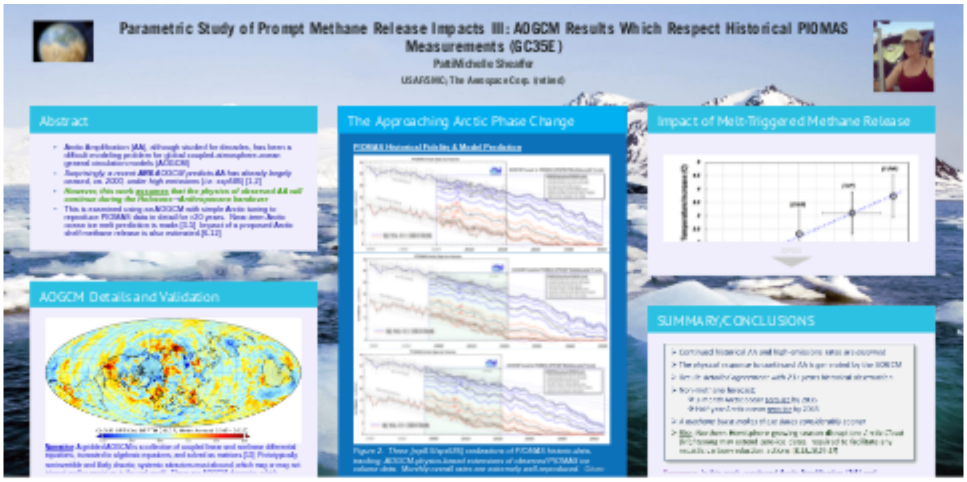
Parametric Study of Prompt Methane Release Impacts III: AOGCM Results Which Respect Historical PIOMAS Measurements (GC35E)



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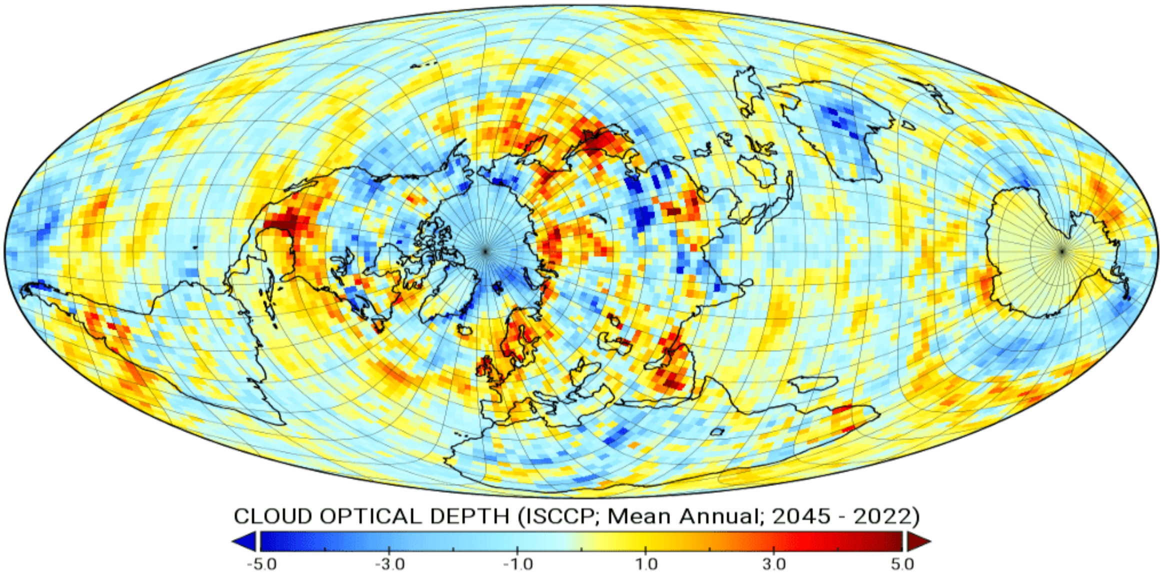
ABSTRACT

- Arctic Amplification (AA), although studied for decades, has been a difficult modeling problem for global coupled-atmosphere-ocean general circulation models (AOGCM)
- *Surprisingly, a recent **AR6** AOGCM predicts AA has already largely ceased, ca. 2000, under high emissions (i.e. ssp585)* [1,2]
- ***However, this work <u>assumes</u> that the physics of observed AA will continue during the Holocene→Anthropocene handover***
- This is examined using an AOGCM with simple Arctic tuning to reproduce PIOMAS data in detail for >20 years. Near-term Arctic ocean ice melt prediction is made.[3-5] Impact of a proposed Arctic shelf methane release is also estimated.[6-12]

AOGCM DETAILS AND VALIDATION

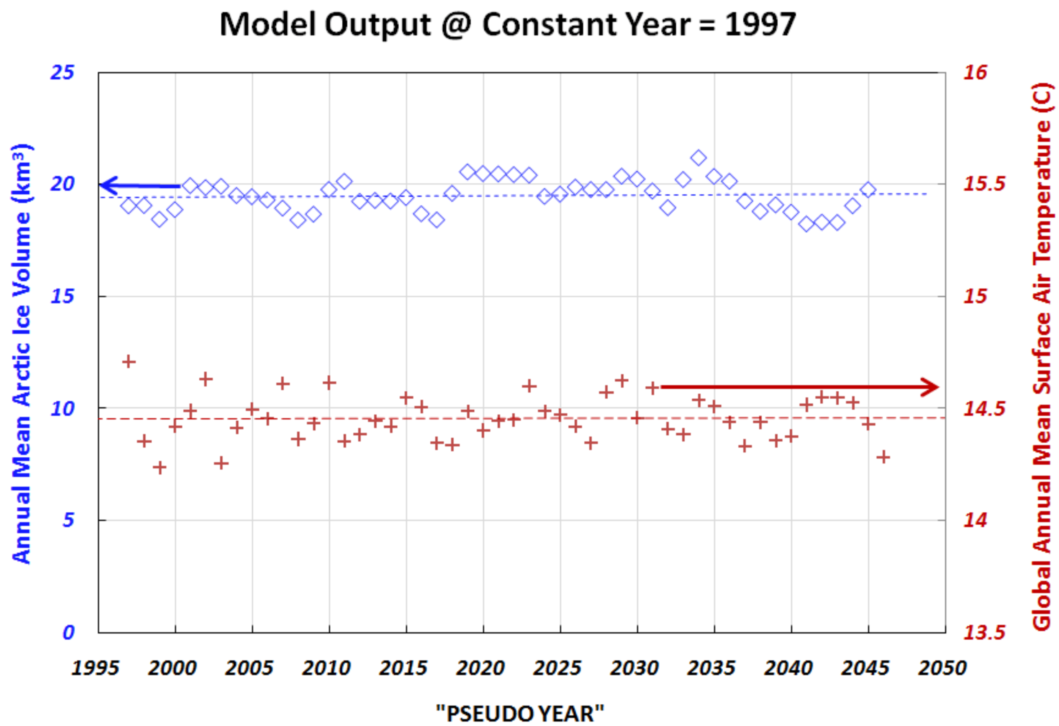


Narrative: A gridded AOGCM is a collection of coupled linear and nonlinear differential equations, truncated to algebraic equations, and solved as matrices.[13] Prototypically noninvertible and likely chaotic; systemic attractors must abound, which may or may not interact and/or persist *as in the real-world*.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

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, so ***the value of this work relies on highly-accurate tracking of the long-term historic Arctic ice volume and the assumption of continued AA***. *(above: changes in cloud optical depth presented to illustrate model grid resolution)*

This work is particluarly critical in this juncture of the Holocene→Anthropocene handover, as useful and necessary global changes to emissions are not being undertaken and large-scale planetary tipping points approach mankind. This work examines one fell example, the Arctic phase change. **It is likely that the Arctic phase change will produce a significant, temporally-localized acceleration in the rate of the Holocene→Anthropocene handover**, producing significant or fatal disruption of global civlization. Hence, we acknowledge **Arctic cloud brightening** [8,24-27] to regional, straightforward "apply the brakes" to the Arctic phase change while elsewhere simultaneously accelerating the collapse process in carbon-emission industries.

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



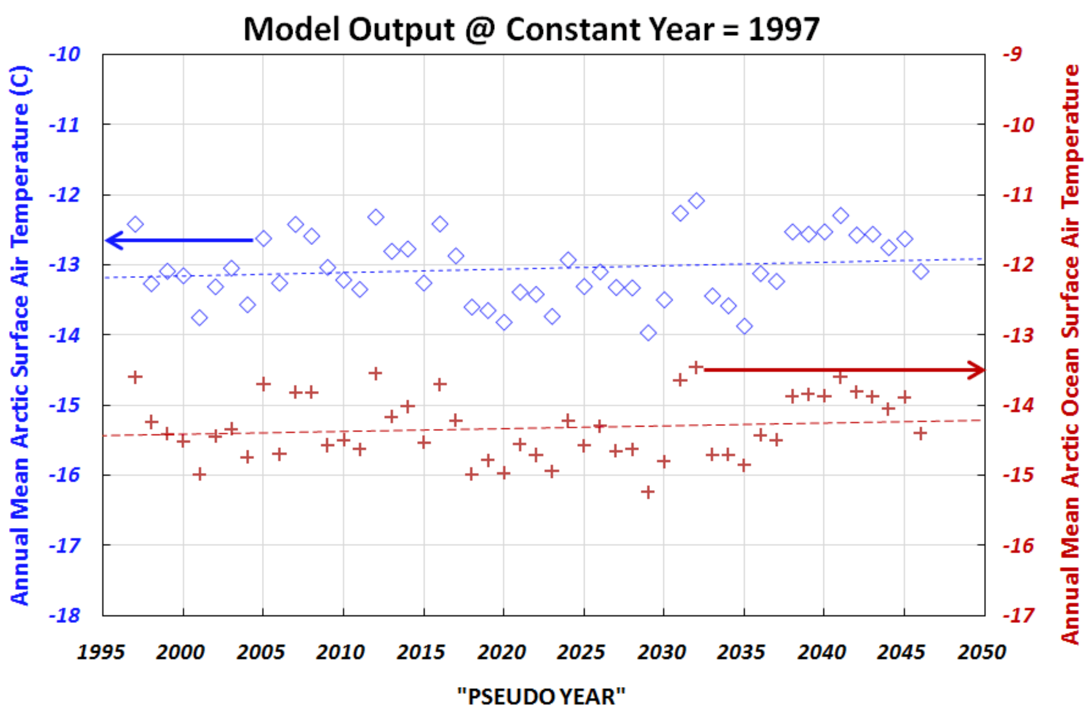


Figure 1. AOGCM stability check run for constant year 1997 over time period of interest, after initial spin-up. All data demonstrate a mean drift rate less than 0.5% per year.

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

It was 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.

AOGCM Tuning In order to avoid complex and *ad hoc* modifications to existing, relatively well understood atmospheric parameterizations, it was chosen to simply divert an insiginificant fraction of 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 of the latent energy needed to melt the observed mean annual icemelt (i.e., 2.5 x 0.4 Wm^{-2}).[7]

A constant winter nighttime insolation was also required (~110 Wm^{-2}) at the Arctic ocean surface to offset the model bias toward excessive Arctic ice-growth under winter nighttime conditions. These sorts of insolation adjustments are disfavored by many researchers (although relatively minor). However, they provide a controlled energy input, primarily at ground level as is typically associated with AA[8], and do not otherwise alter existing model grid-level parameterizations. 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 handover, especially the food supply.[15-17]

The global mean surface air temperature rise during the modeled time period is shown in Figure 2. The modeled rate least-squares linear fit line (0.43C per decade) reasonably reproduces NOAA globally estimated rates.

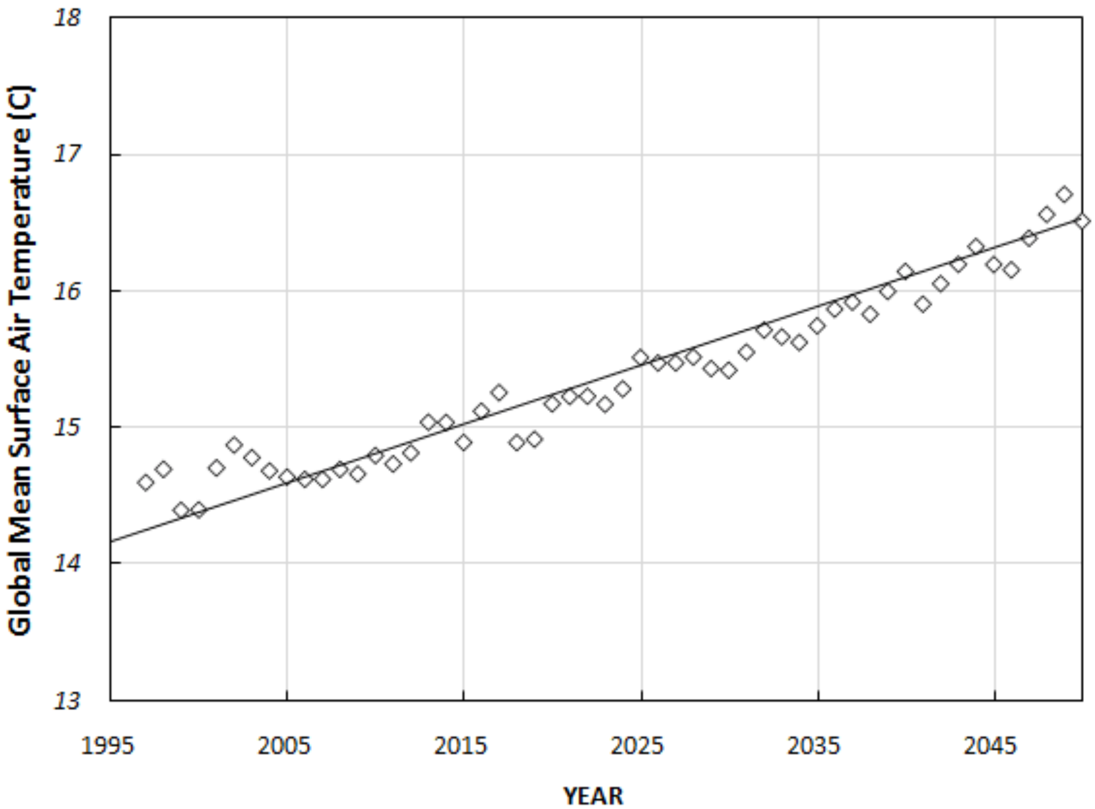


Figure 2. Global mean surface air temperature as modeled in this document. Linear-fit least squares line slope = 0.043 C/year

THE APPROACHING ARCTIC PHASE CHANGE

<u>PIOMAS Historical Fidelity & Model Prediction</u>

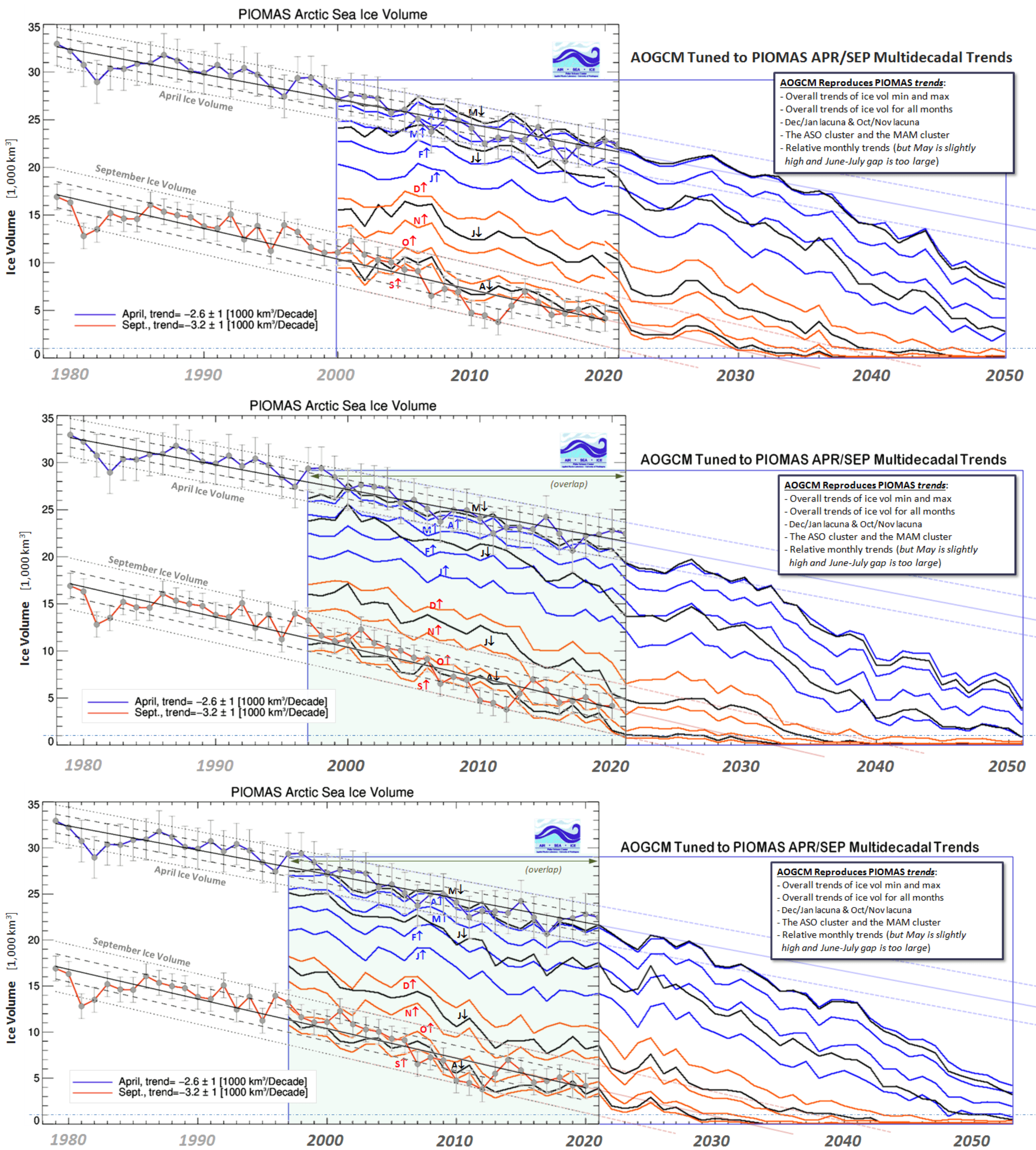


Figure 2. Three {rcp8.5/sps585} realizations of PIOMAS historic-data-tracking, AOGCM-physics-based extensions of observed PIOMAS ice volume data. Monthly overall rates are extremely well-reproduced. Given more time, detailed agreement with PIOMAS data over the entire PIOMAS dataset would be clearly obtained with this one parameterization adjustment to the model. The shown "historic" period overlaps with model calculations - 1997 to 2021. Summer-season phase-change is predicted to be complete ca. 2035, and <u>half-year</u> phase-change is predicted to be complete ca. 2045. Impacts on Northern hemisphere growing seasons are therefore a serious concern.

The most obvious feature shared by all realizations is that winter ice phase change (melt) begins to accelerate significantly faster than the historical rate when the summer phase change is nearly complete. Other features of consonance between PIOMAS and the model are indicated in the figure text.

The three realizations provided in Figure 2 demonstrate, from top to bottom, progressively larger modeled effects of AA up until the present. Variabilities over the 23-year historical overlap period make it difficult to know which realization is most representative. It could reasonably be argued that AOGCM simulations have always under-predicted global changes due to Anthropogenic climate change and the Holocene→Anthropocene handover. This would suggest that the most aggressive simulation, at the bottom of Figure 2, should probably be considered most reliable in the real world. **On the other hand, concurrent warming feedbacks are NOT included - hence 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 with certainty, so *global weather pattern changes* resulting from the modeling here of Arctic phase are of low reliability. On the other hand, *localized Arctic responses, being dominated by Arctic thermodynamics, are inherently more reliable*.

Nonetheless, the modeled Arctic responses have general implications for global weather patterns in the real world, such as the generally accepted theory of the importance of equatorial/Arctic temperature differences driving jets and the Westerly atmospheric flows. In this regard, the 500 mb height data presented in Figure 6 suggest slowing in the jets and Westerlies, and perhaps disruption of the jets and hence, Northern hemisphere food growing seasons. The model reveals the proximity of such a disaster.

Due to previously mentioned dynamic uncertainties[23], the modeled global results of Arctic phase change are not presented except for one attempt to forecast changes in long duration precipitation events (Figure 7).[18]

Monthly Mean Arctic Ocean Surface Air Temperature

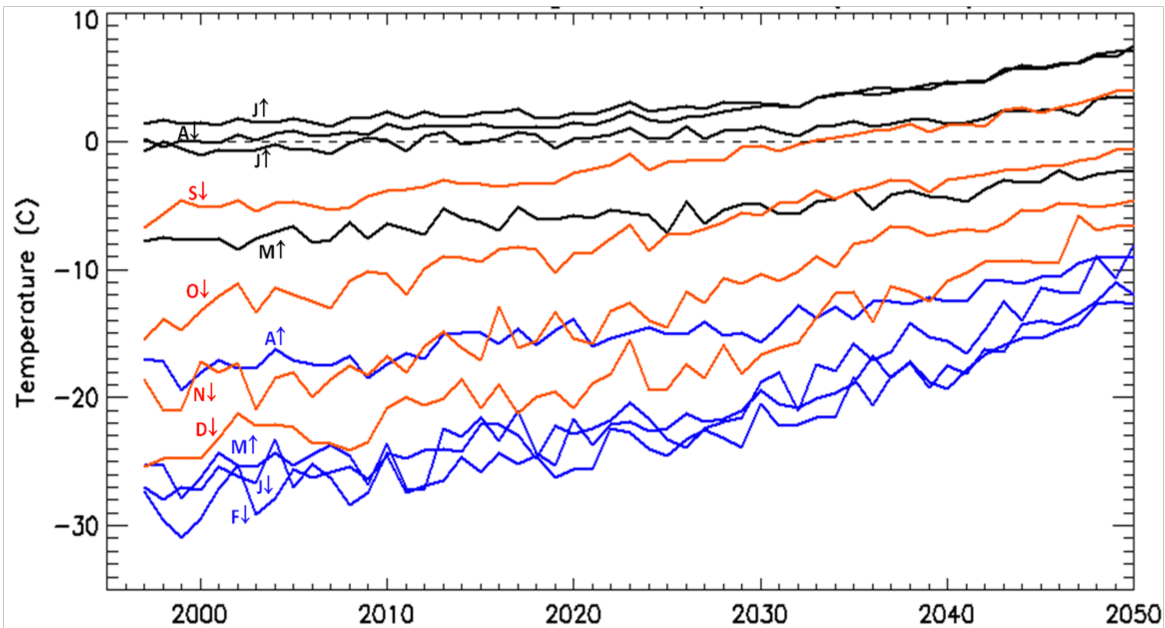


Figure 3. Monthly mean Arctic ocean surface air temperature.

Modeled Arctic September Ice Fraction 2030 - 2040

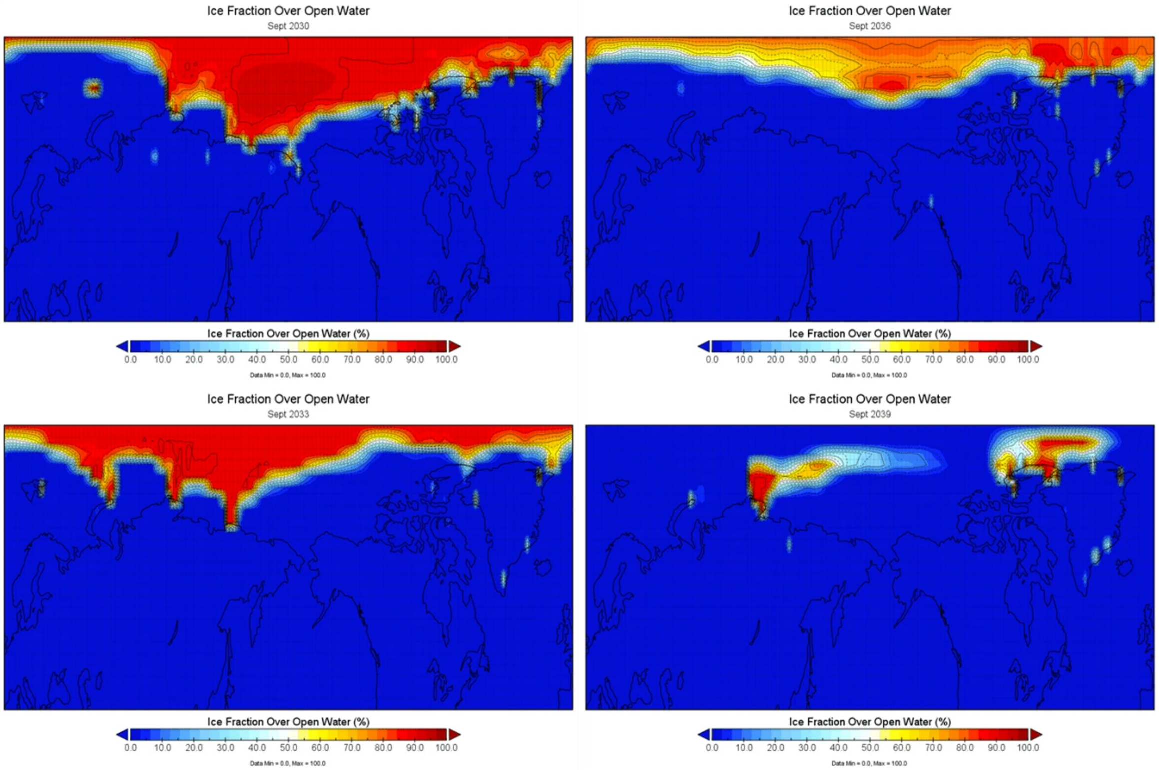
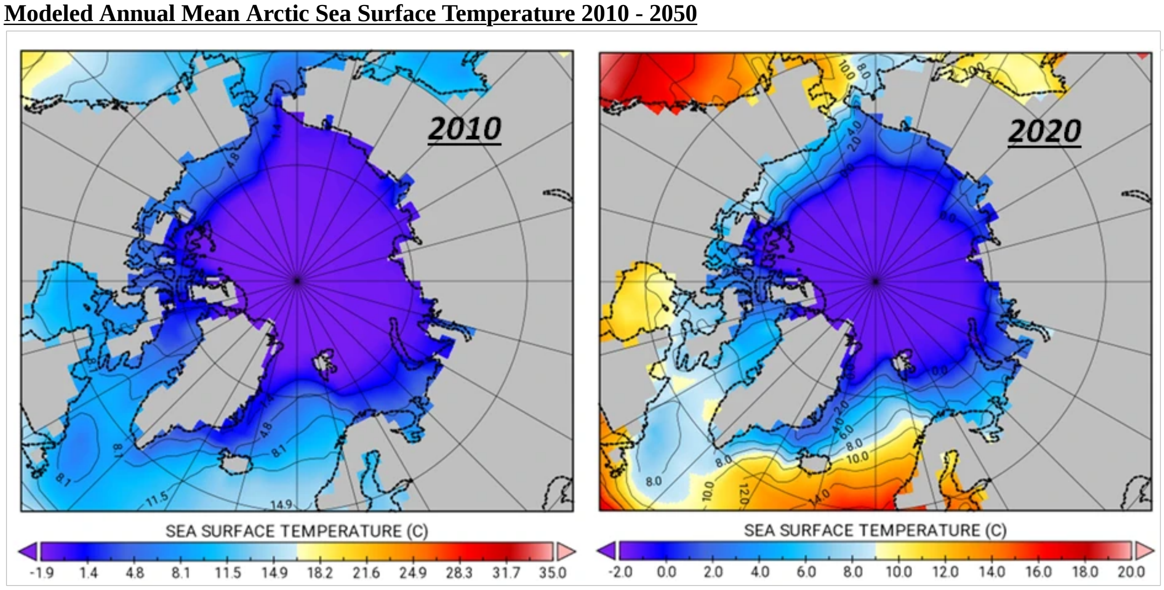


Figure 4. Ice geometry predictions (surface area and thickness) are much less reliable than predictions of ice volume, which is more closely tied to the thermodynamics; thus ice fraction here only roughly illustrates expected changes.

Modeled Annual Mean Arctic Sea Surface Temperature 2010 - 2050



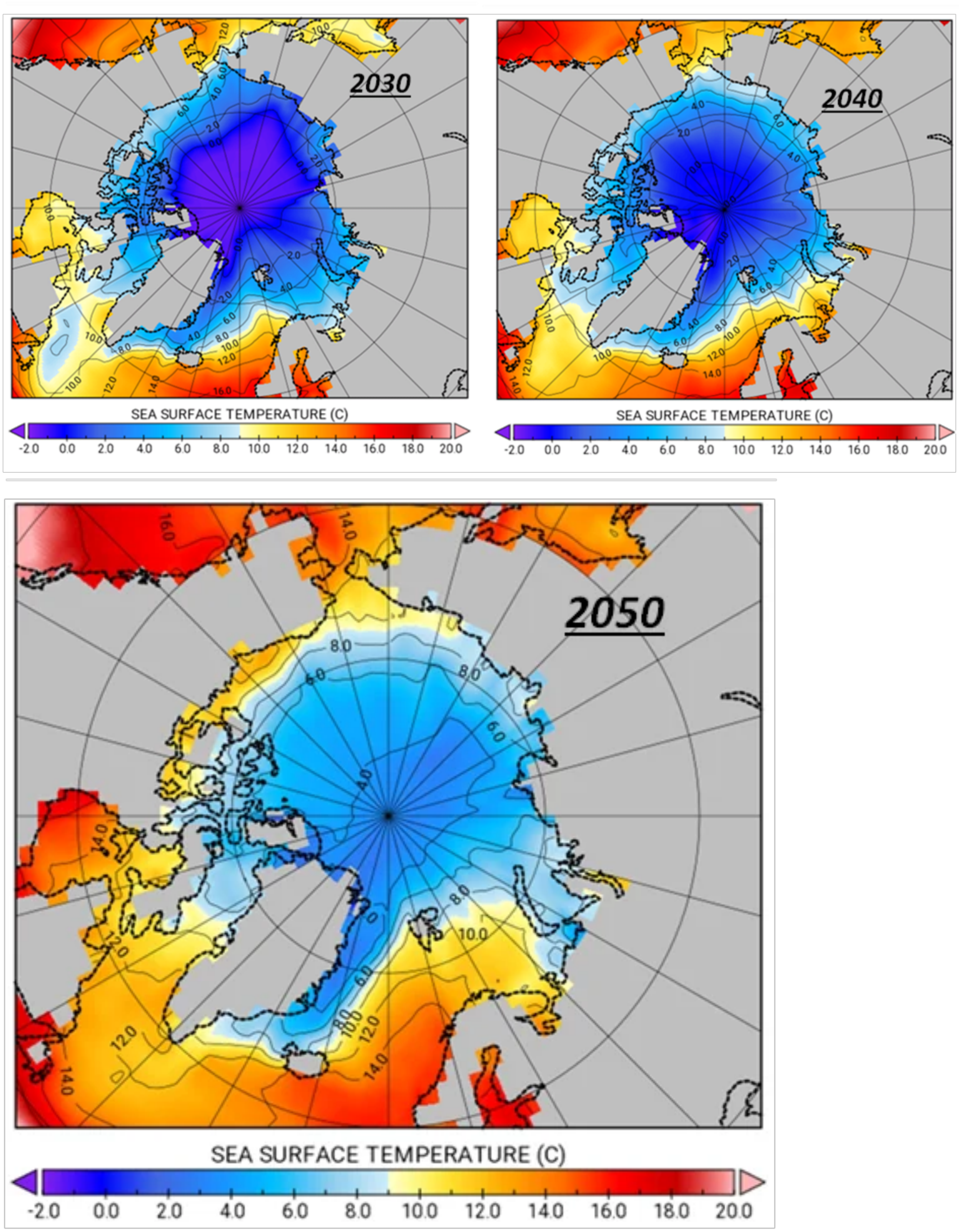


Figure 5. Modeled annual mean sea surface temperature on selected years over the time period investigated.

The mean annual Arctic 500mb height (*below*) is associated with the strength of the Westerly geostrophic flows and jets. Decreased Westerly flows are suggested by the modeled Arctic phase change. Example years are shown in Figure 6.

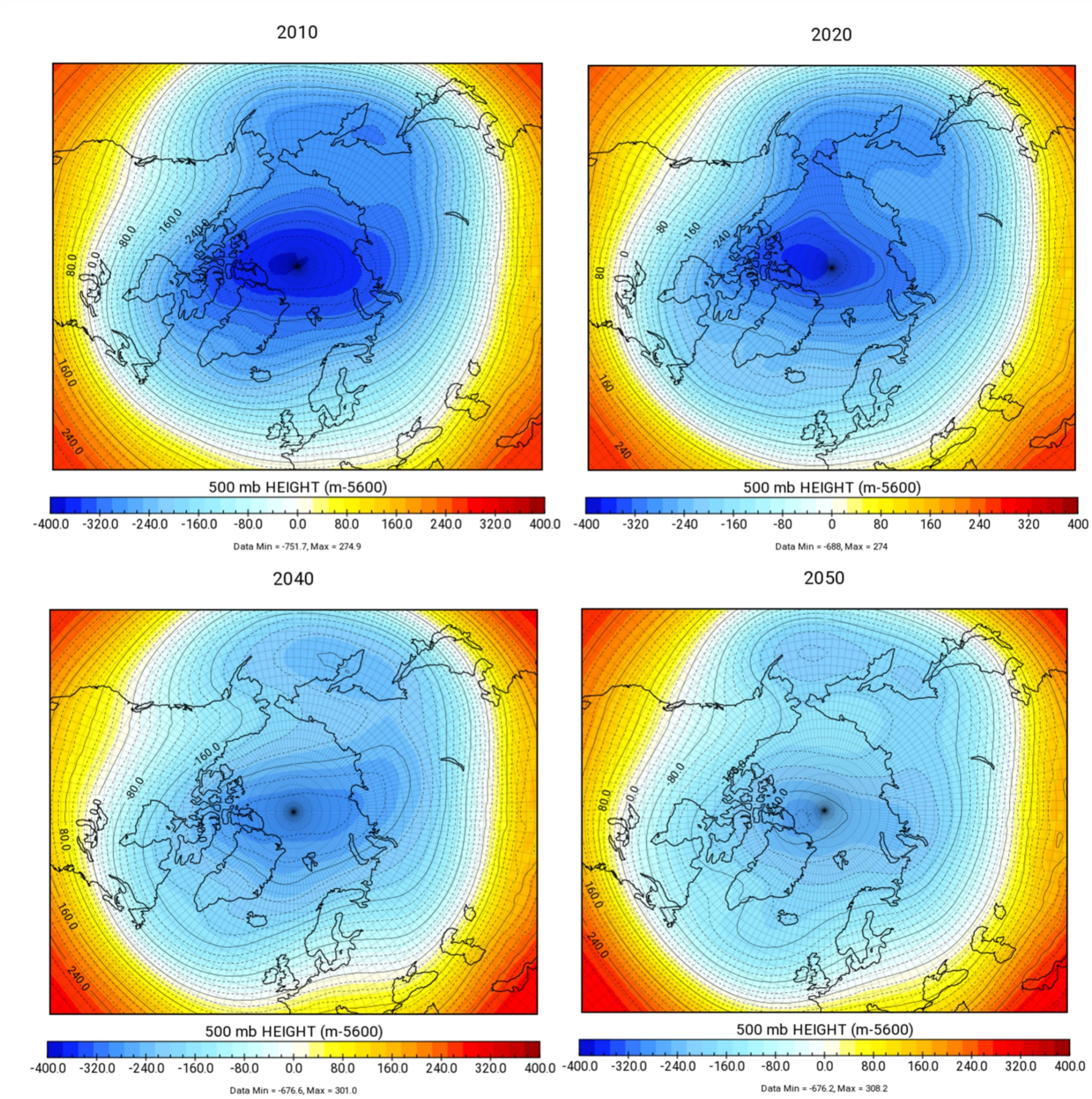


Figure 6. Modeled annual mean 500mb height in the Arctic, modeled-historical (above) and predicted (below).

Long duration precipitation events (**LDE**) are one suggested metric for changes in the geostrophic Westerly flow and/or changes in the flow of the Jet.[18,20] Since these are controlled by global model *dynamics*, there are significant uncertainties involved.[23] 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. Changes in LDE patterns have been suggested to indicate changes in Westerly/Jet patterns.[20]

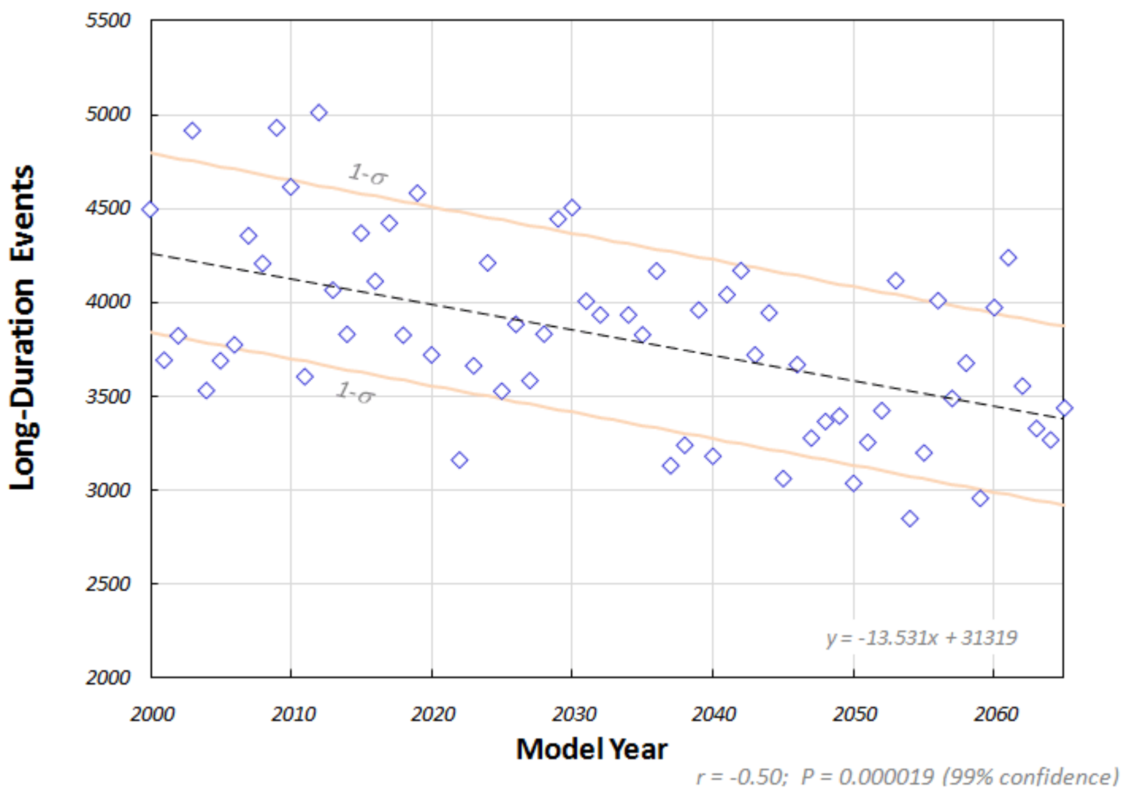


Figure 7. Number of 5-consecutive-day events per year with grid-resolved precipitation above 5 mm/day. Above: grid region = 76W-126W by 30N-60N (North America); Below: grid region = 10W-45E by 30N-60N (Europe). The p-value suggests reasonable confidence; however, direct AOGCM predictions of regional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

IMPACT OF MELT-TRIGGERED METHANE RELEASE

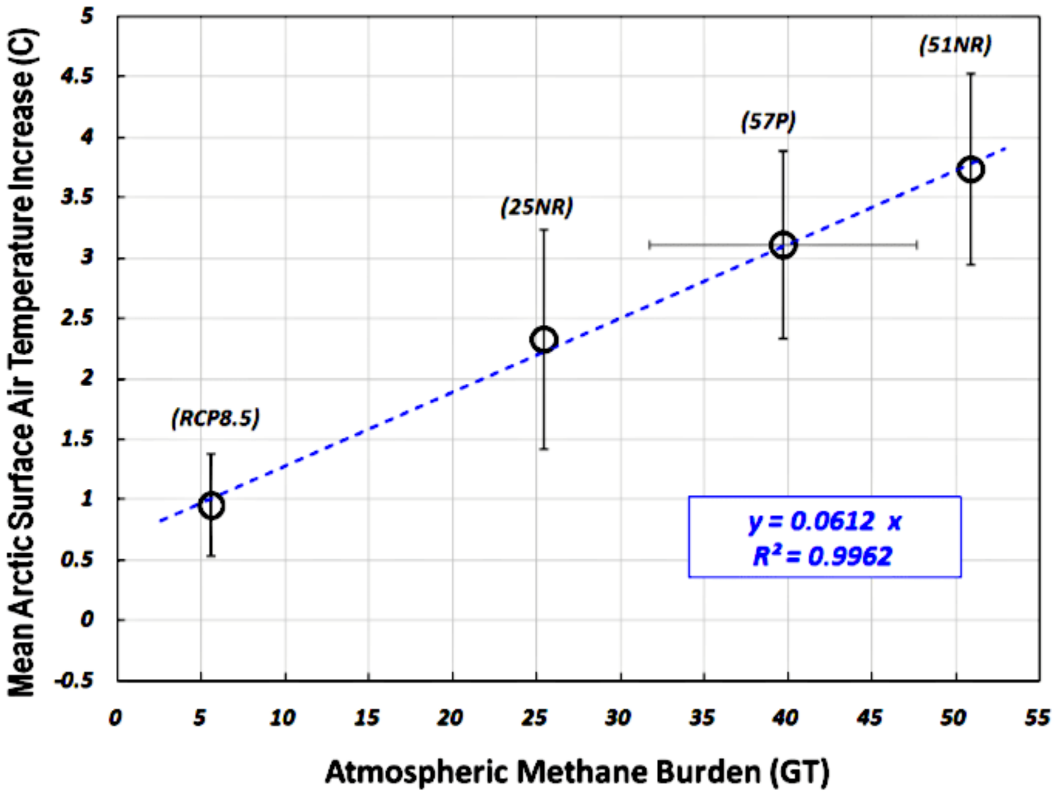


Figure 12. Arctic (68°N – 90°N) mean surface air temperature rise above mean of 2020-2025 Arctic temperatures, for all scenarios. Y-axis 1-σ error bars represent combined annual model variation and the observed upward drift of each scenario over that time period. The single X-axis 1-σ error bar represents 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. From reference [6]; Arctic response to several methane burst scenarios. 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, **shallow continental shelf methane releases** from a seasonally ice-free Arctic ocean have been measured.[8-12] The potential impacts of a sudden methane burst were applied to the results already presented, using an *offline* method - that is, not included in the sources/dynamics/feedbacks of the model itself. Instead, the model results are adjusted after-the-fact, 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 for a guide as to when ice-free conditions are obtained.

Assuming the changes in mean Arctic surface air temperature shown in Figure 8 [6], it can be estimated, based on the slopes of the monthly data, that the Arctic phase change may be accelerated by as much as 8 years (Figure 10).

This would suggest half-year Arctic phase change occurring by the mid-2030's with nearly complete non-winter phase change by the mid-2040's.

These 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 Arctic temperature changes occur during the NH growing seasons.

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

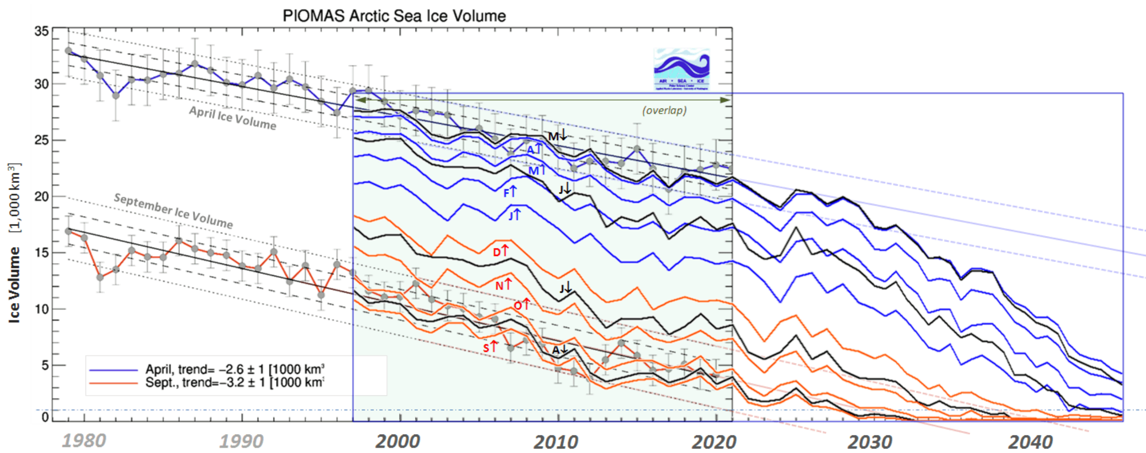


Figure 9. Accelerated ice melt estimates, using the (non-methane) model outputs shown in Figure 2, and assuming ~1°C increase in Arctic temperatures suggested by Figure 8 [6], for a ~20 GT total atmospheric methane burden (also assumes AA continues at approximately the historically observed rates).

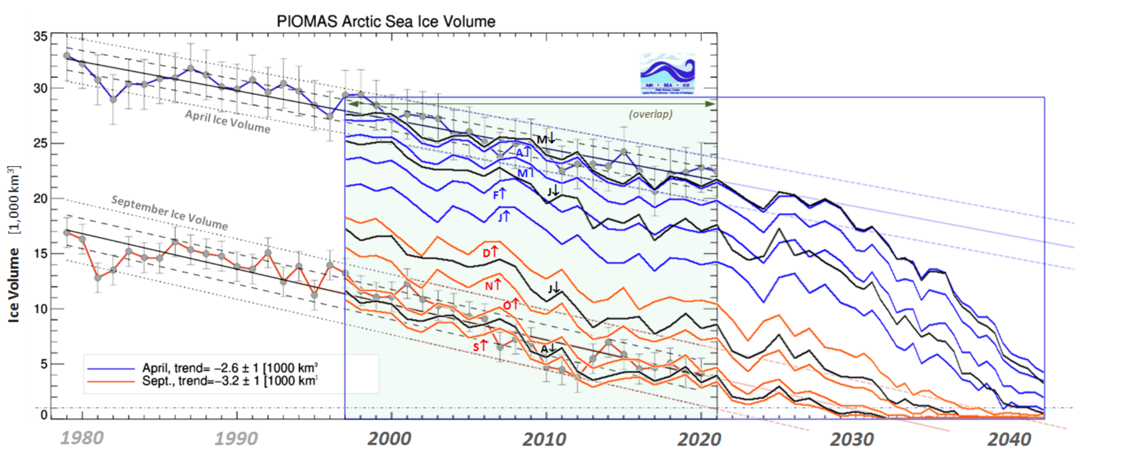


Figure 10. Accelerated ice melt estimates, using model outputs shown in Figure 2, and assuming ~2.5°C increase in Arctic temperatures suggested by Figure 8 [6], for a ~45 GT total atmospheric methane burden (also assumes AA continues at approximately the historically observed rates).

SUMMARY/CONCLUSIONS

- Continued historical AA and high-emissions rates are *assumed*
- The *physical response* to continued AA is generated by the AOGCM
- *Result: detailed agreement with 23+ years historical observation*
- Non-methane forecast:
  - 3-month Arctic ocean zero-ice by 2035
  - Half-year Arctic ocean zero-ice by 2045
- *A methane burst makes these dates considerably sooner*
- Risk: Northern Hemisphere growing season disruption: *Arctic Cloud Brightening* may extend zero-ice dates, required to facilitate any *realistic* carbon-reduction actions [*8,15,16,24-27*]

Summary The importance of forecasting a *seasonal zero ice condition* in the Arctic *ca* 2035 is the significant potential for periodic disruption of Northern hemisphere (NH) food production, especially grave given that the global NH food production rate already has a decreasing trajectory.

Additionally, based on previous work, it is estimated that if large scale Arctic ocean warming triggers a methane burst, 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 such a burst.

The anticipated Arctic phase change is suggested as a rational target for a minimal impact geoengineering effort, Arctic cloud brightening, to attempt to slow Arctic ice melt, maintaining the NH food-production basis for global technological civilization.[8,15,16,24-27] AOGCM estimates of the impacts of insolation reduction have been previously made.[6]

In this work, continued Arctic Amplification (AA) and RCP8.5/sps585 emissions rates were *assumed* for the near term; this maintains consistency with recent carbon-release rates and weak CoP/IPCC results concerning the Holocene→Anthropocene weather/climate handover. Some AR6 model contributions suggest that *AA ceased ca. 2020* - but these models only poorly reproduce historical PIOMAS trends (over a historic interval that is too short for confidence (given variances of model results).

AA is enforced here by moving a small fraction of global TOA insolation to Arctic ocean basin TOA insolation - avoiding localized paramaterization (e.g., cloud model) changes. This maintains Arctic ocean surface warming under thermodynamic control rather than control of the dynamics of the atmosphere (atmospheric rivers, weather events, etc.), as appropriate for the Arctic. The model outputs exceptionally well-reproduced, long-term Arctic historical observations.

The author expresses her gratitude to the dedicated scientists at GISS for outstanding software.[22,23]

AUTHOR INFORMATION

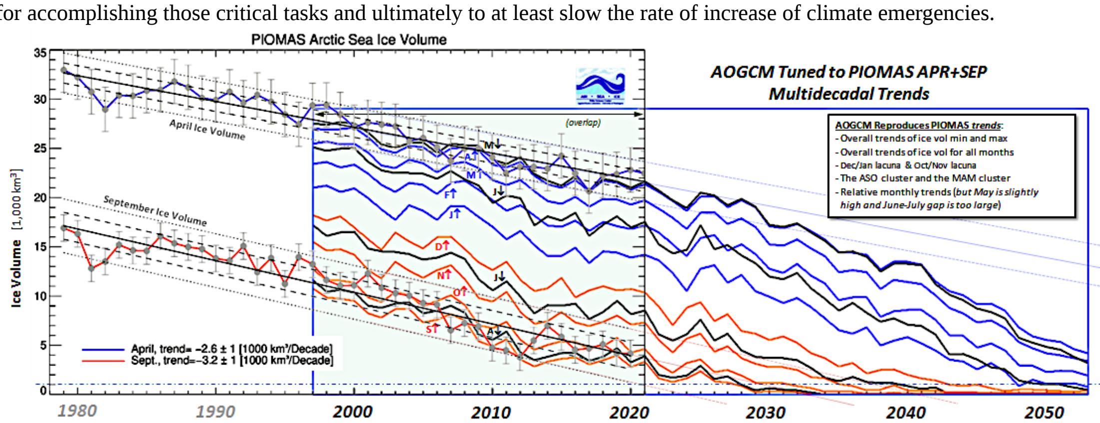
Patricia Michelle Sheaffer is a retired Level-II chemical physicist and materials scientist for the US Air Force Space and Missile Systems Center under contract with The Aerospace Corporation at the Ivan A. Getting Research Laboratories, having a 36 year career in multidisciplinary science there. Her research included designing laboratory and remote sensing equipment to research the chemical species present in rocket jet-engine plumes, including operating a 4,000 LOX/hydrocarbon rocket engine. Her early career involved research in carbon pyrolysis materials science, in both the gas and condensed phases. Her work also includes studying the impacts of anthropogenic emissions on climate change using global climate models.

Her multidisciplinary research also included an important contribution to the NASA DebriSat Hypervelocity Impact experiment by designing and building Debris-LV - which simulated one of the 100+ launch vehicle upper stages still on orbit. In this experiment, she discovered the process which creates highly-destructive "space flakes" which result from hypervelocity impacts against metallic vehicles, such as upper stages - a fundamental contribution to space debris research. Public outreach included presentation on a BBC science special on orbital debris: https://www.bbc.co.uk/programmes /p02yvrtq

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.



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