CLIMATE CHANGE
A SURFERS PERSPECTIVE

A Surfers Against Sewage report into the potential impacts of climate change on surfers in the UK.

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Introduction

Climate change. Two words that never seem to be out of the media spotlight these days. Whether it be a report about a rare species of Bolivian swamp rat that is on the brink of extinction as its habitat dries out, reports of oil companies funding 'anti-climate change' institutes or news of someone making apocalyptic predictions that suggest mankind will be dead before breakfast, climate change is a hard subject to avoid.

The basic science behind climate change is now accepted by the overwhelming majority of the scientific community and most scientists agree that the impact will affect the whole planet in many different ways.

So what does climate change mean for surfers in the UK? Putting aside all the other global problems that climate change may cause for a moment, what predictions can be made about surfing in the future? Will it mean we can all surf in boardies as swell after swell generated from more intense storms slam into the coast or will sea level rise mean that a day at your local beach is a thing of the past?

In the following pages, we will look at the available evidence and try to establish how climate change might impact on surfing in the future. But before we do this, it is important to understand what climate actually is and how it could change.

Section 1. A Changing Climate

1.1. What is 'climate'?

The climate describes the pattern of weather that can be expected for any particular region. For instance in the UK, the winters are expected to be wet and mild. The weather will not always correspond exactly to what the climate describes. A winter may be stormier or a summer hotter than usual, but when the weather is averaged over a long enough period, any fluctuations should cancel out. To understand climate (and how it may change), it is helpful to have a basic knowledge of what causes the weather.

Wind

As energy from the Sun reaches the Earth, its surface warms up. This occurs at different rates depending on the relative position of the sun and the nature of the Earth's surface (for instance, the land warms up quicker than the sea).

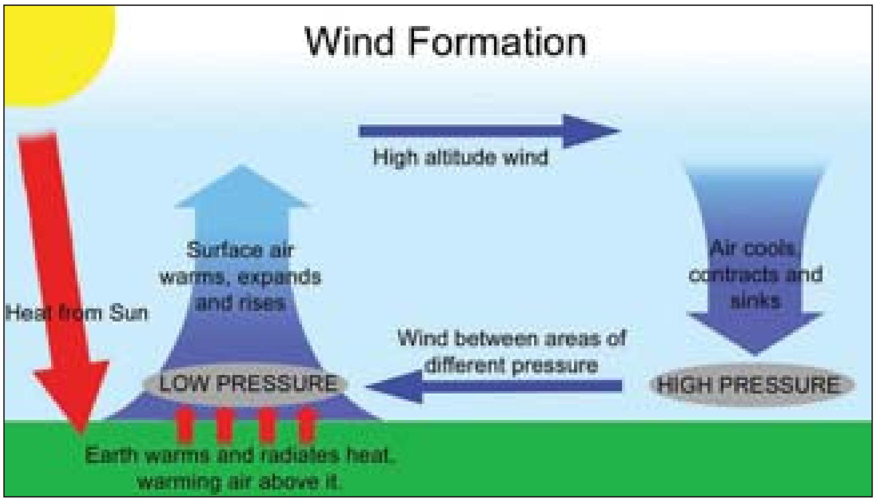
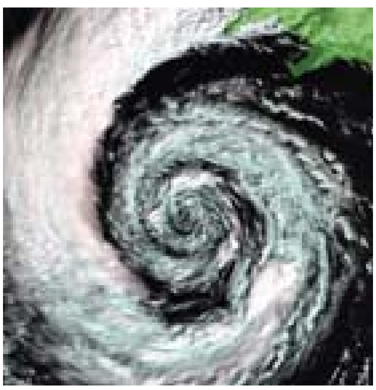


Figure 1. Heat from the Sun results in pressure differences that drive air movements. We feel this air movement as wind

As a surface warms up, it radiates heat, warming the air above it. This air expands which reduces its density and causes it to rise. This results in a lower pressure at the Earth's surface. In other areas, air cools and sinks (being denser). This results in higher pressure. To balance this difference in pressure, air moves from areas of high pressure to areas of low pressure. This movement of air is what we know as wind.

Because the Earth is spinning, the wind does not move between these areas in straight lines but follows a curved path. This is known as the Coriolis effect and is why wind rotates around the centre of pressure systems.



A weather system showing anticlockwise rotation of winds. Photo courtesy of the European Space Agency.

Rain

As well as driving the wind, the Sun's energy results in water evaporation. The warmer the air, the more moisture it can hold. If warm moist air cools, the water condenses resulting in cloud formation. When a cloud contains too much water, it releases some, which falls to the Earth as rain or snow. These steps form a large part of the water cycle.

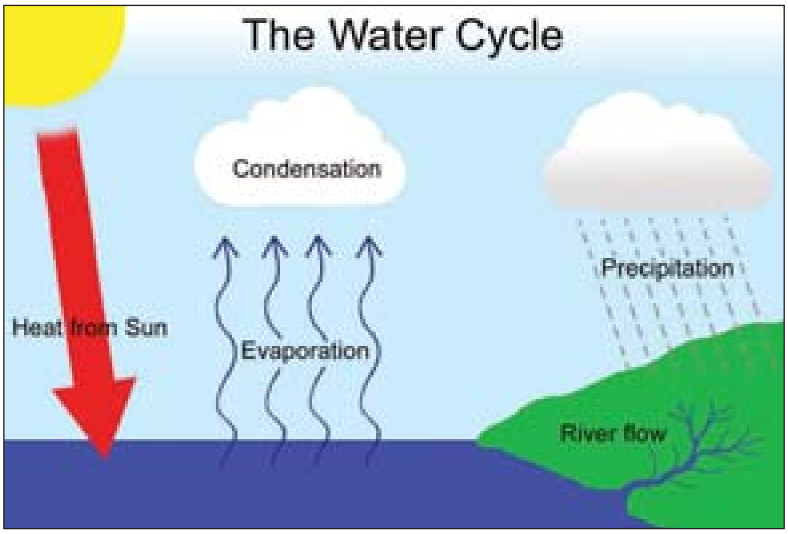


Figure 2. Heat from the Sun results in evaporation and is the driving force behind the water cycle.

The Ocean

Circulation in the ocean can be driven by the wind blowing across its surface and by variations in water density. Water density is controlled by temperature and salinity (how much salt is dissolved in it). Warm fresh water is less dense than cold saline water. Heat from the Sun affects both of these factors. The Sun warms the surface of the sea directly and also increases its salinity through evaporation. The Sun can also melt glaciers and ice that then flow as fresh water into the sea, decreasing its salinity. Areas of dense water sink to the ocean depths, driving deep sea currents. This, along with areas of upwelling, also drives the surface currents needed to complete the cycle. This process is often known as 'the ocean conveyor belt' or more technically, thermohaline circulation. It is a very important process in terms of the climate as it helps to transport heat around the globe.

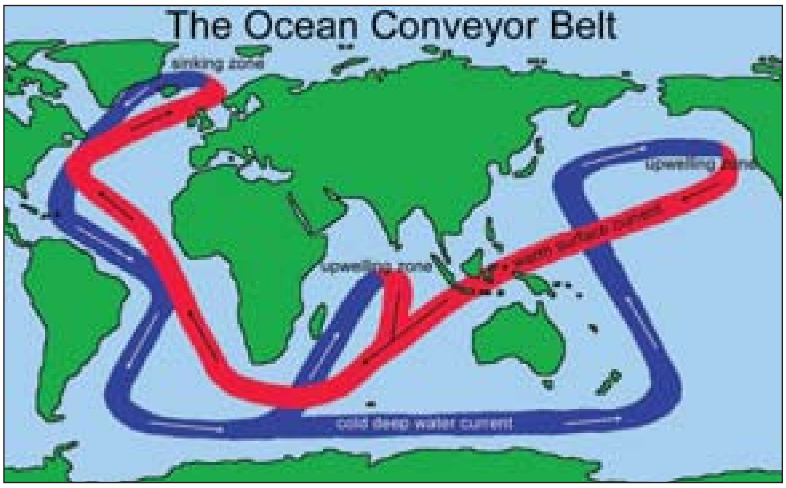


Figure 3. Many large ocean currents are a result of differences in water temperature and salinity. Both are influenced by heat from the Sun.

The Gulf Stream

The Gulf Stream is one of the planet's strongest ocean currents which brings warm water from the Gulf of Mexico north into the Atlantic. This water is of high salinity so as it cools in the far north, its density increases to such an extent that it sinks to the ocean depths. This sinking water is replaced by more warm water from the tropics.

As well as just increasing the water temperature around our coast, this current results in the winter climate of north west Europe being much milder than the average for the latitude.

Wave climate

For surfers, wind is an important aspect of the weather as it is the wind blowing across the sea that produces the waves that we surf.

The longer and stronger the wind blows, the more energy is transferred from the wind to the water and the larger the waves become. In this windy area, there will be waves of many different heights and periods on top of each other, moving in different directions. This produces a rather confused looking sea. As waves travel away from the area in which they were generated, waves of different period move at different speeds that eventually result in regular swell lines forming.

These swell waves can travel for many thousands of miles across the oceans. If they travel into coastal water that is shallow enough, the waves will break and the energy they contain will be dissipated.

As with other aspects of the weather, the wind (and therefore the waves they produce) tend to follow climatic patterns throughout the year. A wave climate describes the type of waves that can be expected during the different seasons of the year as a result of this wind.

Summary

It can be seen that heat from the sun is the driving force behind our climate. Energy from solar radiation directly or indirectly causes the wind to blow, waves to break, rain to fall and ocean currents to flow.

The climate itself is a product of a highly complex system of interactions between the atmosphere, ocean and land. For surfers, it is the climate that ultimately dictates where and when the waves that we ride are likely to be found.

1.2. Is the Climate Changing?

This graph shows the Earth's average surface temperature since 1860. It shows an increase of approximately 0.6 °C over the last 140 years. Whilst this does not sound like much, it should be remembered that during the coldest depths of the last ice age, average global temperatures were less than 10 °C cooler than they are today[2]. Small temperature changes can have a big impact! The upward trend also suggests that the global average temperature may continue to rise.

Additional evidence of a changing climate comes from glacier and sea ice records. The two charts below show how both glaciers and sea ice have decreased in extent over the last centuries and decades. This melting is a direct result of increasing global temperatures.

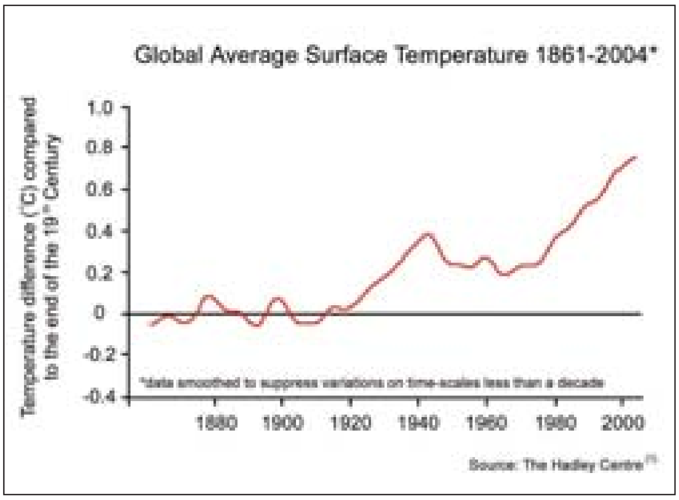


Figure 4. Increases in average surface temperatures suggest that the globe is warming[1].

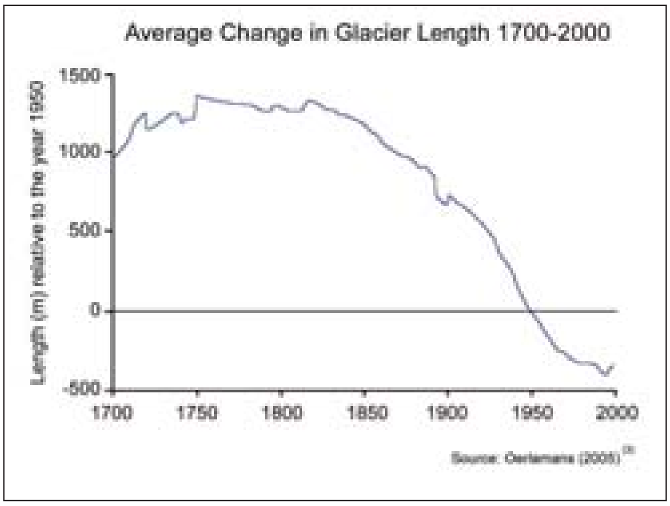


Figure 5. Average glacier lengths have shown a significant reduction over the last 300 years [3].

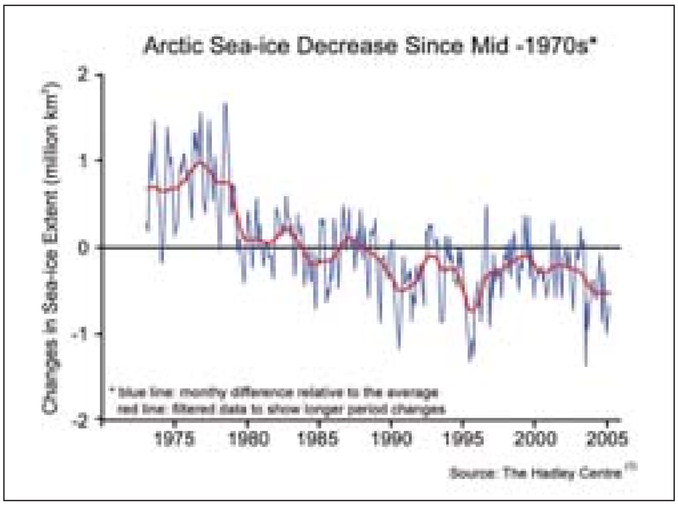


Figure 6. Arctic sea-ice has decreased by more than 1 million square kilometers since the late 1970's [1].

Recent reports suggest glaciers are melting quicker than previously thought[4]. Photo courtesy of the NOAA.

Is this change natural?

Studies into past conditions have revealed that the climate is not fixed and has changed before. Could the change we are seeing now just be part of a natural cycle rather than a result of man's actions? The United Nations Intergovernmental Panel on Climate Change (IPCC) was formed to try to answer this and other climate questions.

One key piece of evidence they analysed was based on using highly sophisticated computer models to try to replicate the global climate change seen over the last 140 years. Only when both natural and human (often termed 'anthropogenic') factors were included could the model accurately reflect the observed change in temperature.

After analysing all the evidence available, the IPCC concluded that "Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." [5]

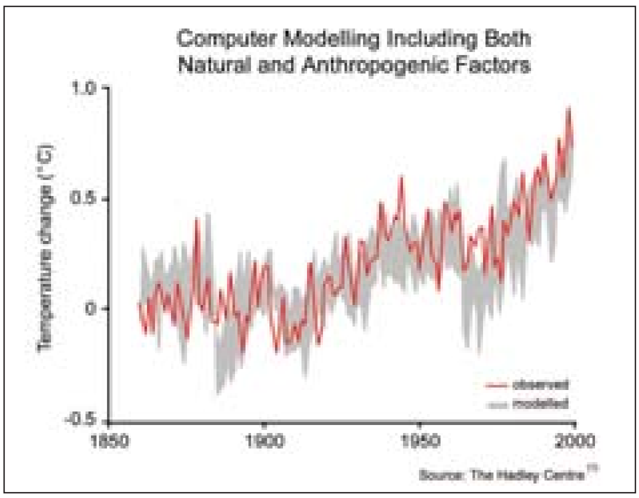


Figure 7. Observed climate patterns over the last century can only be replicated by computer models when both natural and anthropogenic factors are included [1]

The greenhouse effect

As the energy from the Sun reaches our atmosphere, some is reflected but the rest reaches the Earth's surface and warms it up. As it warms, the Earth emits heat in the form of infrared radiation energy back into the atmosphere. In the atmosphere, some gases (such as CO_2, methane and water vapour) absorb this energy and re-emit it, a proportion of which is directed back to Earth, warming it further. In essence, these gases in the atmosphere act like a blanket around the Earth retaining some of the heat it loses. Without this natural process, the Earth would be very cold indeed with an average global temperature of -18 °C [6].

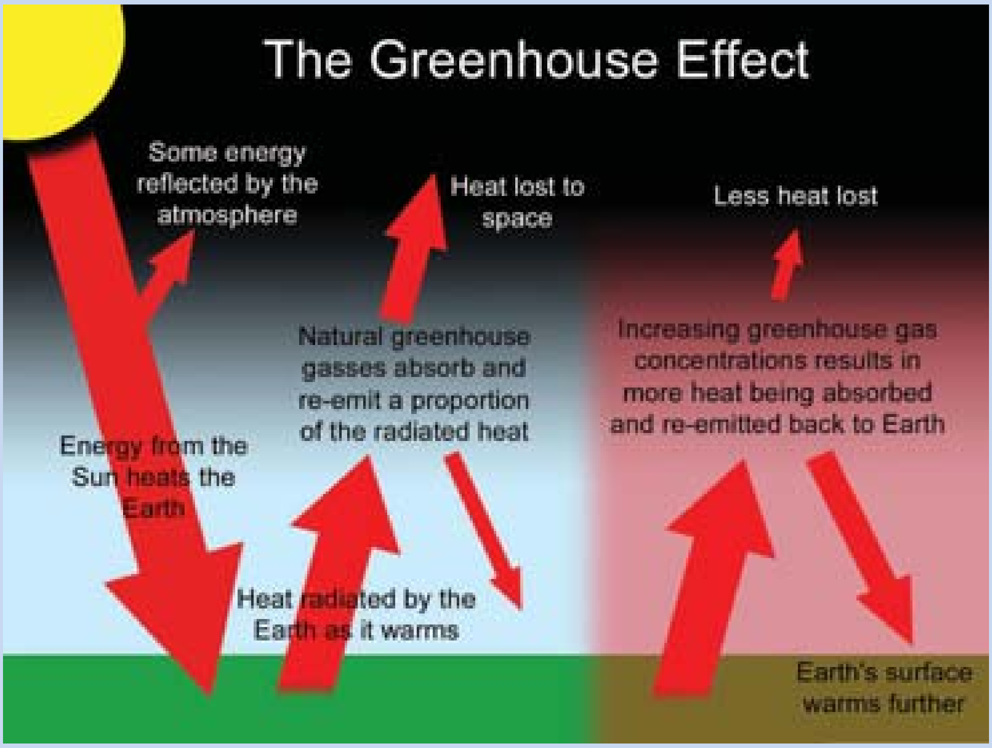


Figure 8. Certain gasses in the atmosphere absorb heat and reflect some back, warming the Earth. Increasing the concentration of these gasses results in more heat being reflected back to Earth, warming it further.

Greenhouse gas emissions

By increasing the amount of greenhouse gases such as CO_2 in the atmosphere, more heat is absorbed and retained. This results in an increase in average global temperature.

Since the industrial revolution in the mid to late 1800s, fossil fuels such as coal, gas and oil have been burnt to provide energy for many processes. These days around three quarters of the UK's electricity comes from the burning of fossil fuels[7], adding to the significant volumes burnt to provide energy for transportation such as cars and aeroplanes.

This release of CO_2 into the atmosphere has increased the concentration from around 280ppm (parts per million) during pre-industrial times to around 360ppm at the start of the 21st century.

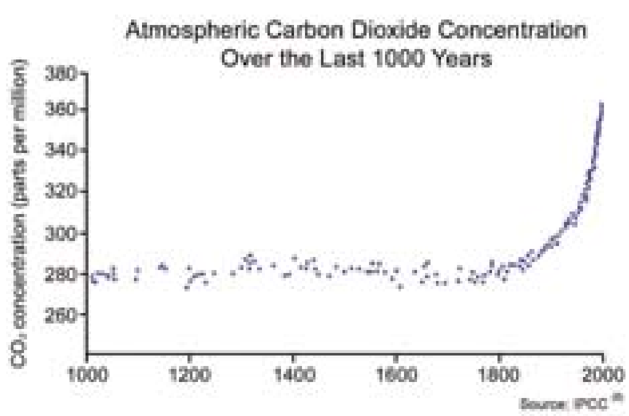


Figure 9. Carbon dioxide concentration in the atmosphere has increased rapidly since the mid 1800s to previously unrecorded levels [8].

Forecasted atmospheric concentrations of CO_2 by 2100 depend on carbon usage over the next century. Estimations range from 530ppm under a low emission scenario to 920ppm under a high emission scenario[9].

1.3. Impacts of climate change

Global warming is not just a case of the whole world getting uniformly hotter.

As previously mentioned, the driving force behind climate is energy from the Sun. If more heat is retained, this will have an effect on the patterns of wind and rainfall around the world, as well as impacting on ocean circulation.

Whilst average global temperatures will increase, some areas may actually witness a fall in temperatures. Likewise, whilst some areas will become drier, some will experience more rainfall.

As well as increasing average global temperatures and a change in weather patterns, increased heat retention will also result in a decrease in glacial extent and sea ice mass. The addition of water to the sea that was previously locked up on land as ice will result in global sea level rise. This rise will be exacerbated by the expansion of sea water as it warms.

It has also been predicted that as there is more energy in the form of heat available, extreme weather events such as hurricanes may become more intense. In addition to this, an increase in the temperature gradient between the equator and the poles could lead to an increase in 'storminess' in some locations[10].

As with all predictions, there are uncertainties. Whilst confidence in some predictions is high (i.e. it is agreed by the experts that it is highly likely that these predictions will come true), the confidence in other predictions is low, meaning they are less likely to come true.

Different emissions mean different futures

Whilst some degree of climate change is thought by climate scientists to now be inevitable because of past emissions of greenhouse gases, future emissions will determine the severity of these impacts. For instance, the increase in global temperature by 2080 is predicted to be around twice as high under a high emission scenario than under a low emission scenario[11]. The vast majority of climate scientists agree that reducing global emissions now will reduce the scale of climate change we witness in the future.

Predictions for the UK

The UK Climate Impacts Programme (UKCIP), working with experts from the Met Office's Hadley Centre and the Tyndall Centre for Climate Change Research have produced a series of forecasts about how the UK climate will change during this century[11]. Over the coming decades, they predict the following:

- The UK's climate will become warmer.
- High summer temperatures will be more frequent.
- Cold winter temperatures will become increasingly rare.
- Winters will become wetter.
- Intense rainfall events in winter will become more frequent.
- Summers may become drier.
- Relative sea levels will rise.
- Extreme high sea levels will be experienced more frequently.

Section 2.
Impact for Surfers

So how will these, plus other impacts of climate change, affect surfers and other recreational water users in the UK and are these impacts likely to be positive or negative?

The impacts can be divided into five main areas:

2.1. Changes in water quality
2.2. Changes in water level
2.3. Changes in wave climate
2.4. Changes in water temperature
2.5. Changes in water acidity

2.1. Changes in water quality

Rainfall

Climate change could impact on water quality around the UK by altering the pattern of rainfall we experience.

According to the UKCIP, winter rainfall will increase across the UK(11). By 2080, the increase ranges from between 10 and 35%, depending on the region and future emission scenario. As well as there being more rain in winter, the average intensity (i.e. the amount that falls over a short period) is also likely to increase, possibly by more than 20% in some areas(11).

"It is very likely that heavy precipitation events will continue to become more frequent." IPCC 2007(12).

Studies have suggested that we have already begun to experience an increase in the occurrence of intense rainfall events over the last 50 years(13).

In contrast, summers are likely to be drier than they are at present(11).

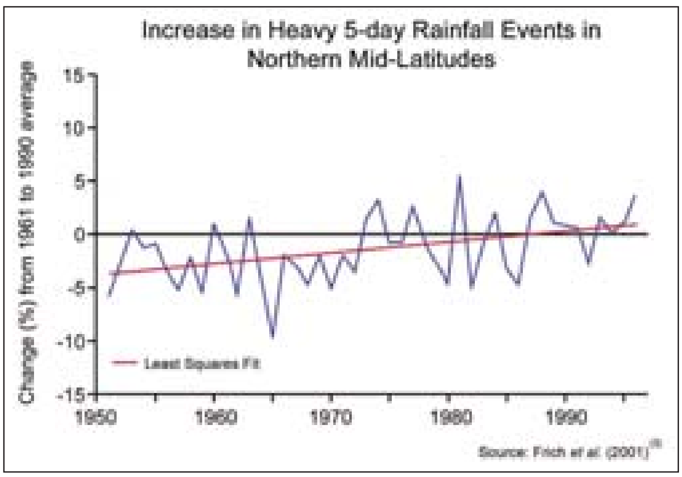


Figure 10. Intense rainfall seems to be becoming increasingly more common (13).

Rain and the sewage system

When it rains, water falling on roofs, roads and other built up areas gets channelled into drains. Some of these drains empty directly into rivers and streams but others get diverted into the same sewers that that our toilets and sinks are connected to. This is known as a combined sewerage system.

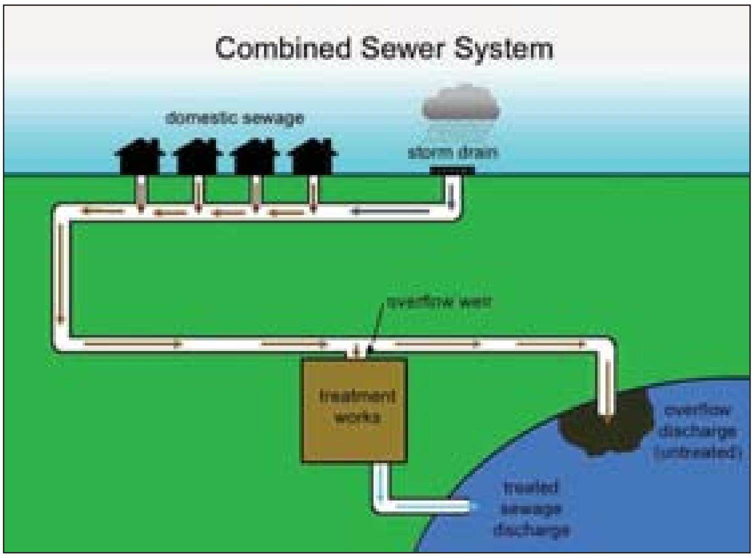


Figure 11. Heavy rainfall can overwhelm sewage treatment works, resulting in untreated sewage being discharged into rivers and the sea.

This means that during rainy periods, the sewage treatment works receives a higher volume of wastewater compared to when it is dry. Because of this, sewage treatment works are often designed to treat three times the dry weather flow to allow for small amounts of rain.

If the rain is either very heavy or it rains for a long time, the flow to the treatment works may increase to a level that cannot be processed quickly enough. Two things can then happen. Either the rainwater and sewage mixture is diverted to a storage holding tank for later treatment or, if there is no storage available, it is discharged untreated into a river or the sea through a 'combined sewer overflow' (CSO). Even if storage is available, too much rain will soon fill it up, again resulting in raw sewage being discharged.

Intense rainfall leads to sewage overflows

In the future, our combined sewerage system will have to cope with higher volumes during winter, a period where many systems are already overstretched. This means that the likelihood of an overflow of untreated sewage will increase. The UK Climate Impacts Programme view increased sewer overflows as an impact of National importance[14].

Untreated sewage contains a huge number of disease causing bacteria and viruses. Coming into contact with water containing sewage is a serious health risk, especially for those enjoying active sports that result in immersion under the water, where the swallowing of small volumes of water is unavoidable. Examples of diseases that can be caught are gastroenteritis, hepatitis A and ear, nose and throat infections.

Rainfall and diffuse pollution

As well as putting pressure on combined sewage systems, rainfall can also result in diffuse pollution. Unlike a sewage outfall, diffuse pollution comes from many different sources at the same time. This makes pollution prevention a much more complicated process. When it rains heavily, water tends to runs over the ground rather than penetrate into it.

Combined storm overflows can discharge raw sewage directly onto beaches in heavy rain.

In some areas, heavy rain can lead to high levels of pollution from agricultural run-off.

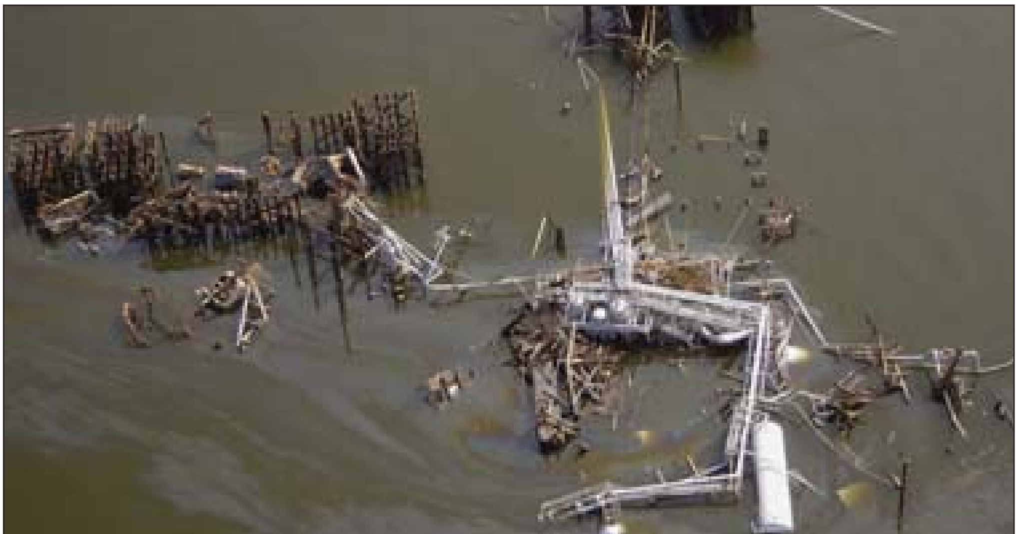
This results in 'run-off' water that can contain many pollutants that have been washed off the ground. In urban areas, this can include substances such as oil and heavy metals whereas in rural areas, agricultural run-off can contain high levels of pesticides or pathogens from animal faeces. Increased rainfall is likely to result in an increase in diffuse pollution in many areas.

Flooding

The increase in rainfall combined with rising sea levels are likely to increase the number of flooding incidents occurring in the UK[15]. Flooding, as well as causing widespread damage, can also result in the mobilisation of pollutants.

In our towns and cities, there are many substances that have the potential to pollute the aquatic environment. To prevent pollution occurring, they are contained in such a way that prevents them from contaminating rivers, streams and water stored underground (groundwater). Examples of such areas include waste landfill sites, sewage treatment works and industrial areas.

During a flood however, many of these containment strategies are breached, resulting in the pollutants entering the water. For instance, a landfill may have a liner to stop chemicals leaching into the groundwater but this is pretty useless at preventing pollution if everything is submerged under several feet of water!



In August 2005, New Orleans was flooded by storm surges created by Hurricane Katrina. This resulted in billions of litres of flood water heavily polluted with sewage, other organic waste and industrial chemicals as well as oil, diesel and petrol. Photo courtesy of the NOAA.

Summary

Predicted changes in rainfall patterns are likely to impact severely on water quality in the following ways:

- An increase in winter rainfall will result in more sewage overflows, increasing the health risk for water users.
- Increased runoff is likely to increase diffuse pollution from sources such as urban areas and agriculture.
- Flooding will mobilise pollutants into the marine environment. This cocktail of chemicals and pollutants is likely to pose a significant health risk to water users.

2.2. Changes in sea level

Global warming results in sea level rise for two reasons; the melting of land ice which then flows into the sea and the expansion of the water in the ocean as it warms.

It is predicted that by 2080, global sea levels will have risen by between 9cm (low end of low emissions scenario) and 69cm (high end of high emissions scenario)[16].

In the UK, we have a large tidal range that is generally over 4m (termed macrotidal) and in some places, more than twice as large. The scale of global sea level rise due to climate change over the next century is therefore unlikely to result in the complete inundation of the intertidal zone we have today. Instead, the tidal zone will shift slightly so that low tides are not so low and high tides are higher than they are today.

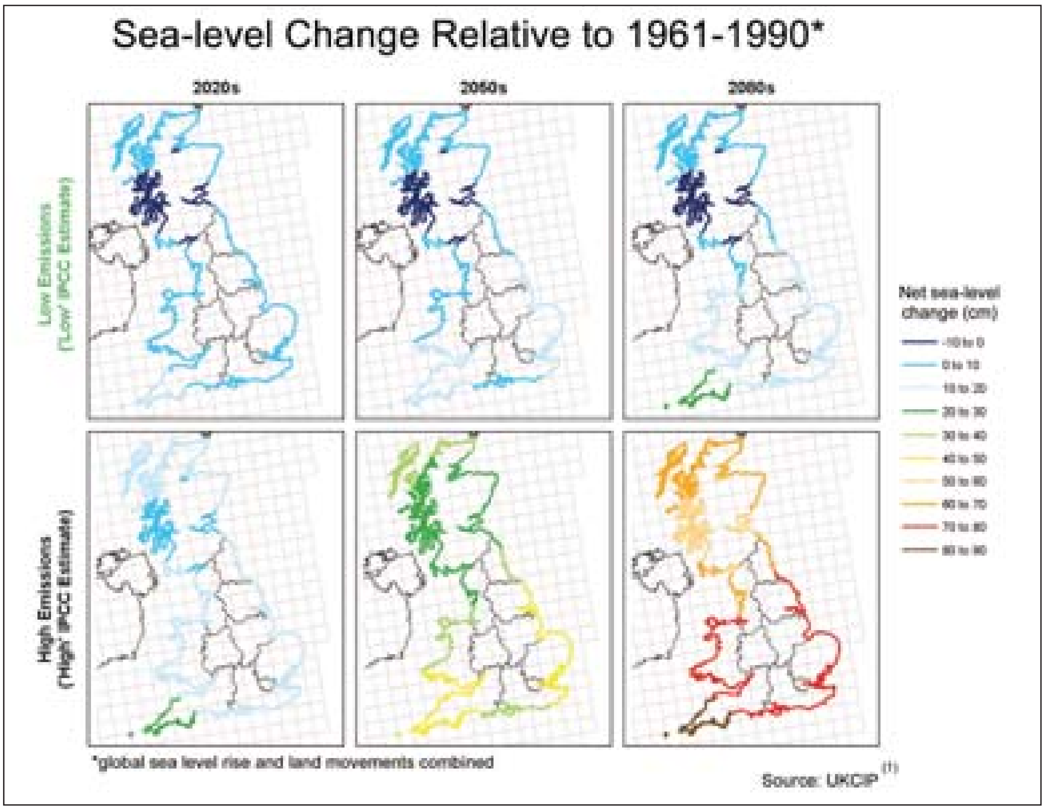


Figure 12. Predicted sea level rises due to global warming, combined with natural land movements, could result in a net increase of 80 to 90 centimetres by 2080, if global emissions of greenhouse gases continue to increase unchecked [16].

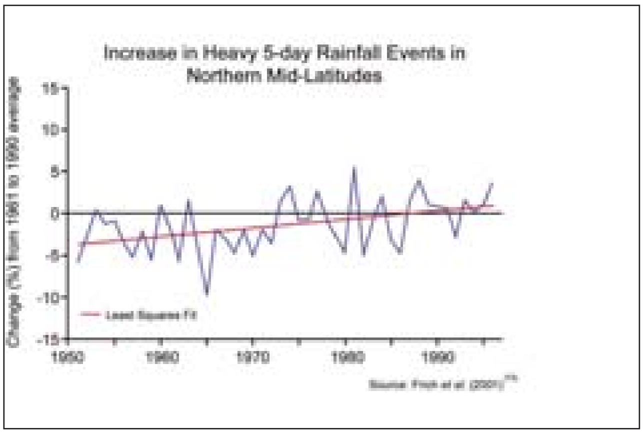


Figure 13. In tidal areas, sea level rise will result in the tidal zone shifting further up the shore.

Waves and sea levels

Waves break when the water in which they are travelling through becomes too shallow. Interaction between the wave and the sea bed causes the wave to become unstable and break. This break point depth depends on the height of the wave, with bigger waves breaking in deeper water.

So how is this affected by increasing the sea level? In an area where the sea bed slope is regular, the wave will break further inshore of its original point. In areas where the sea bed is irregular and the waves break due to an anomaly in the profile (such as a reef), increasing depth will increase the likelihood that a wave will pass over without breaking. In the UK, we witness these processes happening every day due to our large tidal range. Some breaks work throughout the tide while some only work at specific tidal height.

Global sea level rise could impact a surf break in several different ways. Whilst in practice, detailed studies would have to be undertaken on a case by case basis, some generalisations can be made.

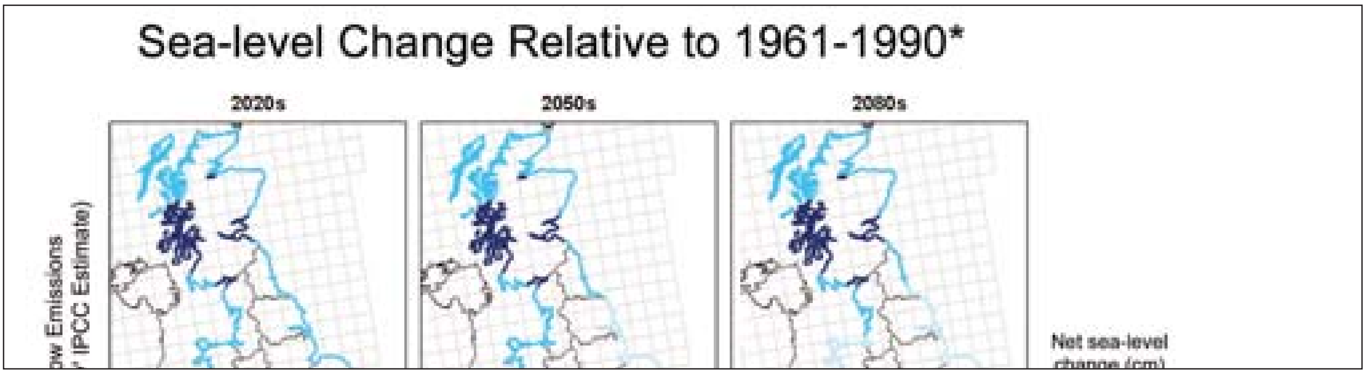


Figure 14. Depending on the type and profile of the sea bed, sea level rise could result in a waves break point moving landward, or could preventing a wave breaking altogether.

Reef breaks

Predicting the effects of sea level rise on waves that break on solid rock is relatively straight forward, as the bathymetry (underwater profile) should remain unchanged apart from a uniform increase in depth.

At a reef that only produces a surfable wave at today's low tide level, sea level rise will result in a reduction in time that the break works. On the other hand, a reef that only works at high tide now will work for more time in the future.

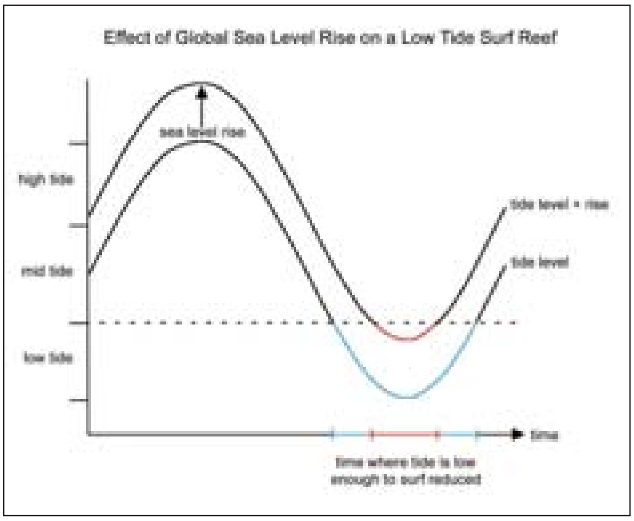


Figure 15. With increasing sea levels, the proportion of each tidal cycle where the tide is low enough for a low tide reef breaks to be surfed is reduced.

Unfortunately, analysis of the type of reef breaks in the UK suggests there are more low tide reef breaks than high tide reefs.

Since there are more low-tide reefs, this suggests that there will be more surfing time lost than gained as a consequence of sea level rise. The bottom line is therefore a net reduction of the surf at reefs throughout the UK.

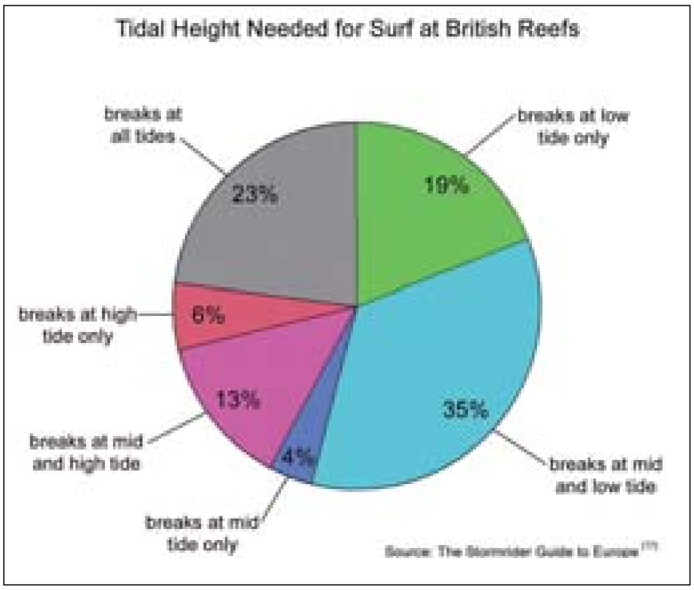


Figure 16. There are proportionally more reef breaks that work at low tide than high tide in the UK[17].

Beach breaks

Unlike reef breaks, predicting the effects of sea level rise on the surf at beach breaks is much more complicated. This is due to the fact that the sea bed is not fixed but moveable.

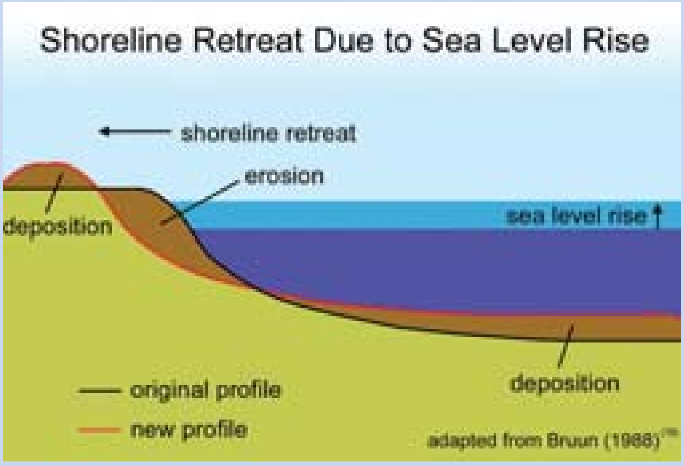
Waves result in currents of water that can move sediment inshore, offshore or along the shore. This changes the bathymetry which then alters the ways in which the waves break. This then affects the wave induced currents that move the sediment and so on.

Changing sea level will alter the position at which the waves break which will then result in a change to the sediment transport regime. Accurately predicting what the outcome of this will be is very difficult but in general it leads to erosion and a retreating of the shoreline.

Erosion of the cliff by several meters has resulted in this World War II pillbox falling onto the beach. Such erosion could become more widespread with rising sea levels.

The Bruun Model

One of the most widely used methods for predicting the effect of sea level rise on beaches is the Bruun Model[18]. The idea behind this model is that the profile of a beach (i.e. how the depth changes as you move offshore) is in equilibrium and will try to re-establish itself in response to sea level rise. What this basically means is that sand will be eroded from the beach front and accumulated offshore, until the shore profile re-establishes itself. Essentially the shape of the shore profile remains unchanged but moves upward and landward.



Equations derived from this model predicts that the distance a beach is eroded will tend to be 50 to 100 times the increase in sea level[19] (i.e. a 1cm rise will result in 0.5 to 1m of beach eroded). This suggests that even relatively small sea level rises could result in significant erosion. Because real beach systems tend to highly complex, this model cannot readily be used to predict erosion at specific locations. Actual erosion could be significantly more or less than this model suggests.

Figure 17. According the Bruun model[18], sea level rise results in erosion at the shoreline and shoreline retreat.

While erosion and movement of the beach profile itself will not necessarily result in a decrease in the quality of surf, it does depend on there being sediment available at the back of the beach. In many areas where either a beach backs onto a cliff or there has been development close to the shoreline, this sediment may not be available. This may prevent the beach from re-establishing itself and could lead to wave reflection or backwash that would make riding the waves impossible except for at extreme low tide.

Increase in coastal protection schemes

In some areas where erosion due to sea level rise threatens developed areas, coastal protection schemes may be introduced such as the building of breakwaters and sea walls. These can often lead to the destruction of surf spots. Past wave 'extinctions' due to coastal developments include Ponta Delgada in Madeira, The Cove in Washington and Stanley's Reef in California. The increase in coastal protection schemes due to sea level rise should be considered a major indirect threat of climate change.

Coastal protection schemes can result in the loss of surf breaks, as seen here at Ponta Delgada, Madeira. Photo courtesy of Save The Waves (www.savethewaves.org).

Extreme sea level rise

The sea level rise predictions used by the UK Climate Impacts Programme do not take into account catastrophic events such as the melting of major ice sheets such as the Greenland or the West Antarctic ice sheets[20]. If either of these melted, the resulting sea level rise would be around 7m. If both of these plus the East Antarctic ice sheet melted, the rise would be 84m![20]. While this last scenario is extremely unlikely, according to the Benfield Hazard Research Centre based in the University College of London, the West Antarctic ice sheet is showing signs of becoming increasingly unstable and has a 1 in 20 chance of collapsing and melting within the next 200 years[20].

Current predictions an underestimate?

The most recent research suggests that glaciers may be melting significantly faster than previously estimated. Satellites measuring the mass of Greenland's glaciers show that they are accelerating towards the sea and are losing 20% more than is being replaced by snowfall[21].

This suggests that previous estimations (including those used above), may significantly underestimate the rate of sea level rise we could experience over the next few decades and also suggests an increase in the likelihood of extreme sea level rise.

Summary

Sea level rise is likely to have a significant impact on the coast and therefore the surf. While some impacts are to a certain extent predictable, many are not. The possible effects of sea level rise on surf are:

- A possible net loss of surf resource at the UK's reef breaks.
- Increased erosion at many beaches could impact on many surf breaks.
- The destruction of some surf spots due to the building of coastal defence structures.
- Pollution due to increases in flooding events (see previous chapter).

2.3. Changes in wave climate

Waves are formed as a result of wind blowing across the ocean surface. Energy is transferred from the wind to the water and this energy is eventually dissipated as the waves break, often far away from where the waves were created. In general, waves that reach the UK are produced by depressions formed in the North Atlantic but can also result from decaying tropical hurricanes that swing out into the Atlantic after battering the east coast of North America.

As waves are a direct result of climatic conditions, any change in these is likely to have an impact on the surf we ride.

Unfortunately, impact on the wave climate is one area of uncertainty in climate research at present. The few modelling studies that have tried to quantify these effects have not proved conclusive and variation between models is high[11].

Despite this, it is worth looking at other evidence to try to assess what the likely impact of climate change on the wave climate could be.

Generation of Atlantic swells

Mid Atlantic depressions are formed when warm air from the south meets cold air from the north. The boundary between them is known as the polar front.

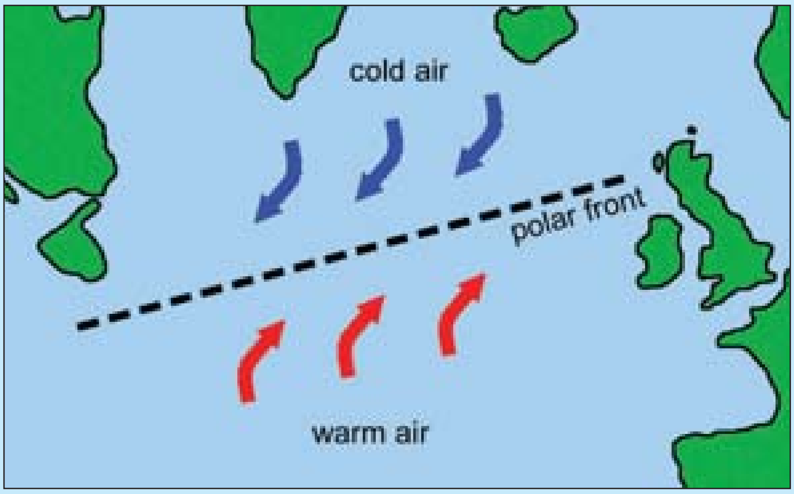


Figure 18. Warm and cold air masses collide along the polar front.

Kinks across this boundary result in areas where warm air slides over the cold air, leading to a localised drop in surface pressure. This pressure difference results in wind but instead of it blowing directly from surrounding areas of higher pressure into the area of lower pressure, the Coriolis force results in the formation of an anticlockwise vortex around it.

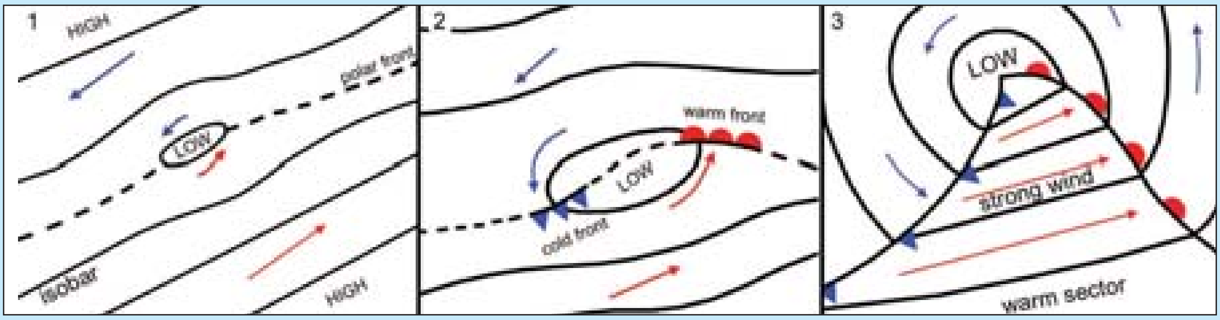


Figure 19. Small imperfections along the polar front develop into a low pressure system (also known as a mid Atlantic depression).

The wind within the warm sector of the depression system blows strong and in a fairly constant direction. This strong wind results in rapid wave growth. The direction of the wind (and therefore the resulting waves) varies but is generally northwest, west or southwest.

Increasing hurricane Intensity

Some of the surf during the autumn is produced by decaying tropical hurricanes. Hurricanes occur in regions where the surface sea water temperature exceeds around 26 °C [22]. They are fuelled by evaporated water being drawn up into storms that then condenses and releases energy. The warmer the ocean surface, the more readily water evaporates meaning that more energy is available to fuel hurricanes.

It is thought that man made global warming has been the cause of the majority of the increase in tropical sea surface temperatures measured over the last century[23]. During the last few decades, we have also witnessed an increase in hurricane intensity and duration[24]. If climate change continues to result in increasing sea surface temperatures, this could result in more intense hurricanes being the norm.

"Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense" IPCC 2007[12]

Whether this will lead to bigger or better surf for the UK is not certain as all hurricanes do not necessarily result in surf reaching this side of the Atlantic. Despite this, if increasing hurricane intensity results in higher wind speeds in the Atlantic, chances are we would see bigger waves hit our shores during the early autumn.

Storminess of the North Atlantic

Global warming will not affect everywhere equally. It is expected that the tropics will warm up more than the poles as at these extreme latitudes, a lot of heat will be 'used up' melting ice. Because of this difference, the temperature gradient between the tropics and the poles is likely to increase, which could result in an increase in 'storminess'[25], i.e. the intensity, duration or frequency of occurrence of mid Atlantic depressions.

A meteorological phenomenon closely linked to these temperature gradients is the North Atlantic Oscillation (NAO). It is essentially a measure of the pressure difference between high and low latitudes during winter. When the difference is high (positive on the NAO index), conditions are stormier with westerly winds being stronger and more persistent compared to when the difference is low (negative on the NAO index).

The strong, westerly winds associated with the positive state lead to bigger waves in the Atlantic, and therefore bigger surf reaching our shores[26].

It has been predicted that climate change will lead to an increase in the likelihood of a positive phase of the NAO[11]. This will mean the Atlantic will tend to be 'stormier' in the winter. This will increase the occurrence of large waves reaching the west coast of Europe.

Because of the naturally high variation between years, a small change may be hard to identify but by 2050, the increase could become significant[11].

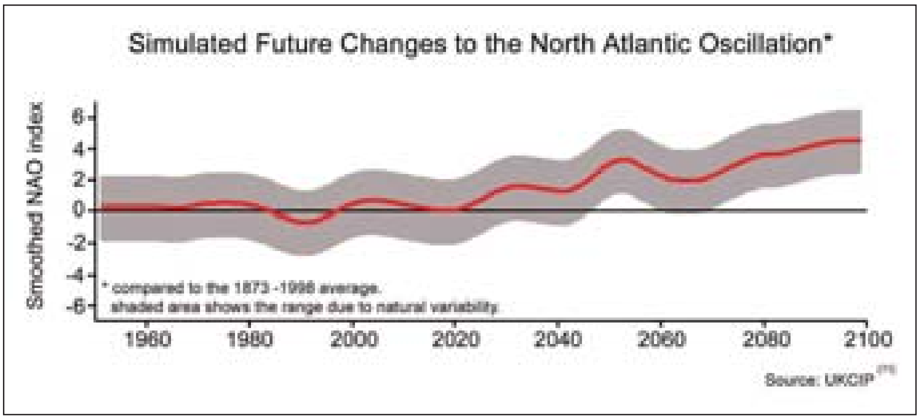


Figure 20. It is predicted that the positive phase of North Atlantic Oscillation will become more slightly common over the next few decades. The positive phase is associated with strong westerly winds [11].

Storm Tracks

A storm track is essentially the path a mid Atlantic depression travels from west to east. This is important as it determines in which region the strongest winds blow and therefore the location on the coast that get the biggest surf.

The most recent research suggests that climate change may result in a poleward shift in storm tracks[12,27]. This basically means the chances of a storm following a path to the north of the British Isles are higher.

"Extra-tropical storm tracks are projected to move poleward" IPCC 2007[12]

This is significant because it could result in more surf for some areas of the UK such as Scotland but less for areas such as the South West and Wales due to swell being blocked by Ireland.

At present, there is a great deal of uncertainty about these predictions but what this research does highlight is that climate change could potentially lead to a reduction in winter wave climate in some regions.

Figure 21. A storm generated in the Atlantic travels in a roughly westerly direction, but the exact track varies. This will change which region receives surf.

Summer surf

While nowhere near as powerful or consistent as autumn or winter surf, the long, warm days and warmer water of summer undoubtedly make surfing in this season enjoyable. All of the research mentioned above focuses on winter, but it is also important to know how summer surf is likely to be affected.

It is predicted that UK summers may see an increase in sunnier, calm periods[11]. These generally occur when a high pressure system sits over western Europe. As it is often the case that long sunny spells in the summer coincide with flat conditions, this suggests that if we witness an increase in the likelihood of stable, sunny weather, we could see a corresponding decrease in the occurrence of summer surf. In other words, the winter-summer difference in surf will become more noticeable.

Does bigger always mean better?

So just say that climate change does result in an increase in the wave heights reaching the coast. Will this result in better conditions for surfers? Not necessarily. Height is only one factor in determining the quality of surf. Strong storms can lead to a huge confused sea (i.e. lots of different sized waves on top of each other) reaching the coast that are pretty useless for surfing. If an increase in wave height corresponded with a decrease in wave 'quality', this could be bad news for surfers in the UK.

January storm on the Atlantic coast. Big waves don't necessarily mean good surf.

Summary

The impact climate change will have on the surf climate of the UK is still unclear at present and there is a high degree of uncertainty about many of the predictions made. Confidence in predictions about the North Atlantic Oscillation and storm track changes are low. It should also be remembered that bigger waves don't necessarily mean better waves.

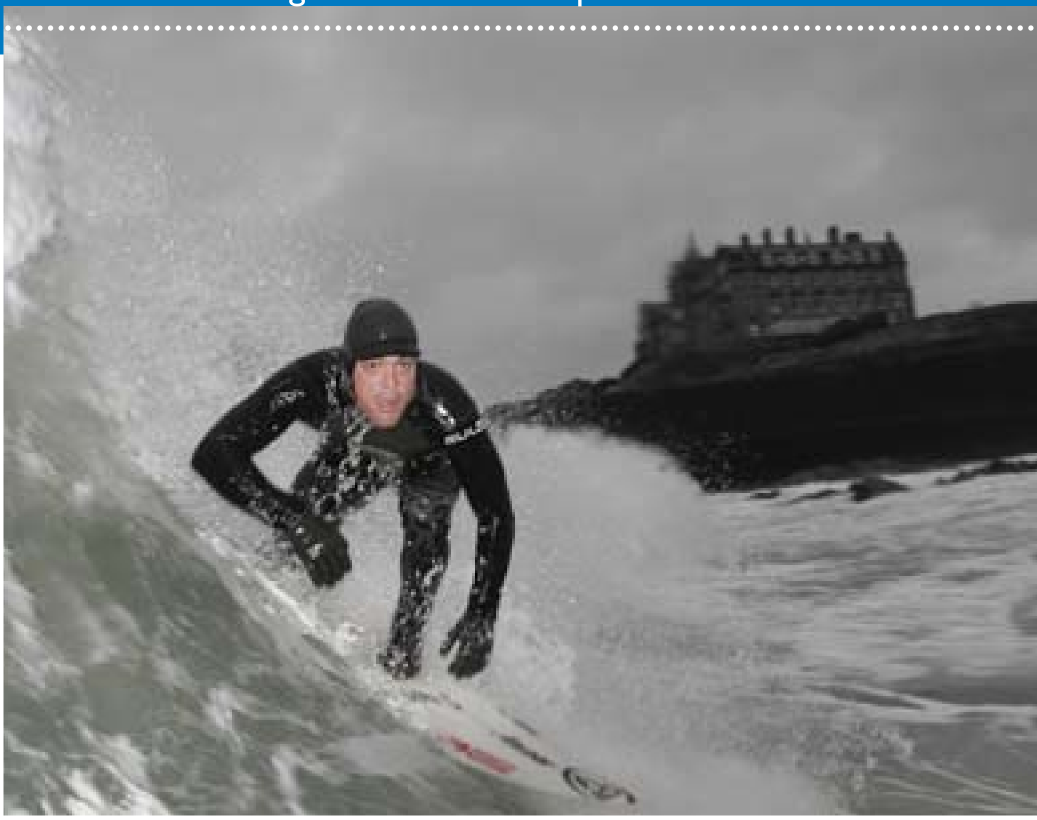
Given the available evidence, it is likely that climate change could have both positive and negative impacts on the wave climate:

- An increase in chances of a stormy winter in the North Atlantic could slightly increase the likelihood of bigger surf reaching the UK coast.
- Increasing hurricane intensity and duration could mean bigger or more consistent autumn swells.
- Changing storm tracks could potentially alter the amount of surf reaching different regions, with popular surfing areas such as the South West possibly receiving less surf.
- Summer surf may become more inconsistent.

2.4. Changes in water temperature

The temperature of the water has a huge impact on anyone who enjoys watersports. In tropical locations, the water is warm enough that no additional insulation is needed. Unfortunately, in the UK, we are not lucky enough to be able to surf just in boardies. In colder waters like ours, wetsuits are required. The thickness of the wetsuit will depend on how much extra insulation is needed. A down side of this is that wetsuits decrease your flexibility, making surfing harder and less enjoyable.

In the UK, you can get away with a 2 - 3mm thick fullsuit or shortie in the summer but in the winter and early spring, a 4 - 5mm suit plus boots, gloves and maybe a hood are generally required. In addition to colder water meaning thicker wetsuits, it also makes watersports generally less comfortable and lead to 'ice-cream headaches' when duckdiving and the occasional flush of freezing cold water down your wetsuit.



Wearing lots of rubber is essential to stay warm on cold winter days in the UK. Photo by Tony Plant.

So how will climate change affect the water temperature? As average global temperatures increase, more heat is absorbed by the ocean resulting in an increase in sea surface temperatures.

Over the past 100 years or so, the average sea surface temperature around the UK has risen by 0.5°C, but much of this increase has occurred during the last 20 years[11]. It is predicted that by 2080, average sea surface temperatures will have increased around the UK by between 0.5 and 4 °C, depending on the region and the future emission scenario[11]. The biggest increases are likely to be seen in the shallow areas of the North Sea and eastern part of the English Channel.

The Gulf Stream and the Water Temperature

The Gulf Stream is part of the global ocean conveyor system that brings warm, saline water from the tropics to the North Atlantic.

It is driven by differences in water density due to variations in temperature and salinity. In the far north, high salinity water cools and sinks. This is replaced by more warm water from the tropics. Once it has sunk, the dense water flows south in the deep ocean.

As global temperatures rise and glaciers melt, input of fresh water near the sinking points will make the surface water less dense. This would reduce the water's ability to sink and therefore could reduce the driving force behind the Gulf Stream.

Recent studies analysing the southerly flow of deep cold water have showed a 30% reduction since 12 years ago, suggesting a weakening in Gulf Stream circulation[28].

If the Gulf Stream was severally weakened or shut down altogether, it would lead to water temperatures (and the climate in general) becoming substantially colder in the UK.

The chances of a complete shutdown any time soon are generally thought to be low[29] and it is consequently viewed as a low risk but high impact event. While it is thought there is a relatively low probability of it occurring soon, it is still important because of the enormous impact it would have if it did occur. It could result in a rapid air temperature drop reaching down to -10°C during winter[29] and a reduction in water temperature that would make surfing become very uncomfortable indeed.

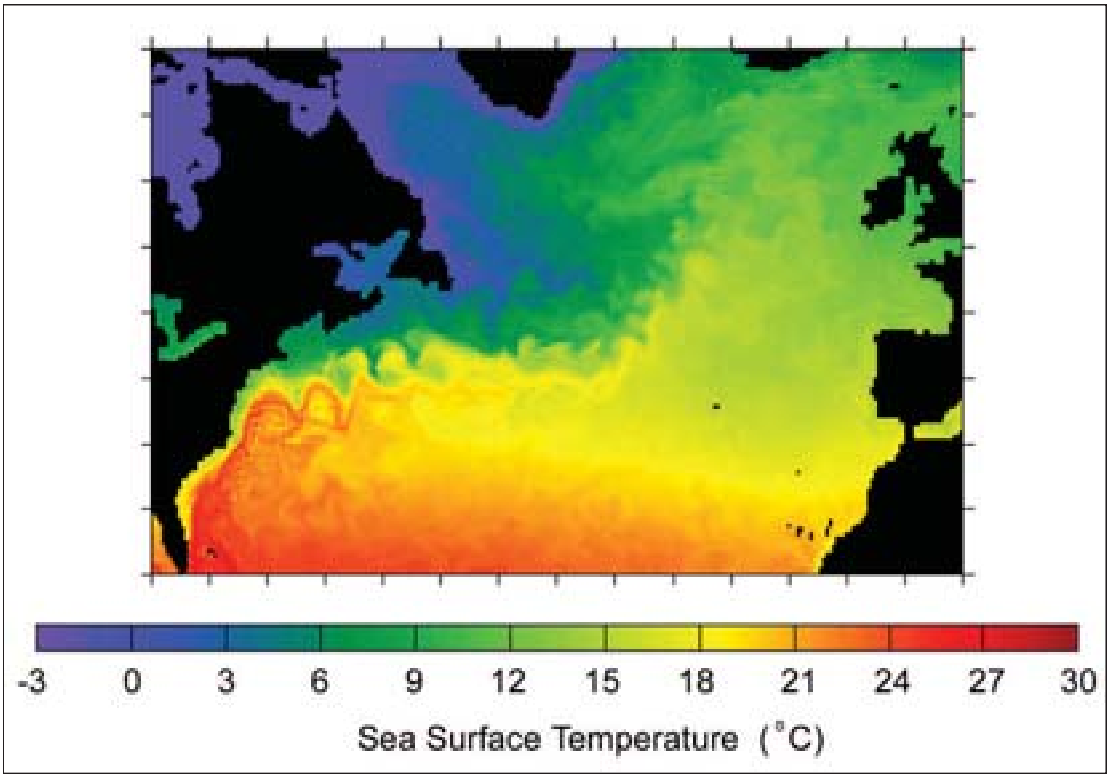


Figure 22. Typical sea surface temperature in the North Atlantic in early spring. The Gulf Stream results in relatively warm water around the UK compared with similar latitudes on the east coast of America. Image: HiGEM simulation courtesy of the British Atmospheric Data Centre.

Summary

Increasing water temperatures due to climate change is likely to mean a shortening of the period of the year when thick winter wetsuits, boots, gloves and hoods are required. While it won't allow wetsuits to be abandoned in the summer altogether, the general situation throughout the year will probably be that less insulation is needed. On the other hand, if a catastrophic event such as the shutdown of the Gulf Stream and associated currents were to occur, the water around the UK (and the climate in general) would be likely to get very cold indeed.

- Increasing water temperature due to global warming will mean less time in thick wetsuits and increase comfort.
- A significant slowing or shut down of the Gulf Stream, while at present thought to be unlikely to occur soon, could mean a rapid decrease in water temperature.

2.5. Changes in ocean acidity

Carbon dioxide and pH

The oceans absorb CO_2 from the atmosphere. Increasing the concentration of CO_2 in the atmosphere results in more being absorbed by the ocean. This alters the chemistry of the ocean making it more acidic (decreasing its pH).

It has been estimated that the oceans have absorbed approximately half of the CO_2 produced by man since the industrial revolution[30]. This has led to a decrease in pH of 0.1 units, equivalent to a 30% increase in the concentration of hydrogen ions[30] (hydrogen ion concentration is what pH is measuring but on a logarithmic scale).

If global emissions continue to rise on current trends, by 2100 the average pH of the ocean could fall by 0.5 units, equivalent to a 3 fold increase in hydrogen ion concentration. This would possibly make the pH lower than it has been for thousands of millennia, at a rate of change 100 times greater[30].

Ocean chemistry and pH

CO_2 reacts with water to form a weak acid. This acid exists in several different forms and results in the release of bicarbonate (HCO_3^-) and carbonate ions (CO_3^{2-}). It also acts as a buffer system that resists sharp changes in pH by mopping up or releasing hydrogen ions (H^+).

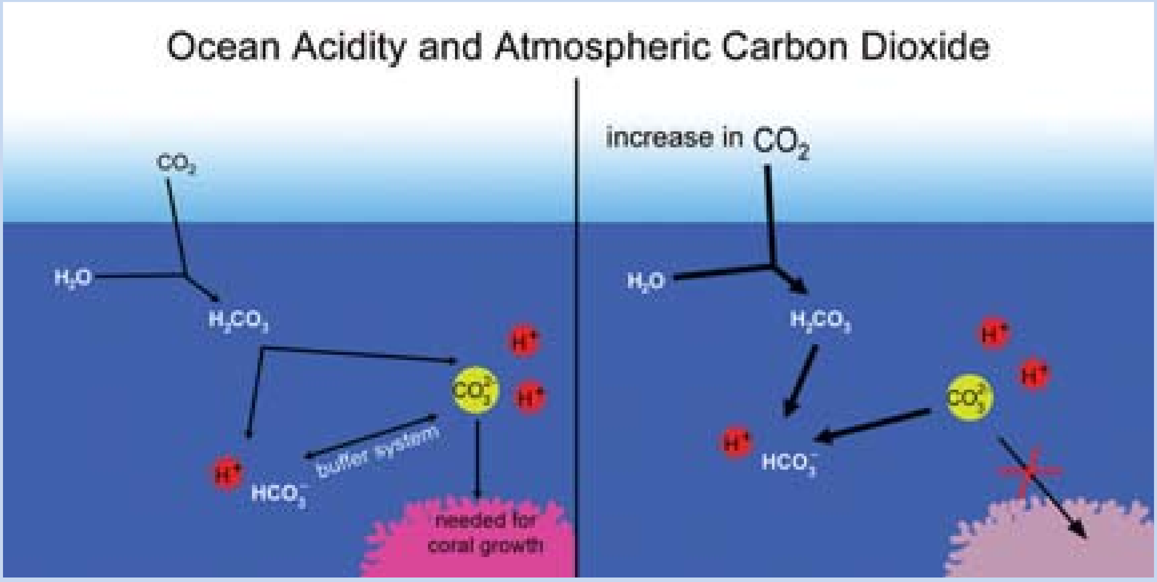


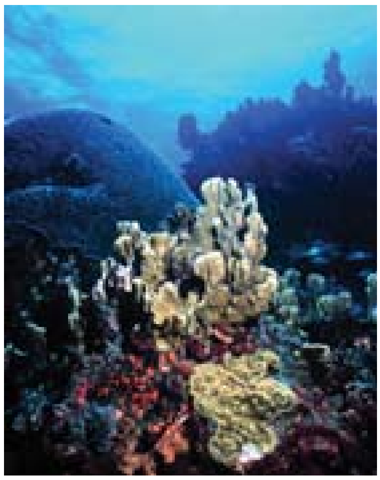
Figure 23. Increases in carbon dioxide dissolved in the ocean makes it harder for organisms such as coral to absorb and retain the chemicals it needs to grow.

As the concentration of CO_2 in the atmosphere increases, more dissolves into the ocean forming more acid. To compensate for the increase in free H^+ ions, some combine with carbonate ions (CO_3^{2-}) to form bicarbonate (HCO_3^-). This resists some (but not all) of the change to pH. The knock on effect is that this means there are less carbonate ions available for calcifying animals such as coral to make calcium carbonate ($CaCO_3$).

Coral reefs

So why is this brief lesson in ocean chemistry important for surfers? While it may not directly affect the surf in the UK, it could have a huge impact for other surf locations around the globe due to its effect on one type of animal - coral.

Many popular destinations around the world produce good surf when swell from deep water hits a coral reef. These reefs are built by millions of tiny coral polyps each secreting a solid calcium carbonate frame in which they live. This process is known as calcification. Over time, a reef can grow into a huge structure. Because it is living, it can repair and rebuild itself after damage by storms.



Coral reefs are under threat from ocean acidification. Photo courtesy of the NOAA

The world-class wave at Cloudbreak, Fiji, breaks over a coral reef. Photo by Tom Servais.

Increasing ocean acidity results in chemical changes that make the process of calcification much more difficult for coral. This would have severe implications for the health of the reef, impacting on its stability and longevity. Added to this, it has been shown increasing sea temperatures can also damage coral reefs.

If the coral can't survive and build new structures, the reefs will eventually degrade and possibly disappear, taking with it a large number of world class surf breaks.

Summary

- Increasing ocean acidity could make it harder for coral species to survive, threatening the reefs that are responsible for many tropical surf breaks.

The majority of energy production in the UK comes from the burning of fossil fuels such as coal and gas, resulting in large amounts of CO_2 being released into the atmosphere. In order to reduce these emissions, we need to get more of our energy from clean, renewable sources.

One area that is increasingly being considered as a source of renewable energy is the marine environment. Marine renewables can be divided into three main sectors: offshore wind, tidal and wave. Of these, wave power is arguably of most interest to surfers as it taps into the same resource.

Wave power resource

Because of its exposed position, the UK has one of the largest wave power resources in the world[31]. The areas with the largest wave power resource in the UK are the north and west coast of Scotland and south west of England[32].

Some studies suggest that the accessible wave power resource in UK waters could be as much as 700 TWh per year - almost twice the current UK energy consumption[33]. Estimates on how much of this energy can practically be harnessed are more conservative, (e.g. over 50 TWh per year[33]), but still significant.

Wave power converters

Wave energy is harnessed by a device that can change the motion of waves into electricity. There are many different designs being promoted that can do this, varying in size from a few meters to several hundred. It is envisaged that these devices will generally be deployed offshore in arrays (wave farms) in areas with suitable wave climates. Many devices are still at the prototype or demonstration phase of development and require further sea trials to find out if they can provide a viable source of power. Because the technology is at an early stage of development, it is likely to be several years before any devices are deployed on a large commercial scale.

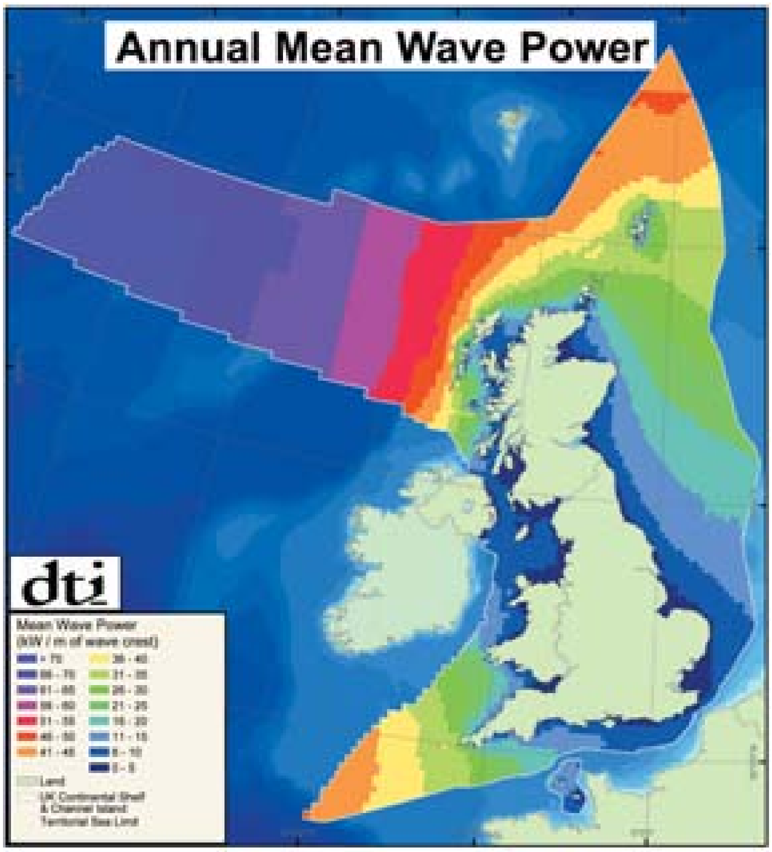


Figure 24. Annual mean wave power. Map shows the largest resource off Scotland and south west England. Source: Dti[32].

Conflict of interest?

So if wave farms are harnessing offshore wave energy, won't that mean there is less available for surfers in the lee? Technically speaking, this is true. As well as removing wave energy, when any structure is built in the marine environment, the potential exists for additional impacts on the local wave climate and sediment transport systems in such a way that may result in the degradation of any surf spots in its lee.

Scale of impacts

The scale of reduction in wave height will depend on how much energy is removed and the distance offshore the wave farm is situated. For instance, several computer modelling studies done on a proposed wave energy development site situated 20km off the north coast of Cornwall suggests that the only impact will be a very small reduction of wave height at the shore. A study by Exeter University suggests the impact will result in a reduction of less than 5cm[34]. Similarly, an independent review by leading surf oceanographer Dr Kerry Black concluded that the reduction should be less than 3-6% at the beaches in the direct shadow of the development [35]. Clearly, wave height reductions on this scale are too small to be noticed by surfers.

A prototype Pelamis, developed by Ocean Power Delivery Ltd, deployed at the European Marine Energy Centre at Orkney. This site allows developers the opportunity to test and monitor equipment. Such tests provide important information needed when determining future impacts. Photo courtesy of Ocean Power Delivery Ltd.

Summary

The technology is still emerging at the moment so the actual impacts are still unknown to a certain extent. While it is likely that unsuitably sized or designed wave farms situated in inappropriate locations could damage surf breaks in their lee, the research carried out so far [34,35,36] suggests that sympathetically designed and positioned wave farms could operate whilst having a negligible (i.e. unnoticeable) impact on the surf.

From a surfer's point of view, case by case analysis of each proposed project is needed to determine whether they are likely to have a detrimental effect. Comprehensive environmental impact assessments for projects such as this are mandatory in the UK. Developers will be required to produce detailed environmental statements when seeking consents, which require stakeholder consultation that would include the surfing community. This allows any potentially damaging proposals to be opposed while allowing ones with little or no impact to proceed. If this is done, surfers and wave farms will be able to coexist without impinging on each other. As the previous chapters in this report show, surfers are likely to benefit by any steps taken to avoid the impacts that climate change can bring.

- Wave farms help reduce CO_2 and therefore combat climate change.
- Appropriately designed and located wave farms are likely to have an unnoticeable impact on the surf.

Conclusions

It looks as though climate change has the potential to have a significant impact on UK surfers and other watersports enthusiasts.

Increasing winter rainfall is expected to lead to more raw sewage overflows and more diffuse pollution from urban and agricultural runoff. Subsequently, water quality during the winter is likely to suffer significantly. This will undoubtedly lead to an increase in the chances of contracting a sewage related illness while in the water. An increase in the occurrence of flooding events due to a combination of high rainfall and sea level rise will also result in further water pollution.

Sea level rise will result in some reefs breaks working less often or possibly disappearing altogether. While some may start to work more frequently, because the UK has more low tide reef breaks, it looks as though the net result could be negative. Beach erosion is likely to have a profound effect on the coastal zone and will undoubtedly impact many surf spots. While some may shift slightly landward and be otherwise relatively unaffected, others may disappear as they are squeezed up against immovable structures such as cliffs or shoreline developments. It is also likely that an increase in shoreline protection schemes to combat sea level rise will result in a loss of surf breaks.

Forecasts suggest that the wave climate itself may change, leading to a small increase in the likelihood of bigger and more consistent waves during the winter. Whether these waves will be of the quality needed for surfers is uncertain, bigger waves do not necessarily mean better surf. Changes in storm tracks may mean that any increase does not benefit all regions and it is possible some locations could see a reduction in wave climate at the shore. Whilst winter may see more storm activity, it looks possible that summer could become even more inconsistent with longer flat periods. For all of these wave climate predictions, it should be remembered that there is a great deal of uncertainty in this area at present. To a certain extent, the effects of climate change are as yet unknown.

Water temperatures will almost certainly increase slightly in the short term. This will benefit all surfers except those who enjoy putting on as much rubber as possible! There is however, the threat of much colder water if the Gulf Stream did shut down.

Whilst it will not affect UK surf breaks, increases in ocean acidity could be potentially devastating for the health of coral reefs (which are already showing signs of stress due to increases in sea surface temperature). This could result in the degradation of many tropical destinations popular with UK surfers.

Switching from fossil fuels to renewable energy sources in order to reduce CO_2 emissions is one way of combating climate change. In addition to well-established wind and solar energy technologies, the viability of harnessing wave power in the ocean is also being investigated. While wave farms have the potential to impact on the surf we ride, all the research so far suggests that if the developments are designed sympathetically and located far enough offshore, the impact will be on a scale so small it will be unnoticeable.

So what's the bottom line? If left unchecked, climate change is likely to have a significant impact on surfing in the UK. Whilst there may be some benefits at some locations, on balance, there seems to be much more potential for negative impacts to occur.

As surfers, we rely on the weather to supply us with waves we ride and the coast to supply us with a place to ride them. Because of our close association with the natural environment, any change in climate is likely to be felt more by surfers and other recreational water users when compared to others in the UK whose lifestyle distances themselves from the great outdoors.

Even though the exact effects of global warming on the climate are still uncertain, that is no excuse to ignore it. Looking at the evidence available to date, the chances are that climate change will make conditions less suitable for surfers in the UK rather than improving the situation.

What you can do

In order to limit the impact of climate change and reduce the probability of extreme events such as the global collapse of major ice sheets or shut down of the Gulf Stream, measures must be taken to reduce global CO_2 emissions.

While industry and both the UK and foreign governments have important roles to play, so do individuals (and that includes surfers!).

Here is a list of things you can do to start to reduce your individual carbon footprint:

- When travelling to the beach, share the driving with your mates.
- Change to low energy light bulbs in your house.
- After watching TV or a surf dvd, turn stuff off rather than leaving it on standby.
- Change to a renewable energy supplier.
- When making a flask of post surf coffee / tea / hot chocolate in the winter, only boil the water you need.
- Save water. Each litre takes a lot of energy to supply and then treat - saving water is saving energy!
- When planning a surf holiday, consider your destination and the impact of your method of travel. Carbon emissions from air travel are considerable. Perhaps replace a flight to Bali with road trip to France or Spain every once in a while.

These ideas are just a start but if everyone did them, it would make a huge difference. Some of them will even save you money!

Becoming greener doesn't necessarily mean you have to knit your own sandals or travel everywhere on a wooden bicycle. It is about giving a bit more consideration to the impact you are having on the planet and acting accordingly. The surf we enjoy is a phenomenon of the natural world. Perhaps it's time to give a little back.

To find out more about Surfers Against Sewage's campaigning on this issue go to:
www.sas.org/uk/campaign/climate_chaos/index.php

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