Parametric Study of Prompt Methane Release Impacts III: AOGCM Results Which Respect Historical PIOMAS Measurements

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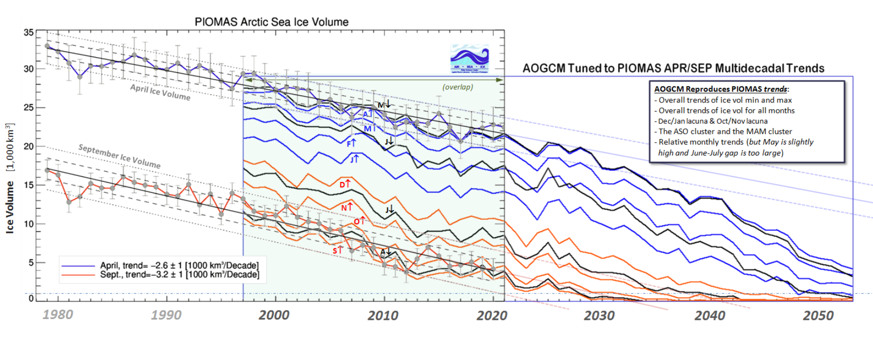
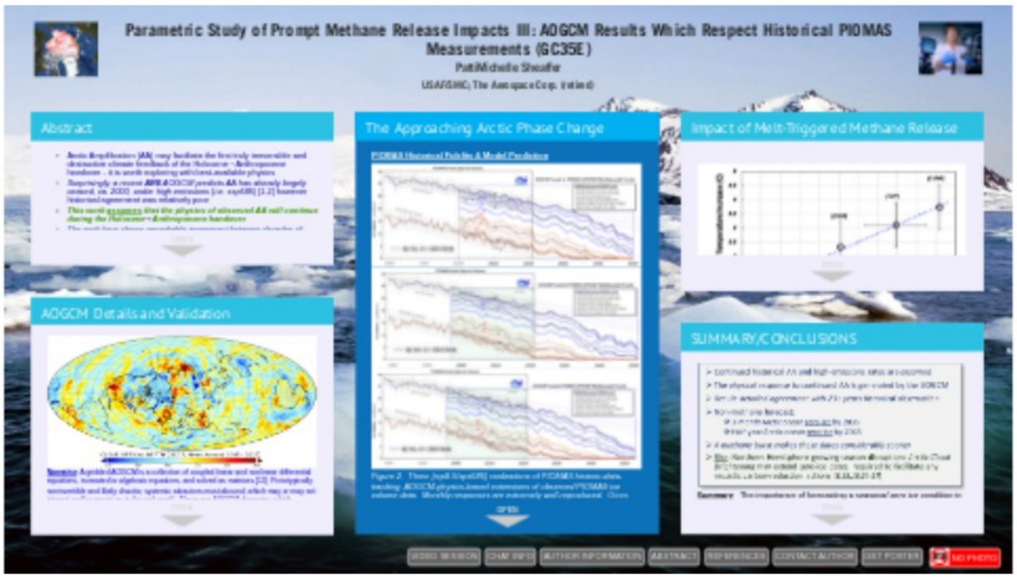
Abstract

Of immediate widespread concern is the accelerating transition from Holocene-like weather patterns to unknown, and likely unstable, Anthropocene patterns. A fell example is irreversible Arctic phase change. It is not clear if existing AOGCMs are adequate to model anticipated global impacts in detail; however, the GISS ModelE AOGCM can be used to locally compare and extend the PIOMAS Arctic ocean historical ice-volume dataset into the near future. Arctic Amplification (AA) mechanisms are poorly understood; to enable timely results, a simple linear, Arctic TOA grid-boundary energy-input is used to enforce AA, avoiding the perils of arbitrary modification of relatively well-studied parameterizations (e.g., restriction of cloud-top height to induce local warming). Only PIOMAS springtime/max and fall/min Arctic ice-volume decadal, linear trends were enforced. This temporally-broad grid-boundary modification produces a surprisingly detailed consonance with monthly trends in the historical PIOMAS dataset from 2003 to 2021, and is integrated to 2050. The result is a zero-ice-volume, summer/fall half-year, beginning ca. 2035 (onset 1-sigma of ± ˜5 years), with mean annual Arctic temperatures increasingly trending above freezing. Persistent, Arctic phase change follows this half-year transition about 20 years later. Also present in later stages, the 500 hPa height minimum is no longer nearly-coincident with the pole, suggesting jet stream disruption and its consequences. Hypothesized large clathrate-methane releases likely associated with Arctic temperature and phase change are also examined. This work establishes a reasonably detailed timeline for the Arctic phase change based on well-studied AOGCM physics, slightly tuned to decades of PIOMAS data. This result also points to the Arctic as a key, near-term site for localized, nondestructive intervention to mitigate Arctic phase change (e.g., Stjern [2018]), thereby slowing the Holocene -> Anthropocene growing-season disruption. Although such an intervention cannot itself accomplish the requirements of the IPCC SP-15 [2018], nor Planetary Boundaries theory, delaying the Arctic phase change will likely extend the time-window for accomplishing those critical tasks and ultimately to at least slow the rate of increase of climate emergencies.



Parametric Study of Prompt Methane Release Impacts III: AOGCM Results Which Respect Historical PIOMAS Measurements (GC35E)



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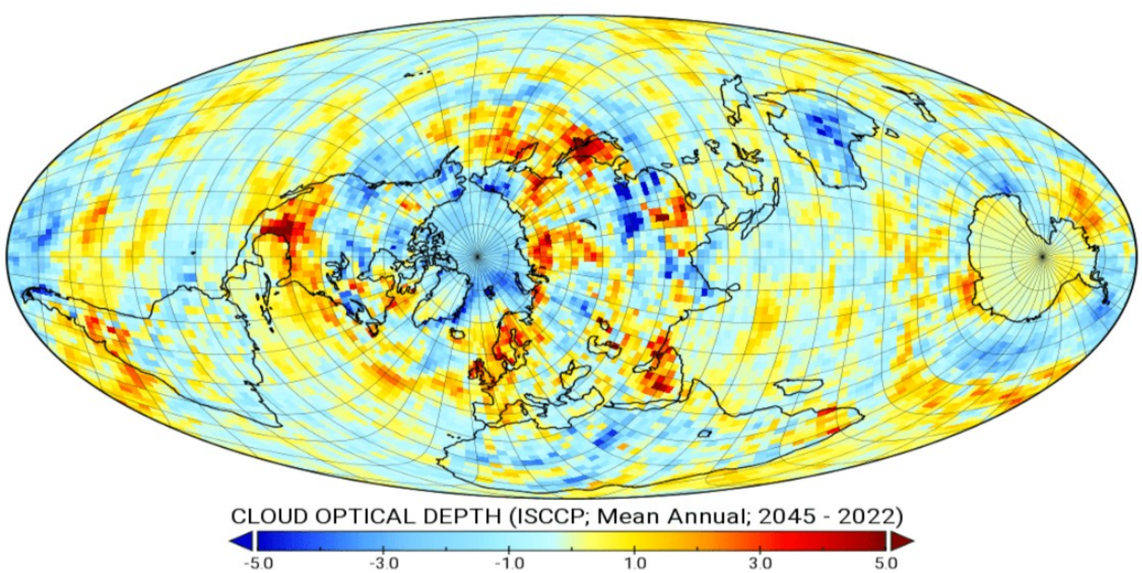
ABSTRACT/INTRODUCTION

- Arctic Amplification (AA) may facilitate the first truly irreversible and destructive climate feedback of the Holocene → Anthropocene handover - it is worth exploring with best-available physics
- Surprisingly, a recent AR6 AOGCM submission predicts AA has already largely ceased, *ca* 2000, under high emissions (i.e. ssp585); however, historical agreement was relatively poor [1,2]
- This work *assumes* that the physics of both observed AA and observed RCP8.5 will continue during the Holocene → Anthropocene climate handover in the near-term
- An AOGCM with simple Arctic tuning is used to reproduce PIOMAS data in detail for >20 years.
- The results presented here show remarkable agreement between decades of PIOMAS data and model predictions, typically within the 1-σ error bars of PIOMAS.

A near-term Arctic Ocean ice melt AOGCM model prediction is made. Afterward, the impact of methane release from an Arctic shelf clathrate and/or permafrost-capped natural gas province is also estimated.[6-12,28,31] It must be emphasized that this work is not considered an incremental improvement on AOGCM development and sophistication. The development cycle on AOGCMs is far too slow given evident rapid acceleration of global change impacts. Rather, and for prompt results, this work is a small tuning of an existing AR5 AOGCM. This tuning produces a remarkably detailed consonance with the PIOMAS data record over more than 20 years, and will soon be extended to the entire record. Thus, these results are a physics-based, timely and reasonable near-term prediction of the Arctic phase change which is expected to have a massive impact on civilization. However, it is not clear how far beyond the near-term (e.g., *ca* 2040) that these model parameterizations provide reliable predictions especially given non-modeled Arctic feedbacks, such as snowline retreat and permafrost melt.

This work was driven by the view that the sooner such reasonable near-term estimates are available, the better; this despite the ongoing lack of effective global climate rhetoric and action.



***Above**: Changes in cloud optical depth between 2045 and 2022, presented here to illustrate the model grid resolution.*

AOGCM DETAILS AND VALIDATION

Narrative: *A gridded AOGCM is a collection of coupled linear and nonlinear differential equations which are truncated to algebraic equations and then solved as matrices.[13] Prototypically noninvertible and likely chaotic; mathematical systemic attractors must abound, which may or may not interact and/or persist as in the same manner as weather attractors in the real-world. These AOGCM flow dynamics generally yield low agreement between different models, but nonetheless dominate the large-scale atmospheric circulations in the real-world.[14,20] Large changes in these general circulations will undoubtedly affect Northern Hemisphere food production, and are thus of grave concern, but, as mentioned, are difficult to predict with AOGCM models.*

Because of the above dynamical considerations, minimal results beyond the Arctic itself are presented herein. We are also unaware of any accurate historical validations of AOGCMs to the near-term regional progress of very rapid Arctic phase change. The value of this work relies upon highly-accurate reproduction by the model of the long-term historic PIOMAS Arctic ice volume dataset, coupled with the assumption of continued AA.

The results of this work is particularly critical at this time during the Holocene → Anthropocene climate handover, as substantive global changes to emissions are not undertaken and large-scale planetary climate tipping points approach civilization unhindered. This work examines one fell example: ***the Arctic phase change****.[3-5]* ***It is likely that the Arctic phase change will produce a significant, temporally-localized acceleration in the rate of the Holocene → Anthropocene climate handover****, possibly producing significant or fatal disruption of global civilization. Hence, we acknowledge* ***Arctic cloud brightening*** *[8,24-27] as a regional, straightforward "applying of the brakes" to the Arctic phase change in conjunction with simultaneously accelerating the collapse process in global carbon-emission industries – neither are small tasks.*

The AOGCM and its preparation was described previously [6] and used for the calculations here. Following spin-up, it was tested for short-term stability and drift while held at constant 1997 (Figure 1).

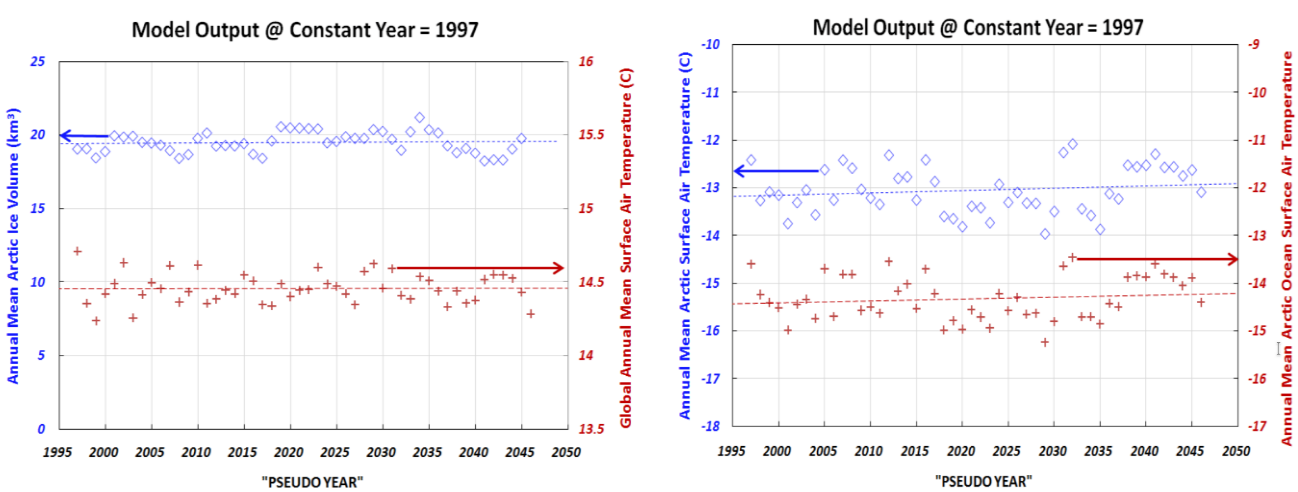


Figure 1. AOGCM stability check run for ***constant year 1997****, over time period of interest, after initial spin-up. All data demonstrate a mean drift rate less than 0.5% per year.*

The AOGCM was then tuned and tested to reproduce the PIOMAS historical data measurements and then integrated forward to produce an AOGCM-physics-based estimate of the near-future of the Arctic basin ice cover.

It proved necessary to "tune" the AOGCM to comply with the PIOMAS historical data set. The tuning used was simple and very successful in detailed reproduction of the PIOMAS monthly and annual data archive.

The AOGCM Tuning was selected to avoid complex localized ad hoc modifications to existing, relatively well understood atmospheric parameterizations. The boundary-condition tuning method was to simply divert a small fraction of top of atmosphere (TOA) global insolation to the Arctic Ocean basin TOA insolation. The daytime Arctic basin insolation was increased at a constant annual rate of about 2.5x the latent energy needed to melt the PIOMAS observed mean annual icemelt (i.e., 2.5 x 0.4 Wm^{-2}).[7] Unfortunately, a constant winter *nighttime* insolation was also required (~110 Wm^{-2}) in the Arctic Ocean basin to offset the model bias toward excessive Arctic ice regrowth under winter nighttime conditions.

These sorts of insolation adjustments are disfavored by many researchers, although they are relatively straightforward and have the advantage of providing a controlled energy input, primarily at sea surface level as is typically associated with AA[8], and they do not otherwise alter existing physical grid-level parameterization schemes. Thus, AA is maintained under thermodynamic control and is more or less immune to weather dynamics. *It is noted that this particular tuning is not considered an advancement in AOGCM science per se, but rather aims to provide a prompt, physics based, historically-accurate and results-focused Arctic phase-change prediction in the near term since the integrity of civilization is rapidly being challenged by the deepening Holocene → Anthropocene climate handover, especially the food supply*.[15-17] (e.g., There may not be enough time left to wait for significant Arctic/AA model advances.)

The global mean surface air temperature rise during the modeled time period is shown in Figure 1a. After the onset of Arctic Ocean phase change *ca* 2030, the global warming rate increases by a factor of approximately 1.7, a significant increase in the global mean surface temperature rate of increase, due only to ocean changes.

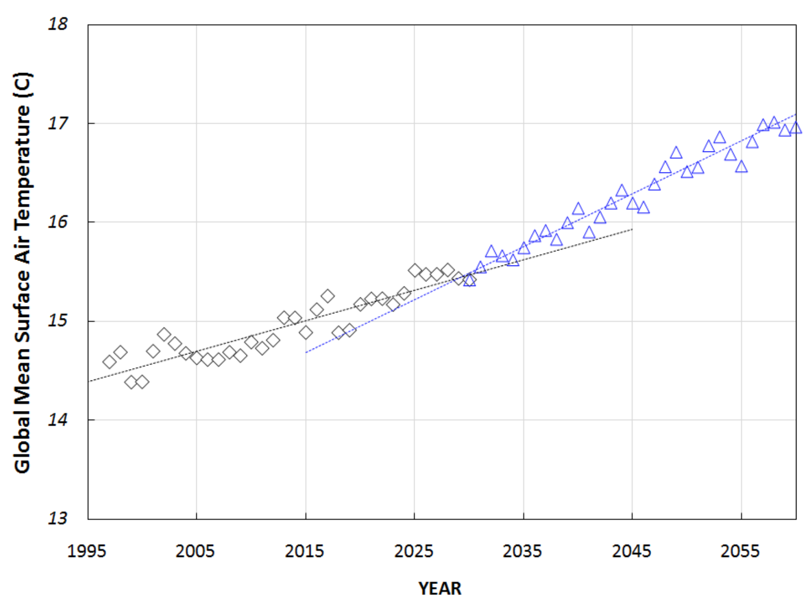


Figure 1a. Rapid acceleration in rise of global mean surface air temperature associated with the onset of Arctic phase change, as modeled in this work. ***Diamonds:*** *prior to onset of Arctic phase change, the rate is 0.3 °C/decade;* ***Triangles:*** *after Arctic phase change onset, 0.5 °C/decade.*

THE APPROACHING ARCTIC PHASE CHANGE

PIOMAS Historical Fidelity and Model Prediction

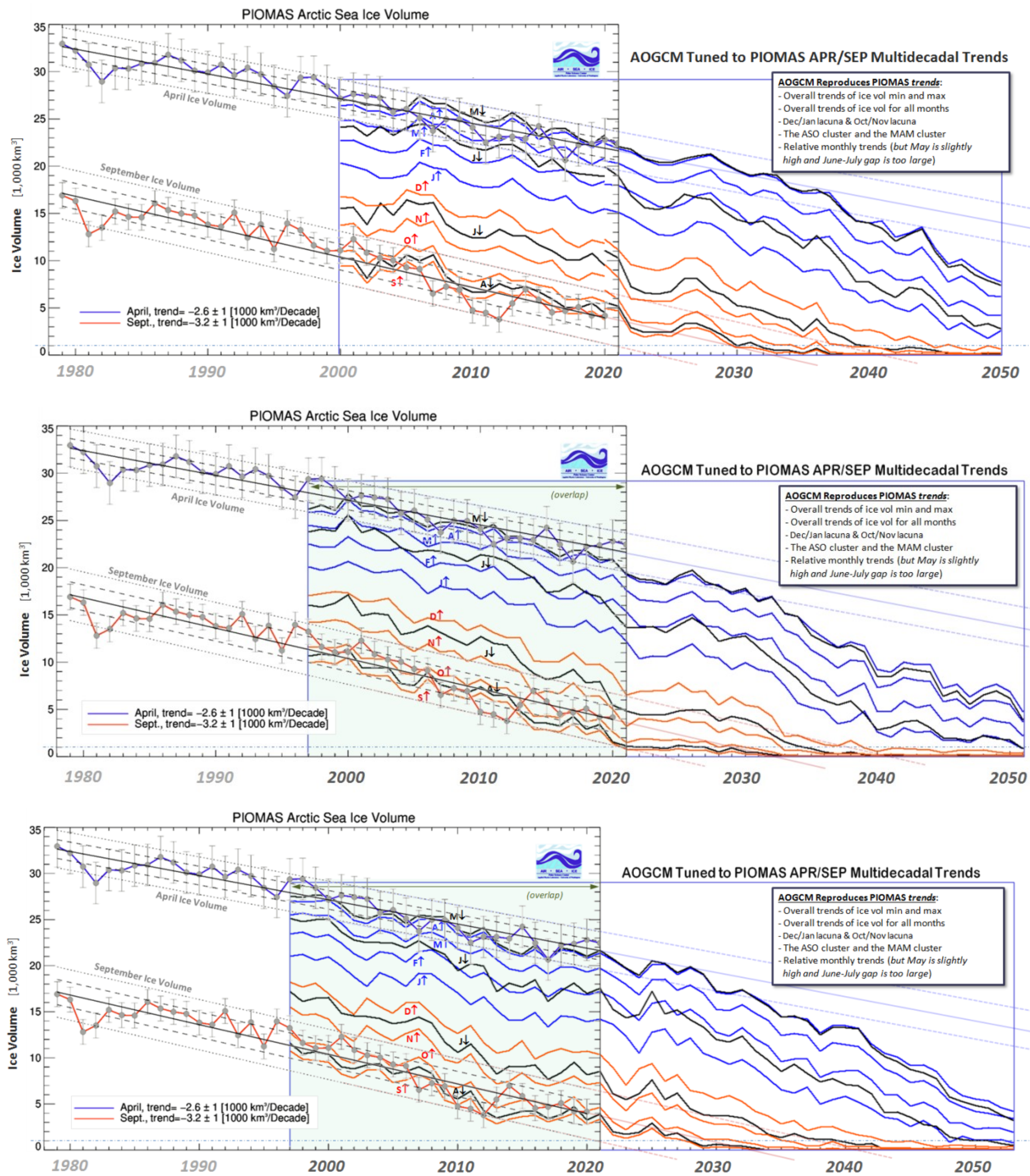


Figure 2. Three {rcp8.5/sps585} realizations of PIOMAS historic-data-tracking by the AOGCM, along with AOGCM-physics-based predictive extensions of observed PIOMAS ice volume data. Monthly responses are extremely well-reproduced for over 2 decades. Given more model run-time, this simple tuning would produce detailed agreement with PIOMAS data over the entire PIOMAS dataset. The shown "historic" period overlaps with model calculations - 1997 to 2021. Summer-season phase-change is predicted to be complete ca 2035, and half-year phase-change is predicted to be complete ca 2047. Impacts on Northern Hemisphere growing seasons are therefore a serious concern. ***(Compare with Figure 1a)***

The historical September and April ice volume realizations shown in Figure 2 lie almost exclusively within the 1-σ scatter provided by the PIOMAS data set *throughout* the period investigated. Other features of consonance between PIOMAS and the model are indicated in the figure text. The monthly agreement and temporal accuracy with respect to PIOMAS is remarkable. An obvious feature shared by all realizations in Figure 2 is that winter seasonal ice melt begins to accelerate significantly when the ASO (August-September-October) phase change is nearly complete. This is concomitant with the acceleration of modeled global mean temperature increase shown in Figure 1a. Physically, this may relate to what is essentially the vanishing of a "virtual" latent-heat reservoir (melting summertime ice mass), which had been historically available in Arctic summer, but will become permanently unavailable ASO, with unavailability expanding into other seasons.

The three realizations provided in Figure 2 demonstrate, from top to bottom, progressively larger modeled effects of AA up until the present. Variability over the 23-year historical overlap period makes it difficult to know which realization is most representative, so new integrations spanning 40 years of PIOMAS data are underway. However, it could reasonably be argued that AOGCM simulations have always under-predicted global changes from the Holocene $\rightarrow$ Anthropocene climate handover, suggesting that the most aggressive simulation, at the bottom of Figure 2, should probably be considered most reliable of the three scenarios from the perspective of real-world changes.

Additionally, most concurrent warming feedbacks (e.g., land snow-cover retreat and potential releases of methane from continental shelves and permafrost-capped natural gas provinces) are NOT included in the model (Figure 2) – *hence ALL the Figure 2 predictions are likely overly-optimistic*. Nonetheless, more results from the third realization are investigated below.

As indicated in the *Narrative*, global circulation dynamics are difficult to model accurately, so *global weather pattern* changes resulting from the modeling here of Arctic phase change are of relatively low reliability and not pursued here. On the other hand, it is generally understood that the localized Arctic modeled responses, being dominated by Arctic thermodynamics, are inherently more reliable. [14,18,19]

Despite the lack of global weather pattern results being presented, the modeled Arctic responses do have general implications for global weather patterns in the real world, such as the role of the equatorial/Arctic temperature gradient in driving jets and the westerly atmospheric flows. In this regard, the Arctic 500 mb height data presented in Figure 6 suggests slowing of the jets and westerlies, and perhaps disruption of the jets, likely impacting Northern Hemisphere seasonal agriculture. The model thus reveals the temporal proximity of such a disaster.

Due to previously mentioned dynamic uncertainties, the modeled global results of Arctic phase change are not presented except for one attempt to forecast changes in long duration precipitation events (**LDE**) over continents (Figure 7).[20]

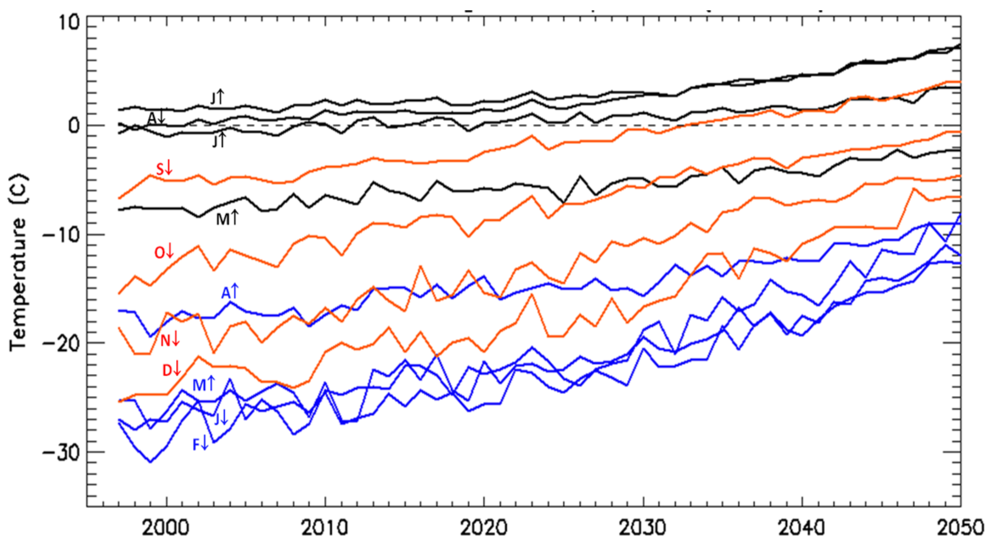


Figure 3. Monthly mean Arctic Ocean surface air temperature.

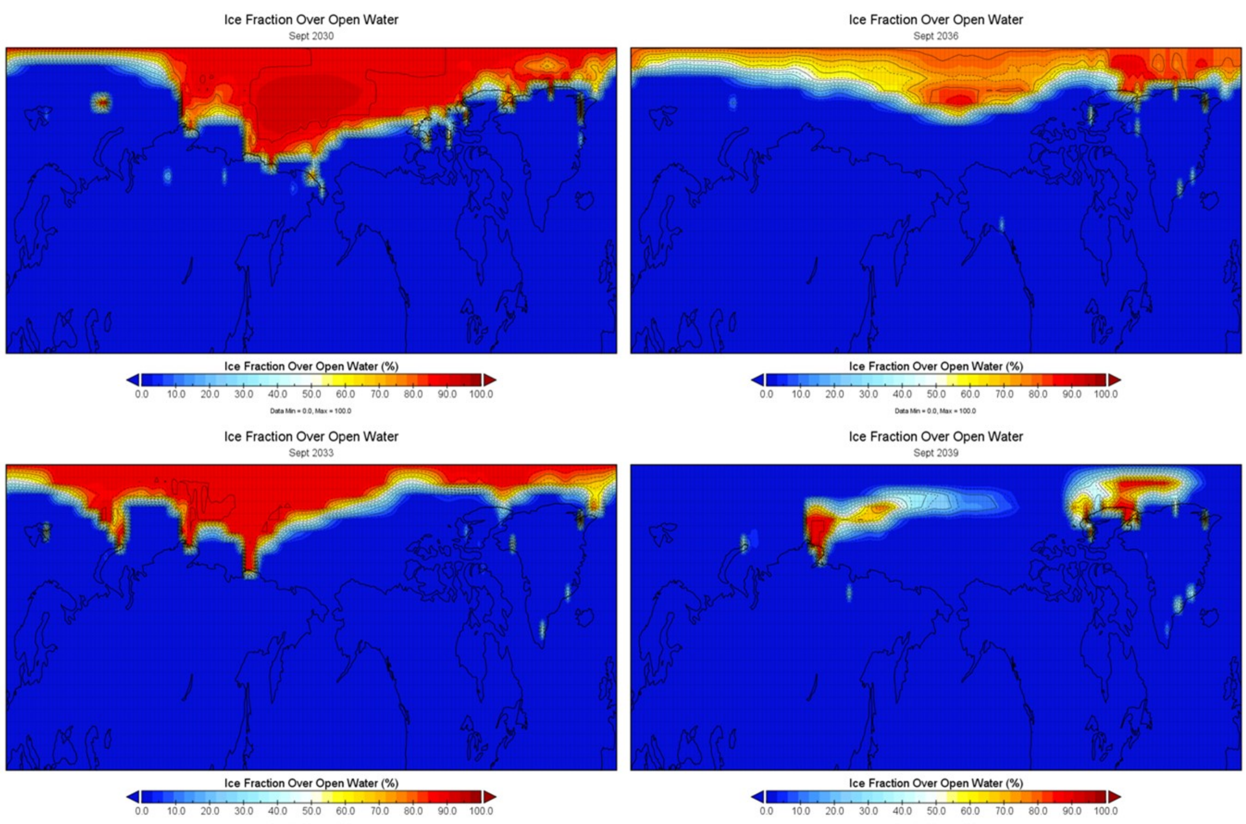


Figure 4. Ice geometry predictions (surface area and thickness) are much less reliable than predictions of ice volume (Figure 2), the latter of which is more closely tied to the thermodynamics. Thus ice fraction here only roughly illustrates expected changes. (Also, note representational biases of the map projection used here.)

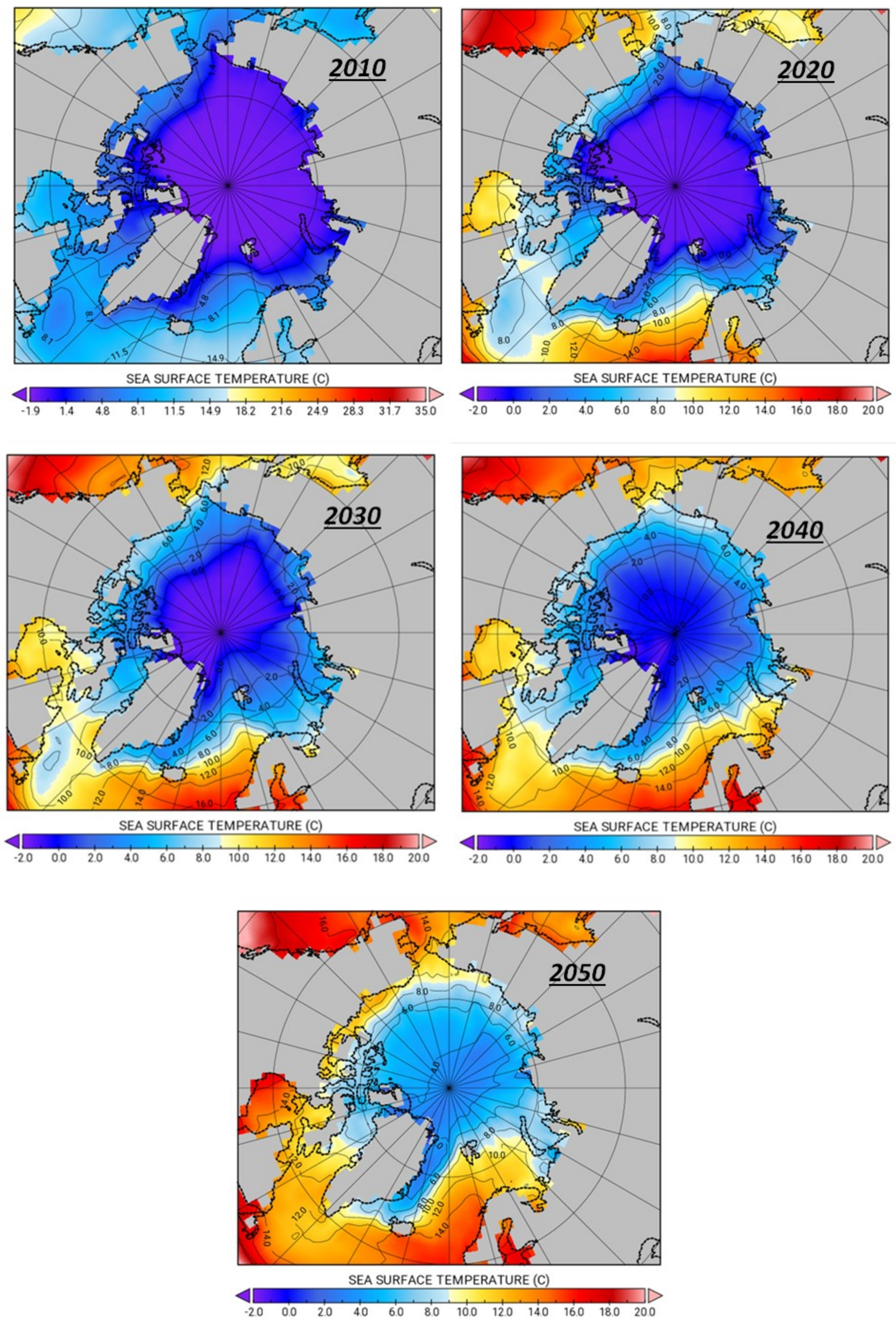


Figure 5. Modeled annual mean sea surface temperature in selected years over the time period investigated.

The mean annual Arctic 500mb height (below) is associated with the strength of the Westerly flows and jets. Decreased Westerly flows and jet disruption are suggested by the modeled Arctic phase change. Such atmospheric model dynamics are unreliable and not explored here despite the importance of changes in the equatorial/Arctic gradient. Example years are shown in Figure 6.

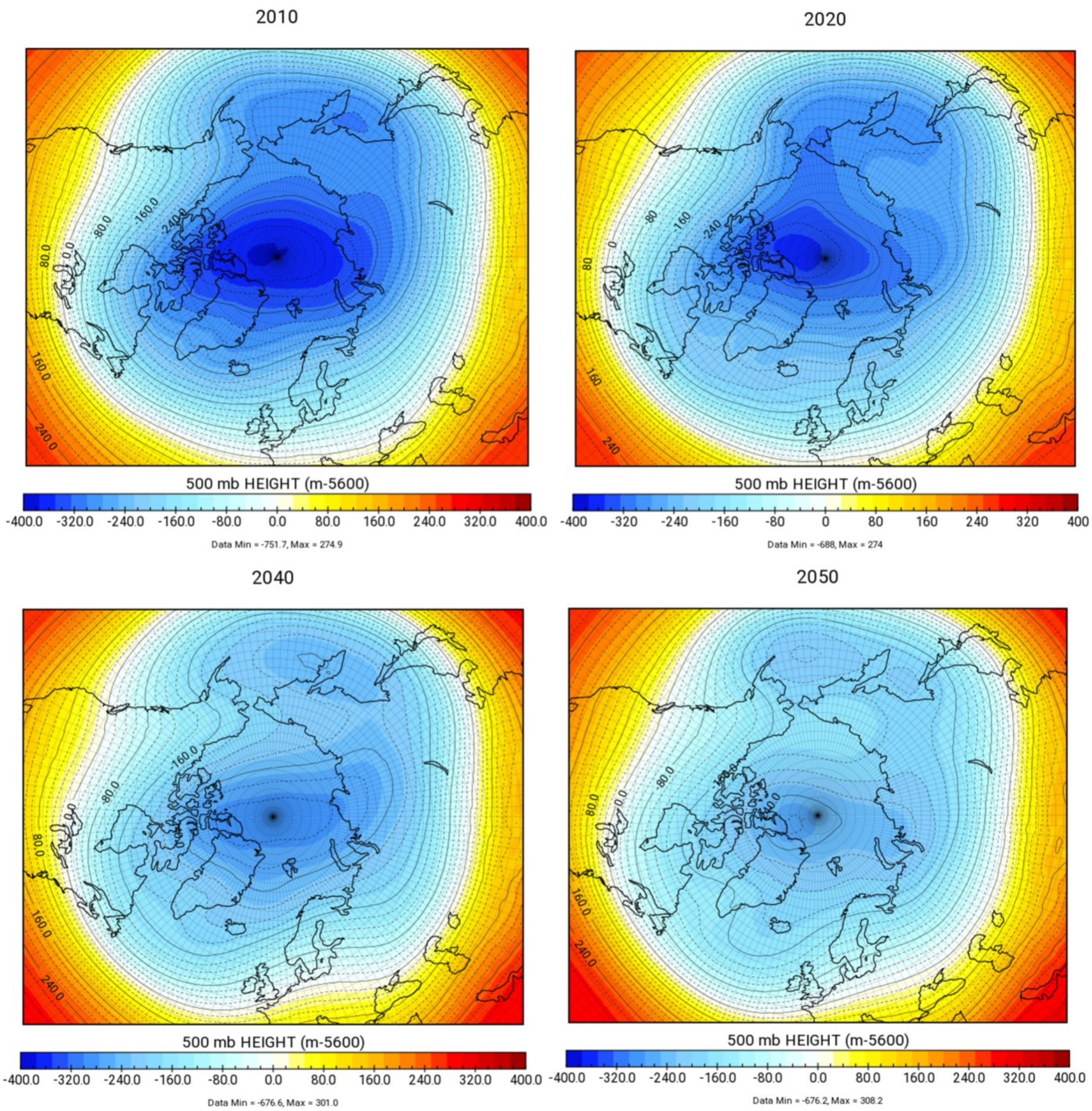


Figure 6. Modeled annual mean 500mb height in the Arctic, modeled-historical (above) and predicted (below).

Long duration precipitation events (LDE) are one suggested metric for detecting changes in the geostrophic Westerly flow and/or changes in the flow of Jets.[20,21] Since these are controlled by global model dynamics, there are significant uncertainties involved. In Figure 7 is plotted the number of 5-day LDE precipitation events – defined as 5 consecutive days with grid-level precipitation above 5 mm per day. Unfortunately, these are low-confidence predictions given the uncertainties of modeling global dynamics.

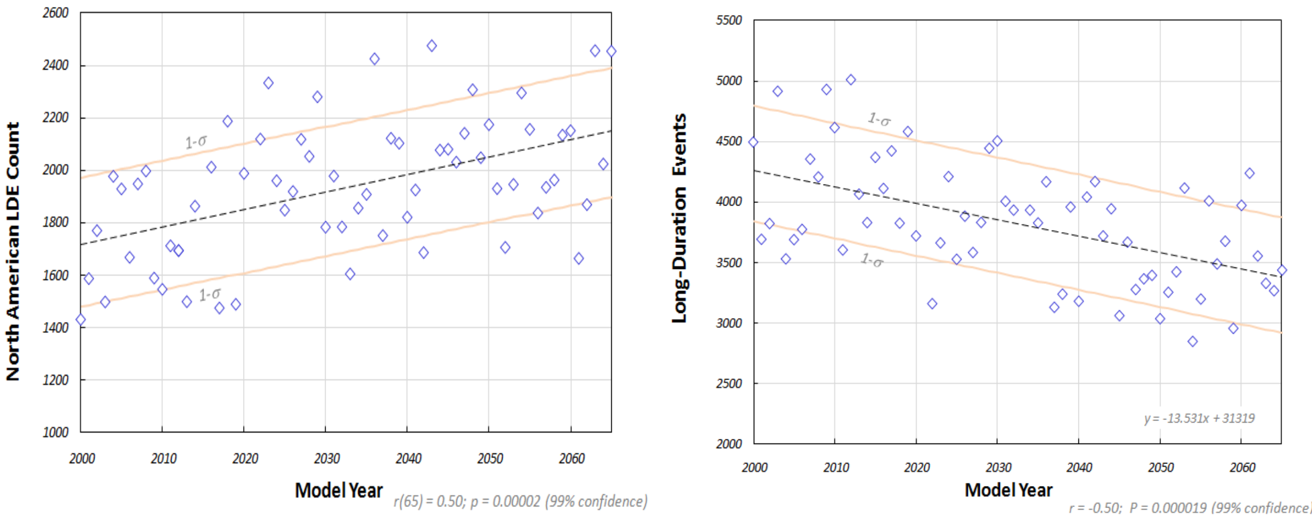


*Figure 7. Number of 5-consecutive-day events per year having grid-resolved precipitation above 5 mm/day. **Above**: grid region = 76W-126W by 30N-60N (North America); **Below**: grid region = 10W-45E by 30N-60N (Europe). The p-value suggests reasonable statistical confidence; however, direct AOGCM predictions of regional precipitation, which are controlled by the dynamics of the large-scale atmosphere, are subject to considerable uncertainty in AOGCM models. [14,18-20]*

MODELED IMPACT OF MELT-TRIGGERED METHANE RELEASE

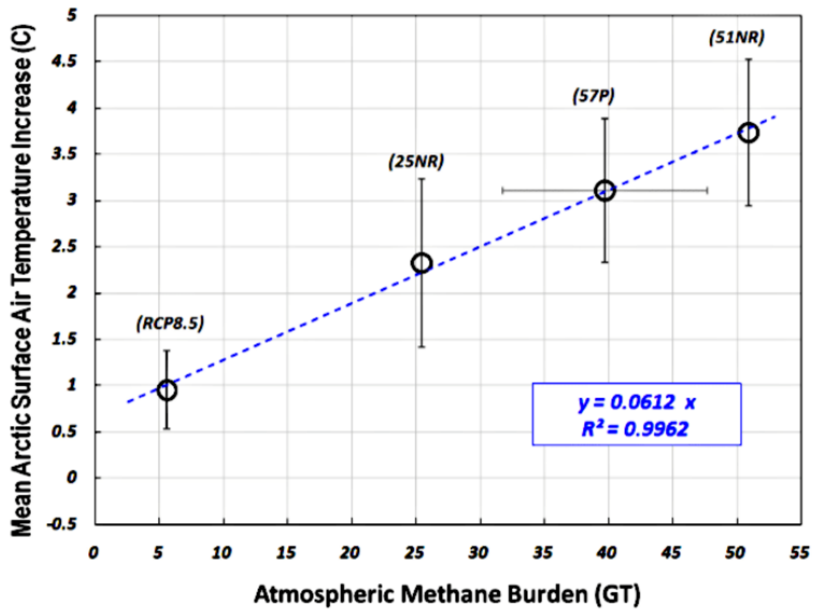


Figure 12. Arctic (68°N – 90°N) mean surface air temperature rise above mean of 2020-2025 Arctic temperatures, for all scenarios. Y-axis 1-σ error bars represent combined annual model variation and the observed upward drift of each scenario over that time period. The single X-axis 1-σ error bar represents the exponential decrease in methane burden as the 51P scenario decays back toward RCP8.5 (see Figure 5.). Temperature rise is roughly double that of the mean global surface air temperature rise.

Figure 8. Modeled Arctic response to several methane burst scenarios taken from Ref. [6] ***Example****: A methane burst yielding a total of a 20 GT atmospheric methane burden would increase Arctic surface air temperature ~1°C.*

Although controversy exists, rapid methane releases from shallow continental-shelf methane clathrates in a seasonally ice-free Arctic ocean are of concern, and some have been measured.[8-12] Arctic permafrost-capped natural gas provinces, which may be released by melting permafrost, have also been observed.[28,31] The potential impacts of a sudden methane release were applied to the results already presented here by using an *offline method* – that is, not included in the *numerics* of the AOGCM model itself. Instead, the timings of model results are adjusted after-the-fact, to provide estimates based on previously-modeled methane-induced Arctic ocean-basin surface air temperature increases (Figure 8).[6] Acceleration in the Arctic phase change is estimated by using Arctic ocean basin surface air temperature as a guide to the accelerated timing of ice-free condition occurrence.

Depending on the total increase of the atmospheric methane burden from such a release, and the timing of such a burst event, the Arctic phase change may be accelerated by as much as 8 years (Figure 10). For these estimates, it is assumed that the sudden methane increase occurs starting in 2029. Note that the methane model in Ref. [6] assumes a globally uniform increase in methane burden; however, an Arctic-localized methane release could accelerate these times still further. The real-world interactions between AA itself and the methane burden are not well understood.

Two examples are shown in Figures 9 and 10. Again, such changes likely pose a serious concern for Northern Hemisphere (NH) seasonal food production since the major changes in Arctic temperature patterns occur during the NH growing seasons. These scenarios result in half-year Arctic phase change occurring by the mid-2030's with nearly complete non-winter phase change by the mid-2040's.

It must be emphasized that these are estimates most reliable for the *near term* based on an offline comparison to the modeled data presented here (Figure 2), Arctic Amplification (AA) continuing at historic rates, a continued high carbon-emission scenario, and the rate of Arctic warming modeled in ref. [6].

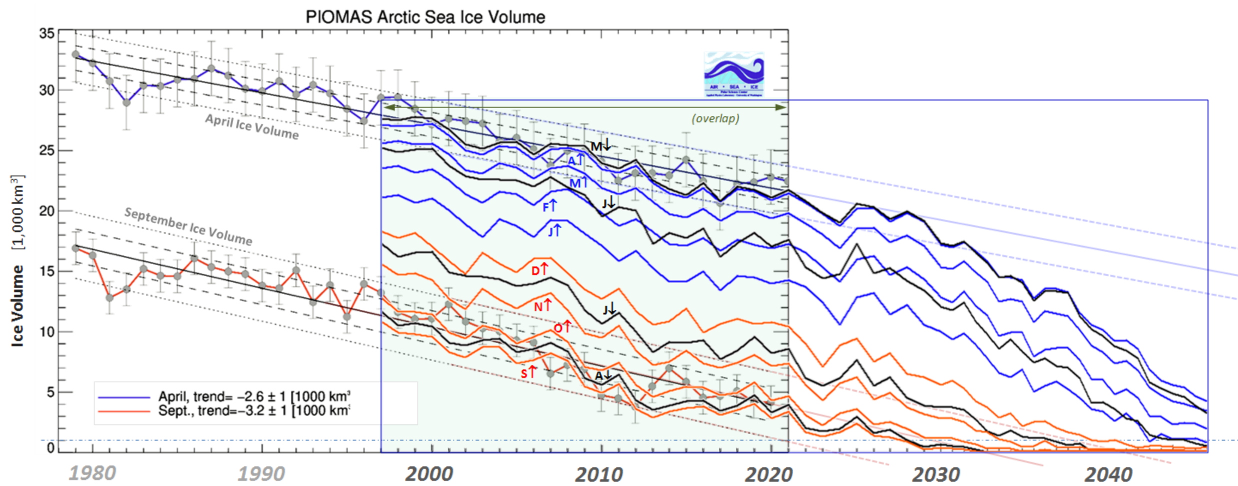


Figure 9. Accelerated ice melt estimates, using the (non-methane) model outputs shown in Figure 2, and assuming ~1 °C increase in Arctic temperatures suggested by Figure 8, for a ~20 GT total atmospheric methane burden (also assumes AA continues at approximately the historically observed rates).

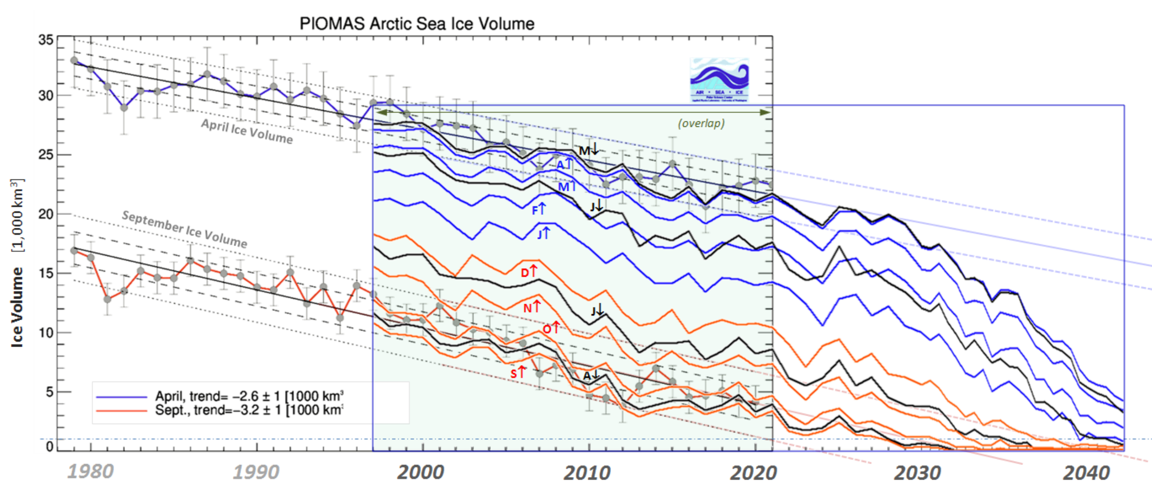


Figure 10. Accelerated ice melt estimates, using the (non-methane) model outputs shown in Figure 2, and assuming ~2.5 °C increase in Arctic temperatures suggested by Figure 8, for a ~45 GT total atmospheric methane burden (also assumes AA continues at approximately the historically observed rates).

SUMMARY/CONCLUSIONS

- ❖ **Continued historical AA and GHG increases are *assumed* AOGCM inputs**
- ❖ **The *physical response* to continued AA and GHG increase is calculated by the AOGCM**
- ❖ **Result: detailed agreement with 20+ years of Arctic sea ice mass observations**
- ❖ **Non-methane forecast:**
  - ➢ *3-month Arctic Ocean zero-ice by 2035*
  - ➢ *Half-year Arctic Ocean zero-ice by 2045*
- ❖ **Risk: Northern Hemisphere growing season disruption**
  - ➢ *Arctic Ocean Cloud Brightening may extend modeled zero-ice dates [6]*
  - ➢ *Probably required to facilitate any realistic carbon-reduction actions [8,15,16,24-27]*
- ❖ **A methane burst (clathrates/provinces) moves these dates considerably closer**

Narrative Summary *The importance of forecasting the approaching seasonal zero-ice condition in the Arctic (ca 2035) is the significant potential for periodic disruption of Northern Hemisphere (NH) food production, which is especially grave given that the global NH food production rate already has a decreasing trajectory.[15-17] Additionally, based on previous work, it is estimated that if large scale seasonal Arctic ocean warming and permafrost melt facilitates a rapid increase in the atmospheric methane burden[6,8-12,28,31], the model-estimated dates for Arctic phase changes could be accelerated to 2030 and 2038, respectively, depending on the resulting atmospheric burden of methane as well as the precise rate of increase and timing of release. Even in the absence of a methane burst, the modeled acceleration of global temperature rise by loss of a seasonal sea-ice cover associated with the onset of Arctic phase change (i.e., Figure 1a) is of concern. The anticipated Arctic phase change is therefore recommended as a rational target for a "minimally-damaging" geoengineering effort:* ***Arctic cloud brightening****, to attempt to stave off seasonal Arctic ice clearance and maintain the NH food-production basis for global technological civilization.[8,24-27] AOGCM estimates of the impacts of insolation reduction were previously made.[6] Unfortunately, any putative geoengineering effort is likely useless without a concurrent global halving of industrial and transportation output.[29,30]*

In this work, continued Arctic Amplification (AA) and RCP8.5/sps585 emissions rates were assumed for the near-term. This assumption is consistent with measured carbon release rates.

Some AR6 model contributions suggest that AA ceased ca. 2020 – but these tend to poorly reproduce historical PIOMAS trends over the AR6 *historic* interval, which is too short to provide high confidence given variances of model results and the PIOMAS dataset.[1,2] This work examined an up-to 24 year long *historic* interval and found exceptional agreement between modeled results and the PIOMAS data. This interval is currently being extended to 40 years.

Lastly, in this work, AA is enforced and tuned to the PIOMAS historical record by moving a small fraction of global TOA insolation to Arctic Ocean basin TOA insolation – avoiding localized grid-level atmospheric parameterization changes to obtain Arctic warming (e.g., cloud-model height adjustments). This maintains Arctic Ocean surface warming under thermodynamic control rather than control of the dynamics of the atmosphere (atmospheric rivers, weather events, etc.), as is appropriate for the Arctic Ocean basin region. This method does exceptionally well at reproducing essentially the entire PIOMAS historical dataset. *** ***The author expresses her gratitude to the dedicated scientists at GISS for outstanding software.****[22,23]* ***

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