

I created my knowledge base by looping through the articles and finding the sentences that contained the given word. I created a dict where the key is the word in my top 10 and the value is a list of sentences that contain the given word.

Dialog 1:

Bot: Hi, I'm ClimateBot, a bot that talks about climate change. What's your name?

User: My name is Vedant.

Bot: Hi, Vedant. Do you think climate change is a problem?

User: Yes, I think that it is a problem.

Bot: Me too! Did you know [random fact about global warming]

User: Yes, I did know that.

Dialog 2:

Bot: Hi, I'm ClimateBot, a bot that talks about climate change. What's your name?

User: My name is Vedant.

Bot: Hi, Vedant. Do you think climate change is a problem?

User: No, I don't believe it is a problem.

Bot: You don't? Did you know [random fact about global warming]

User: I don't believe that is true.

Bot: You don't? Did you know [quote scientific study]. This was discovered by scientists after doing extensive research.

User: I am not going to change my mind.

Bot: Ok

Knowledge Base:
climate:

[' Science & information for a climate-smart nation', 'This tremendous ability to store and release heat over long periods of time gives the ocean a central role in stabilizing Earth's climate system.', 'Knowing how much heat energy the ocean absorbs and releases is essential for understanding and modeling global climate.', 'Converting the temperatures to joules (a standard unit of energy) allows them to compare heat in the ocean to heat in other parts of Earth's climate system.', 'Recent studies estimate that warming of the upper oceans accounts for about 63 percent of the total increase in the amount of stored heat in the climate system from 1971 to 2010, and warming from 700 meters down to the ocean floor adds about another 30 percent.', 'Warming ocean waters are also implicated in the thinning of ice shelves and sea ice, both of which have further consequences for Earth's climate system.', ' While the Sun has played a role in past climate changes, the evidence shows the current warming cannot be explained by the Sun.', ' Ice cores are scientists' best source for historical climate data.', 'Other proxies, such as benthic cores, extend our knowledge of past climate back about a billion years.', '"Since systematic scientific assessments began in the 1970s, the influence of human activity on the warming of the climate system has evolved from theory to established fact."', ' Studies show that solar variability has played a role in past climate changes.', 'Your questions about climate change answered.', 'Test your knowledge of climate science.', ' Judith Lean, "Cycles and trends in solar irradiance and climate," Wiley Interdisciplinary Reviews: Climate Change, vol.', 'Ozone and climate go hand in hand – in more ways than one.', 'Thus, the greenhouse effect, which is essential for creating the climate for life on Earth, is also responsible for the Earth getting warmer than it was before we started burning large amounts of fossil fuels.', 'The Sun can influence Earth's climate, but it isn't responsible for the warming trend we've seen over recent decades.', 'Is the ozone hole causing climate change?', 'What do volcanoes have to do with climate change?', 'Solar radiation is a primary driver of climate.', ' Earth system science is the study of how scientific data coming from various fields of research, such as the atmosphere, oceans, land ice, and others, fit together to form the current picture of our planet as a whole, including its changing climate.', ' Climate scientists separate factors that affect climate change into three categories: forcings, feedbacks, and tipping points.', ' Forcings: The initial drivers of climate.', '1 The solar cycle is incorporated into climate models.', 'Very small airborne particles come from both human and natural sources and have various effects on climate.', ' Climate feedbacks: processes that can either amplify or reduce the effects of climate forcings.', 'Clouds have an enormous impact on Earth's climate, reflecting about one-third of the total amount of sunlight that hits Earth's atmosphere back into space.', 'A warmer climate causes more water to be held in the atmosphere, leading to an increase in cloudiness and altering the amount of sunlight that reaches Earth's surface.', 'Global climate models show that precipitation will generally increase due to the increased amount of water held in a warmer atmosphere.', 'The most abundant greenhouse gas, it acts as a feedback to amplify climate warming forcings.', ' Climate tipping points: When Earth's climate abruptly moves between periods of relatively stable climates.', 'This highlights the importance of ocean circulation in maintaining regional climates.', 'Ozone and climate go hand in hand – in more ways than one.', ' Hurricanes are subject to a number of climate change-related influences.', 'A study of Hurricane Katrina estimated that higher sea levels led to flood elevations 15-60 percent higher than climate conditions in 1900.', ' Scientists predict that climate change will have many effects on freshwater and marine environments.', 'Warmer water due to climate change might favor harmful algae in a

number of ways:', ' Learn more about climate change's impacts on water resources', ' UN climate talks', ' State of the climate', ' State of the climate', ' UN climate talks', ' State of the climate', ' UN climate talks', ' UN climate talks', ' UN climate talks', ' Tipping points Explainer: Nine 'tipping points' that could be triggered by climate change', ' Explainer: Nine 'tipping points' that could be triggered by climate change', ' The persistent march of a warming climate is seen across a multitude of continuous, incremental changes.', ' And while climate records are being routinely broken , the cumulative impact of these changes could also cause fundamental parts of the Earth system to change dramatically and irreversibly.', 'This article is part of a week-long special series on "tipping points", where a changing climate could push parts of the Earth system into abrupt or irreversible change', ' Explainer: Nine 'tipping points' that could be triggered by climate change', ' Guest post: Could climate change and deforestation spark Amazon 'dieback'?', ' A glance at the news media on any given week will likely highlight all sorts of climate change impacts.', ' Broadly, these impacts reflect gradual changes caused by a climate that is steadily warming.', ' "A climate tipping point, or any tipping point in any complex system, is where a small change makes a big difference and changes the state or the fate of a system."', ' It is worth noting that a tipping point can be caused by natural fluctuations in the climate as well as by an external forcing, such as global warming.', ' Natural fluctuations can also be the final nudge for a tipping point pushed to the brink by human-caused climate change, says Prof Mat Collins , joint Met Office chair in climate change at the University of Exeter and coordinating lead author on the "Extremes, Abrupt Changes and Managing Risks" chapter of the Intergovernmental Panel on Climate Change (IPCC) special report on the ocean and cryosphere in a changing climate ("SROCC").', 'In a Nature commentary in 1987, for example, Prof Wally Broecker of Columbia University – who died in 2019 – warned that palaeoclimate data suggests the "Earth's climate does not respond to forcing in a smooth and gradual way.", ' According to a 2009 paper on the use of the term "tipping points" in climate science and the media, a presentation (pdf) in 2005 by Dr James Hansen of Columbia University's Earth Institute helped "initiate a tipping point trend in climate change communication that was quickly reflected in public debate".', ' In Hansen's talk – a tribute to scientist Prof Charles Keeling , given at the American Geophysical Union (AGU) Fall Meeting – Hansen warned that "we are on the precipice of climate system tipping points beyond which there is no redemption".', ' By its Fall Meeting of 2008, the AGU had an entire half-day session dedicated to climate tipping points.', 'A Science briefing about the meeting declared that "tipping points, once considered too alarmist for proper scientific circles, have entered the climate change mainstream".', ' "Technically, an abrupt climate change occurs when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause."', ' "We define abrupt climate change as a large-scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems."', ' Typically, definitions for a tipping point fall into two categories, says Dr Ricarda Winkelmann , junior professor of climate system analysis at the Potsdam Institute for Climate Impact Research (PIK).', ' "One is simply that one vital part of the climate system shows some kind of threshold behaviour and that means that a small perturbation around that element can cause a huge qualitative change.", ' "In some cases, there is evidence that once the system has jumped to a different state, then if you remove the climate forcing, the climate system doesn't just jump

back to the original state – it stays in its changed state for some considerable time, or possibly even permanently.”, 'This is in line with projections by climate models', says Dr Richard Wood.', 'And that would have big impacts on the climate of, well, the whole northern hemisphere, but particularly Europe.”, ' (According to Climate Action Tracker, current global climate policies put the world on track for around 3C of warming.)', ' And it is “important to emphasise that climate models are not suggesting a complete shutdown of the AMOC in the next 100 years or so”, adds Wood: “We’re looking at what we call a ‘low-probability, high-impact’ event”.', 'So it would actually reinforce the climate-change signal.”, 'For example, a recent study in the new journal Nature Food suggests that an AMOC shutdown would cause “widespread cessation of arable farming” in the island of Great Britain with “losses of agricultural output that are an order of magnitude larger than the impacts of climate change without an AMOC collapse”.', 'As the IPCC’s special report on the ocean and cryosphere in a changing climate (“SROCC”) explains, this means that it sits “upon bedrock that largely lies below sea level and [is] in contact with ocean heat, making [it] vulnerable to rapid and irreversible ice loss”.', 'RCP8.5 is a “very high baseline” emission scenario brought about by rapid population growth, high energy demand, fossil fuel dominance and an absence of climate change policies.', 'But the forest itself plays a critical role in the local climate.', 'The result is that either reducing the amount of rainfall or the amount of forest can shift the climate into a drier state that cannot support a rainforest.', 'There are three potential causes of this, explains Prof Richard Betts, head of climate impacts at the Met Office Hadley Centre and chair of climate impacts at the University of Exeter.', 'The first is a decline in rainfall in response to a warming climate.', '“The post-deforestation climate will no longer be a very wet climate like the Amazon.”, 'Factoring in climate change and “widespread use of fire” brings the tipping point closer, say Lovejoy and Nobre in their editorial.', 'Amazon dieback would also make it more difficult to tackle climate change, he notes.', 'Mortality rates of wet climate species are increased, whereas dry climate species are showing resilience.', 'The effect was reinforced by the “climate-vegetation feedback”, where drier conditions saw less vegetation growth, a reduction in evapotranspiration and even less rainfall.', 'This is due, in part, to a warming climate and a reduction in air pollution rates.', 'Theory suggests that a warming climate could actually bring more rainfall to the Sahel.', 'Evidence from palaeoclimate data – such as lake sediments – suggest the region was widely covered with vegetation and deep freshwater lakes during this time, resulting in a “Green Sahara”.', 'Therefore, it provides limited insight into how the WAM will be affected by climate change.', 'And, more generally, projections from different climate models have suggested both drier and wetter futures for the Sahel under a changing climate – with the latter linked to a tipping point of 3C of localised warming in the Gulf of Guinea.', 'A 2018 study using a high-resolution climate model, for example, simulated “decreasing precipitation over the southern Sahel and increase of precipitation over the western Sahara” by the end of the century under the very high emissions RCP8.5 scenario.', 'The evidence for this mainly comes from palaeoclimate data from the end of the last ice age, says Prof John Chiang, who runs a climate dynamics research group at the University of California, Berkeley.', 'As the climate warms, there is an increasing risk that that permafrost will thaw.', 'Thus, large-scale thawing of permafrost has the potential to cause further climate warming.', 'The IPCC’s special report on the ocean and cryosphere in a changing climate (“SROCC”), for example, says that there is “very high confidence” that record high temperatures at ~10–20m depth in permafrost have been “documented at many long-term monitoring sites in

the northern hemisphere circumpolar permafrost region".', ' "These observations signify that the feedback to accelerating climate change may already be underway."', ' The SROCC says there is "high confidence" in projections of "widespread disappearance of Arctic near-surface permafrost...this century as a result of warming, with important consequences for global climate".', 'This is projected to release 10s to 100s of billions of tonnes [or gigatonnes, GtC], up to as much as 240 GtC, of permafrost carbon as CO₂ and methane to the atmosphere with the potential to accelerate climate change."', ' "Ice melt or the thawing of permafrost involve thresholds (state changes) that allow for abrupt, nonlinear responses to ongoing climate warming."', ' For example, explains Dr David Armstrong McKay – a postdoctoral researcher at the Stockholm Resilience Centre , focusing on modelling nonlinear biosphere-climate feedbacks – some areas of decomposition may release so much warmth that it triggers a so-called " compost bomb ".', ' Overall, the evidence indicates that there are several mechanisms for abrupt regional thawing, says Armstrong McKay, while for permafrost thaw more generally, it is expected that it "will act as more of a continuous positive feedback on climate change rather than an abrupt tipping point".', 'At the COP25 climate talks in Madrid, he told Carbon Brief:', ' The map below, from the IPCC's special report on the ocean and cryosphere in a changing climate ("SROCC"), shows how coral reefs around the world were affected in 2015-16.', 'Such "decadal timescales" are "coherent with the observations that coral cover across the Caribbean declined by 80% from 1977 to 2001 and may completely disappear by 2035, depending on rates of further overfishing, climate change and ocean acidification", the authors note.', ' In 2016, the first study to compare the widespread impacts of climate change at 1.5C and 2C of warming warned that 90% of tropical reefs would be "at risk of severe degradation due to temperature-induced bleaching from 2050 onwards" in a 1.5C warmer world.', ' Eakin says "we've already reached" a tipping point for corals on a global basis because of climate change:', ' The study warns that "the most likely scenario" is that "coral reefs throughout the tropics will continue to degrade over the current century until climate change stabilises, allowing remnant populations to reorganize into novel, heat-tolerant reef assemblages".', ' "The large-scale loss of functionally diverse corals is a harbinger of further radical shifts in the condition and dynamics of all ecosystems, reinforcing the need for risk assessment of ecosystem collapse, especially if global action on climate change fails to limit warming to 1.5-2C."', 'Another is that climate models can struggle to simulate the monsoon system, in part because of the intricate interplay of circulation, temperature and topography that drives it.', ' Palaeoclimate studies , using " proxy " reconstructions of past conditions, suggest that shifts to a low rainfall monsoon state have occurred in the past in response to changes in how much of the sun's radiation reaches the Earth's surface.', ' "The key phrase here is 'abrupt shift' – monsoons may change a lot, but there simply is no evidence for them being here one year and gone the next in response to human-induced climate change."', ' The "vast majority of studies on abrupt changes in monsoons focus on changes that are 'abrupt' relative to the past evolution of the climate system that occurred over tens of thousands to millions of years", adds Boos:', ' "Palaeo changes are important, but their relevance to human-caused climate change is unclear; feedbacks that take hundreds to thousands of years to operate – involving large changes in ice sheets or continental vegetation and soil types – may not be relevant if we are interested in changes taking place over a few years or a few decades."', ' Prof Anji Seth , who leads a physical climate research group at the University of Connecticut , agrees that "there is

no evidence that there is a tipping point where you would go from a wet monsoon to a threshold of very dry".', 'A tipping point for Greenland ice melt is unlikely to be abrupt, says climate scientist Dr Ruth Mottram of the Danish Meteorological Institute, but it is clear that there will be a threshold beyond which its eventual collapse is irreversible.', '“The continued decline of the ice sheet after this threshold has been passed is highly dependent on the future climate and varies between about 80% loss after 10,000 years to complete loss after as little as 2000 years (contributing about six metres to sea level rise).”', 'The IPCC’s special report on the ocean and cryosphere in a changing climate (“SROCC”) also notes that decay of the ice sheet would not be abrupt.', '“It is clear from even very early work that the ice sheet is only there because it is already there – if there was no ice sheet in Greenland under today’s climate we would not be able to build it up again.”', 'So once it’s gone it’s gone until at least the next glacial period – and we’ll be waiting some tens of thousands of years given current climate change and the slow rate of carbon removal by natural means.”', 'Boreal forests are found in the cold climates of the northern hemisphere high latitudes.', 'Research also indicates that “rather than showing gradual responses”, boreal ecosystems “will tend to shift relatively sharply between alternative states in response to climate change”.', 'But while trees at the southern edge of the boreal zone risk dieback, research suggests that forests at the northern edge could move into tundra under climate change.', 'Under the existing Paris emissions reduction pledges, the study projects “major climate change effects for more than 80% of the tundra and more than 40% of all boreal forests”.', 'Illustration of the potential tundra-boreal biome shift under a warming climate.', 'Shifts in vegetation cover will affect the reflectivity of the land surface – known as its “albedo”, says Prof Colin Prentice, chair in biosphere and climate impacts at Imperial College London.', 'This is well attested both from first principles and climate model experiments.”', '“We know from palaeoclimate literature that northward forest and tall shrub migration is a major Earth system feedback, mostly because of the darkened surface.”', 'But the boreal is a vast zone, with variation in climates and landscapes that may ‘tip’ at different times.”', 'It is worth noting also that very large shifts in the distribution of the boreal forests have happened in the relatively recent geological past in response to natural climate changes that are reasonably well understood.”', 'Some examples include: shutdown of Antarctic bottom water formation; loss of alpine glaciers; a climate change-induced hole in the ozone layer above the Arctic; ocean anoxia (where areas of the ocean see a dramatic decline in oxygen); and a change in the frequency and/or strength of El Niño events.', 'The paper has not been universally welcomed by climate scientists.)', 'Cases where a little bit of policy intervention or incentive could tip us onto a path towards a more sustainable future that essentially avoids the worst of the climate tipping points.”', '“These social tipping interventions comprise removing fossil-fuel subsidies and incentivising decentralised energy generation, building carbon-neutral cities, divesting from assets linked to fossil fuels, revealing the moral implications of fossil fuels, strengthening climate education and engagement, and disclosing greenhouse gas emissions information.”', 'Explainer: Nine ‘tipping points’ that could be triggered by climate change', 'Nine ‘tipping points’ that climate change could trigger', 'Very specialized species like the American Pika (*Ochotona princeps*), that live only on high, rocky mountainsides, may be sensitive to even small changes in the climate.', 'Snowcapped peaks, swelling rivers, industrious beavers, and delicate alpine flowers all thrive in the long-term pattern of weather conditions that make up the park’s climate.”', 'As the climate changes, park managers anticipate

new challenges for the preservation of park landscapes and resources.', 'Imagine climate change is like a fever – if your temperature went up 3.4° F, you would feel sick.', ' What a changing climate means for Rocky Mountain National Park', " A warming climate means shorter, milder winters and longer, warmer summers, which can affect the park's unique landscapes, plants and animals.", " Invasive species well suited to a new climate, such as cheatgrass (*Bromus tectorum*), become new competitors for the park's native plant cover.", ' Very specialized species like the American Pika (*Ochotona princeps*), that live only on high, rocky mountainsides, may be sensitive to even small changes in the climate.', ' Check out the Climate Change in RMNP Frequently Asked Questions for more in-depth information about climate change impacts in the park.', " The National Park Service and its partners are working to understand how climate change will affect the park's natural resources, infrastructure, and your visitor experience now and into the future.", 'Volunteer to become a citizen scientist and help park scientists better understand climate change effects and improve habitat for native species.', 'Make a climate friendly visit to Rocky Mountain National Park!', ' "I am convinced that climate change, and what we do about it, will define us, our era, and ultimately the global legacy we leave for future generations.', ' Indigenous peoples and the role they may play in combating climate change are rarely considered in public discourses on climate change.', ' The effects of climate change on indigenous peoples', ' Indigenous peoples are among the first to face the direct consequences of climate change, due to their dependence upon, and close relationship, with the environment and its resources.', ' In the Amazon, the effects of climate change include deforestation and forest fragmentation and consequently, more carbon is released into the atmosphere exacerbating and creating further changes.', ' Responding to climate change', 'In addition, indigenous peoples interpret and react to the impacts of climate change in creative ways, drawing on traditional knowledge and other technologies to find solutions which may help society at large to cope with impending changes.', ' Indigenous peoples in the Central, South American and Caribbean regions are shifting their agricultural activities and their settlements to new locations which are less susceptible to adverse climate conditions.', ' In North America, some indigenous groups are striving to cope with climate change by focusing on the economic opportunities that it may create.', ' Drawbacks and difficulties of responding to climate change', ' The potential threat of climate change to indigenous peoples' very existence combined with various legal and institutional barriers, which affect their ability to cope with and adapt to climate change, makes climate change an issue of human rights and inequality to indigenous peoples.', ' nature climate change', ' How insurance can support climate resilience', ' Insurance is gaining importance in and beyond the climate negotiations and offers many opportunities to improve climate risk management in developing countries.', 'However, some caution is needed, if current momentum is to lead to genuine progress in making the most vulnerable more resilient to climate change.', " Was 2015 'the year of climate insurance'?", 'Article 8 of the Paris Agreement includes "Risk insurance facilities, climate risk pooling and other insurance solutions" as areas of action 1 .', 'Earlier in the year, at their summit in Germany, the leaders of the G7 launched a new Initiative on Climate Risk Insurance (InsurResilience), pledging to bring climate insurance to 400 million currently uninsured individuals in poor countries by 2020.', 'In many ways the G7 initiative and the Paris Agreement are the culmination of a long process to establish insurance as an accepted climate adaptation instrument 2 , 3 , 4 .', ' Managing climate change risk: the case of the Italian Churches', 'How insurance can support climate

resilience.', '<https://doi.org/10.1038/nclimate2979> Download citation Published : 24 March 2016 Issue Date : April 2016 DOI : <https://doi.org/10.1038/nclimate2979> Share this article Anyone you share the following link with will be able to read this content: Get shareable link Sorry, a shareable link is not currently available for this article.', ' Risk management alone fails to limit the impact of extreme climate events', ' Effective climate change adaptation means supporting community autonomy', ' Building social resilience in North Korea can mitigate the impacts of climate change on food security', ' Risk transfer policies and climate-induced immobility among smallholder farmers', ' Managing climate change risk: the case of the Italian Churches', ' nature climate change', ' How insurance can support climate resilience', ' Insurance is gaining importance in and beyond the climate negotiations and offers many opportunities to improve climate risk management in developing countries.', 'However, some caution is needed, if current momentum is to lead to genuine progress in making the most vulnerable more resilient to climate change.', " Was 2015 'the year of climate insurance'?", 'Article 8 of the Paris Agreement includes "Risk insurance facilities, climate risk pooling and other insurance solutions" as areas of action 1 .', 'Earlier in the year, at their summit in Germany, the leaders of the G7 launched a new Initiative on Climate Risk Insurance (InsurResilience), pledging to bring climate insurance to 400 million currently uninsured individuals in poor countries by 2020.', 'In many ways the G7 initiative and the Paris Agreement are the culmination of a long process to establish insurance as an accepted climate adaptation instrument 2 , 3 , 4 .', ' Managing climate change risk: the case of the Italian Churches', 'How insurance can support climate resilience.', '<https://doi.org/10.1038/nclimate2979> Download citation Published : 24 March 2016 Issue Date : April 2016 DOI : <https://doi.org/10.1038/nclimate2979> Share this article Anyone you share the following link with will be able to read this content: Get shareable link Sorry, a shareable link is not currently available for this article.', ' Risk management alone fails to limit the impact of extreme climate events', ' Effective climate change adaptation means supporting community autonomy', ' Building social resilience in North Korea can mitigate the impacts of climate change on food security', ' Risk transfer policies and climate-induced immobility among smallholder farmers', ' Managing climate change risk: the case of the Italian Churches', ' UN climate talks', ' State of the climate', ' State of the climate', ' UN climate talks', ' State of the climate', ' UN climate talks', ' UN climate talks', ' UN climate talks', ' Explainer: Why a UN climate deal on HFCs matters', ' GHGs and aerosols Explainer: Why a UN climate deal on HFCs matters', ' This week, countries will gather in Kigali, the capital city of Rwanda, to tackle a small but potent cause of climate change: hydrofluorocarbons (HFCs).', ' The conference is the second in a trio of important UN climate meetings this year.', 'Source: HFCs: A critical link in protecting climate and the ozone layer \xa0(opens pdf), UNEP.', ' This is problematic because of their impact on the climate.', 'Source: HFCs: A critical link in protecting climate and the ozone layer \xa0(opens pdf), UNEP', ' The world went through a lot of effort in December last year to sign a UN climate deal, so why do HFCs get special treatment?', 'They argued that the issue should be discussed instead at the UN's climate change body (UNFCCC).', ' Countries gather in Rwanda to try to tackle a small but potent source of climate change: HFCs', ' Explainer: Why a UN climate deal on HFCs matters', 'While stronger on paper, India will already

achieve these targets with its current level of climate action and the new targets will not drive further emissions reductions.', 'In essence, India has replaced its first NDC targets (that would have been overachieved) with targets close to its current level of climate action.', '** India was severely impacted by COVID 19 during the second wave in the first half of 2021, which has further reduced the resilience of climate change vulnerable populations already at risk of displacement by storms, floods, extreme heat, droughts and other climate related disasters.', 'However, India's most recent stimulus (2021) is more climate-friendly, with two-thirds of the resources targeted towards a green recovery, including roughly USD 3bn in battery development and solar PV.', 'The CAT rates India's climate targets and policies as "Highly insufficient", indicating that India's climate policies and commitments are not consistent with the Paris Agreement's 1.5°C temperature limit.', 'Its updated NDC strengthened its targets on paper, but will not drive real world emission reductions beyond its current level of climate action.', 'India's projected emissions in 2030 under its current level of climate action are higher than our last assessment, largely due to higher historical emissions, and, as a result, now fall under the 'Insufficient' range.', 'India should adopt targets that will drive actual emissions reductions and accelerate climate policy implementation.', ' Skip to main content Skip to navigation

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the Green party, told the broadcaster Deutschlandfunk, the ruling was “both a slap and a wakeup call for the government to finally start on an ambitious climate protection policy”.’, ‘In future, decisions on all levels would have to be critically reviewed to see if they corresponded with long-term climate goals, she said.’, ‘Altmaier said he was relieved that the court had supported the “most important” obligation in his 2020 climate initiative, which required that reduction targets up to the year 2050 were “broken down into concrete reduction targets for each individual year between 2022 and 2050”.’, ‘Neubauer said the climate lobby’s success at Karlsruhe was only the beginning, emphasising that the five months leading up to the federal elections in September, in which the pro-environmental Greens have a good chance of entering government, would be crucial.’, “We will continue to fight for a 1.5 degree policy which protects our future freedoms, instead of endangering them,” she said, adding, “gone are the days when we were called ignorant for demanding climate action”.’]

global:

[‘Heat content in the global ocean has been consistently above-average (red bars) since the mid-1990s.’, ‘More than 90 percent of the excess heat trapped in the Earth system due to human-caused global warming has been absorbed by the oceans.’, ‘Knowing how much heat energy the ocean absorbs and releases is essential for understanding and modeling global climate.’, ‘To get global coverage, scientists turned to satellites that measure the height of the ocean’s surface.’, ‘They process the range of measurements to calculate an estimate for global average ocean heat content every three months.’, ‘Less than a watt per square meter might seem like a small change, but multiplied by the surface area of the ocean (more than 360 million square kilometers), that translates into an enormous global energy imbalance.’, ‘It means that while the atmosphere has been spared from the full extent of global warming for now, heat already stored in the ocean will eventually be released, committing Earth to additional warming in the future.’, ‘In the present, warming of ocean water is raising global sea level because water expands when it warms.’, ‘Human activities are driving the global warming trend observed since the mid-20th century.’, ‘Scientists attribute the global warming trend observed since the mid-20th century to the human expansion of the “greenhouse effect” — warming that results when the atmosphere traps heat radiating from Earth toward space.’, ‘The above graph compares global surface temperature changes (red line) and the Sun’s energy that Earth receives (yellow line) in watts (units of energy) per square meter since 1880.’, ‘Over the same period, global temperature has risen markedly.’, ‘It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century.’, ‘But several lines of evidence show that current global warming cannot be explained by changes in energy from the Sun.’, ‘This extends a long-term downward trend due to global warming.’, ‘Find a chemistry community of interest and connect on a local and global level.’, ‘Is the Sun causing global warming?’, ‘The above graph compares global surface temperature changes (red line) and the Sun’s energy received by Earth (yellow line) in watts (units of energy) per square meter since 1880.’, ‘Over the same period, global temperature has risen markedly.’, ‘It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century.’, ‘One of the “smoking guns” that tells us the Sun is not causing global

warming comes from looking at the amount of solar energy that hits the top of the atmosphere.', 'A second smoking gun is that if the Sun were responsible for global warming, we would expect to see warming throughout all layers of the atmosphere, from the surface to the upper atmosphere (stratosphere).', 'This and/or other changes would significantly change regional (but not global) weather patterns.', 'This extends a long-term downward trend due to global warming.', 'Making immediate reductions in greenhouse gas emissions, with the aim of halting global warming, is essential to reduce the risk of the strongest storms in the future.', 'From declining Arctic sea ice and record-breaking heatwaves to melting glaciers and worsening droughts, the increase in global average temperature is being felt around the world.', 'The gradual increase in global temperature sees block after block removed from the tower and placed on top.', 'It is worth noting that a tipping point can be caused by natural fluctuations in the climate as well as by an external forcing, such as global warming.', 'If the Greenland ice sheet were to pass a tipping point that led to its disintegration, simply reducing emissions and lowering global temperatures to pre-industrial levels would not bring it back again.', 'The AMOC forms part of a wider network of global ocean circulation patterns that transports heat all around the world.', 'And that makes the water lighter and, therefore, unable to sink – or at least less able to sink – which, basically, slows down that whole engine of the global overturning circulation.'", '“But, I would say, most people think that to trigger a real shutdown would require substantial global warming – like 3C or 4C [above pre-industrial levels].', ' (According to Climate Action Tracker, current global climate policies put the world on track for around 3C of warming.)', 'The IPCC’s special report on 1.5C of warming, for example, concludes that while “it is very likely that the AMOC will weaken over the 21st century”, there is “no evidence indicating significantly different amplitudes of AMOC weakening for 1.5C versus 2C of global warming, or of a shutdown of the AMOC at these global temperature thresholds”.', 'It means that once you go over the tipping point, even if global warming is stopped or reversed, the AMOC does not necessarily switch back on again immediately.', 'This could either offset or magnify the changes caused by global warming, he says:', '“In northern parts of Europe, we might expect from global warming to see wetter winters and then the drying would compensate.', 'In other regions, more in southern Europe, where we would already be expected to see a drying signal from the global-warming signal, so paradoxically, the cooling would give you a further drying.', 'Although much smaller than its neighbour to the east, the WAIS still holds enough ice to raise global sea levels by around 3.3 metres.', 'If the ice sheet loses more ice to the ocean than it gains in snow, it adds to global sea levels.', 'Antarctica’s contribution to global sea levels is currently dominated by ice loss from Amundsen sea sector glaciers.', 'This temperature threshold refers to regional warming in Antarctica, rather than a global average figure.', 'However – as lead author Prof Frank Pattyn explains to Carbon Brief – because the poles warm more quickly than the global average, 2C of warming on Antarctica from present is approximately equivalent to 2C of global warming since pre-industrial levels.', 'By 2100, global temperatures are likely to rise by 1.3-1.9C above pre-industrial levels.', 'By 2100, global temperatures are likely to rise by 2-3C above pre-industrial levels.', 'The likely range of global temperatures by 2100 for RCP8.5 is 4.0-6.1C above pre-industrial levels.', 'A Science Advances editorial last year by Prof Carlos Nobre of the University of São Paulo’s Institute for Advanced Studies and Prof Thomas Lovejoy of George Mason University noted that “many studies show that in the absence of other contributing factors, 4C of global warming would be

the tipping point to degraded savannahs in most of the central, southern and eastern Amazon".', ' One of those contributing factors is deforestation, which could hasten a shift to savannah as a "fragmented forest is probably more sensitive to rainfall reductions driven by global heating", says Betts.', ' Without global warming, a tipping point for Amazon dieback could be reached "if you exceed 40% total deforested area in the Amazon", says Nobre:'.', ' The impacts of losing the Amazon rainforest would be felt locally and globally.', 'As land heats up faster than the water, rising global temperatures could strengthen the land-sea contrast that helps drive the WAM northwards each year.', ' The SROCC says there is "high confidence" in projections of "widespread disappearance of Arctic near-surface permafrost...this century as a result of warming, with important consequences for global climate".', 'This is where the "internal heat generation becomes the main driving force for further thaw and carbon release", he explains to Carbon Brief, "even if global warming stopped".', ' (For comparison, global emissions from fossil fuels and industry in 2019 amounted to around 10bn tonnes of carbon.),' ' Coral reefs are often cited as one of the ecological systems most sensitive to global warming.', ' "Atmospheric CO2 concentration is expected to exceed 500 parts per million (ppm) and global temperatures to rise by at least 2C by 2050 to 2100, values that significantly exceed those of at least the past 420,000 years during which most extant [i.e.', 'The first global mass-bleaching event was recorded in 1998.', 'It is typical of ecosystems to show "threshold, rather than linear, responses to slowly building drivers of change such as fishing pressure, added nutrients and rising global temperatures", says another review paper .', ' "Even achieving emissions reduction targets consistent with the ambitious goal of 1.5C of global warming under the Paris Agreement will result in the further loss of 70-90% of reef-building corals compared to today, with 99% of corals being lost under warming of 2C or more.", ' Eakin says "we've already reached" a tipping point for corals on a global basis because of climate change:', ' "We are already seeing severe bleaching around the world and the recent 2014-17 global coral bleaching event has been devastating for many reefs around the world.", ' The 2016 marine heatwave "has triggered the initial phase of that transition on the northern, most-pristine region of the Great Barrier Reef", the study says, "changing it forever as the intensity of global warming continues to escalate".', ' "The large-scale loss of functionally diverse corals is a harbinger of further radical shifts in the condition and dynamics of all ecosystems, reinforcing the need for risk assessment of ecosystem collapse, especially if global action on climate change fails to limit warming to 1.5-2C.", ' With land areas warming faster than oceans, a strengthening of this pressure gradient and the monsoon itself "may be expected under global warming", says the 1.5C report.', 'It holds enough water to raise global sea levels by 7.2 metres and, as a result, its disintegration would change the shape of the world's coastlines.', ' Melting of the Greenland ice sheet is accelerating and it is currently adding around 0.7mm to global sea levels each year.', ' "Thus, crossing the limit of 1.5C global warming this century may impose a commitment to much larger and possibly irreversible changes in the far future.", ' Depending on the emission scenario, the Greenland ice sheet will have lost 8 to 25% (RCP2.6), 26 to 57% (RCP4.5), or 72 to 100% (RCP8.5) of its present-day mass, contributing 0.59 to 1.88 metres, 1.86 to 4.17 metres, or 5.23 to 7.28 metres to global mean sea level, respectively.", ' However, the boreal zone, along with the tundra, is warming rapidly – approximately twice as quickly as the global average.', ' It further notes that a potential "tipping point has been estimated to exist between 3C and 4C of global warming (low confidence), but given the complexities of the various forcing

mechanisms and feedback processes involved, this is thought to be an uncertain estimate".', ' "I don't know that anyone has put a number on a species-specific tipping point, but we have high confidence that with global temperature increases of 1.5 or 2C, which in the boreal will translate into about double those temperature increases, we will see widespread changes in tree species composition and fire regimes."', ' "Obviously great permafrost degradation means a lot more carbon emitted to the atmosphere, which would have the effect of increasing the cycle of warming and even more degradation, with global implications."', ' There are tipping points across society that could lead to a rapid global transformation, recent research in Proceedings of the National Academy of Sciences (PNAS) argues.', ' Skip to global NPS navigation', ' UN global brand bar', ' /UN global brand bar', ' /UN global brand bar and language switcher', ' "I am convinced that climate change, and what we do about it, will define us, our era, and ultimately the global legacy we leave for future generations.", 'One study estimates that, in a business-as-usual scenario, HFCs could rise to 9-19% of projected global emissions by 2050.', 'While emissions are dwarfed against global CO2 emissions, their capacity to warm the atmosphere is stronger.', 'Availability of alternatives also varies by region and country, although some of the largest suppliers of alternatives are multinational corporations with a broad global reach.", 'India's target is at the least stringent end of what would be a fair share of global effort and is not consistent with the Paris Agreement's 1.5°C limit unless other countries make much deeper reductions and comparably greater effort.', ' The US Inflation Reduction Act an historic moment in global efforts to hal...', 'It said that it was only possible to reduce the rise in average global temperatures to between 1.5C and 2C – as set out in the 2015 Paris agreement – with "more urgent and shorter term measures".']

warming:

[' Heat already stored in the ocean will eventually be released, committing Earth to additional surface warming in the future.', 'More than 90 percent of the excess heat trapped in the Earth system due to human-caused global warming has been absorbed by the oceans.', ' More than 90 percent of the warming that has happened on Earth over the past 50 years has occurred in the ocean.', 'Recent studies estimate that warming of the upper oceans accounts for about 63 percent of the total increase in the amount of stored heat in the climate system from 1971 to 2010, and warming from 700 meters down to the ocean floor adds about another 30 percent.', 'It means that while the atmosphere has been spared from the full extent of global warming for now, heat already stored in the ocean will eventually be released, committing Earth to additional warming in the future.', ' In the present, warming of ocean water is raising global sea level because water expands when it warms.', 'Finally, warming ocean waters threaten marine ecosystems and human livelihoods.', 'Ultimately, people who depend upon marine fisheries for food and jobs may face negative impacts from the warming ocean.', 'Human activities are driving the global warming trend observed since the mid-20th century.', ' While the Sun has played a role in past climate changes, the evidence shows the current warming cannot be explained by the Sun.', ' Scientists attribute the global warming trend observed since the mid-20th century to the human expansion of the "greenhouse effect" — warming that results when the atmosphere traps heat radiating from Earth toward space.', ' "Since systematic scientific

assessments began in the 1970s, the influence of human activity on the warming of the climate system has evolved from theory to established fact."', 'It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century.', ' But several lines of evidence show that current global warming cannot be explained by changes in energy from the Sun:', ' If a more active Sun caused the warming, scientists would expect warmer temperatures in all layers of the atmosphere.', 'Instead, they have observed a cooling in the upper atmosphere and a warming at the surface and lower parts of the atmosphere.', 'This extends a long-term downward trend due to global warming.', 'The huge amount of water vapor hurled into the atmosphere, as detected by NASA's Microwave Limb Sounder, could end up temporarily warming Earth's surface.', 'Is the Sun causing global warming?', 'It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century.', 'The Sun can influence Earth's climate, but it isn't responsible for the warming trend we've seen over recent decades.', 'But the warming we've seen in recent decades is too rapid to be linked to changes in Earth's orbit and too large to be caused by solar activity.', ' One of the "smoking guns" that tells us the Sun is not causing global warming comes from looking at the amount of solar energy that hits the top of the atmosphere.', ' A second smoking gun is that if the Sun were responsible for global warming, we would expect to see warming throughout all layers of the atmosphere, from the surface to the upper atmosphere (stratosphere).', 'But what we actually see is warming at the surface and cooling in the stratosphere.', 'This is consistent with the warming being caused by a buildup of heat-trapping gases near Earth's surface, and not by the Sun getting "hotter."', '2 These greenhouse gases absorb and then re-radiate heat in Earth's atmosphere, which causes increased surface warming.', 'Other kinds of particles, such as black carbon, have a warming effect.', 'A feedback that increases an initial warming is called a "positive feedback."', 'A feedback that reduces an initial warming is a "negative feedback."', 'Less heat could get absorbed, which could slow the increased warming.', 'Conversely, changes in cloud cover could lead to faster and greater warming.', 'The most abundant greenhouse gas, it acts as a feedback to amplify climate warming forcings.', 'While a change in the Gulf Stream could lead to a significant cooling in Western Europe, the U.S. East Coast will experience faster warming and greater sea-level rise.', 'As the environment warms and the permafrost thaws, these deposits can be released into the atmosphere and present a risk of enhanced warming.', 'This extends a long-term downward trend due to global warming.', 'The huge amount of water vapor hurled into the atmosphere, as detected by NASA's Microwave Limb Sounder, could end up temporarily warming Earth's surface.', ' Changes in the atmosphere , like the warming of the Arctic, may be contributing to other trends seen in the hurricane record.', ' The warming of mid-latitudes may be changing the pattern of tropical storms , leading to more storms occurring at higher latitudes.', ' Making immediate reductions in greenhouse gas emissions, with the aim of halting global warming, is essential to reduce the risk of the strongest storms in the future.', ' Ocean warming', ' Ocean warming', ' Ocean warming', ' Ocean warming', ' The persistent march of a warming climate is seen across a multitude of continuous, incremental changes.', ' Broadly, these impacts reflect gradual changes caused by a climate that is steadily warming.', ' However, there are parts of the Earth system that have the potential to change abruptly in response to warming.', ' So, rather than a bit more warming causing slightly hotter heatwaves or more melting of glaciers, it causes a dramatic shift to an entire system.', ' That extra bit of warming would be, as the saying goes,

the straw that breaks the camel's back.', ' It is worth noting that a tipping point can be caused by natural fluctuations in the climate as well as by an external forcing, such as global warming.', ' Climate change affects this process by diluting the salty sea water with freshwater and by warming it up, he says:', ' "But, I would say, most people think that to trigger a real shutdown would require substantial global warming – like 3C or 4C [above pre-industrial levels].', 'And we could pretty well minimise this risk by limiting the warming to below 2C.', ' (According to Climate Action Tracker , current global climate policies put the world on track for around 3C of warming.)', ' The IPCC's special report on 1.5C of warming , for example, concludes that while "it is very likely that the AMOC will weaken over the 21st century", there is "no evidence indicating significantly different amplitudes of AMOC weakening for 1.5C versus 2C of global warming, or of a shutdown of the AMOC at these global temperature thresholds".', 'It means that once you go over the tipping point, even if global warming is stopped or reversed, the AMOC does not necessarily switch back on again immediately.', 'This could either offset or magnify the changes caused by global warming, he says:', ' "In northern parts of Europe, we might expect from global warming to see wetter winters and then the drying would compensate.', 'In other regions, more in southern Europe, where we would already be expected to see a drying signal from the global-warming signal, so paradoxically, the cooling would give you a further drying.', ' "For example, a collapse of the AMOC may induce causal interactions like changes in ENSO [El Niño–Southern Oscillation] characteristics, dieback of the Amazon rainforest and shrinking of the West Antarctic Ice Sheet due to seesaw effect, ITCZ [Intertropical Convergence Zone] southern migration and large warming of the Southern Ocean."', ' However, the SROCC notes that "such a worst-case scenario remains very poorly constrained" as a result of the large uncertainties around how systems such as AMOC will respond to warming.', ' A Nature Climate Change review paper published in 2018 concluded that "under sustained warming, a key threshold for survival of Antarctic ice shelves, and thus the stability of the ice sheet, seems to lie between 1.5 and 2C mean annual air temperature above present".', ' This temperature threshold refers to regional warming in Antarctica, rather than a global average figure.', 'However – as lead author Prof Frank Pattyn explains to Carbon Brief – because the poles warm more quickly than the global average, 2C of warming on Antarctica from present is approximately equivalent to 2C of global warming since pre-industrial levels.', ' "The palaeo record strongly suggests that the WAIS largely disappeared, perhaps during the past few hundred thousand years and more confidently during the past few million years, in response to warming similar to or less than that projected under business-as-usual CO2 emission scenarios for the next few centuries."', ' The first is a decline in rainfall in response to a warming climate.', 'Betts says that "3C is the lowest level of warming that might trigger it, but it might need much higher warming".', ' A Science Advances editorial last year by Prof Carlos Nobre of the University of São Paulo's Institute for Advanced Studies and Prof Thomas Lovejoy of George Mason University noted that "many studies show that in the absence of other contributing factors, 4C of global warming would be the tipping point to degraded savannahs in most of the central, southern and eastern Amazon".', ' Without global warming, a tipping point for Amazon dieback could be reached "if you exceed 40% total deforested area in the Amazon", says Nobre:', ' Subsequent research by Giannini has shown the combination of warming of the tropical oceans (in response to rising greenhouse gases) and cooling in the North Atlantic (as a result of air pollution from northern hemisphere countries) led to drying of the Sahel.', 'This is due, in part, to a warming climate and a reduction

in air pollution rates.', 'Theory suggests that a warming climate could actually bring more rainfall to the Sahel.', 'Prof Martin Claussen, professor of meteorology at the University of Hamburg and director at the Max Planck Institute for Meteorology tells Carbon Brief that even in model projections under “strong warming”, the “response of the Sahara is much weaker than it was in response to the change in insolation several thousand years ago”.', 'The response to recent warming has actually been more variability in the WAM, Giannini says:', 'And, more generally, projections from different climate models have suggested both drier and wetter futures for the Sahel under a changing climate – with the latter linked to a tipping point of 3C of localised warming in the Gulf of Guinea.', 'Even if a 3C temperature rise did bring significantly more beneficial rainfall to the region, the IPCC says “it should be noted that there would be significant offsets in the form of strong regional warming and related adverse impacts on crop yield, livestock mortality and human health under such low mitigation futures”.', '“The question is which influence will win out for West Africa in the future – the direct influence of warming, which wettens, or the AMOC influence, that dries West Africa.”, 'Thus, large-scale thawing of permafrost has the potential to cause further climate warming.', 'There is already evidence of permafrost warming.', 'The SROCC says there is “high confidence” in projections of “widespread disappearance of Arctic near-surface permafrost...this century as a result of warming, with important consequences for global climate”.', '“Ice melt or the thawing of permafrost involve thresholds (state changes) that allow for abrupt, nonlinear responses to ongoing climate warming.”, 'This is where the “internal heat generation becomes the main driving force for further thaw and carbon release”, he explains to Carbon Brief, “even if global warming stopped”.', '“If we stop warming, then we should see the emissions from permafrost stop, but in terms of that carbon going back into permafrost, pragmatically that’s not possible.”, 'The theory suggests that ocean warming could melt these ice crystals, releasing vast amounts of methane into the atmosphere.', 'A few years ago, for example, scientists identified “widespread seepage of methane from seafloor sediments offshore Svalbard”, which they said “may, in part, be driven by hydrate destabilisation” due to ocean warming.', 'In addition, while permafrost soils are in direct contact with a warming atmosphere, methane hydrates occur in sediments at great depths below the seafloor.', 'As a result, research indicates that it will “barely be affected by warming over even 10,000 years”.', 'Coral reefs are often cited as one of the ecological systems most sensitive to global warming.', 'These events were caused by marine heatwaves – extended periods of unusually high temperatures that were themselves boosted by human-caused warming and El Niño.', 'In 2016, the first study to compare the widespread impacts of climate change at 1.5C and 2C of warming warned that 90% of tropical reefs would be “at risk of severe degradation due to temperature-induced bleaching from 2050 onwards” in a 1.5C warmer world.', 'For 2C, this risk rose to 98% of reefs, the study says, indicating that the extra 0.5C of warming “is likely to be decisive for the future of tropical coral reefs”.', '“Even achieving emissions reduction targets consistent with the ambitious goal of 1.5C of global warming under the Paris Agreement will result in the further loss of 70-90% of reef-building corals compared to today, with 99% of corals being lost under warming of 2C or more.”, 'The 2016 marine heatwave “has triggered the initial phase of that transition on the northern, most-pristine region of the Great Barrier Reef”, the study says, “changing it forever as the intensity of global warming continues to escalate”.', '“The large-scale loss of functionally diverse corals is a harbinger of further radical shifts in the condition and dynamics of all

ecosystems, reinforcing the need for risk assessment of ecosystem collapse, especially if global action on climate change fails to limit warming to 1.5-2C.”, ' With land areas warming faster than oceans, a strengthening of this pressure gradient and the monsoon itself “may be expected under global warming”, says the 1.5C report.', 'Another study says the aerosol cooling in South and East Asia “may have masked up to 1C of greenhouse-gas-induced surface warming since the pre-industrial era ”.', ' Overall, the IPCC’s 1.5C report concludes that there is “low confidence” in any projected changes in the Indian monsoon under warming of 1.5-2C, but that increases in the intensity of monsoon rainfall are “likely” in a 3C warmer world.', 'A review paper in Nature Climate Change in 2018 concluded that 1.8C (with a range of 1.1-2.3C) of warming above pre-industrial levels would be enough to trigger feedback loops of decline in parts of the ice sheet in summer.', ' “Thus, crossing the limit of 1.5C global warming this century may impose a commitment to much larger and possibly irreversible changes in the far future.”, ' However, the boreal zone, along with the tundra, is warming rapidly – approximately twice as quickly as the global average.', ' A 2017 Nature Climate Change review paper concluded that rapid warming and “naturally lower tree species diversity” could put boreal regions at particular risk of natural forest “disturbances” by factors such as drought, fire, pests and disease .', ' For example, a 2014 study finds that “continued summer warming in the absence of sustained increases in precipitation” brought about a “turning point” around the mid-1990s that “shifted western central Eurasian boreal forests into a warmer and drier regime”.', ' The IPCC’s special report on 1.5C notes that “increased tree mortality would result in the creation of large regions of open woodlands and grasslands, which would favour further regional warming and increased fire frequencies, thus inducing a powerful positive feedback mechanism”.', ' A 2018 modelling study finds that, even if the Paris warming limits are met, “boreal forests are simulated to expand into the tundra, while on the other hand tree composition shifts toward temperate species along their warm edge”.', ' Illustration of the potential tundra-boreal biome shift under a warming climate.', ' The IPCC’s 1.5C reports concludes that it has “high confidence” that “woody shrubs are already encroaching into tundra and will proceed with further warming”.', ' It also says that abrupt increases in tree cover are “unlikely” at 1.5-2C of warming.', ' Above 2C of warming, there is “potential” for abrupt increases, the report says – albeit with “low confidence”.', ' For the boreal biome, the report says there is “medium confidence” of “further increases in tree mortality” at the southern boundary at 1.5C and 2C of warming.', ' It further notes that a potential “tipping point has been estimated to exist between 3C and 4C of global warming (low confidence), but given the complexities of the various forcing mechanisms and feedback processes involved, this is thought to be an uncertain estimate”.', ' Significant changes in boreal forests are made more likely by the rapid rate of warming, says Goetz:', ' “Northward expansion of the boreal forest is certainly expected as a result of warming and, indeed, there is evidence that it is happening already.”, ' Similarly, shrub tundra is expanding into colder regions as a result of warming and this process will continue... There will be, as a result, a decrease in vegetation albedo – especially in spring – which will amplify the warming locally.', ' “Obviously great permafrost degradation means a lot more carbon emitted to the atmosphere, which would have the effect of increasing the cycle of warming and even more degradation, with global implications.”, ' For the modern day, “we expect this to be a warming effect, and we’re already witnessing shrubs getting denser and taller, and trees migrating north”, he says.', ' But, he says, “the effect of warming is simply to gradually shift the geographic location of the threshold”.', '

However, Goetz points out that “fire is the wildcard and can shift forests much more rapidly than from warming effects on tree growth alone”.', ' “Arctic sea-ice loss is amplifying regional warming, and Arctic warming and Greenland melting are driving an influx of fresh water into the North Atlantic.”', ' Figure 1: In the 20th century, the area including Rocky Mountain National Park experienced a warming trend.', " A warming climate means shorter, milder winters and longer, warmer summers, which can affect the park's unique landscapes, plants and animals.", ' Ocean warming', ' Ocean warming', ' Ocean warming', ' Ocean warming', ' Scientists estimate that HFCs in the atmosphere account for 1% of the warming caused by all greenhouse gases, but their usage is on the rise.', ' One study has argued that phasing out HFCs could help to avoid up to 0.5C of warming by the end of the century.', 'Since the Paris Agreement has an aspirational but difficult goal of limiting warming to 1.5C above pre-industrial levels, such a boost could prove vital.', ' A 2014 study undertaken for the European Commission found that, in developing countries, approximately 90% of HCFCs and highly potent HFCs could be replaced with substances that have a low or moderate warming impact.', 'If all countries were to follow similar approach, warming would reach over 2°C and up to 3°C.', ' Analysis: Aviation industry emissions plans consistent with 4°C of warming']

change:

['The changes in areas covered with the gray shading were not statistically significant.', ' Less than a watt per square meter might seem like a small change, but multiplied by the surface area of the ocean (more than 360 million square kilometers), that translates into an enormous global energy imbalance.', ' While the Sun has played a role in past climate changes, the evidence shows the current warming cannot be explained by the Sun.', ' In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change, composed of scientific experts from countries all over the world, concluded that it is unequivocal that the increase of CO₂, methane, and nitrous oxide in the atmosphere over the industrial era is the result of human activities and that human influence is the principal driver of many changes observed across the atmosphere, ocean, cryosphere and biosphere.', ' Scientists use a metric called Total Solar Irradiance (TSI) to measure the changes in energy the Earth receives from the Sun.', ' Studies show that solar variability has played a role in past climate changes.', "The above graph compares global surface temperature changes (red line) and the Sun's energy that Earth receives (yellow line) in watts (units of energy) per square meter since 1880.", ' But several lines of evidence show that current global warming cannot be explained by changes in energy from the Sun:', ' Climate models that include solar irradiance changes can't reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.', 'Your questions about climate change answered.', 'images of change', 'Climate change is influencing habitat conditions and migratory patterns.', 'images of change', 'images of change', 'The straight red arrow passing from the surface through the atmosphere represents the fraction of the emitted infrared radiation that passes into space through the atmosphere without change.', "The above graph compares global surface temperature changes (red line) and the Sun's energy received by Earth (yellow line) in watts (units of energy) per square meter since 1880.", 'We know subtle changes in Earth's orbit around the Sun are responsible for the comings and goings of the ice ages.', 'But the warming we've seen in recent decades is too rapid to be linked to changes in

Earth's orbit and too large to be caused by solar activity.', 'Is the ozone hole causing climate change?', 'What do volcanoes have to do with climate change?', ' Climate scientists separate factors that affect climate change into three categories: forcings, feedbacks, and tipping points.', 'Solar irradiance is the change in solar radiation (sunlight) Earth receives from the Sun.', 'Even small changes in cloud amount, location, and type could have large consequences.', 'Conversely, changes in cloud cover could lead to faster and greater warming.', 'Changes in precipitation patterns may present both positive and negative changes in plant growth.', 'This and/or other changes would significantly change regional (but not global) weather patterns.', 'While a change in the Gulf Stream could lead to a significant cooling in Western Europe, the U.S. East Coast will experience faster warming and greater sea-level rise.', 'images of change', 'Climate change is influencing habitat conditions and migratory patterns.', 'images of change', 'images of change', ' Climate change is worsening hurricane impacts in the United States by increasing the intensity and decreasing the speed at which they travel.', 'Scientists are currently uncertain whether there will be a change in the number of hurricanes, but they are certain that the intensity and severity of hurricanes will continue to increase .', ' Hurricanes are subject to a number of climate change-related influences:', 'This shift could put much more lives and property at risk, however more research is required to better understand how hurricane tracks might change.', ' Climate change is adding to the cost and threat of hurricanes.', ' Scientists predict that climate change will have many effects on freshwater and marine environments.', 'Warmer water due to climate change might favor harmful algae in a number of ways:', ' Climate change might lead to more droughts, which make freshwater saltier.', ' Climate change might affect rainfall patterns, leading to alternating periods of drought and intense storms.', 'Climate change is expected to alter the timing and intensity of coastal upwelling.', ' Learn more about climate change's impacts on water resources', ' Tipping points Explainer: Nine 'tipping points' that could be triggered by climate change', ' Explainer: Nine 'tipping points' that could be triggered by climate change', ' The persistent march of a warming climate is seen across a multitude of continuous, incremental changes.', ' And while climate records are being routinely broken , the cumulative impact of these changes could also cause fundamental parts of the Earth system to change dramatically and irreversibly.', ' These "tipping points" are thresholds where a tiny change could push a system into a completely new state.', 'This article is part of a week-long special series on "tipping points", where a changing climate could push parts of the Earth system into abrupt or irreversible change', ' Explainer: Nine 'tipping points' that could be triggered by climate change', ' Guest post: Could climate change and deforestation spark Amazon 'dieback'?', ' Irreversible change?', ' A glance at the news media on any given week will likely highlight all sorts of climate change impacts.', ' Broadly, these impacts reflect gradual changes caused by a climate that is steadily warming.', ' However, there are parts of the Earth system that have the potential to change abruptly in response to warming.', ' "A climate tipping point, or any tipping point in any complex system, is where a small change makes a big difference and changes the state or the fate of a system."', 'These are called " noise-induced " tipping points and include, for example, periods of abrupt change during the last ice age called " Dansgaard-Oeschger (D-O) events ".', ' Natural fluctuations can also be the final nudge for a tipping point pushed to the brink by human-caused climate change, says Prof Mat Collins , joint Met Office chair in climate change at the University of Exeter and coordinating lead author on the "Extremes, Abrupt Changes and Managing Risks" chapter of the Intergovernmental Panel

on Climate Change (IPCC) special report on the ocean and cryosphere in a changing climate (“SROCC”).’, ‘Irreversible change?’, ‘The theory of potentially abrupt changes in the Earth system is not new.’, ‘“There has been an intensive debate in the field of tipping points, abrupt change and irreversibility about the definitions of these terms.”’, ‘According to a 2009 paper on the use of the term “tipping points” in climate science and the media, a presentation (pdf) in 2005 by Dr James Hansen of Columbia University’s Earth Institute helped “initiate a tipping point trend in climate change communication that was quickly reflected in public debate”.’, ‘A Science briefing about the meeting declared that “tipping points, once considered too alarmist for proper scientific circles, have entered the climate change mainstream”.’, ‘This was the first of its assessment reports to use the term “tipping point” – though the third assessment report (“TAR”, pdf) in 2001 had discussed “large-scale discontinuities” that have the “potential to trigger large-scale changes in Earth systems”.’, ‘“Technically, an abrupt climate change occurs when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause.”’, ‘“We define abrupt climate change as a large-scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems.”’, ‘“One is simply that one vital part of the climate system shows some kind of threshold behaviour and that means that a small perturbation around that element can cause a huge qualitative change.”’, ‘So that means there is something that’s self-reinforcing and then that could lead to irreversible changes as well.”’, ‘“In some cases, there is evidence that once the system has jumped to a different state, then if you remove the climate forcing, the climate system doesn’t just jump back to the original state – it stays in its changed state for some considerable time, or possibly even permanently.”’, ‘Nonetheless, each of the nine – explained below – are examples of where seemingly small changes have the collective potential to pack a potent punch.’, ‘Climate change affects this process by diluting the salty sea water with freshwater and by warming it up, he says:’, ‘This could either offset or magnify the changes caused by global warming, he says:’, ‘So it would actually reinforce the climate-change signal.”’, ‘For example, a recent study in the new journal Nature Food suggests that an AMOC shutdown would cause “widespread cessation of arable farming” in the island of Great Britain with “losses of agricultural output that are an order of magnitude larger than the impacts of climate change without an AMOC collapse”.’, ‘“The whole North Atlantic ecosystem is adapted to the existence of this overturning circulation, which really sets the conditions – the seasonal cycle, the temperature, the nutrient conditions – in the North Atlantic, and so the intricate web of the Atlantic ecosystem will be substantially disrupted if allow such a massive change in the ocean circulation to happen.”’, ‘“For example, a collapse of the AMOC may induce causal interactions like changes in ENSO [El Niño–Southern Oscillation] characteristics, dieback of the Amazon rainforest and shrinking of the West Antarctic Ice Sheet due to seesaw effect, ITCZ [Intertropical Convergence Zone] southern migration and large warming of the Southern Ocean.”’, ‘Therefore, even a partial loss of its ice would be enough to change coastlines around the world dramatically.’, ‘However, it also notes that “observational data are not yet sufficient to determine whether these changes mark the beginning of irreversible retreat”.’, ‘RCP8.5 is a “very high baseline” emission scenario brought about by rapid population growth, high energy demand, fossil fuel dominance and an absence of climate change policies.’, ‘Model projections suggest this would be a result of “particular patterns of sea

surface temperature (SST) change in the tropical Atlantic and Pacific”, says Betts, but there is a lot of variation between models as to how strong the impact would be on the Amazon.’, ‘Reports suggest that a change in policy under Brazilian president Jair Bolsonaro is encouraging development at the expense of the rainforest.’, ‘Factoring in climate change and “widespread use of fire” brings the tipping point closer, say Lovejoy and Nobre in their editorial.’, ‘Amazon dieback would also make it more difficult to tackle climate change, he notes.’, ‘There are already “ominous signals” of changes in the Amazon, say Lovejoy and Nobre in another Science Advances editorial published in December 2019.’, ‘(Giannini emphasises that, while the ITCZ and monsoon are “part of the same season and the same latitudinal migration of the rain band”, some researchers prefer to “distinguish between the ITCZ over the ocean from the monsoon inland” and so do not use the terms interchangeably.)’, ‘These changes show that the WAM is a “very sensitive system”, says Giannini and the Sahel is most at risk because it is at the edge of the monsoon.’, ‘There is evidence of similar changes in Earth’s distant past.’, ‘The changes were being driven primarily by the sun, not large increases in greenhouse gases.’, ‘Therefore, it provides limited insight into how the WAM will be affected by climate change.’, ‘Prof Martin Claussen, professor of meteorology at the University of Hamburg and director at the Max Planck Institute for Meteorology tells Carbon Brief that even in model projections under “strong warming”, the “response of the Sahara is much weaker than it was in response to the change in insolation several thousand years ago”.’, ‘It also notes that while there are “uncertain changes” associated with a 1.5C or 2C warmer world, it is “unlikely” that a tipping point would be reached that these temperature levels.’, ‘One is that colder conditions in the high-latitude North Atlantic can be transmitted via the atmosphere to the WAM, mainly through the cold conditions permeating into North Africa and affecting the monsoon...The other is that ocean circulation changes resulting from the AMOC slowdown ‘rewires’ the currents around the tropical Atlantic, leading to a warmer South tropical Atlantic and thus causing a weakening of the WAM.’, ‘“These observations signify that the feedback to accelerating climate change may already be underway.”’, ‘This is projected to release 10s to 100s of billions of tonnes [or gigatonnes, GtC], up to as much as 240 GtC, of permafrost carbon as CO₂ and methane to the atmosphere with the potential to accelerate climate change.’, ‘“Ice melt or the thawing of permafrost involve thresholds (state changes) that allow for abrupt, nonlinear responses to ongoing climate warming.”’, ‘Overall, the evidence indicates that there are several mechanisms for abrupt regional thawing, says Armstrong McKay, while for permafrost thaw more generally, it is expected that it “will act as more of a continuous positive feedback on climate change rather than an abrupt tipping point”.’, ‘“Tipping points relate to the fact that you have a change and then that change almost drives itself, so it means you go from one state into another.”’, ‘It is typical of ecosystems to show “threshold, rather than linear, responses to slowly building drivers of change such as fishing pressure, added nutrients and rising global temperatures”, says another review paper.’, ‘Such “decadal timescales” are “coherent with the observations that coral cover across the Caribbean declined by 80% from 1977 to 2001 and may completely disappear by 2035, depending on rates of further overfishing, climate change and ocean acidification”, the authors note.’, ‘In 2016, the first study to compare the widespread impacts of climate change at 1.5C and 2C of warming warned that 90% of tropical reefs would be “at risk of severe degradation due to temperature-induced bleaching from 2050 onwards” in a 1.5C warmer world.’, ‘Eakin says “we’ve already reached” a tipping point for corals on a global

basis because of climate change:', ' The study warns that “the most likely scenario” is that “coral reefs throughout the tropics will continue to degrade over the current century until climate change stabilises, allowing remnant populations to reorganize into novel, heat-tolerant reef assemblages”.', ' “The large-scale loss of functionally diverse corals is a harbinger of further radical shifts in the condition and dynamics of all ecosystems, reinforcing the need for risk assessment of ecosystem collapse, especially if global action on climate change fails to limit warming to 1.5-2C.”, 'It describes a seasonal shift in winds – specifically a 180-degree reversal that triggers the change from the dry to the wet season.', 'And so, in theory, “anything which alters either the north-south temperature gradient, or the amount of moisture evaporated from the ocean, could change the monsoon rains”, notes Turner.', ' Some papers have suggested the possibility for more abrupt changes in the Indian monsoon.', 'Thus “relatively weak external perturbations” could lead to “abrupt changes” in the monsoon, the PNAS paper says.', ' Palaeoclimate studies , using “ proxy ” reconstructions of past conditions, suggest that shifts to a low rainfall monsoon state have occurred in the past in response to changes in how much of the sun’s radiation reaches the Earth’s surface.', ' However, a 2006 study also shows that the albedo changes required to push the monsoon into a dry state – as in the 2005 study – are a long way from modern conditions.', ' “The key phrase here is ‘abrupt shift’ – monsoons may change a lot, but there simply is no evidence for them being here one year and gone the next in response to human-induced climate change.”, ' The “vast majority of studies on abrupt changes in monsoons focus on changes that are ‘abrupt’ relative to the past evolution of the climate system that occurred over tens of thousands to millions of years”, adds Boos:', ' “Palaeo changes are important, but their relevance to human-caused climate change is unclear; feedbacks that take hundreds to thousands of years to operate – involving large changes in ice sheets or continental vegetation and soil types – may not be relevant if we are interested in changes taking place over a few years or a few decades.”, ' Overall, the IPCC’s 1.5C report concludes that there is “low confidence” in any projected changes in the Indian monsoon under warming of 1.5-2C, but that increases in the intensity of monsoon rainfall are “likely” in a 3C warmer world.', ' Monsoon onset dates are likely to become earlier or not to change much.', 'It holds enough water to raise global sea levels by 7.2 metres and, as a result, its disintegration would change the shape of the world’s coastlines.', ' “Thus, crossing the limit of 1.5C global warming this century may impose a commitment to much larger and possibly irreversible changes in the far future.”, 'So once it’s gone it’s gone until at least the next glacial period – and we’ll be waiting some tens of thousands of years given current climate change and the slow rate of carbon removal by natural means.”, 'Continued temperature rise could generate rapid changes in boreal forests, including dieback.', 'When compared to other ecosystems around the world, the study finds that “future changes in disturbance are likely to be most pronounced in coniferous forests and the boreal biome”.', 'Research also indicates that “rather than showing gradual responses”, boreal ecosystems “will tend to shift relatively sharply between alternative states in response to climate change”.', 'A new modelling study shows these changes will result in much reduced “aboveground” biomass – i.e.', ' But while trees at the southern edge of the boreal zone risk dieback, research suggests that forests at the northern edge could move into tundra under climate change.', ' Under the existing Paris emissions reduction pledges , the study projects “major climate change effects for more than 80% of the tundra and more than 40% of all boreal forests”.', ' Significant changes in boreal forests are made more likely by the

rapid rate of warming, says Goetz: ' "I don't know that anyone has put a number on a species-specific tipping point, but we have high confidence that with global temperature increases of 1.5 or 2C, which in the boreal will translate into about double those temperature increases, we will see widespread changes in tree species composition and fire regimes." ' Such changes could occur within decades, he adds: ' Rogers agrees that the change in albedo is a key impact of shifting boreal forests. ' It is worth noting also that very large shifts in the distribution of the boreal forests have happened in the relatively recent geological past in response to natural climate changes that are reasonably well understood. ' Some examples include: shutdown of Antarctic bottom water formation ; loss of alpine glaciers ; a climate change-induced hole in the ozone layer above the Arctic ; ocean anoxia (where areas of the ocean see a dramatic decline in oxygen); and a change in the frequency and/or strength of El Niño events . ' While the term "tipping point" is often applied quite loosely regarding political and societal change, it is clear that a number of them will need to be crossed – and quickly – to avoid toppling those in the Earth system. '

Explainer: Nine 'tipping points' that could be triggered by climate change '

Nine 'tipping points' that climate change could trigger '

Very specialized species like the American Pika (*Ochotona princeps*), that live only on high, rocky mountainsides, may be sensitive to even small changes in the climate. ' As the climate changes, park managers anticipate new challenges for the preservation of park landscapes and resources. ' Imagine climate change is like a fever – if your temperature went up 3.4° F, you would feel sick. ' Some observed and expected changes include: ' Very specialized species like the American Pika (*Ochotona princeps*), that live only on high, rocky mountainsides, may be sensitive to even small changes in the climate. ' Check out the Climate Change in RMNP Frequently Asked Questions for more in-depth information about climate change impacts in the park. ' " The National Park Service and its partners are working to understand how climate change will affect the park's natural resources, infrastructure, and your visitor experience now and into the future. " Volunteer to become a citizen scientist and help park scientists better understand climate change effects and improve habitat for native species. ' " I am convinced that climate change, and what we do about it, will define us, our era, and ultimately the global legacy we leave for future generations. '

Indigenous peoples and the role they may play in combating climate change are rarely considered in public discourses on climate change. ' Hence, it is not surprising that the special theme for the 7th session of the United Nations Permanent Forum on Indigenous Issues, which will take place from 21 April to 2 May 2008 in New York, is "Climate change, bio-cultural diversity and livelihoods: the stewardship role of indigenous peoples and new challenges". '

The effects of climate change on indigenous peoples '

Indigenous peoples are among the first to face the direct consequences of climate change, due to their dependence upon, and close relationship, with the environment and its resources. ' Climate change exacerbates the difficulties already faced by indigenous communities including political and economic marginalization, loss of land and resources, human rights violations, discrimination and unemployment. ' In the Amazon, the effects of climate change include deforestation and forest fragmentation and consequently, more carbon is released into the atmosphere exacerbating and creating further changes. ' Some of the concerns facing indigenous peoples in the region include the change in species and availability of traditional food sources, perceived reduction in weather predictions and the safety of traveling in changing ice and weather conditions, posing

serious challenges to human health and food security.', ' Responding to climate change', ' Climate change poses threats and dangers to the survival of indigenous communities worldwide, even though indigenous peoples contribute the least to greenhouse emissions.', 'In addition, indigenous peoples interpret and react to the impacts of climate change in creative ways, drawing on traditional knowledge and other technologies to find solutions which may help society at large to cope with impending changes.', ' In North America, some indigenous groups are striving to cope with climate change by focusing on the economic opportunities that it may create.', ' Drawbacks and difficulties of responding to climate change', ' The potential threat of climate change to indigenous peoples' very existence combined with various legal and institutional barriers, which affect their ability to cope with and adapt to climate change, makes climate change an issue of human rights and inequality to indigenous peoples.', ' nature climate change', ' Climate change Environmental economics', 'However, some caution is needed, if current momentum is to lead to genuine progress in making the most vulnerable more resilient to climate change.', ' Managing climate change risk: the case of the Italian Churches', ' Effective climate change adaptation means supporting community autonomy', ' Building social resilience in North Korea can mitigate the impacts of climate change on food security', ' Managing climate change risk: the case of the Italian Churches', ' Protocol Exchange', ' nature climate change', ' Climate change Environmental economics', 'However, some caution is needed, if current momentum is to lead to genuine progress in making the most vulnerable more resilient to climate change.', ' Managing climate change risk: the case of the Italian Churches', ' Effective climate change adaptation means supporting community autonomy', ' Building social resilience in North Korea can mitigate the impacts of climate change on food security', ' Managing climate change risk: the case of the Italian Churches', ' Protocol Exchange', ' This week, countries will gather in Kigali, the capital city of Rwanda, to tackle a small but potent cause of climate change: hydrofluorocarbons (HFCs).', 'They argued that the issue should be discussed instead at the UN's climate change body (UNFCCC).', ' Countries gather in Rwanda to try to tackle a small but potent source of climate change: HFCs', ' Land use, land-use change and forestry', 'India's overall CAT rating remains unchanged at 'Highly insufficient', but the rating of its NDC against its fair contribution to the Paris Agreement has improved by one category to 'Insufficient'.', '** India was severely impacted by COVID 19 during the second wave in the first half of 2021, which has further reduced the resilience of climate change vulnerable populations already at risk of displacement by storms, floods, extreme heat, droughts and other climate related disasters.', 'While coal subsidies in absolute terms have remained largely unchanged since 2017, they are still approximately 35% higher than subsidies for renewables.', 'This is a huge win for the climate movement, it changes a lot.' The court said it was unconstitutional for emission reduction targets to have been postponed for so many years and stated that the law was not detailed enough about how reductions would happen.', 'They added: "Virtually every freedom is potentially affected by these future emission reduction obligations because almost every area of human life is associated with the emission of greenhouse gases and is therefore threatened by drastic restrictions after 2030." The government responded quickly to the ruling, promising a swift implementation of changes to the law.']

ocean:

[' Averaged over the full depth of the ocean, the 1993–2020 heat-gain rates are 0.58-0.78 watts per square meter.', ' Increasing ocean heat content is contributing to sea level rise, ocean heat waves and coral bleaching, and melting of ocean-terminating glaciers and ice sheets around Greenland and Antarctica.', ' Heat already stored in the ocean will eventually be released, committing Earth to additional surface warming in the future.', 'Most of the excess atmospheric heat is passed back to the ocean.', 'As a result, upper ocean heat content has increased significantly over the past few decades.', ' Seasonal (3-month) heat energy in the top half-mile of the ocean compared to the 1955-2006 average.', 'Heat content in the global ocean has been consistently above-average (red bars) since the mid-1990s.', 'More than 90 percent of the excess heat trapped in the Earth system due to human-caused global warming has been absorbed by the oceans.', 'According to the State of the Climate 2019 report, "Summing the three layers (despite their slightly different time periods as given above), the full-depth ocean heat gain rate ranges from 0.58 to 0.78 W m⁻² applied to Earth's entire surface.", ' Change in heat content in the upper 2,300 feet (700 meters) of the ocean from 1993-2020.', 'Between 1993–2019, heat content rose by up to 6 Watts per square meter in parts of the ocean (dark orange).', 'Some areas lost heat (blue), but overall, the ocean gained more heat than it lost.', ' The ocean is the largest solar energy collector on Earth.', 'This tremendous ability to store and release heat over long periods of time gives the ocean a central role in stabilizing Earth's climate system.', 'The main source of ocean heat is sunlight.', 'Additionally, clouds, water vapor, and greenhouse gases emit heat that they have absorbed, and some of that heat energy enters the ocean.', 'Waves, tides, and currents constantly mix the ocean, moving heat from warmer to cooler latitudes and to deeper levels.', ' Heat absorbed by the ocean is moved from one place to another, but it doesn't disappear.', 'Thus, heat energy in the ocean can warm the planet for decades after it was absorbed.', 'If the ocean absorbs more heat than it releases, its heat content increases.', 'Knowing how much heat energy the ocean absorbs and releases is essential for understanding and modeling global climate.', ' Measuring ocean heat', ' Historically, taking the ocean's temperature required ships to dangle sensors or sample collectors into the water.', 'This time-consuming method could only provide temperatures for a small part of the planet's vast ocean.', 'To get global coverage, scientists turned to satellites that measure the height of the ocean's surface.', 'As water warms, it expands, so estimates for ocean temperature can be deduced from sea surface heights.', ' To get a more complete picture of ocean heat content at different depths, scientists and engineers also use a range of in situ temperature-sensing instruments.', 'Among these are a fleet of more than 3,000 robotic "floats" that measure ocean temperature around the world.', 'Known as Argo floats, the sensors drift through the ocean at different depths.', ' Instruments for taking ocean temperatures include Conductivity-Temperature-Depth instruments (known as CTDs), Expendable Bathythermographs (known as XBTs), and Argo floats.', 'They process the range of measurements to calculate an estimate for global average ocean heat content every three months.', 'Converting the temperatures to joules (a standard unit of energy) allows them to compare heat in the ocean to heat in other parts of Earth's climate system.', ' More than 90

percent of the warming that has happened on Earth over the past 50 years has occurred in the ocean.', 'Recent studies estimate that warming of the upper oceans accounts for about 63 percent of the total increase in the amount of stored heat in the climate system from 1971 to 2010, and warming from 700 meters down to the ocean floor adds about another 30 percent.', 'Annual ocean heat content compared to the 1993 average from 1993-2019, based on multiple data sets: surface to depths of 700 meters (2,300 feet) in shades of red, orange, and yellow; from 700-2,000 meters (6,650 feet) in shades of green and blue; and below 6,650 feet (2,000 meters) as a gray wedge.', 'Less than a watt per square meter might seem like a small change, but multiplied by the surface area of the ocean (more than 360 million square kilometers), that translates into an enormous global energy imbalance.', 'It means that while the atmosphere has been spared from the full extent of global warming for now, heat already stored in the ocean will eventually be released, committing Earth to additional warming in the future.', 'In the present, warming of ocean water is raising global sea level because water expands when it warms.', 'Warming ocean waters are also implicated in the thinning of ice shelves and sea ice, both of which have further consequences for Earth's climate system.', 'Finally, warming ocean waters threaten marine ecosystems and human livelihoods.', 'Ultimately, people who depend upon marine fisheries for food and jobs may face negative impacts from the warming ocean.', 'Information on how ocean heat content is calculated from ocean temperatures is available from NOAA's National Oceanographic Data Center.', '"Global ocean heat content 1955–2008 in light of recently revealed instrumentation problems" Geophysical Research Letters, 36, L07608, doi:10.1029/2008GL037155.', 'Corals also form growth rings that provide information about temperature and nutrients in the tropical ocean.', 'In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change, composed of scientific experts from countries all over the world, concluded that it is unequivocal that the increase of CO₂, methane, and nitrous oxide in the atmosphere over the industrial era is the result of human activities and that human influence is the principal driver of many changes observed across the atmosphere, ocean, cryosphere and biosphere.', 'Earth system science is the study of how scientific data coming from various fields of research, such as the atmosphere, oceans, land ice, and others, fit together to form the current picture of our planet as a whole, including its changing climate.', 'The delicate balance between the absorption and release of carbon dioxide by the ocean and the world's great forested regions is the subject of research by many scientists.', 'There is some evidence that the ability of the ocean or forests to continue absorbing carbon dioxide may decline as the world warms, leading to faster accumulation in the atmosphere.', 'Ice is white and very reflective, in contrast to the ocean surface, which is dark and absorbs heat faster.', 'As the atmosphere warms and sea ice melts, the darker ocean absorbs more heat, causes more ice to melt, and makes Earth warmer overall.', 'As Arctic sea ice and the Greenland ice sheet melt, ocean circulation in the Atlantic may slow the Gulf Stream.', 'This highlights the importance of ocean circulation in maintaining regional climates.', 'Coastal upwelling is the process by which winds push surface water offshore and deep water moves towards the coast, bringing nutrients from the ocean floor to the surface.', 'Natural fluctuations can also be the final nudge for a tipping point pushed to the brink by human-caused climate change, says Prof Mat Collins, joint Met Office chair in climate change at the University of Exeter and coordinating lead author on the "Extremes, Abrupt Changes and Managing Risks" chapter of the Intergovernmental Panel on Climate Change (IPCC) special report on the ocean and cryosphere in a changing climate

("SROCC").', ' The illustration below shows the two main features of the AMOC: the first is the flow of warm, salty water in the upper layers of the ocean northwards from the Gulf of Mexico (red line).', ' The AMOC forms part of a wider network of global ocean circulation patterns that transports heat all around the world.', 'It is "driven by deep water formation", explains Prof Stefan Rahmstorf, professor of physics of the oceans at Potsdam University and co-chair of earth system analysis at PIK.', ' In addition, there will be implications for the ocean itself, notes Rahmstorf:', ' "The whole North Atlantic ecosystem is adapted to the existence of this overturning circulation, which really sets the conditions – the seasonal cycle, the temperature, the nutrient conditions – in the North Atlantic, and so the intricate web of the Atlantic ecosystem will be substantially disrupted if allow such a massive change in the ocean circulation to happen."', 'As the IPCC's special report on the ocean and cryosphere in a changing climate ("SROCC") explains, this means that it sits "upon bedrock that largely lies below sea level and [is] in contact with ocean heat, making [it] vulnerable to rapid and irreversible ice loss".', 'If the ice sheet loses more ice to the ocean than it gains in snow, it adds to global sea levels.', ' Where the ice meets the ocean, floating ice shelves form.', ' Sitting on the ocean surface, ice shelves are at risk of melting from above and below from warm air and water, respectively.', 'But thinning and/or collapse of the WAIS's ice shelves could trigger a positive feedback loop that sees rapid and irreversible loss of land ice into the ocean – which would add to sea levels.', 'This is called Marine Ice Cliff Instability (MICI), which would see towering cliffs of glacier ice collapse into the ocean under their own weight.', 'Here, the grounded ice flows directly into the ocean with "no significant ice shelf barrier" to hold it back.', ' "When the system reverses, the low pressure over the Sahara – or the land [more generally] – drives winds from the southwest inland and those are moist winds because they're from the ocean."', ' (Giannini emphasises that, while the ITCZ and monsoon are "part of the same season and the same latitudinal migration of the rain band", some researchers prefer to "distinguish between the ITCZ over the ocean from the monsoon inland" and so do not use the terms interchangeably.)', ' The warm ocean temperatures reduced the temperature contrast between the continent in the hot summer and the cooler surrounding waters.', ' Subsequent research by Giannini has shown the combination of warming of the tropical oceans (in response to rising greenhouse gases) and cooling in the North Atlantic (as a result of air pollution from northern hemisphere countries) led to drying of the Sahel.', 'One is that colder conditions in the high-latitude North Atlantic can be transmitted via the atmosphere to the WAM, mainly through the cold conditions permeating into North Africa and affecting the monsoon...The other is that ocean circulation changes resulting from the AMOC slowdown 'rewires' the currents around the tropical Atlantic, leading to a warmer South tropical Atlantic and thus causing a weakening of the WAM.'', 'Submarine permafrost also occurs in shallow parts of the Arctic and Southern oceans.', 'The IPCC's special report on the ocean and cryosphere in a changing climate ("SROCC"), for example, says that there is "very high confidence" that record high temperatures at ~10–20m depth in permafrost have been "documented at many long-term monitoring sites in the northern hemisphere circumpolar permafrost region".', 'It is almost exclusively found under the seafloor on continental shelves – areas of seabed immediately surrounding a land mass, where the sea is relatively shallow compared to the open ocean beyond it.', 'The theory suggests that ocean warming could melt these ice crystals, releasing vast amounts of methane into the atmosphere.', ' A few years ago, for example, scientists identified "widespread seepage of methane from seafloor sediments

offshore Svalbard”, which they said “may, in part, be driven by hydrate destabilisation” due to ocean warming.’, ‘The map below, from the IPCC’s special report on the ocean and cryosphere in a changing climate (“SROCC”), shows how coral reefs around the world were affected in 2015-16.’, ‘They are also at risk from other factors, including overfishing, destructive fishing practices, sedimentation associated with sea level rise, runoff of nutrients from the land, storm damage, ocean acidification and shifts in ocean circulation.’, ‘Such “decadal timescales” are “coherent with the observations that coral cover across the Caribbean declined by 80% from 1977 to 2001 and may completely disappear by 2035, depending on rates of further overfishing, climate change and ocean acidification”, the authors note.’, ‘According to the International Union for Conservation of Nature (IUCN), “despite covering less than 0.1% of the ocean floor, reefs host more than one quarter of all marine fish species”.’, ‘“They heat up more quickly than nearby oceans – for example, the northern Indian Ocean – since land (soil) has a much lower heat capacity than water.”’, ‘The contrast in heating between the land and ocean causes a pressure gradient that drives southwesterly winds across India.’, ‘And so, in theory, “anything which alters either the north-south temperature gradient, or the amount of moisture evaporated from the ocean, could change the monsoon rains”, notes Turner.’, ‘With land areas warming faster than oceans, a strengthening of this pressure gradient and the monsoon itself “may be expected under global warming”, says the 1.5C report.’, ‘This, the paper explains, is where “the land-to-ocean pressure gradient, which drives the monsoon circulation, is reinforced by the moisture the monsoon itself carries from the adjacent Indian Ocean”.’, ‘Total mass balance – which includes the ice lost through calving and ocean melt – switched from overall gains to overall losses between the 1970s and 1980s.’, ‘The IPCC’s special report on the ocean and cryosphere in a changing climate (“SROCC”) also notes that decay of the ice sheet would not be abrupt.’, ‘Some examples include: shutdown of Antarctic bottom water formation; loss of alpine glaciers; a climate change-induced hole in the ozone layer above the Arctic; ocean anoxia (where areas of the ocean see a dramatic decline in oxygen); and a change in the frequency and/or strength of El Niño events.’, ‘“Less sea ice in one year implies more absorption of solar heat by the ocean, thus more warmth available to melt ice further, thus causing less sea ice the year after.”’, ‘“More recent work argues that the trajectory to a seasonally ice-free ocean will be pretty much along the path that we are observing – a downward trend with strong ups and downs from year to year (and over multiple years) reflecting the influences of natural variability.”]

ice:

[‘Increasing ocean heat content is contributing to sea level rise, ocean heat waves and coral bleaching, and melting of ocean-terminating glaciers and ice sheets around Greenland and Antarctica.’, ‘The heat energy eventually re-enters the rest of the Earth system by melting ice shelves, evaporating water, or directly reheating the atmosphere.’, ‘Warming ocean waters are also implicated in the thinning of ice shelves and sea ice, both of which have further consequences for Earth’s climate system.’, ‘Printing Office, Wash., D.C., 216 pp., DVDs.’, ‘Arctic sea ice reached its annual minimum extent (lowest amount of ice for the year) on Sept. 18, 2022, shrinking to an area of 4.67 million square kilometers (1.80 million square miles).’, ‘New

research on Antarctica, including the first map of iceberg calving, doubles the previous estimates of loss from ice shelves and details how the continent is changing.', 'Launch and grow your career with career services and resources', 'The rest is reflected, largely by clouds in the atmosphere and ice and snow on the surface, and not absorbed.', 'The increased amounts of greenhouse gases human activities are adding to the atmosphere have upset the balance that has been in place since the end of the last ice age.', '1155 Sixteenth Street, NW, Washington, DC 20036, USA | service@acs.org | 1-800-333-9511 (US and Canada) | 614-447-3776 (outside North America)', 'We know subtle changes in Earth's orbit around the Sun are responsible for the comings and goings of the ice ages.', 'Will we enter into a new ice age?', 'Earth system science is the study of how scientific data coming from various fields of research, such as the atmosphere, oceans, land ice, and others, fit together to form the current picture of our planet as a whole, including its changing climate.', 'As the atmosphere warms and sea ice melts, the darker ocean absorbs more heat, causes more ice to melt, and makes Earth warmer overall.', 'The ice-albedo feedback is a very strong positive feedback.', 'As Arctic sea ice and the Greenland ice sheet melt, ocean circulation in the Atlantic may slow the Gulf Stream.', 'Due to the strong feedback of the ice albedo, if enough ice melts, causing Earth's surface to absorb more and more heat, we may hit a point of no return.', 'Shrinking land-based ice sheets contribute to sea-level rise.', 'Arctic sea ice reached its annual minimum extent (lowest amount of ice for the year) on Sept. 18, 2022, shrinking to an area of 4.67 million square kilometers (1.80 million square miles).', 'New research on Antarctica, including the first map of iceberg calving, doubles the previous estimates of loss from ice shelves and details how the continent is changing.', 'Diversity, Equity, Inclusion, and Justice', 'These systems are critical in providing essential services to communities and supporting business continuity.', 'Environmental Topics Air Bed Bugs Chemicals and Toxics Climate Change Emergency Response Environmental Information by Location Environmental Justice Greener Living Health Land, Waste, and Cleanup Lead Mold Pesticides Radon Science Topics Water Topics A-Z Topic Index', 'About EPA EPA Administrator Organization Chart Staff Directory Planning, Budget, and Results Jobs and Internships Headquarters Offices Regional Offices Lab and Research Centers', 'Privacy and Security Notice', 'COP24 Katowice', 'Sea ice', 'COP24 Katowice', 'Sea ice', 'Sea ice', 'COP24 Katowice', 'Sea ice', 'COP24 Katowice', 'Guest post: How close is the West Antarctic ice sheet to a "tipping point"?', 'In this article, Carbon Brief explores nine key tipping points across the Earth system, from collapsing ice sheets and thawing permafrost, to shifting monsoons and forest dieback.', 'West Antarctic ice sheet disintegration 3.', 'Greenland ice sheet disintegration 9.', 'From declining Arctic sea ice and record-breaking heatwaves to melting glaciers and worsening droughts, the increase in global average temperature is being felt around the world.', 'Scientists have estimated, for example, that for every tonne of CO₂ emitted into the atmosphere, summer sea ice cover in the Arctic shrinks by three square metres.', 'Or, to use a more animal-friendly metaphor, a game of Jenga – where a particular component within the Earth system, such as an ice sheet, circulation pattern or ecosystem, is represented by the tower of blocks.', 'These are called "noise-induced" tipping points and include, for example, periods of abrupt change during the last ice age called "Dansgaard-Oeschger (D-O) events".', 'Natural fluctuations can also be the final nudge for a tipping point pushed to the brink by human-caused climate change, says Prof Mat Collins, joint Met Office chair in climate change at the University of Exeter and coordinating lead

author on the “Extremes, Abrupt Changes and Managing Risks” chapter of the Intergovernmental Panel on Climate Change (IPCC) special report on the ocean and cryosphere in a changing climate (“SROCC”).', ' In Hansen’s talk – a tribute to scientist Prof Charles Keeling , given at the American Geophysical Union (AGU) Fall Meeting – Hansen warned that “we are on the precipice of climate system tipping points beyond which there is no redemption”.', ' Passing an irreversible tipping point would mean a system would not revert to its original state even if the forcing lessens or reverses, explains Dr Richard Wood , who leads the Climate, Cryosphere and Oceans group in the Met Office Hadley Centre .', ' For example, part of the reason that Greenland has an ice sheet today is that it has had that ice sheet for hundreds of thousands of years.', 'If the Greenland ice sheet were to pass a tipping point that led to its disintegration, simply reducing emissions and lowering global temperatures to pre-industrial levels would not bring it back again.', 'It would probably require another ice age to achieve that.', ' “The dilution happens through increased rainfall and also melting of continental ice in the vicinity of mainly the Greenland ice sheet.', ' West Antarctic ice sheet disintegration', ' Although much smaller than its neighbour to the east, the WAIS still holds enough ice to raise global sea levels by around 3.3 metres .', 'Therefore, even a partial loss of its ice would be enough to change coastlines around the world dramatically.', ' The long-term stability of the WAIS is of particular concern because it is a “marine-based” ice sheet.', 'As the IPCC’s special report on the ocean and cryosphere in a changing climate (“SROCC”) explains, this means that it sits “upon bedrock that largely lies below sea level and [is] in contact with ocean heat, making [it] vulnerable to rapid and irreversible ice loss”.', ' Bedrock topography below the existing ice sheets in Antarctica.', ' Acting under the force of gravity, the ice of the WAIS gradually flows out from its interior towards the coast and into the Southern Ocean.', 'Fresh snowfall on the interior of the ice sheet replenishes the lost ice.', 'If the ice sheet loses more ice to the ocean than it gains in snow, it adds to global sea levels.', ' For example, analysis published in Nature in 2018 showed that the rate of ice loss from the WAIS had tripled from 53bn tonnes a year during 1992-97 to 159bn tonnes a year in 2012-2017.', ' Where the ice meets the ocean, floating ice shelves form.', 'These ice shelves have a “buttressing” effect, holding back the glaciers on land that flow into them.', ' Sitting on the ocean surface, ice shelves are at risk of melting from above and below from warm air and water, respectively.', 'In the Antarctic Peninsula, for example, research has shown that the collapse of the Larsen B ice shelf in 2002 was primarily driven by warm air temperatures.', 'While the Larsen C ice shelf, which is “ thinning rapidly ”, is being melted from above and below.', ' Because ice shelves float on water, their collapse does not directly cause sea level rise.', 'But thinning and/or collapse of the WAIS’s ice shelves could trigger a positive feedback loop that sees rapid and irreversible loss of land ice into the ocean – which would add to sea levels.', 'This theory is called “marine ice sheet instability” (MISI).', 'As an ice shelf thins, more ice lifts off the seafloor and begins to float.', 'This pushes back (see blue arrows) the “grounding line” – the transition point between grounded and floating ice (indicated by dashed lines).', 'Floating ice flows more rapidly than grounded ice and so the rate of ice flow near the grounding line increases (black arrows).', 'Faster flow means thinning, which may in turn cause more ice to lift off and float.', 'And because greater thickness also causes the ice to flow faster, grounding-line retreat into deeper sections of the ice sheet can also produce faster flow.', 'Not only is much of the bedrock beneath the ice sheet below sea level, large portions of it slope downwards away from the coast.', 'This means that once ice sheet retreat reaches this

point, it is self-sustaining.', 'Thinning of the buttressing ice shelf leads to acceleration of the ice sheet flow and thinning of the marine-terminated ice margin.', 'Because bedrock under the ice sheet is sloping towards the ice sheet interior, thinning of the ice causes retreat of the grounding line followed by an increase of the seaward ice flux, further thinning of the ice margin, and further retreat of the grounding line.', 'This is called Marine Ice Cliff Instability (MICI), which would see towering cliffs of glacier ice collapse into the ocean under their own weight.', 'Here, the grounded ice flows directly into the ocean with “ no significant ice shelf barrier ” to hold it back.', ' Antarctica’s contribution to global sea levels is currently dominated by ice loss from Amundsen sea sector glaciers.', ' Ronne ice shelf', ' Ross ice shelf', ' Research indicates that glaciers in this sector are “undergoing a marine ice sheet instability that will significantly contribute to sea level rise in decades to centuries to come”.', ' For example, model simulations in a 2014 study in Science have suggested that the “process of marine ice-sheet destabilisation is already under way on Thwaites Glacier”.', ' “Although [ice] losses are likely to be relatively modest over the next century (<0.25 mm/year of sea level equivalent, SLE), rapid collapse (>1 mm/year of SLE) will ensue once the grounding line reaches the basin’s deeper regions, which could occur within centuries.”’, ' A Nature Climate Change review paper published in 2018 concluded that “under sustained warming, a key threshold for survival of Antarctic ice shelves, and thus the stability of the ice sheet, seems to lie between 1.5 and 2C mean annual air temperature above present”.', ' “Studies show that under RCP2.6 the ice sheets continue to lose mass but seem stable, while for RCP4.5, in some cases irreversible mass loss is encountered.”’, 'Spanning nine countries in South America, it is twice the size of India.', 'There are three potential causes of this, explains Prof Richard Betts , head of climate impacts at the Met Office Hadley Centre and chair of climate impacts at the University of Exeter .', 'The evidence for this mainly comes from palaeoclimate data from the end of the last ice age, says Prof John Chiang , who runs a climate dynamics research group at the University of California, Berkeley .', ' Permafrost is the name given to ground – soil or rock – that contains ice or frozen organic material that has remained at or below 0C for at least two years .', 'There is around twice as much carbon in permafrost than is currently in the Earth’s atmosphere.', ' Similarly, rapid permafrost thaw can also be triggered – and enhanced – by disturbances such as fire, abrupt drying events , soil subsidence and erosion resulting from ice-rich permafrost thaw (known as “ thermokarst ”).', ' Dr Andy Wiltshire , terrestrial carbon cycle manager at the Met Office Hadley Centre, agrees.', 'This is an ice-like substance formed when methane and water combine at low temperatures and moderate pressure .', 'The theory suggests that ocean warming could melt these ice crystals, releasing vast amounts of methane into the atmosphere.', 'They are also at risk from other factors, including overfishing, destructive fishing practices , sedimentation associated with sea level rise, runoff of nutrients from the land, storm damage , ocean acidification and shifts in ocean circulation.', 'For example, in the last ice age and during more recent cold periods such as the Little Ice Age .', 'Snow and ice tend to have a higher albedo than, for example, soil, forests and open water.', ' “Palaeo changes are important, but their relevance to human-caused climate change is unclear; feedbacks that take hundreds to thousands of years to operate – involving large changes in ice sheets or continental vegetation and soil types – may not be relevant if we are interested in changes taking place over a few years or a few decades.”’, ' Greenland ice sheet disintegration', ' The Greenland ice sheet is the second largest mass of ice on Earth.', ' Aerial view of the Greenland ice sheet.', ' Melting of the

Greenland ice sheet is accelerating and it is currently adding around 0.7mm to global sea levels each year.', 'A tipping point for Greenland ice melt is unlikely to be abrupt, says climate scientist Dr Ruth Mottram of the Danish Meteorological Institute, but it is clear that there will be a threshold beyond which its eventual collapse is irreversible.', 'Around half of the melt that the Greenland ice sheet experiences occurs at the surface.', 'The remainder occurs through melting at the ice sheet base and via the breaking off, or "calving", of icebergs from its edge.', ' "Probably the most important 'tipping point' feedback though are elevation feedbacks – as the ice sheet gets lower via melting, more areas are at lower and warmer altitudes, leading to further melting." ', 'In the clip below, Dr Ricarda Winkelmann of PIK outlines the processes involved in a tipping point for the Greenland ice sheet.', 'Also important is the "snowline" – the elevation at which the ice sheet is covered in snow.', 'Bright white snow has a higher albedo than dark, bare ice – which means it reflects back much more of the sun's energy.', 'So if the snowline migrates to higher elevations as the ice sheet warms, it means the ice will be absorbing more of the incoming solar radiation, causing more melting.', 'The combination of these processes means that a tipping point in Greenland ice melt is "very much related to how much melting is happening at the surface and how much of a snowpack there is to absorb that meltwater", says Mottram.', 'This has "cascading consequences as the meltwater can affect ice sheet flow speeds and calving processes".', 'The IPCC's most recent full assessment report – AR5, published in 2013 – concluded that (pdf) it is "exceptionally unlikely" that the Greenland ice sheet will suffer near-complete disintegration in the 21st century – equivalent to a 0-1% likelihood of it happening.', 'However, more recent research suggests that the ice sheet is at risk on longer timescales.', 'A review paper in Nature Climate Change in 2018 concluded that 1.8C (with a range of 1.1-2.3C) of warming above pre-industrial levels would be enough to trigger feedback loops of decline in parts of the ice sheet in summer.', 'The IPCC's special report on 1.5C – published in 2018 – noted that a "useful indicator" for the elevation feedback mentioned above is the "threshold at which annual mass loss from the ice sheet by surface melt exceeds mass gain by snowfall".', 'As an example, the SMB for 2019 was 169bn tonnes of ice, the seventh lowest on record.', 'Total mass balance – which includes the ice lost through calving and ocean melt – switched from overall gains to overall losses between the 1970s and 1980s .)', ' "The continued decline of the ice sheet after this threshold has been passed is highly dependent on the future climate and varies between about 80% loss after 10,000 years to complete loss after as little as 2000 years (contributing about six metres to sea level rise)." ', 'The fate of the Greenland ice sheet is, therefore, still strongly dependent on the rate of greenhouse gas emissions in future.', 'A 2019 modelling study published in Science simulated the Greenland ice sheet out to the year 3000 under different emissions scenarios.', ' "In a thousand years, the Greenland ice sheet will look significantly different than today.", 'Depending on the emission scenario, the Greenland ice sheet will have lost 8 to 25% (RCP2.6), 26 to 57% (RCP4.5), or 72 to 100% (RCP8.5) of its present-day mass, contributing 0.59 to 1.88 metres, 1.86 to 4.17 metres, or 5.23 to 7.28 metres to global mean sea level, respectively." ', 'This is illustrated in the maps below, taken from the paper, which show the observed state of the ice sheet (A) and the projected ice cover by the year 3000 under the three different scenarios (B to D).', 'The shading in the maps shows the likelihood of future ice cover, with dark blue areas indicating areas with remaining ice in 16% of model runs, blue for 50% of model runs and white for 84%.', 'Greenland ice sheet maps showing the observed extent in 2008 (A) and the projected

extent in the year 3000 under RCP2.6 (B), RCP4.5 (C), and RCP8.5 (D) across 500 model simulations.', 'Shading indicates likelihood (in percentiles from model simulations) of ice cover remaining by the year 3000: Dark blue (16%), blue (50%) and white (84%).', 'Following a relatively low emissions pathway, such as RCP2.6 – which is consistent with a 1.5-2C warmer world – may, therefore, be regarded as “representing moderate risk, in that it may trigger...irreversible loss of the Greenland ice sheet”, concludes the IPCC 1.5C report.', 'The IPCC’s special report on the ocean and cryosphere in a changing climate (“SROCC”) also notes that decay of the ice sheet would not be abrupt.', 'While it is possible that the ice sheet could stabilise at some intermediate point during its collapse, it would not regain its previous vast size until the next ice age, says Mottram:', '“It is clear from even very early work that the ice sheet is only there because it is already there – if there was no ice sheet in Greenland under today’s climate we would not be able to build it up again.', 'However, the boreal zone, along with the tundra, is warming rapidly – approximately twice as quickly as the global average.', 'Shifts in vegetation cover will affect the reflectivity of the land surface – known as its “albedo”, says Prof Colin Prentice, chair in biosphere and climate impacts at Imperial College London.', 'In fact, he adds, “the full extent of ice ages [in Earth’s history] is impossible without this feedback”.', 'Prentice argues that a gradual shift is more likely.', 'Another example that is often cited is the decline of Arctic sea ice.', 'Climate model simulations have suggested that summer sea ice extent in the Arctic could see abrupt and accelerating declines during this century.', 'Such a potential decline is associated with the ice-albedo mechanism, explains Dr Dirk Notz, head of the Sea ice in the Earth system research group at the Max Planck Institute for Meteorology.', '“Less sea ice in one year implies more absorption of solar heat by the ocean, thus more warmth available to melt ice further, thus causing less sea ice the year after.”', 'The “idea of such a sea-ice tipping point was quite popular perhaps a decade ago”, says Prof Mark Serreze, director of the US National Snow and Ice Data Center (NSIDC).', 'A 2005 paper in the Journal of Climate, for example, asked “Have we passed a tipping point?” in response to thinning Arctic sea ice between 1988 and 2003.', '“More recent work argues that the trajectory to a seasonally ice-free ocean will be pretty much along the path that we are observing – a downward trend with strong ups and downs from year to year (and over multiple years) reflecting the influences of natural variability.”', 'Research by Notz and colleagues, for example, has shown that large declines in summer sea ice are reversible.', '“After a year with anomalously little sea ice, the sea ice usually recovers somewhat in the year afterwards.”', 'This is because in addition to the amplifying ice-albedo feedback, there are dampening feedbacks that stabilise the ice cover from one year to the next.”', 'For example, less ice in summer means more open water going into winter.', 'Without the insulating effect of the ice, the Arctic Ocean subsequently loses a greater amount of heat, which means it sees more ice growth in winter.', 'In addition, thin ice in winter grows faster than thick ice, giving the chance for some degree of recovery after a small extent in summer.', 'Arctic sea ice breaking apart.', 'These feedbacks “imply that the memory of the sea ice cover is largely reset during winter”, says Notz, making the ice loss approximately linear in response to rising greenhouse gases.', 'However, while sea ice itself might not be a tipping element, ecological systems associated with it might well be, adds Notz:', '“If the ice is gone completely in a given summer, any ecosystem that needs the continuous existence of sea ice might be wiped out ‘forever’.”', '“Arctic sea-ice loss is amplifying regional warming, and Arctic warming and Greenland melting are driving an influx of fresh water

into the North Atlantic.', ' In addition, rapid Greenland melting and further slowdown of the AMOC could “destabilise the West African monsoon, triggering drought in Africa’s Sahel region”, the authors say, as well as “dry the Amazon, disrupt the East Asian monsoon and cause heat to build up in the Southern Ocean, which could accelerate Antarctic ice loss”.', ' A groundswell of demand can push a behaviour, product or technology from the fringe and into the mainstream, often as a result of falling prices.', ' Published under a CC license .', ' Content Copyright National Park Service', ' National Park Service Logo', ' National Park Service', " The National Park Service and its partners are working to understand how climate change will affect the park's natural resources, infrastructure, and your visitor experience now and into the future.", 'Buy local products that are sourced and manufactured in environmentally friendly ways to influence economic practices.', 'The Information Office is open year-round: 8:00 a.m. - 4:00 p.m. daily in summer; 8:00 a.m. - 4:00 p.m. Mondays - Fridays and 8:00 a.m. - 12:00 p.m. Saturdays - Sundays in winter.', ' National Park Service', 'Notices', 'Contact The National Park Service', ' Indigenous peoples in Africa’s Kalahari Desert are forced to live around government drilled bores for water and depend on government support for their survival due to rising temperatures, dune expansion and increased wind speeds which have resulted in a loss of vegetation, and negatively impacted traditional cattle and goat farming practices.', 'Some of the concerns facing indigenous peoples in the region include the change in species and availability of traditional food sources, perceived reduction in weather predictions and the safety of traveling in changing ice and weather conditions, posing serious challenges to human health and food security.', 'Indigenous peoples may be more vulnerable to irregular migration such as trafficking and smuggling due to sudden displacement by a climactic event, limited legal migration options and limited opportunities to make informed choices.', ' Privacy Notice', ' Subscribe to Journal Get full journal access for 1 year \$99.00 only \$8.25 per issue Subscribe All prices are NET prices.', '\$32.00 Buy All prices are NET prices.', ' Press office', ' Author & Researcher services', ' Librarian service & tools', ' Partnerships & Services', ' Legal notice', ' Subscribe to Journal Get full journal access for 1 year \$99.00 only \$8.25 per issue Subscribe All prices are NET prices.', '\$32.00 Buy All prices are NET prices.', ' Press office', ' Author & Researcher services', ' Librarian service & tools', ' Partnerships & Services', ' Legal notice', ' COP24 Katowice', ' Sea ice', ' COP24 Katowice', ' Sea ice', ' Sea ice', ' COP24 Katowice', ' Sea ice', ' COP24 Katowice', 'During this grace period, early action by others is expected to advance the necessary technologies and bring down the price of transitioning to HFC alternatives.', ' Published under a CC license .', 'India provides subsidies for both fossil fuels and renewable energy, including direct subsidies, fiscal incentives, price regulation and other government support.', 'India needs to provide price support, in the form of feed-in-tariffs, and the transfer of subsidies from fossil to non-fossil sources could be an important driver of higher penetration of renewables in energy mix.', ' This website saves small pieces of information (cookies) on your device to provide you with an improved user experience, and to allow us to analyse our website’s traffic.', ' Skip to main content Skip to navigation Advertisement US edition US edition UK edition Australia edition International edition The Guardian - Back to home The Guardian: news website of the year Search jobs Sign in Search News Opinion Sport Culture Lifestyle Show More Show More News US news World news Environment Soccer US politics Business Tech Science Newsletters Fight to vote Opinion The Guardian view Columnists Letters Opinion videos Cartoons Sport Soccer NFL Tennis MLB MLS NBA NHL F1 Culture Film Books Music Art &

design TV & radio Stage Classical Games Lifestyle Fashion Food Recipes Love & sex Home & garden Health & fitness Family Travel Money Search Search Make a contribution Subscribe Search jobs Digital Archive Guardian Puzzles app Guardian content licensing site The Guardian app Video Podcasts Pictures Inside the Guardian Guardian Weekly Crosswords Corrections Facebook Twitter Search jobs Digital Archive Guardian Puzzles app Guardian content licensing site Environment Climate crisis Wildlife Energy Pollution Green light Germany This article is more than 1 year old 'Historic' German ruling says climate goals not tough enough This article is more than 1 year old Judges order government to strengthen legislation before end of next year to protect future generations Environmental activist Luisa Neubauer, one of the complainants, said the court's decision was 'a huge win for the climate movement'.', 'Climate protection is not nice to have; climate protection is our basic right and that's official now.']

carbon:

[' Five key greenhouse gases are CO₂ , nitrous oxide, methane, chlorofluorocarbons, and water vapor.', ' Over the last century, burning of fossil fuels like coal and oil has increased the concentration of atmospheric carbon dioxide (CO₂).', 'This increase happens because the coal or oil burning process combines carbon with oxygen in the air to make CO₂ .', ' The industrial activities that our modern civilization depends upon have raised atmospheric carbon dioxide levels by nearly 50% since 1750.', ' Friedlingstein et al 2021: " The mass of carbon in the atmosphere increased by 48% from 590 GtC in 1750 to 876 GtC in 2020.', 'All gases whose molecules have three or more atoms are greenhouse gases—carbon dioxide (CO₂), water vapor (H₂O), and methane (CH₄) are important greenhouse gases that have maintained Earth's warm temperature for billions of years.', 'Since the Industrial Revolution, concentrations of greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) have risen in the atmosphere.', 'Burning fossil fuels such as coal, oil, and gas has increased the concentration of atmospheric carbon dioxide (CO₂) from 280 parts per million to 416 parts per million.', 'Other kinds of particles, such as black carbon, have a warming effect.', 'Natural processes, such as tree growth, remove about half of human carbon dioxide emissions from the atmosphere every year.', 'Scientists are currently studying where this carbon dioxide goes.', 'The delicate balance between the absorption and release of carbon dioxide by the ocean and the world's great forested regions is the subject of research by many scientists.', 'There is some evidence that the ability of the ocean or forests to continue absorbing carbon dioxide may decline as the world warms, leading to faster accumulation in the atmosphere.', 'Deposits of frozen methane, a potent greenhouse gas, and carbon dioxide lie beneath permafrost in polar regions.', ' Higher carbon dioxide levels', ' Algae need carbon dioxide to survive.', 'Higher levels of carbon dioxide in the air and water can lead to rapid growth of algae, especially toxic blue-green algae that can float to the surface of the water.', ' <link href="https://www.carbonbrief.org/wp-content/themes/carbonbrief/css/ie8.css" rel="stylesheet">', 'RCP2.6 (also sometimes referred to as "RCP3-PD") is a "peak and decline" scenario where stringent mitigation and carbon dioxide removal technologies mean atmospheric CO₂ concentration peaks and then falls during this century.', 'These policies include a shift to low-carbon energy technologies and the deployment of carbon capture and storage.', ']

“Increased release of CO₂ from forest fires and tree death would accelerate CO₂ rise, and with the forest gone we would also have lost an important carbon sink which would mean that deeper emissions cuts would be needed to stop the rise in atmospheric CO₂.”, ' This frozen ground holds a vast amount of carbon, accumulated from dead plants and animals over thousands of years.', 'There is around twice as much carbon in permafrost than is currently in the Earth's atmosphere.', 'This brings microbes in the soil out of hibernation, allowing them to break down the organic carbon in the soil.', ' Meanwhile, the 2019 Arctic Report Card from the US National Oceanic and Atmospheric Administration (NOAA) concluded that thawing permafrost across the Arctic “could be releasing an estimated 300-600m tonnes of net carbon per year to the atmosphere”.', ' The lead of author of the permafrost chapter, Prof Ted Schuur of Northern Arizona University, told the Washington Post that recent research indicates “we’ve turned this corner for Arctic carbon”.', 'This is projected to release 10s to 100s of billions of tonnes [or gigatonnes, GtC], up to as much as 240 GtC, of permafrost carbon as CO₂ and methane to the atmosphere with the potential to accelerate climate change.”, 'This is where the “internal heat generation becomes the main driving force for further thaw and carbon release”, he explains to Carbon Brief, “even if global warming stopped”.', ' Dr Andy Wiltshire, terrestrial carbon cycle manager at the Met Office Hadley Centre, agrees.', 'The carbon contained in the soils has built up over “incredibly long periods of time”.', ' “If we stop warming, then we should see the emissions from permafrost stop, but in terms of that carbon going back into permafrost, pragmatically that’s not possible.”, 'Research also suggested that there were “ready to release” deposits of hydrates in the East Siberian Arctic Shelf (ESAS) under the Arctic Ocean – containing as much as 1,400bn tonnes of carbon.', ' (For comparison, global emissions from fossil fuels and industry in 2019 amounted to around 10bn tonnes of carbon.)', 'So once it’s gone it’s gone until at least the next glacial period – and we’ll be waiting some tens of thousands of years given current climate change and the slow rate of carbon removal by natural means.”, 'They are a very important store of carbon.', 'While there is a lot of uncertainty around the precise amount of carbon they hold, estimates suggest it is more than one third of all terrestrial carbon.', ' “Obviously great permafrost degradation means a lot more carbon emitted to the atmosphere, which would have the effect of increasing the cycle of warming and even more degradation, with global implications.”, 'And Rogers adds that while “forest composition may be reversible”, the carbon emitted from thawing permafrost “would take much, much longer” to reaccumulate:', ' “That carbon took millennia to be sequestered by the land and gradually accumulate in frozen soil layers.”, 'For example, the study identifies six “social tipping interventions” that could help lead to a carbon-neutral society by 2050:', ' “These social tipping interventions comprise removing fossil-fuel subsidies and incentivising decentralised energy generation, building carbon-neutral cities, divesting from assets linked to fossil fuels, revealing the moral implications of fossil fuels, strengthening climate education and engagement, and disclosing greenhouse gas emissions information.”, ' In the Amazon, the effects of climate change include deforestation and forest fragmentation and consequently, more carbon is released into the atmosphere exacerbating and creating further changes.', 'In addition, there may be opportunities for carbon sequestration.', ' <link href="https://www.carbonbrief.org/wp-content/themes/carbonbrief/css/ie8.css" rel="stylesheet">', ' This week, countries will gather in Kigali, the capital city of Rwanda, to tackle a small but potent cause of climate change: hydrofluorocarbons (HFCs).', 'Countries have agreed to tackle

them through the Montreal Protocol instead — a UN treaty better known for tackling the hole in the ozone layer by phasing out chlorofluorocarbons (CFCs).', 'At first, this was hydrochlorofluorocarbons (HCFCs) — a group of chemicals that deplete the ozone layer 10 to 50 times less than CFCs, which were considered “transitional substitutes” under the Protocol until ozone-safe replacements could be commercialised.', 'These include natural refrigerants, such as hydrocarbons, ammonia and carbon dioxide (which would have a negligible impact in the small quantities released by cooling systems, since it is thousands of times weaker than some of the HFCs currently used).', 'On 6 November 2015, nations accepted the Dubai Pathway on Hydrofluorocarbons .', ' CAT Decarbonisation Memo Series', ' India's first NDC has three main elements: An emissions-intensity target of 45% below 2005 levels by 2030; A target of achieving 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030; and Creation of a carbon sink of 2.5 to 3 GtCO₂e through additional forest and tree cover by 2030.', ' Global reaction to energy crisis risks zero carbon transition']

emissions:

[' The greenhouse effect is essential to life on Earth, but human-made emissions in the atmosphere are trapping and slowing heat loss to space.', ' Greenhouse gas emissions.', 'Natural processes, such as tree growth, remove about half of human carbon dioxide emissions from the atmosphere every year.', 'Carbon dioxide uptake by plants is unable to offset emissions from human activities.', ' Making immediate reductions in greenhouse gas emissions, with the aim of halting global warming, is essential to reduce the risk of the strongest storms in the future.', ' Global emissions', ' Rest of world emissions', ' UK emissions', ' EU emissions', ' Negative emissions', ' EU emissions', ' Global emissions', ' Negative emissions', ' Rest of world emissions', ' UK emissions', ' Negative emissions', ' EU emissions', ' Global emissions', ' Rest of world emissions', ' UK emissions', ' Negative emissions', ' EU emissions', ' Global emissions', ' Rest of world emissions', ' UK emissions', 'Each creeps up year after year, fuelled by human-caused greenhouse gas emissions.', ' Guest post: The irreversible emissions of a permafrost ‘tipping point’, 'If the Greenland ice sheet were to pass a tipping point that led to its disintegration, simply reducing emissions and lowering global temperatures to pre-industrial levels would not bring it back again.', 'Referring to the different “ Representative Concentration Pathway ” emissions scenarios, he adds:', ' “Increased release of CO₂ from forest fires and tree death would accelerate CO₂ rise, and with the forest gone we would also have lost an important carbon sink which would mean that deeper emissions cuts would be needed to stop the rise in atmospheric CO₂.”', 'A 2018 study using a high-resolution climate model, for example, simulated “decreasing precipitation over the southern Sahel and increase of precipitation over the western Sahara” by the end of the century under the very high emissions RCP8.5 scenario .', ' “If we stop warming, then we should see the emissions from permafrost stop, but in terms of that carbon going back into permafrost, pragmatically that’s not possible.”', ' (For comparison, global emissions from fossil fuels and industry in 2019 amounted to around 10bn tonnes of carbon.)', 'CO₂ levels have already surpassed 410ppm and are projected to exceed 500ppm by 2100 in all but the most stringent mitigation scenarios for emissions this

century.', '“Even achieving emissions reduction targets consistent with the ambitious goal of 1.5C of global warming under the Paris Agreement will result in the further loss of 70-90% of reef-building corals compared to today, with 99% of corals being lost under warming of 2C or more.”’, '“Air pollution comes in several forms, but most of it is in the form of sulphur compounds – for example, emissions of sulphur dioxide from industry and transport – that form sulphates in the atmosphere.’, ' This pollution “will preferentially cool the northern hemisphere region over Eurasia relative to the equator or southern Indian Ocean – where there are no pollution emissions”, says Turner.’, ' The fate of the Greenland ice sheet is, therefore, still strongly dependent on the rate of greenhouse gas emissions in future.’, 'A 2019 modelling study published in Science simulated the Greenland ice sheet out to the year 3000 under different emissions scenarios.’, ' Following a relatively low emissions pathway, such as RCP2.6 – which is consistent with a 1.5-2C warmer world – may, therefore, be regarded as “representing moderate risk, in that it may trigger...irreversible loss of the Greenland ice sheet”, concludes the IPCC 1.5C report.’, ' Under the existing Paris emissions reduction pledges, the study projects “major climate change effects for more than 80% of the tundra and more than 40% of all boreal forests”.’, ' Carbon emissions from permafrost thaw and dieback of forests at the southern edge of the boreal biome would be a “double-whammy”, says Rogers.’, ' “These social tipping interventions comprise removing fossil-fuel subsidies and incentivising decentralised energy generation, building carbon-neutral cities, divesting from assets linked to fossil fuels, revealing the moral implications of fossil fuels, strengthening climate education and engagement, and disclosing greenhouse gas emissions information.”’, ' Climate change poses threats and dangers to the survival of indigenous communities worldwide, even though indigenous peoples contribute the least to greenhouse emissions.’, 'For example, the increased demand for renewable energy using wind and solar power could make tribal lands an important resource for such energy, replacing fossil fuel-derived energy and limiting greenhouse gas emissions.’, 'The Great Plains could provide a tremendous wind resource and its development could help to reduce greenhouse gas emissions as well as alleviate the management problem of the Missouri River hydropower, helping to maintain water levels for power generation, navigation, and recreation.’, 'For instance, biofuel initiatives are a means of reducing greenhouse gas emissions may lead to an increase in monoculture crops and plantations and an associated decline in biodiversity and food security.’, ' Global emissions', ' Rest of world emissions', ' UK emissions', ' EU emissions', ' Negative emissions', ' EU emissions', ' Global emissions', ' Negative emissions', ' Rest of world emissions', ' UK emissions', ' Negative emissions', ' EU emissions', ' Global emissions', ' Rest of world emissions', ' UK emissions', ' Negative emissions', ' EU emissions', ' Global emissions', ' Rest of world emissions', ' UK emissions', 'One study estimates that, in a business-as-usual scenario, HFCs could rise to 9-19% of projected global emissions by 2050.’, 'While emissions are dwarfed against global CO2 emissions, their capacity to warm the atmosphere is stronger.’, 'In comparison, the island states have proposed cutting developing country emissions to 85% of the 2015-2017 average by 2020.’, ' Global emissions and temperature', ' Estimating national emissions', 'It strengthened both the value of its 2030 emissions intensity target and the share of electricity that will come from non-fossil fuel-based sources, compared to its first NDC.’, 'While stronger on paper, India will already achieve these targets with its current level of climate action and the new targets will not drive further emissions reductions.’, 'At most, it could drive minor reductions in real world

emissions, given the 500 GW does not go beyond current government plans.', 'India needs to propose further cuts in 2030 emissions, conditional to international finance, to put India on a 1.5°C pathway.', 'Our analysis is based on updated emissions data and projections for India; however, we have not yet updated our Policies and Action tab.', 'CAT analysis shows emissions to 2030 will rise less than in pre-COVID 19 projections, mainly because of the pandemic's impact on the economy.', 'To get on a 1.5°C emissions pathway, it is important for India to phase out old, high-capacity power plants with lower efficiency and higher emissions and stop any new coal capacity additions.', 'Its updated emissions intensity target is 'Insufficient' when compared to India's fair share contribution, an improvement of one category.', 'India's conditional NDC target is still 'Critically insufficient' when compared to a modelled 1.5°C emissions pathway for the country.', 'India's projected emissions in 2030 under its current level of climate action are higher than our last assessment, largely due to higher historical emissions, and, as a result, now fall under the 'Insufficient' range.', 'India should adopt targets that will drive actual emissions reductions and accelerate climate policy implementation.', ' India's 2030 emissions will reach around 4.1-4.3 GtCO₂e (excluding LULUCF) in 2030 under current policies, which the CAT rates as 'Insufficient'.', 'Emissions are higher than our previous estimate, largely due to higher historical emissions caused by a stronger-than-expected rebound of emissions after COVID19.', ' India's first NDC has three main elements: An emissions-intensity target of 45% below 2005 levels by 2030; A target of achieving 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030; and Creation of a carbon sink of 2.5 to 3 GtCO₂e through additional forest and tree cover by 2030.', ' We interpret India's emissions-intensity target as being its unconditional contribution to meeting the Paris Agreement.', 'We rate this target against what India's fair share contribution under the Agreement should be and find it to be "Insufficient." The "Insufficient" rating indicates that India's emissions in 2030 needs substantial improvements to be consistent with the Paris Agreement's 1.5°C temperature limit.', ' Analysis: Aviation industry emissions plans consistent with 4°C of warming', 'Under the 2019 law Germany is obliged to cut greenhouse gas emissions 55% by 2030, compared with 1990 levels.', 'Annual upper limits for greenhouse gas emissions across the energy, transport, agriculture and construction sectors are also set in the law.']

temperature:

['Not only does water cover more than 70 percent of our planet's surface, it can also absorb large amounts of heat without a large increase in temperature.', ' Historically, taking the ocean's temperature required ships to dangle sensors or sample collectors into the water.', 'This time-consuming method could only provide temperatures for a small part of the planet's vast ocean.', 'As water warms, it expands, so estimates for ocean temperature can be deduced from sea surface heights.', ' To get a more complete picture of ocean heat content at different depths, scientists and engineers also use a range of in situ temperature-sensing instruments.', 'Among these are a fleet of more than 3,000 robotic "floats" that measure ocean temperature around the world.', 'Every 10 days or so, according to their programmed instructions, they rise through the water, recording temperature (and salinity) as they ascend.', ' Instruments for taking ocean

temperatures include Conductivity-Temperature-Depth instruments (known as CTDs), Expendable Bathythermographs (known as XBTs), and Argo floats.', 'Seals have even been fitted with instruments to obtain temperatures in areas that are difficult to reach.', 'Converting the temperatures to joules (a standard unit of energy) allows them to compare heat in the ocean to heat in other parts of Earth's climate system.', 'Information on how ocean heat content is calculated from ocean temperatures is available from NOAA's National Oceanographic Data Center.', 'Why did Earth's surface temperature stop rising in the past decade?', 'How do we know what greenhouse gas and temperature levels were in the distant past?', 'Other tools for learning about Earth's ancient atmosphere include growth rings in trees, which keep a rough record of each growing season's temperature, moisture and cloudiness going back about 2,000 years.', 'Corals also form growth rings that provide information about temperature and nutrients in the tropical ocean.', 'The above graph compares global surface temperature changes (red line) and the Sun's energy that Earth receives (yellow line) in watts (units of energy) per square meter since 1880.', 'Over the same period, global temperature has risen markedly.', 'It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century.', 'If a more active Sun caused the warming, scientists would expect warmer temperatures in all layers of the atmosphere.', 'Climate models that include solar irradiance changes can't reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.', 'The amount of infrared radiation energy a warmed object gives off depends on its temperature—the higher the temperature, the more energy is given off.', 'The amount of infrared radiation energy the Earth gives off depends on its temperature.', 'The average Earth temperature required for energy balance with the sun would be a frigid -18°C (0°F), if there were no atmospheric greenhouse effect.', 'The greenhouse effect has kept the Earth's average temperature a good deal higher for billions of years, making it possible for life as we know it to evolve.', 'Over the past several millennia the average Earth temperature has been about 15°C (59°F).', 'All gases whose molecules have three or more atoms are greenhouse gases—carbon dioxide (CO_2), water vapor (H_2O), and methane (CH_4) are important greenhouse gases that have maintained Earth's warm temperature for billions of years.', 'For several millennia—until the past two centuries—an average surface temperature of about 15°C kept the sun and Earth in energy balance.', 'The above graph compares global surface temperature changes (red line) and the Sun's energy received by Earth (yellow line) in watts (units of energy) per square meter since 1880.', 'Over the same period, global temperature has risen markedly.', 'It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century.', 'Warmer sea surface temperatures intensify tropical storm wind speeds, giving them the potential to deliver more damage if they make landfall.', 'Warmer sea temperatures also cause wetter hurricanes, with 10-15 percent more precipitation from storms projected.', 'Warming water temperature', 'Harmful algae usually bloom during the warm summer season or when water temperatures are warmer than usual.', 'Warmer temperatures prevent water from mixing, allowing algae to grow thicker and faster.', 'Global temperature', 'Rest of world temperature', 'UK temperature', 'Global temperature', 'Rest of world temperature', 'UK temperature', 'Global temperature', 'Rest of world temperature', 'UK temperature', 'From declining Arctic sea ice and record-breaking heatwaves to melting glaciers and worsening droughts, the increase in global average temperature is

being felt around the world.', 'The gradual increase in global temperature sees block after block removed from the tower and placed on top.', 'If the Greenland ice sheet were to pass a tipping point that led to its disintegration, simply reducing emissions and lowering global temperatures to pre-industrial levels would not bring it back again.', 'The IPCC's special report on 1.5C of warming, for example, concludes that while "it is very likely that the AMOC will weaken over the 21st century", there is "no evidence indicating significantly different amplitudes of AMOC weakening for 1.5C versus 2C of global warming, or of a shutdown of the AMOC at these global temperature thresholds".', ' "The whole North Atlantic ecosystem is adapted to the existence of this overturning circulation, which really sets the conditions – the seasonal cycle, the temperature, the nutrient conditions – in the North Atlantic, and so the intricate web of the Atlantic ecosystem will be substantially disrupted if allow such a massive change in the ocean circulation to happen."', 'In the Antarctic Peninsula, for example, research has shown that the collapse of the Larsen B ice shelf in 2002 was primarily driven by warm air temperatures.', 'A Nature Climate Change review paper published in 2018 concluded that "under sustained warming, a key threshold for survival of Antarctic ice shelves, and thus the stability of the ice sheet, seems to lie between 1.5 and 2C mean annual air temperature above present".', 'This temperature threshold refers to regional warming in Antarctica, rather than a global average figure.', 'By 2100, global temperatures are likely to rise by 1.3-1.9C above pre-industrial levels.', 'RCP4.5 is a "stabilisation scenario" where policies are put in place so atmospheric CO2 concentration levels off around the middle of the century, though temperatures do not stabilise before 2100.', 'By 2100, global temperatures are likely to rise by 2-3C above pre-industrial levels.', 'The likely range of global temperatures by 2100 for RCP8.5 is 4.0-6.1C above pre-industrial levels.', 'Model projections suggest this would be a result of "particular patterns of sea surface temperature (SST) change in the tropical Atlantic and Pacific", says Betts, but there is a lot of variation between models as to how strong the impact would be on the Amazon.', ' "It happens that the same model simulations show that if the so-called 'CO2 fertilisation effect' – as a basic input to photosynthesis, when atmospheric CO2 increases it theoretically enhances plant productivity – really exists and expresses itself in the Amazon, then it would counteract the bad effects of higher temperature and lower rainfall, leaving the forest basically the way it is now.'', 'The warm ocean temperatures reduced the temperature contrast between the continent in the hot summer and the cooler surrounding waters.', 'As land heats up faster than the water, rising global temperatures could strengthen the land-sea contrast that helps drive the WAM northwards each year.', 'It also notes that while there are "uncertain changes" associated with a 1.5C or 2C warmer world, it is "unlikely" that a tipping point would be reached that these temperature levels.', 'Even if a 3C temperature rise did bring significantly more beneficial rainfall to the region, the IPCC says "it should be noted that there would be significant offsets in the form of strong regional warming and related adverse impacts on crop yield, livestock mortality and human health under such low mitigation futures".', 'The IPCC's special report on the ocean and cryosphere in a changing climate ("SROCC"), for example, says that there is "very high confidence" that record high temperatures at ~10–20m depth in permafrost have been "documented at many long-term monitoring sites in the northern hemisphere circumpolar permafrost region".', 'In some places, these temperatures are 2-3C higher than 30 years ago.', 'In one study, a tipping point for this internal heat production occurred by the time local mean [absolute] annual air temperature reached around 1.2C, which is when organic decomposition

became significant in their model.', 'This is an ice-like substance formed when methane and water combine at low temperatures and moderate pressure .', ' "Atmospheric CO2 concentration is expected to exceed 500 parts per million (ppm) and global temperatures to rise by at least 2C by 2050 to 2100, values that significantly exceed those of at least the past 420,000 years during which most extant [i.e.', ' Recent years have seen a series of " mass bleaching " events in warm water corals, caused primarily by prolonged exposure to high sea temperatures.', 'These events were caused by marine heatwaves – extended periods of unusually high temperatures that were themselves boosted by human-caused warming and El Niño .', '(DHW is a measure of cumulative heat stress that "describes how much heat has accumulated in an area over the past 12 weeks by adding up any temperatures that exceed 1C above the maximum summertime mean".)', 'It is typical of ecosystems to show "threshold, rather than linear, responses to slowly building drivers of change such as fishing pressure, added nutrients and rising global temperatures", says another review paper .', ' In 2016, the first study to compare the widespread impacts of climate change at 1.5C and 2C of warming warned that 90% of tropical reefs would be "at risk of severe degradation due to temperature-induced bleaching from 2050 onwards" in a 1.5C warmer world.', 'And so, in theory, "anything which alters either the north-south temperature gradient, or the amount of moisture evaporated from the ocean, could change the monsoon rains", notes Turner.', 'Another is that climate models can struggle to simulate the monsoon system, in part because of the intricate interplay of circulation, temperature and topography that drives it.', 'They lie just to the south of the Arctic tundra, where tree growth is restricted by year-round freezing or near-freezing temperatures and a lack of rain.', 'Continued temperature rise could generate rapid changes in boreal forests, including dieback.', ' "I don't know that anyone has put a number on a species-specific tipping point, but we have high confidence that with global temperature increases of 1.5 or 2C, which in the boreal will translate into about double those temperature increases, we will see widespread changes in tree species composition and fire regimes."', 'The much talked-about paper , published as a perspective in PNAS , concludes that "the risk of tipping cascades could be significant at a 2C temperature rise and could increase sharply beyond that point".', ' It is getting warmer (a 3.4° F rise in average annual temperature over the last century) in Rocky Mountain National Park.', 'What does it mean to see a 3.4° F rise in average temperature?', 'Imagine climate change is like a fever – if your temperature went up 3.4° F, you would feel sick.', ' Alpine plants and animals may lose access to essential moisture due to earlier snowmelt in the spring and warmer temperatures in the summer.', ' Indigenous peoples in Africa's Kalahari Desert are forced to live around government drilled bores for water and depend on government support for their survival due to rising temperatures, dune expansion and increased wind speeds which have resulted in a loss of vegetation, and negatively impacted traditional cattle and goat farming practices.', ' Global temperature', ' Rest of world temperature', ' UK temperature', ' Global temperature', ' Rest of world temperature', ' UK temperature', ' Global temperature', ' Rest of world temperature', ' UK temperature', ' Global emissions and temperature', ' Paris temperature goal', ' The CAT rates India's climate targets and policies as "Highly insufficient", indicating that India's climate policies and commitments are not consistent with the Paris Agreement's 1.5°C temperature limit.', 'We rate this target against what India's fair share contribution under the Agreement should be and find it to be "Insufficient." The "Insufficient" rating indicates that India's emissions in 2030 needs

substantial improvements to be consistent with the Paris Agreement's 1.5°C temperature limit.', 'It said that it was only possible to reduce the rise in average global temperatures to between 1.5C and 2C – as set out in the 2015 Paris agreement – with “more urgent and shorter term measures”.']

science:

['Learn about the people behind NASA Earth science.', 'Test your knowledge of climate science.', '5702 p. 1686 DOI: 10.1126/science.1103618', ' Promoting excellence in science education and outreach', ' Explore the interesting world of science with articles, videos and more.', ' Earth system science is the study of how scientific data coming from various fields of research, such as the atmosphere, oceans, land ice, and others, fit together to form the current picture of our planet as a whole, including its changing climate.', '183-186, doi: 10.1126/science.1228729', ' According to a 2009 paper on the use of the term “tipping points” in climate science and the media, a presentation (pdf) in 2005 by Dr James Hansen of Columbia University’s Earth Institute helped “initiate a tipping point trend in climate change communication that was quickly reflected in public debate”.', 'For example, a Nature Geoscience review paper from 2011 notes:', ' It is worth noting that heat stress has the same destructive effect on seaweed, such as kelp, in temperate systems, says Dr Maria Beger , an academic fellow in marine conservation science at the University of Leeds .', ' Prof Scott Goetz from Northern Arizona University , who is science lead on NASA’s Arctic Boreal Vulnerability Experiment (ABOVE), explains to Carbon Brief how disturbances could cause forests to “tip”:', 'Volunteer to educate youth about science, improve science literacy across the country, and get involved in your local community.', ' Sign up for the Nature Briefing newsletter — what matters in science, free to your inbox daily.', ' Get the most important science stories of the day, free in your inbox.', ' Sign up for the Nature Briefing newsletter — what matters in science, free to your inbox daily.', ' Get the most important science stories of the day, free in your inbox.', 'Among them was Sophie Backsen, 22, an agricultural science student from the North Frisian island of Pellworm, on Germany’s North Sea coast, together with her younger brothers, Hannes, Paul and Jakob.']