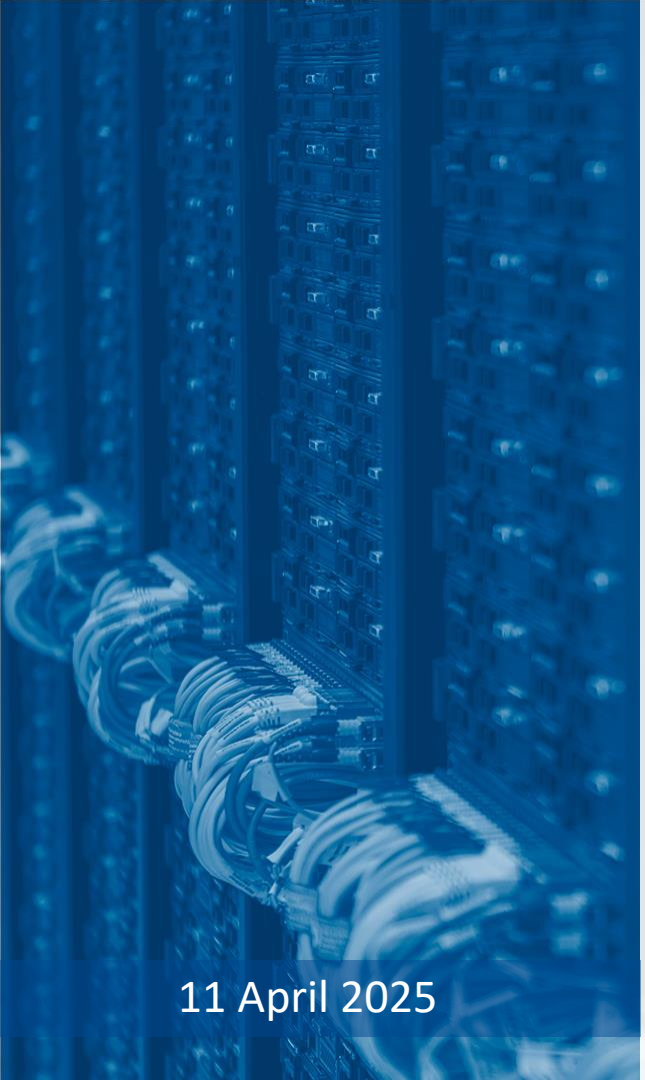


Barcelona Supercomputing Center
Centro Nacional de Supercomputación

ICREA

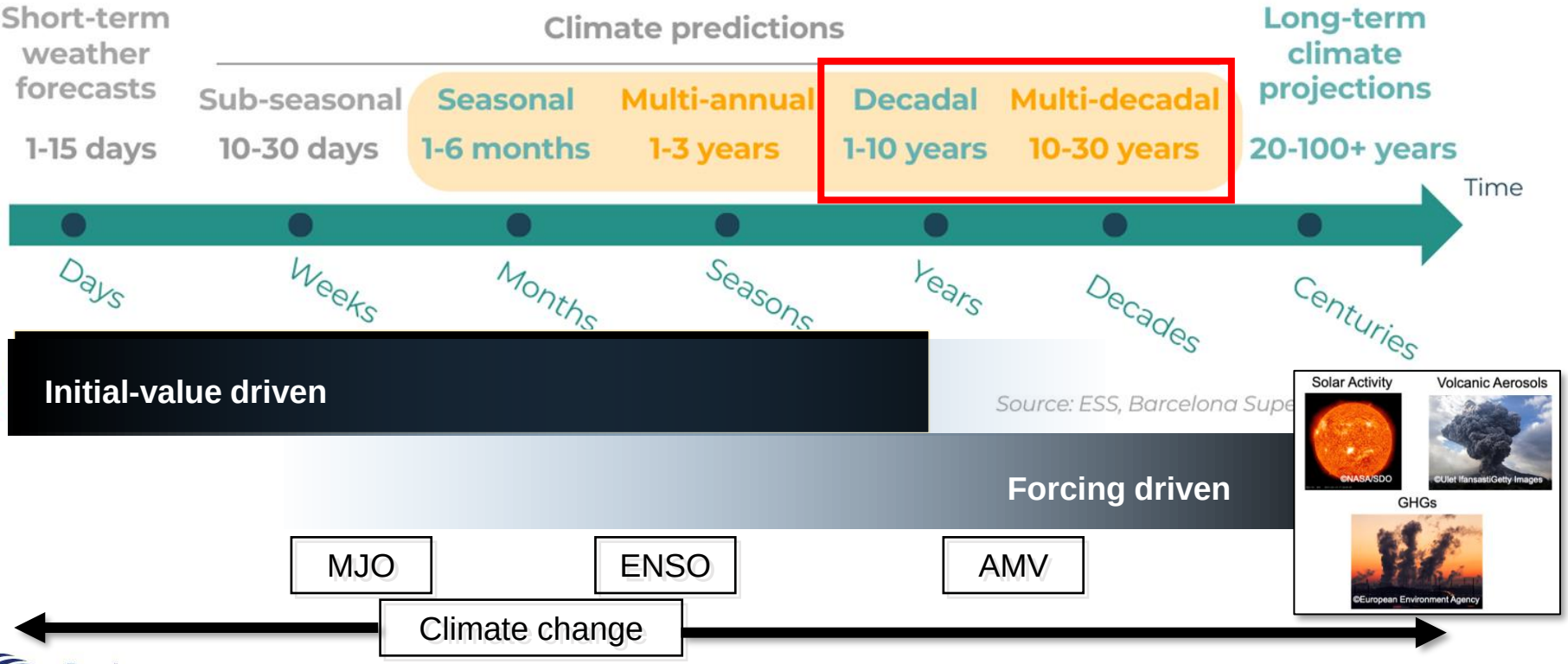
Production and Use of Decadal Climate Predictions

F.J. Doblas-Reyes with many BSC and ASPECT Horizon Europe project colleagues

11 April 2025

ASPECT
FACILITATING SEAMLESS CLIMATE ADAPTATION

Time scales of interest



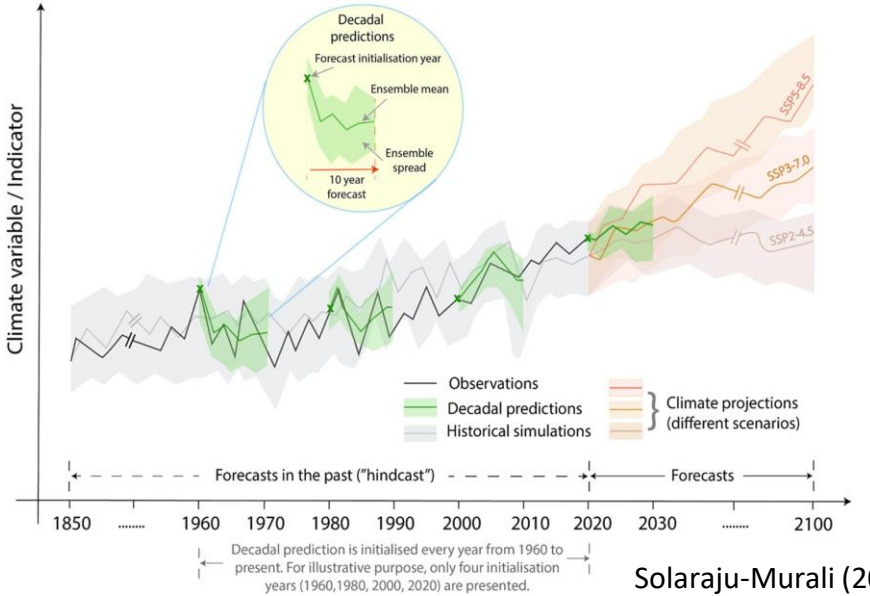
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Adapted from Meehl et al. (2009)

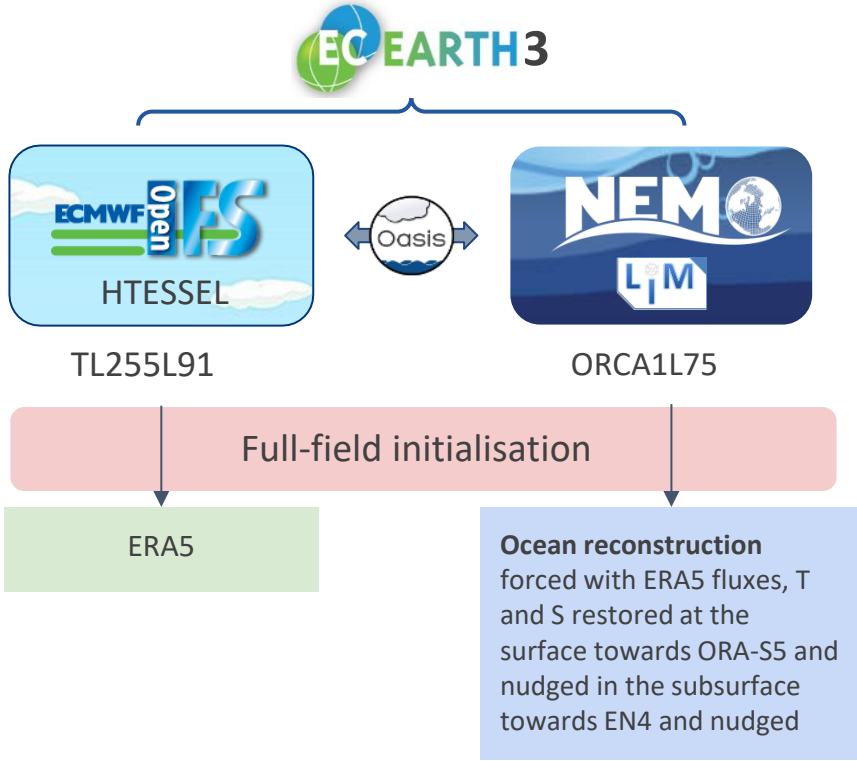
Decadal climate predictions

CMIP6 DCPP A+B (Boer et al., 2016):

- Hindcast Period: 1960-present
- Initialised: 1st November
- Ensemble: 10 members
- Forecast range: 10 years
- Forcings: CMIP6 Hist up to 2024 + SSP245



Solaraju-Murali (2022)

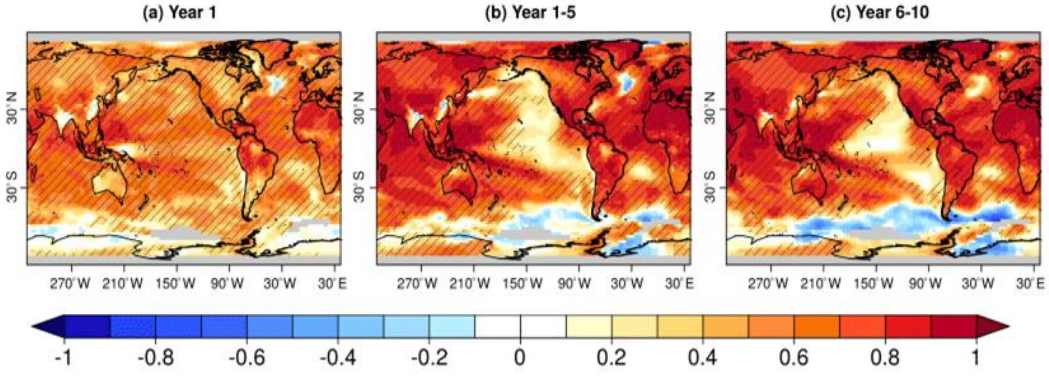


Decadal climate predictions

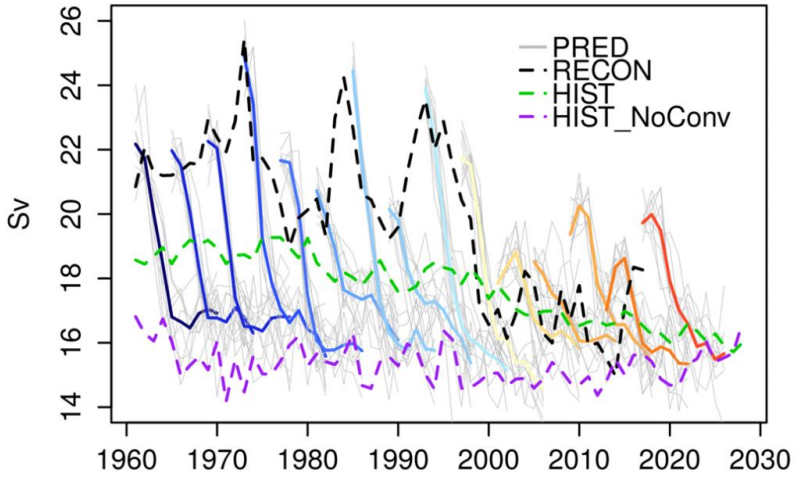
BSC decadal forecasts:

- The system skilfully simulates the regional features of past surface temperature variations.
- Initialisation improves the information quality (wrt what climate projections would provide) in the tropical Pacific and North Atlantic areas.
- The central subpolar North Atlantic suffers from initialisation shock and related drift.

Ensemble-mean correlation for the annual near-surface temperature



Evolution of the AMOC at 45°N



(Bilbao et al., 2021)

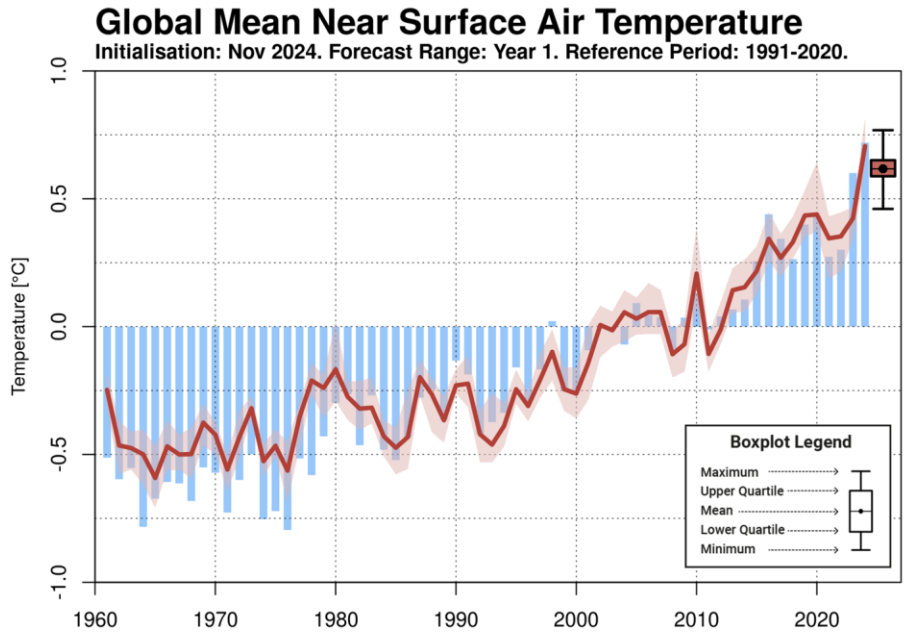
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Decadal climate predictions: real time

WMO Lead Centre for Annual-to-Decadal Climate Prediction

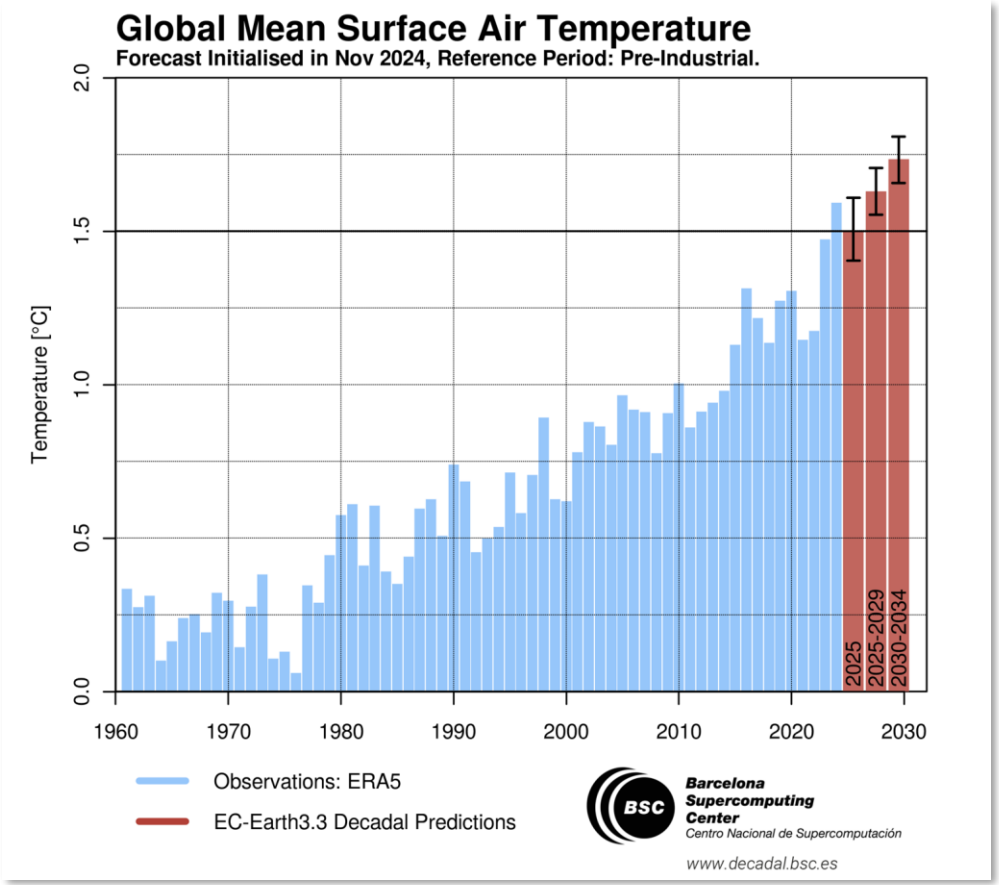
The Lead Centre for Annual-to-Decadal Climate Prediction collects and provides hindcasts, forecasts and verification data from a number of contributing centres worldwide.

https://hadleyserver.metoffice.gov.uk/wmolc/



BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Decadal climate predictions: real time

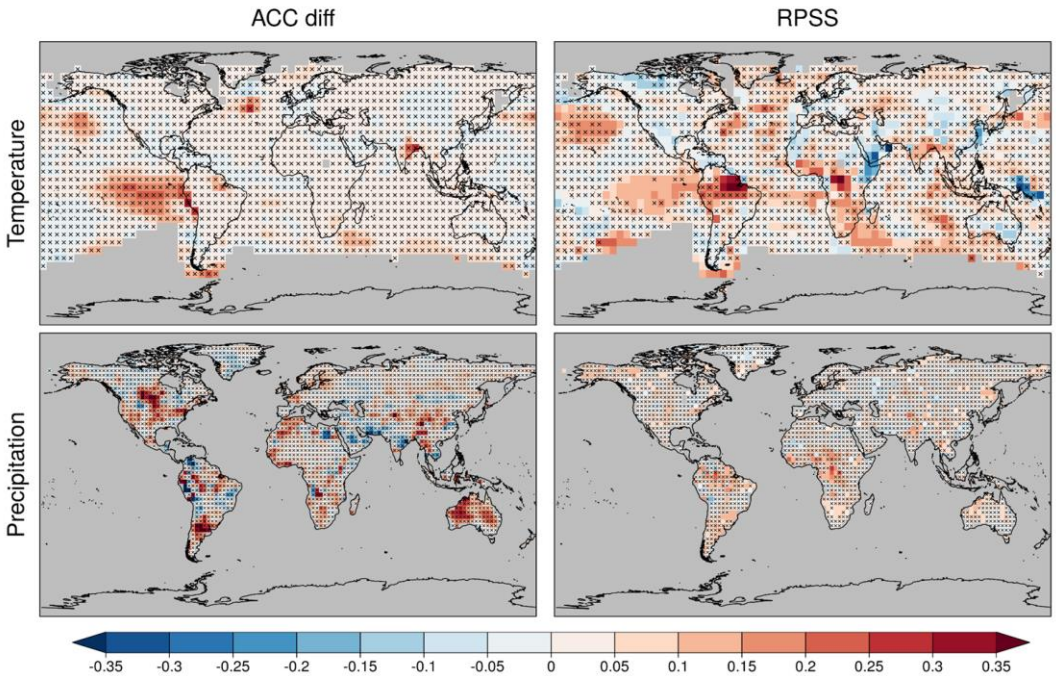


Barcelona Supercomputing Center
Centro Nacional de Supercomputación

System design in decadal prediction

Systematic assessment of the multi-model decadal prediction forecast quality helps illustrating, among other things, the importance of a large enough operational multi-model.

Comparison between a research (DCPP, **169 members, 13 forecast systems**) and an operational (C3S_34c, **40 members, 4 forecast systems**, CMCC-CM2-SR5, EC-Earth3-i1, HadGEM3-GC3.1-MM and MPI-ESM1.2-HR)



Delgado-Torres et al. (2022)

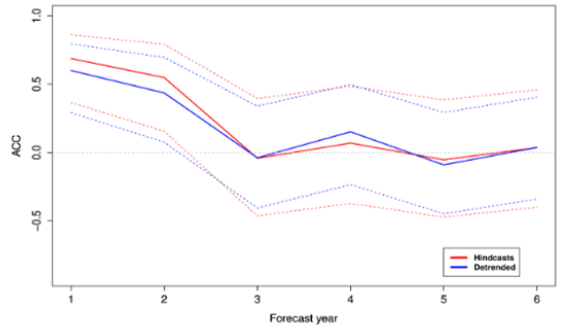
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Decadal climate predictions: carbon cycle

Predictions with EC-Earth3-CC simulate the carbon cycle interactively: includes LPJ-GUESS (vegetation), TM5 (atmospheric chemistry) and PISCES (ocean biogeochemistry).

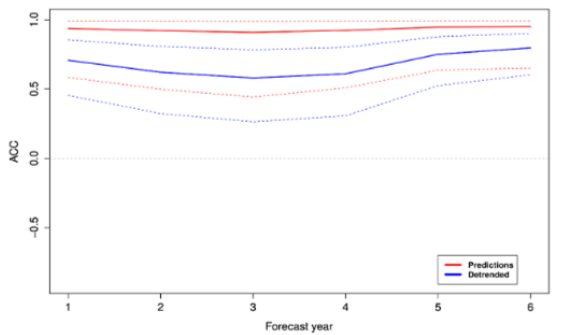
- The ocean and land carbon sinks determine the atmospheric CO2 concentration.
- Ocean CO2 flux has high predictive skill, while for the land CO2 flux it is limited to 2 years.
- Limited skill of land and ocean carbon dioxide sinks linked to biases in physical climate.
- Contribution to Global Carbon Budget 2024.

Skill of global land CO2 flux anomalies



Land C flux skill is limited to 2 years lead time

Skill of global ocean CO2 flux anomalies



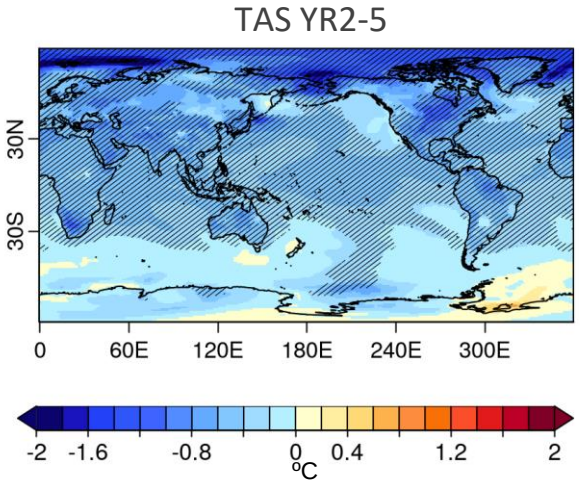
Ocean C flux skill is high and remains significant

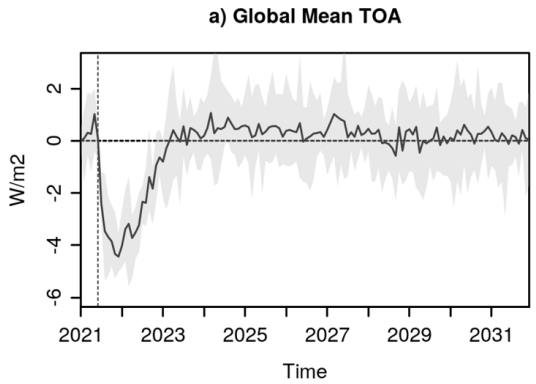
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

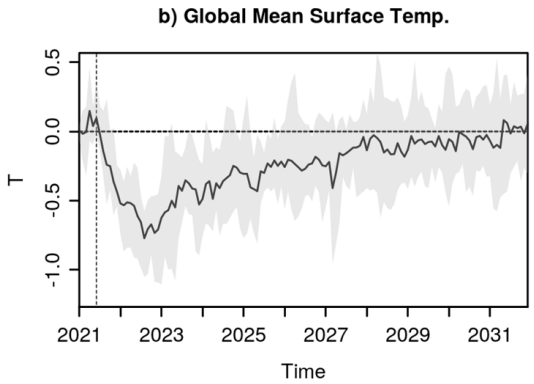
(Etienne Tourigny)

Decadal climate predictions: volcanic forcing

Explosive volcanoes are not included in the climate projections and predictions but create signatures that could last from years to decades.
Results from the Decadal Prediction Volcanic Response Readiness Exercise (VolRes-RE).
A 2xEl Chichón eruption is set in April 2022 for the EC-Earth3 decadal forecast started in late 2021 and the difference with respect to DCPP-A made.







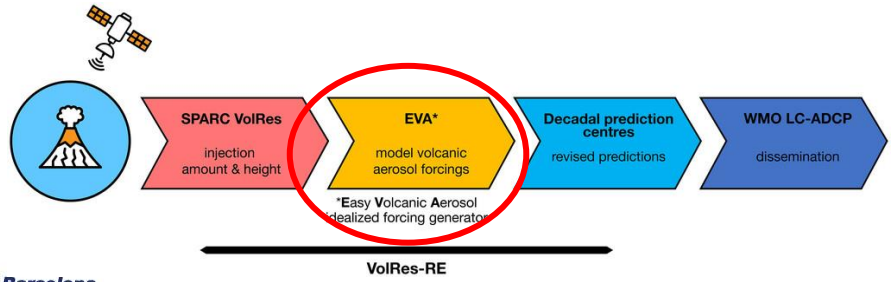
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

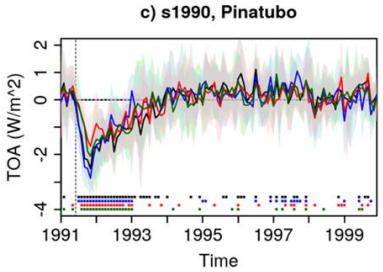
Bilbao et al. (2024)

Decadal climate predictions: volcanic forcing

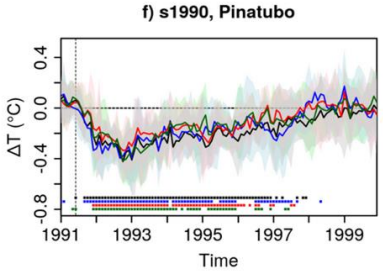
Real-time systems require a solution after an explosive volcanic eruption has taken place:

- Comparison of the volcanic forcings generated with EVA and EVA_H for Agung, El Chichón, and Pinatubo.
- EVA and EVA_H forcings can be reasonable choices for predicting the post-volcanic radiative and thermal effects.

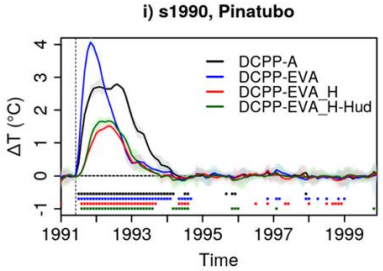




TOA



Near-surface air temperature



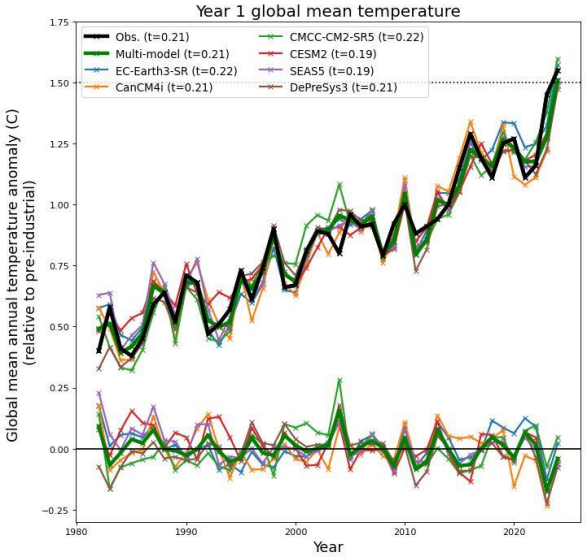
Stratospheric temperature

(Sospedra-Alfonso et al., 2024)

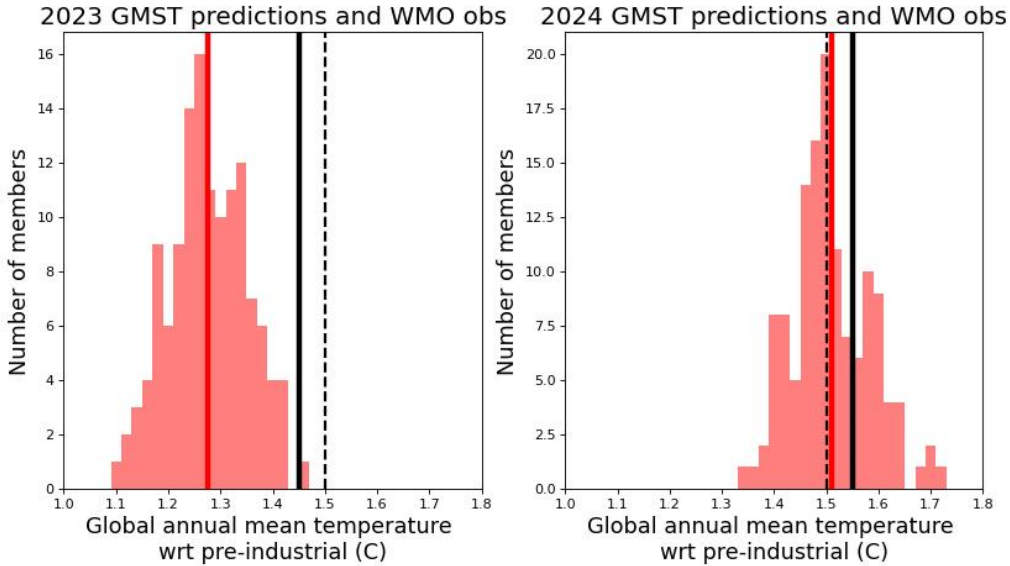
Decadal climate predictions: 2023

2023 was an exceptional year in terms of global-mean temperature. Multiannual and decadal prediction systems failed to predict the extraordinary anomaly.

Global-mean, annual-mean near-surface temperature anomalies (forecast year 1)



Global-mean, annual-mean near-surface temperature
2023 was the largest near miss in ~43 years of hindcasts, only 1 member (from 125) exceeded the observations;
2024 was well predicted with anomalies >1.5 K.



(Nick Dunstone, Met Office)

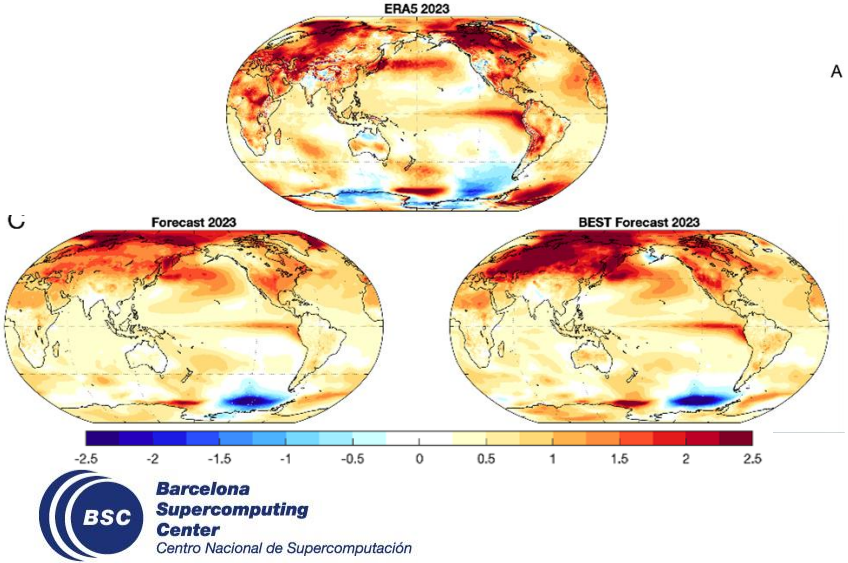
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Decadal climate predictions: 2023

Record warmth in 2023 resulted from ENSO and Northern Hemisphere shortwave anomalies:

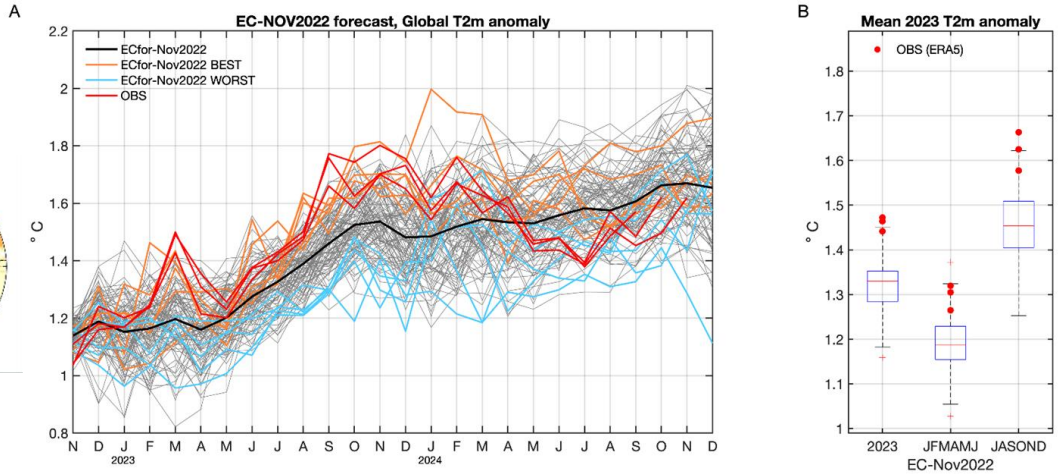
- 100-member ensemble started in Nov 2022: 70% of the 2023 warming was predictable.
- Forecast accuracy depends on forecasting a strong El Niño in 2023 and anomalously high absorbed shortwave radiation in the Northern Hemisphere during spring and summer 2023.

2023 annual-mean near-surface temperature anomalies



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Global-mean near-surface air temperature



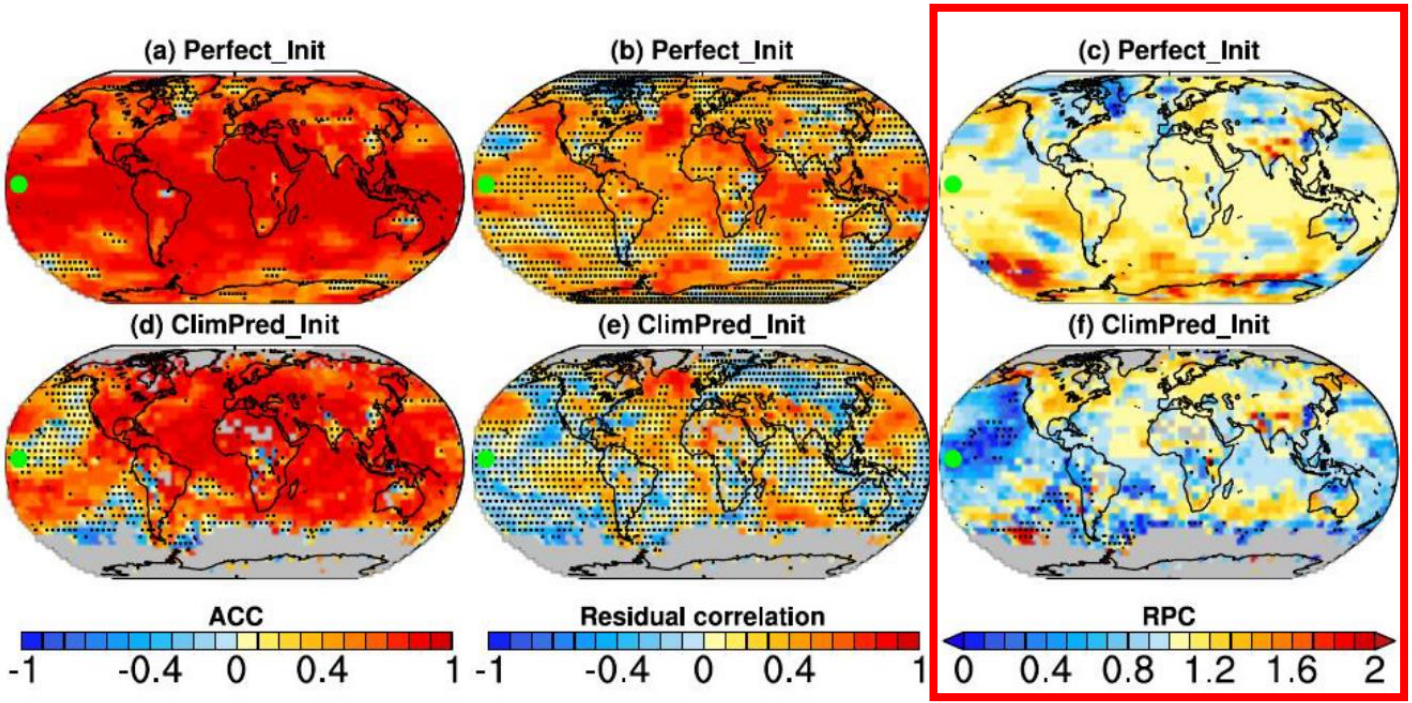
(Blanchard-Wrigglesworth et al., submitted)

Decadal climate predictions: signal-to-noise paradox

Perfect-model decadal predictions (i.e., ensemble initialised every year over 1960-2005 from a continuous historical simulation) with EC-Earth3 are also affected by the signal-to-noise paradox measured by the RPC = sqrt($r^2_{(em,o)}/r^2_{(em,m)}$)>1. And this is counterintuitive.

Metrics for the perfect-model 10-member hindcasts for near-surface air temperature (forecast period 2-9)

Metrics for the DCPP-A 10-member hindcasts for near-surface air temperature (forecast period 2-9)



(Mahmood et al., 2025)

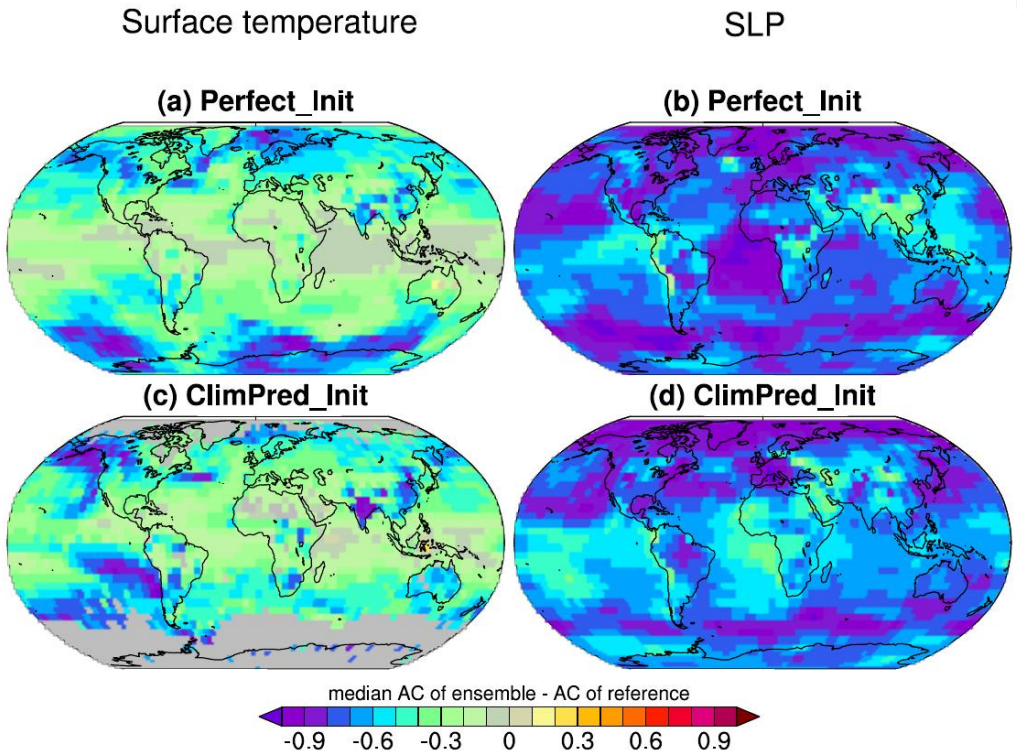
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Decadal climate predictions: signal-to-noise paradox

Coincidentally, difference in lag-1 autocorrelation between the ensemble members and the reference (observation in DCPP-A and continuous historical simulation in the perfect-model predictions) is always negative, which affects the nature of $r^2_{(em,o)}$ and $r^2_{(em,m)}$.

Metrics for the perfect-model 10-member hindcasts for near-surface air temperature (forecast period 2-9)

Metrics for the DCPP-A 10-member hindcasts for near-surface air temperature (forecast period 2-9)



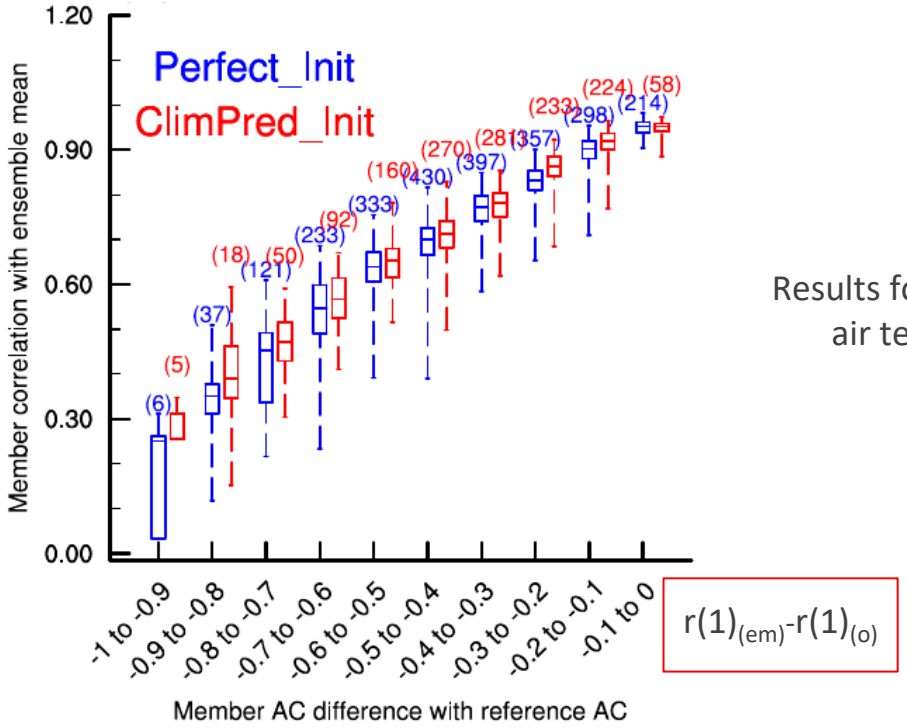
(Mahmood et al., 2025)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Decadal climate predictions: signal-to-noise paradox

Coincidentally, difference in lag-1 autocorrelation between the ensemble members and the reference (observation in DCPP-A and continuous historical simulation in the perfect-model predictions) is always negative, which affects the nature of $r^2_{(em,o)}$ and $r^2_{(em,m)}$.

$r^2_{(em,m)}$



$r(1)_{(em)}$-$r(1)_{(o)}$

Results for near-surface air temperature

(Mahmood et al., 2025)

Eddy-resolving decadal climate predictions

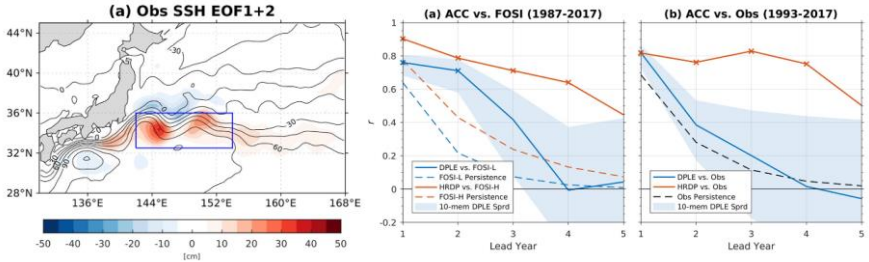
CESM-HRDP shows great skill in the Kuroshio Extension up to 4 yrs ahead, much higher than for CESM-DPLE (Kim et al., 2023)

ihesp.github.io/archive/products/ds_archive/Datasets.html?utm_source=chatgpt.com

3. CESM-HRDP

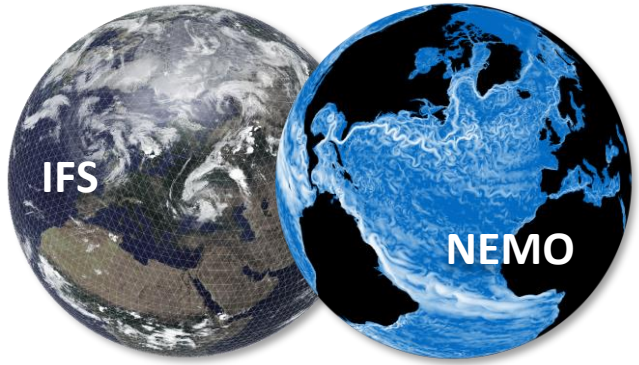
- 62-month hindcasts initialized every November 1st from 1982, 1984, ..., 2016 (18 start dates). For each start date, the hindcast ensemble size is 10. The experiment therefore comprises 930 simulation years at ocean-mesoscale-eddy resolving and TC-permitting horizontal resolution.
- A 61-year FOSI simulation spanning 1958-2018 that was used for initializing the ocean and sea ice components in HRDP. The FOSI simulation is the 5th cycle of an OMIP2 spinup run utilizing JRA55-do surface forcing and performed with the high resolution configuration of CESM's ocean and sea-ice component models.

These dataset will be made available on the NCAR side in the near future.



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

PREDDYCT will use IFS-NEMO to conduct global scale predictions at 10-km resolution to investigate the role of mesoscale eddies and their interactions on the predictability of the climate of the North Atlantic region from seasonal to multiannual timescales



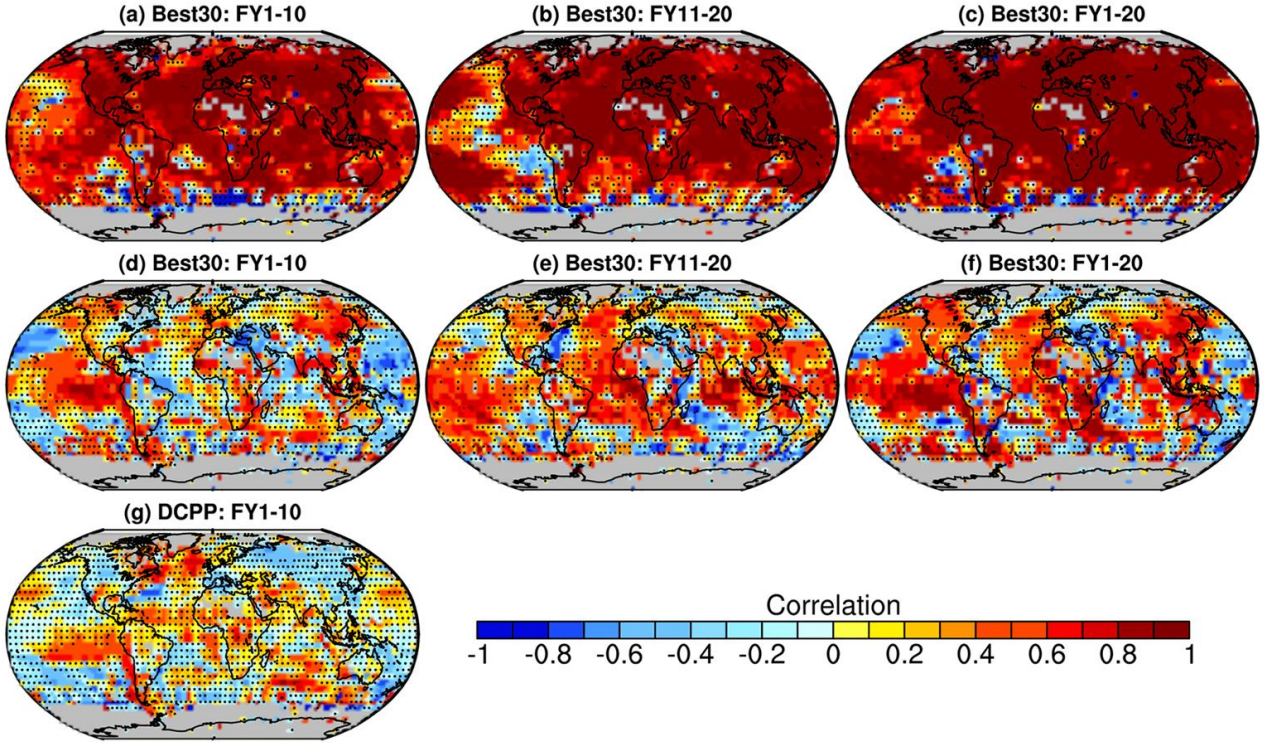
erc Consolidator Grant

PREDDYCT

(Pablo Ortega)

Decadal predictions by constraining projections

Ensemble-mean correlation (top row) and residual correlation of 10 and 20-year predictions for near-surface temperature anomalies with nine-year global SST selection and 30 best members

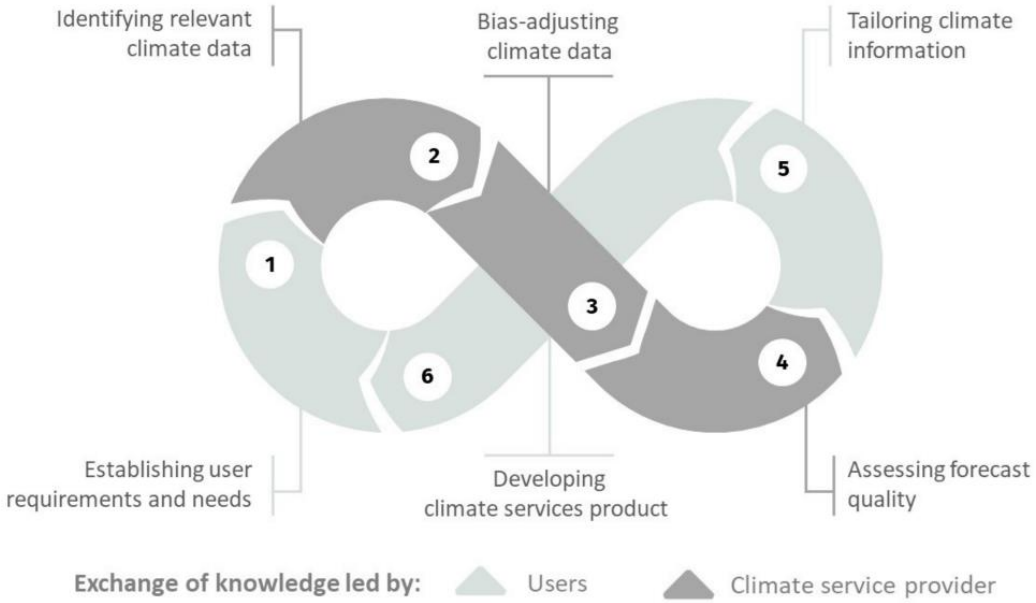


Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Mahmood et al. (2021), Mahmood et al. (2022)

Climate services: Making data and knowledge useful

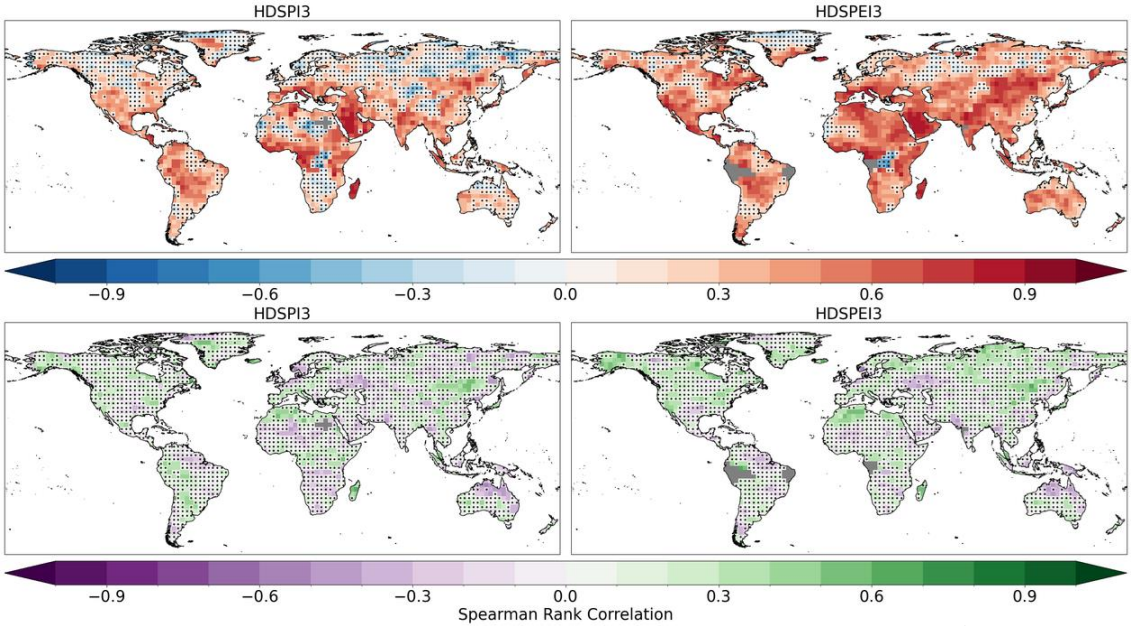
Climate services consist in the provision of climate information to support decision-making in context. The service component involves appropriate engagement and co-production approach, an effective delivery mechanism, an evaluation system, and the recognition of a variety of knowledge systems.



Hot-dry compound extremes

- Hot days as days above the 90th percentile of daily maximum temperature.
- Dry days as days falling in a month with SPI/SPEI <=-1.
- Compound hot-dry extreme events show significant skill in the 2-5 years range. Most skill is linked to the trend.

Spearman correlation for compound extreme indices (top) and added skill from initialisation measured with the residual correlation (bottom) for DCPP predictions and forecast years 2-5



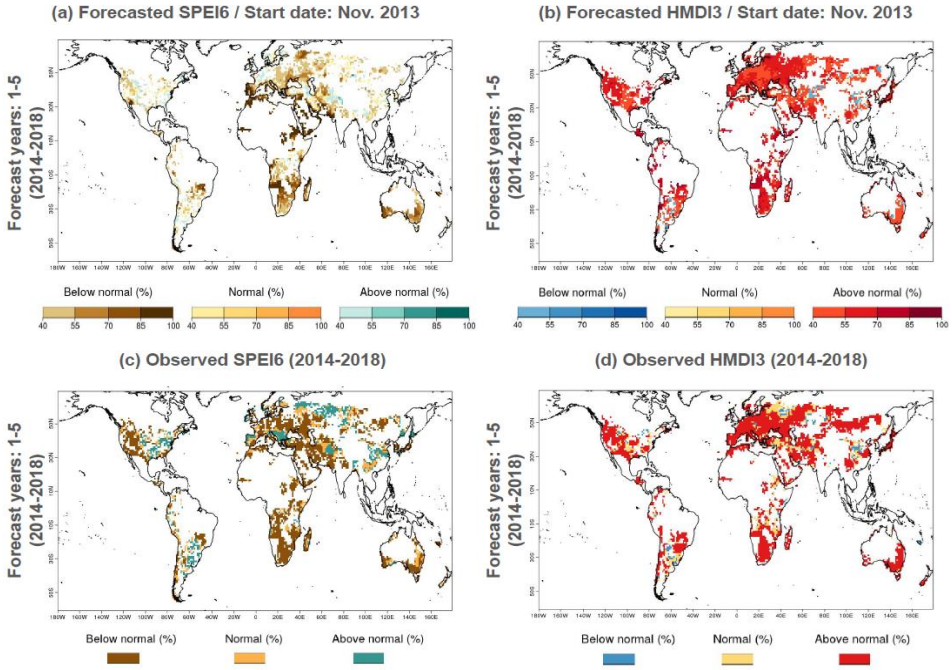
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

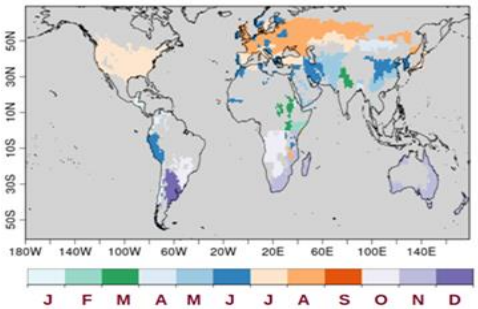
Aranyossy et al. (submitted)

Product for food security

JRC is interested in multiyear predictions of global crop-related indicators.
The standardised precipitation-evaporation index (SPEI6) and heat magnitude day index (HMDI3) indicators were computed from the decadal prediction multi-model ensemble.

Multi-year probabilistic calibrated forecast (a, b) and observed (c, d) most likely tercile category of SPEI6 (left) and HMDI3 (right) for 2014–2018 over the wheat-harvesting areas with positive skill





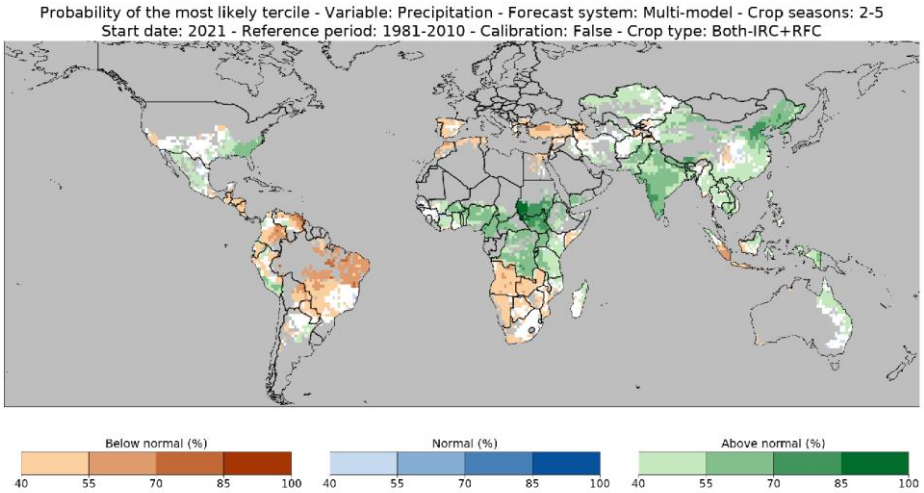
Solaraju-Murali et al. (2022)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

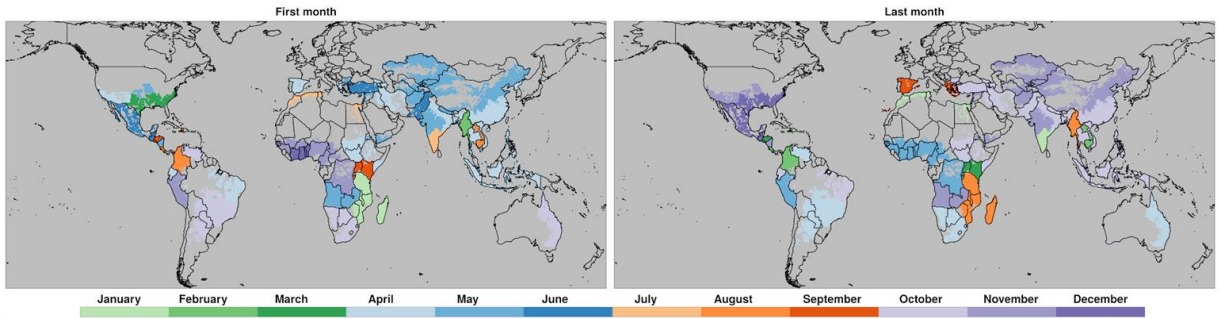
Climate Change Service
climate.copernicus.eu

Product for cotton producers

Multi-model precipitation forecast targeting cotton production



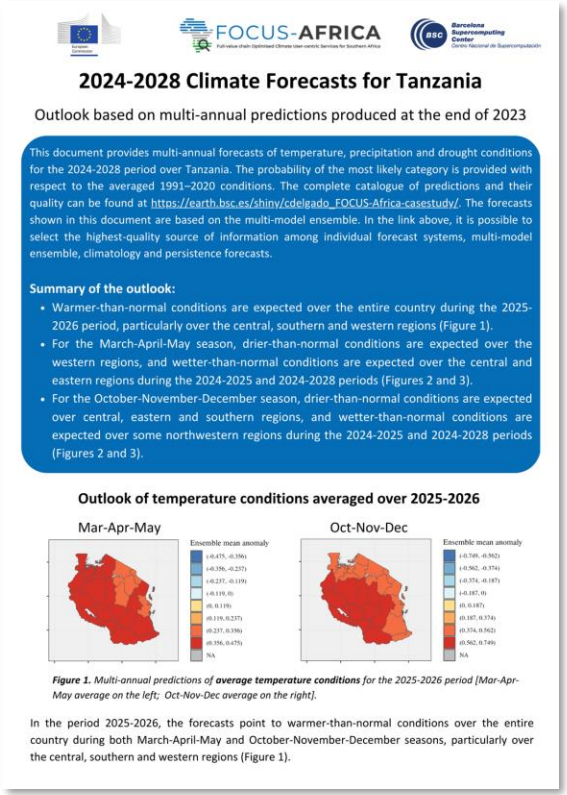
Beginning and end month of relevant precipitation information for cotton production



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Carlos Delgado-Torres

Products for regional farming



FOCUS-AFRICA

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

2024-2028 Climate Forecasts for Tanzania

Outlook based on multi-annual predictions produced at the end of 2023

This document provides multi-annual forecasts of temperature, precipitation and drought conditions for the 2024-2028 period over Tanzania. The probability of the most likely category is provided with respect to the averaged 1991–2020 conditions. The complete catalogue of predictions and their quality can be found at https://earth.bsc.es/shiny/cdelgado_FOCUS-Africa-casestudy/. The forecasts shown in this document are based on the multi-model ensemble. In the link above, it is possible to select the highest-quality source of information among individual forecast systems, multi-model ensemble, climatology and persistence forecasts.

Summary of the outlook:

- Warmer-than-normal conditions are expected over the entire country during the 2025-2026 period, particularly over the central, southern and western regions (Figure 1).
- For the March-April-May season, drier-than-normal conditions are expected over the western regions, and wetter-than-normal conditions are expected over the central and eastern regions during the 2024-2025 and 2024-2028 periods (Figures 2 and 3).
- For the October-November-December season, drier-than-normal conditions are expected over central, eastern and southern regions, and wetter-than-normal conditions are expected over some northwestern regions during the 2024-2025 and 2024-2028 periods (Figures 2 and 3).

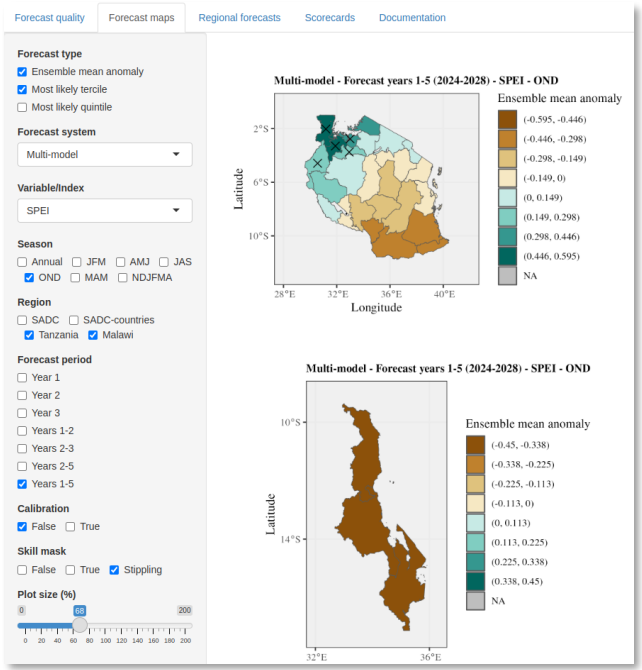
Outlook of temperature conditions averaged over 2025-2026

Mar-Apr-May | Oct-Nov-Dec

*Figure 1. Multi-annual predictions of **average temperature conditions** for the 2025-2026 period [Mar-Apr-May average on the left; Oct-Nov-Dec average on the right].*

In the period 2025-2026, the forecasts point to warmer-than-normal conditions over the entire country during both March-April-May and October-November-December seasons, particularly over the central, southern and western regions (Figure 1).

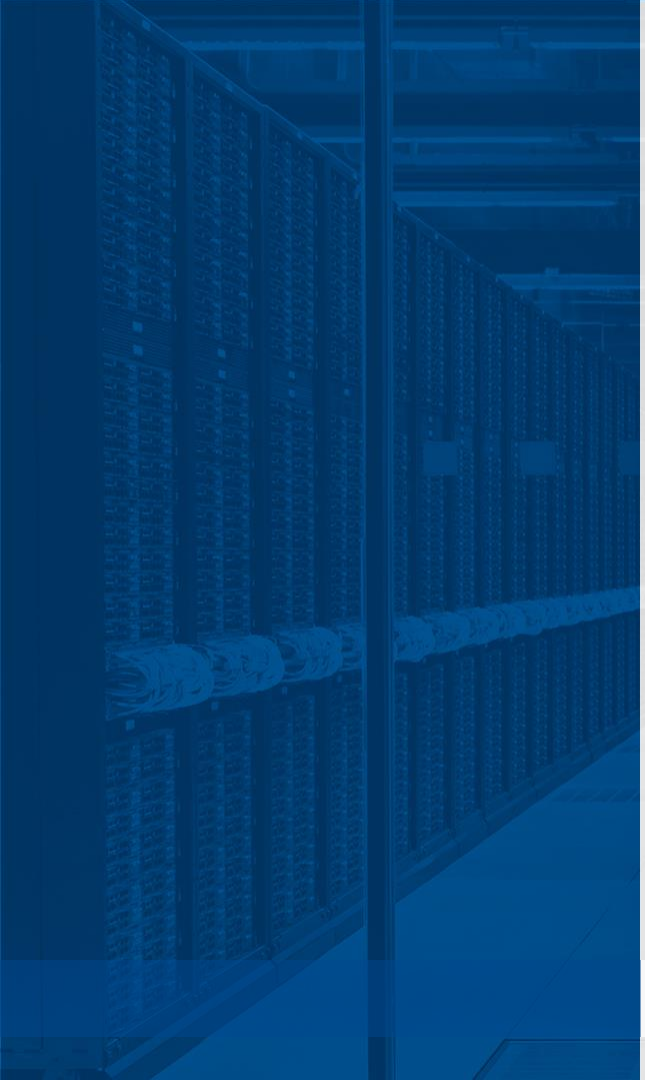
Climate information co-developed with local organisations (via field work) and the national weather services has been provided through printed bulletins summarising the predictions and an online interactive platform.



Delgado-Torres et al. (2025)

Summary

- Decadal climate prediction has evolved substantially since its emergence 20 years ago.
- Global producing centres are complemented by contributing centres delivering predictions every year with physical systems, including CO2 fluxes.
- Systematic errors penalise severely decadal predictions.
- Work on updated climate forcings is fundamental and needs to team up with shorter-term forecasting and reanalyses.
- Predictions can support the understanding of climate anomalies (2023 warming).
- A part of the signal-to-noise paradox in decadal predictions can be explained by the different nature of prediction and reference time series. This is common to prediction systems at other time scales.
- There is an increasing number of examples of the use of decadal predictions in climate services.



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

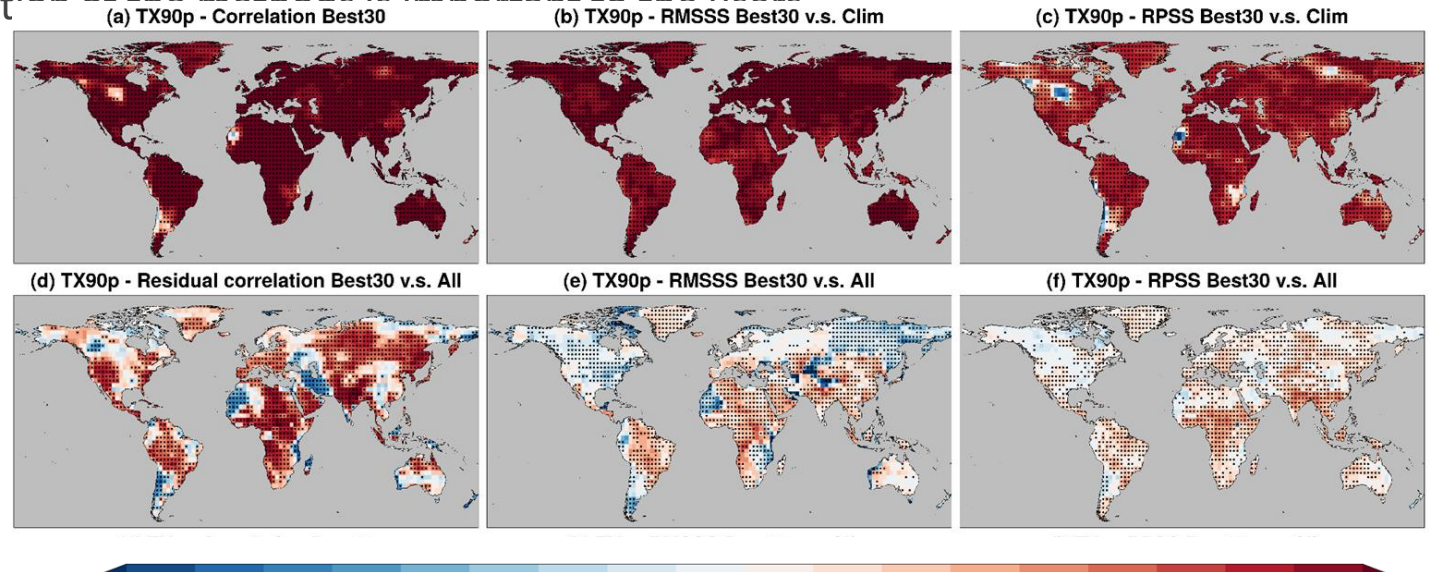
Thanks and happy anniversary

francisco.doblas-reyes@bsc.es

Near-term seamless climate information

Skill of 20-year projections using previous observations to select a 30-member ensemble.

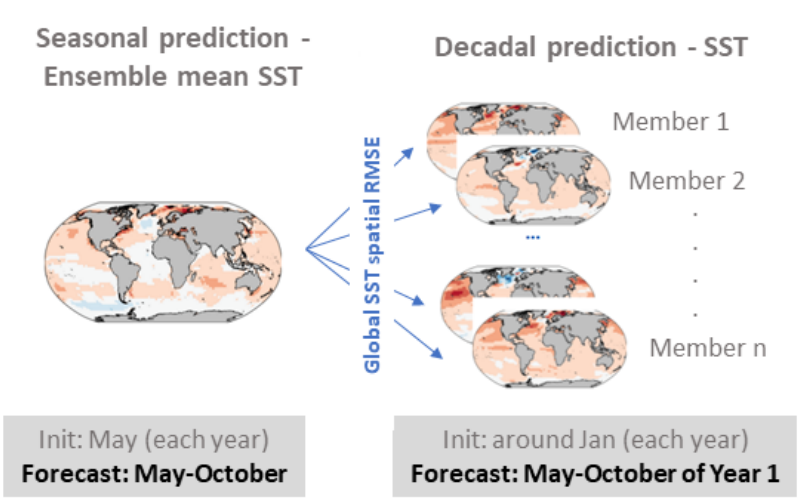
- Heterogeneous improvements with respect to the full ensemble of historical simulations
- Verification of the methods is important to the users



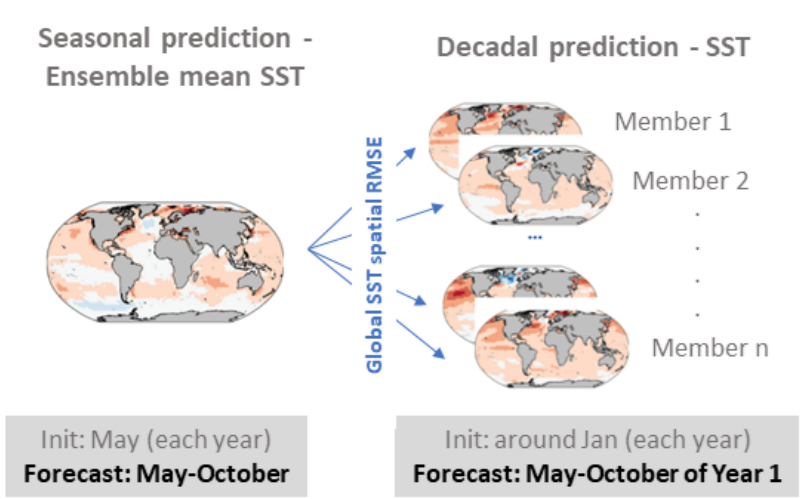
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Di Luca et al. (2024, J. Climate)

Temporal merging seasonal and decadal predictions



Select **Top30 decadal prediction members** with **lowest global SST spatial RMSE values** for the year 1981



Select **Top30 decadal prediction members** with **lowest global SST spatial RMSE values** for the year 1982

1981 — 1982 — *Selection till the end of the study period (2016, in our case)*

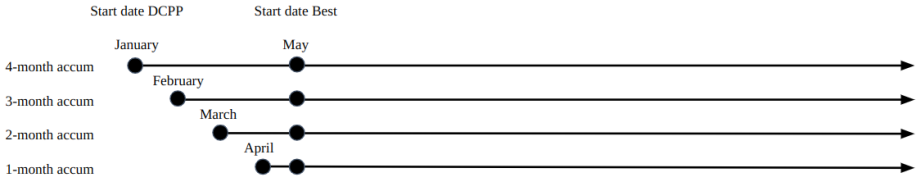
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

ASPECT
FACILITATING SEAMLESS CLIMATE ADAPTATION

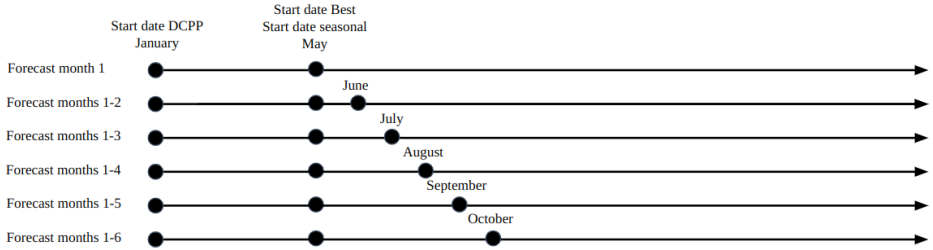
Solaraju-Murali et al. (in prep.)

Niño3.4 forecast quality for seasonal, multia-annual, decadal and S2D constrained ensembles (May init.)

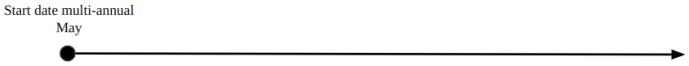
- Decadal predictions **constrained by previous observations**

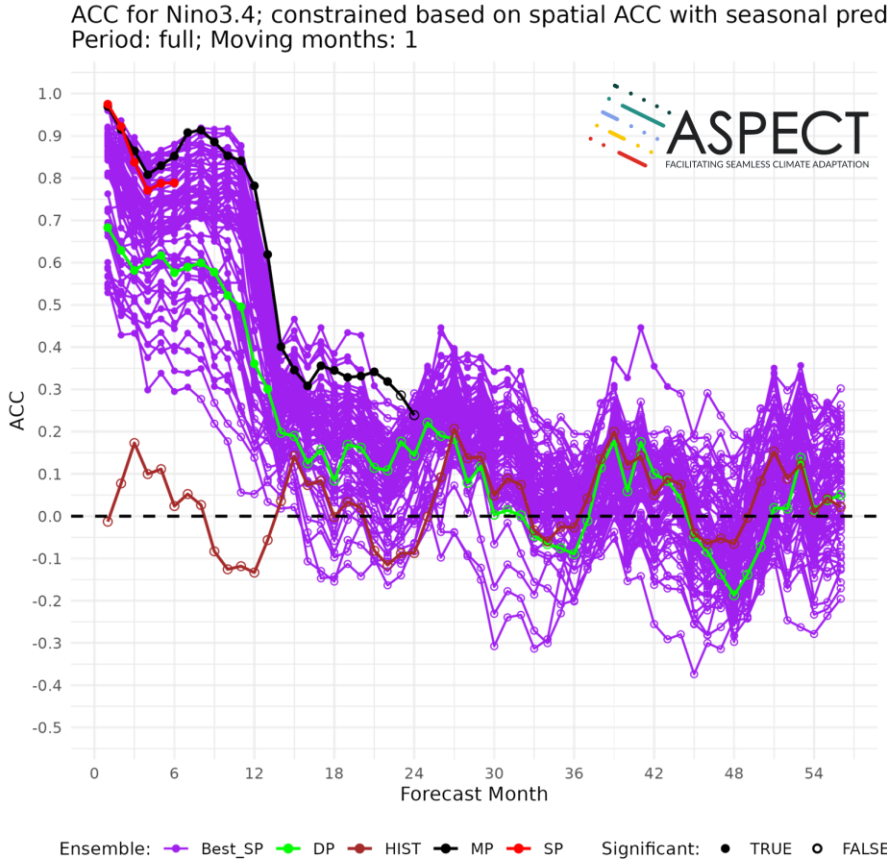


- Decadal predictions **constrained by seasonal predictions**



- **Multi-annual predictions**

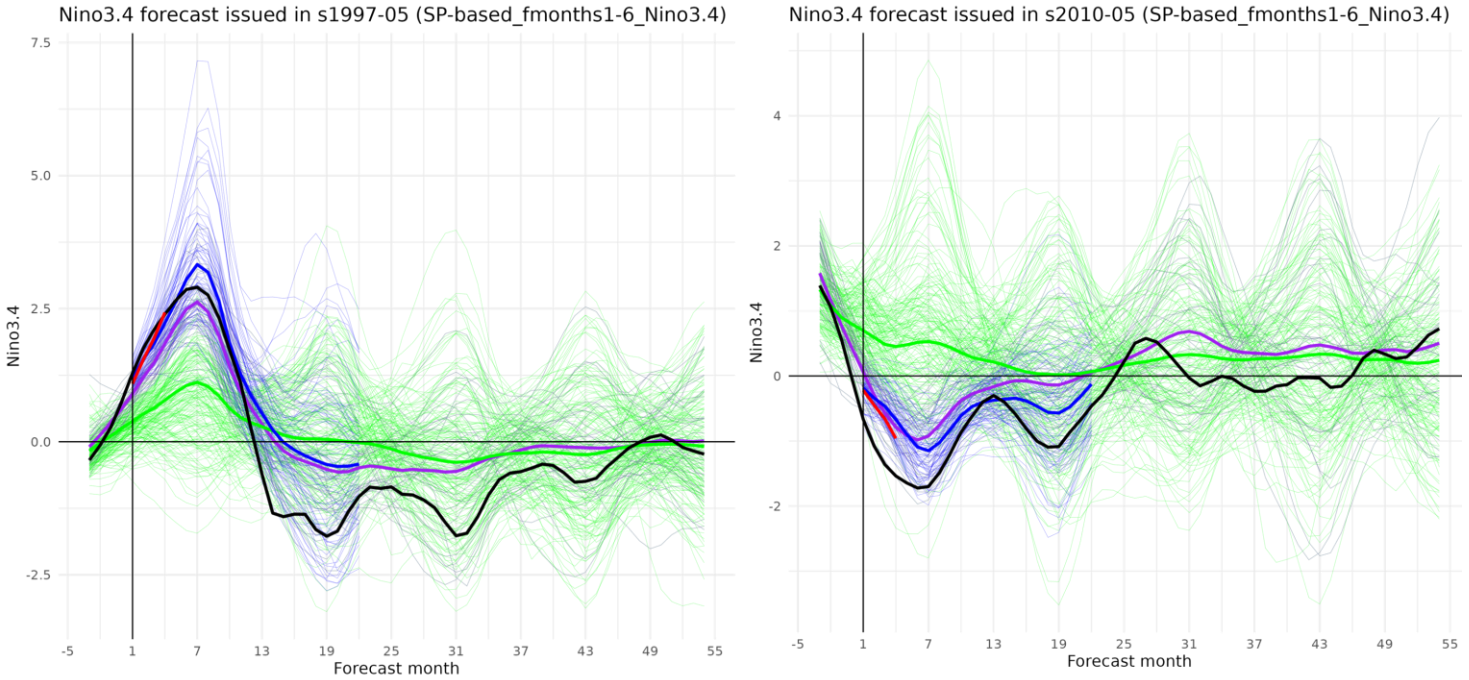




Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Delgado-Torres et al. (in prep.)

Seamless forecasts of Niño3.4 index



Delgado-Torres et al. (in prep.)

- ERA5
- Seasonal predictions initialised in May
- Multi-annual forecast initialised in May
- Decadal predictions initialised at the end of the previous year
- Seamless forecast (decadal predictions constrained in May)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

ASPECT
FACILITATING SEAMLESS CLIMATE ADAPTATION