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Human Gains and Losses from Global Warming: Satisfaction with the Climate in the USA, Winter and Summer, North and South

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Abstract The scientific understanding of the causes of global warming is based on a vast body of rigorous, peer-reviewed research, but there is little systematic empirical evidence on consequences for humans. Using direct questions about satisfaction with winter and with summer weather, I show that warming's effects on subjective well-being can be reliably estimated from cross-sectional survey data across a broad temperature spectrum and, moreover, that these effects are large. Combining a US national survey (N = 2295) and standard National Oceanic and Atmospheric Administration data on actual month-by-month temperatures at each location over many years, shows that changes to be expected from the widely discussed, allegedly "dangerous", 2 °C of global warming are both familiar and small, equivalent to moving from Wisconsin to Michigan, or Virginia to North Carolina, or more generally 180 miles south. Such warming will greatly *increase* Americans' satisfaction with winter weather, especially in the north, but somewhat decrease satisfaction with summer weather in both north and south. On balance, the nation benefits slightly. Regional differences are large, with northerners' gains roughly equivalent to a 1–2 % increase in their GDP, while southerners losses are about the same size. These changes are important, about as large as the *combined* financial implications of all other aspects of global warming. They have important policy implications, suggesting that prompt action to reduce carbon emissions may not be optimal because that would restrict warming both in the summer and in the south (gains) but also in the winter and in the north (losses).

Keywords Climate change · Global warming · Subjective well-being · Quality of life · Public opinion · USA

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1 Introduction

Climate change looms large among the global problems of the twenty-first century. This urgency has stimulated a huge outpouring of research. Current scientific understanding of the *causes* of global warming is based on a vast body of rigorous, peer-reviewed research and the anthropogenic causes are amply documented (Farnsworth and Lichter 2012; IPCC 2007, 2014 and the vast literature summarized there).

By contrast, the *human consequences* of global warming are less thoroughly studied. Many particular consequences of global warming for the environment are indeed well documented (for example, for the spatial distribution of temperature-sensitive plant and animal species); some of these may be relevant for human concerns, although that relevance is more often assumed than demonstrated. Some specific consequences directly relevant to human concerns are also well documented (for example for agricultural production and for human health), although little research has studied how heavily these specific matters, and the policies suggested to mitigate them, weigh in the overall level of human well-being. Importantly, the *overall balance* of gains and losses directly relevant to human well-being is rarely assessed systematically (see Online Appendix, Section #1).

This paper makes one step toward redressing that lack. By linking temperature variation from the far north to the the deep south of the US to survey data on satisfaction, it provides quantitative estimates of the consequences of global warming for the American public's satisfaction with their climate and the impact that has on their overall subjective well-being. The estimates are based on a representative national sample survey of the USA (N = 2295). They rely on direct questions to each respondent about where they live (which can be linked to objective measures of climate), about their satisfaction with their winter weather and with their summer weather there, and about their overall subjective well-being.

Our methods illustrate how global warming's effects on subjective well-being can be reliably estimated from cross-sectional survey data. They offer quantitative estimates of the magnitude of the effects, so superseding armchair speculation, and give rough but serviceable estimates of their financial implications.

How much warming should we consider? There is a broad international consensus that global warming of 2 °C (some 3° or 4 °F) above pre-industrial levels would be "dangerous" and ought to be avoided if at all possible (e.g. European_Union 2015; Schreurs and Tiberghien 2007). The European Union adopted this benchmark years ago (European Union 2007) and it is now supported by the UN, the IPCC, the Pope, presidents and prime ministers in nations throughout the world, and by many others besides. However it has been accepted for reasons having much to do with international politics—see for example (European_Union 2015; Schreurs and Tiberghien 2007)—but little to do with dispassionately evaluated, properly peer-reviewed social science research. Nonetheless, because the 2 °C change has achieved widespread recognition, it makes a useful benchmark: How much harm or good a 2 °C change will do to humans is not yet known.

The impacts on subjective well-being estimated in this paper are based on multiple instances of 2 °C differences. Fortunately for this analysis, the US includes a wide range of temperatures within one polity, ranging from frigid Minnesota (mean of 15 °F in the winter) to steamy Florida (81 °F in the summer), a dozen 3 or 4 °F steps warmer. Millions of Americans live in locations across this temperature spectrum. That provides the opportunity to reliably measure people's reactions to such temperatures using appropriate data from a straightforward sample survey.

Our survey data, combined with standard NOAA data on actual temperatures at each location, month-by-month over many years, suggest that the changes in well-being to be expected from the benchmark amount of global warming are both familiar and small. The essential comparison is between those living in one region in the US and otherwise similar people living in regions 2 or 3 °C warmer: This gives a real-world estimate of the effects that could be expected from global warming. For example, we compare people living in Wisconsin with those living in a place 2 or 3 °C warmer (Michigan); those living in Virginia (near the average temperature for the US) with those living in a place 2 or 3 °C warmer (North Carolina), those living in Arizona with to their peers in even warmer Florida, and so on. The analysis reveals that residents of many of the warmer locations are actually *more* satisfied with their weather.

Compared to other consequences of global warming, these differences in ordinary citizens' satisfaction with the weather loom large. The IPCC (2014) concludes that global economic impacts from climate change are "difficult to estimate" but accepts an estimate of global annual economic losses from 2 °C warming of between 0.2 and 2.0 % of national income—this with "medium evidence, medium agreement" as the IPCC judges the matter.[1] This evidence of loss is uncertain, with Tol's careful review, for example, suggesting something like a 2 % *gain* (Tol 2002). By comparison, our (admittedly rough) estimates of the gain or loss of a single climate satisfaction point (out of 100)—a difference seen in many of our comparisons—is equivalent to that coming from the gain or loss of somewhere between $1500 and $3000 per capita per year. Aggregated over the US as a whole that comes to something like 1 or 2 % of national income.

Thus the changes in the general public's climate satisfaction that we address in this paper appear to be, in and of themselves, roughly as large as the *combined* financial implications of all other aspects of global warming.

These estimates have important policy implications. They suggest that global warming may not be an uniquely urgent problem for the near future because its consequences are small rather than large and "dangerous". Moreover, the now dominant policy response of seeking to control global carbon emissions may *not* be optimal, because it would reduce global warming both in summer and in the south (beneficial) and also in winter and in the north (harmful). Instead, geo-engineering approaches that have different effects in summer and winter, and in north and south, might well be preferable.

We turn now to the evidence.

2 Data, Measurement, and Methods

2.1 Methods

We use existing temperature differences in the US to develop a quantitative estimate of the effects of global warming: This proxies climate change by cross-sectional climate differences. A similar logic has been followed previously in studies of climate change on

[1] The effects assessed include, among other things, human health, agriculture, energy use, extreme climate events, and neo-Malthusian risks (e.g. Barreca 2008; Ezzati et al. 2004; Patz et al. 2005; Shi et al. 2015; Tol 2002; Darwin et al. 1995; Deschenes and Greenstone 2007; IPCC 2007; IPCC 2014; Nemani et al. 2003; York et al. 2003; Zhang et al. 2011).

European cities, US and world agriculture, within Russia, and across nations (Darwin et al. 1995; Deschenes and Greenstone 2007; Frijters and Van Praag 1998; Hallegatte et al. 2007; Rehdanz and Maddison 2005).

To clarify the logic, consider this example of one case from the survey, a young lady from Madison, Wisconsin. She hates the winter there and loves the summer:

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Box 1: Example case.

     Sex: Female
     Age: 25
     State: Wisconsin
     Unmarried
     Job: Skilled worker
     Income: $25,000 a year
     Satisfaction with winter weather: 0 points out of 100
     Satisfaction with summer weather: 90 points
     Satisfaction with life as a whole: 80 points
     Zip code: 53704
     Latitude: 43.12 North (from Zip code)
     Longitude: 89.34 East (from Zip code)
     Temperature at that latitude & longitude (11 year average, from NOAA)
         January: 19.04 F
         Feburary: 21.38 F
         ...
         December: 23.54 F
```

Our estimates are based on facts like these for over 2000 people.

Specifically, Fig. 1 shows the means of satisfaction with winter and summer climate by location (defined by latitude and longitude), interpolated using the QGIS global information system software version 2.8.1 (www.qgis.org). The results in Table 1 are based on the climate satisfaction questions, state, and average annual temperature at that half degree latitude–longitude grid location (from NOAA). Other individual level analyses presented subsequently in the text and in the Online Appendix are OLS regressions based on those facts and the survey questions. Details are given at appropriate points in the text below and in the Online Appendix, Sections #2, #3, and #4.

2.2 Survey Data

This analysis is based on a survey "Attitudes toward Stem Cell Research 5" conducted in the US by the International Survey Center in May, 2009 with 2295 cases (Evans and Kelley 2011). The sample is national and representative of English-speaking US adults, ages 18 and older. It is based on an internet panel provided by the well regarded private firm Survey Sampling International.

Recent US experience suggests that high quality internet based samples of this sort are a very effective method of assessing public opinion (Couper and Miller 2008; Evans and Kelley 2011; Kreuter et al. 2008; Toepoel et al. 2008). This is partly because inclusion of standard control variables such as age and education in the models adjusts for deviations from representativeness, barring exotic interactions. Importantly, where the questions are comparable, results from this survey show frequency distributions and correlations very similar to those from other representative national samples in the US and Australia in recent years (Evans and Kelley 2011). Further evidence is given in the Online Appendix, Sections #7, #8, and #9.

The climate questions were included as a separate module on multiple aspects of life satisfaction. To avoid ideological stereotypes and political biases, which are prominent for

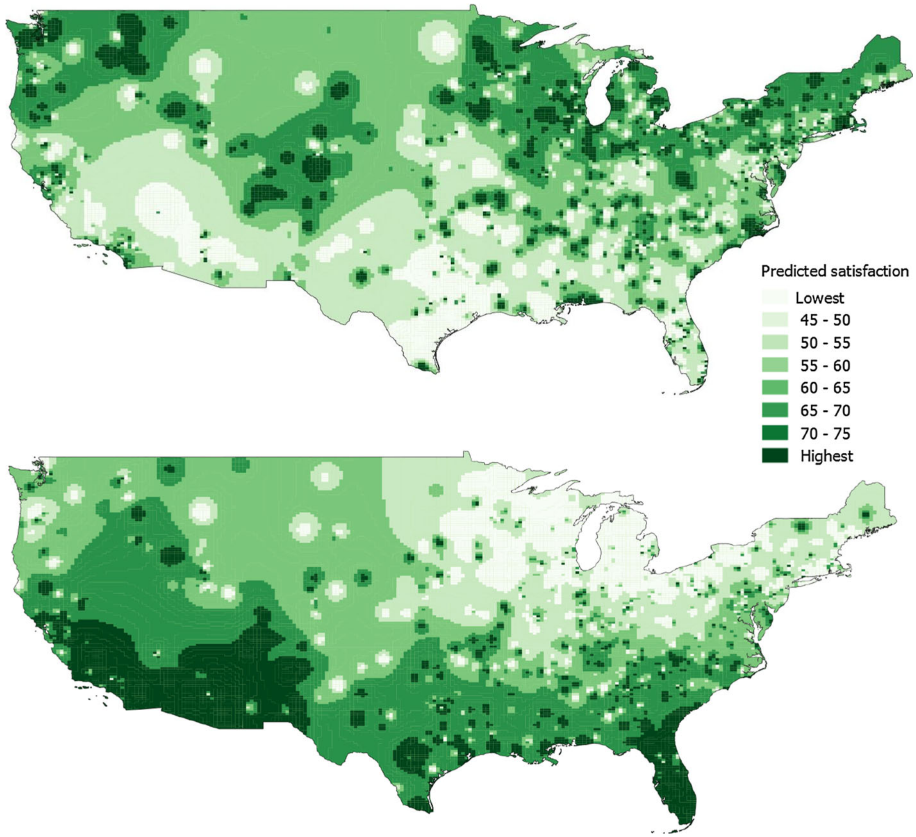

Fig. 1 Satisfaction with summer weather (*top*) and with winter weather (*bottom*). Interpolated satisfaction ratings. USA 2009 (N = 2097 for summer and 2121 for winter). *Darker green* = better. (Color figure online)

many environmental issues (Frank et al. 2000), the module did *not* explicitly mention climate change or global warming. This is unlike most attitude surveys on climate change (e.g. Dietz et al. 2007; Leviston and Walker 2011). The exact questions are given below.

2.3 Climate Data

Average monthly surface temperature data are from a standard National Oceanic and Atmospheric Administration (NOAA) source. They give monthly average temperatures for each year from 1900 to 2009 on a half degree latitude/longitude grid. Specifically, we use data in the form provided by Willmott and Matsuura of the University of Delaware (Willmott and Matsuura 1995) downloaded from http://www.esrl.noaa.gov/psd/data/gridded/data.UDel_AirT_Precip.html (accessed January 11, 2011). For methods and sensitivity analyses see Legates and Willmott (1990) and Willmott et al. (1985), and the references cited there.

The half degree latitude/longitude grid boxes are approximately 25–30 miles wide in the East–West direction and 35 miles North to South, varying somewhat depending on their location. There are over 3000 of them for the continental US. They give a reasonably fine-grained image of the US climate, without dramatic differences between adjacent grid boxes.

Table 1 Temperature and subjective satisfaction with climate in the USA. States are listed from coldest annual temperature to warmest. Temperatures are daily averages in degrees Fahrenheit averaged over 11 years ending in 2009; separately for winter (December, January, February) and summer (June, July, August). Satisfaction is in points out of 100. States with fewer than 20 sample cases not shown separately. Highlighted states provide one illustration of possible climate change: they differ by about 4 °F, rather more than the 2 °C benchmark. [1] Particularly high levels of climate satisfaction (70+ points) are highlighted in green

State	Annual temperature (11 year average) Fahrenheit (1)	Winter temperature (11 year average) Fahrenheit (2)	Summer temperature (11 year average) Fahrenheit (3)	Satisfaction with winter weather (4)	Satisfaction with summer weather (5)	Satisfaction, summer & winter weather averaged (6)	Cases
USA	57	39	74	61	67	64	2,097
#1, Minnesota	43	15	69	38	72	55	39
Other northern states	45	22	66	59	73	66	94
Wisconsin	46	20	69	44	74	59	54
#2, Michigan	47	24	69	39	73	56	81
Colorado	47	29	67	61	75	68	51
Massachusetts	48	28	68	46	71	59	35
Connecticut	49	28	69	37	67	52	20
Iowa	49	24	73	35	74	54	22
New York	49	28	70	48	70	59	123
Illinois	50	27	72	44	71	58	78
Washington state	50	38	62	58	76	67	56
Ohio	51	29	71	43	69	56	100
Oregon	51	39	64	54	70	62	33
#3. Pennsylvania	51	30	71	56	70	63	102
New Jersey	52	32	72	45	71	58	42
Indiana	53	31	74	51	72	61	41
Maryland	54	34	73	61	62	62	34
Missouri	56	33	77	57	69	63	44
Other mid-latitude states	56	35	76	58	67	62	56
#4, Virginia (base= average US)	56	37	74	61	62	61	46
Kentucky	56	36	75	62	65	64	31
Tennessee	59	41	77	64	66	65	46
California	60	50	70	77	67	72	206
#5. North Carolina (base +4F)	60	43	77	72	70	71	61
Arkansas	61	42	79	62	61	62	21
Nevada	61	42	81	68	43	55	23
Other southern states	62	52	73	74	63	68	25
Georgia	62	46	78	73	67	70	78
Alabama	63	47	79	58	58	58	28
South Carolina	63	47	79	69	62	66	31
#6. Mississippi (base +8F)	65	48	80	76	65	70	20
Texas	67	50	82	73	55	64	140
Louisiana	68	53	81	75	58	66	23
#7. Arizona (base +12F)	68	51	85	86	58	72	67
#8. Florida (base +16F)	72	63	81	82	62	72	177

Sources: Temperature data f rom NOAA at www.esrl.noaa.gov/psd/data/gridded/data.UDel_AirT_Precip.html, averaged over 10 years ending in 2009. Satisfaction data f rom the International Social Survey/USA www.international-survey.org

[1] Current climate models suggest global warming at roughly 4 °F per century (on a middling emissions scenario). So starting at Virginia, with an annual temperature around average for the US, a century of warming might lead to a climate like North Carolina's; two centuries to one like Mississippi's; and three century's to one like Arizona's. Warming might well be slower (perhaps 3° per century) or faster (perhaps 7° per century)

[2] Loss (−) or gain (+) in climate satisfaction to be expected from 4 °F global warming if the highlighted states are representative

The correlation between winter temperatures in adjacent grid boxes average around 0.96 and for summer temperatures around 0.87 (details in the Online Appendix, Section #8).

For our baseline, we use average climate figures month-by-month for the 11 years up to the date of the survey, 2009. The choice of which years to measure hardly matters: winter temperatures in 2009 are correlated fully 0.98 with winter temperatures the year before and, indeed 0.98 with winter temperatures more than a century earlier (see the Online Appendix, Section #8). So, too, for summer temperatures: They are correlated 0.98 with temperatures a year before and almost as highly with temperatures a century before.

We merge these climate figures into the survey data using the latitude and longitude of respondents' zip codes. There are around 30,000 general purpose zip codes in the US, so the level of geographic precision is good. We characterize each zip code by its average latitude and longitude and attach the climate data for the half-degree grid box that includes that latitude and longitude.

Further details on measurement are given in the Online Appendix, Sections #2 and #8.

3 Description: Satisfaction with Winter and Summer

The climate satisfaction questions were asked in a widely used 100 point "delighted/ terrible" format, separately for satisfaction with summer weather and satisfaction with winter weather (Box 2). This question format has been widely and successfully used for life satisfaction and related questions. The climate satisfaction questions were asked just following questions on satisfaction with standard of living and with life as a whole. Question wording (respondents saw only the parts shown below in sans-serif italic font):

Box 2: The questions on climate satisfaction:.

How do you feel about your life – how satisfied are you with...

...

The weather here in the winter?

The summer weather?

	Winter	Summer
100 -- delighted	16%	14%
90	9%	11%
80	14%	18%
70	12%	17%
60	9%	10%
50	13%	13%
40	6%	5%
30	5%	4%
20	5%	2%
10	4%	2%
0 -- terrible	7%	3%
	100%	100%
	(N = 2,121	2097)
	(Mean = 61	67)

Summer weather Some 14 % of the American population is "delighted" with the summer weather where they live, giving it 100 points out of 100. Almost as many, 11 %, are only a little less delighted, giving it 90 points out of 100. Some 18 % give it 80 points and almost as many, 17 % give it 70. The rest are less satisfied: around 10 % give it 60 or 50. Only a few are less satisfied than that. Just 3 % say it is “terrible”. For the nation as a whole the average is 67 points out of 100.

Winter weather On the whole, Americans are also satisfied with their winter weather. Some 16 % are “delighted”, giving it 100 points out of 100. Around 10 or 12 % give it 90, 80, 70, 60, or 50 points respectively. Few give it less, although some 7 % do feel their winter weather is “terrible”. For the nation as a whole, the average is 61 points, six points lower than the average for summer.

3.1 Good Summers in the North

There are big differences in satisfaction between north and south in the US (Fig. 1). In the summer, those living in the north are on average *more* satisfied with their weather than those living in the south. Satisfaction is particularly high in the Pacific Northwest, in the Rocky Mountains, in the upper Midwest along the Great Lakes, and in New England and the north Atlantic states. Satisfaction is particularly low in the Southwest and southern Texas.

This seems to reflect differences in summer temperature between the (cool) north and the (hot) south. The link between average *summer* temperatures and satisfaction with the summer weather is clear, with each 1 °F reducing satisfaction by almost one point, −0.82 ($p < 0.001$).

3.2 Good Winters in the South

All this is reversed in the winter. Those living in the south are, on average, *more* satisfied with their winter weather (Fig. 1, bottom panel). Satisfaction is particularly high in Southern California, the Southwest, southern Texas, and Florida. In the north, winter weather is not popular, with satisfaction lowest in the cold belt in the upper Midwest, along the Great Lakes, and in New England.

This seems to reflect differences in winter temperature between the (cold) north and the (warmer) south. The correlation between average *winter* temperatures and satisfaction with the winter weather is clear, with each 1 °F increasing satisfaction by about one point, +1.03 ($p < 0.001$).[2]

3.3 Individual Variation

Summer There is much individual variation in all this (Fig. 2). Most northerners rate their summer weather between 50 and 100 (Panel A). Fewer are that happy in mid-latitude states (not shown). In southern states yet fewer are happy and many are decidedly unhappy (Panel C).

Winter Northerners have diverse although often negative feelings about their winters (Fig. 2, Panel B). More than 10 % hate their winter, giving it the lowest possible score of

[2] Thus absolute magnitude the effect of temperature on satisfaction with summer weather (just under 1 point) is not much smaller than its effect on winter weather (just over 1 point). But there is a much larger difference in absolute magnitude between the correlations (0.20 for the summer versus 0.44 for the winter) because summer temperatures in the US vary much less (standard deviation 6) than winter temperatures (standard deviation 13).

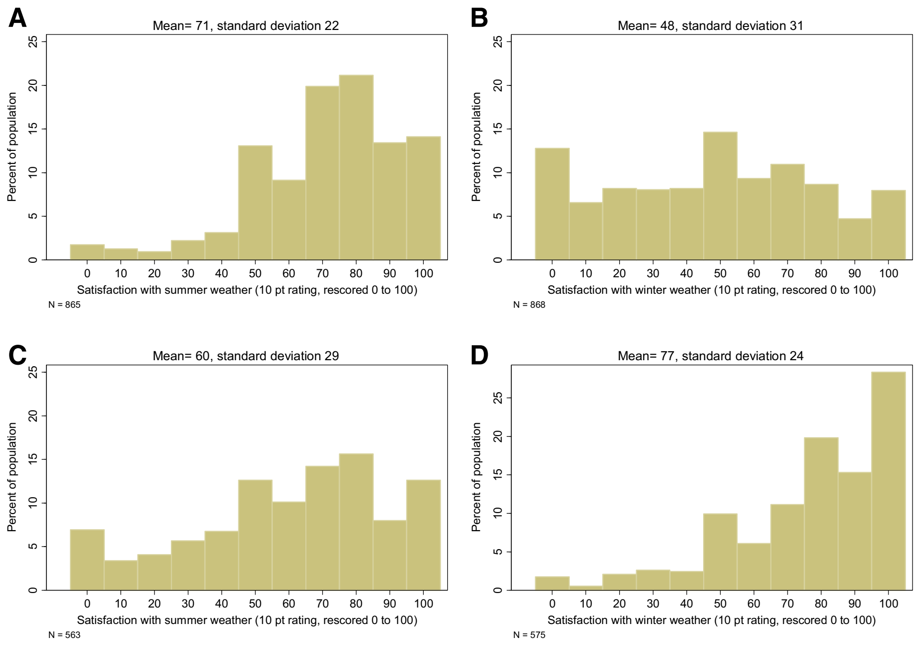

Fig. 2 Satisfaction with summer weather and with winter weather in northern states (latitude 40+) and in southern states (latitude 35−). Middle latitude states are not shown. USA 2009. **a** Summer, northern states (mean = 71, standard deviation 22). **b** Winter, northern states (mean = 48, standard deviation 31). **c** Summer, southern states (mean = 60, standard deviation 29). **d** Winter, southern states (mean = 77, standard deviation 24)

zero but others have neutral or even favorable feelings. By contrast, in southern states winter is highly popular, almost 30 % giving it the highest possible score of 100 (Panel D). Mid-latitude states (not shown) are in between.

4 Analysis: Differences Between US States

Recall that the standard benchmark of serious global warming global warming is 2 °C (3.6 °F); it is also a reasonable mid-range guess for the global warming to be expected over the next century or two.[3] To be conservative, let us look at the upper end of the range, at differences of around 4 °F. Comparing satisfaction, all else equal, between states where temperatures differ by this amount gives us a reasonable estimate of the effect of global warming on subjective well-being over time.

[3] Projections about actual levels of global warming to be expected in the next century or so are uncertain, both because of scientific uncertainty in the modeling and policy uncertainty about future levels of carbon dioxide emissions (IPCC 2007 Fig. 3.2; IPCC 2014; Schmittner et al. 2011). The change could easily be as low as 3 °F or as high as 7° (IPCC 2014). Perhaps the most persuasive historical data are from the distinguished Berkeley group (www.berkeleyearth.org) showing a rise of 1 °F per century over the last two and a half centuries, but five degrees per century more recently. So we can take changes of around 4 °F a plausible mid-range guess.

The US forms a valuable case study, giving clear evidence about the effects of global warming on people's satisfaction with the climate through the sharp variations among US states in temperature and, correspondingly, with satisfaction with summer and winter climate. Multiple instances of 2 °C change are well within the range of temperatures actually found in the US today. Culture, technology, wealth, and national-level policy and practices are much the same across a very wide array of temperatures. This climate diversity within a single country provides some hard facts which contribute to the policy debate by superseding armchair speculation and help counterbalance the all-too-human tendency for emotional commitment to shape perceptions of fact, as sometimes happens in areas like this (Kelley 2014). Instead we can observe how people *actually* feel about these temperatures based on their own experiences of living in them for many years (Table 1).

4.1 US States in the Winter

Let us start cold and work our way warmer by 4 °F increments, essentially simulating what climate change over the next century is likely to bring.

Coldest in the continental US is **Minnesota** (Table 1, entry #1, highlighted in dark blue). Minnesota is very cold in the winter (column 2), averaging around 15 °F, far below the US average. (These are average temperatures for the whole 24 h, so afternoons are warmer and nights colder). Satisfaction with winter weather is correspondingly low, 38 points out of 100 (column 4), far below the US winter average of 61. In contrast, summers are agreeable, at 69 °F around 5° cooler than the US average and about 5 points more enjoyable than the average.

Then 4 °F of global warming (column 1) would probably give Minnesota a climate much like **Michigan** (entry #2, highlighted in middle blue)—a lot warmer in winter, not much different in summer. But, if anything, people find this warming a fraction *more* satisfactory, not less.

Another 4 °F of global warming would take Michigan's climate to something like **Pennsylvania's** (highlighted in light blue)—noticeably nicer in winter (by 17 points out of 100) but a little worse in summer (by 3 points). On balance, Pennsylvania's 4 °F warmer climate is *more* satisfactory for ordinary Americans than Michigan's, by about 7 points out of 100, a worthwhile gain in subjective well-being.

Thus, across this range from very cold to fairly cold baseline temperatures, 4 °F would yield a substantial net *gain* in subjective well-being: Warming would be beneficial, not harmful. And if they react like Americans, residents of Northern Europe, Russia, and other cold nations would likely find global warming beneficial as well.

The same lack of harm is evident elsewhere in the US. For example, take as a starting point **Virginia**, which has a climate much like the median for the US (entry #4, highlighted in light yellow). A 4 °F warming from this baseline would make it much like **North Carolina** is today (entry #5). Judging from North Carolina, that would *increase* satisfaction with both summer and winter weather. Another 4 °F of global warming (and so 8 °F in all from the Virginia baseline) would bring us to a climate like **Mississippi** is today. Judging from that, satisfaction with winter weather would rise again, but summers would be getting too warm, with satisfaction dropping. Twelve degrees Fahrenheit of global warming, perhaps three centuries worth, would bring us to temperatures much like **Arizona** is today. And judging from that, satisfaction with winter weather would be higher yet, but summers would be too hot. Finally 16 °F warming, perhaps four centuries worth, would bring us to temperatures like **Florida** today, with better winters but indifferent summers. Florida is indeed warm, but nonetheless many people move there voluntarily and live there happily.

In short, the general pattern is for warmer *winter* temperatures to make the weather better (Fig. 3). Winter temperatures around 15, 20 or 25 °F make for misery; temperatures around 50, 55 or 60 °F are very agreeable.

4.2 US States in the Summer

Summer temperatures are quite another matter (Table 1, column 3). Summers around 70 °F are very pleasant (column 5). **Minnesota** (entry #1, highlighted in dark blue), **Michigan** (entry #2 in middle blue), and **Pennsylvania** (entry #3, light blue) are good examples; so are Wisconsin and Colorado.

But summers a bit warmer than that are mixed. **Virginia** (entry #4 in light yellow) is around 62 and not popular, although **North Carolina** (entry #5 in dark yellow) at 70 is surprisingly satisfactory.

Summers in the 80 s are mostly less pleasant: Texas, **Arizona** (entry #7), and **Florida** (entry #8) are examples.

The general pattern is for higher summer temperatures to reduce satisfaction for the most part, but not always—there are many exceptions (Fig. 4). Global warming thus appears to have mostly a mildly negative impact in summer, but note that satisfaction with summer is above the midpoint of 50 points out of 100 everywhere except Nevada (mostly reflecting Las Vegas). Florida is hot, but millions live there happily throughout the summer (average of 62 points out of 100 in summer climate satisfaction); their danger is not the heat but the alligators.

4.3 US States over the Year as a Whole

Over the year as a whole, the effect of the benchmark 4 °F is mixed (Table 1, column 6 averages winter and summer satisfaction to give an approximation for the year as a whole[4]). On the whole, warmer states (column 1) are usually happier with their weather (column 6). At the top are **Arizona** and **Florida** (entries #7 and #8), together with California. It is no accident that retirees move there rather than to **Minnesota** or **Michigan** (entries #1 and #2).

The general pattern is for climate satisfaction over the whole year to be a bit higher in warmer states, although there are exceptions (Fig. 5).

4.4 Predicted Satisfaction Gains or Losses from Warming, Controlling for Other Things

The differences we have just described are straightforward and familiar but necessarily remain somewhat impressionistic. That is partly because there is some uncertainty about which states to compare and different choices do not always give the same results. But it is also because the states themselves do not give a perfect representation of temperature differences. For example Minnesota is, to be sure, cold in the winter but there are other places in the Dakotas, Michigan, and New England which are equally cold and those should logically be included when we are trying to estimate the consequences of a climate

[4] This is an imperfect approximation because it neglects spring and autumn. Their temperatures are intermediate between winter and summer, so the approximation should be reasonable.

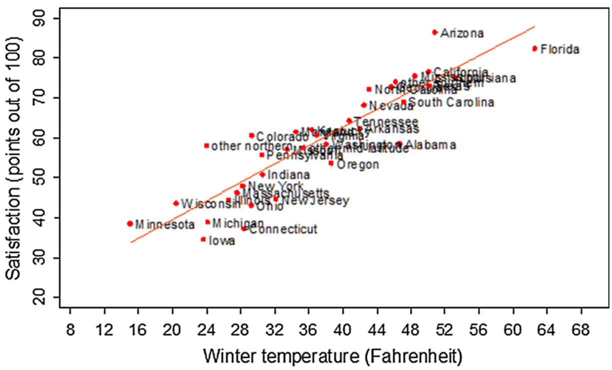

Fig. 3 Temperature and satisfaction with the winter climate USA, 2009

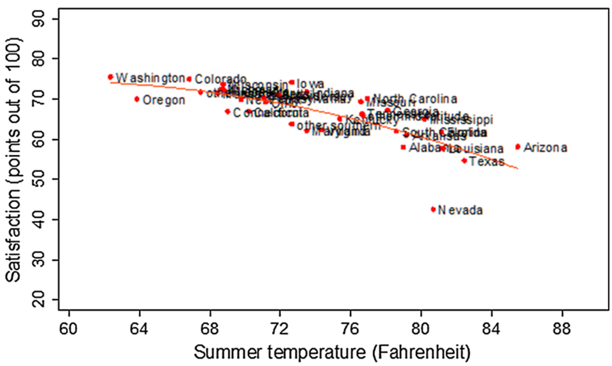

Fig. 4 Satisfaction with the summer climate USA, 2009

like Minnesota's. Similarly when we compare Minnesota with "dangerously" warmer Michigan, not everyone who is that warm lives in Michigan—there are plenty others living in climates like that in Colorado and New England, for example. They too should logically be included in the comparison. And so it goes throughout the country.

This logic suggests that we should compare people who live in places with annual temperatures around 44 °F (not just Minnesotans) with everyone who lives in places around 48 °F (not just Michiganders). Logic also suggests that we should adjust for any salient demographic and SES differences (although those are few). Hence we switch the focus for this analysis from the state to the *locality* (defined as a half-degree latitude by longitude box). The analyses in Table 2 do this, for example comparing everyone who lives in a 44 °F locality with everyone who lives in a 48 °F locality, regardless of what states the localities are in. And in addition to comparing the 44 and 48 °F localities (a difference of 4°), Table 2 also extends the analysis to compare the 44 °F localities with the 52 °F localities (a difference of 8°).

We make similar comparisons with other temperature localities ranging up to 68 °F (we can't go as far as 72 °F because there is nothing warmer in the US to compare it with). Details are in the Online Appendix, Section #3.

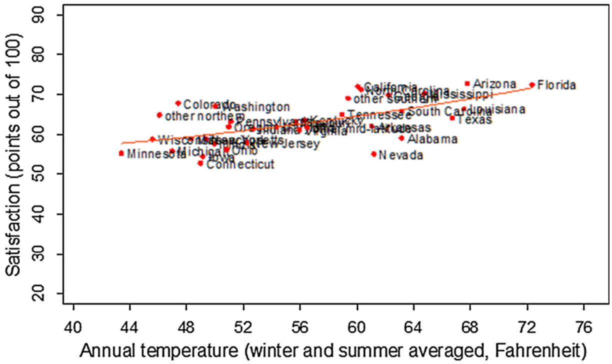

Fig. 5 Satisfaction with the climate year around USA, 2009

4.4.1 Temperature Localities: Global Warming and Satisfaction with the Winter

Starting with localities in the cold 44 °F temperature range (row 1, like the Minnesota average), the impact of 4 °F warming in the winter seems to be small (Table 2, first row, column 3). The point estimate is a modest 2 point *gain*, but statistically this is not significantly different from zero. However, 8° warming does produce a statistically significant 9 point gain (column 4).

Starting next at 48 °F localities (row 2, which includes Michigan), 4 °F warming would give a statistically clear 7 point *gain* in satisfaction with the winter weather (column 3). Twice that warming would give almost twice the gain (column 4).

Similarly, starting the comparison with localities that have even warmer temperatures also leads to gains, which are especially clear for 8 °F warming (last few rows of Panel A, columns 3 and 4).

Overall 4 °F of warming in the winter leads to a gain in satisfaction with winter weather of about 5 points out of 100, while twice the warming leads to at least twice the gain (last row of Panel A, columns 3 and 4).

4.4.2 Temperature Localities: Global Warming and Satisfaction with the Summer

By contrast, global warming would typically reduce satisfaction with summer weather, although not in every case, not by all that much, and the effect is not always statistically significant (Table 2, columns 5 and 6). The average is a loss of 2 points from 4 °F warming and over twice that from 84 °F warming.

4.4.3 Temperature Localities: Global Warming and Year Round Satisfaction

For the year as a whole—assuming that the average of winter and summer gives a reasonable approximation for the year round average—a benchmark 4 °F of global warming would mostly lead to small *gains* in satisfaction (Table 2, columns 7 and 8). However, the patterns are not especially consistent and only a few of the effects are statistically significant. All in all, 87 % of the changes in subjective well-being with 4 °F of global warming are positive or neutral and only 15 % are negative (and they are not statistically significant, so they might well be neutral, too).

Table 2 predicted gain or loss in climate satisfaction from 4 °F global warming and from 8 °F global warming, based on observed differences between individuals in the USA. Regression estimates controlling socio-economic differences, separately for 4 °F temperature localities [1] and for mainland USA as a whole [2]

Average annual temperature locality (1)	*Example* of states typical of each locality (2)	Satisfaction with winter: Winter: +4F: Gain or loss (3)	Satisfaction with winter: Winter: +8F: Gain or loss (4)	Satisfaction with summer: Summer: +4F: Gain or loss (5)	Satisfaction with summer: Summer: +8F: Gain or loss (6)	Winter & summer averaged: Year +4F: Gain or loss (7)	Winter & summer averaged: Year +8F: Gain or loss (8)	Minimum # cases (+4F & +8F) (9)
Panel A: Separately by 4 degree Fahrenheit temperature localities [1]								
44F	#1, Like the Minnesota average	2	**9 gain**	0	-3	1	3	525 & 444
48F	#2, Like the Michigan average	**7 gain**	**12 gain**	-3	**-8 loss**	2	2	757 & 613
52F	#3. Like the Pennsylvania average	5	**15 gain**	-5 loss	-3	0	**6 gain**	537 & 528
56F	#4, Like Virginia (base= average US)	**11 gain**	**13 gain**	2	-4	**6 gain**	4	383 & 362
60F	#5. Like North Carolina (base +4F)	2	**12 gain**	-7 loss	-7 loss	-2	3	355 & 356
64F	#6. Like Mississippi (base +8F)	**9 gain**	**11 gain**	0	-2	5 gain	4	333 & 283
68F	#7. Like Arizona (base +12F)	1	--	-2	--	-1	--	284
	Mean (unweighted):	5 gain	12 gain	-2 loss	-5 loss	2 gain	4 gain	--
Panel B: USA as a whole [2]								
57F	All 48 mainland states	**3.20 gain**	**3.02 gain**	**-1.00 loss**	**-1.69 loss**	**1.89 gain**	**2.00 gain**	2060+

The 95 % confidence intervals for the global warming effect in Panel A are typically plus or minus 4–6 satisfaction points. Highlighted entries are significantly different from zero at $p < 0.05$; highlighted and boldface entries are significant at $p < 0.01$

Source: Regression analyses shown in Appendix Table A

[1] Method: The results in row 1, column 1 (for example) are from a regression analysis of all respondents living in areas (half degree latitude/longitude grid) with annual temperatures in either the 44 or 48 °F temperature bands, regardless of what state they live in. The regression predicts satisfaction the winter climate on the basis of band (a dummy variable for those in the warmer temperature band) and individual demographic and socio-economic characteristics. Row 1, col. 1 reports the metric regression coefficient for the band dummy variable; a negative coefficient suggests that 4 °F global warming would reduce satisfaction with the winter climate while a positive coefficient suggests it increases satisfaction. The entry in row 1, col. 2 is f rom a similar analysis restricted to respondents in the 44 and 52 °F temperature bands. Residents of the three Pacific coast states are excluded because of their distinctively higher levels of climate satisfaction

[2] Details in the Online Appendix

In sum, 4 °F or thereabouts of global warming likely has offsetting effects for Americans' satisfaction with their weather, making things worse in the summer (by around 2 satisfaction points out of 100) but better in the winter (by around 5 points) and in all slightly *better* for the year as a whole (perhaps by 2 points).

4.5 The Monetary Value of Climate Satisfaction

4.5.1 Estimating Monetary Value

How important are these effects—is climate satisfaction something that matters greatly, like love or marriage, or something of little consequence? And how does it weigh in the balance compared to more familiar metrics, such as monetary gains and losses?

Logic and a plethora of research suggests Jeremy Bentham's answer: The key to evaluating something's moral and policy impact lies in its impact on human happiness

(Bentham 1780 [1907]; Carruthers and Espeland 1998; IPCC 2007; Kahneman et al. 1997; OECD 2011; Stiglitz et al. 2010)—also called subjective well-being, quality of life, utility, or life satisfaction (we will use the terms interchangeably). For example, a blue ribbon panel convened by the then President of France, composed largely of economics Nobel Laureates (Stiglitz et al. 2010), concluded that the best candidate for an overall, inter-personally comparable measure of welfare, and so a proper goal for public policy, is individuals' survey reports of their subjective well-being (see also Thin 2012).

Survey based measurement of happiness has long been strongly established in sociology and social psychology, and more recently in economics. It is thoroughly validated by comparisons with observers' reports and physiological measurements (Diener and Suh 1997; Headey and Wearing 1992; Veenhoven 1984) and linking changes in well-being to monetary estimates is a method now widely used in the contingent evaluation literature (Argyle 1999; Arrow et al. 1993; Daly and Rose 2007; Diener et al. 2003; Diener and Suh 1997; Evans and Kelley 2004; Headey and Wearing 1992; Mitchell and Carson 1989; Ng 1997; Rehdanz and Maddison 2005; Rollins and Dumitras 2005).

Our implementation of this approach for valuing climate satisfaction builds on a small but promising literature combining climate data with survey research (Barreca 2008; Frijters and Van Praag 1998; Pray 2007; Rehdanz and Maddison 2005; Van Praag 1988).

4.5.2 Results: Climate Satisfaction Versus All Other Gains and Losses from Global Warming

Regression analysis on our data shows that satisfaction with climate has a powerful impact on well-being (Table 3). Each climate satisfaction point produces just under one-fifth (0.183) of a life satisfaction point (column 1). In contrast, \$1000 in income produces only a third as much life satisfaction (0.054; column 2). To raise subjective well-being by 0.183—the amount it is raised by one point of climate satisfaction—would require about \$3000 (\$1000 raises subjective well-being by 0.054, so \$3000 raises it by three times that, $3 \times 0.054 = 0.162$, which is nearly as large as the 1.83 gain from 1 additional point of climate satisfaction). Thus it takes about \$3000 in income to produce as much well-being as is produced by one climate satisfaction point, judging from the regressions in Table 3.

In short, each climate satisfaction point is equivalent (in terms of its effect on human well-being) to some \$3000 in income. These calculations are approximate, but they do give the big picture.[5]

There is, however, a further complication. There is some reason to suspect that the effect of climate satisfaction on well-being may be overestimated by about half because in the regression analysis of Table 3 we are unable to control for other domain satisfactions

[5] In rich nations like the US and western Europe, valuations made in this way typically seem, intuitively, to be on the high side. But in poor nations like Romania or India, they usually seem more reasonable, perhaps even low. This probably reflects the diminishing marginal utility of money. For a poor Romanian farmer, for example, US \$1000 is likely to be spent on highly valued meat for his family, on education for his children, and on health care, and so contributes a lot to his well-being. But a prosperous American banker already has ample meat, education and health care, so her extra \$1000 goes on indulgences, perhaps a silk dress, that probably add little to her overall well-being. For an analysis like Table 3, the consequence is that money contributes a lot for the Romanian farmer, perhaps a regression coefficient of 0.36 (which would value climate satisfaction at \$500 a point for him), while it contributes little for the American banker, perhaps a regression coefficient of 0.02 (which would value climate satisfaction at \$6000 a point for her). The high value of climate satisfaction for the American banker thus reflects the *low* value of money for someone as rich as she is. Conversly, the low value of climate satisfaction for the Romanian farmer reflects the *high* value of money for someone as poor as he is. Logical this is, although intuitive it is not.

Table 3 Effects of satisfaction with the climate on subjective well-being, controlling for other things. [1] OLS regression estimates. Metric coefficients. USA, 2009

	Subjective well-being	
	b (1)	b (2)
Climate satisfaction, year around (points out of 100)	0.183***	–
Income ($1000 s)	–	0.054**
Satisfaction with money	0.603***	
Age	0.119***	0.217***
Male	−2.136**	−3.731***
Education	−0.049	0.359
Rural resident	0.657	0.627
Churchgoing	0.029**	0.080***
(constant)	13.555***	51.694***
R-squared	0.56	0.053
Cases	2077	2115

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

[1] Implies each climate satisfaction point produces as much well-being as 0.183/0.054 = $3000 approximately

(e.g. marriage satisfaction, job satisfaction) in addition to satisfaction with money. This is discussed in detail in Online Appendix Section #9. Thus climate satisfaction's effect might well be around 0.091 instead of 0.183. If so, on this conservative estimate it would take about $1500 in income to produce as much well-being as is produced by one climate satisfaction point rather than our initial estimate of $3000. That is nonetheless large compared to other consequences of global warming.

By our (admittedly rough) estimates for warming's effect over the year as a whole, combining its gains for winter and losses for summer and aggregating over the US as a whole, the $3000 gain from a single climate satisfaction point comes to something like 2 or 3 % of GDP.[6] Two climate satisfaction points, our best guess for the change that would result from the benchmark 4 °F for the US, would be twice that (Table 2, column 6). More conservatively, if we take the gain from a single climate satisfaction point as half that, i.e. $1500, our best guess for the benchmark 4 °F warming in the US would something like 1 or 1.5 % of GDP.

If these results are even approximately correct, they imply that global warming's effects on ordinary citizens' satisfaction with their weather loom large in comparison to the other (modest) financial costs and benefits attributed to warming. These other effects come about through warming's effects on health, agriculture, extreme climate events, and the like. Although admittedly hard to evaluate, the best summary is probably from the IPCC who note that global economic impacts from climate change are difficult to estimate with incomplete estimates of losses from 2 °C warming of between 0.2 and 2.0 % of national income (IPCC 2014)—this with "medium evidence, medium agreement" as IPCC judges

[6] At the time of the survey gross national income at parity purchasing power was around $47,000 per person. Income as shown in household surveys makes up something around 50 % of GDP in rich nations (Milanovic 2002). So a climate satisfaction point comes to something like ($3000/$47,000) *(0.50) = 3 % approximately, or half that on our more conservative estimate. All this is very approximate but should at least be in the right general ballpark.

the matter. Even this evidence of loss is uncertain, with Tol's careful review, for example, suggesting something like a 2 % *gain* (Tol 2002). But an any case the figure is most likely somewhere between a 1 or 2 % loss and a 1 or 2 % gain.

Thus the changes in the general public's climate satisfaction that we analyze in this paper appear to be, in and of themselves, about as large as the *combined* financial implications of all other aspects of global warming even on our more conservative estimates.

4.6 Other Aspects of Climate Change: Precipitation, Hurricanes

In addition to warming per se, other aspects of climate change could also influence people's well-being and (at least in some cases) the methods of this paper would also be appropriate. While we must defer a full consideration of these for future research, a brief consideration of two of them is of interest for setting the broad context: precipitation (changes in rainfall are implied by many climate models) and one example of the kind of extreme climate events implied by some climate models, namely hurricanes.

Our analysis, admittedly approximate, simply adds measures of precipitation and hurricane incidence to our basic model and estimates their impact on satisfaction with the climate. Details are in the Online Appendix, Section #10.

This analysis suggests that precipitation in the summer has no statistically significant effect on satisfaction with summer weather ($z = 1.07$, $p = 0.285$). Nor does precipitation in the winter have any statistically significant effect (at the usual 0.05 level) on satisfaction with winter weather ($z = -1.74$, $p = 0.077$). A much larger sample might find statistically significant effects, but our results imply that they would be small in magnitude, nothing like the large effects of temperature.

Similarly, our analysis suggests that the probability of being struck by a major hurricane has no statistically significant effect on satisfaction with summer weather ($z = -0.09$, $p = 0.924$).

4.7 Robustness Checks

4.7.1 Sampling Issues

This analysis is based on an internet panel provided by a well regarded private firm and recent US experience, as noted earlier, suggests that high quality internet based samples of this sort are a quite satisfactory method of assessing public opinion. But this is contrary to what was prevailing professional opinion in past decades (including the author's), so it may be well to further consider the adequacy of the sample.

The sample is (by construction) representative in many demographic characteristics but whether it is representative in respect to all, and especially to attitudes and beliefs, is another matter. We can obtain further evidence on this from our survey itself. To illustrate, suppose we were worried that the young might differ from the old in some relevant way, perhaps by being more inclined to outdoor activities, and so more influenced by the weather. Then if our sample under represented young people, that could bias our estimates of temperature's on satisfaction with the climate.

We can check out this possibility in our actual sample by randomly removing some young people and re-calculating our key regressions. Specifically, we split the age distribution near the median, randomly remove 50 % of younger respondents, re-do the key analyses, and compare that to the full sample (details are in the Online Appendix, Section #7). That will show the potential bias, if it actually exists. Results on this are in Appendix Table A6; line #0 has our main results based on the full sample and line #1 the results when half the younger respondents have been removed.

The results suggest that age biases (if they existed at all) would matter little[7]: The model returns virtually the same results as on the main sample even with the induced under sampling.

Similar analyses suggest that it would hardly matter if the internet sample underrepresented the prosperous—or equivalently, overrepresented the poor (Appendix Table A6, line #2). Similarly, the results of the model are robust even when we under sample environmentalists by randomly removing 50 % of them from the sample; this would probably not make any discernable difference (line #3). Nor would it matter if the sample underrepresented the scientifically knowledgeable (line #4). Whether the sample is, or is not, representative with respect to trust in scientists is also virtually irrelevant for our analysis (line #5). Nor does it matter if the sample is, or is not, representative of those more scientifically inclined people who believe in Darwin's theory of evolution (line #6).

In all, we conclude (consistent with the recent technical literature) that potential biases in our internet based sample are unlikely to have any substantial effect on our results.

4.7.2 Reliability of Temperature Measurements

In our analysis, we use average climate figures month-by-month for the eleven years up to 2009. The choice of which years to measure might seem to be problematic. However in practice it hardly matters: winter temperatures in 2009 are correlated fully 0.98 with winter temperatures the year before and, indeed 0.98 with winter temperatures more than a century earlier (Appendix Table A7). The same is true for summer temperatures, correlated 0.98 with temperatures a year before and almost as highly with temperatures more than a century before. In short, temperature differences are very stable over time.

In addition, adjacent half-degree grid areas generally have very similar temperatures (Appendix Table A8). Winter temperatures are correlated around 0.97 and summer temperatures around 0.90. So even if people spend a good deal of time at work some miles away from home, the climate is likely to be similar. But if they spend months far away on vacation in a benign climate, say in Florida, that would matter, likely leading us to somewhat underestimate the impact of climate (see Online Appendix Section #8).

We conclude that both time and geographic imprecision in measuring temperature is likely to be of little consequence to the analysis.

4.7.3 Time and Geographic Imprecision as Measurement Error

Imprecision in time and geography could be thought of as random measurement error. As has long been known, the effect of such random measurement error can easily be estimated and we do so in Appendix Table A6.

If there is little measurement error either in time or geography (line 7) the consequence is that we have slightly *underestimated* the impact of temperature on climate satisfaction by ignoring it. For example each degree Fahrenheit in winter would increase satisfaction with the winter weather by 1.03 points rather than 1.01. If there is more measurement error

[7] This inference assumes that the conditional representativeness of the sample holds, e.g. that the linkage between age and climate satisfaction is approximately the same for cases in the sample and those not in the sample.

(line 8), it would be 1.06. And if there were a large amount of measurement error (line 9) it would be 1.19.

Thus the more measurement error there is in our temperature estimates, the more our results *understate* the impact of temperature on satisfaction with the climate, and so indirectly on well-being. Fortunately however, there is little measurement error in temperature, so the practical implications of all this are small.

5 Conclusion

5.1 Evidence About the Effects of Global Warming on Humans

These results suggest that the effects of a few degrees Celsius of global warming on climate satisfaction for the vast majority of ordinary Americans can be reliably estimated from survey data. The US includes a wide range of temperatures, ranging from frigid Minnesota (15 °F in the winter) to steamy Florida (81° in the summer), more than a dozen of the allegedly "dangerous" 2 °C (3 or 4 °F) steps warmer.

Millions of Americans have long lived in such hot climates, so survey data allow reliable measurement of Americans' reactions to such temperatures rooted in the everyday living experiences of millions of people. For the typical American such an increase in temperature is less than that from moving from Minnesota to Michigan, or from Virginia to North Carolina, or from Arizona to Florida; they are vastly less than moving from Minnesota in the far north to Florida far south.

5.2 Effects are Small and Mixed

The effects of the anticipated 2 °C (3 or 4 °F) of global warming are small—on average equivalent for a typical American to moving just 180 miles south (see the Online Appendix, Section #4). Thus the likely impact of a century of warming is small. But perhaps even more importantly, the net impact is positive.[8] According to my estimates, most Americans would *benefit* from a few degrees of global warming, with gains from warming in the winter outweighing losses from warming in the summer. And if they react to temperature the way Americans so, residents of Canada, Northern Europe, Russia, and other cold nations would also benefit from a few degrees of global warming.

Thus, global warming in the range anticipated over the next century is not in any obvious way "dangerous" for the vast majority of ordinary citizens, despite the assertions to the contrary put forward by the UN, the European Union, the Intergovernmental Panel on Climate Change, and many others.

This implies that prompt and aggressive actions to reduce carbon emissions and so slow global warming may *not* be a good idea. Over the next five to ten decades, there is no great problem for Americans: The changes from current rates of global warming are small and familiar, millions of Americans living in climates that warm or even moving voluntarily to them. Since global warming will likely do more good than harm for most Americans over the next decades, preventing it is a net cost, not a benefit.

[8] It is possible that these effects are somewhat underestimated because we do not have complete climate profiles of where people stay during the year.

However, over two or three centuries, it might be a problem.[9] This lengthy time frame before bad things happen suggests caution: A century of scientific and technological progress may bring new possibilities (compare what we could understand and do in 1900 with what we know and can do now).

5.3 Implications for Climate Mitigation Policies

Our results also suggest that the usual policies under consideration for mitigating global warming by restricting increases in CO_2, including those adopted by the 2015 Paris climate accord, are too broad to be optimal. The difficulty is that they would reduce warming both in winter and in summer, and both in the north and in the south. For the US, these policies would on balance harm northerners and benefit southerners. The ethical and political difficulties of pursuing policies that would harm the majority of the population are apparent.

Moreover, financially compensating northerners to offset their losses from this climate mitigation policy would be expensive, requiring an annual subsidy from the south of perhaps 1–4 % of southern GDP.

Since only southerners on balance benefit from controlling global warming in this way, they should presumably also bear the costs of mitigation policies. Mitigation costs might be in the neighborhood of a further 2–3 % of southern GDP, adding to the heavy financial burden for the south. Paying such a heavy price would seem unlikely to appeal to southern voters.

Alternative geo-engineering policies (National Academy of Sciences 2015; Wigley 2006) might be more beneficial and so should be considered. For example, policies aimed at controlling global warming year-round but only in southern latitudes (rather like the Mount Pinatubo eruption did naturally in 1991–1993) could benefit the south while not harming the north. Even more beneficial would be policies which could control global warming only in the summer, leaving both north and south to benefit from warming in the winter.

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[9] Averaged over the US as a whole, our preliminary estimates suggest that the gain from global warming peaks around a century from now; drops to nothing around a century and a half from now, and declines to a substantial loss three centuries on. This assumes a global warming rate of around 4 °F per century.

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