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Smart adaptation in an era of rising climate risks

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ABSTRACT
Around the globe, the number and cost of weather-related events that cause financial losses have been increasing rapidly, in parallel with growing evidence for the effects of climate change. Yet surprisingly, since 1980 – when global-scale data become reliable – the strongest driver of the trend in costs is increasing wealth and not increasingly severe or frequent hurricanes. In fact, there is no strong evidence pointing to an additional role for climate change in the trend of increasing financial losses for weather disasters. Recognizing that disasters are always complex, should this be interpreted to mean that climate change has not been a major factor in disaster losses? Will it be a major factor in the future? How can we use historical experience as a guide to building climate-change proof infrastructure? Understanding climate change and its links to weather-related extremes is one key to answering these questions. Another is appreciating the role of human actions in amplifying or suppressing the impacts of weather-related extremes. As climate change impacts become more frequent and severe, we need smart adaptation that builds on science, integrates experience from history, capitalizes on opportunities for win-win solutions, and is designed to accommodate new information as it becomes available.

KEYWORDS
Climate change; resiliency; disaster risk reduction; adaptation; infrastructure; vulnerability

As a starting point for thinking about a US climate adaptation strategy, consider the following scenario. It is the beginning of 2051 – just after mid-century – and climate related-disasters continue to deliver a series of punishing blows. 2050 was among the most active Atlantic hurricane seasons on record, with 10 hurricanes total and six major hurricanes of Category 3 or stronger. The total accumulated cyclone energy of all these hurricanes reached the highest level ever, and individual storms set records for total rainfall and strongest Atlantic hurricane outside the Gulf of Mexico and the Caribbean. In 2050, hurricanes made landfalls from Texas to Puerto Rico, leaving a challenging landscape for recovery, with millions of people without shelter, water, and power nearly six months later. In the West, 2050 was a wildfire nightmare; in California alone, over a million acres and 10,000 structures burned, and dozens of lives were lost. This vision of a possible near-future provides a compelling motivation for smart investments in preparation.

But, of course, this scenario is not something a half-century in the future, but our actual experience here and now, in the year 2017 – abundant evidence that we are woefully underprepared for the disasters we already face. And if we can barely hold on now, what are our prospects down the line? As we look to a future of continuing climate change, how can we combine experience from past disasters with scientific knowledge about possible futures to guide investments in climate-change adaptation?

Answering this question requires an exploration of three related issues: (1) the essence of disaster risk, (2) possible trajectories of climate-related disaster risk in the future, and (3) the relationship between investments in disaster-risk reduction and other societal goals.

Aiming at a moving target

Planning for possible future disasters is one of the most challenging responsibilities of any society. Everyone expects their interests to be considered when disaster strikes, but nobody wants to pay more than their fair share for disaster preparation, response, and recovery. Because the damages from a disaster typically increase almost exponentially with the magnitude of a heat wave, storm, drought, or wildfire, it is important to plan for the biggest events – but these are also the most infrequent. Consequently, building public support for preparations that may be needed only once or twice a century is a heavy lift, especially for communities that do not have any recent history with a comparable event. When a factor like climate change creates the risk of disasters that are fundamentally outside the range of historical experience, the challenge of effective preparation is even greater.

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My background is in understanding the impacts of climate change, and so it has always been clear to me that disasters are a part of the spectrum of climate change effects. But I, like many climate change researchers, had not given them much focus until I had the opportunity to co-lead the development of a report, published in 2012, on “Managing the risks of extreme events and disasters to advance climate change adaptation” for the Intergovernmental Panel on Climate Change, also known as the IPCC. The report assembled perspectives from researchers representing three very different disciplines: disaster risk reduction, climate science, and climate change adaptation (IPCC 2012). Each community brought unique skills and insights to the report: The disaster-risk-reduction specialists brought deep, real-world experience, while the climate scientists provided up-to-date information on changes in the probability of different kinds of extremes occurring in different places. And the climate-change-adaptation specialists contributed plans and research on how community engagement and adaptive management can help societies identify shared goals – and find affordable ways to achieve them.

The surprise was that the three research communities had not worked together before, which meant that each started with different vocabularies, historical references, and conceptual models. In particular, the disaster-risk-reduction researchers emphasized the role of human actions in setting the stage for disaster. They described a history where the most costly disasters could be triggered by even moderately extreme events, with damages amplified through cascading weaknesses in preparation and response. Meanwhile, the climate scientists came from a tradition that had focused predominantly on understanding the role of human actions in changing the average state of the climate. The climate scientists recognized the importance of making useful projections of rare events, but also the technical difficulty involved in doing so. And the climate-change-adaptation researchers started from the perspective that resilience requires not only physical protection but also strong social institutions, healthy environmental conditions, and good governance.

Initially, the clash of contrasting perspectives was jarring. But eventually, the cacophony led to an integrated framework that has since served as a foundation for understanding and managing risks of disaster from a changing climate. The essential feature of this approach is that the risk of disaster impacts emerges from the intersection of hazard (the triggers from climate extremes), vulnerability (the lack of preparedness), and exposure (the quantity of assets at risk), as depicted in this Venn diagram (Figure 1).

Risk tends to increase when the hazards are more intense or frequent, but it can also increase independently of hazard through changes in vulnerability or

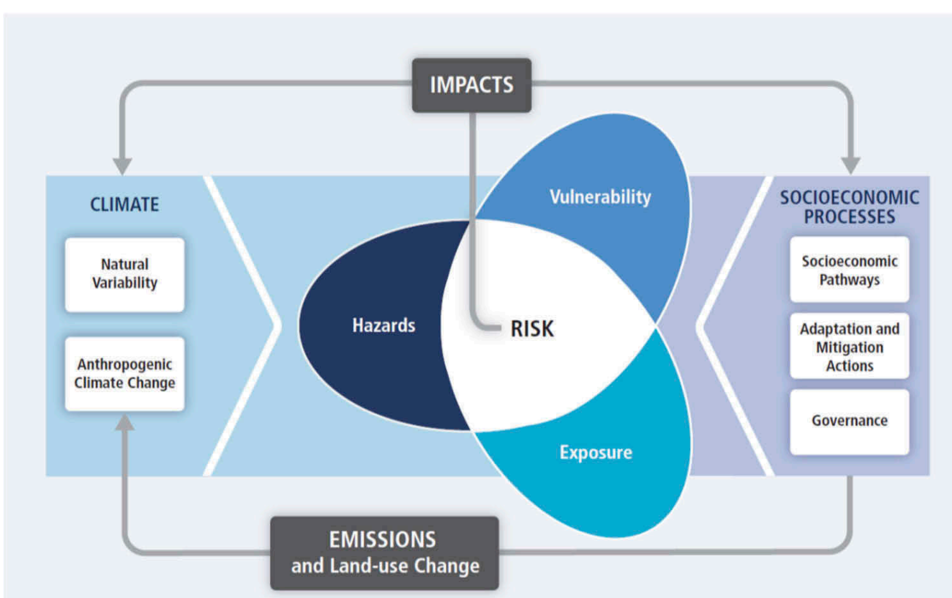

Figure 1. Conceptual basis for emergence of risks from a changing climate.
Conceptual basis for the emergence of risks from climate-change impacts, illustrating the interacting roles of triggers from climate extremes (Hazards), lack of preparedness (Vulnerability), and quantity of assets at risk (Exposure). Many of the human influences on hazards are indirect, such as through the emissions of greenhouse gases. At the same time, human influences on vulnerability and exposure are much more direct, reflecting important drivers from wealth, inequality, and the quality of government and other institutions. Image courtesy of IPCC (2012), used with permission.

exposure, or by some combination of change in the two. Conversely, risks can be managed by limiting the amount of climate change, reducing the hazard component, or though addressing vulnerability and exposure by increasing preparation or moving assets out of harm's way.

If we want to understand risks of future disasters, historical data can be instructive. Fortunately for researchers, three organizations – the Center for Research on Epidemiology of Disasters and the reinsurance firms of Swiss Re and Munich Re – maintain major databases on disasters at the global scale. For example, the Munich Re database known as NatCatService covers about 36,000 events, starting in 1950, with a focus on financial and insured losses (Hoeppe 2016).

While disasters are not the only pathway through which climate change risk is realized, damages are clearly concentrated in extreme events. Even decisions that use long-term information – concerning, for example, which crops to plant, whether to harvest crops, or where to locate a business – often depend largely on experience with extremes.

The recent trajectory of disasters is striking. The number of weather-related events in the NatCatService database rose from about 300 in 1980 to about 900 in recent years (Figure 2 and Figure 3).

The increase has been much larger for weather-related events than for geophysical events like earthquakes and volcanic eruptions. Economic losses from weather-related events, corrected for inflation, have also increased. Losses from natural disasters in 2017 were about $300 billion, the third-highest total ever, according to Swiss Re. Indeed, things have gotten so bad that Munich Re – the world's biggest company in the field of insuring the insurance companies – suffered a 1.4 billion euro ($1.63 billion) loss after the triple-whammy of hurricanes Harvey, Irma, and Maria sent claims soaring. The head of Munich Re's Corporate Climate Center warned Bloomberg News: "Sometime in the future there will be a situation where people cannot afford any longer to buy catastrophe insurance…" (Shankleman 2017)

The cause for the increase in losses – specifically the relative importance of changes in hazard, vulnerability, and exposure – has been a surprise. The stronger trend in losses from climate-related than geophysical disasters suggests a role for climate change. On the other hand, several careful analyses have concluded that, at the global scale, there is no clear evidence for a role of increasing climate hazards contributing to the trend in disaster losses (Mohleji and Pielke 2014). The reason for this is that once the data on disaster losses are adjusted for inflation and changes in exposure (using gross domestic product or another measure of wealth as a proxy for exposure), the trend disappears.

Which brings us to a conundrum. Overwhelming evidence establishes that the climate is changing and that the impacts of climate changes to date, including changes in some kinds of extreme events, are widespread and consequential. But the disaster loss data show a different pattern. What explains this contrast,

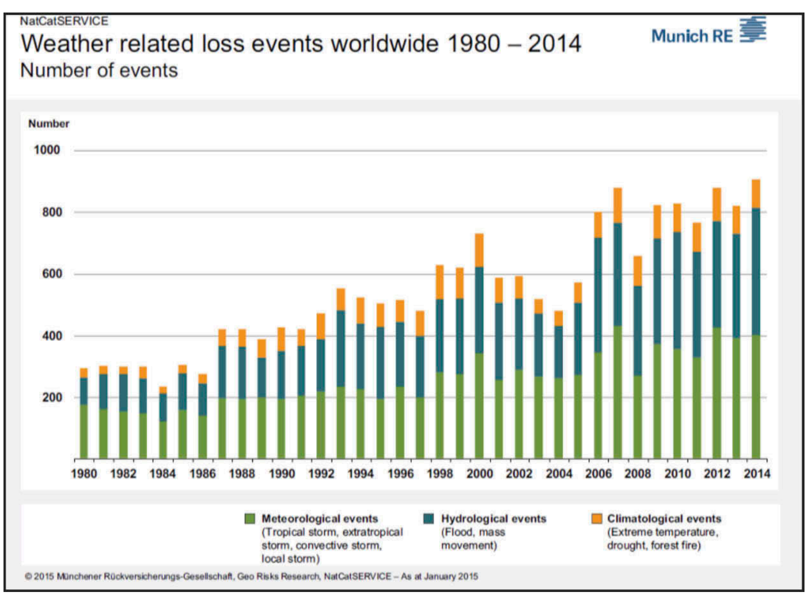

Figure 2. Number of disasters.
Trends in the total number of weather related loss events at the global scale for 1980 to 2014, indicating losses from storms (green, bottom), floods and landslides (blue, middle), and droughts and wildfires (orange, top). From Hoeppe (2016). Image courtesy of Elsevier, used with permission.

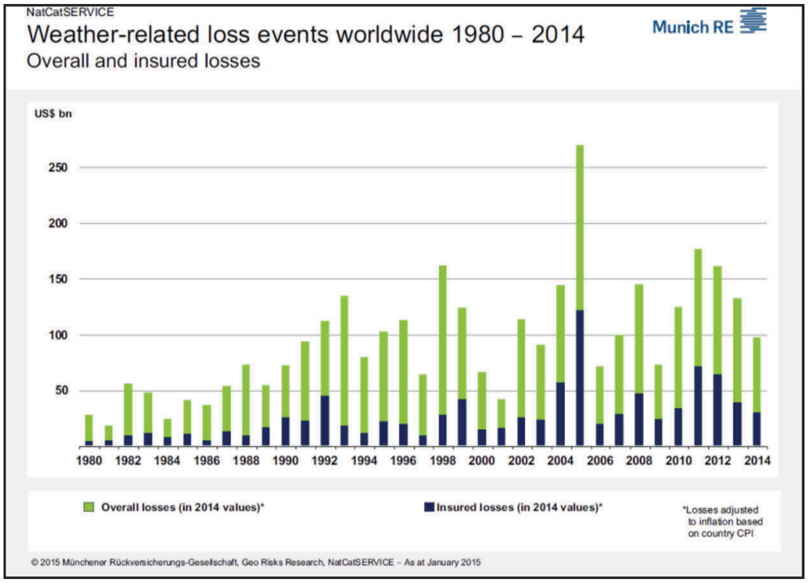

Figure 3. Costs of disasters.
Trends in the economic costs of weather related loss events at the global scale for 1980 to 2014, indicating insured (blue, bottom) as well as total losses. From Hoeppe (2016). Image courtesy of Elsevier, used with permission.

and what are its implications for the way we address climate change, especially investments in adaptation?

There are four possible, nonexclusive answers to this conundrum. The first is that climate change, so far, has not altered financially important climate hazards. While it is clear that climate changes have had impacts on some kinds of extremes, the question of whether these include the costly ones warrants exploration. The second possibility is that the rarity of costly weather-related disasters creates a statistical nightmare, where data availability always limits policy relevance. A third possibility is that counteracting physical processes are suppressing trends that would otherwise be apparent. And fourth, it is possible that social processes are suppressing the emergence of trends in disaster losses attributable to climate change.

All four possible answers to the conundrum are consistent with a pattern where the future trajectory of disaster losses is strongly influenced by climate change. Assessing the relative role of each can help set the stage for addressing the most important topic – smart preparation for the risk of future disasters.

Climate change and economically important hazards

Has climate change altered the frequency or intensity of extreme events? The IPCC tells us that the answer is a solid "yes" for temperature extremes, with clear global trends toward more hot extremes and fewer cold extremes. (This does not, of course, mean that there are no longer cold extremes. The US East Coast deep freeze of early January 2018 chillingly illustrates this point.) Extremes of high sea level are also increasing globally, with short-term tides and storm surges basically piled on top of the rising baseline level. Incidences of heavy precipitation have increased in many areas, along with drought in some others. There has not been a global trend in the number or intensity of hurricanes, but the number of intense storms in the North Atlantic has increased since 1970.

Are these the economically important extremes? From 1980 to 2014, 81 percent of insured losses and 65 percent of total losses were from storms or floods. In contrast, events related to temperature, drought, or fire accounted for only 10 percent of insured losses, or 8 percent of total losses. Events for which the climate trends are most clear are those related to temperature, which comprise a relatively small fraction of total disaster losses. At the other extreme, the largest contributor to losses is storms, for which the evidence from climate change is still unclear, largely because so many landscape and human processes operate as intermediate steps between heavy rainfall and a flood (Hoeppe 2016).

The IPCC report also tells us that we should not expect a one-to-one relationship between more extremes or stronger extremes and disasters. Every disaster has its own trajectory, and human actions almost always play a role in making the final outcome worse or not as bad. Even with gigantic events like

Hurricane Katrina, the level of damages is strongly modulated by particulars like whether levees fail. Because the specific amplifiers and suppressors have unique features for every event, the relationship between more events or stronger events and increased economic losses is certain to be noisy. When the noise is large relative to the signal from a changing climate, it is difficult to establish the existence of a trend, even if one exists.

The challenging statistics of trends in rare events

What about the second possibility, that there is a disconnect between the questions that we want to ask and the capabilities of the available statistical tools? The basic challenge is that most of the losses come from a few major disasters, and these are very rare. While the rarity of major disasters is a good thing, it complicates the task of trend analysis. Confidence in the ability to detect a trend increases with the number of samples available. But with disaster losses, the main two options for increasing the sample size are not really relevant. Extending the analysis further back in time is a challenge for the global scale, because data on losses and insurance are complete enough for much of the world only after about 1990. The other option – expanding the definition of a disaster to include more events – is not helpful because the overwhelming majority of the damages come from the few largest events. With very rare events, the reality is that it can take a frustratingly long time to build confidence in a trend. In the context of climate change and disasters, the implication is that the accumulation of damages and the integration of risk of further damages may be unacceptably advanced by the time a trend becomes clear. It is important to avoid a situation where we depend on results of an analysis that we know will not be complete until it is too late to use the information.

Because trend detection is so strongly dependent on the number of major events, restricting the analysis to a particular region usually decreases the probability that significant trends will emerge. But it is worth looking specifically at regions where the high-quality data records are longest. That is what Barthel and Neumayer (2012) did for the United States and Germany. They found a significant trend in insured US losses (after adjusting for inflation and wealth) for 2,674 weather-related disasters from 1973 to 2008. There were also significant trends in adjusted insured losses from thunderstorms, flooding, high temperature events, and winter storms. For this period, the trend in adjusted insured losses from hurricanes was not significant using the standard 5 percent criterion, but it was at the less stringent 10 percent level. In Germany, using data for 1980–2008, none of the trends in insured losses were significant at the five percent level.

The question of whether there is a trend in hurricane losses in the US has been widely explored. Most of the analyses conclude that, after adjusting for inflation and wealth, there is no remaining trend (Pielke et al. 2008). Taking a different approach to accounting for trends in wealth, Estrada, Botzen, and Tol (2015) concluded that in 2005, 2-to-12 percent of the hurricane losses might be attributable to climate change.

Opposing components of climate change

A third factor that might explain the limited evidence for a climate-change signal in trends in disaster losses is the presence of offsetting physical processes. For example, warming tends to increase evaporation, heightening the risk of drought. But the increased carbon dioxide concentrations that cause warming also cause plants to close the pores through which water evaporates, offsetting some of the effect of warming (Swann et al. 2016). In the long term, the implications of climate change for drought will depend on the balance between these two mechanisms. Offsetting physical processes appear to be relatively common, though substantial offsetting in the early stages of climate change does not imply that the offsetting will continue at the same level as the climate continues to warm. One example concerns severe thunderstorms and tornadoes. These events require the atmosphere to have high potential for lofting air parcels upward (expected to increase with warming), combined with steep gradients in wind speed (expected to decrease with warming). But while the broadest trends point to offsetting changes in the lofting potential and wind speed gradients, in the climate model outputs for the last few decades of the 21st century, days with high lofting potential also have strong wind speed gradients (Diffenbaugh, Scherer, and Trapp 2013). In other words, as the climate changes, offsetting looks to be less important, pointing to a trend of increased severe thunderstorms and tornadoes.

The case with hurricanes is mixed. In 2005, climate scientist Kerry Emanuel (Emanuel 2005) demonstrated that the total power given off by tropical cyclones (the general term for the storms called hurricanes in the Atlantic) in the Atlantic and the Western North Pacific has increased dramatically since about 1970. Total power can increase because storms are larger, or more intense, or because they persist longer. This measure of power dissipation is also a measure of the destructive potential of hurricanes.

In 2015, the research group of Francisco Estrada and his colleagues reported some evidence for a trend in hurricane losses, but the pattern is not nearly as strong as one might expect from the trend in power dissipation. Some of the answer may be coming from another kind of offsetting mechanism. Columbia University's Adam Sobel and his team (Sobel et al. 2016) looked at trends in a measure of the ability of the ocean and atmosphere to generate and sustain hurricanes. This measure, potential intensity, is greater when the ocean is warm, relative to the atmosphere. Climate warming should lead to an increase in hurricane potential intensity, but there is no evidence of a trend before 1960 and a relatively weak trend after that. Climate model simulations point to offsetting mechanisms. Forcing of climate change by greenhouse gases leads to a strong increase in hurricane potential intensity, but this is almost entirely offset, until recent decades, by the role of atmospheric aerosols (Figure 4). Consequently, the trend in hurricane potential intensity was driven in opposite directions by two components of climate change. In the future, the expectation is that aerosol emissions will decrease, leading to an overall response that is more affected by the increase of greenhouse gases.

Progress in decreasing vulnerability

The fourth possible explanation for the lack of a climate-change signal in the trend in disaster losses comes from social offsets. The standard approach for accounting for the effects of changing exposure is to make an adjustment based on wealth. The simplest correction uses gross domestic product, or GDP, which is the sum of all goods and services produced within a nation's borders. Another option uses housing prices, since the value of homes lost or damaged is often a major component of disaster losses. The idea is that any remaining trend in losses should be due to changes in the hazard from climate change. But this need not be the case, because another possibility is that the rising risks from climate change are offset by declining vulnerability.

This makes sense conceptually. As societies have more to spend on housing, roads, businesses, and other infrastructure, it would be reasonable to see at least some of these extra resources go to features that increase preparedness and the ability to withstand climate shocks. Bangladesh is good as a case study for this approach (Mechler and Bouwer 2015). Over the last several decades, Bangladesh has made impressive progress in decreasing its vulnerability to natural disasters, especially tropical cyclones. At least in this case, the investments in vulnerability reduction are already yielding benefits in the form of decreased loss of life and less economic damages. While Bangladesh is somewhat unusual in the ambition of its vulnerability reduction efforts, it is reasonable to speculate that other nations have made some progress, and that vulnerability reductions are playing a role in offsetting a trend in increasing hazard from climate-related extremes.

Building from disaster trends to smart adaptation

Each of these four mechanisms has some support. Importantly, the consistent theme across all of them is that the absence of a climate change signal in the

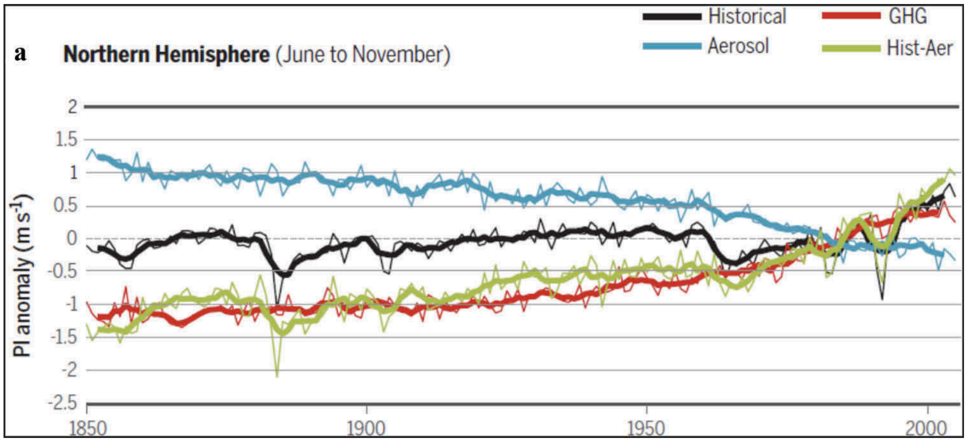

Figure 4. Trends in hurricane potential intensity.
Trends in hurricane potential intensity (labeled PI anomaly on the y axis) from 1850 to 2010. The observed historical trend (black) changes little from 1850 to about 1960 and rises thereafter. The calculated trend in hurricane potential intensity due to greenhouse gases (red/dark gray – which tend to warm the planet) rises continuously, while that due to aerosols (blue/medium gray - which mostly tend to cool the planet) falls steadily. The close parallel between the greenhouse gas trend (red) and the difference between the historical trend and the aerosol trend (difference shown in green/light gray) illustrates how aerosols in the past offset the effects of greenhouse gases, from Sobel et al. (2016). Image courtesy of the American Association for the Advancement of Science, used with permission.

global trend in disaster losses cannot be read as indicating that the climate is not changing, that climate is not increasing risks of disasters, that effects of climate change on disaster losses are small, or that we need not worry about effects of climate change on disaster losses in the future.

To the contrary, the main message from this exploration of the relationship between climate change and disaster losses is that losses are likely to increase in the future unless broad actions are taken.

There are three main reasons for this.

First, one of the reasons why the evidence is limited to date has to do with the time and data requirements for confirming the existence of a trend. Waiting to act until a trend is statistically robust is simply foolish, especially with rare events. When we know that statistical power is weak and that a trend needs to be very advanced for statistical confidence, it is important to integrate additional lines of evidence and use a comprehensive approach for policy support.

Second, clear evidence supports the conclusion that, for several kinds of climate-related extremes, climate change has more than one kind of effect. In some cases, these effects can act in opposite directions. While this may have suppressed the signal from climate change, the pattern could be different in the future. Examples with drought, severe storms, and hurricane potential intensity all point to the expectation of decreased offsetting with further climate change.

Third, it is likely that proactive investments in preparation have damped some of the effects of climate change. This is a good news story, demonstrating that adaptation can make a difference.

This brings us back to the IPCC report and the different perspectives of the three communities who came together to produce it. The disaster-risk-reduction experts made it clear that a disaster is never only natural. The climate science experts spoke to the risk of changing extremes and the benefits of limiting warming to control that risk. The climate-change-adaptation researchers emphasized the way that smart choices can provide multiple benefits, with investments in strategies such as improved networks for transportation, communication, and public health that decrease disaster vulnerability while also supporting economic growth. Effective disaster preparation needs to involve understanding the sources of vulnerability, making smart investments in empowering people to be prepared, making sure institutions are responsive, and deploying resources at levels from the local to the international scale for effective responses.

All of this points to seven specific recommendations that can be a foundation for smart action now and in the future:

(1) The most important enabler for effective adaptation is limiting the amount of warming that occurs. We have substantial ability to adapt to a changing climate, but that ability will be overwhelmed unless warming is limited to the low end of the possible range: around 2 degrees Celsius.
(2) Look for investments that contribute to more than one objective. Many of the highest-impact adaptation strategies can also stimulate economic growth and promote broad opportunity. 2017 was a powerful reminder that we are not prepared for the disasters we currently face.
(3) Dealing with present risk can be an excellent starting point for addressing risks from future climate change.
(4) Projections of future climate change impacts, from sea-level rise to heat waves, are increasingly robust, detailed, and policy relevant. Building these projections into adaptation planning is an important component of preparation.
(5) Effective adaptation should be flexible, based on plans that can be adjusted as new information becomes available. We know a lot about the trajectory of future climate change, but we do not know all of the details. In other words: *Surprises are inevitable*.
(6) Human institutions, from communities and companies to nations and the international community, all need to work effectively to support robust climate-change adaptation.
(7) Adapting to climate change will require a mix of responses. Many of these will be incremental, but some will likely be transformational, involving big changes in where we live, how we work, or how we interact with each other. Openness to transformational changes that also advance other objectives may well be the key to adapting in ways that are practical, affordable, and broadly beneficial.

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