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Key Points:
- Human-induced global warming has greater influences on some undeveloped countries
- Cloud has the largest contribution to polar amplification, rather than the frequently blamed sea ice decline
- Heat uptake by the deeper ocean greatly favors the terrestrial amplification

Supporting Information:
- Supporting Information S1

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Robust Regional Warming Amplifications Directly Following the Anthropogenic Emission

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Abstract Amplified regional warming suggests that some regions suffer more from global warming. However, present knowledge is still not enough to understand this paramount aspect of global warming. By using climate model simulations, we first highlight that regional warming amplifications directly following anthropogenic emission would torment many undeveloped countries. Then, we find that cloud has the largest contribution to polar amplification, rather than the frequently blamed sea ice decline. The summertime sea ice decline plays the second role in generating strong wintertime polar amplification via lagged energy release. Our findings also propose that heat uptake by the deeper ocean greatly favors the terrestrial amplification. Additionally, the cloud also shows its importance in helping dryland amplification. Our findings suggest that these robust regional warming amplifications are very likely inevitable under anthropogenic emission, therefore strictest global mitigation is required to prevent unacceptable warming over the high risk regions.

Plain Language Summary Amplified regional warming points out that some regions are more suffering under global warming. Thus, we performed this study to figure out robust regional warming amplifications directly following the anthropogenic greenhouse gas emission. We addressed the influences of these regional warming amplifications to human society, such an amplified dryland warming (relative to humid regions) has greater influences on some undeveloped countries. Furthermore, we achieved some new scientific findings that are crucial to understanding causes of amplified regional warming, such as cloud's dominant role on amplified pole warming (relative to lower-latitudes) rather than the frequently blamed sea ice decline. We also found the important role of deeper ocean heat uptake and cloud in helping amplified land warming (relative to ocean) and amplified dryland warming, respectively. Taken together, our study greatly helps to understand human influences on regional climate change.

1. Introduction

Global warming is a hot topic, if not the hottest, in climate change research. However, the previous global "warming hiatus" caused doubts about the reality of human-induced global warming (Fyfe et al., 2016; Held, 2013; Huang, Xie et al., 2017; Xie et al., 2017). Then the consecutive record-breaking hottest years that have occurred since 2015 are highlighting the dominant role of human influence on long-term global warming (Medhaug et al., 2017). Beyond the reality of global warming, the nonuniform magnitude of warming across the world is vital, because which could be devastating for regions with amplified warming (Brown et al., 2017; Fu et al., 2006; Manabe & Stouffer, 1980; Xie et al., 2016). Among the regional warming amplifications, the most famous is polar amplification (Manabe & Stouffer, 1980; Screen & Simmonds, 2010; Stouffer & Manabe, 2017).

However, the focus on polar amplification means that less attention is given to other warming amplifications. For example, a robust amplified warming over land than ocean is observed in observation and climate models (Fasullo, 2010; Joshi et al., 2008; Sutton et al., 2007), hereafter referred as terrestrial amplification analogously. It is lack of quantification in the causes of terrestrial amplification, although some explanations existed (Dong et al., 2009; Fasullo, 2010; Joshi et al., 2008; Sutton et al., 2007). Regarding warming over global land domain, amplified warming over dryland than humid regions is proposed (Huang et al., 2016; Huang, Yu et al., 2017), hereafter referred as dryland amplification. Nevertheless, whether the dryland warming has a directly anthropogenic origin is still not robust. Furthermore, substantial disagreement exists in explanations of polar amplification, such as the debate whether the leading factor is the snow/ice albedo feedback or the temperature feedback (Pithan & Mauritsen, 2014; Screen & Simmonds, 2010). Simply put, the understanding of regional warming amplifications is still insufficient.

Here, our focus is on long-term regional warming amplifications induced directly by anthropogenic greenhouse gas (GHG) emission. Therefore, the historical simulations forced only by anthropogenic GHG emission from multiple contemporary climate models, that is, the Coupled Model Intercomparison Project Phase 5 (CMIP5) models (Taylor et al., 2012), are examined.

2. Data and Methods

All the models examined in this study are listed in Table S1. Only the first ensemble member from each CMIP5 model was used. To acquire the ensemble mean regarding both spatial pattern and zonal mean results, the results from models were bilinear interpolated into a 1.5° by 1.5° (latitude by longitude) grid. Additional results that do not need a uniform grid were calculated directly from the raw data for each model.

Surface energy budget is $E^{\downarrow}_{\mathrm{net}} = R^{\downarrow}_{\mathrm{SW}}\text{-}R^{\uparrow}_{\mathrm{SW}} + R^{\downarrow}_{\mathrm{LW}}\text{-}R^{\uparrow}_{\mathrm{LW}}\text{-}H^{\uparrow}_{\mathrm{S}}\text{-}H^{\uparrow}_{\mathrm{L}}$, in which the left-hand term is the net energy and the right-hand terms are incident solar radiation, reflected solar radiation, incident thermal infrared radiation, emitted thermal infrared radiation, upward sensible heat flux, and upward latent heat flux, respectively. In this budget, the horizontal energy transport and surface heat uptake are not covered in the right-hand terms. Therefore, the left-hand net energy term actually involves both the surface heat uptake and horizontal energy transport. For the surface, the net solar radiation and incident thermal infrared radiation are its energy source. Incident and emitted thermal infrared radiation as well as sensible heat flux are the energy sources for the near-surface air. The long-term (e.g., centurial scale) changes in surface skin temperature and near surface air temperature are nearly identical, because the thermal infrared radiation and sensible heat couple them together (Figure S7). Thus, we can derive our conclusions clearly from the surface energy budget without involving the complex and error-prone offline radiation transfer calculations concerning the explicit energy budget of near-surface air.

The population data used here are gridded population of the world, version 4 (GPWv4) population density, revision 10, which has a resolution of ~0.5°, and available for the years 2000, 2005, 2010, and 2015. The data are managed by Center for International Earth Science Information Network Columbia University, 2017, Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC), https://doi.org/10.7927/H4DZ068D.

The gross domestic production per capita data are provided by Kummu et al. (2018), in which gross domestic production is given in 2011 international US dollars. Data have global extent at 5 arc-min resolution for the 26-year period of 1990–2015.

3. Results

3.1. Regional Warming Amplifications in Response to Anthropogenic GHG Emission

In response to anthropogenic GHG emission, the most outstanding amplified warming is located in Arctic over past one and a half centuries (Figure 1, top), which is why Arctic amplification is a top rated topic in climate change realm. Then, the other remarkable phenomenon is amplified warming over land than ocean, say terrestrial amplification. Solid evidences have been demonstrated for both Arctic and terrestrial amplifications in previous studies (Collins et al., 2013). In sharp contrast, Antarctic look special at first glance, because it shows no evident polar amplification, and where the land shows weaker warming than surrounding ocean (Figure 1, top). However, the ocean regions in Antarctic show a similar warming amplification with which in Arctic ocean (although weaker in magnitude), especially over the regions with sea ice (see Figure 4.7 in Vaughan et al., 2013). And the Antarctic continent actually has a larger warming than general oceans without sea ice. In such sense, polar (Figure S1) and terrestrial amplifications actually are presented in Antarctic, therefore Antarctic is also identical with the general case. Intuitively, sea ice plays an important role in polar amplification (Screen & Simmonds, 2010), but quantified attribution is required before find a robust explanation.

Given land is where humans live, the amplified regional warming over land domain should be given more attentions from a utilitarian thinking. Previous work has proposed an amplified warming over dryland than

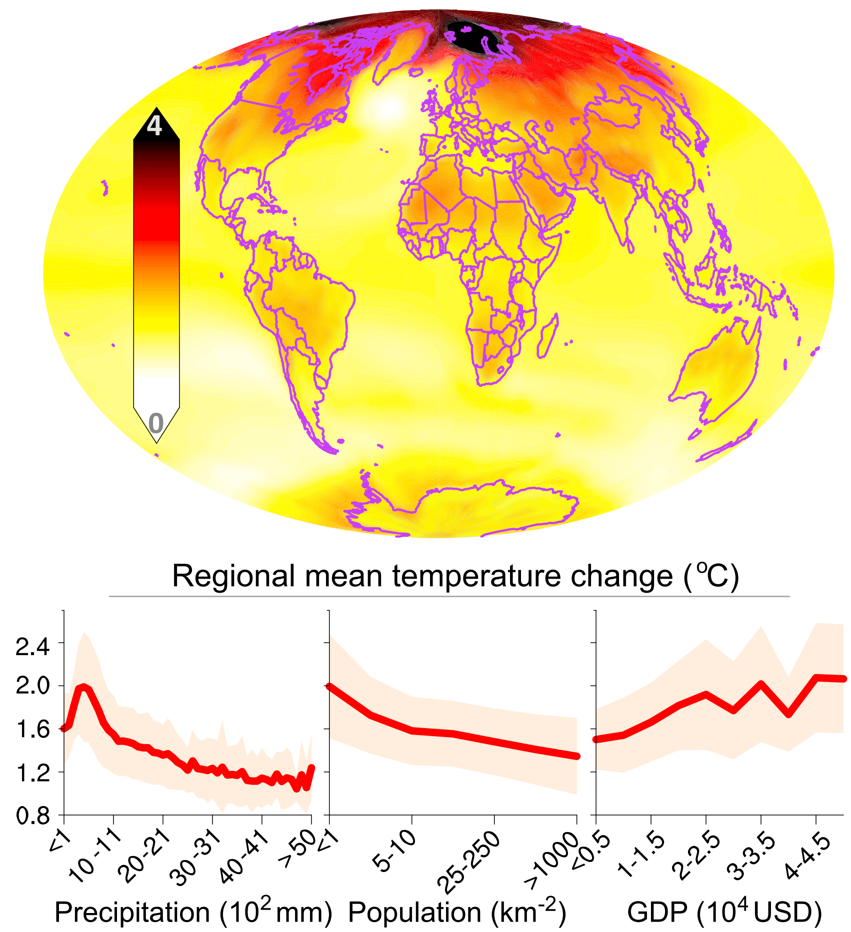

Figure 1. Temperature changes for the period from 1861 to 2004 in response to anthropogenic greenhouse gas emissions. The results are all ensemble means from the historical greenhouse gas simulations of CMIP5 models (listed in Table S1). (top) The spatial pattern of annual mean near-surface air temperature trends, in unit of °C per 144 years. (bottom-left) The regional mean trends of annual mean near-surface air temperature as a function of the climatological precipitation of land region. The shade represents the one standard deviation range of all CMIP5 models. (bottom-middle, -right) The same as bottom-left but replacing climatological precipitation with the population density and gross domestic production (GDP) per capita, respectively.

humid regions (Huang et al., 2016; Huang, Yu, et al., 2017). Then, it is important to explore whether the dryland amplification is robustly generated by anthropogenic GHG emission. Here, our results suggest that the dryland amplification directly follows the anthropogenic GHG emission (Figure 1, bottom-left). The dryland amplification is evident in both summertime and wintertime, and observed in all the CMIP5 models (Figures S2–3). Therefore, the anthropogenic origin of dryland amplification is robust.

Given many parts of dryland are deserts, the dryland amplification would have no realistic influence on human, if the warming amplification over dryland mainly occurred in depopulated zones. Therefore, the practical impact of dryland amplification should be explored in order to tell a whole story. First, the result shows that the warming is more amplified over the regions with less population (Figure 1, bottom-middle), which means dryland amplification only influence little people intuitively. However, you will find many exceptions existed by comparing the population density distribution (Figure S4) with global warming map (Figure 1, top). For example, some countries in western and southern Africa, western Asia, western China, and western United States are in the reach of dryland amplification (Figure 1, top). On the other hand, the national power is also a key factor to assess the regional impact of dryland amplification, because wealthier countries have greater power to perform adaptation strategies. The result demonstrates that wealthier regions generally experienced stronger warming (Figure 1, bottom-right; Figure S4). However, there are also many exceptions. Taken together, many undeveloped regions, such as western

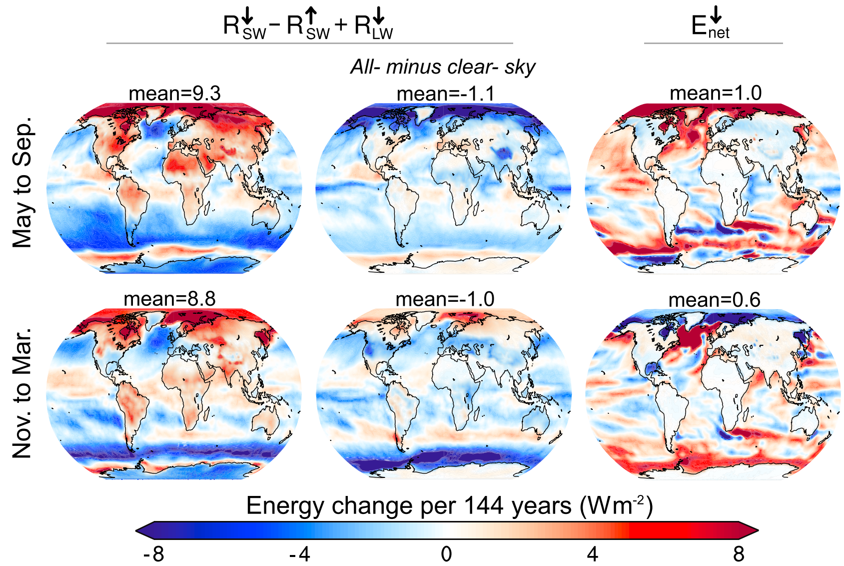

Figure 2. The energy source ($R_{SW}^{\downarrow}$-$R_{SW}^{\uparrow}$ + $R_{LW}^{\downarrow}$) and net energy ($E_{net}^{\downarrow}$) changes at the surface for the period from 1861 to 2004. $R_{SW}^{\downarrow}$, $R_{SW}^{\uparrow}$, and $R_{LW}^{\downarrow}$ are incident and reflected solar radiation and incident thermal infrared radiation, respectively. The results are all ensemble means from historical greenhouse gas simulations. (left) The linear trend of $R_{SW}^{\downarrow}$-$R_{SW}^{\uparrow}$ + $R_{LW}^{\downarrow}$ during May to September, and November to March, respectively, in unit of W/m^2 per 144 years. (middle) The effect of cloud represented by the differences using all-sky results (left) minus clear-sky results (Figures S5–6). (right) Same as (left) but for $E_{net}^{\downarrow}$. For a better illustration, the global average value annotated in the right corner of (left) and (right) is removed.

Africa, western Asia, and western China, will suffer more from dryland amplification by considering all the aforementioned conditions.

3.2. Causes of the Featured Regional Warming Amplifications

How are the foregoing three warming amplifications generated? We explore the answer via examining the local energy budget at the surface. We begin by investigating the surface energy source changes in response to GHG increases (Figure 2). On average, the energy increases substantially (Figure 2) due to increase of downward thermal infrared radiation induced by increased GHGs (Figure S5), while solar radiation has little contribution to the global mean changes. In terms of spatial patterns, changes in energy sources apparently favor polar and terrestrial amplifications (Figure 2, left). The results also show an enhanced increase in incoming energy over dryland (e.g., over Africa and Asia), which indicates that energy source changes also favor dryland amplification.

By including the clear-sky results, we show that cloud favors the enhanced energy gain in polar regions during local winter, while the opposite impact is observed during local summer (Figure 2, middle). Therefore, the pronounced energy increase over the summertime polar regions is probably generated by changes in surface albedo due to the polar ice/snow decline. This origin of the energy increase is robustly indicated by the very large reduction in clear-sky reflected short wave radiation in the polar regions during local summer (Figure S6), when the largest decline in sea ice occurs (Notz & Stroeve, 2016; Serreze et al., 2007; Stroeve et al., 2012). Nevertheless, as constrained by the physical law concerning a constant temperature of the ice-water mixture, summertime polar amplification is nearly absent (Figure S1; Collins et al., 2013). Thus, polar amplification exists mainly in the wintertime. Taken together, the results suggest that the direct effect of cloud on polar amplification is positive because the observed negative effect of cloud on energy source in the summertime has no direct influence on simultaneous temperature in the Arctic. Further quantified investigations in relative contributions of cloud and other factors on polar amplification were demonstrated later.

Besides energy source, how the changing incident energy is released is vital to the final warming pattern (Sutton et al., 2007). The net energy in our formulated budget will not be zero (Figure 2, right) because the net energy term involves both the surface heat uptake and horizontal energy transport (Chen & Tung, 2014; Fasullo, 2010). Remarkable positive and negative net energy changes are observed in polar oceans

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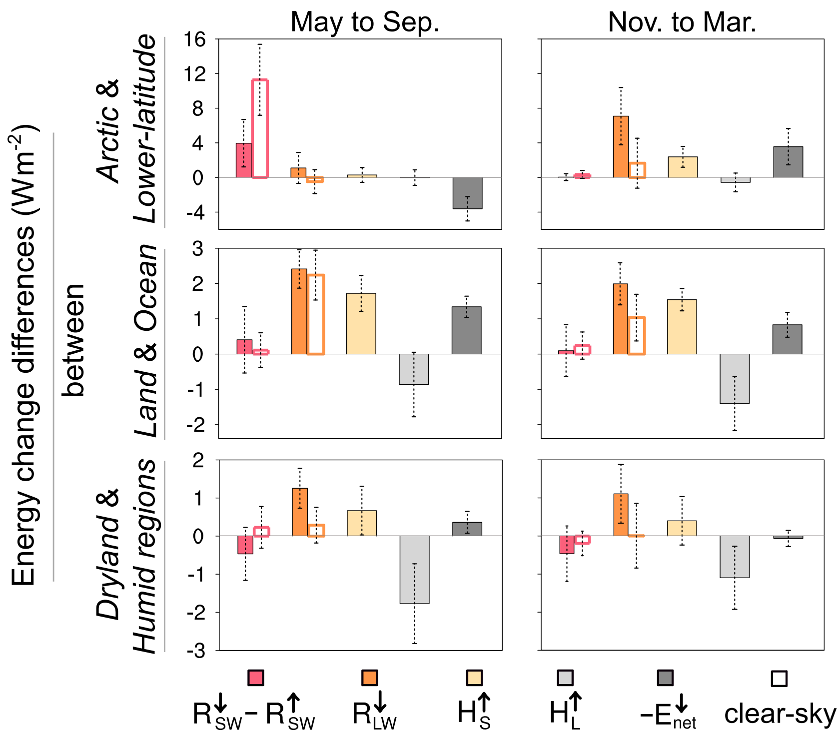

Figure 3. The energy budget changes at the surface for the period from 1861 to 2004. (top) The differences in the regional mean linear trends of the energy budget components between Arctic and lower-latitude regions, in unit of W/m^2 per 144 years. The means of Arctic and lower-latitude are averaged over 60 to 90 and 0 to 60°N, respectively. (middle) Same as (top) but for differences between land and ocean. (bottom) Same as (top) but for differences between dryland and humid regions. For May to September, dryland and humid regions are represented by precipitation less or more than 300 mm, respectively, while the cutting line of precipitation is 200 mm for November to March. $R^{\downarrow}_{SW}$-$R^{\uparrow}_{SW}$, $R^{\downarrow}_{LW}$, $H^{\uparrow}_{S}$, $H^{\uparrow}_{L}$, and $E^{\downarrow}_{net}$ are the net solar radiation, incident thermal infrared radiation, sensible, latent heat flux, and net energy, respectively. The open column represents the clear-sky result. Note that the original values for the six regions are presented in Tables S2–3.

during local summer and winter, respectively (Figure 2, right). This result suggests that the excess energy absorbed by the melting sea ice and open water during summertime is later released during the following winter (Screen & Simmonds, 2010), and this phenomenon is apparently responsible for the pronounced polar amplification occurring during local winter rather than summer (Figure S1).

To achieve quantification, the surface energy budget changes for the three warming amplifications are further examined (Figure 3). First, the wintertime Arctic amplification is clearly dominated by the enhanced downward thermal infrared radiation, which is about two times of the contributions from summertime sea ice change (Figure 3, top-left, $R^{\downarrow}_{LW}$ and -$E^{\downarrow}_{net}$). And the contribution from cloud to Arctic amplification is about one point five times of which from summertime sea ice change. Note again, the negative effect of cloud on summertime net solar radiation (Figure 3, top-left) has little direct influence on simultaneous Arctic amplification due to a constant temperature of the ice-water mixture. Therefore, cloud plays the first role in observed Arctic amplification, rather than the commonly blamed sea ice change (Screen & Simmonds, 2010). The previous work (Screen & Simmonds, 2010) only examined changes during 20 years (1989–2008), which must involve great influence from decadal variability (Steinman et al., 2015; Trenberth, 2015). Therefore, their conclusion is not suitable for long-term global warming. This is why our conclusion is quite different with theirs. The situation for Antarctic ocean is identical with which for Arctic (Figures S5–6). Thus, our conclusion is applicable for general polar amplification.

In contrast to polar amplification, terrestrial and dryland amplifications show no substantial seasonal difference (Figure S7). As well, their energy budgets are mostly consistent between different seasons (Figure 3, middle and bottom). Consistent with previous understanding (Huang, Yu, et al., 2017; Sutton et al., 2007), it is clear that the allocation of gained energy between latent and sensible heat is the fundamental reason of terrestrial and dryland amplifications (Figure 3 middle and bottom; Figure S8). However, the net energy change is also about half of the enhanced downward thermal infrared radiation over land than ocean (Figure 3, middle), which suggests horizontal energy transport and surface heat uptake may also play some role. Given the net energy change over land is nearly balanced (zero), the difference of changes in net energy between land and ocean regions is dominated by the ocean heat uptake transported to the deeper ocean (Tables S2–3), and effect of horizontal heat transport is negligible. Thus, enhanced heat uptake by the deeper ocean also plays an important role in favoring terrestrial amplification. Furthermore, cloud shows a dominant contribution to enhanced downward thermal infrared radiation for dryland amplification (Figure 3, bottom), while cloud has a little contribution to terrestrial amplification (Figure 3, middle). Our main conclusions regarding energy budget analyses are robust, although discrepancies across models inevitably exist (Figure 3).

4. Discussion

We show here that robust regional warming amplifications are directly following the anthropogenic GHG emission. We address that the featured regional warming amplifications would have large impacts on many undeveloped countries by considering both climate change and social-economic conditions. Therefore, the most rigorous GHGs reduction roadmap should be carried out to prevent the regions with warming amplification from miserable future (Brown & Caldeira, 2017; Chen & Tung, 2018; Rockström et al., 2016). New scientific findings are also demonstrated in this study. First, we find that polar amplification is dominated by cloud, rather than previously proposed sea ice changes or temperature feedback (Pithan & Mauritsen, 2014; Screen & Simmonds, 2010). Second, we demonstrate that enhanced deeper ocean heat uptake makes substantial contributions to terrestrial amplification. Additionally, the favoring of cloud to dryland amplification is also highlighted.

Actually, the impacts of aforementioned regional warming amplifications on human are not fully assessed in this paper. For example, terrestrial and dryland amplifications could directly facilitate the aridification of human habitat (Huang, Yu, et al., 2017; Sherwood & Fu, 2014) and induce the expansion of existing dryland (Huang et al., 2016). Therefore, terrestrial and dryland amplifications could lead to the substantial deterioration of human habitat. In addition to the direct influences on polar ecosystem (Post et al., 2009), polar amplification may have significant remote impacts, such as its influences on midlatitude weather and climate via altering atmospheric circulation (Cohen et al., 2014; Huang, Xie, et al., 2017; Serreze & Barry, 2011; Wyatt & Curry, 2014). Thus, achieving a right understanding of these warming amplifications is of infinite significance.

Besides the three warming amplifications investigated here, there are some other regional warming amplifications as well. For example, the elevation-dependent warming (Minder et al., 2018; Pepin et al., 2015), which is also suggested by warming amplification in Tibet Plateau (Figure 1). However, instead of examining every detail, this study mainly focused the most remarkable and robust warming amplifications across all the models. Although this study has arrived at a quantified attribution of the three warming amplifications, we are still far from a whole story. Because some fundamental aspects are waiting to reveal, such as the connection between general atmospheric circulation changes and these regional warming amplifications.

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References

Brown, P. T., & Caldeira, K. (2017). Greater future global warming inferred from Earth's recent energy budget. *Nature*, *552*(7683), 45–50. https://doi.org/10.1038/nature24672

Brown, P. T., Ming, Y., Li, W., & Hill, S. A. (2017). Change in the magnitude and mechanisms of global temperature variability with warming. *Nature Climate Change*, *7*(10), 743–748. https://doi.org/10.1038/nclimate3381

Chen, X., & Tung, K.-K. (2014). Varying planetary heat sink led to global-warming slowdown and acceleration. *Science*, *345*(6199), 897–903. https://doi.org/10.1126/science.1254937

Chen, X., & Tung, K.-K. (2018). Global surface warming enhanced by weak Atlantic overturning circulation. *Nature*, *559*(7714), 387–391. https://doi.org/10.1038/s41586-018-0320-y

Cohen, J., Screen, J. A., Furtado, J. C., Barlow, M., Whittleston, D., Coumou, D., et al. (2014). Recent Arctic amplification and extreme midlatitude weather. *Nature Geoscience*, *7*(9), 627–637. https://doi.org/10.1038/ngeo2234

Collins, M., Knutti, R., Arblaster, J., Dufresne, J. L., Fichefet, T., Friedlingstein, P., et al. (2013). *Long-term climate change: projections, commitments and irreversibility* (pp. 1062–1064). Cambridge: Cambridge University Press.

Dong, B., Gregory, J. M., & Sutton, R. T. (2009). Understanding land–sea warming contrast in response to increasing greenhouse gases. Part I: Transient adjustment. *Journal of Climate*, *22*(11), 3079–3097. https://doi.org/10.1175/2009JCLI2652.1

Fasullo, J. T. (2010). Robust land–ocean contrasts in energy and water cycle feedbacks. *Journal of Climate*, *23*(17), 4677–4693. https://doi.org/10.1175/2010JCLI3451.1

Fu, Q., Johanson, C. M., Wallace, J. M., & Reichler, T. (2006). Enhanced mid-latitude tropospheric warming in satellite measurements. *Science*, *312*(5777), 1179–1179. https://doi.org/10.1126/science.1125566

Fyfe, J. C., Meehl, G. A., England, M. H., Mann, M. E., Santer, B. D., Flato, G. M., et al. (2016). Making sense of the early-2000s warming slowdown. *Nature Climate Change*, *6*(3), 224–228. https://doi.org/10.1038/nclimate2938

Held, I. M. (2013). Climate science: The cause of the pause. *Nature*, *501*(7467), 318–319. https://doi.org/10.1038/501318a

Huang, J., Ji, M., Xie, Y., Wang, S., He, Y., & Ran, J. (2016). Global semi-arid climate change over last 60 years. *Climate Dynamics*, *46*(3–4), 1131–1150. https://doi.org/10.1007/s00382-015-2636-8

Huang, J., Xie, Y., Guan, X., Li, D., & Ji, F. (2017). The dynamics of the warming hiatus over the Northern Hemisphere. *Climate Dynamics*, *48*(1–2), 429–446. https://doi.org/10.1007/s00382-016-3085-8

Huang, J., Yu, H., Dai, A., Wei, Y., & Kang, L. (2017). Drylands face potential threat under 2 °C global warming target. *Nature Climate Change*, *7*(6), 417–422. https://doi.org/10.1038/nclimate3275

Joshi, M. M., Gregory, J. M., Webb, M. J., Sexton, D. M., & Johns, T. C. (2008). Mechanisms for the land/sea warming contrast exhibited by simulations of climate change. *Climate Dynamics*, *30*(5), 455–465. https://doi.org/10.1007/s00382-007-0306-1

Kummu, M., Taka, M., & Guillaume, J. H. (2018). Gridded global datasets for gross domestic product and Human Development Index over 1990–2015. *Scientific data*, *5*, 180004. https://doi.org/10.1038/sdata.2018.4

Manabe, S., & Stouffer, R. J. (1980). Sensitivity of a global climate model to an increase of CO_2 concentration in the atmosphere. *Journal of Geophysical Research*, *85*(C10), 5529–5554. https://doi.org/10.1029/JC085iC10p05529

Medhaug, I., Stolpe, M. B., Fischer, E. M., & Knutti, R. (2017). Reconciling controversies about the 'global warming hiatus'. *Nature*, *545*(7652), 41–47. https://doi.org/10.1038/nature22315

Minder, J. R., Letcher, T. W., & Liu, C. (2018). The character and causes of elevation-dependent warming in high-resolution simulations of Rocky Mountain climate change. *Journal of Climate*, *31*(6), 2093–2113. https://doi.org/10.1175/JCLI-D-17-0321.1

Notz, D., & Stroeve, J. (2016). Observed Arctic sea-ice loss directly follows anthropogenic CO2 emission. *Science*, *354*(6313), 747–750. https://doi.org/10.1126/science.aag2345

Pepin, N., Bradley, R., Diaz, H., Baraër, M., Caceres, E., Forsythe, N., et al. (2015). Elevation-dependent warming in mountain regions of the world. *Nature Climate Change*, *5*(5), 424–430.

Pithan, F., & Mauritsen, T. (2014). Arctic amplification dominated by temperature feedbacks in contemporary climate models. *Nature Geoscience*, *7*(3), 181–184. https://doi.org/10.1038/ngeo2071

Post, E., Forchhammer, M. C., Bret-Harte, M. S., Callaghan, T. V., Christensen, T. R., Elberling, B., et al. (2009). Ecological dynamics across the Arctic associated with recent climate change. *Science*, *325*(5946), 1355–1358. https://doi.org/10.1126/science.1173113

Rockström, J., Schellnhuber, H. J., Hoskins, B., Ramanathan, V., Schlosser, P., Brasseur, G. P., et al. (2016). The world's biggest gamble. *Earth's Future*, *4*(10), 465–470. https://doi.org/10.1002/2016EF000392

Screen, J. A., & Simmonds, I. (2010). The central role of diminishing sea ice in recent Arctic temperature amplification. *Nature*, *464*(7293), 1334–1337. https://doi.org/10.1038/nature09051

Serreze, M. C., & Barry, R. G. (2011). Processes and impacts of Arctic amplification: A research synthesis. *Global Planet Change*, *77*(1–2), 85–96. https://doi.org/10.1016/j.gloplacha.2011.03.004

Serreze, M. C., Holland, M. M., & Stroeve, J. (2007). Perspectives on the Arctic's shrinking sea-ice cover. *Science*, *315*(5818), 1533–1536. https://doi.org/10.1126/science.1139426

Sherwood, S., & Fu, Q. (2014). A drier future? *Science*, *343*(6172), 737–739. https://doi.org/10.1126/science.1247620

Steinman, B. A., Mann, M. E., & Miller, S. K. (2015). Atlantic and Pacific multidecadal oscillations and Northern Hemisphere temperatures. *Science*, *347*(6225), 988–991. https://doi.org/10.1126/science.1257856

Stouffer, R. J., & Manabe, S. (2017). Assessing temperature pattern projections made in 1989. *Nature Climate Change*, *7*(3), 163–165. https://doi.org/10.1038/nclimate3224

Stroeve, J. C., Kattsov, V., Barrett, A., Serreze, M., Pavlova, T., Holland, M., & Meier, W. N. (2012). Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations. *Geophysical Research Letters*, *39*, L16502. https://doi.org/10.1029/2012GL052676

Sutton, R. T., Dong, B., & Gregory, J. M. (2007). Land/sea warming ratio in response to climate change: IPCC AR4 model results and comparison with observations. *Geophysical Research Letters*, *34*, L02701. https://doi.org/10.1029/2006GL028164

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1

Trenberth, K. E. (2015). Has there been a hiatus? *Science*, *349*(6249), 691–692. https://doi.org/10.1126/science.aac9225

Vaughan, D. G., Comiso, J. C., Allison, I., Carrasco, J., Kaser, G., Kwok, R., et al. (2013). Observations: Cryosphere. *Climate Change*, *2103*, 317–382.

Wyatt, M. G., & Curry, J. A. (2014). Role for Eurasian Arctic shelf sea ice in a secularly varying hemispheric climate signal during the 20th century. *Climate Dynamics*, *42*(9–10), 2763–2782. https://doi.org/10.1007/s00382-013-1950-2

Xie, Y., Huang, J., & Liu, Y. (2017). From accelerated warming to warming hiatus in China. *International Journal of Climatology*, *37*(4), 1758–1773. https://doi.org/10.1002/joc.4809

Xie, Y., Liu, Y., & Huang, J. (2016). Overestimated Arctic warming and underestimated Eurasia mid-latitude warming in CMIP5 simulations. *International Journal of Climatology*, *36*(14), 4475–4487. https://doi.org/10.1002/joc.4644