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Risk & Insurance Economics

Warming of the Oceans and Implications for the (Re)insurance Industry

A Geneva Association Report

June 2013

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Executive summary

- There is new, robust evidence that the global oceans have warmed significantly. Given that energy from the ocean is the key driver of extreme events, ocean warming has effectively caused a shift towards a "new normal" for a number of insurance-relevant hazards. This shift is quasi irreversible—even if greenhouse gas (GHG) emissions completely stop tomorrow, oceanic temperatures will continue to rise.
- In the non-stationary environment caused by ocean warming, traditional approaches, which are solely based on analysing historical data, increasingly fail to estimate today's hazard probabilities. A paradigm shift from historic to predictive risk assessment methods is necessary.
- Due to the limits of predictability and scientific understanding of extreme events in a non-stationary environment, today's likelihood of extreme events is ambiguous. As a consequence, scenario-based approaches and tail risk modelling become an essential part of enterprise risk management.
- In some high-risk areas, ocean warming and climate change threaten the insurability of catastrophe risk more generally. To avoid market failure, the coupling of risk transfer and risk mitigation becomes essential.

Introduction

There is now evidence that, over recent decades, the climate has changed and we have already reached a "new normal" for many climate- and weather-based (extreme) indices (IPCC, 2012). Even former "sceptics" of climate change have started to admit that global warming is detectable and that it is most likely attributable to human emissions of greenhouse gases (GHG) (Muller, 2012). In fact, this is true not only for the land surface of our planet, but also for the global ocean.

Ocean warming is a topic of growing concern, as it indicates a long-term (on the order of centuries) change of our climate, even if anthropogenic GHG emissions stopped entirely tomorrow.

The global ocean and its currents are of fundamental importance for the storage and distribution of solar energy absorbed by the climate system. Energy is exchanged between the atmosphere and ocean mainly via radiative transfer and the transport of latent heat from evaporation and condensation. By transporting vast amounts of energy and being the main source of water to the atmosphere, the oceans determine weather patterns and provide the energy needed for the development of extreme events. Understanding the changes of ocean dynamics and the complex interactions between the ocean and the atmosphere is the key to understanding current changes in the distribution, frequency and intensity of global extreme events relevant to the insurance industry, such as tropical cyclones, flash floods or extra-tropical winter storms.

Recently, improved observational records and the increased length of reliable time series have provided new evidence of the degree of global ocean warming and the distribution of energy within the ocean (e.g. Levitus *et al.*, 2012). A positive temperature trend in the ocean is now detectable and has already changed selected but relevant metrics for extreme events away from what we have observed in the past (e.g. Elsner, 2008).

The implications of the level of ocean warming that already has been attained include the need to reassess the way we quantify and manage today's catastrophe risk; specifically, after moving away from historical averages, the need to define a "new normal" which is itself highly uncertain.

Historical data-driven (or climatological) approaches to estimate the background risk of different events will fail in a non-stationary environment as they don't adequately incorporate recent changes. Even if some of the changes might not be significant yet, risk estimation has to include the consequences of what current physical understanding can tell us about the implied changes of the observed ocean warming. New methods in risk estimation, such as scenario-based approaches and tail risk modelling, are becoming an essential part of the insurance business with a variety of different applications, such as capital requirement determination, pricing and/or risk mitigation.

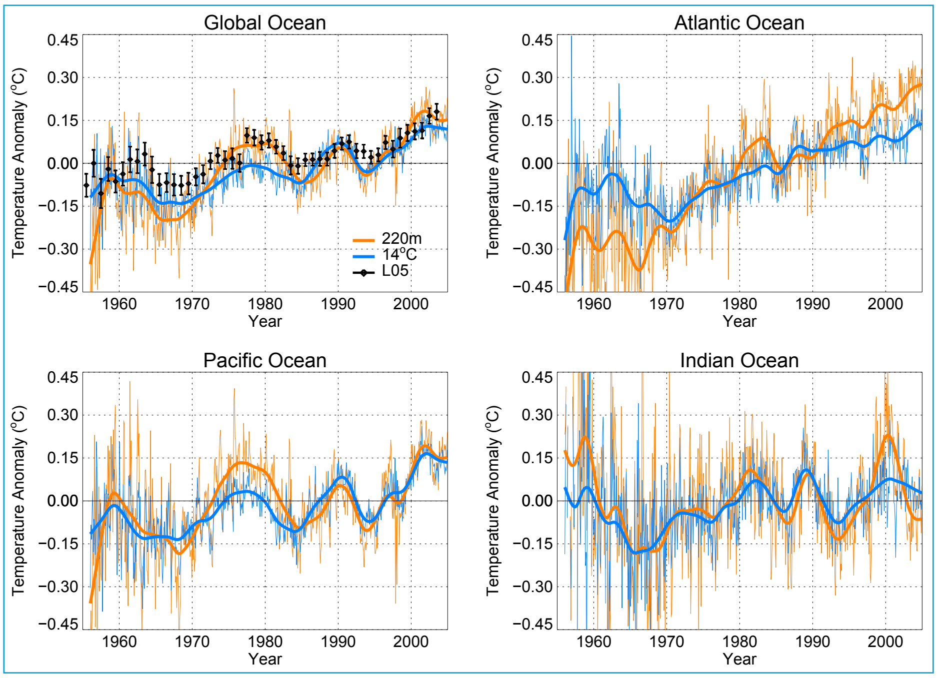
This report gives an overview of the detected changes in the oceans (Chapter 1) and their impact on extreme events and hazard probabilities over the last decades (Chapter 2). It summarises the changes in risk management strategies (Chapter 3) that (re)insurance companies can implement in order to address the new situation appropriately, comply with regulatory requirements and ultimately improve their ratings.

1

Evidence for ocean warming since the mid-20th century

Since the Industrial Revolution, the atmospheric CO_2 concentration has increased substantially (IPCC, 2007a). This fact, together with the well-known radiative properties of CO_2 and other gases such as methane with similar characteristics, produces the colloquially known "greenhouse effect". GHG trap some of the infrared radiation emitted from the Earth, resulting in a warming of the atmosphere. Consequently, as the atmosphere exchanges heat with the ocean, the ocean has gradually been storing this energy, causing an increase in sea surface temperatures (SSTs), the temperature of the upper ocean layer (see Figure 1) and the vertically-integrated ocean heat content (OHC) (Figure 2).

Figure 1



Time series of monthly mean temperature abnormally above the 14ºC isotherm (blue) and 220 (orange) for (a) Global Ocean, (b) Atlantic Ocean, (c) Pacific Ocean, and (d) Indian Ocean. The thick lines show these data after a 5-year low-pass filter has been applied. These data have been selected to have identical geographical coverage for the 14ºC and 220m analyses. Also shown are the annual temperature anomalies with error bars (black) for the upper 300m of the Global Ocean (L05).

Source: Palmer *et al.*, 2007.

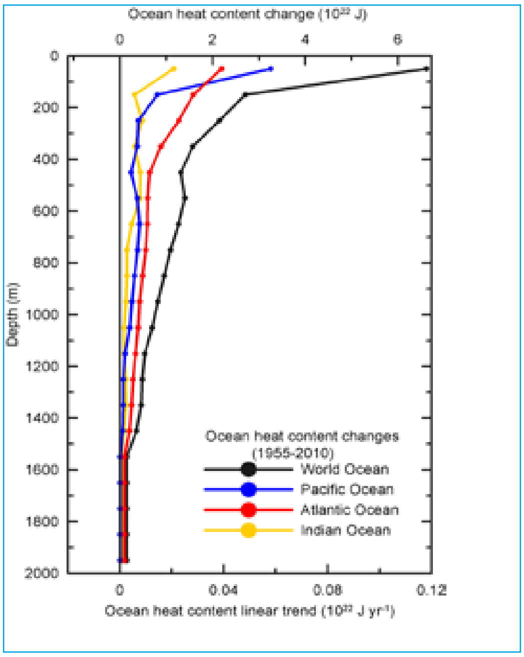
The OHC plays an important role in powering the dynamics of global climate (Hansen *et al.*, 2005, Arndt *et al.*, 2010). The increase in OHC is accompanied by the thermal expansion of sea water, which is the dominant component of sea level rise, and represents a direct threat to coastal regions around the world. In addition, rising mean sea level indirectly increases the damage potential of extreme events, such as extra-tropical cyclones or tsunamis. The OHC is also of direct relevance to many types of weather extremes, such as tropical cyclones or severe convective events, because OHC is the energy source for the development of these atmospheric phenomena.

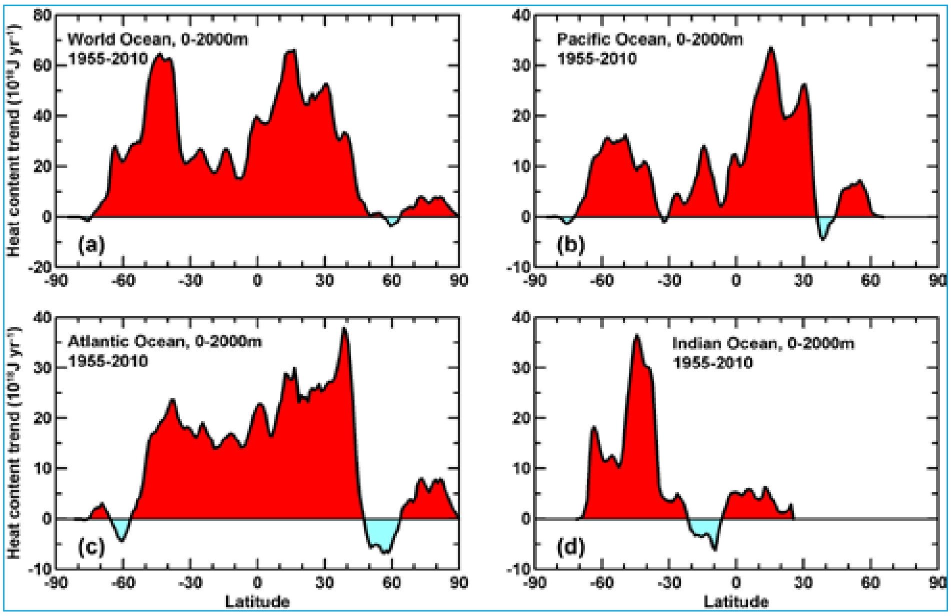
The first observations of rising levels of OHC were published in the year 2000 (Levitus *et al.*, 2000) and have been confirmed by the International Panel on Climate Change (IPCC) *Fourth Assessment Report* (IPCC, 2007a). Since then, substantial improvements have been made to better constrain the observed increase in OHC. Observational records from sources ranging from ship measurements, satellite observations and recently established networks of autonomous floaters in the oceans, improve our knowledge about the extent of ocean warming and reveal that it is more pronounced than previously reported (Domingues *et al.*; 2008, Ishii and Kimoto 2009; Levitus *et al.*, 2012).

Tornado and storm clouds forming over rough sea.

Current observations of OHC (as derived from temperature anomalies in upper ocean layers, see Figure 1) show a positive trend over the last decades on a global level, which is also apparent in individual ocean basins (Palmer *et al.*, 2007, Levitus *et al.*, 2012). It is most pronounced in the Atlantic basin and evident in the Pacific basin. Additionally, the Indian Ocean shows a minor upward trend, which is more pronounced in the tropical part of the Indian Ocean (see Figure 2). Beside these trends, short- and long-term variations in the OHC can be observed; these are caused by natural variability in the climate system. The variability on different timescales and the uncertainty estimation for the estimates have caused considerable debate in the scientific community about the quality of the data sets used and the mechanisms involved (see *Real Climate* for a summary). Although some uncertainty remains, different studies now agree not only on the fact that OHC has indeed been rising, but also more or less on the extent of the ocean warming (see Figure 4). Furthermore, recent modelling studies suggest that the observed ocean warming can be attributed to anthropogenic emissions of GHG (Gleckler *et al.*, 2012).

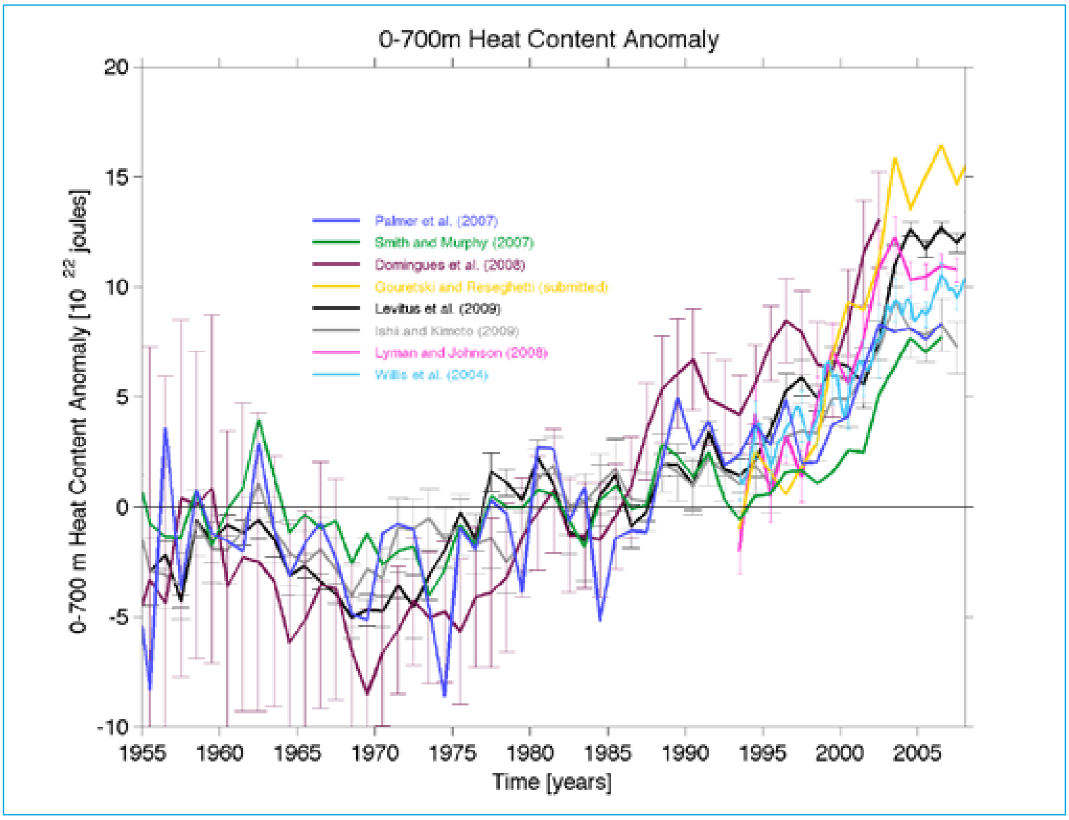
Figure 2: The linear trend in ocean heat content for different basins as a function of depth (top) and latitude (bottom)





Source: Levitus *et al.*, 2012.

Figure 3: Annual ocean heat content anomaly (1022 J) for the 0–700 m layer



A number of observation-based estimates of annual ocean heat content anomaly for the 0-700 m layer. Differences among the time series arise from: input data; quality control procedure; gridding and infilling methodology (what assumptions are made in areas of missing data); bias correction methodology; and choice of reference climatology. Anomalies are computed relative to the 1955–2002 average.

Source: Palmer *et al.*, 2010.

2

The impact of ocean warming on extreme events

The energy stored in the ocean has changed and, consequently, so too have the distribution, frequency and intensity of different extreme events in the climate system (IPCC, 2012). Changes in SSTs (an indicator of OHC change) are not homogenous and this has implications for global weather patterns. A stronger than average increase can be observed in the tropics (see Figure 2) and this has, in a manner similar to the El Niño Southern Oscillation (ENSO), various local and remote effects on extreme events.

In addition to overall warming, increased evaporation from the ocean's surface has led to local increases of humidity in the lower atmosphere in various regions (Willet *et al*., 2010; Santer *et al*., 2007). Because of the important role of humidity in atmospheric dynamics, weather patterns have changed and, consequently, so has the occurrence of extreme events in various regions.

In this chapter we provide a brief summary of the changes for different natural hazards and the confidence in the detection of change.

2.1 Main drivers of change

Many insurance-relevant hazards show increased loss potential due to the warming of the oceans. The main drivers of change in the loss potential associated with ocean warming are: (i) sea level rise, (ii) an intensified hydrological cycle and (iii) changes in large-scale climatic phenomena like ENSO.

(i) Sea level rise

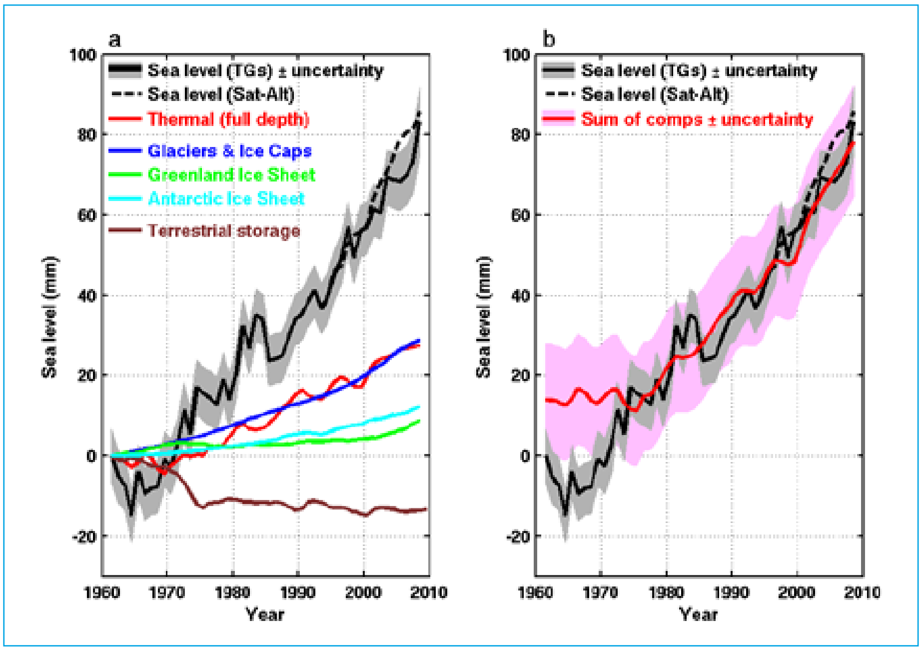
A first and direct consequence of rising OHC is sea level rise. This is not only due to the thermal expansion of the warming ocean water but also to melting continental ice shelves and glaciers. The global sea level has risen roughly 20 cm over the last century and has been rising with accelerated speed since

Erosion caused by rising sea levels due to global warming.

1930 (see Figure 4) (Church and White, 2011). Various mechanisms have already translated higher sea-levels into an increased flood risk in many coastal regions (IPCC, 2012). An indirect effect of sea level rise is an increased impact of storm events, like tropical or extra-tropical cyclones (see 2.2 and 2.3) through an increase in coastal flooding and storm surge. In general, sea level rise decreases the return period of events coastal infrastructure is designed for, e.g. the Dutch dykes or the Thames barrier. Considering all the consequences, sea level rise is probably the major driver of increased risk due to natural catastrophes.

Note that some of the changes in the world's oceans are also linked to certain geophysical risks. Sea level rise, for example, increases the severity of inundation by tsunamis. The probability of the tsunami event itself remains unchanged, but the damage caused is increasing as the sea level rises.

Figure 4: The global sea-level budget from 1961 to 2008. (a) The observed sea level using coastal and island tide gauges and (b) observed sea level and the sum of components.



The global sea-level budget from 1961 to 2008. (a) The observed sea level using coastal and island tide gauges and (b) observed sea level and the sum of components. Source: Church *et al.*, 2011.

(ii) Intensified hydrological cycle

The exchange of energy between ocean and atmosphere is described by an exponential increase in the evaporation from the ocean's warming surface (Yu and Weller, 2007). With enhanced evaporation from the warmer ocean surface, increasing water-holding capacity and a vertical extension of the warming troposphere, the hydrological cycle of the climate system has intensified in many regions. Significant positive trends in specific humidity have been observed for most parts of the globe (Peterson *et al.*, 2011). Increasing amounts of precipitable water in the atmosphere and more energy available for convection have both worked to significantly increase the potential intensity of precipitation events, such as from tropical cyclones or local convective events (Trenberth, 2008; Yang *et al.*, 2011).

A recent study by Min *et al*. (2011) found evidence that the effects of global warming have contributed to the observed intensification of heavy precipitation events found over approximately two thirds of data-covered parts of northern hemispheric land areas. As the average annual rainfall amount has not increased at a rate comparable to extreme events, the variability of precipitation over space and time has significantly increased. Drought periods and flood conditions are both on the rise (IPCC, 2012) resulting in drier dry and wetter wet events.

Brisbane flood, January 2011. Aerial view of homes under water in Australia's worst flooding disaster.

Just as for sea level rise, the intensified hydrological cycle increases the impacts of a variety of extreme events and, thus, is one of the major drivers of changes in the loss potential of natural catastrophes.

(iii) Dominant drivers for large-scale variations in the climate system

Variability and extremes in the atmosphere–ocean system are dominated by different large-scale modes of climate variability. Phenomena like ENSO, the North Atlantic Oscillation (NAO) or different monsoon systems have well-known, dominant, local and remote effects on the variability in extreme events. These modes are very likely to be affected by the warming of the ocean, as they are driven by sensitive ocean–atmosphere interactions. Unfortunately, due to the long timescales of ocean dynamics and the relative short length of observational data, these changes are difficult to detect. The underlying dynamics of these modes are highly complex, and the scientific understanding of them is still far from being complete. Consequently, an estimation of the impacts of the changes in climate modes on catastrophe risk remains a serious challenge and is simply not quantifiable.

2.2 Tropical cyclones

Although issues remain with regard to the quality of historical data records on tropical cyclone activity, there is evidence that increased SSTs have led to an increase in the intensity of the most severe tropical cyclones over the last decades (Emanuel, 2005; Kossin *et al.*, 2007; Elsner *et al.*, 2008). This finding, based on analyses of the latest observations, is consistent with the physical fact that tropical cyclones are powered by the exchange of latent heat between the atmosphere and the warming oceans. Although there is still some debate about the link between global warming and tropical cyclone intensity and even more so with their frequency (Vecchi *et al.*, 2008; Knutson *et al.*, 2010), it is becoming increasingly obvious that the observations describe a non-stationary behaviour of cyclonic activity in the Atlantic as well as in the Pacific (Wang *et al*., 2011).

Another implication of ocean warming is the potential for longer tropical cyclone seasons. This can be observed for example in the North Atlantic, where the increase in SST is most pronounced (Kossin, 2008). A longer hurricane season, starting earlier and ending later, can change some of the storm characteristics and increase the damage potential of cyclone season. There are indications that this is the case for example in the Hurricane Sandy on the U.S. East Coast at the end of October 2012. Sandy's interaction with an extra-tropical upper trough, a phenomenon that is more likely later in the season, helped to increase its damage potential by maintaining the storm's intensity and influencing the cyclone towards making landfall.

Serious damage to the buildings at the Seagate neighbourhood due to impact from Hurricane Sandy in Brooklyn, New York, U.S., on Thursday, 1 November 2012.

The impact of ocean warming on other loss-relevant hurricane characteristics, such as size, genesis potential and location of landfall, is deeply uncertain and, because of the sparse data, it will take some time until a potential signal may appear in observational time series.

However, the damage potential of tropical cyclones has risen not only due to the observed intensification, but also due to the links with sea level rise and the intensified hydrological cycle (see 2.1). Both effects add to the flood risk associated with tropical cyclones by increasing the storm surge and precipitation amounts.

2.3 Extra-tropical winter storms

Due to the amplified warming of the polar oceans, the poleward temperature gradient between the tropics and the poles has decreased. This has an impact on the position of the jet streams and consequently for the main storm tracks of extra-tropical cyclones (ETCs) in both hemispheres. It is likely that these changes have already led to a poleward shift in extra-tropical storm tracks (Berry *et al*., 2011; Wang *et al*., 2012) which has changed the spatial distribution of risk associated with these storms.

A recent analysis of newly available data (Wang *et al*., 2012) suggests that ETC activity has increased slightly over the period 1871–2010 in the Northern Hemisphere with more substantial increases being seen in the Southern

Hemisphere. Notable regional and seasonal variations in trends are evident, as is profound decadal or longer-scale variability. For example, the Northern Hemisphere increases occur mainly in the mid-latitude Pacific and high-latitude Atlantic regions.

Also, the damage potential of ETCs has changed due to a significant positive trend in precipitation as well as their wave heights (IPCC, 2012; IPCC, 2007a). The IPCC Fourth Assessment Report (AR4) reported statistically significant positive trends in wave heights over the period 1950–2002 over most of the mid-latitudinal North Atlantic and North Pacific. Global trends in 99th-percentile satellite-measured wave heights show a mostly significant positive trend of between 0.5 and 1.0 per cent per year in the mid-latitude oceans, but less clear trends over the tropical oceans from 1985–2008. However, some of these trends remain insignificant due to the length of reliable observations (Young *et al*., 2011; Young *et al.*, 2012).

It is important to note that the flood risk of storm surge of ETCs also positively couples with sea level rise and is driven by an intensified hydrological cycle (see 2.1).

2.4 Severe convective storms

Due to issues with observational data for small-scale convective events like tornadoes and hailstorms, it is particularly difficult to detect trends in these events. Findings from existing data sets are uncertain, owing to changes in the observational standards and population densities, as well as high inter-annual variability in the number of severe convective events (Kunkel *et al*., 2012; Doswell *et al*., 2009; Verbout *et al*., 2006).

Since the analysis of raw event data is problematic, research has focused on trends in the large-scale environmental conditions which are favourable for the development of severe convective storms. The overall positive trend in humidity (see 2.1), especially in the lower troposphere, has led to a positive trend in the instability of the atmosphere which is necessary for severe convection to take place. On the other hand, vertical wind shear in higher levels of the atmosphere is another precondition for convective events to happen, and is understood to decrease together with a decreasing poleward temperature gradient. Thus, the necessary condition for increased frequency of convective events is a balance between an increase in lower tropospheric instability and a decrease of vertical wind shear. It is this co-dependence which makes it difficult to detect significant trends in the large-scale environment producing severe thunderstorms (Brooks and Dotzek, 2008).

However, although the overall confidence is medium only, physical understanding and model results consistently indicate an increase in the number and volatility of severe convective events, especially in the U.S. (Trapp *et al*., 2009; Sander *et al*., 2013).

2.5 Uncertain future of the marine ecosystems

Warming of our oceans has a significant influence on their ecosystems. The vitality of many important parts of sensitive ecosystems, like corals or

A field of corals has been bleached as high sea surface temperatures have caused the corals' symbiotic dinoflagellates to exit the corals' tissues. If temperatures do not fall the corals will die.

plankton, are critically dependent on water temperatures as well as levels of acidity, which increase with rising CO_2 concentrations, a phenomenon referred to as ocean acidification. The impacts of ocean warming and acidification affect the whole maritime fauna and flora and have repercussions on ocean productivity, human health, resource management and the tourism industry. Although significant scientific progress has been made in recent years, there are still considerable uncertainties in the implications of ocean warming and acidification on various marine ecosystems. Further research is needed to quantify the potentially huge risks for mankind of warming oceans, including impacts on the ocean's carbon uptake, biodiversity, food security or medical resources. The implications for insurance are, as yet, unclear but could potentially be significant and, therefore, the marine biological response to ocean warming should be monitored.

2.6 Summary: ambiguity[1] in today's hazard probabilities

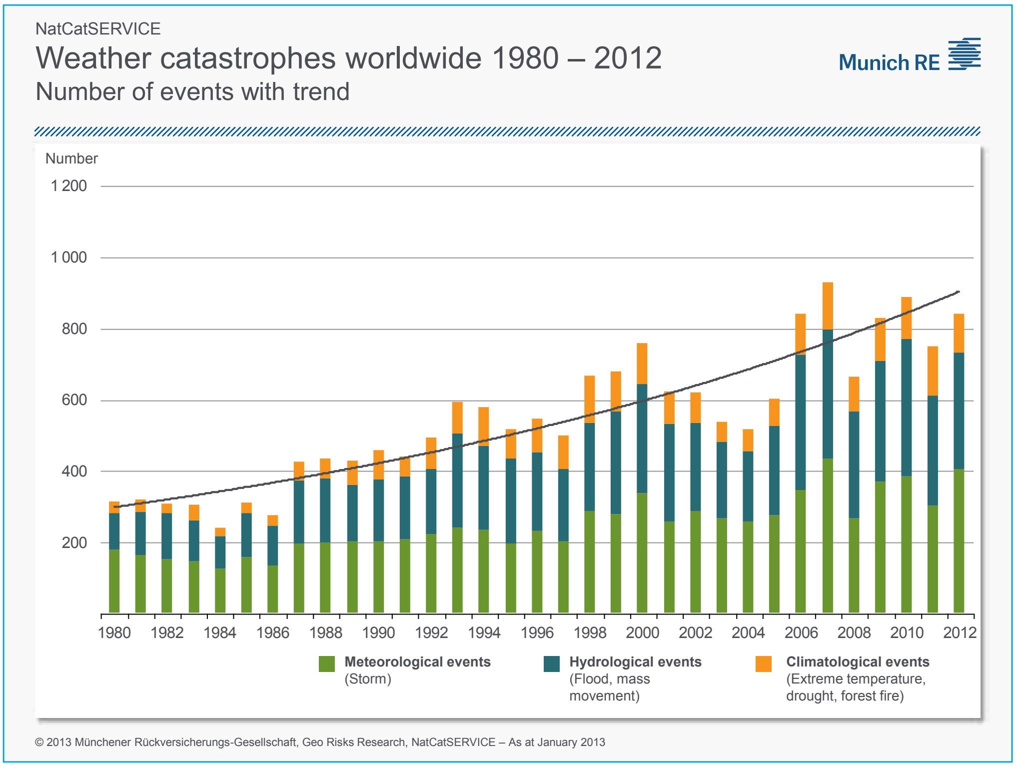
Most impacts of ocean warming on extreme events are qualitatively well understood and, consequently, it is rather obvious that, for many regions, hazard risk can no longer be seen as stationary. Even if they are not yet significant, recent changes in the occurrence of extreme events consistently follow the storyline of the scientific understanding of the impacts of ocean warming. However, it remains a challenge to quantify the changes for any given time frame or region due to data issues, the infrequent occurrence of extreme events and, more generally, the complexity of the climate system. In most cases there is simply not enough data to reasonably estimate a linear trend, and that aside, inherent non-linear coupling and feedback effects in the climate system make the assumption of linearity very likely to fail. For a variety of different hazards, it is uncertain whether apparent trends will progress over time, or whether they are part of the stochastic nature of the climate system. Ranger and Niehörster (2012, Appendix A. Supplementary data) demonstrate how this leads to an inability to accurately estimate current risk levels.

An alternative approach to traditional data-based methods in a transient environment is to move from the current historic to predictive risk estimation methods. These forward-looking approaches have the potential to overcome the data issues in the estimation of current likelihoods of extreme events. The available tools are time-dependent model forecasts which incorporate the improved observations of changes in the ocean and simulate its likely influence

1 It is important for this paper to understand the meaning of ambiguity. Ambiguity in this paper describes the inability to assign probabilities to future events with a satisfactory precision. Walker and Dietz provide a formal, mathematical definition of ambiguity (Walker and Dietz, 2012). Note that the concept of ambiguity applies whenever there is Knightian uncertainty (Knight, 1921), but Knightian uncertainty doesn't necessarily imply ambiguity since decision-makers might still treat Kightian uncertainty as if it was risk.

on the short- to medium-term future. Such time-dependent or medium-term outlooks, which go beyond historical averages, are already provided by commercial model vendors, such as Risk Management Solutions (RMS). These products represent, at least in principal, a significant improvement over simple long-term averages of historical data.

Figure 5



Also, an increasing number of weather and research centres around the world offer seasonal to multi-year forecast products based on global numerical weather models (GCMs or general circulation models), which build the basis of the medium-term outlook as part of the upcoming 5th IPCC assessment report on climate change. GCMs are cost-intensive simulation tools, as they need to be high-resolution coupled atmosphere–ocean models running in ensemble mode, and intend to incorporate the physical changes in the climate system.

Unfortunately, time-dependent, model-based estimates of hazard probabilities also come with significant uncertainties, arising from general model imperfections, their numerical structure and parameter estimation problems inherent in models of high-dimensional chaotic systems (Smith, 2002). There remain challenges with the underlying model assumptions as well as with the historical data (Niehörster and Murnane, 2012) which lead to alternative and maybe equally likely views and have caused substantial intra-model and inter-model differences. This uncertainty is irreducible, which by no means implies that the existing models are not useful or scientifically sound. It rather reflects the limits of the scientific understanding and the ability to predict extreme events in a chaotic system.

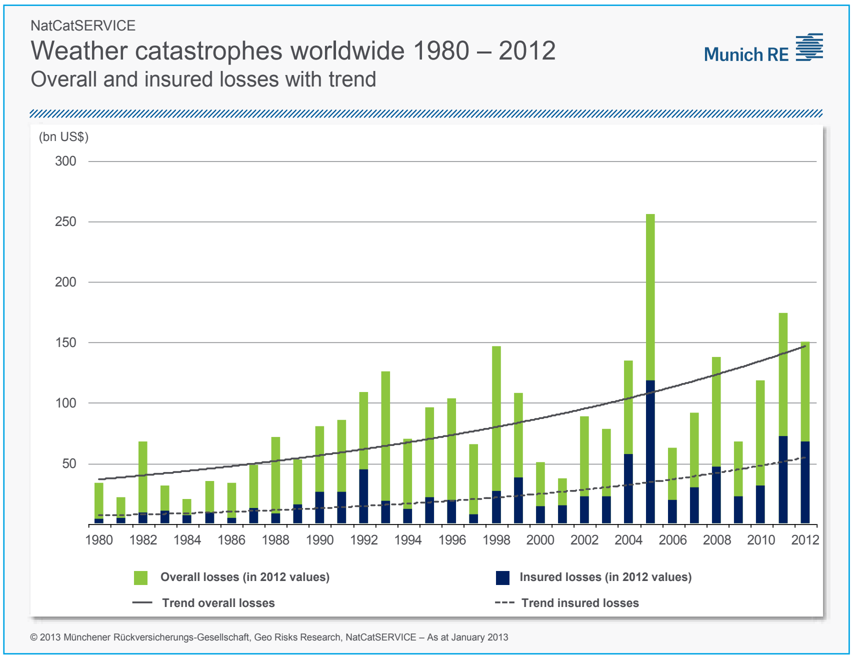
In summary, the lack of historical and observational data and the existence of competing theories formalised in competing forecasting models, leads to a multitude of different answers for the return periods of certain extreme events in today's transient environment. Unfortunately, it is difficult to assign confidence or the probability of one answer being better than the other, a situation which can be described as ambiguity. It is characterised by a secondary uncertainty in the shape of the probability distribution function (PDF) rather than the lack of knowledge of where exactly in the PDF next year might fall.

3 Impact of ocean warming on the global insurance industry

There is a significant upward trend in the insured losses caused by the extreme weather events discussed in Chapter 2 (see Figure 6). This is true for primary insurance, which is impacted by an increasing attritional loss burden caused by severe local weather events, as well as for reinsurance losses caused by large-scale catastrophic extreme events. There is broad agreement among experts that this global trend in economic as well as insured losses from natural disasters is primarily driven by socio-economic factors (e.g. Bouwer, 2011; Neumayer and Barthel, 2011). However, the serious challenge to adequately estimate present-day hazard risks, which follows from ocean warming, puts additional pressure on a market that is already facing the stress of upward trends in absolute disaster loss.

As a consequence of ocean warming and global change, the return periods for a number of high-loss extreme events are ambiguous rather than simply uncertain. Furthermore, this is true also for the timing of loss claims and the correlations of losses within portfolios. This has direct implications for the financial risk in catastrophe insurance, appropriate levels of capital requirement and the pricing of insurance premiums.

Figure 6



On a more general level, there are growing concerns about the indirect impact of changes in the risk landscape which question the sustainability of the catastrophe risk business in many countries. For some regions, the combination of rising risk levels and a heavily regulated market might lead to decreasing commercial viability. One option to address the insurability challenges of rising risk levels is to engage in efforts to couple risk transfer to risk reduction.

This chapter provides an overview of the responses in internal risk management strategies (3.1) and potential strategies to help improve risk reduction measures (3.2).

3.1. Internal: risk management strategies under ambiguity

Evidence for a non-stationary environment of natural catastrophes raises the important question of how risk management strategies can reflect the ambiguity about the changes of the underlying risk, ensure adequate pricing strategies and set a robust capital requirement.

It is clear that a continuous use of simple stationary climatological approaches to quantify probabilities of extreme events, in combination with expected utility-based methods to quantify financial risk, will increasingly fail in the presence of ocean warming. In the future, this might be reason enough for rating agencies to penalise companies which fail to address these issues in the enterprise risk management.

As it will be impossible to exactly predict the behaviour of the atmosphere and ocean in the medium term (see 2.7), it will be vital for risk management to amend any multi-model probabilistic modelling with defined and deterministic scenarios that reflect the wide range of plausible developments (Swiss Re, 2009; Davis, 1998). A rigorous scenario approach improves the knowledge of the (tail) value at risk (TVaR)[2] where existing models might fail. Although the scenario approach is traditionally used primarily for long-term planning purposes, in the current environment it has become an important part even in short-term risk management.

The selection of scenarios should include a reasonably wide range of hypothetical but scientifically justifiable scenarios, including an upper limit defining the worst case. Alongside hypothetical scenarios, a set of scenarios should also include all available and scientifically justifiable models (e.g. Ranger and Niehörster, 2012). It is important to note that stress-testing a single model is not sufficient to cover the range of potential future outcomes, as the structure of this particular model might not allow the full exploration of all plausible events.

The need for an unbiased set of scenarios has the potential to change the risk modelling business substantially. The structural limitation of a single model to produce the full range of potential outcomes makes it desirable to have a platform in which components of risk models, such as event sets or vulnerability functions, can be exchanged in a modular way rather than stress-testing a monolithic model. Although there remain technical challenges, the development of platforms showing the potential to facilitate such an approach is underway. Not only commercial risk model vendors but also public open-source platforms

2 The TVaR quantifies the expected loss caused by an event below a certain probability level (Sweeting, 2011).

are currently developing the necessary infrastructure for rigorous scenario approaches.

An unbiased set of scenarios can be used for the pricing of ambiguous insurance contracts and estimating the associated TVaR. The existing ambiguity about the hazard occurrence, or in other words, the unknown probabilities of the realisation of certain scenarios, precludes the usage of expected utility-based approaches (Savage, 1954). Nevertheless, other methods of decision theory provide rational ways to adjust the capital requirements for any additional ambiguity load and the price for ambiguous insurance contracts (Walker and Dietz, 2012).

In general, ambiguity leads to increased capital requirements for constant probability of ruin (0.005 for Solvency II) when compared to a well-quantified risk in a portfolio. However, the additional capital requirement will depend on the belief over the set of scenarios and the preferences for ambiguity levels of the decision-maker. The price of ambiguous contracts will actually depend on the distribution of scenarios, which might, for example, all predict the same variance in losses, but differ in the annual average loss (AAL). For a given portfolio, the characteristics of the scenario distribution will decide if the prices for ambiguous insurance contracts should be higher or lower relative to a situation with no ambiguity.

3.2. External: maintaining insurability through promoting risk mitigation

As shown, ocean warming implies that the threat of natural catastrophes is ambiguous. At the same time, it can be shown that the ambiguity aversion of rational individuals may increase self-insurance but decrease self-protection (Alary *et al.*, 2010). The interplay between the potential of rising risk levels and insurance demand, but decreasing self-protection, could create a risk environment that is uninsurable in some regions (Herweijer *et al*., 2009). Examples for markets with this potential are U.K. flood or Florida wind storm insurance.

In general, the only way to ensure that ambiguous risks remain insurable is to promote risk mitigation today (Ranger and Surminski, 2012). The insurance industry should play an active role in raising awareness of risk and climate change through risk education and disseminating high-quality risk information (Ward *et al*., 2008). In addition, there is real benefit for the industry in supporting and encouraging adaptation through innovative product design. This can and should be done in collaboration with local authorities through engagement in public–private cooperation. This will, as well as enhancing reputation, lead to a more resilient building stock and an overall reduction of risk.

On the investment side, there are new market opportunities associated with the transition to a low-carbon economy. Investment in innovation and global capacity-building for new energy technologies and infrastructure does not only promise good returns but also contributes to the reduction of greenhouse gas emissions which will ultimately create a more resilient society. To support this transition, the industry should use its unique knowledge base to inform the debate on climate change and actively lobby government to take action to reduce risks and curb emissions of greenhouse gases.

These actions, alongside the support of science in tackling the major challenges in projecting the impacts of ocean warming and climate change more generally, will help the insurance industry to avoid market failures and increase societal resilience.

Abbreviations

AAL	annual average loss
CAPE	convective available potential energy
ERM	enterprise risk management
ENSO	El Niño Southern Oscillation
ETC	extra-tropical cyclone
GCM	general circulation model
GHG	greenhouse gas
IPCC	International Panel on Climate Change
NAO	North Atlantic Oscillation
OHU	ocean heat uptake
OHC	ocean heat content
PDF	probability distribution function
SST	sea surface temperature
TVaR	tail value at risk

Bibliography

Alary, D., Gollier, C. and Treich, N. (2012) *The Effect of Ambiguity Aversion on Insurance and Self-protection*, final version of a paper presented at the World Risk and Insurance Economics Congress, 25–29 July 2010 in Singapore.

Arndt D.S., Baringer, M.O. and Johnson, M.R. (eds) (2010) "State of the Climate in 2009", *Special Supplement to the Bulletin of the American Meteorological Society*, 91(7): S1–S224.

Berry, G., Jakob, C. and Reeder, M. (2011) "Recent global trends in atmospheric fronts", *Geophysical Research Letters*, 38(21), L21812.

Blunden, J., Arndt, D. S. and Baringer, M.O. (eds) (2011) "State of the Climate in 2010", *Bulletin of the American Meteorological Society*, 92(6): S1–S266.

Bouwer, L. M. (2011) "Have Disaster Losses Increased Due to Anthropogenic Climate Change?", *Bulletin of the American Meteorological Society*, 92(1), 39–46.

Brooks, H. E. and Dotzek, N. (2008) "The spatial distribution of severe convective storms and an analysis of their secular changes", in H.F. Diaz and R. Murnane (eds) *Climate Extremes and Society*, Cambridge: Cambridge University Press, pp. 35–53.

Church, J.A. et al (2011) "Revisiting the Earth's sea-level and energy budgets from 1961 to 2008", *Geophysical Research Letters,* 38(18).

Church, J.A. and White, N.J. (2011) "Sea-Level Rise from the Late 19th to the Early 21st Century", *Surveys in Geophysics*, 32(4–5): 585–602.

Davis, G. (1998) *Creating Scenarios for Your Company's Future*, paper presented at the 1998 Conference on Corporate Environmental, Health and Safety Excellence: Bringing Sustainable Development Down to Earth, New York City, 28 April 1998.

Domingues, C.M., Church, J.A. White, N.J., Gleckler, P.J., Wijffels, S.E., Barker, P.M. and Dunn J.R. (2008), "Improved estimates of upper-ocean warming and multi-decadal sea-level rise", *Nature*, 453, 1090-1094, doi:10.1038/nature07080.

Doswell III, C. A., Brooks, H. E. and Dotzek, N. (2009) "On the implementation of the enhanced Fujita scale in the USA", *Atmospheric Research,* 93(1–3): 554–563.

Elsner, J.B., Kossin, J.P. and Jagger, T.H. (2008) "The increasing intensity of the strongest tropical cyclones", *Nature* 455(7209): 92-95.

Emanuel, K. (2005) "Increasing destructiveness of tropical cyclones over the past 30 years", *Nature*, 436(7051): 686–688.

Gleckler P.J., Santer, B.D., Domingues, C.M., Pierce, D.W., Barnett, T.P., Church, J.A., Taylor, K.E., AchutaRao, K.M., Boyer, T.P., Ishii, M. and Caldwell, P.M. (2012) "Human-induced global ocean warming on multidecadal timescales", *Nature Climate Change*, 2: 524–529.

Hansen, J., Nazarenko, L., Ruedy, R., Sato, M., Willis, J., Del Genio, A., Koch, D., Lacis, A., Lo, K., Menon, S., Novakov, T., Perlwitz, J., Russell, G., Schmidt, G.A. and Tausnev, N. (2005) "Earth's Energy Imbalance: Confirmation and Implications", *Science*, 308(5727): 1431–1435.

Herweijer, C., Ranger, N. and Ward, R.E.T. (2009) "Adaptation to Climate Change: Threats and Opportunities for the Insurance Industry", *The Geneva Papers on Risk and Insurance—Issues and Practice*, 34(3): 360–380.

IPCC (2012) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen,M. Tignor, and P.M. Midgley (eds.)). Cambridge and New York: Cambridge University Press.

IPCC (2007a) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007b) *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]Geneva: IPCC.

Ishii, M. and Kimoto, M. (2009) "Reevaluation of historical ocean heat content variations with time-varying XBT and MBT depth bias corrections", *Journal of Oceanography*, 65(3): 287–299.

Knight, F. H. (1921) *Risk, Uncertainty, and Profit*. Boston, MA: Hart, Schaffner & Marx; Houghton Mifflin Company

Knutson, T.R., McBride, J.L., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J.P., Srivastava, A.K. and Sugi, M. (2010) "Tropical cyclones and climate change", *Nature Geoscience* 3(3): 157–163.

Kossin, J.P. (2008) "Is the North Atlantic hurricane season getting longer?", *Geophysical Research Letters*, 35(23), L23705.

Kossin, J. P., Knapp, K. R., Vimont, D. J., Murnane, R. J. and Harper, B. A. (2007) "A globally consistent reanalysis of hurricane variability and trends", *Geophysical Research Letters*, 34(4), L04815.

Kunkel, K.E., Karl, T.R. Brooks, H., Kossin, J., Lawrimore, J.H., Arndt, D., Bosart, L., Changnon, D., Cutter, S.L., Doesken N., Emanuel, K., Groisman, P.Y., Katz, R.W., Knutson, T., O'Brien, J., Paciorek, C.J., Peterson, T.C., Redmond, K., Robinson D., Trapp, J., Vose, R., Weaver, S., Wehner, M., Wolter, K. and Wuebbles, D. (2012) "Monitoring and Understanding Trends in Extreme Storms: State of Knowledge", *Bulletin of the American Meteorological Society*, (AOP) doi: http://dx.doi.org/10.1175/BAMS-D-11-00262.1.

Levitus, S., Antonov, J., Boyer, T. and Stephens, C. (2000) "Warming of the World Ocean", *Science*, 287(5461): 2225–2229.

Levitus, S., Antonov, J. I., Boyer, T.P., Baranova, O.K., Garcia, H.E., Locarnini, R.A., Mishonov, A.V., J.R., Seidov, D., Yarosh, E.S. and Zweng, (2012) "World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010", *Geophysical Research Letters,* 39(10), L10603.

Min, S.-K., Zhang, X., Zwiers, F.W. and Hegerl, G.C. (2011) "Human contribution to more-intense precipitation extremes", *Nature*, 470(7334): 378–381.

Muller, R.A. (2012) "The Conversion of a Climate-Change Skeptic, *The New York Times*, The Opinion Pages, 28 July.

Neumayer, E. and Barthel, F. (2011) "Normalizing economic loss from natural disasters: A global analysis", *Global Environmental Change*, 21 (1): 13–24.

Niehörster F. and Murnane, R. (2012) "Medium-term rates of hurricane landfalls in RMS [Risk Management Solutions] RiskLink v11.0", *RMS Workshop Proceedings—Outcomes of a Scientific Assessment*, RPI Members Report No1/2012, n.p.: Risk Prediction Initiative.

Palmer, M. .D. *et al*. (2010). "Future Observations for Monitoring Global Ocean Heat Content", in J. Hall, D.E. Harrison, and D. Stammer (eds) *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society* (Vol. 2), Venice, Italy, 21-25 September 2009, ESA Publication WPP-306.

Palmer M.D., Haines, K., Tett, S.F.B. and Ansell, T.J. (2007) "Isolating the signal of ocean global warming", *Geophysical Research Letters*, 34(23), L23610.

Peterson, T.C., Willett, K.M. and Thorne , P.W. (2011) "Observed changes in surface atmospheric energy over land", *Geophysical Research Letters*, 38(16), L16707.

Ranger, N. and Niehoerster, F. (2012) "Deep uncertainty in long-term hurricane risk: Scenario generation and implications for future climate change experiments", *Global Environmental Change*, 22(3): 703–712. Appendix A. Supplementary data, available at *http.//dx.doi.org/10.1016/j.gloenvcha.2012.03.009*

Ranger N., Surminski, S. (2012) "A preliminary assessment of the impact of climate change on non-life insurance demand in the BRICS economies", *International Journal of Disaster Risk Reduction*, 3 (March): 14–30.

Sander, J., Eichner, J.F., Faust, E. and Steuer, M. (2013) "Rising variability in thunderstorm-related U.S. losses as a reflection of changes in the large-scale thunderstorm forcing", *Weather, Climate and Society*, (AOP).

Santer, B.D., Mears, C., Wentz, F.J., Taylor, K.E., Gleckler, P.J., Wigley, T.M.L., Barnett, T.P., Boyle, J.S., Bruggemann, W., Gillett, N.P., Klein, S.A., Meehl, G.A., Nozawa, T., Pierce, D.W., Stott, P.A., Washington, W.M. and Wehner, M.F. (2007) "Identification of human-induced changes in atmospheric moisture content", *Proceedings of the National Academy of Sciences of the United States of America*, 104(39): 15248–15253.

Savage, L. (1954) *The Foundations of Statistics*, New York: John Wiley and Sons.

Smith, L. A. (2002) "What might we learn from climate forecasts?", *Proceedings of the National Academy of Sciences of the United States of America*, 99 (Suppl.): 2487–2492.

Sweeting, P. (2011) "15.4 Risk Measures", in *Financial Enterprise Risk Management*, International Series on Actuarial Science, New York: Cambridge University Press, pp. 397–401.

Swiss Re (2009) *Scenario analysis in insurance,* sigma, 1/2009.

Trapp, R. J., Diffenbaugh, N. S. and Gluhovsky, A. (2009) "Transient response of severe thunderstorm forcing to elevated greenhouse gas concentrations", *Geophysical Research Letters*, 36(1), L01703.

Trenberth, K. E., (2008) "The Impact of Climate Change and Variability on Heavy Precipitation, Floods, and Droughts", *The Encyclopedia of Hydrological Sciences*, Chichester, U.K.: John Wiley & Sons, Ltd.

Tu, J.-Y., Chou, C. and Chu, P-S. (2009) "The Abrupt Shift of Typhoon Activity in the Vicinity of Taiwan and Its Association with Western North Pacific–East Asian Climate Change", *Journal of Climate*, 22(13): 3617–3628.

Vecchi, G.A., Swanson, K.L. and Soden, B.J., (2008) "Whither hurricane activity?", *Science*, 322(5902): 687–689.

Verbout, S. M., Brooks, H. E., Leslie, L. M. and Schultz, D. M. (2006) "Evolution of the U.S. Tornado Database: 1954-2003", *Weather and Forecasting*, 21(1), 86–93.

Walker, O. and Dietz, S. (November 2012) *Ambiguity and insurance: robust capital requirements and premiums*, Working Paper No 97, London, U.K.: Grantham Research Institute.

Wang, Ruifang, Wu, Liguang and Wang, Chao (2011) "Typhoon Track Changes Associated with Global Warming", *J. Climate*, 24(14): 3748–3752.

Wang, X.L., Feng, Y., Compo, G. P., Swail, V. R., Zwiers, F. W., Allan, R. J. and Sardesmukh, P.D. (2012) "Trends and low frequency variability of extra-tropical cyclone activity in the ensemble of Twentieth Century Reanalysis", *Climate Dynamics.*

Ward, R.E.T, Herweijer, C., Patmore, N. and Muir-Wood, R. (2008) "The role of Insurers in Promoting Adaptation to the Impacts of Climate Change", *The Geneva Papers on Risk and Insurance—Issues and Practice*, 33(1): 133–139.

Willett K. M., Alexander, L. V. and Thorne, P. W. (eds) (2010) "Global Climate" in "State of the Climate in 2009", *Bulletin of the American Meteorological Society* , 91 (7): S19–S53.

Yang, M.-J., S. A. Braun and D.-S. Chen (2011) "Water Budget of Typhoon Nari (2001)", *Monthly Weather Review*, 139(12) 3809–3828, doi: 10.1175/MWR-D-10-05090.1.

Young, I.R., Babanin, A.V. and Zieger S. (2011) "Global Trends in Wind Speed and Wave Height", *Science*, 332(6028): 451–455.

Young, I.R., Vinoth, J., Zieger, S. and Babanin, A.V. (2012) "Investigation of trends in extreme value wave height and wind speed", *Journal of Geophysical Research*, 117(C3), C00J06, doi:10.1029/2011JC007753.

Yu, L., and Weller, R. A. (2007) "Objectively Analyzed Air–Sea Heat Fluxes for the Global Ice-Free Oceans (1981–2005)", *Bulletin of the American Meteorological Society*, 88(4): 527–539.

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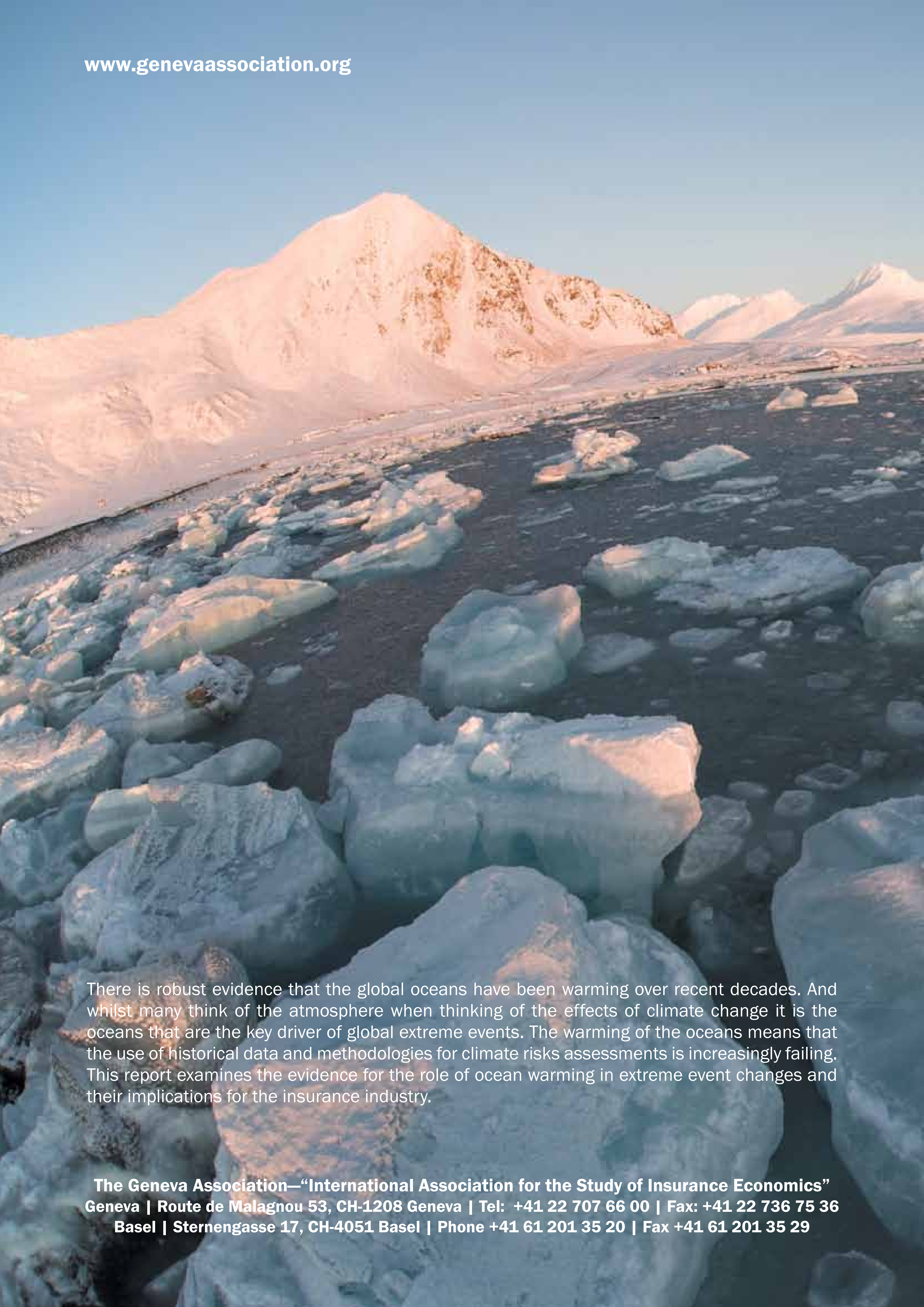

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There is robust evidence that the global oceans have been warming over recent decades. And whilst many think of the atmosphere when thinking of the effects of climate change it is the oceans that are the key driver of global extreme events. The warming of the oceans means that the use of historical data and methodologies for climate risks assessments is increasingly failing. This report examines the evidence for the role of ocean warming in extreme event changes and their implications for the insurance industry.

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