SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	06/2025
Project Title:	Climate impacts of space-based geoengineering: EC-Earth simulations for optimal non-uniform radiative forcing by a Planetary Sunshade System
Computer Project Account:	spitmato
Principal Investigator(s):	Catello Leonardo Matonti
Affiliation:	Politecnico di Torino
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Jost von Hardenberg, Shuting Yang
Start date of the project:	01 Jan, 2025
Expected end date:	31 December, 2025

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	\\	\\	19,000,000	3,126,439
Data storage capacity	(Gbytes)	\\	\\	40,000	4

Summary of project objectives (10 lines max)

The GeoMIP experiments G1, G1ext, G2 and G6Solar considered an instantaneous or gradual variation of the solar constant, and so not addressing the possibility of non-uniform radiative forcing through differential shading.
In this project, we aim for the first time, through a global climate model, at addressing three core questions regarding the use of a Planetary Sunshade System as a space-based geoengineering strategy for solar radiation management: (a) What is the climate impact on Earth of different insolation patterns? (c) Which are the effects during the transition phase before final deployment of the planetary sunshade? (d) And finally, can we prove the reversibility of this mitigation strategy?

Summary of problems encountered (10 lines max)

Initial challenges involved correctly integrating the solar geoengineering attenuation factor into EC-Earth3. This was not a direct substitution of the solar constant but required implementing an attenuation array, as the effect varies across the horizontal grid. Additionally, the IFS code includes several radiative routines (some with different variable names for the same flux calculation and there were also multiple versions of the same routines), necessitating a thorough search to identify and modify all relevant instances. Further complications arose from unit mismatches and parameters not propagating consistently across subroutines. Early simulations showed no difference between baseline and modified cases, prompting an extended debugging phase. Once resolved, the expected solar flux reduction became evident. Additional difficulties were related to compiling the model on ATOS, handling restart files correctly, and setting up preliminar CMOR-compliant post-processing.

Summary of plans for the continuation of the project (10 lines max)

We plan to extend the simulations with a 100-year run under fixed 1990 radiative forcing and a non-uniform solar attenuation pattern, representing the effect of a large space-based sunshade located at the Sun–Earth L1 point. This will help assess the long-term equilibrium climate response. Subsequently, we will implement a time-dependent scenario (2040–2180) including gradual deployment, full operation, and dismantling of the sunshade to evaluate the reversibility of its climatic effects. We start by implementing an historical simulation case with a fixed radiative forcing, and next simulations will explore the use of SSP245 radiative forcing. After completing the simulation with the "all world coverage", additional simulations will explore alternative configurations such as polar-only shading. We also aim to refine the methodology for computing the spatial attenuation pattern and to test a perforated sunshade design simulating a solar sail swarm. Post-processing of preliminary results will focus on identifying temperature and precipitation anomalies. The modified IFS code and technical documentation will be finalized and made available for future use and reproducibility.

List of publications/reports from the project with complete references

None so far.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during**

the third project year, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

During the first six months of the project, significant progress has been made toward integrating the planetary sunshade concept into EC-Earth3. We start with an initial bibliographic review and analytical modeling of the sunshade's radiative effect, considering the difference in the daily average insolation Q between the sunshade and the natural one and how to calculate the attenuation factor to insert in the code. Then, we focused on modifying the IFS radiation scheme to include this solar attenuation factor representing the presence of a disk-like sunshade positioned near the Sun–Earth L1 point. Analytical simplifications to avoid the use of elliptic integrals were validated through simulations, showing negligible error for the uniform case.

We identified and updated the relevant subroutines (e.g., \`radlsw\`, \`radina\`,..) to apply a non-uniform reduction in the incoming solar flux across the model's horizontal grid and launch first test historical simulations from 1990 to 2010, revealing, after the first attempts and setting up, the expected global reduction in solar flux, consistent with the attenuation factor.

We set up and executed simulations on the ATOS HPC system, handling compiling and CMOR preliminary post-processing. First comparisons between baseline and sunshade runs indicate a measurable difference in the daily-averaged top-of-atmosphere solar flux across latitudes, confirming correct implementation. The infrastructure is now in place for long-term and scenario-based simulations.

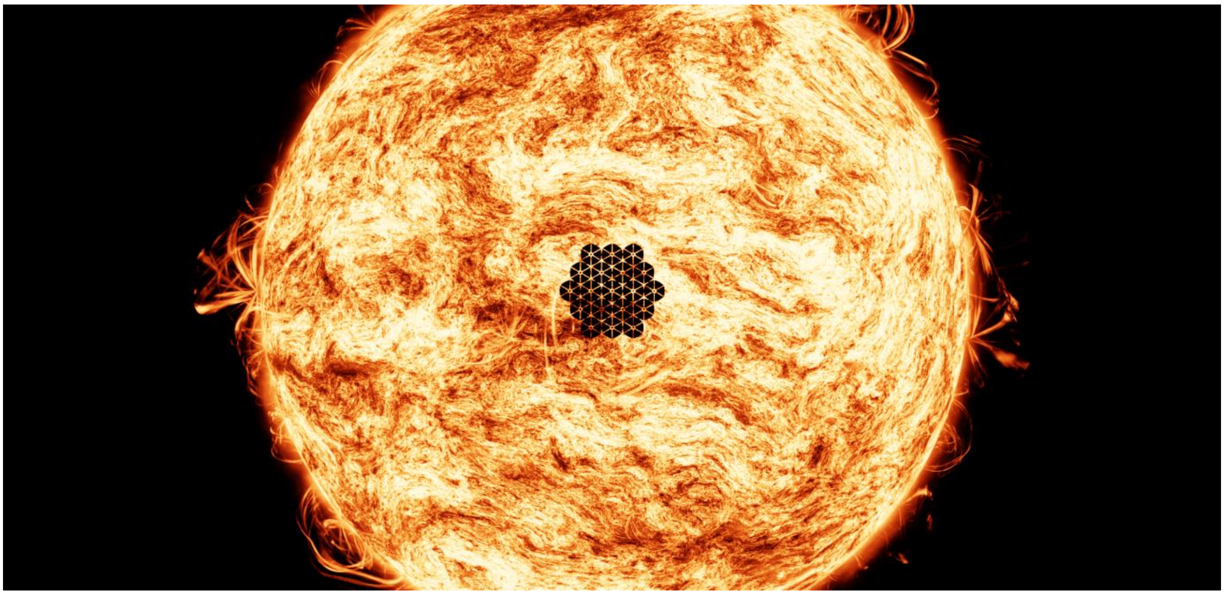

Fig.1 The planetary Sunshade Concept as a solar disk fixed in the Sun-Earth line, as it would be seen for a observer on Earth.

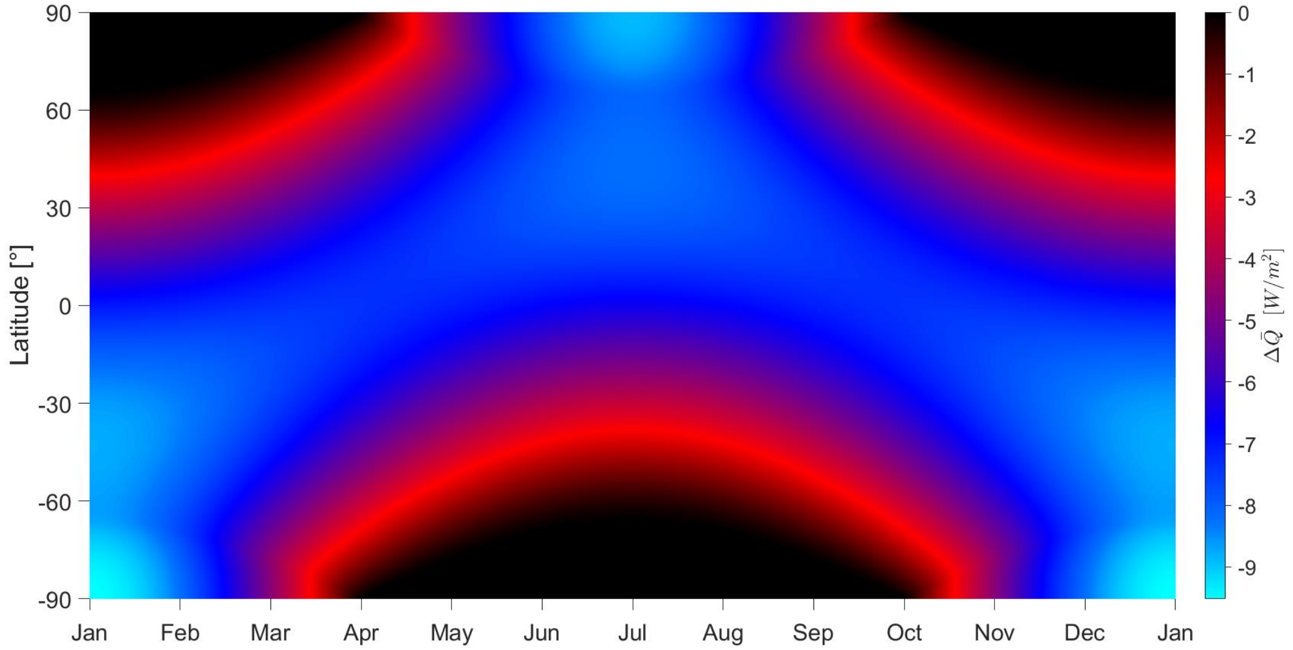

Fig.2 Delta daily average insolation $\bar{Q}$ between the sunshade and the natural one

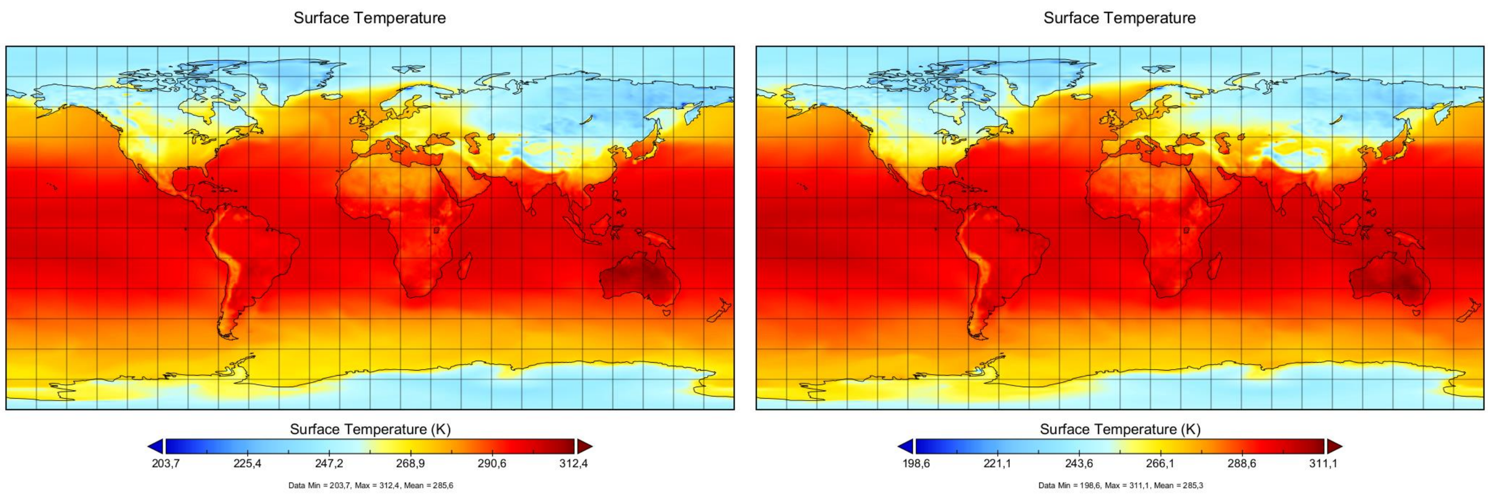

Fig.3 First test on sunshade historical analysis 1990-2010, EC-Earth3 simulations with standard resolution, surface temperature comparison between historical case and with a sunshade positioned at L_1 , in December 2010, with respect to latitude and longitude.

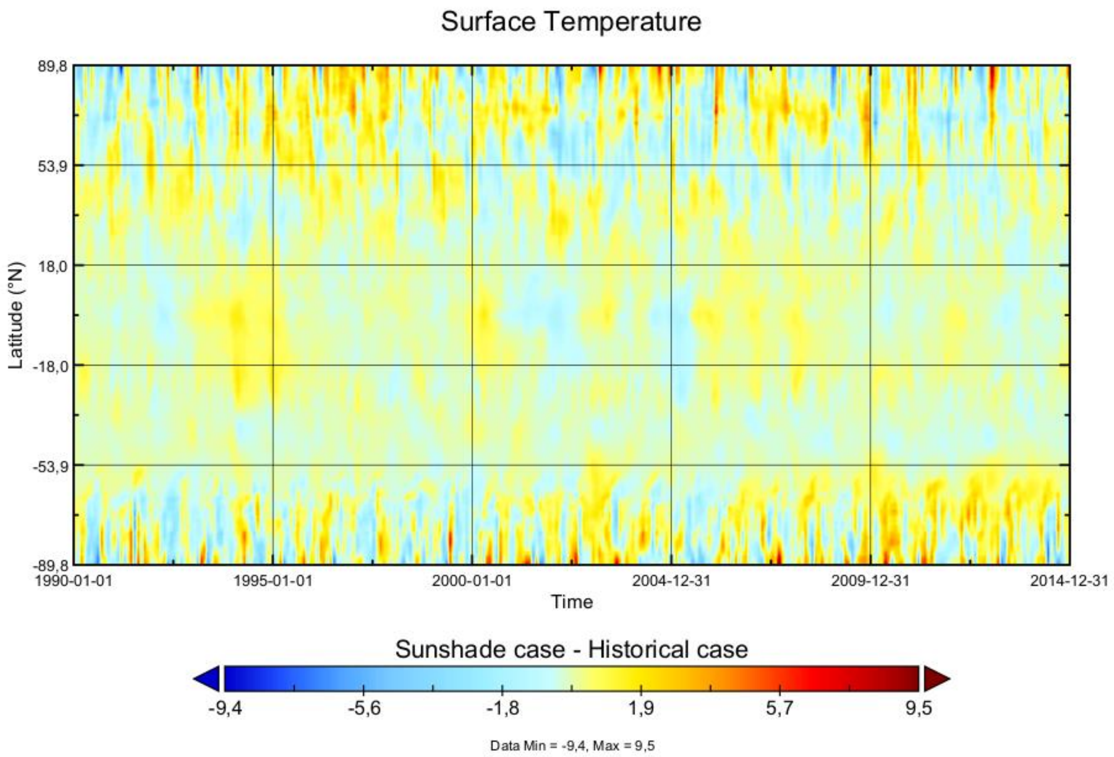

Fig.4 First test on sunshade historical analysis 1990-2010, EC-Earth3 simulations with standard resolution, surface temperature anomalies: difference between the one of the historical case and the one with a sunshade positioned at L_1 , with respect to latitude and time, averaged in longitude.