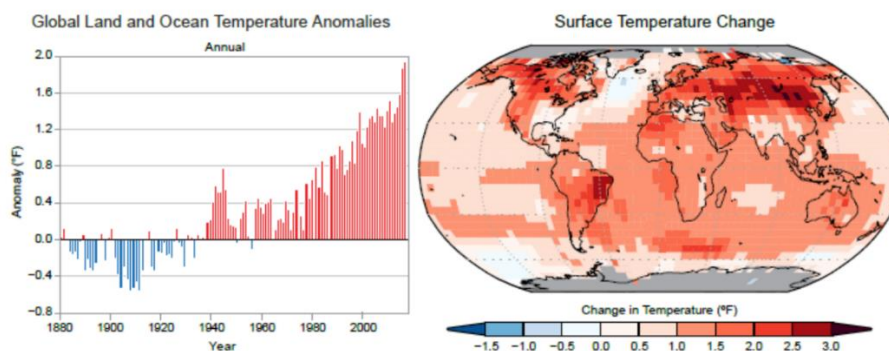

The CSSR's right hand map shows that the warming has been strongest over the land in the Northern Hemisphere and greater toward the pole. As can be found in other CSSR figures, there are other suggestions of modest warming in recent decades, including growing heat in the oceans, rising sea levels, shrinking Artic ice, shrinking glaciers, and a more humid atmosphere.

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The story, however, is more complex than might be inferred from the figure. To a scientist looking at the left-hand panel, a few things stand out. First, there are no uncertainty bars, an unfortunately common practice in representations of climate change; it turns out that the uncertainties are 0.2F (0.1C) in recent decades, increasing to about twice that in the earliest parts of the record. Second, much of the seemingly alarming rise in the last few years is due to an El Nino condition, as was also present during the 1998 temperature spike. Finally, the rise in the temperature anomaly is not smooth on the few-decade scale. For example, it was actually decreasing from about 1940-1970. As human influences were significant only after about 1950, the graph suggests that the climate is quite capable of varying significantly on its own.

To buttress that point, consider the longer-term geologic record depicted schematically in the following figure, which shows more directly that the global temperature anomaly has changed dramatically over
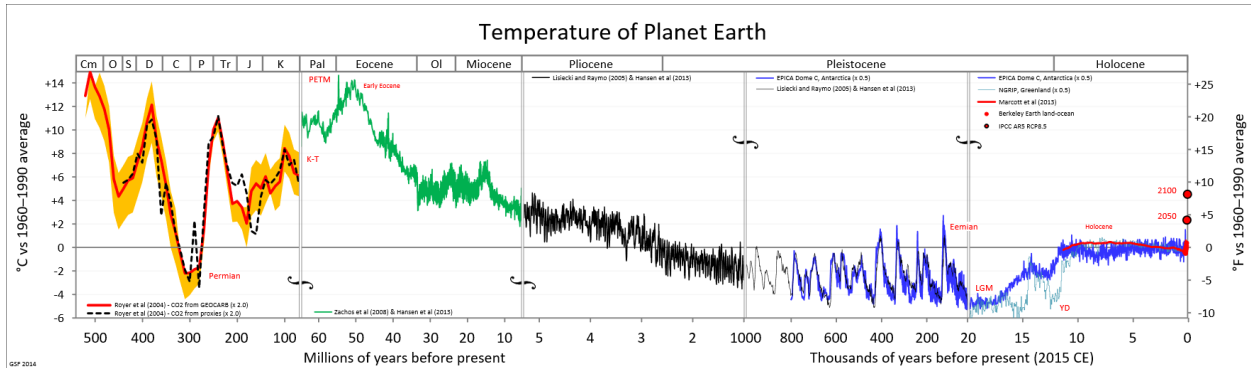
the past 500 million years (only 10% of the earth's history!). There has been significant warming over the past 20,000 years (blue line) since the end of the last glaciation and 120,000 years ago there was an interglacial period (the Eemian) when it was the 2C warmer than today and the sea level was 6 meters higher. Over the past million years, there has been a succession of warm and cold periods driven largely by variations in the earth's orbit and orientation, with even larger temperature rises over the past 100 million years. The two red dots on the right show notional projected temperature rises at 2050 and 2100 due to human influences. We discuss the reliability of those projections below.
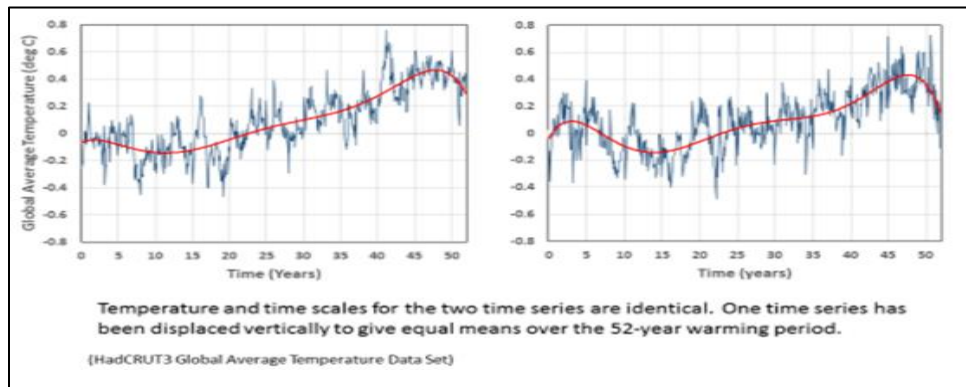

Even within the instrumental record, the warming of the past four decades is not unusual, as illustrated in the adjacent figure, which compares two 50-year periods, one from the early 20th century where human influences were minimal, and one from the latter 20th century, where they were much stronger. It is difficult to tell them apart, as the rates and magnitudes of warming were comparable. [The left-hand panel is the more recent data showing the 1998 El Nino spike at year 42.]

2. Human influences on the climate are a small (1%) perturbation to natural energy flows

To characterize and quantify human influences, we need to look at the energy flows in the climate system, as depicted in the following figure (CSSR Figure 2.1):
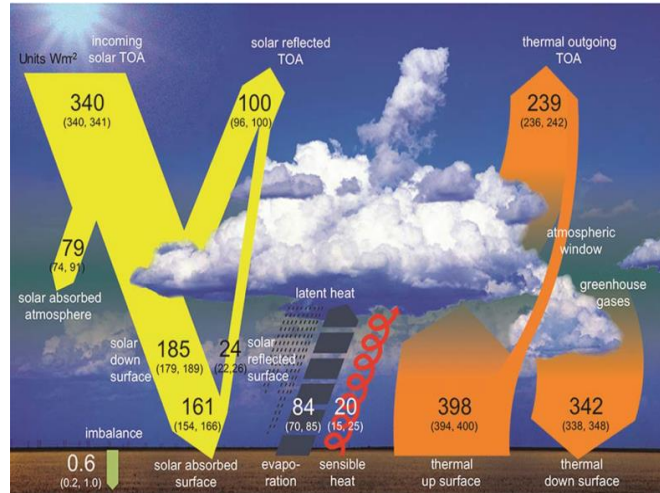
The earth's climate system is a giant heat engine, reflecting about 30% of the incoming sunlight, absorbing the rest, and then radiating an almost equal amount back into space as heat, driving the winds, precipitation, and ocean currents in the process. Note that the natural energy flows are measured in 100's of W/m^2 (Watts per square meter) and, as shown in the lower left-hand corner, there is a claimed net imbalance of 0.6 [0.2, 1.0] W/m^2 warming the planet.

The chart below (CSSR Figure 2.3) shows how human influences on the climate have grown since 1750. The units are W/m^2, commensurate with the energy flow graphic above. Carbon dioxide, which is accumulating in the atmosphere largely due to fossil fuel use, exerts the strongest warming influence, although small compared to the natural energy flows. Methane and other well-mixed greenhouse gases (WMGHG) are also important.
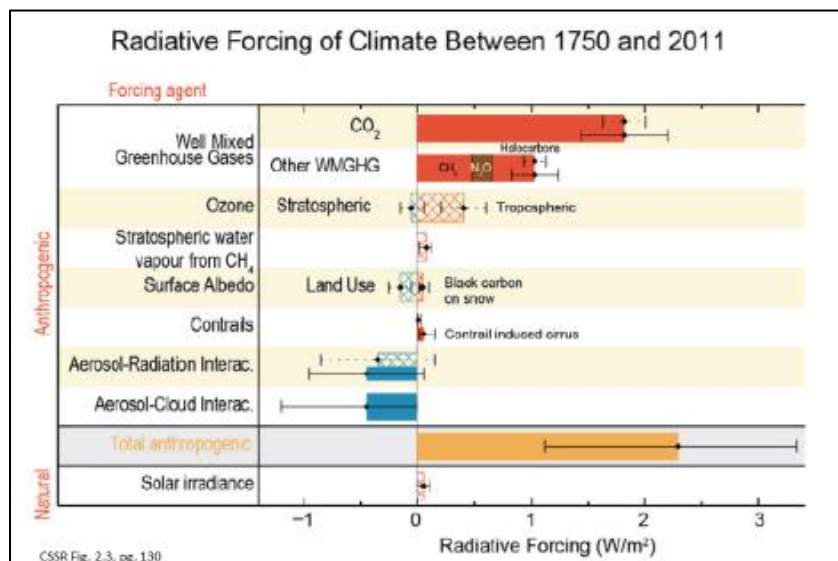
The largest anthropogenic cooling influences are associated with aerosols; they are quite uncertain. Changes in the solar irradiance over the past 250 years are shown to be negligible.

The bottom of the chart above shows that total human influence is currently some 2.3 W/m^2, or less than 1% of the natural energy flows in the system. Isolating and predicting the effects of such a physically small influence in a chaotic, noisy system where we have limited observations is not an easy task. Not only must we have the large parts of the system understood to high precision, but we also have to be sure we've accounted for all of the other phenomena operating at the 1% level.

3. It is not possible to tell how much of the modest recent warming can be ascribed to human influences

General Circulation Models (GCMs) of the climate system are important tools for attributing observed changes in the climate system.   Here, the earth is covered with a 3-dimensional grid, typically 100 × 100 km in the atmosphere and 10 × 10 km oceans, with 10-20 vertical layers and up to 30 vertical layers, respectively. The air, water, momentum, and energy are transported through the grid boxes using the basic laws of physics under imposed forcings (e.g., the sun, aerosol loading) with a time step as small as 30 minutes. The results of computer runs extending over centuries are compared with both average and historical climate properties to validate the models.
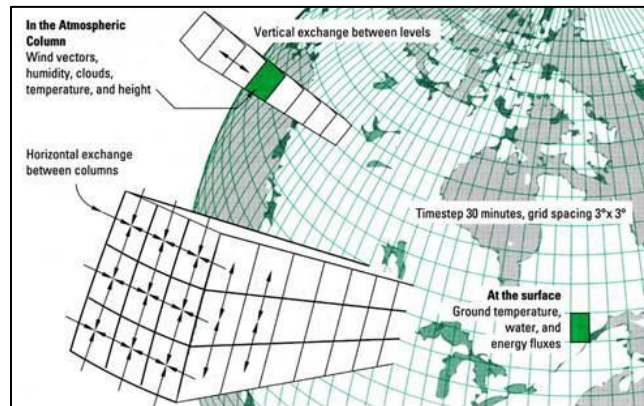

This sounds straightforward in principle, but it is in fact fraught with difficulty. One major challenge is that there are many important weather phenomena that occur on scales far smaller than the grid size (*e.g.,* topography, clouds, storms) and so the modeler must make assumptions about these "sub grid-scale" processes to build a complete model. For example, given the temperature and humidity profiles of the atmosphere in a grid box, "How high, how many, and of what type are the clouds?" While these sub-grid-scale parametrizations can be based upon observations of weather phenomena, there is still considerable judgment in their formulation. So the models are not, as one often hears, "just physics" since the parameters in each must be "tuned" to reproduce aspects of the observed climate.

A second major problem is that there is no unique tuning that reproduces the historical climate data. Since aerosol cooling plays against GHG warming, a model with low aerosol and GHG sensitivities can reproduce the data as well as a model with high sensitivities. As a result, the GHG sensitivity is today uncertain by a factor of three (as it has been for forty years), therefore enlarging the uncertainty in any projection of future climates.

A third problem is that the models must reproduce the natural variabilities of the climate system, which we've seen are comparable to the claimed anthropogenic changes. Climate data clearly show coherent behaviors on multi-annual, multi-decadal, and multi-centennial timescales, at least some of which are due to changes in ocean currents and the interaction between the ocean and the atmosphere. Not knowing the state of the ocean decades or centuries ago makes it difficult to correctly choose the model's starting

point. And even if that were possible, there is no guarantee that the model will show the correct variability at the correct times.

Despite these problems, the IPCC pushes on, averaging model results over an indiscriminately assembled "ensemble of opportunity" comprised of some 50 different models from different research groups around the world. These models give results that differ dramatically both from each other and from observations on the scales required to measure the response to human influences. This proliferation of discordant models is further evidence that they are not "just physics".
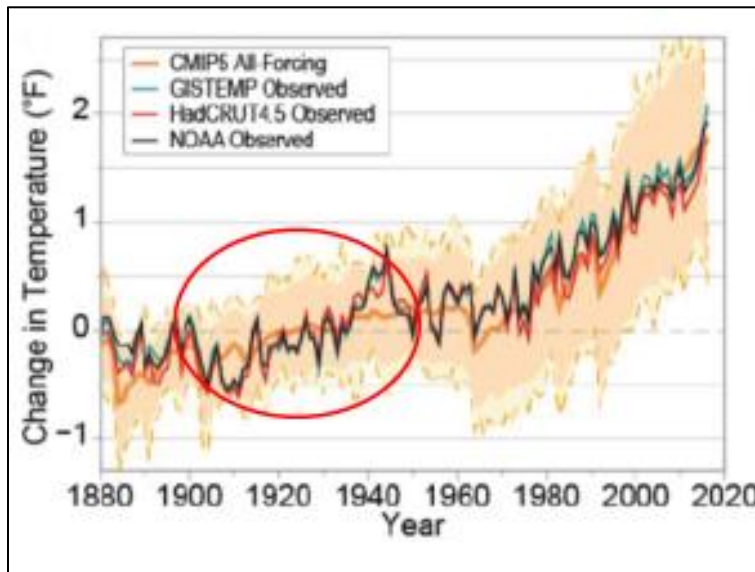
This figure (CSSR Figure 3.1; red circle added) shows a comparison of observed global mean temperature anomalies from three observational datasets to results from the CMIP5 [Climate Model Intercomparison Project, version 5] model ensemble. The thick orange curve is the CMIP5 ensemble mean across 36 models while the orange shading and outer dashed lines depict the ± 2 standard deviation and absolute ranges of annual anomalies across all individual simulations of the 36 models. All time series are referenced to a 1901–1960 baseline value. Note in particular that while the model mean does a fair job of reproducing the record over the past few decades, it fails entirely during the time from 1910-1940 (red circle) where the data warm at a rate several times the model mean.

Similar data-model comparisons for other climate variables, both global and regional, also show their own problems. Indeed, as the CSSR states (pg 58) in discussing the role of human influences on the climate:

> *Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to observe these changes at sufficient resolution and to simulate and attribute such changes using climate models.*

4. There have been no detrimental changes observed in the most salient climate variables and today's projections of future changes are highly uncertain

Here is what IPCC says about changes in various weather extremes observed over the past decades. These bullets do not constitute "cherry picking", as each is a modest paraphrase of the text summarizing the discussion in AR5 (WGI, Chapter 2) of a particular weather phenomenon.

- …since about 1950 it is ***very likely*** that the **numbers of cold days and nights have decreased and the numbers of warm days and nights have increased** … there is ***medium confidence*** that globally the length and frequency of **warm spells, including heat waves**, has increased since the middle of the 20th century

- … *likely* that since 1951 **increases in the number of heavy precipitation events** in more regions than there have been decreases, but there are strong regional and subregional variations

- … *low confidence* regarding the sign of trend **in** the magnitude and/or frequency of **floods** on a global scale.

- *… low confidence* in a global-scale trend in **drought or dryness** since the middle of the 20th century,

- *…low confidence* in trends in **small-scale severe weather phenomena** such as hail and thunderstorms

- *… low confidence* in any **long term (centennial) increases in tropical cyclone activity,** … *virtually certain* **increase** in the frequency and intensity of the **strongest tropical cyclones since the 1970s** in the North Atlantic.

- … *low confidence* in large scale changes in the **intensity of extreme extratropical cyclones** since 1900

Contrary to the impression from most media reporting and political discussions, the historical data (and the IPCC assessment) do not convey any sense that weather extremes are becoming more common globally.

Heat waves: The most definitive of the IPCC statements on weather extremes concerns temperatures, and even here the story is not so simple. Consider the figure below (CSSR Figure 6.3) documenting temperature extremes in the US. [Even though the contiguous US is only 1.6% of the earth's surface, it is among the most densely instrumented regions and has one of the longest data records.]
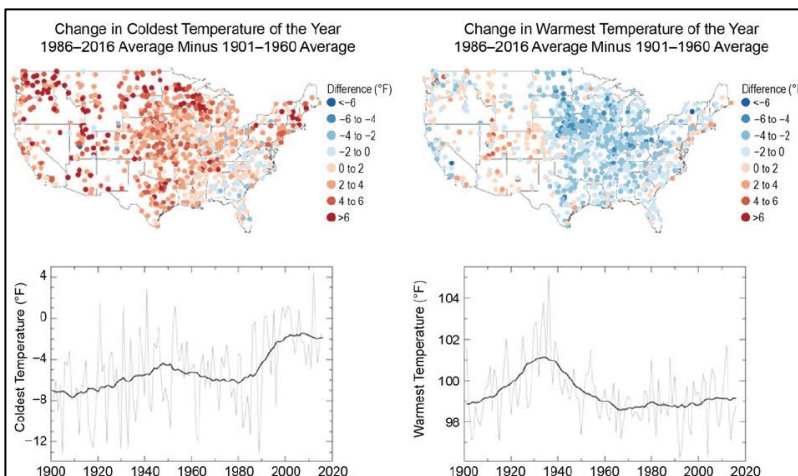
Caption: Observed changes in the coldest and warmest daily temperatures of the year in the contiguous United States. Maps (top) depict changes at stations; changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960). Time series (bottom) depict the area-weighted average for the contiguous United States. Estimates are derived from long-term stations with minimal missing data in the Global Historical Climatology Network – Daily dataset (Menne *et al*. 2012). (Figure source: NOAA/NCEI).

While the coldest temperatures have been rising, the warmest temperatures have not, and have actually gotten cooler over the eastern half of the country. Taken as a whole, the average climate is becoming "milder" across most of the United States. Very recent work attributes the lack of rising temperatures across the eastern half of the country to agricultural intensification: denser plant growth and rising CO_2 levels release more moisture, which both cools the air and increases the amount of rainfall.
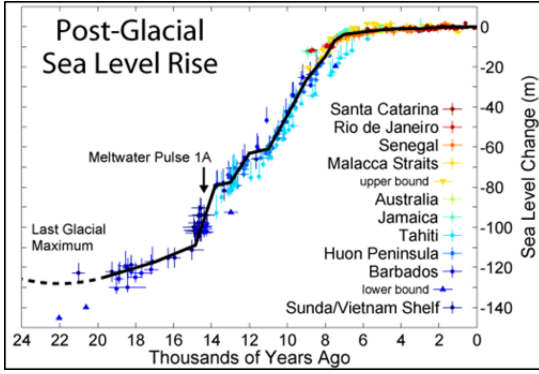
Sea level rise: As shown in the adjacent chart, sea levels began rising some 20,000 years ago at the end of the last glacial maximum. They rose some 120 meters until about 7,000 years ago, after which the rate of rise slowed dramatically.
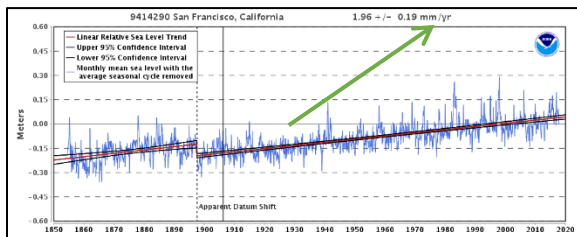
To best assess whether human influences are causing sea level rise to accelerate, we must look at the past century of data, which is available from tide gauges around the globe. Three analyses are shown in the left-hand figure below; these analyses must correct the raw data for the local rising or falling of the coast at each site. The data show that global sea level has risen by some 200 mm since 1900, or an average rate of 1.8 mm/yr, although with considerable decadal-scale variability. Sea level has also been measured by satellite altimetry since 1993; detection of acceleration in that short record remains controversial.
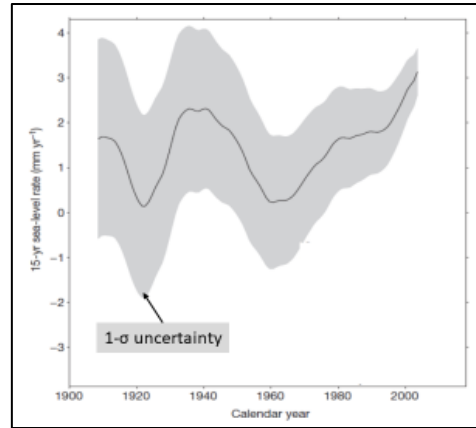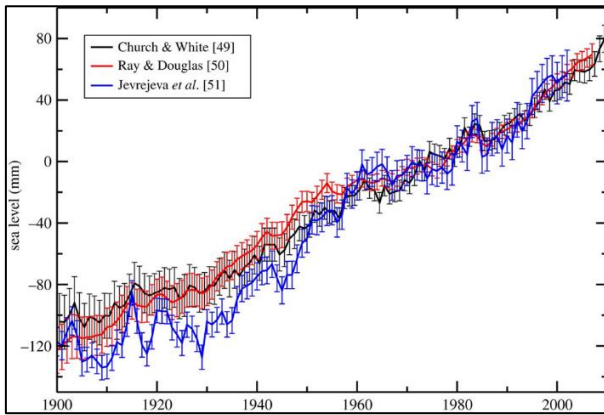
A signature of human impacts on sea level would be an increase in the rate of rise after about 1950, when human influences started to become significant. Such a signature is not evident in the rate over the past century, as shown in the right-hand figure above (adapted from the reference cited by the CSSR); in fact, the acceleration post-1990 is not statistically different from the (presumably natural) acceleration experienced during the 1930s. Given the observed variation prior to 1950 and the steady quadrupling of human influences since 1950, one must conclude there are other important drivers of sea level rise beyond CO_2.
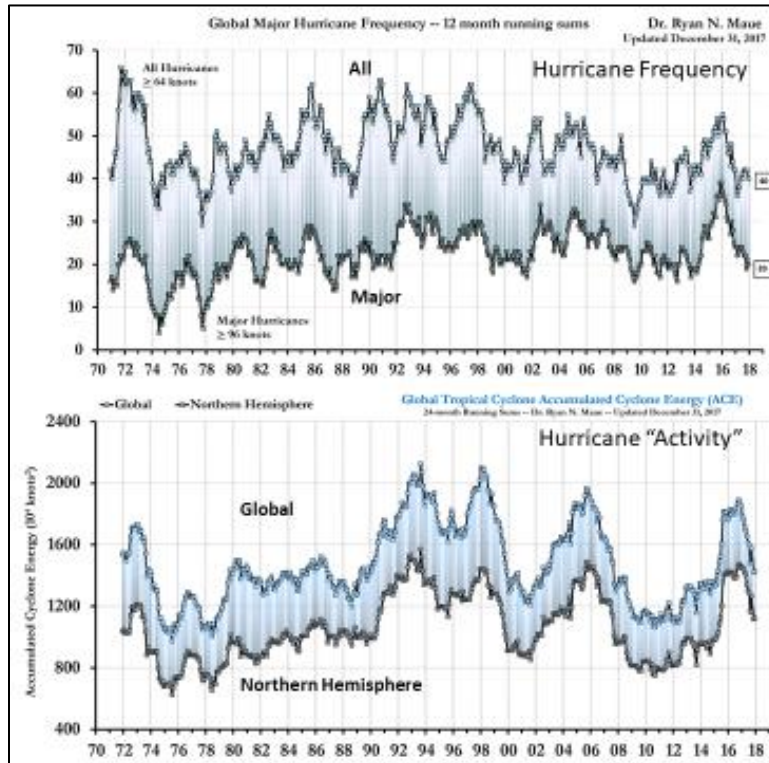
Consensus projections of global sea level rise through 2100 are remarkably discordant with local

observations. The figure below shows the NOAA record of monthly mean sea level (corrected for seasonal variation) as measured at the San Francisco station. Apart from obvious shifts due to station movement, the record shows a steady rise at some 2 mm/year. To realize a 1 meter rise by 2100, roughly the mean of IPCC projections, sea level would have to rise *six* times more rapidly (12 mm/yr) averaged over the rest of this century, a slope illustrated by the green arrow.

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Tropical cyclones: Another weather phenomenon of concern are the storms termed "hurricanes" in the Atlantic and "typhoons" in the Pacific. The adjacent chart summarizes data on the number and strength of these storms, which include the recent active North Atlantic 2017 season (even so, hurricanes Harvey and Irma were not even among the Top 10 most intense recorded hurricanes). The upper figure shows 12-month running sums of the Global Hurricane Frequency (for all and for major storms). The top time series is the number of global tropical cyclones that reached at least hurricane-force (maximum lifetime wind speed exceeds 64-knots). The bottom time series is the number of global tropical cyclones that reached major hurricane strength (96-knots+).

The lower figure shows the last four decades of 24 month running sums of Global and Northern Hemisphere Accumulated Cyclone Energy (ACE). ACE is a measure of aggregate storm intensity (each storm is weighted by the square of its wind velocity). Note that the year indicated represents the value of ACE through the previous 24-months for the Northern Hemisphere (bottom line/gray boxes) and the entire global (top line/blue boxes). The area in between represents the Southern Hemisphere total ACE.

Despite considerable multi-year variability in these data, there is no clear trend. In fact, NOAA's Geophysical Fluid Dynamics Laboratory posted the following statement in Spring, 2016:

> "It is premature to conclude that human activities–and particularly greenhouse gas emissions that cause global warming–have already had a detectable impact on Atlantic hurricane or global tropical cyclone activity. …"

Overview summary

To summarize this overview, the historical and geological record suggests recent changes in the climate over the past century are within the bounds of natural variability. Human influences on the climate (largely the accumulation of CO_2 from fossil fuel combustion) are a physically small (1%) effect on a complex, chaotic, multicomponent and multiscale system. Unfortunately, the data and our understanding are insufficient to usefully quantify the climate's response to human influences. However, even as human influences have quadrupled since 1950, severe weather phenomena and sea level rise show no significant trends attributable to them. Projections of future climate and weather events rely on models demonstrably unfit for the purpose. As a result, rising levels of CO_2 do not obviously pose an immediate, let alone imminent, threat to the earth's climate.

Section II: Answers to specific questions

Question 1: What caused the various ice ages (including the "little ice age" and prolonged cool periods) and what caused the ice to melt? When they melted, by how much did sea level rise?

The discussion of the major ice ages of the past 700 thousand years is distinct from the discussion of the "little ice age." The former refers to the growth of massive ice sheets (a mile or two thick) where periods of immense ice growth occurred, lasting approximately eighty thousand years, followed by warm interglacials lasting on the order of twenty thousand years. By contrast, the "little ice age" was a relatively brief period (about four hundred years) of relatively cool temperatures accompanied by the growth of alpine glaciers over much of the earth.

As evidence for the hundred thousand year cycle of major glaciation emerged, the Serbian astrophysicist Milutin Milankovitch (1941) noted that there was always winter snow in the arctic, but that the growth of glaciers depended on whether this snow survived the summer. He suggested that this would be determined by the amount of sunlight reaching the arctic in summer, and that this quantity varied greatly with the variations in the earth's orbital parameters [primarily variations in the obliquity (order 40 thousand years), the precession of the equinoxes (order 20 thousand years, but modulated by the eccentricity), and the variation of the eccentricity (order 100 thousand years)].

Arctic insolation in the summer is commonly referred to as the Milankovitch parameter. When reliable time series for the Milankovitch parameter and for ice volume became available, it was noted that the ice volume displayed spectral peaks corresponding to the orbital variations (Imbrie, 1984). However, doubts about the theory were expressed because the correlation between the Milankovitch parameter and the ice volume was not particularly good. This problem was independently resolved by Edvardsson *et al.* (2002) and Roe (2006), both of whom noted that one should not be comparing ice volume with the Milankovitch parameter, but rather one should be comparing the time rate of change of the ice volume (*i.e.*, d Ice Volume/dt).

The rate of change of the ice volume correlates remarkably will with the Milankovitch parameter [See
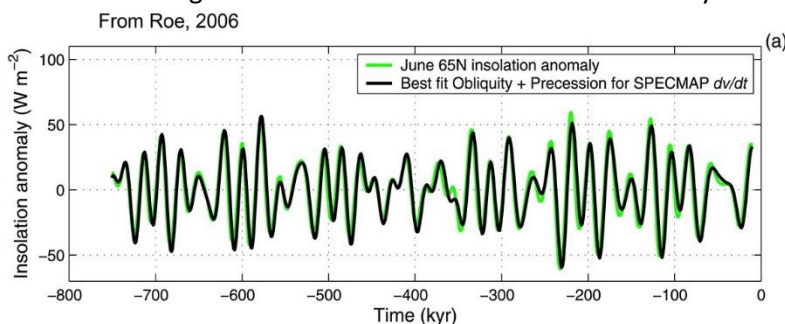

figure adjacent, which compares the June insolation anomaly (green) with the time rate of change of ice volume (black).] Note that the Milankovitch parameter varies over some 100 W/m^2, comparable to the global average energy flows in the climate system. Edvardsson *et al.* (2002) showed that these variations were sufficient to account for the melting of the continental glaciers. By contrast, the change in radiative forcing associated with the changes in CO_2 that follow the changes in temperature associated with the major glacial cycles is on the order of 2 W/m^2.

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The last glacial episode ended somewhat irregularly. Ice coverage reached its maximum extent about eighteen thousand years ago. Melting occurred between about twenty thousand years ago and thirteen thousand years ago, and then there was a strong cooling (Younger Dryas) which ended about 11,700 years ago. Between twenty thousand years ago and six thousand years ago, there was a dramatic increase in sea level of about 120 meters followed by more gradual increase over the following several thousand years. Since the end of the "little ice age," there has been steady increase in sea-level of about 6 inches per century.

As to the cause of the "little ice age," this is still a matter of uncertainty. There was a long hiatus in solar activity that may have played a role, but on these relatively short time scales one can't exclude natural internal variability. It must be emphasized that the surface of the earth is never in equilibrium with net incident solar radiation because the oceans are always carrying heat to and from the surface, and the motion systems responsible have time scales ranging from years (for example ENSO) to millennia.

There remains the interesting question of what was going on before 800,000 years ago. There were episodes of glaciation beginning about 6 million years ago (Bender, 2013), but the temporal behavior appears to be dominated by the obliquity cycles (about 40 thousand years). The reasons for this have not been extensively studied, but a clue appears to be that the current cycle involves the growth and decay of permanent ice, while during the earlier period there appear to have been periods almost completely free of arctic ice.

The claim that orbital variability requires a boost from CO_2 to drive ice ages comes from the implausible notion that what matters is the orbital variations in the global average insolation (which are, in fact, quite small) rather than the large forcing represented by the Milankovitch parameter. This situation is very different than in the recent and more modest shorter-term warming, where natural variability makes the role of CO_2 much more difficult to determine.

Question 2: What is the molecular difference by which CO₂ absorbs infrared radiation but oxygen and nitrogen do not?

Radiation is emitted or absorbed by time-dependent electrical charge and current densities of appropriate spatial symmetry.

Thermal infrared radiation can be absorbed or emitted by a molecule if the vibrations and rotations of the molecule occur at infrared frequencies AND if the vibrations and rotations of the molecules produce time-varying electric dipole moments in the molecules.
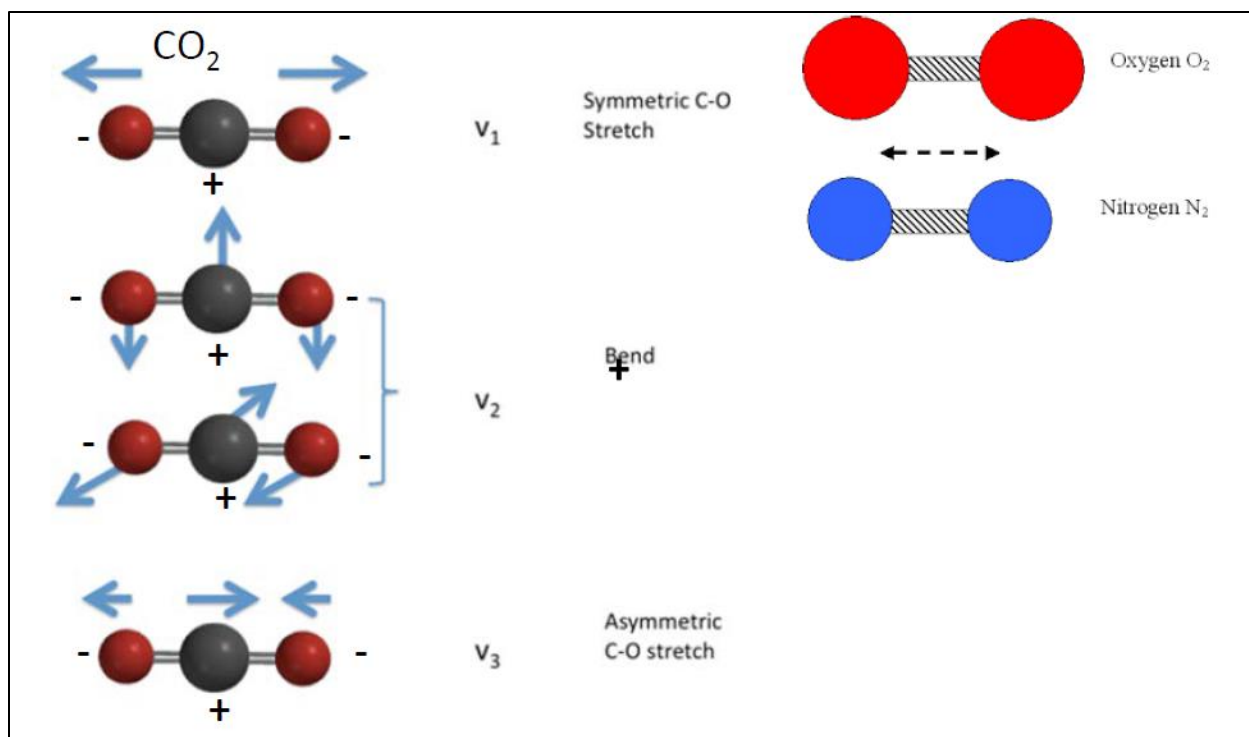
As shown in the figure above, the two oxygen atoms O at either end of a linear CO_2 molecule are negatively charged and the carbon atom C in the center is positively charged. The magnitude of the charge on the C atom is about half the positive charge on a proton. A bent CO_2 molecule has an "electric dipole moment," that is, the "center" of positive charge is displaced from the "center" of negative charge.

Time-changing electric dipole moments can emit or absorb radiation very efficiently. As indicated in the figure, a bent CO_2 molecule will vibrate, much like a xylophone bar, and produce a vibrating electric dipole moment pointing from the midpoint between the O nuclei and toward the C nucleus. The dipole moment will efficiently emit or absorb radiation at the vibrational frequency ν_2. The simultaneous rotation of the CO_2 molecule spreads the range of frequencies that can be absorbed or emitted by the bending-mode vibration.

CO_2 molecules also have modes where the atoms vibrate along a straight line. These are called the symmetric-stretch and the asymmetric stretch modes and they are labeled with the frequencies ν_1 and ν_3 in the figure. The frequencies of the asymmetric-stretch mode is higher than most thermal radiation

frequencies so it absorbs or emits thermal radiation much less efficiently than the bending mode. The symmetric stretch mode has no electric dipole moment and it is therefore an extremely poor emitter or absorber of radiation.

The negative charges of the two O atoms at the ends of a CO_2 molecule come from electrons that have been "robbed" from the C atom in the center. This leaves positive charge on the C atom. On the upper right of the figure we sketch an O_2 and an N_2 molecule, the two dominant components of air. The two O atoms at the ends of an oxygen molecule, O_2, are uncharged since they have equal affinity for electrons. For analogous reasons, the two N atoms of a nitrogen molecule, N_2, are uncharged.

Both O_2 and N_2 molecules have stretching vibrations, analogous to the symmetric stretch vibration ν_2 of the CO_2 molecule. The O_2 and N_2 molecules can also rotate. The combined frequencies of vibration and rotation are equal to thermal infrared frequencies, but vibrating and rotating O_2 and N_2 do not absorb or emit radiation efficiently since they have no time-dependent electric dipole moments. O_2 and N_2 do have "electric quadrupole moments," which change with vibrations and rotations, but vibrating quadrupole moments of molecules emit and absorb thermal radiation at least a million times less efficiently than dipoles. Diatomic molecules like NO or CO, which are not symmetric like O_2 and N_2, do have electric dipole moments. They can efficiently emit or absorb thermal infrared radiation at their vibrational frequencies and are diatomic greenhouse gases.

Molecules like CO_2, H_2O, CO or NO are called a greenhouse-gas molecules, because they can efficiently absorb or emit infrared radiation, but they are nearly transparent to sunlight. Molecules like O_2 and N_2 are also nearly transparent to sunlight, but since they do not absorb or emit thermal infrared radiation very well, they are not greenhouse gases. The most important greenhouse gas, by far, is water vapor. Water molecules, H_2O, are permanently bent and have large electric dipole moments.

Question 3: What is mechanism by which infrared radiation trapped by CO_2 in the atmosphere is turned into heat and finds its way back to sea level?

CO_2 molecules radiate very slowly, requiring about a second to lose energy by emitting a quantum of infrared radiation. But a CO_2 molecule can also lose energy in nearly every collision that it has with an N_2 or O_2 molecule; these happen about a billion times per second at sea level. So any infrared radiation absorbed by CO_2 molecules almost instantaneously heats the surrounding air through "inelastic" molecular collisions.

Unscattered infrared radiation is very good at *transmitting* energy because it moves at the speed of light. But the energy per unit volume *stored* by the thermal radiation in the Earth's atmosphere is completely negligible compared to the internal energy of the air molecules.

Although CO_2 molecules radiate very slowly, there are so many CO_2 molecules that they produce lots of radiation, and some of this radiation reaches sea level. The figure following shows downwelling radiation measured at the island of Nauru in the Tropical Western Pacific Ocean, and at colder Point Barrow, Alaska, on the shore of the Arctic Ocean.
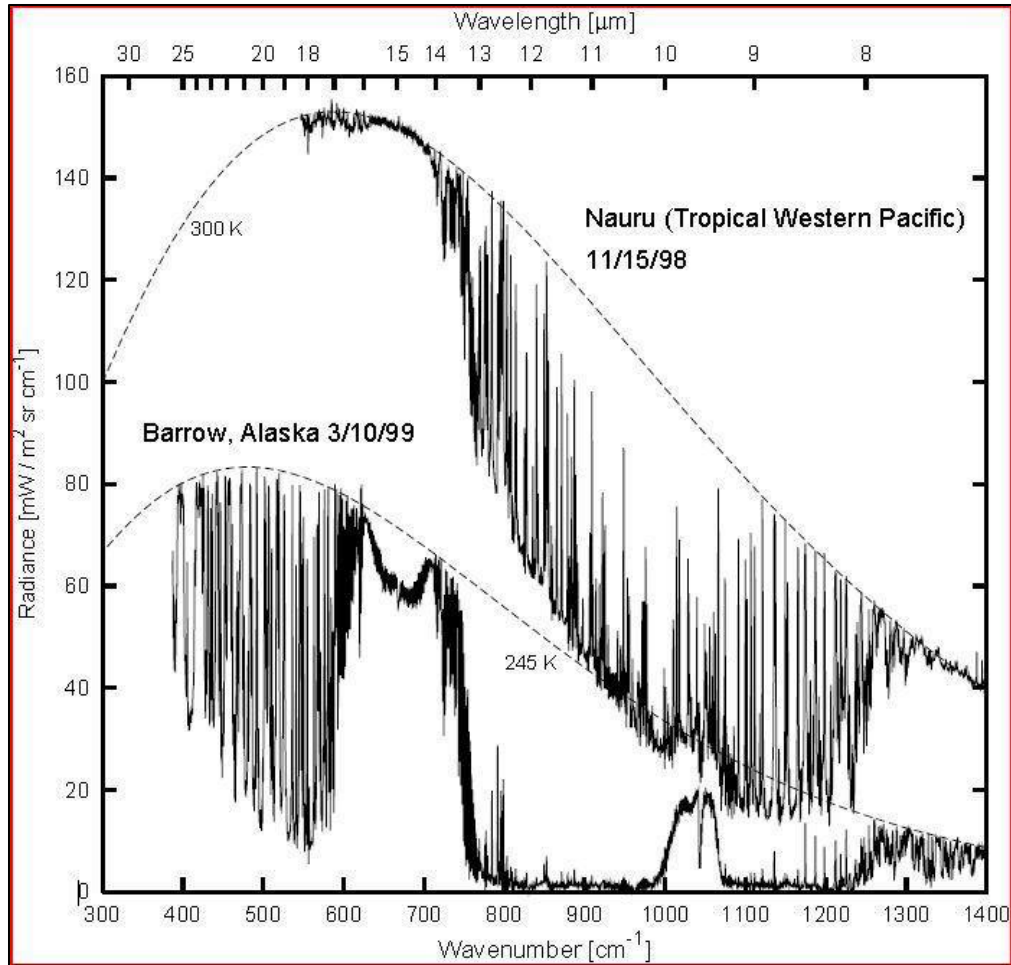
The horizontal scale here is the frequency of the radiation in wavenumbers. [If one could take a "snapshot" of an infrared wave, the number of peaks in a 1 cm segment is the wave number.] The complicated solid lines in the figure are the intensity of the observed downwelling radiation. The CO_2 bending mode produces the downwelling radiation with frequencies between about 580 cm^{-1} to 750 cm^{-1}. Downwelling radiation for frequencies less than 580 cm^{-1} and from more than 1200 cm^{-1} is from water vapor, H_2O.

At Nauru much of the downwelling comes from CO_2 and H_2O molecules that are only a few hundred meters above the surface. The air at these low altitudes has almost the same temperature as the surface, 300 K. The radiation with frequencies less than 750 cm^{-1} and more than 1200 cm^{-1}, where there is strong molecular absorption at nearly every frequency, differs little from thermal-equilibrium (Planck) radiation at the 300 K surface temperature, which is shown as the dashed line. For frequencies between about 750 cm^{-1} and 1200 cm^{-1} there is considerably less downwelling radiation than the Planck limit, since there are few molecular emission lines in this interval.

At Point Barrow, the surface temperature is much colder than at Nauru and there is a pronounced temperature inversion with the air getting warmer instead of colder at higher altitudes. The downwelling intensity at the 667 cm^{-1} center of the CO2 band implies a surface temperature of about 233 K, some 12 C colder than the temperature of the dashed blackbody curve, which corresponds to the temperature of

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higher-altitude, warmer air. The more intense "shoulders" of the CO_2 downwelling come from this warmer air. At Point Barrow, there is relatively little downwelling radiation from water vapor compared to CO_2, since the extreme cold has frozen out much of the moisture.

So the answer to the last part of the question, "What is the mechanism by which … heat … finds its way back to sea level?" is that the heat is radiated to the ground by molecules at various altitudes, where there is usually a range of different temperatures. The emission altitude is the height from which radiation could reach the surface without much absorption, say 50% absorption. For strongly absorbed frequencies, the radiation reaching the ground comes from low-altitude molecules, only a few meters above ground level for the 667 cm^{-1} frequency at the center of the CO_2 band. More weakly absorbed frequencies are radiated from higher altitudes where the temperature is usually colder than that of the surface. But occasionally, as the data from Point Barrow show, higher-altitude air can be warmer than the surface.

The extreme cold surface at Point Barrow implied by the data in the figure shows that the heat transfer to space there is almost entirely by radiation. The data were taken in early spring when there was little solar heating of the surface. Buoyant, upward convection of surface air cannot occur in regions of temperature inversions.

Closely related to Question 3 is how heat from the absorption of sunlight by the surface gets back to space to avoid a steadily increasing surface temperature. As one might surmise from the figure, at Narau there is so much absorption from CO_2 and by water vapor, H_2O, that most daytime heat transfer near the surface is by convection, not by radiation. Especially important is moist convection, where the water vapor in rising moist air releases its latent heat to form clouds. The clouds have a major effect on radiative heat transfer. Cooled, drier, subsiding air completes the convection circuit. Minor changes of convection and cloudiness can have a bigger effect on the surface temperature than large changes in CO_2 concentrations.

Question 4: Does CO₂ in the atmosphere reflect any sunlight back into space, such that the reflected sunlight never penetrates the atmosphere in the first place?

The short answer to this question is "No", but it raises some interesting issues that we discuss below.

Molecules can either scatter or absorb radiation. CO_2 molecules are good absorbers of thermal infrared radiation, but they scatter almost none. Infrared radiant energy absorbed by a CO_2 molecule is converted to internal vibrational and rotational energy. This internal energy is quickly lost in collisions with the N_2 and O_2 molecules that make up most of the atmosphere. The collision rates, billions per second, are much too fast to allow the CO_2 molecules to reradiate the absorbed energy, which takes about a second. CO_2 molecules in the atmosphere do emit thermal infrared radiation continuously, but the energy is almost always provided by collisions with N_2 and O_2 molecules, not by previously absorbed radiation. The molecules "glow in the dark" with thermal infrared radiation.
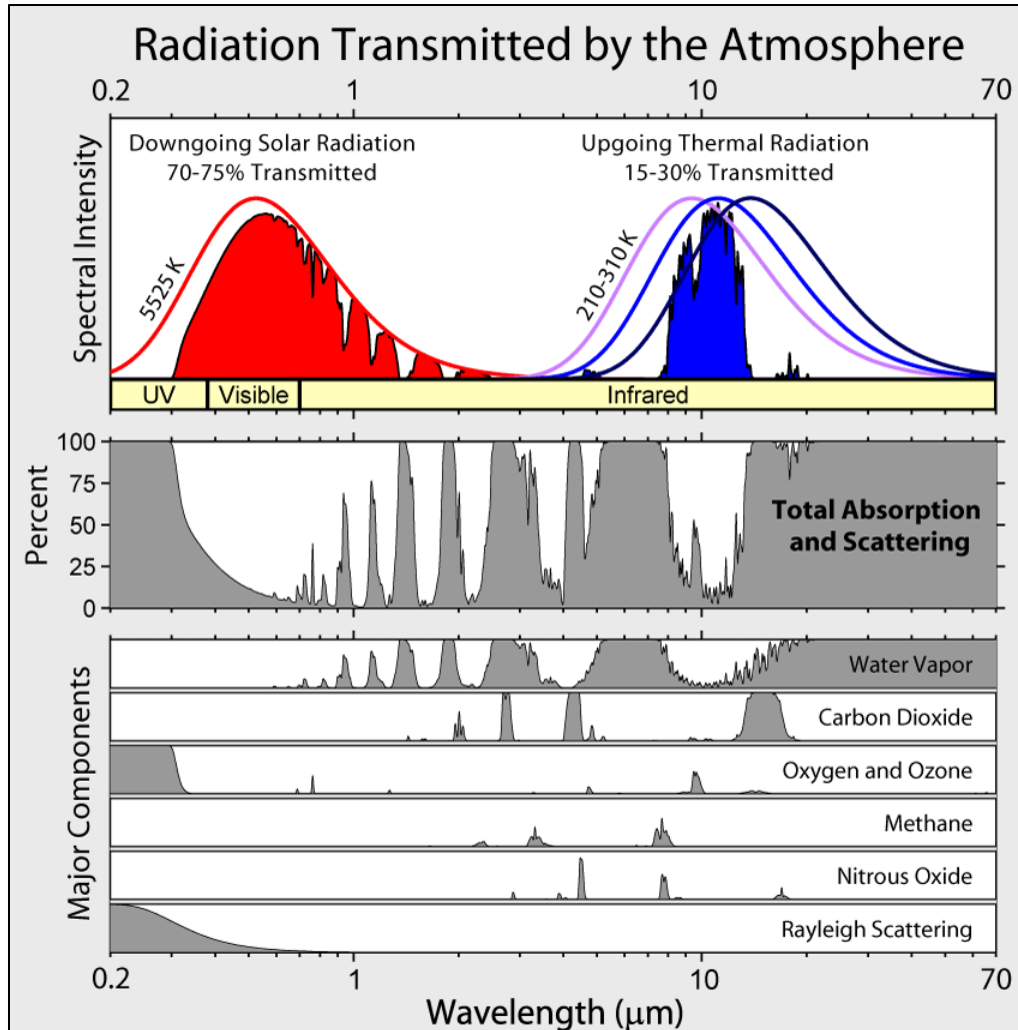
In the figure above the radiation wavelength, in micrometers, is plotted along the horizontal axis. From left to right, the top panel shows the ultraviolet (UV), visible, and infrared portions of the spectrum. Typical visible wavelengths are 0.4 to 0.7 micrometers. Most thermal infrared wavelengths of the earth are longer than 3 micrometers. The red line on the top left is the ideal radiation spectrum of the Sun, that is, the solar power per wavelength increment. In this model, the Sun is assumed to have a temperature of 5525 K. On the right are radiation spectra of the earth at various surface temperatures. The violet line corresponds to a temperature of 310 K or about 98 F, a very hot summer day in temperate latitudes. The blue line corresponds to a temperature of 250 K or about -10 F, a very cold winter day. The black curve is for a temperature of 210 K or about -82 F, similar to the temperature of the ice cap in the wintertime Antarctic. The spectral intensity curves are not to scale, but drawn to show the wavelengths of maximum intensity.

The second panel from the top of the figure shows the fraction of radiation of a given wavelength that can pass vertically from the surface to outer space without being scattered or absorbed by molecules of air. The lower panels, 3 to 8, show contributions to the atmospheric opacity from water vapor (H_2O), carbon dioxide (CO_2), oxygen and ozone (O_2 and O_3), methane (CH_4), nitrous oxide (N_2O), and Raleigh scattering (to which all atmospheric molecules contribute). Blue skylight on a clear, sunny day is Raleigh-scattered sunlight. Since CO_2 molecules constitutes only about 0.04 % of the total number of molecules

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in the atmosphere, their contribution to Raleigh scattering is completely negligible, compared to that of N_2 and O_2.

The figure shows that water vapor is by far the most important absorber. It can absorb both thermal infrared radiation from the Earth and shorter-wave radiation from the Sun. Water vapor and its condensates, clouds of liquid or solid water (ice), dominate radiative heat transfer in the Earth's atmosphere; CO_2 is of secondary importance.

If Question 4 were "Do clouds in the atmosphere reflect any sunlight back into space, such that the reflected sunlight never penetrates the atmosphere in the first place?" the answer would be "Yes". It is common knowledge that low clouds on a sunny day shade and cool the surface of the Earth by scattering the sunlight back to space before it can be absorbed and converted to heat at the surface.

The figure shows that very little thermal radiation from the surface can reach the top of the atmosphere without absorption, even if there are no clouds. But some of the surface radiation is replaced by molecular radiation emitted by greenhouse molecules or cloud tops at sufficiently high altitudes that the there are no longer enough higher-altitude greenhouse molecules or clouds to appreciably attenuate the radiation before it escapes to space. Since the replacement radiation comes from colder, higher altitudes, it is less intense and does not reject as much heat to space as the warmer surface could have without greenhouse-gas absorption.

As implied by the figure, sunlight contains some thermal infrared energy that can be absorbed by CO_2. But only about 5% of sunlight has wavelengths longer than 3 micrometers where the strongest absorption bands of CO_2 are located. The Sun is so hot, that most of its radiation is at visible and near-visible wavelengths, where CO_2 has no absorption bands.

Question 5: Apart from CO2, what happens to the collective heat from tail pipe exhausts, engine radiators, and all other heat from combustion of fossil fuels? How, if at all, does this collective heat contribute to warming of the atmosphere?

Most of the energy humans use comes from fossil fuels, with nuclear and renewables making up the balance, as shown in this figure:
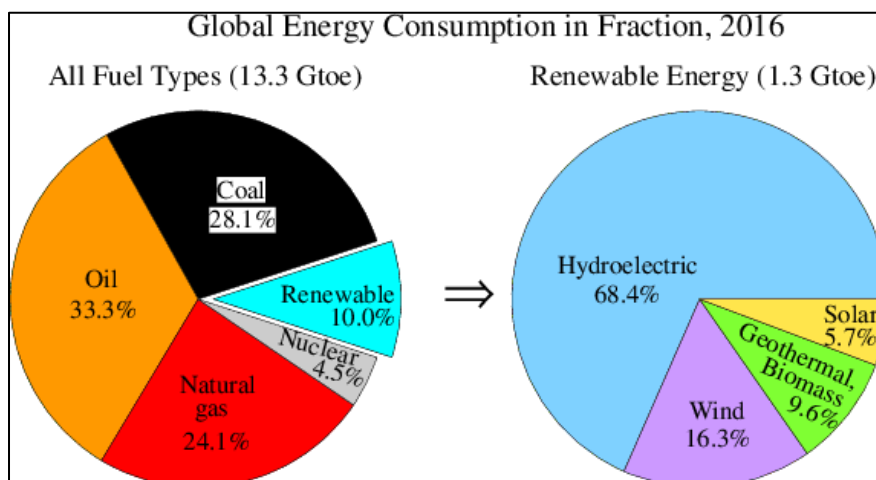
After that energy is used for heat, mobility, and electricity, the Second Law of Thermodynamics guarantees that virtually all of it ends up as heat in the climate system, ultimately to be radiated into space along with the earth's natural IR emissions. [A very small fraction winds up as visible light that escapes directly to space through the transparent atmosphere, but even that ultimately winds up as heat somewhere "out there."]

How much does this anthropogenic heat affect the climate? There are local effects where energy use is concentrated, for example in cities and near power plants. But globally, the effects are very small. To see that, convert the global annual energy consumption of 13.3 Gtoe (Gigatons of oil equivalent) to 5.6×10^{20} joules. Dividing that by the 3.2×10^7 seconds in a year gives a global power consumption of 1.75×10^{13} Watts. Spreading that over the earth's surface area of 5.1×10^{14} m^2 results in an anthropogenic heat flux of 0.03 W/m^2. This is some four orders of magnitude smaller than the natural heat fluxes of the climate system, and some two orders of magnitude smaller than the anthropogenic radiative forcing.

The geothermal heat flux (largely from decay of radioactive elements in the earth) is a comparable source of heat. While it can be quite large in localized sources (volcanoes, hot springs, geothermal vents on the sea floor, …) the global average is 0.09 W/m^2, three times larger than the direct heating from human energy consumption, but still too small to have a meaningful direct effect on the climate's power balance. However, there can be indirect effects, such as the melting of ice by subglacial Antarctic volcanoes.

Question 6: In grade school many of us were taught that humans exhale CO$_2$ but plants absorb CO$_2$ and return oxygen to the air (keeping the carbon fiber). Is this still valid? If so why hasn't plant life turned the higher levels of CO$_2$ back into oxygen? Given the increase in population on earth (four billion), is human respiration a contributing factor to the buildup of CO$_2$?

Plants and other photosynthetic organisms use energy from sunlight, together with a CO$_2$ molecule and water, to produce simple sugars (carbohydrates). One molecule of oxygen, O$_2$, is released as a waste product for every carbon dioxide molecule CO$_2$ molecule used. The photosynthetic organism uses the simple sugars and their chemical energy to build other organic compounds needed for life. These include the fiber mentioned in the question, as well as starch, oils, nitrogen-containing amino acids, and many others.

Photosynthetic organisms are estimated to fix about 1.05×10^{11} tons of carbon per year, which would require 3.85×10^{11} tons of CO$_2$. Since the total mass of the Earth's atmosphere is about 5.15×10^{15} tons, the mean molar weight of air is 29 grams and the molar weight of CO$_2$ is 44 grams, this would amount to about 50 ppm (parts per million by volume) of the CO$_2$ in the air. At present, there is a little more than 400 ppm of CO$_2$ in the air, so if large amounts of CO$_2$ were not being added to the air by various mechanisms (some of which we will discuss in the answer to Question 7) plants would use up the atmospheric CO$_2$ in about eight years and die of starvation.

Primary photosynthetic productivity is dominated by land plants, and most land plants are in the northern hemisphere. During the northern summer, the growth of land plants is fast enough to cause a substantial
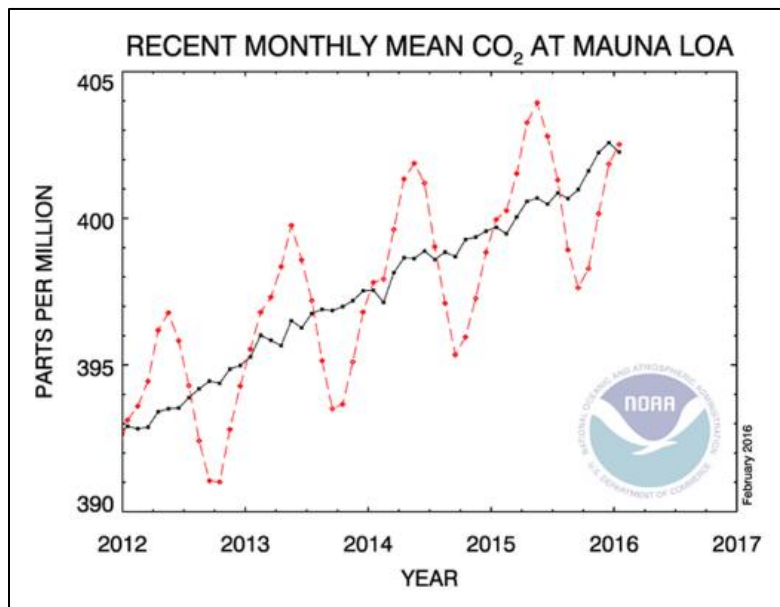
drawdown of atmospheric CO_2 as can be seen in the figure below. During the northern winter, when plant growth slows or ceases over much of the northern hemisphere, living organisms, notably soil organisms like fungi, oxidize or ferment some of the organic matter accumulated the past summer and return it to the air as CO_2. At Mauna Loa, the winter-summer swings of CO_2 are less than 10 ppm. But at more northerly observatories the swings are more extreme, for example, 20 ppm in the high Arctic measured in Alert, Canada.

If all of the CO_2 produced by current combustion of fossil fuels remained in the atmosphere, the level would increase by about 4 ppm per year, substantially more than the observed rate of around 2.5 ppm per year, as seen in the figure above. Some of the anthropogenic CO_2 emissions are being sequestered on land or in the oceans.
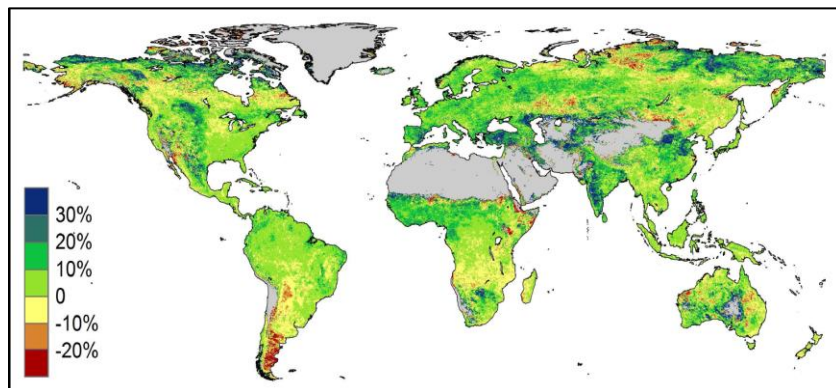
There is evidence that primary photosynthetic productivity has increased somewhat over the past half century, perhaps due to more CO_2 in the atmosphere. For example, the summer-winter swings like those in the figure above are increasing in amplitude. Other evidence for modestly increasing primary productivity includes the pronounced "greening" of the Earth that has been observe by satellites. An example is the map above, which shows a general increase in vegetation cover over the past three decades

The primary productivity estimate mentioned above would also correspond to an increase of the oxygen fraction of the air by 50 ppm, but since the oxygen fraction of the air is very high (209,500 ppm), the relative increase would be small and hard to detect. Also much of the oxygen is used up by respiration.

The average human exhales about 1 kg of CO_2 per day, so the 7 billion humans that populate the Earth today exhale about 2.5×10^9 tons of CO_2 per year, a little less than 1% of that is needed to support the primary productivity of photosynthesis and only about 6% of the CO_2 "pollution" resulting from the burning of fossil fuels. However, unlike fossil fuel emissions, these human (or more generally, biological) emissions do not accumulate in the atmosphere, since the carbon in food ultimately comes from the atmosphere in the first place.

Question 7: What are the main sources of CO_2 that account for the incremental buildup of CO_2 in the atmosphere?

The CO_2 in the atmosphere is but one reservoir within the global carbon cycle, whose stocks and flows are illustrated by Figure 6.1 from IPCC AR5 WG1:
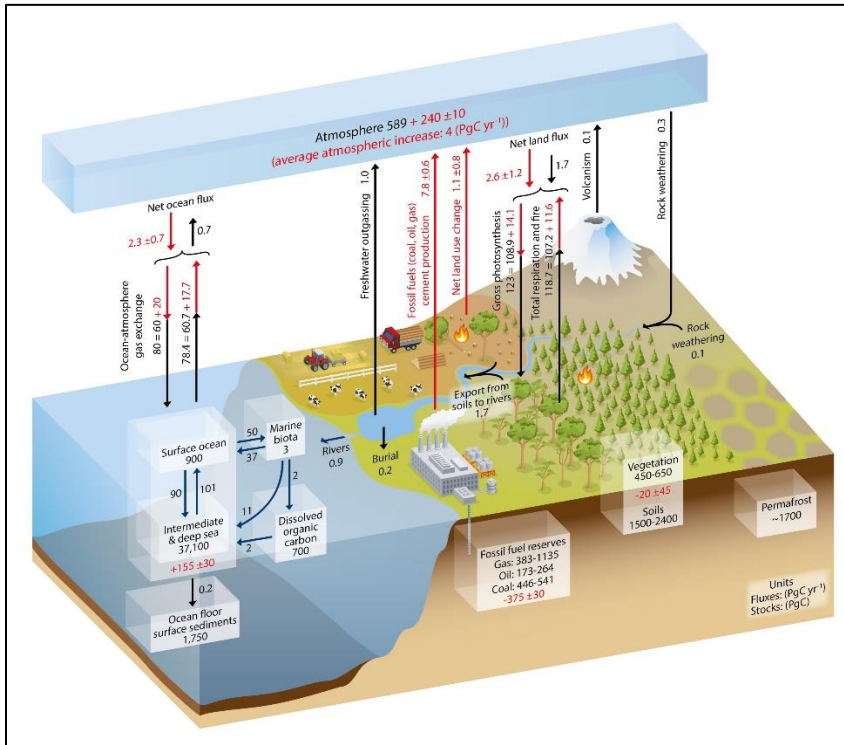

Caption: Simplified schematic of the global carbon cycle. Numbers represent reservoir mass, also called 'carbon stocks' in PgC (1 PgC = 10^{15} gC = 3.8 $GtCO_2$) and annual carbon exchange fluxes (in PgC/yr). Black numbers and arrows indicate reservoir mass and exchange fluxes estimated for the time prior to the Industrial Era, about 1750; red numbers and arrows indicate current human influences.

There is a nearly-balanced annual exchange of some 200 PgC between the atmosphere and the earth's surface (~80 Pg land and ~120 Pg ocean); the atmospheric stock of 829 Pg therefore "turns over" in about four years.

Human activities currently add 8.9 PgC each year to these closely coupled reservoirs (7.8 from fossil fuels and cement production, 1.1 from land use changes such as deforestation). About half of that is absorbed into the surface, while the balance (airborne fraction) accumulates in the atmosphere because of its multi-century lifetime there. Other reservoirs such as the intermediate and deep ocean are less closely coupled to the surface-atmosphere system.

Much of the natural emission of CO_2 stems from the decay of organic matter on land, a process that depends strongly on temperature and moisture. And much CO_2 is absorbed and released from the oceans, which are estimated to contain about 50 times as much CO_2 as the atmosphere. In the oceans CO_2 is

stored mostly as bicarbonate (HCO_3^-) and carbonate (CO_3^{--}) ions. Without the dissolved CO_2, the mildly alkaline ocean with a pH of about 8 would be very alkaline with a pH of about 11.3 (like deadly household ammonia) because of the strong natural alkalinity.
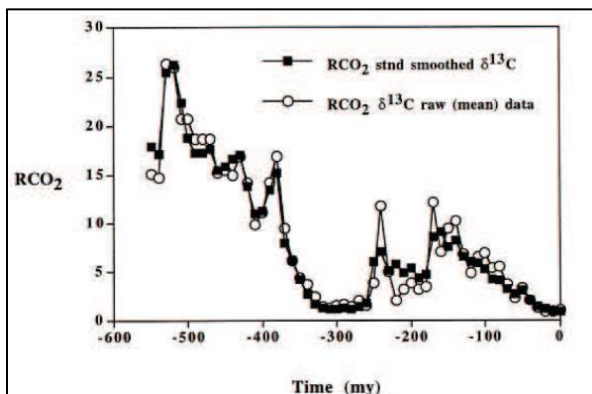
By geological standards, the Earth is currently starved for atmospheric CO_2. Past CO_2 levels estimated from various proxies are shown in the adjacent figure. The
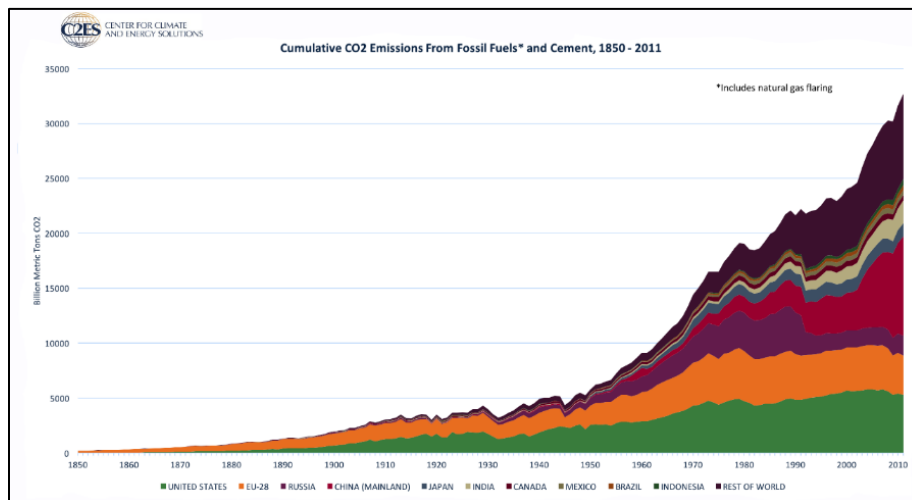
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horizontal scale is geological time since the Cambrian, at about 550 million years ago. The vertical axis is the ratio, RCO_2, of past atmospheric CO_2 concentrations to average values (about 300 ppm) during the past few million years, This particular proxy record comes from analyzing the fraction of the rare stable isotope ^{13}C to the dominant isotope ^{12}C in carbonate sediments and paleosols. Other proxies give qualitatively similar results.

Only once in the geological past, the Permian period about 300 million years ago, have atmospheric CO_2 levels been as low as now. Life flourished abundantly during the geological past when CO_2 levels were five or ten times higher than those today.
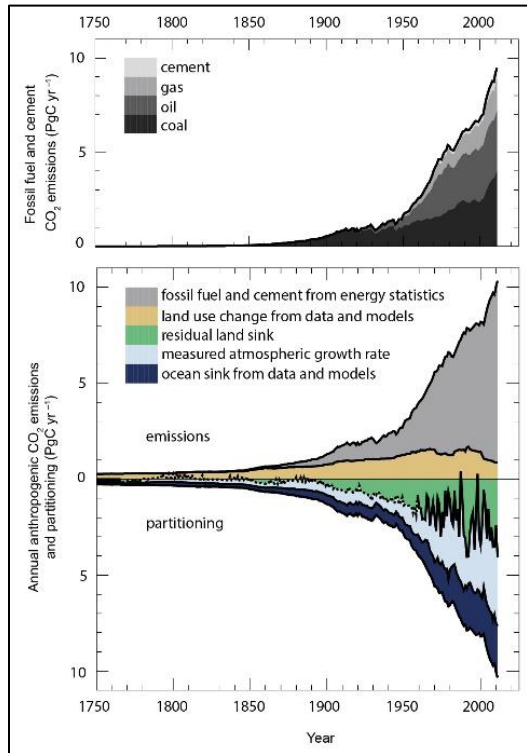
Returning to the present, human emissions of CO_2 have grown dramatically since 1900, as shown in the adjacent AR5 WG1 Figure 6.8. Most of this CO_2 comes from combustion of fossil fuels for generating electrical power, heating, and mobility, but about 4% is from cement manufacture, where fossil fuel is used to bake limestone, or calcium carbonate ($CaCO_3$) to make calcium oxide (CaO) and CO_2. The natural land and ocean sinks have kept pace with human emissions, maintaining the airborne fraction at about one half.

Growing human emissions have increased the atmospheric concentration of CO_2, from about 280 ppm in 1900 to just over 408 ppm today. The long atmospheric lifetime of CO_2 and the roughly constant airborne fraction mean that this concentration growth is proportional to the cumulative human emissions. As shown in the chart below, cumulative fossil fuel emissions to date have been dominated by today's developed countries, but cumulative emissions in the future are expected to be dominated by developing countries because of their scale and economic growth. Note also that because climate is influenced by the concentration of CO_2 (and hence cumulative emissions), rather than emissions themselves, it is challenging to mitigate human influences by reducing emissions. For example, CSSR Figure ES.3 shows that *all* global emissions must cease beyond 2075 if human influences are to be stabilized at allegedly "safe" levels. The US and California currently account, respectively, for about 14% and 1% of global emissions.

Question 8: What are the main sources of heat that account for the incremental rise in temperature on earth?

The only important primary heat source for the Earth's surface is the Sun. But the heat can be stored in the oceans for long periods of time, even centuries. Variable ocean currents can release more or less of this stored heat episodically, leading to episodic rises (and falls) of the Earth's surface temperature.

The "temperature" normally means the average surface temperature anomaly of the Earth. The actual temperature varies tremendously with latitude and longitude and with altitude. It also varies daily and diurnally: day-to-day or day-to-night temperature variations of 10 C are common. Daytime temperatures of 40 C occur routinely in the tropics, and polar temperatures range from around 0 C in summer to as low as -89 C in the Antarctic night. At the cruising altitudes of airliners, around 11 km, temperatures are often around -60 C, as shown in the figure below. The incremental rises (and falls) in the global mean temperature anomaly studied by climate scientists have been much smaller (about 1 degree Centigrade over almost two centuries) than the natural variations of temperature mentioned above.
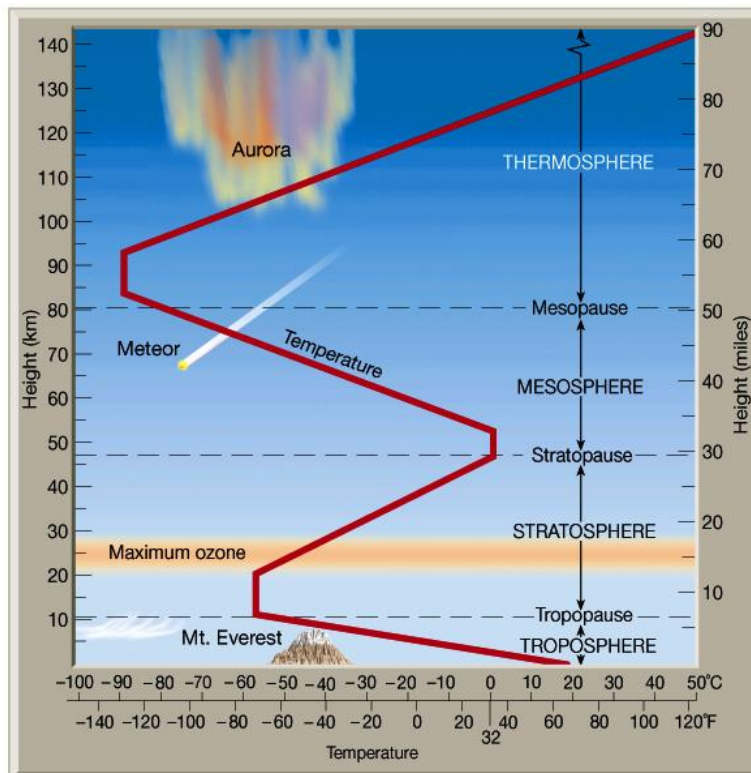
Incremental changes of the surface temperature anomaly can be traced back to two causes: (1) changes in the surface heating rate; (2) changes in the resistance of heat flow to space. Quasi periodic El Nino episodes are examples of the former. During an El Nino year, easterly trade winds weaken and very warm deep water, normally blown toward the coasts of Indonesia and Australia, floats to the surface and spreads eastward to replace previously cool surface waters off of South America. The average temperature anomaly can increase by 1 C or more because of the increased release of heat from the ocean. The heat source for the El Nino is solar energy that has accumulated beneath the ocean surface for several years before being released.

Longer-term ocean cycles that share some characteristics with El Ninos are the Pacific Decadal Oscillation and the Atlantic Multi-decadal Oscillation. Like El Ninos, these longer-term oscillations episodically release solar heat that has been stored at depth for many years, decades, or centuries.

The atmosphere, alone, is capable of internal variations on time scales of years. The Quasi-Biennial Oscillation of the tropical stratosphere is an example, although it has almost no impact on surface temperature. This is to be expected since the heat capacity of the stratosphere is very small compared to that of the lower atmosphere, and heat exchange between the stratosphere and lower atmosphere is not very efficient.

An example of a cause (2) [*i.e.*, temperature increase due to a changing resistance to the heat flow to space, with the same solar heating rate of the surface], is an increase in the concentration of the greenhouse gas CO_2. This greenhouse warming is such a central issue that we expand this part of the answer to say a little more about it.

On average, the absorption rate of solar radiation by the Earth's surface and atmosphere is equal to emission rate of thermal infrared radiation to space. Much of the radiation to space does not come from the surface but from greenhouse gases and clouds in the lower atmosphere, where the temperature is usually colder than the surface temperature, as shown in the figure on the previous page. The thermal radiation originates from an "escape altitude" where there is so little absorption from the overlying atmosphere that most (say half) of the radiation can escape to space with no further absorption or scattering. Adding greenhouse gases can warm the Earth's surface by increasing the escape altitude. To maintain the same cooling rate to space, the temperature of the entire troposphere, and the surface, would have to increase to make the effective temperature at the new escape altitude the same as at the original escape altitude. For greenhouse warming to occur, a temperature profile that cools with increasing altitude is required.
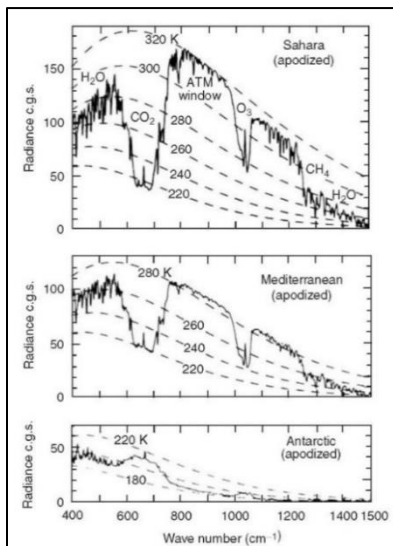
The escape altitude will depend strongly on frequency, especially in cloud-free areas, where it is dominated by the complicated absorption bands of greenhouse-gas molecules. Some examples of cooling infrared radiation observed by satellites over cloud-free regions are given in the adjacent figure, which shows spectra of the thermal radiation upwelling from the Earth to space. ["Apodized" means that the raw data was processed to remove instrumental artifacts.] One can see that the upwelling radiation varies greatly with location, being most intense over the hot Sahara desert and weakest over the cold Antarctic ice sheet. One can recognize various escape altitudes: between about 800 cm^{-1} and 1200 cm^{-1}, most of the radiation comes from the surface since the atmosphere is largely transparent in this "window" of frequencies. Over most of the CO_2 absorption band (between about 580 cm^{-1} and 750 cm^{-1}) the escape altitude is the nearly isothermal lower stratosphere shown in the first figure. The narrow spike of radiation at about 667 cm^{-1} in the center of the CO_2 band escapes from an altitude of around 40 km (upper stratosphere), where it is considerably warmer than the lower stratosphere due heating by solar ultraviolet light which is absorbed by ozone, O_3. Only at the edges of the CO_2 band (near 580 cm^{-1} and 750 cm^{-1}) is the escape altitude in the troposphere where it could have some effect on the surface temperature. Water vapor, H_2O, has emission altitudes in the troposphere over most of its absorption bands. This is mainly because water vapor, unlike CO_2, is not well mixed but mostly confined to the troposphere.

Section III: Biographies

Dr. William Happer, Professor Emeritus in the Department of Physics at Princeton University, is the President of the CO2 Coalition, a non-profit (501 (c)(3)) organization established in 2015 to educate thought leaders, policy makers and the public about the vital contribution made by carbon dioxide to our lives and our economy. Dr. Happer began his professional career in the Physics Department of Columbia University in 1964, where he served as Director of the Columbia Radiation Laboratory from 1976 to 1979. He joined the Physics Department of Princeton University in 1980. From 1987 to 1990 he served as Chairman of the Steering Committee of JASON. He served as Director of Energy Research in the U.S. Department of Energy from 1991 to 1993. He is the Chairman of the Richard Lounsbery Foundation. He was a co-founder in 1994 of Magnetic Imaging Technologies Incorporated (MITI), a small company specializing in the use of laser-polarized noble gases for magnetic resonance imaging. He invented the sodium guidestar that is used in astronomical adaptive optics systems to correct for the degrading effects of atmospheric turbulence on imaging resolution. He has published over 200 peer-reviewed scientific papers. He is a Fellow of the American Physical Society, the American Association for the Advancement of Science, and a member of the American Academy of Arts and Sciences, the National Academy of Sciences and the American Philosophical Society.

Dr. Steven E. Koonin has been the director of the Center for Urban Science and Progress since its creation in April 2012 by New York University, where he is also a University Professor, a Professor of Information, Operations, and Management Sciences in the Stern School of Business and a Professor of Civil and Urban Engineering in the Tandon School of Engineering. Prior to his current roles, Dr. Koonin served as Undersecretary for Science at the U.S. Department of Energy from May 2009, following his confirmation by the U.S. Senate, until November 2011. Prior to joining the government, Dr. Koonin spent five years, from March 2004 to May 2009, as Chief Scientist for BP, p.l.c. From September 1975 to July 2006, Dr. Koonin was a professor of theoretical physics at Caltech and was the institute's Provost from February 1995 to January 2004. Dr. Koonin was a director of CERES, Inc., a publicly traded company pursuing genetically enhanced bioenergy crops, from 2012 to 2015 and has been a Director of GP Strategies since 2016. His memberships include the U.S. National Academy of Sciences, the American Academy of Arts and Sciences, the Council on Foreign Relations and, formerly, the Trilateral Commission. He has been a member of the JASON advisory group from July 1988 to May 2009, and from November 2011 to present, and served as the group's chair from 1998 to 2004. Since 2014, he has been a trustee of the Institute for Defense Analyses and has chaired the National Academies' Divisional Committee for Engineering and Physical Sciences. He also has served as an independent governor of the Los Alamos and Lawrence Livermore National Security LLCs since July 2012 and of the Sandia Corporation from 2016 to 2017 and was a member of the Secretary of Energy's Advisory Board from 2013 to 2016. Dr. Koonin holds a B.S. in Physics from Caltech (1972) and a Ph.D. in Theoretical Physics from MIT (1975) and has published some 200 peer-reviewed papers.

Dr. Richard S. Lindzen, Professor Emeritus of Atmospheric Sciences in the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology, is a specialist in Atmospheric Physics. Dr. Lindzen received his B.S. in Physics in 1960, and his M.S. (1961) and Ph.D. (1964), both in Applied Mathematics, from Harvard University, but his thesis (*Radiative and photochemical processes in strato- and mesospheric dynamics*.) was in Atmospheric Physics. From 1968 to 1972 he served of the faculty of the University of Chicago. From 1972 to 1983 he held the Gordon McKay and then the

Robert P. Burden chairs in Meteorology at Harvard University where from 1980 until 1983, he was Director of the Center for Earth and Planetary Physics. From 1983 until July 2013, he was the Alfred P. Sloan Professor of Atmospheric Sciences at the Massachusetts Institute of Technology. He was a lead author of the 2001 Scientific Assessment Report of the Intergovernmental Panel on Climate Change, and a member of the Climate change science Program Product Development Advisory Committee of the Department of Energy (term ended in 2009). . He has served as a member of the Woods Hole Oceanographic Institution Corporation and the Council of the American Meteorological Society. He received the Leo Prize of the Wallin Foundation in Sweden (2006), the Distinguished Engineering Achievement Award of the Engineers' Council (2009), and the Petr Beckmann Award of Doctors for Disaster Preparedness (2012). He has published over 250 peer-reviewed scientific papers. He is a Fellow of the American Meteorological Society, the American Geophysical Union, and the American Association for the Advancement of Science, and a member of the American Academy of Arts and Sciences, the National Academy of Sciences, and the Norwegian Academy of Letters and Science.

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and Richard S. Lindzen

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UNITED STATES DISTRICT COURT

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NORTHERN DISTRICT OF CALIFORNIA

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SAN FRANCISCO DIVISION

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THE PEOPLE OF THE STATE OF
CALIFORNIA,

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12

            Plaintiff,

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v.

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B.P. P.L.C., *et al.*,

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            Defendants.

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Case No. C 17-06011 WHA	
Case No. C 17-06012 WHA	

Hearing Date: March 21, 2018 at 8:00 a.m.

[PROPOSED] ORDER GRANTING ADMINISTRATIVE MOTION OF WILLIAM HAPPER, STEVEN E. KOONIN, AND RICHARD S. LINDZEN FOR LEAVE TO SUBMIT PRESENTATION IN RESPONSE TO THE COURT'S TUTORIAL QUESTIONS

The Honorable William H. Alsup

18   On March 19, 2018, William Happer, Steven E. Koonin, and Richard S. Linzen filed an

19   Administrative Motion of William Happer, Steven E. Koonin, and Richard S. Lindzen for Leave to

20   Submit Presentation in Response to the Court's Tutorial Questions.

21   Having considered the papers and pleadings on file, the Court GRANTS leave and accepts the

22   presentation as filed with the motion.

23   IT IS SO ORDERED.

24   DATED: _____, 2018

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        _____
        THE HONORABLE WILLIAM H. ALSUP
        UNITED STATES DISTRICT COURT JUDGE

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[PROPOSED] ORDER
                                                 Case No.: C 17-06011-WHA
                                                 Case No.: C 17-06012-WHA