Executive Summary

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1. What Are Extremes and Why Do They Matter

Weather and climate extremes have always posed serious challenges to society. Changes in extremes are already observed to be having impacts on socioeconomic and natural systems, and future changes associated with continued warming will present additional challenges. Increased frequency of heat waves and drought, for example, could seriously affect human health, agricultural production, water resources, and water quality.

Extremes are a natural part of even a stable climate system and have associated costs (Figure 1) and benefits. For example, extremes are essential in some systems to keep insect pests under control. While hurricanes cause significant death, injury, damage, and disruption, they also provide needed rainfall to certain areas, and some tropical plant communities are dependent on hurricane winds toppling tall trees, allowing more sunlight to rejuvenate low-growing trees. But on balance, because systems have adapted to their historical range of extremes, the majority of the impacts of events outside this range are negative impacts.

The impacts of changes in extremes depend on both changes in climate and ecosystem and societal vulnerability. Vulnerability is shaped by factors such as population dynamics and economic status as well as developing and utilizing adaptation measures such as appropriate building codes, disaster preparedness, and water use efficiency. Some actions taken to lessen the risk from extreme events can lead to increases in vulnerability to even larger extremes. For example, moderate flood control measures on a river can stimulate development in a now “safe” floodplain, only to see those new structures damaged when a very large flood occurs.

Multiple extreme events over a short period reduce the time available for recovery and adaptation. The cumulative effect of compound or back-to-back extremes has far larger impacts than the same events spread out over a longer period of time. For example, heat waves, droughts, air stagnation, and resulting wildfires often occur concurrently and have more severe impacts than any of these alone.

Human activities are known to affect climate averages. This is relevant to extremes because small changes in the averages of some variables result in larger changes in their extremes (Figure 2).

2. Temperature–related Extremes

2.1 Observed Changes

Most of North America is experiencing more unusually hot days and nights. The number of hot spells has been increasing since 1950. However, the heat waves of the 1930s remain the most severe in the U.S. historical record. (What about extremely high annual average temperatures?)

There have been fewer unusually cold days during the last few decades. The last 10 years have seen fewer severe cold waves than for any other 10-year period in the historical record, which dates back to 1895. There has been a decrease in frost days and a lengthening of the frost-free season over the past century.

The western half of North America has experienced the largest increases in heat extremes and decreases in cold extremes.

2.2 Attribution of Changes

Human-induced warming has likely caused much of the average temperature increase in North America over the past fifty years. This affects changes in temperature extremes.

2.3 Projected Changes

Future changes in extreme temperatures will generally follow changes in average temperature. Abnormally hot days and nights and heat waves are very likely to become more frequent. Cold days and cold nights are very likely to become much less frequent. The number of days with frost is very likely to decrease.

Climate models indicate that currently rare extreme events will become more commonplace. For example, for a mid-range emissions scenario, a day so hot that it is currently experienced once every 20 years would occur every three years by the middle of the century over much of the continental U.S. and every five years over most of Canada. By the end of the century, it would occur every other year or more.

Episodes of unusually high sea-surface temperature are very likely to become more frequent and widespread. Sustained (e.g., months) unusually high temperatures could lead, for example, to more coral bleaching and death of the corals along with other impacts.

Sea ice extent is expected to decrease and may even disappear entirely in the Arctic Ocean in summer in the coming decades, increasing coastal erosion in Arctic Alaska and Canada due to the increased exposure of the coastline to strong wave action.

3. Precipitation Extremes

3.1 Observed Changes

Extreme precipitation episodes (heavy downpours) have become more frequent and more intense in recent decades over most of North America. Extreme precipitation events now account for a larger percentage of total precipitation. For example, intense precipitation (the heaviest 1%) in the continental U.S. increased by 20% over the past century while total precipitation increased by only 7%.

The monsoon season is beginning about 10 days later than usual in Mexico. In general, for the summer monsoon in southwestern North America, there are fewer rain events, but the events are more intense.

3.2 Attribution of Changes

Heavy precipitation events averaged over North America have increased over the past 50 years, consistent with the increased water holding capacity of the atmosphere in a warmer climate and the observed increase in water vapor over the oceans.

3.3 Projected Changes

Over most regions, precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase. For example, for a mid-range emission scenario, daily precipitation so heavy that it now occurs only once every 20 years is projected by climate models to occur every eight years or so by the end of this century over parts of North America.

4. Drought

4.1 Observed Changes

Drought can be defined in many ways, from acute short-term to chronic long-term hydrological drought, agricultural drought, meteorological drought, and so on. The assessment in this report focuses primarily on meteorological drought as measured by the Palmer Drought Severity Index (PDSI), though some other indices are included where and when available.

Averaged over the continental U.S. and southern Canada the most severe droughts occurred in the 1930s and there is no indication of an overall trend in the observational record, which dates back to 1895. In Mexico and the U.S. Southwest, the 1950s were the driest period, though winter droughts in the past 10 years now rival the 1950s drought. There are also recent regional tendencies toward more severe droughts in parts of Canada and Alaska.

4.2 Attribution of Changes

No formal attribution studies for greenhouse warming and changes in drought severity in North America have been attempted. However, it is likely that the increasing temperatures are already contributing to droughts that are longer and more intense. Droughts are also affected by the spatial pattern of sea surface temperatures, which appear to have been a factor in the severe droughts of the 1930s and 1950s.

4.3 Projected Changes

Droughts are likely to become more frequent and severe in some regions as higher air temperatures increase the potential for evaporation.

Droughts will be exacerbated by earlier and possibly lower spring snowmelt run-off in the mountainous West, which results in less water available in late summer.

In southwestern North America, the winter rainy season is projected to continue to shrink, increasing the risk of drought.

5. Storms

5.1 Hurricanes and Tropical Storms

5.1.1 Observed Changes

Atlantic tropical storm and hurricane destructive potential as measured by the Power Dissipation Index (which combines storm intensity, duration, and frequency) has increased. This increase is substantial since about 1970, and is likely substantial since the 1950s and 60s, in association with warming Atlantic sea surface temperatures (Figure 4).

There have been fluctuations from decade to decade and data uncertainty is larger in the early part of the record compared the satellite era beginning in 1965. Taking these into account, the balance of evidence suggests that the annual numbers of tropical storms/hurricanes and major hurricanes in the North Atlantic has increased over the past 100 years, a time in which Atlantic sea surface temperatures also increased. Despite this increase, there is no observational evidence for an increase in North American mainland land-falling hurricanes since the late 1800s, though there has been an increase in landfalls in the Caribbean.

Hurricane intensity in the eastern Pacific, affecting the Mexican west coast and shipping lanes, has decreased since 1980. However, coastal station observations show that rainfall from hurricanes has increased since 1949, in part due to slower moving storms.

5.1.2 Attribution of Changes

It is likely that human activities have caused a discernible increase in sea surface temperatures in the hurricane formation region of the tropical Atlantic Ocean over the past 100 years. The balance of evidence suggests that human activity has caused a discernible increase in tropical storm/hurricane and major hurricane frequency in the North Atlantic.

5.1.3 Projected Changes

According to theory and models for North Atlantic hurricanes (both basin-wide and land-falling) rainfall rates are likely to increase [12% per degree C?]. [It is likely/the balance of evidence suggests] that surface wind speeds will increase [4-5% per degree C?]. The spatial distribution is likely to change. Frequency changes are too uncertain for confident projections. Due to projected sea-level rise, the potential for storm surge damage will very likely increase.

Future changes in North Pacific tropical storms/hurricanes are projected by models and theory to be similar to those for the North Atlantic, except that hurricane surface wind speeds are *likely* to increase [check with change above].

5.2 Other Storms

5.2.1 Observed Changes

There has been a northward shift in the tracks of strong low-pressure systems (storms) in both the N. Atlantic and N. Pacific over the past fifty years. In the North Pacific, the strongest storms are becoming even stronger. Evidence in the Atlantic is insufficient to draw a conclusion about changes in storm strength.

Increases in extreme wave heights have been observed along the Atlantic and Pacific coasts of North America based on three decades of buoy data. Increases along the U.S. east coast coincide with the peak of the hurricane season. Increases along the West coast have been greatest in the Pacific Northwest, and are likely a reflection of changes in cold season storm tracks.

While snow cover extent has decreased over North America, overall trends in snowstorms and episodes of freezing rain have not been observed over the past century.

The data used to examine changes in the frequency and severity of tornadoes and severe thunderstorms are inadequate to make definitive statements about actual changes.

5.2.2 Attribution of Changes

Human influences on changes in sea-level pressure patterns have been detected over the Northern Hemisphere and this affects the location and intensity of storms.

5.2.3 Projected Changes

There are likely to be more frequent strong low-pressure systems (storms) outside the tropics, with, stronger winds and more extreme wave heights (Figure 5).

6. Recommendations: What measures can be taken to improve the understanding of weather and climate extremes?

Drawing on the material presented in this report, recommendations are described in detail in chapter 4. Briefly summarized here, they emphasize the highest priority areas for rapid and substantial progress in improving understanding of weather and climate extremes.

- The continued establishment and maintenance of high quality climate observing systems to monitor climate variability and change should be of highest priority.
- Research to homogenize and analyze long-term observations in the instrumental record should be continued.

- Efforts to extend reanalysis products using surface observations should be pursued, as well as studies to directly identify strong extratropical cyclones from the sparse observations.
- Research is needed to create annually resolved, regional-scale reconstructions of temperature and precipitation for the past 2,000 years.
- Substantial increases in computational resources should be made available to fully investigate climate models' ability to recreate the recent past as well as make predictions under a variety of forcing scenarios.
- Modeling groups should be encouraged to post-process and submit daily averaged datasets that already exist but have not yet been archived.
- Research needs to move beyond purely statistical analysis and focus more on linked physical processes that produce extremes and the associated changes in climate.
- Communication between the science community and the user community should be enhanced in both directions.
- Greater human and computing resources need to be provided for improving our understanding of changes in weather and climate extremes, for example, hurricanes, strong convective storms, and heavy rainfall.

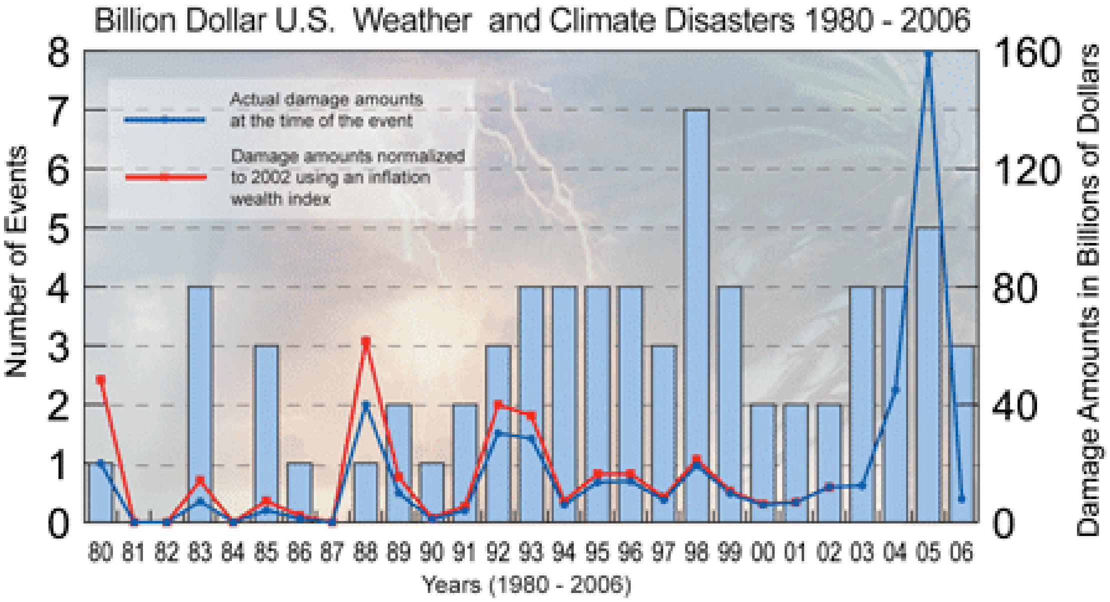

Figure 1. The blue bars show the number of billion dollar or more events by year and are scaled to the left side of the graph. The blue line (actual costs at the time of the event) and the red line (costs adjusted for wealth/inflation) are scaled to the right side of the graph, and depict the annual damage amounts in billions of dollars.

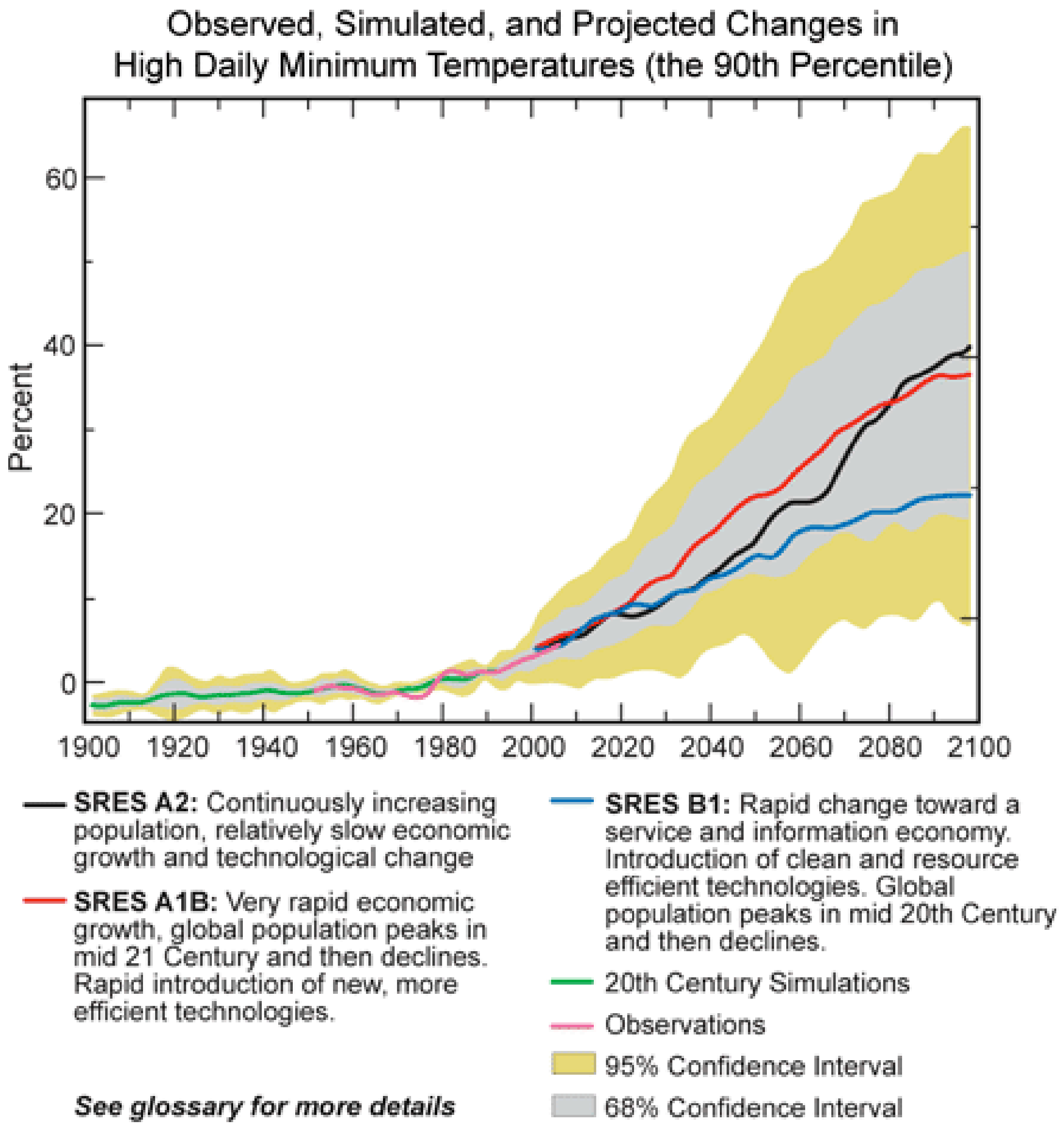

Figure 2. Changes in the percent of days within a year with the minimum temperature falling in the upper tenth percentiles of mean daily minimum temperatures using 1961-1990 as a base. Various emission scenarios are used for future projections and historical simulations. The confidence intervals are calculated using numerous models and simulations.

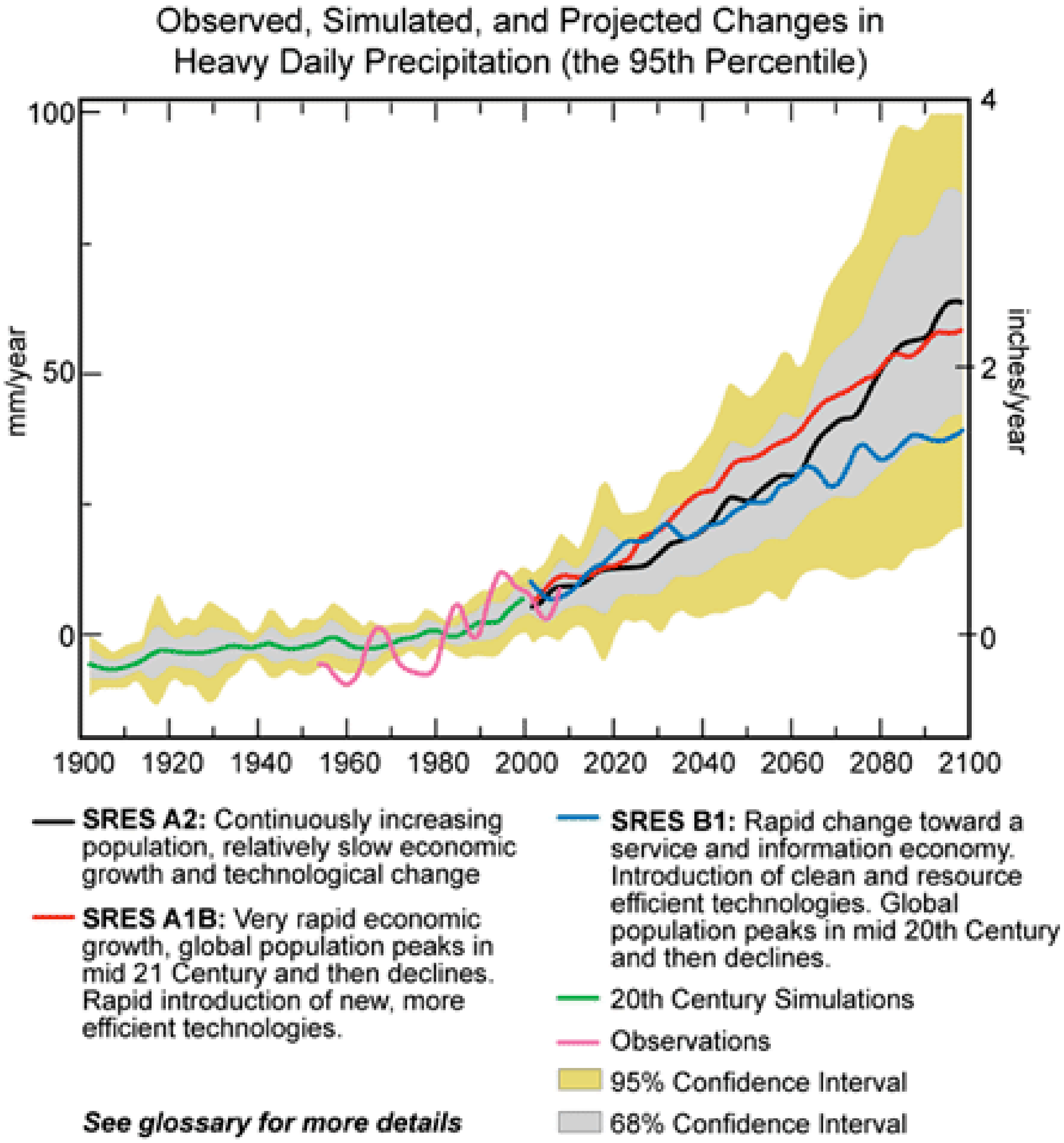

Figure 3. Changes in the amount of daily precipitation occurring in the upper five percentiles (heavy precipitation events) compared to the precipitation pattern during the period 1961-1990. Various emission scenarios are used for future projections and historical simulations. The confidence intervals are calculated using numerous models and simulations.

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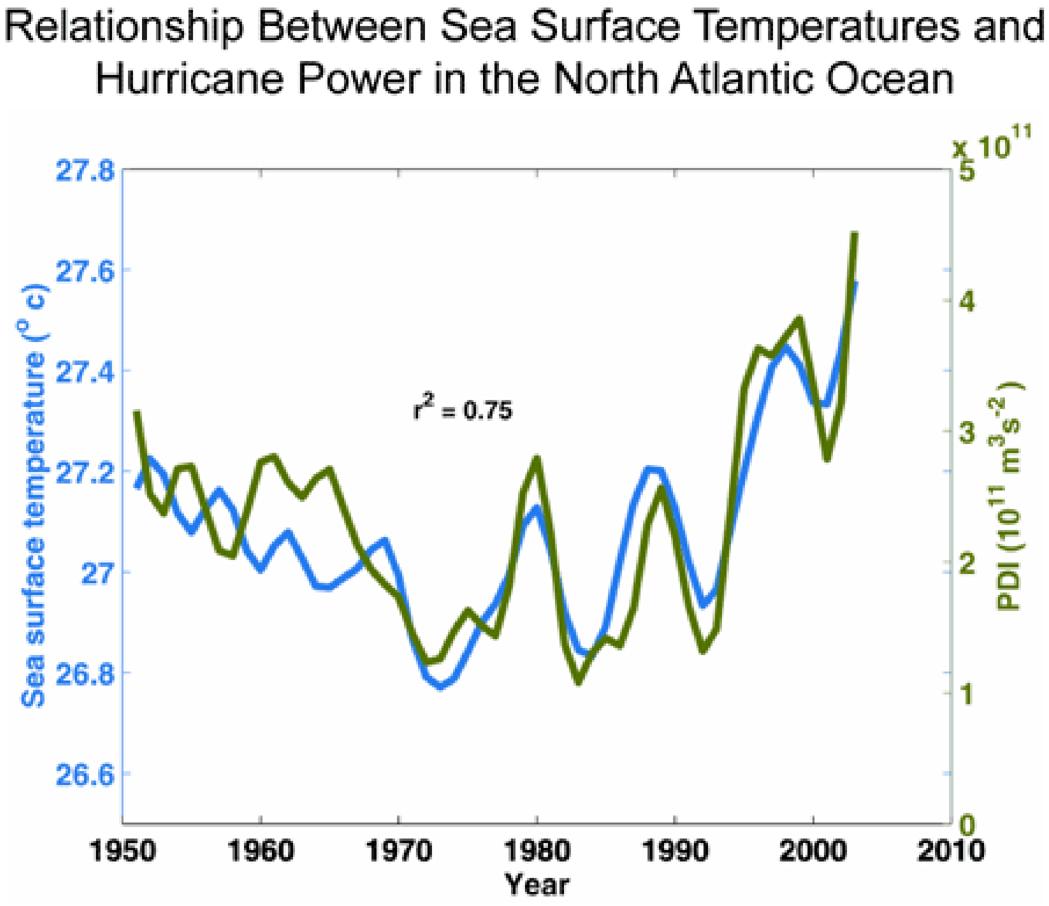

Figure 4 Sea surface temperatures (blue) and the Power Dissipation Index for North Atlantic hurricanes (Emanuel, 2007)

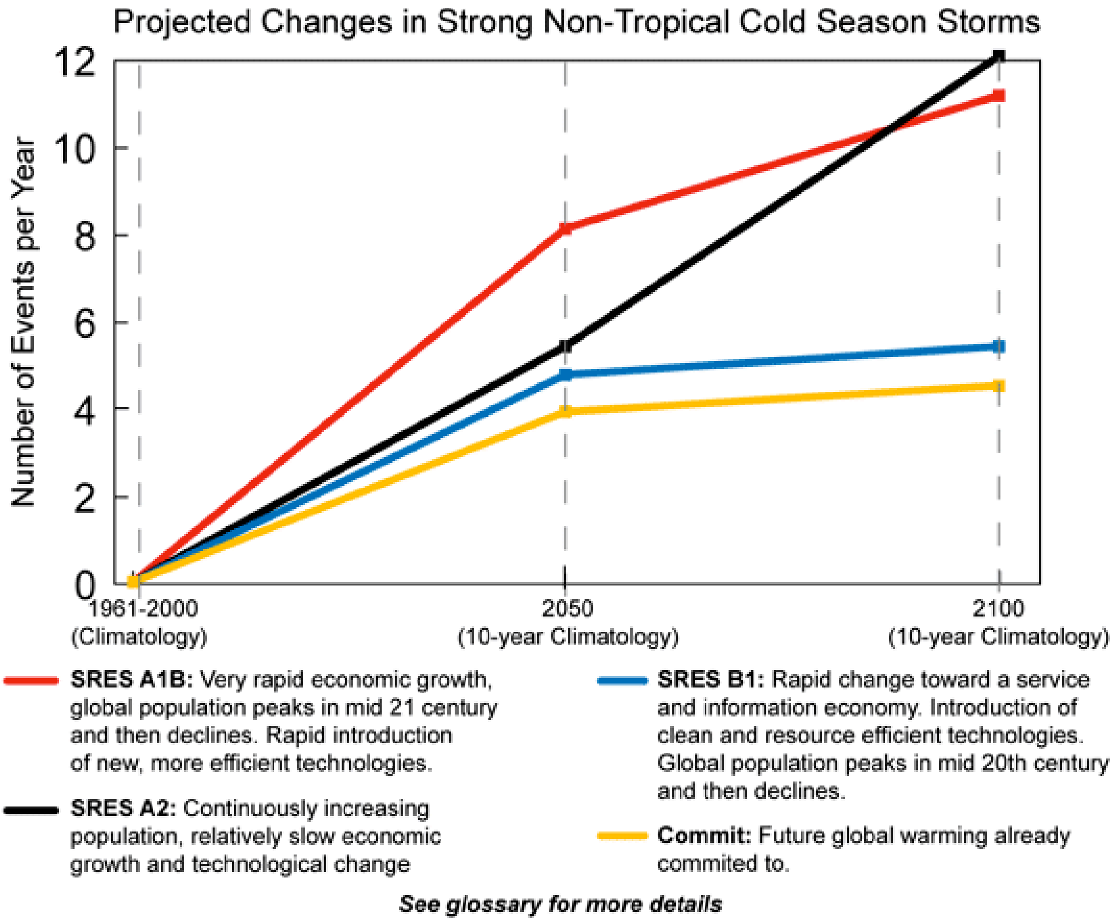

Figure 5. The projected change of intense non-tropical cyclones (mostly cold season storms) for various emission scenarios (adapted from Lambert and Fyfe; 2006).