**State of the art in the prediction of high-impact weather**

Steady increase of scientific knowledge and technological advances since the first ideas of numerical weather prediction in the 1940s have led to a tremendous increase in weather prediction capabilities. Given that global weather prediction is comparable to the simulation of the human brain, this increase in forecast skill, in particular over the last 40 years, is a story of success (Bauer et al. 2015). With every decade, forecast skill is improved by about one day, i.e. today´s 6 day forecast is as accurate as a 5 day forecast was 10 years ago (Figure 1, Bauer et al. 2015)

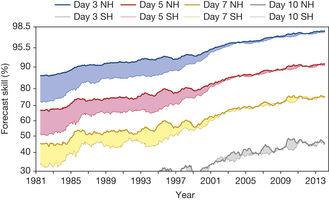


Fig. 1: One of the standard variables for evaluating forecast accuracy is the so-called 500 hPa geopotential height, which indicates at which height the pressure accounts for 500hPa. It thus resembles the pressure pattern (high- and low pressure systems) in about 5-6km height. Here, forecast skill is computed as the correlation between the forecasts and the verifying analysis of the height of the 500-hPa level, expressed as the anomaly with respect to the climatological height, for the Northern (upper curve) and Southern (lower curve) hemisphere. Values greater than 60% indicate useful forecasts, while those values greater than 80% represent a high degree of accuracy. A significant increase in forecast skill, in particular for the Southern Hemisphere is seen from the early 2000s onward, mainly due to the availability of satellite observations.

Although the increase in these large scale variables also comes along with increased prediction for weather variables near the surface, and in particular high-impact weather events, one has to keep in mind that clear distinctions exist between what we can forecast on global scales and longer lead times (up to two weeks), and on small scales with lead times of hours to a few days. Current global NWP models are able to explicitly capture the large scale dynamics. Smaller scale processes, in particular those associated with moisture, like clouds and convection, but also radiation and diffusion, and processes at the interface between atmosphere and surface can not be resolved and captured by current global NWP models. This means that these processes have to be parametrized, i.e. an estimation of the processes is made on the effect they may have and added throughout the model integration. Thereby, the formulation of this estimation is often limited by our understanding of the processes, and some uncertainty is introduced, which then grows from smaller to larger scales, deteriorating also the skill of the global forecasts. On the other hand, this parametrization of clouds, for example, also leads to large uncertainties in the prediction of precipitation.

Nevertheless, even global predictions of hazardous weather become more and more accurate on longer time scales. As stated in Bauer et al. (2015), the unusual path and intensification of Hurricane Sandy was predicted about 8 days in advance, while the Russian heat wave in 2010 and the 2013 US cold-spell was forecast 1-2 weeks in advance. As of 2017, the European Centre for Medium-range Weather Forecasts (ECMWF) high resolution Atmospheric Model, with 10km horizontal resolution, provides the highest resolution possible for a global forecast.

But NWP does not only rely on these global NWP models. Many NMHS around the world run their own regional models. These models are driven by input from a global model and produce forecasts of much higher resolution over limited areas, e.g country size. These models are usually run only up to forecast day 3-5, because for longer lead times, too much uncertainty would penetrate from the global into these local scales and make the forecasts useless. The highest resolution of such operational regional models ranges at around 2-3 km. However, availability and quality of these regional model vary greatly across countries.

Caution has to be exercised when interpreting the horizontal resolution of the models, as mentioned above. The 10km for global, and 2-3 km for regional models states that data is provided every 10/2-3 km. However, to resolve a weather system, like a Hurricane, not only one data point is necessary, but more, up to 6-8 (Abdalla et al. 2013), which means that the effective resolution for global models is thus 60-80km.

Beside the above mentioned uncertainty that is introduced by processes that act on small, unresolved scales (e.g. below 10/2-3km), another key factor for forecast uncertainty comes from observations. While a reasonable number of observations is available in the Northern Hemisphere, there exist huge data-sparse regions across the oceans, deserts and also in less industrialized regions. Nowadays, satellite data are the key tool to overcome these gaps in global coverage. However, information that can be derived from satellites is still limited, in particular information about the vertical structure of the atmosphere, which is crucial for atmospheric dynamics.

All of this indicates that there still exist huge sources of uncertainty, degrading forecast skill. Given that the atmosphere is a chaotic system, such small errors may grow rapidly, deteriorating the forecast completely. For this reason, ensemble forecast become more and more state of the art in weather prediction, on global as well as local scales. Such an ensemble forecast basically consists of several realisations of the same forecast, but in each of these integrations small modifications are added to the initial conditions or during model integration. This provides a means to assess the uncertainty that is associated with a forecast and provides probabilities for the most likely outcomes.

When it comes to current capabilities in the prediction of extreme events, like flooding, now general conclusions can be drawn on the accuracy of such forecasts worldwide. It rather depends on the capabilities available in the country of interest, the location of the country (in data sparse regions). But it also depends on the source of the flooding. For events that result from larger-scale weather systems, like extratropical cyclones, information about the impact might be available on lead-times of 1 week or even more. For convective events, which develop on very small scales, often beyond what can actually be resolved by a regional model, a general thread of such an event, and also a rough estimate of the region affected can be provided a couple of days in advance. However, if and where the convective system actually develops is still highly uncertain and can often just be predicted with the onset of the system.

The challenges, HIWeather is focussing upon is to improve the prediction of such events, e.g trough improved parametrizations, exploration of novel and unconventional data sources, research on error growth and appropriate consideration and communication of uncertainty associated with forecasts.

Abdalla S, Isaksen L, Janssen PAEM, Wedi NP. *2013 Effective spectral resolution of IFS. ECMWF Newsl. 137, 19–22*

Bauer, P., Thorpe, A. and Brunet, G. (2015) The quiet revolution of numerical weather prediction. Nature, 525, 47–55, doi:10.1038/nature14956