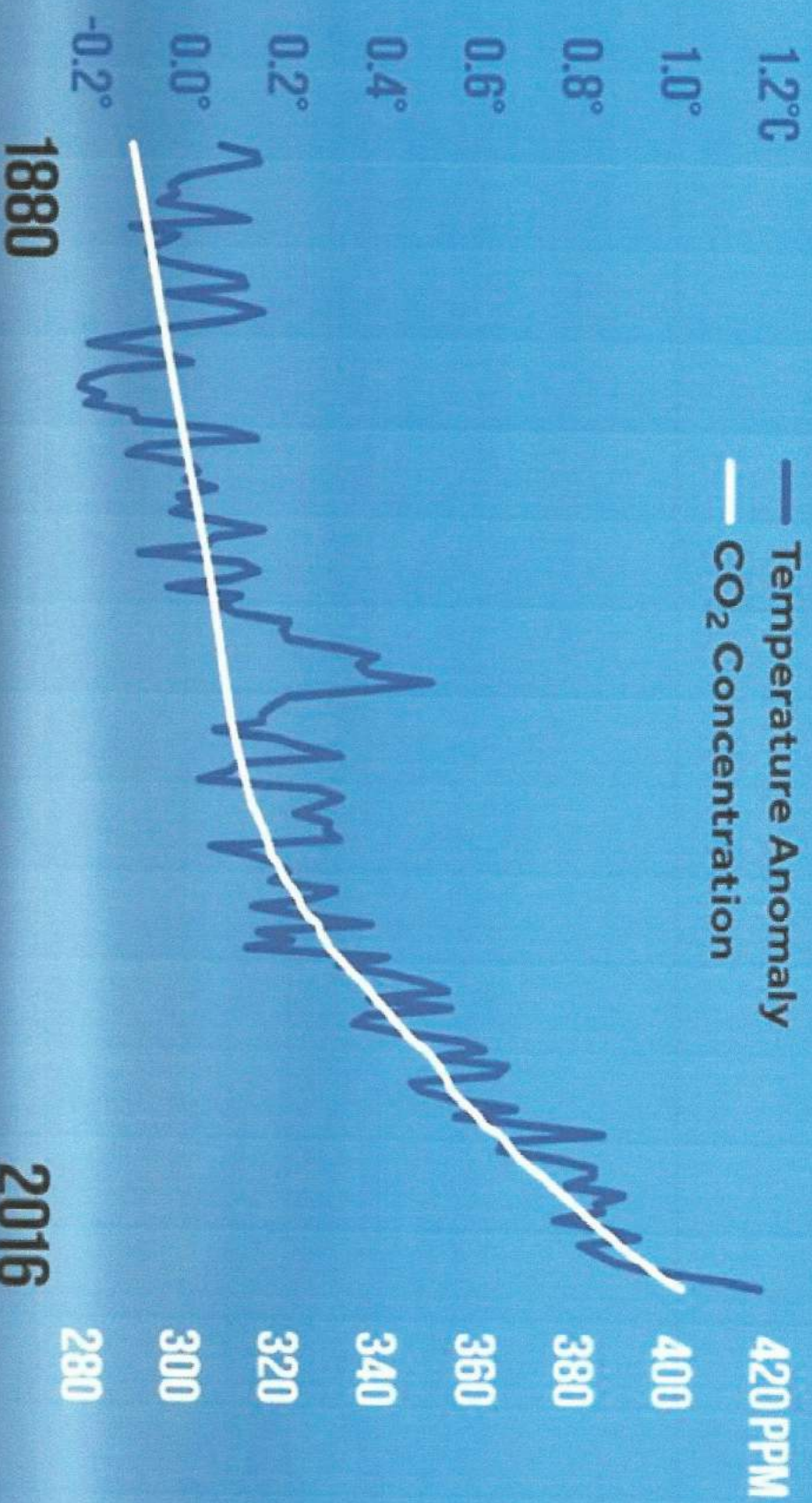


Global Temperature and Carbon Dioxide



Global temperature data averaged and adjusted to early industrial baseline (1881 - 1910).
Source: NASA GISS, NOAA NCEI, ESRL

CLIMATE  CENTRAL

An Earth Scientist's Perspective on Climate Change

October 2018 | Ray Leonard

Geoscientists have a special obligation. We are the historians of Earth's past, much as medical researchers have a responsibility regarding the understanding and honest communication of the functions of the human body and lawyers to understand and correctly interpret the law. Many of the tools we have established in our search for oil and gas, from plate tectonics to seismic stratigraphy, to study of paleoenvironments and paleontology, are being applied to understanding the geologic past in ways that document climate change.

To deny what is happening is also to ignore what our own profession and science is telling us and is a disservice to the public at large who depend on our expertise to help them make informed decisions.

The 20th century witnessed the greatest rise in living standards in human history, supported by the energy provided from fossil fuels. Now, however, we face the consequences; the great challenge of the 21st century, which may define how we live in the future: how to deal with a changing climate caused in large part by the emission of CO₂ due to the burning of these fossil fuels.

The evidence for climate change comes from three main sources:

- The actual measurements taken from the ground, water, atmosphere and from space in recorded history
- The scientific principles behind the effects of solar radiation, the components in our atmosphere and an understanding of the applicable chemistry, physics and mathematics
- The geologic record of the past, which clearly demonstrates the changes in climate in the past and how to relate those changes with current processes

Global Warming

Careful measurements have documented the world temperature rise over the past century, particularly since 1950, with the overall rise of 1.3 degrees Celsius since 1880 (see figure 1). The rate of increase is accelerating and is now about 0.25 degrees per decade. The past three years (2015-17) have been the hottest ever recorded. However, temperature increases have not been uniform, north and south polar regions (above 60-degree latitude) have been warming at approximately twice the rate of tropical and temperate latitudes. The effects on both polar caps have been immense: as carefully monitored by NASA, the September (minimum ice period) north polar cap has lost 70 percent of its ice

volume in the 1980-2016 period (figure 2). This would project to a September ice-free pole by around 2040. West Antarctica temperatures have actually risen at four times the planetary rate since 1950. The yearly ice loss from Antarctica has tripled in the 2007-17 period and the ice surrounding Antarctica reached an historic minimum in November 2016.

The rapid reduction in temperature differential between the poles and temperate and tropical latitudes, particularly in the northern hemisphere is weakening global circulation systems, such as the jet stream. This results in slower moving and stalled frontal and/or high-pressure systems and can produce prolonged record-breaking heat waves as seen this summer in East Asia and Northern Europe, and catastrophic levels of precipitation, such as we have seen in Houston last year. The number of extreme precipitation events on an annual basis doubled in the United States in the past 20 years compared with the last half of the 20th century.

The warming of the polar regions, plus the increased temperature in higher altitude at lower latitudes is melting the ice caps and glaciers, contributing to an accelerating average sea-level rise of 1 millimeter per year from 1880-1920, 2 millimeters per year from 1920-1980 and 3 millimeters per year from 1980-2010.

Ocean temperatures have also increased and the thermal expansion of water is contributing to about a third of sea-level rise.

Increasing Green House Gases

The warming of the planet, particularly in the past 50 years is primarily due to increases in the atmosphere in heat trapping gasses. These gasses include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Taking into account their heat-trapping properties, they account for 76 percent, 16 percent and 6 percent, respectively, of the greenhouse gasses in the atmosphere (figure 3).

Approximately 80 percent of CO_2 released in the atmosphere (32 gigatons annually) comes directly from the combustion of fossil fuels, mostly from the combustion of coal, oil and natural gas. That amount has doubled in the past 50 years on an annual basis.

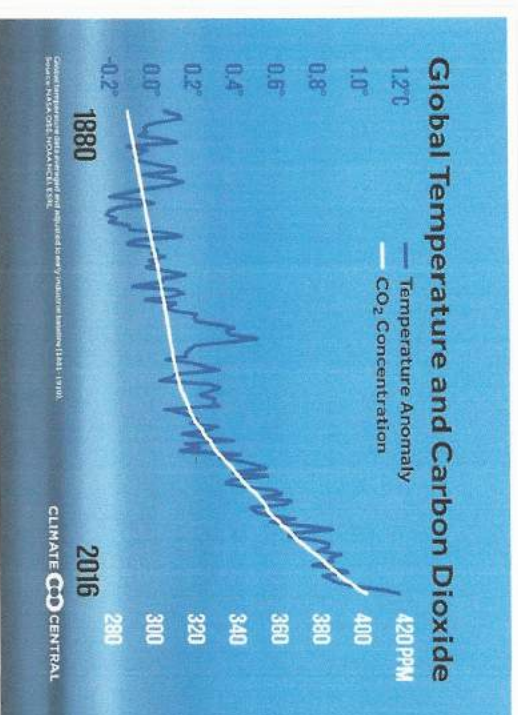


Figure 1. Global temperature has increased approximately 1.3 degrees C since 1880. A sharp increase in the rate of temperature rise was observed after 1950 which coincided with the increase in CO_2 content in the atmosphere. CO_2 content is now 411 ppm.

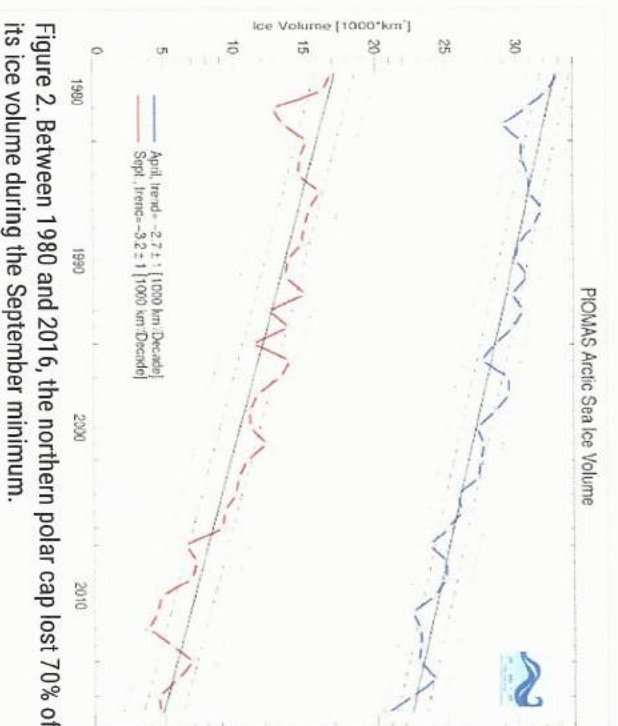


Figure 2. Between 1980 and 2016, the northern polar cap lost 70% of its ice volume during the September minimum.

The largest proportion (42 percent) comes from the burning of coal, followed by oil at 34 percent and natural gas at 18 percent (see figure 4). Coal is far more CO₂ intensive in emissions than oil, with gas being the cleanest hydrocarbon fuel. The burning of hydrocarbon fuels is estimated to account for only 20 percent of the GHG emissions of methane, whose rise is more closely correlated with overall human population and other activities and processes.

However, the melting of the permafrost accompanying the warming of the Arctic is beginning to cause massive methane emissions that are as yet unquantified, which may increase the methane warming effect. Most of the GHG emissions of N₂O come from agriculture, with only 10 percent due to the burning of fossil fuels, so that increase is again more closely related to human population rise.

The largest factor, therefore, in climate change, is the level of CO₂ in the atmosphere. From the fossil record we have multiple means of estimating the level of CO₂ in the past (figure 5). Certain plants form differently depending upon CO₂ level in the atmosphere. Chemical composition of shells of marine organisms also differ with CO₂ atmospheric variation. From air bubbles in ice cores recovered from up to 800,000 years ago in the Antarctic, these variations have been tested and verified. Throughout most of the Mesozoic, a period with overwhelming geological evidence of warm climate and higher sea levels than the present, the CO₂ level was around 800 parts per million. By the end of the Cretaceous, it had declined to about half that level before rising again in the Paleogene (65-30 million years ago) warming period, during which it rose back up to around 800 ppm. There is much geologic evidence that the CO₂ rise and consequent Paleogene warming was due to increased vulcanism. About 30 million years ago, it again declined to about 400 ppm and at that time, along with a cooler climate, the Antarctic ice sheet formed. About 3 million years ago, a further decline is recorded, to below 300 ppm with evidence of the formation of the northern polar cap.

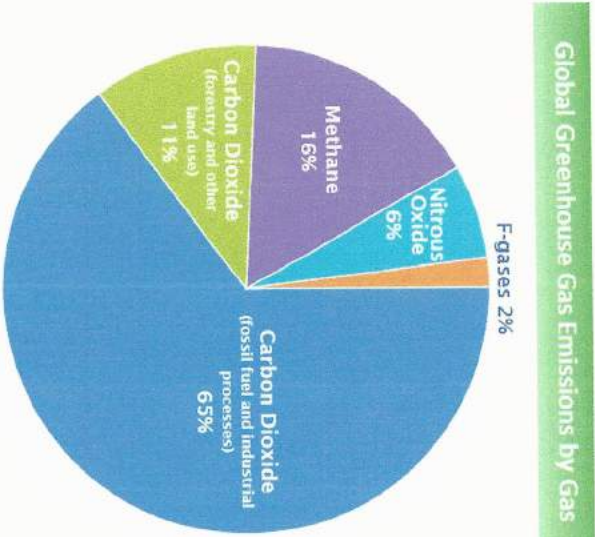


Figure 3. Greenhouse gas emissions are dominated by CO₂ (76 percent) followed by Methane, CH₄ (16 percent) and Nitrous Oxide, N₂O, (6 percent). 80 percent of CO₂ emissions come from burning of hydrocarbon fuel and related industrial processes. Source: EPA, 2017

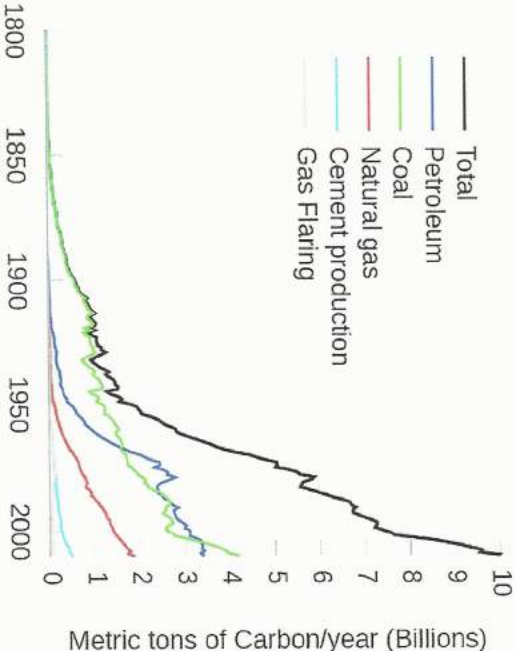


Figure 4. Comparative CO₂ emissions: CO₂ emissions rose steadily until 1950 when economic expansion in the "developed world" led to

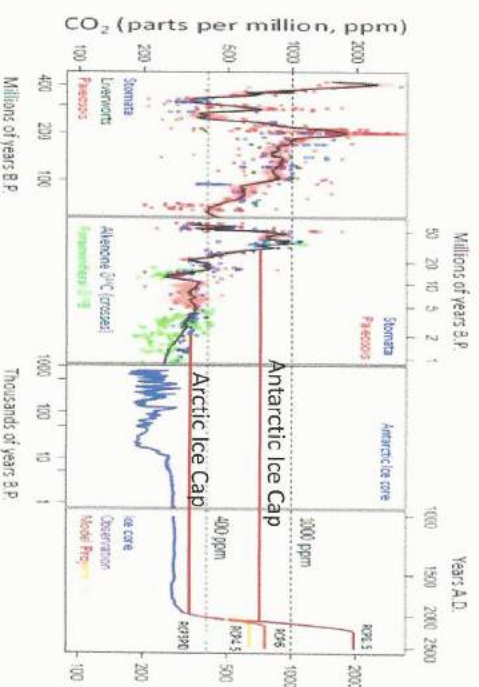
Since that time, as documented in detail by ice cores from the last 800,000 years (figure 6) the CO₂ level has fluctuated between 180 and 300 ppm, with the lower number associated with a cold climate and extreme glaciation with sea level of about 100 meters below the present. We emerged from the last glaciation period about 12,000 years ago and the CO₂ level has ranged from about 260 to 280 ppm through historic times until the late 19th century with the lower levels associated with “mini-ice ages” and the higher with the warmer periods.

The CO₂ level began to rise as the industrial revolution gathered momentum and reached 300 ppm around 1900 and slowly rose to around 320 ppm by 1950. At that point, the explosion in economic activity and use of hydrocarbon fuels, especially oil, led by the United States, Europe and the Soviet Union pushed the level to 380 ppm by 2000. The industrialization of China, mainly fueled by coal, has been the most prominent factor in the rise in this century to the current level of 411 ppm. At the current increase of 2.7-3 ppm per year, consistent with the emission of 40 gigatons of CO₂ emitted annually, a level of 500 ppm will be reached around 2050, a level not seen since the end of the Paleogene warming period, 30 million years ago.

Rising Sea Level

Based on the historical record and present-day observations and trends, by that time, the late summer north polar cap will be largely gone and the glaciers of the northern hemisphere, including Greenland, melted or well into the process of melting. The climate will have irrevocably changed in ways we are only now beginning to understand as the temperature differential between the poles and temperate and tropical latitudes will be further diminished. Sea level rise will be less than one meter by that time, but the rate of rise will be increasing. However, 90 percent of the planet's ice above sea level is locked in the Antarctic ice sheet, protected by surrounding ice, and it is this melting that would cause the catastrophic sea level rise that would change the world as we know it. The fossil record indicates that it was when the CO₂ level dropped significantly below 800 ppm that the Antarctic ice sheet began to form, and the achievable task facing mankind is to slow and then halt the rise in CO₂ atmosphere content and find a way to gradually reduce it so that the CO₂ level remains significantly below the 800 ppm level.

vastly increased emissions. The economic development of China, fueled mostly by coal resulted in another spike. Source: CDIAC, DOE



Foster et al, 2017, adapted Montenez, 2018

Figure 5 The fossil record demonstrates the 800 ppm CO₂ level in the Mesozoic and Paleogene and the lower levels afterwards, coinciding with the formation of the Antarctic and then Arctic ice caps. Our rise above 400 ppm and inevitable rise to 500 ppm by 2050 shows that we are reaching levels not seen since the Paleogene. Source: adapted from Foster (2017) and Menendez (2018).

Conclusion

To deny the existence of global warming and climate change means to ignore or suspect that data provided by worldwide weather stations and NASA satellites has somehow been fabricated or altered. Looking at a half century of data, the trend and correlation between temperature and atmospheric CO₂ content is obvious. The data from the Arctic and Antarctic is most troubling as it demonstrates an acceleration of the process beyond many of the earlier predictions.

There are natural climate variations documented in the ice cores of the past 800,000 years. These are likely due to eccentricities in the Earth's orbit and variations in solar radiation. However, those natural variations over that time period caused CO₂ levels to range from 180 ppm to a maximum of 300 ppm with cycle times of 50,000 to 100,000 years. We have had a 50-percent increase in CO₂ from 280 to 411 ppm since 1880 – less than 150 years, with more than half of that increase in the past 40 years! This increase can be directly tied to the amount of CO₂ emitted from the burning of fossil fuels and is clearly not "normal variation."

(Editor's Note: The opinions and positions stated here do not necessarily represent those of the EXPLORER editorial staff nor those of AAPG leadership or membership, but are the author's own.)

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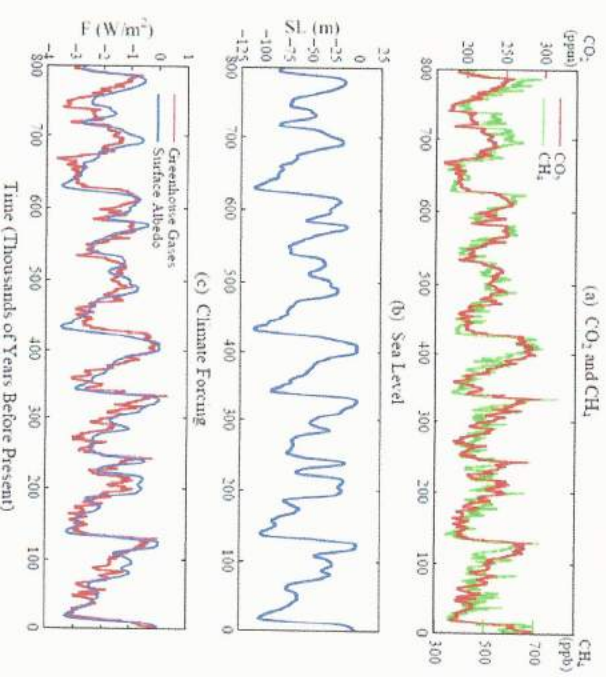


Figure 6 The record from ice cores over the past 800,000 years documents the range of CO₂ content of 180-300 ppm, the cycle time of 50,000-100,000 years and the interpellation of atmospheric CO₂ content with sea level rise and fall. Adapted from Hansen and Sato, 2013.

Bravo

Thank you, Ray, and the AAPG editorial staff, for an article which speaks to our organization's values of advancing the science of geology and fostering the spirit of scientific research throughout our community.

10/25/2018 10:57:35 AM **Edith Newton Wilson**

Global temperature 'hockey stick'

Gentlemen I am questioning the continued use of the global temperature hockey stick illustrated in figure 1. Even a cursory review of the literature surrounding how it was calculated, automatically taints the rest of the article! That really is a shame.

10/19/2018 5:34:10 PM **Paul V. Pedersen**

Let's separate cause and action to deal with the consequences

While I fully support the conclusions made by this article, I think we need to take a different approach when dealing with the larger population who are generally ignorant of the scientific process and are easily swayed by unsubstantiated headlines. My suggestion is that we focus on 1) the fact that temperatures are rising quickly (easy to show as seen in this article) and 2) the consequences of that increase. We don't have to agree on the cause of the increase, which seems to be the big point of debate, to recognize that increasing temperatures will mean larger hurricanes, rising sea level, etc. Once we agree on those two points, we then collectively admit that we have a problem and we have the basis of conversation regarding what we should do next. This approach doesn't solve the issue of the cause(s) of the temperature increase, but it should move society as a whole closer to taking action rather than continuing to debate.

10/19/2018 1:49:58 PM **Allan Scardina**

Climate Science

Congratulations to Ray Leonard for a reasoned discussion fortified by diverse data sets. Having known Ray years ago I respect his judgement and attention to detail. And I complement the editor of AAPG Explorer for publishing this essay following the previous essay that attracted spirited response. Debate is healthy. The comments by Monte Naylor focus on two aspects of the climate science: how Earth temperature is measured and on the meaning of climate change recorded in ice cores. Earth temperature is measured by a set of different tools from thermometers mounted in a grid above the surface, by ocean stations and by satellites. This set of data distinguishes between local noise, such as urban effects, and regional trends. The ice cores show that for the past 800,000 years CO₂ has varied no higher than 300 ppm, in contrast to the current level of 411 ppm measured at the top of a Hawaiian volcano. The effect of solar energy on atmospheric CO₂ is clear and the correlation between rising CO₂ and temperature is solid science. As explorationists/exploitationists, a key issue is how do we use our scientific skills to continue providing hydrocarbons and yet ameliorate its effects on rising temperatures, melting glaciers and rising sea level.

Robert W. Scott

10/18/2018 7:56:32 PM **Robert William Scott**

Thank you for a climate reality article

Thanks to Ray Leonard and the editors of the EXPLORER for this article. Although, Mr. Leonard is not a climate scientist, he is a "trusted source" since he is a distinguished AAPG lecturer. It certainly is a positive step that the EXPLORER has published a climate change article that voices the majority opinion of climate scientists instead of a minority opinion of a climate change denier (August 2018 EXPLORER). Granted that majority opinions should not be considered the last word, to ignore conclusions of 97% of peer reviewed papers that attributed a causation to climate change is to ignore how we daily perform as geologists (97% is based on published surveys by Cook et al., 2013 and 2016). Hopefully the AAPG membership finally agrees the climate is changing. Even President Trump now states it is not a hoax. And being scientists, we know "things" don't just happen. Even ignoring climate models, a published examination of historical climate change records indicates no other plausible explanation for global warming other than increased CO₂ levels (Rhode et al., 2013). Addressing a point brought up in the comments that in the geologic past increased global temperatures generally preceded increased atmospheric CO₂ levels, this is true. But prior to the late Holocene there were not billions of humans injecting prodigious amounts of CO₂ into the atmosphere. Speaking of humans, in order to insure our kids and grandkids do not have to face the worst of the hazards predicted by the latest IPCC Special Report on Global Warming 1.5oC, there needs to be a greater than a 700% increase in renewable energy within decades. This transition cannot occur without the assistance of the O&G industry. We need to be part of the discussions on how to get there but we can't unless we recognize the problem.

10/18/2018 9:48:38 AM

James "Jim" Rine

Climate Change

Like Monte Naylor, I'm resubmitting my comment. I haven't yet seen what I sent, so I'll take this opportunity to edit my response. (Like him, I wonder about formats with respect to paragraphs. Whatever.) ¶ I want to thank my colleague Ray Leonard for making his reasoned summary of our responsibility as geologists to help our fellow humans understand climate change. ¶ I see two frequent tropes among geologists like me, we who have made a good living finding fossil fuels for our fellow consumers. First comes the question "How did you get here?" Oh, you drove your car. Cheap shot. Then we claim, "Climate has always changed." To which I reply, "it's changing faster than ever." So many of us geologists are pridefully stuck in deep time, thinking of millions of years, even billions. We understand so much about long-term change that we forget about RATES of change. Humankind has never experienced the kind of rapid climate change that is coming upon us. Try as we might to slow it, let alone reverse it (which we should do), we MUST start reacting to what is happening! Move cities inland, sea level will rise, deal with diseases, they will migrate; water shortages will come, we must adjust agricultural patterns, and maybe even give up eating meat -- sorry, barbecue joints, but that might have to happen. Party-hearty for the moment, my friends! The end is nigh. No, seriously; Ray is right. Read the Conclusion in his piece, and think about our progeny. ¶ I wonder: At the very end of the Permian, during that Great Extinction, did lots of species panic, saying WHAT is happening? Even though they didn't cause it. Or did they play a part? What about that big oxygen event several hundred million years before that? Organisms almost certainly affected climate then, but whatever was alive probably didn't see change coming. We, on the other hand, are aware. And yet ...

10/15/2018 6:04:26 PM

Arthur W. Browning

Another Earth Scientist's Perspective on Climate Change

I want to thank my colleague Ray Leonard for making his reasoned summary of our responsibility to help our fellow humans understand humans and climate change. I see two, frequent tropes among us geologists who have made our living from the finding fossil fuels. We ask, first, "How did you get here?" Oh, you drove your car. Cheap shot. Then we say, "Climate has always changed." To which I say, "it's changing faster than ever." Too many of us geologists are stuck in deep time. We understand so much about long-term change that we forget about RATES of change. Humankind has never experienced the kind of rapid climate change that is coming upon us. Try as we might to slow it, let

alone reverse it (which we should do), we MUST start reacting to what is happening! Move cities inland, sea level will rise; deal with diseases, they will migrate; water shortages will come, we must adjust agricultural and habits. Party-hearty for the moment, my friends! The end is nigh. No, seriously; Ray is right. Read the Conclusion in his reasonable commentary, and think about our progeny. Do you think that at the very end of the Permian, lots of species panicked, saying WHAT? Nothing like now.

10/15/2018 3:40:53 AM **Arthur W. Browning**

recent submission

In my recent comment submission, a review screen seemed to remove the paragraphing. I will try again with the submission. I am disappointed to see this researcher showing the correlation of CO₂ and temperature from ice core and thermometer data and then stating that increasing carbon dioxide in the atmosphere is causing atmospheric warming. He must know that the increasing CO₂ in the ice core records is the result of atmospheric warming, not the cause. Numerous studies of ice core data from both the Antarctic and Greenland show a 400 to 1000-year lag between increasing atmospheric temperatures and increasing CO₂ concentrations in the atmosphere. Atmospheric warming (whether from orbital eccentricities, variable solar irradiation, or otherwise) is followed by ocean warming and the release of carbon dioxide. The ice core data shows the very opposite of this researcher's assertion. Carbon dioxide concentrations remain very high long after the rapid onset of atmospheric cooling at the beginning of these "cyclical" glacial events. Carbon dioxide seems to have little influence on atmospheric temperature. It is just along for the atmospheric warming and cooling ride. I would add that the global temperature history from thermometer data that the researcher shows at the beginning of the article is highly questionable. My own studies of thermometer-derived temperature histories (TOB adjustment of USHCN stations and then averaging a group of station temperature histories from an area, for example, the eastern plains of Colorado) show about half as much warming as NOAA shows for this area. Other researchers have discussed and demonstrated the contamination of the thermometer data due to expanding urban-heat-island at some USHCN weather stations, along with significant problems with the temperature reporting at a great number of the United States Historical Climatological Station over the previous 120 years.

10/14/2018 7:50:00 PM **Monte Naylor**

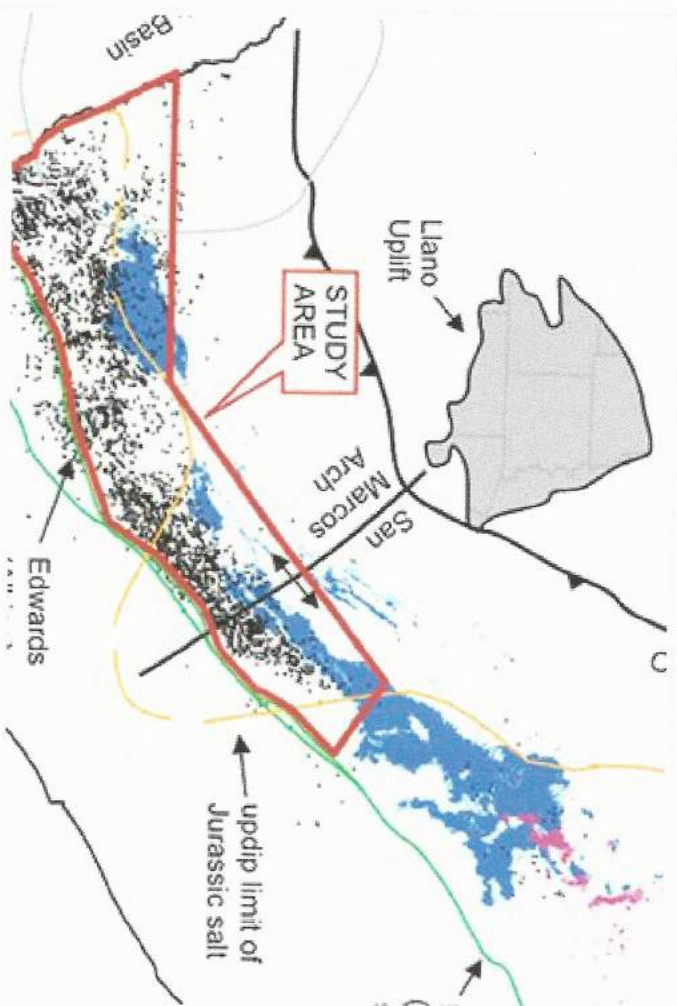
CO₂ as climate driver

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10/14/2018 4:16:58 PM **Monte Naylor**

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