How to survive the coming century

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Explore an interactive map of the world warmed by 4 °C

ALLIGATORS basking off the English coast; a vast Brazilian desert; the mythical lost cities of Saigon, New Orleans, Venice and Mumbai; and 90 per cent of humanity vanished. Welcome to the world warmed by 4 °C.

Clearly this is a vision of the future that no one wants, but it might happen. Fearing that the best efforts to curb greenhouse gas emissions may fail, or that planetary climate feedback mechanisms will accelerate warming, some scientists and economists are considering not only what this world of the future might be like, but how it could sustain a growing human population. They argue that surviving in the kinds of numbers that exist today, or even more, will be possible, but only if we use our uniquely human ingenuity to cooperate as a species to radically reorganise our world.

The good news is that the survival of humankind itself is not at stake: the species could continue if only a couple of hundred individuals remained. But maintaining the current global population of nearly 7 billion, or more, is going to require serious planning.

Four degrees may not sound like much - after all, it is less than a typical temperature change between night and day. It might sound quite pleasant, like moving to Florida from Boston, say, or retiring from the UK to southern Spain. An average warming of the entire globe by 4 °C is a very different matter, however, and would render the planet unrecognisable from anything humans have ever experienced. Indeed, human activity has and will have such a great impact that some have proposed describing the time from the 18th century onward as a new geological era, marked by human activity. "It can be considered the Anthropocene," says Nobel prizewinning atmospheric chemist Paul Crutzen of the Max Planck Institute for Chemistry in Mainz, Germany.

A 4 °C rise could easily occur. The 2007 report of the Intergovernmental Panel on Climate Change, whose conclusions are generally accepted as conservative, predicted a rise of anywhere between 2 °C and 6.4 °C this century. And in August 2008, Bob Watson, former chair of the IPCC, warned that the world should work on mitigation and adaptation strategies to "prepare for 4 °C of warming".

A key factor in how well we deal with a warmer world is how much time we have to adapt. When, and if, we get this hot depends not only on how much greenhouse gas we pump into the atmosphere and how quickly, but how sensitive the world's climate is to these gases. It also depends whether "tipping points" are reached, in which climate feedback mechanisms rapidly speed warming. According to models, we could cook the planet by 4 °C by 2100. Some scientists fear that we may get there as soon as 2050.

If this happens, the ramifications for life on Earth are so terrifying that many scientists contacted for this article preferred not to contemplate them, saying only that we should concentrate on reducing emissions to a level where such a rise is known only in nightmares.

"Climatologists tend to fall into two camps: there are the cautious ones who say we need to cut emissions and won't even think about high global temperatures; and there are the ones who tell us to run for the hills because we're all doomed," says Peter Cox, who studies the dynamics of climate systems at the University of Exeter, UK. "I prefer a middle ground. We have to accept that changes are inevitable and start to adapt now."

Bearing in mind that a generation alive today might experience the scary side of these climate predictions, let us head bravely into this hotter world and consider whether and how we could survive it with most of our population intact. What might this future hold?

The last time the world experienced temperature rises of this magnitude was 55 million years ago, after the so-called Palaeocene-Eocene Thermal Maximum event. Then, the culprits were clathrates - large areas of frozen, chemically caged methane - which were released from the deep ocean in explosive belches that filled the atmosphere with around 5 gigatonnes of carbon. The already warm planet rocketed by 5 or 6 °C, tropical forests sprang up in ice-free polar regions, and the oceans turned so acidic from dissolved carbon dioxide that there was a vast die-off of sea life. Sea levels rose to 100 metres higher than today's and desert stretched from southern Africa into Europe.

While the exact changes would depend on how quickly the temperature rose and how much polar ice melted, we can expect similar scenarios to unfold this time around. The first problem would be that many of the places where people live and grow food would no longer be suitable for either. Rising sea levels - from thermal expansion of the oceans, melting glaciers and storm surges - would drown today's coastal regions in up to 2 metres of water initially, and possibly much more if the Greenland ice sheet and parts of Antarctica were to melt. "It's hard to see west Antarctica's ice sheets surviving the century, meaning a sea-level rise of at least 1 or 2 metres," says climatologist James Hansen, who heads NASA's Goddard Institute for Space Studies in New York. "CO2 concentrations of 550 parts per million [compared with about 385 ppm now] would be disastrous," he adds, "certainly leading to an ice-free planet, with sea level about 80 metres higher... and the trip getting there would be horrendous."

Half of the world's surface lies in the tropics, between 30° and -30° latitude, and these areas are particularly vulnerable to climate change. India, Bangladesh and Pakistan, for example, will feel the force of a shorter but fiercer Asian monsoon, which will probably cause even more devastating floods than the area suffers now. Yet because the land will be hotter, this water will evaporate faster, leaving drought across Asia. Bangladesh stands to lose a third of its land area - including its main bread basket.

The African monsoon, although less well understood, is expected to become more intense, possibly leading to a greening of the semi-arid Sahel region, which stretches across the continent south of the Sahara desert. Other models, however, predict a worsening of drought all over Africa. A lack of fresh water will be felt elsewhere in the world, too, with warmer temperatures reducing soil moisture across China, the south-west US, Central America, most of South America and Australia. All of the world's major deserts are predicted to expand, with the Sahara reaching right into central Europe.

Glacial retreat will dry Europe's rivers from the Danube to the Rhine, with similar effects in mountainous regions including the Peruvian Andes, and the Himalayan and Karakoram ranges, which as result will no longer supply water to Afghanistan, Pakistan, China, Bhutan, India and Vietnam.

Along with the exhaustion of aquifers, all this will lead to two latitudinal dry belts where human habitation will be impossible, say Syukuro Manabe of Tokyo University, Japan, and his colleagues. One will stretch across Central America, southern Europe and north Africa, south Asia and Japan; while the other will cover Madagascar, southern Africa, the Pacific Islands, and most of Australia and Chile (Climatic Change, vol 64, p 59).

The high life

The only places we will be guaranteed enough water will be in the high latitudes. "Everything in that region will be growing like mad. That's where all the life will be," says former NASA scientist James Lovelock, who developed the "Gaia" theory, which describes the Earth as a self-regulating entity. "The rest of the world will be largely desert with a few oases."

So if only a fraction of the planet will be habitable, how will our vast population survive? Some, like Lovelock, are less than optimistic. "Humans are in a pretty difficult position and I don't think they are clever enough to handle what's ahead. I think they'll survive as a species all right, but the cull during this century is going to be huge," he says. "The number remaining at the end of the century will probably be a billion or less."

Humans will survive as a species, but the cull this century will be huge

John Schellnhuber of the Potsdam Institute for Climate Impacts Research in Germany is more hopeful. The 4 °C warmer world would be a huge challenge, he says, but one we could rise to. "Would we be able to live within our resources, in this world? I think it could work with a new division of land and production."

In order to survive, humans may need to do something radical: rethink our society not along geopolitical lines but in terms of resource distribution. "We are locked into a mindset that each country has to be self-sustaining in food, water and energy," Cox says. "We need to look at the world afresh and see it in terms of where the resources are, and then plan the population, food and energy production around that. If aliens came to Earth they'd think it was crazy that some of the driest parts of the world, such as Pakistan and Egypt, grow some of the thirstiest crops for export, like rice."

Taking politics out of the equation may seem unrealistic: conflict over resources will likely increase significantly as the climate changes, and political leaders are not going to give up their power just like that. Nevertheless, overcoming political hurdles may be our only chance. "It's too late for us," says President Anote Tong of Kiribati, a submerging island state in Micronesia, which has a programme of gradual migration to Australia and New Zealand. "We need to do something drastic to remove national boundaries."

Cox agrees: "If it turns out that the only thing preventing our survival was national barriers then we would need to address this - our survival is too important," he says.

Imagine, for the purposes of this thought experiment, that we have 9 billion people to save - 2 billion more than live on the planet today. A wholescale relocation of the world's population according to the geography of resources means abandoning huge tracts of the globe and moving people to where the water is. Most climate models agree that the far north and south of the planet will see an increase in precipitation. In the northern hemisphere this includes Canada, Siberia, Scandinavia and newly ice-free parts of Greenland; in the southern hemisphere, Patagonia, Tasmania and the far north of Australia, New Zealand and perhaps newly ice-free parts of the western Antarctic coast.
We will need to abandon huge areas and move people to where the water is

If we allow 20 square metres of space per person - more than double the minimum habitable space allowed per person under English planning regulations - 9 million people would need 18,000 square kilometres of land to live on. The area of Canada alone is 9.1 million square kilometres and, combined with all the other high-latitude areas, such as Alaska, Britain, Russia and Scandinavia, there should be plenty of room for everyone, even with the effects of sea-level rise.

These precious lands with access to water would be valuable food-growing areas, as well as the last oases for many species, so people would be need to be housed in compact, high-rise cities. Living this closely together will bring problems of its own. Disease could easily spread through the crowded population so early warning systems will be needed to monitor any outbreaks.

It may also get very hot. Cities can produce 2 °C of additional localised warming because of energy use and things like poor reflectivity of buildings and lower rates of evaporation from concrete surfaces, says Mark McCarthy, an urban climate modeller at the UK Met Office's Hadley Centre. "The roofs could be painted a light, reflective colour and planted with vegetation," McCarthy suggests.

Since water will be scarce, food production will need to be far more efficient. Hot growing seasons will be more common, meaning that livestock will become increasingly stressed, and crop growing seasons will shorten, according to David Battisti of the University of Washington in Seattle and his colleagues (Science, vol 323, p 240). We will need heat and drought-tolerant crop varieties, they suggest. Rice may have to give way to less thirsty staples such as potatoes.
Vegetarian dystopia

This will probably be a mostly vegetarian world: the warming, acidic seas will be largely devoid of fish, thanks to a crash in plankton that use calcium carbonate to build shells. Molluscs, also unable to grow their carbonate shells, will become extinct. Poultry may be viable on the edges of farmland but there will simply be no room to graze cattle. Livestock may be restricted to hardy animals such as goats, which can survive on desert scrub. One consequence of the lack of cattle will be a need for alternative fertilisers - processed human waste is a possibility. Synthetic meats and other foods could meet some of the demand. Cultivation of algal mats, and crops grown on floating platforms and in marshland could also contribute.

Supplying energy to our cities will also require some adventurous thinking. Much of it could be covered by a giant solar belt, a vast array of solar collectors that would run across north Africa, the Middle East and the southern US. Last December, David Wheeler and Kevin Ummel of the Center for Global Development in Washington DC calculated that a 110,000-square-kilometre area of solar panels across Jordan, Libya and Morocco would be "sufficient to meet 50 to 70 per cent of worldwide electricity production, or about three times [today's] power consumption in Europe". High-voltage direct current transmission lines could relay this power to the cities, or it could be stored and transported in hydrogen - after using solar energy to split water in fuel cells.

If the comparatively modest level of solar installation that Wheeler and Ummel propose were to begin in 2010, the total power delivery by 2020 could be 55 terawatt hours per year - enough to meet the household electricity demand of 35 million people. This is clearly not enough to provide power for our future 9 billion, but improving efficiency would reduce energy consumption. And a global solar belt would be far larger than the one Wheeler and Ummel visualise.

Nuclear, wind and hydropower could supplement output, with additional power from geothermal and offshore wind sources. Each high-rise community housing block could also have its own combined heat and power generator, running on sustainable sources, to supply most household energy.

If we use land, energy, food and water efficiently, our population has a chance of surviving - provided we have the time and willingness to adapt. "I'm optimistic that we can reduce catastrophic loss of life and reduce the most severe impacts," says Peter Falloon, a climate impacts specialist at the Hadley Centre. "I think there's enough knowledge now, and if it's used sensibly we could adapt to the climate change that we're already committed to for the next 30 or 40 years."

This really would be survival, though, in a world that few would choose to live. Large chunks of Earth's biodiversity would vanish because species won't be able to adapt quickly enough to higher temperatures, lack of water, loss of ecosystems, or because starving humans had eaten them. "You can forget lions and tigers: if it moves we'll have eaten it," says Lovelock. "People will be desperate."

Still, if we should find ourselves in such a state you can bet we'd be working our hardest to get that green and pleasant world back, and to prevent matters getting even worse. This would involve trying to limit the effects climate feedback mechanisms and restoring natural carbon sequestration by reinstating tropical

forest. "Our survival would very much depend on how well we were able to draw down CO2 to 280 parts per million," Schellnhuber says. Many scientists think replanting the forests would be impossible above a certain temperature, but it may be possible to reforest areas known as "land-atmosphere hotspots", where even small numbers of trees can change the local climate enough to increase rainfall and allow forests to grow.

Ascension Island, a remote outpost buffeted by trade winds in the mid-Atlantic, may be a blueprint for this type of bioengineering. Until people arrived in the 17th century, vegetation was limited to just 25 scrubby species. But plantings by British servicemen posted there produced a verdant cloud forest. "It shows that if you have rainfall, forest can grow within a century," says ecologist David Wilkinson of Liverpool John Moores University in the UK, who studied the phenomenon.

Even so, the most terrifying prospect of a world warmed by 4 °C is that it may be impossible to return to anything resembling today's varied and abundant Earth. Worse still, most models agree that once there is a 4 °C rise, the juggernaut of warming will be unstoppable, and humanity's fate more uncertain than ever.

"I would like to be optimistic that we'll survive, but I've got no good reason to be," says Crutzen. "In order to be safe, we would have to reduce our carbon emissions by 70 per cent by 2015. We are currently putting in 3 per cent more each year."