Extreme Climate

By John Benson

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1. Introduction

In my writing on climate change, I frequently point out that the complexity of the Earth's climate greatly reduces our ability to understand the future effects that we will see from secondary, tertiary and higher-order effects of climate change. There are several things that we can do to clarify this cloudy future:

1) Continue to develop ever more powerful computer-simulations of our climate
2) Continue to support scientists' work to better understand future climate-related effects, and integrate this knowledge into the above simulations

This post covers both of these subjects. Section 2 describes a better understanding we have of a secondary effect of climate change that I have written about previously. Section 3 describes awards that the U.S. Department of Energy recently made to perform the work described in (2) above. Section 4 describes parts of the recently passed Inflation Reduction Act that incentivizes the Petroleum Industry to reduce its methane emissions. Section 5 reviews California's $54 billion in new spending on clean energy and drought resilience.

2. Accelerated Biogenic Methane Emissions

I posted the paper linked below more than two years ago. At that time it was widely known that atmospheric methane concentrations were accelerating, but what was not known was why. Many automatically assumed that the petroleum industry was the boogieman. Although this source is a major problem (see section 4 in this post), as it turned out, it was not the major source, but rather most of the recent acceleration was a secondary effect of climate change.

https://www.energycentral.com/c/ec/methane-growth

Now we are starting to better understand this effect, and the fact it involves a positive feedback loop makes it very worrisome.

If carbon dioxide is an oven steadily roasting our planet, methane is a blast from the broiler: a more potent but shorter lived greenhouse gas that's responsible for roughly one-third of the 1.2°C of warming since preindustrial times. Atmospheric methane levels have risen nearly 7% since 2006, and the past 2 years saw the biggest jumps yet, even though the pandemic slowed oil and gas production, presumably reducing methane leaks. Now, researchers are homing in on the source of the mysterious surge. Two new preprints trace it to microbes in tropical wetlands. Ominously, climate change itself might be fueling the trend by driving increased rain over the regions.[1]

If so, the wetlands emissions could end up being a runaway process beyond human control, although the magnitude of the feedback loop is uncertain. "We will have handed

[1] Paul Voosen, Science, "Feedback loop may be accelerating methane emissions," July 13, 2022, https://www.science.org/content/article/ominous-sign-global-warming-feedback-loop-may-be-accelerating-methane-emissions , Note that access may be limited for individuals that are bot AAAS Members.

over a bit more control of Earth's climate to microorganisms," says Paul Palmer, an atmospheric chemist at the University of Edinburgh and co-author of one of the studies, posted late last month for review at Atmospheric Chemistry and Physics.

Most climate scientists already agreed that the post-2006 methane spike has largely not come from fossil fuel production. That's because atmospheric methane has become ever more enriched in carbon-12, the lighter isotope of carbon, reversing what had been a multi-century trend, says Xin Lan, a carbon cycle scientist at the Earth System Research Laboratories (ESRL) of the National Oceanic and Atmospheric Administration. "This is a very significant signal," she says. It points to microbes as the source because they favor reactions that use light carbon, giving the methane they produce a distinctive light signature.

Author's comment: there are only two stable isotopes of carbon, carbon-12 and carbon-13. Thus, carbon 12 is commonly called "light carbon" and carbon-13 is called "heavy carbon."

Yet the isotopic signal cannot distinguish between microbes in a swamp, a landfill, or a cow's gut. "A cow is a walking wetland," says Euan Nisbet, an atmospheric chemist at Royal Holloway, University of London. Most researchers think a mix of cattle ranching and landfills in the tropics are the main driver of the post-2006 increase, because they have expanded dramatically alongside populations in the region.

But the sharp acceleration in the past couple of years seemed to require some other source. Studies are now implicating the Sudd in South Sudan, the continent's largest swamp and a region researchers have been unable to study on the ground because of the long-term conflict in the region. Using Japan's Greenhouse Gases Observing Satellite, which measures the amount of light absorbed by methane at infrared wavelengths, Palmer and his colleagues were able to show the Sudd had grown as a methane hot spot since 2019, adding some 13 million extra tons per year to the air—more than 2% of annual global emissions. A second study, posted in late June by Harvard University researchers and submitted to Environmental Research Letters, finds nearly the same story, especially the surge in East Africa. When combined with smaller increases from the Amazon and the northern forests, it largely explains the observed rise in the atmosphere.

Author's comment: Note *"…northern forests,"* immediately above. This points out some other positive feedback loops, and one of them involves beavers. See the earlier paper described and linked below:

Positive Feedback Accelerates Sea Level Rise: The surface air temperature of the arctic is rising twice as fast as the global air temperature. This is the result of many positive feedback forces, and causes previous simulations of how fast the Greenland ice sheet is melting to be out of date almost as soon as they are published, and not in a good way. Furthermore, Mother Nature seems to have many surprises for climatologists and many of these involve positive feedback.

This paper will look at the positive feedback loops that we have seen recently.

https://www.energycentral.com/c/ec/positive-feedback-accelerates-sea-level-rise

Climate change may be setting the pace of the emissions. In work published earlier this year in Nature Communications, Palmer and colleagues showed how East African methane emissions from 2010 to 2019, measured by satellite, synced up with a

temperature pattern in the Indian Ocean that periodically warms the waters off the Horn of Africa, causing increased rainfall on land. Climate projections call for this positive phase of the Indian Ocean dipole, as it's known, to grow in strength and duration with continued global warming. If it does, Palmer says, warming will beget more methane emissions from the Sudd, which in turn could fuel more warming and rains—a positive feedback loop.

Ed Dlugokencky, an atmospheric chemist at ESRL, agrees East African wetlands may well play a big role in the methane emissions of the past 2 years. "But the question of whether it's a climate feedback yet is very difficult to answer," simply because of limited records and large yearly variations in rainfall and wetland emissions. Nisbet notes, though, that the same dynamic may be playing out across other tropical wetlands. "A warming world is a wetter world in the moist tropics," Nisbet says. "We have good reason to expect, if we have a moisture and temperature increase, then biological productivity follows." Research flights over wetlands in Zambia found methane levels 10 times higher than models suggested, Nisbet and his colleagues reported in May.

The researchers who identified the East Africa link also worked to rule out another possible driver of the 2-year surge: a slowdown in the destruction of atmospheric methane. Unlike carbon dioxide, which lingers for centuries, methane only lasts a dozen years or so before it is washed out of the air, primarily by an atmospheric cleanser called the hydroxyl radical (OH). Nitrogen oxides, common pollutants from fossil fuel burning, help form OH—and nitrogen oxides declined as traffic and industry subsided during the early part of the pandemic, which should have reduced OH and allowed more methane to survive. "But we find that's not the case at all," says Daniel Jacob, an atmospheric chemist at Harvard and co-author on the second study. Matching the pandemic's estimated OH reduction in their models led to a negligible change in methane levels…

Author's comments: More specific to the above, methane is removed from the atmosphere (mainly converted to CO_2) by chemical reactions, primarily with the hydroxyl radical and by chemical reactivity with soil. The net effect is an exponential rate of reduction with a half-life of 8.6 years. This means that if a given volume of methane is released today, the volume remaining after 30 years is about 10% of the original volume.

Note that the above-described increase is caused by a primary and secondary effect of climate change. The primary effect is global warming which heats up the environment in which Methanogenic Bacteria live, thus accelerating their metabolism. The secondary effect is increased humidity and precipitation caused by the warming atmosphere's increased ability to carry and release this moisture (via rain in this case). The latter effect provides more habitat for the Methanogenic bacteria, expanding their emissions.

3. Improving Climate Change Predictions

In the introduction I discussed the importance of "*scientists' work to better understand future climate-related effects*." The U.S. Department of Energy also understands this and has recently invested in this effort.

The U.S. Department of Energy (DOE) today announced $14 million in funding for 22 projects aimed at improving climate change predictions. As extreme weather events and impacts of climate change continue to escalate, the research projects will advance fundamental scientific understanding of atmospheric processes, ranging from cloud formation to Arctic weather. Expanding the scientific understanding of extreme weather

and climate patterns is key to tackling the climate crisis and meeting President Biden's climate goals like slashing greenhouse-gas emissions. [2]

"Climate-fueled weather events from drought, to fires, to hurricanes, and polar vortices are becoming more common and more intense and wreaking havoc on our communities," said U.S. Secretary of Energy Jennifer M. Granholm. "We must expand our understanding of changing weather patterns and equip scientists, researchers, and lawmakers with every possible tool to tackle the climate crisis. President Biden and DOE are committed to protecting American communities from extreme weather events and fighting climate change through critical investments in science and research that illuminate pathways to decarbonization and broaden our scientific foundation…"

The data and analysis from these projects will help improve prediction and understanding of the atmosphere, which is essential to addressing President Biden's goal of achieving a 50-52% reduction from 2005 levels in economy-wide net greenhouse gas pollution by 2030. The President is also focused on helping communities mitigate damage from climate change, and, in 2021, the Biden Administration announced nearly $5 billion in funding to help communities prepare for extreme weather...

The awards announced today were chosen by competitive peer review from proposals submitted to a funding opportunity under the Atmospheric System Research program, sponsored by the Office of Biological and Environmental Research (BER), within the Department's Office of Science.

Funding totals $14 million in Fiscal Year 2022 dollars for projects lasting three years. A table with a list of projects can be found below (next page).

4. Methane Emissions Reductions

The following are two federal government programs to reduce methane emissions.

4.1. Inflation Reduction Act Stick

The Inflation Reduction Act (IRA) has been described as being "all carrot" and "no stick" but that is not entirely correct. It is certainly true that the IRA uses "carrots" – principally in the form of tax credits – to incentivize actions that will reduce greenhouse gas emissions… For example, the Environmental Protection Agency (EPA), for instance, has been allocated over $1.5 billion for "grants, rebates, contracts, loans" and "other activities" to reduce greenhouse gas emissions from the oil and natural gas sector. That sector is also affected by an important new "stick" created by the IRA.[3]

The stick takes the form of a "methane emissions charge," which EPA must collect from certain entities in the oil and natural gas sector, unless and until stringent regulations controlling the sector's methane emissions are implemented. While the charge is somewhat limited, its inclusion in the IRA is nevertheless a big deal. It represents the first time the federal government has levied a fee on the emission of any greenhouse gas. *(Continued on page 6)*

[2] Department of Energy, "DOE Awards $14 Million to Improve Climate Change Predictions," July 7, 2022, https://www.energy.gov/articles/doe-awards-14-million-improve-climate-change-predictions

[3] Romany Webb, Columbia Law School, Climate Law Blog, "The New Methane Emissions Charge: One (Limited but Important) Stick in The Inflation Reduction Act," Aug 23, 2022, https://blogs.law.columbia.edu/climatechange/2022/08/23/the-new-methane-emissions-charge-one-limited-but-important-stick-in-the-inflation-reduction-act/

Department of Energy Announces $14 Million for New Atmospheric Research

Annoucement Number: DE-FOA-0002579 *List Posted: 7/8/2022*

Principal Investigator	Title	Institution	City	State	9-digit zip code
Adams-Selin, Rebecca	Establishing a Holistic Understanding of Mesoscale Convective System Stratiform Precipitation Regions	Atmospheric and Environmental Research, Inc.	Lexington, MA	MA	02421-3126
Ahmed, Fiaz	Thermodynamic and Non-thermodynamic Controls on Deep Convection in ARM Observations	University of California	Los Angeles, CA	CA	90095-1406
Ajoku, Osinachi	Modeling Impacts on the Stratocumulusto- Cumulus Transition Associated with Southern Africa Biomass Burning Outflow Constrained by ARM Observations	Howard University	Washington, DC	DC	20059-0001
Choi, Yunsoo	Incorporating ARM TRACER Campaign Data into a Fine-Resolution WRF-Chem- SBM Data Assimilation Framework: Sensitivity Analysis of Microphysics and Thermodynamics to CCN Profile	University of Houston	Houston, TX	TX	77204-2015
Collins, Don	Understanding the Impact of Pollution Aerosol from Los Angeles/Long Beach on Clouds and Radiation in and Upwind of the EPCAPE Study Domain	University of California	Riverside, CA	CA	92521-0217
Dzambo, Andrew	Surface, Aerosol, and Meteorological Controls on Arctic Boundary Layer Clouds: Observations and Simulations from MOSAiC and COMBLE	University of Oklahoma	Norman, OK	OK	73019-9705
Farmer, Delphine	Observational Constraints on Size- Resolved Particle Deposition Across Landscapes	Colorado State University	Fort Collins, CO	CO	80523-2002
Hallar, Anna	Using ARM Data to Understand the Impact of New Particle Formation on Cloud Condensation Nuclei Concentration in Different Environments	University of Utah	Salt Lake City, UT	UT	84102-9023
Horowitz, Hannah	Improving the Representation of Arctic Sea Salt Aerosols in Climate Models Using Observations from Field Campaigns and Remote Sensing	University of Illinois	Champaign, IL	IL	61820-7406
Kuang, Zhiming	Analyses of Cumulus Mixing Using ASR Aircraft Observations and LES Simulations	Harvard College	Cambridge, MA	MA	02138-5369
Lamb, Kara	Connecting Laboratory Experiments and In-Situ Observations of Depositional Ice Growth	Columbia University (Morningside Campus)	New York, NY	NY	10027-7922
Li, Zhanqing	Investigation of Surface-Cloud Coupling over Land Using ARM observations and Model Simulations	University of Maryland	College Park, MD	MD	20742-5141
Lombardo, Kelly	Understanding the Life Cycle of Deep Convective Storms Trave	Pennsylvania State University	University Park, PA	PA	16802-7000
Mechem, David	Using ARM Observations and Large- Eddy Simulation to Constrain Cloud Processing of CCN in Boundary-Layer Clouds over the Eastern North Atlantic	University of Kansas Center for Research, Inc.	Lawrence, KS	KS	66045-7568
Persson, Ola	The Arctic Atmospheric Boundary-Layer Structure and its Interactions with the Free Troposphere and Surface	University of Colorado	Boulder, CO	CO	80303-1058
Smalley, Mark	The Aerosol-Cold Pool Connection: Impacts on Marine Low Cloud Morphology	University of California	Los Angeles, CA	CA	90095-1406
Smith, James	Ultrafine Aerosol Particle Formation and Impacts During EPCAPE	University of California	Irvine, CA	CA	92697-7600
Sullivan, Ryan	Potentially Large Contribution of Biomass-Burning Aerosol to Global Ice Nucleating Particle Concentrations and Implications for Aerosol Lifecycle and Cloud Microphysics	Carnegie Mellon University	Pittsburgh, PA	PA	15213-3589
Tan, Ivy	Exploiting Ground-Based Observations to Infer Arctic Surface Cloud Feedbacks	McGill University	Montreal	Canada	H3A 0G4
van Leeuwen, Peter Jan	Aerosol-Cloud Interactions in Warm Clouds Using Advanced Causal Discovery	Colorado State University	Fort Collins, CO	CO	80523-2002
Wexler, Anthony	The Hygroscopicity and CCN Potential of Organic Aerosol Moieties	University of California, Davis	Davis, CA	CA	95618-6153
Witte, Mikael	The aerosol-cold pool connection: impacts on marine low cloud morphology	Naval Postgraduate School	Monterey, CA	CA	93943-5004

Starting with methane was likely more politically feasible than carbon dioxide for several reasons. For one thing, methane is emitted in smaller quantities than carbon dioxide, accounting for just 11 percent of total national greenhouse gas emissions (compared to 79 percent for carbon dioxide). Despite that, however, reducing methane emissions could have major climate benefits. Methane is a much more potent warming agent than carbon dioxide, trapping 87 times more heat in the earth's atmosphere in the first twenty years after it is released (on a pound-for-pound basis). Given that, and since methane has a relatively short atmospheric life (see author's comment at the end of section 2)*, reducing methane emissions now could help to mitigate climate change in the short term and thus buy us time to reduce carbon dioxide emissions.*

Controlling methane emissions should, at least in theory, also be somewhat easier than reducing carbon dioxide emissions. Whereas carbon dioxide is emitted by a wide range of activities, most methane emissions come from just three sectors. According to EPA, agriculture is the largest source of methane emissions (accounting for 38% of the national total in 2020), followed by oil and natural gas (33%), and waste management (16%). (Previous studies have shown that EPA significantly underestimates methane emissions from the oil and natural gas sector, which may, in fact, be a larger source of methane than agriculture.) The methane emissions charge in the IRA will only apply to certain parts of the oil and natural gas sector, but its adoption is still an important development that could deliver significant climate benefits.

Most methane emissions from the oil and natural gas sector are the result of accidental leakage and intentional venting of natural gas, which predominantly methane. Preventing leaks and venting not only helps to reduce methane emissions and thus mitigate climate change, but also has financial benefits for oil and gas producers who can sell any natural gas they capture or do not leak. The proceeds from the sale help to offset any investment in capture systems, meaning that emissions reductions can often be achieved at little or no cost. Indeed, according to a 2021 report by the International Energy Agency, almost 45 percent of global methane emissions from oil and natural gas operations could be avoided at no net cost. An earlier study focused on the U.S. found that domestic emissions from onshore operations could be cut by 40 percent at a cost of less than one cent per thousand cubic feet of natural gas produced. (To put that in perspective, on average, U.S. households currently pay $17.55 per thousand cubic feet of natural gas.)

Nevertheless, to date, federal regulation of methane emissions from the oil and natural gas sector has been fairly limited. In 2016, EPA adopted regulations (known as "New Source Performance Standards" or "NSPS") aimed at controlling methane emissions from certain facilities used in the production, processing, transmission, and storage of oil and natural gas. The NSPS only applied to so-called "new facilities" constructed after September 18, 2015 but, even so, EPA estimated that they would cut methane emissions by 510,000 short tons or 11 million metric tons of carbon dioxide equivalent in 2025. Seeking to further reduce emissions, shortly after finalizing the NSPS, EPA began developing regulations to control emissions from existing facilities constructed before September 18, 2015. However, when President Trump took office a few months later, EPA halted work on the existing facility regulations. It also commenced a review of the NSPS and, in 2020, rescinded them.

Shortly after President Biden's inauguration, Congress passed a resolution to undo EPA's 2020 rescission of the 2016 NSPS, effectively reinstating it. Later, in November 2021, EPA proposed to strengthen the 2016 NSPS and establish new regulations for

existing facilities. That proposal has not yet been finalized, however. Meanwhile, Congress has forged ahead, establishing a new "Methane Emissions Reduction Program" in the IRA.

Central to the program is the methane emissions charge, which the IRA authorizes EPA to collect from certain entities in the oil and natural gas sector starting in 2024. EPA can, however, waive the charge if it finalizes the NSPS and existing facility regulations it proposed in November 2021 (or other regulations that result in equivalent emissions reductions) and those regulations are "in effect in all states." (Note that any existing facility regulations EPA adopts will need to be implemented by the states through so-called "state implementation plans." If one or more states fail to act, EPA can adopt a "federal implementation plan." No waiver can be granted unless and until all of the state plans, and any federal plan, are finalized and in force.)

The methane emissions charge will start at $900 per metric ton of methane emitted in 2024 and increase to $1,200 in 2025 and $1,500 in 2026. Only facilities meeting the following two criteria will be subject to the charge:

Facilities must fall within one of the following industry segments:

- *On- or offshore oil and natural gas production;*
- *Onshore natural gas processing;*
- *Onshore oil and natural gas gathering;*
- *Onshore natural gas transmission;*
- *Underground natural gas storage; or*
- *Liquified natural gas (LNG) import, export, or storage; and*

Facilities must have annual reported methane emissions exceeding 25,000 metric tons of carbon dioxide equivalent.

Initial analysis by the Congressional Research Service estimates that over 2,100 facilities meet these requirements and thus would be subject to the charge. Methane emissions from the covered facilities totaled approximately 78.3 million metric tons of carbon dioxide equivalent in 2019. Covered facilities will not, however, be required to pay the charge on all of those emissions.

4.2. Derelict Oil and Gas Well Clean Up

The Interior Department is giving 24 states a total of $560 million to start cleaning high-priority derelict oil and gas wells abandoned on state and private land, the department said Thursday.[4]

It said up to 10,000 wells could be dealt with as the government begins allocating $4.7 billion set aside to create an orphan well cleanup program under the bipartisan

[4] Janet McConnaughey, AP, "24 states get $560M for high-priority cleanup of wells," Aug 25, 2022, https://apnews.com/article/climate-and-environment-abac8672bf9e4f45ac944cb76d84a7cf?utm_medium=email&et_rid=17039174&et_cid=4389358

infrastructure plan approved late last year. The Environmental Protection Agency estimates there are more than 3 million abandoned oil and gas wells around the nation.

The infrastructure law "is enabling us to confront long-standing environmental injustices by making a historic investment to plug orphaned wells throughout the country," Secretary Deb Haaland said in a news release.

A dozen states including Arkansas, Kansas, New Mexico and Ohio, have prioritized wells in disadvantaged communities, the department said.

Louisiana said it would plug 250 to 900 wells near low-income communities, providing a chance for unemployed energy workers from such areas to learn how to plug orphaned wells and to get work doing so, a separate release said.

Most of the states are getting $25 million each to clean wells and measure methane, with 15 using some of the money to enable measurement of the potent greenhouse gas.

Arkansas, which has 227 wells on its priority list, and Mississippi, which plans to use part of its grant to inventory orphaned wells, are getting $5 million each.

In April, the department announced $33 million to cap and clean up 277 wells on federal land.

States have identified anywhere from a dozen to more than 2,000 wells to plug with these initial grants, the department said…

5. California Legislature's 54 Billion Climate Bill

See the summary at the end of this section. Note that these bills were all proposed by Governor Newsom, so it is safe to assume that he will sign them. As of a few days before this paper is due to post, I haven't seen any news reports of the signing. Note that the signing will be posted on each of the bill's web sites (linked at the end of this section).

California state lawmakers worked late into Wednesday night (8/31) to pass an aggressive climate legislation package, including $54 billion in new spending on clean energy and drought resilience measures, and a bill to stop the planned closure of the state's last nuclear plant.[5]

The legislative action comes as California and other Western states are in the grip of an intense heatwave amid a devastating, 22-year drought. And it follows state air regulators' vote to phase out new gas-powered car sales in the state by 2035.

Among other things, the legislation will codify new benchmarks to get California to 90% clean electricity by 2035 and 95% by 2040 -- stepping stones toward its already established goal of 100% clean electricity by 2045.

The package's passage is a major victory for Gov. Gavin Newsom, who advocated strongly for new climate measures at the start of the state's legislative session.

[5] Ella Nilsen, CNN, "California passes massive climate and clean energy package, halts closure of state's last nuclear plant," Sep 1, 2022, https://www.cnn.com/2022/09/01/politics/california-passes-climate-legislation/index.html

"Our state is facing the most extreme temperatures we've experienced this year, putting our communities, especially our most vulnerable neighbors, at risk," Senate President pro Tempore Toni G. Atkins said in a statement. "We're also continuing to deal with an historic drought and the ongoing threat of wildfires.

Atkins called the legislation "tremendous, decisive action" that will help protect California from the climate crisis.

The $54 billion, intended to be spent over five years, contains around $6 billion for electric vehicles and more than $8 billion to decarbonize the state's electrical grid -- which is still heavily reliant on natural gas. It also includes close to $15 billion to improve public transit, and over $5 billion for climate and drought resilience programs.

The legislature also postponed closing California's Diablo Canyon nuclear power plant, voting to keep the plant open until at least 2030. Proponents said the vote will help stabilize the state's electric grid with zero-emissions energy, as the plant provides about 9% of the state's electricity…

For the record, the following are bills passed during this flurry. For a given bill, go through the link and scroll down to the Legislative Counsel's Digest for a (relatively) brief summary of the bill:

AB-1279: The California Climate Crisis Act.

https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279

SB-1137: Oil and gas: operations: location restrictions: notice of intention: health protection zone: sensitive receptors.

https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB1137

SB-1020 Clean Energy, Jobs, and Affordability Act of 2022:

https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB1020

SB-905 Carbon sequestration: Carbon Capture, Removal, Utilization, and Storage Program.

https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB905

AB-1757 California Global Warming Solutions Act of 2006: climate goal: natural and working lands.

https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220AB1757

SB-846 Diablo Canyon power-plant: extension of operations.

https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB846