Climate Change:

growing elephant, shrinking room

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Sustainable Blewbury
30 October 2017

Welcome to the Anthropocene

Holocene epoch – the past 12,000 years

- Stable, favourable conditions for human civilisations to develop
- Recently, huge increase in knowledge and technology
  - For many, longer, easier and better lives

But

- Dramatic rise in population (more than tripled in my lifetime)
- Greatly increased individual consumption

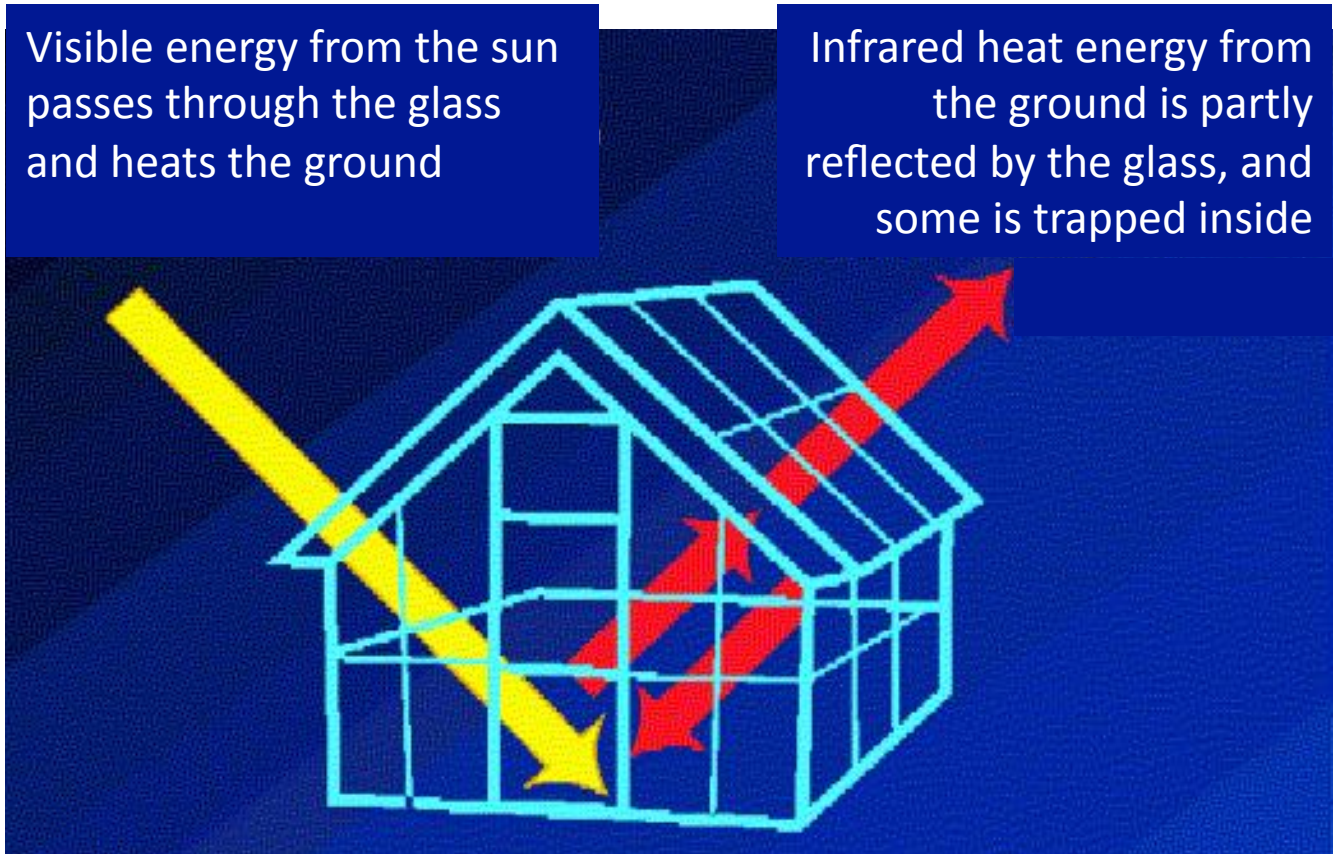
Humans now cause global effects

- Huge environmental changes
- Resources seriously depleted
- Risks of irreversible damage to Earth
  - e.g. ozone layer
- 'Planetary Boundaries' define the risks
  - Including **climate change**

New epoch: Anthropocene

- There is no 'Planet B'

The greenhouse effect



The glass lets visible light through, but not infrared (heat)

Greenhouse gases in the atmosphere

Composition of dry air

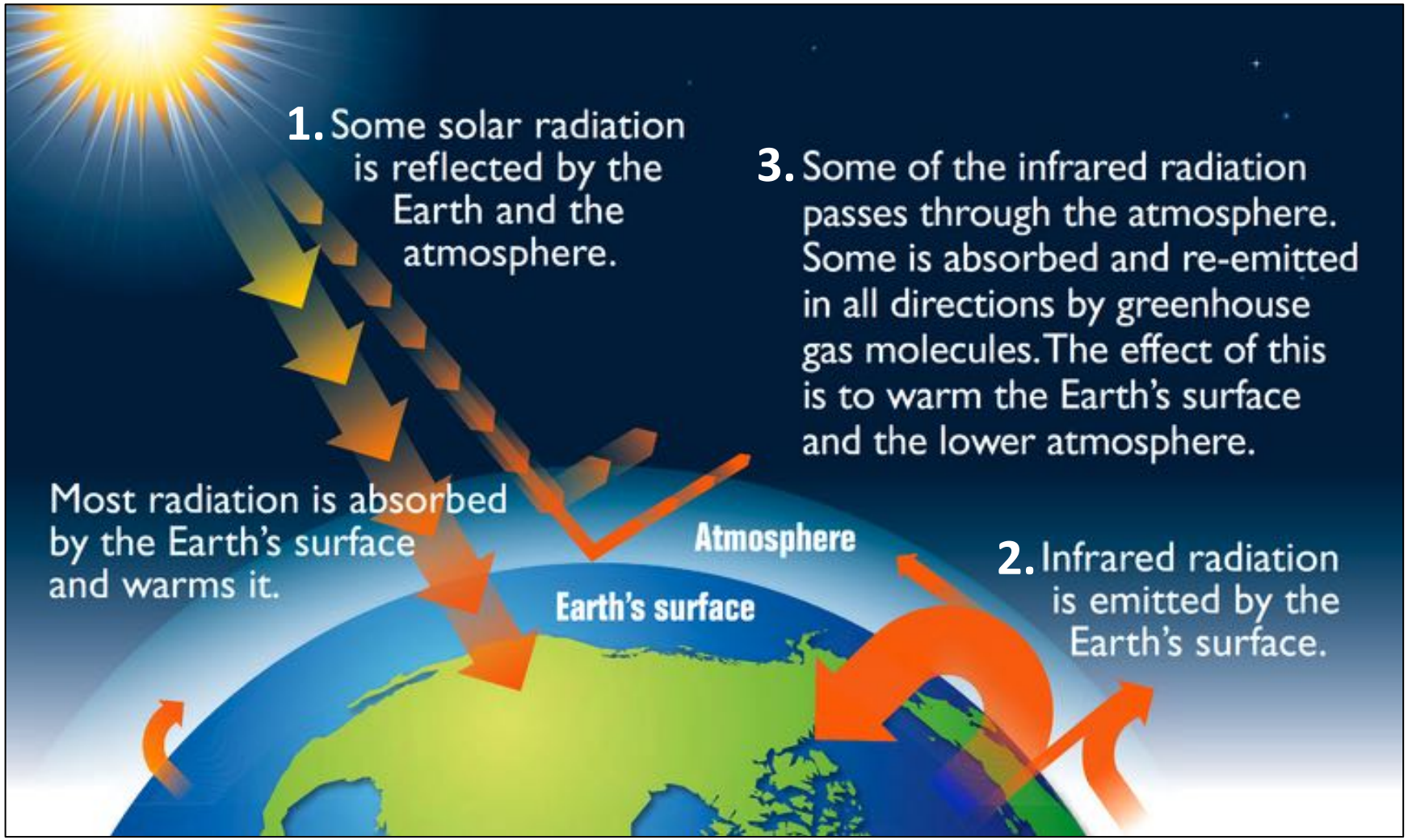
- Nitrogen – 78.1%, Oxygen – 21.0%, Argon – 0.9%
- **Infrared-absorbing greenhouse gases**
  - Carbon dioxide (CO_2) – 0.041% (410 parts per million, or ppm)
  - Methane (CH_4) – 0.00018% (1.8 ppm), main component of natural gas

Greenhouse gases are old physics, not controversial

- Proposed by Joseph Fourier in 1824, observed by John Tyndall in 1860
- Investigated quantitatively by Svante Arrhenius in 1896
- Full scientific description by Guy Stewart Callendar, 1930s to 1960s

Without greenhouse gases, the current +15°C global average temperature would be much colder: –18°C

Earth as a greenhouse



Fossil fuels

Why fossil fuels are so attractive

- Easy to extract – until recently
- Energy dense (9.5 kWh/litre of petrol)
- Easy to store and transport
- Transforms our way of life – space heating, electricity generation, transport, etc.

Nearly 50 kWh inside

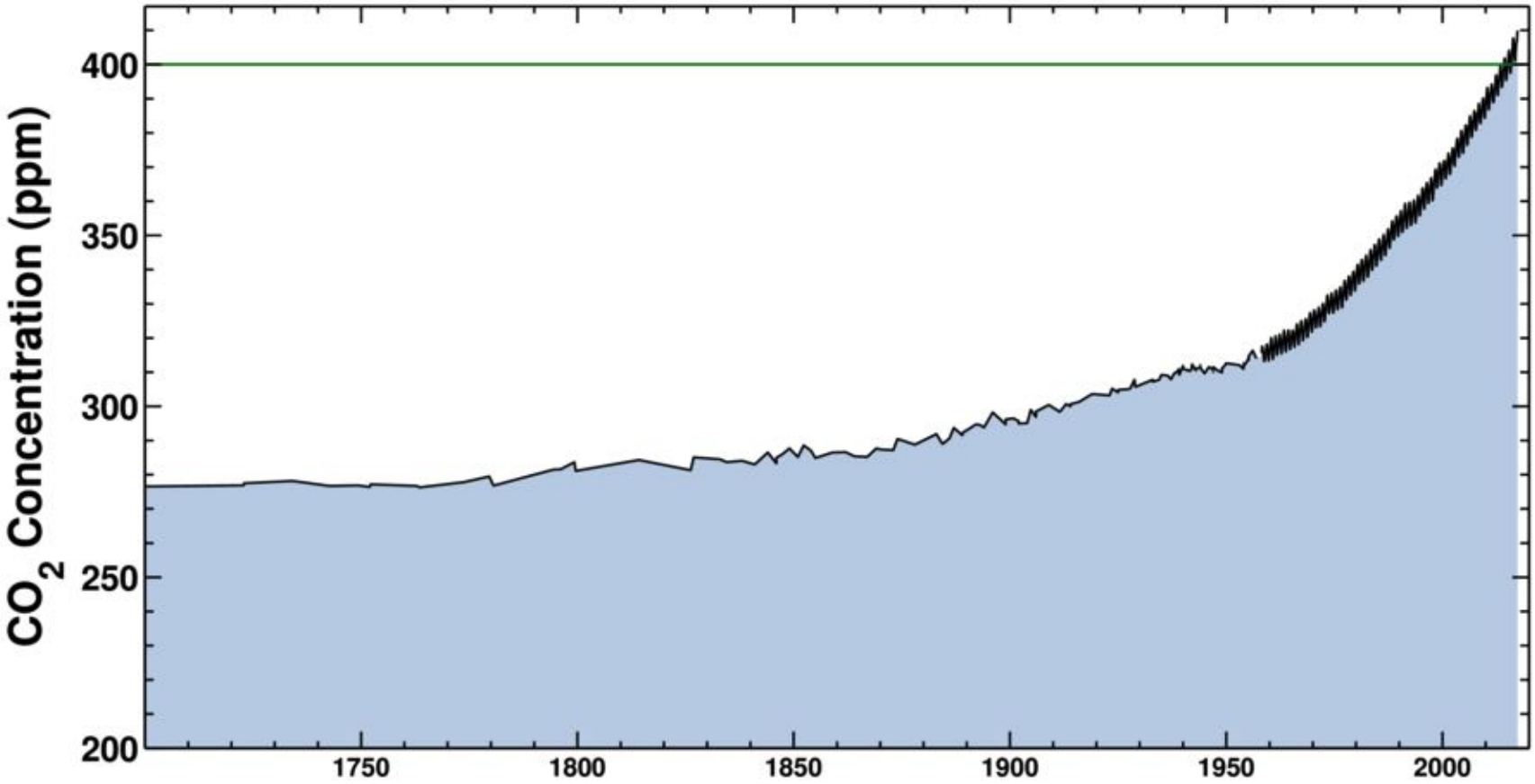
But

- Formed over millions of years
  - Coal from dead plant material, oil and gas from dead marine organisms
- Easily accessible sources depleted in just a century
- New sources difficult, expensive, environmentally damaging
  - Arctic, seabed, tar sands, shale

Burning emits carbon dioxide – over 30 billion tonnes per year

- Gas emits about half as much carbon dioxide as coal and oil

Increasing carbon dioxide



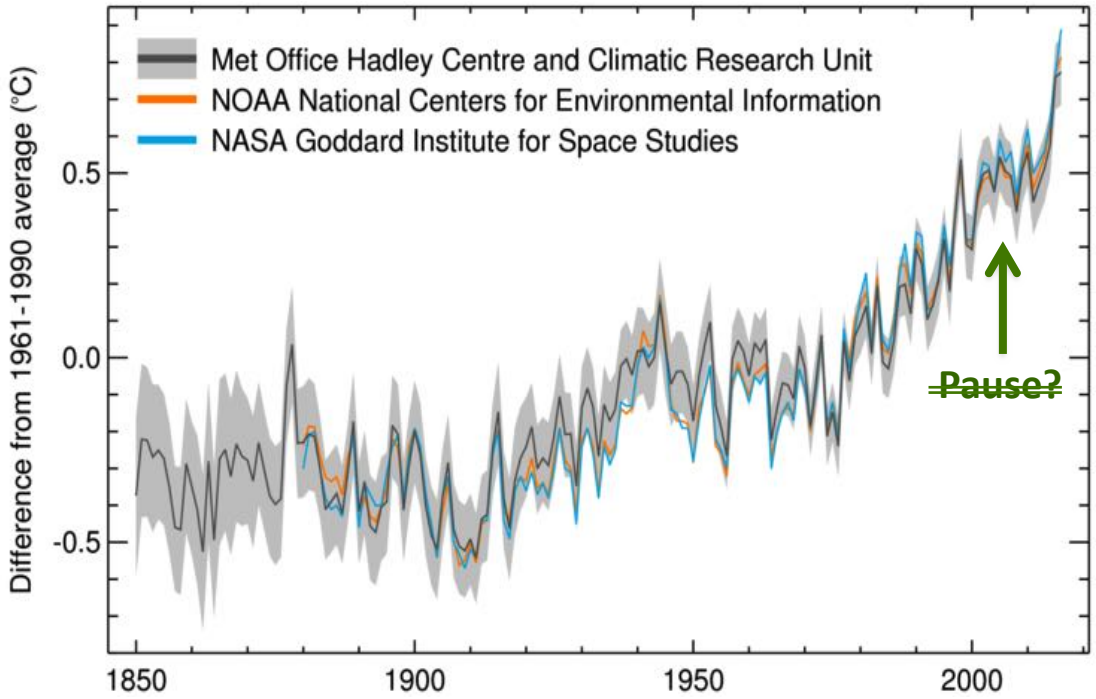
Pre-industrial level: **280 ppm**

Current level: **400–410 ppm**, up by 45%, mostly from burning fossil fuel

Higher than for 3–5 million years *and still rising*

Methane has also increased, from **0.7 ppm** to **1.8 ppm**

Global warming



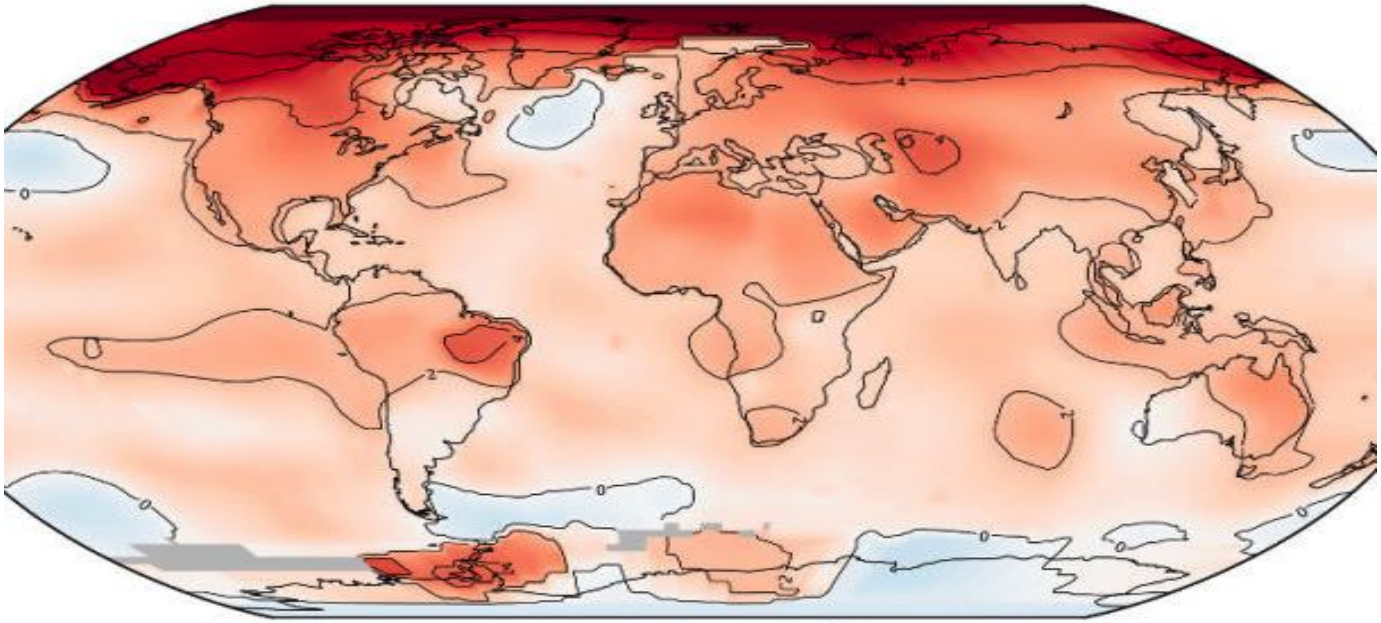
Temperature rise isn't smooth due to factors such as El Niño. However …

- 2016 was warmest year on record – third record in a row
- 16 warmest years have all been since 1998
- Now about 1.1°C above pre-industrial temperature

No one has convincingly explained the rise without taking increased carbon dioxide and methane from human activity into account

- How could we add so much greenhouse gas *without* having an effect?

Temperature rise map



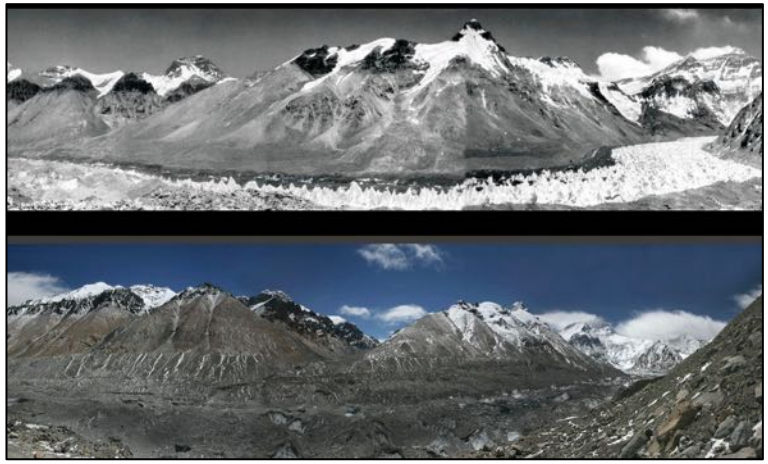
2016 mean surface temperatures (baseline 1951–1980)

Increase not uniform – Arctic has already warmed by more than 2°C

Important factor in disrupting normal weather patterns and causing increase in extreme weather

Evidence for climate change

Muir Glacier, Alaska: Aug. 1941 and Aug. 2004

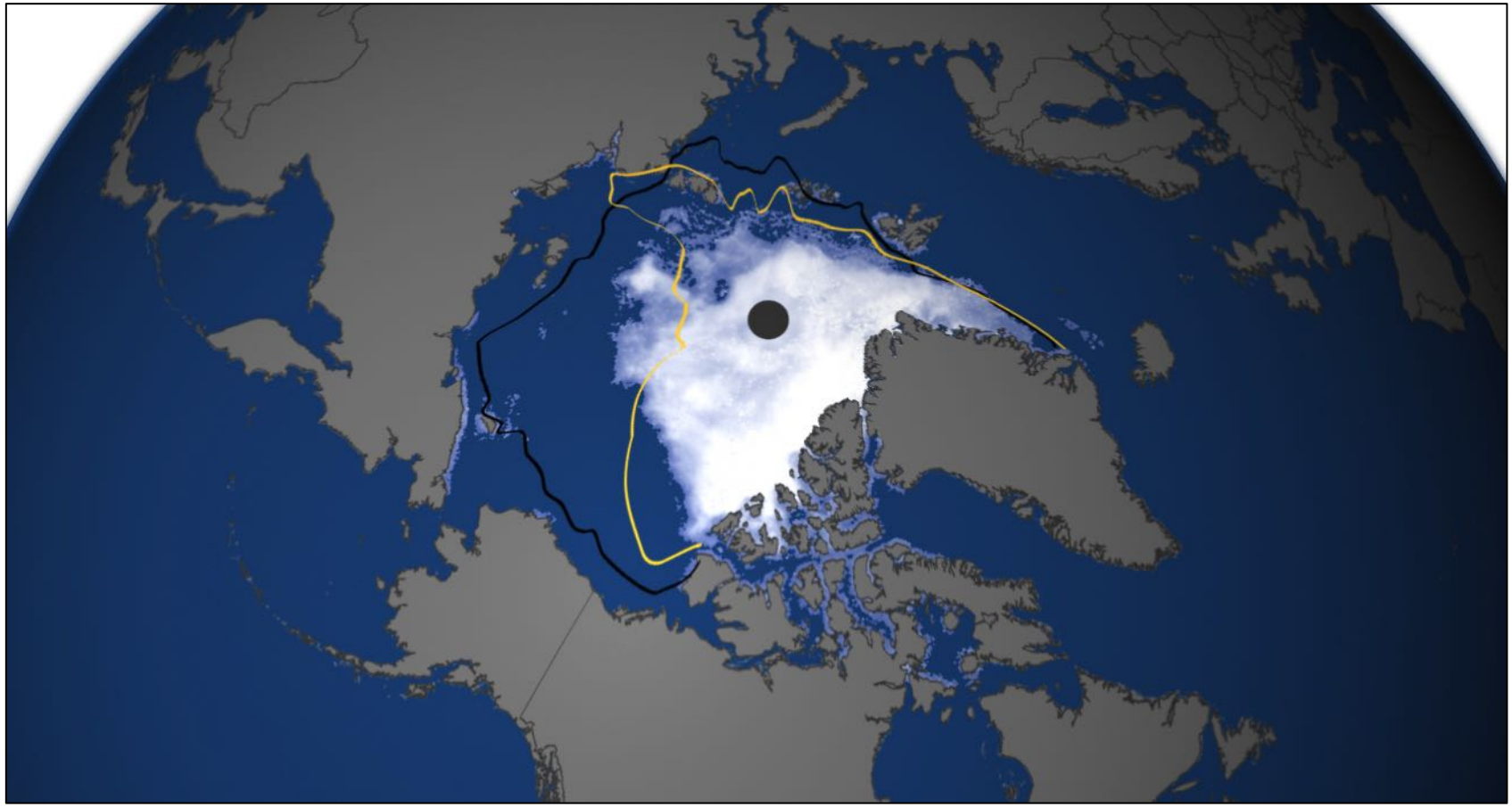


Rongbuk Glacier, Tibet: 1921 and 2008

Rhone Glacier, Switzerland: 1870 and 2006

Kirkenes, Norway (70°N), Feb. 2017: Until a few years ago, this fjord always froze in winter

Arctic sea ice

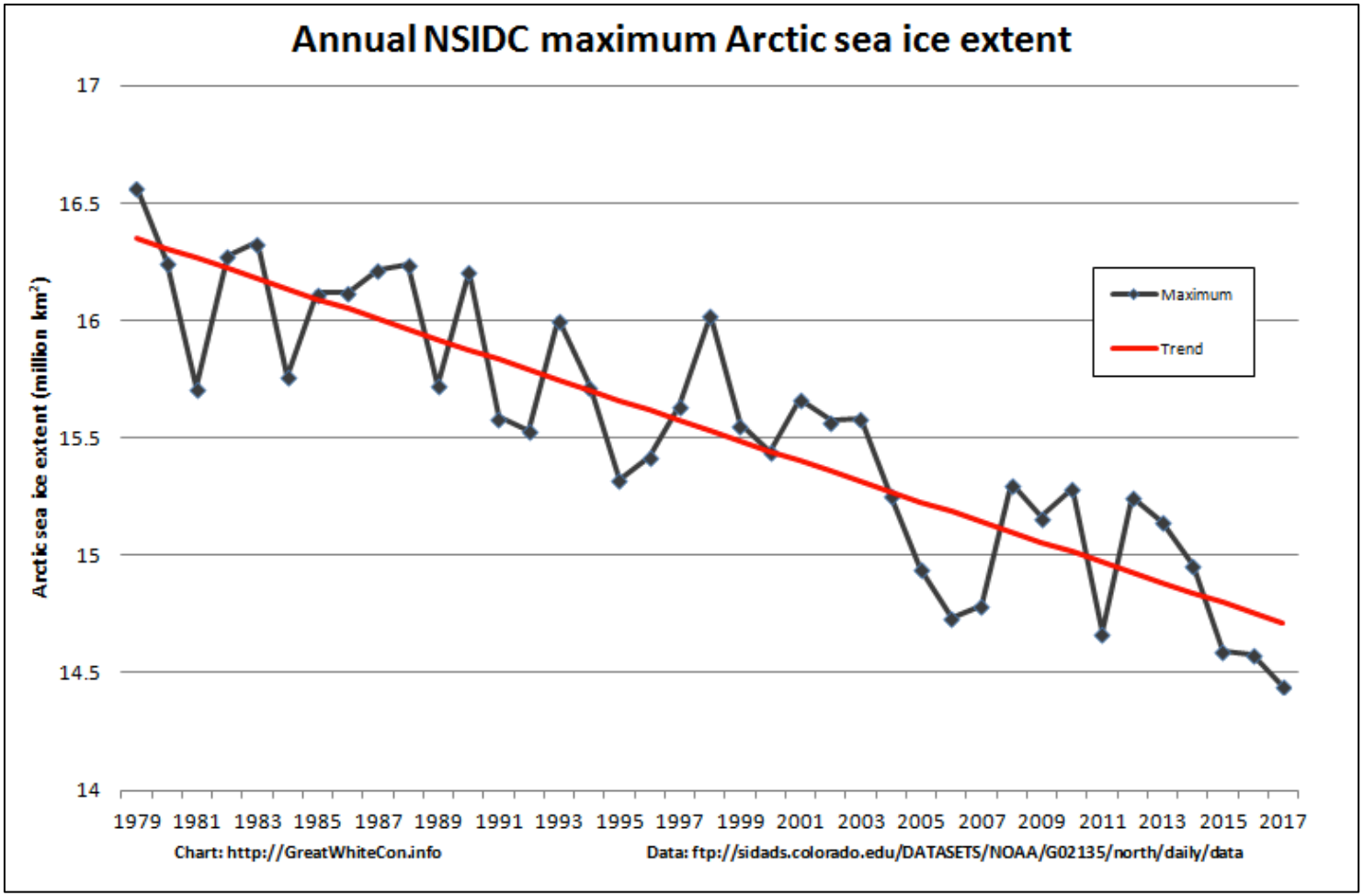


Annual *minimum* extent of Arctic sea ice in 2012, the lowest on record

(Black line is 1979–2000 average; yellow line is previous record low in 2007)

Ice has also become much thinner, so total ice volume is hugely reduced

Arctic sea ice (cont'd.)



Annual *maximum* extent of Arctic sea ice – 2017 was lowest on record

Feedbacks

Warming causes even more warming: examples

Arctic snow and ice cover reduced

- Ice and snow reflect most sunlight back into space
- Open water and bare ground reflect less and absorb more energy
  - So the Arctic has warmed more than elsewhere

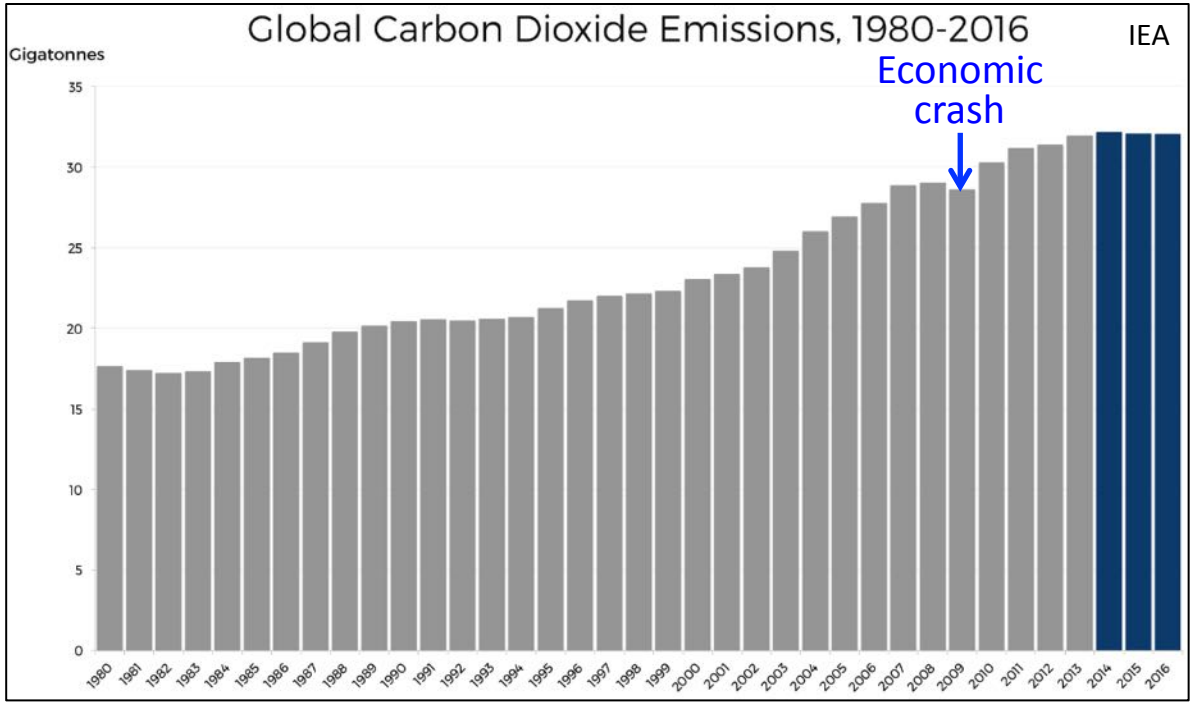
Melting of permafrost (notably Siberian peat bogs)

- Decaying organic matter emits huge amounts of methane
  - Methane is a more potent greenhouse gas than CO_2

Very difficult to predict feedbacks accurately

Frequently asked questions

CO_2 emissions have recently stabilised – isn't that enough?



- ***No.*** CO_2 remains in the atmosphere for centuries, so the total amount keeps rising
- Flat emissions are welcome progress, but emissions must go to ***zero***

Frequently asked questions (cont'd.)

Climate change has happened before and life survived – what's the problem?

- Current temperature rise is *much* faster than in the past
- Interdependent society of 7.5 billion people

- Abrupt climate changes in the past caused *mass extinctions*
  - Permian extinction ('the Great Dying'), 250 million years ago, was the worst – over 90% of species lost
  - Enormous volcano emitted huge amounts of CO_2
  - Warming led to huge methane release, causing runaway greenhouse effect

Effects of global warming

Caution: Distinguish between *climate* and *weather*

- Weather is very variable, and extreme events can occur
- Warming makes extreme weather more likely
  - e.g. 'once per hundred years' flooding becomes more frequent
- Can't say an individual extreme event was 'caused' by global warming – only that warming made it more likely and/or more extreme

Yorkshire? Scottish champagne?

The effects of global warming are complex – not just a uniform temperature rise

- Some regions (e.g. northern Canada) might benefit, with warmer weather and longer growing seasons

Higher temperatures

Many areas will get substantially hotter

- Above 40°C and even 50°C – dangerous for health
- Increase in severe droughts, due to higher evaporation rates
- Decrease in crop yields
  - Major food-growing areas could become semi-desert
- Increase in wildfires

Valparaiso, Chile (2014)

Arctic has already warmed more than anywhere else

- Ecosystem upset
  - Some species decrease, others increase, food chain disrupted
- Winter 2016/17 heat wave – up to 15°C above normal, melting permafrost on Svalbard, etc.

Melting glaciers

Mountain glaciers shrunk by over 50% in past century

- Melting accelerated since 1995
- Glaciers store winter snowfall, and provide water in summer for drinking and crops
- Without glaciers, would have spring floods from snow melt and dry rivers in summer

- Example
  - Himalayas and Hindu Kush feed Asia's biggest rivers: Ganges, Indus, Brahmaputra, Yangtze, Mekong and Yellow
  - Tibetan plateau is warming much faster than elsewhere in Asia
  - Loss of Himalayan glaciers could affect more than 2 billion people, in India, Pakistan, Bangladesh, Nepal, China, Myanmar, Vietnam, Cambodia, Laos and Thailand

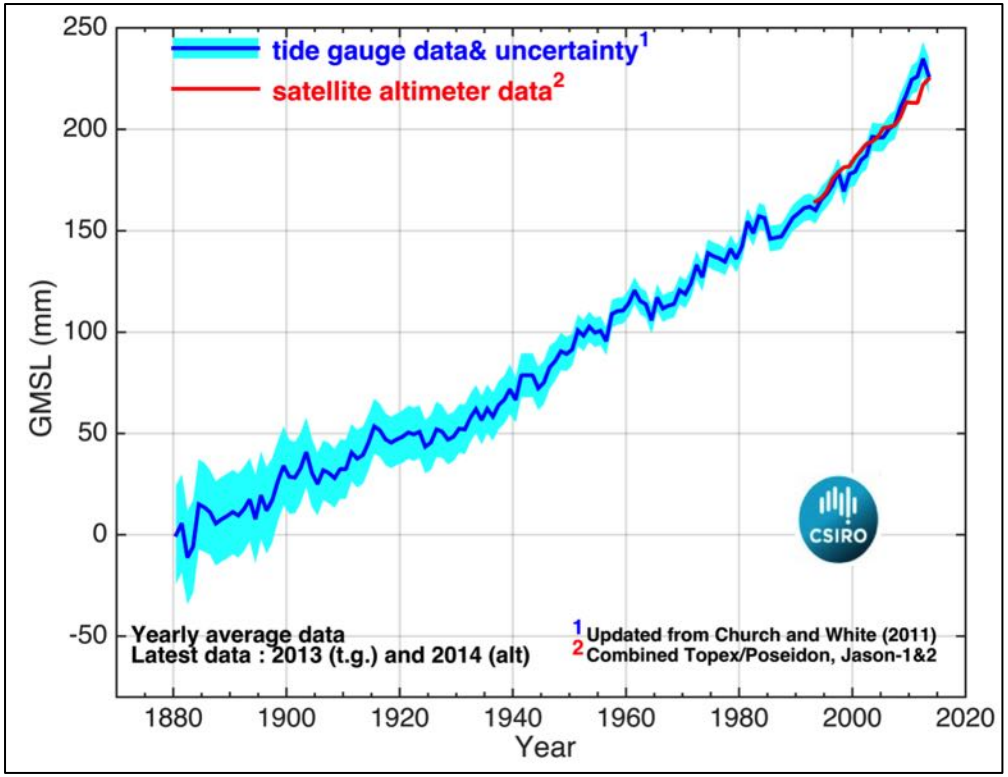
Rising sea level

Main causes

- Thermal expansion of seawater above 4°C, due to rising temperature
- Increased melting of *land*-based ice (glaciers and ice sheets) – notably Greenland and Antarctica
  - Melting *sea* ice does not raise sea level

How much?

- 23 cm since 1880, but recently increased to 3.4 mm/year
- Projection for 2100 is 0.5 m rise, but depends on CO_2 emissions – might be 1 metre or more



Rising sea level (cont'd.)

What's clear

- Destructive storm surges push further inland, causing flooding and damaging infrastructure
- Many coastal cities, and some countries and islands, could become uninhabitable
  - e.g. Bangladesh, Maldives

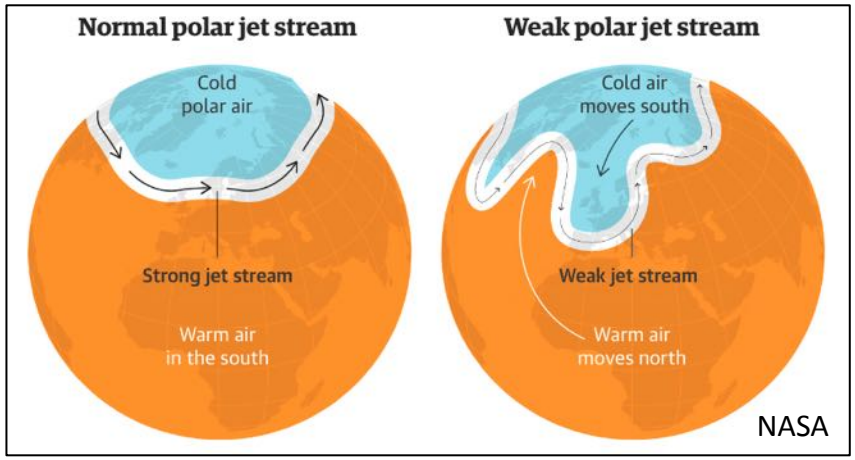
Flooding due to storm surge of Hurricane Sandy, New York (2011)

But it might be worse

- Ice sheet melting may be triggered in coming decades, adding 7 metres from Greenland and 2–4 metres from West Antarctica
- Changes in ocean circulation might shut down the Gulf Stream

North polar jet stream

- Fast-moving band of air, between cold Arctic and warmer temperate air
  - 6–10 km altitude, 200+ mph winds
  - Largely driven by temperature difference
- Arctic heating up faster than further south – smaller temperature difference weakens jet stream and produces bigger loops



- A jet-stream loop south of the UK can trap cold Arctic weather. A loop north of the UK can trap warm air from the tropics
  - Loops can be stuck in place for weeks, rather than being blown eastwards as in the past – so extreme but stable weather possible

Snow in Blewbury (2010)

Weather patterns

- Heat waves and droughts increase in number and severity
- More heavy precipitation – warmer air can hold more water vapour
- Some areas become much wetter, others drier
- Violent storms will be more severe and frequent, so more frequent flooding
- In the UK, wetter and stormier winters but hotter, drier summers

Some ecosystems won't adapt to changes, and many species would become extinct

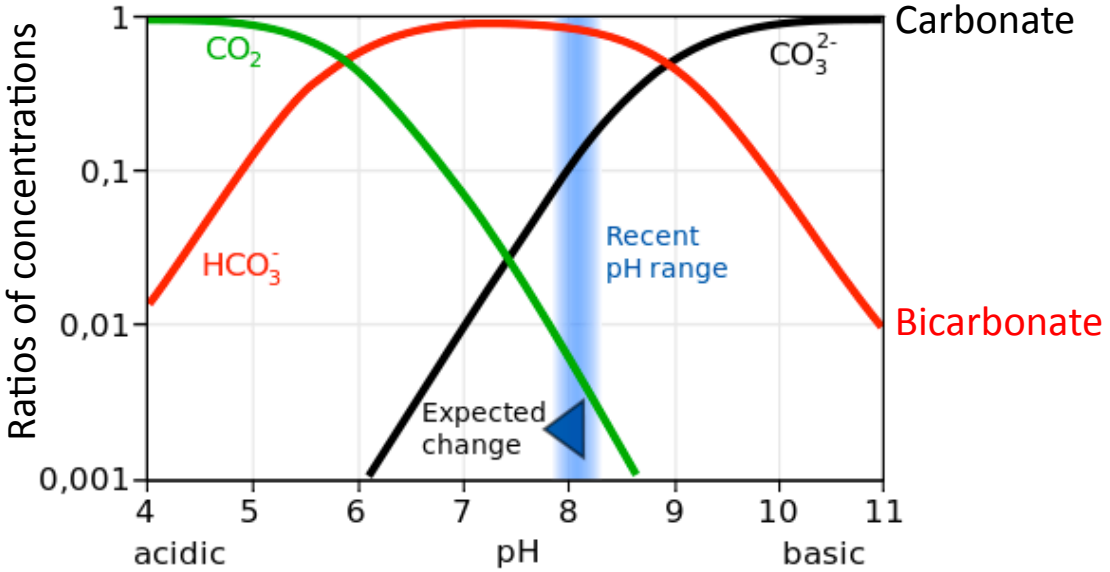
Extreme weather impacts harder on people in poor-quality housing and/or lacking essential infrastructure and services

Many of the effects mentioned could lead to mass migrations – where will they go?

Ocean acidification

‘Global warming’s evil twin’

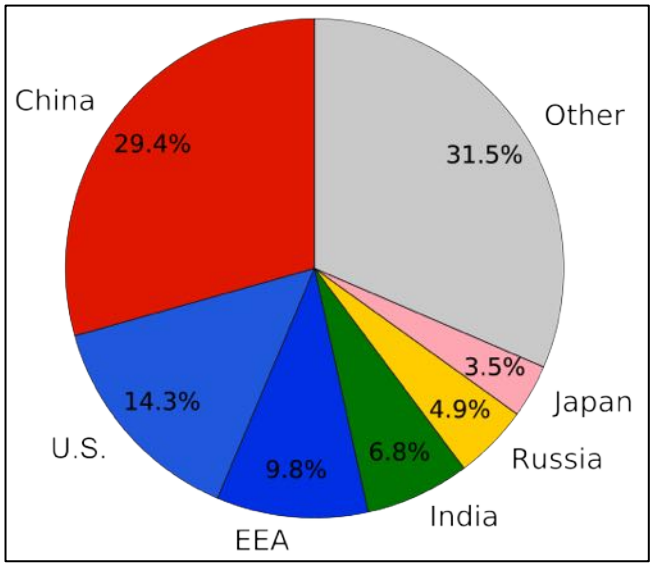
- Wide variety of sea life – shellfish, and phytoplankton crucial to the food chain – use carbonate ions in sea water to manufacture their shells
- Increase in CO_2 dissolved in the oceans. Reacts with water to make carbonic acid, which turns carbonate ions into bicarbonate
  - Ocean pH has already decreased from 8.2 to 8.1: 25–30% rise in acidity
- High CO_2 emissions to 2100 might reduce pH by 0.4 to 7.7 – 150% increase in acidity, the highest for millions of years
  - Harder to build shells, and existing shells might partially dissolve
  - In the Permian extinction, acidification was probably why 95% of marine species were wiped out



Paris Climate Agreement

Agreed December 2015 within UN Framework Convention on Climate Change

- Signed by 195 countries and EU
- Ratified (so far) by 169 – UK in Nov. 2016
- In June 2017 US announced it will withdraw



CO_2 emissions by country

What it does

- Countries set their own targets
  - No mechanism to force specific targets by specific dates, or to reach those targets
- Provides $100 billion per year, from 2020–2025, to aid developing countries with climate change adaptation and mitigation

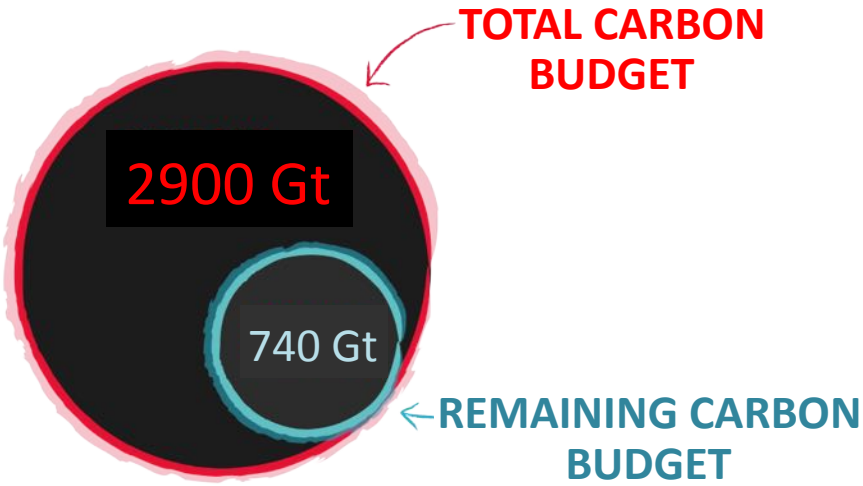
Aims to limit warming to less than 2°C, and to try to keep it to 1.5°C

- However, agreed contributions would only limit warming to about 2.7°C – even if all countries honour their promises

Carbon budget

How much more fossil fuel can we burn for a 2°C limit?

- To stay below 2°C, IPCC's estimated 'budget' for CO_2 emissions since industrial revolution is about **2900 gigatonnes**
- We've already emitted about **2160 gigatonnes**, mainly from fossil fuels, so 75% of our budget is used up
  - Emissions steady at current level would hit the limit in about 19 years
- Proven fossil fuel reserves are 3 to 7 times the remaining budget, with huge investments to find more
- Most reserves of coal, oil and gas **must remain in the ground** – pressure for change from **fossil fuel divestment campaign**



Renewable energy

Onshore wind

- Now a cheap electricity source
  - Led by China, US, Germany, India, Spain, Denmark

Offshore wind

- Big drop in cost, now affordable
  - Led by UK and Germany

Solar photovoltaic

- Now a cheap electricity source
  - Led by China, Germany, Japan, US

Concentrating solar

- Works best where very sunny
  - e.g. Spain, south-west US, Morocco

Solar thermal

- Inexpensive and widely used for domestic hot water heating

Westmill wind and solar co-op, Watchfield, Oxon

Andasol 150 MW concentrating solar power plant (parabolic troughs, molten salt) near Guadix, Spain

Renewable energy (cont'd.)

Hydro

- Large-scale using big dams
- Small-scale using weirs, etc.

Tidal power

- Tidal barrage – e.g. Rance estuary at St. Malo; barrage blocks entire estuary mouth
- Tidal stream – e.g. trials in Scottish islands; like wind turbines but underwater
- Tidal lagoon – e.g. plans for Swansea Bay

Biomass and biofuels

- Wood, ethanol, biodiesel and biomass crops
- For heating, transport, electricity generation
- Beware of effects on food crops and forests

Anaerobic digesters

- Dispose of agricultural and food waste
- Methane biogas, for electricity or heating

Osney Lock Hydro, Oxford

Proposed Swansea Bay tidal lagoon

Agrivert food-waste digesters and 2.4 MW generators, Crowmarsh, Oxon

Intermittent renewables

Wind and solar are not totally predictable

- Used to think the grid could only handle 20–30% wind and solar, but now looking at much more, e.g. 50–75%
  - Denmark already gets about 40% from wind

Need diverse mix of renewables

- Some gas needed until new technologies for generation and storage developed

Wide area grid with long-range interconnectors

- Existing links to France and Netherlands; new ones being built and planned
- Averages out weather and shares technologies (e.g. French nuclear, Norwegian hydro, UK wind)

Long-range interconnectors

Smart grids and responsive reserves

- Shifting from centralised generation to local microgeneration
- Requires some generators that can be switched on and off rapidly, *not* always-on sources like nuclear *(very expensive, slow to build, problems)*

Intermittent renewables (cont'd.)

Load management

- Smart charging for electric cars
- Smart appliances
- Many other possibilities, from industrial to domestic

14 kWh battery for domestic solar panels

Energy storage

- Batteries – for solar, wind and electric cars
  - Integral part of some new wind and solar farms, e.g. Clay Hill solar farm, Bedfordshire
  - Need cheaper, safer, higher capacity types of batteries
- Pumped storage hydro
  - e.g. Dinorwig in Wales and Cruachan in Scotland; others being built

Using renewable energy (solar or wind) when not needed for grid

- Compressed air storage, flywheels, supercapacitors, etc.
- Power-to-gas: electrolyse water to produce hydrogen
  - For vehicles, or gas mains (direct, or combine with CO_2 for methane)

Reducing energy use and emissions

Energy efficiency (also saves money)

- Zero-carbon new buildings
- Insulate old buildings
- LED lighting: efficient and long life
- Efficient heating: heat pumps, district heating, combined heat & power

Transport (also reduces air pollution)

- Electric vehicles: develop better batteries
  - Hydrogen fuel cells?
- Better public transport

Air-source heat pump, Arctic Norway (70°N)

Lifestyle changes (also healthier)

- Walk or cycle for short distances
- Reduce food waste
- Eat less (or no) meat – especially beef and lamb
- Choose longer-lasting products; 'repair, reuse, recycle'

UK situation

General

- Must reduce emissions 57% by 2032, 80% by 2050 (base 1990)
- Started well (e.g. feed-in tariffs), but huge, abrupt subsidy reductions – especially solar
- New onshore wind stopped, despite low cost
- Only encouraged renewable is offshore wind
- Community energy projects not strongly supported (unlike Germany)
- Dept. of Energy & Climate Change abolished
- Coal being phased out by 2025 – good!

Housing

- Need to insulate millions of old, leaky houses
- Green Deal failed, but not (yet?) replaced
- New houses zero-carbon from 2016 dropped

Painting by Leah Saulnier

Government manifesto had *no* new policies

Required report on meeting carbon reduction targets was due in 2016

UK 'Clean Growth Strategy'

Finally appeared October 2017 – some main points

- Aim: all fuel-poor and privately rented homes upgraded to EPC Band C by 2030, and as many other homes as possible to Band C by 2035
  - '… where practical, cost-effective and affordable'
  - No indication how this would be achieved
- End sale of new conventional petrol and diesel cars and vans by 2040
  - Subsidise cost of new electric vehicles, expand charging network
  - Improved taxis, buses and lorries

- Nuclear beyond Hinkley Point C at a 'competitive price'
- Support for research on energy storage, smart grids, carbon capture, future nuclear, cost of renewables, greener agriculture

Positive step, despite information missing and past failures ignored

Outlook

From an article by Lord Nicholas Stern:

(Author of the Stern Review on the Economics of Climate Change)

"The basic scientific conclusions on climate change are very robust. The greenhouse effect is simple science. Humans are emitting ever more greenhouse gases. … The logic of the greenhouse effect is rock-solid. The long-term trends [due to] human emissions are clear in the data.

"The arguments from those who would deny the science look more and more like those who denied the association between HIV and AIDS, or smoking and cancer."

Outlook (cont'd.)

Reasons for pessimism

- Temperature rise 1.1°C already, so 1.5°C unlikely, 2°C difficult; 2.7°C if Paris Agreement commitments honoured
- Trump, and politicians in general
- Many other urgent global problems
- Vested interests and comfortable lifestyles
- Lack (so far) of a good solution for planes, ships, etc.
- *Huge migrations likely – especially from poorer areas – to where?*

Reasons for optimism

- Paris Climate Agreement
- Positive attitudes of many countries, progressive companies, governments (e.g. individual cities) and much of the population
- Coal consumption dropping rapidly (near zero in UK)
- Renewables becoming affordable and mainstream

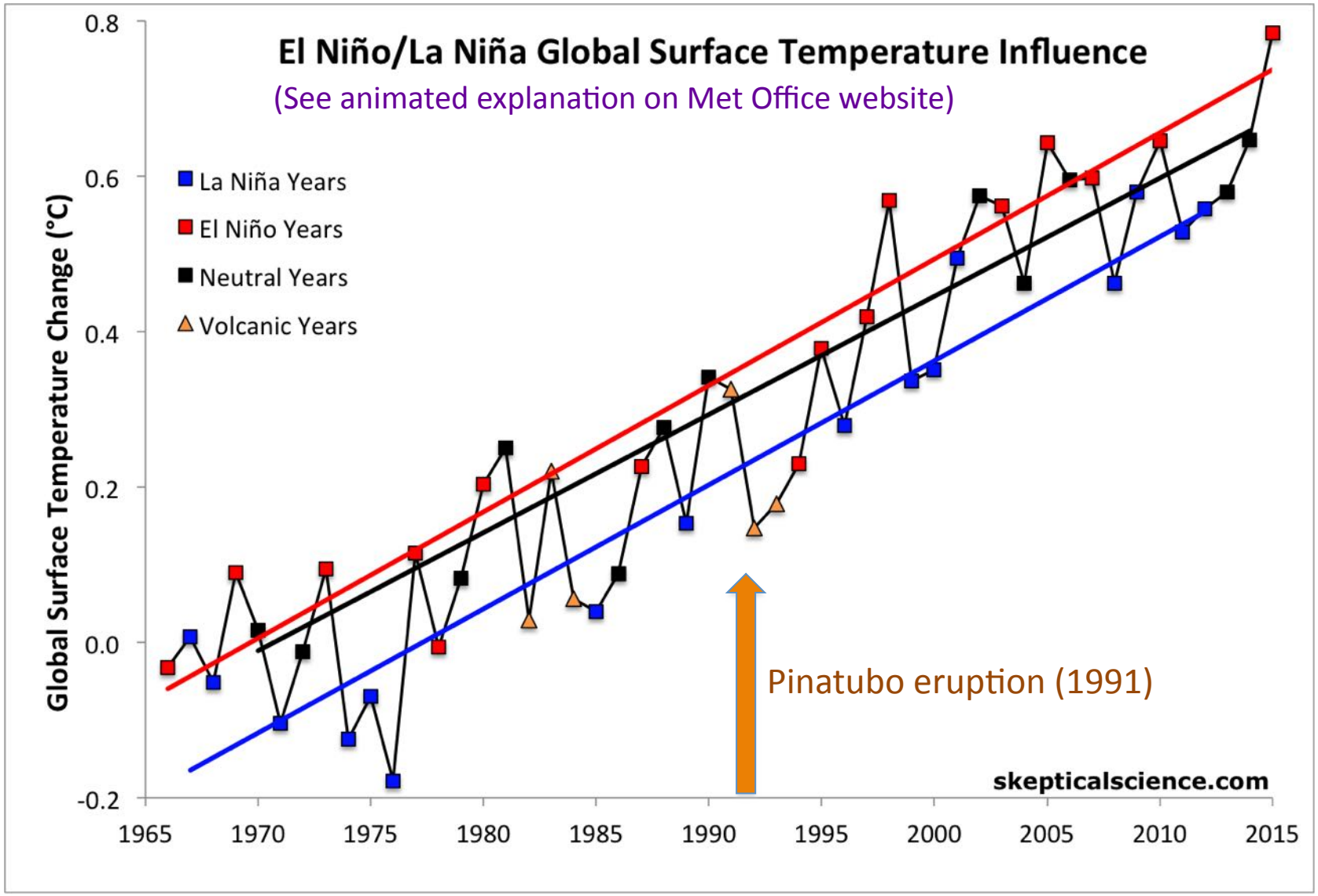
Supplementary slides

Planetary boundaries

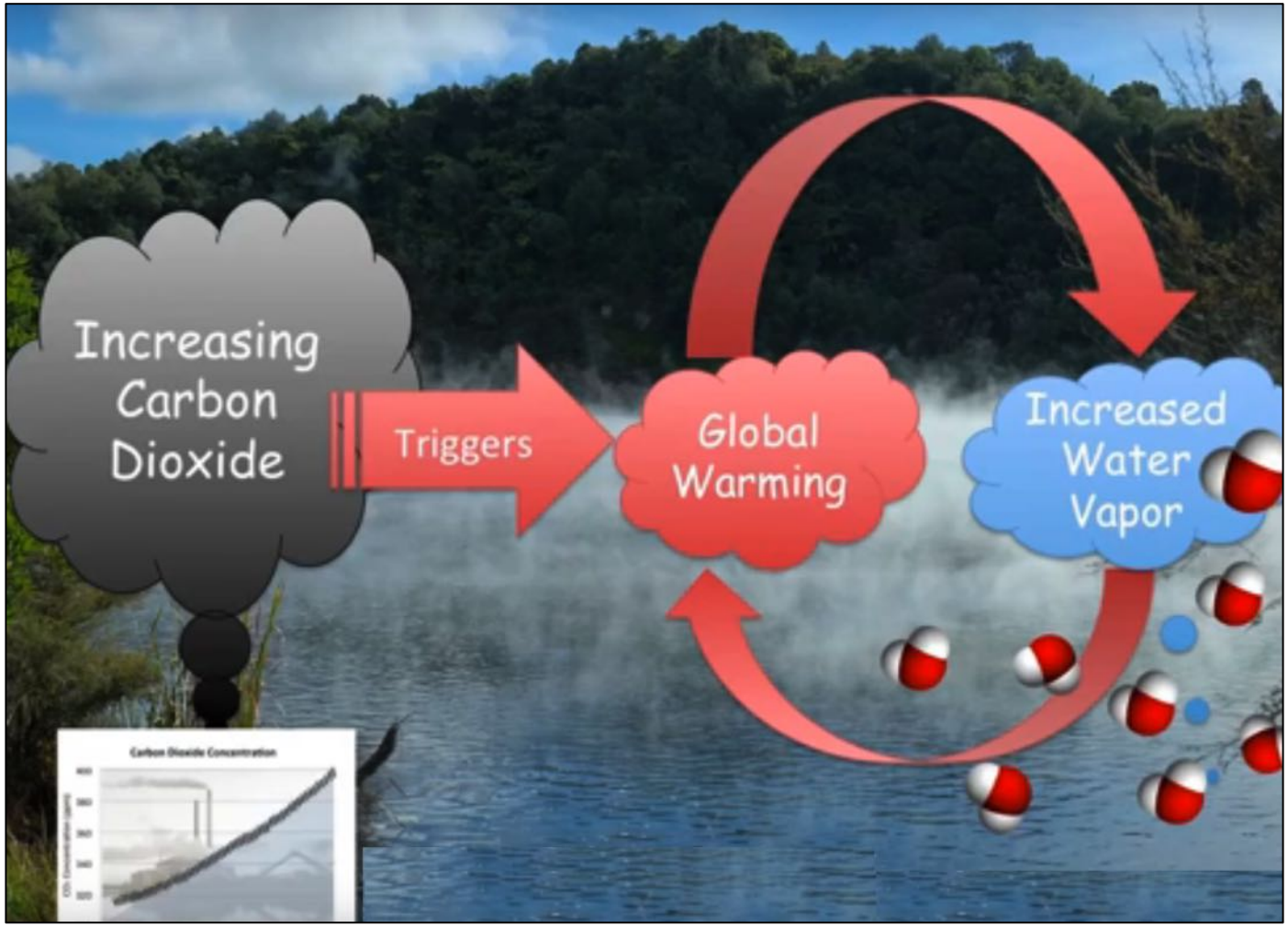
Changes that might trigger tipping points (Stockholm Resilience Centre)

- Stratospheric ozone depletion
  - Example of SUCCESS!
- Change in biosphere integrity
  - Biodiversity loss and extinction
- Ocean acidification
  - Related to climate change
- Nitrogen and phosphorus cycles
  - Farming
- Land-system change
  - e.g. deforestation
- Freshwater use
  - Depletion and pollution of water supplies
- Atmospheric aerosol loading
  - Microscopic particles that affect climate and living organisms
- Introduction of novel entities
  - e.g. chemical pollutants, radioactive materials, nanomaterials and micro-plastic
- **Climate change**

Influence of other factors



Feedbacks

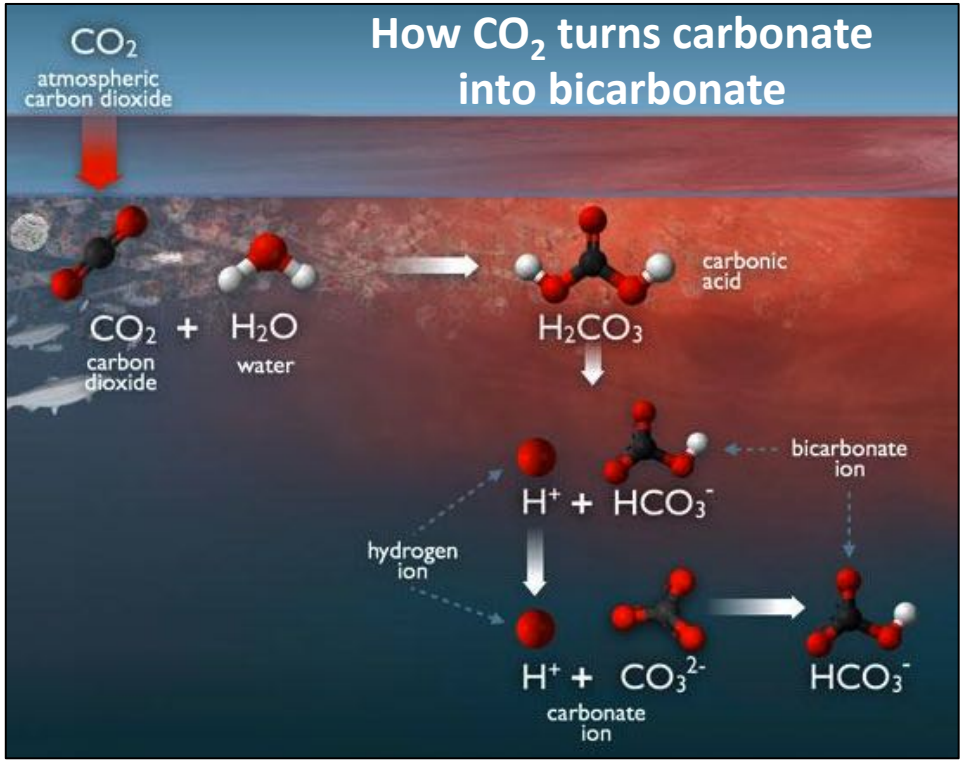


Water vapour is a greenhouse gas. If added CO_2 raises air temperature by 1°C, the air can hold more water vapour – causing a further 1°C rise

Ocean acidification

'Global warming's evil twin'

- Amount of CO_2 dissolved in the oceans is increasing. It reacts with water to make carbonic acid, and ocean pH has decreased from 8.2 to 8.1 – a 30% rise in acidity
- Carbonic acid turns carbonate ions into bicarbonate ions



Fossil fuel divestment

Keep it in the ground

- Proven fossil fuel reserves 3 to 7 times more than remaining budget; unproven reserves still larger
- Therefore, most reserves of coal, oil and gas ***must remain in the ground***, unless we can capture and store CO_2 generated when it's burned
  - Carbon capture is problematic and progress slow
- Huge fossil fuel investments could become worthless, which might de-stabilise the global financial system
- Divestment campaign aims to shame and influence fossil fuel company managements into rethinking plans
- Almost 800 institutions, with funds worth over $5.5 trillion, have made a divestment commitment

Nuclear power

Nuclear power is *low* carbon, not *no* carbon (uranium extraction and enrichment, waste disposal, reactor decommissioning, …)

The longstanding problems

- Much higher costs than predicted, and heavily delayed timescales
- 'Mature' technology, but still demands subsidies, e.g. in UK
- Waste disposal keeps being put off
- Reactor decommissioning difficult and cost keeps rising
- Safety – few accidents, but catastrophic
- Nuclear weapons proliferation
- Countries phasing out nuclear, e.g. Germany, Switzerland, Japan, S. Korea

No longer what's needed to provide backup for renewables

- Nuclear now much more expensive than renewables; the gap will widen
- Can't be switched on or off quickly, which is what's now needed
  - Running nuclear 24/7 for baseload would be very expensive

Nuclear Power (cont'd.)

Hinkley Point C is a special case, a very risky business deal and bad value for money even if it's completed and works

- The most expensive nuclear power reactors ever, and rising (Brexit etc.)
- Disastrous track record for this design – costs more than tripled, timescales tripled, and none working yet!
- UK guaranteed cost (for 35 years and indexed) too high
- EDF nearly bankrupt and no longer trying to sell this design
- Chinese partner company
- Even nuclear power enthusiasts say this will be a 'white elephant'
- National Audit Office says it's too expensive and risky

Other nuclear proposals for UK (notably Toshiba) also in trouble

Nuclear Power (cont'd.)

Many new reactor technologies promoted as having big advantages

- Safer
- Breed their own fuel
- Produce less waste and/or burn waste as fuel
- Make nuclear weapons proliferation more diffiult

But

- Need a lot of development, so at least several decades until a grid-ready solution
- Little R&D actually being done
- Tend to use very difficult technologies (e.g. liquid sodium cooling)
- Even if they work, will they be affordable and good value in a future of varied and cheaper renewables with energy storage?

Human impacts of climate change

Poor people will be the worst affected

- Worsen existing and create new poverty traps – particularly in urban areas and hotspots of hunger
- Impact on peoples' livelihoods
- Reduce agricultural productivity or cause crop failures – particularly for poor farmers in semi-arid regions
- Create water supply problems
- Increase food prices and cause food shortages
- Destroy homes
- Increase risks of violent conflicts, e.g. civil war and inter-group violence, by amplifying poverty and economic shocks
- Large areas uninhabitable

Huge migrations – especially from poorer areas – to where?