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Copernicus Seasonal Forecast Tools Package: Bridging Seasonal Climate Predictions and Impact Models for Operational Risk Assessment

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Summary

The landscape of disaster risk management is undergoing a significant transformation, driven by two increasingly complementary approaches: Impact-Based Forecasting (IBF) and seasonal forecasts. While traditional forecasting focuses solely on weather predictions, IBF integrates hazard information—such as extreme temperature patterns—with socioeconomic exposure and vulnerability information, enabling quantitative risk assessments in areas as diverse as public health and infrastructure resilience. On the other side, seasonal forecasts spanning several months provide stakeholders with probabilistic predictions that enable forward-thinking adaptation planning well before conditions materialize.

A three-step conceptual framework illustrates the progression from prediction to actionable advice: 1) seasonal climate prediction, 2) impact modeling, and 3) actionable impact-based forecasting. While significant advances have been made in the first two steps separately, a critical gap remains in operational systems that systematically connect seasonal forecasts with impact models to enable the third step. To address this challenge, we introduce the Copernicus Seasonal Forecast Package, a tool that integrates seasonal climate predictions into the CLIMADA risk modeling pipeline. This work helps bridge the strategic gap between traditional seasonal forecasts and impact-oriented services, contributing to the development of operational, reproducible workflows that connect probabilistic climate forecasts to warning systems and decision-making processes.

The package automates the entire data flow—from data retrieval via the Copernicus Climate Data Store (Copernicus Climate Change Service, 2024), through preprocessing and heat index calculation, to the generation of CLIMADA-compatible hazard objects. This integration enables researchers and practitioners to transform seasonal climate forecasts into concrete impact assessments, supporting proactive risk management strategies months ahead of potential events.

Statement of need

Despite the growing interest in both seasonal prediction (Murphy et al., 2000; Ngoungue Langue et al., 2025; Osman et al., 2023) and impact modelling — aiming to shift from describing what the hazard will look like to how the hazard will impact (Merz et al., 2020; Shyrokaya et al., 2024), and moving from weather-centric forecasts to impact-oriented services — there is still a lack of operational and reproducible tools to link probabilistic seasonal climate predictions with quantitative impact assessment frameworks (Geiger et al., 2024). Current workflows are typically fragmented, requiring manual intervention across multiple stages including data access, preprocessing, and hazard transformation. These inefficiencies can delay critical risk assessments and compromise reproducibility (Potter et al., 2025; Wyatt et al., 2023).

While existing libraries such as xclim (Bourgault et al., 2023), icclim (Pagé et al., 2022), and Thermofeel (Brimicombe et al., 2022) provide robust implementations of climate indices, they do not offer an operational pathway from seasonal forecasts to impact modeling frameworks. Our work complements these established tools by focusing specifically on the operational gap between seasonal climate predictions and risk assessment. We utilize Thermofeel as a reference for specific index calculations, ensuring our formulas align with published definitions to maintain comparability and facilitate reuse across the scientific community.

The Copernicus Seasonal Forecast Tools Package addresses this gap by providing an automated, flexible, and modular solution. It connects seasonal forecast data from the Copernicus Climate Data Store (Copernicus Climate Change Service, 2024) with the hazard and impact modeling capabilities of the CLIMADA platform (Aznar-Siguan & Bresch, 2019), an open-source platform for climate risk analysis and the evaluation of adaptation benefits (Bresch & Aznar-Siguan, 2021). This integration allows users to efficiently transform raw seasonal predictions into actionable climate risk insights. The package supports the definition of custom climate indices, the integration of data from multiple providers, and the adaptation to emerging hazard types and regional contexts. Thereby, it strengthens the operational implementation of impact forecasting and facilitates downstream components of the warning value chain or operational pipeline (Golding et al., 2019), bridging the gap between probabilistic seasonal forecasts and concrete impact assessments in an actionable timescale.

Implementation and functionality

The Copernicus Climate Data Store currently offers one of the most comprehensive and globally accessible repositories of seasonal forecast data (Buontempo et al., 2022). It brings together high-dimensional, hourly-resolution outputs from approximately eight major meteorological centers, encompassing more than 50 climate variables. These datasets span both hindcast and forecast periods, starting from around 1996 to the present, with up to 6-month lead times and multiple ensemble members per forecasting provider (Copernicus Climate Change Service, 2023). While the richness of this dataset enables advanced climate research, its size and complexity renders direct use challenging.

To address this issue, the Copernicus Seasonal Forecast Package provides streamlined tools to access data via Climate Data Store API (Python client: cdsapi), and to filter and aggregate raw GRIB/netCDF files into daily netCDF outputs, facilitating their downstream use in climate index calculation and risk modeling. Once retrieved, it processes the raw files into gridded daily netCDF datasets, structured by forecast date, ensemble member, latitude, and longitude. In all steps of the process, the package checks if the corresponding output files already exist before proceeding. Each file includes multi-ensemble data for daily mean, maximum, and minimum values.

Once daily data is calculated, users can select from twelve available heat indices (based on index definitions given in (Brimicombe et al., 2022)), including temperature-based indices (Tmean, Tmin, Tmax), heat stress indicators (HIA—Heat Index Adjusted, HIS—Heat Index Simplified, HUM—Humidex, AT—Apparent Temperature, WBGT—Wet Bulb Globe Temperature), and extreme event indices (HW—Heat Wave, TR—Tropical Nights, TX30—Hot Days).

Calculated index data is saved in netCDF format and organized by index and time period, with file paths printed during processing. Statistical summaries of the index across ensemble members are computed and saved simultaneously, providing insight into forecast behavior. In addition to summary statistics, full access to all ensemble members is preserved to allow users to explore the full range of forecast uncertainty, rather than relying solely on aggregated values. This design choice supports transparent communication of uncertainty and more robust decision-making in impact-based applications. Users can then transform the index into a CLIMADA-compatible hazard object, enabling integration into impact-based forecasting workflows.

Status

The current version of the Copernicus Seasonal Forecast Tools Package supports:

- Automated download of the high dimensionality seasonal forecasts data via the Copernicus API
- Preprocessing of sub-daily forecast data into daily formats
- Calculation of heat-related climate indices (e.g., heatwave days, tropical nights)
- Conversion of processed indices into CLIMADA hazard objects ready for impact modeling
- Flexible modular architecture to accommodate additional indices or datasets updates

The package has been tested within CLIMADA workflows and demonstrated in example notebooks. Planned future developments include integrating skill metrics from Copernicus, when available, across ensemble members to improve transparency in the impact-based forecasting chain. Further enhancements will support adaptation to new forecast data versions from Copernicus as they become available, including those with improved spatial resolution.

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