OCEAN CRUISING CLUB®

Climate Change and Ocean Cruising

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CLIMATE CHANGE AND OCEAN CRUISING

Contents

FOREWORD
Simon Currin
Commodore, Ocean Cruising Club

The very essence of the Ocean Cruising Club is based on sailing the oceans of the world adventurously, enthusiastically, safely, sensitively, and in tune with the marine environment. Massive changes have taken place in technology, boat design, and construction since our Club was formed in 1954, enabling more people to sail the oceans. Yet, our ability to continue to do so is threatened on a scale and at a speed that was beyond the imagination of our founding members some 70 years ago.

The marine habitat is degrading through pollution from chemicals, plastics, and the extensive use of agricultural and horticultural nutrients. In turn, this is leading to species extinction and biodiversity loss. This is compounded by illegal fishing, overfishing, and careless and unnecessary bycatch. Some of the most evident degradation of the marine environment is witnessed in the damage and destruction of coral reefs. As cruisers, we all know that healthy coral reefs are teeming with life and many thousands of species depend on them for their continued existence. These vital habitats are threatened by a range of human activities and especially from the effects of acidification due to increased levels of carbon dioxide and rising sea temperatures.

Climate change is also impacting where and when we sail. The oceans are heating up and marine heatwaves are on the increase all around our world. Data from the National Oceanic and Atmospheric Administration (NOAA) shows that in April 2023 the average temperature at the ocean's surface was 21.1°C – the highest since records began.

Moreover, this is at a time when La Niña conditions have contributed to restricting temperature increases and to some extent mitigating the impact of greenhouse gas emissions. Yet, NOAA issued an El Niño watch in April 2023 signalling that La Niña conditions were at an end. If El Niño conditions do materialise then the risks of extreme weather events will increase.

Cruisers have been reporting disturbances in expected weather conditions over the last several years. Evidence from scientific research is continuing to emerge that backs up their observations. Present conditions mean that the effect of climate change is likely to be seen much more clearly.

The observations and reports of Ocean Cruising Club members and other cruisers led us to seek the views of leaders in the fields of weather forecasting, passage planning and weather routing on what impact global warming and climate change may be having on the oceans and how ocean cruising might be affected. The OCC has also published numerous articles here:

https://www.oceancruisingclub.org/environment

This review addresses these issues and contains suggestions about how ocean cruisers might deal with emerging challenges, continue to enjoy the freedom of the oceans, and cruise fascinating places.

Credits for front cover photo collage:

- Bleached coral: The Ocean Agency/Ocean Image Bank
- Plastic litter: Wikimedia Commons – Vberger
- Anchorage and image composition: Alex and Daria Blackwell, OCC

INTRODUCTION
Phil Heaton
Vice Commodore, Ocean Cruising Club

As the world continues to grapple with the devastating impacts of climate change, an often-overlooked area is the effect it has on ocean sailing. Although sailors have long been attuned to the natural rhythms and patterns of the sea, climate change appears to be causing significant disruptions to these systems, posing new challenges and risks to those who venture out on the open water.

According to the Intergovernmental Panel on Climate Change (IPCC), the world's oceans are becoming warmer, more acidic, and less oxygenated due to human-induced climate change. These changes not only have significant impacts on marine biodiversity and ecosystems but also affect ocean sailors and their safety. The Ocean Cruising Club whose members cruise the world's oceans has reached out to experts in weather forecasting, passage planning, and weather routing to find out what they make of the changes that are taking place, and what advice they can offer to cruising sailors.

As reported by the IPCC, the ocean's surface temperature has risen by about 0.8°C since the pre-industrial era. This warming trend is predicted to continue, with ocean surface temperatures projected to increase by 1.5°C to 4°C by the end of the 21st century. This increase in temperature affects ocean currents, wind patterns, and weather systems, creating more volatile and unpredictable conditions for sailors.

The changing and unpredictable wind patterns and ocean currents can make sailing more challenging. For example, warming ocean temperatures are causing shifts in the location and strength of subtropical high-pressure systems, altering the direction and intensity of trade winds. This not only affects the speed and direction of sailing but also impacts the movement and distribution of marine life.

Ocean acidification caused by the absorption of carbon dioxide (CO2) from the atmosphere is another significant challenge for ocean sailors. The IPCC has reported that the ocean has absorbed around 30% of the CO2 released by human activities, leading to a significant increase in acidification levels. This acidification has the potential to affect marine life, such as shellfish and coral reefs.

Additionally, the IPCC has warned that climate change can contribute to extreme weather events, including more frequent and intense storms, cyclones, hurricanes, and typhoons. These extreme weather events pose a significant threat to sailors, who risk encountering strong winds, high waves, and dangerous currents. As global warming continues, it is expected that the frequency and intensity of these storms will increase, requiring ocean sailors to pay even greater attention to safe passage planning and weather forecasting.

The IPCC emphasizes that urgent action is needed to reduce greenhouse gas emissions and limit global warming to below 2°C to prevent the worst impacts of climate change. As sailors, it is essential to practice sustainable sailing, reduce our carbon footprint, and raise awareness about the impacts of climate change on the ocean and our safety.

In response to these challenges, many sailors are taking steps to mitigate their impact on the environment and adapt to the changing conditions. Many are investing in more sustainable and energy-efficient boats, using alternative fuels, and reducing their carbon footprint in other ways. Some are also adopting new technologies and strategies to navigate changing ocean conditions, such as real-time weather tracking and forecasting.

The IPCC's reports on climate change and its impacts on the ocean highlight the urgency to take action to protect the marine environment and enhance safety for ocean sailors. The reports have shown that climate change is a significant threat that must be addressed through collective action and sustainable practices to ensure a safer and healthier future for ourselves and future generations.

In addition, the observations of cruisers and anecdotal evidence of climate change and its impact on ocean cruising and passage planning led the Ocean Cruising Club to ask experts in these fields and in weather forecasting and routing to share their views on what seems to be happening and what steps ocean cruisers should be taking to ensure continued safe and enjoyable ocean passages and cruises.

We publish here the perceptions of the impact of climate change on passage-making and weather routing of these experts:

Jimmy Cornell has influenced the contemporary cruising scene probably more than any other sailor. An accomplished sailor, public speaker, and author, he has sailed over 200,000 miles in all oceans of the world including three circumnavigations as well as voyages to Antarctica and the Northwest Passage.

Thousands of sailors have fulfilled their dream of blue water cruising with the help of Jimmy Cornell's books, among them the international bestseller World Cruising Routes. Now in its 9th edition, and with over 200,000 copies sold to date, this is one of the best-selling nautical publications in the world.

- www.cornellsailing.com
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Frank Singleton is renowned for the information and advice he has provided on weather for sailors. He is a longstanding member of the Royal Meteorological Society, from which he received an award for "Increasing the understanding of meteorology among the sailing community". He has also received awards from the Royal Cruising Club, the Royal Yachting Association, and the Cruising Association. He provides the major component of the MailASail Weather Window that gives quick and easy access to many forecasts.

- www.weather.mailasail.com/Franks-Weather/Home
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Fred Pickhardt of Ocean Weather Services provides global ocean weather forecasts and ship routing services to the maritime industry. Fred has 45+ years as a professional marine meteorologist with extensive experience in optimum ship routing. In addition, Ocean Weather Services experts provide accurate ocean storm and hurricane tracking services as well as professional marine meteorological research reports for admiralty lawyers and marine insurance companies.

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Sebastian Wache is a senior meteorologist at WetterWelt GmbH. He supports regatta crews worldwide, using special high-resolution models for pre-routing. He also assists anyone from beginners to professionals in any geographical location. WetterWelt produces highly individualised weather forecasts using constantly updated technology to generate high-precision weather analyses and forecasts, drawing on and refining a magnitude of raw data material from the world's best forecast models available.

- www.wetterwelt.de

- www.wetterwelt.de/en/contact/

An expert team at **Weather Routing Inc** comprising Meteorologist Jared Young, Assistant Operations Manager Ernesto Findlay, and Jeremy Davis, Director of Operations Yachting/Fishing Division. Yachtsmen worldwide rely on WRI to provide timely and accurate weather for trans-ocean crossings, coastal transits, area cruises, and day trips. Since 1961, Weather Routing, Inc. has established a reputation as the World Leader in Yacht Forecasting, combining the best of technology with experienced marine meteorologists to ensure vessels are kept safe by providing such as detailed, personalized World-Wide forecasts, heavy weather alerts and tropical surveillance.

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Bob McDavitt is based in New Zealand with over 40 years' experience as a meteorologist forecasting for marine, aviation, and the general media around New Zealand and in Fiji. He is a veteran from two campaigns for the America's Cup and has helped break records for crossing the Tasman Sea and circumnavigating NZ, and the vessels of Earth Race, Jessica Watson, Donna Lange, and Lisa Blair in circumnavigating the world. He provides weather advice for recreational yachts crossing the Pacific Ocean, helping with departure date planning, waypoints for the voyage and updates along the way.

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In addition, **Jon Bilger** of PredictWind has explained that their weather models do not use historical data, but they have a feature called "Local Knowledge" – www.predictwind.com/news/get-local-knowledge-with-predictwind/ - which uses a rolling 10 year average of climate data. As it is only the last 10 years, it is not affected by long-term climate averages that are often done over 30 years or longer. However, with concerns about climate change, PredictWind tools become even more valuable, especially using the departure planning tool:

- www.help.predictwind.com/en/articles/2884534-overview-of-departure-planning

I
Jimmy Cornell:
The effects of climate change on voyage planning

"Sailing routes depend primarily on weather, which changes little over the years. However, possibly as a result of the profound changes that have occurred in the ecological balance of the world environment, there have been several freak weather conditions in recent years. The most worrying aspect is that they are rarely predicted, occur in the wrong season and often in places where they have not been known before. Similarly, the violence of some tropical storms exceeds almost anything that has been experienced before. All we can do is heed those warnings, make sure that the seaworthiness of our boats is never in doubt and, whenever possible, limit our cruising to the safe seasons. Also, as the sailing community depends so much on the forces of nature, we should be the first in protecting the environment, and not contribute to its callous destruction."

Those words were written in 1994 in the foreword to the second edition of my book World Cruising Routes. I have been monitoring global weather conditions ever since and have used any relevant data to revise my various books. The latest research was carried out to update the Ocean Atlas, a compendium of pilot charts for the entire world, and World Voyage Planner, both produced in collaboration with my son Ivan. Our findings revealed an astonishing acceleration in the changes that have occurred in the global climate, even in the relatively short period of time since the previous editions were published.

In its sixth assessment on the impact of climate change published in 2022, the Intergovernmental Panel on Climate Change warns that climate change is having a severe impact on weather conditions throughout the world. These changes are affecting not just the global climate but sailing conditions in all the oceans.

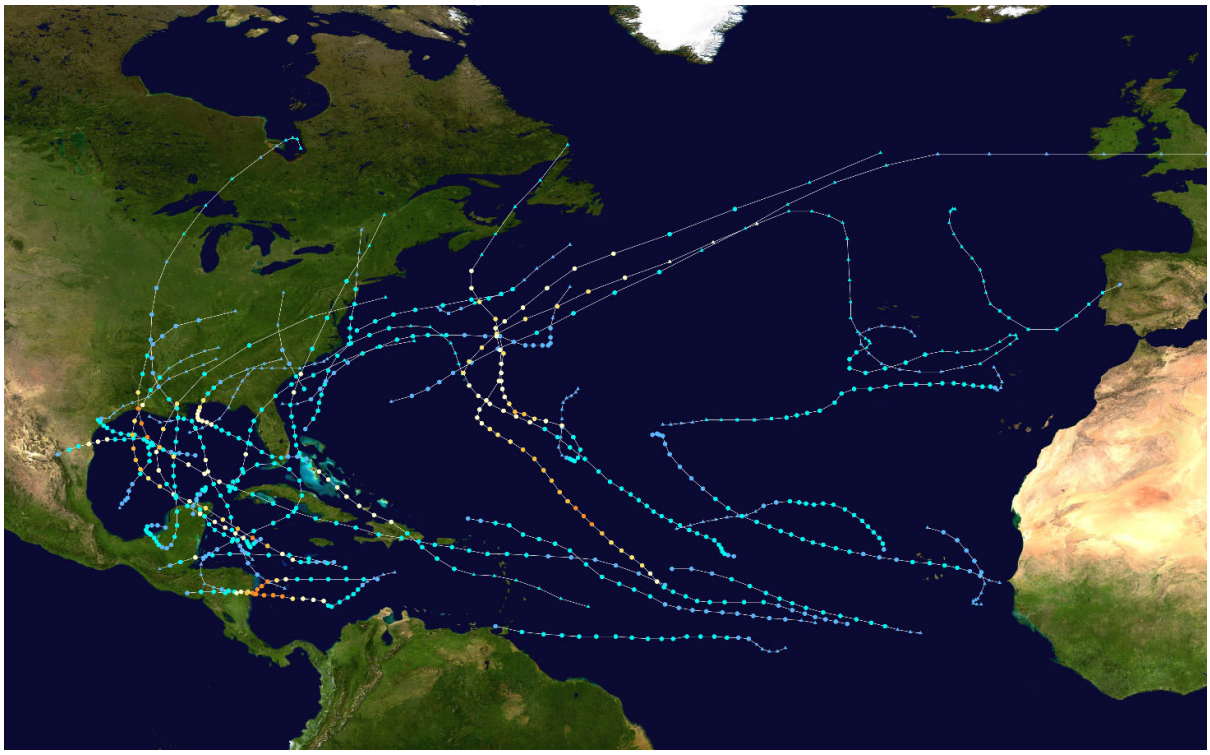
- The oceans are getting warmer and are affecting the constancy of prevailing winds.
- Tropical storm seasons are less clearly defined and becoming more active.
- Extra-seasonal tropical storms are more common.
- The Gulf Stream rate is slowing down.
- The Arctic icecap is melting at a faster rate than in any recorded time.
- The ice shelf surrounding Antarctica is also diminishing at an unprecedented rate.

According to a report published by the International Union for Conservation of Nature, the astonishing pace of warming in the oceans is the greatest hidden challenge of our generation, altering the distribution of marine species from microbes to whales, reducing fishing areas and spreading diseases to humans. This is the most comprehensive analysis yet of ocean warming. It states that if the oceans had not absorbed the enormous amount of heat due to escalating carbon emissions, the atmosphere would be 36 degrees warmer.

As a result, one of the most significant changes is the increased intensity and extent of tropical cyclones, both in the duration of the critical seasons and the areas affected. Another phenomenon, which directly affects offshore sailing, is the inconsistency of the trade winds in areas where they used to be a constant and reliable feature, as witnessed by sailors on some of the frequently travelled ocean routes. This is also believed to be a consequence of climate change. As the polar regions, and especially the Arctic, are getting warmer at a faster rate than the low latitudes due to global warming, the poleward temperature gradient is weakening and thereby affects both the strength and consistency of trade winds.

An immediate consequence of the warming of surface temperatures is the change in the behaviour of the jet streams resulting in reversed atmospheric air pressure patterns and decreasing strength of trade winds. The source of energy of the jet streams is the temperature gradient between subpolar and subtropical regions. Warmer ocean temperatures and higher sea levels are expected to magnify their impact and intensity. These conditions have resulted in the climate of the 21st century having much more heat energy in it. This means more extreme weather events in the form of stronger hurricanes, hotter heat waves, and more devastating droughts, wildfires and floods. The global climate has thus reached a state of instability that is caused by more available heat and having to find ways to redirect this added energy. Recent extreme events are the direct consequence of the global climate seeking to reach a new equilibrium.

Summary of 2020 hurricane season



As a sign of the intensification of climate change, the 2020 North Atlantic hurricane season was the most active since records began in 1851. Of the 30 tropical storms, 13 developed into hurricanes, and six intensified into super-hurricanes. In recent years several early hurricanes have occurred in May, while others have occurred in late November. Among the 88 hurricanes recorded in the last 11 years, six have occurred before the start of the officially accepted season (1 June to 30 November).

Similarly, in the Northeast Pacific, in the area between Mexico, Central America and Hawaii, the critical season is also expanding. Although the official hurricane season is from 15 May to 30 November, in the last 11 years among the 115 hurricanes recorded in that area five hurricanes developed in the first half of May. Among the late hurricanes, four have occurred in the second half of November.

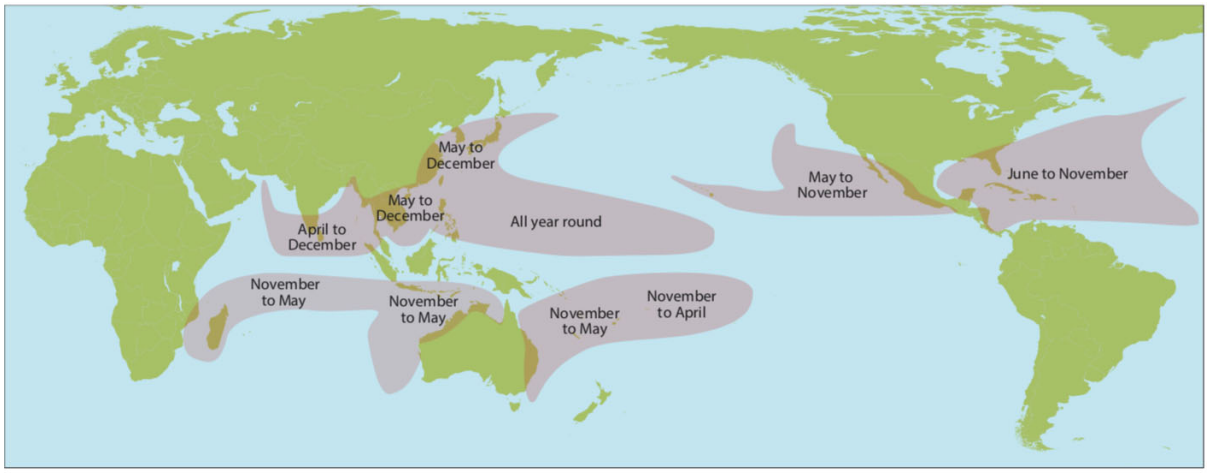
In the Northwest Pacific both the frequency and intensity of typhoons is also on the increase, with some super-typhoons having gusts of 200 knots. Typhoons have been recorded in every month of the year, with a well-defined safe typhoon-free season being absent in most years.

In the North Indian Ocean, the severity and destructive power of the cyclones has also intensified. Their extent has now reached as far west as the Horn of Africa and beyond.

The trend in the southern hemisphere points in the same direction. In the South Pacific the cyclone season now lasts longer, and in the Coral Sea extra-seasonal cyclones have been recorded as late as June, July and September – all months in the accepted safe season.

The South Indian Ocean is another area where tropical cyclones have increased in intensity and the seasons last longer. Cyclones are occurring earlier, with two recorded in October, and two extra-seasonal cyclones recorded in July and September. In the last ten years a total of 81 cyclones have affected that area, with a large proportion of the most intense storms being recorded in the last four years.

Global Tropical Storm Seasons



As the above examples are directly related to a changing climate, the safety factor in voyage planning is now even more important than in the past. The timing of the cyclone seasons is an essential factor in voyage planning and tropical storms are now occurring outside both the accepted timeframe and previously affected areas. These facts have a direct bearing on voyage planning and show the importance of not arriving in a hurricane-prone area too early in the accepted safe season and to leave it before its end. Such a precaution is recommended in any tropical area of the world.

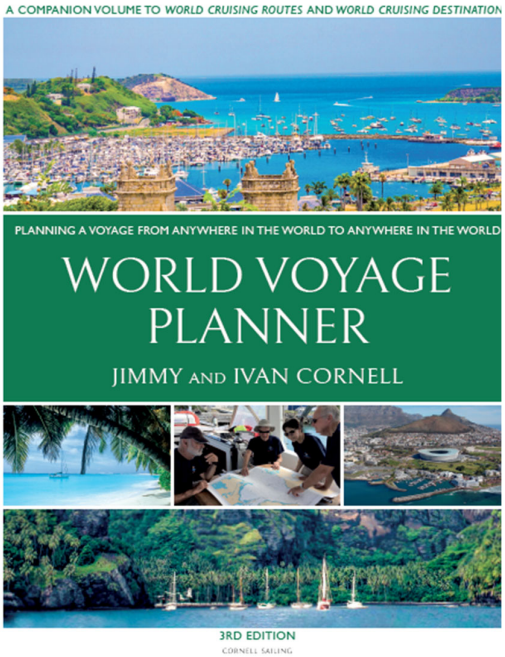
With careful planning, and by being aware of the consequences of climate change, tropical storm seasons and critical areas can still be avoided.

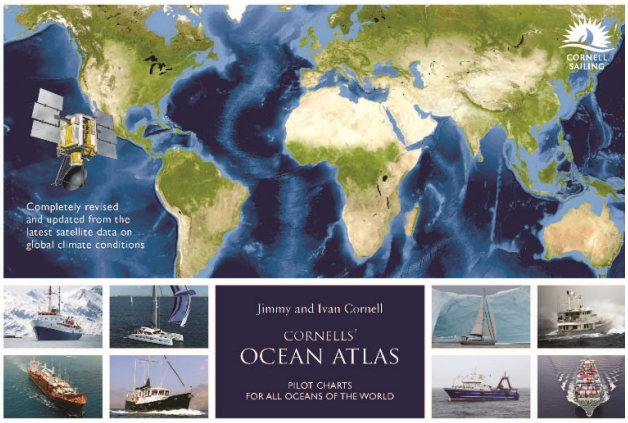
Bearing in mind the changed circumstances, these are the basic safety measures that should be adhered to when planning a voyage now or in the near future.

- Arriving in the tropics too close to the start of the cyclone-free season should be avoided, and a safe margin should be allowed by leaving a critical area before the end of the safe period.
- Cruising during the critical period in an area affected by tropical storms should be avoided. Those who plan to do so should monitor the weather carefully and make sure to be close to a place where shelter could be sought in an emergency.
- Those who decide to leave the boat unattended should make sure that their insurance company agrees with those plans.

Caution lies at the heart of voyage planning and by abiding by those precautions, as well as the greatly improved reliability of long-term weather forecasts, should still make it possible to plan a safe voyage even in these changing times.

Jimmy and Ivan Cornell's latest edition of World Voyage Planner was published in March 2023. The third edition of Cornells' Ocean Atlas, containing 160 pilot charts for all oceans of the world, is due for publication in May 2023.





II
Frank Singleton:
Climate change and cruising

Climate change

The natural changes in climate caused by long, slow changes in the earth's orbit and the much quicker man-made effects are well understood in general terms. There are good, clear descriptions on the UK Met Office and US NASA websites. As so often with weather, detail is highly variable and not always intuitively obvious.

In brief, the so-called Greenhouse Gases have increased greatly above pre-industrial levels causing an overall warming of the global climate. However, the atmosphere-ocean-cryosphere system is highly interactive so that detailed effects are inordinately complex and difficult to define unambiguously. To use Donald Rumsfeld's famous terminology there are few known knowns and many known unknowns. Three known knowns are that globally averaged sea levels, air and sea temperatures are all rising.

Sea levels

Being in an inter-glacial period, sea levels remained more or less constant for about 6,000 years but have been rising since the late 19th century. Over that period, the rate of rise has more than doubled. Sea levels, globally, are around 20cm higher than in 1900. Fairly conservative predictions are that by 2035 levels could be a further 6-10cm higher. That might not sound much but has to be considered in the light of low-lying islands or coasts and storm surges. Some Pacific islands are already close to being uninhabitable. In 2012, the cost of raising 150 miles of roads linking the Florida Keys was put at nearly US$2 billion.

Sea levels have risen due to melting of glaciers and icecaps plus thermal expansion of water. A third, contributory effect is that water shortages in populated areas have led to pumping up of groundwater which, after use, goes into the sea. Local variation can occur, such as tectonic plate movement causing the land to rise or fall. Melting of Greenland ice is reducing the gravitational pull-on seas around the Arctic so countering the expansion effect.

A known unknown is the Thwaite's glacier in the western Antarctic, about the size of Britain, and averaging about 1.5kkm depth. Unlike many other glaciers, it extends over the sea and, so, is being eroded by warming seas. It has broken away from the main ice sheet and is now moving slowly, if somewhat erratically, towards the ocean. Currently, it contributes about 4% of the total global meltwater. If it collapses, and some predictions suggest it could do so within 10 years, it would raise global sea levels by about 60cm. The whole of the west Antarctic ice sheet would then follow over the next 1000-2000 years raising sea levels by a few metres. If Thwaite's does not collapse, it will just carry on as one significant contributor to the general melting leading to a global sea level rise of up to 2metres by 2100.

Wet bulb temperature[1]

Another known known is the wet bulb temperature. With wet bulb temperatures near 35°C, the human body cannot perspire and death by heatstroke becomes likely. Over the sea, the wet bulb temperature

[1] The wet-bulb temperature (WBT) is the temperature read by a thermometer covered in water-soaked cloth over which air is passed. At 100% relative humidity, the wet-bulb temperature is equal to the air temperature (dry-bulb temperature); at lower humidity the wet-bulb temperature is lower than dry-bulb temperature because of evaporative cooling.

is limited by the sea temperature. The Persian Gulf is the only area where sea temperatures approach 35°C. So, over the oceans generally, wet bulb temperatures will be less than 35°C but the risk of encountering high temperatures with high humidity will increase. There are, already, coastal areas with short periods of dangerously high wet bulb temperatures. Parts of Florida and California are two examples. This will be an increasing danger. Some European and Mediterranean ports are already becoming uncomfortably hot and humid, if only for brief spells.

The first and, maybe, most obvious effect of global warming is the restriction in where we can go.

Sea surface temperature

The third known known is the effect of rising sea temperatures on the weather. This is particularly significant for the formation of tropical cyclones (or hurricanes and typhoons; meteorologically, they are synonymous). Their main source of energy is the release of latent heat when moist air rises and cools to give condensation. The warmer the sea, the more energy can be released thereby increasing the potential for severe storms. There is already some evidence of this happening. One of the high confidence predictions of the Intergovernmental Panel on Climate Change is the increasing risk of major tropical cyclones. It has been suggested that a further category, Category 6, is required on the Saffir-Simpson hurricane scale. Non-intuitively, there is low confidence in the prediction of total numbers of these storms. There might even be fewer tropical cyclones, but with a greater risk of major storms (>Cat 3).

A sea temperature of 26°C over a large area is a pre-requisite for tropical depressions to reach hurricane force. Warming seas will result in higher sea temperatures over wider areas and lasting longer. There is some evidence that tropical cyclone tracks are extending nearer the poles than in the past. There have always been some off-season tropical cyclones, but the risk could increase.

Extra tropical low-pressure systems also derive much of their energy from latent heat. Although no statistical data are yet available, it is reasonable to assume that there will be an increasing risk of severe storms. Another IPCC prediction is the increased likelihood of extreme weather.

Weather tracks

Interactions between the atmosphere and ocean are complex and there are few definitive statements that can be made about impacts likely to affect sailing. Changes in major ocean currents will probably occur and studies have shown that the Gulf Stream is weakening. This will lead to changes in tracks of Atlantic weather systems, but it is too soon to make positive statements about these effects. This is another known unknown.

Finally

No doubt, there are still some unknown unknowns, but the science is sufficiently sound to say that these may affect detail, perhaps only on regional scales. There is no reason to doubt our understanding of global climate change.

In the short term, bear in mind the increasing potential for strong winds, especially with tropical cyclones. Without air conditioning, give some thought to the possibility of heat stroke. For longer term planning, think about sea levels. That seemingly attractive berthing contract becomes less attractive with a small rise in sea levels.

III
Fred Pickhardt:
Will Climate Change Impact Cruise Planning?

Which Ocean Routes will be affected and how?

I don't believe that in the near-term (5-10 years) there will be any significant changes to routes due to climate change, except perhaps, opening up opportunities to explore more northern Arctic regions as sea ice during the late summer retreats farther.

In the southern hemisphere temperatures have not warmed as much as in the northern hemisphere, so little change is anticipated here.

Are long-established currents and winds being altered?

There have been conflicting studies about how climate change may affect ocean currents. Some studies make the claim that there is evidence that the currents are decreasing while others show evidence of an increase. There is little certainty here in the short-term.

As with currents, studies of wind speeds have also shown conflicting results. A recent study showed declines in surface winds over Europe between 1978 and 2010, while in 2019 another group of researchers found that since about 2010, global average wind speeds had actually increased slightly. Again, uncertainty here is also high.

At this point it is too early to conclude whether any observed changes are significant or are a result of natural variations or climate change.

Are there detectable changes already taking place that need to be taken into account?

The Arctic region has been warming faster than the equatorial region which suggests a gradual decrease in the temperature gradient between the pole and the equator. This suggests that there should be an overall slowing of the prevailing upper-level jet streams which would result in a wavier pattern increasing short-term regional temperature differences with more warm air intrusion into the Arctic and more Arctic air intrusions during winter into the mid-latitudes that could enhance winter storms. In the tropics there could be a slowing of the trade winds, however, there is little evidence so far, mostly due to a lack of long-term observations.

The most notable change is in the extent and volume of the summer Arctic Sea: the extent has been decreasing at an overall average rate of about 12% per decade, however, since about 2007, the average extent has been relatively flat.

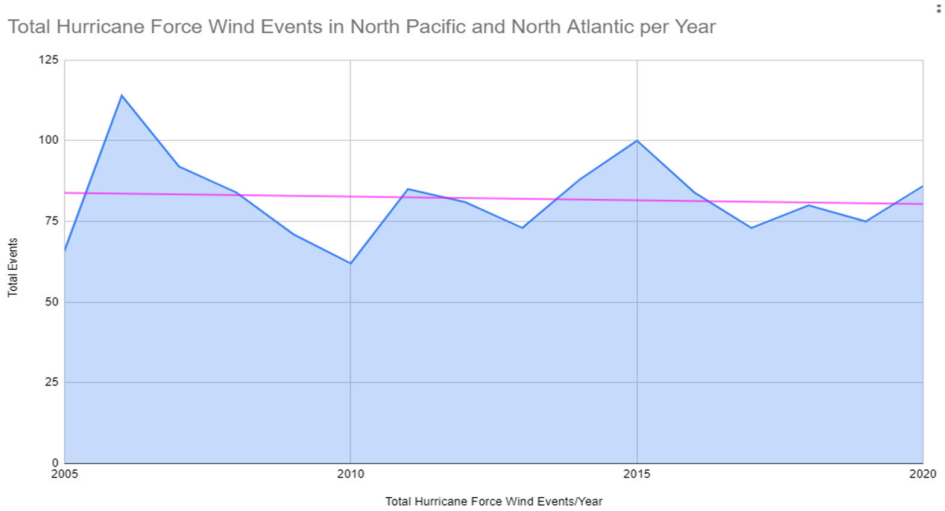
Are there environmental factors that are now less predictable than they once were and how might that affect how sailors think about long-distance passages?

Weather forecasts have vastly improved in recent decades and are likely to continue to improve over time. A modern five-day forecast is as accurate as a one-day forecast in 1980. Some believe that climate change will make predicting some aspects of weather more difficult, however, improvements in technology and forecasting skill should easily overcome this.

Are storm patterns changing and how might that affect where cruisers choose to sit out storm seasons?

Can't say if there has been any detectable change in storm patterns outside of a slight northward drift of latitude that tropical cyclones recurve. There has been no significant trend in global number of tropical cyclones or even major (Cat. 3-5) storms. There is some suggestion that rapid intensification of hurricanes may be increasing, however, that may be due solely to better observational methods.

There appears to be little change (since 2005) in the frequency of hurricane-force wind events over the North Pacific and North Atlantic oceans during the cold season extratropical storms months.



What changes do you anticipate occurring over the next 5 to 10 years?

I would not expect any significant changes in the next 5-10 years due to climate change. Temperature may increase very slightly, but not noticeably. Sea levels likely will increase by about 40-50 mm (1.5 to 2 inches) and also won't be very noticeable.

How are traditional seasonal passage plans being affected?

I don't expect any significant changes in traditional routes; however, more northerly summer routes may open up as sea ice retreats. Better communications and forecast accuracy should allow somewhat more flexibility in choosing routes or making changes while underway.

What changes in cruise planning should sailors anticipate?

I would think that improved forecasting and communication technologies will allow more flexibility with route options.

How to get the best out of weather forecasters and routers?

Good communication between the crew on board and the routers ashore will produce the best results. Make sure the routing service is aware of any special circumstances regarding the vessel and how it handles in various weather conditions as well as the safe limits for wind and sea conditions. Also let them know how open you are to alternate routes or possible diversions if significant weather changes present an issue.

IV
Sebastian Wache:
Weather change in weather routing

The weather system is very complex, but meanwhile also very well understood. It is therefore also clear that humans have been intervening in weather patterns since industrialisation with the burning of fossil fuels. To be more precise, this is a long-term process. So here we are looking at climate, which is nothing other than the statistics of weather.

On long scales, we can already see that it is getting warmer globally. The greenhouse effect, which is what makes life on Earth possible in the first place, is intensified by the increase in greenhouse gases in the atmosphere. The fact that we have been burning materials for more than 150 years is therefore changing the climate. But in the meantime, we are also interfering with all day weather. With a wide variety of effects on the regions of the earth.

Even the oceans and the popular sailing routes and areas are not exempt from this. But you have to understand what exactly is happening. Assuming global warming, it affects the polar latitudes harder than the tropics, for example. And so, we see a continuous decrease of the ice surface in the Arctic. If there is less ice or snow there, then the sun's reflection is no longer as high. Dark surfaces absorb more heat. So, it gets warmer there. Normally, we need cold poles and warm tropical regions. This is because these strong contrasts drive the so-called jet stream, a strong wind band at about 60°N, which normally blows from west to east. It is true that the wind band occasionally takes on wave patterns, transporting warm air masses to the north and cold air to the south. But these waves (Rossby waves) regularly dissipate again and then we have the typically west-east flow again. But due to the warming of the poles, the temperature contrasts are weaker. Thus, the jet stream is not always necessarily as strong and tends more towards these wave patterns. If a region is under a wave that tends to the north, then it lies in a so-called ridge and warm air can accumulate underneath. A high-pressure area forms, which often remains very stable for a long time in one and the same place. It blocks low-pressure areas that have to move north and south. And we are seeing these so-called blocking phases more and more frequently, especially in the last 5 to 10 years.

This also has an impact on regions that lie further south than 60°N. Because lows, which are thus also deflected to the south, sometimes make it to 30°N and even further south with their bad weather zones. And the further south the cold air from the north penetrates, the more intense the weather there becomes. This is because an unstable stratification forms in the atmosphere. Cold air at high altitude is transported with the low pressure to warmer regions. And this warm air is then below the cold air (e.g. warm water or land masses). This triggers bigger cumulus clouds with powerful showers and thunderstorms, as well as storms. Often with severe weather potential. And this is where climate change comes into play again. For every degree of temperature increase in the atmosphere, 7% more water vapour can be absorbed into the air.

Water vapour is an energy carrier. If this energy is "let out" through such weather patterns, there will be massive storms with heavy rain, flooding, storms, and so on. And as long as the high continues to lie stably in place, lows are produced on its edges at the same time, which also cannot leave there. So, we see that climate change is already having a massive impact on our weather and thus weather extremes (too dry in one place, too wet with storms in another). And since the oceans in particular also absorb a huge amount of excess heat from the atmosphere, but at the same time also interact with the atmosphere and thus influence the weather, changes are also to be expected here. Warmer water evaporates more moisture. More water vapour and more energy enter the atmosphere. At the same

time, differences in salinity and temperature drive global ocean currents. Here, too, changes in currents are to be expected, although not as immediately as we are currently seeing in the weather.

Nevertheless, with the melt water from the cold Greenland Ice Sheet or the Antarctic, it must be assumed that, in addition to the temperature differences, an increase in fresh water also disturbs the salinity differences and thus exerts a considerable influence on the ocean currents. Calculations show, for example, a weakening of the North Atlantic Current.

As there are currently no major influences on the tropical regions, weather conditions here are likely to remain fairly normal despite the climate change. Therefore, the Barefoot Route[2] is still the least affected. But away from it, with each degree of latitude more, we are already seeing significant changes. For the wind and weather patterns, as you may still know them from books or pilot charts, are now subject to ever greater fluctuations. Nevertheless, they are not yet so great that the global circulation collapses.

As long as the earth rotates, there will continue to be trade winds and westerly winds in the higher latitudes. But it is precisely these long wave blocking phases that cause disturbances in the wind field and thus also in the weather pattern. For example, at the ARC Atlantic Rally for Cruisers, I have been experiencing a frequently disturbed trade wind for years now. It may be a coincidence that this happens exactly at the start phase in the last few years because the trade wind usually regenerates again. But I also accompany countless yachts across the Atlantic away from the ARC and here, too, we have to pay more and more attention to suitable weather windows while routing, because the trade winds at the height of the Canaries are now being disturbed more often, and that is just one example.

Based on the aforementioned blocking phases with a huge stationary high, this also has an impact on other regions. In autumn 2022, such a very stable situation over Central Europe ensured that lows repeatedly penetrated the Bay of Biscay for weeks and caused high waves and storms there. Sailors did not come out of their marinas for weeks to get to the Canaries. Another example is in the summer, in the middle of the main sailing season. If such a high pressure lies over the North and Baltic Seas in July or August, for example, there is often no wind for sailing for a long time. Thermals are hardly an issue then either, because they also need warm land and cold water. And that becomes difficult when the water is already over 20 degrees and is often as warm as the air. The year 2018 and also 2022 were characterised by too little wind in these regions.

At the same time, the low-pressure systems elsewhere provide a much higher potential for destruction, such as on Corsica in 2022 or Mallorca in 2023, to name just a few examples. This shows what higher global temperatures bring with them in terms of energy.

Tropical storms are also part of this. They are also low-pressure systems that get their energy from the warmth of the air and especially the water. And here Hurricane Ian 2022 showed us what it was capable of doing in Florida. Although the number of tropical cyclones is not increasing, but the intensity of the systems can now be far greater.

Now this all sounds very dramatic, and in a sense it is. But we weather forecasters and sailors have to deal with it. And to take something positive out of all the negative, one could say that it is almost getting a little easier with weather planning for the cruisers. Because the weather conditions become more stable, due to the formation of Rossby Waves in the high-altitude stream, and so easier to predict, at least in the longer-term prediction. However, since sailors' knowledge of the weather and

[2] The classic barefoot route runs from east to west along the equator: from Europe via the Canary Islands, the Caribbean, through the Panama Canal, Galapagos, South Pacific to Australia and New Zealand, Indonesia, and Suez Canal to the Mediterranean.

their assessment of the upcoming conditions is not as pronounced as that of us weather forecasters, it is therefore only easier on paper. In addition, even the weather models have not necessarily adjusted to the new intensities. Taking the example of the severe weather situation on Corsica in 2022, it was not clear until shortly beforehand that such a situation would occur. The strength of the gusts with over 80 knots was underestimated by all models. One model came closest to reality with just 50 to 60 knots.

In principle, it is important to update weather data regularly, even during stable blocking phases. If possible, you should update the data twice a day so that you can plan in good time if a dangerous weather situation appears on the horizon. Even if you are in port, it is important to always keep an eye on the weather. At least to take a look at how the situation will develop in the next 7 days. With today's maps on the internet, that's a maximum of 3-4 minutes of time that you have to spend on it during the day.

If you are planning a longer journey across different oceans, then the planning should first be the same as before. Familiarise yourself with the global wind and current circulation. First of all, you should know how winds develop and where they normally blow. You can also use pilot charts for this purpose, but you should be careful and not rely too much on the wind statistics because in the end it always depends on the weather situation on site, which these statistics do not necessarily show. This also shows why my webinars for sailors are so well attended and why weather routers are requested more and more often. Crews are very uncertain about the weather, and it increases when they suddenly can't find the weather from the statistics on the spot. This may not be so dramatic for a crew that has a lot of time. They simply wait for the next weather window, but if the yacht has been chartered or it is a transfer, then there is often time pressure or deadlines that have to be met. Then the changing weather patterns can be a big problem.

During the Medicane (Mediterranean Hurricane in the Ionian Sea 2020), I received a lot of requests, especially from charter sailors, about where to go to avoid the storm. They had to leave the base ports, too, because they were threatened by the storm. I sent a lot of crews to Corfu at that time, as they were safe there. The development of this storm, however, could be seen quite early. You can rely very well on weather models even in such changed times. You just have to look at them very often, maybe even more often than before.

In the meantime, however, I see a development among sailors in this direction. Whether it's Ventusky, Windy, WXcharts or others, these are all websites that display weather in a very user-friendly way without requiring a degree in meteorology. Understanding and watching weather has become very much easier, and more and more people are becoming enthusiastic about it. From my point of view, a very positive development. Consequently, we weather routers are now asked detailed questions. Also, because these highly complex displays cannot be shown on the open ocean. Starlink may bring a breakthrough for very fast internet on board.

The influence on cruise planning is therefore already in full swing. At weather seminars in sailing clubs, I also notice how the younger generation in particular, but also many of the older ones, are getting to grips with the new-fangled possibilities. And this is immediately the change of direction in cruise planning. Due to the change in global weather patterns, there will (have to) be more short-term planning in the future. If I plan today for next year's summer, of course I don't know what I'll be facing. If I have time, I simply postpone for 2 or 3 weeks. If I'm tied to my time frame, I might be threatened by a stable weather situation that can become extreme and thus not fun or even dangerous. That's why I see a trend towards more last-minute holidays. I look at the weather development of the next 10 to 14 days and then book quite spontaneously. I also see this development among crews.

For long cruises, such as across the Atlantic, the classic seasons remain. In autumn we head for the Caribbean and in spring we return to Europe. Here, the hurricane season continues to steer the sailing season, but here, too, it has become apparent in recent years that there are "new" influences of global warming.

For the years 2017 to 2020 (2017 Hurricane Ophelia, 2018 Tropical Storm Pablo, Tropical Storm 2020 Theta) have shown what too warm water in autumn can lead to. Cold air masses from the north met water that was still too warm on the Atlantic and thus lows could form into tropical storms and even hurricanes in regions where they normally do not form at all. Near the Azores, Madeira and the Canary Islands, eddies of enormous strength suddenly appeared, which are completely untypical for the season and region. Even Portugal, Spain and Ireland were very afraid of getting the full force of these storms. Fortunately, they weakened considerably or did not hit the land masses of these countries at all. However, this is a new quality in weather development in the autumn phase. Again, we see that such storms do enter the statistics, but if they only appear on one day of the year in one of the quadrants of the pilot charts and then move on to the next, they do not stand out in the statistics. Thus, it is even more important to know what can theoretically happen in a given season and then look at the actual weather data to identify or eliminate all hazards. Regular work with weather is therefore a must. We routers and weather experts are happy to help with this, either through on-site training, webinars or even routings on the road, especially for a better understanding in weather and developments.

V
Jared Young, Ernesto Findlay, and Jeremy Davis: The Effects of Climate Change on Cruise Planning

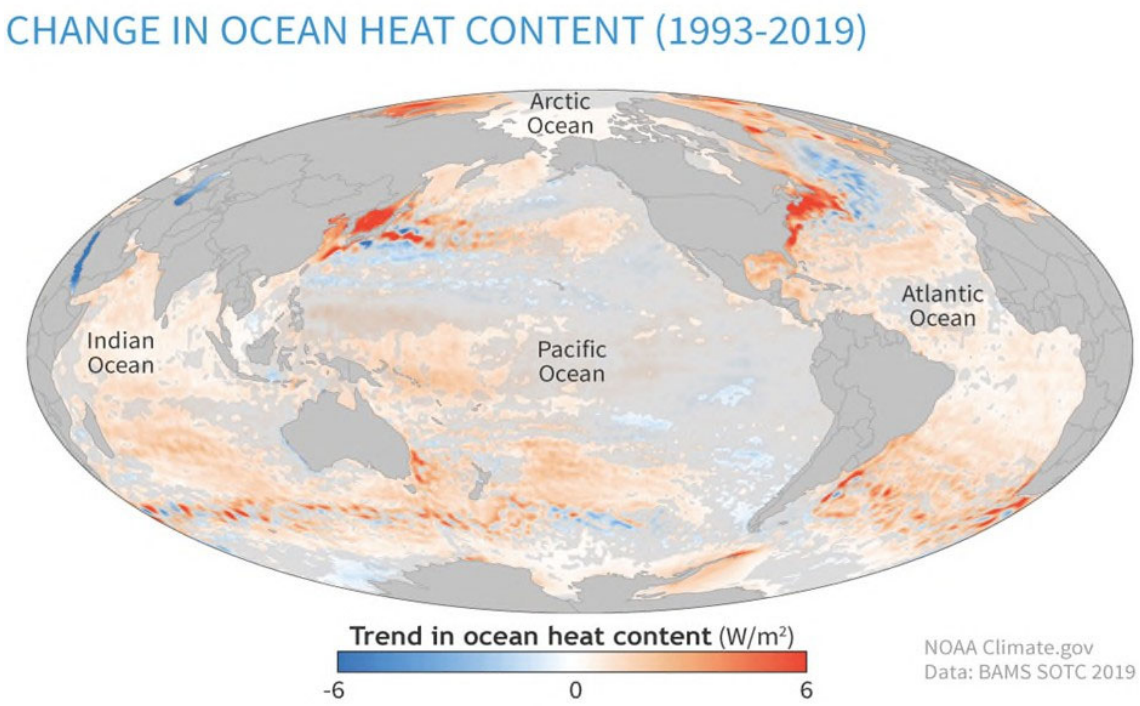
Our planet is warming. According to an analysis produced by NASA, 2022 ranked as the fifth warmest year on record. Arctic sea ice has been melting at alarming rates, causing sea level rise and rapidly increasing frequencies of coastal flooding along the Eastern United States. Tropical cyclones are also becoming stronger in regions such as the North Atlantic and Southwest Pacific, while more extreme monsoonal seasons have led to increasing amounts of coastal flooding along Southern Asia.

Many of these changes to long-established patterns are crucial when it comes to cruise planning, and the cruising industry has certainly been affected as a result. When reviewing recent climate analyses and comparing historical storm data, these changes are rather evident and have certainly influenced seasonal patterns which cruisers heavily rely on when planning out their routes and passages. Furthermore, we also expect these changes to continue well into the future.

Known Impacts

Atlantic Meridional Overturning Circulation (AMOC)

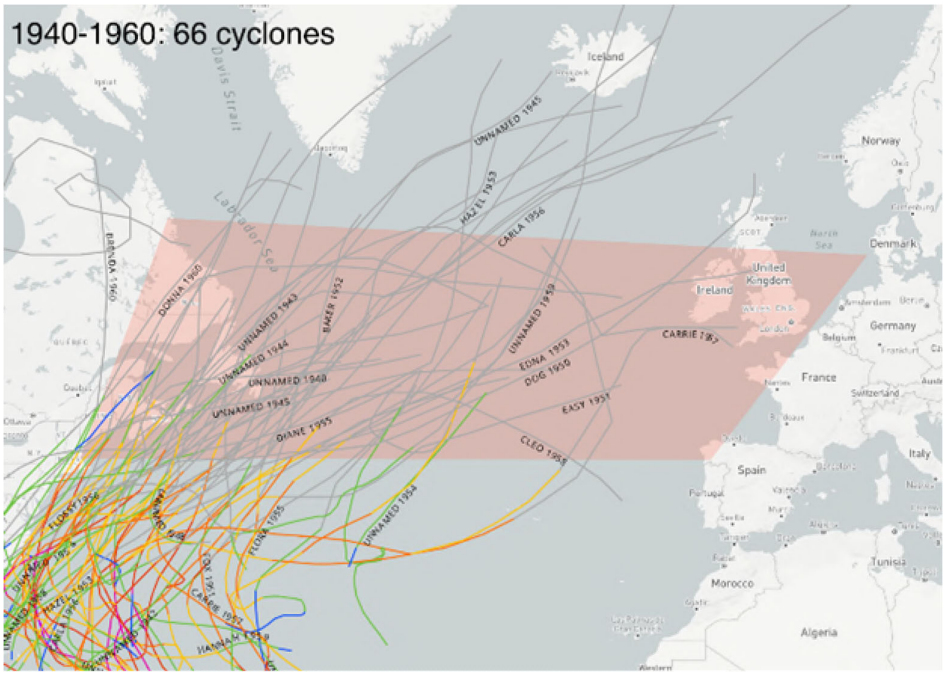
Long-established currents such as the Atlantic Meridional Overturning Circulation (AMOC) have been significantly affected by climate change, and according to recent studies the AMOC has weakened by about 15% since the mid-20th century due to recent melting in the Greenland ice sheet. As freshwater flows into the North Atlantic and weakens overturning within the AMOC warm water transported from the Equator tends to build in pools, ultimately resulting in warming sea surface temperatures across the subtropical latitudes (See next figure). This warming across the subtropics is rather important for cruise planning because recent studies have linked this warming to a recent poleward shift in average storm tracks.



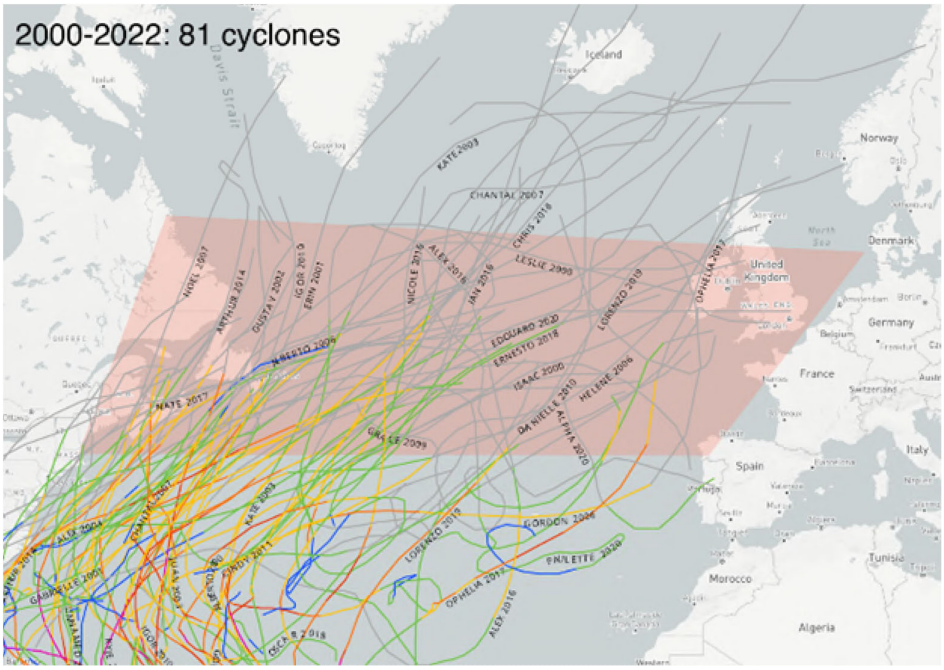
Heat content trends in the upper 700 meters (2,300 feet) of the world ocean shows where the oceans gained or lost heat between 1993 and 2019. Large parts of most ocean basins are gaining heat (orange)—and the global average trend is positive—but some areas have lost heat. Places with gray shading have trends that are not statistically significant. Courtesy of NOAA.

Tropical Seasons and Storm Tracks

When temperatures increase across the subtropics, temperature gradients across the mid-latitudes weaken considerably. This weakened temperature gradient has been linked to a recent poleward shift in storm tracks across both hemispheres. After evaluating two 20-year spans of historical tropical and extratropical cyclone tracks from NOAA, stronger systems have certainly had the ability to lift farther north in recent years. Between 1940-1960, there were 66 recorded tropical and extratropical cyclones in the higher latitudes of the North Atlantic. As shown in the following two figures, between 2000-2020 this number increased to 81. Additionally, these systems were maintaining tropical characteristics at latitudes much higher than previously due to abnormally warm sea surface temperatures across subtropical waters. There have also been early signs that climate change is affecting the ability for tropical cyclones to form in areas previously not expected. In January of 2022, satellite imagery and ASCAT data confirmed that a low-pressure system was able to sustain some tropical characteristics in the Eastern South Pacific basin, which has never been recorded before in the basin's history.



Historical cyclone tracks in the North Atlantic between 1940 and 1960. Image Courtesy of NOAA/NCEI.



Historical cyclone tracks in the North Atlantic between 2000 and 2020. Note the recent increase in both extratropical and tropical cyclones within the boxed region. Images Courtesy of NOAA/NCEI.

Studies have also shown that the recent increase in the intensity of hurricanes in the North Atlantic basin has been linked to warming sea surface temperatures in the Western Atlantic, Caribbean Sea and Gulf of Mexico. Tropical disturbances and lows which move over these warm waters can rapidly strengthen as they track through the Caribbean and/or Gulf of Mexico toward the coastal United States. For cruisers, this means that finding safe shelter from hazardous storm surge and stronger winds becomes increasingly important in popular boating areas such as the Bahamas, especially when many marinas will ask boats to leave if an intensity threshold is reached. As these thresholds become more commonly reached, this can lead to more stressful situations when marinas

fill up rather quickly. Similarly, abnormally warm sea surface temperatures in the Mediterranean Sea have led to stronger Mediterranean cyclones. When North Atlantic low- pressure systems track into the Mediterranean Sea, warming sea surface temperatures have allowed these systems to strengthen more rapidly as they track toward popular cruising areas across the central Mediterranean.

Monsoonal Patterns

For cruise planning in the Indian Ocean and Southeast Asia, warming sea surface temperatures have also been affecting monsoonal patterns. As these monsoonal patterns become more erratic and rainfall rates increase, coastal flooding has become more common throughout regions such as the Philippines and Indonesia. Cruisers must be wary about this not only while navigating these harsher waters, but also while choosing marinas and anchorages where they choose to store their vessels. As these events become more erratic, planning seasonal passages between peaks in these monsoonal seasons becomes much more crucial as well so that cruisers may comfortably make their crossings without encountering unfavourable conditions while underway.

The various by-products of climate change have already begun to affect routes used by cruisers for many years. Changes in the duration and intensities of seasonal weather patterns across the globe have led to overlapping with typical seasonal passages around the world. While increasing accuracy in long term forecasting has certainly improved the ability for captains to plan passages, this overlapping has faced many cruisers with frequent complications such as longer delays and less intuitive routing to ensure the safety of the vessel and crew while navigating these stronger systems.

Predictability and What the Future Holds

Storm Tracks

We expect the warming trend on the current climate to continue over the next 5-10 years. In a recent study performed by Chemke et al 2012 it was found that the frequency of storms is expected to shift poleward in both hemisphere, and this is more evident in the Southern Hemisphere, where the melting ice over the Antarctic Continent will lead to a poleward retreat of the ice caps. This poleward shift in the ice caps will lead to the poleward shift of the temperature contrast which fuel storm systems.

The poleward shift of storm tracks may allow for farther north routing during trans ocean season as storms are expected to be farther north and weaker. In addition, this shift allows for less frequent and weaker storms in the Mediterranean Sea. This will allow for more favourable weather during summer months for the chartering season and a more favourable location to sit out during hurricane season. Furthermore, the poleward shift on storm tracks along southern Australia will allow for more favourable weather during the summer months in this region.

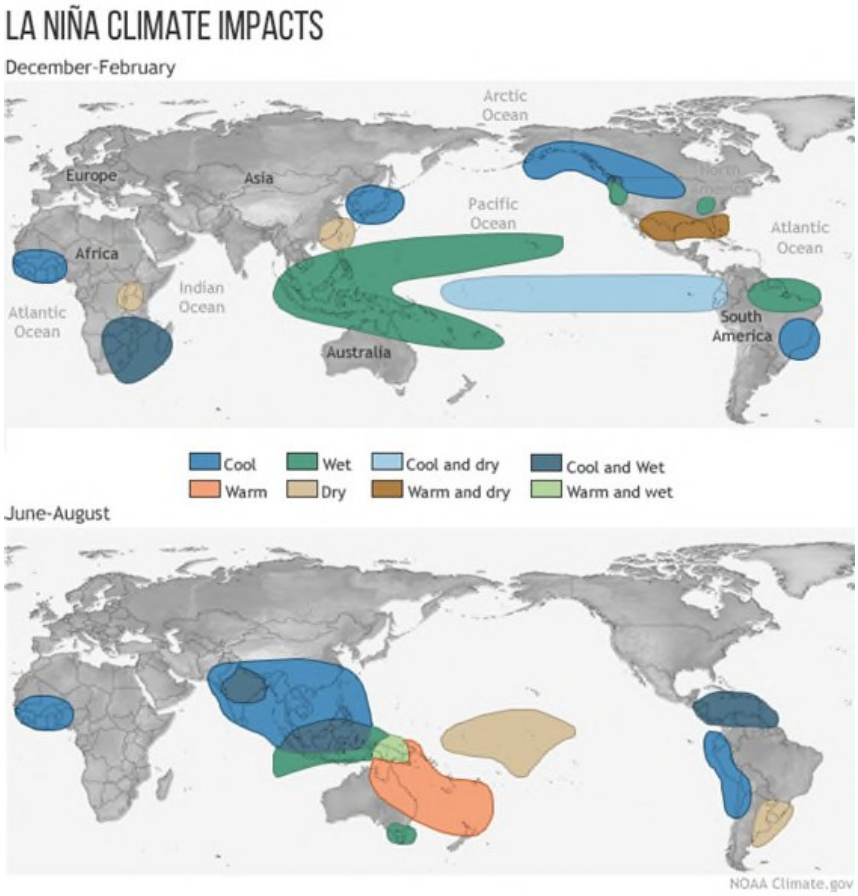
Warming Ocean

Warming ocean trends are expected to continue over the coming decades, and warmer sea surface temperatures across the middle latitudes will lead to longer hurricane seasons due to a larger area with favourable sea surface temperature. These longer seasons may affect timing of trans ocean season by having more early and late season tropical cyclones. In addition, tropical cyclones tracking farther north along the Eastern United States will affect the cruising season along the East Coast of the United States.

Predictability factors

One of the main sources of year-to-year variability in the world's climate is the El Niño Southern Oscillation (ENSO), which has strong effects on the storm patterns over the entire globe. These patterns are well defined for each phase. Fig.4 shows the effect of La Niña phase on the world's climate. These patterns are much better defined when each phase of ENSO lasts for 1-2 years, however, in the recent climate we have seen an increase on the length of ENSO. This increase in the length of each phase of ENSO makes the above patterns more unpredictable the longer each phase lasts. A good example of this is current La Niña event which has lasted 3 years. In a usual event California remains dry, however, this year has been nearly a record-breaking wet year for the state of California. This is contrary to what would be expected during La Niña.

Therefore, in a warmer climate an increase of this type of long duration El Niño /La Niña may make the expected patterns during these events more unpredictable.



Typical weather anomalies during a La Nina episode for December, January and February on top and June, July and August on the bottom. Courtesy of NOAA.

Weather Sources - How can we help?

It is easy for the day-to-day person to look at a weather models and make a routing decision from numbers that are being shown in a map, however, what is shown in a weather model is one of the many potential scenarios that may occur for any given location. This is where meteorologists come in, we utilize our knowledge of weather patterns, and past experiences to forecast the future.

For example, a mariner is planning a trans ocean voyage across the Atlantic and they see a storm is expected to affect their transit a week into their trip. The mariner has used one source of data, where meteorologists can diagnosis multiple model sources and real-time data to evaluate the likelihood of this storm occurring. In addition, this storm is a week out which means that data this far out has low confidence in occurring, nevertheless, we can use our knowledge of weather patterns and past experiences to diagnose if this storm is likely to occur.

In conclusion, meteorologists provide the "human element" that weather models can't provide. We can assist mariners in the interpretation of the data provided by the model to aid in making decisions regarding routing options to make their trip as pleasant as possible.

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VI
Bob McDavitt:
Climate Change and Cruise Planning

There are many unknowns at this time.

The route that is being most affected will be around the Northwest passage of Canada, allowing safe passage from North Pacific into the North Atlantic. These routes are opening now.

Long-established currents and winds are being altered in a slow way. There are environmental factors that are now less predictable than they once were. The atmosphere tends to somehow move the extra heat energy it picks up from place-to-place generating storms 'downstream'. The parameters we watch to follow these trends are ENSO[3], MJO[4], AO[5] and SAM[6] but these may be becoming more erratic.

Storm patterns may be changing in that if there is more energy available then a tropical storm can become more powerful. However, tropical cyclones can only form at a certain rate and the atmosphere needs to 'reset' between them.

In the next few decades, we should be able to see the impact of climate change on the subtropical ridges which circle the planet at around 30 degrees latitude. These zones are where our larger anticyclones form and thus where the earth's main dry zones occur. These subtropical ridges already have an annual cycle due to our solar orbit, drifting north from March to September and south from September to March. In the northern hemisphere the subtropical ridge crosses Eurasia, making the monsoons, and they impact the tropics. There are some quasi-stationary anticyclones in the Eastern Pacific and in the Atlantic (so dependable they have been named), but elsewhere there are mobile anticyclones that come and go.

My personal opinion is that over the past 40 years the highs are getting higher, and it seems to me that Highs with a central pressure over 1036hPa are becoming more frequent. The depressions seem to be much the same as they were 40 years ago, but with higher Highs we have closer isobars and thus stronger squash zones (where the isobars are squeezed together) and thus more frequent gales. Squash zones are the bane of a cruising sailor, so the news is not good.

However, there is at present no detectable change that might affect traditional seasonal passage plans - the earth continues to orbit the sun much the same as it has in the past.

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[3] El Niño–Southern Oscillation is a large-scale climatic phenomenon that originates in the tropical Pacific but affects global climate patterns. The warm phase is known as El Niño, and the cold phase is La Niña. El Niño occurs irregularly every two to seven years and peaks in winter.

[4] Madden - Julian Oscillation is the largest element of the intraseasonal (30- to 90-day) variability in the tropical atmosphere, a large-scale coupling between atmospheric circulation and tropical deep atmospheric convection.

[5] Arctic Oscillation or Northern Annular Mode/Northern Hemisphere Annular Mode (NAM) is a weather phenomenon at the Arctic pole north of 20 degrees latitude. It is an important mode of climate variability for the Northern Hemisphere.)

[6] The Southern Annular Mode (SAM), also known as the Antarctic Oscillation (AAO), is the southern hemisphere analogue to the Arctic Oscillation and describes the north–south movement of the westerly wind belt that circles Antarctica, dominating the middle to higher latitudes of the southern hemisphere.

VII
Afterword
Simon Currin, Commodore Ocean Cruising Club

I wish to thank all the contributors for taking the time to share their knowledge and experience with us. We hope that readers will have found their views and observations to be extremely valuable whether you determine to stick with the established advice or make adjustments such as avoiding the outer limits of traditional sailing seasons.

Sailors are in the enviable position of being able to take to the seas, cross oceans, and explore remote, interesting and, in some parts, places that are virtually untouched by human beings, albeit there is increasing evidence of plastic pollution reaching the whole of our world.

Having reliable information about weather is a vital part of being safe at sea and we have long relied on the historical records of vessels sailing the oceans to guide us in determining safe routes and safe seasons. At present we appear to be in a period of transition, and the rate of change continues to be explored by scientists and, indeed, debated. However, I commend the advice from our contributors because sailors being independent-minded and adventurous folk will ultimately make their own decisions and plans. After all, it is the skipper's responsibility to make decisions to keep vessel and crew safe and well.

The review has been undertaken at a point in time – early 2023 – and it is the intention of the OCC to revisit it in the future. At the same time, I encourage anyone with expertise in the fields of weather forecasting, passage planning, and weather routing to share their thoughts and observations with us. Our contact is: environment@oceancruisingclub.org

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