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Setting the record straight on Europe's mild winters

RICHARD SEAGER discusses his research into the Gulf Stream and other factors that influence the European climate

I GREW UP IN NORFOLK and had a typically mild and damp English boyhood. My recollections of days spent sledging in deep snow are probably so vivid because those days were so rare. Now I live in New York and my own children are bored with the snow long before winter is over. These personal experiences are backed up by the meteorological data. The average January temperature in the British Isles is about 15–20°C warmer than it is on the North American side of the Atlantic at the same latitude (Figure 1). A gardener might be more interested in the number of winter days when night-time temperatures drop below zero (frost days). For the December through March season that is almost zero in Ireland and typically less than 20% of days in Britain but even for New York and its suburbs, substantially further south, on some two thirds of the nights between December and March the temperature drops below freezing (Figure 2).

Origins of the Gulf Stream-European climate myth

Everyone in the English speaking world, and elsewhere, grows up being told that it is the Gulf Stream that keeps Europe's winters so mild. The Gulf Stream is a powerful current that flows north from the Gulf of Mexico hugging the American coast until at Cape Hatteras it departs into the interior North Atlantic Ocean to become the North Atlantic Drift and flow northeastward to the British Isles (Figure 3). It is clearly seen in maps of sea surface temperature as the boundary between warm waters to its south and cold waters to its north. But along its path it cools as it releases into the atmosphere the heat it has been carrying from the tropics. Supposedly it is this heat, picked up by the winds and blown eastward into Europe that keeps Europe's winters mild.

The idea originated with Maurice Fontaine Maury, an officer in the American Navy, who, in 1855, published a book *The Physical Geography of the Sea*. Maury's book is widely thought to be the first physical oceanography text book and went through 19 printings and was translated into 3 different languages.

In the book, Maury expounds on his Gulf Stream theory for Europe's mild climate at length, 'One of the benign offices of the Gulf Stream is to convey heat from the Gulf of Mexico, where otherwise it would be excessive, and to disperse it in regions beyond the Atlantic for the amelioration of the climates of the British Isles and of all Western Europe' and, were the Gulf Stream not to do this 'the soft climates of both France and England would be as that of Labrador, severe in the extreme, and ice bound' and finally, 'Every west wind that blows crosses the stream on its way to Europe, and carries with it a portion of this heat to temper there the northern winds of winter. It is the influence of this stream upon climate that makes Erin the Emerald Isle of the Sea and that clothes the shores of Albion in ever-

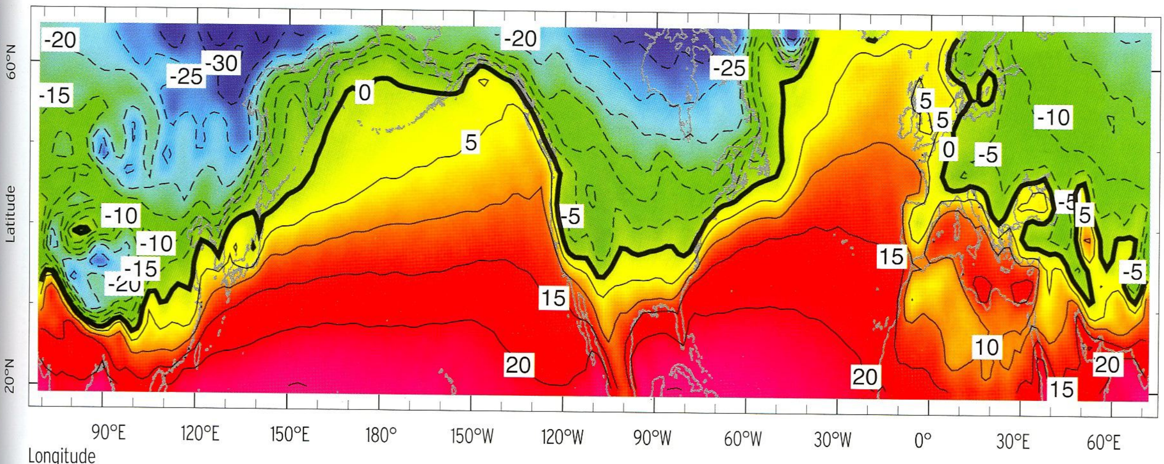


Figure 1 The average January surface air temperature in the northern hemisphere.
Western Europe is 15-20°c warmer than eastern North America at the same latitude. This difference in winter climate is often explained in terms of the movement of heat by the Gulf Stream, but in fact it owes more to a simple maritime versus continental climate distinction and the pattern of movement of heat by the atmosphere, which is strongly influenced by the forcing of waves in the air flow by the Rocky Mountains

green robes, while in the same latitude, on this side, the coasts of Labrador are fast bound in fetters of ice.'

Much the same kinds of statements can be found in the modern scientific literature and the idea remains a mainstay of popular accounts. For example, in *An Inconvenient Truth* (2006) Al Gore states, 'Incidentally the heat drawn from the Gulf Stream and carried to Europe makes cities like Paris and London much warmer than Montreal or Fargo, North Dakota, even though they are close in latitude.'

I should have thought there was something fishy in this story when I moved to Seattle on America's northwest coast to take up a postdoctoral position. Seattle has a climate that was notably similar to England's: summers that were comfortably warm but not hot and long, grey, cool, damp winters almost free of snow and frosts. Meanwhile across the Pacific we are all aware of the bitter cold winters of Korea and eastern Siberia. In fact this temperature contrast is quite similar to that across the North Atlantic Ocean. However, the ocean circulations of the North Pacific and North Atlantic are quite different. Both have strong western boundary currents that flow from the tropics into the mid-latitude ocean. This is the Gulf Stream in the Atlantic and the Kuroshio Current in the Pacific. But, whereas, after the Gulf Stream leaves the American coast, it flows northeastward towards northwest Europe, the Kuroshio, after leaving the coast off Japan, heads almost due east to Oregon. Thus there is almost no transport of heat by the Pacific Ocean into the regions north of about 40°N (ie north of California) whereas there is in the Atlantic. However, the west coasts of Europe and America both have mild climates.

Mild winters in Seattle may not have forced me to question the Gulf Stream story but my time there did lead me to the answer in the person of Prof. David Battisti. David is one of those great scientists who takes delight in questioning conventional wisdom. One day after we had been mulling over the lack of evidence that variation of mid-latitude ocean surface temperatures have any impact on the atmosphere, David laughed that 'it makes you wonder if the Gulf Stream story is right after all!'. And so we went to work.

On the relative roles of atmospheric and oceanic poleward heat transports

In the tropics the amount of solar radiation absorbed by the Earth exceeds the longwave radiation that the Earth radiates back to space. The opposite is true in the high latitudes. The imbalance is accounted for by the movement of heat polewards by the wind and current circulations of the atmosphere and ocean.

Recent advances in climate research have allowed these heat transports to be more accurately measured. In the deep tropics the ocean heat transport exceeds the atmosphere transport and the two are equal at about 15 degrees north and south of the

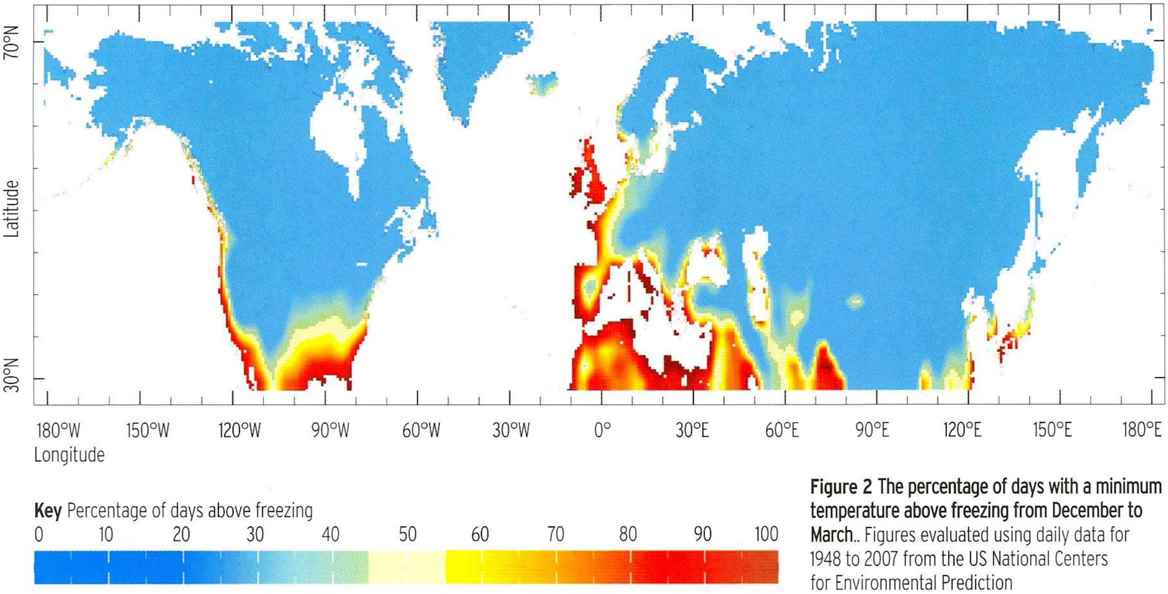


Figure 2 The percentage of days with a minimum temperature above freezing from December to March.. Figures evaluated using daily data for 1948 to 2007 from the US National Centers for Environmental Prediction

Equator and, in the mid and high latitudes, the atmosphere heat transport exceeds the ocean heat transport severalfold, a simple fact that suggests a potentially dominant role of the atmosphere in determining extra-tropical climates.

The atmosphere accomplishes this poleward transport of heat by moving warm air poleward and cold air equatorward - a process that warms higher latitudes and cools lower latitudes. A large part of this heat transport is accomplished within stationary waves – meanders of the atmosphere circulation forced by spatial variations in the Earth's surface and which remain fixed relative to the Earth's surface. In the northern hemisphere winter the Aleutian and Icelandic low pressure systems are semi-permanent features over the North Pacific and Atlantic Oceans respectively.

The atmospheric flow around the Icelandic Low brings cold air equatorward in eastern North America and warm air poleward over western Europe, helping explain the winter climate contrast. A similar flow occurs across the Pacific Ocean around the Aleutian Low. This flow helps make eastern Asia cold and western America warm.

Travelling waves – the storm systems that give us our weather – also move heat poleward but they act like egg beaters in the atmosphere mixing up the temperature. They move heat into cold regions - such as wintertime eastern North America and out of warmer regions - such as wintertime western Europe.

The maritime versus continental climate distinction

So, the stationary waves help explain the difference between North American and European climates. However, even in the absence of stationary waves we would expect differences in climate across the ocean. The high heat capacity of water means that the oceans warm more slowly in summer than land surfaces do, and cool off more slowly in winter. Further, wind stirring mixes heat down in the ocean so that the Sun's summer heat warms a larger mass of ocean than it does of land where the heat can only diffuse downward. Both effects mean that the annual cycle of temperature for the oceans is much smaller – cooler in summer and warmer in winter – than for land surfaces at a similar latitude. Since, in the mid-latitudes the prevailing winds blow from west to east, land areas to the east of oceans receive cool winds in summer and warm winds in winter, creating a moderate, 'maritime' climate. Land areas on the east side of continents receive warm winds in summer and cold winds in winter and have a more extreme 'continental' climate.

Indeed, when we analysed the data, we found that over almost all of the North Atlantic Ocean some three quarters of the heat released from the ocean in winter was absorbed in the previous summer, a process that does not require ocean currents. Only immediately east of the southeastern United States and west of northern Norway does the convergence of heat by ocean currents sustain as much as half of the total winter heat release.

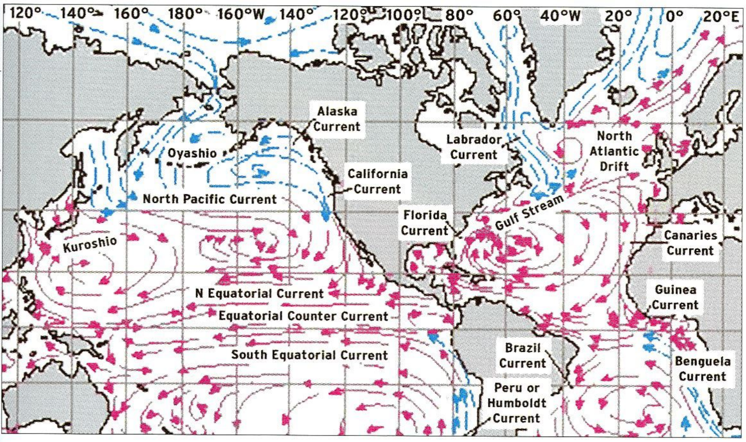


Figure 3 A schematic diagram of the surface ocean circulation. The Gulf Stream flows from the Gulf of Mexico along the southeast coast of the United States and then northeastward across the North Atlantic Ocean as the North Atlantic Drift. Waters sink to depth in the Icelandic and Norwegian Seas and flow southward near the ocean bottom and out of the Atlantic connecting the Gulf Stream into a global overturning circulation (which is not shown here). Note that the Gulf Stream's sister current in the Pacific Ocean, the Kuroshio, does not flow northeast but instead flows nearly due east towards Oregon

Testing the impact of ocean currents on European climate using climate models

The next step was to test these conclusions using computer models of the Earth's climate system. We had two climate models available to us which in their standard configuration accounted for the movement of heat by ocean currents. We simply replaced that part of the models with a layer of water that exchanged heat with the atmosphere but could not move heat from one place to another. This removed ocean heat transports not just in the North Atlantic but everywhere. Given that the ocean moves heat from the deep tropics to higher latitudes, not surprisingly the effect of removing the ocean heat transport was to warm the equatorial band and cool the climate elsewhere. The January temperature in Britain dropped by about 3°C.

But what was remarkable was how uniform this cooling was with longitude: the cooling in eastern North America and elsewhere at the same latitude was about the same. In other words, the 15–20°C difference in winter temperature between western Europe and eastern North America remained the same when we removed the Gulf Stream (and all other currents)! (Figure 4).

These model results confirmed what analysis of observations had implied: the ocean heat transport has a modest impact on European climate and that the much larger temperature difference across the North Atlantic Ocean is caused by other processes. However, it was clear that the heat transport of the Norwegian Current, fed by the North Atlantic Drift, does keep the coast of northern Norway free of sea ice in winter and, hence, considerably warmer than it would be otherwise.

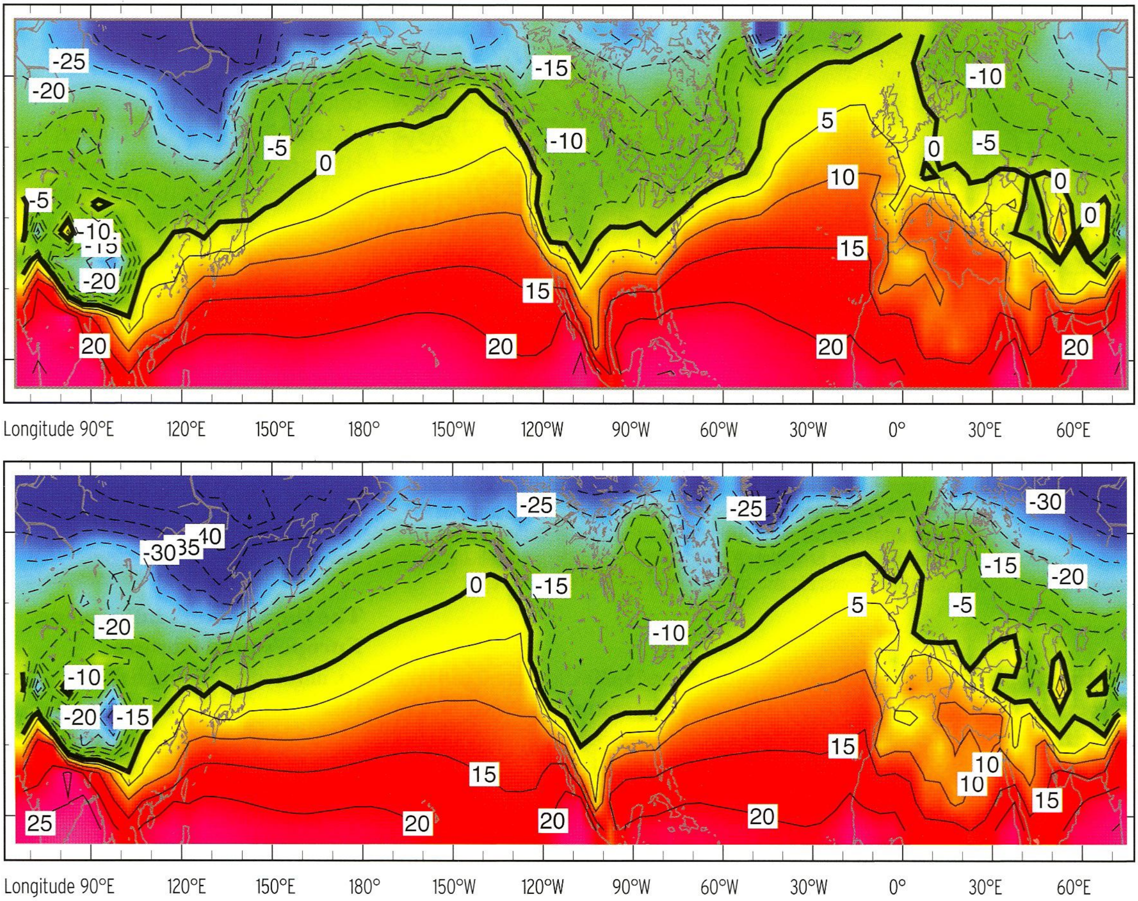
But it turned out that the cross-Atlantic temperature difference was not solely caused by the simple maritime versus continental climate distinction. The mountain ranges of the Earth significantly affect atmospheric flow creating stationary waves. Most pertinently, when air flows over the Rocky Mountains it is compressed in the vertical and, due to the need to conserve angular momentum, it has to move to the south. This brings cold air from the northwest into eastern North America. But this flow is part of a stationary wave forced by the mountains and the flow curves and begins to flow northward again over the Atlantic Ocean. This brings warm air from the southwest into western Europe warming the climate. When we did another model simulation in which we replaced the real topography of the Earth with a flat Earth this mountain-forced wave was eliminated and the temperature contrast across the North Atlantic Ocean dropped to half of its observed value.

The three factors influencing Europe's mild winters

So, in summary, about half the 15–20°C difference in winter temperature between western Europe and eastern North America is caused by a simple maritime versus continental climate distinction. The other half is caused by the pattern of air flow and heat transport forced by the Rocky Mountains. Ocean heat transport contributes almost nothing to the climate difference but instead contributes a modest – about 3°C – warming to the winter climates on both sides of the Atlantic Ocean.

Implications for future climate change

In considering human-induced climate change and ocean circulation it is important to remember that the ocean circulation is driven by the action of the winds blowing on its surface. The atmosphere is quite different and is a heat engine that absorbs heat released from the Earth's surface and converts it into the kinetic energy of the winds. The great ocean currents like the Gulf Stream and the Kuroshio arise as a ➤



non-local response to the wind stress. The overturning circulation – the sinking of surface waters to depth in the North Atlantic, flowing south at the bottom of the Atlantic and upwelling around Antarctica – is also mechanically driven. This is because the sinking of cold water at high latitudes has to be balanced by a downward movement of heat which is accomplished, in large part by wind mixing. (It is quite misleading to name the overturning circulation the 'thermohaline circulation', which implies driving by heat and freshwater fluxes at the ocean surface – and this name is indeed falling out of favour.) As climate changes, the winds will continue to blow. Therefore, the ocean circulation, including the Gulf Stream, will continue to flow and the deep overturning circulation will continue as well.

Figure 4 The January surface air temperature in a climate model that accounts for ocean heat transport (top) and in which ocean heat transport is removed (above). Note how the east to west differences in winter temperature are preserved in the absence of ocean heat transport and, therefore, must have other causes. The strong cooling off northern Norway is caused by a southward expansion of sea ice that is held back in nature by the Norwegian Current

The only way that fluxes of heat and freshwater come into play in explaining the global ocean circulation is through determining the exact location of the downwelling and upwelling: waters sink to depth in the North Atlantic and not in the North Pacific because the Atlantic water is saltier and hence more dense. Most climate models predict that, as the current century progresses, warming of the subpolar Atlantic Ocean and increased precipitation – a consequence of increased atmospheric water vapour transport from the subtropics – will make the water less salty and less dense. This reduces the sinking of surface waters to depth and weakens the North Atlantic branch of the meridional overturning circulation. The models do not project it to stop entirely but to just weaken. Of course, the wind-driven ocean currents will continue to flow and there will still be a Gulf Stream,

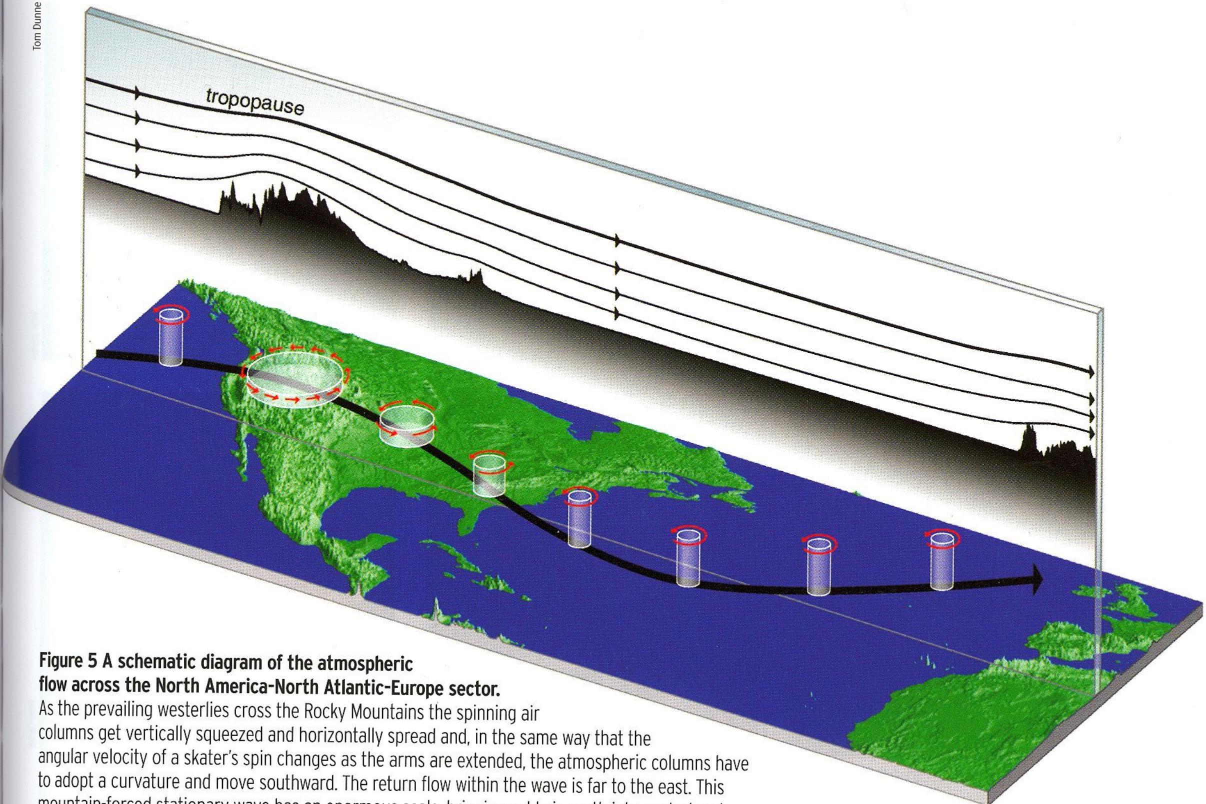


Figure 5 A schematic diagram of the atmospheric flow across the North America-North Atlantic-Europe sector. As the prevailing westerlies cross the Rocky Mountains the spinning air columns get vertically squeezed and horizontally spread and, in the same way that the angular velocity of a skater's spin changes as the arms are extended, the atmospheric columns have to adopt a curvature and move southward. The return flow within the wave is far to the east. This mountain-forced stationary wave has an enormous scale, bringing cold air south into central and eastern North America and warm air north into the eastern Atlantic and western Europe. It explains about half of the difference in winter temperatures across the Atlantic Ocean

North Atlantic Drift and Norwegian Current.

Given that we know from models that an utterly artificial total removal of ocean circulation and heat transport only cools western Europe by a few degrees centigrade, the impact of the projected weakening of the overturning circulation is quite modest. It introduces a regional cooling tendency that is overwhelmed by the radiatively driven warming associated with rising greenhouse gases. This leads to a local minimum in the pattern of global warming, but warming nonetheless.

Only an utter confusion that explains the entire east-west winter temperature contrast across the Atlantic as a consequence of the Gulf Stream and ocean heat transport would make one think that a slowdown of the ocean overturning circulation will plunge Europe back into an ice age! The reality is that Europe, like elsewhere, can expect warmer winters and summers as a consequence of human-induced climate change. The warm climate species that Britain's gardeners have been able to cultivate will still thrive.

The more real and worrying threat to British horticulture and, indeed, to its agriculture, comes from a projected increase in summer drought and associated heat waves, as well as an increase in the proportion of rainfall that comes in very heavy events. So, even if an ice age is not coming, human-induced climate change will still present many new challenges to the British gardener.

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FURTHER READING

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