sense about science

making sense of the weather and climate

An introduction to forecasts and predictions of weather events and climate change

Scientists have noticed frequent misunderstandings about weather and climate science in public discussions. This briefing looks at the problems they have identified. It explains what they think is wrong and how to make better sense of what they are predicting.

Weather and climate are news. They will be even more in the spotlight as governments respond to the fourth report of the Intergovernmental Panel on Climate Change and try to agree policies. A group of climate and weather scientists have been reviewing how weather and climate issues are discussed in media coverage and policy debates. We challenged them to come up with ways that non-specialists can get to grips with how the weather and climate works, and how they are modelled and predicted.

In the many discussions about the effects of global warming, air pollution and energy policy in the media, policy and economic worlds, scientists are worried that we risk losing sight of what the science is telling us. It creates better headlines to simplify messages about weather and climate science but this often leads to confusion. Scientific understanding of weather and climate are constantly developing, which can make it appear that the science is more uncertain than it really is. Extreme weather events and future climates also make good fiction: 'The Day After Tomorrow', 'The Perfect Storm', 'Twister', and 'Poseidon Adventure' are just a few recent hits.

From their review, the scientists identified five frequent misunderstandings about how weather and climate are understood. These are:

weather and climate predictions say what is going to happen with certainty;

weather and climate are quite unpredictable;

all extreme weather events are caused by man-made global warming;

we are facing a point of no return;

there is little scientific consensus or understanding about abrupt climate change.

They explain these misunderstandings in this short briefing. It is not intended to be an education in all things climate and weather related, but to alert readers to misunderstandings and provide some helpful points for everyone trying to make sense of the discussions. Its aim is to help to avoid losing sight of the science amidst the entertainment, the rows about policy and alarmism. In short, it is intended to promote a stronger understanding of what weather and climate predictions are based on.

March 2007

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Sense About Science

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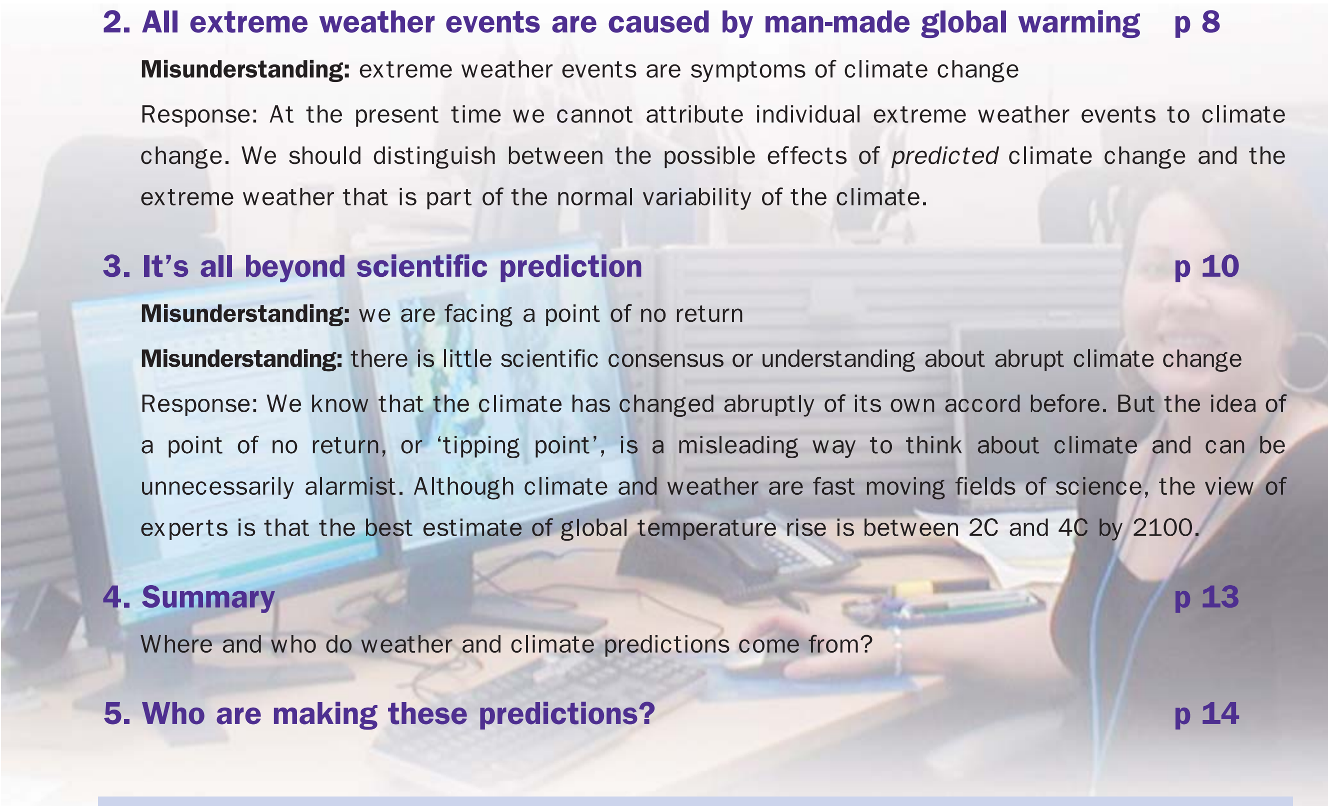


Photo: The Met Office

Fundamental Tools

Modelling

The only way we can properly forecast weather for the next few days, or climate for the next 100 years, is to use very complex mathematical models, containing equations that describe the physical processes at work in the atmosphere, ocean, cryosphere (areas of ice and snow) and on land.

We use observations of what's happening to the weather across the globe to drive the weather models and changes in greenhouse gas emissions to drive the climate prediction models. Some of the biggest models contain ten million lines of computer code and require some of the world's largest super-computers to run them. New developments in modelling will soon make it possible to forecast weather on a very small scale.

1. Weather forecasters are always getting it wrong

This idea is based on two misunderstandings: that weather and climate predictions say what is going to happen with absolute certainty, and that weather and climate are quite unpredictable.

Response: Weather is predictable but we don't have the information and the tools to predict it equally well everywhere all of the time. Forecasts are based on probabilities of certain events occurring, for example the likelihood that it will rain at a certain time in a certain place. Climate predictions look at long term trends, which include large variations. Forecasting may be imperfect but the physical laws that govern weather and climate are well understood and do not change.

WEATHER AND CLIMATE

The reason we have weather (and climate) is because the Earth is hotter at the equator (where the sun is more intense) than at the poles; weather acts to redistribute heat between low and high latitudes (although part of this work is also done by ocean currents). Weather is what is happening in the atmosphere at any one time: how warm, windy, sunny or humid it is. Climate is the description of the average weather we might expect at a given time, usually taken over a 30 year period to average out year to year variability perhaps due to a particularly hot summer or very cold winter, and it also includes information about variability and extremes.

Tim Palmer FRS

Meteorology is 'exact' in the sense that we know the laws governing weather to extremely great accuracy. The problem is that weather forecasts are sensitive to initial conditions and hence predictions are always subject to uncertainties in these initial conditions.

Short-range weather forecasts are developed from expected changes in the atmosphere only. In contrast, seasonal predictions depend on factors like ocean temperatures and currents. Climate predictions depend on emissions of greenhouse gases, which in turn depend upon less certain factors such as population growth and energy use. Many reported differences in weather and climate predictions result from the use of different forecasting models or how far ahead the prediction is made.

Standard forecast definitions:

Nowcasting:	0 to 6 hours ahead	Medium range:	48 hours to 10 days
Short range:	0 to 48 hours ahead	Long range:	beyond 10 days

FORECASTING WEATHER

Predicting future weather is a complex science. We live in the very lowest layer of the Earth's atmosphere where the weather is most difficult to forecast. Even with the best numerical models available it is not possible to predict all the fine detail, such as the exact distribution of showers or fog. Inaccuracies also arise because the models approximate to reality: some complex calculations are too much for even the most powerful computers.

Brian Golding

Predicting small scale weather variations presents a major challenge to scientists, who are drawing together expertise from an ever increasing range of fields to achieve further gains in forecast accuracy.

Paul Hardaker

At the moment small scale features, like thunderstorms that might rain on just one housing estate, are only represented in numerical weather prediction models schematically, by what we call parameterisations. The next generation of forecast models will have to resolve these and this is a really big and exciting challenge, almost as big as when forecast models were first introduced.

Provided scientists can represent the small scale physics, our ability to forecast more accurately will increase with computing power.

Who provides television weather forecasts?

Keith Groves

The Met Office supplies forecast information to the BBC, ITV and Sky. They all present it in different ways, but we try to ensure that all the media users of our information will deliver a similar story on the forecast. At the BBC, national presenters are Met Office employees and in the regions the staff are a mix of Met Office and BBC staff, although they all use Met Office forecasts.

There is not just one way to forecast the weather. Differences between forecasts can occur through using different numerical models or from their interpretation, such as in the timing or distribution of rain. As well as the Met Office, several companies provide forecast services to the UK, although the Met Office is the only one which develops and uses large weather prediction models.

Forecast accuracy is affected by your local physical environment

The variability of the Earth's surface affects the weather. Mountainous areas have more rainfall: as air encounters hills and ascends, the water vapour in the air condenses into clouds and, put simply, once the droplets are big enough they fall out as rain. Crops, forests and urban areas have different surface roughness, causing the air to behave differently and creating local air circulations and temperature anomalies. This means that the weather can be varied even in areas that are close together, like a city park next to high rise offices.

Chris Collier

Local weather can be affected by built up urban areas. City areas are warmer than rural areas because of heat generated in buildings and the use of air conditioning. This can cause the air over the city to rise, water vapour to condense into cloud, causing showers, usually a few kilometres downstream because it takes time for the droplets to grow into rain. These effects depend very much on the materials in the buildings, how tall and far apart they are and the amount of heat they emit.

Our knowledge of how weather develops has come a long way in 30 years

Advances in meteorology have resulted from large-scale investigations of weather systems, improvements in models of the atmosphere and the availability of super computers. These have helped us to understand the three-dimensional nature of weather systems, such as the banded structure of rainfall associated with weather fronts. We now know much more about how weather systems move, develop and decay, information essential for accurate forecasting. Satellite images have helped meteorologists to compare predicted changes in the atmosphere with what is actually happening.

We can also now differentiate between two types of processes in the atmosphere: the equations governing large-scale air motion (dynamical) and the equations governing the formation of certain weather such as rain and snow, evaporation and turbulence (physical). Weather may change in the future but our understanding of it won't because it's underpinned by the laws of physics.

The Met Office's weather forecasts are now as accurate for two days ahead as they were for one day ahead 10 years ago

Fundamental Tools

International data collection

A constant, accurate flow of information about the weather in the atmosphere is essential for weather forecast models and for investigating the conditions present when extreme weather events occur. Data are collected by trained observers and automated systems across the world for use in numerical models. Observations and instruments comply with World Meteorological Organisation (the UN Agency) standards. Meteorology is unique in sharing standardised information freely between 187 countries and territories.

PREDICTING CLIMATE

But how can we predict changes in 50 or 100 years when we can't always get the weather forecast right for tomorrow?

Climate predictions tell us about how the trends and patterns will change: will it be generally wetter in winter? Will there be more heavy downpours? That sort of thing.

A climate prediction might say that average summer rainfall over London is predicted to be 50% less by 2089; it will not predict that it will be raining in London on the morning of 23rd August 2089.

Geoff Jenkins

How are climate predictions generated?

To make climate forecasts, we need estimates of the gases and particles that will be released into the atmosphere in the future. These are created by making assumptions about population growth, energy use, economic and technological developments. Once emissions are estimated, the amount of greenhouse gases that will remain in the atmosphere is calculated. For carbon dioxide this is done using a model of the carbon cycle, which simulates the transfer of carbon between sources and sinks (where it is absorbed) in the atmosphere, ocean and land. For gases like methane, models simulate the chemical reactions that determine its concentration in the atmosphere. The heating effect can then be calculated from this estimate. And finally, the effect of this increased heating on the climate system is calculated – these are the predictions of climate change. In the UK, the models used are developed at the Met Office's Hadley Centre for Climate Prediction and Research in Exeter. The latest model is called the Hadley Global Environment Model (HadGEM1).

GREENHOUSE GASES (GHGS)

Water vapour A natural greenhouse gas, which increases as the climate warms because warmer air holds more moisture.

Carbon dioxide (CO_2) Mainly from nature, but our burning of fossil fuels has increased its concentration in the atmosphere by over 30%. CO_2 has an effective lifetime in the atmosphere of about 100 years, so a large part of any increase in its concentration will still be present in 100 years time.

Methane (CH_4) Emitted from agriculture and leaks in gas pipelines as well as from many natural processes. The amount in the atmosphere has doubled since pre-industrial times but is no longer rising significantly. There are vast stores of methane trapped in ice (methane hydrates) under the sea bed, which could be released into the atmosphere if greenhouse warming penetrates deeper into the oceans, although this is thought unlikely. However, there is evidence that it is being emitted from melting permafrost.

Other GHGs, such as **nitrous oxide (N_2O)**, **lower atmospheric ozone (O_3)** and **CFCs (now banned)**, are less important but still contribute. Each of these gases has a different 'heating power' per kg; scientists sometimes express changes in all the gases as if they were changes in CO_2 concentrations, referred to as 'equivalent CO_2' or CO_2e.

There won't be a steady journey to the end of the century.

Even if the climate model gives a highly accurate prediction, change is not expected to be steady – each year will not necessarily be warmer than the previous one. Natural variability will continue to play a role. This means that there will be years, or even decades, that are warmer, cooler, drier or wetter than the average. This doesn't mean that the climate prediction is wrong, but that there has been a temporary deviation from the long-term trend.

The Intergovernmental Panel on Climate Change (IPCC) "best estimate" of global warming is 2-4C (degrees Celsius) by the end of the century. This may not seem like much but it is an average; it conceals a greater warming in some seasons and some areas (particularly at higher latitudes) and less in others, for example nearer the equator. Changes in extreme temperatures are also expected to be greater than changes in the annual average. And it is worth noting that it took a global warming of just 5-8C to bring us from the depth of the last ice age to the ice-free conditions over the UK and most of the world today.

Source: The Met Office

2. All extreme weather events are caused by man-made global warming

This is based on the misunderstanding that extreme weather events are symptoms of climate change.

Response: At the present time we cannot attribute individual extreme weather events to climate change. We should distinguish between the weather we experience today and the predicted climate of the future. Some of the recent events that commentators have blamed on climate change are actually part of normal variability. Climate change is said to be occurring when the observed changes cannot be attributed solely to normal variability. Man-made ('anthropogenic') climate change refers to the global warming that can be attributed to human activity, mainly CO_2 from burning fossil fuels.

In a few cases, man-made climate change appears to be causing more extremes – heat waves, for example. But it is too simple to blame every weather disaster on man-made change; there have been catastrophic floods and storms recorded throughout history. Some events, such as certain tornadoes, cannot be said to be increasing and indeed aren't predicted to change in a warmer world. And even when we think increasing events may well be due to climate change, we cannot blame each single event on human activity.

What about the Summer heat wave of 2003?

The 2003 summer heat wave is said to have been responsible for at least 35,000 extra deaths across Europe. Although it is difficult to associate individual events like a flash flood or a hurricane with climate change, there are tools that help us understand how patterns of weather, like a prolonged heat wave or rainy spell, relate to a changing climate. By using methods more commonly applied to epidemiological studies, the Met Office's Hadley Centre recently showed that about half of the blame for the sort of hot summer that Europe experienced in 2003 can be related to human activity. In pre-industrial times, the 2003 heat wave would have been a 1 in 1000 event. By the 2040s the average summer is predicted to be like the one we experienced in 2003; this in turn would be viewed as cold compared to the average summer temperature predicted for the 2060s.

Ten of the hottest years on record have occurred since 1990

What about the El Niño?

Scientists' predictions of the El Niño reflect a better understanding of the climate rather than climate change. The El Niño is a warming of the tropical Pacific Ocean that occurs every three to seven years. It is part of a wider natural phenomenon called the El Niño Southern Oscillation (ENSO), caused by interactions between the atmosphere and ocean, that affects climate all over the world.

It is a well observed phenomenon that has been documented since the 16th Century (by fishermen in Peru) and archaeological evidence suggests that it has been occurring for 15,000 years. Nowadays, data gathered by satellite, air and sea is shared by international research centres, which generate computer models to document ENSO. With this and the historical information, scientists are able to give notice of when an El Niño season is starting, allowing time for measures to mitigate its impact. The cause of El Niño is not fully understood, but its frequency is not thought to be linked to global warming.

Extreme weather events, such as the 1 in 400 year floods in Boscastle, seem to be happening one year after the next since we started talking about climate change…

The probability of a weather event like a flood is calculated from historical weather data. It is expressed as a 'return period', that is, assuming the future climate to be similar to the past, how often such an event would return. In the UK reliable weather observations are available from the 17th Century but only from a few places; widespread reliable observations are available from the 1850s. Using these data, we can perform statistical calculations to estimate the frequency of an event. So even with only 150 years of actual data, we can work out how likely it is that an event will occur in, say, a 500 year period.

It can sound alarming to know that a 1 in 400 year flood has happened two years running. But a '1 in 400' return period translates into a 0.25% chance of the flood happening in any one year; the chance remains the same each year, what ever happened last year. As a description of isolated events, return periods are not particularly meaningful. They are only helpful for forecasters and for planners and engineers who have to build to a design standard, e.g. ensuring the Thames Barrier can withstand a 1 in 400 year flood.

What about hurricanes?

Two papers published in scientific journals in 2005 showed that over the past 50 years tropical cyclones have become more destructive and that over the past 30 years there were more hurricanes in the most intense categories. The devastation of New Orleans by Hurricane Katrina also occurred in 2005, during the North Atlantic hurricane season. Together this fuelled speculation that warmer temperatures are leading to more frequent and intense tropical storms.

There are about 90 tropical cyclones (the generic term for a storm with winds over 65 knots that is called a hurricane, typhoon or cyclone in different parts of the world) each year. Tropical cyclones are known to have natural cycles; for example, hurricanes in the North Atlantic are strongly influenced by the natural El Niño phenomenon. There is no evidence that all tropical cyclones are becoming more frequent but, although there is still a debate among scientists, it looks more likely than not that the warming climate played a role in the recent increase in the most intense category. However, even if we removed the possible effects of climate change from the picture, tropical storms with the destructive power of Hurricane Katrina would still occur.

Scientists are not sure that a warmer climate will lead to an increase in the number of hurricanes in the future. This is because hurricanes not only need warm sea surface temperatures (they are fuelled by warm, moist air), which are already occurring due to human activities, but also other conditions such as a particular wind pattern with height (low windshear) and it is not clear how this will change. However, it looks likely that future tropical cyclones will be more intense, with stronger winds and more intense rainfall.

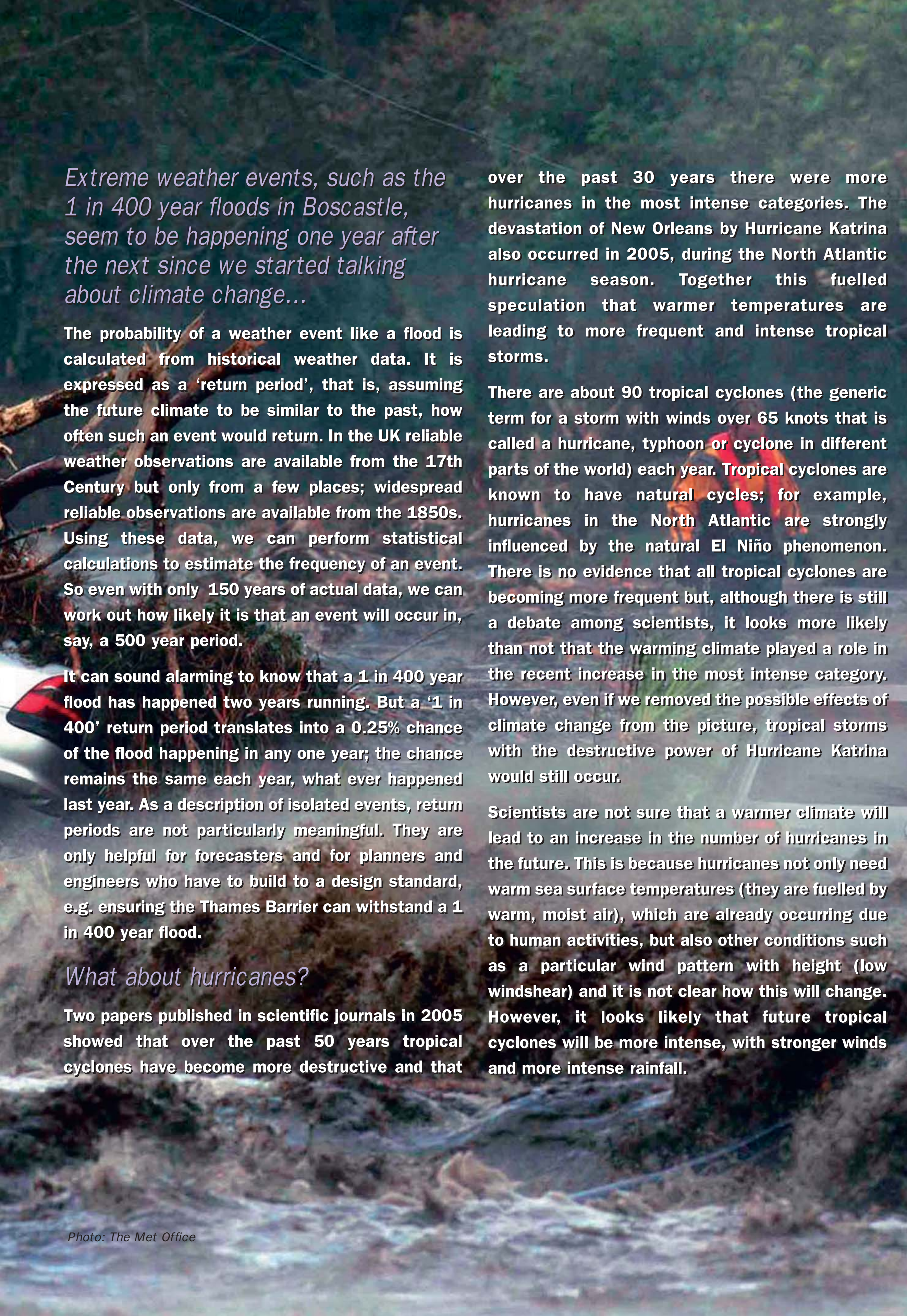
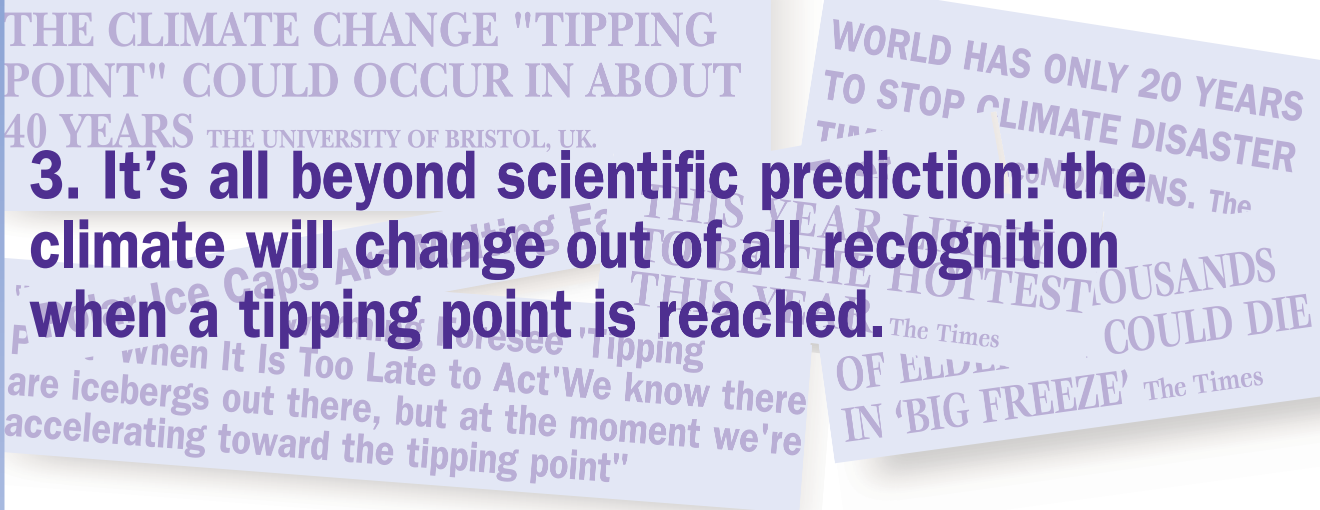


Photo: The Met Office



3. It's all beyond scientific prediction: the climate will change out of all recognition when a tipping point is reached.

This is based on two misunderstandings: that we are facing a 'point of no return' and that there is little scientific consensus or understanding about abrupt climate change.

Response: Mapping worst-case scenarios is an important scientific exercise because the climate has changed abruptly in the past, albeit in circumstances very different from now. But the idea of a point of no return, or tipping point, is a misleading way to think about climate and can be unnecessarily alarmist. Although climate and weather are fast moving fields of science, the best estimate of warming by the end of the century is about 2-4C and this prediction has not changed substantially over the last decade. This analysis does already incorporate likely effects that increased temperatures will have on the Earth's systems that might in turn speed up or slow down the rate of warming.

Climate models and feedbacks

A tipping point sounds exciting and adds colour to reports about the Earth's future, but as it has no scientific definition so many scientists dislike the term. They prefer to talk about scenarios and climate simulations. In circumstances where scientists cannot predict accurately – for example, the world population in 2100 – scenarios are used. These are plausible projections of population growth, energy use and hence greenhouse gas emissions. They are used in climate models to estimate what changes will occur in the atmosphere, oceans and on land. These provide useful insights: it is through modelling that the impact of human activities on the climate can be discovered.

The models also include things called 'feedbacks', which strongly affect changes in climate. Feedbacks are consequences of the initial change that can either increase warming (positive feedbacks) or reduce it (negative feedbacks). The accuracy of climate predictions (such as speed and size of change) depends on getting feedbacks right. This in turn depends on how accurately the climate models represent all the physical processes in the atmosphere. Research, mainly observational, into climate system processes will continue to improve the models. However, the ability of climate models to replicate reasonably well the changes over the past century gives us confidence that their predictions of the future are useful.

Will the weather be more unpredictable in the future?

Keith Groves

There is no reason to believe that the weather will become less predictable in the future. In fact quite the opposite: as more powerful supercomputers become available and better observations of the earth's atmosphere are provided from satellites the accuracy of forecasts is expected to improve.

What is the scientific consensus on future abrupt climatic change?

Bill Burroughs

Abrupt climate change has occurred in the past. A gigantic release of methane from below the ocean bed 56 million years ago led to a sudden warming of 6C in the climate at a time when global temperatures were much higher than now. During the last ice age, collapses in the ice sheet over North America led to the Gulf Stream switching direction and the temperature across the North Atlantic dropping some 10C within decades. More recently, around 5000 years ago, the sudden desiccation of the Sahara ended a pastoral economy that had existed for several thousand years.

Source: National Oceanic & Atmospheric Administration

The occurrence of dramatic changes long ago encourages the view that some aspects of climate change could be sudden and unpredictable. This idea of dramatic change feeds the huge appetite for climate and weather stories and has led to many headlines about worst case scenarios, such as Gulf Stream collapse, Greenland ice-sheet meltdown, slippage of the West Antarctic ice sheet, release of methane trapped in ice (hydrates) at the ocean floor and die-back of rain forests, to name but a few. Nevertheless, the potential for climate to change relatively rapidly does exist and scientists continue to research these sorts of "low risk, high impact" futures.

Doomsday scenarios get a lot of attention and it is difficult for non-specialists to work out from this how likely they are. The likelihood of certain climate scenarios becoming reality depends on two factors: how much greenhouse gas emissions grow and how sensitive the climate system is to these emissions. The lowest emissions and lowest sensitivity climate model predicts about a 1C rise by 2100. The highest emissions and highest sensitivity model predicts just over 6C. From time to time estimates outside the 1-6C range appear in the news. These have rarely been published in scientific journals so information is missing about how the figures are generated; sometimes they are the result of preliminary research from new models. These are not especially useful until they have been published and reviewed by others in the field.

The range of predictions makes planning to adapt to climate change difficult. A development that may help to overcome this in the future is the move towards giving predictions not as single numbers, or ranges of possibilities, but as probabilities of different outcomes.

Mike Hulme

With 2C warming during this century it should be possible (given sufficient will) to design fair and effective interventions to limit climate damages to no more than we have experienced over the previous century. With 4C warming we cannot afford to be so sanguine; we may have to get used to living in a radically different world in which many of our more cherished environments are lost or transformed. Weather is already a killer – it strikes mostly at the poor, or the vulnerable, or the uninsured.

What about the Greenland ice-sheet?

Most climate models predict that by the end of the century temperatures will have risen enough for the Greenland ice-sheet to start to melt. If these temperatures are maintained, a complete meltdown, adding seven metres to global sea level, will happen in a few millennia. (IPCC predicts Sea Level Rise this century to be 20-60cm, possibly 20cm more if recent changes to Greenland and Antarctica are substantiated and persist.)

Researchers are continuing to look at the extent to which a melting Greenland ice-sheet could be re-grown after melting starts. This would need a reduction in CO_2 concentrations which, though physically possible, implies reductions of 70% or more in global man-made CO_2 emissions. Greenhouse gases that have a warming effect on the atmosphere now will continue to cause temperature rises in the future, mainly due to the lag effect of the huge thermal inertia of the oceans. This means that even if all emissions of greenhouse gases stopped today the climate would go on changing for a few decades. And sea level would go on rising for many hundreds of years, as heat from the atmosphere continued to penetrate to deeper and deeper levels and caused the oceans to expand. With current and past emissions already a part of the climate system, changes in emissions over the next few decades will not influence the rate of change in the climate until the second quarter of the 21st Century and beyond.

How have climate predictions have changed since the IPCC's Third Assessment Report?

The IPCC brought out the scientific part of its Fourth Assessment Report (AR4) in February 2007. The main developments in how the climate predictions are generated since the Third Assessment Report (TAR) are:

The physical representation of most climate processes (atmosphere-land-cryosphere-ocean) in models has improved and this has helped to narrow the range of predictions for future emissions scenarios.

At the same time, other feedbacks that are not in standard climate models are now thought to be known sufficiently well for their effect to be included in the predictions for the first time. The main one is the carbon cycle feedback. Currently, about half of man-made CO_2 emissions are absorbed by vegetation, soils and oceans (sinks). As the climate warms, these sinks (particularly soil) will not be able to absorb the same amount of CO_2, leaving more in the atmosphere. This will increase temperature by about 1C by 2100 (which is included in predicted range of 2-4C).

Improvements in models have also lead to a narrowing of the range of sea level rise predictions. In TAR this was about 10-90cm by 2100, current estimates put this closer to 20-60cm, with a best estimate range of about 30-40cm. This narrower range results from better estimates of glacier melt and from more advanced models to estimate the contribution of warmer seas (thermal expansion).

What about Kilimanjaro?

Geoff Jenkins

The disappearing snows of Kilimanjaro have become an icon of man-made climate change. But the reasons for changes on Kilimanjaro are not straightforward and may not have much to do with man's activities. Glacier retreat appears to have begun in the 1880s, and the most likely explanation seems to be the change to drier conditions in East Africa. This is shown by rapid falls in lake levels, which happened around the time of the glacier retreat, and appear to be linked with changes in large scale winds and sea-surface temperatures. There is little evidence that the retreating glaciers can be blamed on rising temperatures, and hence on human activity.

Will the Gulf Stream collapse?

One much-talked about scenario is the 'Gulf Stream collapse'. The Atlantic Ocean circulation brings warm water from the Gulf of Mexico past northern Europe, which makes the UK's climate milder than it would otherwise be. The release of large quantities of freshwater into the North Atlantic could produce conditions similar to those that led to the Gulf Stream switching off in the past. Experiments with the Hadley Centre model show that, if the ocean circulation stopped, the UK would be some 3-5C cooler than now. (That would probably be a bigger problem for infrastructure such as transport and utilities than warming of 3-5C.)

No model, however, predicts a complete collapse of the Gulf Stream. A warming climate is expected to affect ocean circulation. Greater rainfall over the Arctic seas will dilute their salinity, and this, together with higher arctic sea surface temperatures, would be expected to affect the areas of sinking water in the northern seas which drive the ocean circulation. All the full climate models see this effect, ranging from a small to a 50% decrease in ocean circulation strength by 2100 – the Met Office Hadley Centre model shows a change in the middle of this range. Our understanding of ocean circulation is improving, which may lead to some development of modelling that changes this analysis. At the moment though, a Gulf Stream collapse is seen as very unlikely.

Paul Hardaker

Most scientists believe that at current emissions levels there is a point at which the Earth's natural carbon sinks (like rainforests and oceans) will, as a result of atmosphere warming, start releasing more carbon than they absorb, changing them from 'sinks' to 'sources'. This would accelerate climate change. However, being alarmist about this helps no-one. What's important is that we concentrate on how this knowledge informs our scientific efforts, the resources we need to reduce the uncertainty in these predictions and how this can help to form agreement on tackling problems.

4. Summary

Climate and weather are fast moving fields of science with new discoveries being made all the time. The forecasts and models may be imperfect, but the weather itself is predictable – the laws of physics don't change even if the climate does. Improvements in weather modelling may enable us to forecast on which streets showers will fall, but we will still be using probabilities. Gaps in long-term climate predictions are narrowing but, with the multitude of factors that we need to consider, they will always be provisional and contain uncertainties. However, this uncertainty doesn't mean that 'anything goes' as a prediction! We already have the tools to investigate climate change and predict future trends such as the 2-4C temperature rise. Even though uncertainty exists (and always will to some degree), there is a lot of very valuable information within this.

Mankind has never been able to control the weather or climate but has, historically, been able to adapt to changes, surviving ice ages and desertification. Developments in our understanding of the science of weather and climate will play a crucial role in informing how humans deal with the expected climate changes of the next century.

5. Who are making these predictions?

METEOROLOGISTS have a science degree, normally physics or maths, and sometimes an MSc in meteorology or a PhD. They work at the Met Office, the Environment Agency, consultancy or private forecasting companies.

CLIMATOLOGISTS typically hold a degree in geography or environmental sciences and follow a similar training program to meteorologists.

WEATHER FORECASTERS usually have a scientific degree. Those who work for the Met Office will typically undergo a 12-month period of training and supervised experience.

WEATHER PRESENTERS don't have to hold a formal qualification unless they are involved in generating the weather forecast, in which case they have the same qualification as a weather forecaster. Presenters without forecaster training will normally undergo a period of basic training in meteorology.

ORGANISATIONS OPERATING IN THE UK

THE ROYAL METEOROLOGICAL SOCIETY, RMetS, (www.rmets.org) is the UK's professional and learned society for weather and climate. Established in 1850, its role is to advance the science, the application and the understanding of weather and climate. Anyone or any organisation with an interest in weather, climate and related sciences (such as oceanography and hydrometeorology) can become a member of the society. It has a broad range of accessible activities and resources across education, professional standards and public understanding.

THE MET OFFICE (www.metoffice.gov.uk) is the UK's National Weather Service. The Met Office runs Numerical Weather Prediction models, which use equations to determine the future state of the atmosphere. The information is provided to the general public through media outlets such as BBC, ITV and Sky and via internet and telephone through Weather Call and a customer centre. The Met Office provides forecasts to government departments and agencies, as well as forecasts and warnings to many businesses, including aviation, marine, transport and utilities. Although part of the Ministry of Defence, the Met Office is a Trading Fund and operates on a commercial basis. It has 1700 staff at more than 50 locations around the world and funds leading research centres and programmes.

THE NATIONAL CENTRE FOR ATMOSPHERIC SCIENCES, NCAS, (www.ncas.ac.uk) is a NERC-funded collaborative centre that brings together the UK university groups and research institutes working in Atmospheric Sciences. NCAS's role is to promote research excellence and enhance scientific knowledge and understanding of the atmosphere in the Earth's System. NCAS science helps to underpin Government policy and the scientific and technical developments of a range of operational agencies and industry providers.

INTERNATIONAL WEATHER ORGANISATIONS

WORLD METEOROLOGICAL ORGANISATION (www.wmo.ch) is an intergovernmental organisation of the UN with 187 members. It provides an international outlook on the Earth's atmosphere, climate, oceans and the distribution of water resources. It lists approved national weather centres around the world.

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS (www.ecmwf.int) is an independent organisation of 28 member states; its aim is to provide members with accurate medium range forecasts. In addition they supply assistance in education and to the WMO.

WEATHER GROUP PROFILES

DR BILL BURROUGHS is a professional science writer. After seven years at the UK National Physical Laboratory researching atmospheric physics, Bill Burroughs spent three years as a UK Scientific Attaché in Washington DC. Between 1974 and 1995 he held a series of senior posts in the UK Departments of Energy and then Health. He has published 11 books on various aspects of weather and climate and written widely in newspapers and popular magazines.

PROFESSOR CHRIS COLLIER is a physicist and professor of environmental remote sensing at the University of Salford. After 27 years working in the Met Office in research, operational instrumentation and commercial services, Chris joined Salford in 1995 becoming Dean of the Faculty of Science, Engineering & Environment (1999-2003). He was President of the Royal Meteorological Society (2004-06) and has published over 80 refereed journal papers, two books on radar hydrometeorology and over 100 conference papers and reports. He has chaired and served on many national and international committees.

MR KEITH GROVES has been Head of Forecasting at the Met Office for the past three years. In over 30 years with the Met Office he has undertaken a variety of jobs, including atmospheric chemistry, operational forecasting, observations and several roles in support of the defence area of the Met Office.

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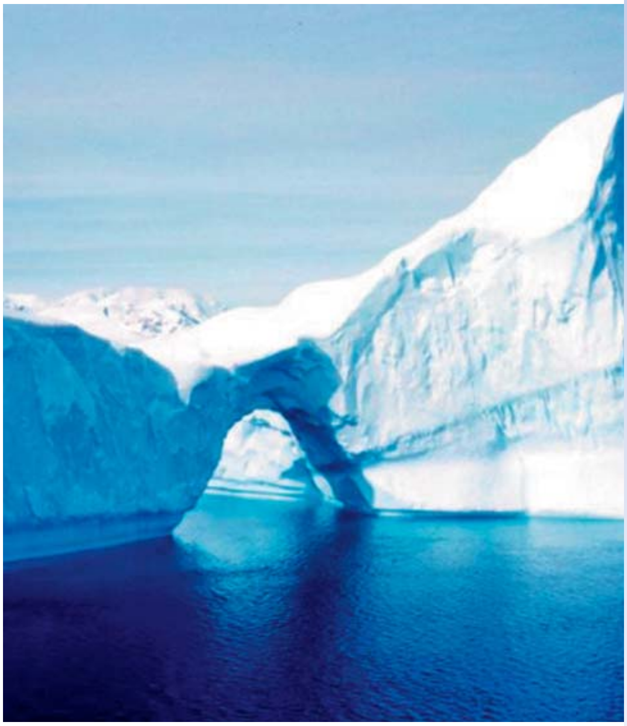

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