Climate Change 2016
Eight Ways the World Has Changed Since the Last IPCC Report

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Abstract

The Intergovernmental Panel on Climate Change releases periodic reports that serve as definitive sources of information concerning what is known and what is not known about the science of climate change. The most recent comprehensive report, released in 2013 and 2014, assesses studies published through early 2013 (for the physical science basis) or mid 2013 (for impacts, adaptation, vulnerability and mitigation).\(^1\)

The state of the climate, the maturity of the science and the landscape of climate policy are all dynamic, with some large and consequential changes in the two years since the IPCC report. Eight changes paint a portrait of the magnitude and importance of the shifts. The eight changes concern the following observations, projections and solutions:

1. The idea of a warming pause or slowdown has been debunked, and recent warming has been rapid.
2. In both 2014 and 2015, global CO\(_2\) emissions barely grew or even decreased during years of modest economic growth. These trends demonstrate initial stages of disconnecting emissions and economic activity.
3. The science of single-event attribution matured to a stage where it is now routinely used to assess the way climate changes to date have altered the odds of actual extremes. The results in many cases underscore that climate change made particular extremes substantially more likely.
4. For the loss of ice from major ice sheets, especially in Antarctica, new studies use information from a wider range of past conditions and incorporate a broader suite of physical mechanisms. These advances have led to a substantial increase in the projections for maximum sea-level rise during the 21st century compared to past assessments.
5. New analysis of global macroeconomic patterns indicates that economies may be much more sensitive to warming than previously estimated, particularly in regions where historical conditions were already warm.
6. Several lines of evidence point to the feasibility of building an energy system with very low or even zero emissions based on continued improvement and integration of existing technologies.

7. New studies identify a wide range of possible co-benefits, with investments in climate change mitigation, climate change adaptation or sustainable development potentially reinforcing each other.

8. The Paris Agreement represents only first steps in bringing greenhouse gas emissions to zero. But its global consensus on ambitious goals and a process moving forward creates a strong signal about the direction of future policy, contributing to the predictability that is so important for long-term investments in the public and private sectors.

The overall implication of these eight changes is that the case for rapid, ambitious and sustained action to reduce emissions is substantially strengthened, even compared to the most recent report from the IPCC.
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Hiatus? Hardly

In the period from about 2007 until 2013, the concept of a warming hiatus or slowdown was a prominent feature of questions, especially from climate skeptics. Most of the questions were grounded in the optics of starting a time series from 1998, an exceptionally warm El Niño year, and in limited appreciation of the relative roles of long-term (multidecade) climate forcing from greenhouse gas (GHG) emissions and short-term (year-to-year) variability. The IPCC Fifth Assessment Report on the physical science basis of climate change, released in 2013, dedicated a substantial amount of discussion to the hiatus, explaining it as reflecting a combination of internal variability (especially with the transition to the cold phase of the Interdecadal Pacific Oscillation), atmospheric aerosols (through incomplete representation of cooling effects of volcanic eruptions), solar radiation (with an effect of the declining phase of the 11-year solar cycle) and the tendency of a casual observer to overemphasize the very warm El Niño year of 1998.2

While scientifically sound, the IPCC analysis is complicated. Still, emphasis on a hiatus has rapidly faded for three reasons. First and most important, recent years have been exceptionally warm. 2014 was the warmest year in the instrumental record until 2015, which broke the previous record by the largest margin ever (see Figure 1). 2015 was also the first year in the instrumental record with a global average temperature more than 1 C (1.8 F) above preindustrial. The first part of 2016 has been even warmer, with the first three months scraping 1.5 C (2.7 F) above preindustrial. July 2016 was the 15th consecutive month with record-warm global land and ocean temperatures. In a plot of global temperatures running from the beginning of systematic measurements in 1880 to the present, it is easy to see year-to-year variability but hard to see indications that the last two decades deviate from the trend. Careful statistical analysis indicates that recent warming is slower than many model projections,3 but there is no question that warming has continued.

A second line of evidence comes from a reanalysis of the global temperature data. Karl and colleagues found that the global temperature record produced by NOAA can be made slightly more accurate with improved corrections for the technology used to measure ocean temperatures (from buckets thrown overboard to engine intakes to autonomous buoys) and through using information from an expanded network of land-based weather stations.4 These corrections were so small that they had hardly any effect on temperature trends over the second half of the 20th century, but they approximately doubled the average rate of warming over the period from 1998 to 2012. With this correction, the rate of global warming is close to the same for the “hiatus” period of 1998–2012 and the second half of the 20th century. Improving the analysis strengthens the case for continuing warming.

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A third line of evidence comes from asking the question about whether there was a hiatus in more precise statistical terms. Rajaratnam and colleagues tested for a hiatus defined in four different ways, using the historical temperature dataset with and without the corrections from Karl and colleagues. None of the tests suggested a slowing or a cessation of warming.


In 2013, addressing the possibility of a warming hiatus was appropriate. Now, it is clear that warming has not slowed. In contrast, much of the recent discussion has focused on the regularity and magnitude of recent record warmth.

**Moderating Trends in Emissions Growth**

A striking feature of the GHG emissions trajectory from the IPCC Fifth Assessment Report is the acceleration after 2000. The average growth rate in global GHG emissions from energy, agriculture, industry and land use was 1.3 percent per year from 1970 to 2000 and 2.2 percent per year from 2000 to 2010, the most recent year considered in the report. Looking at carbon dioxide only, the rate of increase was 1 percent per year from 1990 to 1999 and 3.2 percent per year from 2000 to 2009. Even the major recession of 2008–2009 resulted in only a brief pause in the rate of carbon dioxide emissions growth.

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6 IPCC, *Climate Change 2014*.
But the pattern changed dramatically for the last two years. In 2014, global carbon dioxide emissions were 0.6 percent greater than in 2013. For 2015, initial estimates put them at 0.6 percent less than 2014. In contrast to past emissions dips, 2014 and 2015 were both years of modest economic growth at the global scale. According to the World Bank, global gross domestic product (GDP) grew at 2.6 percent in 2014 and 2.4 percent in 2015 (see Figure 2).

This dramatic slowing of carbon dioxide emissions growth during a time of economic growth should not be interpreted to imply that emissions have peaked. Several lines of evidence, including pledges for the Paris Agreement, indicate that increases will continue for some time. The encouraging feature of the pattern over the last two years is in the decoupling of global GDP and carbon dioxide emissions. The new data make it clear that, even before emissions have peaked, the path for future growth need not be based on carbon.


Single-Event Attribution

Until recently, climate scientists had a more or less standard response to questions about whether climate change caused a particular storm, flood or heatwave. The answer was, “We know that some kinds of extremes are expected to become more frequent or severe with climate change, but it is not possible to

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9 Ibid.
forge a causal link between climate change and any particular extreme event.” Single-event attribution, the technical term for establishing the role of climate change in particular events, does not occur in the glossary or the index of the 2013 IPCC report on the physical science basis of climate change.\textsuperscript{10}

But the science is changing rapidly, and single-event attribution is increasingly in the mainstream of climate science. The first papers on single-event attribution appeared about a dozen years ago. By comparing the frequency of simulated heat waves in climate models with and without anthropogenic GHGs, Stott and colleagues were able to demonstrate that climate change at least doubled the odds of an event like the European heat wave.\textsuperscript{11} They did not conclude that climate change was the direct cause, but they showed how it altered the risks. Technical approaches for single-event attribution have advanced rapidly. Research teams around the world are applying sophisticated approaches for analyzing extreme events. Beginning in 2012, the Bulletin of the American Meteorological Society started publishing an annual supplement on “Explaining Extreme Events,”\textsuperscript{12} a supplement that has grown to 32 events in the most recent 2015 version.\textsuperscript{13} The technology for single-event attribution is now so robust that several groups are discussing rapid-response capabilities to provide information on the human role in close to real time.

Since 2012, papers in the “Explaining Extreme Events” supplements have analyzed 79 events. In more than half of these events, human-caused climate change had an influence. The influence was most consistent for extreme heat events, with detectable human influence in 21 of 22 cases.\textsuperscript{14} For extremes of heavy precipitation, there was a human role in 10 of 20. Human influence has been detected in the odds of some but not all droughts,\textsuperscript{15} tropical cyclones,\textsuperscript{16} and wildfires.\textsuperscript{17} The available analyses do not say that climate change is involved in every extreme. They do, however, establish a foundation for adding context to broad discussions, for considering specific implications of real events and for detailed analyses of the costs of the climate changes that have already occurred.

Reconsidering Century-Scale Risks from Sea-Level Rise

Threats from rising seas are among the most palpable concerns about climate change. Risks from rising seas are diverse, extending well beyond gradual inundation. Earlier and more widespread risks include coastal erosion, loss of coastal ecosystems, salination of freshwater aquifers, increased sunny-day

\textsuperscript{10} IPCC, \textit{Climate Change 2013}.
nuisance flooding and more frequently overtopped coastal defenses. One of the reasons sea-level rise plays such a prominent role in discussion of climate change risks and damages is its deeply existential nature. Entire communities, indeed entire nations, will be forced to relocate if sea level overtops their low-lying homelands. Kiribati, under the presidency (2003–2016) of Anote Tong, was the first nation to develop a detailed plan for relocation of the entire population.

Sea-level rise has two main components: thermal expansion of warmer water and transfer of water from ice on land to the oceans. The first process, thermal expansion, is challenging to model because an accurate prediction requires detailed knowledge of the way heat spreads through the oceans, a process that requires many centuries to reach equilibrium. But models of ocean circulation are increasingly sophisticated, facilitating robust projection.

The transfer of water from ice on land to the oceans is the big unknown. The quantity of sea-level equivalent is massive: ice on Greenland represents 24 feet of sea-level equivalent, Antarctica 190 feet, and alpine glaciers about 1.5 feet. The mechanisms that control the transfer of water from ice on land to the oceans are diverse and incompletely understood. Major mechanisms are hotly debated in the scientific literature, as are rates and magnitudes of past changes.

The IPCC has struggled with ways to accurately reflect the state of knowledge concerning the potential for sea-level rise in the 21st century and beyond. In the 2007 report, the working group on physical sciences reported projections that were a sum of projected thermal expansion and glacier melt, plus a contribution from ice sheet loss set nominally as a continuation at the rate of the late 20th century. This led to a likely range of 7 to 21 inches above late 20th-century levels, explicitly excluding any effects from accelerating flows of major ice sheets. The working group on impacts took a more risk-based approach, noting that major deglaciation of Greenland and West Antarctica, possible over centuries to millennia, could lead to sea-level rise of 13 to 20 feet or more.

By the time of the IPCC Fifth Assessment Report, quantitative models of ice sheet loss were advanced enough for incorporation into estimates but with important caveats about the limited number of mechanisms included. With these new models, the projected likely range for the 21st century grew to 10 to 39 inches above late 20th century levels, with a comment that collapse of grounded ice (resting on surfaces below sea level) could increase this range.

This picture has changed substantially with the publication of three important new lines of evidence. The first is that the combination of historical evidence and models enables improved estimates of the potential range for 21st-century sea-level rise, setting a new likely range of 11 to 52 inches, with the top

21 IPCC, Climate Change 2013.
of the range 33 percent higher than in the IPCC report. Second, new work on the physical strength of tall ice cliffs makes it clear that the IPCC models were missing an important mechanism. Including the strength of ice cliffs in the calculation leads to the conclusion that potential for 21st-century ice loss from Antarctica alone could be more than 40 inches, compared to the IPCC estimate of 8 inches or less from both Antarctica and Greenland combined. Finally, several new studies focus on risks of sea-level rise over several centuries to millennia. With very large amounts of warming caused by burning the world’s entire reserves of fossil fuels, commitment to sea-level rise over several millennia includes all the ice currently on Antarctica, about 190 feet, rising at a rate of almost a foot per decade during the first millennium.

Macro-Trends in the Economics of Climate Change

Most of the existing literature on economic damages from climate change is based on integrated assessment models developed in the 1990s. These models include estimates of the climate sensitivity of various economic sectors and use relationships built into the model to track the implications of these impacts as they spread across the global economy. The treatment of climate impacts in these models is far from complete. Among the unanswered questions is whether impacts should be understood as affecting current output, future growth, or both.

A summary of results of these models from the 2014 IPCC Fifth Assessment Report on Impacts, Adaptation, and Vulnerability concludes that with 2100 global average temperatures somewhere in the range of 2 to 10 degrees F warmer than preindustrial, the world can expect a GDP impact in the range of +2.3 percent (a positive impact of climate change) to -6.1 percent, with an average of -1.1 percent for models that project 2,100 warming in the middle of the range (4–5 F).

One recent study of the sensitivity of macroeconomic output to historic climate sensitivity comes to a dramatically different conclusion. Burke and colleagues detected a general pattern of warm conditions increasing economic growth in cool areas but decreasing it in warm areas. Extrapolating from these observations through the 21st century leads to an estimate that warming by 2100 decreases global GDP by 23 percent, with effects that are largest in countries that are currently poor (see Figure 3). While this much larger economic impact is from one study only, the new results open several important questions,

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26 D. J. Arent et al., Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A.
28 Ibid.
suggest new research approaches and imply that economic damages from climate change may be much larger than the estimates discussed by the IPCC.

Figure 3. Projected impact of warming through 2100 with continued high emissions on per capita GDP, relative to constant climate at 1980–2010 average conditions. This analysis is based on macroeconomic responses to historical temperature variations, from M. Burke, S. M. Hsiang, and E. Miguel, “Global Non-linear Effect of Temperature on Economic Production. *Nature* 527 (2015): 235.”

**Feasibility of a Zero Emissions Energy System**

Over the past couple of decades, the dialogue about pathways for reducing GHG emissions has wandered between two poles. At one pole, Hoffert and colleagues stressed the magnitude of the challenge and expense of decarbonizing energy production, the limitations of currently available technologies and the need for intensive research and development to discover, scale and mature new technologies. At the other pole, Pacala and Socolow argued that continued progress with existing technologies can get the world well along the path to solutions. From either perspective, decarbonization requires appropriate incentives and regulations. But the perspectives differ in their emphasis on the need for massive investments in new energy technologies.

The IPCC AR5 presents an overall picture of decarbonized energy systems that share features of both perspectives. Energy systems that limit warming to 2 C (3.6 F) place a huge emphasis on energy efficiency and are feasible at lower costs when they use the widest range of technologies (as argued by both Hoffert et al. and Pacala and Socolow). But in the IPCC report, some of the energy models cannot solve for a cost-

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 efective energy system that limits warming to 2 C, especially without overshoot (as argued by Hoffert et al.), and the costs are high – an average reduction in consumption of 4.8 percent, relative to pathways without decarbonization.31

Costs of some renewable energy technologies, especially solar photovoltaics, have fallen very rapidly. At the same time, technologies for energy storage, grid integration and demand management all continue to improve. While Hoffert and colleagues, writing in 1998, were fully justified in arguing about the need for new technologies, it is increasingly feasible to sketch the outlines of a zero-GHG energy system based on technologies that are either proven at scale or well along that trajectory. Jacobson and colleagues, for example, sketch a portrait of a zero emissions energy system that meets 100 percent of the energy needs of the United States based on renewable only, without nuclear or fossil energy with carbon capture and storage.32 While the technology assumptions in this study are optimistic, the evidence for feasibility of a 100-percent renewable energy system suggests that the discussion is entering a new era, where the focus is increasingly not on whether the world can build a zero-GHG energy system but on how it can be built most inexpensively.

**Co-benefits from Investments in Climate Action**

The classic framing of the climate challenge is as a trade-off. Critical resources can be invested in economic development or reducing the amount of climate change that occurs or adapting to the climate changes that cannot be avoided. With this framing, investments in climate change mitigation or adaptation compete with each other and pull resources away from other important development goals. While this framing is not intrinsic to the way the IPCC analyzes the climate challenge, it is reflected in important features of the structure of the IPCC reports and the nature of the IPCC process. In the IPCC, mitigation and adaptation are considered by separate working groups that write separate reports. The costs and benefits of adaptation tend to be framed with different metrics, vocabularies and emphases. Because the working group on mitigation is not looking at avoided damages, investments in mitigation tend to look like costs, even when the consequence of mitigation is a net benefit for the economy.

Sustainable economic development is a top priority across the United Nations (UN) system, especially in the sustainable development goals, but the agenda for development is handled by government organizations largely unconnected to the IPCC and other organizations that deal with climate change.

As a consequence of these structures, it is not surprising that the topic of co-benefits has not been a central feature of IPCC reports or of other climate change activities, but this is beginning to change. In the IPCC AR5, the mitigation report examines one important co-benefit, improvements in air quality from decreased particulate emissions from energy production.33 The special report on managing the risks of extreme

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33 IPCC, *Climate Change 2014*. 
events and disasters places a major emphasis on low-regrets actions that simultaneously address development and reduce vulnerability to climate change.

Recently, the picture has begun to change in two ways. First, discussion about two categories of co-benefits considered by the IPCC, health from reducing combustion emissions and adaptation-development interactions, has intensified. Second, policymakers are increasingly interested in structuring investments in adaptation, mitigation and development to encourage co-benefits.

Health benefits of decreased combustion are prominent, partly because the health impacts of combustion emissions are so clear. Caiazzo and colleagues estimate that combustion emissions in United States account for approximately 200,000 premature deaths per year, with major contributions from electricity generation, industry, buildings and transportation. Worldwide, the World Health Organization estimates that air pollution results in seven million early deaths per year, or one of every eight deaths. The potential to address health impacts from air pollution is a huge co-benefit of decreasing the use of fossil fuels (especially coal), in electricity generation, industry and heating buildings. Health benefits feature prominently in the Environmental Protection Agency (EPA) analysis of the U.S. Clean Power Plan.

Investments in adaptation and development can be competitive, but they can also be mutualistic. Co-benefits of development for adaptation and vice versa have been documented in many cases, especially in lower-income countries. Investments in transportation infrastructure, agricultural technology and public health infrastructure can all play a role in climate adaptation, especially in dealing with extremes; at the same time they promote economic activity more broadly. Economic development can also help increase adaptive capacity and decrease vulnerability to climate shocks.

Adaptation and mitigation can also be competitive or mutualistic. High-performance buildings provide clear cases of mutualism, with occupants better equipped to deal with climate extremes while at the same time energy requirements are reduced. Other examples of adaptation-mitigation mutualisms include the role of a more reliable electrical grid in coping with extremes and the role of improved energy access in fighting poverty.

Many potential co-benefits from addressing climate change involve new jobs in climate- and energy-related areas. Evaluating the net balance of jobs lost in the fossil energy sector and new jobs created in climate mitigation and adaptation is not straightforward. Opportunities in an innovation-oriented economy are clear, but these will be successful only if coupled to programs designed to address the changing needs of the workplace.

Other potential mutualisms with development include broadened energy access and decreased reliance on imported energy. While none of these co-benefits occurs automatically, the recognition of possibilities can provide a compelling dimension of a multidimensional case for climate action.

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The Paris Agreement: Implications of a Global Goal

For many years, two of the most consistent concerns about steps to address climate change have been (1) that actions in some but not all countries will create unfair advantages for countries that do not participate, and (2) that the lack of predictability in regulatory frameworks and market signals increased the cost and risk of investments in climate change solutions. The fundamental advance from the Paris Agreement, especially with last week’s commitment of ratification from the United States and China, is that it resolves both concerns.

The agreement is as close to universal as possible. As of September 3, 2016, 179 states and the European Union (accounting for more than 95 percent of global GHG emissions) have signed the agreement. Twenty six (accounting for 38 percent of emissions) have ratified. The agreement goes into force when ratifying nations account for 55 percent of global greenhouse gas emissions. The Paris Agreement builds on the concept of common but differentiated responsibility. This core element of the UN Framework Convention on Climate Change lays a framework for ground rules to establish mutually agreed-upon standards of fairness. A central element of the Paris Agreement, missing from the earlier Kyoto Protocol, is the recognition that all nations need to participate in emissions reductions and that GHG emissions eventually need to fall to zero. The framework of common but differentiated responsibility allows for differences in timing, with earlier commitments by the countries with financial and technical resources. But it does this in a way that acknowledges both sides of the fairness issue – the concern that nonparticipants should not receive an unfair advantage and the concern that it is unfair to demand early commitments from countries with minimal contributions to historical GHG emissions and with pressing needs for economic development. While individuals or corporations might have liked adjustments to the specifics, the existing agreement addresses the fairness issue in a way judged acceptable by the vast majority of the world’s nations.

The Paris Agreement is a strong starting point for predictable regulatory frameworks and market signals. It sets clear targets for emissions reductions through 2025 and establishes a broad pattern for the pattern of emissions after that. The commitments in the Paris Agreement, crafted individually by each country through their Intended Nationally Determined Contributions, are, for developed countries, ambitious but reachable. Achieving the emissions reductions they specify will require continued progress and sustained investment, but it will not require dramatically new technologies or policy environments. Achieving the emissions reductions will require what the private sector has been requesting – a consistent policy framework adjusted gradually over time to accommodate new information. This is something the world can do.