7. EXTREME EASTERN U.S. WINTER OF 2015 NOT SYMPTOMATIC OF CLIMATE CHANGE

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Despite severe cold waves and record-breaking extreme cold-day occurrences during 2015, no long-term increase in winter daily temperature extremes has occurred in the eastern United States—winters have become warmer and less variable.

Introduction. In late February 2015, a massive cold wave struck the entire U.S. eastern seaboard, bringing record cold temperatures from Maine to Florida (NOAA 2015). Due to the persistent cold, February 2015 ranked in the top ten coldest Februarys on record for a number of eastern seaboard states. Blizzard conditions accompanied the cold wave, placing the month among the top twenty snowiest for most of the northeastern United States (NOAA 2015). Collectively, the heavy snowfall and frigid temperatures were responsible for more than $3 billion (U.S. dollars) in insured losses and 87 deaths (Bevere et al. 2016; NOAA 2016).

The 2015 winter was the second in a row characterized by extreme cold along the East Coast. These cold events have occurred even while human-related climate change has led to long-term global declines in extreme cold temperatures (Seneviratne et al. 2012). However, global warming has been hypothesized by some to not only shift the temperature distribution toward warmer temperatures, but also to increase the probability of cold extremes in certain regions by enhancing the meandering of the midlatitude jet stream (Francis and Vavrus 2015). Trenary et al. (2015), however, demonstrated that the variance of winter daily temperature along the U.S. eastern seaboard has been decreasing, suggesting a decrease in variability and in the likelihood of cold waves. Decreased variance combined with increasing mean temperatures indirectly indicates a reduction in the likelihood of cold extremes. In this study, we apply extreme value theory to directly quantify the intensity and duration of the eastern U.S. 2015 cold wave and long-term changes in the likelihood of cold extremes.

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Data and Methods. Daily temperatures are estimated by averaging the minimum and maximum surface temperatures from station data from the Global Historical Climatology Network–Daily Database (Menne et al. 2012). Since the 2015 cold wave was concentrated in February, we analyze 1 January–31 March (i.e., February and the two adjacent months) over the period 1950–2015. Area average time series are computed for the North, South, and mid-Atlantic United States. The spatial distribution of the February 2015 temperatures is evaluated using NCEP/NCAR reanalysis and shown in Fig. 7.1a.

We also analyze climate model simulations from phase 5 of the Coupled Model Intercomparison Project (CMIP5; Taylor et al. 2012). Models with daily surface temperature data were selected (see Table 7.1 for model list). Historical simulations for 1950–2004 contain both anthropogenic and natural forcing, and the historical simulations were extended to 2015 using the representative concentration pathway experiment 8.5. For consistency with our observational analysis, model data are area averaged over the North (40°–48°N, 83°–65°W), the mid- (35°–40°N, 83°–72°W), and the South Atlantic (25°–35°N, 89°–75°W).

Daily temperature anomalies are evaluated as departures from the mean seasonal cycle (a third order polynomial fit of the January–March daily temperature) for the period 1950–2015.

The intensity of the 2015 cold wave is quantified by the minimum daily temperature anomaly during JFM of that year, and its corresponding return period is estimated from a generalized extreme value (GEV) distribution. Long-term changes are modeled as a linear trend in the location parameter of the GEV distribution (Coles 2001; Zwiers et al. 2011; Gilland and Katz 2011). The duration of the event is quantified by the number of days the temperature anomaly falls

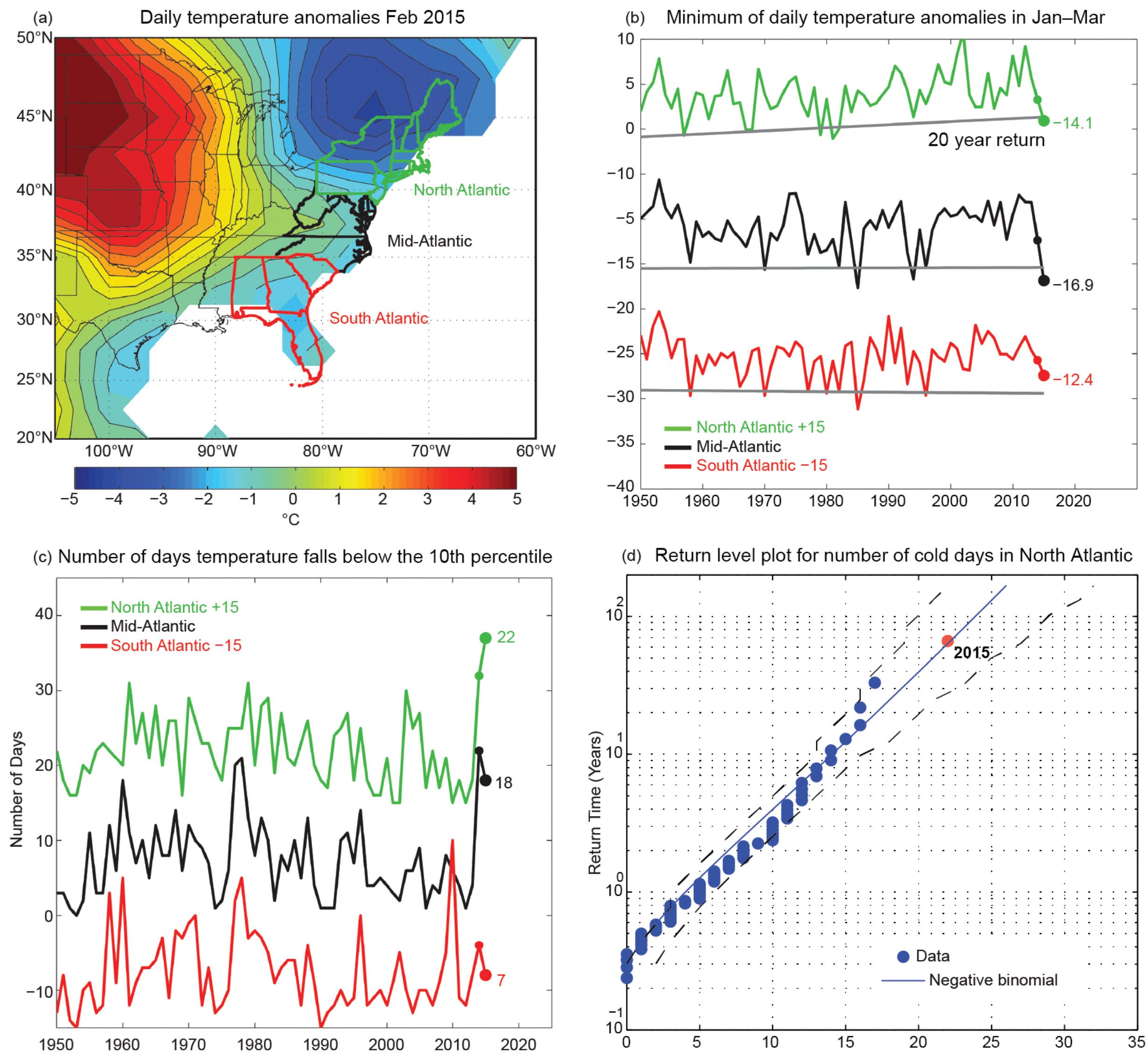

Fig. 7.1. (a) Feb 2015 average temperature anomaly (relative to 1950–2015). Colored state boundaries indicate regions analyzed here. (b) Minimum Jan–Mar daily temperature anomalies in the North, mid-, and South Atlantic regions. North/South Atlantic time series are offset by +15° and −15°C, respectively. The gray lines show the 20-year return level, estimated from a GEV distribution in which the location parameter is fit as a linear function of time. (c) Number of days in which daily temperatures during Jan–Mar fall below the 10th percentile (relative to 1961–90) in the North, mid-, and South Atlantic. North/South time series are offset by +15°/−15°C. (d) Return period for the number of extremely cold days in the North Atlantic (blue circles) and fit to a negative binomial (solid blue line). The red dot shows the return level for 2015. The 95% confidence intervals for the negative binomial fit are shown as dashed curves.

below the tenth percentile. The return period for the 2015 duration is estimated from a negative binomial distribution (Winkelmann 2008).

Results. Figure 7.1b shows the winter (JFM) daily minimum temperature anomalies in the North (green), South (red), and mid-Atlantic (black) regions for 1950–2015. The magnitude of the 2015 winter daily minimum temperature anomaly for each region is displayed next to the respective curve. Both the North (Fig 7.1b, large green dot) and mid-Atlantic (Fig 7.1.b, large black dot) regions experienced notably colder temperatures during 2015, where minimum daily temperatures were the 7th and 2nd coldest, respectively. It was the 13th coldest minimum daily temperature in the South Atlantic. According to the GEV fit, these minimum temperatures roughly correspond to 15-year return levels for both the North

Table 7.1. Climate modeling centers and associated models examined in this study.

CMIP5 I.D. (Experiment)	Modeling Center
CanESM2 (r1i1p1)	Canadian Centre for Climate Modeling and Analysis – Canada
CNRM-CM5 (r1i1p1)	National Centre for Meteorological Research – France
CSIRO-BOM0 (r1i1p1)	Commonwealth Scientific and Industrial Research Organisation – Australia
HADGem2-CC (r1i1p1)	Met Office Hadley Centre – United Kingdom
IPSL-CM5A-LR (r1i1p1)	Institute Pierre Simon Laplace – France
IPSL-CM5A-MR (r1i1p1)	Institute Pierre Simon Laplace – France
IPSL-CM5B-LR (r1i1p1)	Institute Pierre Simon Laplace – France
MIROC5-ESM-CHEM (r1i1p1)	CCSR/NIES/FRCGC – Japan
MRI-CGCM3 (r1i1p1)	Meteorological Research Institute – Japan
NCC-NorESM1-M (r1i1p1)	Norwegian Climate Centre – Norway
GFDL-ESM2G (r1i1p1)	NOAA/Geophysical Fluid Dynamics Laboratory – United States
GFDL-ESM2M (r1i1p1)	NOAA/Geophysical Fluid Dynamics Laboratory – United States

and mid-Atlantic, indicating that the intensity of cold temperatures was not all that extreme.

Trends in the 20-year return level for each region are shown as gray lines in Fig. 7.1b. A statistically significant trend was found only for the north Atlantic region. Because the 20-year return level has increased over the past 66 years, cold events considered normal by 1950s standards are now rare in a warming climate.

The number of days with daily JFM temperature anomalies below the 10th percentile ("extremely cold days") is shown for the three regions in Fig. 7.1c, and the number observed in 2015 is displayed next to each respective curve. The 2015 event in the North Atlantic broke last year's record (Fig 7.1c, small green dot). In the mid-Atlantic, this quantity dropped relative to 2014 but was still high, with 2015 having the 5th largest number of extremely cold days in the region (Fig 7.1c, large black dot). There is no systematic trend in the number of extremely cold days, thus no evidence to suggest that the frequency or persistence of cold events is systematically changing. We estimate the return period for the duration of the cold event by fitting the number of extremely cold days to a negative binomial distribution. We focus our analysis on the North Atlantic, where the duration of cold was record breaking. The negative binomial distribution (blue line in Fig. 7.1d) fits reasonably well the return times for the number of North Atlantic extremely cold days (blue circles in Fig. 7.1d) and indicates that the 2015 event (red dot in Fig. 7.1d) was approximately a one-in-64-year event in terms of the number of extremely cold days.

Observational analysis alone is unable to isolate the relative importance of natural versus human forcing in driving the above changes. To do so, we estimate the trend in the location parameter of the GEV distribution fit to the minimum JFM daily temperature from a suite of CMIP5 climate experiments. The location trends and corresponding 95%

confidence intervals for the historical simulations (black) and observations (red) are shown in Fig. 7.2. The observed trend in the North Atlantic is positive and statistically significant. Observed trends in the other two regions are not statistically significant and are not shown. Like observations, all of the climate models have an upward trend (warmer minimum temperatures) in the location parameters of the GEV for North Atlantic minimum JFM daily temperature anomaly, and this positive trend is statistically significant in more than half of the models. These results suggest that events like the 2015 cold wave are becoming less likely in response to climate change.

Discussion. The 2015 cold wave that impacted the eastern United States can be described as a one-in-15-year event in terms of intensity and a one-in-64 year event in terms of duration. Only the magnitude of cold extremes in the North Atlantic United States shows significant long-term trend. Consistent with observations, the majority of climate models find that climate change has led to a shift in the distribution of winter daily minimum temperatures toward warmer conditions, and subsequently a decrease in the likelihood of extreme cold waves in the North Atlantic. This result contradicts the hypothesis that cold winter temperatures are becoming more extreme (Francis and Vaurus 2015). Rather we find observed trends toward a warmer, less variable climate, and a decrease in the likelihood of such cold winter extremes.

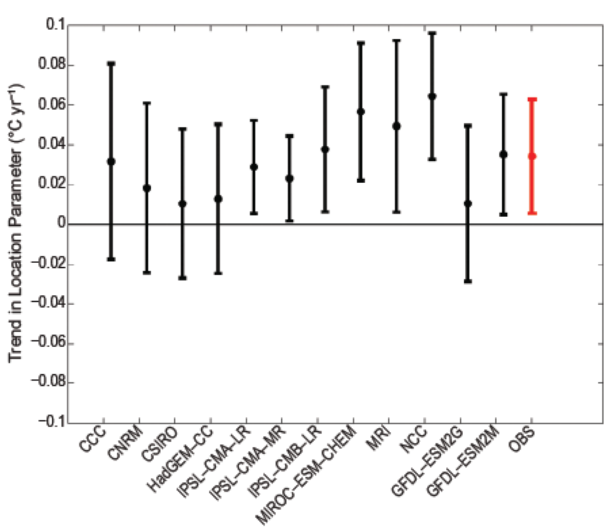

Fig. 7.2. Trend in the location parameter of the GEV distribution fit to the minima of JFM daily temperature from observations (red) and CMIP5 historical simulations (black) for the North Atlantic region during the period 1950–2015. The bars indicate the 95% confidence intervals. The fit of the location parameter is assumed to change linearly over time.

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