Comment on:
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# Response of methane sources to rapid Arctic warming.

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Arctic response to global warming is already very strong, very rapid, and of major global significance. It poses an immediate and troubling danger to global climate that will likely have severe consequences both for the biosphere and the human economy. Accordingly, sustained monitoring, focused research and sound risk analysis are crucial for the predictions of future impact. Arctic hydrates have long been identified as a likely source of strong positive feedback[1,2]. However, the analysis by Whiteman et al. (2013) cannot be supported, as it is based on a hypothetical release of 50 Gt of hydrate-sourced methane, at a flux of 5 Gt per year over a period of a decade from 2015-2025. A methane release on this scale is orders of magnitude greater than found in the geological record, is much larger than suggested by hydrate modelling, and is not seen to date in atmospheric measurements (either locally in the Arctic or globally).

Our observations (e.g. NOAA network data available online at http://www.esrl.noaa.gov/gmd/ccgg/) from the atmospheric boundary layer in the Arctic show recent increases in atmospheric $CH_4$ at approximately the current global mean trend. Although 2007 showed strong growth in Arctic methane, other regions also show similar year-on-year episodes. There is currently no large sustained Arctic anomaly. The lack of trend in the difference between surface zonal means calculated for 53 to 90° North and South indicates no significant relative increase of Arctic emissions during the past two decades [3]. Wind travels - it is not static: Daily-average methane concentrations depend on air transport, typically over hundreds to thousands of kilometers. The beginnings of emission as large as that suggested by Whiteman et al (2013) would readily manifest as a large deviation from the regional mean.

The atmospheric record of $\delta^{13}C$ in $CH_4$ also gives no support for major hydrate-sourced methane releases currently reaching the atmosphere. Our isotopic evidence[4] shows that in air sampled in the high Norwegian Arctic, the regional summer methane increments are dominantly from Arctic wetland, not from hydrate. Since methane release from buried hydrate is from below the influence of seasonal temperature cycles, an absence of significant summer hydrate-sourced methane reaching the air also implies its absence in winter. Large hydrate-sourced releases are indeed already occurring, such as submarine plumes we have observed offshore Spitsbergen[5] but most gas is taken up in the water column, and the methane flux entering the air is currently limited. On the shallow East Siberian Shelf, extensive venting to the atmosphere does indeed occur[6], but gas hydrates are only one among several possible sources of methane in this area and the total magnitude of the methane emissions is the subject of debate[7].

Methane hydrate is stable at moderate pressures and low temperatures[8]. Thus hydrate occurs in the upper tens to hundreds of metres of sediment at water depths greater than 350 to 600 m on continental margins, in areas of continuous permafrost at depths greater than about 225 m, and at similar depths below the sea surface on shallow-water, high-latitude continental shelves that host relic subsea permafrost. On land, warming of the overlying atmosphere propagates downward and requires substantially longer than decades to destabilize the top of the gas hydrate stability zone. The thermal response to surface warming of ocean water at 400 m depth or more is strongly dependent on major ocean currents such as the West Spitsbergen current, and lags behind atmospheric warming. Shallower shelf waters can warm more rapidly, but heat must still penetrate underlying sediment at a rate limited by sediment thermal properties.

Methane released from gas hydrate deposits must find migration pathways to reach the land's surface or the seafloor, sometimes passing through permafrost-bearing sediments on the way. Methane also encounters oxidation zones in seafloor sediments and the water column and dissolution, not direct migration through the water column, is strongly favored in many areas due to the undersaturation of ocean waters with respect to methane. Mathematical models of hydrate decomposition [1,2] suggest the bulk of hydrate degassing will be "chronic"[9], spread over centuries or millennia, rather than catastrophic.

In the global context, there are roughly 5 Gt of methane in the modern atmospheric burden, with a total global flux of about 0.5 Gt per year[3]. Sudden Arctic warming, with very sharp temperature rises over a period of a few decades, has occurred in the past during glacial terminations[9], accompanied by increases in the global methane burden of about 1 Gt, supported by flux increases of very roughly 0.1 Gt/yr. This was likely driven dominantly by increased wetland emissions [11], but probably also with releases from decaying methane hydrate deposits [1,2,7]. This would imply that in glacial terminations, despite the scale and speed of Arctic warming, the likely hydrate-sourced flux was probably less than 0.05 Gt annually[2]. Recent modelling for the Arctic Ocean [12] suggests hydrate-sourced fluxes of roughly 0.1 Gt/yr over the next century even in the worst-case scenario. This flux is strongly limited by the rate of delivery of heat required to dissociate hydrate.[13]

Clearly large individual events can and probably will occur in the near future, such as major pockmark bursts and perhaps massive submarine landslides on hydrate [14,15], while local bubbling may be widespread on shelf seas[6]. But even with such events the geological record shows that the total decadal hydrate-sourced methane reaching the atmosphere is very unlikely to exceed 1 Gt, and may be far less than that. After millennia of cold, Late Glacial hydrates were probably more abundant and more rapidly destabilized by marine transgression and warming than will be the case in the current rapid Arctic warming. A 50 Gt decadal release, at a rate ~100x greater that during glacial/postglacial transitions, is thus improbably large.

Arctic methane emission is certainly an important, and even potentially dangerous climate feedback, and is of global significance. Great single events, like submarine landslides, or methane pockmark outbursts, may well occur. Increased Arctic methane output is likely from wetlands, which will be sharply more productive as they warm, from new methane production associated with microbial degradation of organic carbon released by thawing permafrost, and from marine and terrestrial hydrates. This is potentially a powerful consequence and reinforcer of global warming. Thus Arctic methane emission needs to be closely studied and carefully monitored. However, while hydrate deposits are indeed important, they need to be understood in context. In the global natural system, the response of wetlands (including tropical wetlands) to climate change also demands careful monitoring. The climate debate is complex: to be credible, risk scenarios need to be factually based and rooted on ongoing observations.

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