Cold Facts on Climate Change

Dr Emily Shuckburgh, British Antarctic Survey

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This apparently unremarkable stone is in fact the oldest object in the British Museum. It is the first ever technology invention – a cutting tool made by early humans in Africa nearly two million years ago. The ability to create and use tools is, of course, the skill that sets us apart from other animals. Hence it marks the very start of the journey of humankind.

But, at no point on that journey have our forebears lived in a world with atmospheric carbon dioxide as high as it is today. To find equivalent CO_2 levels you have to travel back at least a million years more: today's atmosphere is unprecedented throughout human history, pre-history and beyond.

Ice cores extracted from the Antarctic ice sheet themselves provide a unique museum of the past. As snow fell, over time it piled up, layer-upon-layer, year-after-year, trapping within it tiny bubbles of air. By drilling down through the ice to recover these ancient, frozen bubbles, samples of the past atmosphere can be analysed.

This photograph shows a slice through an ice core containing such bubbles. The data [*Lüthi et al.*, 2008] reveals how the amount of atmospheric CO_2 varied over the past million years – fluctuating between about 180 and 280 parts per million – as the orbit of the Earth about the Sun slowly changed, moving us in and out of ice ages. An extremely rapid, post-industrial revolution spike has put the value today at an incredible 405 parts per million. This recent change lies far outside the natural cycle.

So, what has driven such dramatic change?

Since 1850, global population has increased six-fold. Society in many countries of the world has been transformed, as indicated by the hundred-fold increase in global GDP. Much of that transformation has been driven by industrialisation, powered primarily by the burning of fossil fuels for energy. And we have transformed the land surface, cutting down forests to make way for settlements and farming. These activities produce carbon dioxide.

Earth's atmosphere forms a layer as thin in relative terms as the skin of an apple. It should come as no surprise, therefore, that the effects of this explosion in human activities can be observed in changes to the composition of our air and in particular in the amount of carbon dioxide it contains.

As a so-called "greenhouse gas" one would expect an increase in carbon dioxide to be accompanied by an increase in temperature of the Earth's surface.

And, indeed, the temperature, averaged over the surface of the land and oceans, has increased by about 1 degree Celsius since the late nineteenth century. The past three years rank as the warmest on record, with the decade being on-course to be the forth in a row of record-breaking warmth.

As the ocean waters have warmed they have expanded in volume and together with melting ice from glaciers and the polar ice sheets, this has raised sea levels.

But these global average numbers mask important regional differences. Here is a map of the changes in temperature over the past hundred years, wherever there is sufficient data.

The Arctic has seen the greatest warming, impacting daily life for those who live there. When I visited the Canadian Arctic a few years ago, I was told that "It is as if a friend that we could trust is suddenly acting strangely". The extent of Arctic sea ice is plummeting. Today, September sea ice coverage is

less than two-thirds of that at the end of the twentieth century. That's a drop equivalent to the area of the United Kingdom, Ireland, France, Spain, Germany and Italy put together, in just two decades.

The population-weighted average temperature, which accounts for where people live, has been increasing at more than twice the rate of the global-average [*Watts et al.*].

Moreover, a modest increase in average temperature can translate to a large increase in the risk of extreme heat. Just an additional 0.5 degrees Celsius in global-average temperature could lead to a doubling of the number of extremely hot days in Beijing, for example.

Extreme heat, especially when combined with high humidity, can prove deadly for vulnerable people. It is estimated that already today 30% of the world's population experience such potentially deadly conditions each year [*Mora et al.*, 2017].

Around the world, temperature and rainfall records are being broken again and again as what were once extreme conditions are starting to become normal. Evaluation of recent extreme weather events has revealed numerous cases – highlighted in orange here – where the risk of occurrence has increased as a consequence of the climate change we have already seen. The impacts of climate change are already being felt here and now. This raises questions about how to adapt and about liability.

Analysis indicates that the kind of heavy downpours responsible for some of the terrible flooding of recent years in the UK – such as in 2014 – have become more likely because of climate change [*Schaller et al.*, 2016]. In part, this is because a warmer atmosphere holds more water. The result has been billions of pounds worth of damage.

Hurricanes provide a stark reminder of the power of nature to wreak devastation on even the most advanced of our societies. Last year, hurricanes Harvey, Irma and Maria battered the Caribbean and southern United States, resulting in tragic loss of life and hundreds of billions of dollars of damage. The mechanics of tropical cyclones and how they interact with our changing climate is extremely complex, however, it is clear that increases in heavy rainfall, combined with sea level rise and can exacerbate the flooding from hurricane-induced storm surges [*Oldenborgh et al.*, 2017; *Shuckburgh et al.*, 2017].

In 2016, a severe drought in Southern Africa resulted in millions of people in need of humanitarian assistance in countries such as Malawi. The other side of the world, Southeast Asia experienced record-breaking heat, with temperatures in Thailand soaring above 40 degrees Celsius. In both cases it has been determined that climate change exacerbated the effects of El Niño [*Funk et al.*, 2018; *Thirumalai et al.*, 2017]. The risks of these two far-away events were correlated. The systemic risks from such correlated events can easily be underestimated.

Another set of risks that can easily be underestimated are tipping points and black swan events.

Climate disruption is causing shifts in the conditions that sustain many wildlife species, including Emperor penguins, leatherback turtles and beluga whales. For those species that are already rare, declining or very specialize, further climate change may push them beyond their tipping point to extinction, with knock-on impacts throughout the food-web.

In some cases, a tipping point may still be crossed even if temperature increase is limited to that agreed in Paris – i.e. to keep temperatures well below 2 degrees Celsius increase from pre-industrial times with an ambition to limit the increase to 1.5 degrees.

Coral reefs are vulnerable to warming seas and to ocean acidification caused by CO_2 emissions. Comparable rates of acidification were last seen 250 million years ago, when the biggest mass extinction of species took place. Even future CO2 emissions that are consistent with the Paris

Agreement pose an existential threat to the coral reefs of the world. This is not only an environmental threat – healthy coral reefs support commercial and subsistence fisheries, jobs and businesses through tourism and recreation, and contribute billions of dollars each year to the global economy.

Turning to possible black swan events, we know that dramatic and rapid regional change in temperature can occur: in the North Atlantic, there are more than 20 examples of this in the last 100 thousand years. As can be seen from this Greenland ice core record, at the end of the last ice age there were numerous abrupt swings in temperature of up to 10 degrees Celsius in as little as a decade [*Buizert et al.*, 2014]. This is a fundamental non-linear characteristic of the Earth System. It has happened in the past; it could happen in the future.

Recent millennia have been characterised by unusual stability. But it is clear that as temperatures increase, the risk of triggering black swan events increases. Again, for some systems this is a concern even within the Paris Agreement limits.

Modest temperature rise may threaten the vast ice sheets covering Greenland & West Antarctica. There is evidence that 400 thousand years ago – when temperatures were perhaps only slightly warmer than today – a large fraction of Greenland was ice-free and sea levels rose slowly over centuries to be more than six metres higher than they are now. Melting has been seen across more than half the Greenland ice sheet during some recent summers, emphasising the current threat.

The West Antarctic ice sheet is grounded below sea level and vulnerable to warm ocean waters encroaching beneath it. This is already happening [*Konrad et al.*, 2018] and there is evidence that key glaciers that are critical to the ice sheet's stability may already be in irreversible retreat.

Such changes to the polar ice sheets would lead to seas eventually rising by metres, transforming global coastlines.

Here is a map of the world's cities, with projections for their population growth over the next two decades. The majority are in coastal regions. Just a few tens of centimetres of sea level rise, especially in combination with heavy rain and storm surges, could destroy infrastructure and displace hundreds of millions of people; a black swan event involving the polar ice sheets would be catastrophic. Are these risks being fully accounted for in development planning or scenario analysis?

Let me now turn to the scale and urgency of the challenge of responding to climate change in a way that meets the Paris Agreement objectives.

The amount of carbon dioxide that can be released before dangerous levels of warming are reached can be seen as a carbon budget. The entire budget to stay below 2°C of warming is about 3,000 billion tonnes of CO_2, but it is estimated that our emissions since 1870 already amount to over 2,000 billion tonnes. At the present rate of emissions, we are on course to exhaust the budget for 2 degrees within the next twenty to thirty years, with the budget for 1.5 degrees being exhausted even sooner.

This graph shows the current trajectory of CO_2 emissions in black and a set of pathways for future emissions in blue that are broadly consistent with the Paris Agreement. There is no escaping: transformation change is required, starting today.

I started this presentation with the object, invented by early Humans, that led us as a species to becoming the dominating influence on Earth. If our society is to thrive and prosper long into the future, we must use our ingenuity to find ways of living in harmony with the world that sustains us. Surely each of us must take responsibility, individually and collectively, because future generations will have to live with the consequences of the choices we make today.

The cold fact is: we only have one Earth.

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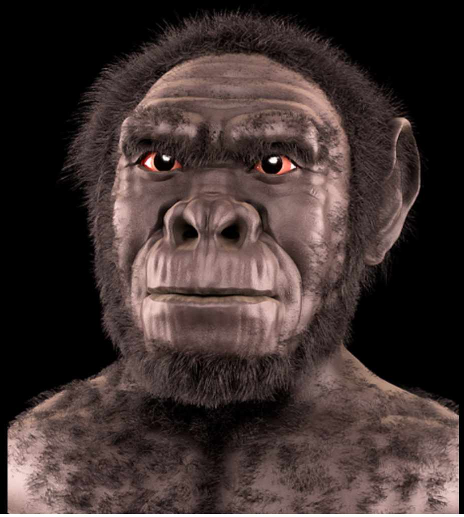
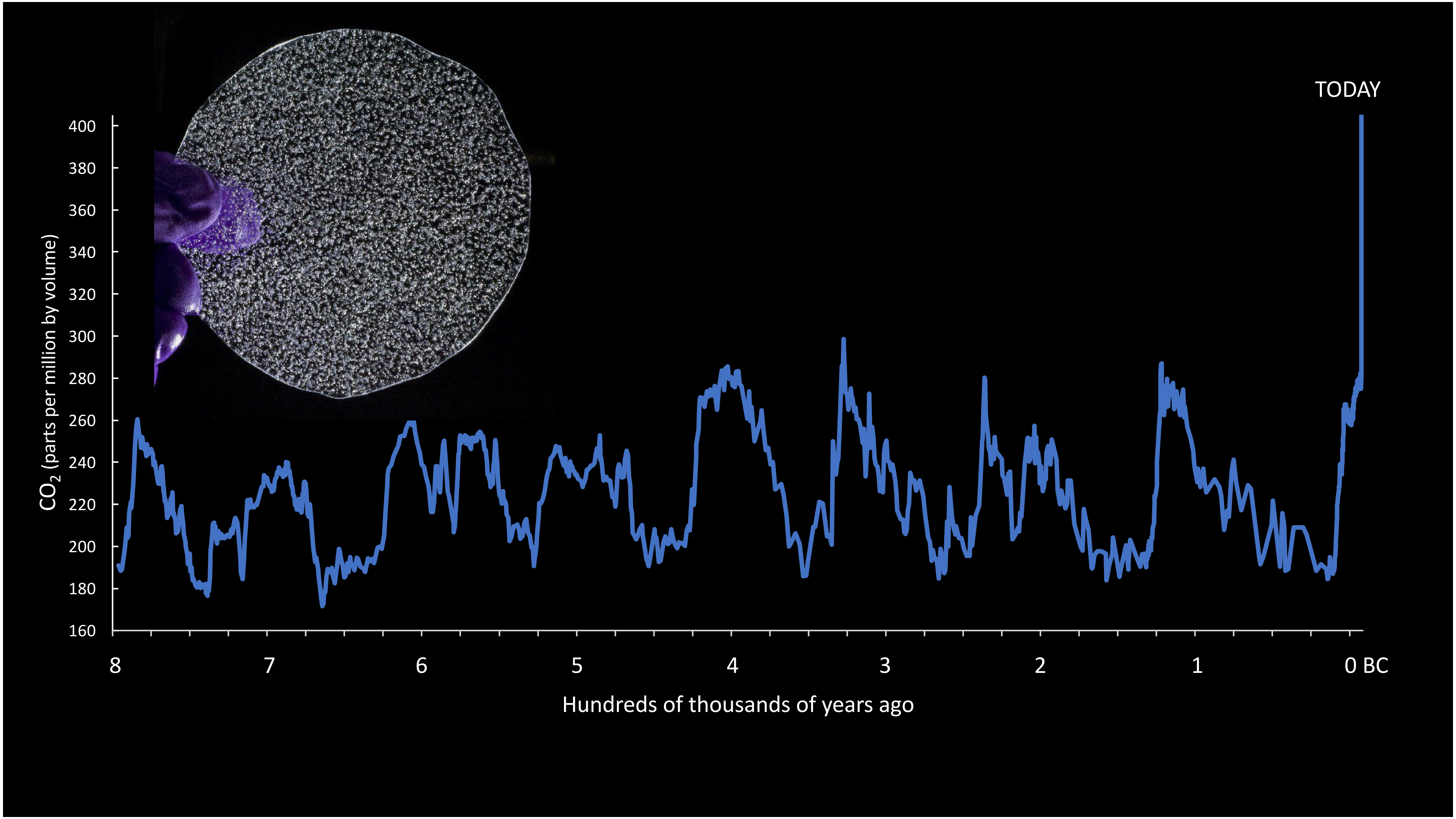
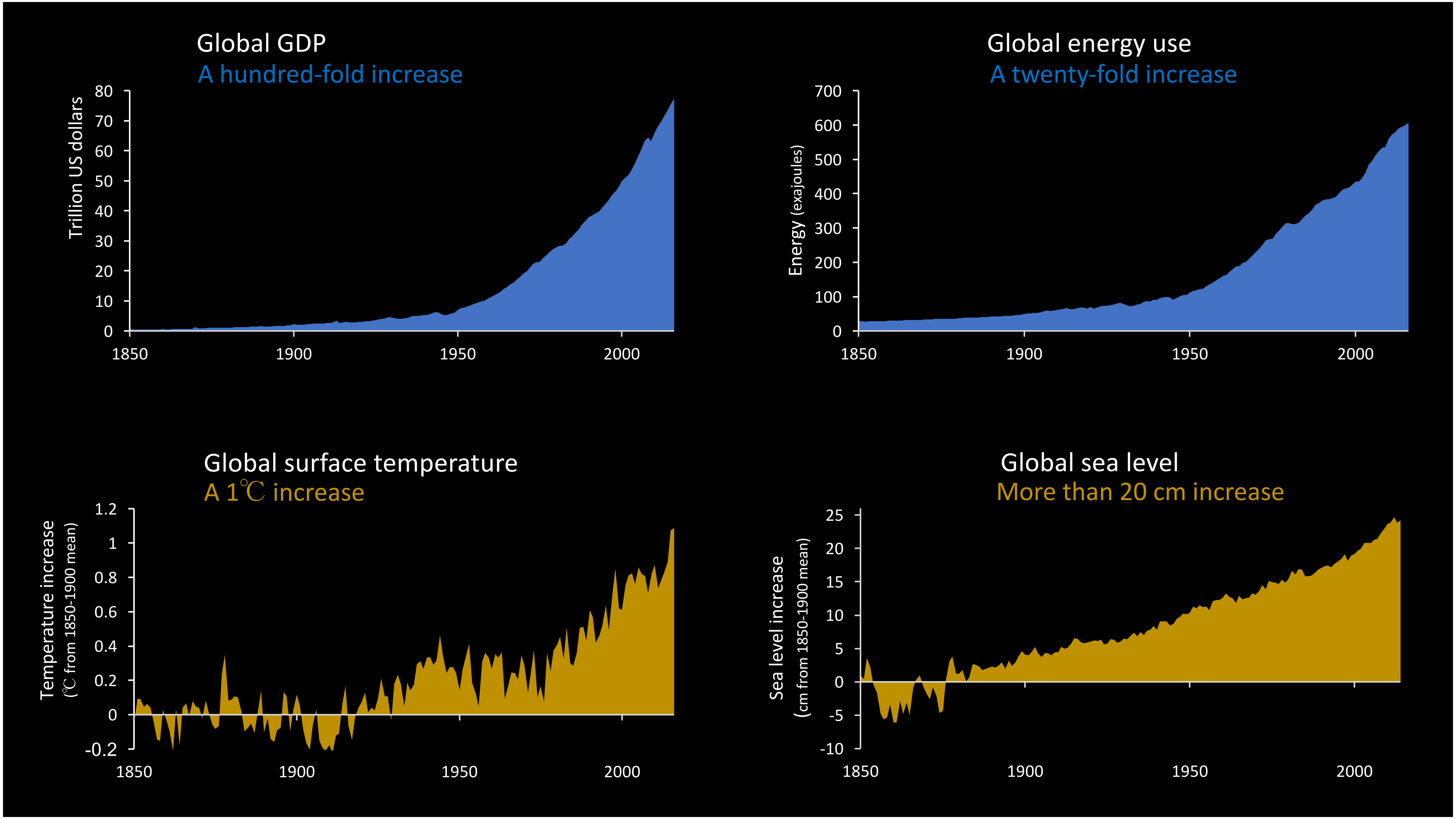
The Cold Facts on Climate Change

Olduvai stone chopping tool
1.8 million years old

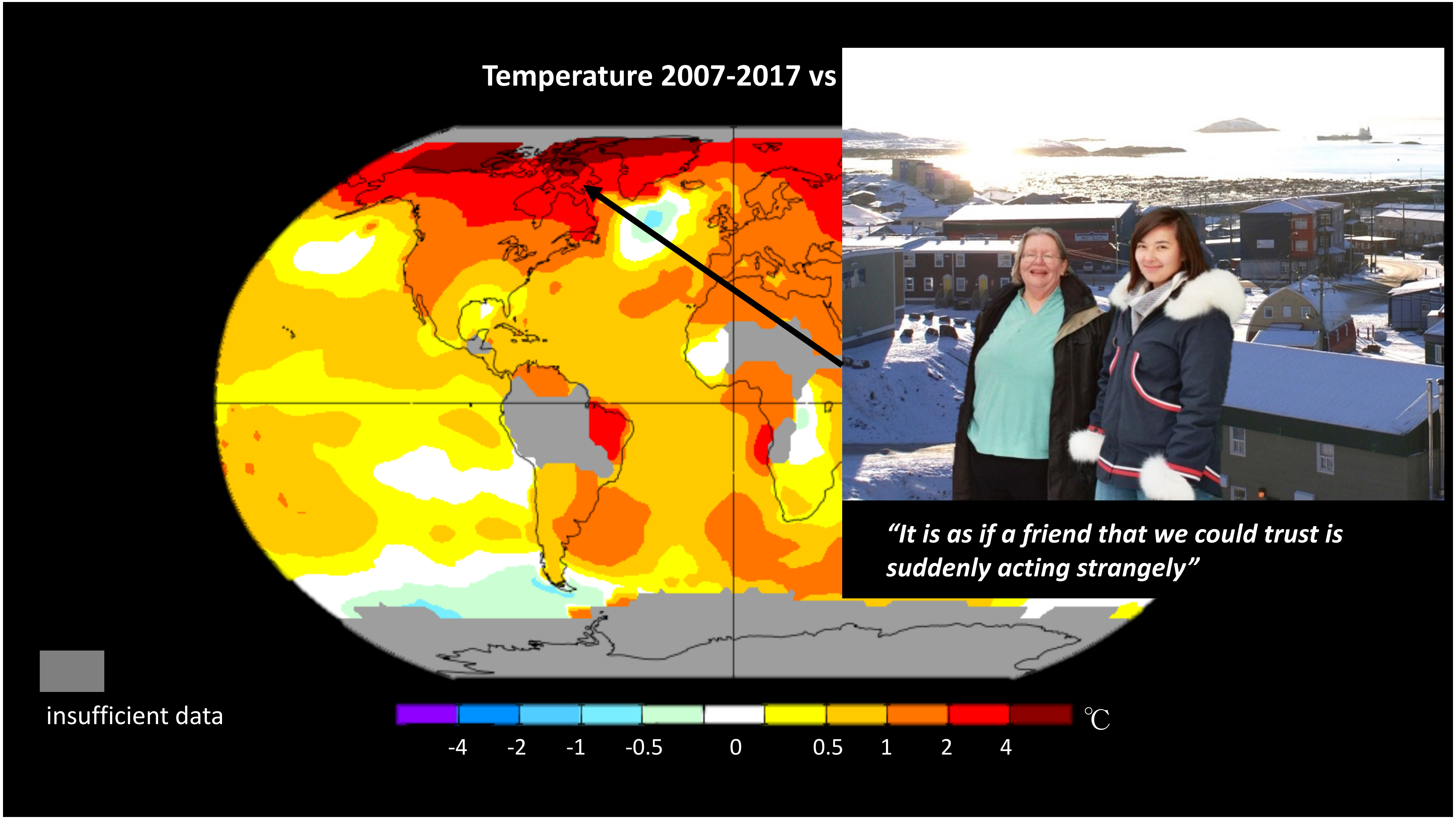


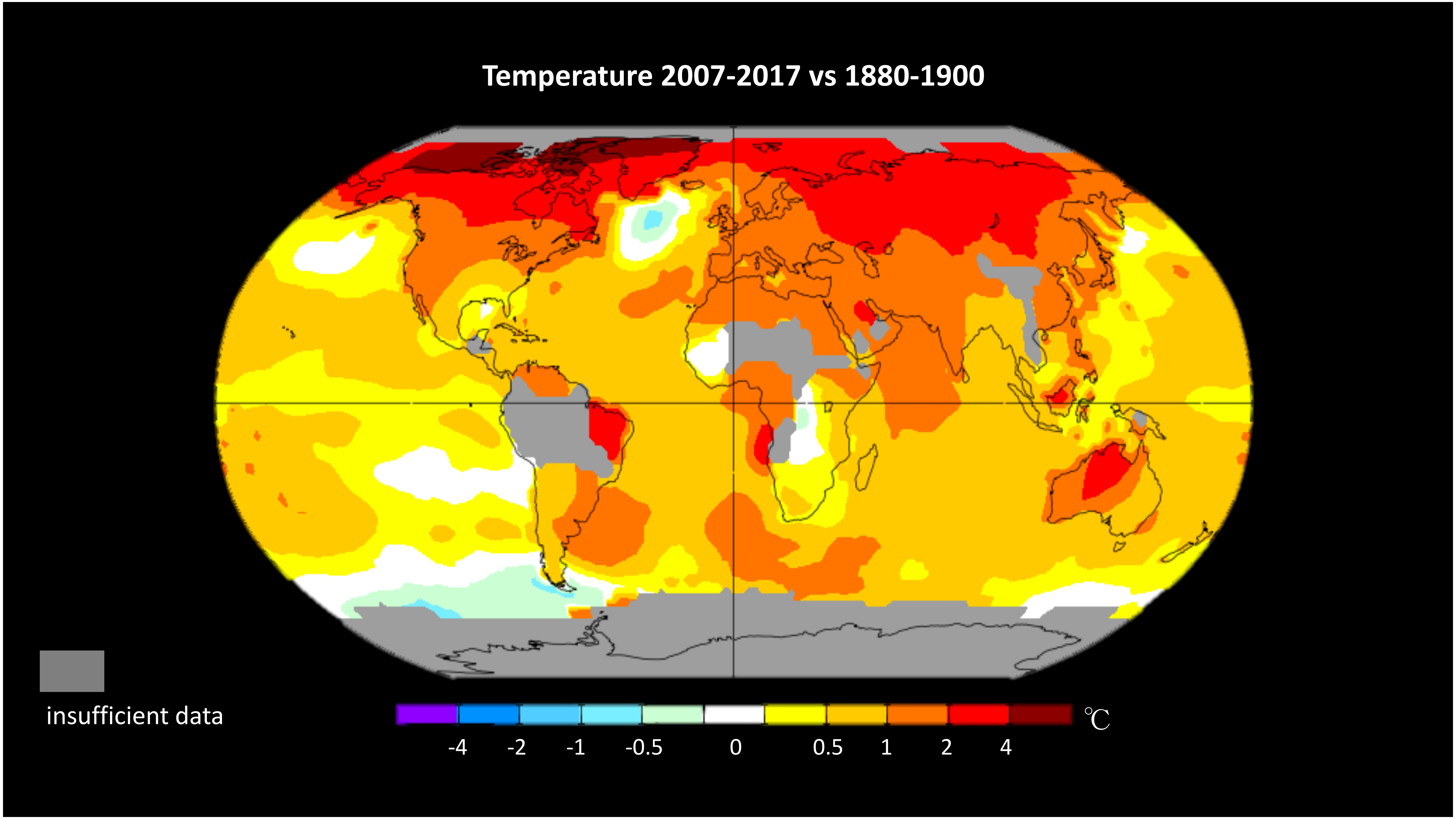


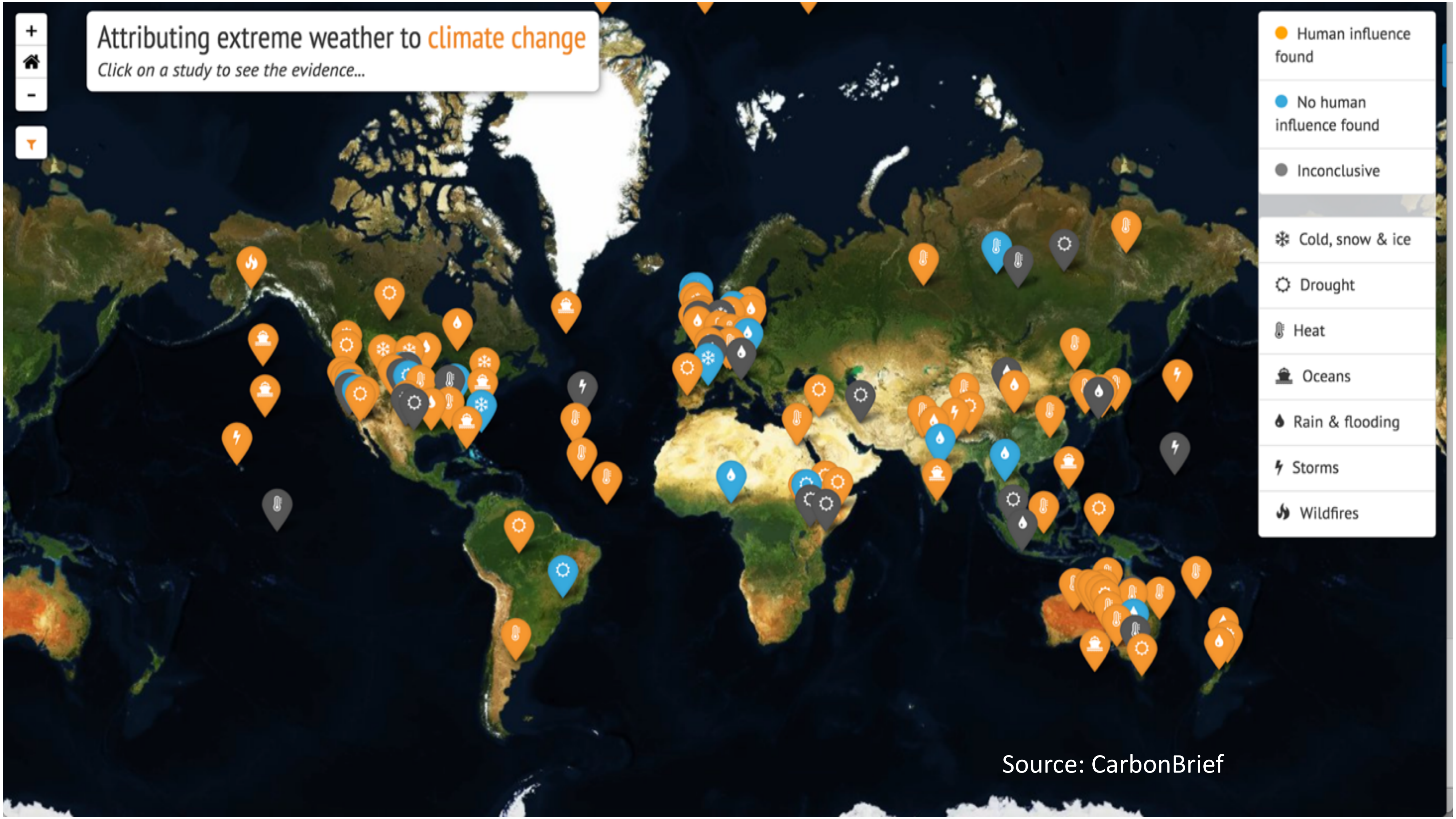
TODAY
400
380
360
340
320
300
280
260
240
220
200
180
160
CO2 (parts per million by volume)
8
7
6
5
4
3
2
1
0 BC
Hundreds of thousands of years ago



Global GDP
A hundred-fold increase
Trillion US dollars
80
70
60
50
40
30
20
10
0
1850
1900
1950
2000
Global energy use
A twenty-fold increase
Energy (exajoules)
700
600
500
400
300
200
100
0
1850
1900
1950
2000
Global surface temperature
A 1℃ increase
Temperature increase
(℃ from 1850-1900 mean)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
1850
1900
1950
2000
Global sea level
More than 20 cm increase
Sea level increase
(cm from 1850-1900 mean)
25
20
15
10
5
0
-5
-10
1850
1900
1950
2000


Temperature 2007-2017 vs
“It is as if a friend that we could trust is suddenly acting strangely”
insufficient data
-4
-2
-1
-0.5
0
0.5
1
2
4
℃


Temperature 2007-2017 vs 1880-1900
insufficient data
-4
-2
-1
-0.5
0
0.5
1
2
4
℃


Attributing extreme weather to climate change
Click on a study to see the evidence...
Human influence found
No human influence found
Inconclusive
Cold, snow & ice
Drought
Heat
Oceans
Rain & flooding
Storms
Wildfires
Source: CarbonBrief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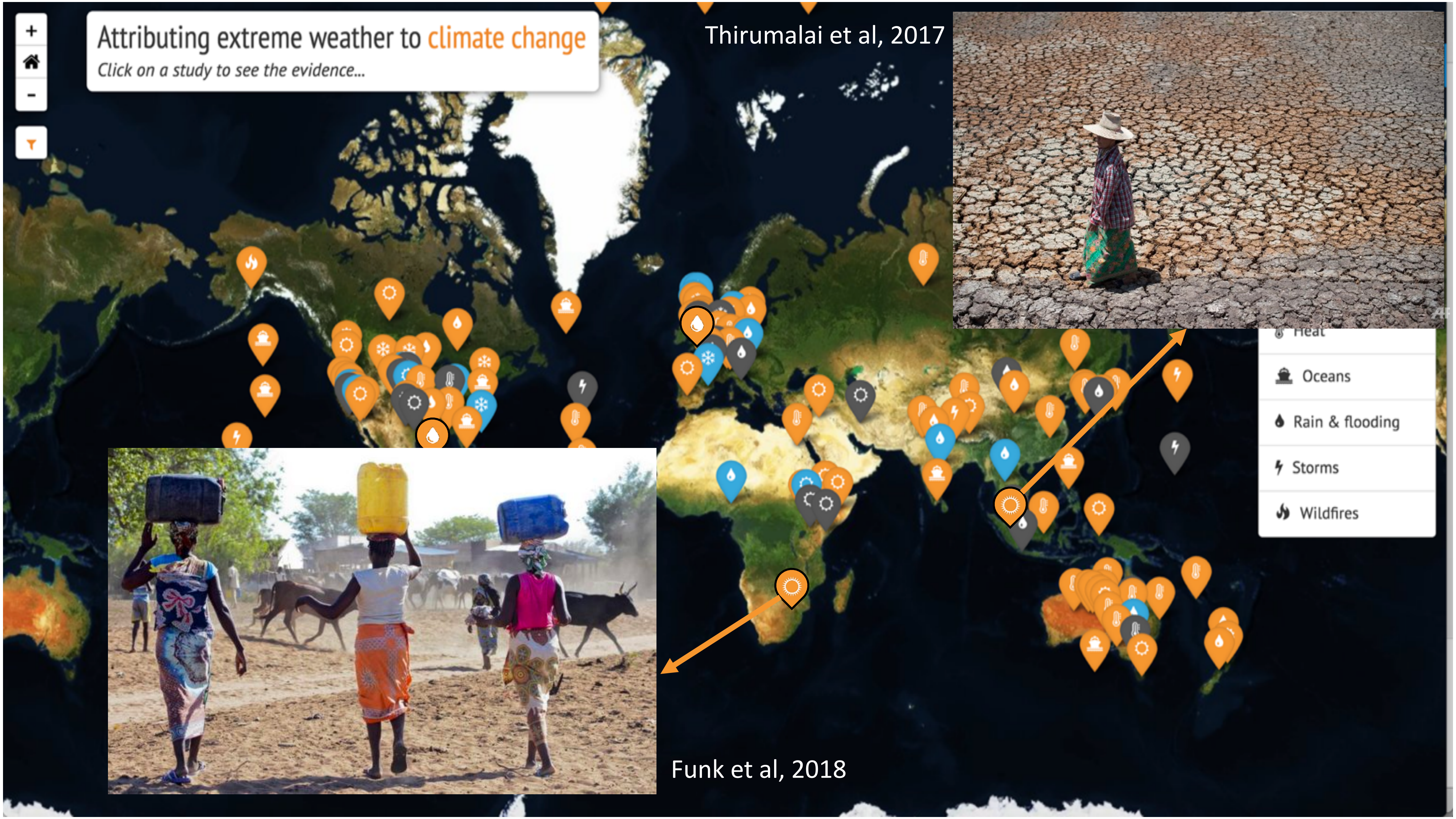
Storms
Wildfires
RB FRS
© PA
Schaller et al, 2016

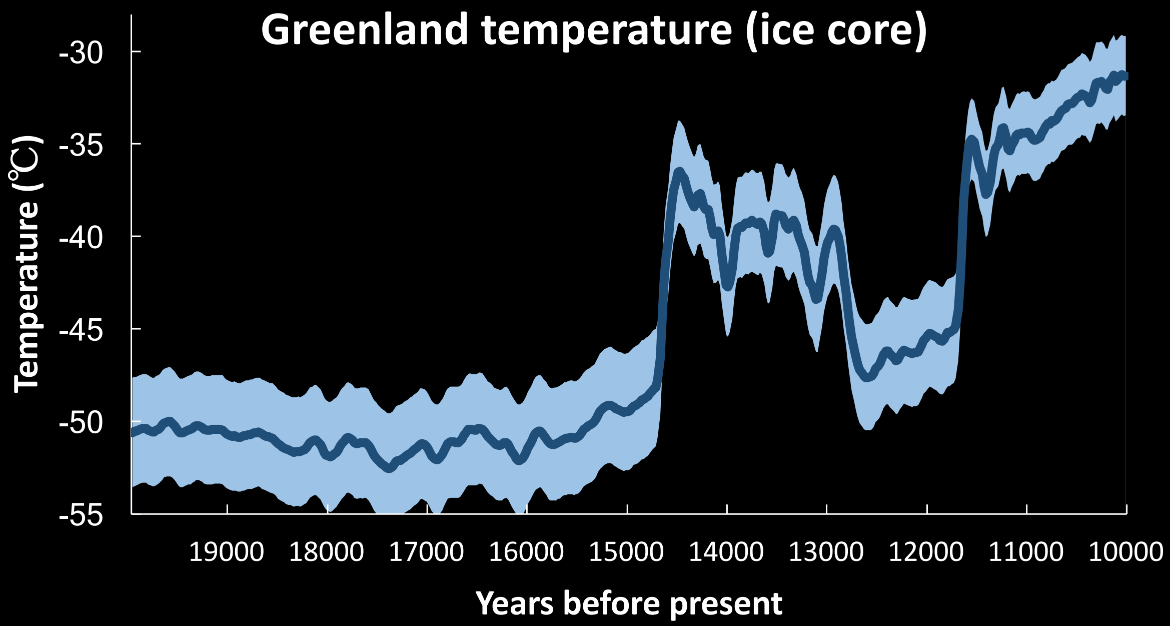
Van Oldenborgh et al, 2017

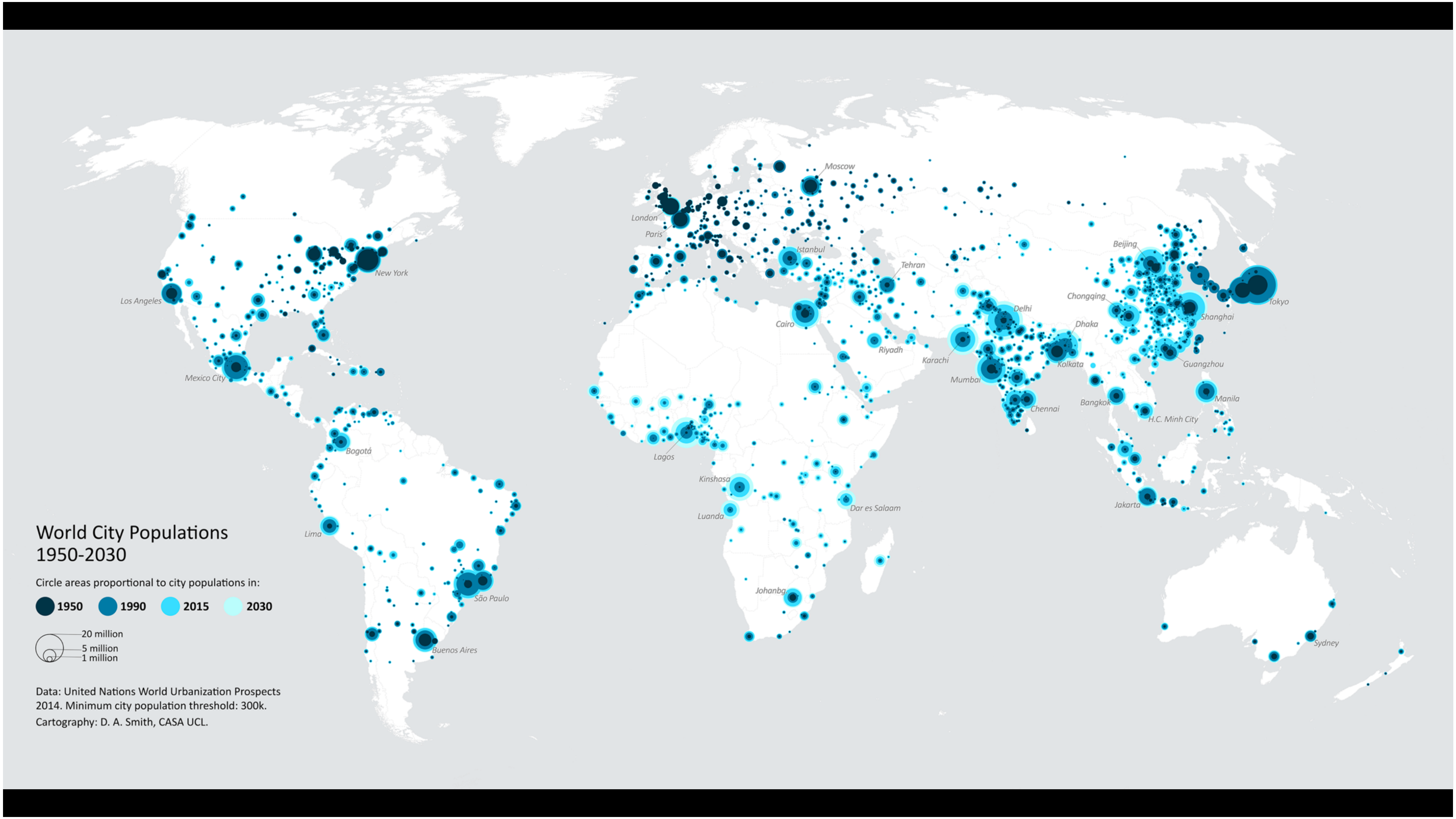


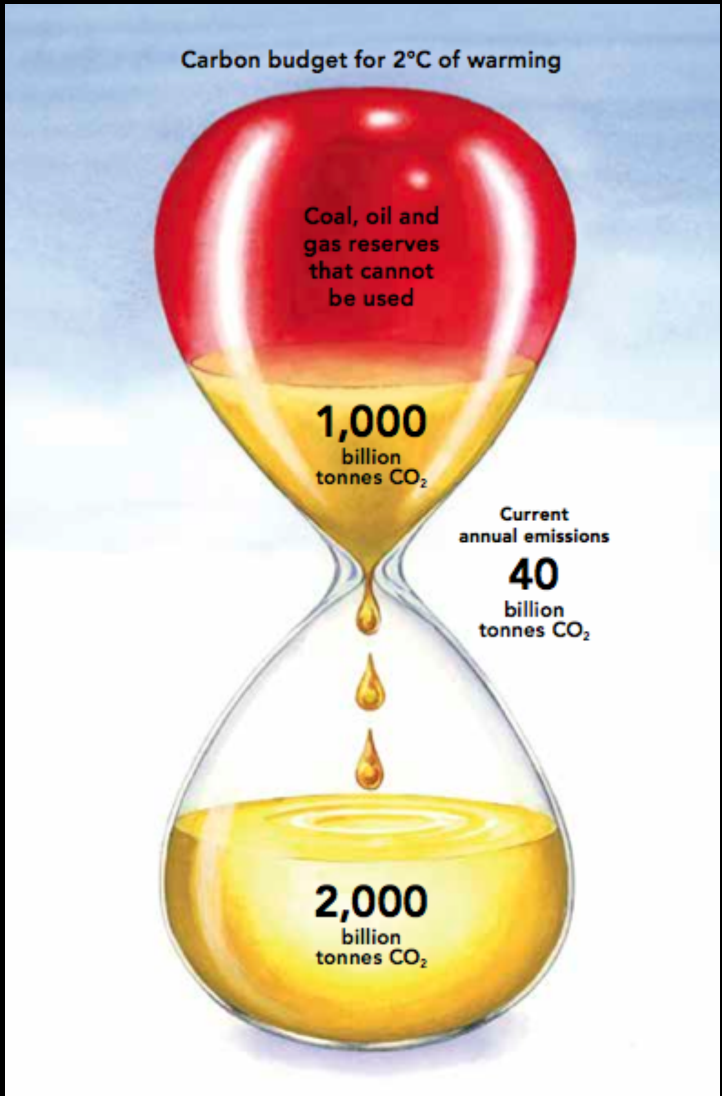
Attributing extreme weather to climate change
Click on a study to see the evidence...
Thirumalai et al, 2017
Heat
Oceans
Rain & flooding
Storms
Wildfires
Funk et al, 2018

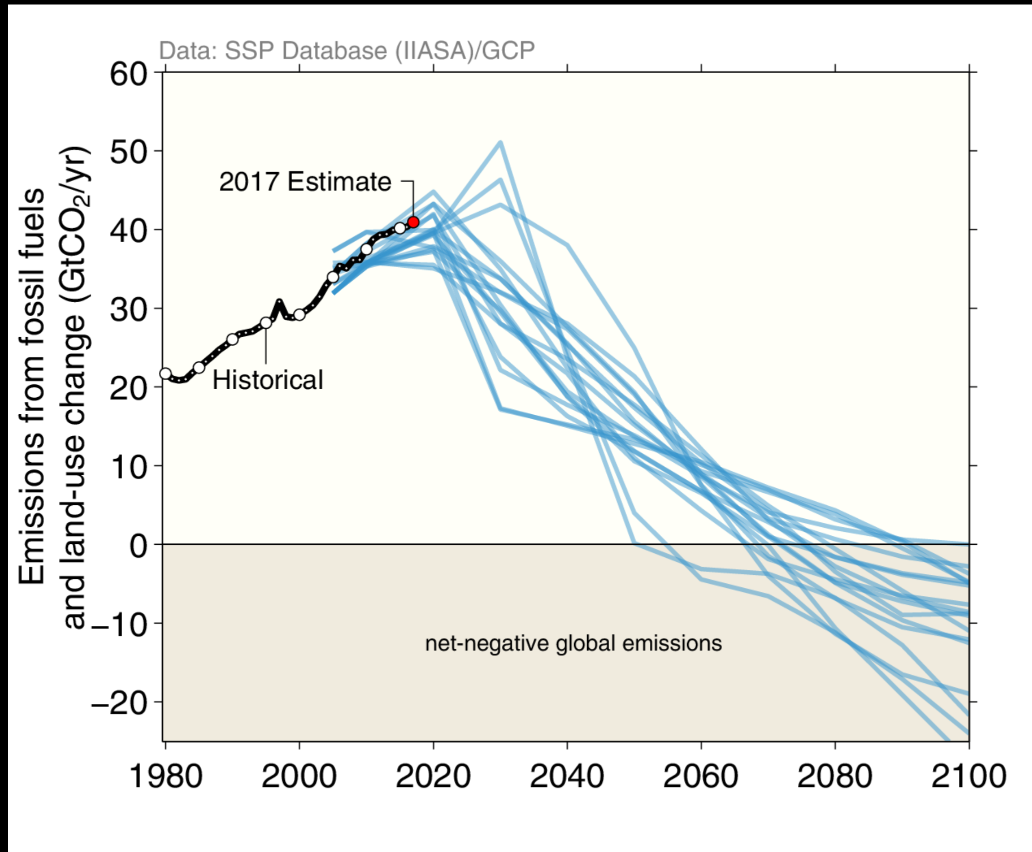
Credit: Pete Bucktrout, BAS

Non-linear characteristics of the Earth System




World City Populations
1950-2030
Circle areas proportional to city populations in:
1950
1990
2015
2030
20 million
5 million
1 million
Data: United Nations World Urbanization Prospects 2014. Minimum city population threshold: 300k.
Cartography: D. A. Smith, CASA UCL.
Los Angeles
New York
Mexico City
Bogotá
Lima
São Paulo
Buenos Aires
London
Paris
Moscow
Istanbul
Tehran
Cairo
Riyadh
Karachi
Delhi
Mumbai
Dhaka
Kolkata
Chennai
Bangkok
H.C. Minh City
Jakarta
Beijing
Chongqing
Shanghai
Guangzhou
Manila
Tokyo
Sydney
Lagos
Kinshasa
Luanda
Dar es Salaam
Johanbg





Budget for 2°C exhausted within 20-30 years; that for 1.5°C even sooner

Credit: NASA