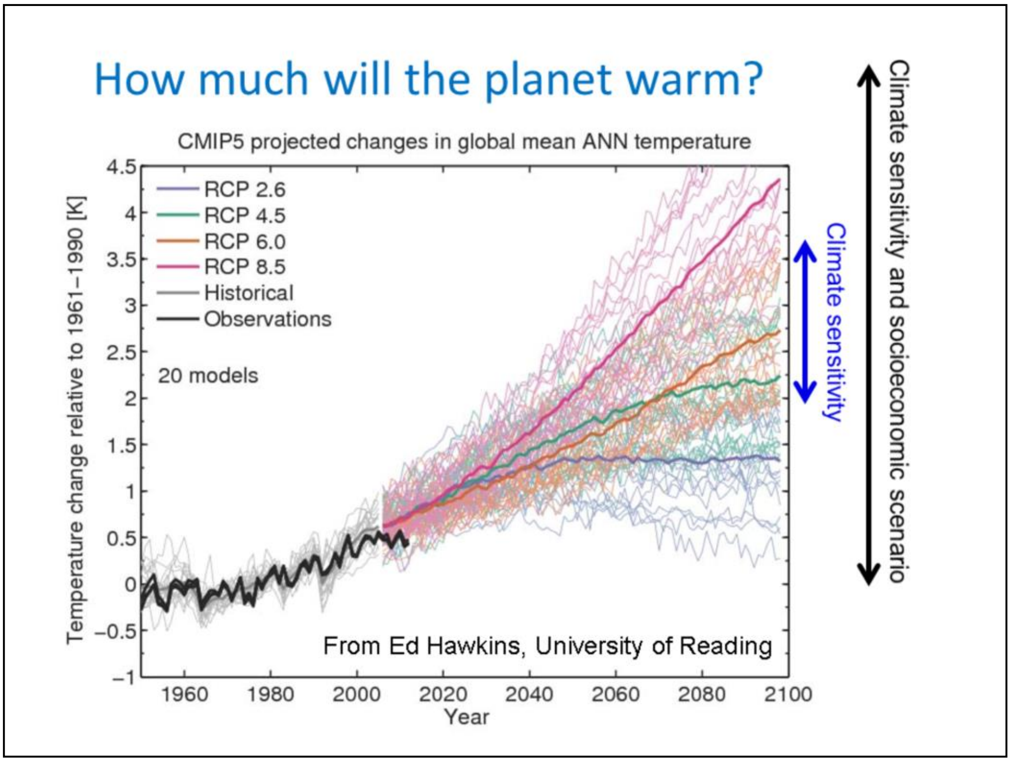
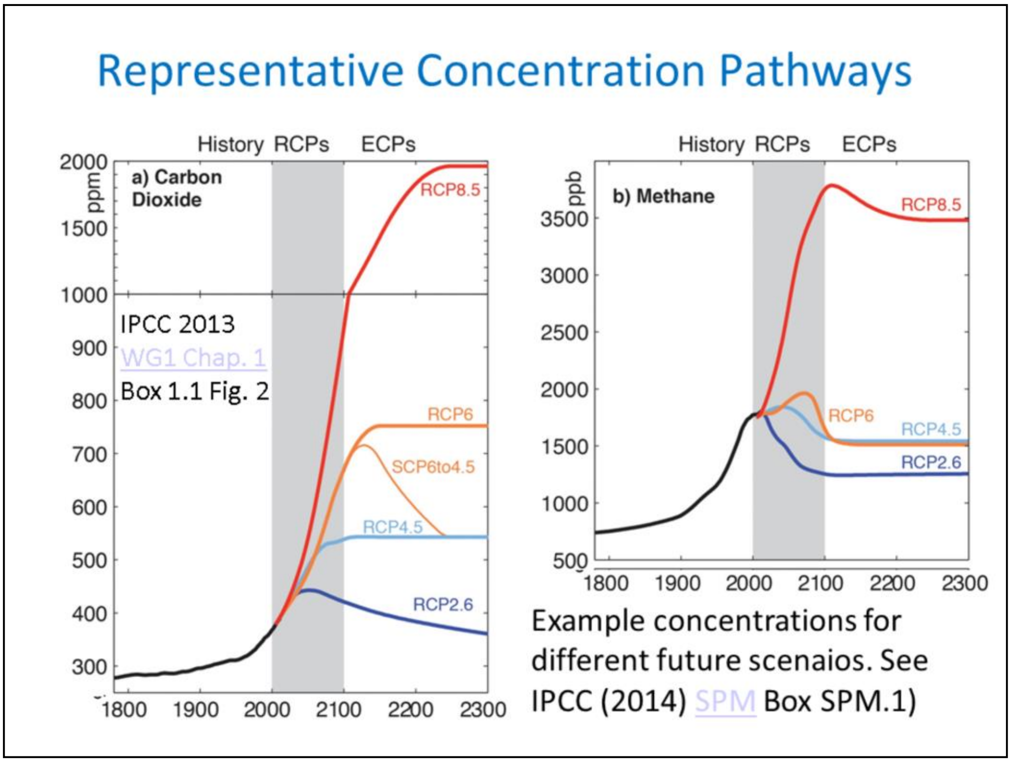


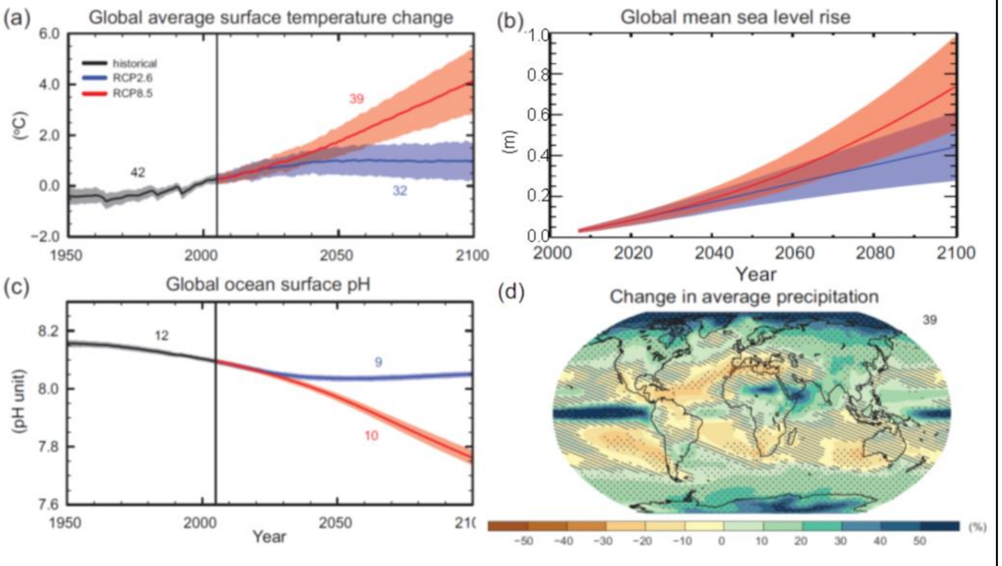
While future changes in emission are the largest uncertainty on future climate change, another important uncertainty is how sensitive Earth's climate is to a given change in greenhouse gas concentrations. Above, the thick lines show different possible future scenarios (Representative Concentration Pathways) ranging from low emission (RCP2.6) up to high emission (RCP 8.5) which explain a large range in future predicted global temperature change. Even if future emissions were known, different climate simulators generate different temperature responses due to uncertainty in re-enforcing or counteracting feedbacks.



"Long-term climate change projections require assumptions on human activities or natural effects that could alter the climate over decades and centuries. Defined scenarios are useful for a variety of reasons, e.g., assuming specific time series of emissions, land use, atmospheric concentrations or radiatve forcings across multiple models allows for coherent climate model intercomparisons and synthesis." IPCC (2014) Box 1.1.

Representative Concentration Pathway (RCP) scenarios used in the IPCC (2014)report specify concentrations and that lead to varying degrees of heating (or cooling) in the future and work out the corresponding emissions (of CO_2 or methane for example) that meet these future pathways. RCP8.5 is a high emissions scenario and RCP2.6 is a scenario in which there is aggressive policy in place to reduce greenhouse gas emissions.

Future projections to 2100 from climate models



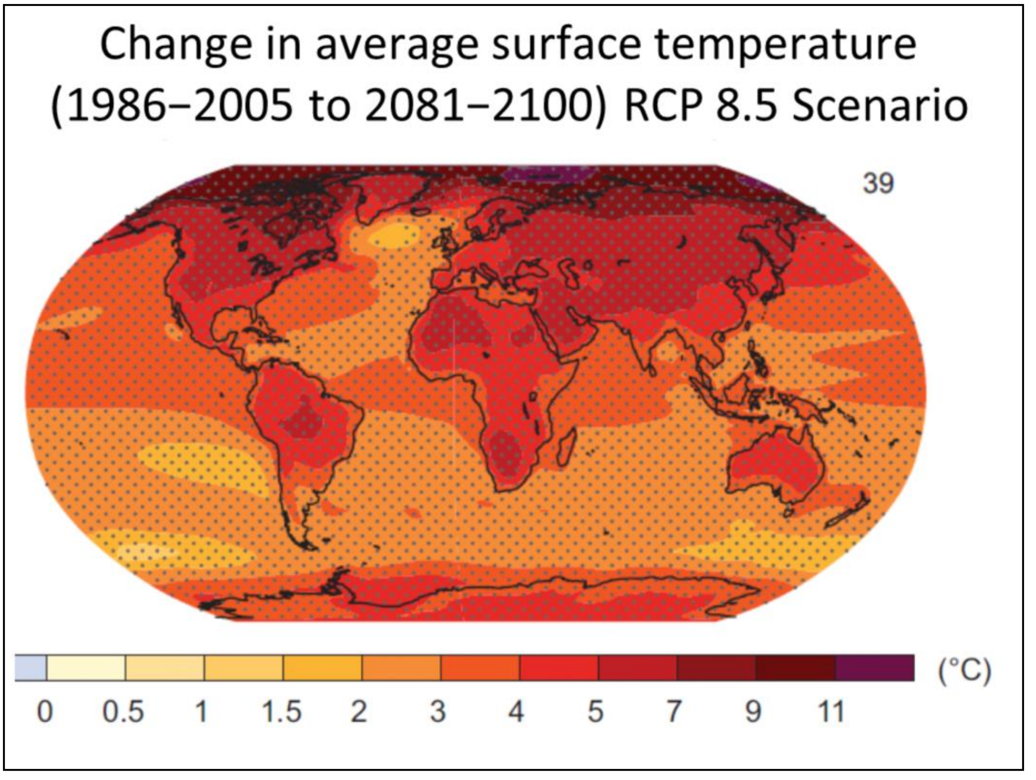
IPCC (2014) WG1 Summary for Policy Makers

Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be in the ranges 0.3°C to 1.7°C for the lowest emissions scenario (RCP2.6) and 2.6°C to 4.8°C for the highest emissions scenario (RCP8.5). The Arctic region will warm more rapidly than the global mean, and mean warming over land will be larger than over the ocean.

Global mean sea level rise is projected to range from 0.52 to 0.98 m by 2100 for RCP8.5, with a rate during 2081 to 2100 of 8 to 16 mm per year. Further uptake of carbon by the ocean will increase ocean acidification.

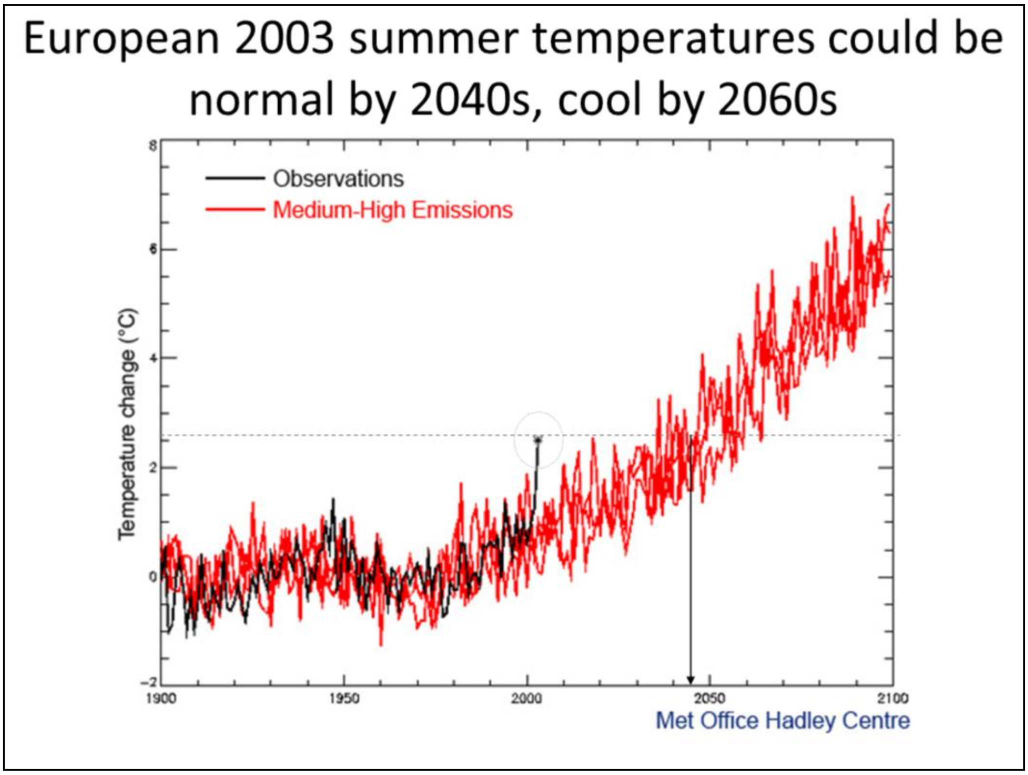
Heavy rainfall is expected to become more intense with wet regions generally seeing more rainfall and dry sub-tropical regions or seasons less.

For further details, see the IPCC (2014) WG1 Summary For Policy Makers, Section E.

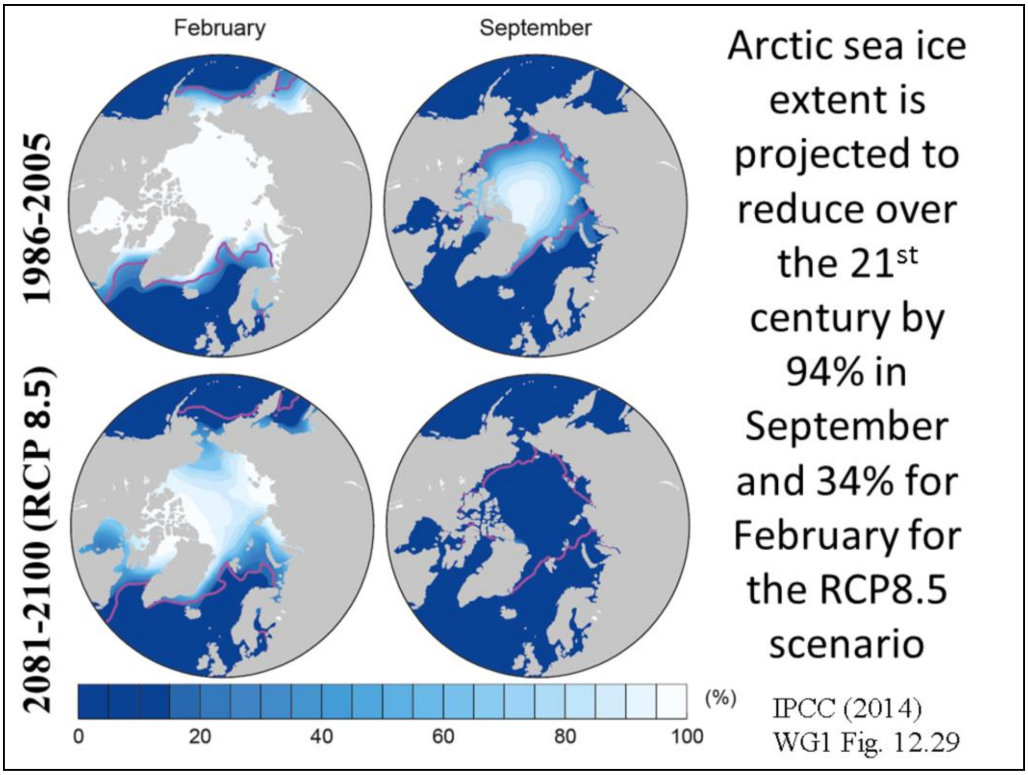


Models show a stronger warming over land and over polar regions compared to the oceans due to changes in circulation but also due the large heat capacity of the deep oceans.

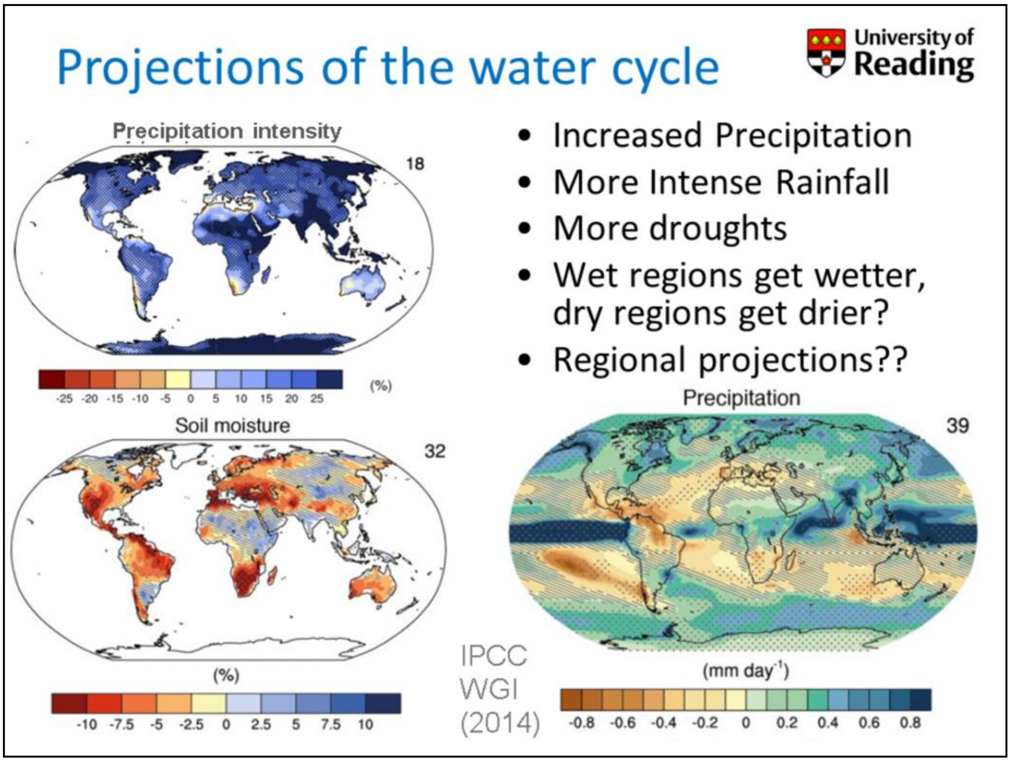
Temperatures over land are expected to increase about twice as rapidly as temperatures over the ocean. The annual average warming by 2100 over land areas, where of course we live and work, is predicted to be in the range 3 °C to 8 °C for the high emissions scenario. Although the Earth's temperature has varied considerably over the last 1,000 years for natural reasons, the rise over the next 100 years due to human activities is predicted to be very much larger than natural variability, even with the lowest projected man-made emissions scenario.



The simulation from 1900 to 2000 agrees well with the observations (black), except for the summer of 2003 (black asterisk) which was much warmer than either the model simulation or the climatic norm. In the absence of any human modification of climate, temperatures such as those seen in Europe in 2003 are estimated to be a 1-in-1,000 year event. Despite this, it is seen that, by the 2040s, a 2003- type summer is predicted to be about average, and by the 2060s it would typically be the coldest summer of the decade. Recent work has demonstrated that hot, 2003-type, European summers would already be being experienced much more frequently (more than once per decade on average) were it not for the cooling effect of man-made sulphate aerosols. Once the shielding effect of these aerosols is removed, the warming commitment from past greenhouse gas emissions will mean that such hot summers are likely to become a regular occurrence, even without any further man-made greenhouse warming.



Under the High Emissions scenario many models find that ice in the month of September (when it is at its minimum extent in the annual cycle) will have almost completely disappeared the middle of the 21st century. Other emissions scenarios lead to a slower reduction in Arctic ice. Reductions are also predicted for other seasons and also for the Antarctic although models are at present not able to capture the observed increases in Antarctic sea ice extent which is thought to relate to changes in atmospheric and oceanic circulation changes in response to increases in greenhouse gases and decreased stratospheric ozone.



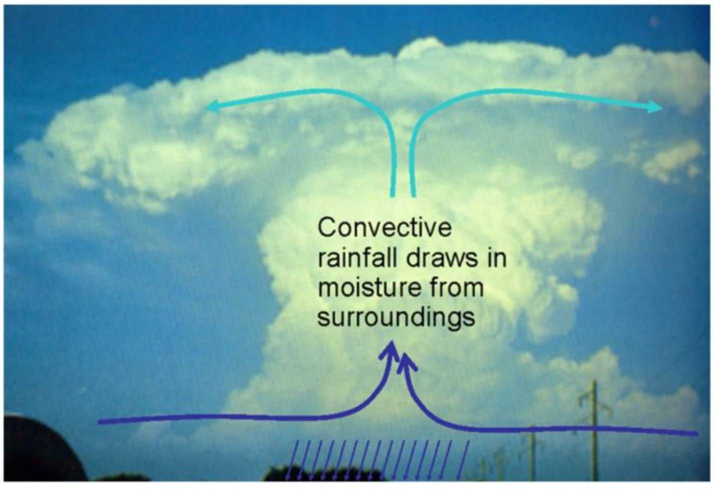
The above graphs from the IPCC (2014) WG1 report show:

(top left) Increases in 5-day precipitation intensity (%) for 2081-2100 relative to 1981-2000 for RCP8.5 (**Fig. 12.26, Chapter 12**) where stippling denotes a significant change.

(bottom left) Annual average % changes in soil moisture in the upper 10cm of soil in the RCP8.5 scenario where stippling shows significant changes (Technical Summary, **TFE.1, Figure 3**)

(bottom right) Annual average changes in precipitation (mm per day) for the RCP8.5 scenario where stippling shows significant changes (Technical Summary, **TFE.1, Figure 3**).

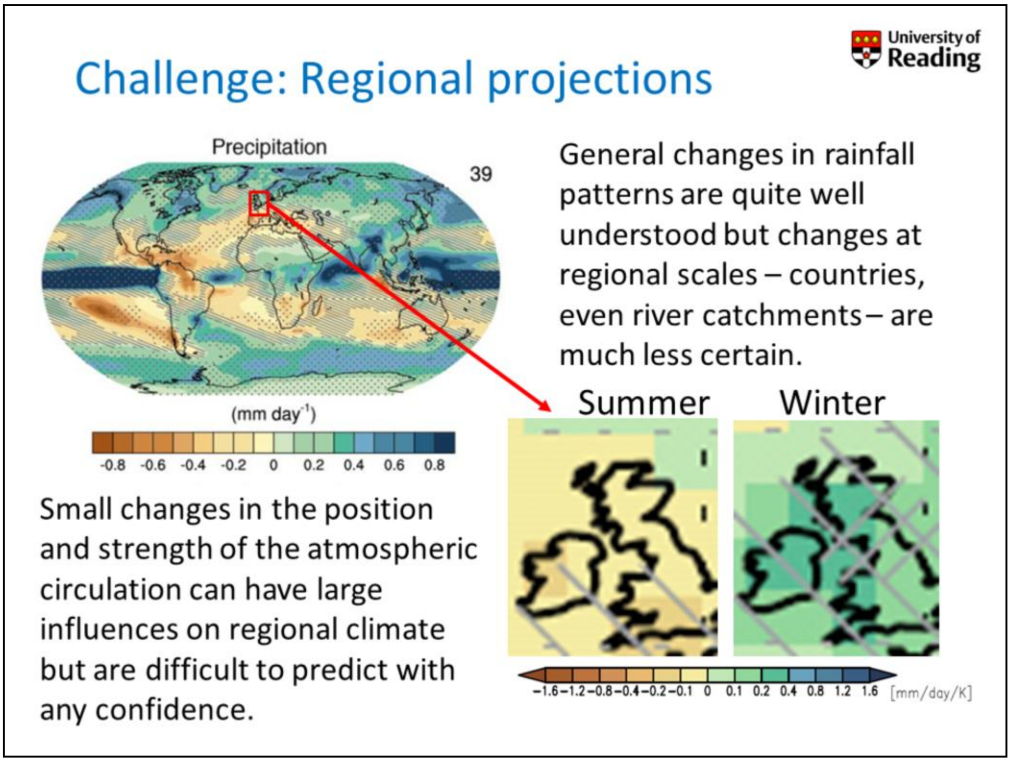
Enhancement of Extreme Precipitation



- Large-scale rainfall events fuelled by moisture convergence
  - e.g. Trenberth et al. (2003) *Bulletin of American Meteorolog. Soc.*

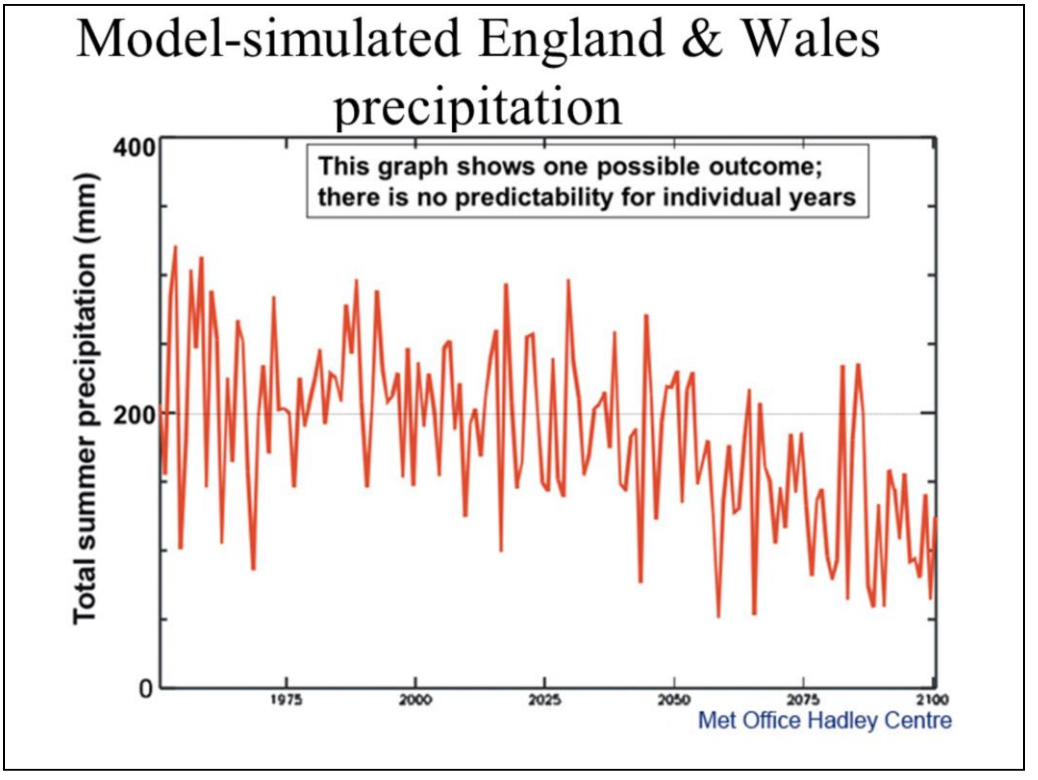
→ Rainfall intensifies at same rate as moisture increases? (~7%/K?)

Confidence in many aspects of projected future climate change are strengthened where they are physically understandable. Since heavy rainfall events are fuelled through convergence of atmospheric moisture and basic physics, observations and simulations agree that atmospheric moisture increases with warming, it is no surprise to discover that the simulations predict an intensification in extreme rainfall in a warmer world. Although standard climate simulators are not able to represent thunderstorms, higher space resolution simulations help in verifying and gauging the expected increases in this type of convective rainfall also. See recent analysis by Kendon et al. (2014) Nature Climate Change.

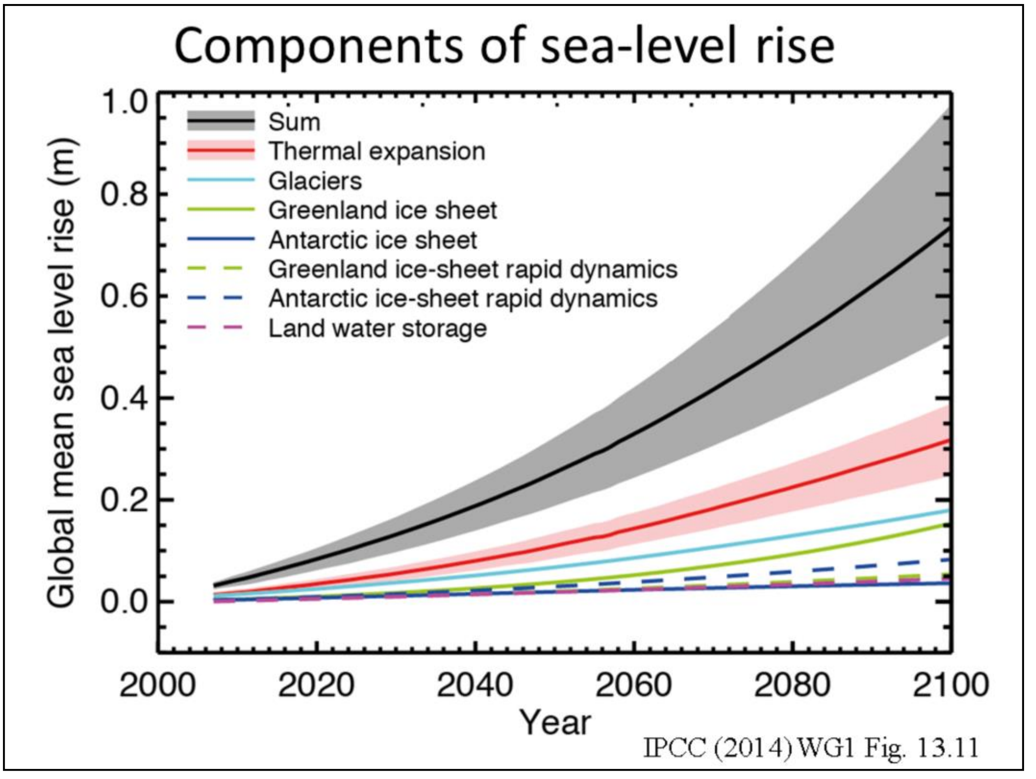


Basic physics and complex modelling indicate that the wettest regions will become wetter while dry, subtropical regions and/or dry seasons may become drier. However, the details of the changes at the scale of countries or even river catchments is much less certain. Extreme weather usually depends on small changes in the atmospheric circulation - on the position of the monsoon and the jet stream – which are much less certain and may depend upon complex local feedbacks.

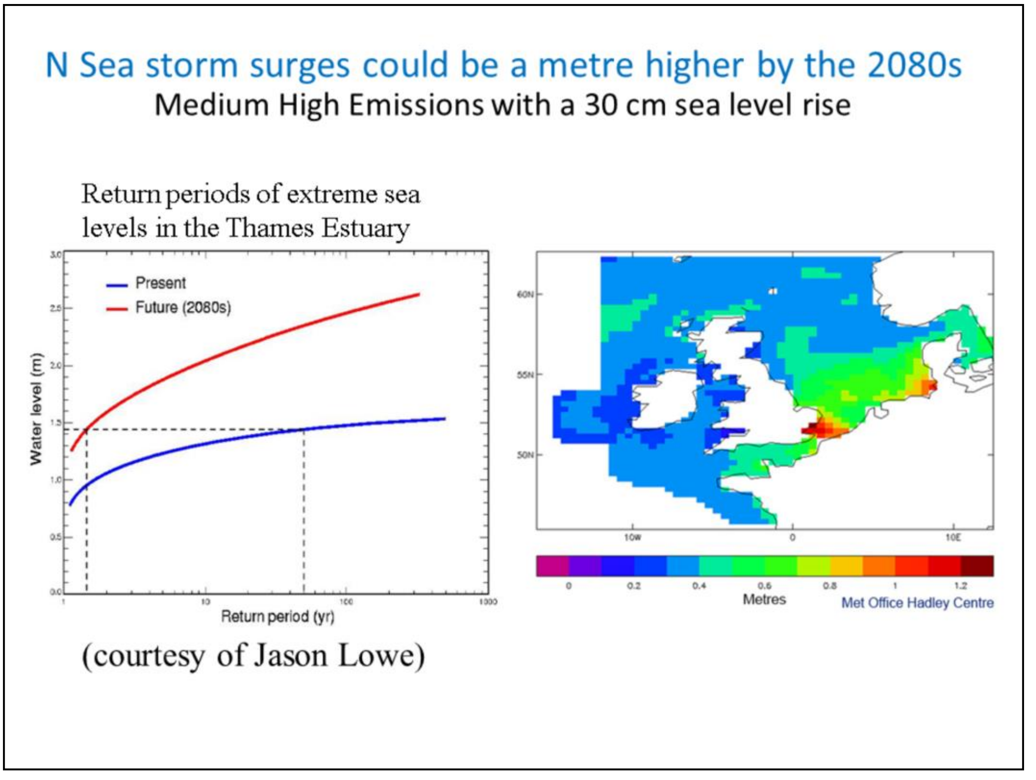
The British Isles, being at the boundary of the Atlantic Ocean and the Eurasian landmass, and at the eastern end of Atlantic storm tracks, experiences one of the most variable climates in the world.



The North Atlantic Oscillation is the main driver of winter climate variability; in winters when the pressure difference between the Azores and Iceland is greater than the average (that is, relatively lower pressure over Iceland) we tend to wetter, stormier and milder winters; when the NAO is in the reverse phase we tend to drier, calmer but colder winters. This gives rise to a marked variability in winter rainfall. Summer rainfall is also very variable, as shown in the slide above of total summer rainfall over England and Wales simulated by the Hadley Centre model from 1950–2100. (Note that the model gives a reasonable representation of year-to-year variability but cannot predict rainfall for a particular summer.) The downward trend in summer rainfall during the 21st century due to man-made climate change is clearly seen, but it is noticeable that even in the latter quarter of the century there are still likely to be summers which are wetter than average.

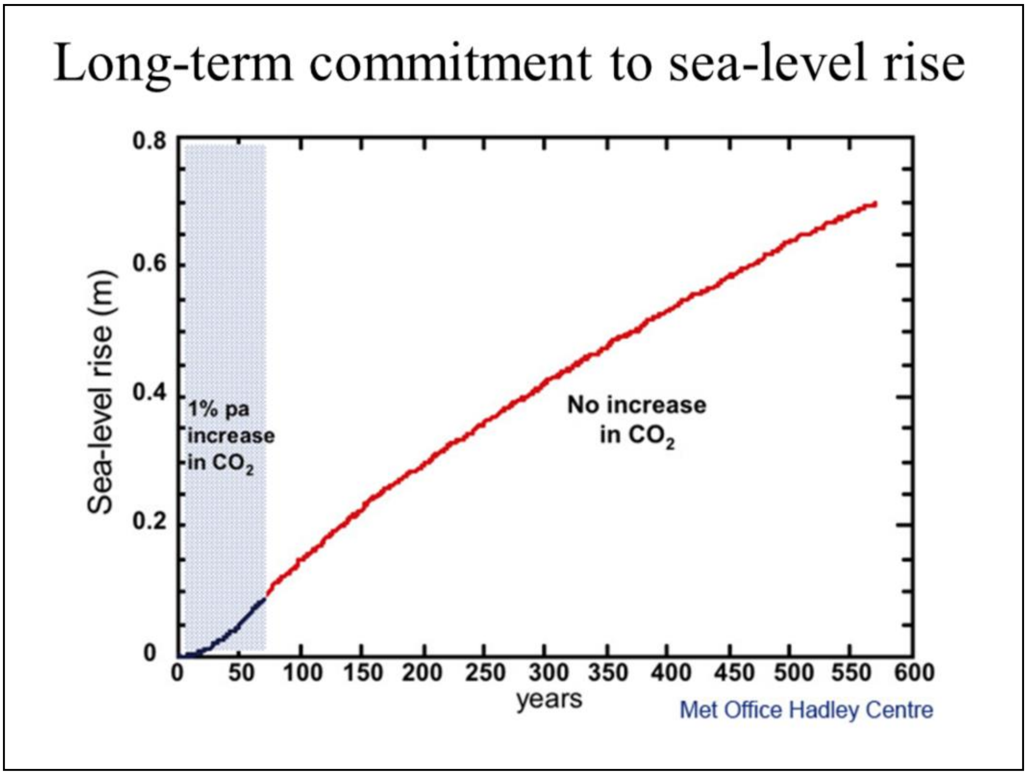


There is substantial interest in the effects of climate change on sea level, as the increased risk of coastal flooding could markedly affect society. Sea level will change due to expansion of oceans as they warm, and due to the influx of water from melting of glaciers and other snow and ice, and changes in the two large ice sheets in Antarctica and Greenland. Above is a plot of changes in sea level predicted by a range of models from the years 2005 to 2100, due to each of these contributors, under the High Emissions RCP8.5 scenario. The green lines shows the expected change of sea level due to changes in the Greenland ice sheet. The blue line shows predicted changes due to melting of glaciers and snow on land. The red line shows the major component of sea-level rise which is thermal expansion of ocean waters. Dynamic changes in the Greenland and Antarctic ice sheets (dashed green and dashed blue lines) are quite uncertain.



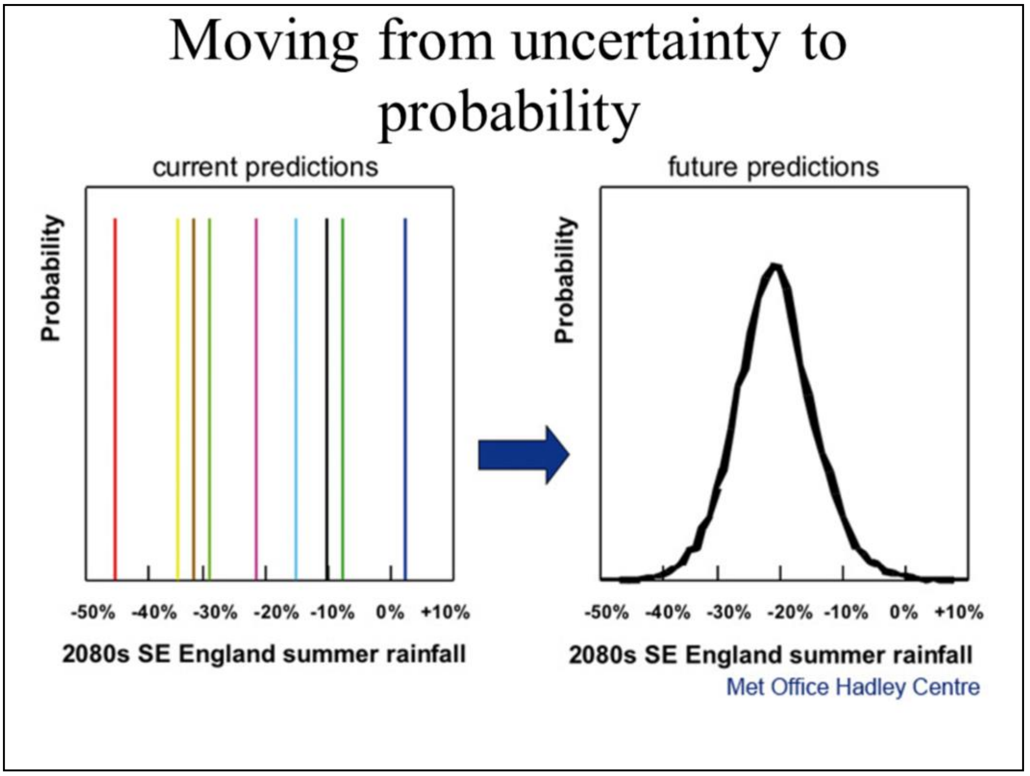
The main consequence of sea-level rise will probably come from an increase in extreme high water levels, which arise from storm surges as mid-latitude depressions or tropical storms and cyclones track across the area. The effect of sea-level rise on storm surges around the British Isles was investigated as part of the development of the UKCIP02 scenarios of climate change. This involved driving a storm surge model developed at the Proudman Oceanographic Laboratory, Liverpool, with meteorological predictions (pressure, winds, etc.) from the Hadley Centre regional climate model.

Above shows the change by the 2080s in the height of a 1-in-50-year high water event, under the Medium High Emissions scenario, with a 30 cm sea-level rise, and including the effects of land movement. As can be seen, increases of a metre or more in extreme high water levels, three or four times the sea-level rise, are predicted in the Thames Estuary and southern North Sea, whereas surges around Wales change by a similar amount to the mean sea-level rise.



Greenhouse effect heating in the atmosphere is rapidly transferred into surface ocean waters. It then slowly penetrates deeper and causes more and more of the ocean depth to expand and, hence, leads to further sea-level rise. This figure shows the sea-level rise due to ocean thermal expansion, estimated from a climate model experiment where CO_2 concentration in the atmosphere was hypothetically increased by 1% per year from time zero to 70 years (that is, until it had doubled) and was then stabilised at that concentration, (no further increase).

The initial blue line shows thermal expansion while the CO_2 concentration was rising, the continuing red line shows sea-level rise after CO_2 concentration had been stabilised. Despite the fact that CO_2 in the atmosphere did not change after year 70, the sea level carries on rising for many hundreds of years, with only a slow decrease in the rate of rise. So at any time the sea-level rise caused by the man-made greenhouse effect carries with it a commitment to an additional, inescapable, rise.

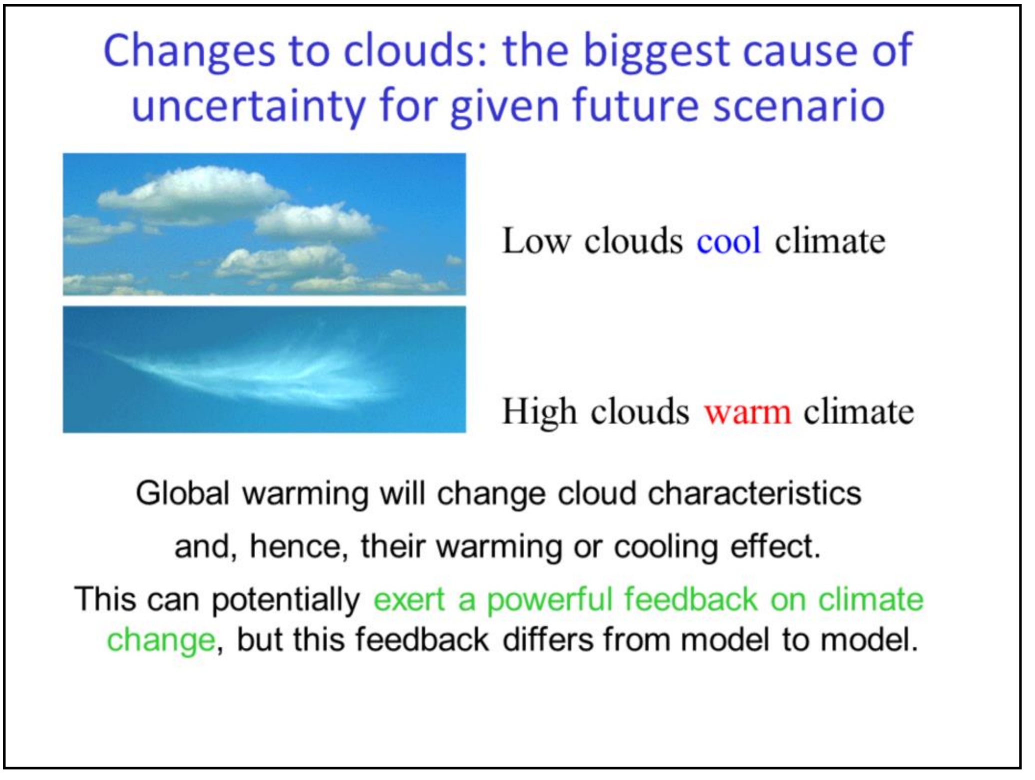


While models give a wide range of predictions in global-mean quantities; the uncertainty at a smaller scale is even bigger. The IPCC climate models give changes to south east England summer-mean rainfall by the 2080s, under Medium-High future emissions, ranging from a small increase to a 45% decrease — shown schematically in the left-hand panel. Because we have no way of assigning the skill of each of the models, all of the predictions must be assumed to have the same (unknown) probability. This is obviously unhelpful to planners trying to adapt to climate change; hydrologists deciding on whether a new reservoir should be built to avoid summer water shortages, for example. If they plan for the smallest climate change then they could be caught out if predictions of greater change come about. On the other hand, if they spend large sums adapting to the highest predictions, these may be wasted if smaller predictions turn out to be more realistic. Recognising that models give different predictions because they use different representations of the climate system, modelling centres, including the Hadley Centre and climateprediction.net, are building large numbers of climate models, each having different but plausible simulations.

Summary: Climate Change Predictions

- If high emissions continue up until 2100 we can expect a global surface temperature rise of 3-5°C
  - Based on high emissions scenarios and multiple models
  - Actual uncertainty range could be larger
- Precipitation changes highly uncertain
  - Likely more heavy rain events
  - Drier regions drier, wet regions wetter
- Sea level rise about 50-100cm by 2090s
  - If continue high emissions
- Predicted rise in ocean acidity
- Total loss of September Arctic sea ice by 2050s
- Changes in cloud cover/altitude/properties the single largest contributor to uncertainty in models
  - more next week…

The biggest uncertainty in climate predictions arises because we do not know what future emissions of greenhouse gases will be but additionally the is uncertainty because climate models are imperfect representations of the climate system. Running many different climate models for different future scenario gives us an idea about the range of possible futures we can expect. This uncertainty range becomes very large when looking at the spatial scales of countries or even river catchments which is what planners require. The probability of different outcomes is extremely useful information.



Clouds have a great effect on climate. Low clouds reflect sunlight but have little effect on the escape of infrared radiation, so they have a cooling influence on climate. High clouds, on the other hand, trap infrared radiation but do not reflect much sunlight; they have a warming influence. The net effect in the present day is an overall cooling effect. However, changes to the characteristics of clouds — their amount, height, thickness or the size of their water droplets or ice crystals — can drastically alter their climate properties, and hence could change size of the cooling effect. Many other processes in the climate system will change, and cause similar feedbacks, positive or negative. Because different climate models represent processes in different ways, the feedbacks will be different, and this is the main reason why climate models give different predictions for the future from each emissions scenario.