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Analysis on the multiple forcing factors of polar amplification

Chenxuan Zhang

No.2 Secondary School Attached to East China Normal University, Shanghai, 201203, China

pierides114514@gmail.com

Abstract. Among the most striking characteristics of the currently imbalanced global warming process is the amplification of heat in the polar regions. Historical records and computer-generated weather patterns both attest to its recurrence. Although the causes of this phenomenon are complex, they can be boiled down to the following three primary factors, including the albedo feedback, the Planck feedback, and the tropical lapse rate feedback. A different study from the past has highlighted the significance of all three reasons separately but without agreement. Literature review and interaction analysis are used to zero in on the key aspects of the corresponding climate model simulation, such as the increased CO_2 forcing brought about by quadrupling the level of CO_2 from the pre-industry level results by earlier scientists, and the predominate feedback forcing, the lapse-rate feedback. Using the CPL models in the same conditions allowed researchers to determine that the lapse-rate feedback is the primary factor in Arctic amplification, while the Planck feedback's curvature and the surface-albedo problem played secondary roles. In addition, the paper found that decreasing zonal radiative forcing in the polar regions may be more successful than previously anticipated in reducing Arctic amplification because local forcing is larger than external forcing.

Keywords: Polar Amplification, Arctic Amplification, Climate Change, Global Warming.

1. Introduction

It is common knowledge that the melting of glaciers and sea ice is being accelerated to an unprecedented degree due to global warming, which is having a devastating effect on the delicate ecosystems of the polar regions. Polar amplification, as an essential and distinct feature of global warming, has captured the public's attention. Temperature, humidity, and cloud feedbacks are currently the primary area of study. The decrease in albedo as a result of melting ice and snow is commonly cited as the primary cause of this phenomenon. However, models without ice and snow cover changes also find Arctic amplification. It has become clear from recent research that other primary stressors, such as lapse rate and heat interchange, are significantly more important than was previously believed. However, the specifics of this issue are still very much up for debate. While the bulk of this paper is dedicated to comparing and contrasting the models developed by different researchers in the past, it does cover the general consensus reached by these experts in their individual publications.

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As a result, the bulk of the research focuses on providing a synthesis on prior research into the various components that contribute to polar amplification. Because the climate's linear reaction to regional forcing is similar to the response to global forcing, we can use climate model simulations to discover the root cause of polar amplification.

Through a series of comparisons across numerous latitudes and seasons, this study intends to highlight the distinct mechanism and varying phases of importance of all three key forcings of the polar amplification. The findings allow for a quantitative assessment of the importance of single feedback and a systematic understanding of the susceptibility of decompositions to shifts in the spatial distribution of forcings. Theoretical findings are also important for determining the most efficient and effective approach to polar amplification, which could have practical implications in areas like polar preservation legislation.

2. Polar amplification

If we want to accurately estimate polar warming and learn more about the role of polar ice in the global climate system, marine ecosystems, and human civilizations, we need to understand polar amplification, or the ratio of polar warming to warming in the tropics. When it comes to the surface temperature response to greenhouse gas forcing, polar-amplification is most evident in the Northern Hemisphere. The impact of CO_2 on the average temperature around the globe is depicted in Figure 1. Simulated temperature with twice as much CO_2 is shown by the dashed line.

A consensus on what triggers polar amplification has yet to be reached. The high albedo of the polar ice sheet has been blamed by certain research as the cause of this phenomenon. Another possible rationale is radiation feedback [1-3]. Adjustments in cloud cover alter the net surface radiation received by Earth's surface throughout the year (see Figure 2). Clouds, as expected, have a net warming influence in cold seasons and a net cooling effect in warm seasons. Polar amplification could be influenced by shifts in atmospheric and oceanic heat transport. Annual mean surface temperature, vertical integrated atmospheric temperature, and water vapor kernels are shown in Figure 3. As a result, an increase in atmospheric temperature results in a greater rate of energy loss for the atmosphere due to radiation to space and the surface of the Earth.

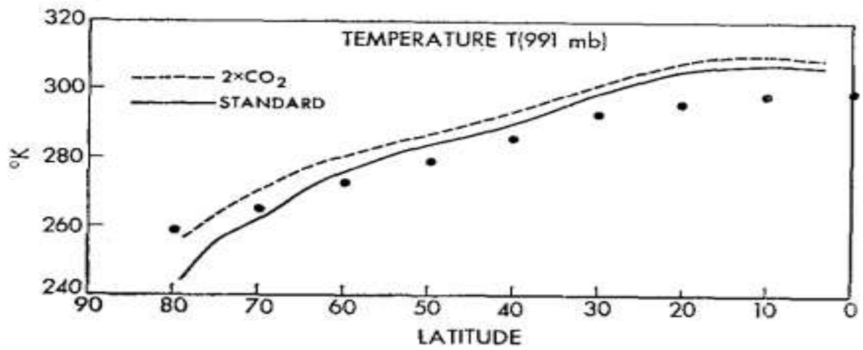

Figure 1. Zonal (Polar) mean temperature at the lowest prognostic level (Dots are the observed distribution of zonal mean surface air temperature) [4].

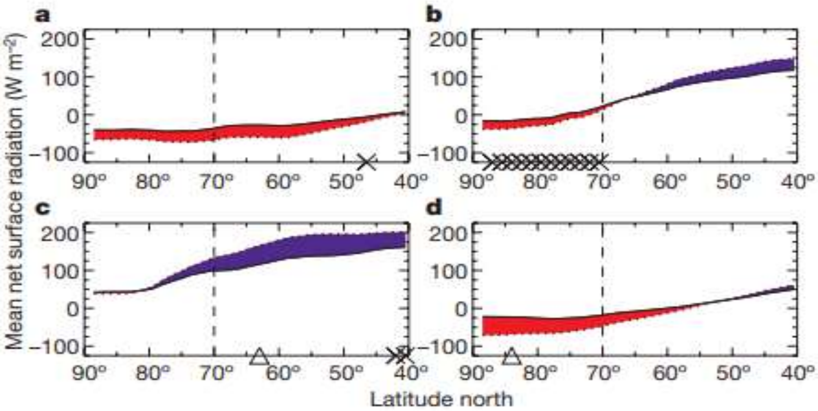

Figure 2. Impacts of cloud-cover changes on the net surface radiation (Means are averaged around circles of latitude for winter (a), spring (b), summer (c), and autumn (d)) [5].

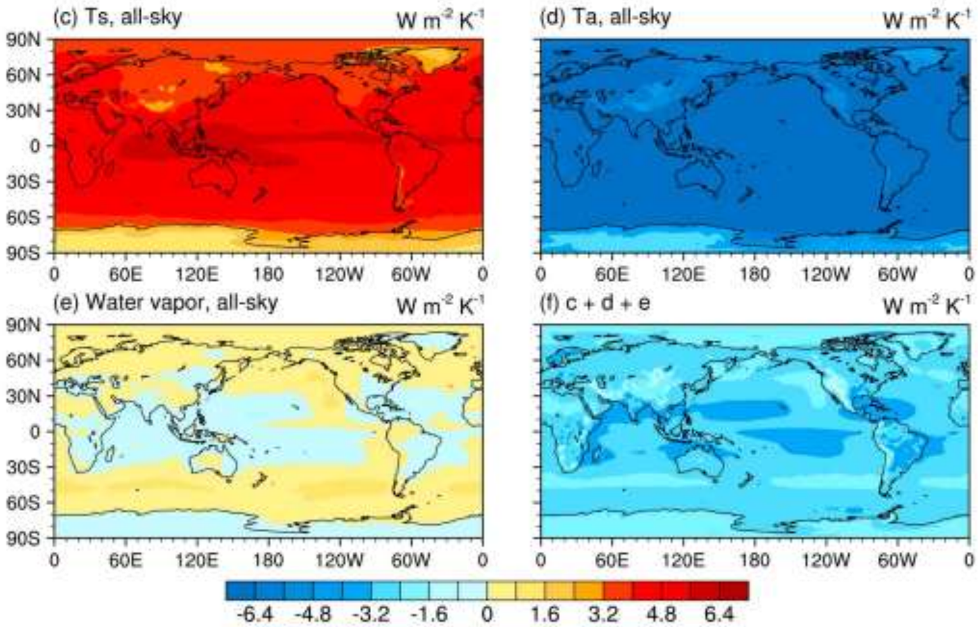

Figure 3. All-sky atmospheric radiation kernels (Geographic distributions of annual mean surface temperature, vertically integrated atmospheric temperature, and vertically integrated water vapor kernels) [2].

3. Analysis of methods and results

Polar amplification under greenhouse gas forcing is studied by simulating the atmosphere and ocean in an idealized general circulation model (Methods). Comparing the climatic reaction in the polar areas to local CO_2 radiative forcing with that of remote CO_2 radiative forcing in the deep tropics, where the area over which force is supplied is roughly comparable to that of the polar forcing, is presented. To evaluate the linearity of the climate response to regional forcings, simulations are also run with CO_2 forcing in the tropics, subtropics, midlatitudes, and globally. A quadrupling of CO_2 from pre-industrial levels is assumed in all scenarios (figure 4) and multiple group members are employed to separate the forced signal [3].

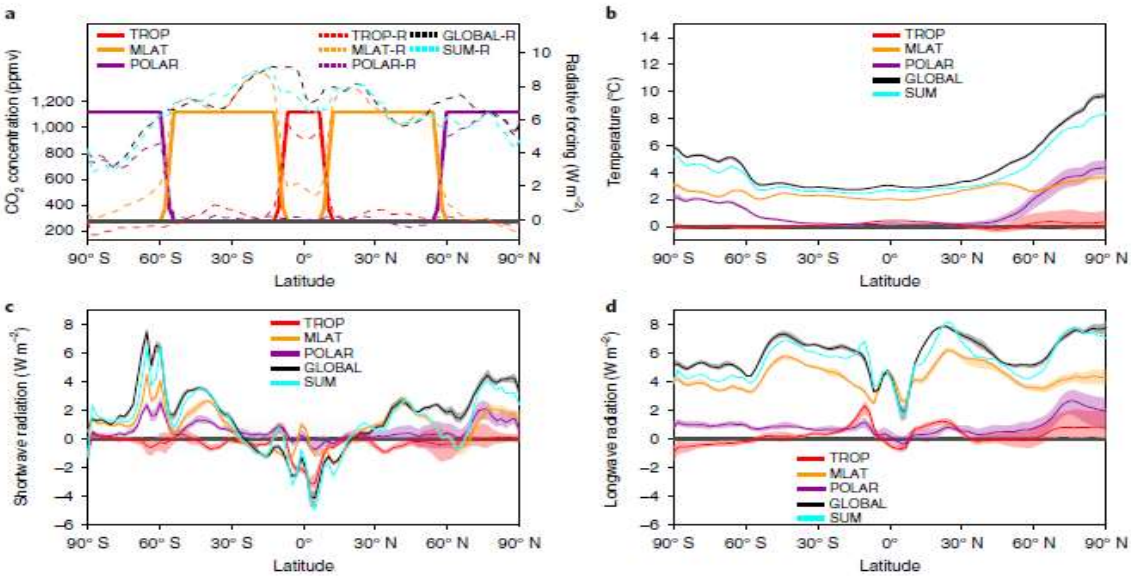

Figure 4. Forcing structure and climate response (a, CO_2 forcing structure for the TROP (solid red). b, TAS. c, SWR (absorbed TOA CPL response shortwave radiative force). d, LWF:outgoing TOA longwave CPL response longwave radiative forcing) [3].

It is taken into account how the tropospheric temperature reacts to varying degrees of regional forcing. As far as we can tell, polar forcing causes significant surface and lower tropospheric warming at the poles. The CPL simulations showed that the polar troposphere warmed more uniformly in response to extra-polar forcing (Fig. 4a, b), implying that ocean dynamics had a role in this regulation.

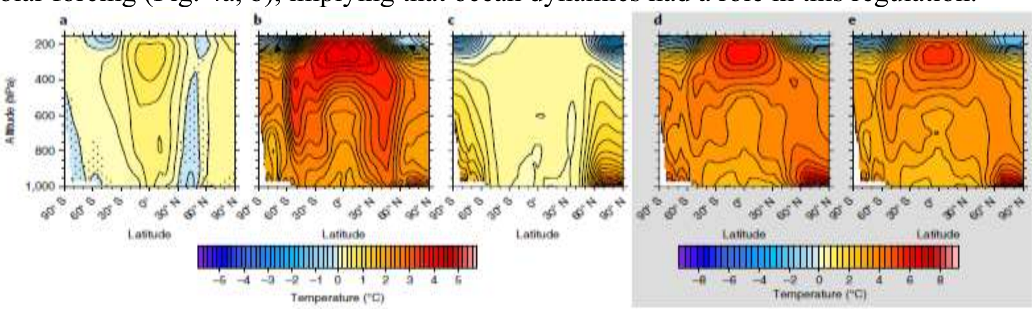

Figure 5. Tropospheric temperature responses (a-d) Tropospheric zonal mean, the ensemble mean temperature responses for TROP-CPL (a), MLAT-CPL (b), POLAR-CPL (c), and GLOBAL-CPL (d) [3].

The simulated data from both the CPL and SOM experiments indicate that the regional response of air temperature (TAS) at the 2m reference altitude to regional forcing closely approximating the response to global forcing. This finding is in excellent agreement with previous research on the theoretical aqua planet model. This spatial linearity is also important because it implies that GLOBAL warming at the poles may be broken down into its component parts—the regional reactions to the forcing. Although the global average warming caused by polar has increased fourfold and the poles have warmed by an order of magnitude, this is consistent with previous studies on local forcing models and allows for direct comparison of the relative contribution of TROP and POLAR on surface warming in tropical regions (30°s - 30°n). In terms of absolute global average warming, MLAT is responsible for more of it, but this is because it affects a wider region than the polar regions do.

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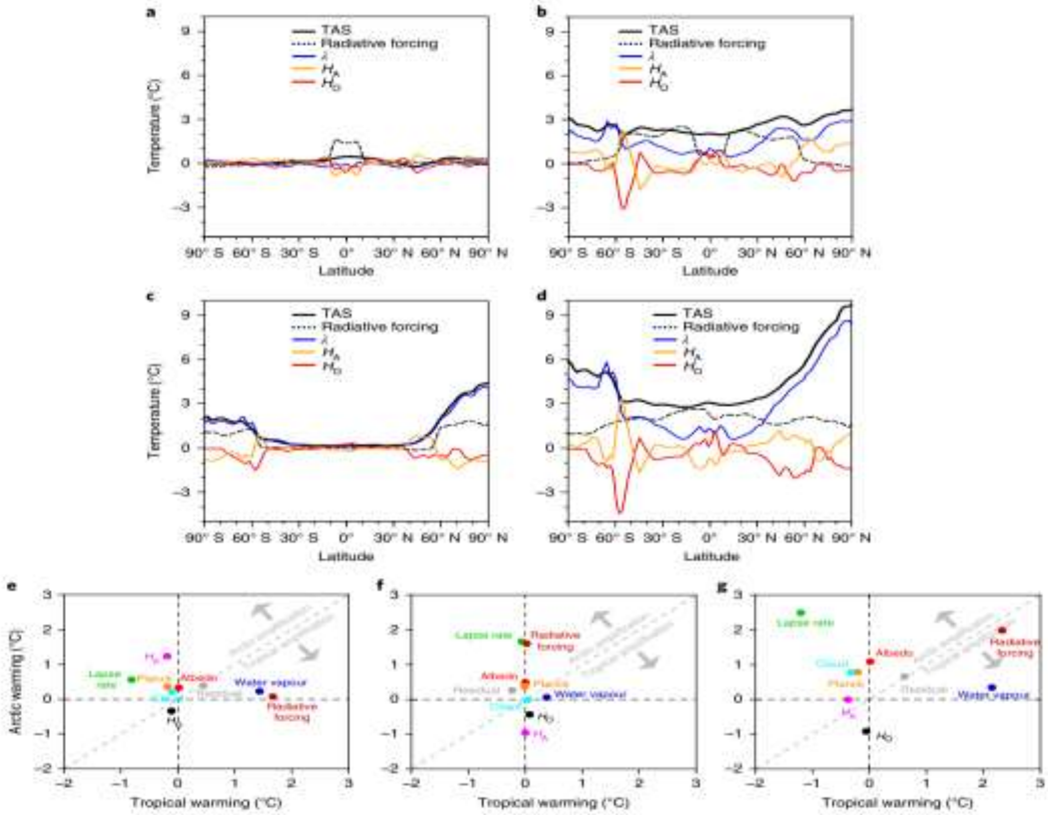

Figure 6. Warming contributions by different physical processes. (Radiative forcing, oceanic heat intake, atmospheric heat transfer, and the local feedback parameter (λ) contribute to zonal mean TAS warming in TROP-CPL (a), MLAT-CPL (b), POLAR-CPL (c), and GLOBALCPL (d). (d). MLAT-CPL (e), POLARCPL (f), and GLOBAL-CPL (g) tropical (30° S-30° N) and Arctic (60° N-90° N) warming feedbacks (g). Residuals represent decomposition ambiguity) [3].

Radiation forcing and climatic response (Fig. 1-3) appropriate to each region are added to the global response to examine each mechanism's contribution to polar amplification. We break down the zonal average temperature response in the CPL simulation (Fig. 4a-d) into "warming contributions" from radiative forcing, local feedback, atmospheric heat transfer, and net surface heat flux (ocean heat absorption). A small fraction of Arctic warming owing to deep tropical forcing is attributable to air heat transport (Orange Line in Fig. 6A). In MLAT-CPL, on the other hand, the Arctic warms due to both local feedback and atmospheric heat transport (blue and orange lines in Fig. 6b, respectively). POLAR-(blue CPL's line in Fig. 6C) polar warming is dominated by local feedback, while local radiation forcing contributes to warming and changes in heat transfer contribute to cooling. In the case of mid-latitude forcing, the difference in warming rates between the Antarctic and the Arctic is primarily attributable to differences in ocean heat absorption and atmospheric heat transfer; however, in the case of polar forcing, the difference is primarily attributable to differences in local feedback.

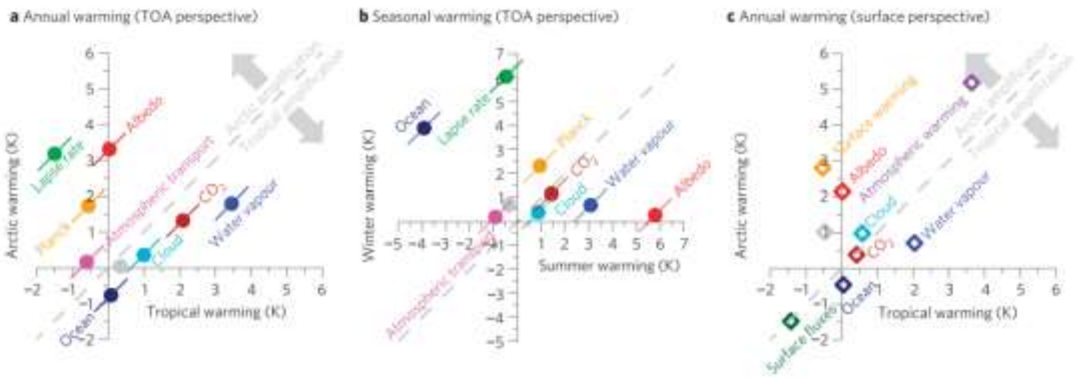

Figure 7. Warming contributions of individual feedback mechanisms (a, TOA Arctic vs. tropics warming. b, Polar cold vs. summer warming. c, Arctic vs. tropical surface warming) [6].

Humidification and warming of the atmosphere are not two separate feedback mechanisms, but rather the result of a single mechanism, the feedback generated by rising temperatures under conditions of constant relative humidity. Planck feedback pair amplifies the North Pole slightly more than the alternative decay rate feedback (North Pole: +3.8 K, tropical: −2.2 K) and the specific surface albedo feedback (Arctic: −2.2 K +5.7 K) (near to zero). RH-temperature correlation at a fixed temperature. The Arctic albedo feedback is more pronounced in the winter (Dec-Feb) than in the summer (June-August). wintery. Longwave radiation has decreased by 26%, and warming has been connected to the release of air and ocean heat. Warmer summers are attributed to feedbacks from the surface albedo and water vapor, but these effects are offset by the seasonal heat storage ocean and time delay rate. In the summer, albedo shifts by around 2/3. In the winter, the ocean's stored heat is released. This, in conjunction with the reinforcement of the winter pattern via the lapse rate, is rather powerful. Summer Arctic warming is substantially lower than winter, and the North Pole decay rate feedback is somewhat negative. If the troposphere is adequately mixed in the tropospheric temperature profile, surface temperature fluctuations can be easily understood by TOA flux changes [6]. Positive lapse rate feedback decouples the Arctic's troposphere and ground. The North Pole decay rate feedback represents the failure of the vertical coupling assumption, not a physical mechanism. We can learn more about surface magnification triggering Arctic warming from analyses beyond TOA (Fig. 7c).

4. Conclusion

The findings reveal that the CPL simulation agrees with the work of Pithan and Mauritsen in most respects [6]. The rate-of-change feedback was shown to be the most important contributor to Arctic amplification in both the POLAR-CPL and GLOBAL-CPL experiments; the curvature and surface albedo feedback in the Planck feedback of the heavy tropospheric warming profile also contributed, albeit to a lesser extent. Furthermore, air heat transmission significantly contributes to MLAT amplification, but has the opposite effect in the polar region. These findings point out the dangers of extrapolating global causes for Arctic amplification. Radiative forcing, for instance, is thought to contribute to warming amplification under tropical global forcing but is viewed as the primary cause of Arctic amplification when the forcing is administered regionally.

In conclusion, the North Pole's curvature in the Planck feedback is mostly amplified by the lapse-rate feedback, while the surface albedo feedback acts as a subsidy. This may also cause us to accept the findings of earlier studies that highlight the significance of surface albedo feedback in Arctic amplification [7]. It's possible that this result was attained without resorting to extensive coupling modeling due to the shift in SST and sea ice boundary conditions brought on by CO_2 forcing [8].

The application of CO_2 forcing within the context of the coupled model is the system response that must be evaluated because inefficient feedback is itself dependent on forcing. Because the spatial distribution of radiative forcing greatly affects the relative contributing effect of each feedback and

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external heat transfer. Putting more emphasis on the polar region may be a more efficient strategy for reducing Arctic amplification. Traditional carbon dioxide forcing simulations have limited worldwide applicability, and thus fail to adequately assess the central mechanism of polar amplification.

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