Parametric Study of Prompt Methane Release Impacts II: Effect of a Dynamic Ocean on Model Results

PattiMichelle Sheaffer

Research Scientist (ret.) - Aerospace Corporation (USAF/SMC, El Segundo, CA)

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1. INTRODUCTION / BACKGROUND

A unique event in 2020 was the nearly complete lack of ice cover over the shallow Kara Sea and Laptev Sea continental shelves at the end of October [*1*] – a necessary antecedent to a hypothesized continental-shelf clathrate methane-release runaway-warming feedback (https://www.mdpi.com/2076-3263/9/6/251/htm) [*2,13,14*] (not well-addressed in AR5). Although the current state of coupled Atmosphere/Ocean General Circulation Models (AOGCMs) is such that they probably cannot reliably predict resulting weather-pattern changes in detail, a potential lower-bound for the overall *impact* of such releases can be explored on a decadal scale; *impact* is an important factor in *risk-assessment*, in turn important for governance.

PREVIOUS ESTIMATE

Previous work (Figure 1., below) [*3*] with a prescribed-ocean, atmospheric circulation model suggested a ~0.01 C global land surface air temperature increase per gigaton of additional atmospheric methane burden. The inclusion of a coupled dynamic ocean model in the present work yielded a tripling of that estimate to about 0.03 C global warming per gigaton increase in atmospheric methane burden. Additionally, much larger Arctic responses were observed when specifying model changes chosen to approximate increased cloud brightness over the Arctic ocean. In this work, the AR5 RCP8.5 GHG scenario was chosen as the baseline in order to most faithfully represent current and anticipated trends over the relatively short time period investigated here (i.e., 2020 – 2040).

After an extended model spin-up, the model global mean temperature was constant for two decades of integration using a constant model-year (2019), and closely reproduced the mean warming rate reported for 2020 – 2040 in the AR5 data when run in baseline RCP8.5 transient-mode over the subject time period. As is typical for the AOGCM used in this work (AR5 GISS ModelE2.0 07.50.01), the modeled Arctic sea-ice losses were less than is currently observed in the real-world; hence, the results presented here are regarded as no more than a lower bound to the magnitude of expected Arctic response to such a release.

Prior Result *[essoar.org/doi/10.1002/essoar.10503094.1 (https://www.essoar.org/doi/10.1002/essoar.10503094.1)(2019)]

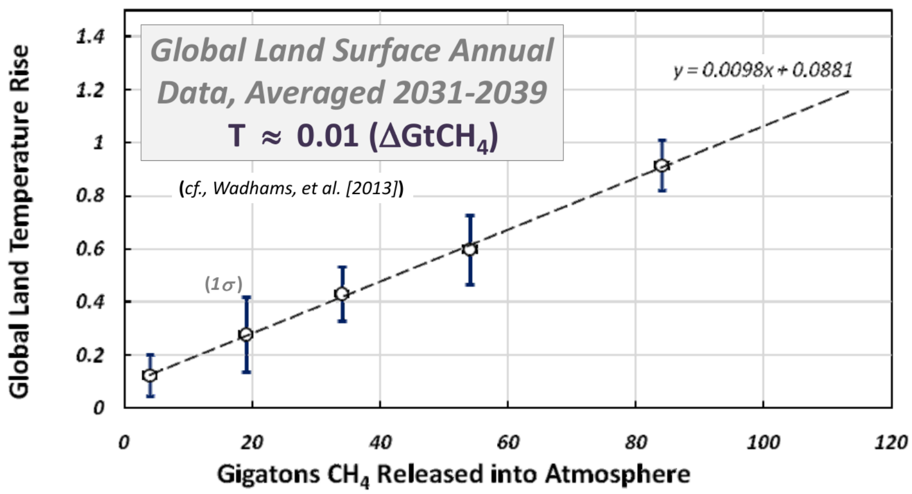


Figure 1. Previous results for increase in global mean land surface temperature as a function of gigatons of methane released.

2. JUSTIFICATION / EXPERIMENTAL

October 31, 2020 extended exposure of Kara/Laptev Sea shallow continental shelf to warm, ice-free surface conditions (link (https://worldview.earthdata.nasa.gov/?v=-7916735.291496202,-4239114.436450839,7044218.533702437,2625781.563549161&p=arctic&t=2020-10-31-T14%3A40%3A05Z&l=AMSRU2_Sea_Ice_Concentration_12km,Reference_Labels,Reference_Features,Coastlines,BlueMarble_ShadedRelief_Bathymetry)) [*1*]

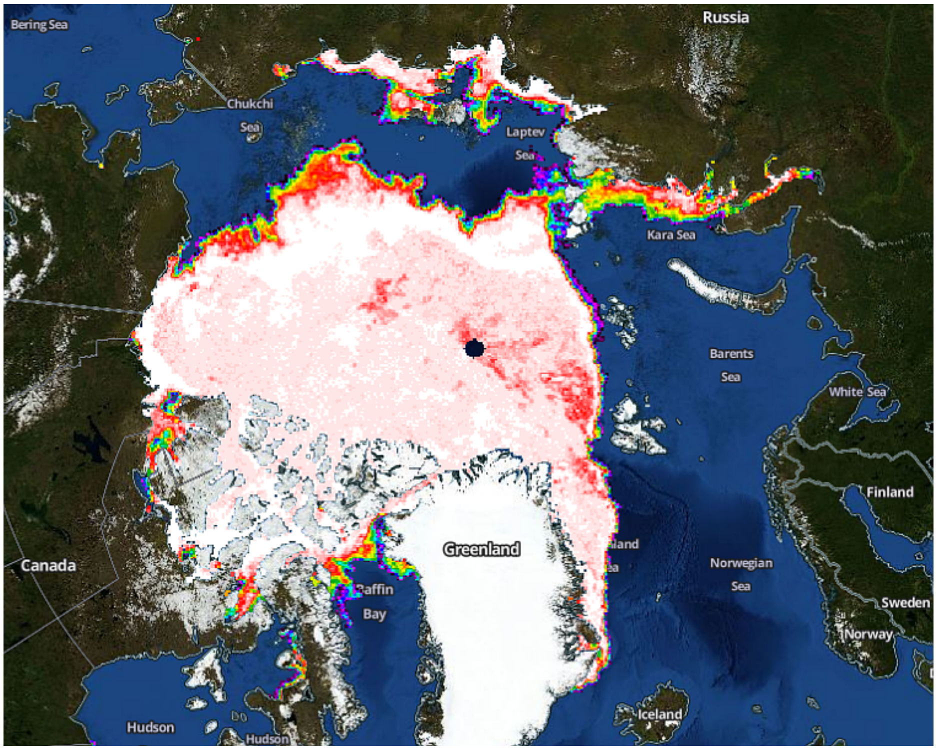


Figure 2. Advanced Microwave Scanning Radiometer-E/Advanced Microwave Scanning Radiometer-2 (AMSR-E/AMSR2) unified Sea Ice Concentration (12 km resolution) for October 31, 2020. As far as known, this is the first such event following the onset of the Holocene.

IMPACT / PROBABILITY

This work seeks to more clearly define parameters and impacts of a hypothesized methane release to support assessment of *Risk* (i.e., *Probability* x *Impact*). Colloquially, it is desired to know whether the hypothesized methane release is of *Probability*-class suggested for supervolcano eruptions and large asteroid/comet strikes, or if it is more akin to the likelihood of the large family of climate events anticipated as the Anthropocene deepens. However, if the *Impact* of the hypothesized methane release is sufficiently large, then it warrants more careful study and consideration (i.e., IPCC WG-I) than it has received to date, independently of *Probability* estimates. Therefore, this work studies only *Impact*, and briefly examines one proposed mitigation, Arctic marine cloud brightening (https://royalsocietypublishing.org/doi/pdf/10.1098/rsta.2014.0053) [*4-7*], for the purpose of maintaining the equatorial/polar pressure gradient force (mitigating Arctic sea-ice melt).

This work models the years 2020-2040, with the a primary methane release occurring in the years 2025-2030.

MODEL & VALIDATION

The AR5 version of the Goddard Institute for Space Studies Atmosphere/Ocean General Circulation Model (AOGCM) ModelE2.0 (https://www.giss.nasa.gov/tools/modelE/) was used in non-interactive atmosphere (NINT) + dynamic "Russel" ocean model (https://pubs.giss.nasa.gov/docs/2014/2014_Schmidt_sc02500z.pdf). [*8,9*] The model was spun-up for 200 years with 1850 climatology on an Opteron/OpenSUSE workstation (E_AR5_V2_NINT_oR.R template, MASTER_YEAR=1850), then was restarted as a dynamic simulation from 1850 to 2020. The resulting 1JAN2020 dataset was then used as initial conditions (IC) for subsequent runs. To assess spinup, this IC was restarted for a steady 20 year run (MASTER_YEAR = 2019) to quantify the modeled global temperature "drift" over the time period examined, and then restarted as a dynamic case under RCP8.5 conditions to validate against the mean AR5 modeled temperature increase trends from 2020-2040. (see Figure 3.) Repeat integrations of runs following large changes in methane or insolation essentially retrace. The results of this validation suggest that the model numerics [*15*] are running well enough for estimation of planetary response to a large-scale methane release.

Atmospheric methane is herein presumed to have a mean half-life of 9 years, converting mole-for-mole to CO_2 (moles of H_2O thus produced are ignored).

It must be noted that the modeled methane-release scenarios are only approximate because, among other reasons, uncertainties of methane dynamics in the real-world, and because the methane here is always well-mixed and globally dispersed - there is no consideration of the real-world time needed to disperse methane globally from regional sources, temperature- and concentration-dependent reaction rates, etc.

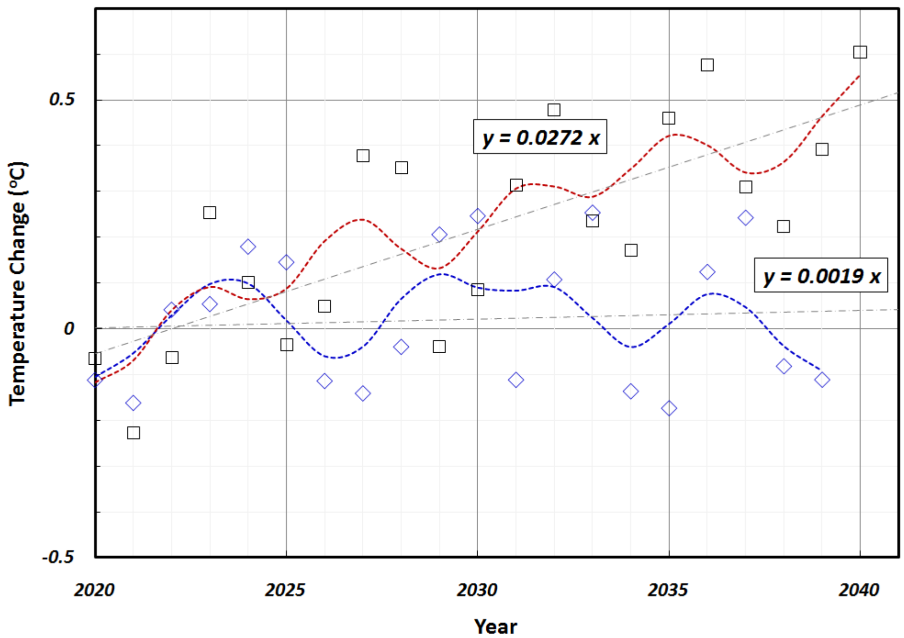


Figure 3. Mean annual surface air temperature data. Blue/Diamonds: constant 2020 model run showing annual data and smoothed data (dashed line), with low global mean temperature drift; Red/Squares: transient model run (AR5;RCP8.5 GHG scenario) showing annual data and smoothed data; showing a linear-fit mean global temperature rise of 0.272 °C per decade. This compares well with estimates from the ensemble-mean AR5 (Figure 4.) data, which was estimated at 0.31°C per decade for this time period.

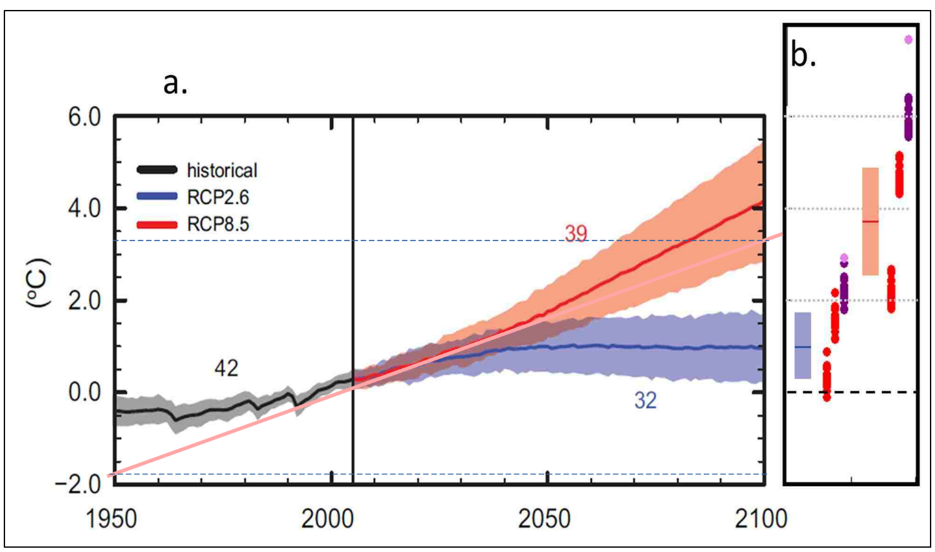


Figure 4. [AR5 Scenario Comparison (https://unfccc.int/files/science/workstreams/the_2013-2015_review/application/pdf/3_stocker13sed2_2_rev.pdf)] [Fig. SPM.7a] *with line used to estimate average temperature rise 2020-2040 ~ 0.31°C per decade. This compares favorably with the model result for this time period in this work (Figure 3.).*

SCENARIO METHANE INPUTS

The methane GHG input temporal profiles for the data presented here are shown in Figure 5. *Obviously, there is no precedent to know, a-priori, the temporal profile of such a release,* since it depends on many factors; e.g., associated with as-yet uncharacterized reinforcing feedback loops. A possible feedback could facilitate a transition to new methane emission rates on the order of 1 gigatons of methane per year in the near-term, e.g., 45NR and 20NR, from unspecified sources. A methane-pulse-only scenario (51P) was included, which suddenly halts after 2031 and decays back toward RCP8.5. The latter may seem somewhat unlikely given the event magnitude.

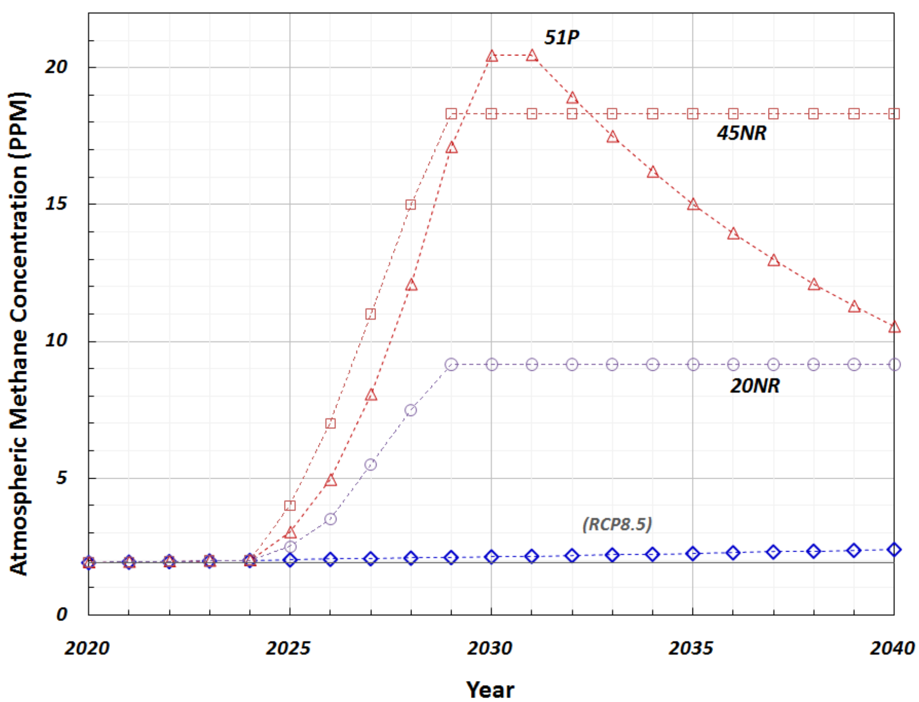


Figure 5. Hypothetical methane release scenarios: RCP8.5; 20 gigaton release with transition to new regime of methane emissions (20NR); 45 gigaton release with transition to new regime (45NR); and 51 gigaton pulse-release which abruptly ends and begins to decay toward the RCP8.5 methane scenario (51P). Gigatonnages are estimates based on scenario PPM. [11]

3. PRIMARY GLOBAL RESULTS

DATA SUMMARY

Global estimated annual mean surface air temperature increase (2032 – 2040) above that of the AR5 RCP8.5 scenario, as a function of atmospheric methane burden:

✲ **~0.03 ºC mean increase per gigaton methane released**.

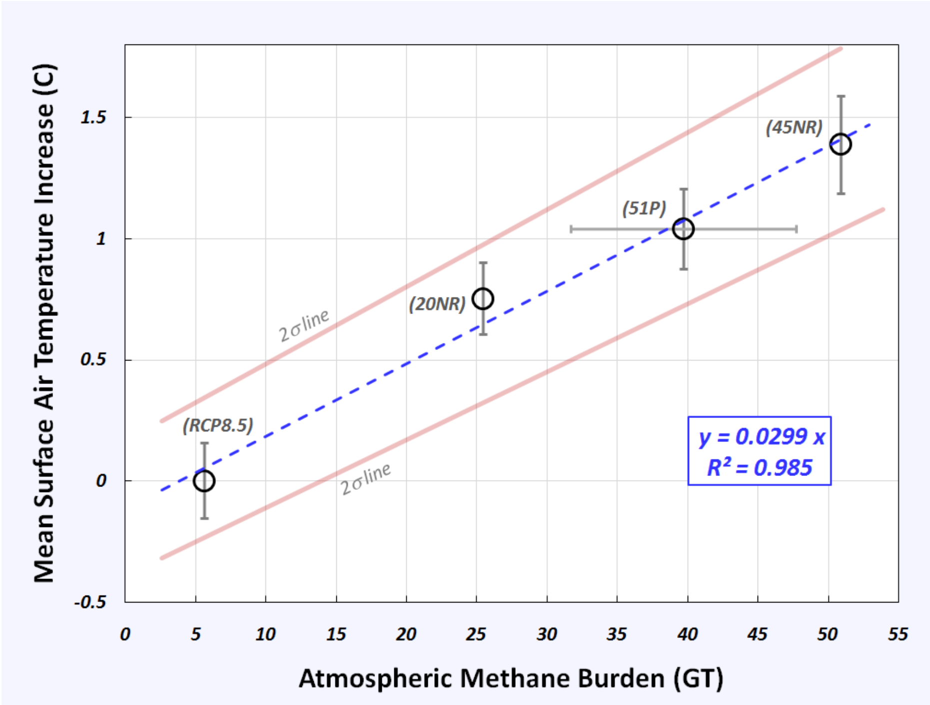


Figure 6. Mean ***global*** *annual surface air temperature increase above mean RCP8.5, for given approximate methane burdens, averaged over the years 2032-2040. Y-axis 1-σ error bars represent combined annual model* *<u>variation</u>* *and the observed upward* *<u>drift</u>* *of each scenario over that time period. The single X-axis 1-σ error bar represents the exponential decrease in methane burden as the 51P scenario decays back toward RCP8.5 (see Figure 5.). Other X-axis error bars are not shown due to uncertainty in methane dynamics for the real-world. The two-σ lines are fitted to the combined Y-axis 2-σ points of the dataset.* ***Scenarios show continuing upward temperature drift (see Figure 7.).***

ANNUAL DATA DETAIL

✲ ***Post-release scenarios have everywhere-increasing temperature trends***

✲ ***<u>Initial</u> temperature trend for all scenarios is ca. 0.2ºC/year***

✲ ***Although not shown, global mean land-surface-only air temperatures for this time period may be ca. 20% higher.***

The annual mean global surface air temperature data for all scenarios are shown in Figure 7., **and warming continues after the methane has stopped increasing or decreases strongly**. In previous work with an *atmosphere-only climate model* (https://doi.org/10.1002/essoar.10503094.1) (prescribed oceans) it was found that land surface air temperature rise nearly halted when methane release halted.[*3*] Although not shown, the land surface air temperature increases in this work were significantly greater than in the previous study. These results suggest a strong role for the dynamic oceans in the current model by magnifying and introducing inertia into the land surface and global temperature rise.

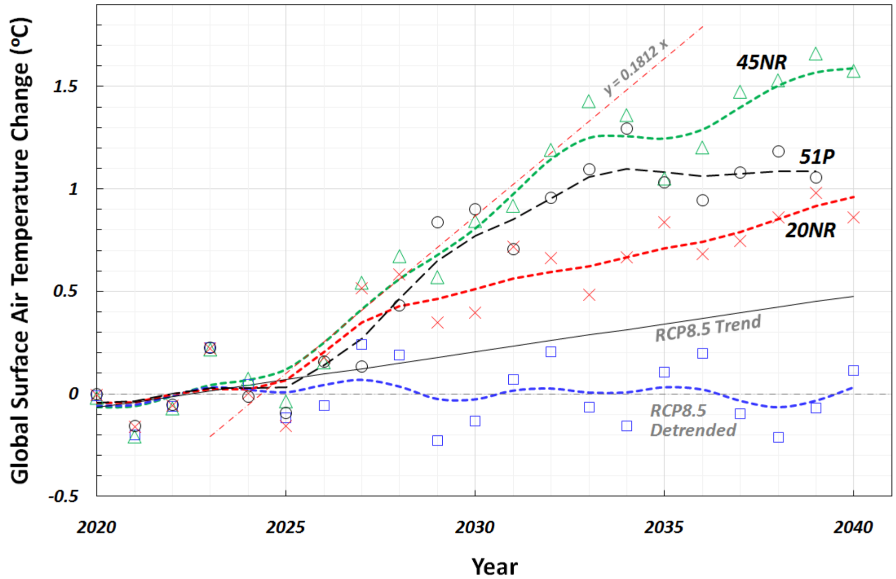


Figure 7. Detrended annual mean global surface air temperature data points for all scenarios (with the RCP8.5 trend removed, since it is dominated by CO_2). Curves are smoothed by convolution of data with a 6-element Hanning function. 20NR and 45NR continue to rise in this plot after methane stops rising, and 51P appears to level-off despite rapidly decreasing methane concentration, but is actually still increasing if the total RCP8.5 trend is added back into the detrended 51P data.

5. ARCTIC SCENARIO RESULTS / CONCLUSIONS

Arctic estimated mean surface air temperature increase.

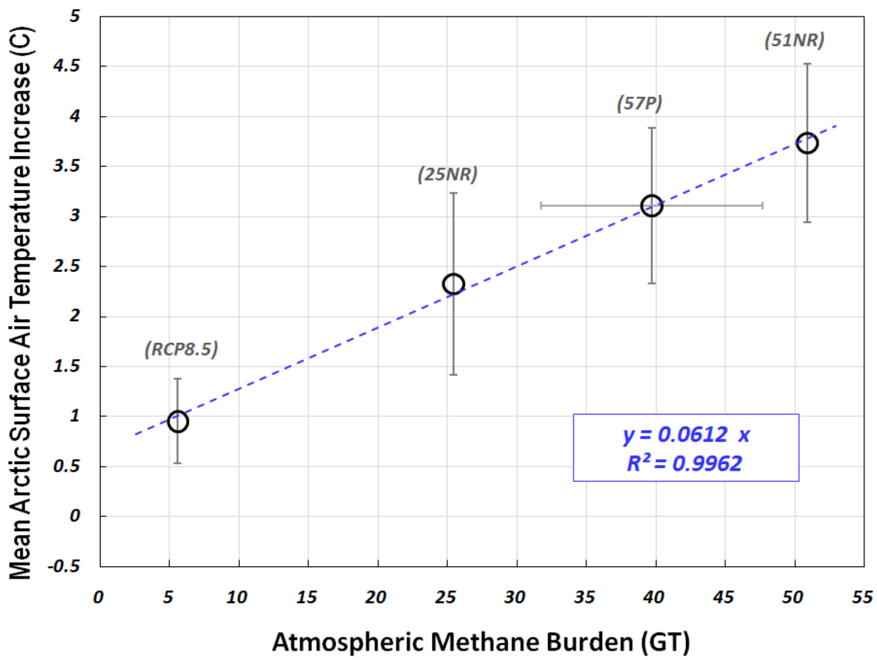


Figure 12. Arctic (68°N - 90°N) mean surface air temperature rise above mean of 2020-2025 Arctic temperatures, for all scenarios. Temperature rise is roughly double that of the mean global surface air temperature rise.

The mean annual Arctic surface air temperature data are significantly more scattered than the mean global data, with roughly double the mean increase. The trends suggest that these results likely constitute *a lower-bound to scenario-associated Arctic temperature increases.*

DISCUSSION/CONCLUSIONS

The spin-up of the AOGCM used here was validated with a steady-state drift test and for the RCP8.5 scenario global mean surface air temperature change over the time period of interest. The scenarios remain stable and appear to produce numerically-consistent integrations.[*15*] The temporal profile of a shallow Arctic methane release is unknown, so two types of release were investigated and produced similar results:

- **Significant increases in mean global surface air temperature are seen when rapid, large methane increases are modeled: ≥0.03C per gigaton of methane** *(...because...)*
- **Mean surface air temperatures likely to continue to rise beyond 2040.**
- **Given the documented behavior of the AOGCM used, the results presented probably represent a *lower bound* for modeled real-world changes, at least for the Arctic.**

Global and Arctic temperature changes are somewhat crude indicators of climate change impacts; however, this is all that can be presented at this time. Work is ongoing to study mesoscale impacts of these scenarios (e.g., changes in precipitation and jets), but no strong trends have yet emerged. Some regional trends could be inferred from the data herein and based on AR5 temperature results, but this should likely be done with some caution, especially given the unprecedented rapidity of the changes observed in these model results (ca. 0.2°C/year, mean). Comparable simulations with other AR5/6 models should be done for model consensus and increased confidence. *An important unknown is a dynamic response to methane-release timing with respect to the observed low-frequency, multi-year global temperature cycles, at a minimum this would introduce additional scatter in the results.*

ACKNOWLEDGMENT

The decades of study and effort by the many scientists and contributors, whose hard work and persistence has made it possible to model the weather and climate processes of *Spaceship Earth* in some detail, is gratefully acknowledged.

4. ARCTIC CLOUD BRIGHTNESS IMPACTS

Uncertainty in AOGCM cloud brightness for the scenarios.

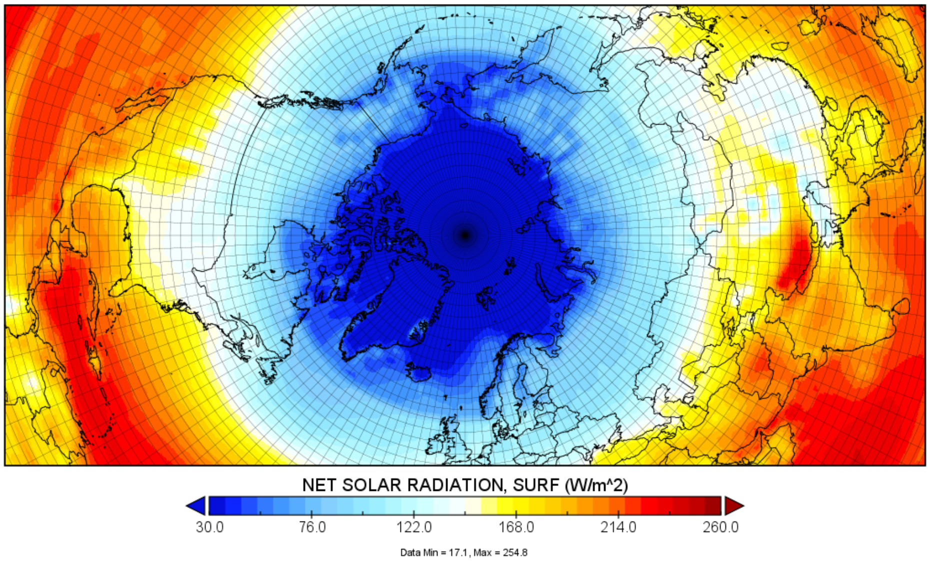


Figure 8. Illustration of the region of reduced annual TOA insolation over Arctic ocean (see text). It is assumed that changes in the Arctic ocean surface lead to increased cloudiness (or else intentional cloud brightening efforts), confined to the Arctic ocean.

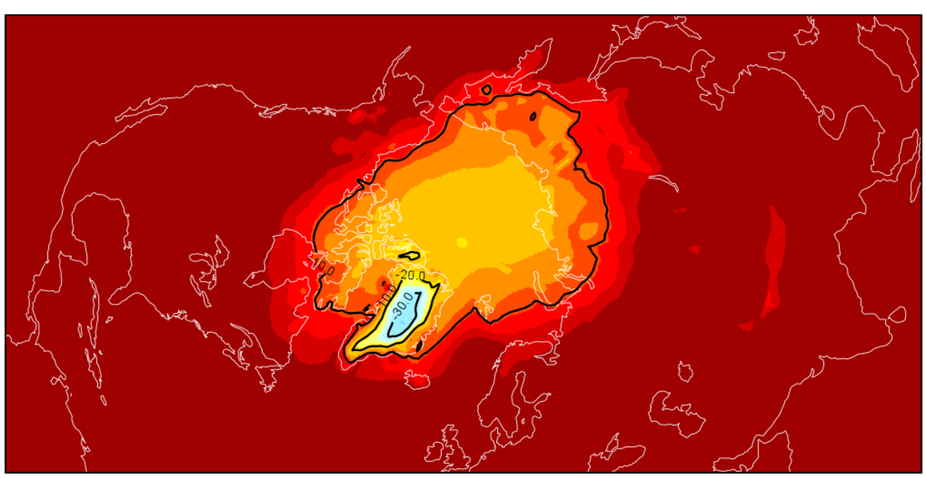
Cloud processes are among the least well-simulated aspects of current-generation AOGCMs, especially considering extreme events such as modeled here. The impacts of Arctic cloud brightness are explored as a sensitive aspect for the modeling of diminishing summer sea-ice coverage and similar runaway feedbacks in the Arctic, such as snowline retreat (http://eprints.whiterose.ac.uk/138040/).[*6*]

Arctic cloud brightness is studied here in an *approximate* and *minimally-intrusive* way by noting that the dominant energy-balance effect of brighter cloud cover is the rejection of visible insolation. The AOGCM's cloud-process algorithms themselves are not modified, only top-of-atmosphere (TOA) insolation.

On the other hand, considered from the point of view of Marine Cloud Brightening, [*6,7*] **these observations on marine clouds are confined to the Arctic, and the Arctic only; strongly invoking a Precautionary Principle (https://www.mdpi.com/2071-1050/12/21/8858/pdf), while still aiming for a key impact in the imminent climate emergency (https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf).**[*10,12*] Of course, such an effort is probably misguided unless the IPCC SR-15 [*2018*] recommendations are implemented; i.e., large scale-scale halting of carbon emissions during the time period modeled here. [*12*]

SPATIAL DATA

A substantial increase in area with mean annual surface air temperature at -20C (Figure 9.) is noted when 50% brighter clouds are assumed over Arctic ocean:



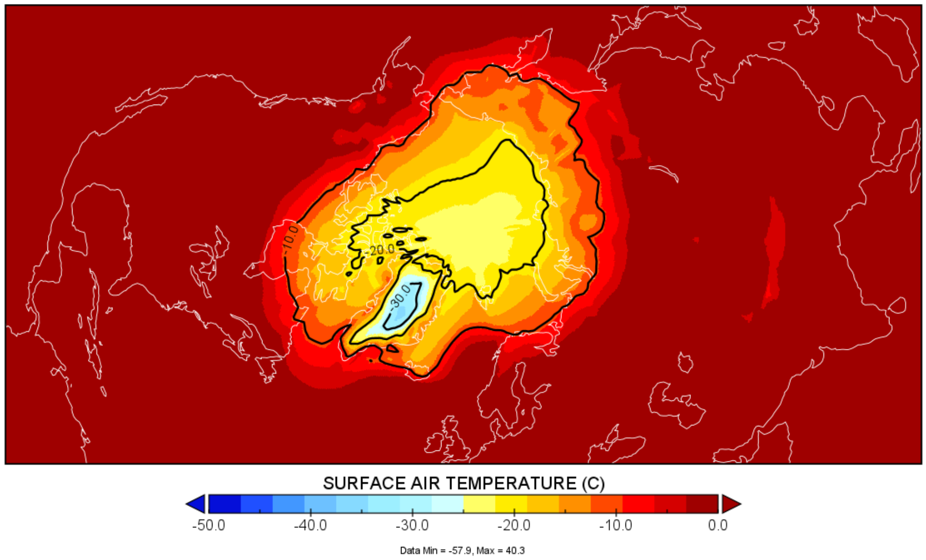


Figure 9. Substantial increase in the area of the Arctic sea below -20C mean annual surface air temperature. Top: 2031 mean annual surface air temperature for scenario 45NR; Bottom: same as Top, but with 50% brighter clouds (i.e., 50% less Arctic insolation in the model).

<u>TEMPORAL DATA</u>

If cloud brightness is parametrically increased beginning in the year 2030 for scenario 45NR, the temporally-averaged, mean annual Arctic surface air temperature responds by decreasing (Figure 10.). Temporal trends in the results are shown in Figure 11. Significant changes occur if the fraction of insolation removed increases above about 0.2, after which Arctic air temperature may continue to decrease beyond the time period investigated. *Note that cloud brightness is modeled to uniformly increase (insolation decrease) across the entire Arctic Ocean region indicated in Figure 8.*

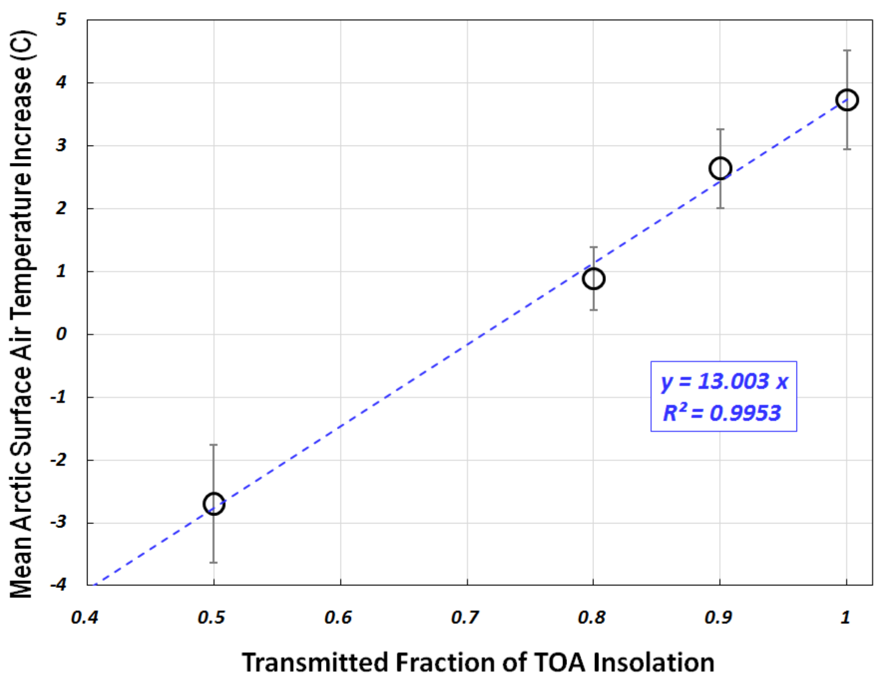


Figure 10. Mean Arctic annual surface air temperatures averaged from 2032 – 2040 as a function of insolation fraction (model proxy for increased cloud brightness; i.e., decreased insolation = increased cloud brightness). Error bars include both trend and scatter of data points in Figure 11.

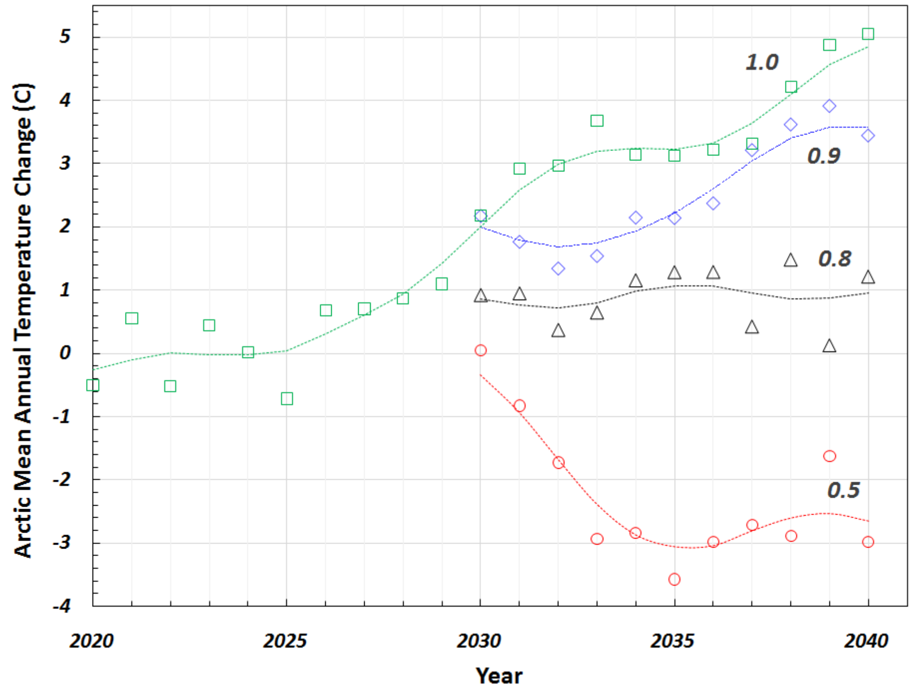


Figure 11. Arctic mean annual surface air temperature data trends, with insolation fractions as-noted on the curves. Evidently, for insolation fractions less than about 0.8, the trend changes sign from increasing to decreasing, over the time period modeled here.

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