Economic impacts of carbon dioxide and methane released from thawing permafrost

Hope, C. *et. al., Nature Climate Change* (2015)
doi: 10.1038/nclimate2807

Objectives:

- This study was designed to show the range of potential global economic impacts of CO_2 and CH_4 emissions from thawing permafrost due to current rates of climate warming in the Arctic.
- The study links an integrated assessment model (PAGE09) with the Simple Biosphere/Carnegie-Ames-Stanford Approach (SiBCASA) biophysical land surface parameterization model.
- The default PAGE09 model is used to show the range of possible global economic impacts if the CO_2 and CH_4 emitted from permafrost thaw is released into the atmosphere on top of the anthropogenic emissions from the Intergovernmental Panel on Climate Change (IPCC) scenario A1B as well as three other scenarios.
- In the IPCC scenario A1B, anthropogenic emissions continue until the atmospheric concentration reaches ~700 ppm in 2100; this study makes the conservative assumption that there are zero anthropogenic emissions after 2100.
- The study runs 100,000 simulations of the PAGE09 integrated assessment model, perturbing various model parameters to explore fully the risks associated with anthropogenic and permafrost emissions.
- Economic impacts are defined as those that are included directly in gross domestic product (GDP), such as agricultural losses and air conditioning costs; non-economic impacts are those not included directly in GDP such as human health and ecosystem impacts; however, in this paper these are all called "economic" impacts and were included in the study.
- Additional economic losses, such as damage to infrastructure and to the foundations of buildings are not included in this study.
- The study assumes that permafrost emissions are uncorrelated with any of the other inputs of the PAGE09 model.
- The balance of competing effects which would occur from a serious attempt to limit anthropogenic emissions of greenhouse gases were also explored by running the model with an aggressive abatement policy, the 2015r5low scenario from the UK Met Office.
- The largest source of uncertainty in these estimates is the transient climate response (TCR) to anthropogenic warming used to drive permafrost thaw.

New Science:

- Under the A1B scenario, CO_2 and CH_4 released from permafrost increases the mean net present value (NPV) of the impacts of climate change by US$43 trillion, or about 13% (5-95% range US$3 – 166 trillion), proportional to the increase in total emissions due to thawing permafrost.
- In the default PAGE 09 model, without the permafrost CO_2 and CH_4 emissions, the mean NPV of the impacts of climate change is US$326 trillion; with the permafrost emissions this rises to US$389 trillion, an increase of 13%.
- Although the conservative assumptions mean that anthropogenic emissions stop in 2100, permafrost emissions continue to affect the global mean temperature to 2200 and beyond.
- In the default PAGE09 model the permafrost emissions increase the global mean temperatures in 2100 by an additional 0.17˚C (5-95% range: 0.11-0.25˚C) above temperature increases due to anthropogenic emissions.

- This effect is greater in the twenty-second than the twenty-first century because of the many lags in the global response to changes in emissions, increasing the global mean temperature by the mean value of 0.26˚C in 2150 and 0.29˚C in 2200.
- By 2200 permafrost emissions represent about 10% of cumulative anthropogenic emissions since pre-industrial times and contribute about 7% of the total mean warming.
- The default PAGE09 model mean annual value of all the extra impacts is about US $2.8 trillion in 2100 (about 0.35% of the projected global GDP in that year) and peaks at about US $30 trillion in 2200 (about 0.7% of the projected GDP in that year), the same peak date as additional temperature rise.
- The uncertainty range is wide because this calculation carries the full range of uncertainty in model parameters all the way through the nonlinear model interactions between the physical processes and economic impacts.
- Making different assumptions from the default PAGE model shows that six inputs are the most influential: the TCR, the pure time preference (PTP) rate, the elasticity of marginal utility of consumption (EMUC), the permafrost emissions, the feedback response time (FRT) and the exponent of the non-economic impact function with temperature (POW_2).
- Running the PAGE09 model with the same A1B emissions scenario but changing the socio-economic scenarios (to SSP2 and SSP3) increases the mean NPV of extra economic impacts to US$54 trillion and US$91 trillion, respectively.
- Using the UK Met Office 2015r5low scenario to explore aggressive abatement, the mean NPV of the extra impacts falls to US$6 trillion, with a 5-95% range of US$ 0.4-17trillion.

Significance:

- Permafrost soils contain about 1,700 gigatons (Gt) of carbon, nearly all of it in the form of frozen organic matter buried over thousands of years by dust deposition, alluvial sedimentation and peat development.
- Permafrost temperatures have risen and annual summer surface thaw depths have increased over the past few decades, indicating that permafrost has begun to thaw in response to the warming in the Arctic, where warming is happening twice as fast as the global average.
- If greenhouse gas emissions continue to increase at current rates, it will lead to widespread thawing of permafrost and the release of hundreds of billions of tons of CO_2 and billions of tons of CH_4 into the atmosphere, which in turn will amplify warming.
- Prior to this study there have been no estimates of the possible extra economic impacts from permafrost emissions of CO_2 and CH_4.
- The higher temperatures from with the permafrost CO_2 and CH_4 emissions result in higher economic and non-economic impacts and a higher chance of a catastrophic event such as the thawing of the Greenland and West Antarctic ice sheets.
- The extra impacts of the permafrost CO_2 and CH_4 emissions release are sufficiently high to justify urgent action to minimize the scale of the release.
- An aggressive abatement strategy that will reduce emissions from thawing permafrost is needed; such a policy will, among other benefits, reduce the mean extra impact of emissions by about US$37 trillion.

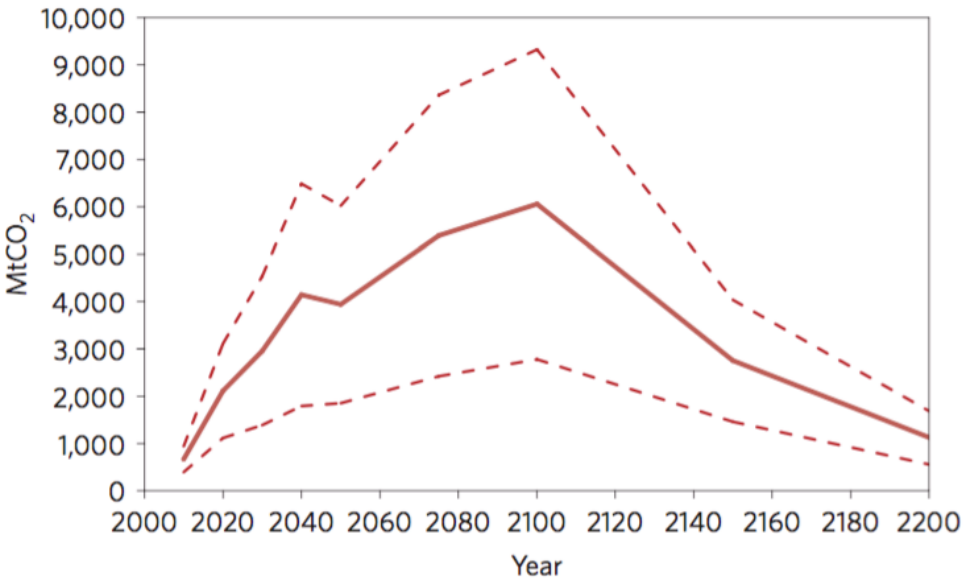

Figure 1
Estimated annual emissions of CO_2 from thawing permafrost for the A1B scenario from the IPCC AR4.
The solid line shows the mean values and the dashed lines are the 5 and 95% confidence intervals.

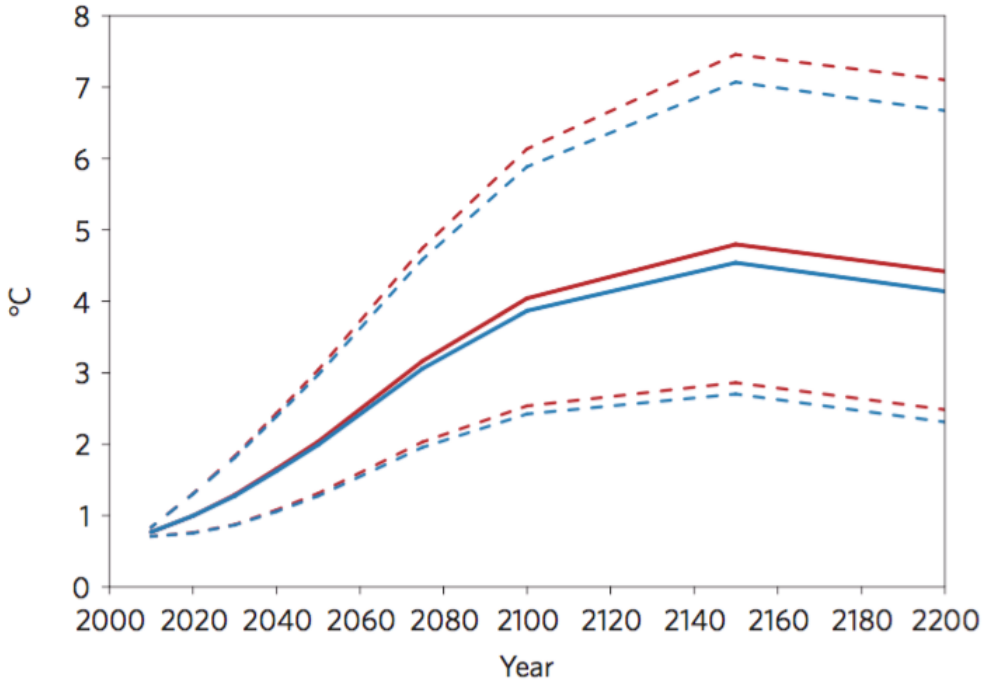

Figure 3
Global mean temperature rise relative to pre-industrial conditions by date, with and without permafrost and CO2 and CH4 emissions for the IPCC AR4 A1B scenario. The solid lines represent the ensemble mean of the 100,000 default PAGE9 simulations and the dashed lines represent the 5 and 95% confidence intervals. The red lines are with the permafrost emissions and the blue lines without.

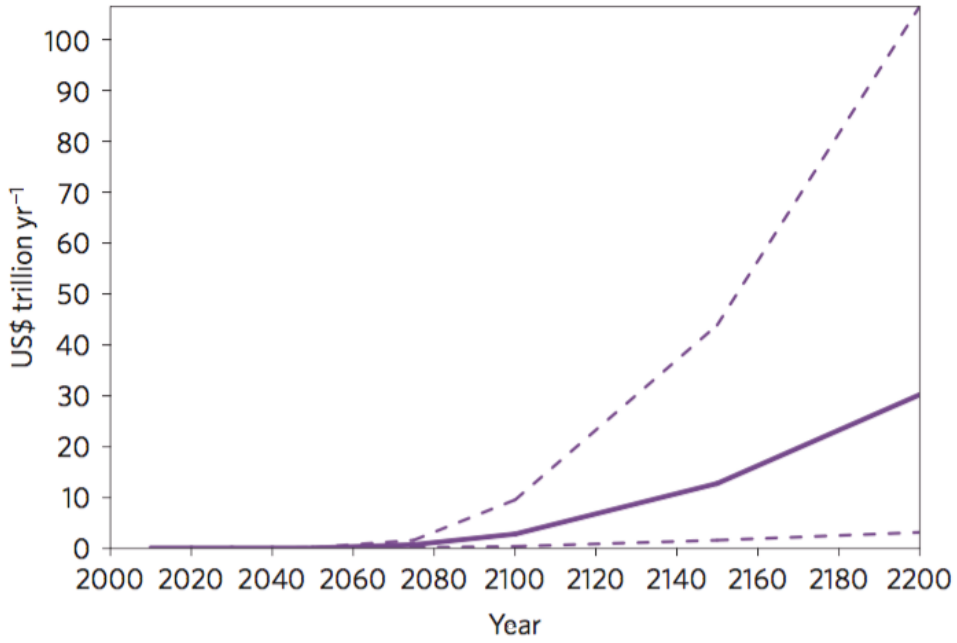

Figure 4
Extra annual economic impacts from permafrost CO2 and CH4 emissions, by date, for the IPCC AR4 A1B scenario estimated using the default PAGE9 method. The solid lines show the mean value, the dashed lines show the 5 and 95% values.

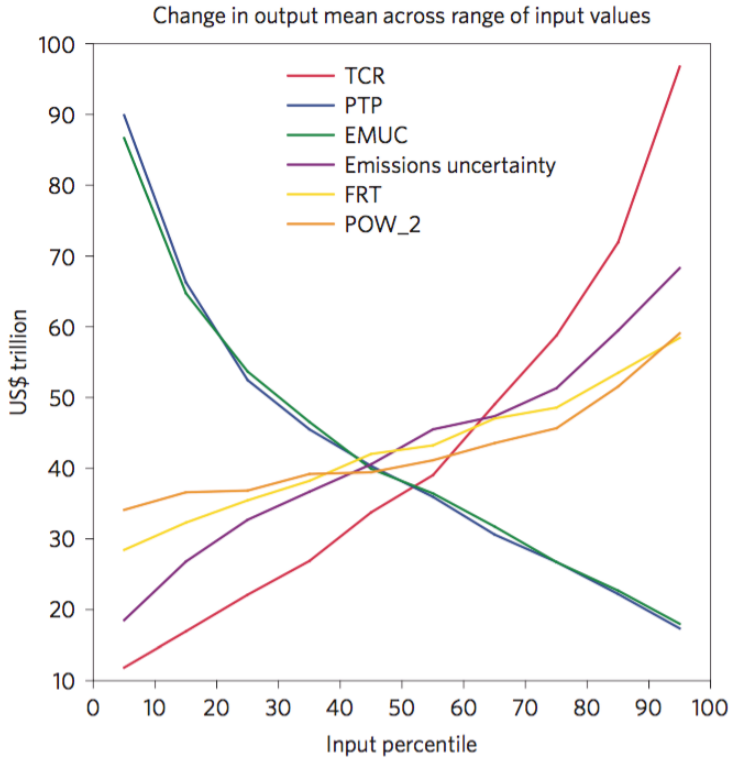

Figure 6
The inputs in the default PAGE9 model that most strongly influence the NPV of the extra impacts from thawing permafrost for the IPCC AR4 A1B scenario.