Medium Range Forecast of Ciaràn Storm Using Artificial Intelligence (AI)

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Abstract

Over the past year or so, the performance of neural network-based weather forecasting models has progressed significantly and has begun to attract the interest of forecasters. Using the example of the passage of the Ciaràn windstorm over western France, we evaluate the strengths and shortcomings of four of them, namely: GraphCast (Google Deepmind), Pangu-Weather (Huawei), AIFS (European Center for Medium-Range Weather Forecasts, ECMWF) and FourCastNet (NVIDIA). We show that, although far from being operational, AI-based forecasting models are able to propose useful information to anticipate damaging storms.

Introduction

During 2023, the race to simulate weather forecasts using artificial intelligence (AI) accelerated dramatically. NVidia published the results of FourCastNet, then Huawei shared the results of Pangu-Weather, and Google DeepMind presented the GraphCast model (later we saw the arrival of Fudan University's FuXi model). These models use deep-learning to make weather forecasts; they are presented in Lguensat's article [1], in French, which also summarizes how they work. A recent evaluation showed that Pangu-Weather and GraphCast were sometimes better than current deterministic models [2]. Since then, the creators of Pangu-Weather have published their work in Nature [3], Google DeepMind has published the GraphCast model in Science [4] and the European Centre for Medium-Range Weather Forecasts (ECMWF) has made forecasts from its own emulator, AIFS (Artificial Intelligence/Integrated Forcasting Model), available on an experimental basis.

Since October 2023, these four models have been used by ECMWF to calculate, on the basis of analyses of its IFS (Integrated Forecasting System) model, a number of variables over ten day forecasts at six hourly time steps. The data are shared in the form of maps for each of these time frames on the public website https://charts.ecmwf.int/.

Various studies have already highlighted the weaknesses of the forecasts proposed by these systems: lack of physical consistency on the one hand (for example, the fundamental principle of conservation of mass is not respected); and smoothing of the forecast fields with increasing time scales on the other [5]. Nevertheless, it is almost certain that in the years to come, these models, and new ones such as FuXi (available as of December 2023 on the ECMWF website), will become more and more efficient and will significantly improve the quality of forecasts.

Let's recall a few characteristics of these 4 AI-based models:
- They are all based on ERA5 reanalysis data from the European center. Their resolution is 0.25°, like the reanalyses, except for AIFS whose resolution is 1° (until January 2024, when the resolution was also changed to 0.25°). For comparison, the European IFS model is available at 0.1° resolution.
- FourCastNet and Pangu-Weather use vision transform architectures combined with spectral transforms for FourCastNet [1, 6].
- GraphCast and AIFS use a combination of an encoder-decoder model and a graph-based neural network.
- These models simulate 13 (FourCastNet, AIFS and Pangu-Weather) and 37 (GraphCast) atmospheric levels, in addition to surface fields. The number of levels available in IFS is 137.
- The parameters simulated are very similar. On several vertical levels we have: the two wind components, geopotential and humidity; for the surface: sea level pressure, temperature at 2m and wind at 10m. On the other hand, only the GraphCast model forecasts precipitation.

In November 2023, a severe windstorm named *Ciaràn* hit France and the south of the UK [7]. It reached the 'Finistère' coast on the evening of November 1st, then moved along the English Channel, causing widespread damage and loss of life, with at least 16 fatalities in Europe. We used this violent storm as a case study to make an initial assessment of these 4 models, which are already showing very interesting metrics, often better than those of the European IFS model. Are they already capable, as the authors announce in their respective articles, of correctly forecasting violent events earlier, requiring only a few minutes of calculation?

We worked on two parameters available on a daily basis for all the models studied: atmospheric pressure at sea level (MSLP) and wind strength at 850 hPa (FF850). This wind at 850 hPa corresponds to the wind at an altitude of around 1.5 km, it is easily calculated by AI-based models as it corresponds to the geostrophic wind and is unaffected by friction with the surface so is therefore less turbulent.

Three physical model calculations are used as a reference. The Arpège model analysis provides the most accurate representation possible of the situation on the night of 1st into 2nd of November, at 00 h UTC when the storm was at its strongest (all the figures concerning forecasts in this article are for this hour). This analysis corresponds to the atmospheric state we wish to forecast. Both of the forecasts of ECMWF's IFS deterministic model, and the average of the 51 members of its ensemble forecasting system (EPS) [8] (resolution of around 9 km) will serve as a reference for the forecast.

We propose here a subjective assessment of the operational efficiency of methods still under development using artificial intelligence. We compare the medium-term forecasts (4 to 10 days ahead) of deep learning-based models with those provided by the physics-based IFS model and its ensemble version EPS.

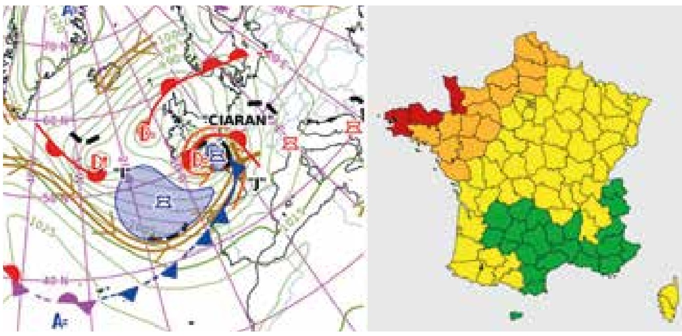
Three criteria are used in our study:
- position and deepening of the depression,
- extent and strength of FF850 winds,
- stability of forecasts from several successive production networks.

The *Ciaràn* windstorm

Ciaràn formed from a low-pressure system initially located to the east of the United States. As it moved across the Atlantic, the low found itself north of a powerful upper-level jet, and its deepening accelerated. Around Tuesday the 30th of October, it came into phase with an altitude (PV) anomaly, and its deepening became even more intense, falling around 34 hPa in 24 hours, corresponding to explosive cyclogenesis. Violent winds were noted in the southwest quadrant of the low, and the temporary presence of a sting jet could not be ruled out [7].

On Thursday the 2nd of November, 2023 at 00 h UTC, *Ciaràn* was located south of the tip of Cornwall, with a deepening that reached 955 hPa (figure 1a). A red warning for violent winds (figure 1b) was issued by Météo-France on the morning of 1st November for the Brittany departments, excluding Morbihan and Ille-et-Vilaine, which were expected to be less affected by the strongest gusts. The storm's trajectory took it to cover the Cotentin region, which was also covered by the same red warning.

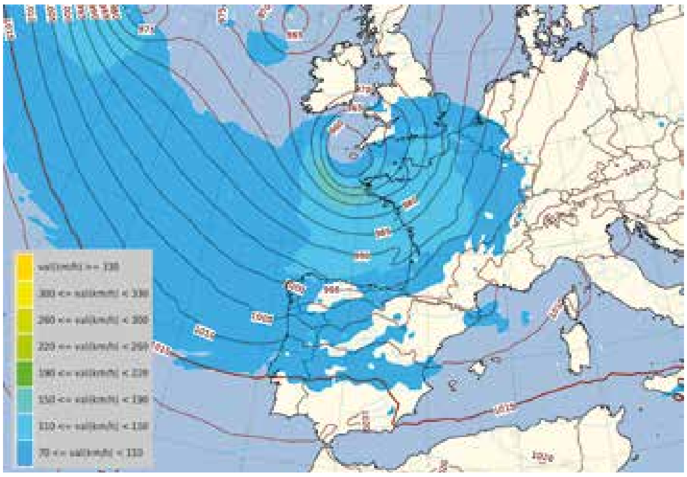
Ciaràn made landfall on the Brittany coast, causing considerable damage to people and property. Across Europe, at least 16 people lost their lives, millions were cut off from the electricity and telephone networks, and many flights were cancelled. Exceptional wind speeds were recorded. For instance, the 193 km/h gust with an average wind speed of 141 km/h recorded at Pointe St Mathieu (Finistère, a French department), which for sailors corresponds to 12 on the Beaufort scale. The maximum gusts recorded on the island of Batz reached 196 km/h.



▲ *Figure 1. (a) Surface Pressure Chart the 2nd November at 00 h UTC; (b) wind warning map ('Vigilance') issued on 1st November at 6 h UTC. Source : Météo-France.*

State of the atmosphere on Thursday, 2nd of November at 00 h UTC

On Thursday, 2nd November at 00 h UTC, storm *Ciaràn* reached the tip of Finistère, and was at its strongest around this time. All the forecasts



▲ *Figure 2. Analysis at 0.25° resolution (different from the native resolution of 5km over France) from Arpège on Thursday, 2nd November. The isolines correspond to the pressure at sea level and the shades of blue represent the winds at 850 hPa (~1.5 km above sea level). Source : Météo-France.*

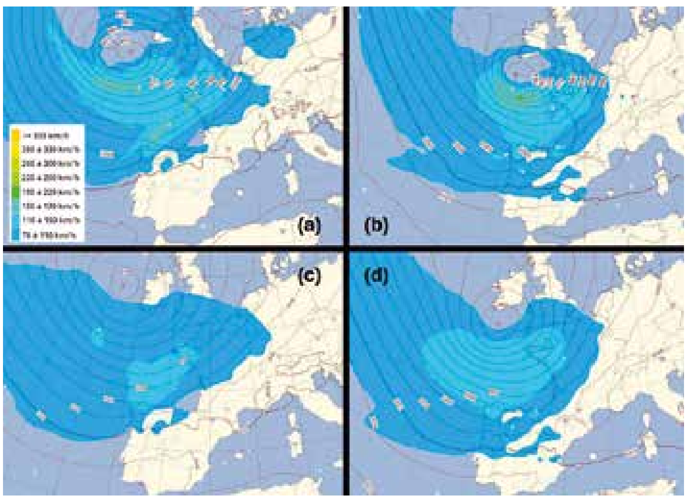
we compare in this article are for that hour. Figure 2 shows the Arpège analysis of surface pressure and wind strength at 850 hPa for 2nd November at 00 h UTC. This figure will be the reference for the rest of this article, as it is the best global map of the atmospheric state available at time of writing. It shows: surface pressure at 955 hPa over the tip of Cornwall, and winds aloft between 150 km/h and 190 km/h off the Iroise Sea (West of Finistère) in the south-western quadrant of the low. Over a large north-western part of France, winds are estimated at between 110 and 150 km/h.

IFS model and EPS ensemble forecasts

The reference for medium-range forecasting is the ECMWF IFS model which is highly regarded for its accuracy. IFS forecasts in its high-resolution HRES version are available on a 0.125° × 0.125° grid resolution, up to 10 days ahead at an hourly timestep. For the two parameters of interest to us, forecasts from both AI-based models and IFS are available at https://charts.ecmwf.int/.

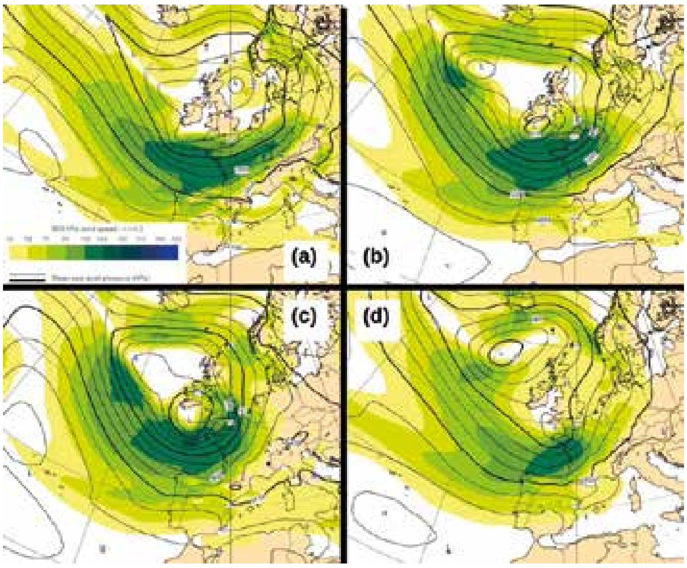
Analysis of the various IFS model forecasts of the event with a lead time of between 10 and 5 days enables us to assert several points: (i) from Wednesday 25th October to Saturday 28th October, the MSLP and FF850 field forecasts for Thursday 2*nd* November place the low-pressure system to the west of Ireland (forecasts not shown in this article), i.e. far from its final position; (ii) the forecast of Thursday 26th of October at 00 h UTC (figure 3a) indicates a low-pressure center that is already deep (951 hPa) but poorly positioned; (iii) between Saturday 28th October and Sunday 29th October, the forecast shifted this center increasingly towards the tip of Cornwall, and by 29th October (figure 3b), the forecast winds were very close to what was actually observed, with a slight shift towards the Atlantic. The central pressure is now forecast to be 956 hPa, a value that will actually be observed on Thursday 2*nd* November.

The average forecasts of the ECMWF's EPS ensembles are, by their nature, smoothed fields, so that lows appear to be less deep as the time horizon lengthens. The forecast for Thursday 26th of October (Fig. 3c) is comparable to that of the IFS deterministic model: the low-pressure system, with a central value of 966 hPa, is still a long way from its final position, and will move closer to the correct position in the subsequent simulations. In the forecast for Sunday 29th of October (Figure 3d), the position is much better and the depression deeper. What's interesting about these simulations is their statistical stability, an important element in operational forecasting. Nevertheless, the average of the ensemble forecast (Ensemble Mean) was not the best indicator of an extreme event to come.

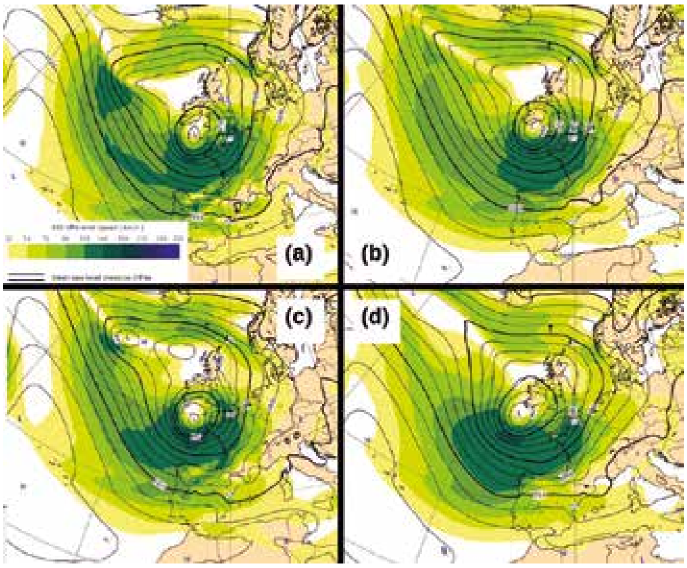


◀ *Figure 3. Wind at 850 hPa (blue colours) and sea level pressure (isolines). (a) IFS forecast base time Thursday 26th October validity time for Thursday 2nd November. (b) IFS forecast base time Sunday 29th October valid for the same date. (c) Average forecast of the EPS ensembles (Ensemble Mean) base time Thursday 26th October, valid for the same date. (d) Average forecast of the EPS ensembles (Ensemble Mean) base time Sunday 29th October valid for the same date. Source : Météo-France.*

Comparison of AI-based models



▲ *Figure 4. Forecasts of sea level pressure fields and wind speed at 850 hPa base time Thursday 26th of October by the 4 AI-based models for Thursday 2nd of November (168 h lead time) (a) GraphCast, (b) AIFS, (c) Pangu-Weather and (d) FourCastNet. Source: ECMWF.*



▲ *Figure 5. As in Figure 4 with a forecast base time of Sunday 29th of October for Thursday 2nd of November (96 h time horizon). Source: ECMWF.*

For Google's GraphCast model, the forecast of Thursday 26th of October (Figure 4a) is relatively far from the final situation: the position and deepening of the depression are not yet correct. The first simulation to show the presence of a storm over the correct zone of France is that of Thursday 26th October at 12:00 UTC (not shown), but forecasts would continue to fluctuate until Sunday 29th October at 0:00 UTC (figure 5a). In the final figure, the position and deepening are now perfectly forecast, with a zone of strong winds (between 144 and 180 km/h) present in the same quadrant as that finally observed. Nevertheless, operational forecasting can hardly rely on such variable forecasts from one simulation to the next.

For the ECMWF's AIFS model, as of Wednesday 25th of October (not shown), the low-pressure area was very deep, with strong winds in its southern part (but still below 144 km/h) covering the entire northwest of the country. However, it is not yet correctly located (positioned over Ireland), and the winds are generally lower than the final analysis. Nevertheless, it is possible to identify the presence of a storm over a large part of France very early on, as the simulation of Thursday 26th October at 00 h UTC (Figure 4b) already shows very good placement unlike GraphCast. The simulation of Sunday 29th October at 00 h UTC (figure 5b) was the first to suggest strong winds aloft in the southern zone of the low-pressure system, a zone that was to disappear from subsequent forecasts.

Huawei's Pangu-Weather model quickly simulated a low-pressure system to the south of Cornwall, with strong winds covering much of France. By Thursday 26th October at 00 h UTC (Figure 4c), all the elements were already in place, even if the low had not yet deepened sufficiently. Pangu-Weather forecast a restricted zone of stronger winds, between 144 and 180 km/h, off the Iroise achieving the best lead time of any model. The later simulations still show significant variations, but remain close to the final result. The calculation for Friday 27th October at 12:00 UTC (not shown) gives an excellent representation of Ciaràn, with a central pressure of 955 hPa over the tip of Cornwall.

For NVidia's FourCastNet model, the first satisfactory simulation occurs on Saturday 28th October at 12:00 UTC. Figure 4d shows that wind location and strength are not correctly forecast on Thursday 26th October at 00 h UTC. On Sunday 29th October at 00 h UTC (Figure 5d), the location of the low is good, but the central pressure is still insufficiently deepened. Nevertheless, like the other models, FourCastNet was forecasting a south-westerly direction for the low-pressure area, with stronger winds.

Current limitations of AI

The AI-based forecasting models currently available to the public are embryonic models that offer a very partial representation of the atmosphere,

still far from the richness of forecasts derived from physical modeling. Among the major shortcomings for weather forecasting, we can mention:
- the absence of many important parameters such as CAPE (Convective Available Potential Energy), CIN (Convective INhibition), hourly precipitation totals and cloud cover,
- the smoothing of certain fields with time lag; this limitation has been noted for Pangu-Weather [3], and Bonavita [5] has shown that the energy spectrum of the fields (after Fourier transform) falls more sharply than with the IFS model as time lag increases,
- the small number of levels simulated, which makes it difficult to analyze vertical profiles, an important tool for forecasters,
- finally, the forecasting of surface phenomena, such as gusts, which are absent from the forecasts even though they are essential for operational forecasting.

Conclusions

We observed during the *Ciaràn* storm that these models were already producing pressure and wind fields that could be used for operational forecasting. The subjective analysis made here (which should be repeated for different situations) shows that the storm was correctly predicted by these models a few days before the deterministic IFS model: even if still very unstable, with a more fluctuating forecast of the most violent winds in these models by AI. The forecasts (not all shown in this article for reasons of readability) indicate that they were able to anticipate *Ciaràn* with respectable lead times. Special mention should be made of Pangu-Weather, which performed particularly well in anticipating strong winds above the boundary layer. The other models had variable performance at longer lead times, but also provided excellent forecasts comparable to IFS.

However, this situation is unusual in that storms are weather events for which forecasting has made particular progress in recent years. At present, AI-based models are still unable to predict thunderstorms, heavy snowfall and freezing rain for example. However, we can be sure that in the coming years, these models will make significant progress, and that others will undoubtedly enter the competition (in 2024, high-resolution models such as FengWU-GHR are expected). The work of forecasters is likely to benefit rapidly from this information, improving the quality of their broadscale forecasts.

Finally, a recent study [9] complements this one, offering a similar comparison of short-term forecasts from the same models for the *Ciaràn* storm.

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