BAMS
Meeting Summary

Combining Observations, Forecasts, and Projections into Seamless Climate Information: Recent Advances and Insights in User Applications

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Extreme events;
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Postprocessing;
Probability forecasts/models/distribution;
Seasonal forecasting;
Climate services

Workshop on Methods to Integrate Climate Information across Time Scales into User-Oriented Forecasting

What: About 20 participants from the Universities of Oxford and Leeds, the U.K. National Centre for Atmospheric Science, the Barcelona Supercomputing Centre, the Catalan Institution for Research and Advanced Studies, the Met Office (U.K.), the Swedish Meteorological and Hydrological Institute, and the Max-Planck Institute for Meteorology in Hamburg gathered to discuss recent advances in combining multiple sources of climate information—from observations and seasonal, multiannual, and decadal forecasts to long-term projections—to develop seamless climate products for real-world applications.

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Where: Oxford, United Kingdom

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1. Introduction

Extreme weather and climate events are placing increasing pressure on societies, economies, and ecosystems. Decision-makers across sectors, from agriculture and health to finance and governance, face growing demand for actionable climate information to support planning and preparedness in a changing climate (Fiedler et al. 2021; Doblas-Reyes et al. 2024).

Climate information spans multiple sources and time scales, including observations and reanalyses, initialized predictions or forecasts from monthly to decadal time scales, and free-running simulations used to generate historical and future projections (Palmer et al. 2008). These systems differ in modeling frameworks, assumptions, initialization and verification methods, forecast skill, and uncertainty, making their combination into temporally consistent information challenging. Structural differences, bias mismatches, and gaps across lead times can limit coherence and usability, leaving seamless climate information across time scales a central challenge for climate services. In addition, for forecasts to be useful for decision-making, reliability, where forecast probabilities match observed frequencies, is a key requirement (Weisheimer and Palmer 2014).

Temporal merging, or blending, encompasses a range of methods that integrate climate information from multiple sources to produce a single, coherent outlook across time scales. By exploiting the strengths of each system within its designed range, this approach allows short-term predictability to inform longer-term outlooks.

The main advantages of temporal merging are that it enables the combination of existing climate simulations with observations and short-range predictions, often generated through routine operational forecasting, thereby making the resulting seamless information comparatively low in computational cost. It can also reduce user confusion arising from multiple products that may appear inconsistent, making it difficult to know which information to use. Yet significant challenges remain, including maintaining physical consistency across systems, avoiding discontinuities at transition points, and transparently representing uncertainty. Effective temporal merging therefore depends on careful calibration and statistically robust assumptions about forecast bias, drift, and uncertainty, given that forecast systems often differ in their biases, drift behavior, ensemble characteristics, and overall forecast quality.

The Oxford workshop brought together partners from Adaptation-Oriented Seamless Predictions of European Climate (ASPECT) consortium to discuss methodological advances and user-facing implications, with a particular focus on key sectoral users, termed *Super Users*. Building on the legacy of the European Climate Prediction project (https://www.eucp-project.eu/), ASPECT develops and tests methods for temporal combination of climate predictions and

Table 1. Super User case studies across different sectors and their needs *for seamless climate information across multiple decision time scales*. Note that the scope of the ASPECT project is limited to 30 years into the future.

Sector/user needs	Seasonal climate predictions *(1–6 months)*	Multiannual climate predictions *(1–3 years)*	Decadal climate predictions *(1–10 years)*	Multidecadal climate predictions *(10–30 years)*	Long-term climate projections *(20–100+ years)*
Agriculture	Grape/wine (Codorniu, Catalonia, Spain) • *Spring frost protection* • Water management				
Finance	Pensions • Generation and communication of climate risk information for synthetic portfolios				
Governance	EU Mission for Climate Adaptation (Emilia-Romagna, Italy) • Strategic climate risk assessment				
Emergency response	British Red Cross, United Kingdom • *Response planning for increasing heatwave events*				
Humanitarian	Health (Save The Children International) • *Anticipatory action for malnutrition*				

projections (e.g., Donat et al. 2024; Delgado-Torres et al. 2026) to facilitate adaptation-based seamless decisions. Seamless decision-making relies on *seamless climate information*, delivered either through *temporal merging* or through innovative prediction experiments spanning new forecast horizons (1–3 and 10–30 years), as described by Terrado and colleagues in a submitted manuscript. *Climate information is coproduced by working with Super Users* (Table 1) via case studies, user forums (https://www.aspect-project.eu/user-forums/), and different upscaling strategies. This hybrid workshop was designed to support more collaborative synthesis and to foster alignment on possible user applications of temporally combined products. Beyond reviewing recent methodological advances, the workshop also aimed to identify shared priorities and practical next steps for advancing seamless climate information across prediction time scales. Workshop discussions emphasized that user needs differ across sectors and planning horizons at different time scales.

2. Temporal combining methodologies

The first step in temporal combining is to perform a skill assessment of predictions from individual start dates and prediction types, which we refer to as the *premerging skill assessment*. This step is particularly relevant for initialized forecasts, where demonstrable skill relative to climatology indicates whether forecasts add value beyond a baseline reference. Other sources of climate information, such as climatological forecasts, may not be skillful at specific lead times but can still be reliable. The skill assessment therefore determines where forecast information should meaningfully contribute to the merged product and helps identify the source of predictability for the hazard in question.

Various terminologies are used to describe the different flavors of temporal combination of information such as prediction and projection model output in the context of *postprocessing: stitching, shadowing, constraining, subsampling, storyline, and pooling*. It highlights the need for clearer terminology, shared evaluation datasets and protocols, and transparent documentation of methodological choices. These approaches differ in how climate information across time scales is combined: Pooling aggregates ensemble members from multiple start dates, subsampling identifies longer-term members consistent with shorter-term signals, storyline methods weight projections using information from initialized forecasts to describe plausible near-term deviations, and stitching concatenates forecasts across lead times by replacing shorter-range initialized predictions with longer-term projections as predictive skill declines. Below, we describe each research method, *from shorter- to longer-term* *merging to produce seamless forecasts*, and discuss its opportunities and limitations in user applications.

a. Ensemble pooling approach. A new temporal merging method has been proposed to produce *seamless forecasts from monthly to multiyear lead times*. An ensemble-democracy approach is used to pool ensemble members across all available lead times (i.e., from lead month 1 to lead month 22) of the target season (Fig. 1). All ensemble members from all available start dates for a target season are pooled together with equal weighting to produce seamless climate information across multiple time scales from the ECMWF seasonal forecasting system (SEAS5; Johnson et al. 2019). This approach assumes that all ensemble members are equally probable. It is important to note that the equal-weighting strategy can be adjusted depending on the user application. Although SEAS5 has been used here, which provides multiyear forecasts up to 2 years ahead for the target season, this method can also be tested with other prediction systems. The seamless approach primarily represents a single modeling system used *across multiple (seasonal to multiannual) time scales to produce one consistent dataset for users*, which would then provide a novel climate information application. The assumption of using a single modeling system only, rather than combining data from different systems, minimizes the impact of systematic biases between different forecast types available from the same system. A manuscript describing this method has recently been submitted by M. A. Abid et al (2026, unpublished manuscript).

The premerging skill assessment of the required variable was performed for each start date for the target season. This provides an initial indication of the possible outcomes when using different start dates. Combining them helps to recover forecast skill and provides a stable and persistent level of skill for the target season across time scales, without incurring the additional cost of generating new forecasts. This means that valuable information may already exist within the ensembles from different forecasts, and combining them helps to reduce internal variance, with a positive impact on overall forecast skill.

A practical implication is that pooled seamless products can be postprocessed to ensure reliability of probabilities. Pooling leverages ensemble information already present in the system but extracts a signal earlier and with more confidence due to larger ensemble sizes.

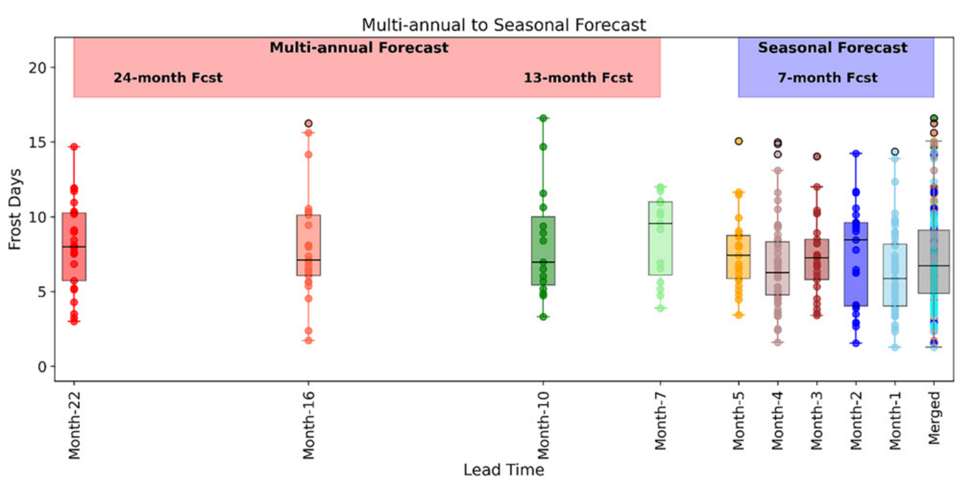

Fig. 1. Illustration of the ensemble pooling temporal merging approach. Monthly to multiyear forecasts for the Catalonia region are shown for each start date using SEAS5 output from multiannual (24 and 13 months) and seasonal forecasts, with dots denoting individual ensemble members and colors indicating forecast length. Merged forecasts (*x* axis, gray box) are produced by pooling ensemble members from all start dates. The example shown is the March 2022 frequency of frost days, with ensemble members from different start dates plotted on a nonlinear lead-time axis. Boxplots denote the spread and median for each start date and for the merged forecasts.

Potential user applications including ASPECT Super User applications: Within ASPECT, the ensemble pooling approach is codeveloped for seamless spring frost risk information for Catalonian vineyard farmers (monthly to 2-yr horizons) and is also explored for U.K. extreme-heat risks relevant to the emergency response sector. Where marginal skill limits predictive value, products may still support structured preparedness discussions, provided guidance makes limitations explicit and avoids presenting information as deterministic foresight. The technique could be applied in regions beyond the areas of our initial research to fulfil widespread interest in preparing for the impact of heat extremes following severe impacts in recent summers.

b. Subselection approach. Recently, several approaches have been developed to subsample ensembles on longer time scales that closely follow the information on shorter time scales. Here, those individual realizations are selected that best match a target variable according to a measure of similarity. The approach, sometimes referred to as *shadowing, constraining, or subsampling*, has been applied to shadow seasonal predictions in decadal forecasts, or to shadow decadal predictions in climate projections, and to shadow the observations (Befort et al. 2020; Mahmood et al. 2022; De Luca et al. 2023; Cos et al. 2024; Donat et al. 2024). A similar methodology has been applied to produce seamless information at seasonal-to-multiannual time scales by selecting those decadal prediction or climate projection members that most closely resemble the seasonal forecast or recent observations (Solaraju-Murali et al. 2025; Acosta Navarro et al. 2025; Delgado-Torres et al. 2026). The target variable is often a sea surface temperature pattern (De Luca et al. 2023; Solaraju-Murali et al. 2025; Acosta Navarro et al. 2025) or some index that represents a large-scale driver of a regional climate hazard that has an impact on society. Indices are chosen as they are larger scale and potentially more predictable (e.g., Delgado-Torres et al. 2026), but it is important that there is predictability and that the driver is linked by a mechanism to the impact hazard. The overarching objective is to transfer some predictability of shorter-term forecasts into longer time scales from a research methodological perspective. However, from a user perspective, the information must be usable and reliable regardless of whether it is derived from combining a driver variable or a hazard variable.

The years 1997/1998 witnessed one of the strongest El Niño events on record. An illustration of a *seamless seasonal-to-decadal forecast* constrained in May 1997 is shown in Fig. 2. In this example, seasonal forecasts capture the developing El Niño, but a naive transition to decadal predictions introduces a "jump" (a discontinuity between the last seasonal value and the corresponding decadal value). Constraining selects decadal (and historical simulation) members that match the seasonal evolution for months 1–6, yielding a continuous trajectory of Niño-3.4 that is easier to interpret in a user context.

Potential user applications including ASPECT Super User application: Within ASPECT, the Barcelona Supercomputing Center applies constraining to provide seasonal-to-multiannual ENSO-driven information for a Super User case study in the humanitarian sector, supporting climate-smart nutrition initiatives that reduce malnutrition risk in Malawi and Niger. In this region, the food and agricultural-relevant temperature and precipitation variability are mainly modulated by the ENSO teleconnections.

c. Storyline approach. The Met Office (United Kingdom) is developing *a variant of the shadowing technique* that focuses on resilience to a plausible range of outcomes and on helping users understand how initialization may influence near-term decisions relative to long-term projections. Initialized forecasts are used to diagnose near-term deviations in key modes, and projections are weighted by how well they match the phase of that deviation. The *merged product for several large-scale drivers* (global temperature, summer subpolar North Atlantic temperatures,

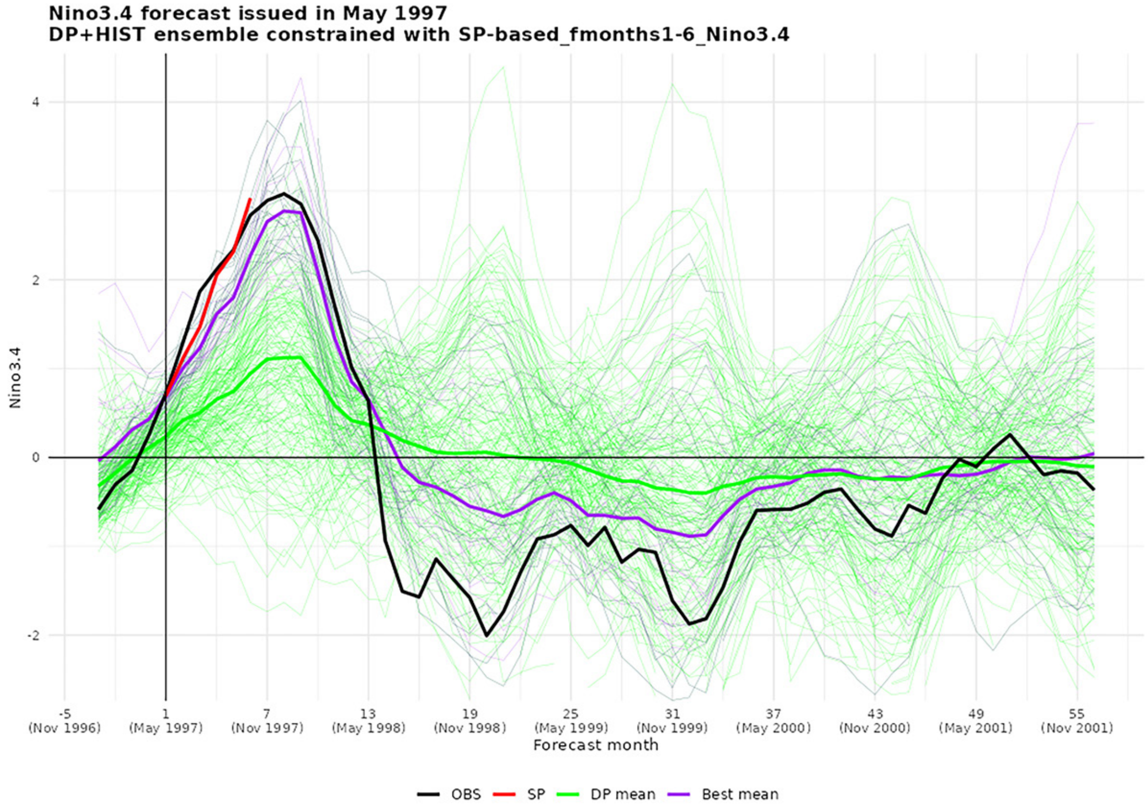

FIG. 2. Seamless seasonal-to-decadal forecast of the Niño-3.4 index initialized in May 1997. Observations (black), seasonal forecasts (red), decadal forecasts (green), and the seamless forecast (purple). The seamless product is constructed using a constraining method that selects decadal prediction and historical simulation members consistent with seasonal Niño-3.4 evolution during forecast months 1–6. Adapted from Delgado-Torres et al. (2026).

ENSO, winter NAO) shows added skill at short time scales relative to the projections weighted by observed trends. However, the merged product can be underdispersive; in the case of the subpolar North Atlantic temperatures, this is mainly due to the weighting by observed trends shifting the multimodel mean downward away from the observed anomalies. The merged product is just the first stage. Ultimately, the output will be presented in terms of the hazards that cause the impact to society rather than the large-scale driver itself. The approach is *storyline based* as the output will be a narrative that describes how the initialized forecasts have caused deviations in the near term in the context of the long-term projection. A manuscript based on this method is about to be submitted by D. Sexton et al. (2026, unpublished manuscript), with ongoing work focusing on assessing forecast skill and reliability across lead times.

Potential user applications: Users focused on the near term often prioritize skillful forecasts. Those planning on longer time scales may focus on resilience to a plausible range of outcomes. For organizations that must take an overall view of physical climate risk, coherent information across time scales is essential, including clarity on when and why the information basis transitions.

Discussion also highlighted design choices that affect robustness of climate information. The period used to match historical analogs to initialized predictions matters: Short windows can be dominated by interannual variability and statistical noise, whereas longer windows emphasize persistent, low-frequency signals but can reduce qualifying members. Another choice is whether shadowing is performed against the decadal prediction ensemble mean or per initialized member; the latter increases spread yet may still preserve predictability in the mean for low-frequency modes, which matters when moving to probabilistic forecasts or analysis of distributions.

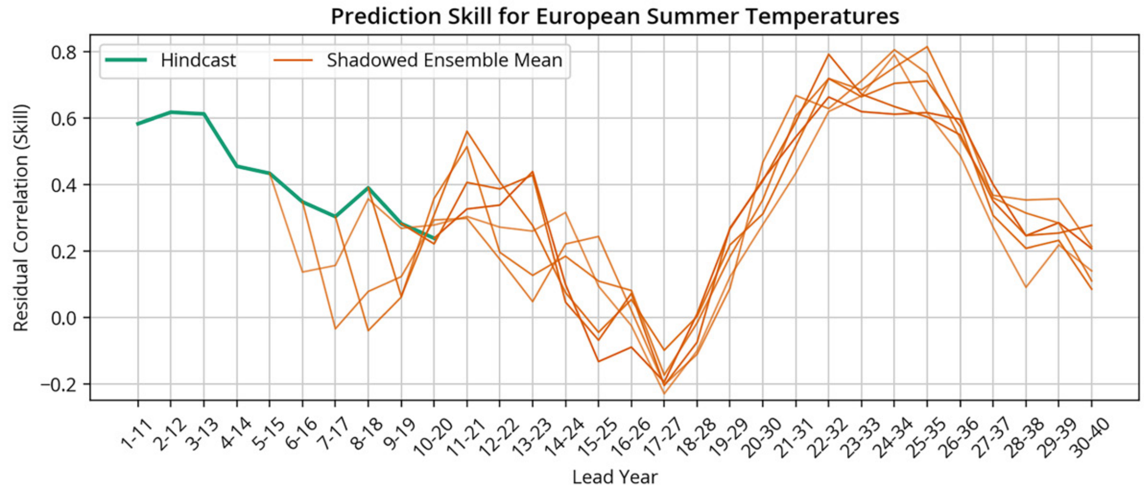

Fig. 3. Prediction skill (residual correlation with ERA5) for 11-yr mean European summer temperature at different lead times. The 16-member, 20-yr initialized hindcast is shown in green; analog uninitialized members selected via shadowing (following Befort et al. 2020) are shown in orange shades.

Within a decision-making context that already uses projections, the storyline approach removes the forced signal from target variables prior to matching to focus the selection on the phase of variability and avoid unjustifiably narrow ranges; more multimodel realizations can be reintroduced as the value of initialization wanes.

Large-scale climate variable–based shadowing work at the Max Planck Institute (MPI) for Meteorology, *using new 20-yr initialized predictions on multidecadal time scales*, indicates that the benefits of initialization for European summer climate can persist beyond a decade. This enables analog matching with large uninitialized ensembles, such as the MPI Grand Ensemble, to prolong predictability while avoiding common issues immediately after initialization. Figure 3 demonstrates this for 11-yr mean European summer temperatures using residual correlations with ERA5. This work is ongoing (D. Krieger et al. 2026, unpublished manuscript).

d. Concatenating time series. In this approach, also termed *stitching*, the most skillful predictions are used for early lead times and progressively replaced by longer-term information as skill declines. Befort et al. (2022) applied this method by *combining decadal predictions with climate projections* across standard regions. The approach performs well for median temperature changes but struggles for extremes and some regions due to discontinuities at the concatenation point. Calibration can reduce bias and maintain distributional consistency, though univariate methods may introduce cross-variable inconsistencies. Multivariate calibration or model weighting may help address these limitations, provided sufficient ensemble size.

3. Research to user applications to operationalization: Opportunities, lessons learnt, and limitations

Translating methodological advances in temporal combining into operational climate services requires more than technical robustness. As highlighted in recent work on the coproduction of climate services (Jacob et al. 2025), successful implementation depends on sustained dialogue, institutional alignment, and clear communication of uncertainty, in addition to scientific credibility.

New ASPECT prediction datasets such as the 24-month reforecast or hindcast products (e.g., Balmaseda 2025) offer new *opportunities* to test and evaluate temporal merging frameworks over extended lead times. These extended reforecasts have been particularly useful for codeveloping combining methodologies.

Lessons learnt from sharing knowledge and from better understanding the purpose of each application during the workshop discussions are the following:

- Participants reflected that "usefulness" depends on the decision context. For near-term applications, added value is typically tied to demonstrable skill relative to climatology, whereas for longer-term planning, reliability, robustness, and physical consistency of ranges often become more important. Participants therefore recommended evaluating merged products with a balanced set of diagnostics: skill metrics alongside reliability and sharpness, and, where possible, decision-relevant value assessment in partnership with climate service providers and users.
- Single-model initial-condition large ensembles (SMILEs) offer a consistent modeling framework that reduces artificial jumps between time scales, improves quantification of internal variability and uncertainty, and supports more physically interpretable and operationally viable temporal combining approaches. Ideally, methods should be applied to single models and then pooled across multiple models, rather than applied once to a multimodel ensemble and treated as if it were a single model system. Alternatively, the method can be applied to the multimodel ensemble if the members have been bias-adjusted.
- There exists a point in time where conventional modeling/shadowing/pooling approaches reach their limit in terms of providing user-oriented, local, and tailored prediction products. Even with the current combining methods, it may be unrealistic to expect the model to be skillful in predicting the large-scale climate system, appropriate for these temporal combining methods, and also provide output data at a spatial resolution good enough to meet certain user needs. At this point in time, other approaches, such as statistical downscaling, may be needed to translate the added value of the temporal combining methods into added value for the desired end product.

Research to user application to operationalization hurdles. There is still more predictability research to be done in assessing robustness before these approaches can be used to provide real-time information to climate service providers and end users beyond consortium partners.

Further work is needed to identify appropriate target variables that both demonstrate skill in initialized forecasts and are physically linked to impact-relevant hazards. Strengthening understanding of predictability mechanisms and conducting robust premerging skill assessments are essential for integrating these metrics into climate services.

Stronger *two-way engagement with climate service providers and applied scientists* at national meteorological services is needed to support appropriate guidance for operational use. Working with expert users to explore future applications of temporal merging can enable functional scaling and further codevelopment of the methods. Webinars and updates through user forums are intended to demonstrate to potential users the benefits they may gain from these approaches.

A clear narrative is needed on what information is realistically available at different time scales, recognizing that relevance depends on decision context and data release cycles. Methodological research must also balance predictive skill and physical consistency in the methods and communicate these trade-offs transparently to users.

Workshop discussions stressed that *seamless products* must clearly distinguish forecast skill, climatological baselines, and scenario-based information, with transparent communication of uncertainty. This is particularly *important for extremes*, given strong organizational demand for extreme heat and precipitation information; related insights from a European survey have recently been submitted by Grainger and colleagues.

The workshop also highlighted *practical constraints for operational forecasting workflows*, i.e., the routine production and dissemination of forecast products used by climate service providers. Release schedules for seasonal, multiannual, and decadal products are often not aligned with user decision windows because these forecasts are produced and made available at different times of the year and on different update cycles. Temporal merging methods may therefore need to accommodate asynchronous updates, where new information from one system becomes available while others remain unchanged.

Finally, the group emphasized several *limitations and research priorities*: (i) nonstationarity can undermine calibration and analog selection; (ii) approaches can be sensitive to ensemble size and dependence, especially when subselecting; (iii) maintaining physical consistency across multiple variables remains challenging for many postprocessing approaches; and (iv) evaluation should increasingly include storyline and process-based diagnostics, not only scalar skill scores. These considerations highlight the opportunities and challenges involved in translating temporal merging methods into operational climate services.

4. Summary and way forward

The methodological advances in temporal combining showcased here represent a rapidly evolving field with diverse and complementary approaches to *bridging temporal gaps in climate information*. The term *"seamlessness" of the seamless climate information* can, in this context, be viewed as an umbrella term for 1) ultimately providing a single time series that starts from short term (here, monthly to seasonal) and evolves coherently to extend beyond the decadal range to long term (e.g., Delgado-Torres et al. 2026); 2) a means to introducing coherence across risk assessments made for different time scales which might include an assessment of when one moves from a time scale where skill is the focus to one where the aim is resilience to a plausible range [e.g., ongoing work by D. Sexton et al. (2026, unpublished manuscript)]; and 3) a way to combine output from different prediction systems within a single model framework addressing multiple time scales [e.g., submitted manuscript by M. A. Abid et al. (2026, unpublished manuscript)].

While *seamlessness in climate information across particular chunks of time (e.g., in the monthly to multiannual time scales or multiannual to decadal time scales) has begun to fill some of the current gaps in user needs*, reconciling seamlessness across longer time scales (e.g., in the monthly to multidecadal time scales) that lend themselves to different seamless decision-making frameworks remains a challenge. While progress is emerging in the research and development mode for most of the methods, further work is needed to assess the robustness and reliability of the method, standardize the combining frameworks, evaluate real-world cases, and integrate these methods within user-oriented climate services in an operational mode. Aligned with the intended outcomes of this user-oriented research project, research in the ASPECT project provides progress in that direction.

The workshop highlighted several methodological and practical challenges in combining climate information across time scales, including differences in terminology, evaluation practices, and user requirements. These discussions underscored the need for clearer coordination across methods and closer engagement with climate service providers. *Key next steps* include the following: 1) agreeing on a common vocabulary across methods (what seamless means for different products); 2) adopting shared benchmark datasets and evaluation protocols (including hindcast periods, reference baselines, and reliability diagnostics); 3) documenting method choices that affect outcomes (target variable, matching window, selection criteria, weighting strategy, and handling forced trends); and 4) piloting a small set of prototype products with climate service providers, where success criteria are defined jointly via two-way feedback. Participants also identified the value of intercomparison exercises, applying multiple merging approaches to the same hazard and region, to illuminate when methods converge and when they offer genuinely different information.

Across all steps, the group emphasized that operationalization should be approached as a staged process: *start with limited-scope products for expert users or communities of practice*; expand only when robustness has been demonstrated; and treat guidance, training, and feedback loops as part of the coproduced product. Overall, the workshop highlighted the need for coordinated methodological development, shared evaluation frameworks, and closer engagement with climate service providers. Continued collaboration will be essential to translate advances in temporal merging into reliable and usable climate information across time scales.

"*The challenge is not only to predict the future climate, but to make that knowledge useful for society*"—a message that has remained relevant since the first IPCC assessment in 1990.

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References

Acosta Navarro, J. C., A. Aranyossy, P. De Luca, M. G. Donat, A. Hrast Essenfelder, R. Mahmood, A. Toreti, and D. Volpi, 2025: Seamless seasonal to multi-annual predictions of temperature and Standardized Precipitation Index by constraining transient climate model simulations. *Earth Syst. Dyn.*, **16**, 1723–1737, https://doi.org/10.5194/esd-16-1723-2025.

Balmaseda, M. A., 2025: ECMWF 24-month extended-seasonal reforecasts (19812024) for the ASPECT project. ECMWF, accessed 11 December 2023, https://doi.org/10.21957/5e60-rf82.

Befort, D. J., C. H. O'Reilly, and A. Weisheimer, 2020: Constraining projections using decadal predictions. *Geophys. Res. Lett.*, **47**, e2020GL087900, https://doi.org/10.1029/2020GL087900.

——, and Coauthors, 2022: Combination of decadal predictions and climate projections in time: Challenges and potential solutions. *Geophys. Res. Lett.*, **49**, e2022GL098568, https://doi.org/10.1029/2022GL098568.

Cos, P., R. Marcos-Matamoros, M. Donat, R. Mahmood, and F. J. Doblas-Reyes, 2024: Near-term Mediterranean summer temperature climate projections: A comparison of constraining methods. *J. Climate*, **37**, 4367–4388, https://doi.org/10.1175/JCLI-D-23-0494.1.

Delgado-Torres, C., and Coauthors, 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. *Earth Syst. Dyn.*, **17**, 41–56, https://doi.org/10.5194/esd-17-41-2026.

De Luca, P., C. Delgado-Torres, R. Mahmood, M. Samsó-Cabré, and M. G. Donat, 2023: Constraining decadal variability regionally improves near-term projections of hot, cold and dry extremes. *Environ. Res. Lett.*, **18**, 094054, https://doi.org/10.1088/1748-9326/acf389.

Doblas-Reyes, F. J., and Coauthors, 2024: Standardisation of equitable climate services by supporting a community of practice. *Climate Serv.*, **36**, 100520, https://doi.org/10.1016/j.cliser.2024.100520.

Donat, M. G., R. Mahmood, P. Cos, P. Ortega, and F. J. Doblas-Reyes, 2024: Improving the forecast quality of near-term climate projections by constraining internal variability based on decadal predictions and observations. *Environ. Res. Climate*, **3**, 035013, https://doi.org/10.1088/2752-5295/ad5463.

Fiedler, T., A. J. Pitman, K. Mackenzie, N. Wood, C. Jakob, and S. E. Perkins-Kirkpatrick, 2021: Business risk and the emergence of climate analytics. *Nat. Climate Change*, **11**, 87–94, https://doi.org/10.1038/s41558-020-00984-6.

Jacob, D., and Coauthors, 2025: Co-production of climate services: Challenges and enablers. *Front. Climate*, **7**, 1507759, https://doi.org/10.3389/fclim.2025.1507759.

Johnson, S. J., and Coauthors, 2019: SEAS5: The new ECMWF seasonal forecast system. *Geosci. Model Dev.*, **12**, 1087–1117, https://doi.org/10.5194/gmd-12-1087-2019.

Mahmood, R., M. G. Donat, P. Ortega, F. J. Doblas-Reyes, C. Delgado-Torres, M. Samsó, and P.-A. Bretonnière, 2022: Constraining low-frequency variability in climate projections to predict climate on decadal to multi-decadal timescales—A poor man's initialized prediction system. *Earth Syst. Dyn.*, **13**, 1437–1450, https://doi.org/10.5194/esd-13-1437-2022.

Palmer, T. N., F. J. Doblas-Reyes, A. Weisheimer, and M. J. Rodwell, 2008: Toward seamless prediction: Calibration of climate change projections using seasonal forecasts. *Bull. Amer. Meteor. Soc.*, **89**, 459–470, https://doi.org/10.1175/BAMS-89-4-459.

Solaraju-Murali, B., V. Torralba, C. Delgado-Torres, M. G. Donat, P. Cos, N. Gonzalez-Reviriego, A. Soret, and F. J. Doblas-Reyes, 2025: Constraining decadal climate predictions with seasonal forecasts: A step toward seamless multi-year climate information. *Environ. Res. Lett.*, **20**, 104046, https://doi.org/10.1088/1748-9326/adfd73.

Weisheimer, A., and T. N. Palmer, 2014: On the reliability of seasonal climate forecasts. *J. Roy. Soc. Interface*, **11**, 20131162, https://doi.org/10.1098/rsif.2013.1162.