The limits of weather forecasting: How far into the future can we look?

February 5 2024

Credit: Pixabay/CC0 Public Domain

Weather-related disasters and climatological extremes, including rivers bursting their banks and flooding as well as heat waves and droughts, cause tragic loss of life and cost billions of dollars in property damage

each year.

Therefore, weather forecasts and protective measures are enormously important and will become even more relevant in the future. However, there is a natural limit to the predictability of the weather, which has not yet been reached.

"There is still great potential to further improve weather forecasts for middle latitude regions," said Dr. Michael Riemer from Johannes Gutenberg University Mainz (JGU). "But there is also a point beyond which reliable prediction is just not possible."

Riemer and his colleagues have investigated the accuracy of weather forecasts in best-case scenarios. According to their calculations, it should be possible to extend the forecast period by up to four or five days. The study is published in the *Journal of the Atmospheric Sciences*.

Weather forecasts have become more reliable

Midlatitude weather can be predicted with reasonable accuracy for seven to 10 days in advance. This was not always the case. The quality of weather forecasts has improved considerably over recent decades. A forecast covering seven days is now as accurate as that for four days 30 years ago. Better computer performance and the availability of new data have contributed to this improvement, but the quality of the prognoses is still extremely poor in some cases.

Weaknesses and flaws in forecasting methods are part of the problem, but certain weather conditions are inherently difficult to predict in a chaotic atmosphere. Extensive storm cyclones, for example, can be identified about seven days in advance, whereas the period is much shorter for thunderstorms. As the forecast period increases, so does the likelihood of errors.

Decisive factors for the limits of predictability

The limitations of weather forecasting have been subject of research since the 1960s. Unlike the tides and the orbit of planets, the atmospheric system has an intrinsic limit that represents a natural and ultimate boundary beyond which prediction is no longer possible. "Research has repeatedly reached the same conclusions: We can predict the weather up to 14 days in advance at best," said Dr. Michael Riemer, a meteorologist at the JGU Institute of Atmospheric Physics.

In collaboration with his colleagues Dr. Tobias Selz and Professor George Craig of LMU Munich, Riemer has confirmed the existence of the intrinsic limit of predictability. The researchers also investigated the responsible processes. "The predictions are currently most affected by errors in our initial conditions," added Riemer. "If we improve these initial conditions from which our computer models start their predictions, then our predictions will also be more accurate."

The butterfly effect in weather forecasting

Using quantitative estimates, the team demonstrated that it is necessary to account for large-scale factors such as wind, wind pressure, temperature, and the jet stream more closely. "We have to reduce the initial uncertainty by 80% to 90% to reach the intrinsic limit inherent in the system," stated Riemer. This could extend the period of reliable forecasts by another four to five days.

Once this 90% of error reduction has been exploited, the mechanisms involved will change and the large-scale factors will no longer be decisive. From this point onwards, the butterfly effect will dominate events. "Thunderstorms as the main driver of the butterfly effect will then come into play." However, this effect is so small that even a severe

thunderstorm would not affect the reliability of a current-day weather forecast for the next few days.

More precise weather predictions require increased allocation of resources to atmospheric observation

U.S. meteorologist Edward Lorenz coined the term "butterfly effect" in the 1970s to describe how small changes in initial conditions of a complex system, such as the atmosphere, can lead to significant differences in a later state, which limits the predictability of such systems. Even disturbances that are too small to be detected in the very beginning can snowball and cause extensive changes to the weather after a certain period of time.

"The individual thunderstorm cells in our study are like those butterflies," added Riemer. "To improve our predictions, we must focus on the major influencing factors." The scientist recommends intensifying atmospheric observations and measurements, possibly with the assistance of satellites. The potential for weather forecasting has not yet been exhausted and could be improved significantly in the coming decades.

More information: Tobias Selz et al, The Transition from Practical to Intrinsic Predictability of Midlatitude Weather, *Journal of the Atmospheric Sciences* (2022). DOI: 10.1175/JAS-D-21-0271.1

Provided by Universitaet Mainz