ASPECT Shorts

Temporal merging of climate information

This infosheet is for decision-makers, practitioners, and researchers who are interested in learning about temporal merging of climate information. Temporal merging will enable improved use of different types of climate information, and facilitate better decision making on time-scales up to more than a decade ahead.

This infosheet explains what temporal merging is, why it's useful, and the ASPECT project's latest research in this area.

What is temporal merging?

Temporal merging is an emerging approach being developed with the aim of combining information from different climate predictions or projections into a single, consistent source of climate information. These predictions and projections are produced using computer models that simulate the future climate in several different ways. Seasonal climate predictions usually cover one to six months into the future, while decadal predictions typically cover up to ten years. These types of predictions are started as close as possible to an observed climate state (known as initialisation) and follow observed climate variability. Long-term climate projections are used to study changes between now and up to 100 years into the future matching the range of climate variability over the longer term. They show how the climate might change in different future scenarios.

As these predictions and projections cover different future timescales or may run in different modelling systems, temporal merging is being developed to help remove any inconsistencies between them.

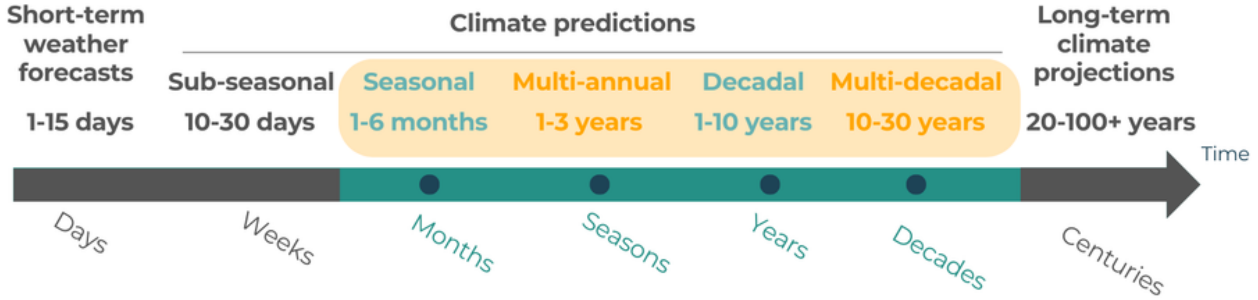

Figure 1. The various timescales covered by different climate prediction and projection categories. The box denotes the focus of new prediction simulations being studied in the ASPECT project. Source: ESS, Barcelona Supercomputing Center

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Why is ASPECT exploring temporal merging?

Users of climate information need to make decisions across many time horizons, and currently these decisions may use information from different sources that may not be consistent. While climate predictions and projections provide useful information for the timescales they cover, temporal merging is being developed as an approach to provide user-friendly seamless information across different timescales, and facilitate improved decision-making on climate sensitive issues.

This is done by coherently integrating information from overlapping sources of climate information. Without this, different predictions may be hard to use together, as they may use different model configurations, spatial resolutions, or starting conditions, stopping them from being easily compared and combined. Additionally, not all prediction centres carry out decadal prediction, meaning a given seasonal prediction may not have a comparable decadal prediction from the same organisation or model.

This lack of consistency could hinder users in making consistent decisions across seamless timescales. Temporal merging aims to bridge the gap between different categories of climate predictions and projections. This allows users to base their decisions on one set of information that combines information from multiple sources, making the most of their strengths and countering some of their weaknesses. In certain situations, temporally-merged simulations are outperformed by new multi-annual simulations but they may still be able to benefit users. They can provide information earlier, as their constituent simulations can be updated more frequently than multi-annual simulations, and they can accommodate different timescale-based decision-making frameworks in the same, consistent system.

How does temporal merging work?

Researchers are exploring several methods of temporal merging, each with different advantages and limitations. Choosing which method to use in each situation is based on an assessment of the effectiveness of different prediction categories and lengths of forecasts. Based on this, the appropriate method can be chosen to maximise these strengths.

Temporal merging methods include:

Stitching: This chains together decadal predictions, which can account for the climate's natural, short-term variability, and multi-decadal projections, which better capture long-term trends. This method works well in some regions where predictions and projections are consistent with each other, such as the Americas, eastern Asia and Australia but can struggle if the predictions and projections differ at the point they are joined together. This issue is most pronounced in the North Atlantic, Greenland and Northern Europe, potentially due to issues with modelling sea surface temperatures or near-surface air temperatures. Newer climate models may help in addressing these problems with improved simulations.

Sub-selection: Several similar approaches that choose from a range of longer-term predictions produced by multiple models based on how well they match shorter predictions or climate observations at the beginning of their simulations. The resulting subset of projections more closely matches the shorter-term information, then seamlessly continues past their maximum length to provide a longer-term picture (see Figure 2). It is important to choose the right variable to compare between the predictions and use one that is linked to forecast accuracy. A variant of the sub-selection approach that weights projections according to how well they match climate variability predicted by a decadal forecast is currently under development. This research uses predictions over an area of the Atlantic relevant to European climate, but the method could potentially yield useful alternative forecasts for a range of applications.

Pooling: Combines predictions of multiple lengths from one model, such as forecasts running for between 1 month and 24 months, producing a single, continuous forecast. This can provide useful information earlier and improve information on climate risk by effectively increasing the sample size. The resulting seamless forecast can also be updated more frequently than multi-annual simulations as newer forecasts become available and can help reveal information in existing forecasts, avoiding the need for them to be re-run as frequently. Pooling allows users to work within a single, consistent decision-making framework across multiple timescales. This method, developed by the University of Oxford, has demonstrated improved predictions in a user application using a single model and has the potential to be applied in a multi-model framework.

ASPECT temporal merging research for Super Users

ASPECT has been working to develop temporal merging methods that could help meet the needs of many different users of climate information. The project has also worked on applying temporal merging to specific user needs within case studies being developed with key partners called Super Users, including:

- The development of seamless forecasts of the El Niño Southern Oscillation (ENSO), which influences temperature and rainfall conditions around the world. We are exploring how this can help humanitarian action in Africa, supporting climate-conscious nutrition initiatives to address malnutrition in Malawi.
- Co-developing new methods with users to provide seamless spring frost risk information for vineyard farmers in Catalonia on a timescale of months out to two years.
- Developing merging methods to explore the potential of extending seasonal forecasts of extreme heat in the UK or other areas of Europe further into the future than those used today, supporting climate resilience and adaptation, including emergency response.

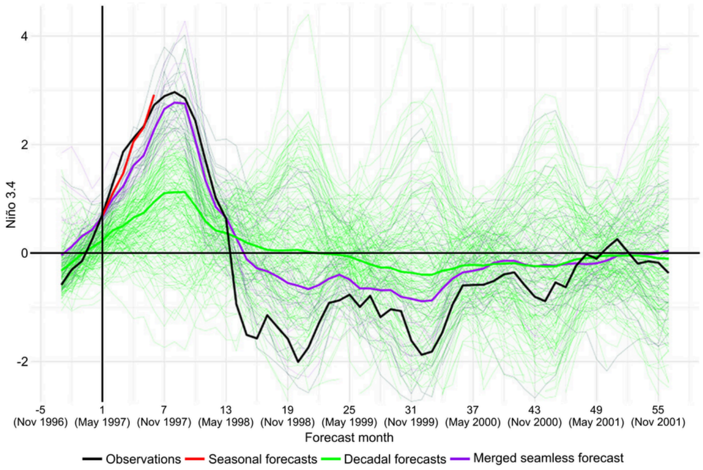

Figure 2. Seamless seasonal-to-decadal forecast of the Niño3.4 index of El Niño activity, showing observations (black), seasonal forecasts (red), decadal forecasts (green), and the merged seamless forecast (purple). The seamless forecast has been built by choosing decadal predictions that most closely match seasonal predictions. (modified from Delgado-Torres et al. (2026))

Temporal merging limitations and areas for future research

Currently, temporal merging has known potential flaws and limitations that should be kept in mind when it is used. However, these issues are subject to active research by the ASPECT project, as well as by the wider scientific community, aimed at making temporal merging part of the climate prediction toolkit.

In climate predictions, errors introduced by a high level of noise relative to the climate change signal can mean that variability (the background noise) obscures the forced climate response (the signal). This problem is common in some types of climate prediction.

Climate projections are affected by variability biases as well as these same signal-to-noise issues. In practice, this can bias projected responses; for example, for North Atlantic circulation changes, the climate change signal may be underestimated, leading to inaccurate simulations.

Temporal merging methods inherit these limitations from both predictions and projections. Reducing the underlying errors requires sustained model development, which is a long-term goal. In parallel, active research is exploring statistical adjustments to partially mitigate signal-to-noise errors in both predictions and projections. Ideally, such adjustments would be applied before merging, but these adjusted datasets are not yet routinely published. All these datasets should be used with an understanding of these limitations.

Other concerns around temporal merging methods include issues around the low spatial detail of many techniques, meaning they are hard to apply at a local level. In these cases, non-merged predictions might be preferred if they can provide more information at a higher resolution. Also, in some cases, different model simulations might be selected for merging in different regions, meaning that while the simulations are consistent between timescales, they are no longer consistent in different areas.

ASPECT research is continuing to explore our novel multi-annual and multi-decadal prediction simulations, which produce unbroken data out to two years and 30 years in the future respectively. Depending on the application, use of these simulations could be a potential alternative to certain temporal merging approaches.

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Find out more

See the following papers for the latest research from scientists involved in ASPECT on temporal merging.

- ***Acosta Navarro et al. (2025)*** Seamless seasonal to multi-annual predictions of temperature and Standardized Precipitation Index by constraining transient climate model simulations
- ***Balan Sarojini et al. (2026)*** Combining Observations, Forecasts, and Projections into Seamless Climate Information: Recent Advances and Insights in User Applications
- ***Befort et al. (2020)*** Constraining Projections Using Decadal Predictions
- ***Befort et al. (2022)*** Combination of Decadal Predictions and Climate Projections in Time: Challenges and Potential Solutions
- ***Cos et al. (2024)*** Near-Term Mediterranean Summer Temperature Climate Projections: A Comparison of Constraining Methods
- ***De Luca et al. (2023)*** Constraining decadal variability regionally improves near-term projections of hot, cold and dry extremes
- ***Delgado-Torres et al. (2026)*** Seamless climate information from months to multiple years: constraining decadal predictions with seasonal predictions and past observations, and their comparison to multi-annual predictions
- ***Donat et al. (2024)*** Improving the forecast quality of near-term climate projections by constraining internal variability based on decadal predictions and observations
- ***Mahmood et al. (2022)*** Constraining low-frequency variability in climate projections to predict climate on decadal to multi-decadal timescales – a poor man's initialized prediction system
- ***Solaraju-Murali et al. (2025)*** Constraining decadal climate predictions with seasonal forecasts: a step toward seamless multi-year climate information

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