

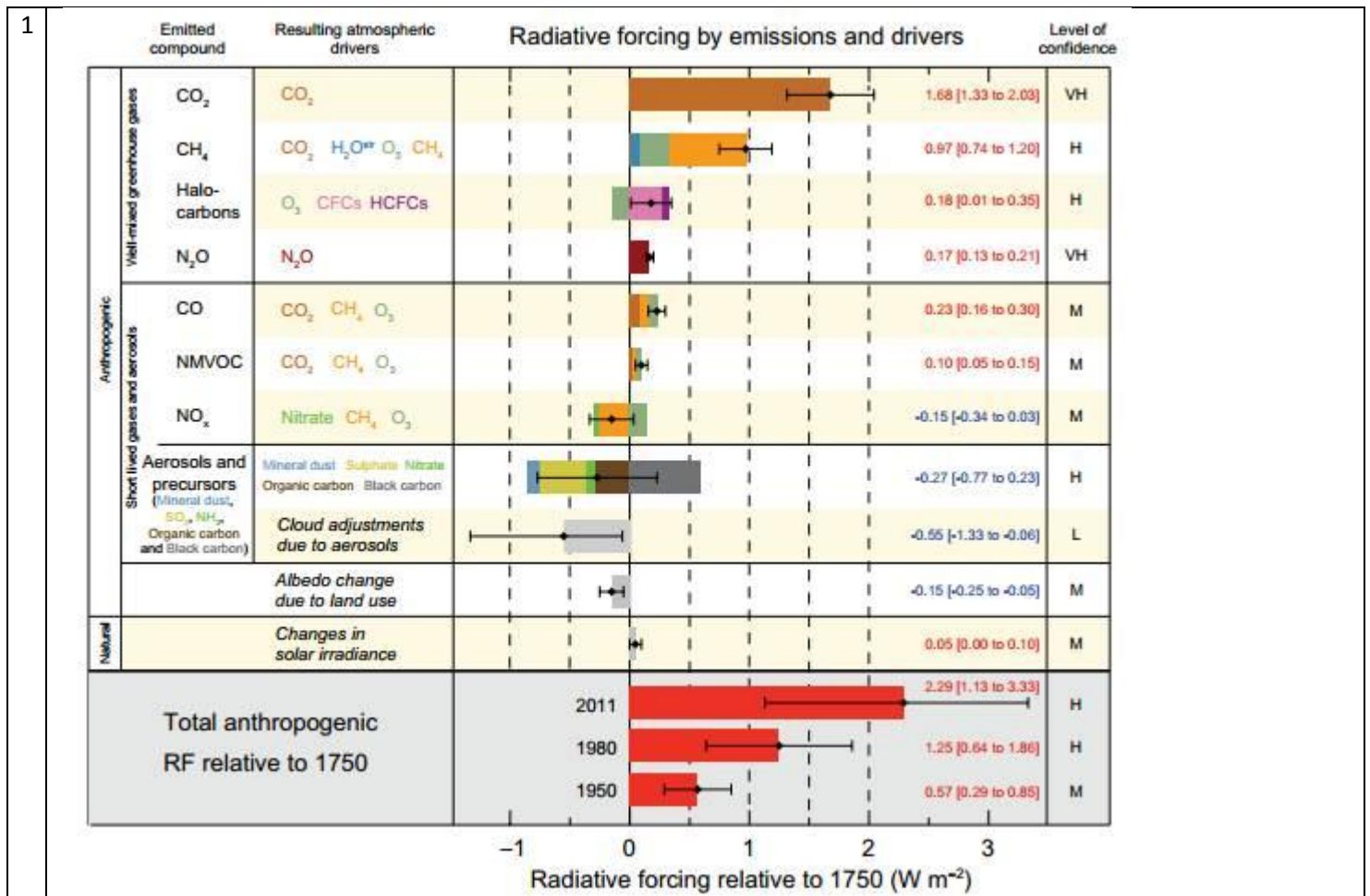
Methane Expectations

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<http://ccdatacenter.org/documents/MethaneExpectations.pdf>

- The radiative forcing of methane (CH₄) is about 60% that of CO₂¹
- Global methane concentrations had risen from 722 parts per billion (ppb) in pre-industrial times to about 1850 ppb in 2017^{2,3}
- Since methane is removed from the atmosphere relatively quickly, if annual methane emissions are relatively constant the atmospheric concentration will not change much⁴
- There are substantial quantities of methane in the Arctic. Release of even a small percentage of this methane (10%?) could have a significant on global temperature, but the seriousness of this problem is a matter of debate.^{4,5}



2 Methane

Methane (CH₄) is the next-most important anthropogenic greenhouse gas (GHG), after carbon dioxide (CO₂). With methane and carbon dioxide at current levels, It is calculated by both [MODTRAN](#) Tropical Atmosphere and the NCAR Radiation Code that a 0.1 ppmv increase in atmospheric methane level has about the same warming effect as a 4.5 ppmv increase in CO₂ level. (Some other authorities estimate more or less than that 45:1 ratio, e.g., the IPCC's

AR5 [Table 8.A.1](#) estimates [26.5:1](#).)

Methane is also involved in a widely discussed, hypothetical, [positive feedback process](#).

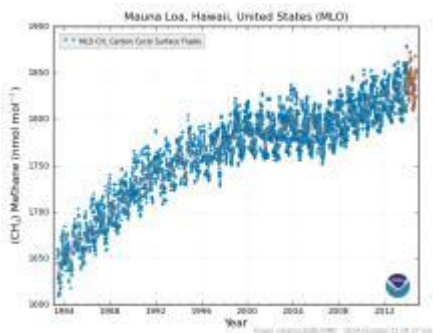
However, even if you don't burn it, methane in the atmosphere oxidizes fairly rapidly, changing ultimately into (negligible amounts of) harmless CO₂ and water:



[Various sources](#) give the half-life of CH₄ in the atmosphere as 6 to 8 years, which would make the average lifetime 1.4427 times that (because oxidation is an exponential process, rather than linear), yielding an average lifetime for a molecule of CH₄ in the atmosphere of 8.7 to 11.5 years. Page 11 of [this](#) source gives the directly-calculated atmospheric lifetime of CH₄ as ~8 years, but identifies a [feedback mechanism](#) that (they say) effectively increases the atmospheric lifetime of *additional* CH₄ to ~12 years.

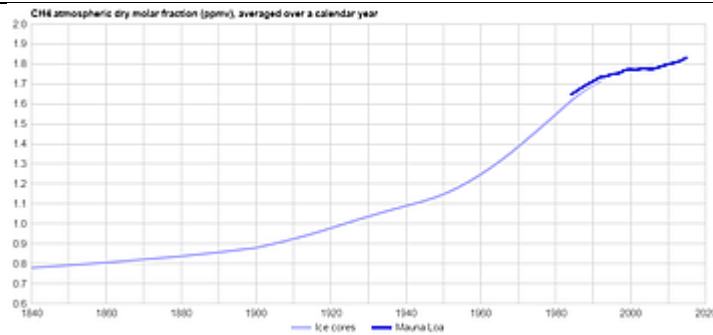
Call it 8-12 years. That's pretty short. It means the only reason CH₄ levels are as high as they are (about 1.86 ppmv[†]) is that CH₄ emissions are already high. There would have to be a very large,[‡] sustained increase in CH₄ emissions to cause much increase in long-term average atmospheric CH₄ levels.

Methane levels have been monitored at Mauna Loa, Hawaii since 1983. During most of that time they've been inching [up slightly](#), from about 1.65 ppmv to about 1.86 ppmv now. Here's a graph:



[Click for full-sized, latest version](#)

Ice core samples have extended the methane measurement record much further. Here's a smoothed graph of methane levels from 1840 to present:



[Click for full-sized, latest version](#)

†Methane levels vary slightly by location; [this site](#) has some maps.

‡How large is “very large?” Well, for comparison, it would take about [3 Gt](#) of CH₄ to increase the atmospheric methane level by 1 ppmv.

<https://www.sealevel.info/methane.html>

3 Attribution of recent increases in atmospheric methane through 3-D inverse modelling

Abstract. The atmospheric methane (CH₄) growth rate has varied considerably in recent decades. Unexplained renewed growth after 2006 followed seven years of stagnation and coincided with an isotopic trend toward CH₄ more depleted in ¹³C, suggesting changes in sources and/or sinks. Using surface observations of both CH₄ and the isotopologue ratio value (δ¹³CH₄) to constrain a global 3D chemical transport model (CTM), we have performed a synthesis inversion for source and sink attribution. Our method extends on previous studies by providing monthly and regional attribution of emissions from 6 different sectors and changes in atmospheric sinks for the extended 2003–2015 period. Regional evaluation of the model CH₄ tracer with independent column observations from the Greenhouse gases Observing SATellite (GOSAT) shows improved performance when using posterior fluxes (R = 0.94–0.96, RMSE = 8.3–16.5ppb), relative to prior fluxes (R = 0.60–0.92, RMSE = 48.6–64.6ppb). Further independent validation with data from the Total Carbon Column Observing Network (TCCON) shows a similar improvement in the posterior fluxes (R = 0.90, RMSE = 21.4ppb) compared to the prior (R = 0.71, RMSE = 55.3ppb). Based on these improved posterior fluxes, the inversion results suggest the most likely cause of the renewed methane growth is a post-2006 1.8±0.4% decrease in mean OH, a 12.9±2.7% increase in energy sector emissions, mainly from Africa/Middle East and Southern Asia/Oceania, and a 2.6±1.8% increase in wetland emissions, mainly from Northern Eurasia. The posterior wetland increases are in general agreement with bottom-up estimates, but the energy sector growth is greater than estimated by bottom-up methods. The model results are consistent across a range of sensitivity analyses performed. When forced to assume a constant (annually repeating) OH distribution, the inversion requires a greater increase in energy sector (13.6±2.7%) and wetland (3.6±1.8%) emissions but also introduces an 11.5±3.8% decrease in biomass burning emissions. Assuming no prior trend in sources and sinks slightly reduces the posterior growth rate in energy sector and wetland emissions and further increases the amplitude of the negative OH trend. We find that possible tropospheric Cl variations do not to influence δ¹³CH₄ and CH₄ trends, although we suggest further work on Cl variability is required to fully diagnose this contribution. While the study provides quantitative insight into possible emissions variations which may explain the observed trends, uncertainty in prior source and sink estimates and a paucity of δ¹³CH₄ observations limit the accuracy of the posterior estimates. <https://www.atmos-chem-phys-discuss.net/acp-2018-474/>

4 Arctic and American Methane in Context

— david @ 24 November 2013

Lots of interesting methane papers this week. In Nature Geoscience, [Shakhova et al \(2013\)](#) have published a substantial new study of the methane cycle on the Siberian continental margin of the Arctic Ocean. This

paper will get a lot of attention, because it follows by a few months a paper from last summer, [Whiteman et al \(2013\)](#), which claimed a strong (and expensive) potential impact from Arctic methane on near-term climate evolution. That economic modeling study was based on an Arctic methane release scenario proposed in an earlier paper by [Shakhova \(2010\)](#). In PNAS, [Miller et al \(2013\)](#) find that the United States may be emitting 50-70% more methane than we thought. So where does this leave us?

The Context

Because methane is mostly well-mixed in the atmosphere, emissions from the Arctic or from the US must be seen within the context of the global sources of methane to the atmosphere. Estimates of methane emissions from the Arctic have risen, from land (Walter et al 2006) as well now as from the continental shelf off Siberia. Call it 20-30 Tg CH₄ per year from both sources. The US is apparently emitting more than we thought we were, maybe 30 Tg CH₄ per year. But these fluxes are relatively small compared to the global emission rate of about 600 Tg CH₄ per year. The Arctic and US anthropogenic are each about 5% of the total. Changes in the atmospheric concentration scale more-or-less with changes in the chronic emission flux, so unless these sources suddenly increase by an order of magnitude or more, they won't dominate the atmospheric concentration of methane, or its climate impact.

American Methane Emissions Higher Than Previously Thought

Miller et al (2013) combine measurements of methane concentrations in various locations through time with model reconstructions of wind fields, and “invert” the information to estimate how much methane was released to the air as it blew over the land. This is a well-established methodology, pushed to constrain US anthropogenic emissions by including measurements from aircraft and communications towers in addition to the ever-invaluable NOAA flask sample network, and incorporating socioeconomic and industrial data. The US appears to be emitting 50-70% more methane than the EPA thought we were, based on “bottom up” accounting (adding up all the known sources).

Is this bad news for global warming?

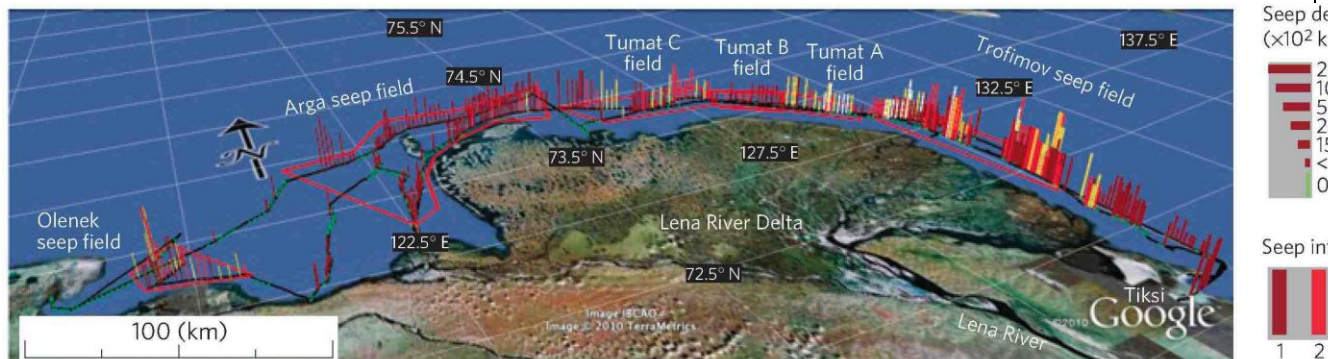
Not really, because the one real hard fact that we know about atmospheric methane is that it's concentration isn't rising very quickly. Methane is a short-lived gas in the atmosphere, so to make it rise, the emission flux has to continually increase. This is in contrast to CO₂, which accumulates in the atmosphere / ocean system, meaning that steady (non-rising) emissions still lead to a rising atmospheric concentration. There is enough uncertainty in the methane budget that tweaks of a few percent here and there don't upset the apple cart. Since the methane concentration wasn't rising all that much, its sources, uncertain as they are, have been mostly balanced by sinks, also uncertain. If anything, the paper is good news for people concerned about global warming, because it gives us something to fix.

Methane from the Siberian continental shelf

The Siberian continental shelf is huge, comprising about 20% of the global area of continental shelf. Sea level dropped during the last glacial maximum, but there was no ice sheet in Siberia, so the surface was exposed to the really cold atmosphere, and the ground froze to a depth of ~1.5 km. When sea level rose, the permafrost layer came under attack by the relatively warm ocean water. The submerged permafrost has been melting for millennia, but warming of the waters on the continental shelf could accelerate the melting. In equilibrium there should be no permafrost underneath the ocean, because the ocean is unfrozen, and the sediment gets warmer with depth below that (the geothermal temperature gradient).

Ingredients of [Shakhova et al \(2013\)](#)

1. There are lots of bubbles containing mostly methane coming up from the shallow sea floor in the East Siberian Arctic shelf. Bubbles like this have been seen elsewhere, off Spitzbergen for example ([Shakhova et al \(2013\)](#)). Most of the seep sites in the Siberian margin are relatively low flow but a few of them are much larger.



2. The bubbles mostly dissolve in the water column, but when the methane flux gets really high the bubbles rise faster and reach the atmosphere better. When methane dissolves in the water column, some of it escapes to the atmosphere by evaporation before it gets oxidized to CO₂. Storms seem to pull methane out of the water column, enhancing what oceanographers call “gas exchange” by making waves with whitecaps. Melting sea ice will also increase methane escape to the atmosphere by gas exchange. **However**, the concentration of methane in the water column is low enough that even with storms the gas exchange flux seems like it must be negligible compared with the bubble flux. In their calculation of the methane flux to the atmosphere, Shakhova et al focused on bubbles.
3. Sediments that got flooded by rising sea level thousands of years ago are warmer than sediments still exposed to the colder atmosphere, down to a depth of ~50 meters. This information is not directly applied to the question of incremental melting by warming waters in the short-term future.
4. The study derives an estimate of a total methane emission rate from the East Siberian Arctic shelf area based on the statistics of a very large number of observed bubble seeps.

Is the methane flux from the Arctic accelerating?

[Shakhova et al \(2013\)](#) argue that bottom water temperatures are increasing more than had been recognized, in particular in near-coastal (shallow) waters. Sea ice cover has certainly been decreasing. These factors will no doubt lead to an increase in methane flux to the atmosphere, but the question is how strong this increase will be and how fast. I'm not aware of any direct observation of methane emission increase itself. The intensity of this response is pretty much the issue of the dispute about the Arctic methane bomb (below).

What about the extremely high methane concentrations measured in Arctic airmasses?

[Shakhova et al \(2013\)](#) show shipboard measurements of methane concentrations in the air above the ESAS that are almost twice as high as the global average (which is already twice as high as preindustrial). Aircraft measurements published last year also showed plumes of high methane concentration over the Arctic ocean ([Kort et al 2012](#)), especially in the surface boundary layer. It's not easy to interpret boundary-layer methane concentrations quantitatively, however, because the concentration in that layer depends on the thickness of the boundary layer and how isolated it is from the air above it. Certainly high methane concentrations indicate emission fluxes, but it's not straightforward to know how significant that flux is in the

global budget.

The more easily interpretable measurement is the time-averaged difference between Northern and Southern hemisphere methane concentrations. If Arctic methane were driving a substantial increase in the global atmospheric methane concentration, it would be detectable in this time-mean interhemispheric gradient. Northern hemisphere concentrations are a bit higher than they are in the Southern hemisphere ([here](#)), but the magnitude of the difference is small enough to support the conclusion from the methane budget that tropical wetlands, which don't generate much interhemispheric gradient, are a dominant natural source ([Kirschke et al 2013](#)).

What about methane hydrates?

There are three possible sources of the methane in the bubbles rising out of the Siberian margin continental shelf:

1. **Decomposition (fermentation) of thawing organic carbon** deposited with loess (windblown glacial flour) when the sediment was exposed to the atmosphere by low sea level during the last glacial time. Organic carbon deposits (called Yedoma) are the best-documented carbon reservoir in play in the Arctic.
2. **Methane gas that has been trapped by ice**, now escaping. [Shakhova et al \(2013\)](#) figure that flaws in the permafrost called taliks, resulting from geologic faults or long-running rivers, might allow gas to escape through what would otherwise be impermeable ice. If there were a gas pocket of 50 Gt, it could conceivably escape quickly as a seal breached, but given that global gas reserves come to ~250 Gt, a 50 Gt gas bubble near the surface would be very large and obvious. There could be 50 Gt of small, disseminated bubbles distributed throughout the sediment column of the ESAS, but in that case I'm not sure where the short time scale for getting the gas to move comes from. I would think the gas would dribble out over the millennia as the permafrost melts.
3. **Decomposition (melting) of methane hydrates**, a peculiar form of water ice cages that form in the presence of, and trap, methane.

Methane hydrate seems menacing as a source of gas that can spring aggressively from the solid phase like pop rocks (carbonated candies). But hydrate doesn't just explode as soon as it crosses a temperature boundary. It takes heat to convert hydrate into fluid + gas, what is called latent heat, just like regular water ice. There could be a lot of hydrate in Arctic sediments (it's not real well known how much there is), but there is also a lot of carbon as organic matter frozen in the permafrost. Their time scales for mobilization are not really all that different, so I personally don't see hydrates as scarier than frozen organic matter. I think it just seems scarier.

The other thing about hydrate is that at any given temperature, a minimum pressure is required for hydrate to be stable. If there is pure gas phase present, the dissolved methane concentration in the pore water, from Henry's law, scales with pressure. At 0 degrees C, you need a pressure equivalent to ~250 meters of water depth to get enough dissolved methane for hydrate to form.

The scariest parts of the Siberian margin are the shallow parts, because this is where methane bubbles from the sea floor might reach the surface, and this is where the warming trend is observed most strongly. But methane hydrate can only form hundreds of meters below the sea floor in that setting, so thermodynamically, hydrate is not expected to be found at or near the sea floor. (Methane hydrate can be found close to the sediment surface in deeper water depth settings, as for example in the Gulf of Mexico or the Nankai trough). The implication is that it will take centuries or longer before heat diffusion through that

sediment column can reach and destabilize methane hydrates.

Is there any way nature might evade this thermodynamic imperative?

If hydrate exists in near-surface sediments of the Siberian margin, it would be called “metastable”. Metastability in nature is common when forming a new phase for which a “seed” or starting crystal is needed, like cloud droplets freezing in the upper atmosphere. But for decomposition to form water and gas one would not generally expect a barrier to just melting when energy is available. [Chuvilin et al \(2011\)](#) monitored melting hydrate in the laboratory and observed some quirkiness.

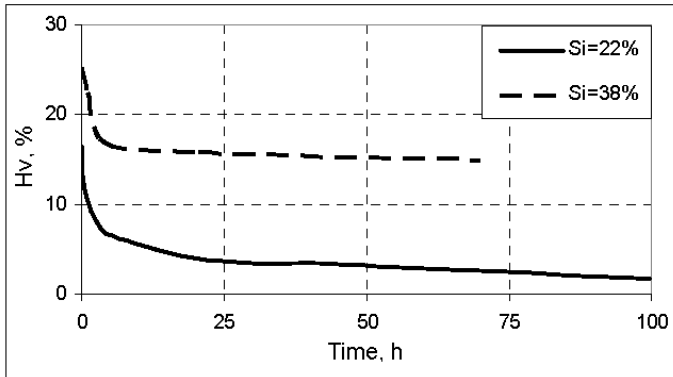


Figure 2: Influence of the ice saturation (S_i) on the kinetics of pore gas hydrates dissociation in the sample of sand 2 ($t = -6 \div -7$ °C; $P = 0.1$ MPa)

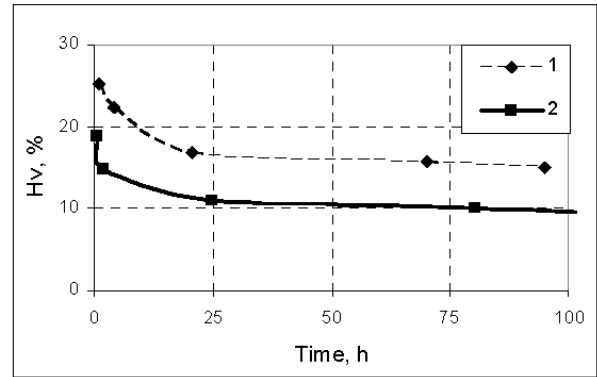



Figure 4: Change of volumetric hydrate-content (H_v) in the samples of sand 2 (1) and sandy loam (2) at pressure release below equilibrium ($W_{in} = 19-22\%$; $t = -5 \div -7$ °C; $P = 0.1$ MPa).

But these experiments spanned 100 hours, while the sediment column has been warming for thousands of years, so the experiments do not really address the question. I have to think that if there were some impervious-to-melting hydrate, why then would it suddenly melt, all at once, in a few years? Actual samples of hydrate collected from shallow sediments on the Siberian shelf would be much more convincing.

What about that Arctic methane bomb?

[Shakhova et al \(2013\)](#) did not find or claim to have found a 50 Gt C reservoir of methane ready to erupt in a few years. That claim, which is the basis of the Whiteman et al (2013) \$60 trillion Arctic methane bomb paper, remains as unsubstantiated as ever. The Siberian Arctic, and the Americans, each emit a few percent of global emissions. Significant, but not bombs, more like large firecrackers.

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<http://www.realclimate.org/index.php/archives/2013/11/arctic-and-american-methane-in-context/>

5 How Guy McPherson gets it wrong
02/17/2014 BY SJ

McPherson leans heavily on claims from people associated with the "Arctic News" blog about a catastrophic, runaway release of methane that supposedly is already underway in the Arctic. Unfortunately (or, rather, fortunately), the data don't match their assertions. The latest IPCC and NAS assessment reports, in fact, deemed such a release "very unlikely" this century. One reason for that is that the Arctic has been this warm or warmer a couple times in the last 200,000 years, yet that methane stayed in the ground. Another reason is that scientists actually bother to study and model the processes involved. One thing McPherson and others like to point to is the recent work by Natalia Shakhova's group observing bubbling plumes of methane coming up from the seafloor on the Siberian Shelf. Since we've only been sampling these plumes for a few years, we have no idea whether that release of methane is increasing or if these are long-term features. Similar plumes off Svalbard, for example, appear to be thousands of years old. (More to put this methane in context here.)

So what are we facing if Arctic methane releases increase? Climate scientist David Archer shows some back-of-the-envelope math here (<http://www.realclimate.org/index.php/archives/2012/01/an-arctic-methane-worst-case-scenario/>). If the release increased by a factor of 100 and lasted for a century, it would be the equivalent of increasing today's CO2 by 25-90%. Bad? Yes. Extinction? No.

<https://fractalplanet.wordpress.com/2014/02/17/how-guy-mcpherson-gets-it-wrong/>

6 **The US natural gas industry is leaking way more methane than previously thought. Here's why that matters**
July 2, 2018 by Anthony J. Marchese And Dan Zimmerle, The Conversation

The EPA currently estimates this methane leak rate to be 1.4 percent.

All told, based on the results of our new study, the U.S. oil and gas industry is leaking 13 million metric tons of methane each year, which means the methane leak rate is 2.3 percent.

An earlier EDF study showed that a methane leak rate of greater than 3 percent would result in no immediate climate benefits from retiring coal-fired power plants in favor of natural gas power plants.

What's more, some scientists believe that the leakage rate could be even higher than our estimate.

	https://phys.org/news/2018-07-natural-gas-industry-leaking-methane.html