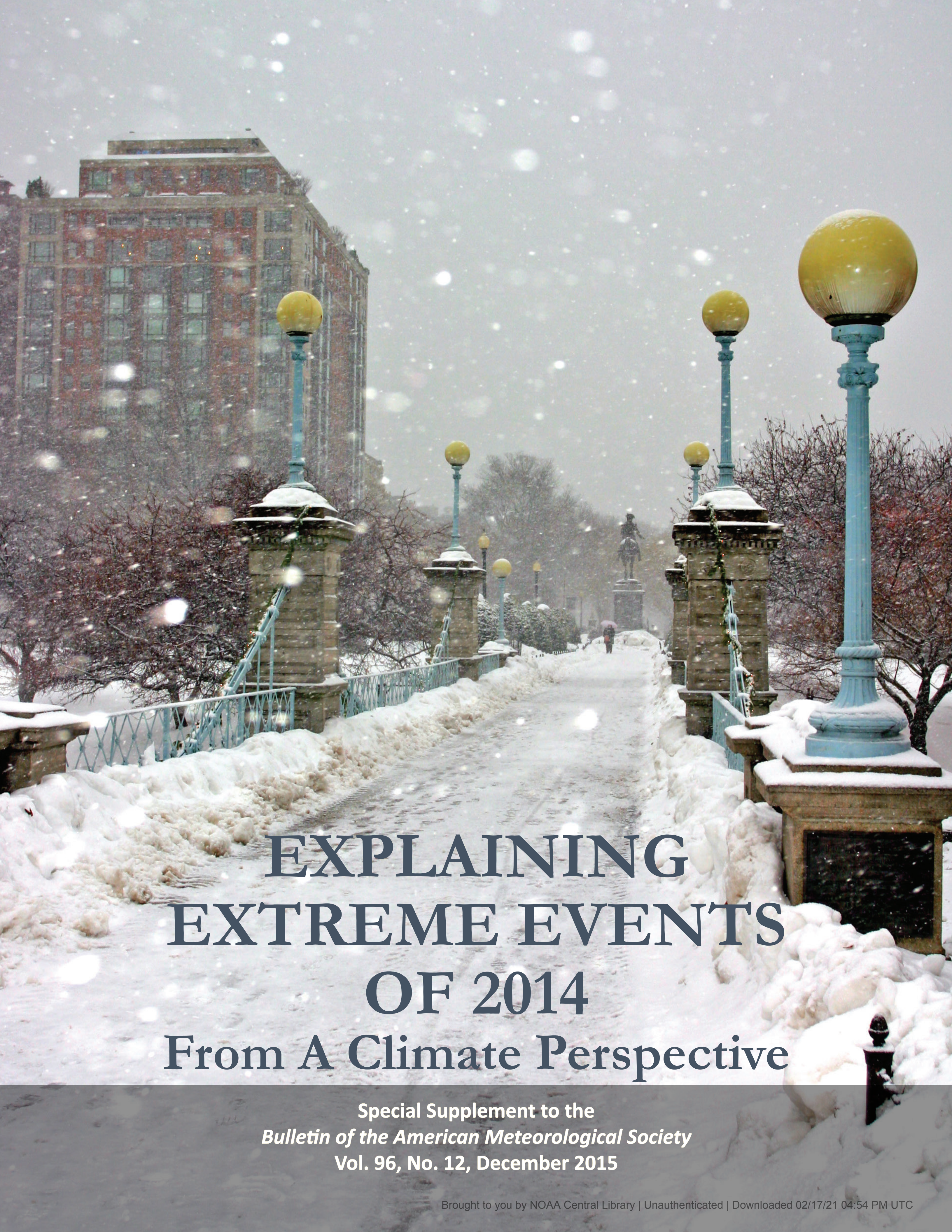

EXPLAINING EXTREME EVENTS OF 2014

From A Climate Perspective

Special Supplement to the
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EXPLAINING EXTREME EVENTS OF 2014 FROM A CLIMATE PERSPECTIVE

Editors

Stephanie C. Herring, Martin P. Hoerling, James P. Kossin, Thomas C. Peterson, and Peter A. Stott

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ABSTRACT—Stephanie C. Herring, Martin P. Hoerling, James P. Kossin, Thomas C. Peterson, and Peter A. Stott

Understanding how long-term global change affects the intensity and likelihood of extreme weather events is a frontier science challenge. This fourth edition of explaining extreme events of the previous year (2014) from a climate perspective is the most extensive yet with 33 different research groups exploring the causes of 29 different events that occurred in 2014. A number of this year's studies indicate that human-caused climate change greatly increased the likelihood and intensity for extreme heat waves in 2014 over various regions. For other types of extreme events, such as droughts, heavy rains, and winter storms, a climate change influence was found in some instances and not in others. This year's report also included many different types of extreme events. The tropical cyclones that impacted Hawaii were made more likely due to human-caused climate change. Climate change also decreased the Antarctic sea ice extent in 2014 and increased the strength and likelihood of high sea surface temperatures in both the Atlantic and Pacific Oceans. For western U.S. wildfires, no link to the individual events in 2014 could be detected, but the overall probability of western U.S. wildfires has increased due to human impacts on the climate.

Challenges that attribution assessments face include the often limited observational record and inability of models to reproduce some extreme events well. In general, when attribution assessments fail to find anthropogenic signals this alone does not prove anthropogenic climate change did not influence the event. The failure to find a human fingerprint could be due to insufficient data or poor models and not the absence of anthropogenic effects.

This year researchers also considered other human-caused drivers of extreme events beyond the usual radiative drivers. For example, flooding in the Canadian prairies was found to be more likely because of human land-use changes that affect drainage mechanisms. Similarly, the Jakarta floods may have been compounded by land-use change via urban development and associated land subsidence. These types of mechanical factors re-emphasize the various pathways beyond climate change by which human activity can increase regional risk of extreme events.

4. WAS THE COLD EASTERN US WINTER OF 2014 DUE TO INCREASED VARIABILITY?

Laurie Trenary, Timothy DelSole, Michael K. Tippett, and Brian Doty

The near-record number of extremely cold days during winter 2014 in the eastern United States cannot be attributed to trends or variability changes. Daily temperature variability is actually decreasing, in contrast to CMIP5 simulations and projections.

Introduction. The eastern United States endured persistent below normal temperatures during the winter of 2014 (Fig. 4.1a), with many states experiencing monthly temperatures ranked amongst the 15th coldest on record (NOAA National Climatic Data Center 2014). Insured U.S. losses from weather damage during winter 2014 (2.4 billion U.S. dollars) were more than double the annual average of the previous decade (Bevere et al. 2015).

The intensity and duration of cold temperatures during winter 2014 sparked considerable discussion about whether the behavior of cold air outbreaks was changing. The prevailing view among climate scientists is that the earth is warming primarily due to emissions of greenhouse gases from fossil fuel burning. Such warming will tend to make frigid winters less likely (Bindoff et al. 2013). On the other hand, extreme cold air outbreaks in the United States are associated with southward meandering of the midlatitude jet stream, which has a complex behavior. To the extent that jet stream variability arises from fluid dynamical instabilities associated with the pole-to-equator temperature difference (Holton 2004), such variability might be expected to decrease as the Arctic warms faster than other parts of the earth. In contrast, Francis and Vavrus (2012) argue that this reduced gradient leads to a slower and more north–south meandering jet stream. They conjecture that continued global warming will increase the "waviness" of the jet stream and lead to more frequent weather extremes.

Apparent trends in the latitudinal extent of atmospheric waves, which Francis and Vavrus (2012) used to support their hypothesis, have been found to be sensitive to methodology (Barnes 2013; Screen and Simmonds 2013). Moreover, van Oldenborgh et al. (2014) analyzed North American cold extremes of both seasonal and daily minimum temperature during the winter of 2014 and concluded that the cold temperatures were not unusual relative to the past, although extreme cold events are occurring less frequently. Finally, numerous studies report a reduction in daily cold temperature extremes over the United States in response to global warming (Hartmann et al. 2013).

Global warming is often conceptualized as a shift of the probability distribution function (PDF) toward warmer temperatures. The width of the PDF characterizes the variability of those temperatures. If cold extremes are becoming more likely in response to climate change, as suggested by Francis and Vavrus (2012), and warm extremes are becoming more likely, as many studies have shown, then the width of the PDF should increase. There is no strong indication of a systematic change in the width of the PDF for monthly mean U.S. temperatures (Kunkel et al. 2015). A goal of this study is to check this implicit consequence of the Francis and Vavrus hypothesis for daily winter temperatures. We also document changes in daily winter temperatures along the U.S. east coast and compare them to climate model simulations. The eastern United States is chosen for study because of its high vulnerability to extreme winter weather [60% of the reported loses from the 2014 winter came from states along the U.S. eastern seaboard (NOAA National Centers for Environmental Information 2014)]

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and because of its dense population [nearly a third of the U.S. population (U.S. Census 2010)].

Data and Methods. Daily temperature is estimated as the average of the maximum and minimum surface temperatures from the United States Historical Climatology Network (Menne et al. 2015), for the days 1 January–31 March between 1950 and 2014. Anomalies are found for each station by removing a third order polynomial fit to the January–March seasonal cycle. Regional estimates for the mid-Atlantic (Fig. 4.1a, states outlined in black), the north Atlantic (Fig. 4.1a, states outlined in green), and the south Atlantic (Fig. 4.1a, states outlined in red), are found by averaging station anomalies in each region.

We also analyze climate model simulations from phase 5 of the Coupled Model Intercomparison Project (CMIP5; Taylor et al. 2012). We use historical runs between 1950 and 2005, which contain both anthropogenic and natural forcing, and pre-industrial control runs, whose forcings do not change. Twelve models with daily surface temperature data and with at least 100 years of daily data from a pre-industrial control run were selected (see Supplemental Table S4.1 for model list). The historical runs were extended using the Representative Concentration Pathways (RCP) 8.5, since the projected greenhouse gas forcing smoothly transitions from the historic runs (Taylor et al. 2012) and is most consistent with present values relative to other RCPs (Peters et al. 2013). To allow for comparison with observations, time series of daily land temperature for January–March were computed from averages in the mid-Atlantic (35°–40°N, 83°–72°W), north Atlantic (40°–48°N, 83°–65°W), and south Atlantic (25°–35°N, 89°–75°W).

Two measures of variability were used: sample standard deviation and the difference between the 95th and 5th percentiles. Confidence intervals for trends in standard deviation were assessed using ordinary least squares and the bias-corrected, accelerated bootstrap (Efron and Tibshirani 1994). The resulting intervals were practically the same so only those produced by ordinary least squares are shown.

Results. The minimum of average daily temperature for each winter in the north (green), mid- (black), and south (red) Atlantic states is shown in Fig. 4.1b. The figure shows that the magnitudes of minimum temperatures along the eastern seaboard during winter 2014 (Fig. 4.1b, green, black, and red dots) were not unusual. The entire eastern seaboard has experienced much colder winters in each of the six preceding decades.

The frequency of extremely cold winter days for the three Atlantic regions is shown in Fig. 4.1c. We define extremely cold days as ones in which the average daily temperature falls below the 10th percentile of winter daily temperatures (relative to 1961–90), for each region respectively. In 2014, the north Atlantic endured the greatest number of extremely cold days on record. In the mid-Atlantic, the frequency of extremely cold days was the second largest since 1978. As a result, the seasonal average of daily temperatures in both the north and mid-Atlantic states yielded the second most frequently cold season since 1978 for each region (not shown).

Lastly, the standard deviation of daily winter temperature anomalies for the mid-Atlantic is shown in Fig. 4.1d. Our analysis focuses on only one region, since variations in average daily winter temperatures are consistent along the eastern seaboard (not shown). The winter temperature variability in 2014 is well within the range of previous observed values. Autocorrelation in daily time series may mask changes in variability. A second order autoregressive model is fit to January–March daily temperature, and its residuals are called "whitened anomalies". No significant or systematic changes in autoregressive model parameters were detected, indicating that there are no detectable changes in the persistence of cold winter temperatures. However, the standard deviation of the whitened anomalies, shown as the dashed blue line in Fig. 4.1d, decreases at a rate of ~0.72°C century^{-1} over the 1950–2014 period. Thus, in contrast to Francis and Vavrus (2012), we find that daily winter temperatures along the U.S. eastern seaboard are becoming less variable. Measuring variability as the difference between the 95th and 5th percentiles of the whitened temperature anomalies confirms that the range of winter temperature fluctuations is decreasing (see red curve in Fig. 4.1d).

Whether the above change in variability is natural or human-forced cannot be ascertained from purely observational analysis. Accordingly, we compute corresponding trends from the CMIP5 climate simulations. The trend in standard deviation of whitened daily winter temperature for three eastern seaboard regions, along with the 95% confidence intervals, are shown in Fig. 4.2 for historic runs (red) and observations (blue) between 1950 and 2014, and pre-industrial controls (black). The observed trend is negative and significantly different from zero in all three regions. In nearly all model projections, there is no significant

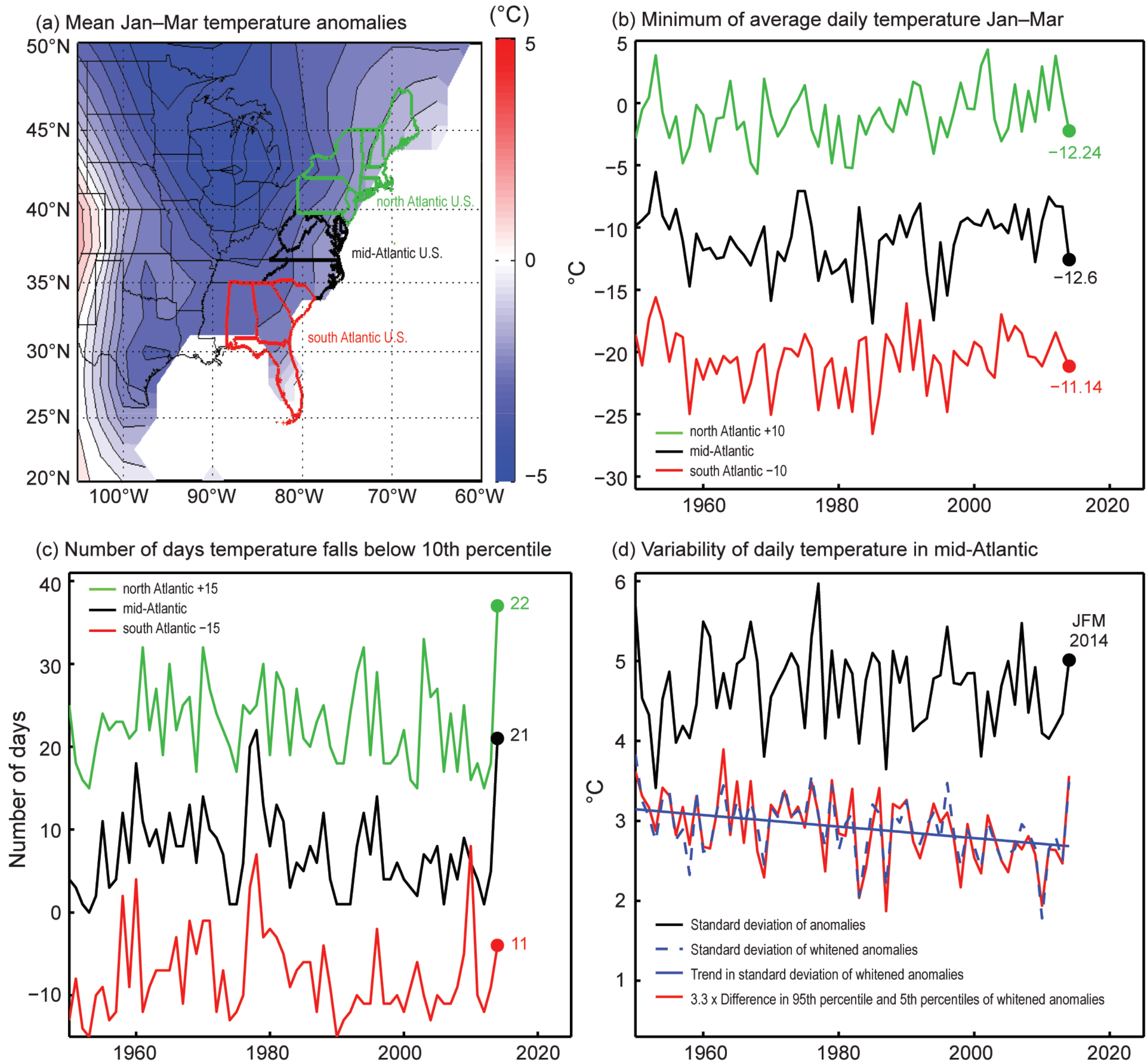

FIG. 4.1. (a) Mean temperature anomaly (°C) from NCEP/NCAR reanalysis for Jan–Mar 2014 (anomalies are computed point wise relative to the Jan–Mar seasonal cycle between 1950 and 2014, which is estimated as a 3rd order polynomial). The different colored states indicate the U.S. regions analyzed in the rest of the paper. All time series analysis is based on station data. (b) Minimum in Jan–Mar average daily temperature anomaly (°C) in the north (green), mid- (black), and south (red) Atlantic regions for the years 1950–2014. The north (south) Atlantic time series have been shifted by +10 (−10). The dot marks the year 2014 and the associated text reports the observed minimum in average daily temperature for that year. (c) Number of days in which the daily temperatures during Jan–Mar fall below the 10th percentile in the north (green), mid- (black), and south (red) Atlantic regions. The north (south) time series have been shifted by +15 (−15). The dot marks the year 2014 and the associated text reports the observed number of days with temperatures below the 10th percentile. (d) Standard deviation of Jan–Mar daily temperature anomalies (black), and the standard deviation of daily whitened temperature anomalies (blue dash) in the mid-Atlantic region. Whitened anomalies are computed as the residual of a second order autoregressive model fit to the Jan–Mar temperature anomalies. The solid blue line shows the least squares line fit to the standard deviation of the whitened anomalies over 1950–2014. The red curve shows the difference between the 95th and 5th percentiles of Jan–Mar whitened daily temperature anomalies, multiplied by 3.3 to convert to standard deviation for a Gaussian distribution.

negative trend. This does not mean that models and observations are inconsistent. All model estimates in mid-/north Atlantic states and half of those from the south Atlantic are consistent with observations, as indicated by the overlap in blue and red confidence intervals. Given the consistency between pre-

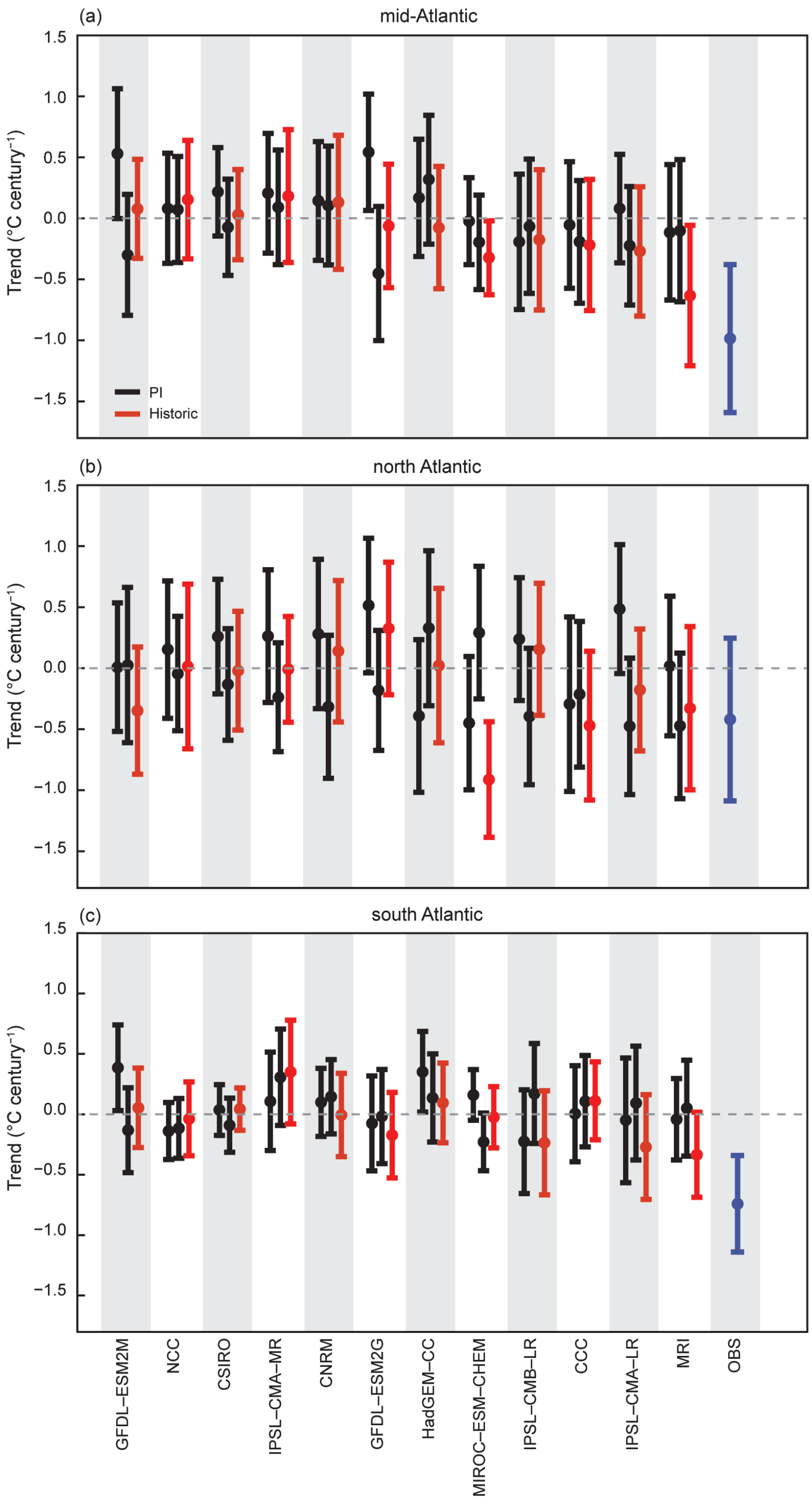

Fig. 4.2. Trends in the standard deviation of Jan–Mar whitened daily temperature anomalies (°C century^{-1}) for observations (blue dots) and historical runs (red) over the period 1950–2014, and the first and last 65 years for CMIP5 pre-industrial control runs (black dots), for three different U.S. regions: (a) the mid-Atlantic , (b) north Atlantic , and (c) the south Atlantic. The bars indicate the 95% confidence intervals.

industrial controls and historic runs across a majority of models (note overlap in the black and red confidence intervals), we conclude that the models do not attribute a significant change in daily winter temperature variability to anthropogenic forcing.

Summary. The north and mid-Atlantic states endured a record number of days with below average temperatures during January–March 2014. In contrast, the variability of winter daily temperature, and therefore of the range of realized temperature, has been decreasing for the past six decades. The decrease in variance is a plausible consequence of polar amplification of global warming, since a decrease in the pole-to-equator temperature gradient reduces the strength of fluid dynamical instabilities (Schneider et al. 2014; Screen 2014). Model simulations suggest that human-induced forcing does not significantly influence the range of daily winter temperatures (with noted exceptions). In any case, we find no evidence that daily winter temperatures are becoming more variable in the eastern United States or that such increased variability could explain the cold winter of 2014.

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Table 34.1. ANTHROPOGENIC INFLUENCE

ON EVENT STRENGTH †			
	INCREASE	**DECREASE**	**NOT FOUND OR UNCERTAIN**
Heat	**Australia** (Ch. 31) **Europe** (Ch.13) **S. Korea** (Ch. 19)		**Australia, Adelaide & Melbourne** (Ch. 29) **Australia, Brisbane** (Ch.28)
Cold		**Upper Midwest** (Ch.3)	
Winter Storms and Snow			**Eastern U.S.** (Ch. 4) **N. America** (Ch. 6) **N. Atlantic** (Ch. 7)
Heavy Precipitation	**Canada**** (Ch. 5)		**Jakarta****** (Ch. 26) **United Kingdom***** (Ch. 10) **New Zealand** (Ch. 27)
Drought	**E. Africa** (Ch. 16) **E. Africa*** (Ch. 17) **S. Levant** (Ch. 14)		**Middle East and S.W. Asia** (Ch. 15) **N.E. Asia** (Ch. 21) **Singapore** (Ch. 25)
Tropical Cyclones			**Gonzalo** (Ch. 11) **W. Pacific** (Ch. 24)
Wildfires			**California** (Ch. 2)
Sea Surface Temperature	**W. Tropical & N.E. Pacific** (Ch. 20) **N.W. Atlantic & N.E. Pacific** (Ch. 13)		
Sea Level Pressure	**S. Australia** (Ch. 32)		
Sea Ice Extent			**Antarctica** (Ch. 33)

† Papers that did not investigate strength are not listed.

†† Papers that did not investigate likelihood are not listed.

* No influence on the likelihood of low rainfall, but human influences did result in higher temperatures and increased net incoming radiation at the surface over the region most affected by the drought.

** An increase in spring rainfall as well as extensive artificial pond drainage increased the risk of more frequent severe floods from the enhanced rainfall.

*** Evidence for human influence was found for greater risk of UK extreme rainfall during winter 2013/14 with time scales of 10 days

**** The study of Jakarta rainfall event of 2014 found a statistically significant increase in the probability of such rains over the last 115 years, though the study did not establish a cause.

	ON EVENT LIKELIHOOD ††			Total Number of Papers
	INCREASE	DECREASE	NOT FOUND OR UNCERTAIN	
Heat	**Argentina** (Ch. 9) **Australia** (Ch. 30, Ch. 31) **Australia, Adelaide** (Ch. 29) **Australia, Brisbane** (Ch. 28) **Europe** (Ch. 13) **S. Korea** (Ch. 19) **China** (Ch. 22)		**Melbourne, Australia** (Ch. 29)	7
Cold		**Upper Midwest** (Ch.3)		1
Winter Storms and Snow	**Nepal** (Ch. 18)		**Eastern U.S.**(Ch. 4) **N. America** (Ch. 6) **N. Atlantic** (Ch. 7)	4
Heavy Precipitation	**Canada**** (Ch. 5) **New Zealand** (Ch. 27)		**Jakarta****** (Ch. 26) **United Kingdom***** (Ch. 10) **S. France** (Ch. 12)	5
Drought	**E. Africa** (Ch. 16) **S. Levant** (Ch. 14)		**Middle East and S.W. Asia** (Ch. 15) **E. Africa*** (Ch. 17) **N.E. Asia** (Ch. 21) **S. E. Brazil** (Ch. 8) **Singapore** (Ch. 25)	7
Tropical Cyclones	**Hawaii** (Ch. 23)		**Gonzalo** (Ch. 11) **W. Pacific** (Ch. 24)	3
Wildfires	**California** (Ch. 2)			1
Sea Surface Temperature	**W. Tropical & N.E. Pacific** (Ch. 20) **N.W. Atlantic & N.E. Pacific** (Ch. 13)			2
Sea Level Pressure	**S. Australia** (Ch. 32)			1
Sea Ice Extent			**Antarctica** (Ch. 33)	1
			TOTAL	**32**

† Papers that did not investigate strength are not listed.

†† Papers that did not investigate likelihood are not listed.

* No influence on the likelihood of low rainfall, but human influences did result in higher temperatures and increased net incoming radiation at the surface over the region most affected by the drought.

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