PCIC SCIENCE BRIEF: THE HUMAN INFLUENCE ON NORTH AMERICAN AND EURASIAN PRECIPITATION

Understanding how human influences are affecting different parts of the climate system allows us to improve future climate projections. Due to the relative sparsity of precipitation data and the large amount of internal variability that it exhibits, detecting and attributing the human influence on precipitation is difficult. This Science Brief covers recent research that uses information about the physical processes responsible for precipitation in order to detect the anthropogenic influence on winter precipitation over North America and Eurasia over the 1920-2015 period.

Publishing in *Geophysical Research Letters*, Guo et al. (2019) use a technique known as "dynamical adjustment," to estimate the atmospheric circulation and thermodynamic contributions to observed precipitation over Eastern North America and Northern Eurasia over the 1920-2015 period. They find that the thermodynamic component, due to anthropogenic emissions, contributes to increases in precipitation in both regions. They then compare the spatial pattern and magnitude of these components to those obtained from global climate models driven with anthropogenic forcings. They find strong agreement between the thermodynamic components of precipitation obtained from the observational data and those obtained from climate model output.

Introduction

The type, amount and timing of precipitation that falls during the winter effects snow depth, the extent of snow cover and its duration, as well as travel and wildlife habitats. For most of British Columbia, aside from the Northern Boreal Mountains and Taiga Plans, no statistically significant changes in winter precipitation have been observed over the length of the instrumental record. Nevertheless, future projections suggest that by the end of the century winter precipitation may increase. At the same time, snowfall is projected to decrease. A better understanding of the anthropogenic contribution to precipitation over the historic period allows for a better evaluation of climate models and thus, potentially, for better projections to be made of future changes.

On Precipitation

Precipitation, including rain, snow, sleet and hail, is very important for the role it plays in driving the hydrologic cycle, but it is also more difficult for climate models to simulate than temperature. This is due, in part, to the fact that the amount of precipitation that falls over a given location is dependent on the details of atmospheric dynamics at a range of scales, from the movement of storm systems to small-scale processes that occur on a scale that is smaller than the individual grid cells of global climate models. The physical shape and features of the landscape, including changes and elevation and mountains, surface terrain and small-scale surface water storage, termed "microtopography," are also smaller than model grid cells and so are represented in a simplified manner in global climate models, both in the shape and distribution of such features. However, the details of such features can be important for precipitation. Because precipitation depends on such complicated atmospheric dynamics and small scale surface features, it also exhibits a large amount of variability. Add to these issues with simulation and variability the fact that precipitation records tend to have limited coverage in space and time, and it becomes clear why detecting the human influence on precipitation is quite challenging.

Detection and attribution work using an "optimized fingerprint" method[1], in which global climate model output

1. Optimized fingerprinting can be interpreted as a regression technique, in which observational data is regressed onto global climate model output that has been driven by a certain set of forcings (this model output is referred to as the "fingerprint" of a given forcing) to determine if the effect of the forcing, such as that due to anthropogenic greenhouse gas emissions, can be detected (i.e. if the regression parameter associated with that fingerprint is positive and significantly different from zero) and then to estimate the magnitude of its contribution to the observed signal (i.e. estimate the size of the regression parameter). For more on optimal fingerprinting, see Allen and Stott, 2003, and Ribes, Planton and Terray, 2013.

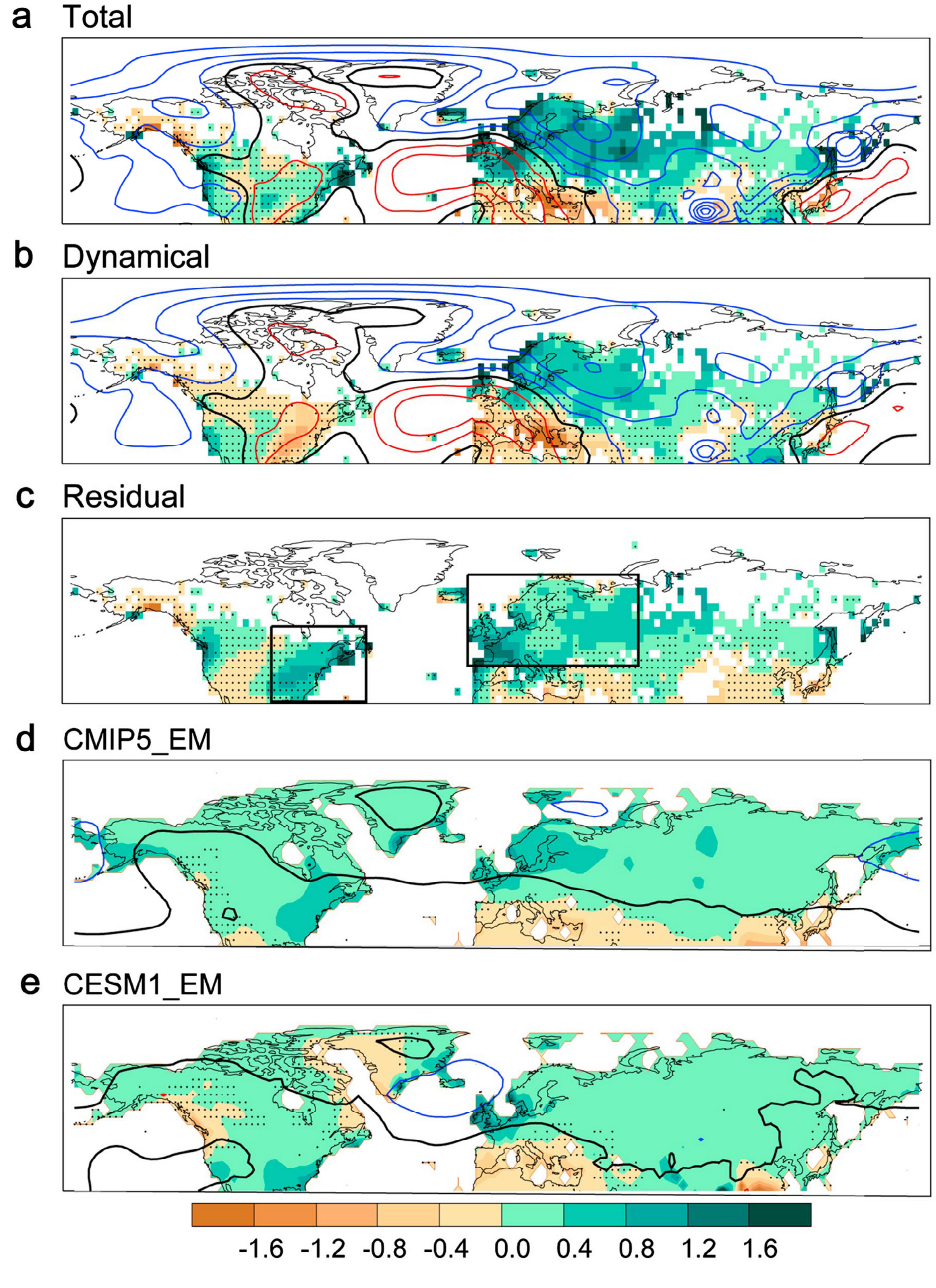

Figure 1: Observed and Simulated Trends in Winter Precipitation and Sea Level Pressure Over 1921-2015 (from Guo et al., 2019). This figure shows the 1921-2015 winter trends in (a) total observed precipitation and sea level pressure (SLP), (b) dynamic contribution to observed precipitation and SLP, (c) thermodynamic contribution to observed precipitation and SLP, (d) ensemble average simulated precipitation and sea level pressure trends from 37 models (one simulation/run each) that participated in the fifth phase of the Coupled Model Intercomparison Project[2], (e) ensemble average precipitation and sea level pressure from 40 runs/simulations with the Community Earth System Model[3], version 1. Precipitation is in millimetres per month per decade. The SLP contour interval is in units of 0.1 hectopascals per decade with positive values in red, negative values in blue and the zero contour in black. Stippled regions indicate areas in which the trends are statistically insignificant at the 10% significance level.

2. For more information on the fifth phase of the Coupled Model Intercomparison Project, see Taylor, Stouffer, and Meehl, 2012.
3. For more information on the first version of the Community Earth System Model, see Hurrell, Holland and Gent, 2013.

is compared to observations using a statistical model, has found an anthropogenic influence on precipitation over some regions and seasons[4]. However, this method is limited in part by the large amount of variability in precipitation observations. It is difficult to pick out the anthropogenic signal from the noise of variability. Recent research by Guo et al. (2019) uses considerations about the underlying mechanisms that drive precipitation in order weed out this variability and arrive at an estimate of the human contribution to winter (here November to March) precipitation in eastern North America and northwestern Europe over the 1921-2015 period.

The underlying processes that generate precipitation can be conceptually divided into two components: a dynamic component having to do with atmospheric circulation and a thermodynamic component that has to do with air temperature. The dynamic component transports water vapour throughout the atmosphere in various weather systems. Changes in patterns of sea level pressure can affect the paths of weather systems and hence affect precipitation. The thermodynamic component affects precipitation by controlling the amount of water vapour that the atmosphere can hold. For example, as air warms, it can hold more water vapour, which is then potentially available for precipitation. It is this latter thermodynamic component that the authors take to be most influenced by anthropogenic greenhouse gas emissions.

The authors use observations of sea level pressure from 1921-2015 and a statistical method[5] to estimate how much dynamic processes contribute to precipitation. They then subtract this portion due to dynamics from the total amount of precipitation, in order to isolate the thermodynamic contribution to winter precipitation. This "dynamical adjustment" technique allows them to tease out an estimate of the thermodynamic signal from the noise of internal, dynamic-driven variability.

Guo et al. first note the overall trend of increasing winter precipitation in the Northern Hemisphere over the 1921-2015 period (Figure 1, panel a). They also note the drying trends in the eastern Mediterranean and the trend of increasing precipitation in Northern Eurasia.

The authors then turn their attention to their estimates of the dynamic contribution to the observed precipitation trends (Figure 1, panel b), finding that changes to atmospheric circulation account for most of the drying in the eastern Mediterranean and about half of the increase in precipitation over Northern Eurasia. In particular, the decrease in atmospheric pressure to the southeast of Iceland (in an area where a region of low pressure called the Icelandic Low typically resides) and the increase in pressure to the southwest of Spain (in an area where a region of high pressure called the Azores High typically resides), causes more warm, moist air and storm systems to be drawn from the lower latitude Atlantic Ocean to Northern Eurasia, which results in milder, wetter winters in that region and dryer winters in the Mediterranean. Readers familiar with weather systems in the region will note that this is consistent with and similar to the winter weather seen in these regions during the positive phase of the North Atlantic Oscillation[6]. They also find that over North America, air circulation produces drying in the east and some increased precipitation over the western United States.

Guo et al. then examine the effect of the thermodynamic contribution to precipitation (Figure 1, panel c). They find that the magnitude and spatial pattern of the thermodynamic component, or residual, that they have isolated matches the ensemble averages of the global climate model runs (Figure 1, panels d and e) better than the total observed precipitation does. In particular, the trend of increased precipitation from the thermodynamic contribution in eastern North America is similar and the spatial pattern of increased precipitation in northern Eurasia and decreased precipitation in southern Eurasia from the thermodynamic contribution is in better agreement with the model ensembles than is the total observed precipitation.

The authors then focus their attention on the winter precipitation in two sub-regions: Eastern North America

4. For more information on the findings of detection and attribution studies on precipitation, see Sarojini et al., 2016 and the references therein.
5. The authors use a regression technique with sea level pressure data to arrive at a set of regression parameters that explain the patterns of sea level pressure for each month and year. They then apply these regression parameters to precipitation data in order to determine the contribution of sea level pressure (i.e. dynamic influences) to precipitation. They subtract the amount of precipitation associated with dynamic influences from the total precipitation and take the remaining residual to be an estimate of the thermodynamic contribution to precipitation. For more information on this technique, called "dynamical adjustment," see Guo et al. (2019) and the references therein.
6. The North Atlantic Oscillation is a climate pattern characterized by periodic variations in the pressure of the atmosphere at sea level in the Atlantic Ocean. Its positive phase is characterized by a strong low pressure region just south of Iceland, called the Icelandic Low and a high pressure region near the Azores, called the Azores high. Its negative phase is characterized by a weaker Icelandic Low and Azores High. It has effects on weather both regionally and globally. In its positive phase, it brings warm, wet winters to northern Eurasia and cooler, drier winters to northeastern North America and the Mediterranean. In its negative phase, it brings the opposite, with cooler, drier winters in northern Eurasia, and warmer, wetter winters to the Mediterranean and northeastern North America. In the summer, its effects are generally weaker, but it can still affect the weather of northern North America, Greenland, northern Eurasia, the Mediterranean and parts of Africa. In Canada, the NAO's effects are generally felt in central and northeastern regions.

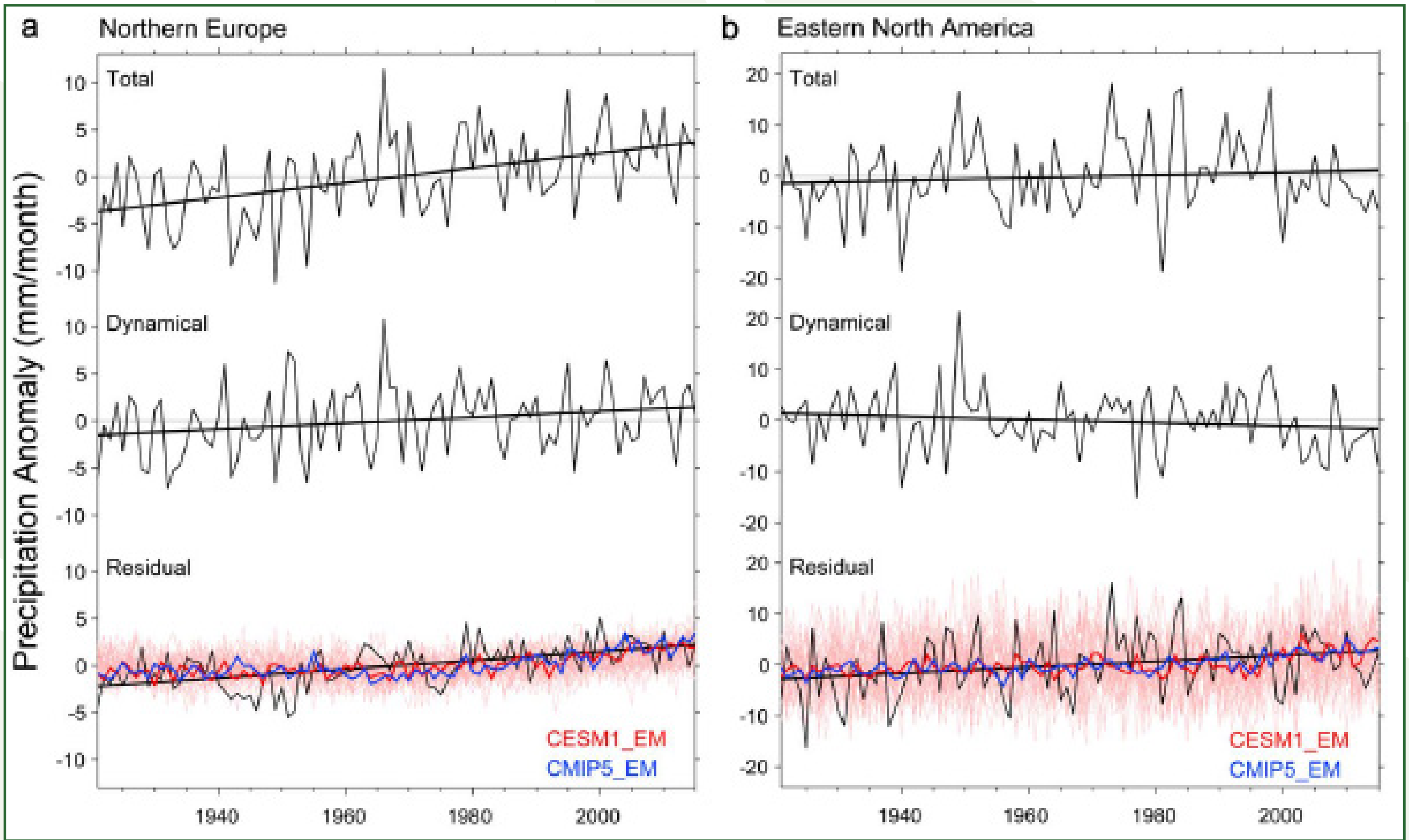

Figure 2: Observed and Simulated Trends in Winter Precipitation, Including Estimated Dynamic and Thermodynamic Contributions, for Northern Europe and Eastern North America (from Guo et al., 2019).
This figure shows the observed trends in winter precipitation (top), the estimated dynamic contribution to observed trends in winter precipitation (middle), and the residual component of observed and simulated precipitation that is assumed to be of thermodynamic origin (bottom), for Northern Europe (a) and Eastern North America (b). Red and blue lines in the bottom panels indicate ensemble averages for the thermodynamic residual from 40 runs/simulations from the Community Earth System Model[4], version 1 (red) and 37 runs/simulations from 37 models participating in the fifth phase of the Coupled Model Inercomparison Project[3] (blue). All trends are for the 1921-2015 period. Red shading indicates the model spread in the thermodynamic risidual for the Community Earth System Model runs.

and Northern Europe. (The regions used can be seen as outlined boxes in Figure 1, panel c.). They compare time series of the total precipitation, as well as the dynamic and thermodynamic contributions to precipitation, in both models and observations (Figure 2, panel a). They find that in Northern Europe dynamic influences account for about 40% of the winter precipitation trend and that the magnitude of the thermodynamic contribution taken from observations is roughly similar to the ensemble-mean trends from the global climate models. The also find that the variance, or "scatter," of the data, is quite similar between the thermodynamic residuals taken from observations and model output. This can be seen in the bottom of Figure 2 (panel a), in which the authors' estimate of the thermodynamic contribution to winter precipitation taken from observations (black line) lies largely within the spread of the same variable taken from climate model output (light red shading).

The winter precipitation trend in Eastern North America is much smaller, shows higher variance and is not statistically significant. The authors find that the contribution of atmospheric dynamics to observed precipitation is actually a drying trend and, once this is removed, a statistically significant increasing trend in precipitation, that they attribute to the thermodynamic contribution, remains. This thermodynamic trend is being mostly offset by the dynamic drying trend. As they found in Northern Europe, the size of the thermodynamic residual in North America is similar to the anthropogenic trends found in the climate model output and, again, the observed thermodynamic contribution to winter precipitation lies largely within the spread of the thermodynamic residual taken from climate model output (Figure 2b, bottom panel).

Returning to the global fields of data, the authors make some general remarks about global patterns of winter precipitation. Guo and coauthors note that climate models match the observed climatology quite well, accurately capturing the overall trends, interannual variance and the magnitude of the dynamic contribution to precipitation. They also find that there is a strong correspondence between the overall winter precipitation climatology of a region and the amount of interannual variance in its winter precipitation. They illustrate this with the example of wetter coastal regions, which exhibit more variability than drier, inland regions. They find that the atmospheric contribution to variance in precipitation is largest in Western North America and Western Europe.

Summary

Guo et al. use a dynamical adjustment technique to estimate the influence of the thermodynamic trend, due to anthropogenic climate change, in the winter precipitation trends of Eastern North America and Northern Europe over the 1921-2015 period. Both the spatial pattern and the overall size of the trends taken from the observations match with the anthropogenic trends taken from global climate model output. The pattern of increased precipitation from the thermodynamic contribution over Eastern North America in particular is close to the pattern seen in the ensemble of climate models, though in the observations, it is offset by a drying trend from the dynamic influence.

The work of Guo and colleagues does not deal with the climate of British Columbia directly. To the extent that information can be gleaned from their work about the climate of the province, it shows essentially no statistically significant trends for winter precipitation in the region. However, being able to pick out the dynamic and thermodynamic contributions to precipitation is potentially useful for the testing and further development of climate models, the improvement of which benefits climate data users from a wide variety of regions. This paper potentially represents one new tool for doing this. Using a different technique, PCIC scientists have also recently examined the effect of circulation changes on projected changes in extreme precipitation over North America (see Li et al, 2019). In addition, the development and application of new detection and attribution methods can serve as the foundation for novel detection and attribution work in other regions and for trends in other aspects of the climate system.

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