A strong bout of natural cooling in 2008

Judith Perlwitz [1,2], Martin Hoerling[2], Jon Eischeid[1,2], Taiyi Xu[1,2], and Arun Kumar[3]

[1]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA

[2]NOAA Earth System Research Laboratory, Boulder, CO, USA

[3]NOAA Climate Prediction Center, Camp Springs Maryland, USA

Corresponding Author Address:

Judith Perlwitz

NOAA/ESRL/PSD

325 Broadway

R/PSD1

Boulder, CO 80305-3328

E-mail: judith.perlwitz@noaa.gov

Abstract

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.

1. Introduction

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 (GHG), 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.

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 (-0.2K 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?

The North American (NA) continent observed a pronounced temperature increase from 1951 to 2006 of +0.9K in which most of the warming occurred after 1970 [*CCSP,* 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

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 et al.* 1997].

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.* 2008]), 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 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.

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).

3. The North American "cold event" of 2008

The 2008 NA temperature was noteworthy for its appreciable departure from the trajectory of warming since 1970 (Fig. 1a). Clearly, a simple extrapolation of the trend pattern would have rendered a poor forecast for 2008 (Fig. 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 (Fig. 1c), and the projection for 2008 (Fig. 1d) agree well with the observed 38-yr change (Fig. 1a). The observed 2008 pattern of NA temperatures (Fig. 1b), however, was considerably different from the anthropogenic fingerprint (middle panels of Fig. 1 and also Fig. 2).

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, Fig. 2b), and substantially reduced from the very high agreement among their 1970-2007 trend patterns (average spatial congruence of 0.8, Fig. 2a). These results indicate the 2008 coolness was more likely caused by a different factor.

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, in particular can it be linked to any known phenomenon of climate variability, and if so, what are 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 (lower panels, Fig 1). 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 (Fig. 1f), and high spatial agreement of the anomaly pattern with observations (average spatial congruence of 0.5, Fig. 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

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.

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 (Fig. 3b) exhibits a mostly uniform warmth and deviates significantly from the observed pattern (Fig. 4a) 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 (Fig. 3b) from the observed anomaly pattern (Fig. 1a) to generate the SST anomaly map shown in Fig. 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.

An additional suite of atmospheric climate model simulations was carried out with the three specified SST forcing shown in Fig. 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 Fig. 3. It is evident that the response pattern to the observed SSTs (Fig. 4a) is mostly inconsistent with the impact of the anthropogenic component of SST conditions (Fig. 4b), but is largely explained by the response to the 2008 natural SSTs alone (Fig. 4c). These 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 Fig. 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 (Fig. S1).

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 (Fig. 1) therefore results from approximate cancellation between these two opposing effects.

5. Concluding remarks

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*., 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 -1.1K suggests a condition colder than any in the instrumental record since 1871

(Fig. 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.

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.

Acknowledgments: This study was supported by the NOAA Climate Program Office. We would like to thank Tao Zhang and Xiao-wei Quan for carrying out the sensitivity experiments and two anonymous reviewers for valuable input. We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.

References

Brohan, P., J.J. Kennedy, I. Harris, S.F.B. Tett and P.D. Jones (2006), Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. *J. Geophys. Res., 111*, D12106,

CCSP (2008), *Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research,* edited by R. Dole et al., 156 pp., National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, USA.

Easterling, D. R., and M. F. Wehner (2009), Is the climate warming or cooling?, *Geophys. Res. Lett.*, *36*, L08706, doi:10.1029/2009GL037810.

Hansen, J., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl (2001), A closer look at United States and global surface temperature change, *J. Geophys. Res.*, *106*, 23,947–23,963.

Hoerling, M., J. Eischeid, X. Quan, and T. Xu (2007), Explaining the record US warmth of 2006, *Geophys. Res. Lett.*, *34*, L17704, doi:10.1029/2007GL030643.

Intergovernmental Panel on Climate Change (2007), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon et al., 996 pp., Cambridge Univ. Press, Cambridge, U. K.

Lean, J. L., and D. H. Rind (2009), How will Earth's surface temperature change in future decades?, *Geophys. Res. Lett.*, *36*, L15708, doi:10.1029/2009GL038932.

Meehl, G., and Coauthors (2007), The WCRP CMIP3 multimodel dataset: A new era in climate change research. *Bull. Amer. Met. Soc.*, *88*, 1384-1394.

New York Times (2008), Skeptics on human climate impact seize on cold spell, New York Times, 2 March. Available at http://www.nytimes.com/2008/03/02/science/02cold.html?_r=1).

Peterson, T. C. and R. S. Vose, (1997), An overview of the Global Historical Climatology Network temperature database, *Bull. Am. Meteorol. Soc., 78*, 2837-2849.

Smith, T. M., and R. W. Reynolds (2005), A global merged land air and sea surface temperature reconstruction based on historical observations (1880–1997), *J. Clim.*, *18*, 2021–2036.

Stott, P. A., D. A. Stone, and M. R. Allen (2004), Human contribution to the European heatwave of 2003, *Nature*, *432*, 610–614.

Figure captions:

Figure 1:

North American surface temperature change for 1970-2007 (left; [K/38yr]) and departures for 2008 (right; in [K] relative to 1971-2000 mean) based on observations (top), ensemble CMIP simulations (middle), and ensemble AMIP simulations (bottom). Inset in (d) and (f) 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.

Figure 2:

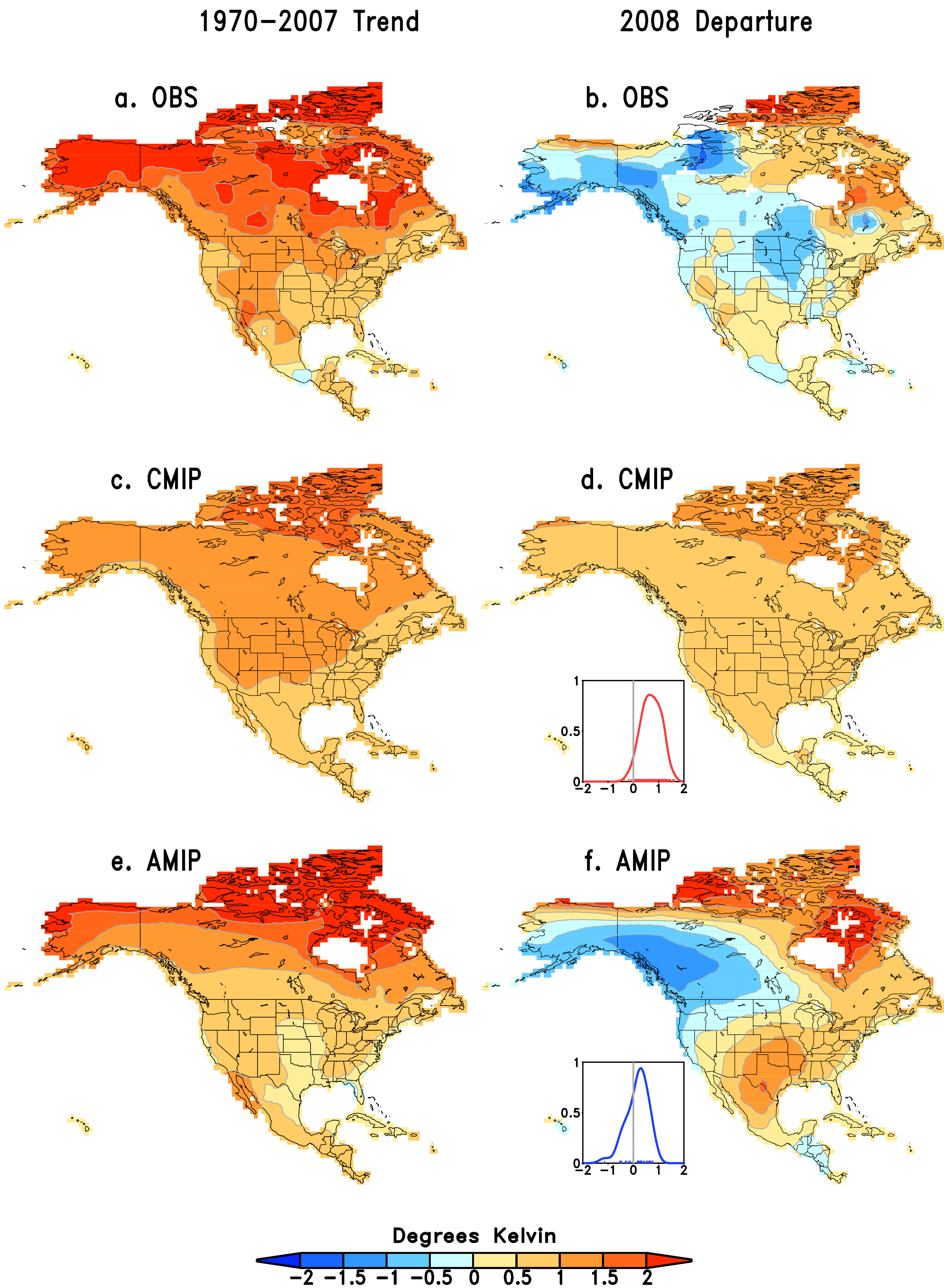
The probability distribution function of spatial congruence between observed and simulated North American temperatures for the pattern of change for 1970-2007 (a), and the pattern of departures for 2008 (b). Congruence refers to spatial agreement with map mean retained.

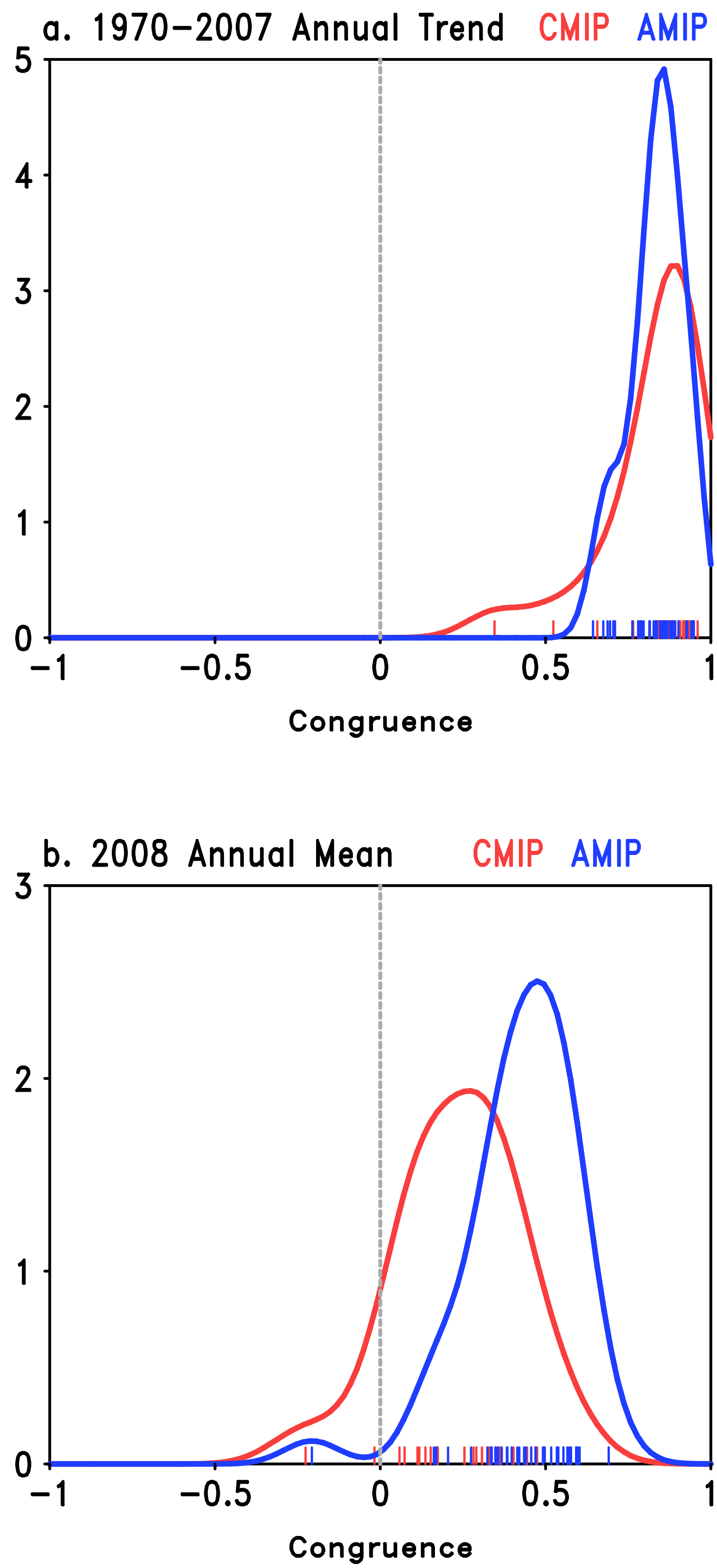
Figure 3:

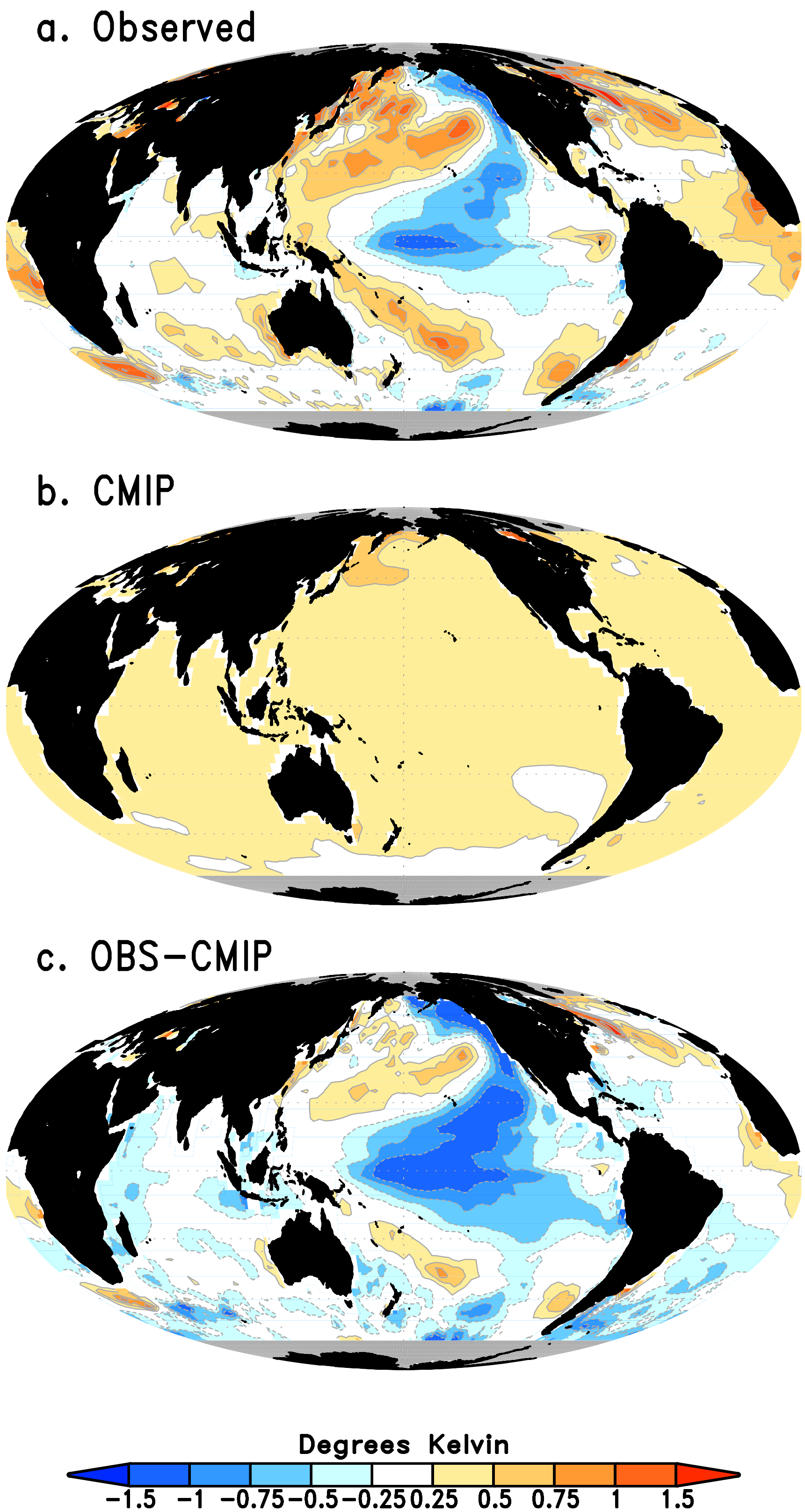
Annual mean 2008 sea surface temperature anomalies [K] for (a) observed (OBS SST), (b) CMIP simulated (GHG SST), and (c) observed minus CMIP simulated. The latter is an estimate of the 2008 SST condition associated with natural internal variability.

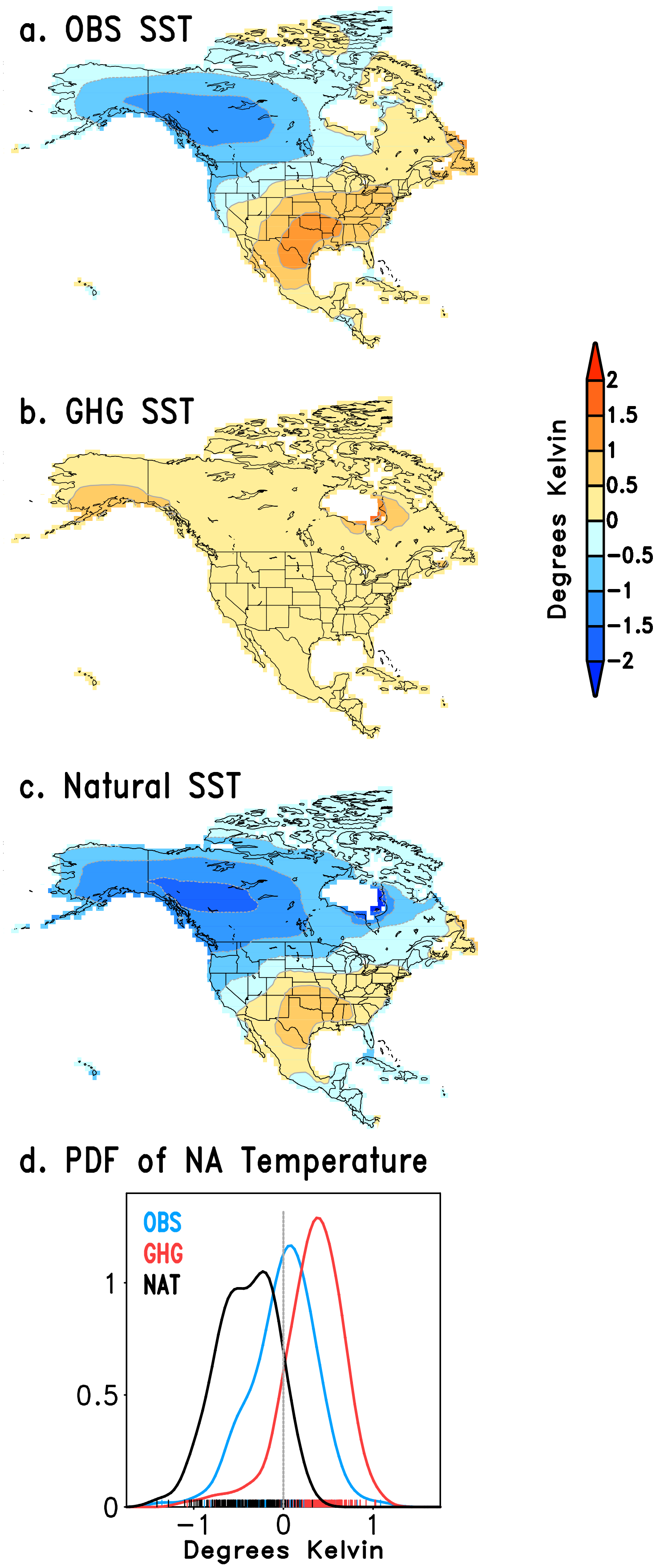
Figure 4:

North American surface temperature response [K] to the 60°N-60°S observed SSTs (a), CMIP SSTs (b), and natural SSTs (c), and 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 (d). The SST forcing are those shown in Fig. 3.


1970–2007 Trend
2008 Departure
a. OBS
b. OBS
c. CMIP
d. CMIP
e. AMIP
f. AMIP
Degrees Kelvin
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2


a. 1970-2007 Annual Trend
CMIP
AMIP
5
4
3
2
1
0
−1
−0.5
0
0.5
1
Congruence
b. 2008 Annual Mean
CMIP
AMIP
3
2
1
0
−1
−0.5
0
0.5
1
Congruence


a. Observed
b. CMIP
c. OBS−CMIP
Degrees Kelvin
−1.5 −1 −0.75 −0.5 −0.25 0.25 0.5 0.75 1 1.5


a. OBS SST
b. GHG SST
c. Natural SST
d. PDF of NA Temperature
Degrees Kelvin
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
OBS
GHG
NAT
1
0.5
0
−1
0
1
Degrees Kelvin

Auxiliary Material Submission for Paper 2009GL041188

A Strong Bout of Natural Cooling in 2008

Judith Perlwitz, Jon Eischeid and Taiyi Xu
Cooperative Institute for Research in Environmental Sciences
University of Colorado, Boulder, Colorado, USA and
NOAA Earth System Research Laboratory, Physical Sciences Division,
Boulder, Colorado, USA

Martin Hoerling
NOAA Earth System Research Laboratory, Physical Sciences Division,
Boulder, Colorado, USA

Arun Kumar
NOAA Climate Prediction Center, Camp Springs, Maryland, USA

Introduction

This auxiliary information contains additional text and two figures that support the findings of the main paper.

1.2009gl041188-txts01.txt
This text file contains additional details on the models used for AMIP simulations and sensitivity experiments. It also includes an appraisal of the intensity of the "natural" tropical Pacific coolness in 2008.

2. 2009gl041188-fs01.eps
Figure S1.Annual 2008 200-hPa height anomalies [m] for observed (a) and simulated in response to the specified 60N-60S observed SSTs (b), CMIP SSTs (c), and natural internal SSTs (d).

3. 2009gl041188-fs02.eps
Figure S2. Probability distribution function of observed annual mean Nino 4 index anomalies (SST anomalies in 5S-5N, 160E-150W). The red large tic mark indicates the estimate for natural observed Nino 4 anomaly.

1. Models and experimental design

1.1 AMIP simulations

We utilize the NCAR Community Climate Model (CCM3; [Kiehl et al. 1996], 16 member ensemble,), the NASA Seasonal-to-Interannual Prediction Project (NSIPP) model ([Schubert et al., 2004], 9 member ensemble), the Experimental Climate Prediction Center's (ECPC) model ([Kanamitsu et al., 2002], 10 member ensemble) and the Geophysical Fluid Dynamics Laboratory Atmospheric Model Version 2.1 (GFDL AM2.1, [Delworth et al., 2006]), 5 member ensemble).

1.2. Sensitivity experiments

An additional suite of atmospheric climate model simulations were carried out using three atmospheric general circulation models: CCM3, AM 2.1 and a version of the National Centers for Environment Prediction (NCEP) Global Forecast System (GFS) used as atmospheric model component in the NCEP Climate Forecast System [Saha et al., 2006]. For each model, 50-member ensembles were conducted in which we specified SST anomalies between 60N-60S superposed on the observed 1971-2000 climatological mean SSTs.

2. How unusual was the intensity of the "natural" tropical Pacific coolness in 2008?

First, we calculated the area-averaged 2008 SST anomaly (the natural component, Fig. 3c) for the region of Nino4. The annual departure is about -1.1K. Then, we compared that value to annual values of SST anomalies for the same domain for the 1871-1970 100-yr period analyzed from the HadISST data [Rayner et al. 2003]. This 100-yr period generally precedes the period of most significant warming of the oceans related to anthropogenic forcing. Annual anomalies, relative to 1871-1970 100-yr mean climatology are computed, and those values are summarized in the frequency distribution shown in Fig. S2.

No single year has witnessed Nino4 SSTs as low as our estimated "natural" coolness of 2008. The "natural coolness" of about -1.1K is colder than the lowest instrumental value of -0.97K. Within the curve of the smoothed PDF, the 2008 natural coolness is likely a 1 in 50yr event or perhaps less frequent. The rarity of the coolness, and the sensitivity of North American surface temperature to such coolness, is thus consistent with the low occurrence (4%) of North American coolness occurring in the 2008 CMIP runs.

References:

Delworth, T. L. and Co-authors, (2006), GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and simulation characteristics. J. Climate, 19, 643-674.

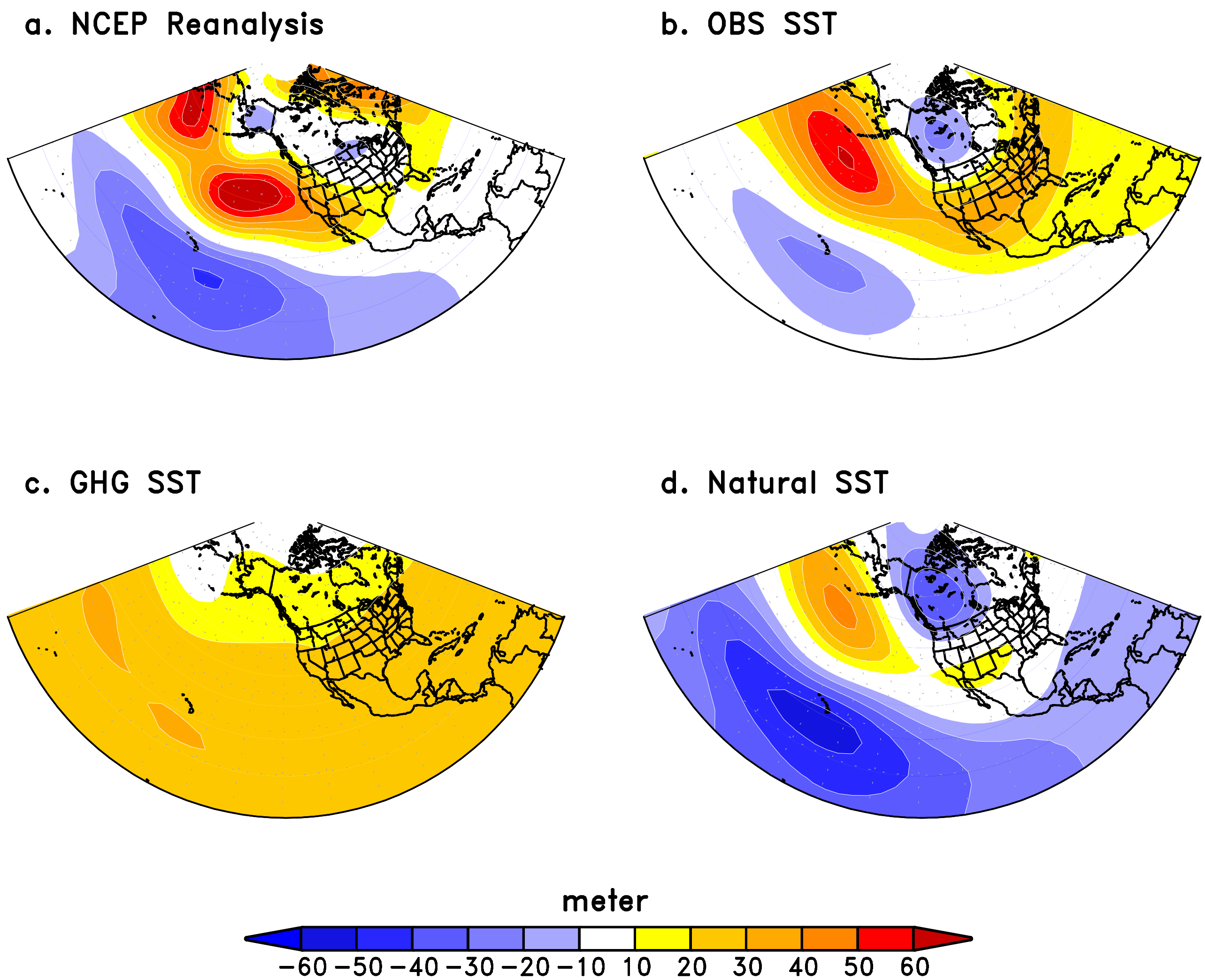
Kanamitsu, M., and Co-Authors (2002), NCEP dynamical seasonal forecast system 2000. Bull. Amer. Meteor. Soc., 83, 1019-1037.

Kiehl, J., J. Hack, G. Bonan, B. Boville, D. Williamson, and P. Rasch (1998), The National Center for Atmospheric Research Community Climate Model: CCM3. J. Clim, 11, 1131-1149.

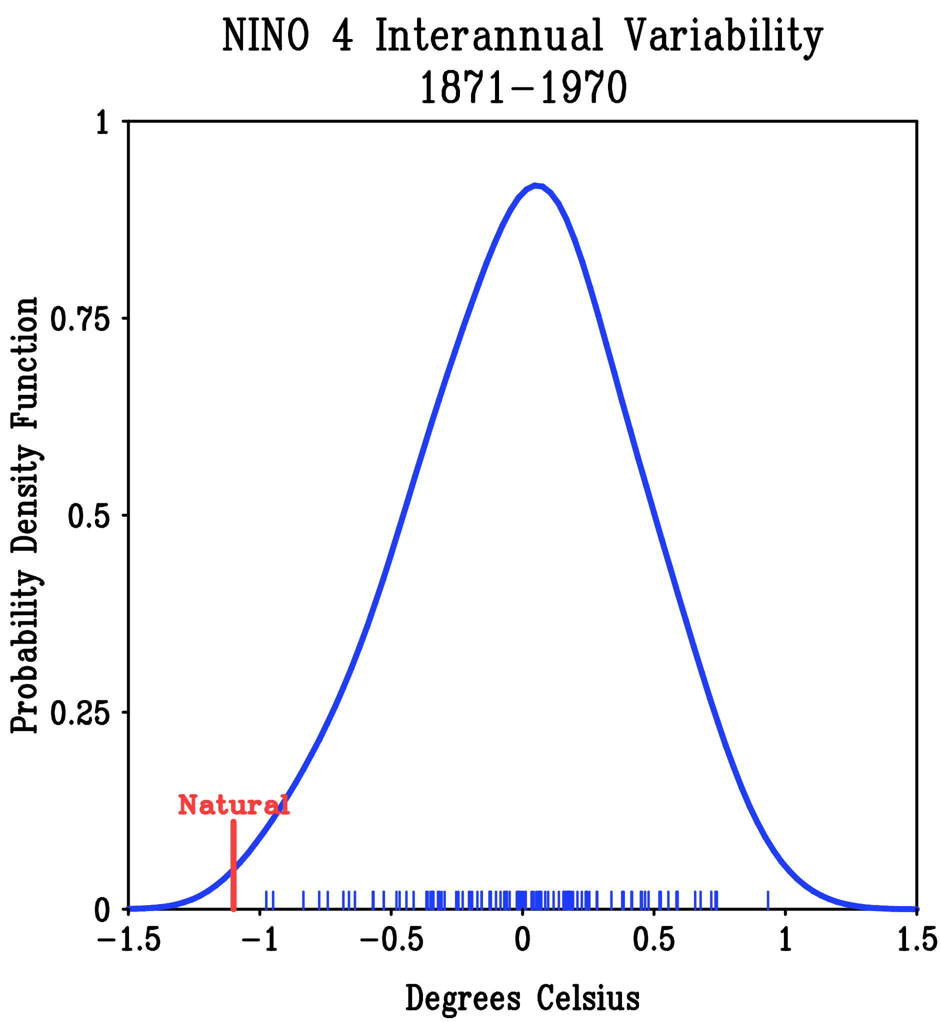
Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent, and A. Kaplan (2003), Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, J. Geophys. Res., 108(D14), 4407, doi:10.1029/2002JD002670.

Saha, S., and Coauthors (2006), The NCEP Climate Forecast System. J. Climate, 19, 3483-3517.

Schubert, S.D., M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister (2004), On the Cause of the 1930s Dust Bowl, Science, 33, 1855-1859.



a. NCEP Reanalysis
b. OBS SST
c. GHG SST
d. Natural SST
meter
−60 −50 −40 −30 −20 −10 10 20 30 40 50 60


NINO 4 Interannual Variability
1871−1970
Probability Density Function
Degrees Celsius
Natural
1
0.75
0.5
0.25
0
−1.5
−1
−0.5
0
0.5
1
1.5