EUCP Policy Brief No 2

EUCP

European Climate Prediction system

RESEARCH NEEDS AND RECOMMENDATIONS

for climate prediction on the 1-40+ year time-horizon identified by EUCP

Predictions and projections of climate can help governments, businesses and other stakeholders better plan how to deal with the challenges and opportunities that a changing climate brings. The EUCP project has provided new science to support both scientists and other climate information providers in producing better climate information for users by developing cutting-edge approaches to using climate predictions and projections, and providing new climate simulations. Some of this science can be used for the benefit of users now and some of it lays the foundation for a future regional climate prediction system for Europe.

New EU Horizon programmes are already exploiting and building on what EUCP has learned and applying it to new projects, such as nextGEMS (nextgems-h2020.eu) building new storm-resolving Earth System models, and climateurope2 building on the success of climateurope to further develop use of climate knowledge for climate services. Other new projects due to commence in the next round of funded Horizon Europe research include ASPECT, which will build on EUCP's progress towards seamless predictions for Europe, and EERIE, which will develop new high-resolution Earth System Models.

In this brief, we highlight some of the further opportunities to build on what EUCP has learned in future research activities. This information is intended to help funders and planners of future research activities to identify where resource could be channelled in order to make step-changes in the climate prediction and projection information available for Europe.

OPPORTUNITIES FOR FURTHER IMPROVEMENT IN DECADAL PREDICTION SYSTEMS

Significant progress in the field of decadal prediction means that these forecasts are now operational through the WMO lead centre supported by EUCP, and their useful application to climate services products has been demonstrated. An increasing body of research has identified new areas in which these predictions are skilful, raising awareness of the value of decadal scale predictions to decision making. However, challenges remain around the further development of key areas of model biases, drift and initialisation shock, and a low signal-to-noise ratio necessitating large ensembles. Challenges also remain around helping users utilise the predictions in their diverse decision relevant applications.

1. Forecast systems could yet be improved to reduce biases, drift and initialization shock

- The advantages of increasing global model resolution need to be exploited in climate forecasting systems. Important benefits of increased resolution have been detected in representing key processes like the Atlantic Meridional Overturning Circulation (AMOC), or variability like the atmospheric circulation response to extratropical sea surface temperatures (SSTs), as well as in reducing drift and biases.

- Identify key predictability sources and the essential role of the teleconnections need to continue. This would enhance understanding of predictability and is potentially one of the best ways to reduce model biases, one of the sources of forecast drift.

- Forecast system initialization could be improved to reduce drift and initialization shock, reducing the gap faced by the model improvement and data assimilation communities. High-quality observations are required to initialise and verify models. The role of short-term forcings on near-term climate variability (solar, different types of aerosols including forcing from volcanoes) is still not well determined, and solutions to implement these forcings on real-time forecasts are needed.

- Investigate the potential benefit of adding earth system processes, such as ice sheets.

2. Significant effort should be invested in understanding the origin of the signal-to-noise problem transecting all timescales of climate prediction

- Large ensembles of both hindcasts and forecasts are required for several purposes, including the more robust prediction of extreme climate events.
- Structural uncertainty is a key element of decadal predictions and could be further explored through approaches like stochastic parameterizations.
- There is a vast amount of research performed in the climate-change modelling context that could be applied to decadal climate prediction to help interpret ensemble predictions. These include the role of climate sensitivity, use of emergent constraints, analysis of genealogies of models and process-oriented validation.

3. New technical and data solutions are required to maximise the value of decadal predictions

- Computational efficiency is a key enabler to ensure the best use of the vast computing resources required by decadal prediction exercises. Many of the latest advances to improve model and data management efficiency have yet to be applied to the field of climate prediction.
- A number of standards for operational forecasting are still to be agreed upon, such as extensions of CMOR metadata conventions, definitions of climatological reference periods, and ensemble size of hindcasts and forecasts.
- Artificial Intelligence (AI) offers promising applications in decadal prediction, as in many other fields. Its role as a tool to formulate alternative (data-based) forecast systems, to postprocess and downscale decadal forecasts, to emulate large ensembles and to accelerate climate models, among others, needs to be assessed.

4. Make decadal forecast information more decision relevant

- Raise awareness of the usefulness of decadal predictions including understanding how decadal skill translates into usable information that directly relates to user decisions. This will draw heavily on social science skills.
- Understand how to establish a user community for decadal forecast information, including building new knowledge on the channels for distributing information to users.

OPPORTUNITIES FOR IMPROVED METHODS TO TREAT CLIMATE PROJECTION ENSEMBLES

Ensembles of climate simulations are one of the main sources of data informing future changes on timescales beyond the use of decadal predictions. However, potential users of this data are often left to navigate and synthesise uncertainties across these simulations with little guidance. EUCP has developed methods to either reduce uncertainty or reduce the complexity of the information. EUCP has used new methods to calibrate climate projections against observed changes, demonstrating clear added value over using raw CMIP climate projections for temperature-related metrics. This is the first time that such skill has been evaluated, for a range of potential methodologies, in a systematic evaluation, and sets out a clear need for the community to now move beyond multi-model democracy when assessing climate projections.

1. Further work is needed to bridge global constraints with regional constraints

- EUCP has demonstrated and evaluated the application of constraints to regional climate projections. The EUCP use of observational constraints at the European scale is likely to be reflecting some common information on more plausible projections from global information (i.e., from climate sensitivity) but further work is needed to reconcile the independence of global and regional observational constraints.
- While it is clear that constraining projections with observations is likely to lead to more reliable regional projections of temperature, there are currently no obvious benefits for rainfall projections in terms of narrowing uncertainty range or mitigating overconfidence. However, observational constraints do not obviously degrade skill for precipitation so may still offer an appropriate approach when exploring constraints on joint distribution of variables.
- There is evidence from the EUCP objective assessment of the value added by constraints that there is independent information in different methodologies of producing more reliable estimates of future temperature change. This suggests that combining information from existing methods could lead to better and more reliable methodologies and this should be explored.
- Increased provision of source code and public code implementations for constraints and weighting approaches will aid adoption and impact.
- Greater awareness of limitations of using the 'raw' CMIP6 ensemble to represent the range of expected outcomes in user communities is needed. There are opportunities to close this gap, by integrating model weighting into data portals such as the IPCC Atlas or European Climate Data Explorer.
- There is still debate as to the value of using application specific constraints, which should also be considered in future research.

2. Further work needed to understand implications of observational constraints for future climate model development

- Observationally constrained ranges for European projections, based on evaluation against observed temperatures, suggest that CMIP6 models in the upper end of the projected temperature range are less credible. At the same time, independent evaluation of model skill in capturing the underlying climate processes relevant for Europe (e.g., storm tracks, blocking) suggest that many of the warmest models are also those which best represent these regional dynamical processes. This work highlights challenges for model developers in reconciling apparently contradictory lines of evidence on the relative plausibility of European climate simulations. Reconciling these lines of evidence should be one of the main climate model development priorities, looking ahead to CMIP7 and beyond.

3. Further work is needed to develop new storylines approaches to climate services

- Efforts to explore storylines approaches to partition and explore uncertainty in atmospheric drivers, as well as perform sub-selection for downscaling or impact studies should continue, however the appropriateness of the information for downstream use should be considered more.
- The trade-off and relative benefits of bespoke sectorial/local climate narratives compared to broader pan-European narrative approaches should be explored.
- Further work could consider whether there is a suitable framework for the diverse range of storylines approaches as a basis for developing climate services and appropriate guidance.
- Future work should include a focus on testing storylines in decision making, risk assessment and communication applications, to better provide guidance to providers and users of the information. The use of storyline methods does not exclude the inclusion of likelihood information but treats it in a more appropriate manner alongside individual model realisations.

OPPORTUNITIES FOR FURTHER PROGRESS IN DEVELOPING SEAMLESS CLIMATE PREDICTIONS

EUCP has pioneered new approaches to merging decadal climate predictions and longer-term climate projections to offer new, seamless prediction products to span 1–40+ year timescales. While EUCP has made significant progress, the skilful combination of information across prediction and projection timescales remains challenging, and a number of frontiers for further development have emerged. It remains necessary to raise these merging techniques to higher technical readiness levels needed for practical application.

1. The approaches to merging initialised and uninitialized simulations developed in EUCP can be further developed

- Further work is needed to fully understand how to use subsampling of large ensembles by matching to phases of variability.
- Further exploration is required to determine the appropriate time-point for merging. This may depend on application and region. Further work is required to apply observations to constrain predictions and projections consistently, including investigating how to best use our understanding of physical process representation in different models.

2. High-resolution information could be integrated into regional prediction products

- Investigate when there could be value in adding spatial information into seamless prediction and projections, through interaction with users.
- Investigate and design methods to include high spatial resolution data in the merged information, for instance to provide better information on weather extremes.

OPPORTUNITIES FOR IMPROVED APPLICATION AND EXPLOITATION OF CONVECTION-PERMITTING MODELS (CPMS)

Through EUCP, very high-resolution CPM simulations of present day and future climate for the 2050s have been made available for the whole of mainland Europe, as well as a number of the EU's outermost territories. These provide improved information about future changes in several important aspects of future high-impact weather including extreme hourly and sub-hourly rainfall, severe windstorms, lightning and hail.

1. Continued and extended co-ordination of multi-model CPM comparison projects are required to offer further information about uncertainty in future extreme events

- There remains significant potential to extend the co-ordinated multi-model experiments pioneered in EUCP and the CORDEX FPS-CONV project towards larger ensembles for more of the European domains and include longer simulations with better representation of climate variability. This will provide more robust information for users.
- Given the huge computational resources needed to achieve this, significant co-ordination between modelling centres will be required to run and analyse simulations.

2. Different experimental setups of CPM simulations should be investigated to explore large scale uncertainties

- Better ensemble designs are needed to gain the maximum benefit from CPMs whilst ensuring they are computationally feasible. This includes new work on choosing optimum GCM/CPM pairs.
- Storylines offer a tool for understanding and partitioning uncertainty and also offer a useful communication tool. Physical storyline approaches can be developed around known physical drivers of changes, for example around large-scale atmospheric circulation change (an important driver of mean seasonal change), or around vertical stability change (an important driver of extreme precipitation change).

3. Continued work is required to develop methods to combine high-resolution detail from small CPM/RCM ensembles with wider uncertainties from GCM ensembles

- Further work is needed to understand under which conditions and for which variables CPMs add value. This understanding will facilitate the smart combination or 'spatial merging' of high- and low-resolution information depending on usage.
- Further work is needed to continue the exploration of bias correction, emulators, local-scale statistical downscaling and AI-based methods for spatial merging.
- Extracting the climate change signal from the variability is a major challenge for the relatively short CPM simulations. For some variables spatial pooling may strongly enhance the signal-to-noise ratio.

4. Improved guidance and usability are required to ensure that users get best value from the available data

- Users should be offered guidance on where high-resolution model simulations sit within the broader envelope of known projection uncertainty. Further guidance could be offered on appropriate modelling streams for a given application/use.
- More guidance could be offered on the difference between extracting the forced signal and exploring the full future climate variability, and their different roles in offering information to users with an interest in a change in systematic risk and users with an interest in prediction.
- A bottleneck in the use of CPMs for various applications is that they produce huge amounts of data, and this creates problems in the storage, access and distribution of the data. Big-data science is needed to address this problem.

EUCP recommends that the methods developed in the project be raised to a higher technical readiness level, including consideration of how the user community can be enabled to use the new approaches to climate prediction and projection.

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