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A strong bout of natural cooling in 2008

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[1] A precipitous drop in North American temperature in 2008, commingled with a decade-long fall in global mean temperatures, are generating opinions contrary to the inferences drawn from the science of climate change. We use an extensive suite of model simulations and appraise factors contributing to 2008 temperature conditions over North America. We demonstrate that the anthropogenic impact in 2008 was to warm the region's temperatures, but that it was overwhelmed by a particularly strong bout of naturally-induced cooling resulting from the continent's sensitivity to widespread coolness of the tropical and northeastern Pacific sea surface temperatures. The implication is that the pace of North American warming is likely to resume in coming years, and that climate is unlikely embarking upon a prolonged cooling. **Citation:** Perlwitz, J., M. Hoerling, J. Eischeid, T. Xu, and A. Kumar (2009), A strong bout of natural cooling in 2008, *Geophys. Res. Lett.*, *36*, L23706, doi:10.1029/2009GL041188.

1. Introduction

[2] Doubts on the science of human-induced climate change have been cast by recent cooling. Noteworthy has been a decade-long decline (1998–2007) in globally averaged temperatures from the record heat of 1998 [*Easterling and Wehner*, 2009]. It seemed dubious, to some, that such cooling was reconcilable with the growing abundance of greenhouse gases (GHGs), fueling assertions that the cooling trend was instead evidence against the efficacy of greenhouse gas forcing [*New York Times*, 2008]. Postulates on the demise of global warming, however, have been answered with new scientific inquiries that indicate the theory of global warming need not be tossed upon the scrap heap of a 10-year cooling. One recent appraisal of the intensity with which global temperatures can vary naturally around the climate change signal revealed that the post-1998 cooling was reconcilable with such intrinsic variability alone [*Easterling and Wehner*, 2009]. That study reminded us that a decade of declining temperatures are to be expected within an otherwise longer-term upward trend resulting from the impact of greenhouse gas emissions.

[3] A common temptation is to extrapolate from recent historical conditions in order to divine future outcomes, and who has not subsequently questioned fundamental understandings of the past when their predictions fail? Such is the story of U.S. temperatures in 2008, which not only declined from near-record warmth of prior years, but were in fact colder than the official 30-yr reference climatology (−0.2 K versus the 1971–2000 mean) and further were the coldest since at least 1996. Questions abounded from the public and decision makers alike: How are such regional "cold conditions" consistent with a warming planet, how can these conditions be reconciled with the prior unbroken string of high temperatures, and what are the expectations going forward?

[4] The North American (NA) continent observed a pronounced temperature increase from 1951 to 2006 of +0.9 K in which most of the warming occurred after 1970 [*Climate Change Science Program*, 2008], a warming that has been previously shown to likely result from human-emissions of greenhouse gases [*Intergovernmental Panel on Climate Change*, 2007]. In the present study, we appraise factors contributing to 2008 temperature conditions over North America using an extensive suite of model simulations. We demonstrate that the anthropogenic impact in 2008 was to warm the region's temperatures, but that such a human-induced signal was overwhelmed by a comparably strong naturally-induced cooling. We identify the source of this natural cooling to be the state of global sea surface temperatures (SSTs), in particular a widespread coolness of the tropical-wide oceans and the northeastern Pacific. We judge this coolness, and its North American impact, to have been a transitory, natural phenomenon with the implications that the continent's temperatures are more likely to rebound in the coming years, and are unlikely embarking upon a precipitous decline.

2. Data and Climate Model Simulations

[5] Observational NA temperature analysis is based on a merger of four data sets: U.K. Hadley Center's HadCRUT3v [*Brohan et al.*, 2006], National Oceanic and Atmospheric Administration (NOAA) Land/Sea Merged Temperatures [*Smith and Reynolds*, 2005], National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies) Surface Temperature Analysis (GISTEMP) [*Hansen et al.*, 2001] and NOAAs's National Climate Data Center (NCDC) Gridded Land Temperatures based on the Global Historical Climatology Network (GHCN) [*Peterson and Vose*, 1997].

[6] Observations are compared with NA temperature estimates based on two climate model configurations: coupled atmosphere-ocean models of the Climate Model Intercomparison Project (CMIP3) [*Meehl et al.*, 2007], and atmospheric model simulations using realistic monthly varying observed SSTs and sea-ice (so-called AMIP simulations). We utilize 22 CMIP models, all of whose simulations were forced by specified monthly variations in greenhouse gases and tropospheric sulphate aerosols, and half of whose simulations include also solar irradiance forcing and the radiative effects of volcanic activity during 1880–1999. All models utilized the Intergovernmental Panel on Climate Change (IPCC) Special Emissions Scenario (SRES) A1B [*Intergovernmental*

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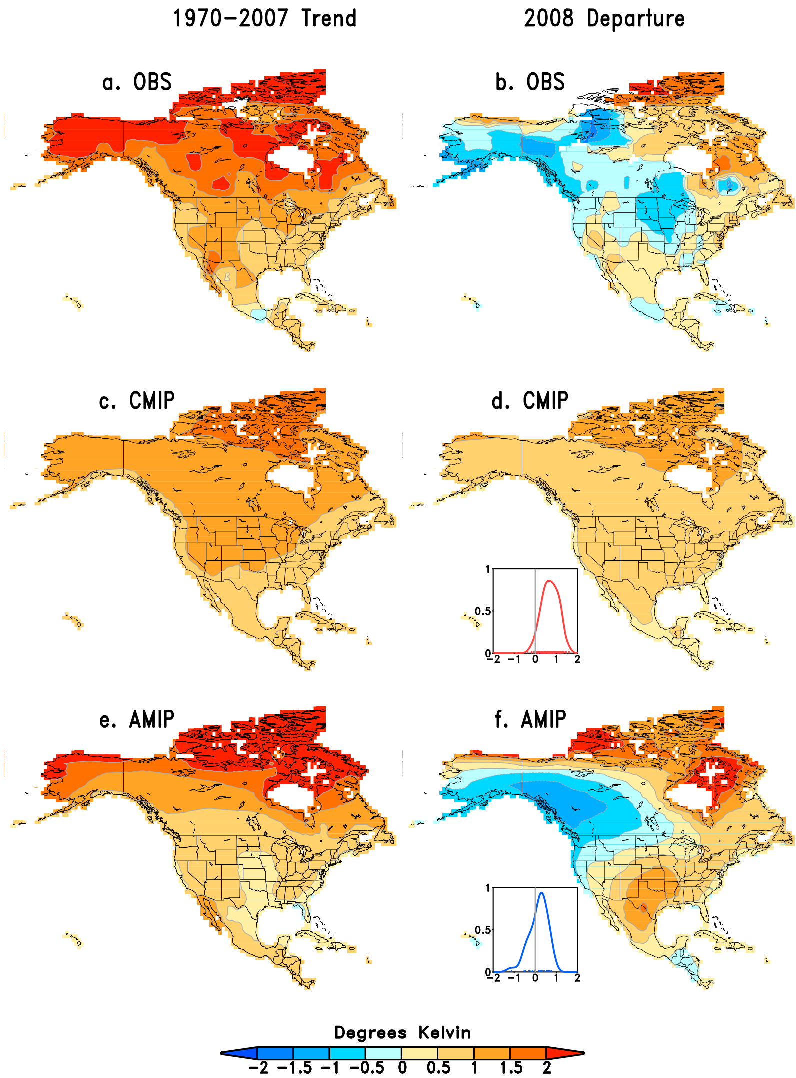

Figure 1. (left) North American surface temperature change for 1970–2007 [K/38 yr] and (right) departures for 2008 (in [K] relative to 1971–2000 mean) based on (a and b) observations, (c and d) ensemble CMIP simulations, and (e and f) ensemble AMIP simulations. Inset in Figures 1d and 1f are probability distribution functions of the individual simulated annual 2008 surface temperature departures area-averaged over North America. The observed 2008 departure was near zero.

Panel on Climate Change, 2007] for simulations after 1999. We diagnose the CMIP model runs for an 11-yr centered window (2003–2013) in order to consider a large ensemble from which both the anthropogenic signal and the intensity of naturally occurring coupled ocean-atmosphere noise during 2008 can be determined. The SRES GHG and aerosol emissions of any year in this window are treated as equally plausible approximations to the actual observed external forcing in 2008, an approach resulting in a 242 run sample from which to derive statistical probabilities of NA temperatures.

[7] For analysis of the effect of the specific SST and sea ice concentrations in 2008, we utilize 4 AMIP models forced with the monthly varying SST and sea ice variations for 1950–2008, but using climatological GHG and aerosol forcing. For each model, a large ensemble is available yielding a total multi-model sample of 40 runs for the actual 2008 surface boundary conditions. An additional suite of 50-member atmospheric climate model simulations using three AGCMs was carried out with various idealizations of SST forcing for 2008 (see auxiliary material for detailed information about models and experimental design).[1]

3. North American "Cold Event" of 2008

[8] The 2008 NA temperature was noteworthy for its appreciable departure from the trajectory of warming since 1970 (Figure 1a). Clearly, a simple extrapolation of the trend pattern would have rendered a poor forecast for 2008 (Figure 1b). Nonetheless, greenhouse gases in 2008 were at least as abundant as they had been during recent warmer years, and hence the expectation was for an anthropogenic warming influence to also be evident in 2008. The CMIP simulated annual temperature trend for 1970–2007 (Figure 1c), and the projection for 2008 (Figure 1d) agree well with the observed 38-yr change (Figure 1a). The observed 2008 pattern of NA temperatures (Figure 1b), however, was consid-

[1] Auxiliary materials are available in the HTML. doi:10.1029/2009GL041188.

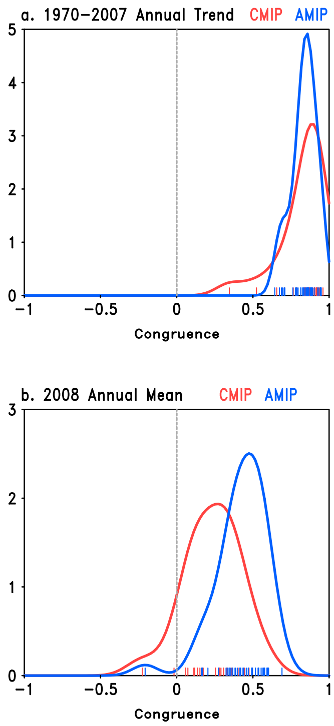

Figure 2. The probability distribution function of spatial congruence between observed and simulated North American temperatures for (a) the pattern of change for 1970–2007 and (b) the pattern of departures for 2008. Congruence refers to spatial agreement with map mean retained.

erably different from the anthropogenic fingerprint (Figure 1, middle, and also Figure 2).

[9] How then is the observed coolness in 2008 reconcilable with the known, growing abundance of greenhouse gases? Only 4% of individual realizations of the CMIP ensemble for 2008 (11 of 242) yielded North American averaged temperature departures as low as observed. Also, the spatial agreement of the CMIP ensemble anomaly pattern with the observations for 2008 was low (average spatial congruence of 0.2, Figure 2b), and substantially reduced from the very high agreement among their 1970–2007 trend patterns (average spatial congruence of 0.8, Figure 2a). These results indicate that the 2008 coolness was more likely caused by a different factor.

[10] A claim might be made that the CMIP simulations for 2008 are severely biased, but that would contradict the excellent agreement between the observed and CMIP simulated change since 1970. Instead, the above statistical measures imply that a strong case of natural variability, perhaps a 1 in 20 year event according to the CMIP probabilities, masked the anthropogenic warming signal. But what of this surmised natural factor? Can it be linked to any known phenomenon of climate variability, and if so, what are the implications for future temperatures? Whereas a close agreement exists between CMIP and AMIP results for the 1970–2007 trend in NA temperatures, only the AMIP results are consistent with the observed 2008 conditions (Figure 1, bottom). The AMIP simulations for 2008 capture both the amplitude of North American temperatures, with 33% of AMIP realizations (13 of 40) as cool as observed in 2008 (Figure 1f), and high spatial agreement of the anomaly pattern with observations (average spatial congruence of 0.5, Figure 2b). The 2008 North American conditions thus reflect a fingerprint of the continent's sensitivity to the actual conditions of sea surface temperatures and sea ice.

4. Diagnosing Factors Responsible for 2008 North American Coolness

[11] The model simulations reveal that the 2008 NA coolness was consistent with a fingerprint pattern of NA temperatures attributable to forcing by the actual sea surface temperature and sea ice conditions. It is probable that these surface boundary states were different from the signal of ocean/ice responses to anthropogenic forcing, as surmised from the fact that the observed North America temperature pattern in 2008 differed considerably from a GHG and aerosol fingerprint as simulated in CMIP. A critical step is to distinguish between the natural factors that are solely internal to the climate system (e.g., coupled ocean-atmosphere-land variability), from the possible effects of natural, external radiative forcing (solar variability, volcanoes). There were no significant volcanic events in the last few years that could have induced a surface cooling via stratospheric aerosol forcing. Solar forcing as a significant factor in the large drop of NA temperatures in 2008 is also unlikely. Although the 11-yr sun spot cycle was at a cyclical minimum, the amplitude of anthropogenic, external radiative forcing is now roughly an order of magnitude greater than the peak-to-trough change in irradiance associated with the 11-yr solar cycle (see *Lean and Rind* [2009] for an estimate of the magnitude and spatial structure of the temperature response to solar forcing). Thus, the main candidate for the strong 2008 deviation from the recent warming trajectory is most likely coupled ocean-atmosphere-land variability.

[12] Focusing on the impact of SST changes, we estimate both the natural and the anthropogenically-induced components to 2008 SST conditions and determine their impacts on NA temperatures. The 2008 SST pattern of ensemble mean CMIP simulations (Figure 3b) exhibits a mostly uniform warmth and deviates significantly from the observed pattern (Figure 3a) that includes cold conditions over the tropical Pacific and North Pacific that were associated with a La Niña event. As an estimate of the natural internally driven state of 2008 SSTs, we have removed the ensemble CMIP GHG/aerosol anomaly pattern from the observed anomaly pattern to generate the SST anomaly map shown in Figure 3c. It closely resembles the observed SST pattern but with colder values as expected from the spatial uniformity of the anthropogenically-induced pattern. Our analysis suggests that without GHG and aerosol forcing, SSTs in 2008 would have been even colder, and that the anthropogenic warming alleviated an otherwise strong natural cooling of the tropical oceans as a whole.

[13] An additional suite of atmospheric climate model simulations was carried out with the three specified SST forcings shown in Figure 3. The results of the additional climate simulations indicate that much of the North American coolness in 2008 resulted from that region's sensitivity to the natural internally driven state of SSTs. Figure 4 shows the NA annual temperature response to each of the three SST forcings of Figure 3. It is evident that the response pattern to the observed SSTs (Figure 4a) is mostly inconsistent with the

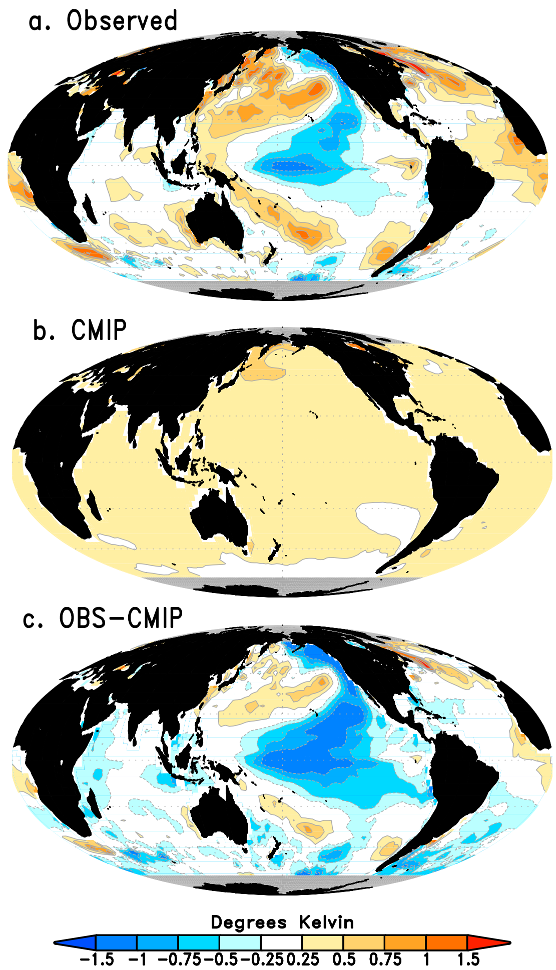

Figure 3. Annual mean 2008 sea surface temperature anomalies [K] for (a) observed (OBS SST), (b) CMIP simulated (GHG SST), and (c) observed minus CMIP simulated. The latter is an estimate of the 2008 SST condition associated with natural internal variability.

impact of the anthropogenic component of SST conditions (Figure 4b), but is coherent with the impact of the 2008 natural SSTs alone (Figure 4c). These NA surface temperature anomaly patterns are at least partly explained by SST impacts on upper tropospheric circulation and their subsequent effect on airmass transports as indicated by 200-hPa height anomalies (see Figure S1 in the auxiliary material). Importantly, the Pacific–North America pattern with negative polarity that was observed during 2008 is realistically simulated in the climate simulations subjected only to the natural SST conditions (Figure S1).

[14] Figure 4d shows the estimated distribution functions of NA annual temperature associated with each SST forcing, derived from the 150-member population of model simulations. The shift of the anthropogenically induced SST and natural SST probability distribution functions (PDFs) relative to the PDF of observed SST is clearly discernable. Mostly cold NA temperatures are simulated from the 2008 natural SST forcing, whereas mostly warm NA temperatures are simulated from the 2008 anthropogenic SST state. The AMIP simulations for 2008 of a near-neutral mean temperature response to the full-field observed SSTs (Figure 1) therefore results from approximate cancellation between these two opposing effects.

5. Concluding Remarks

[15] There is increasing public and decision maker demand to explain evolving climate conditions, and assess especially the role of human-induced emissions of greenhouse gases. The 2008 North American surface temperatures diverged strongly from the warming trend of recent decades, with the lowest continental average temperatures since at least 1996. While not an unusual climate event, as compared with the 2003 European heat wave for instance [e.g., *Stott et al.*,

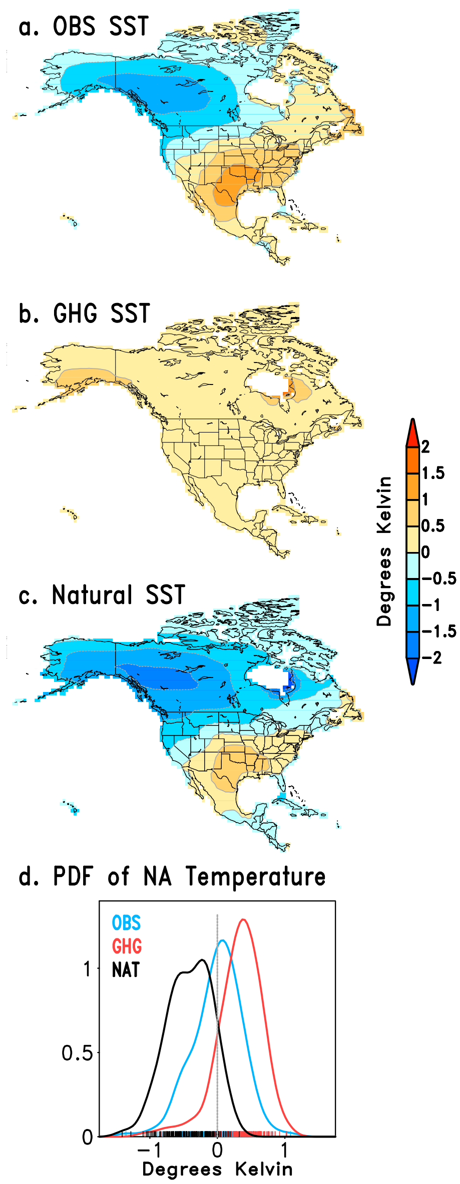

Figure 4. North American surface temperature response [K] to the (a) 60°N–60°S observed SSTs, (b) CMIP SSTs, and (c) natural SSTs, and (d) the probability distribution functions of the individual simulated annual 2008 surface temperature departures area-averaged over North America for each of the three SST forcings. The SST forcing are those shown in Figure 3.

2004], the widespread cool temperatures over the U.S. and Canada in 2008 nonetheless raised a considerable stir among the popular press because it contrasted with the warming expected from increasing anthropogenic influences. This proverbial mystery of "why the dog did not bark in the night" given the threat of anthropogenic warming, generated speculations that the coolness exposed shortcomings in the science of greenhouse gas forcing of climate. The results of our modeling study indicate that the 2008 NA cooling can be mainly attributed to the observed SST anomalies, and in particular to the local cooling of the tropical Pacific SST (especially the Niño 4 region) associated with natural variability of the climate system. Our appraisal of the natural SST conditions in the Niño 4 region, with anomalies of about −1.1 K suggests a condition colder than any in the instrumental record since 1871 (Figure S2 and discussion in the auxiliary material). We illustrated that North America would have experienced considerably colder temperatures just due to the impact of such natural ocean variability alone, and that the simultaneous presence of anthropogenic warming reduced the severity of cooling.

[16] This, and similar recent attribution studies of observed climate events [*Stott et al.*, 2004; *Hoerling et al.*, 2007; *Easterling and Wehner*, 2009] are important in ensuring that natural variability, when occurring, is not misunderstood to indicate that climate change is either not happening or that it is happening more intensely than the true human influence. In our diagnosis of 2008, the absence of North American warming was shown not to be evidence for an absence of anthropogenic forcing, but only that the impact of the latter was balanced by strong natural cooling. Considering the nature of both the 2008 NA temperature anomalies and the natural ocean variability that reflected a transitory interannual condition, we can expect that the 2008 coolness is unlikely to be part of a prolonged cooling trend in NA temperature in future years.

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