Earth’s Climate has always been changing
The planet is warming

www.metoffice.gov.uk/research/monitoring/climate/surface-temperature
Global average sea level is rising…

Satellite Altimeter data

IPCC (2013)
Figure 13.3

http://sealevel.colorado.edu/
Melting of Arctic Ice
Evidence for current climate change

“Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.” IPCC (2013)

Middle: Changes in the July-September average summer Arctic sea ice extent

Bottom: Changes in global average sea level compared with 1900-1905 average

Source: IPCC WGI (2013) SPM
Indirect (or "proxy") observations must be used to piece together past climate. These help us to understand how climate has changed in the past and put current direct observations (top right) in context.

GLOBAL, proxies, Marcott et al. (2013) Science

IPCC (2013) Tech. Summary, Box TS.5

Northern hemisphere proxies

GLOBAL, Instrumental

GLOBAL, proxies, Marcott et al. (2013) Science
Climate change over last 800,000 years

- CO₂
- Antarctic Temperature
- Ice volume proxy
- Sea level

Modern humans

Africa Exodus
Europe
Agriculture

IPCC (2013) Chap. 5 Fig 5.3

400 ppm
Is the warming unusual?

- Over the last 100 years the globe has warmed by around 0.8°C
- 1983-2012 likely the **warmest 30 year period** in N. Hemisphere in past 1400 yrs
  - Comparably warmth in last 1400 years not as coherent in space or time as now
- Last time Arctic was warmer than today was probably **125,000 years ago**
  - Previous (very different) interglacial when sea level was 4-7m higher than today
Changes in greenhouse gases from ice core and modern data

Carbon dioxide, methane and nitrous oxide

IPCC (2007) Summary for Policy Makers Fig. SPM.1
Man-made CO₂ has diluted natural CO₂

Theoretical

Tree Ring Observations
Satellite observations detect enhanced greenhouse effect: 1997-1970

Harries et al. 2001, Nature

These results showed for the first time experimental confirmation of the significant increase in the greenhouse effect from trace gases such as carbon dioxide and methane.
Attributing causes of climate change

• How much of recent warming is explained by natural effects?
• To answer such questions, experiments can be performed with climate simulations
  – including just natural factors (ocean circulation, volcanic eruptions, changes in the sun, ...)
  – including natural and anthropogenic factors (e.g. greenhouse gas emissions which cause heating + sulphate aerosol pollutant particles which cause cooling)
Natural factors cannot explain recent warming

See IPCC FAQ 10.1 and SPM Fig. 6
Recent warming can be simulated when man-made factors are included. See IPCC FAQ 10.1 and SPM Fig. 6.
“Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.” [IPCC 2013 SPM]

IPCC (2014) **WG1 Summary for Policy Makers**
Change in average surface temperature (1986–2005 to 2081–2100) RCP 8.5 Scenario
European 2003 summer temperatures could be normal by 2040s, cool by 2060s
Long-term commitment to sea-level rise

CO$_2$ increases stops here

Mid/low emissions scenario: RCP4.5

Golledge et al. (2015) Nature
Arctic sea ice extent is projected to diminish over the 21st century.

94% decrease in September and 34% decrease in February for the RCP8.5 scenario.

IPCC (2013) WG1 Fig. 12.29
Projections of the water cycle

- Increased Precipitation
- More Intense Rainfall
- More droughts
- Wet regions get wetter, dry regions get drier?
- Regional projections??

IPCC
WGI
(2013)
Summary

• The planet is warming and this is primarily attributable to rising greenhouse gas concentrations
• Greenhouse gases at highest levels for > 800,000 yrs
• Physics of greenhouse effect well understood
• Substantial changes in global temperature and rainfall patterns are projected using computer simulations
• Predicting regional climate change is a challenge...
  – Will substantial greenhouse gas emissions continue?
  – Are “knock on effects” of warming amplifying or reducing the magnitude of change (e.g. clouds, land surface, …)?
  – Changes in atmospheric and oceanic circulations change are crucial for local impacts yet challenging to predict

See Reading MOOC on Our Changing Climate Change
Outstanding questions

• Has there been a hiatus in global warming?
• Are clouds amplifying or reducing climate change?
• How will atmospheric and ocean circulations change?

From the Mail on Sunday 16th March 2013
Has there been a hiatus in global warming?

HadCRUT4 data (plot by Ed Hawkins)
Planet Earth continues to heat up...

The planet is gaining heat at the rate of 300 trillion Watts...

Rapid surface warming

Heating due to rising greenhouse gas concentrations also influenced by aerosol pollution and natural factors e.g. volcanoes, the sun

1980s-1990s: heating of upper layers of the ocean – rapidly rising surface temperature

2000s: heating of deeper layers of the ocean – slower rises in surface temperature

Large body of research – listed on DEEP-C project website
A hiatus in global warming?

• No: the oceans have continued to warm, sea levels have continued to rise and ice is melting...

• But...natural factors have temporarily suppressed the rate of surface warming slightly
  – A slight dimming of the sun and small volcanic eruptions offset some of the heating from rising greenhouse gases
  – Ocean fluctuations rearranged where heat has accumulated
  – Climate models can simulate ocean fluctuations but are not designed to capture timings of lumps and bumps in temperature record.
  – 2014 -2016 likely to be the warmest in the instrumental record

• How much the planet will warm in response to greenhouse gas emissions mostly depends on total emissions...
Implications for projections

CMIP5 projected changes in global mean ANN temperature

From Ed Hawkins: see Climate Lab Book