REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE:	Croatia
Principal Investigator[1]:	Cléa Lumina Denamiel
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Project Title:	Adriatic Sea and Coast (AdriSC) climate model v2.0

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** …………..	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☐	NO x

Computer resources required for project year:		2026	2027	2028
High Performance Computing Facility	[SBU]	308 Million	308 Million	308 Million
Accumulated data storage (total archive volume)[2]	[GB]	200 TB	400 TB	600 TB

EWC resources required for project year:		2026	2027	2028
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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Extended abstract

1) Motivation and Problem Identification

The successful deployment and operation of the Adriatic Sea and Coast (AdriSC) climate modeling framework on ECMWF's high-performance computing (HPC) infrastructure have been pivotal to recent advances in high-resolution regional climate modeling for the Adriatic-Ionian region. The current version of AdriSC couples the Regional Ocean Modeling System (ROMS; Shchepetkin and McWilliams, 2009) and the Weather Research and Forecasting (WRF; Skamarock et al., 2005) atmospheric model at horizontal resolutions down to 1 km and 3 km respectively, making it one of the most detailed regional climate modeling systems used in Southern Europe (Figure 1). The computational demands of such fine-scale simulations, particularly for long-term historical and future projections, necessitate a highly scalable and efficient HPC environment—requirements that ECMWF's systems have met with outstanding performance. During the previous ECMWF Special Projects (SPCRDENA), the AdriSC model successfully completed continuous 31-year simulations for both historical (1987–2017) and far-future (2070–2100, RCP8.5) scenarios using the pseudo-global warming (PGW) methodology (e.g., Schär et al., 1996; Denamiel et al., 2020; Figure 1).

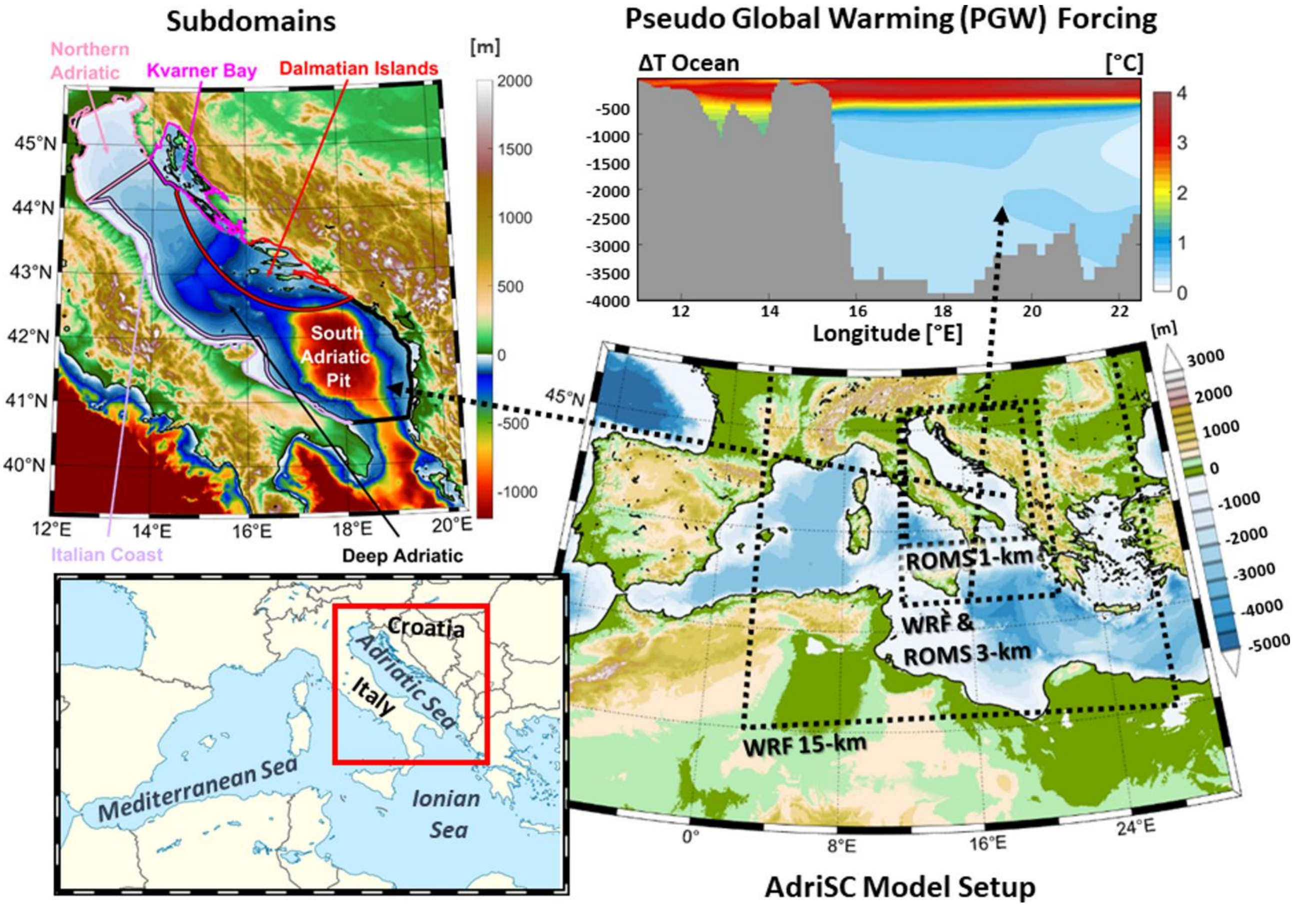

Figure 1. Setup of the current version of the AdriSC climate model. Spatial coverage and horizontal resolution of the different grids including the topo-bathymetry of the AdriSC 1-km model with the locations of 5 Adriatic subdomains (coloured polygons). Pseudo-Global Warming temperature ocean forcing imposed in the AdriSC 3-km model southern boundary for the far-future extreme warming simulation.

These simulations produced an extensive high-resolution dataset, now forming the basis of multiple publications and ongoing climate hazard assessments (e.g., Denamiel et al., 2019, 2021, 2022, 2025; Pranić et al., 2021, 2024; Tojčić et al., 2024, 2025). Notably, the ECMWF HPC platform allowed for optimized model throughput and robust data handling, enabling the completion of more than 60 years of coupled ocean-atmosphere simulation at convection-permitting resolution—an achievement rarely accomplished in the regional climate community.

However, several key limitations emerged that now motivate the transition to a new version of the AdriSC climate model (hereafter, AdriSC climate model v2.0). Chief among these is the intrinsic constraint of the pseudo-global warming (PGW) method used in AdriSC, which—although computationally efficient and able to preserve regional climate features—does not allow for transient climate projections. As such, the current version of the model cannot provide insight into near- to mid-term climate evolution (e.g., 2021–2050), hindering its utility for many adaptation planning and impact assessment needs at the local and national levels. Moreover, the existing model domains, while adequate for the Adriatic Sea, provide only a partial representation of the Ionian basin and lack a realistic exchange interface at the Otranto Strait. This underrepresentation of the broader Adriatic-Ionian system limits the model's ability to simulate large-scale oceanic processes and their feedback on regional dynamics. Additionally, the limited two-way coupling and absence of sea surface temperature (SST) feedback into the atmospheric model restrict the capacity of the current version of AdriSC to fully capture ocean-atmosphere interactions, which are crucial for the development and persistence of marine heatwaves and coastal weather extremes. Finally, the current version of AdriSC relies on the now outdated ERA-Interim reanalysis and CMIP5 forcing under Representative Concentration Pathways (RCP) scenarios, which limits the relevance of the results given the availability of improved datasets such as ERA5 and the CMIP6 ensemble aligned with the latest Shared Socioeconomic Pathways (SSP) scenarios.

Addressing these challenges is the central goal of the AdriSC climate model v2.0 upgrade proposed in this project.

2) AdriSC climate model v2.0 Updated Framework

Climate change impact assessments are increasingly adopting a "storyline" approach—developing physically plausible narrative pathways tied to specific global warming levels or major climatic shifts—to better capture structural uncertainties not represented in probabilistic ensembles (Zappa et al., 2017; IPCC, 2022; Begum et al., 2022). This method is especially relevant for low-likelihood, high-impact events such as abrupt Atlantic Meridional Overturning Circulation (AMOC) collapse (Pörtner et al., 2022). Current applications include Arctic climate risk assessments, where storylines linked to distinct warming scenarios help reveal non-linear regional responses (e.g., sea-ice loss, permafrost thawing; Levine et al., 2024). Building on these concepts, we propose that the AdriSC climate model v2.0 expand its framework across three dimensions: (1) updated grids enhancing fidelity in representing the air-sea interactions and the Ionian-Adriatic system; (2) updated physics by coupling WRF and ROMS with the Simulating WAves Nearshore model (SWAN; Booij et al., 1999) and the Community Land Model (CLM; Oleson et al., 2010) and (3) incorporation of CMIP6 ensemble forcing, enabling scenario projections under multiple warming levels and distinct storyline branches (e.g., 2 °C warming with and without AMOC collapse). This update will allow exploration of climate futures with shared socioeconomic pathways (SSPs) selected to achieve target temperature increases (e.g., 1.5 °C, 2.0 °C, 2.5 °C), consistent with storyline philosophy (e.g., Zappa et al., 2017). The PGW method used in the current version of the AdriSC climate model is retained in version v2.0 to ensure consistency with prior findings. Indeed, the PGW method has not only demonstrated robust skill in simulating regional response to climate forcing but is also aligning well with storyline-driven analysis as it separates thermodynamic from dynamic changes, preserving realistic circulation patterns while superposing CMIP6-based warming perturbations.

The advantages of this Storyline-Centric PGW approach are threefold. First, it captures the structural uncertainties. Unlike ensemble-mean projections that may mask critical risks, storyline scenarios expose plausible extremes—e.g., AMOC shutdown scenarios are low probability but high consequences. Second, it is physically grounded. Forced-dynamics (e.g., temperature rise, circulation changes) associated with different SSP/storyline combinations are embedded in the CMIP6 fields used by PGW. Third it compares multiple futures coherently. By anchoring simulations to definite warming levels and systemic perturbations, the AdriSC climate model v2.0 framework yields directly comparable scenario pairs (e.g., with/without AMOC change) to evaluate regional sensitivity under targeted climate thresholds.

2.1 AdriSC climate model v2.0 Setup

The updated configuration of the AdriSC climate model v2.0, illustrated in Figure 2, introduces several key improvements aimed at enhancing the physical realism, spatial coverage, and coupling capabilities of the modeling system.
First and foremost, the atmospheric and oceanic components will now operate over co-located nested domains, thereby ensuring consistent spatial overlap and enabling full two-way coupling between ocean surface fields and atmospheric processes. Specifically, the atmospheric model will employ a nested grid system with horizontal resolutions ranging from 15 km to 3 km, while the ocean model will operate over a similarly nested domain with resolutions from 5 km to 1 km. This refinement not only facilitates improved air-sea interactions but also provides a more accurate representation of the Adriatic-Ionian basin, including its complex topography and bathymetry.

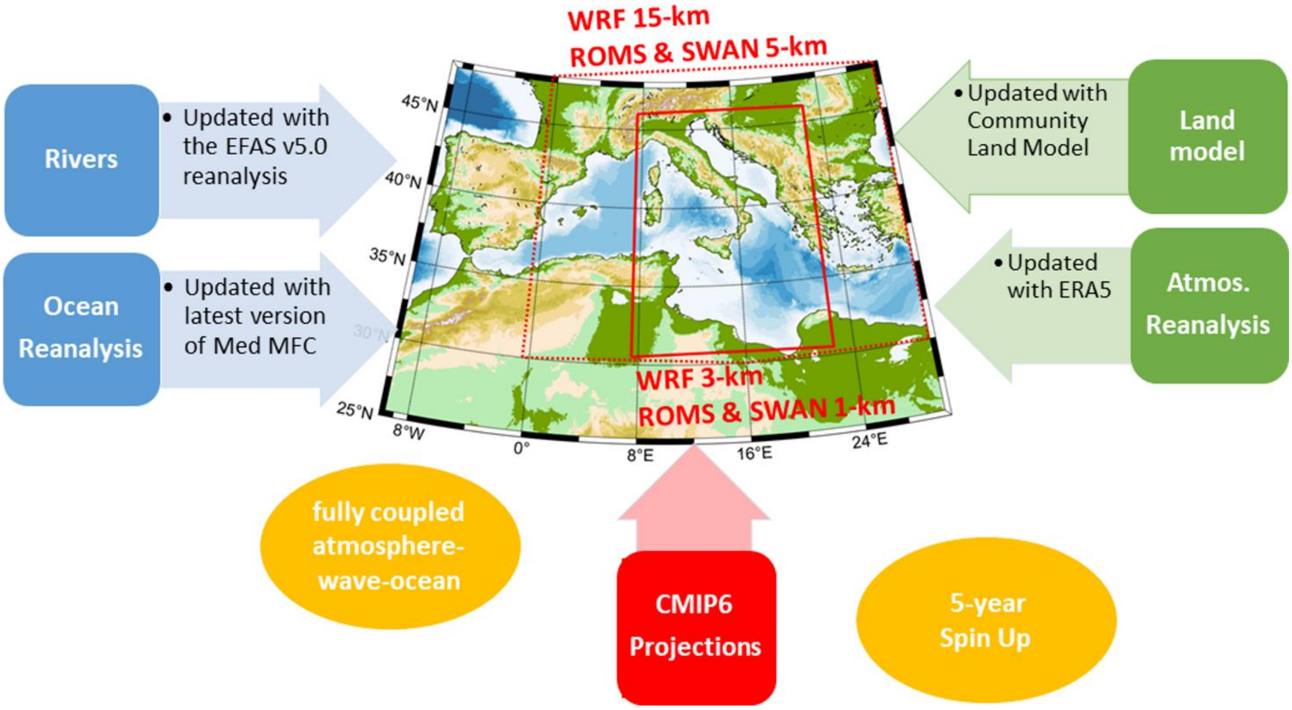

Figure 2. Updated Setup of AdriSC climate model v2.0. Spatial coverage and horizontal resolution of the different grids including the topo-bathymetry of the AdriSC 1-km model with the locations of 5 Adriatic subdomains (coloured polygons). Pseudo-Global Warming temperature ocean forcing imposed in the AdriSC 3-km model southern boundary for the far-future extreme warming simulation.

Second, new physical processes will be incorporated into the AdriSC modelling framework to address previous oversimplifications. These include the addition of a wave model component (SWAN) to account for wind-wave generation and coastal wave dynamics, as well as a land surface model (CLM) to improve the representation of hydrological and surface-atmosphere exchange processes.
Third, the model's external forcing will be significantly upgraded: Med-MFC reanalysis will be used for oceanic boundary conditions, EFAS v5.0 for river discharge, and ERA5 for atmospheric fields, replacing the now outdated products (e.g., ERA-Interim).

Additionally, the initialisation of the coupled model system will benefit from a substantially extended spin-up period, increased from the previous 2 months to 5 years, to allow the system to approach a dynamically balanced and thermally equilibrated state before the climate runs are compared.
Finally, the future climate projections will rely on the most recent CMIP6 ensemble of Global Climate Models (GCMs). These will be used to identify specific Global Warming Levels (GWLs) and storylines (e.g., with and without an AMOC collapse), which will then serve as the basis for generating the Pseudo-Global Warming (PGW) perturbations applied to the boundary and initial conditions of the high-resolution AdriSC simulations.

2.2 CMIP6-derived forcing

Selecting the most suitable CMIP6 Global Climate Models (GCMs) is a critical step in constructing reliable boundary conditions for high-resolution regional climate projections, such as those performed with the AdriSC climate modeling suite. To this end, the **GCMeval** tool (Parding et al., 2020) has been identified as a robust and adaptable solution for evaluating the performance of CMIP6 GCMs against observational benchmarks. Developed as a general-purpose model evaluation framework, GCMeval enables objective comparisons between models and reanalysis products across user-defined variables and domains (e.g., Igel and van Kampenhout, 2021). This tool is used to perform a multi-criteria assessment of available CMIP6 models—particularly focusing on metrics relevant to the Adriatic-Ionian region—to ensure that only the best-performing models are selected to inform the pseudo-global warming (PGW) boundary conditions.
The results of the GCMeval evaluation for the SSP5 8.5 scenario near- and far-future (2021-2050 and 2071-2100, respectively) are presented in Table 1 and Figure 3 at both the global scale and the regional scale over the Mediterranean region. These allow to already select the best 10 GCMs of the CMIP6 ensemble (Table 1) and to visualize the impact of climate change at the global and regional (i.e., Mediterranean) level.

Table 1. CMIP6 Global Climate Models (GCMs) selected with the GCMeval tool.

Model Name	Rank
CMIP6.NorESM2_MM.r1i1p1f1	1
CMIP6.GFDL_ESM4.r1i1p1f1	2
CMIP6.CESM2_WACCM.r1i1p1f1	3
CMIP6.MPI_ESM1_2_HR.r1i1p1f1	4
CMIP6.CESM2.r2i1p1f1	5
CMIP6.CESM2.r1i1p1f1	6
CMIP6.HadGEM3_GC31_MM.r3i1p1f3	7
CMIP6.MRI_ESM2_0.r1i1p1f1	8
CMIP6.MPI_ESM1_2_HR.r2i1p1f1	9
CMIP6.HadGEM3_GC31_MM.r1i1p1f3	10

In parallel, defining future climate forcing through global warming level (GWL) time slices—rather than arbitrary calendar periods—has become an increasingly adopted and scientifically sound practice in climate impact studies (Seneviratne et al., 2021; Hauser et al., 2019). GWLs allow climate modeling experiments to focus on societally relevant thresholds (e.g., +1.5 °C, +2 °C, +3 °C above pre-industrial levels), offering a more policy-relevant framing of future scenarios. The time periods corresponding to these warming levels will be identified by analyzing the ensemble-mean global surface air temperature trajectories of the selected CMIP6 GCMs, following methodologies proposed in recent literature (Li et al., 2020). This will enable the design of physically consistent PGW forcing fields that reflect both intermediate and high-impact storyline conditions, such as the potential collapse of the Atlantic Meridional Overturning Circulation (AMOC) or exacerbated heatwave frequencies under extreme warming pathways. By combining GCMeval-driven model selection with GWL-based time slicing, the updated AdriSC v2.0 framework will be better positioned to support robust, regionally relevant adaptation strategies for the Adriatic and Eastern Mediterranean basins.

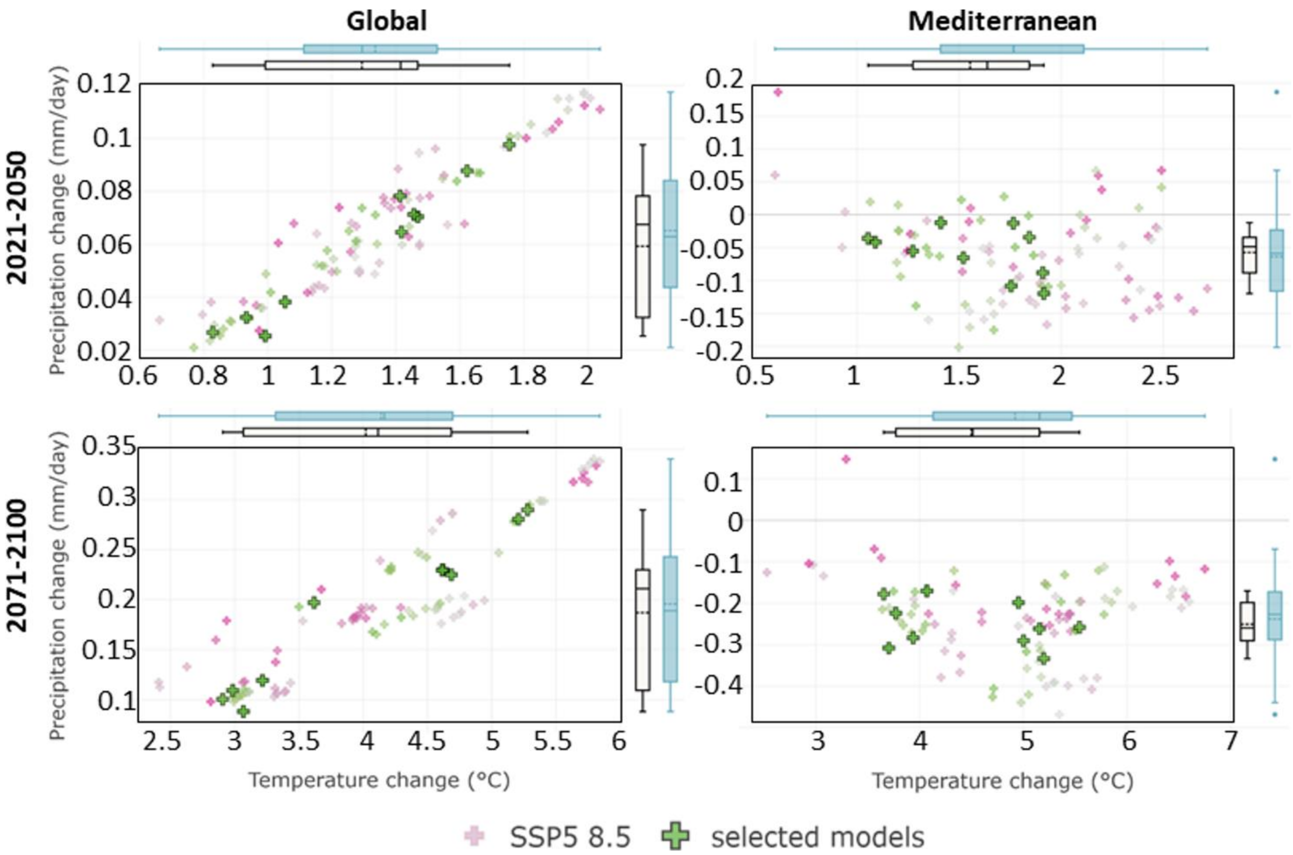

Figure 3. CMIP6 Global Climate Model (GCM) statistics extracted with the GCMeval tool.

3) Proposed Work

To support the proposed objectives of the AdriSC climate model v2.0 project, we request a total of **924 million SBUs over 3 years** (i.e., 308 million SBUs per year). This allocation is based on previous experience running the *AdriSC v1.0* model on the ECMWF HPCF and projections for the updated setup.

3.1 Benchmark from the current setup of the AdriSC climate model

The AdriSC climate model was successfully run over **31-year periods** using a pseudo-global warming (PGW) approach. The model suite, which includes one-way coupled atmosphere-ocean simulation, required approximately:

- **1.5 years of wall time**
- **256 CPUs**

to complete one full 31-year climate simulation (with 2-month spin-up), corresponding to roughly the following core-hours:

256 Cores×1.5 years×365.25 days×86400 seconds×P≈**60 million SBUs**

So, the previous version of the AdriSC climate model used approximately **60 million SBUs per 31-year simulation**.

3.2 Updated AdriSC climate model v2.0 Setup Considerations

The updated AdriSC climate model v2.0 will include:

- bigger domain of computation for both the atmosphere and the ocean,
- full atmosphere-ocean coupling including sea-surface temperature and wave feedbacks to the atmospheric model,

- additional wave and land surface modules,
- a 5-year spin-up period per scenario.

Based on the total allocation request (308 million SBUs per year), and assuming similar computational demand from AdriSC climate model v2.0 thanks to improved efficiency on ATOS, this extended complexity might double or even triple the resource needs per simulation compared to current version of the AdriSC modelling suite. However, thanks to more efficient hardware (ATOS HPC), we conservatively assume **similar computational costs per year of simulation.** However, this is likely an underestimation, since actual job inefficiencies and additional I/O and pre/post-processing are not included here. Experience shows that model runs with extensive coupling (as in AdriSC climate model v2.0) consume significantly more in practice.

3.3 Projected Simulation Plan and SBU Use

Based on the new setup of the AdriSC model, the length of the simulations is **5-years for the spin-up plus 31-year of climate projection or in total 36 years.** We estimate the cost of a **36-year AdriSC climate model v2.0 simulation** at approximately **100 million SBUs**, based on conservative scaling of the current version of the AdriSC modelling suite.

Given a total of **924 million SBUs**, this would allow about **9 full 36-year runs**. This number of realizations aligns well with ensemble approaches based on **CMIP6 model selection and storyline generation**, particularly if the PGW method is applied to a handful of representative warming levels.

3.4 Justification

This level of resource allocation is essential for:

- capturing the GWL across selected CMIP6 GCMs and scenarios,
- ensuring robust spin-up and system equilibrium for each simulation,
- incorporating full coupling and updated physics in AdriSC climate model v2.0,
- supporting ensemble-based storyline projections at high resolution.

As such, the requested 308 million SBUs per year is both justified and necessary to deliver the scientific goals of the project based on the updated AdriSC climate model v2.0.

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