Precipitation changes in a warming climate

Precipitation is vital for life on Earth, and the frequency and severity of precipitation events are changing in response to climate change. Dr Hengchun Ye, from California State University, Stanislaus, has used precipitation data from across Northern Eurasia to assess the impacts of warming air temperatures on precipitation total, intensity, and frequency. The research reveals Northern Eurasia's warming atmosphere is leading to prolonged warmer dry spells punctuated by less frequent, more intense precipitation events for summer, spring, and autumn. This finding is paramount for effective long-term water resource management strategies, as droughts and flooding become more likely.

Precipitation – water particles that fall to the ground as rain, sleet, snow, or hail – occurs when atmospheric water vapour condenses into increasingly larger water droplets in clouds, until gravity takes effect and precipitation falls. This simple process is essential for sustaining all life on our planet, and it is changing as the climate warms.

Understanding those changes and the implications for water management across the globe requires long-term data. Dr Hengchun Ye of California State University, Stanislaus, took on the role of historical detective, to better understand how the many facets of precipitation are related to long-term changes in weather systems.

THE POWER OF CONVECTION

For many of us clouds just compliment a blue sky or ominously foreshadow a storm, but to scientists they mean a great deal more. Clouds are an essential component of the hydrological cycle – the movement of water between the ocean, land, and atmosphere by the processes of evaporation, transpiration (evaporation of water from plant leaves) and precipitation. Broadly speaking they fall into two types: convective clouds are associated with rising warm air and unstable atmospheric conditions, while non-convective clouds are associated with more stable conditions and generally appear higher in the atmosphere and with larger spatial coverage. Convective precipitation is localised, short-lived, intense, and sometimes violent (think thunderstorms and tornados). Non-convective clouds are responsible for all other forms of precipitation.

Our warming climate directly affects how much water vapour the atmosphere can hold, so studying the interconnecting factors that lead to cloud formation is important for understanding how and why precipitation patterns will change as warming continues. This knowledge is critical, because when, where and how precipitation falls to Earth can be a matter of life or death.

PRECIPITATION CHANGE IN NORTHERN EURASIA

The focus of Dr Ye's work was Northern Eurasia, the largest landmass at high northerly latitudes that is experiencing amplified warming, and an area for which long-term historical data are available.

The Global Synoptic Climatology Network (GSCN) provided three-hourly observations of weather conditions (eg. 'showery' or 'thunderstorms'), alongside humidity data from 152 stations across Northern Eurasia for the last three

Convective clouds. Convective precipitation is localised, intense and sometimes violent.

decades of the 20th century. The Carbon Dioxide Information Analysis Centre provided records on daily total precipitation (ie. the sum of all rain experienced in a location over a given period) and mean air temperature records from 517 Russian meteorological stations, which revealed data about the duration of dry and wet spells in Northern Eurasia between 1966 and 2020. By combining these datasets, Dr Ye could assess the number of days with convective versus non-convective precipitation, and their associations with specific humidity and surface air temperature. She was also able to determine the effects of changing precipitation total, intensity and extremes on convective versus non-convective precipitation types.

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Finally, collaboration with the Atmospheric Infrared Sounders Team at NASA's Jet Propulsion Laboratory provided the last piece of evidence, with atmospheric water vapour records revealing the complex dynamics between precipitation characteristics, total water vapour column and air temperature profiles.

CHANGING PRECIPITATION PATTERNS

The capacity of the atmosphere to hold water vapour increases by 7% as air temperature rises (at a constant relative humidity); consequently, water vapour remains in the atmosphere for longer. In essence, this means a warming climate causes precipitation to fall less frequently; when it does fall, however, it falls at much higher intensity – so a single event releases a larger amount of precipitation in a given time.

Dr Ye emphasises that total precipitation or intensity alone cannot give us the answers we need: precipitation frequency – the timescale and number of events during which precipitation falls – is crucial. And while annual and seasonal precipitation at a location are important, we also need to understand frequency on a smaller scale; a single location can experience the same amount of precipitation, but the impacts of the event will vastly differ depending upon the timescale.

What does this mean in practice? Consider a large volume of rain falling over just a few days – for example, a summer season with a prolonged downpour for 10 days at the start of the season, with no precipitation at all for the following 20 days. This scenario would cause significant problems with surface runoff causing flooding in the early season and drought towards the end of the season. Yet the same volume of rain falling over a much longer period (regular precipitation events every three days, for example) could have beneficial impacts, as there is time for absorption by vegetation and recharging of groundwater supplies and reservoirs, essential for human consumption.

SEASONAL PRECIPITATION EXTREMES

Dr Ye's research has also uncovered a shift towards convective precipitation events, characterised by localised, short-lived and severe weather events. The GSCN's historical records showed annual convective precipitation increased by 18.4% per 1°C of warming for the last three decades of the 20th century, with annual daily precipitation extremes also increasing by 7.4% per 1°C of warming since the 1980s in spring and autumn. These more 'summer-like' seasons are therefore now characterised by increasing

A warming climate causes less frequent but more intense precipitation events.

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A drought-damaged corn field: more frequent prolonged dry spells will have a significant impact on food security.

air temperature and atmospheric water vapour content over Northern Eurasia. This knowledge is imperative to implementing future water resource management strategies, as fewer precipitation events in transitional seasons links directly to droughts, while increased levels of atmospheric water vapour exacerbate the greenhouse gas effect.

The question of whether this shift towards convective-type precipitation is enhancing precipitation intensity and extremes needs to consider several factors. Seasonal total precipitation shows that non-convective precipitation is most common in winter, while convective precipitation takes over in summer. Since the 1980s, however, a shift from non-convective to convective precipitation has occurred in spring and autumn. At the same time, these two transitional seasons have seen an overall increase in the daily intensity of convective precipitation. Similarly, annual total precipitation frequency and intensity have seen convective precipitation become the dominant type since the late 1990s (increasing by 25% between 1966 and 2000).

Dr Ye's findings have therefore revealed a surprising correlation between climate change and the mode of precipitation delivery over time. Data reveals that higher atmospheric water vapour content and a warming climate marry to produce more frequent convective events over Northern Eurasia. As a consequence, this landmass has experienced increased precipitation intensity and larger daily precipitation extremes, between the 1960s and 2020.

The research has also revealed striking evidence for changing summer precipitation patterns across Russia between 1966 and 2010. These comprise longer dry spells (total number of consecutive dry days where precipitation was 0.1mm or less), punctuated by short, wet spells (total number of consecutive wet days where precipitation was 1mm or more). Another notable change was seen within the dry spells, where the number of extreme dry events (seven days or more) increased by 6.1% per 1°C of warming compared to the number of short, dry events (three days or less), with a decrease of 2.4% of occurrences per 1°C of warming over the study period. There was also notable geographic distribution of these trends, with the longest dry day periods occurring in southern central Siberia and south-eastern Russia during the winter, whereas the longest dry day periods occurred between the Caspian and Aral Seas of Russia during the summer.

In general, hotter Russian summers therefore appear to accompany more frequent and prolonged dry spells, enhancing drought and heatwave conditions across the country.

THE FUTURE OF PRECIPITATION

Dr Ye's work on Northern Eurasia shows that a warming and moistening atmosphere is producing longer spells of warm, dry weather punctuated by less frequent and more intense precipitation events for summer, spring and autumn. As air temperature rises, winter experiences shorter dry spells and longer wet spells, while the opposite is true for summer.

Understanding the causative link between air temperature, atmospheric water vapour and precipitation helps scientists to understand why there has been a major change towards higher precipitation intensity but lower frequency across Northern Eurasia. Furthermore, Dr Ye's results reveal how these precipitation patterns could intensify as the climate continues to warm. These are not just meteorological phenomena; these changes have severe impacts on human and animal health, agricultural productivity, food security and fire hazards. Dr Ye's findings have major implications for global water resource management strategy and policy, and for society's resilience towards climate change.

These changes have severe impacts on human and animal health, agricultural productivity, food security and fire hazards.

Dr Ye's work helps scientists understand the causative link between air pressure, atmospheric water vapour and precipitation.

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Behind the Research

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Research Objectives

Dr Ye's research interest is in climate change reflected in the critical components of the hydrological cycle.

Detail

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Bio
Dr Ye is a professor in Climatology and the Dean of Graduate Studies and Research at California State University, Stanislaus. With more than 26 years' experience of research, teaching and mentoring, Dr Ye is committed to diversity, equity and inclusion, and dedicated to supporting students of colour and under-represented groups.

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Personal Response

Is it possible to extrapolate your results to make conclusions about precipitation dynamics in a warming climate on a global scale?

" Since these studies are focused on higher latitude land areas, these results could be extrapolated into other similar geographical regions, such as Canada and other European countries. For middle and tropical regions, we need to do more research to reveal change patterns because the atmospheric dynamics and the climate regimes are different from higher latitude areas. Our unique perspectives and methods are straightforward and can easily be adopted in precipitation research in any parts of the world. Also, people can use the climate model's outputs to investigate these changes at global scales. "

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