PREDICTABILITY OF EXTREME WEATHER EVENTS

International Innovation, published by Research Media, is the leading global dissemination resource for the wider scientific, technology and research communities, dedicated to disseminating the latest science, research and technological innovations on a global level. More information and a complimentary subscription offer to the publication can be found at: www.researchmedia.eu
In an engaging interview, Professor Henk W Broer and Dr Alef Sterk discuss the inception of an ambitious collaborative project seeking to improve the prediction of extreme weather events.

As an opener, what inspired your interest in dynamical systems?

HB: The fact that various mathematical sub-disciplines align within dynamical systems theory in a beautiful way.

AS: As a student I took several courses in dynamical systems, and was surprised by the complex behaviour such systems can exhibit, despite the fact that their mathematical description may look quite simple.

How did you first meet and decide to collaborate together?

AS: I had been an undergraduate student in mathematics at the University of Groningen in The Netherlands where I took several courses in dynamical systems. After I finished my MSc thesis, I started my PhD studies under Henk’s supervision.

Upon obtaining my PhD degree in 2010, I started my postdoctoral work at the University of Exeter under the direction of Dr Renato Vitolo – another of Henk’s former PhD students.

Can you give an overview of some of the key questions addressed by the PREDictability of Extreme weather events (PREDEX) project?

HB: Its major conjecture was formed during the project, and was tested and confirmed with various classical toy examples, partly using computational tools. Fundamental research has also been developed to address a larger class of examples.

AS: The key questions of the project are:

- What are the deterministic time limits of predictability for extreme weather events? It is known that ordinary weather can only be predicted for about 10 days. It is not known whether the same time limit applies to weather extremes such as windstorms.

- How do we use emergent dynamical patterns to reduce uncertainty when estimating extremes in deterministic systems?

As a collaborative interdisciplinary project, who were the key players involved in this venture? What expertise did they offer?

HB: Owing to my theoretical knowledge of nonlinear dynamical systems, I myself was a key player. Vitolo shares this knowledge to a large extent, but works in statistical climate modelling and has mastered the computational tools needed to experiment. Dr Mark Holland, working in ergodic theory, brought expertise on probability theory and statistics. Vitolo and Holland were in Exeter, and Alef was a postdoc there studying dynamical systems and mathematical climate models, along with Dr Chris Ferro who works with extreme value statistics and Professor David Stephenson researching statistical climate modelling. In Groningen, we had support from the postdoc Dr Pau Rabassa, who also works in nonlinear dynamical systems, while Carles Simó from Barcelona inspired us in the background mechanisms.

What do you expect to be the far-reaching impact of an improved ability to forecast extreme weather events?

HB: This kind of knowledge will save lives through the development of early warning systems for the public. It might also be extremely useful to insurance companies who will be better prepared for disasters such as hurricane Katrina, which ravaged New Orleans in 2005.

As an area of research that has a significant global impact, do you think there is adequate awareness of extreme weather events, not just among the research community but also the general public? What more can be done?

HB: Good question. For mathematicians, the theory is elegant and appealing, but for the general public, the insurance issue may be of interest. From a more general point of view, the interest in the behaviour of chaotic systems such as weather or the climate is relevant, and the tail width of the probability distribution makes it more interesting. Some might also find the contamination of statistics with determinism appealing.

AS: I think that there is plenty of awareness of weather extremes among the general public. For example, hurricanes Sandy and Katrina have received considerable attention from the media. As Henk already mentioned, the insurance aspects might be most appealing to a wide audience.

However, I think that most people are not fully aware of the scientific challenges that lie ahead. Among my own friends and relatives, I sometimes hear remarks like: ‘Computers are so advanced nowadays. Why can’t we make better weather predictions?’ But in my opinion, scientific advancement does not lie exclusively in building faster computers. I think it should be made clear that we still only have a limited fundamental understanding of complex systems like the weather.
The PREDictability of EXtreme weather events project is investigating complex dynamical systems; vital work that will lead to important real-world applications and better forecasting of extreme weather events.

DYNAMICAL SYSTEMS THEORY seeks to model how the behaviour of complex systems evolves over time. Such systems can exhibit unpredictable behaviour which, though fundamentally deterministic, appears chaotic or random due to the sheer complexity of the system. While it is usually difficult to predict long-term behaviour in complex systems, it is often possible to describe fixed points, or steady states, within them. The Earth’s weather is an example of one such system.

There is concern among climate scientists and observers that as the planet continues to warm, the occurrence and intensity of extreme weather events such as wildfires, tornadoes, heat waves or floods, could increase. As local climates are affected in unexpected ways – a phenomenon dubbed ‘global weirding’ – weather events traditionally unheard of in given areas might become more common, some of which might be characterised as extreme. Although a firm link between anthropogenic climate change and a greater risk of extreme weather events is yet to be proven, what is certain is the threat they present to human life and livelihood, as the planet’s population grows, these risks will amplify. Therefore, tools which can help us better model and predict extreme weather events will become increasingly valuable in reducing our vulnerability.

QUANTIFYING PREDICTABILITY

Henk W. Broer, Professor of Dynamical Systems in the Department of Mathematics at the University of Groningen in The Netherlands is coordinating a project entitled PREDictability of Extreme weather events (PREDEX) – a collaborative interdisciplinary endeavour investigating the deterministic time limits of predictability for extreme weather events. Seeking to determine how we can use emergent dynamical patterns to enhance the predictability of extreme weather events, the project investigates the role of spatial-scale interactions within physical processes, and aims to deliver new mathematical complexity methods for quantifying the predictability of extreme events in complex dynamical systems. “PREDEX aims to estimate the probabilities of unlikely events within a deterministic system that is highly unpredictable. Interestingly, you can still derive statements on probability densities even in a chaotic dynamical system,” Broer outlines. The work is made possible by recent advances in the mathematical theory of extreme events for dynamical systems and on large-scale emergent atmospheric patterns which modulate the behaviour of windstorms.

Broer is working alongside Dr Alef Sterk, a former PhD student who was based at the University of Exeter in the UK during the project. A valuable member of the PREDEX team, Sterk has studied the dynamics of low-order models for atmospheric low-frequency variability and the Atlantic Multidecadal Oscillation. “My PhD work focused on low-frequency variability in climate models, and I became interested in applications of dynamical systems to climate phenomena,” reveals Sterk. “With PREDEX, a key goal was to deliver new mathematical techniques for quantifying the predictability of extreme events in complex systems such as climate models or weather forecasting systems.”

KNOWLEDGE EXCHANGE

Supported by Complexity-NET – a European network of science and technology funding agencies – the project’s roots are firmly embedded in the mathematical and physical sciences, and centres around tight collaboration with operational meteorology and weather forecasting services. The project investigators furnish a unique combination...
The geometry of evolutions of an atmospheric model.

Colours indicate how fast errors in initial conditions can grow – a measure for chaos. Black dots represent initial conditions leading to extreme windspeeds within a fixed time interval; since these initial conditions are associated with large error growth rates, extreme winds speeds are very unpredictable in this model. Reprinted with permission from Sterk A E, Holland M P, Rabassa P, Broer H W and Vitolo R, Predictability of extreme values in geophysical models, 2012, Nonlinear Processes in Geophysics, 19, 529-39.

The geometry of evolutions of an atmospheric model. Colours indicate how fast errors in initial conditions can grow – a measure for chaos. Black dots represent initial conditions leading to extreme windspeeds within a fixed time interval; since these initial conditions are associated with large error growth rates, extreme winds speeds are very unpredictable in this model. Reprinted with permission from Sterk A E, Holland M P, Rabassa P, Broer H W and Vitolo R, Predictability of extreme values in geophysical models, 2012, Nonlinear Processes in Geophysics, 19, 529-39.

The collaboration between Exeter and Groningen arose precisely because of the expertise of the researchers in the field who reside at both institutions which makes them ideally suited to this kind of partnership. "The University of Groningen has a longstanding tradition in research on dynamical systems, both in theoretical and applied contexts, and the University of Exeter is well known for its strong research on mathematical climate modelling," Sterk explains.

PREDEX encourages the exchange of knowledge through strong working relationships with three European National Weather Services: the Met Office, the Met Eireann and the Dutch Koninklijk Nederlands Meteorologisch Instituut (KNMI), and members of these services are involved in steering the project towards real-world applications and monitoring its achievements. To help enhance results, the Johann Bernoulli Institute at the University of Groningen also hosted a three-day workshop in May 2012 investigating extreme events in chaotic systems with weather applications, bringing together a broad group of European nonlinear scientists to discuss topics ranging from ensemble forecasting of hazardous weather, to the clustering of rare events in dynamical systems.

REAL-WORLD APPLICATIONS

The PREDEX team has developed some interesting new mathematical tools, with the researchers' combined backgrounds in nonlinear dynamics and numerical experiments leading to a conjecture on the probability distribution of the variable connected with the extreme values -- the so-called 'tail width' of the distribution. Sterk is enthusiastic about this breakthrough. "One of our major achievements lies in establishing explicit relations between the tail width of extreme value distributions and the geometry of the evolutions of a dynamical system. It is a discovery which also helps to explain why current methods for estimating probability distributions from numerical simulations do not always give accurate results".

The researchers hope that their new modelling tools will assist the three PREDEX European weather service partners in improving their ability to forecast extreme weather events such as catastrophic wind storms -- a rapidly-emerging real-world challenge with possible links to anthropogenic climate change. There will also be further real-world applications which will aid in the forecasting of high-impact, severe weather events. "We now have a more fundamental insight in the mathematical background of the conjecture, and several mathematical and computational techniques were developed to support this insight," Broer enthuses. "Although the project officially ended in August 2012, our research is still ongoing."

EARLY WARNING SYSTEMS

PREDEX has enhanced the research team’s understanding of extreme-value statistics in chaotic, deterministic dynamical systems, and it is hoped their findings will lead to novel methods of estimating probability distributions for extreme-value statistics which perform better than the methods currently available. Broer believes that there is further potential for exploration of the extreme-value issue, and is engaged in an ongoing collaboration on climate models, in cooperation with Carles Simó from the Barcelona Graduate School of Mathematics with the aim of furthering this research.

"During the project, we learned about connections between extreme value statistics and the geometry of evolutions in a dynamical system," Sterk reveals. "For simulation purposes, climate models are often discretised, and this will very likely affect the geometry of the evolutions and, hence, the extreme-value statistics. I would like to study these matters more carefully." Ultimately, the learning generated by PREDEX is expected to improve our ability to forecast weather extremes, and could lead to the development of early warning systems, which will enable forecasters to issue advance alerts to the public about approaching storm systems and other dangerous weather events -- an advance which would undoubtedly save lives.