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Precipitation and the "Enhanced" Hydrological Cycle

David R. Legates, University of Delaware

Executive Summary

One of the most common predictions about future climate is that human emissions of greenhouse gases will lead to an increase in temperature, which in turn will lead to an increase in precipitation. This prediction is usually accompanied by more dire predictions of increases in floods and droughts in some places and the potential for more severe rainstorms. However, biases and errors in precipitation measurements make it difficult to determine whether these changes have actually occurred. In addition, regional precipitation is affected by atmospheric circulation and the transport of moisture, among other factors, so it is difficult to argue that an increase in air temperature should directly lead to an increase in precipitation for any given area.

The "can-type" precipitation gauges traditionally used to measure rainfall and snowfall provide a biased estimate of precipitation. One study estimated that for much of the United States the error in snowfall measurement often exceeds 25 percent, while the error in summer rainfall measurement is less than 8 percent. Another study demonstrated that the *measured* precipitation total would increase by 6.4 percent simply as a result of a 1°C change in air temperature and a 1.15 mph change in wind speed, changes that could occur as the result of urbanization at the precipitation gauge site.

Climate models do a poor job of simulating current precipitation amounts and, therefore, their projections of future precipitation amounts cannot be trusted. Given the difficulty in simulating precipitation with a General Circulation Model (GCM), model projections of drought, floods, and changes in stream flow are tenuous at best. Nevertheless, the Intergovernmental Panel on Climate Change (IPCC) claims that the risk of drought has likely increased in a few areas and that this risk will become greater in the future, particularly in the continental interiors. These claims are not supported by the available science.

Introduction

One of the most common predictions about future climate is that human emissions of greenhouse gases will lead to an increase in temperature, which in turn will lead to an increase in precipitation. The IPCC Third Assessment Report (TAR) states:

> Based on global model simulations and for a wide range of scenarios, global average water vapor concentration and precipitation are projected to increase during the 21st century.[i]

IPCC's Second Assessment Report summarized this potential as follows:

> Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models

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indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events.[2]

Basic theory suggests that increasing air temperatures might be accompanied by a slight increase in globally averaged precipitation. The moisture content of the air at saturation increases with increasing air temperatures. It therefore stands to reason that there will be the potential for slightly more water vapor in a slightly warmer atmosphere. **However, biases and errors in precipitation measurements make it difficult to determine whether these changes have actually occurred**. In addition, regional precipitation is affected by the atmospheric circulation and the transport of moisture, among other factors, **so it is difficult to argue that an increase in air temperature should directly lead to an increase in precipitation for any given area**.

It therefore is quite difficult to ascertain how much of an observed precipitation trend is real, and how much is due to changes in the site characteristics associated with the precipitation gauge.

Biases in Precipitation Measurement and Their Influence on Precipitation Trends

The can-type precipitation gauges traditionally used to measure rainfall and snowfall provide a biased estimate of precipitation. Air flow around the gauge cause a slight updraft, which reduces the amount of precipitation caught and measured by the gauge. The error in snowfall measurement is greater than in rainfall measurement. Legates and DeLiberty[3] estimated that for much of the United States, the error in snowfall measurement often exceeds 25 percent, while the error in summer rainfall measurement is less than 8 percent. Other factors, such as obstructions by trees and buildings or changes in air temperature and wind speed caused by urban heat island effects, can also contribute to inaccurate readings.

Legates[4] examined the effects of a 1°C per century change in air temperature (which changed the proportion of snowfall in the total precipitation) and a 1.15 mph per century change in wind speed—changes that could have occurred from the development of the urban heat island and increased obstructions in the urban environment. Assuming no actual change in precipitation and using a model of precipitation gauge bias, Legates demonstrated that the *measured* precipitation total would have increased by 6.4 percent per century simply as a result of the modest assumed changes to air temperature and wind speed. Thus, subtle changes in the environmental conditions around a precipitation gauge can induce significant trends in the observed precipitation record. It therefore is quite difficult to ascertain how much of an observed precipitation trend is real, and how much is due to changes in the site characteristics associated with the precipitation gauge.

Factors Affecting Flood and Drought Perception

Much of the difficulty in addressing whether the hydrologic cycle is becoming more extreme lies in the definition and perception of floods and droughts. A "flood condition" almost always describes stream flow above a prescribed threshold, which may result from:

- rainfall at a rate which is greater than can be absorbed by soil and lakes,
- amount of snow accumulation and rate at which it melts, or
- channelization of streams and rivers which prevent water from entering its natural flood plain.

Floods depend on the timing of precipitation, its form (rain or snow), and human-induced changes to rivers. Separating these effects from the effects of climate change is extremely difficult.

Droughts likewise are difficult to define. A *meteorological drought* occurs whenever there is below-normal rainfall for a prescribed period of time. This definition is not useful, since it is possible to have a meteorological drought with no discernible impacts. An *agricultural drought* occurs when soil moisture conditions fall a specified degree below normal levels. This definition is useful, as it has a direct relationship to plant growth and crop yield, although for most agricultural areas, soil moisture is almost always replenished to full capacity during the winter. Agricultural droughts rarely extend for longer than a single growing season. A *hydrological drought* occurs when river, lake, or well levels fall below a specified threshold. Water for urban use almost always comes from surface or groundwater reserves, which makes this definition useful as well. However, increased urbanization increases the demand for industrial, residential, and agricultural water use, leading to an increase in hydrological droughts that masks the effect of potential changes in the Earth's climate.

It is important to separate the perception of an increase in the hydrological cycle extremes from the true changes in climate.

Our *perception* of drought and flood frequencies is greatly affected by anthropogenic influences that do not affect the climate. Increased urbanization results in increased demand for water, more impervious surfaces, and channelization of streams and rivers, which lead to an increase in both hydrological droughts and floods. It is important to separate the *perception* of an increase in the hydrological cycle extremes from the true changes in climate.

Modeling Precipitation with General Circulation Models (GCMs)

The Marshall Institute has published a number of reports documenting the shortcoming of climate models.[5] However, when discussing modeling of precipitation, one limitation is critical: in the climate system, everything is interconnected. Anything you do wrong in a climate model will adversely affect the simulation of virtually every other variable and process. Precipitation requires moisture in the atmosphere and a mechanism to force it to condense (e.g., by forcing the air to rise over mountains).

Any errors in representing either the atmospheric moisture content or the precipitation-causing mechanisms will result in errors in the simulation of precipitation. For example, incorrect simulations of air temperature also will lead to incorrect simulation of precipitation patterns, since the ability of the atmosphere to store moisture is directly related to its temperature. If winds, air pressure, and atmospheric circulation are poorly represented, then the simulation of precipitation will be adversely affected, since the atmospheric flow of moisture that may condense into precipitation will be incorrect. Other factors that are important include:

- topography,
- plant transpiration and soil evaporation,
- clouds that alter the amount of solar energy reaching the ground,
- oceanic circulation, and
- sea ice concentrations.

Inaccuracies in precipitation simulations, in turn, adversely affect virtually every other climate variable. Condensation releases heat to the atmosphere and forms clouds, which reflect energy from the sun and trap heat from the earth's surface—both of which affect air temperature, which, in turn, affects winds, atmospheric pressure, and atmospheric circulation. These factors, in turn, affect all of the other parameters described in climate models.

The IPCC Claims for an Enhanced Hydrologic Cycle

Relying largely on GCM outputs, the IPCC TAR makes a number of claims, often contradictory, about changes in the hydrologic cycle as a result of anthropogenic increases in atmospheric concentrations of greenhouse gases. These include:

- changes in total precipitation,
- precipitation intensity,
- floods and droughts, and
- storminess.

Changes in Total Precipitation during the 20th Century

In its *Summary for Policymakers*, the TAR provides a mixed picture for total precipitation change during the 20th century. Total precipitation increased by as much as 1 percent per decade over some parts of the Northern Hemisphere continents, but decreased over other parts of these continents. There were increases over the tropics early in the 20th century, but not during the past few decades. No systemic changes were noted over Southern Hemisphere continents, and there was insufficient data to establish trends over the oceans.[6] New *et al.* (2001)[7] concluded that global precipitation had increased by only 9 mm. per year during the 20th century, with the largest increase in the Southern Hemisphere. However, these trends were not statistically significant, since decadal variability was more than four times that amount.

The IPCC concluded that global average surface temperature increased by 0.6°C during the 20th century, with about half of that increase occurring after 1975.[8] If temperature increase and precipitation increase are linked, there should have been a concurrent increase in precipitation. However, neither the IPCC nor New, *et al.* provide convincing evidence of a global increase in precipitation. The problem is that precipitation is far more variable, exhibiting more inter-annual and spatial fluctuations than temperature. Coupled with the bias in measuring precipitation, and the near complete lack of precipitation data for the world's oceans, it is quite difficult to divine long-term trends from the high degree of variability or "climate noise" present.

Projections of Future Changes in Total Precipitation

The IPCC TAR concluded:

> Based on global model simulations and for a wide range of scenarios, global average water vapor concentration and precipitation are projected to increase during the 21st century.[9]

Such projections are meaningful only if the climate models used have been validated. At a minimum, the climate models should accurately simulate current precipitation patterns. Current climate models fail this test. Using two of the most popular climate models, Doherty and Mearns (2000)[10] demonstrated large differences between model simulated precipitation and the observations for North America. Other researchers[11] have reached the same conclusion.

Changes in Precipitation Frequency and Intensity

The IPCC TAR concluded:

> In the mid-and high latitudes of the Northern Hemisphere over the latter half of the 20th century, it is likely that there has been a 2 percent to 4 percent increase in the frequency of heavy precipitation events.[12]

This conclusion is based on analysis of data for only parts of the 20th century (e.g., that of Karl and Knight (1998))[13]. However, Kunkel *et al.* (2003) considered data for a longer time period. They found that the frequency of heavy precipitation was high during the late 19th and early 20th centuries, reached a minimum in the 1920s and 1930s, and gradually increased to the late 20th century. They concluded:

> … the frequencies at the beginning of the 20th century were nearly as high as during the late 20th century … suggesting that natural variability cannot be discounted as an important contributor to the recent high values.[14]

Both studies, that of Karl and Knight and that of Kunkel, *et al.*, agree for the time periods for which they overlap, but their conclusions about whether there was an unusual change in the latter part of the 20th century depend on starting time for the comparison.

> *Given the difficulty in simulating precipitation with a GCM, model projections of drought, floods, and changes in stream flow are tenuous at best. Nevertheless, the IPCC argues that the risk of drought has likely increased in a few areas and this risk will become greater in the future, particularly in the continental interiors.*

Changes in Flood and Drought Frequencies

Recall that flood frequencies are affected not only by trends in rainfall, but also by changes in land use, urbanization, and channelization. Thus, it is difficult to attribute trends in stream flow to climatic changes. For example, the two major studies that have examined stream flow trends in the United States appear yield divergent results. Lins and Slack (1999)[15] concluded that the "…conterminous US is getting wetter, but less extreme." However, Groisman *et al.* (2001)[16] examined U.S. stream flow and found significant increases, particularly for the highest flow events and months with the highest flows, which is consistent with their analysis of increases in extreme precipitation.

This apparent discrepancy is relatively easy to explain: The two studies answered different questions. Lins and Slack addressed the question "Are trends occurring in stream flow percentiles?" whereas Groisman *et al.*'s question was "Of the total volume of water that changed, how much of that water came from a specific percentile?" Although the percentiles representing the largest stream flow had the smallest percentage increase (by far), that small percentage increase amounts to a considerable volume of water, since the annual maximum flow can be two or three orders of magnitude larger than the annual minimum flow. Thus, Groisman *et al.*'s conclusions appear to be largely a result of the extreme skew in the stream flow distribution.

This discussion serves to underscore the difficulties in interpreting stream flow trends as related to climate changes. As previously stated, stream flow is affected by changes in land use, urbanization, and channelization, as well as precipitation. The large changes that have occurred in the United States resulting from urban growth and efforts of the U.S. Army Corps of Engineers substantially affect stream flow and undermine efforts to detect climate change signals.

Conclusion

Given the difficulty in simulating precipitation with a GCM, **model projections of drought, floods, and changes in stream flow are tenuous at best**. Nevertheless, the IPCC argues that the risk of drought has likely increased in a few areas and this risk will become greater in the future, particularly in the continental interiors.[17] Given the contradictory assessments of current trends in floods, droughts, and stream flow and the lack of accuracy in model projections of present-day precipitation, let alone the questionable changes in precipitation, assertions of changes in the frequencies of these variables resulting from climate changes cannot be relied upon as fact.

Notes

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2. Houghton, J.T., *et al.* (1996): Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Pg. 7.
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5. See, for example: Climate Models: A primer (in Press); Schlesinger, J. and Sproull. R. (2001): Climate Change and Policy: Making the Connection; and Legates, D.R. (2000): Climate Models and the National Assessment. All are available on the Marshall Institute website: ***http://www.marshall.org***.
6. Houghton, *et al.* (2001): *op. cit.*, Pg. 4.
7. New, M., *et al.*, (2001): Precipitation measurements and trends in the twentieth century. *International Journal of Climatology*. **21**: 1899-1922.
8. Houghton, *et al.* (2001): *op. cit.*, Pg. 3.
9. *Ibid.*, Pg. 5.
10. Doughty, R. and L.O. Mearns (2000): A comparison of simulations of current climate from two coupled atmosphere-ocean global climate models against observations and evaluation of their future climates. *Report in Support of the National Assessment*, National Center for Atmospheric Research, Boulder, CO.
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13. Karl, T.R. and R.W. Knight (1998): Secular trends of precipitation amount, frequency, and intensity in the United States. *Bulletin of the American Meteorological Society*, **77**: 231-241.
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16. Groisman, P. Ya., *et al.* (2001): Heavy precipitation and high stream flow in the contiguous United States: trends in the twentieth century. *Bulletin of the American Meteorological Society*, **82**: 219-246.
17. Houghton, *et al.* (2001): *op. cit.*, Pg. 15.

GEORGE C. Marshall INSTITUTE

1625 K Street, NW, Suite 1050 • Washington, DC 20006
Phone 202-296-9655 • Fax 202-296-9714
E-Mail info@marshall.org • Website marshall.org