ALSO BY MARK LYNAS

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Six Degrees of Climate Emergency

Mark Lynas

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province, taking one of the most carbon-intensive and environmentally destructive source of liquid fossil fuels offline, at least for a few days. A year later it was the turn of neighbouring British Columbia, which saw a record 1.5 million hectares (an area three-quarters the size of Wales) burned and 65,000 people displaced during the most extreme fire season on record. A study by Canadian scientists concluded that the 2017 disaster was made two to four times more likely by climate change, which also increased the area burned by a factor of seven to eleven.

Wildfires everywhere seem to be increasing both in frequency and destructive power. The year 2017 saw extensive and severe fires in Chile, the Mediterranean, Russia, the US, Canada and even Greenland, where fires were spotted burning in the tundra along the western coast. Across the world as a whole, researchers have found that the average fire season has lengthened by nearly a fifth, with half of the Earth's entire vegetated surface area seeing an increase in fire weather conditions during the last fifteen years. As the unfortunate residents of the Californian town of Paradise found out in the 2018 disaster, wildfire can strike with unprecedented ferocity and deadly speed – at one point the Camp Fire was spreading at the rate of a football field every single second.

In the first *Six Degrees* I used the image of Dante's Inferno, describing each degree rise in temperature as a descent into one of the successive circles of hell. This was meant to be just a metaphor. But from California to Canada, as smoke rises, it seems that we are entering the Inferno for real.

Heat refugees

Everywhere temperatures are rising, as ever-higher concentrations of greenhouse gases in the atmosphere trap heat at the Earth's surface. When I was beginning to write about climate change in the early 2000s, extremely hot summers might have been expected to occur

twice a century. Now they are expected twice a decade. The shift clear, even in temperate England where I live, with a two- to threefc increase in heatwaves since the pre-industrial period and week-lo extreme heat events seemingly getting more intense each year. On July 2019 a new UK all-time high-temperature record of 38.7°C w set at Cambridge University Botanic Garden, beating the previc record – set in 2003 – of 38.5°C. This seemed pleasantly cool French standards, however. A month earlier, in June 2019, wh much of western Europe baked in an unprecedented heatwa thermometers in the southern French town of Gallargues-Montueux read a stunning 45.9°C, setting a new all-time record. later study of the 2019 French heatwave found that it had been ma five times more likely because of climate change.

This is what one degree of global warming looks like. Just t previous year, in the summer of 2018, almost the entirety of t Northern Hemisphere experienced drastically elevated temperatur with extreme heat in Europe, North America, Asia and North Afri In Oman, the coastal city of Quriyat experienced a 24-hour temp ature that never dropped below 42.6°C, most likely setting a recc for the highest minimum night-time temperature ever observed Earth. In the Algerian Sahara, a high of 51.3°C was measured or July, probably a new all-time record for the continent of Africa. one point temperatures were as hot in Arctic Scandinavia as th were in southern Spain. Japan, too, set a new temperature reco with the city of Kumagaya, 65 kilometres from Tokyo, seeing 41.1° All around the world, records tumbled like dominoes.

A June 2019 study concluded that it was 'virtually certain' that t 2018 Northern Hemisphere heatwave – which affected a fifth of t populated and agricultural areas of the northern mid-latitud concurrently – could not have happened in the absence of huma caused climate change. 'Virtually certain' means 99–100% probabil in IPCC parlance; it is extraordinarily rare to have this level of cor dence declared in any scientific finding. The authors also stated tl

heatwaves like that of 2018 were 'unprecedented prior to 2010'. The human fingerprint has become very clear in modern-day temperature rises – one modelling study suggests that there was only a one-in-a-million chance that the high global temperatures recorded in 2014, 2015 and 2016 could have come about through natural variability.

High temperatures may not seem as immediately dramatic as floods or storms, but they are just as deadly; more than 70,000 additional deaths were recorded in Europe during the extreme heat of August 2003, with those losing their lives primarily being the elderly and most vulnerable. According to a 2018 health review published in the leading medical journal *The Lancet*, vulnerability to extremes of heat has risen steadily since 1990 in every region, with 157 million more people exposed to heatwave events in 2017 compared with 2000. The death tolls for the 2018 and 2019 heatwaves have not yet been calculated, but they will likely be in the many thousands. Preliminary estimates are worrying: in northerly Sweden, for example, the heatwave of 2018 was associated with 635 excess deaths. In Japan, medical authorities reported more than 34,000 cases of heat-related emergency transportation during the 2018 heatwave, with nearly 100 people found clinically dead upon the arrival of the emergency medical services.

But there is another, more subtle, way in which heat kills people. Rising temperatures increase the risk of drought, and in less fortunate parts of the world drought can lead to food shortages and a loss of livelihoods, which exacerbates conflict. Drought risk is particularly increasing in the sub-tropics due to the widening of the tropical belt, a long-predicted and now observed feature of a warming planet. The Sahara is expanding both northwards and southwards, threatening the livelihoods of tens of millions more people living in the increasingly arid zones of West and North Africa. Across the Mediterranean in southern Europe, scientists have calculated that it is more than 95% likely that climate change has increased the probability of drought years. The Levant region – Palestine, Israel, Lebanon and

Syria – suffered 15 years of drought between 1998 and 2012, agair due to the expanding zones of sub-tropical dry air consistent wit global warming. Scientists have studied tree ring data from the regio to try to estimate how often these kinds of droughts occurred in th past; they found that the recent decade was probably drier than an comparable period over the last 900 years.

The impacts on the inhabitants of the region have been utterl devastating. During the worst part of the drought after 2009, 1. million people were displaced from agricultural areas in Syria an forced to migrate to cities as harvests failed and livestock herds die from thirst and starvation. This led to a doubling of food prices an a dramatic increase in childhood undernutrition. 'The rapidly grow ing urban peripheries of Syria, marked by illegal settlements, over crowding, poor infrastructure, unemployment, and crime, wer neglected by the Assad government and became the heart of th developing unrest', reported an assessment for *PNAS*, with this unre later becoming a full-scale civil war. The failure of the Assad dictato ship to initially address the agricultural crisis, and the dire condition suffered by millions of displaced people and refugees who were livin in terrible conditions on the edges of cities, were therefore importa factors in the Syrian uprising that began in 2011. This obviously do not mean that Assad's decision to drop barrel bombs and poison g on civilian populations can be blamed on climate change. The Syria regime's war crimes remain its own responsibility, albeit shared wit the Russian and Iranian governments that propped up the bloo soaked Syrian dictator.

However, there is evidence that climatic calamities do correla with armed conflict, at least in the most ethnically divided countrie The authors of a recent study note that 'about 23% of confli outbreaks in ethnically highly fractionalized countries robustly coi cide with climatic calamities'. This is not a simple cause-and-effe relationship, but it does seem like the disruptions brought on b climate heating play out in ethnically divided countries 'in

particularly tragic way'. The ensuing conflicts can have impacts far afield, as – in the case of Syria – millions of refugees flee to neighbouring countries.

The moral challenge of climate change is writ large in the fate of refugees. Given that the richer countries have done most to cause global warming, I would argue that they have an especially strong responsibility to assist people who are suffering the impacts of drought-related conflicts like that in Syria. One of the proudest moments of my life was speaking to a crowd of 2,000 people at a 'refugees welcome' rally a small group of us organised in 2015 at a few days' notice in Oxford. The spark that made us act, and prompted so many people to come along to show their support, was the photograph of the Syrian toddler Alan Kurdi washed up drowned on a beach in Turkey. Kurdi was a victim of climate, conflict – and callousness: that of European leaders who closed their nations' borders and refused aid to millions of people in distress, forcing the young boy's family to attempt a dangerous night-time crossing to Greece in an open boat. We are all human, and as climate impacts accelerate in decades to come, maybe one day Western readers of this book will be the refugees. I hope – and it might be a forlorn hope – that we can summon up the will to address future climate impacts in a spirit of mutual solidarity rather than division. Otherwise I fear there will be many more Alan Kurdis washed up on the world's beaches in the years ahead.

Against nature

It is not only humans who are suffering from the impacts of ongoing climate breakdown. Global heating is now an increasing factor in wildlife declines and even the outright extinction of species as plants and animals lose their habitat due to shifting climate zones. According to the IPCC, 'the geographical ranges of many terrestrial and freshwater plant and animal species have moved over the last several

decades in response to warming: approximately 17 km poleward and 11 m up in altitude per decade.' In terms of annual distance, that corresponds to 1.7 kilometres per year – or nearly five metres per day – that species are having to shift their ranges to keep up with rising temperatures in our one-degree world. And this is only an average: in many places climate zones are moving much faster.

It may be obvious that plants, which are generally rooted to the ground, will have difficulty keeping up with this increasing 'climate velocity'. But even those species with wings are lagging behind. One recent study found that birds and butterflies were running up 'climatic debts' by lagging 212 and 135 kilometres respectively behind the ongoing speed of climate change. When they do move long distances butterflies may find themselves stranded in a suitable climate but without food to raise their caterpillars, if their larval host plants are slower to disperse into new areas. Birds which then depend on absent insect larvae to feed their chicks may find their own offspring facing starvation. One example is Baird's sandpiper, a species whose migration into the high Arctic used to be timed exactly to coincide with the peak of insect abundance during the short tundra summer. Insects are now emerging earlier as springtimes advance, meaning less food later in the season for hungry sandpiper chicks. Another migratory bird is the pied flycatcher, whose populations have crashed in Holland as the bird arrives from Africa too late to exploit the peak supply of caterpillars. Research has also found an increasing mismatch between the supply of caterpillars in UK oak forests and the demands from nestlings of birds such as blue tits, great tits and pied flycatchers. Such is the reality of unravelling food webs across the world as temperatures rise.

Animals and plants in mountain areas are particularly vulnerable because they are finding themselves squeezed uphill in contracting areas towards mountain summits as temperatures rise. Dubbed the 'escalator to extinction', this topographical effect is particularly worrying among mountains in the tropics, because species would have t

had buildings pitched higgledy-piggledy in different directions, while roads and paths undulated as the ground beneath them sank away. One of my expert guides in investigating this phenomenon was scientist Vladimir Romanovksy from the University of Alaska, Fairbanks, whom I joined on an expedition to study ice lenses wedged in exposed sections of thawing permafrost.

Romanovsky has kept up his interest in the field. He was co-author of a 2018 paper in the journal *Nature Communications* that calculated nearly four million people and 70% of current built infrastructure is located on permafrost zones that will thaw in the two-degree world. The 2050 'highest hazard' zone included more than 36,000 buildings, 13,000 km of roads and 100 airports across high-latitude and high-altitude regions. Three entire cities of more than 100,000 residents – all in Russia – are built on areas that are currently continuous permafrost. This means that railways, roads and pipelines will buckle, airport runways will crack, and houses and other buildings will split apart as the ground underneath them gives way, leading to tens of billions of dollars' worth of economic damage.

Perhaps the greatest threat posed by permafrost thaw is that it will further accelerate the breakdown of the world's climate. In the two-degree world, one study projects that enough of the Arctic permafrost will melt to release 60–70 billion tonnes of additional carbon into the atmosphere. There are considerable uncertainties here; a second study projects a smaller loss of 22–41 billion tonnes in a two-degree world by 2100, but with hundreds of billions more tonnes released over subsequent centuries. Not all of this is CO_2; as much of half of it could come as methane, a much more powerful greenhouse gas. There is a substantial difference between the area of permafrost that melts in a 1.5°C-warmer world as opposed to two degrees. While about 4.8 million km² of permafrost is lost in the former scenario, two degrees of global warming sees the loss of 6.6 million km², with 40% of the entire permafrost area of the Arctic region disappearing.

Whatever the exact numbers, with both CO_2 and methane pouri out of these newly melting areas, humanity's chances of keeping the Paris Agreement targets diminish further. Another study sugge that the additional carbon from thawing permafrost reduces t two-degree-allowable 'budget' of future emissions by 30–50 billi tonnes. Yet another finds that as much as 345 billion tonnes of carb will eventually be released from thawed permafrost, even if successfully stabilise temperatures at two degrees. Unless humani can somehow wave the magic wand of negative emissions, we do n therefore have a high chance of staying permanently in the tw degree world once the Arctic begins to melt. This additional gree house gas release from thawing permafrost will not happen instant – it will take many decades to play out. But the ultimate destinati is clear: unless curbed by carbon cuts, the Arctic permafrost carb feedback is a shortcut to the three-degree world.

Tipping point in the Antarctic

It is not just the Arctic. Recent surveys have shown the Antarctic s ice is in what scientists call 'precipitous' decline, with 'decreases rates far exceeding the rates seen in the Arctic', according to a *PN* paper published in July 2019. The sudden drop was particularly not ble because it reversed a gradual increase in Antarctic sea ice that h been tracked by satellites over the last 40 years.

Even the usually cautious IPCC warns that a potentially disastro Antarctic tipping point may lie somewhere in the two-degree worl In its 2018 report on 1.5°C, it states: 'The threshold of global tempe ature increase that may initiate irreversible loss of the West Antarc ice sheet and marine ice sheet instability (MISI) is estimated to between 1.5°C and 2°C.' The West Antarctic Ice Sheet (WAIS) is cit as of particular concern because it is mostly grounded far below s level, so a collapse could become self-sustaining once the groundi line is crossed. Warmer oceans would then penetrate hundreds

kilometres into the Antarctic interior, fragmenting the entire continental ice sheet and ultimately delivering – alongside East Antarctica and Greenland – more than five metres of sea-level rise. None of today's coastal megacities could survive such a huge boost to global sea levels – not London, not Jakarta, not New York, not Shanghai. Coastal defences can only do so much. They could protect against a metre or two at most, but five metres would require a large-scale relocation of humanity inland, involving upwards of a billion people.

The vastly larger East Antarctic Ice Sheet (EAIS) has similar points of vulnerability. As with the West Antarctic, sections of the eastern ice sheet are in direct contact with the warming Southern Ocean, and have grounding lines which similarly lead inland via reverse-sloping beds down to troughs that are as deep as 1,500 metres below sea level in the continent's interior. If the floating ice shelves that protect these glacial outlets collapse, and ocean waters begin to penetrate underneath the vast ice sheet into the Antarctic's very heart, the result could be catastrophic, delivering as much as 20 metres of additional global sea level rise.

Greenland also has glaciers that are retreating rapidly because of their contact with a much warmer ocean. Numerous massive glaciers draining the Greenland ice sheet have sped up, retreated and thinned in recent years as the climate warmed. As I showed in the previous chapter, surface melt has also increased dramatically, far in advance of that predicted by models. The most recent science suggests that Greenland too has a threshold after which, in the words of a 2018 study in *Nature Climate Change*, 'the ice sheet enters a state of irreversible mass loss and complete melting is initiated.' There are not one but two positive feedbacks that lead to this unstoppable melt. The first is the fact that as the ice sheet diminishes, it will lose altitude and therefore be exposed to increasingly high temperatures due to the lower elevation. The second is the 'melt-albedo feedback', where, as the snow surface thaws, it darkens and thereby absorbs more solar radiation. The ice sheet surface is also darker than any overlying

snow, so once it is fully exposed to the sun's rays on account of t
receding snowline, this too acts as a positive feedback to speed up t
melting process.

So where does this fateful threshold lie? The experts, based or
combination of observations and model simulations, put their be
guess at a regional Greenland summer temperature increase of 1.8°
Given that overall Arctic warming is happening much faster tha
global temperature rise, this 1.8°C point of no return would be rig
at the very start of the two-degree world. In fact, there is a goo
chance – as I suggested in the previous chapter – that we have cross
this line already. While it will take millennia for the entire ice she
to melt and deliver its full complement of seven metres' worth of s
level rise, the gradual elimination of the Greenland ice sheet mea
that our descendants will be faced with irreversibly rising oceans f
centuries to come.

There is evidence that both Greenland and the West Antarctic i
sheets did indeed collapse during the Eemian, 116,000 to 129,0
years ago. As I discussed in the previous chapter, this interglacial ha
a global temperature roughly similar to today, and much lower C
levels, and is therefore a conservative analogue for the two-degr
world. However, this very moderate warmth was enough to result
sea levels six to nine metres higher than now. These dramatical
raised sea levels can only have come via less land ice at the pole
suggesting that moderate levels of global warming will eventually l
enough to significantly reduce both the Greenland and Antarctic i
sheets over the longer term. The question now is by how much for
casts of sea level rise need to be raised for the two-degree world, give
the latest science on the vulnerability of both polar ice sheets.

The IPCC, in its September 2019 report on oceans and th
cryosphere, points out that the loss of ice on Greenland – which tota
250 billion tonnes per year – is unprecedented over at least the la
350 years and that this high rate of melt represents a two to five tim
increase over pre-industrial levels. The IPCC also warns that 'rap

mass loss due to glacier flow acceleration' both in West and East Antarctica may indicate the beginning of 'instability' in these ice sheets which leads to 'irreversible retreat'. It adds that the combined sea level rise contribution from both ice sheets has risen by a staggering 700% since the decade 1992 to 2001.

Even using very moderate estimates of sea level rise, the IPCC projects that 79 million people will be displaced as their homes and communities are inundated in a two degrees world (ten million fewer will lose their homes if temperatures are kept below 1.5°C). Bangladesh would face having more than a million of its citizens permanently displaced by the invading oceans. Even as soon as 2050, large parts of the world's coastlines will be experiencing what was previously a once-in-a-century flood event every single year. In the longer term, even in a 1.5°C stabilisation scenario, the IPCC points out that countries with 50 million people or more on large areas of land exposed to sea level rise include China, Bangladesh, Egypt, India, Indonesia, Japan, the Philippines, the United States and Vietnam. At least 136 megacities are at risk of being at least partially flooded in a two-degree scenario, with flood damage costs totalling $1.4 trillion per year by the end of the century.

These numbers can be reduced with aggressive coastal protection measures, but the costs will be astronomical; one recent report found that the US alone faces more than $400 billion in coastal defence costs over the next 20 years, with longer-term costs for those living in smaller communities as high as $1 million per person. I suspect no one will want to pay for sea walls at such vast expense, and the most vulnerable (and the poorest) communities will simply be abandoned. The gradually rising list of abandoned areas will not just include coastal portions of larger nations such as China and the US. Entire countries will face being submerged or eroded away by the end of the century, with small island nations like the Maldives and Tuvalu first on the list. This process could begin much sooner than we would like to think. According to a 2018 study in *Science Advances*, within as little as 30 years from now many atoll islands will find themselves washed over annually by ocean waves. Once this happens, groundwater will salinise, vegetation will be destroyed, buildings repeatedly damaged and the long-term habitability of the islands fatally undermined. Their residents will eventually have to join the millions of climate refugees all over the world who will be looking for a new home.

Deadly dengue

Sea level rise is clearly a long-term threat to the Maldives, but many people living there have a more immediate concern. Virtually all the islands are infested by mosquitoes; these can transmit dengue fever, a disease that often strikes suddenly and with little warning. This happened to a friend of mine who has an eight-year-old son, a lively boy with blond hair and quick smile. One day the boy was running, jumping and eating sweets at their home in the local island of Eydafushi, on Baa Atoll. The next he had a fever, and three days later was in hospital hooked up to a drip and with a critically low blood platelet count. Desperate doctors gave him a blood transfusion as the disease steadily worsened; dengue can progress to a haemorrhagic stage, and the first signs of bruising were beginning to appear on the boy's feet. They knew any blood loss into the brain could be fatal. Dengue is caused by a virus, so antibiotics are useless – his mother, a medical professional herself, could do little more than pray. The boy was the fourth member of the same family to be struck down with the disease in the space of a few months.

Fortunately the child in this case made a full recovery, but some Maldivians have not been so fortunate. A nine-year-old boy died from dengue in July 2019, after an emergency evacuation from the northern island of Kulhudhuffushi to the main hospital in the Maldives' capital Malé. The disease can strike young and old alike – fatalities in 2016 included a seven-month-old baby and a 61-year-old

Opera House. These sites are not necessarily expected to be eroded away or inundated by 2100; the timescale for the study was 2,000 years, during which time sea levels could rise by nearly seven metres. But this does not mean we should dismiss these impacts as impossibly far off, for many of the cultural sites on the list are already much older than two millennia. Consider the value of the ancient horse paintings in the Cosquer Cave, near Marseille in France; these are 18,500 years old, and have already been partially submerged by natural sea level rise after the last ice age. Future sea level rise may destroy them completely.

In any case, the long time horizon may be instructive. By 2100, as one recent study puts it, 'sea level will be rising faster than at any time during human civilization'. A new world will be emerging, one humans have never experienced before, with ever-higher tides, steadily eroding shorelines and catastrophic storm surges combining to inundate vast areas increasingly far from the current coastline. This is not the stable, relatively benign Holocene world that our ancestors enjoyed and within which human civilisation developed and flourished. That world is gone, never to return – not in our lifetimes, nor even those of our very distant descendants, assuming they survive at all.

Hotter than hell

'Delhi is burning. You can't imagine the heat. As you step out, it's a furnace on your body.'

So described an India-based correspondent on 11 June 2019. That same day, the *Times of India* reported that Delhi had just recorded an all-time high temperature of 48°C, beating the previous record of 47.8°C set in June 2014. A day earlier, the India Meteorological Department issued a rare red warning of extreme heat, with heatwave conditions expected not just in the capital but across large parts of neighbouring states: Haryana, Uttar Pradesh, Madhya Pradesh,

Chandigarh city and Saurashtra. Amid a 50% increase in heatstroke cases compared with a 'normal' summer day, doctors warned Delhi residents to wear light-coloured clothes, carry umbrellas and drink three to four litres of water per day. Even so, four passengers in a non-air-conditioned train carriage on the Kerala Express died from the heat during the journey from Agra to Coimbatore.

Further west, temperatures rose to a blistering high of 51.1°C in Jacobabad, Pakistan, as dangerous heat conditions spread across much of South Asia, from the Iranian border in the west to Bangladesh in the east. The heatwave paralleled the one that affected large areas of India and Pakistan in 2015, killing 3,500 people. In 2010 1,344 people died from a heatwave in Ahmedabad, Gujarat.

The extreme heat of 2019 will be considered an unusually cool summer in the three-degree world. Vast regions of South Asia are projected to experience heatwave episodes 'considered extremely dangerous for most humans' in a world that is just 2.25°C warmer than pre-industrial times. A heatwave so extreme that it might currently be expected only four times a century will become not just a regular occurrence, but take place every other year. The projections show that over half of South Asia's population – hundreds of millions of people living in dozens of major cities – will be experiencing 'dangerous heatwave' conditions never before seen in today's climate. While higher-altitude areas like the Deccan Plateau and the Himalayas will escape the worst, the model projections show an arc of bright red – indicating dangerous heat – encompassing both the Indus and Ganges river valleys, including Bangladesh and the eastern coastal half of India.

While some adaptation is possible – power demand spiked during Delhi's 2019 high-temperature record as people turned on air conditioners – there is a limit to how much normal life can go on in heat conditions that make it dangerous for humans to venture outside unprotected, still less work or move about in the searing heat. All agricultural labour ceases, except for work that uses air-conditioned

machinery such as farm tractors. Road mending and building projects also grind to a halt, and all outside sporting activities stop, with people essentially being trapped indoors. Those who do not have access to an artificially cooled environment risk hyperthermia and death. And while humans may be able to take shelter, livestock are decimated as extreme heat leaves even shade temperatures too hot for survival.

And of course it is not just South Asia. A study projecting the heatwave impacts of three degrees on Africa showed a tenfold increase in extreme heat across the tropical belt and the Horn of Africa. Looking at model projections for 'hot nights' (many people who die do so at night because they are unable to cool down), data visualisations show a huge swathe of the continent – across a vast area from Guinea in West Africa, to Angola in the south, to Tanzania and Somalia in the east – experiencing between 100 and 300 hot nights each year. A second study found that cities in West Africa would be experiencing dangerous heat conditions (defined as maximum air temperature above 40.6°C) for 145 days per year in a simulated three-degree world in the 2090s. Across the whole of the continent, and depending on population and emissions scenarios, African cities would be facing a 20- to 50-fold increase in exposure to dangerous heat.

Heat extremes will not just be affecting the tropics. One 2018 study looking at a three-degree scenario showed that up to a quarter of the global land surface will experience every year the kind of heatwave events that might now be expected only once every 20 years, with the largest changes hitting the US and Canada, Europe and northern Eurasia, as well as central South America. Excess mortality will also affect US cities; in New York, for example, a 1-in-30-year heatwave in the three-degree world will kill at least 2,700 more people than if global warming is kept to a moderate 1.5C. The number 2,700 is a significant one to New Yorkers, as it is roughly the same number of people who died at the World Trade Center on 9/11. For Los Angeles, 1,000 extra heat deaths can be avoided. At the risk of stating the

obvious, the US spends hundreds of billions on military operation to combat terrorism, yet the prospect of the same death tolls cause by heatwaves merits scarcely a mention, or is even faced with outrigh denial.

Vast areas will be affected – a 2017 study found that a third of th global land area will be exposed to temperature and humidity condi tions exceeding the 'deadly threshold' for more than 20 days each yea in a three-degree world. This being a scientific paper, the wor 'deadly' is not used for dramatic effect but has a precise meaning: refers to climatic conditions that have caused documented increase mortality in the past and are projected to be repeated ever mor frequently in future as the world heats up. While 30% of the world population is already exposed to 20 or more days of 'deadly heat' i today's one-degree world, by the time the global average temperatur reaches three degrees that number will have risen to 53%, meanin that half the world's population will be annually exposed to heatwav conditions that can kill. The heatwaves of the future will be 'devastat ing mega-heatwaves' according to a 2018 study, which the autho point out will 'adversely affect human mortality and morbidity'. I other words, they will injure and kill people, probably in larg numbers.

Scientists writing for august publications are now beginning to us terms like 'habitability' and 'survival' in discussing the future state c the planet. A December 2018 paper in *The Lancet Planetary Healt* reported that multiple climate models now predict that at least 5 million people worldwide will be exposed to temperatures 'above th survivability threshold' in a three-degree world. One model – th Hadley Centre's HadGEM2 Earth System model – projects a sudde jump in the number of people exposed once global temperature cross the Paris Agreement level of 1.5°C, with 140 million peopl being catapulted above the heat survivability threshold in 2.5°C-warmer world. Over a billion people worldwide would b exposed to temperatures that exceed the 'workability threshol

where it becomes impossible to safely work outside artificially cooled environments, even in the shade.

The zone of 'extreme risk' in the three-degree world – indicating that working outside is physically impossible without risk of fatal heatstroke – includes parts of 40 countries each with current populations above 10 million. This includes large areas of North Africa, the Middle East and South Asia, encompassing virtually all of India, two-thirds of Pakistan, half of Thailand and Cambodia, with 'extreme risk' heat even intruding into northern regions of Australia. Developing countries are worst hit: in Africa, most of Algeria and parts of Nigeria, Ghana and Cameroon are badly affected, with North and South Sudan, Chad, Niger, Burkina Faso and Mauritania almost completely within the extreme risk zone. In South America much of northern Brazil is in the zone, as are eastern Peru, southern Colombia and lowland parts of Bolivia, while in North America it covers much of coastal Mexico and border areas of the southern United States. The authors warn that 'habitability' will be affected throughout large areas of the tropics, leaving millions of people with no option but to migrate once the 'survivability threshold' is exceeded in their regions.

With entire nations experiencing heat above this survivability threshold, the world potentially faces drastic population movements, with hundreds of millions of people leaving tropical and subtropical countries no longer considered tolerably habitable. These will be refugee flows of greater magnitudes than those provoked by a world war, causing incalculable social and political consequences across the globe.

Invading deserts

And it's not just heat. The lack of moisture in parched soils means that temperatures will soar far higher than is ever the case today. With plants wilting or dead, and no water at all in the ground, there will be nothing to hold back the rising heat. Wildfires will burn vast areas

during the long, hot summers; one model projects an increase o 187% in burned area in the three-degree world, with the Iberia Peninsula, southern France and eastern parts of Italy particularl affected. Virtually all climate models agree that the Mediterranea region will be the centre of drastic precipitation declines in th three-degree world. Some rain will still fall, but it will be the excep tion rather than the rule; according to projections published in 201 the average Mediterranean drought will last a decade or more whe three degrees is reached.

In North Africa, Morocco, Algeria, Tunisia, Libya and Egypt stan to lose virtually all their rainfall. Desert-like conditions will als creep into all of Spain and Portugal except perhaps for their wester and northern Atlantic coastal fringes, extending over souther France, encompassing the Balearic Islands and Sardinia, all of Sicil Malta and Cyprus, most of Italy up to the Alps, all of Greece, most o Turkey, then completing the arc of aridification along the easter Mediterranean shoreline, including Lebanon, Syria, Jordan, Palestin and Israel. None of these countries will have sufficient water to mair tain their current populations without relying on desalinated sea water. While irrigated food production will be possible so long a freshwater can be found, rainfed farming as we know it today wi largely cease to exist. Olive groves, vineyards, citrus orchards – all wi vanish from the desiccated landscape. Only the most resilient tree and shrubs will still be visible through the shimmering heat haz surrounded by spreading sand and cacti. Meanwhile, today Mediterranean climate will spread up into central and norther Europe.

Climate models currently undersimulate the observed dryin trend in today's world, meaning their forecasts for the future are likel to be unduly conservative. Take this into account, as one stud published in *Nature Climate Change* did, and the result is predicte to be arid areas 'covering half the global land surface' in a three degree scenario. This is a world where drylands extend over almo

to 46°C for a few hours with a relative humidity of 49%. This corresponds to a wet-bulb temperature of 34.6°C, just a few tenths of a degree below the critical level. The conclusion is stark. If the temperature can already approach this deadly threshold in the one-degree world, by the time we are living in the four-degree world large areas of the planet will see lethal hothouse conditions for long periods.

More recent model studies – which, given the unforeseen events of 2015, are still likely to be conservative – give an indication of what lies in store, and which areas are likely to be most seriously affected. As you might expect from the event already experienced, one epicentre is the Persian Gulf, with the liveability threshold exceeded regularly in the simulated four-degree world in Abu Dhabi, Dubai, Dhahran (Saudi Arabia) and Bandar Abbas (Iran). Kuwait City is less humid, so keeps a lower wet-bulb temperature, but still faces dry-bulb – normal thermometer measurements, in other words – summertime highs in excess of 60°C in this scenario. (For comparison, 60°C is higher than any temperature recorded so far on Earth. The current record is 54°C, measured in both Kuwait and Death Valley in 2013.) Much of the Arabian Peninsula, including the Muslim holy cities of Mecca and Jeddah, is similarly affected, endangering the safety of millions of religious pilgrims whose sacred Hajj rituals include praying outside over several days in the open air. There may be an irony of sorts that these same Gulf and Arabian states are the major source of the oil and gas whose emissions are now making these same countries intolerably hot – but that will be of little comfort.

It is not only the Middle East that will be transitioning into a biologically uninhabitable state in the four-degree world. Model simulations also project that substantial areas of South Asia will be reaching the critical 35°C wet-bulb temperature limit at the same time. One key study reports that 'the most intense hazard from extreme future heat waves is concentrated around densely populated regions of the Ganges and Indus river basins,' noting that this 'presents a serious and unique risk to South Asia, a region inhabited by about

one-fifth of the global human population.' In a four-degree scenario according to the models, wet-bulb temperature 'is likely to exceed the survivability threshold' in parts of north-eastern India and Bangladesh, and to approach the critical threshold over most of the rest of South Asia. Whole cities, such as Lucknow in Uttar Pradesh and Patna in Bihar, each with a current population of over two million, find themselves stranded beyond the survivability threshold.

Obviously no one is going to build an artificially cooled survival dome over the Indian subcontinent. Such a thing is not even remotely feasible. But the fact remains that these projected future conditions will not be able to support the continued permanent existence of large-scale human habitation in areas currently home to hundreds of millions of people. Patches of habitability may remain in highland areas, like oases in a desert, but in social and political terms India, Pakistan and Bangladesh as we know them will no longer exist, and close to a billion people will face a choice between risking death in each progressively hotter summer or becoming part of the world's burgeoning population of climate refugees.

And the refugee numbers could be astronomical, encompassing a significant fraction of the Earth's people. This is because the other of the world's great human population centres, China, will also be bumping up against the survivability threshold at around this same time. As the authors of another study explicitly state: 'Continuation of the current pattern of global emissions may limit habitability in the most populous region of the most populous country on Earth.' This threat is centred on the North China Plain, the 400,000-square kilometre region that was the cradle of ancient Chinese civilisation and now – inhabited by nearly half a billion people – is one of the most densely populated parts of the world. The authors tick off a list of cities, each with a current population in the millions, where conditions will eventually become unliveable: Weifang, Jining, Qingdao, Rizhao, Yantai, Shanghai and Hangzhou. These are not small towns

Shanghai has a metropolitan population of 34 million people, while Hangzhou is home to 22 million.

China is a technologically advanced economy and its cities are some of the most modern in the world. It is perhaps conceivable that they could transform towards Gulf status, with their giant populations sustained artificially in a technosphere cocoon of air-conditioned high-rises and supplied by desalinated seawater piped in from the warming oceans. Today's Gulf cities like Doha and Dubai are already nearly impossible creations, like glass and steel mirages in the desert, sustained by their consumption of prodigious quantities of energy (mostly generated by burning oil and gas) for air conditioning and water desalination. Perhaps as their physical environments trend closer to outright uninhabitability, megacities from Shanghai to Delhi will be able to seal themselves off in artificial enclosures, like domed space stations on the hostile surface of Mars. But imagine the consequences of a power outage in such circumstances, with millions of people trapped inside glass and steel structures that rapidly transform into greenhouses or even solar ovens once the electricity goes down.

And heatwaves do not always come in calm conditions. One 2019 study looked at the potential for tropical cyclones, which threaten some of the world's most densely populated coastlines, to be followed immediately by deadly heat events. Imagine the scene: devastated coastal cities, with no power, and millions of people faced with the immediate loss of shelter, food and water, in situations of intense heat stress, and with tens or even hundreds of thousands of unburied corpses rotting in the streets. In the four-degree world, the study suggests, such catastrophes would become annual events. Some humans might dream of a future in which we become more and more symbiotic with machines, but what happens when – as E. M. Forster once asked – the machine stops? We might live in increasingly artificial environments, but sooner or later the realities of the physical and biological world will bring us back to Earth.

As the belt of uninhabitability extends around the planet – beginning in the Middle East, but then swallowing up most of India, Pakistan, Bangladesh and eastern China – the future for a substantial portion of the planet's human population looks bleak. With the global temperature at four degrees, humans now face a completely new situation, one where expanding, densely populated zones of the planet, which have sustained our civilisations for millennia, are now functionally unliveable for our species. We are making our world increasingly unsuitable for life, and yet – space stations and moon colonies aside – we have nowhere else to go.

Dust and fire

Brian Allen had only been in Arizona two weeks when the symptoms began. His family of three had moved to Phoenix in April 2018 to start a new life, but had had little time to enjoy the sun. 'As soon as he got the job here, he got sick,' recalled his lifelong partner Franique, whom he had been with for 13 years. 'He was experiencing headaches … and chills.' By the time Brian was admitted to ER he had even stopped recognising his family, including his young son Kal'el. He died on 2 June, less than two weeks after the headaches began. Franique does what she can to console their young son, but 'Kal'el just wants his daddy to come back.'

Neither Franique nor Brian had even heard of valley fever when they first went to Phoenix. But the likely source of the infection was clear. 'He was working and he was caught in a dust storm and he inhaled the fungus in the air and it went to his lungs,' says Franique in a matter of fact way. Valley fever is a fungal infection caused by airborne spores that are lifted out of the arid desert soils in dust and transmitted long distances before being breathed in and lodging in the lungs. Most cases are mild, involving – as Brian Allen at first experienced – fever, fatigue, headaches and chills. But on rarer occasions the more serious form of the disease, disseminated

Heat shock

At five degrees, humanity has lost control of global temperatures, which are now spiralling relentlessly upwards. Food production is decimated, and large areas of the planet are too hot for humans to inhabit. All ice sheets are doomed to vanish, and vast quantities of additional carbon are pouring into the atmosphere from thawed Arctic permafrost and burning forests. Unless something can be done to reverse the upwards spiral, runaway global warming could transform our planet into a wasteland of lifeless rocky continents surrounded by stagnant oceans. It is almost game over.

The entire tropical belt and much of the sub-tropics of Planet Earth are subject to year-round temperatures that would today be classed as 'deadly heat'. The highest temperatures are found in North Africa, the Middle East and South Asia. As I outlined in the previous chapter, when wet-bulb temperatures pass the critical threshold of 35°C, humans can no longer survive outside for any significant period of time. In this kind of humid extreme heat, all other warm-blooded animals will also die unless they can find a cooler refuge – that includes livestock, wildlife, everything. Wet-bulb thresholds aside, ambient temperature extremes of 60°C are now commonplace everywhere from Riyadh to Karachi. The arid sub-tropics have become a kind of global Death Valley, where lack of water and intense heat kill

all plant and animal life. Apart from microbes and bacteria, vast areas of the surface of the planet are gradually becoming sterilised by heat shock.

These places include regions that are home to as much as half the current human population, including East and South Asia, Central America, the southern half of the US and much of Africa. The fate of the Indian monsoon is unknown in such a scenario – a total failure is possible, but so is a further intensification, with colossal downpours eroding the remaining soil from fields and hillsides left bare by drought and fire. In the deep tropics there will be no winter relief, as year-round heatwaves – punctuated by flash floods – denude the land surface. In Africa, a quarter of cities will experience dangerous heat conditions for 200 days every year, with extremes so hazardous that venturing outside for more than a few minutes at a time is impossible without protection. All transport, agriculture and other human activities requiring outside labour cease, triggering famine and economic collapse.

Global food production will be pushed over the limit in such a scenario, with most of the world's breadbaskets too hot or dry to yield any significant harvest. Synchronous harvest failures over multiple years mean that global trade in food ends entirely, and most countries have to attempt some form of self-sufficiency to feed their populations. It is likely that the majority of such attempts will fail. The human species has never experienced a situation where we are unable to gather or grow food over most of our habitual range. What kinds of economies can persist under such a scenario? How can ten billion people avoid mass starvation when world harvests fail completely? Climate models cannot shed much light on this future because it involves social, economic and political scenarios for which human civilisation has no historical precedent. You cannot add a line of code into a climate model to represent the response of a country's political system to ten million climate refugees on its borders. Even with all its complexity and approximations, atmospheric physics is always going

to be much easier to understand and predict than human responses to climate impacts.

It is technically conceivable, as I suggested earlier, that energy-hungry industrial growth will be so successful that humanity is able to build and maintain artificial environments within which we might both live and produce food indefinitely, irrespective of lethally high outside temperatures, using feedstocks such as CO_2 harvested from the air, nuclear power-originated hydrogen and desalinated seawater. This scenario is perhaps reminiscent of futuristic ideas about colonising new planets with space stations, but instead of venturing into new worlds to set up habitable zones, we would be being forced to deploy space-age technology at home in order to continue to live on our own planet. In the 20th century, science fiction writers fantasised about living on Venus. Now we will have brought Venus home to Earth.

And how many people, realistically, could be supported and sheltered under such air-conditioned techno-domes? Surely not the entire global population. Ten billion people take up a lot of space, and feeding them artificially would be a colossal challenge, as would finding the energy required to keep such environments cool. The only realistic concentrated energy option, unless we are to continue burning yet more fossil fuel, is nuclear. This is, however, so feared by so many people – irrationally, in my view – that it is unlikely to be accepted on the scale necessary for such an endeavour. A more pessimistic scenario might be a kind of global apartheid, where the rich are able to sequester themselves away from a collapsing biosphere behind fortified barriers or on remote islands, while the majority of the human population starves outside. This sounds like something out of a zombie movie, and would surely be intolerable to our modern morality. How many of us would really be prepared to machine-gun starving families of climate refugees massed outside the gates of cooling life-preserving compounds reserved for the super-rich? Who knows – but perhaps it is not really so unthinkable, given that we tolerate the current extreme economic inequality in which, according

to the charity Oxfam, eight billionaires own the same amount of wealth as the poorest half of the global population. As I write, 850 million people are malnourished due to lack of food, while the super-rich criss-cross the world in private jets and mega-yachts, each with a staff of hundreds. We all acquiesce in this ongoing moral outrage as if it were the natural state of affairs.

Climate apartheid could therefore be seen as merely an extension of our current extreme inequality, not a new paradigm. Every time I watch the news and see migrants trying to get from North Africa to Europe drown in their dozens – hundreds even – in the Mediterranean, I see the future for millions of climate refugees. While some good people do their best to help, many more turn away in disgust and vote for far-right parties that make a political virtue of demonising the downtrodden, the different and the desperate. It is no accident that these same proto-fascist parties, now in or close to power in many countries, typically also deny or downplay climate change. They are in the business of blaming victims to gain power, and telling lies is second nature to them because they do not believe that the truth matters or even exists. As *Yale Environment 360* reported in October 2019: 'Right-wing populist parties now on the rise across Europe are elevating opposition to climate action into a new culture war issue, American-style.'

How exactly the socio-political collapse might happen, or how post-collapse human societies might evolve, goes too far into the realms of speculation for me to say anything useful about it. I will leave such musings to dystopian fiction authors and Hollywood disaster movie scriptwriters. Suffice to say that most cities will lie dead and abandoned; current superpowers and long-fought-over national borders will largely cease to exist; the human population will be drastically reduced; and much of the remaining life on Earth will be eliminated. Perhaps the end will be dramatic, shrouded in the smoke of war as the survivors battle it out for what is left of our planet's vanishing resources and living space. Or perhaps it will be slow,

and civilisation will die a death by a thousand cuts, as democracy fades away, barriers and borders rise, while the heat keeps on rising and fatal impacts multiply year on year. One local famine becomes regional and then global, 'failed states' multiply, and societies and nations that have survived for thousands of years totter and collapse. Darkness falls gradually as the lights over whole regions flicker and go out.

Climate refuges

As I will outline in the next chapter, at very intense levels of warming the likelihood increases that a runaway greenhouse effect will take place that ultimately sterilises the biosphere. At five degrees this has not yet happened, and substantial areas of the planet's surface do remain tolerably habitable. They are just not the same regions that humans currently generally live in. Nor are they spacious or resource-rich enough to be able to support ten billion desperate people. They are, however, of sufficient extent to mean that some humans should be able to survive in the numbers needed to avoid the outright extinction of our species, which I think is unlikely even with the catastrophic heat-related impacts expected in the five-degree world.

So where might these refuges be? For clues we need to look both at the aggregated outputs of climate models and extrapolations based on the planet's current geographic and climatic zones. In general, areas on the higher-latitude western margins of continents, particularly when their geographies include mountain ranges, should be both wet and cool enough to support humans. For example, while the interior of Alaska will see a continental climate with 35°C heatwaves in the summer months and parching droughts, the southern coast of the state continues to enjoy a temperate climate regime. High mountain ranges – from Denali in the north to Mount Logan, just over the border in Canada – will still see snow even in the five-degree world and catch sufficient precipitation generally on the maritime westerlies

to keep this whole area temperate and well-watered. Further down the North American coast, the western side of the Rockies should also retain high precipitation levels and equable temperatures, through British Columbia and Washington State, and even as far as Oregon. Further south than that, however, California will be baking into dust, with the Sierra Nevada scorched brown and snowless.

In South America the Andean mountains are high enough to stay cool, even as the final remnants of their glaciers disappear. Depending on the fate of the Amazon to the east, sufficient rainfall may still arrive, even in tropical areas. A better bet lies further south and west, in Chilean Patagonia and down into Tierra del Fuego, where westerly storm systems will continue to dump large amounts of precipitation in a latitude high enough to remain in the cool zone. If humanity is well organised, we might consider establishing plantations of tropical rainforest plants in these latitudes to prevent them going extinct globally, perhaps with a view to re-establishing these species in their old ranges once the Earth's temperature can be reduced back to safe levels a few centuries hence. (This could be a kind of global biosphere preserve – a sort of Noah's Ark for the global warming extinction.) The Antarctic Peninsula might be a better bet, however. At this stage it will be fully habitable, and well supplied with freshwater both from precipitation and the year-round melting of its remaining glaciers. Perhaps this will be one of the exclusive locations where the super-rich flee for safety. Flotillas of climate refugees putting out onto the stormy Southern Ocean are unlikely to pose much threat to their Antarctic fastnesses.

Continue to virtually spin the globe searching for habitable places, and the next likely spot that jumps out is the South Island of New Zealand. The Southern Alps will have lost all their ice, but should still attract enough rain to keep the rivers flowing throughout most of the year. Moreover, the location of this small landmass far away from the over-populated conflict zones of Africa, Europe and Asia might also perhaps prove attractive. New Zealand may, however, be pushed to

more immediately attend to the needs of millions of displaced Australians, whose own continent is now too hot to support large-scale human habitation in all but a few small coastal fringes in the very south, in Tasmania and perhaps in the Blue Mountains. What vegetation does persist in Australia burns repeatedly in immense fires, leaving just a few weedy generalist heat- and fire-tolerant species to proliferate. Large-scale agriculture is now a distant memory.

In the tropics, highlands do exist that promise tolerable temperatures even as the lowlands below them are baked out of existence. The spine of New Guinea has a range of peaks high enough to still catch the rain and provide sustenance for a few hundred thousand people. The wettest place on Earth, in the foothills of the Himalayas in eastern India, is another such location – although residents will need to relocate a couple of thousand metres higher up the mountain slopes to escape the rising heat. Altitude rather than latitude may also save western parts of China and the Tibetan Plateau, although the latter is already highly arid and unlikely to receive much more precipitation. There will still be snowfall on the highest Himalayan peaks, although even the largest glaciers and icefields will all be melting fast year-round and will eventually disappear entirely. The problem with highlands as refuges, however, is that by definition they contain very limited flat space and can support little in the way of agriculture. Russia and Siberia will still be cool in winter, but in the summer months their refuge potential is limited. Temperatures will regularly climb into the 40s and 50s Celsius, sparking immense wildfires in what remains of the boreal forest. Around the circum-polar shores of the Arctic Ocean there may also be suitable habitat, but the response of the planetary hydrological cycle to the year-round disappearance of sea ice is a wild card for these regions. Storms might possibly migrate up from the mid-latitudes as the jet stream goes haywire, but on the other hand the area might well remain marooned under dry high-pressure systems for much of the year. Climate models have little useful light to shed on such an epochal shift.

As usual Africa looks likely to suffer more than anywhere. Located almost entirely in the tropics and the sub-tropics, the continent will be experiencing some of the highest temperatures ever seen on Earth. Highs into the mid-60s Celsius occur regularly in North Africa in the five-degree world, and rainfall has virtually ceased across many land areas. Highland zones are small and located far in the continent's interior, such as the Rwenzori mountains and the Ethiopian highlands, endangering their supplies of precipitation. The tropical convergence zone, which currently supplies most of Africa's rainfall, may intensify and further fluctuate, but with temperatures too high in lowland areas to support forests and agriculture it will bring little relief from the scorching sun. The obvious injustice that Africa has done little to contribute to the stock of greenhouse gases that have now heated the planet to such extremes is of no concern to the morally impervious gods of climate physics.

What of Europe? The Iberian Peninsula, much of France, Italy, Greece and the rest of the Mediterranean are now transitioning into full-scale deserts, despite the arrival every few years of medicane tropical cyclones that bring devastating floods. Temperatures in northern Europe reach the 50s Celsius now in summer, with deadly heat conditions for weeks at a time even up to the Arctic Circle. Small tolerable areas exist in the Pyrenees, Alps and British mountains, while Scandinavia still has a relatively equable climate – albeit one uncomfortably shared by 100 million refugees from southern Europe and the Middle East. The margins of Greenland can now also support substantial human populations, helpfully supplied by constant meltwater from thawing ice, and kept cool both by their high latitude and the nearby presence of what remains of the Greenland ice sheet. Perhaps Greenland might be purchased from Denmark by a coalition of African nations in order to host a refugee population that keeps the memory of the old continent alive.

And that is pretty much it. At five degrees we are seeing humanity clinging on in only small refuges, surrounded on all sides by

spreading deserts, forests in flame and rising seas. We will have lo
nine-tenths of our habitable planetary space, including most of ou
lowlands and virtually all land outside the higher latitudes. The re
of our planet is a silent cemetery, suitable for the dead but no longe
with much to offer the living.

Ice-free Antarctic

In a five-degree world, with much of the planet's surface now unin
habitable, continued sea level rise is perhaps the least of humanity
worries. All the same, it is worth noting that massive ongoing me
from both Greenland and the Antarctic ice sheets could raise ocea
levels by as much as three metres by the end of the century. Th
would of course inundate all low-lying islands, and substantial area
of coastline and deltas in larger countries, further cramping what
left of the Earth's habitable space. As I mentioned in the previou
chapter, recent scientific assessments taking into account more rapi
melting of the polar ice sheets now give a potential upper value on se
level rise that is more than twice the worst-case scenario considere
by the IPCC in its 2013 report. The ten countries that lose most lan
in absolute terms are of course some of the largest: China, Russia, th
US, Canada, Brazil, Vietnam, Australia, India, Indonesia and Mexic
About 800 million people are directly flooded out of their homes (th
is assuming that they have not already been displaced by food shor
ages or heat shocks), with about two million square kilometres o
land inundated. All coastal megacities either have to be defended a
enormous cost or permanently evacuated. In Asia alone the lis
includes Jakarta, Manila, Ho Chi Minh City, Bangkok, Guangzhou
Hong Kong, Mumbai, Kuala Lumpur, Tokyo and Shanghai.

The only areas protected from sea level rise are those regions tha
lose so much ice so quickly that the Earth's crust rebounds under
neath them and raises the level of the land, reducing the rate of rela
tive sea-level rise around Greenland, parts of the Canadian Arctic