



ClimateHub: Seasonal to Decadal Predictions for National Renewable Energy Management [†]

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Abstract

ClimateHub, the National Collaboration Programme (NCP) in Greece aims at delivering innovative services to national authorities regulating the energy sector by developing climate-based tools and services building on the C3S experience. As a service provider, ClimateHub fills the knowledge and service gap on climate information at time scales exceeding the typical weather forecast. Through a co-design approach, ClimateHub has identified three applications where public authorities have virtually no access to climate-related impacts on the renewable energy sources (RES) sector at seasonal and decadal time scales, (a) energy demand, (b) solar power and (c) wind power. This study addresses the performance of ECWMF SEAS5 seasonal and the CMCC-CM2-SR5 decadal prediction systems over Greece, for near-surface temperature.

Keywords: climate services; seasonal forecast; decadal prediction; renewable energy; C3S; NCP



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1. Introduction

The European Green Deal provides directives to Member Countries for the clean energy transition, which will help reduce the net greenhouse gas emissions to meet the ‘Fit for 55’ package by 2030, towards a climate-neutral EU by 2050. The Greek National Energy and Climate Plan (NECP), drafted by the Ministry of Environment and Energy (MEEN), raises the country’s targets for renewable energy sources (RES) to 28 GW by 2030, aiming to achieve 80% penetration of renewables in the country’s energy mix by 2030. NECP projects that photovoltaic (PV) power will become the main source of RES, and the share of wind power and installed capacity projected to double in 2030 compared to 2023.

The ClimateHub project (<https://climatehub.gr>, accessed on 8 September 2025), the National Collaboration Programme (NCP) in Greece, fills the knowledge and service gap in climate information at time scales exceeding the typical weather forecast (e.g., 15 days). Two time horizons have been chosen in which previous demonstrators in the Copernicus Climate Change Service (C3S) energy sector have shown considerable potential [1,2], specifically (a) seasonal and (b) decadal. To identify the energy application, the MEEN has also been consulted in the project's preparatory phase. ClimateHub provides actionable climate and energy products to the national authorities, from (a) seasonal and decadal predictions on climate-related electricity demand to (b) seasonal forecasts of solar PV and onshore/offshore wind energy production and decadal outlooks on PV and offshore wind energy production, specifically in the summer, through its dedicated web portal (<https://portal.climatehub.gr>, accessed on 8 September 2025). ClimateHub is supported by MEEN, which is the legislative national authority for the energy sector. Moreover, it is also actively endorsed by the Ministry of Digital Governance, through the involvement of the Hellenic Space Center (HSC), which is the authority for space matters in Greece responsible for the national Copernicus delegation. The HSC participation in ClimateHub aims to boost the communication activity towards the public stakeholders, targeting the ministries of Agriculture, Tourism and Climate Change and including the Regions of Greece.

This study addresses the performance of ECMWF system 51 seasonal forecasts (SEAS5) and CMCC-CM2-SR5 decadal predictions over Greece, which are the main components of the prediction system.

2. Materials and Methods

For the assessment of seasonal forecasts over Greece, the fifth-generation ECMWF seasonal forecasting system (SEAS5) [3] was utilized. It consists of a set of re-forecasts (hindcasts) available in the CDS (<https://cds.climate.copernicus.eu>, accessed on 8 September 2025), starting on the first day of each month for the years 1993–2016, with 25 ensemble members on a global $1^\circ \times 1^\circ$ grid. In this study, the T + 1 forecast is used, corresponding to the second month of prediction. The ERA5 reanalysis (global $0.25^\circ \times 0.25^\circ$ grid) was used as a reference observational dataset [4]. The examined variable was 2m air temperature (T2m), analyzed at 00, 06, 12, and 18 UTC daily. For consistency, the ERA5 data was upscaled to match the resolution of SEAS5. Additionally, a bias correction technique was applied to the latter, following the methodology of Karali et al. [5].

For the assessment of decadal predictions over Greece, the CMCC-CM2-SR5 hindcasts (10 ensemble members) [6] were utilized. In the evaluation process, we considered only those hindcasts that initialized between 1980 and 2014. The performance of the CMCC-CM2-SR5 predictions was also addressed for the monthly near-surface air temperature (T2m) and only for the summer period. This way, we mitigate some of the difficulties in PV power generation related to uncertainties in cloud coverage, when the precipitation and cloud amount over Greece is at their minimum. For the purposes of this study, we investigated the skill of the T + 5-year forecasts, meaning that from each initialization cycle, we took the fifth year's summer months. Thus, the evaluation of the summer period spanned from 1985 to 2019. The reference observational dataset for the decadal predictions was also the ERA5 reanalysis, while no bias-adjustment was applied to the decadal predictions.

The verification metrics that were calculated included (a) the probabilistic relative operating characteristic (ROC) skill score (ROCSS) [7], (b) the Spearman rank correlation and (c) the Ranked Probability Score (RPS) [8]. The metrics were calculated for each grid point and tercile category to evaluate the forecast skill across T2m seasonal forecasts on a monthly basis (however only summer is illustrated in this manuscript), while for decadal predictions, the corresponding metrics were calculated for the months of June, July and August.

3. Results

The presentation of the results follows a tercile-based approach (e.g., [9]), which categorizes forecasted and observed values into three classes, the upper tercile (above normal), middle tercile (normal), and lower tercile (below normal), based on the climatological distribution over each reference period.

3.1. Near-Surface Temperature Seasonal Forecasts

The calculation of ROCSS for the lower tercile shows that during winter, ROCSS values range from 0.2 to 0.6 over Greece, with the highest scores over northern Greece and western mainland regions. The Aegean Sea and coastal areas exhibit lower skill, generally between 0.0 and 0.2, suggesting limited predictability over maritime regions. As the months progress into late spring and summer, ROCSS gradually increases across most of Greece, with values exceeding 0.6 over inland areas, with localized regions exceeding 0.8, further confirming enhanced predictability of below-normal temperatures during warm months (Figure 1, upper row). Regarding the middle tercile, skill remains lower compared to that in the extreme categories. During winter, values over Greece mostly range from -0.2 to 0.2 , with the Aegean and Ionian Seas showing near-zero or slightly negative skill. Over land, western and central Greece experience a slight improvement, with ROCSS reaching 0.2. During summer (Figure 1, middle row), skill remains weaker relative to that in the lower and upper terciles, but there is a noticeable increase, particularly over land, where values around 0.6 are observed. The upper tercile follows a pattern like that seen in the lower tercile, but with higher scores. In winter, ROCSS values over Greece range from 0.2 to 0.8, with northern and western Greece exhibiting the highest predictability, while the Aegean Sea and coastal regions maintain lower skill levels in the zone of 0.0–0.2. As summer approaches, ROCSS increases significantly, exceeding 0.6 across most of Greece, with values above 0.8 in northern and central Greece, as well as the Peloponnese (Figure 1, bottom row).

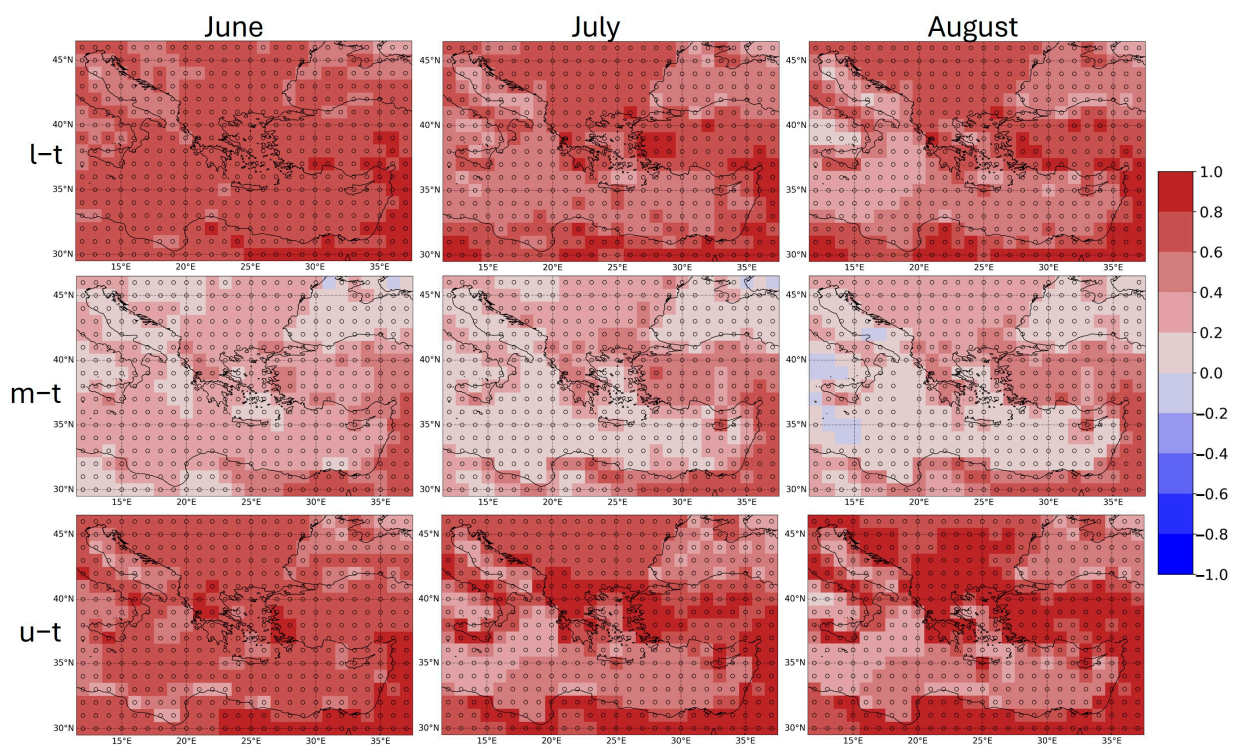


Figure 1. ROC skill scores (ROCSSs) of the lower (**top row**), middle (**middle row**) and upper (**bottom row**)-tercile SEAS5 T2m predictions against ERA5-Reanalysis for June (**left column**), July (**middle column**) and August (**right column**). The grid points with significant ROCSS values are indicated by circles ($\alpha = 0.05$).

3.2. Decadal Near-Surface Temperature Predictions

Figure 2 shows the calculated Spearman correlation coefficient along with its two-tailed p -value (at 95% significant threshold) of CMCC-CM2-SR5 T2m predictions against ERA5 reanalysis for June, July and August. For June (Figure 2, left), there is no correlation between predictions and ERA5 for most of the Greek region. Only a small portion in the southeast Aegean presents moderate correlation for this month. In July (Figure 2, center), the performance of the system increases, since most of the Greek territory presents moderate to strong correlation values, especially over the Aegean and Ionian Sea. In August (Figure 2, right), there is strong correlation between CMCC-CM2-SR5 T2m predictions and ERA5 over the Aegean Sea, while the inland parts of Greece along with the western regions are uncorrelated. The latter points out the strong dependence of the prediction system on Etesian winds, which dominate the Aegean Sea during this month.

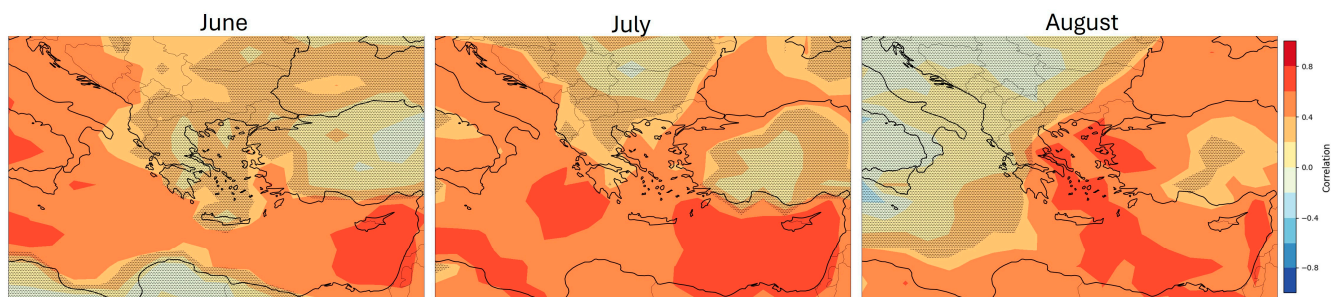


Figure 2. Spearman rank correlation coefficient of CMCC-CM2-SR5 T2m predictions against ERA5 for June (left), July (center) and August (right). Stippling where significance below 95%.

Figure 3 presents the calculated RPS for CMCC-CM2-SR5 T2m predictions (lead year +5) for June, July and August. In June (Figure 3), the RPS values are greater than 0.7 over the wider area of Greece. Due to the nature of RPS, it is difficult to distinguish if the poor performance during this month comes from resolution or reliability deficiencies. For July (Figure 2), RPS values less than 0.5 (but greater than 0.45) are shown over the Ionian Sea and the southeastern part of the Aegean Sea. In August (Figure 3), only the northeast part of the Aegean Sea presents RPS values in the range of 0.38 to 0.5, with its spatial pattern matching the presence of Etesian winds during this month.

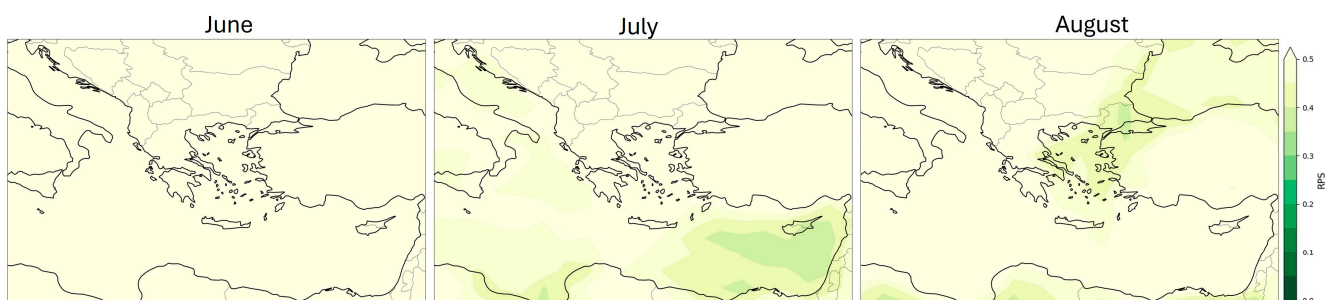


Figure 3. Ranked Probability Score (RPS) of CMCC-CM2-SR5 T2m predictions against ERA5 for June (left), July (center) and August (right).

ROC skill scores (ROCSSs) of the CMCC-CM2-SR5 2 m air temperature in June, July and August are depicted in Figure 4. In June (Figure 4, left column), ROCSS values for the lower tercile (Figure 4, upper row) range from 0 to 0.4 over the Aegean Sea and Ionian Sea, whereas show smaller values (also negative ones) over the mainland regions. Regarding the middle tercile (Figure 4, middle row), there is a distinctive spatial variability in ROCSS values over the wider area of Greece; however, negative values appear over the mainland

Greece. For the upper tercile (Figure 4, bottom row), ROCSS values range from 0 to 0.2 over the Aegean Sea, while negative values lying between -0.2 and 0 are shown over north and central mainland areas. In July (Figure 4, middle column), the ROCSSs in the lower tercile (Figure 4, upper row) present higher values with respect to those for June, where they lie between 0.4 and 0.8 over the Aegean and Ionian Sea. Smaller values are encountered over the mainland. For the middle tercile (Figure 4, middle row), negative ROCSS values dominate over the wider area of Greece, while ROCSSs for the upper tercile (Figure 4, bottom row) present a similar spatial pattern to that of the lower tercile, albeit with smaller values. The best performance is obtained in August (Figure 4, right column), where, both in the lower (Figure 4, upper row) and upper (Figure 4, bottom row) terciles, ROCSS values are above 0.4 over the Aegean Sea, highlighting that the system can predict temperature extremes to a certain degree.

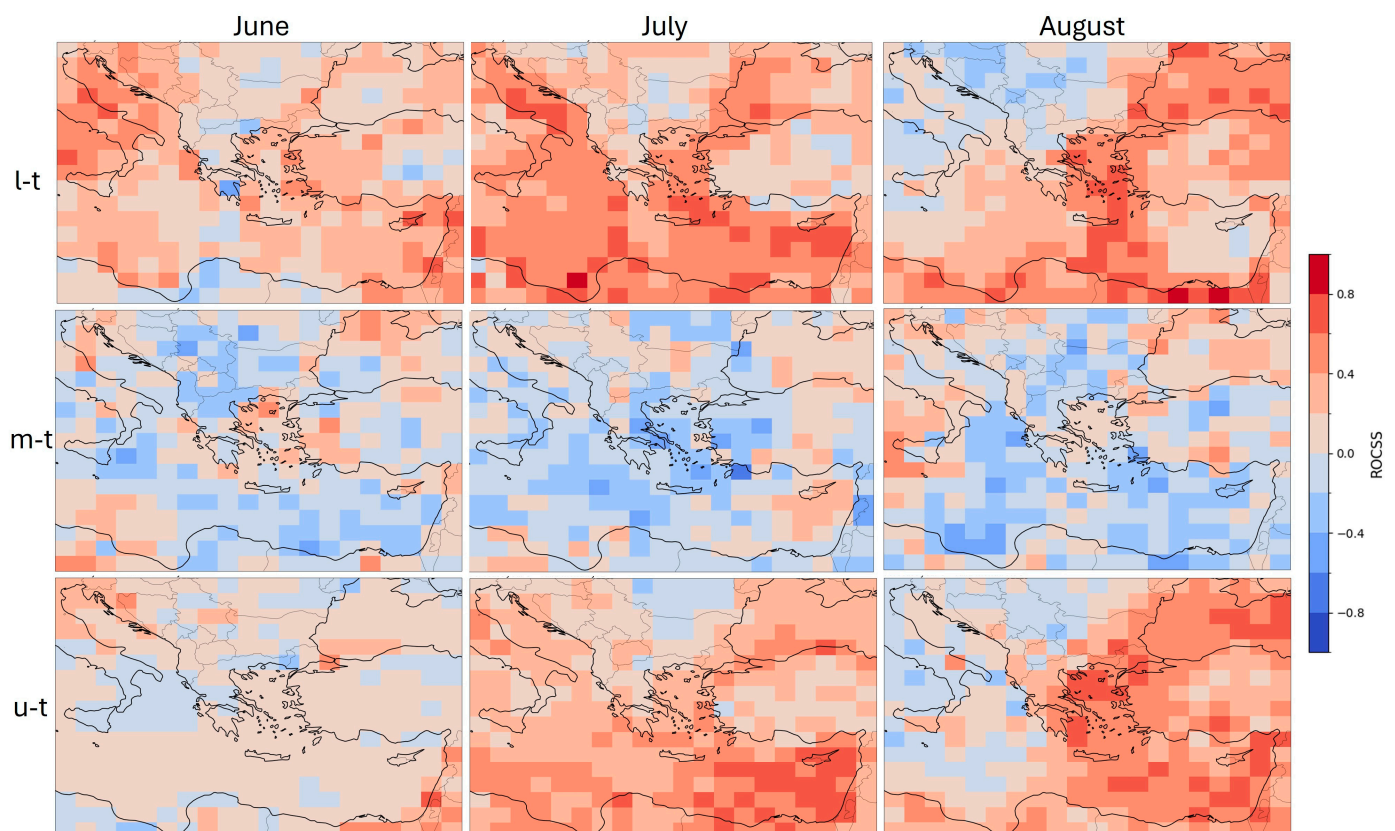


Figure 4. ROC skill scores (ROCSSs) of CMCC-CM2-SR5 T2m predictions against ERA5 of the lower (**upper row**), middle (**middle row**) and upper (**bottom row**) terciles for June (**left column**), July (**middle column**) and August (**right column**).

4. Conclusions

This study evaluates the near-surface temperature seasonal forecasts and decadal predictions from ECMW-SEAS5 and CMCC-CM2-SR5 systems over Greece, for $T + 1$ lead month and $T + 5$ lead year, respectively. Overall, the ECMW-SEAS5 forecasts show increased skill over the Aegean and Ionian Sea, which is more evident for the upper and lower terciles. The examined decadal predictions from the CMCC-CM2-SR5 system provided an insight into the reliability and performance of the system during the summer (JJA), where according to the calculated metrics, the system is less skilled in June and presents notable skill in August.

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Conflicts of Interest: Dimitris Vallianatos was employed by the company IDCOM LP. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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