The Chaucer White Papers

Oceanographic climate change

The impact of ocean-based climate change trends

chaucer
A China Re Company

Climate change is one of the most pressing issues for our planet.

However, it is a vast and complex subject that requires segmentation and structuring before attempting to analyse it in any meaningful way.

We have taken a science-led approach to exploring how existing climate change trends are impacting a subset of our customers and the broader (re)insurance industry. This white paper focuses on how oceanographic climate change trends are affecting the offshore energy and marine sectors, and what we believe this means for the (re)insurance industry.

This paper will:

— Stage 1
Introduce seven oceanographic climate change trends happening now that have been identified by our Catastrophe Research Team

— Stage 2
Provide our thoughts on the impact of these trends on the offshore energy and marine sectors

— Stage 3
Outline what we believe are the implications for the (re)insurance industry

Oceanographic Climate Change trends happening now

7TRENDS

1. Tropical cyclones are changing
2. Extreme weather is worsening
3. More winter storms in new areas
4. Sea levels are rising
5. The salinity of our oceans is changing
6. Larger waves
7. Coastal erosion

'To untangle practical ideas from academic theory, we narrowed our focus to only oceanographic climate change trends that we can prove are happening now.'

Dana Foley
Head of Catastrophe Research at Chaucer

1 Tropical cyclones are changing

There are four main sub-trends to this overarching theme:

1. Increased frequency of severe tropical cyclones
2. Tropical cyclones are likely to degrade more slowly post-landfall
3. Tropical cyclone seasons are beginning earlier
4. Changes to hurricane storm tracks

1. Increased frequency of severe tropical cyclones

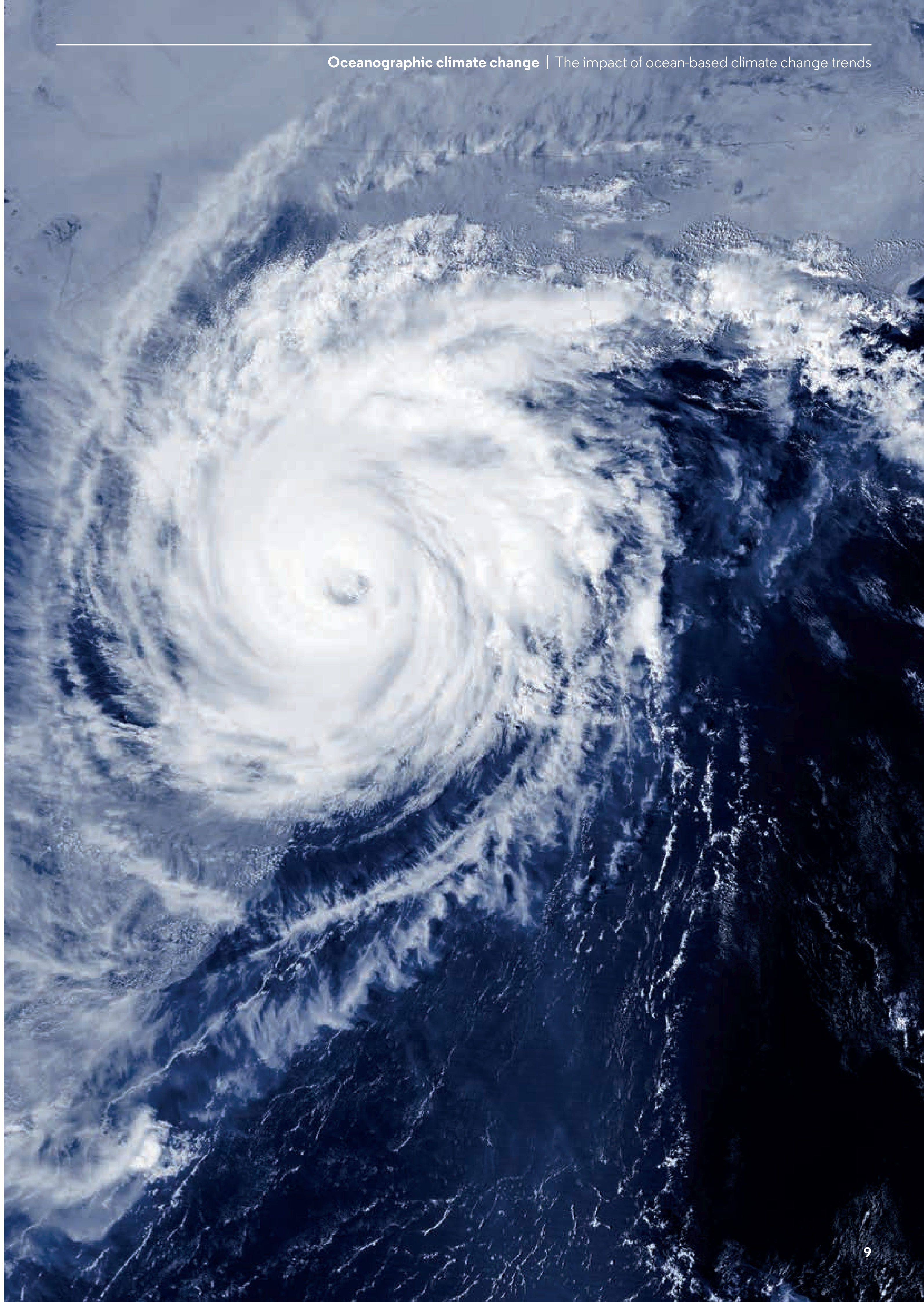
Although the frequency of cyclones overall (categories 1-5) is expected to remain constant or even decrease, the proportion of the most severe tropical cyclones (categories 4 & 5) is expected to increase.[1]

2. Tropical cyclones are likely to degrade more slowly post-landfall

Over the past 50 years, scientists have measured a 94% increase in the time it takes for a hurricane to lose intensity to below tropical storm strength after it makes landfall. This is being caused by a rise in storm moisture, in turn caused by our warmer oceans, which results in storms with more energy.[2]

Warmer oceans also lead to hurricanes being able to store more moisture within the storms, so they travel further inland with greater intensity than if they formed over cooler oceans. Extra moisture results in more rainfall as well, and possibly more flooding.[1]

1. Knutson, T., Camargo, S. J., Chan, J. C. L., Emanuel, K., Ho, C., Kossin, J., Mohapatra, M., Satoh, M., Sugi, M., Walsh, K., & Wu, L. (2020). Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming, Bulletin of the American Meteorological Society, 101(3), E303-E322. Retrieved Dec 14, 2021, from https://journals.ametsoc.org/view/journals/bams/101/3/bams-d-18-0194.1.xml
2. Li, L., Chakraborty, P. Slower decay of landfalling hurricanes in a warming world. Nature 587, 230–234 (2020). https://doi.org/10.1038/s41586-020-2867-7



3. Tropical cyclone seasons are beginning earlier

As the atmosphere warms, so too does the ocean, providing more energy throughout the year for tropical cyclones to form. It is likely that the trend of earlier storms in the North Atlantic will continue with climate change. Where tropical cyclone seasons usually started in mid-June to early July, they are now more likely to begin in May.[3]

According to our Catastrophe Research Team, 2020 was the sixth consecutive season where storms began before the ‘official’ start of the season. The Pacific storm season is less well defined, but the data suggests that storms of greater intensity are occurring in parts of the year outside historical norms.

4. Changes to hurricane storm tracks

Research indicates that the point at which tropical cyclones are reaching their maximum intensity is moving towards the poles in both the Northern and Southern Hemispheres at a rate of 53km and 62km respectively per decade.[4] This correlates to a global average change of about one degree of latitude per decade away from the tropics.

3. HURDAT, North Atlantic hurricane database (Atlantic Ocean, Gulf of Mexico, Caribbean Sea), National Hurricane Center. https://www.nhc.noaa.gov/data/
4. Kossin, J., Emanuel, K. & Vecchi, G. The poleward migration of the location of tropical cyclone maximum intensity. Nature 509, 349–352 (2014). https://doi.org/10.1038/nature13278

Tropical cyclone seasons are beginning earlier

From the National Centre for Atmospheric Research (via Willis Re), the exhibit shows counts of storms occurring within each hurricane season since 1851, and the time at which they occurred. All years are coloured in blue with the exception of 2020, which has been highlighted with green circles to illustrate just how early storms were occurring throughout that hurricane season. This contrasts against the average which is the green line. For instance, in the 7th storm of the 2020 season occurred about two weeks earlier than any other previous season back to 1851, and a month and a half earlier than the long running average.

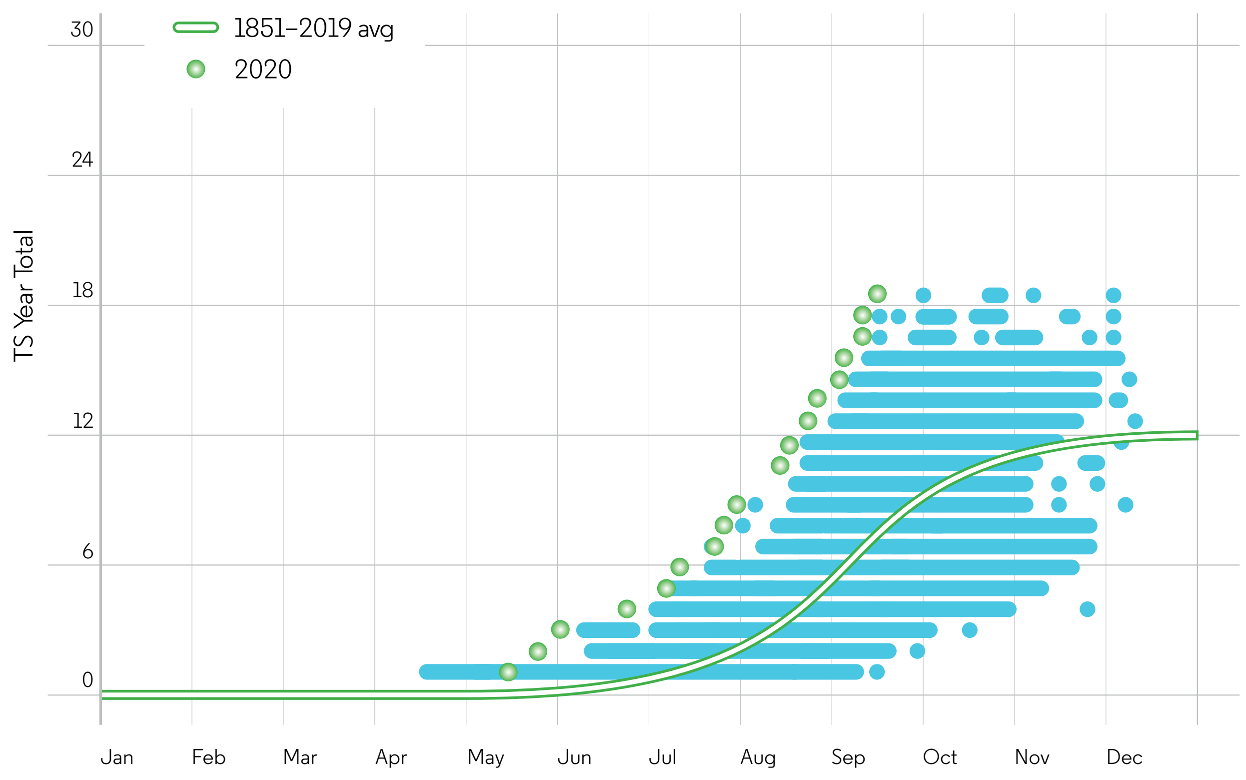


Fig. 1. Tropical Cyclones by Year from 1851-2020[5]

5. Originally presented: Lillo, S. National Center for Atmospheric Research. North Atlantic Tropical Cyclones: Do catastrophe models sufficiently represent ‘the storms of the future’? (Webinar presentation). The Willis Research Network (6 August 2018). Updated since by National Center for Atmospheric Research

2 Extreme weather is worsening

Extreme weather is becoming more severe and more frequent, causing an increase in heatwaves, extreme precipitation and an increase in severity of storminess.

According to the National Centre for Atmospheric Research and Willis Towers Watson, there is a growing trend in both severe droughts and extreme rainfall. Heatwaves are also hitting higher peak temperatures, exceeding previous records in 10-20% of land mass. Additionally, in the mid-latitudes there is a lot of evidence linking Arctic Sea ice disappearance to more extreme weather.[6]

Small changes in average temperature drive more significant changes in extreme weather

The figure below from the National Center for Atmospheric Research shows how different climate scenarios affect the temperature anomaly distribution for the Northern Hemisphere. Small changes in mean temperature are accompanied by large changes in the extremes.

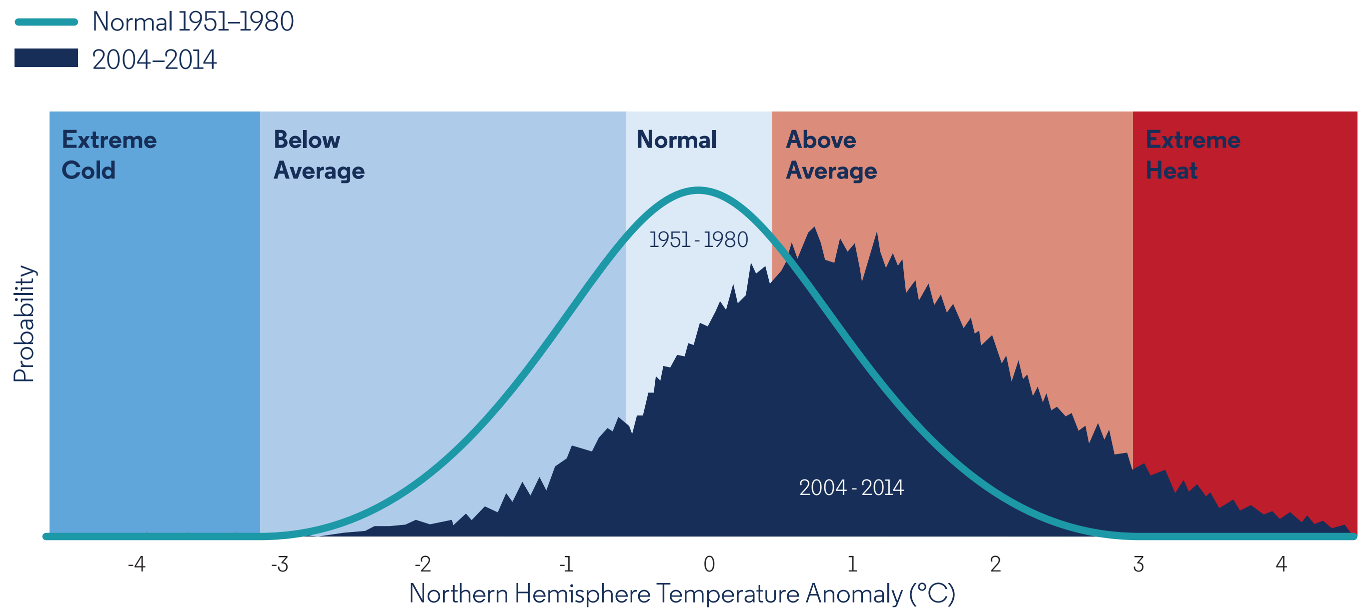


Fig. 2. Climate Impact on Extre[7]

6. Francis, J. A., & Vavrus, S. J. Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophysical research letters, 39(6) (2012). https://doi.org/10.1029/2012GL051000
Tang, Q., Zhang, X., & Francis, J. A. Extreme summer weather in northern mid-latitudes linked to a vanishing cryosphere. Nature Climate Change, 4(1), 45-50 (2014). https://doi.org/10.1038/nclimate2065
Liu, J., Curry, J. A., Wang, H., Song, M., & Horton, R. M. Impact of declining Arctic sea ice on winter snowfall. Proceedings of the National Academy of Sciences, 109(11), 4074-4079 (2012). https://doi.org/10.1073/pnas.1114910109
7. Holland, G. National Center for Atmospheric Research. Tropical cyclones and climate extremes today and in the future (Seminar presentation). The Willis Research Network Autumn Seminar (6 November 2018).

3 More winter storms in new areas

Severe winter weather in southern latitudes is often a result of significant deviations in the jet stream. The jet streams are fast-flowing narrow air currents just below the stratosphere, created by the difference in temperatures between the poles and the equator. As the poles are warming at a faster rate than the equator and the difference reduces, the jet streams become weaker and less stable, and with greater oscillation. This drives cold dry air south and warm moist air north, bringing cold storms to areas without the infrastructure or capabilities to cope with harsh winters. Climate change is making this more likely.

Case study

North America Winter Storm Event 2021

A series of winter storms from 13-20 February 2021 brought freezing temperatures, heavy snowfall, ice accretion and severe convective storms to large parts of the US.

More than 200 million people were under some form of winter weather warning during the week of 15 February. Roofs collapsed due to excessive snow load and pipelines froze, and at its peak over 5 million people were without power. The storms spawned tornadoes that damaged properties in the Southeast US, and more than 50 fatalities were recorded due to carbon monoxide poisoning, car crashes and hypothermia.[8]

8. RMS Event Response 2021

4 Sea levels are rising

Although sea-level rises vary around the world, they are one of the more obvious indicators of climate change, with an average global rise of between 2.6mm and 3mm a year.

Sea levels have been rising at a higher rate since 1993 compared with previous decades, and this increasing acceleration is even higher than that seen in the 20th century.[9-10]

This trend is caused by three climate related factors:

1. Thermal expansion of the oceans
2. Glaciers and small ice caps are melting
3. Major ice sheets are melting and calving.

9. IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1

10. NOAA (National Oceanic and Atmospheric Administration). 2021. Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. Accessed February 2021 www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-erss

1. Thermal expansion of the oceans

Water particles expand as they heat, which contributes substantially to sea-level rise as average global sea surfaces increase year on year.[11-12] In 2020, for example, average sea surface temperatures rose 1.1°C above the long-term average.

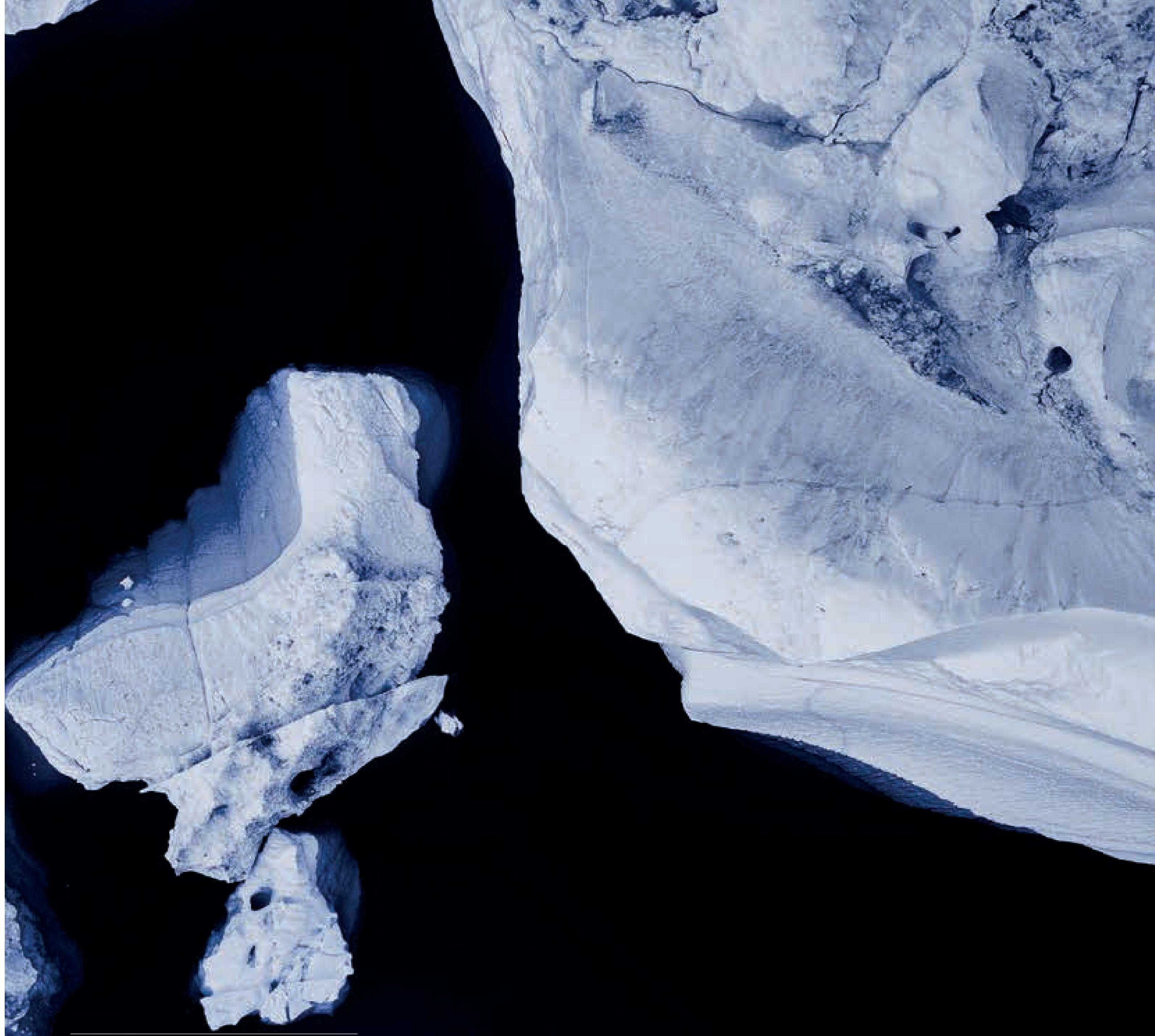
2. Glaciers and small ice caps are melting

The melting of glaciers and small ice caps accounts for 25-30% of total observed sea-level rise. The present mass-loss rates indicate that glaciers could almost disappear in some mountain ranges during this century, while heavily glacierised regions will continue to contribute to sea-level rise beyond 2100.[13-14] While the rate of glacial melting wasn't uniform around the world[11], most glaciers recorded material recessions.[14]

3. Major ice sheets are melting and calving

Both the Greenland and Antarctic ice sheets are calving bigger and more frequent icebergs as the glaciers retreat at record speeds. According to Rignot et al. (2019), "the contribution to sea-level rise from Antarctica averaged 3.6 ± 0.5mm per decade, with a cumulative 14.0 ± 2.0mm since 1979."[15]

As temperatures rise and melting intensifies, we expect the rate of sea level rise to speed up towards the middle of this century. The Greenland ice sheet lost 3,902 billion tonnes of ice between 1992 and 2018 (an average of 150 billion tonnes per year), causing the mean sea level to rise by almost 11mm over that period.[16]



11. IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1
12. Johnson, G. C., & Lyman, J. M. Warming trends increasingly dominate global ocean. Nature Climate Change, 10(8), 757-761 (2020). https://doi.org/10.1038/s41558-020-0822-0
NOAA (National Oceanic and Atmospheric Administration). 2021. Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. Accessed February 2021. www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst.
13. Mottram, R., B Simonsen, S., Høyer Svendsen, S., Barletta, V.R., Sandberg Sørensen, L., Nagler, T., Wuite, J., Groh, A., Horwath, M., Rosier, J. and Solgaard, A. An integrated view of Greenland Ice Sheet mass changes based on models and satellite observations. Remote Sensing, 11(12), p.1407 (2019). https://doi.org/10.3390/rs11121407
14. Zemp, M., Huss, M., Thibert, E., Eckert, N., McNabb, R., Huber, J., Barandun, M., Machguth, H., Nussbaumer, S.U., Gärtner-Roer, I. and Thomson, L. Global glacier mass changes and their contributions to sea-level rise from 1961 to 2016. Nature, 568(7752), pp.382-386 (2019). https://www.nature.com/articles/s41586-019-1071-0?TB_iframe=true&width=921.6&height=921.6
15. Benn, D.I., Cowton, T., Todd, J. and Luckman, A. Glacier calving in Greenland. Current Climate Change Reports, 3(4), pp.282-290 (2017). https://doi.org/10.1007/s40641-017-0070-1
Rignot, E., Mouginot, J., Scheuchl, B., Van Den Broeke, M., Van Wessem, M.J. and Morlighem, M. Four decades of Antarctic Ice Sheet mass balance from 1979–2017. Proceedings of the National Academy of Sciences, 116(4), pp.1095-1103 (2019). https://doi.org/10.1073/pnas.1812883116
16. King, M.D., Howat, I.M., Candela, S.G., Noh, M.J., Jeong, S., Noël, B.P., van den Broeke, M.R., Wouters, B. and Negrete, A. Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat. Communications Earth & Environment, 1(1), pp.1-7 (2020). IMBIE 2019 Greenland Dataset. 02 February 2020. http://imbie.org/data-downloads/

Sea Surface Temperatures (SST) are increasing at an aggregate global level:

The figure below, from the National Oceanic and Atmospheric Administration (NOAA), shows how the average surface temperature of the world's oceans has increased since 1950. It uses the 1971 to 2000 temperature data as a baseline to illustrate the change. The shaded band shows the range of uncertainty driven by the number of measurements and the precision of methods.

According to the NOAA, changing the baseline would result in the same data shape over time.

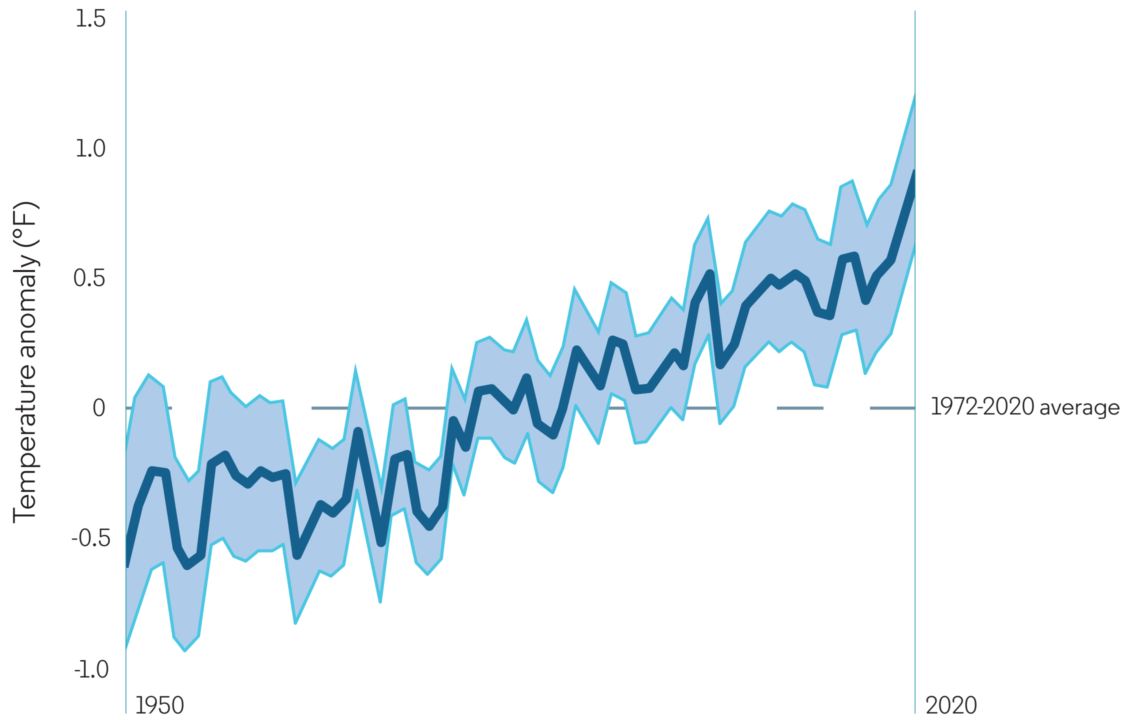


Fig. 3. Average Global Sea Surface Temperatures from 1950 to 2020 (NOAA 2021 [17]*)*

17. NOAA (National Oceanic and Atmospheric Administration). 2021. Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. Accessed February 2021 www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-erss

Sea Surface Temperatures (SST) are increasing everywhere in the world – except near the Greenland ice sheet

According to NOAA (2021) and IPCC (2013), average sea surface temperatures have increased globally except near the Greenland ice sheet. It is likely due to the meltwater from the ice sheet.

The below figure, originally published in the IPCC's Fifth Assessment Report (2013) and since updated using NOAA data, shows the change in sea surface temperature between 1901 and 2015. White areas indicate insufficient data to calculate a long term trend in addition to land masses.

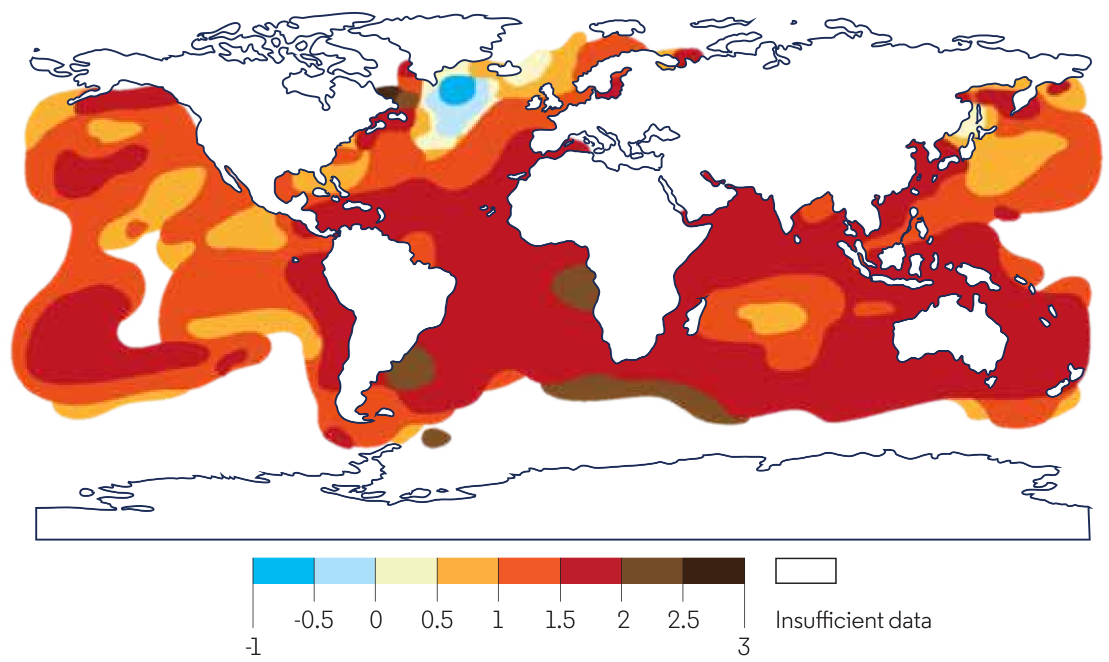
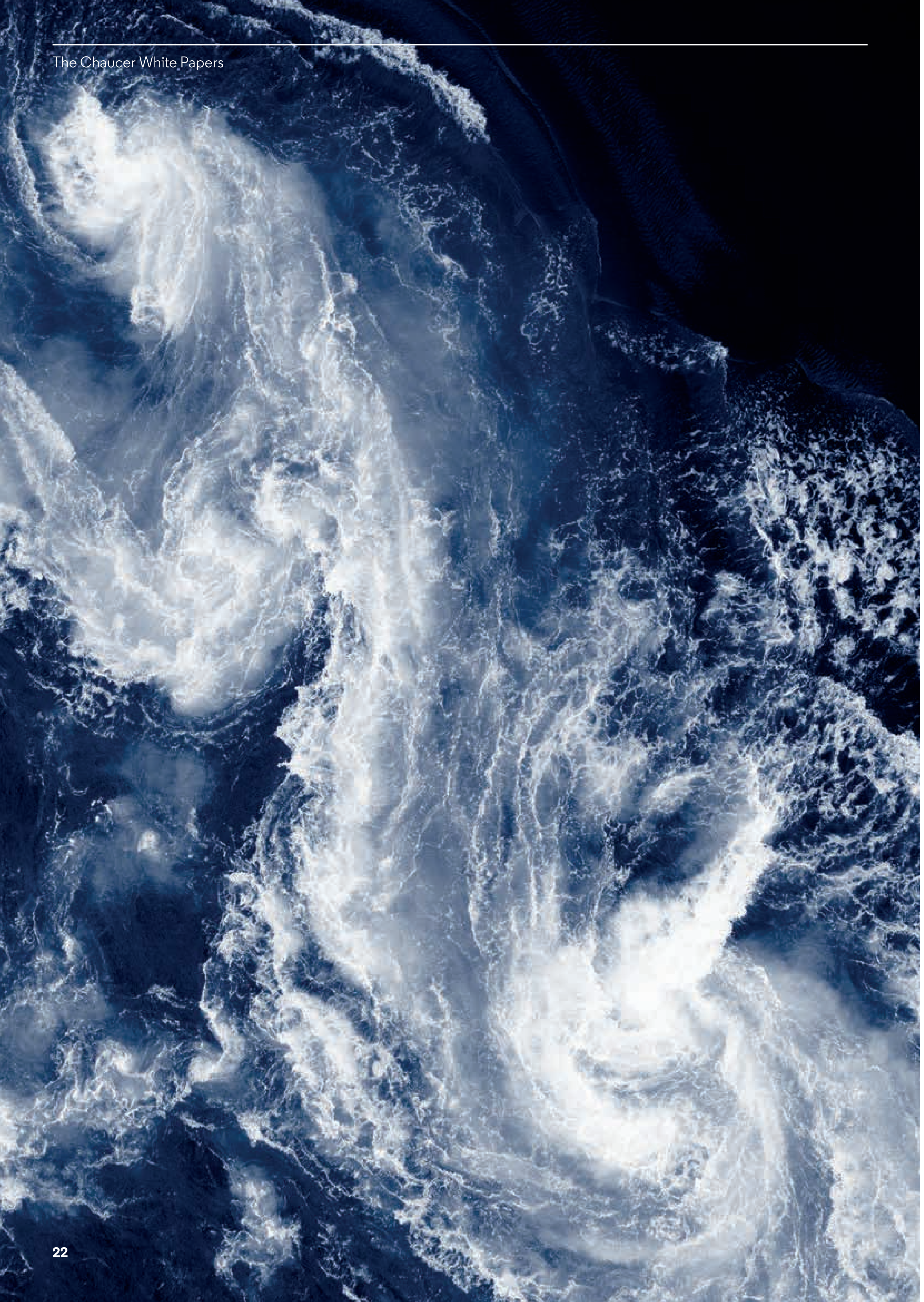


Fig. 4. Change in sea surface temperature between 1901 and 2015 [18-20]

18. IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1
19. NOAA (National Oceanic and Atmospheric Administration). 2021. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp). Accessed March 2021. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp.
20. Accessed via the United States Environmental Protection Agency https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature#ref7



5 The salinity of our oceans is changing

Evaporation is increasing sea salinity at the equator, while meltwater from glaciers and the Greenland and Antarctica ice sheets is decreasing it at the poles.[21]

21. Silvy, Y., Guilyardi, E., Sallée, JB. and Durack, P.J. Human-induced changes to the global ocean water masses and their time of emergence. Nature Climate Change. 10, 1030–1036 (2020). https://doi.org/10.1038/s41558-020-0878-x

6

Larger waves

Wave height appears to have risen over the past 25 years due to more severe and sustained winds. This trend is directly correlated with two of our previous trends addressing increased extremes in storminess and higher proportions of the most severe tropical cyclones; stronger winds lead to larger waves.

However, this increase isn't uniform across the globe, and some waters such as the North Atlantic have seen a greater increase. A large part of this rise may be linked to North Atlantic Oscillation (NAO).[22]

NAO is a fluctuation in the difference in atmospheric pressure at sea level between the subpolar Icelandic low and subtropical Azore high, which affects the strength and direction of Westerly winds into Europe. When both the subpolar low and subtropical high are stronger than average, the Atlantic jet stream is greater and the storm track shifts northward. It's worth noting that there's evidence the influence of NAO has varied significantly over the past 150 years.[23]

22. Woolf, D.K., Challenor, P.G. and Cotton, P.D. Variability and predictability of the North Atlantic wave climate. Journal of Geophysical Research: Oceans, 107(C10), pp.9-1 (2002). https://doi.org/10.1029/2001JC001124
Carter, D.J.T. Variability and trends in the wave climate of the North Atlantic: A review. In The Ninth International Offshore and Polar Engineering Conference. OnePetro. (1999). https://onepetro.org/ISOPEIOPEC/proceedings-abstract/ISOPE99/All-ISOPE99/ISOPE-I-99-227/24857
Wolf, J., & Woolf, D. K. Waves and climate change in the north east Atlantic. Geophysical Research Letters, 33(6) (2006). https://doi.org/10.1029/2005GL025113
23. Jones, P.D., Osborn, T.J., Briffa, K.R., Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. The North Atlantic Oscillation: climatic significance and environmental impact. (2003).

7 Coastal erosion

Although human activity like harbour dredging and river damming are contributing factors, coastal erosion is primarily caused by sea-level rise, which is occurring at a rate of 2-3mm per year.[24]

Although changes in wave and surge conditions, also influenced by our changing climate, are equally or even more important reasons for erosion on many coasts, accelerated sea-level rise is considered the major climate change variable for coastal systems.[24-25]

24. Vitousek, S., Barnard, P.L. and Limber, P. Can beaches survive climate change?. Journal of Geophysical Research: Earth Surface, 122(4), pp.1060-1067 (2017). https://doi.org/10.1002/2017JF004308

25. Hurst, M. D., D. H. Rood, M. A. Ellis, R. S. Anderson, and U. Dornbusch. Recent acceleration in coastal cliff retreat rates on the south coast of Great Britain, Proc. Natl. Acad. Sci. U.S.A. (2016) doi:10.1073/pnas.1613044113

Jones, B. M., C. D. Arp, M. T. Jorgenson, K. M. Hinkel, J. A. Schmutz, and P. L. Flint. Increase in the rate and uniformity of coastline erosion in Arctic Alaska, Geophys. Res. Lett., 36, L03503, (2009). doi:10.1029/2008GL036205

Anderson, T. R., C. H. Fletcher, M. M. Barbee, L. N. Frazer, and B. M. Romine. Doubling of coastal erosion under rising sea level by mid-century in Hawaii, Nat. Hazards, 78(1), 75– 103 (2015). https://doi.org/10.1007/s11069-015-1698-6

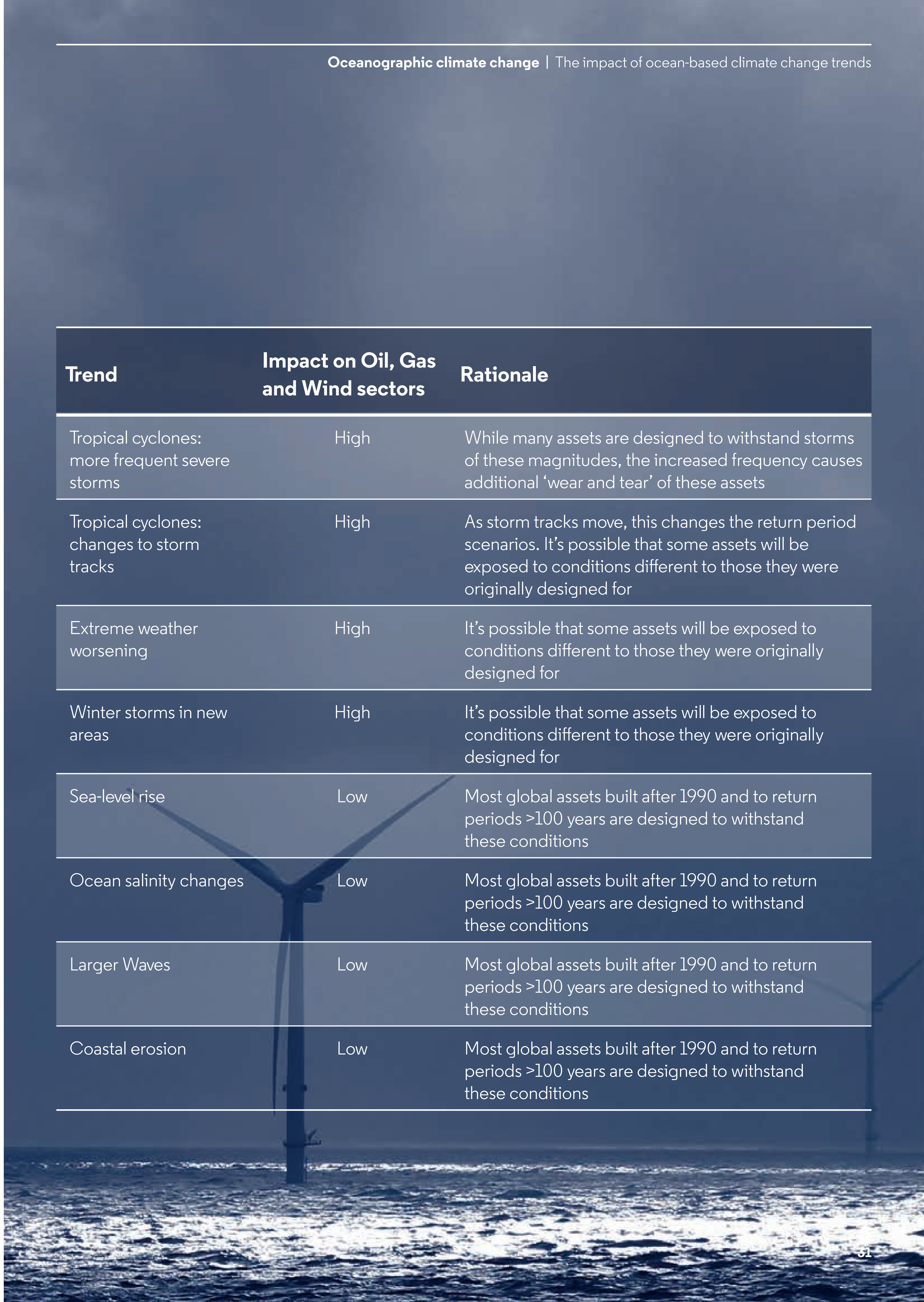
How these trends are affecting the offshore energy and marine sectors

A cross-divisional team of internal experts, including top underwriters, claims experts and our catastrophe research team, examined the impacts of these trends on the offshore energy industry (see table on following page). They focused particularly on property damage to offshore assets (especially oil platforms, wind farm installations, vessels and cargo), supply chain and demand impacts, and the emergence of new engineering technologies and innovations. Our analysis focused mainly on the short to mid-term (next 1 to 10 years).

Impact on Oil and Gas and Wind sectors

While all of these trends are important individually, it is their combined, concurrent impact that is of greatest consequence to our customers, rather than their individual effects. These impacts fall across three main themes:

1. Changes to engineering design requirements
2. Exacerbating existing challenges
3. All at a time of unrivalled change for the sector.



Trend	Impact on Oil, Gas and Wind sectors	Rationale
Tropical cyclones: more frequent severe storms	High	While many assets are designed to withstand storms of these magnitudes, the increased frequency causes additional 'wear and tear' of these assets
Tropical cyclones: changes to storm tracks	High	As storm tracks move, this changes the return period scenarios. It's possible that some assets will be exposed to conditions different to those they were originally designed for
Extreme weather worsening	High	It's possible that some assets will be exposed to conditions different to those they were originally designed for
Winter storms in new areas	High	It's possible that some assets will be exposed to conditions different to those they were originally designed for
Sea-level rise	Low	Most global assets built after 1990 and to return periods >100 years are designed to withstand these conditions
Ocean salinity changes	Low	Most global assets built after 1990 and to return periods >100 years are designed to withstand these conditions
Larger Waves	Low	Most global assets built after 1990 and to return periods >100 years are designed to withstand these conditions
Coastal erosion	Low	Most global assets built after 1990 and to return periods >100 years are designed to withstand these conditions

Climate change considerations should be incorporated into engineering design conditions and time horizons

Offshore energy equipment is clearly built to withstand extreme conditions. However, the scenarios and thresholds incorporated into the design are based on a modelled view at a point in time. As a result, there are potential issues around the engineering technology and its ability to withstand extreme weather events that have not been incorporated into the design.

Of greatest concern are the following:

- Winter storms in non-winterised regions, e.g. the Gulf of Mexico
- Longer tropical cyclone seasons, changing storm tracks and more frequent severe tropical cyclones
- Poor performance of aging infrastructure and assets being decommissioned under changing environmental conditions.

‘It is imperative that we incorporate climate change considerations into engineering design conditions and time horizons.’

Athithan Gnanendran
Head of Risk Engineering (Energy)

Climate change trends may exacerbate existing challenges

In addition to damaging offshore assets, extreme weather and tropical storms can also restrict access to sites after the event. This hinders maintenance, increases costs and makes it hard to source skilled labour.

The impact of large tropical hurricanes and storms on supply chains can also have an effect on post-event repair and recovery. This is especially true for the renewable energy industry, considering demand for wind farm installations is already at record levels. This demand is further heightened by the need for replacement parts after catastrophe events.

Supply chain difficulties, as well as repair and maintenance issues, already impact our energy customers. While climate change does not cause these problems, it does make the associated challenges more frequent and more severe.

‘While each of these underlying climate change trends has material impacts individually, it is the collective consequence of these trends, the sum of the parts, that is of greatest concern.’

Kelan Hunt
Head of Marine, Energy & Aviation
and Active Underwriter, Syndicate 1084

Immense industry change combined with unsurpassed global demand

Global demand for energy has reached record levels, driven largely by rising population combined with increasing prosperity and living standards internationally.[26]

The industry is trying to manage this unprecedented demand while moving to new fuel sources. This requires carefully balancing the management of the existing infrastructure while growing production in a relatively new space, which requires new technologies, processes, techniques and infrastructure. These climate change trends exacerbate the challenges our energy customers face.

26. Ritchie, H. and Roser, M. "Energy". Our World in Data. (2020). Retrieved from: https://ourworldindata.org/energy Data sourced from: Vaclav Smil (2017). Energy Transitions: Global and National Perspectives. http://vaclavsmil.com/2016/12/14/energy-transitions-global-and-national-perspectives-second-expanded-and-updated-edition/ ; & BP Statistical Review of World Energy. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

The transformation of global energy consumption since 1800

The figure below, sourced from Our World in Data, is based on historical estimates of primary energy consumption from Vaclav Smil, combined with updated figures from BP's Statistical Review of World Energy.[26]

The data presents primary energy consumption via the 'substitution method', which corrects for inefficiencies due to energy wasted as heat during combustion in fossil fuel and biomass conversion.

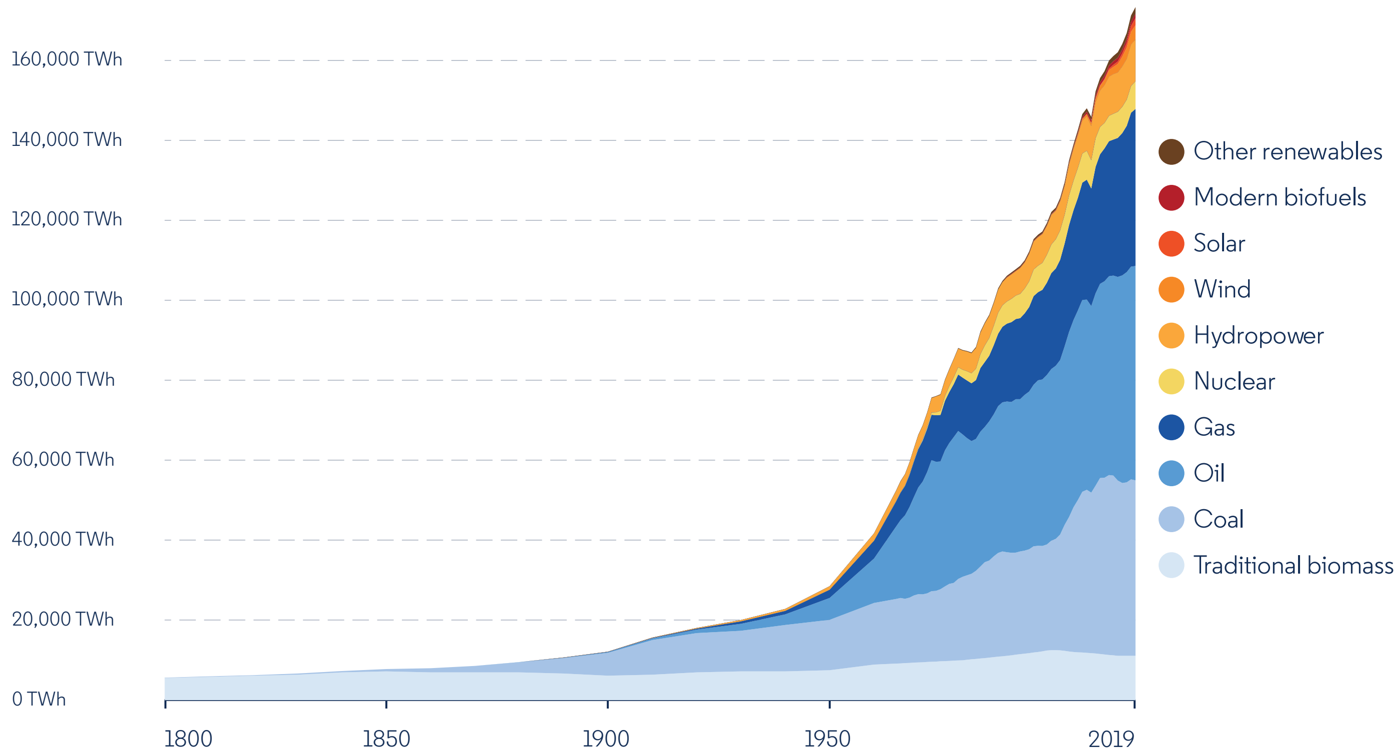


Fig. 5. Global Primary Energy Consumption by Source [26]

Impact on the Marine sector

While we believe some of these climate change trends are of lower risk to the energy industry given the stringent engineering design parameters, we believe all seven of these trends are likely to have material impacts on the marine industry, in particular to vessels, ports and cargo. Some examples of existing impacts, and those that we think are likely to manifest, are outlined below.

Trend	Examples of existing and potential impacts on Vessels, Ports and Cargo
Tropical cyclones: • more frequent severe storms • changes to storm tracks	Greater probability of **delays to vessels leaving and entering ports** as the risk of having to take divergent routes increases **Less port availability** for some classes of container ship is likely to increase **Containers falling overboard (loss of cargo)** **Ships out at sea longer due to inclement weather or bottlenecks** Increasing general wear and tear
Extreme weather & winter storms in new areas	**Damage to vessels** resulting in injuries to people on board, especially large container ships and cruise ships **General wear and tear** on the vessel increasing as the jet stream increases damage to vessels from freeze thaw and subsequent water ingress conditions
Larger waves	**Changes to wave periods** could cause damage or even destruction of vessel hulls **Likely shift to smaller-sized vessels** to enable better navigation of more volatile waters

Trend	Examples of existing and potential impacts on Vessels, Ports and Cargo
Sea-level rise & coastal erosion	**Unnavigable waterways** due to levels in rivers forcing rerouting **More icebergs yielding increased risk of collision** with vessels **Accumulation of vessels in bottlenecks for major shipping lanes** **Port infrastructure with sea level risks could limit routes** – for example, in lower-lying parts of South East Asia and Rotterdam this could be particularly important **Coastal erosion poses** large potential risks to major port infrastructure developments **Ports could be damaged** due to sea levels, which causes delays to unloading of cargo and vessel timetables **Water ingress to cargo**, especially through flooding of ports
Ocean salinity changes	**Increased salinity making vessels less stable** (e.g. in the Middle East this is noticeable) **Vessels sitting differently in the water** (due to salinity differences) could cause navigation issues and require redesign or refitting of vessels to accommodate cargo **Erosion of the containers, vessels and port infrastructure** from increased salinity

Opportunities specific to the Marine sector

While many of the trends outlined on the previous pages are having negative impacts, there are also a number of emerging and potential opportunities for the marine industry. There are two main opportunities we've identified:

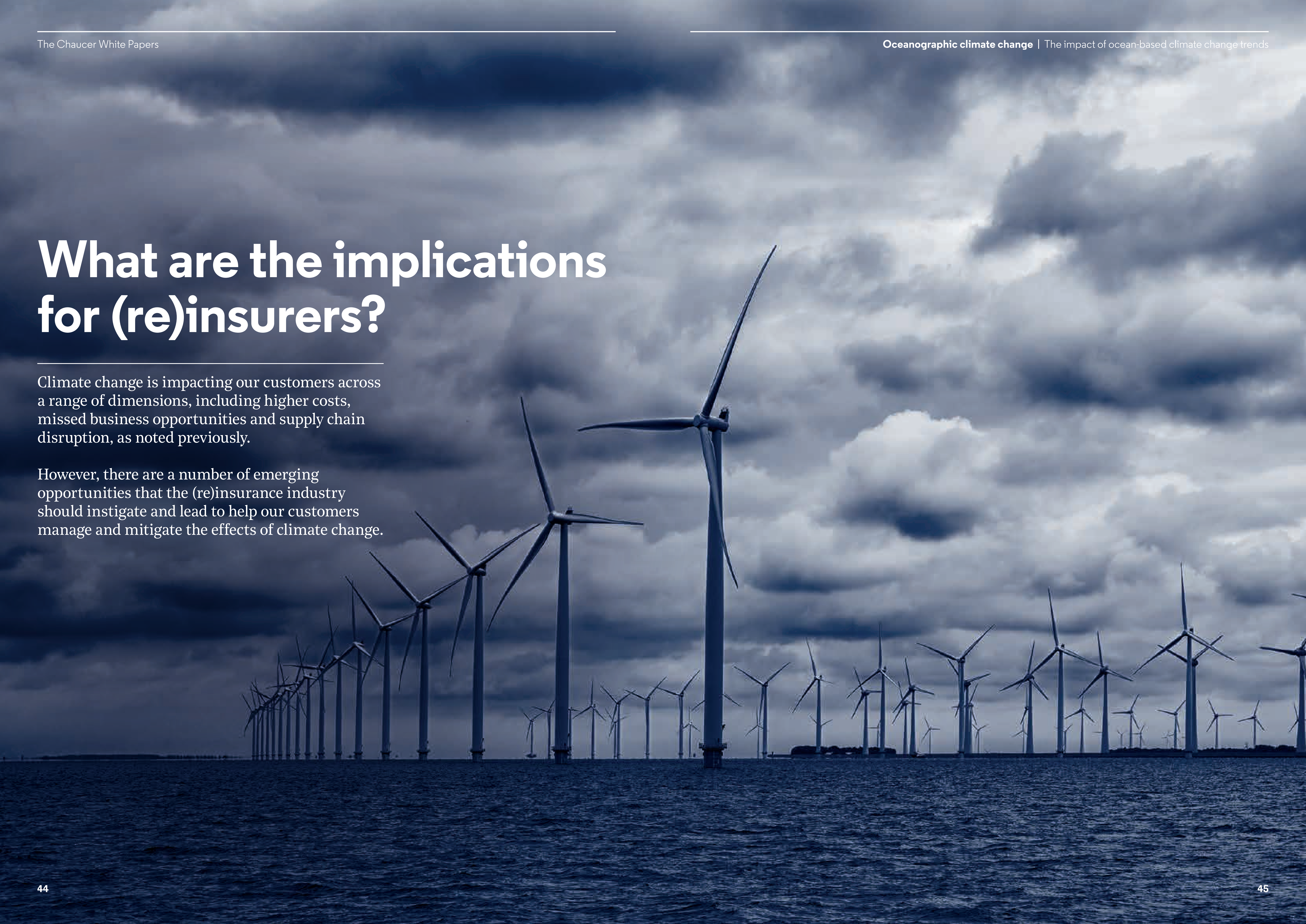
1. Increased importance of new geographies
2. Efficiency gains from new trade routes, technologies and processes.

1. Increased importance of new geographies

- Northwest Passage becoming a commercial route would likely have positive impacts on China & Russia. For example, new ports in Russia could emerge with the increased de-icing of waterways, and Chinese ports would benefit from the increased traffic
- Canada and the Great Lakes could see greater utilisation as routes into North America. While Northern Canadian waterways are currently used for some of the year, many of the riverways are frozen for large parts of the year. The route into North America could become more efficient should the riverways become navigable throughout the year
- The US might start exporting more cargo out of the North East rather than the Gulf of Mexico due to weather disruptions
- The cruise industry could further expand their existing footprint around the poles. As the waterways become increasingly navigable and ecotourism continues to gain traction, it is likely that cruise ships, in addition to shipping vessels, will increasingly navigate the poles

2. Efficiency gains from new trade routes, technologies and processes

- Shorter trade routes could lead to lower costs
- As we design more modern ships for modern routes, container shapes and loading practices will likely change to enable greater fuel efficiency, along with better tide and wind management
- Importance of fuel efficiency and agility in responding to supply chain disruption will likely drive a shift to smaller vessels



What are the implications for (re)insurers?

Climate change is impacting our customers across a range of dimensions, including higher costs, missed business opportunities and supply chain disruption, as noted previously.

However, there are a number of emerging opportunities that the (re)insurance industry should instigate and lead to help our customers manage and mitigate the effects of climate change.

Better climate modelling is crucial

Although climate change is, at least in part, responsible for many of the problems discussed in this paper, it is difficult to make reliable long-term predictions about the extent and scale of the damage.

The industry needs to ensure it is using the best possible information to make its decisions. This includes academic research and advances, industry knowledge, historical data and existing forward-looking models, new and different data sources, and analysis techniques such as open source. This is crucial not just for (re)insurers with respect to portfolio and exposure management, but also for energy customers, especially regarding the design of technologies, tools and processes.

While some advances have been made, models need to improve considerably if they are to be a useful tool in helping to manage and mitigate climate change.

Existing and mounting uncertainty should be addressed through enhanced data collection and more focused analysis

There is material uncertainty as to how offshore assets, supply chains and business models will react to these identified climate change trends.

To combat this, we need to increase the volume, granularity and overall quality of the data we collect. Additionally, we need to engage in more work like this, bringing a range of skill sets and backgrounds around a table to focus on analysing the impacts of defined problem statements.

The time to act is now

As we have examined in this paper, the impact of multiple climate change trends on the offshore energy and marine industries is significant. However, it is not merely the individual climate change trends, but rather the combination of these that is of greatest consequence to both our customers and the broader (re)insurance industry.

For us to combat the challenges of climate change, all stakeholders must engage and collaborate with each other as a matter of urgency. Insurers have the opportunity to drive tangible change with marine and energy customers, brokers, regulators and governments.

Collective action is imperative to ensure we manage these risks, mitigate against future impacts and create new solutions for emerging opportunities in a rapidly changing market.

To be part of the change register your interest for future white papers and events at climate.change@chaucergroup.com

'As the impact of these trends is felt not just by the energy industry, but more broadly by the entire world, it is crucial that we not retreat to our respective corners to solve these problems. Collaboration here and now could not be more critical.'

James Brown
Head of Natural Resources

Endnotes

Page 8

1. Knutson, T., Camargo, S. J., Chan, J. C. L., Emanuel, K., Ho, C., Kossin, J., Mohapatra, M., Satoh, M., Sugi, M., Walsh, K., & Wu, L. (2020). Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming, Bulletin of the American Meteorological Society, 101(3), E303-E322. Retrieved Dec 14, 2021, from https://journals.ametsoc.org/view/journals/bams/101/3/bams-d-18-0194.1.xml
2. Li, L., Chakraborty, P. Slower decay of landfalling hurricanes in a warming world. Nature 587, 230–234 (2020). https://doi.org/10.1038/s41586-020-2867-7

Page 10 - 11

3. HURDAT, North Atlantic hurricane database (Atlantic Ocean, Gulf of Mexico, Caribbean Sea), National Hurricane Center. https://www.nhc.noaa.gov/data/
4. Kossin, J., Emanuel, K. & Vecchi, G. The poleward migration of the location of tropical cyclone maximum intensity. Nature 509, 349–352 (2014). https://doi.org/10.1038/nature13278
5. Originally presented: Lillo, S. National Center for Atmospheric Research. North Atlantic Tropical Cyclones: Do catastrophe models sufficiently represent 'the storms of the future'? (Webinar presentation). The Willis Research Network (6 August 2018). Updated since by National Center for Atmospheric Research

Page 12 - 13

6. Francis, J. A., & Vavrus, S. J. Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophysical research letters, 39(6) (2012). https://doi.org/10.1029/2012GL051000
   Tang, Q., Zhang, X., & Francis, J. A. Extreme summer weather in northern mid-latitudes linked to a vanishing cryosphere. Nature Climate Change, 4(1), 45-50 (2014). https://doi.org/10.1038/nclimate2065
   Liu, J., Curry, J. A., Wang, H., Song, M., & Horton, R. M. Impact of declining Arctic sea ice on winter snowfall. Proceedings of the National Academy of Sciences, 109(11), 4074-4079 (2012). https://doi.org/10.1073/pnas.1114910109
7. Holland, G. National Center for Atmospheric Research. Tropical cyclones and climate extremes today and in the future (Seminar presentation). The Willis Research Network Autumn Seminar (6 November 2018).

Page 14

8. RMS Event Response 2021

Page 16 - 17

9. IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1
10. NOAA (National Oceanic and Atmospheric Administration). 2021. Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. Accessed February 2021 www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-erss

Page 18 - 19

11. IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1
12. Johnson, G. C., & Lyman, J. M. Warming trends increasingly dominate global ocean. Nature Climate Change, 10(8), 757-761 (2020). https://doi.org/10.1038/s41558-020-0822-0
    NOAA (National Oceanic and Atmospheric Administration). 2021. Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. Accessed February 2021. www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst.
13. Mottram, R., B Simonsen, S., Høyer Svendsen, S., Barletta, V.R., Sandberg Sørensen, L., Nagler, T., Wuite, J., Groh, A., Horwath, M., Rosier, J. and Solgaard, A. An integrated view of Greenland Ice Sheet mass changes based on models and satellite observations. Remote Sensing, 11(12), p.1407 (2019). https://doi.org/10.3390/rs11121407
14. Zemp, M., Huss, M., Thibert, E., Eckert, N., McNabb, R., Huber, J., Barandun, M., Machguth, H., Nussbaumer, S.U., Gärtner-Roer, I. and Thomson, L. Global glacier mass changes and their contributions to sea-level rise from 1961 to 2016. Nature, 568(7752), pp.382-386 (2019). https://www.nature.com/articles/s41586-019-1071-0?TB_iframe=true&width=921.6&height=921.6

15. Benn, D.I., Cowton, T., Todd, J. and Luckman, A. Glacier calving in Greenland. Current Climate Change Reports, 3(4), pp.282-290 (2017). https://doi.org/10.1007/s40641-017-0070-1
Rignot, E., Mouginot, J., Scheuchl, B., Van Den Broeke, M., Van Wessem, M.J. and Morlighem, M. Four decades of Antarctic Ice Sheet mass balance from 1979–2017. Proceedings of the National Academy of Sciences, 116(4), pp.1095-1103 (2019). https://doi.org/10.1073/pnas.1812883116
16. King, M.D., Howat, I.M., Candela, S.G., Noh, M.J., Jeong, S., Noël, B.P., van den Broeke, M.R., Wouters, B. and Negrete, A. Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat. Communications Earth & Environment, 1(1), pp.1-7 (2020). IMBIE 2019 Greenland Dataset. 02 February 2020. http://imbie.org/data-downloads/

Page 20

17. NOAA (National Oceanic and Atmospheric Administration). 2021. Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. Accessed February 2021 www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-erss

Page 21

18. IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1
19. NOAA (National Oceanic and Atmospheric Administration). 2021. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp). Accessed March 2021. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp.
20. Accessed via the United States Environmental Protection Agency https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature#ref7

Page 23

21. Silvy, Y., Guilyardi, E., Sallée, JB. and Durack, P.J. Human-induced changes to the global ocean water masses and their time of emergence. Nature Climate Change. 10, 1030–1036 (2020). https://doi.org/10.1038/s41558-020-0878-x

Page 24

22. Woolf, D.K., Challenor, P.G. and Cotton, P.D. Variability and predictability of the North Atlantic wave climate. Journal of Geophysical Research: Oceans, 107(C10), pp.9-1 (2002). https://doi.org/10.1029/2001JC001124
Carter, D.J.T. Variability and trends in the wave climate of the North Atlantic: A review. In The Ninth International Offshore and Polar Engineering Conference. OnePetro. (1999). https://onepetro.org/ISOPEIOPEC/proceedings- abstract/ISOPE99/All-ISOPE99/ISOPE-I-99-227/24857
Wolf, J., & Woolf, D. K. Waves and climate change in the north east Atlantic. Geophysical Research Letters, 33(6) (2006). https://doi.org/10.1029/2005GL025113
23. Jones, P.D., Osborn, T.J., Briffa, K.R., Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. The North Atlantic Oscillation: climatic significance and environmental impact. (2003).

Page 27

24. Vitousek, S., Barnard, P.L. and Limber, P. Can beaches survive climate change?. Journal of Geophysical Research: Earth Surface, 122(4), pp.1060-1067 (2017). https://doi.org/10.1002/2017JF004308
25. Hurst, M. D., D. H. Rood, M. A. Ellis, R. S. Anderson, and U. Dornbusch. Recent acceleration in coastal cliff retreat rates on the south coast of Great Britain, Proc. Natl. Acad. Sci. U.S.A. (2016) doi:10.1073/pnas.1613044113
Jones, B. M., C. D. Arp, M. T. Jorgenson, K. M. Hinkel, J. A. Schmutz, and P. L. Flint. Increase in the rate and uniformity of coastline erosion in Arctic Alaska, Geophys. Res. Lett., 36, L03503, (2009). doi:10.1029/2008GL036205
Anderson, T. R., C. H. Fletcher, M. M. Barbee, L. N. Frazer, and B. M. Romine. Doubling of coastal erosion under rising sea level by mid-century in Hawaii, Nat. Hazards, 78(1), 75– 103 (2015). https://doi.org/10.1007/s11069-015-1698-6

Page 36 - 37

26. Ritchie, H. and Roser, M. "Energy". Our World in Data. (2020). Retrieved from: https://ourworldindata.org/energy
Data sourced from: Vaclav Smil (2017). Energy Transitions: Global and National Perspectives. http://vaclavsmil.com/2016/12/14/energy-transitions-global-and-national-perspectives-second-expanded-and-updated-edition/; & BP Statistical Review of World Energy. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

The team of leaders

Authors

Dana Foley
Head of Catastrophe Research

Kelan Hunt
Head of Marine, Energy & Aviation and
Active Underwriter, Syndicate 1084

Athithan Gnanendran
Head of Risk Engineering (Energy)

James Brown
Head of Natural Resources

Andrew Butcher
Claims Manager (Energy)

Dr Hayley Maynard
Head of Innovation

Phil Graham
Head of Marine Global

Graham Hooper
Class Underwriter

Graham Harrison
Class Underwritter

Trevor Rushbrook
Claims Manager

James Irvine
Senior Class Underwriter

Andy Wells
Class Underwriter

Mike Smith
Head of Marine Specialty

Andrew Robson
Research Lead Analyst

Chaucer Group
52 Lime Street
London EC3M 7AF
chaucergroup.com