https://doi.org/10.5194/nhess-2021-33
Preprint. Discussion started: 10 February 2021

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Invited perspectives: The ECMWF strategy 2021-2030 Challenges in the area of natural hazards

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Abstract.
The European Centre for Medium-Range Weather Forecasts mission is to deliver high quality global medium-range numerical weather predictions and monitoring of the Earth system to its Member States. The modelling and forecasting of natural hazards are an important part of this mission. The new strategy identified several goals: producing world leading weather and earth-system science, cutting edge technology and computational science, high quality products fit for purpose, efficient and easy access to products, and aiming to inspire and hire the best experts. Challenges for the future include integration of innovative observations into the earth system, a realistic representations of water, energy, and carbon cycles, coupling and initialisation of all earth system components, adequate representation of uncertainties and advances in software engineering. Progress in all these areas will need enhanced collaboration with Member States and partners across Europe and beyond.

1 Introduction

The forecasting of weather, hydrology, cryosphere, and oceans, as well as the representation of past and future climates, are all key elements in the understanding and prediction of natural hazards. Forecasts of the Earth system are important to prepare for humanitarian disasters resulting from, for example, tropical cyclones (Emerton et al. 2020, Magnusson, 2019), floods (Lavers et at 2020), extreme precipitation events (Lavers et al 2018) or heat waves (Napoli et al 2020). Representations of the past climate, known as reanalysis, are key to establish risk i.e., return periods (Harrigan et al (2020a), natural and artificial trends (Zsótér et al 2020) as well as understanding scientific challenges. Progress in these areas can only be achieved through an Earth system approach (Harrigan et al 2020b).

The vision is to achieve this by producing cutting-edge science, world-leading weather predictions and monitoring of the Earth system. In order to meet this vision, there are several research challenges which need addressing. The required step changes in science and forecasting can be grouped into 3 pillars (ECMWF, 2021): Science and Technology (World leading weather and earth-system science, cutting edge technology and computational science), Impact (High quality products fit for purpose, efficient and easy access to products) and People (Inspiring and hiring the best experts).

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2 Science and Technology

Earth system model predictions can be substantially improved if we maximise the use of current observation i.e., using all available information from existing satellites over land, snow and sea ice in cloudy, rainy and clear conditions (Geer et al., 2018). Newly available observations from satellites, will need to be efficiently integrated into the Earth system model. For example, the new EUMETSAT MTGs will provide high frequency atmospheric profiles as well as real time lightning detection (lightnings can cause fires). The European Commission's Copernicus Sentinel 6 Michael Freilich (a radar altimeter satellite) will measure sea level change and river levels addressing a range of natural hazards such as floods, storm surges and droughts. In addition, the operational use of innovative new observing systems, e.g., derived through the Internet of Things (observations form cars, mobile phones, etc.), provides the potential to significantly advance science and forecasts of the Earth system and natural hazards. These innovations must be paired with a consistent modelling approach which includes realistic representations of the water, energy and carbon cycles. This is currently not the case for the water cycle, for example, as current data assimilation/forecast does not conserve mass (Zsótér et al 2020). It is also essential to capture and represent in our predictions as many of the model and other uncertainties as necessary: for example, we know that many parts of the Earth system are inadequately observed (Beven et al 2020). However, finite computing and requirements to produce timely forecasts will only allow a limited number of ensemble members to represent these uncertainties. The efficient coupling of many of these different processes poses significant research challenge. This is closely linked to the challenge of how to initialise a complex Earth system consisting of components like land, snow, rivers, oceans, atmospheric compositions. Initialising the snowpack on a global scale which is important for flood forecasts is an example of such a challenge.

The compute and storage power of novel HPC architectures is required to improve the representation of processes and uncertainties, however existing large code bases to model and forecast natural hazards are ill equipped to scale for such novel architectures. This requires significant investment in computational science, for example in the use of high-performance, heterogeneous GPU/CPU architectures through domain specific languages, which will allow domain experts (natural hazard scientists) to easily program independently from the underlying architecture (Mernik et al, 2005). GPU based architectures are particularly suited to be used by artificial intelligence and machine learning, which will play an increasingly revolutionary role throughout the entire operational and research chain, from the quality control of observations and approximation of physical equations to speed up execution, to the improved representation of uncertainties in extreme natural hazards through post-processing (Duben et al., 2021). Other novel ways need to be found to address the need of increasingly compute and storage hungry forecasts and simulations and should therefore also include computing solutions beyond supercomputers. For example, the OpenIFS@home project allows scientists to exploit spare compute cycles on desktop computers to run huge ensembles (Sparrow et al., 2020).

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3 Impact

Advances in science and technology are only relevant within the context of an operational framework if users can maximise the usefulness and accessibility of high-quality products and outputs. ECMWF will aim to provide detailed Earth system simulations of the past, present and future with a particular focus on extreme events for several weeks ahead, for example: skilful predictions of extreme temperature anomalies and hydrological impacts such as droughts, air quality, fires, floods, as well as outputs which monitor the environment (i.e., anthropogenic CO_2 emissions). In addition, forecasts of natural hazards beyond two weeks require improved understanding of the sources of predictability and teleconnections (Mastrantonas et al. 2020). In this context, it is necessary to focus more strongly on a user-oriented evaluation over multiple temporal scales, variables and coupled components which will inform the optimal pathway of model development. Indeed, user feedback needs to be more closely integrated into the evaluation chain to allow for cost benefit assessments and ensure that the proportion of resources employed on all elements of the system provide maximum benefits to users. A key research challenge is to generate detailed and high-resolution Earth system scenarios able to simulate the effects of different environmental policies and sustainable development plans to derive optimal conclusions (European Commission, 2021). Each component of the earth system as well as other processes such as environmental policies have uncertainties attached to them which will interact in complex non-linear ways. Therefore, it is important to fully propagate and cascade all dominant uncertainties through the entire value chain, which is key in supporting efficient user decision making.

Data can only be of use if they are provided reliably and are easily accessible. Future Earth system models and forecasts will generate such large volumes of data that the only feasible way to extract relevant information will be to bring computing to the data rather than transfer the data to a computing infrastructure (Pappenberger and Palkovic, 2020). This also requires research into novel ways for storing and manipulating big data (Hanley et al., 2020). A typical workflow for a natural hazard forecast or model contains the following components: pre-processing, numerical simulation, post-processing and visualization. Numerical simulations are often run on a High-Performance Computer, whilst the other tasks are more suited to be executed in a cloud environment, although these different technologies will converge in the future. Research into the efficient managing and orchestrating of workflows spanning these different compute environments will crucially improve the overall performance of a forecast and model change and thus allow a larger proportion of limited human and compute resources to be used to improve natural hazard forecasts and models. Communication and decision-making using big data representing uncertainties remains a significant challenge which will need to be addressed to increase the impact of natural hazard predictions and reanalysis (Neumann et al., 2018, Thielen et al., 2020).

4 People

Expert and highly motivated people are the most important resource for research or operational activities to improve natural hazard forecasts and models. The working environments are rapidly changing under the pressure and mutual influences of technological advances, globalization and, in the last year, the effects of lockdowns. Successful organisations which see it as their mission to create step changes to advance the science and practise in natural hazards need to harness the opportunities that more dynamic working conditions bring and adapt. The expansion of ECMWF's activities in the area of computational science and AI for numerical weather prediction means also that the organisation needs to position itself and become attractive in a highly competitive and rapidly changing job market, which is a key to be able to address the challenges mentioned above.

5 Conclusion

ECMWF has embarked on a new strategy aiming to produce cutting-edge science and world-leading weather predictions and monitoring of the Earth system in close collaboration with the members of the European Meteorological Infrastructure, for a safe and prosperous society. An essential part of this strategy is to deliver forecasts of high-impact weather events and natural hazards well into the second week and further ahead. For example, our target is to provide skilful predictions of extreme temperature anomalies and hydrological impacts such as droughts up to three weeks ahead on average.

In addition, ECMWF aims to support the natural hazard domain through global reanalyses and re-forecasts of weather and environmental hazards to monitor changing patterns and predictability of high-impact events.

The achievement of these goals will require the adoption of new technologies, the integration of different areas of research, extensive collaboration with National Hydro-meteorological Services and other environmental organisations in Europe and worldwide.

References

1. Beven, K., Asadullah, A., Bates, P., Blyth, E., Chappell, N., Child, S., Cloke, H., Dadson, S., Everard, N., Fowler, H. J., Freer, J., Hannah, D. M., Heppell, K., Holden, J., Lamb, R., Lewis, H., Morgan, G., Parry, L. and Wagener, T., 2020, Developing observational methods to drive future hydrological science: can we make a start as a community? Hydrological Processes, 34 (3). pp. 868-873. ISSN 0885-6087 doi: https://doi.org/10.1002/hyp.13622
2. Di Napoli, C., Barnard, C., Prudhomme, C., Cloke, H.L, Pappenberger, F., 2020, ERA5-HEAT: A global gridded historical dataset of human thermal comfort indices from climate reanalysis, Geoscience Data Journal.
3. Düben, P, Modigliani, U, Geer, A, Siemen, S, Pappenberger, F, Bauer, P, Brown, A, Palkovic, M, Raoult, B, Wedi, N, Baousis, V, 2021, Machine learning at ECMWF: A roadmap for the next 10 years, ECMWF Technical memorandum 878, doi: 10.21957/ge7ckgm
4. ECMWF, 2021, The ECMWF Strategy 2021–2030, https://www.ecmwf.int/en/about/what-we-do/strategy, last accessed: 22/01/2021
5. Emerton, R., Cloke, H., Ficchi, A., Hawker, L., de Wit, S., Speight, L., Prudhomme, C., Rundell, P., West, R., Neal, J., Cuna, J., Harrigan, S., Titley, H., Magnusson, L., Pappenberger, F., Klingaman, N. and Stephens, L. (2020)

Emergency flood bulletins for Cyclones Idai and Kenneth: a critical evaluation of the use of global flood forecasts for international humanitarian preparedness and response. International Journal of Disaster Risk Reduction, 50. 101811. ISSN 2212-4209 doi: https://doi.org/10.1016/j.ijdrr.2020.101811

6. European Commission, 2021, https://ec.europa.eu/digital-single-market/en/destination-earth-destine, last access 22/01/2021.
7. Florian Pappenberger, Martin Palkovic (November 2020) Progress towards a European Weather Cloud, ECMWF Newsletter, issue 165, pp. 24-27. DOI: 10.21957/9pft4uy055
8. Geer, AJ, Lonitz, K, Weston, P, et al. All-sky satellite data assimilation at operational weather forecasting centres. Q J R Meteorol Soc. 2018; 144: 1191– 1217. https://doi.org/10.1002/qj.3202
9. Hanley, J., Siemen, S., Hawkes, J., Vuckovic, M., Quintino, T., Pappenberger, F., 2020, Building Cloud-Based Data Services to Enable Earth Science Workflows. DOI: 10.5194/egusphere-egu2020-10297
10. Harrigan, S., Cloke, H. and Pappenberger, F., 2020b, Innovating global hydrological prediction through an Earth system approach. WMO Bulletin, 69 (1). ISSN 0042-9767
11. Harrigan, S., Zsoter, E., Alfieri, L., Prudhomme, C., Salamon, P., Wetterhall, F., Barnard, D., Cloke, H.L., Pappenberger, F., 2020a, GloFAS-ERA5 operational global river discharge reanalysis 1979–present. DOI: 10.5194/essd-2019-232
12. Lavers, D.A., Rodwell, M.J., Richardson, D.S., Ralph, F.M., Doyle, J.D., Reynolds, C.A., Tallapragada, V., Pappenberger, F., 2018, The Gauging and Modeling of Rivers in the Sky, Geophysical Research Letters n. 15, pp. 7828–7834. DOI: 10.1029/2018GL079019
13. Lavers, D.A.; Ramos, M.-H.; Magnusson, L.; Pechlivanidis, I.; Klein, B.; Prudhomme, C.; Arnal, L.; Crochemore, L.; Van Den Hurk, B.; Weerts, A.H.; Harrigan, S.; Cloke, H.L.; Richardson, D.S.; Pappenberger, F. A Vision for Hydrological Prediction. *Atmosphere* 2020, *11*, 237.
14. Magnusson L., Bidlot J.-R., Bonavita M., Brown A.R., Browne P.A., De Chiara G., Dahoui M., Lang S.T.K., McNally T., Mogensen K.S., Pappenberger F., Prates F., Rabier F., Richardson D.S., Vitart F., Malardel S. (2019) ECMWF activities for improved hurricane forecasts, Bulletin of the American Meteorological Society n. 3, pp. 445-457. DOI: 10.1175/BAMS-D-18-0044.1
15. Mastrantonas, N., Herrera-Lormendez, P., Magnusson, L., Pappenberger, F. and Matschullat, J., 2020, Extreme precipitation events in the Mediterranean: Spatiotemporal characteristics and connection to large-scale atmospheric flow patterns. Int J Climatol. Accepted Author Manuscript. https://doi.org/10.1002/joc.6985
16. Mernik, M., Heering, J., and Sloane, A.M., 2005 When and how to develop domain-specific languages. ACM Computing Surveys, 37(4):316–344, 2005. doi:10.1145/1118890.1118892
17. Neumann, J., Arnal, L., Emerton, R., Griffith, H., Hyslop, S., Theofanidi, S. and Cloke, H., 2018, Can seasonal hydrological forecasts inform local decisions and actions? A decision-making activity. Geoscience Communications, 1. pp. 35-57. ISSN 2569-7110 doi: https://doi.org/10.5194/gc-1-35-2018

https://doi.org/10.5194/nhess-2021-33
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18. Sparrow, S., Bowery, A., Carver, G.D., Köhler, M., Ollinaho, P., Pappenberger, F., Wallom, D., Weisheimer, A., 2020, OpenIFS@home version 1: a citizen science project for ensemble weather and climate forecasting. DOI: 10.5194/gmd-2020-217
19. Thielen-del Pozo, J., Autogena, L, Portway, J., Pappenberger F., (March 2020) The science-policy interface – in need for "society" as a third component. DOI: 10.5194/egusphere-egu2020-21623
20. Zsótér, E., Cloke H., Stephens E., DE ROSNAY P., Muñoz-Sabater J., Prudhomme C., Pappenberger F. (2019) How well do operational numerical weather prediction configurations represent hydrology?, Journal of Hydrometeorology n. 8, pp. 1533-1552. DOI: 10.1175/JHM-D-18-0086.1
21. Zsótér, E., Cloke, H. L., Prudhomme, C., Harrigan, S., de Rosnay, P., Munoz-Sabater, J. and Stephens, E., (2020) Trends in the GloFAS-ERA5 river discharge reanalysis. ECMWF Technical Memoranda. 871. Technical Report. ECMWF doi: https://doi.org/10.21957/p9jrh0xp