White Paper:

Essential Background for Understanding Climate Change and Associated Business Risks
Climate change is a growing global concern. Warming of the planet has been observed over the past century.

Extreme weather events have been occurring more frequently than natural variability would suggest. Awareness of these conditions and the ramifications of drought, flooding, extreme temperatures, and intense storms can help reduce the prospect of disruptions to global businesses. This paper reviews new data on climate change and points out trends that businesses need to consider in their risk assessments.

Climate change could have an adverse effect on business continuity, profitability, and workplace safety. This paper highlights recent and oncoming changes, so that businesses can plan for growth and expansion through greater risk awareness.
According to the National Center for Atmospheric Research, the percentage of Earth’s surface suffering drought has more than doubled since the 1970s. In Africa alone, the IPCC projects that between 75 and 250 million people will be exposed to increased water stress due to climate change.

The last significant volcano to cause cooling was in 1991, when Mt. Pinatubo erupted in the Philippines.

Greenhouse gas emissions have increased since the Industrial Revolution. CO₂, which was estimated to account for 82 percent of U.S. greenhouse emissions in 2015, has demonstrated a steady global increase.

The Atlantic Ocean has been in a warm cycle since 1995, which may have contributed to some of the warming observed in the United States, as well as the arctic region.
In order to understand how the climate is changing, it is important to first understand the distinction between climate and weather. Weather refers to atmospheric conditions over a short period of time (minutes, days, or weeks). Climate is the average weather in a particular location or region over many years. Climate is also defined by the range of possible weather conditions that have been observed in the past. The real difference between weather and climate is time. To coin a phrase, “climate is what you expect and weather is what you get.”

Understanding changes in day-to-day weather requires information about the current state of the atmosphere. Weather is said to be an “initial condition” problem. The weather of tomorrow or a few days into the immediate future is dependent upon the weather today or a few days ago. Climate, on the other hand, is dependent on “forcing conditions” that vary on a global basis. Forcing conditions include the position, and surface composition of, the continents, the extent of the polar ice caps and tropical rain forests, the strength of solar energy, and the amount of atmospheric gases that affect atmospheric radiation through absorption or emission (e.g., carbon dioxide). The forcing conditions dictate the climate of any time period, which is made up of the day-to-day weather patterns that occur during that time.

Climate is rarely static. Change is a normal part of the evolving earth process. Climate varies on seasonal, annual, decadal, centennial, and longer time scales. Since the time that Earth formed an atmosphere, the climate has shifted in cycles. The planet makes adjustments to internal and external influences. When these changes are minor or gradual over time, plants and animals adapt. When climatic changes are swift, or if change occurs in too large an increment,

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the land’s ability to support the changes is impacted, as are the civilizations that inhabit the land. This is why climate change is a concern. As the population grows and more susceptible areas of the globe are impacted by climatic shifts, people may need to adapt or relocate if the change continues in an adverse direction.

A century of warming

The past two decades have seen a dramatic increase in societal awareness regarding the implications of climate change. Many datasets have been examined in an attempt to construct an accurate history of the planet’s temperatures. On a global basis, warmer temperatures have been found to be more prevalent. While there is still some debate on the methods and quality of some of the measurements, clear evidence exists that the Earth’s surface temperatures have risen from the early 20th century to the present time.

Estimates show that the global climate has warmed 1.4 degrees Fahrenheit (0.8 degrees Celsius) since 1901.\(^1\) Much of the climate debate is centered on how changes in the “forcing conditions” are causing this warming. Specifically, the discussion is whether it is a natural or human-influenced climate variation. While both arguments may be correct, how much each of these factors influences the observed warming over the past century is still in question.

Natural causes of climate variability

The natural causes of climatic variability and fluctuation are many. These are most visible on a seasonal basis, with influences from El Niño/La Niña cycles (also known as ENSO). These equatorial Pacific Ocean water temperature cycles influence atmospheric circulation patterns. Wetter/drier and

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warmer/colder patterns emerge when these seasonal events shift the prevailing jet stream winds over parts of the globe. An El Niño or La Niña might change annually, from one phase to the other, or on occasion, repeat for another year or two. Each phase can cause a variation of the seasonal climate for many parts of the globe. Another seasonal influence that operates closer to a monthly timescale is the North Atlantic Oscillation (NAO). This upper-level circulation pattern in the polar latitudes can produce abnormally warm or cold periods over large parts of North America. Figure 2 shows winter temperature departure patterns that result from the combined effects of the NAO and ENSO.

Larger sections of the Pacific and Atlantic Oceans have longer, more slowly-evolving temperature cycles that last for several decades. These periods of abnormal oceanic warmth or coolness have longer-lasting, measured impacts on the temperature and rainfall patterns over land areas, including North America.

The Atlantic Ocean has been in a warm cycle since 1995, which may have contributed to some of the warming observed in the United States, as well as the arctic region. When this cycle potentially reverses, which is estimated to occur within the next decade, this warming influence could disappear for many areas in the Northern Hemisphere, including the United States and Europe. These multi-decadal cycles in the Atlantic and Pacific tend to reverse about every 25-30 years and are often not in phase with one another. The current warm phase in the Atlantic also contributes to more tropical cyclone development in the Atlantic Basin during the warm season.

Volcanic eruptions can also influence the climate for a year or two after an event. Small sulphuric acid particles are ejected upward into the high atmosphere, and can linger for long periods, reflecting sunlight back into outer space. Large volcanic eruptions in the tropical latitudes have a net cooling effect on the planet.

The last significant volcano to cause cooling was in 1991, when Mt. Pinatubo erupted in the Philippines. It had a measured cooling influence on the climate for the next one to two years. Volcanic eruptions are the wild card in climate change — impossible to predict, but which can have a large, albeit temporary, influence on weather and climate.
Another source for natural climate change is one of Earth’s most important sources of energy — the sun. The sun operates on several cycles, with the 11-year solar cycle being the most recognized. During this cycle, the number of sunspots can vary significantly between its peak and trough. However, the amount of energy from the sun varies only minutely, estimated to be only 0.1 percent over the course of the cycle.\(^2\) The current cycle has been unusually weak since the previous peak in 2001. After reaching its most recent peak in 2014, the sunspot cycle has been in a steady decline and is projected to arrive at the minimum within a few years (see Figure 4).

Some researchers suggest this weakness will rival the late-1800s, when both sunspot numbers were low and global temperatures were cold. The solar cycle’s role in climate is still not well understood, but linkages to polar circulation patterns are an area in need of further research. This linkage could be related to the variation in ultraviolet radiation emitted by the sun, which has been observed to vary by approximately 1.5 percent during the 11-year cycle.

**Human influences**

Humans can impact the climate in various ways. One of the more significant influences includes land use changes. Modification of the landscape can play a large role in altering the local and regional climate. Humans have been involved in this practice for centuries. Deforestation, agriculture, and urbanization change the landscape’s surface. Replacing a forest with a city or bare soil raises the temperature of the land due to better heat absorption and/or retention. Planting crops and expanding agriculture tends to cool the area, especially when irrigated.\(^3\) Practices such as deforestation also serve to remove natural biological storage units or sinks of carbon dioxide.

Large tracts of land around the globe have undergone measureable changes over the past century, which has undoubtedly modified temperature patterns. In addition, a practice to expand usable croplands has been the installation of drainage tiling to remove water from flood-prone acreage. This technique increases the amount of run-off into streams and rivers however, heightening the risk of flooding as rivers are required to manage a greater volume of water.

Greenhouse gases, those gases in the atmosphere that keep heat from escaping into space, also play an influential role. The most abundant of the greenhouse gases is water vapor (~95 percent) and it is naturally occurring. Warmer temperatures can increase the water vapor content in the atmosphere, yielding more clouds and precipitation. Carbon dioxide (CO2) is a smaller component (~4 percent) of the total greenhouse gas inventory in the atmosphere, with both natural and human-assisted methods of release into the atmosphere.

The addition of greenhouse gases into the atmosphere, known as greenhouse gas emissions, is both a natural and man-made process. Natural processes may include decomposition, ocean release, respiration, and volcanic eruptions. The majority of human-sourced greenhouse gas emissions come from burning fossil fuels to produce energy. Transportation, industrial processes, cement

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production, and agricultural practices also contribute to greenhouse gas emissions. Even though CO2 and other greenhouse gases are small in terms of their total percentage, they have a much greater impact on trapping heat from escaping into space, which is why they are of concern.4

Greenhouse gas emissions have increased since the Industrial Revolution, mostly due to the conversion of stored carbon to sources of energy. CO2, which was estimated to account for 82 percent of U.S. greenhouse emissions in 2015,5 has demonstrated a steady global increase as shown in Figure 5. CO2 has an estimated residence time in the atmosphere of 400 years,6 so it is only very slowly removed by natural processes once it is introduced into the atmosphere. Even though man-made emissions are only a small part of the total planetary emissions each year, the long residence time of CO2 has a cumulative effect.

Methane is another greenhouse gas that originates from decomposition of plant and animal waste. Although it is a small component of the atmosphere, it is a more effective greenhouse gas. Warming in the arctic regions has contributed to an increased release of methane from both seabed ice and land-based permafrost. Nitrous oxide produced from soil cultivation, fertilizers, and biomass burning (all driven by land use changes) is another powerful greenhouse gas. Chlorofluorocarbons (CFCs) are also a greenhouse gas. CFCs have been shown to destroy the ozone in the upper layers of the atmosphere, and are now globally regulated.

Figure 6 illustrates a representation of 2010 global CO2 emissions, allocated to a spatial grid of 0.1 x 0.1 degree. The emissions are derived from country and sector data. The image demonstrates that CO2 emissions are a global issue. Regions with higher industrial production stand out with greater release rates of CO2. Population and industrial growth in emerging regions of the globe will likely continue to increase the total amount of CO2 that will be emitted into the atmosphere in future years.

Figure 7 (Hannah Ritchie and Max Roser, 2017) illustrates the historical trends of CO2 emissions by country or region as population, industrial and carbon reduction changes evolve over time.

Changing volatility

While much has been learned about how the climate system works, many questions remain unanswered. Many forces, both natural and man-made, can affect the climate, but quantifying those influences and accurately projecting them into the future with climate models is a work in progress. What may be a more significant and observed change, which has been detected in recent years, is the increased volatility of the climate system. Extreme events have become more frequent than natural variability would suggest. Researchers are just starting to examine aspects of a more volatile climate system, but observations have shown the following in some regions of the globe:

- Increased tendency for periods of extreme dryness or wetness
- Extended intervals of either abnormally warm or cold weather
- Higher rainfall totals during the heaviest rain events
- More focused periods of severe weather
- Extension of the warm season
- More common episodes of extreme warmth, but extreme cold still occurs

Attempts to quantify the notion that the climate is producing more extreme weather conditions can be difficult. Taking a single event, such as Hurricane Sandy or Harvey, and attributing it to a changing climate cannot be directly linked. Examining a range of extreme events and comparing them to past decades is one way to measure if these episodes have a higher frequency in more recent times.

Figure 8 is plot of the Climate Extremes Index for the United States. It illustrates the percentage of U.S.-recorded extreme events each year, from a set of more than 1,100 U.S. weather stations, available since 1910. Extreme events in this index include extreme temperatures, severe drought, rainfall totals in the top 10 percent of events, and prolonged dry periods. The chart shows an upward trend in these extreme events since 1970, impacting a greater portion of the United States in recent decades. This follows a period in the middle portion of the last century, which experienced fewer extreme cases across the country.

A very important feature of Earth’s climate system is the difference in temperatures between the tropical and arctic regions. Cold arctic temperatures ensure air pressure in this region is lower than in the tropics, and this causes the west- to-east winds we see in both the northern and southern hemisphere. As the earth warms, however, the polar ice caps recede and the arctic regions warm substantially more than tropical regions, reducing the temperature difference. This effect is having important impacts on global climate. Emerging research has shown that the more extreme events tend to occur when weather patterns slow down or stall over an area. Events, such as the droughts of 2011 and 2012 in the central United States, and the severe drought in Russia in 2010, occurred when high-pressure systems remained anchored over those areas for several months. The extreme drought in California in 2014 and 2015 is another recent example. Very heavy precipitation ended this drought by early 2017.

7. Thomas C. Peterson, Peter A. Stott and Stephanie Herring, Editors, 2012 Explaining Extreme Events of 2011 From a Climate Perspective: http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00021.1
The severe cold that occurred over Europe in recent winters, over Alaska in 2011 and 2012, and over the central and eastern United States in 2014 and 2015, was a result of blocked or stalled circulation patterns that kept the coldest air locked in place, instead of more transient weather patterns changing the air masses from time to time. The cold springs of 2013 and 2014, which impacted the central and eastern United States, are more recent examples of conditions resulting from blocked weather features.

Extreme rainfall events occur when weather systems slow down or stall over an area leading to unrelenting rainfall. August 2017 produced two such examples with over 9" of rain near Kansas City one night and over 50" or rain in the Houston area from nearly stationary Hurricane Harvey.

This link to enhanced arctic warming could help explain some of the causes of recent anomalous weather patterns, such as heat waves, cold, excessive rainfall, and droughts. Extreme weather events have always occurred throughout history, but these recent more active trends seem to suggest that more will occur, and develop more frequently. The increased frequency and duration of blocking weather patterns observed recently could be a response of the climate system to warming, but that is difficult to assess with certainty. Its occurrence however, appears to be having more wide-ranging impacts worldwide.

**Impacts of increased climate volatility**

While no absolute answers are yet available on the changing climate, recent trends suggest an increase in more extreme events. These impacts will not be uniformly distributed across the globe, or evenly spaced in time. Instead they will be focused on regional or smaller areas, and will occur with increasing frequency.

**Increased flooding**

The 2014 IPCC AR5 Assessment Report concluded that the frequency and intensity of heavy rain events have increased in Europe and North American. Excessive rainfall events for local areas are more frequent and with increased run-off from land use changes, more significant flash flood events could occur. Excessive rains tend to occur more often with slow-moving or stationary weather systems.

**Increased drought**

According to the National Center for Atmospheric Research\(^\text{10}\), the percentage of Earth’s surface suffering drought has more than doubled since the 1970s. In Africa alone, the IPCC projects that between 75 and 250 million people will be exposed to increased water stress due to climate change. Drought tends to be cyclic in specific areas, such as the western United States, sub-Saharan Africa, and Central Asia. These areas have experienced extended droughts of 10 to 30 years or more, over climatic timescales (the past 1,000 to 2,000 years), and are likely the first to be impacted by climate volatility. California and parts of the Southwest have recently experienced an extreme drought with very limited rainfall.

**More impactful hurricanes and coastal storms**

As the oceans warm, scientists are concerned that the number of hurricanes, and potentially their intensity, could increase. Associated storm surges pose a particular risk to low-lying coastal cities due to the higher sea levels associated with the expansion of warmer ocean waters, as well as the increase of glacial melt water entering the ocean system. Global ocean levels have risen several inches in recent decades.\(^\text{11}\) Intense, extra-tropical storms, such as Superstorm Sandy, which hit the U.S. East Coast in 2012, are also likely to increase in frequency.

These storms may not have the intensity of a hurricane, but pose the same risks to low-lying coastal cities, including flooding and coastal erosion. Recent global hurricane trends have not yet shown this predicted increase in total annual numbers or intensity, with high year-to-year variability prevailing. The multi-decadal trend has been relatively flat.

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An increase in extended extreme warm or cold periods

The tendency for weather patterns to stall more often may lead to greater instances of extreme and lengthy warm or cold periods, lasting for weeks or even a few months. The disruption of the polar jet stream that causes the normally progressive, wavy pattern of these upper level winds to anchor in place for extended periods has produced recent cases of extreme winter cold in Europe, Asia, Alaska, and parts of the continental United States. The extreme warm season heat in Russia during 2010, and the record warm spring in the United States during 2012 are two examples of anomalous warmth that lasted for a season. While a generally warming global climate might lead to expectations for more hot events, the increased variability of the climate system will also create more extreme cold — which could catch people off-guard. The winters of 2014 and 2015 in the eastern United States brought extreme and persistent cold. Very mild winters returned for the following two years, but these were a result of substantial warmth from a strong El Niño.

An increase in wildfires

Hotter, drier conditions create a tinderbox ideal for wildfires. An increase in drought conditions sets the stage for wildfires. A warmer climate can extend the length of the fire season and the number of fires that occur each year. The acreage burned by wildfires could be higher. This might have a devastating impact on areas, such as the U.S. Southwest or southeast Australia, where drought has been persistent. Wildfires have been on the increase in recent decades across the globe, with humans playing a role. Development encroaching into burn-risk areas increases the threat for losses from these fires, most recently exemplified by the 2016 Great Smoky Mountains wildfire in and around Gatlinburg, Tennessee.

Changing jet stream patterns

The upper-level winds that encircle the globe meander in wavy patterns, which change on daily, weekly, and seasonal time scales. The recent tendency for slower-moving and stationary jet stream orientations could alter the average wind and turbulence patterns, potentially impacting aircraft routing to avoid the more turbulent areas. Recent trends in the past decade show a weakening of the jet stream in more northern latitudes, while stronger winds have been occurring from the central Atlantic into Europe and over the north Pacific. Model simulations of a warming climate suggest that more turbulent patterns could develop in highly traveled flight areas of the North Atlantic Ocean in future decades.

More "Black Swan" events?

A Black Swan event is a surprise event that has a major effect. After the first recorded instance of the event, it is rationalized by hindsight, as if it could have been expected;

that is, the relevant data was available, but unaccounted for in risk mitigation programs. The same is true for the personal perception by individuals.

In terms of weather, such Black Swan events, or extreme outliers, have seemed to happen more frequently in recent years. A few examples include the unprecedented warm March of 2012 in the north central United States, Hurricane Sandy’s sharp left-turn into the Mid-Atlantic region, and the extreme cold snap that occurred in New Mexico in early February 2011. That record-breaking cold period left thousands of people without heat as natural gas and electricity shortages and outages occurred. Hurricane Harvey parked over southeast Texas for nearly a week bringing unprecedented rainfall totals and extreme flooding.

Even though weather observations, modeling, and forecasting have improved, these extreme and unexpected events remain on the edges or outside of the normal bounds, making them more difficult to predict. These outlier events need to be factored in as executives and planners make decisions for where and how to conduct business around the world. Consideration should be given to a longer historical record of possible weather events and not be limited to recent climatology.

**Conclusion**

- Climate change has been an area of great interest, debate, and research in the past two decades. Sorting both natural and human-induced influences is an area of on-going research.
- Recent climate trends have shown a tendency for an increased number of extreme weather events. It is not clear if this increase is a result of changes driven by human activity, natural processes, or a combination of both. There has been an increase in slower or more stalled weather systems, which can lead to extreme temperature, drought and rainfall episodes.
- The most important message to convey is that more disruptive weather events have been happening, and will likely continue to happen at an increased frequency over the coming decades.
- From a business and planning perspective, we recommend greater risk awareness for the higher probability of increased weather volatility. Based on all available information at this time, further adaptation and preparation for greater risks is a reasonable course of action.