

Barcelona Supercomputing Center Centro Nacional de Supercomputación

Climate Forecast Analysis hands-on tutorial: R tools

BSC Training Course 2023: Earth Sciences Simulation Environments

31st October, online

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Outline

- 1. Introduction to Climate Forecasts
- 2. Introduction to the Climate Forecast Analysis Tools
- 3. Hands-On I: Load data by startR
- 4. Hands-On II: Data assessment with CSTools and s2dv
- 5. Hands-On III: SUNSET

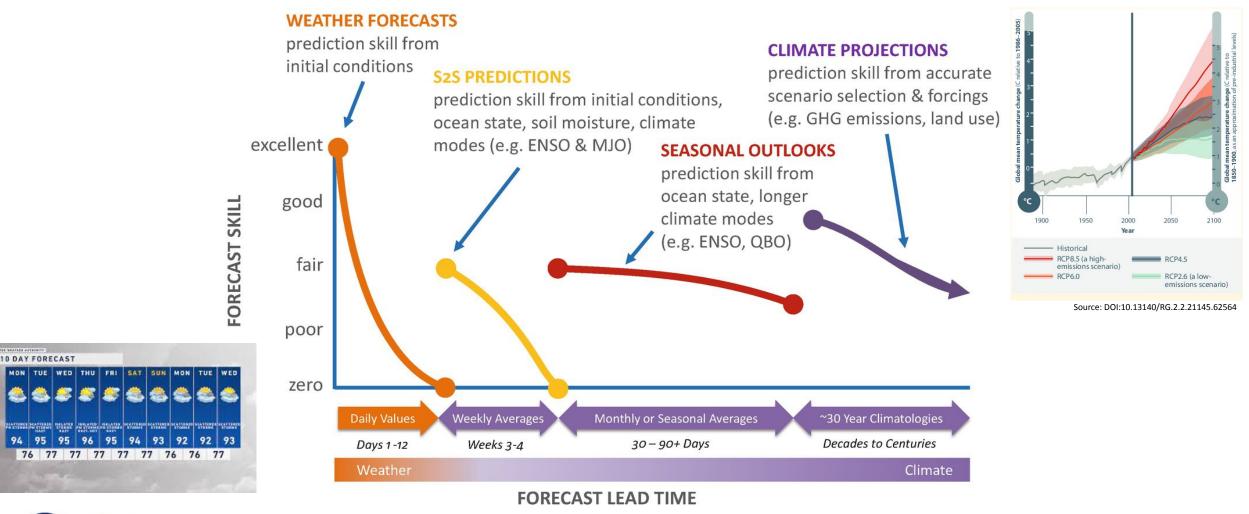
1. Introduction to Climate Forecasts



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Climate Forecast: Forecast horizon

Prediction Types, Skill, and Lead Times



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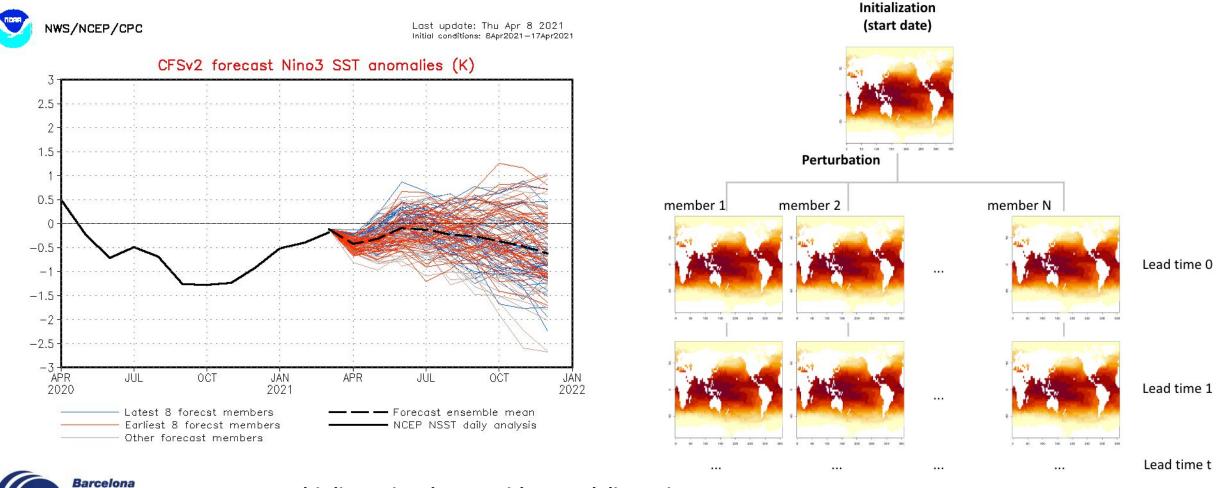
Adapted from iri.columbia.edu/news/qa-subseasonal-prediction-project

Climate Forecast: Ensemble generation

Supercomputing

Center

- Different models represent the equations using different parameterizations
- Perturbations on initial conditions are included to generate a ensemble of simulations





Centro Nacional de Supercomputación e.g.: [model = 2, sdates = 30, members = 25, ftime = 7, lat = 90, lon = 360, levels = 10]

Climate Forecast: From Climate data to Climate product

How to turn climate data into useful result or products?

CLIMATE SERVICE PRODUCT The final products from the FORECAST service provide useful information for specific needs. QUALITY ASSESSMENT Several skill scores have been obtained by the comparison of predictions with observations. Positive skill means an added 2 value with respect climatology. **RAW CLIMATE** PREDICTIONS **TAILORED** ~ Predictions obtained directly **CLIMATE** from different climate PREDICTIONS prediction systems. Climate predictions tailored to specific needs depending on **BIAS ADJUSTMENT** the end-user These adjustments have been applied to improve as much as possible reliability of the climate

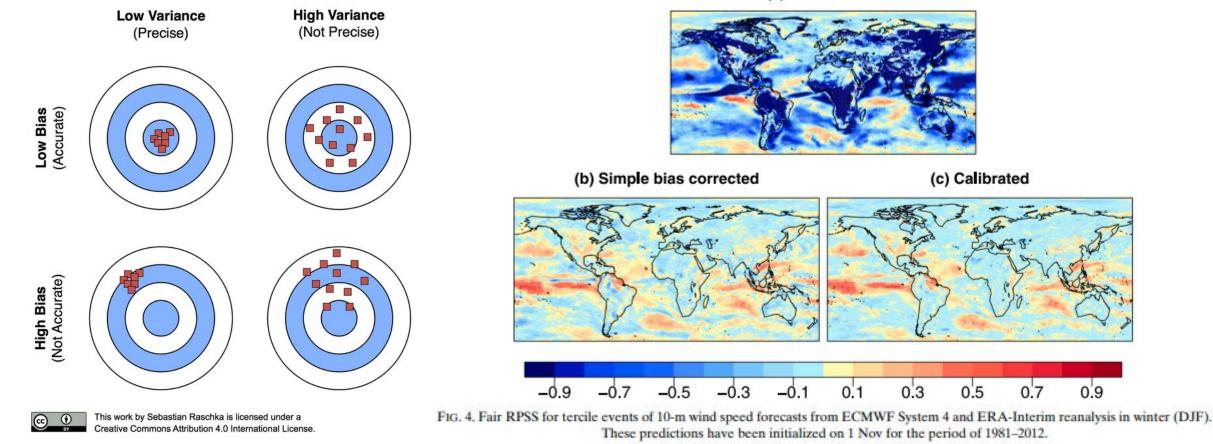
predictions.



6

Climate Forecast: Bias adjustment

- The raw experimental output may have room to be improved by reference data (e.g., observation)
- Many methods can improve the quality of forecast, e.g., bias correction, variance inflation, minimized mean-squared error, etc.







Torralba, V., Doblas-Reves, F. J., MacLeod, D., Christel, I., & Davis, M. (2017). Seasonal Climate Prediction: A New Source of Information for the Management of Wind Energy Resources, Journal of Applied Meteorology and Climatology, 56(5), 1231-1247. Retrieved Apr 9, 2021, from https://journals.ametsoc.org/view/journals/apme/56/5/jamc-d-16-0204.1.xml

0.3

0.1

(c) Calibrated

0.5

0.7

0.9

Climate Forecast Quality assessment

- When issuing a climate product, it is important to provide information about its reliability.
- For every initialization, a climate prediction will include two time periods: a forecast and a hindcast. The hindcast is a simulation covering a historical period, which can be compared to the observational information of the same time period to **evaluate the quality of the model**. This is called a Skill Assessment.

Near-Surface Air Temperature of ECMWF SEAS5 (Interpolation = to system, Aggregation level = score, Cross-validation = anomalies & terciles & crps_clim)

(NOI. LINAS 1995 /	(no. the 1992 to 1)																																						
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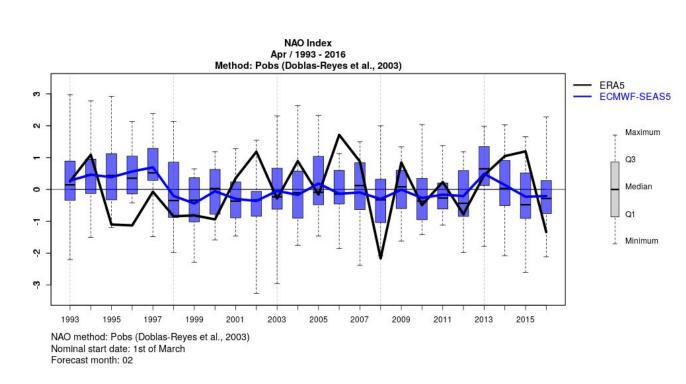
'Scorecard' plot showcasing different prediction skill metrics (credit: Nadia Milders)



-0.56 -0.45 -0.34 -0.23 -0.11 0

(Ref: FRA5 1993-2016)

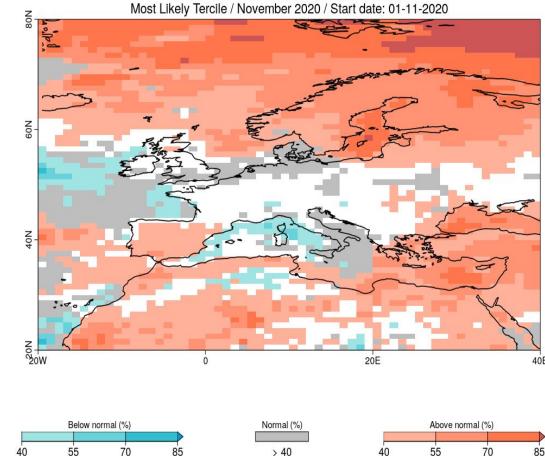
Tailored climate prediction



NAO Index time series box plot

(credit: Núria Pérez-Zanón)



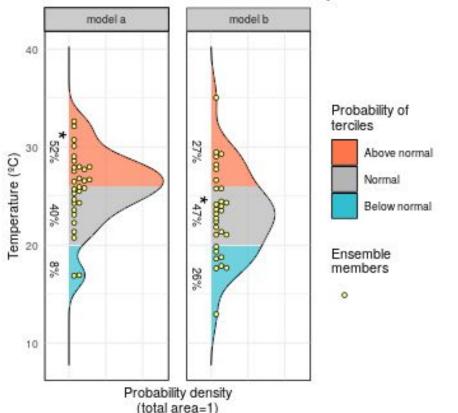


Meteo-France System 7 / 2 Metre Temperature

Map of the Most Likely Terciles

(by CSTools::PlotMostLikelyQuantileMap)

Tailored climate prediction

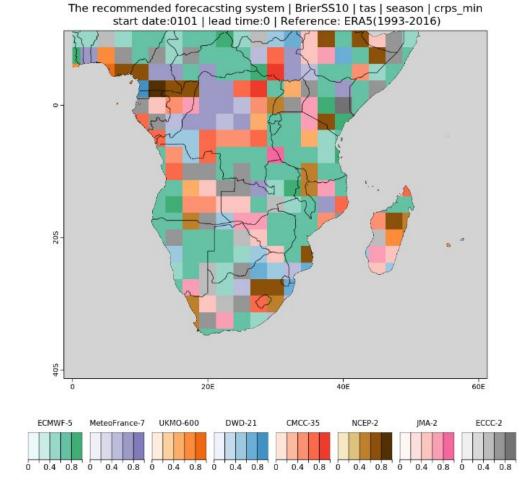


Forecasts valid for 2019-01-01 at Sunny Hills

Probability distribution of ensemble forecast

(by CSTools::PlotForecastPDF.R)





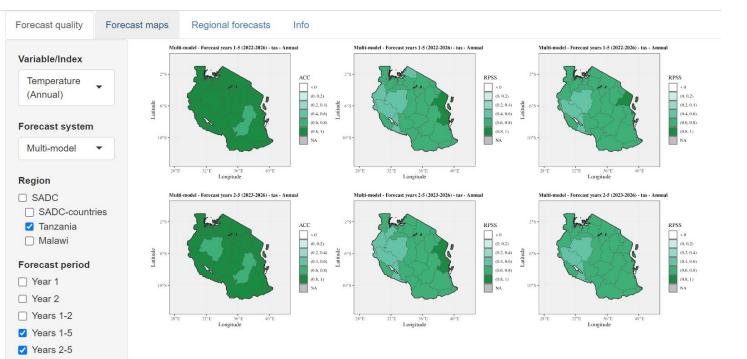
Recommended forecast system based on Brier skill score (credit: Chihchung Chou)

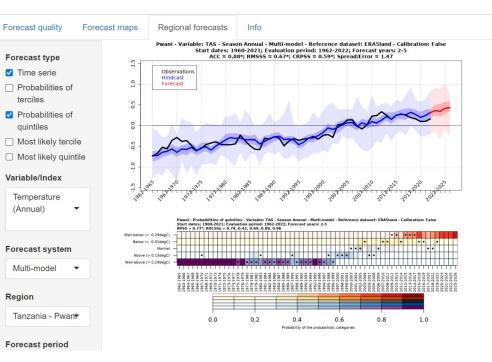
Climate service product: Shiny app

Shiny is an R package that makes it easy to build **interactive web apps** straight from R & Python.

Example: <u>https://earth.bsc.es/shiny/cdelgado_FOCUS-Africa-casestudy/</u> (credit: Carlos Delgado)

- w user: focus-africa-casestudy
- password: climateservices

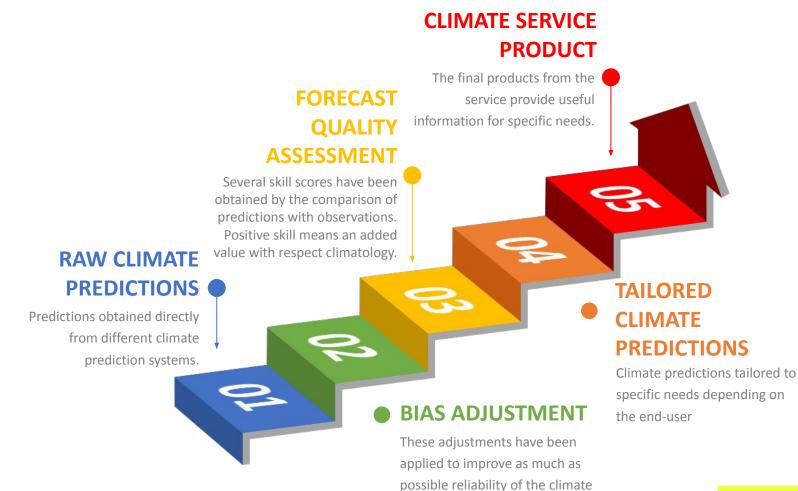




Calibration

Climate Forecast: From Climate data to Climate product

How to turn climate data into useful result or products?



predictions.

We need TOOLs for data processing.



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2. Introduction to Climate Forecast Analysis Tools



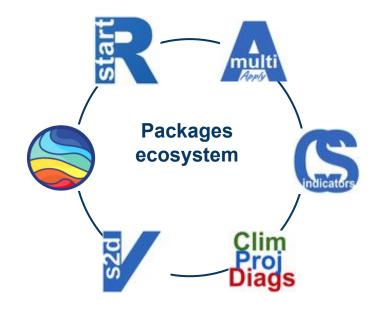
Barcelona Supercomputing Center Centro Nacional de Supercomputación **R** is a generic programming language, especially features in a strong framework for statistical computing and graphics.

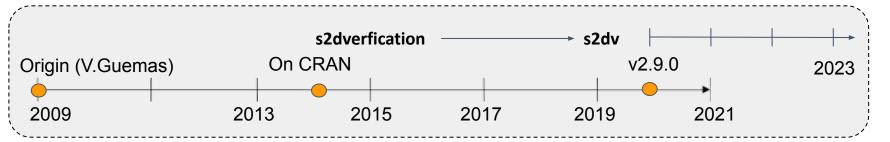
- Free software (under the GNU GPL license.) You can install R from https://cran.r-project.org/
- Provides a wide variety of statistical techniques (linear and non-linear modelling, classical statistical tests, classification and simulation...)
- Well developed plotting tools (e.g., <u>ggplot2</u>)
- Once R is installed, the base R packages are installed along. But you can further install other packages. See the list of all the available packages on CRAN https://cran.r-project.org/web/packages/available_packages_by_name.html



Climate Forecast Analysis Tools: Early version

- ★ Methods developed by the department to assess the quality of the forecast were gathered in s2dverfication R package
- ★ Researchers could easily share their methods and replicate colleagues analysis on their own data
- \star Common needs detected





New packages and tools for different needs are being developed continuously.



Climate Forecast Analysis Tools: Table of packages

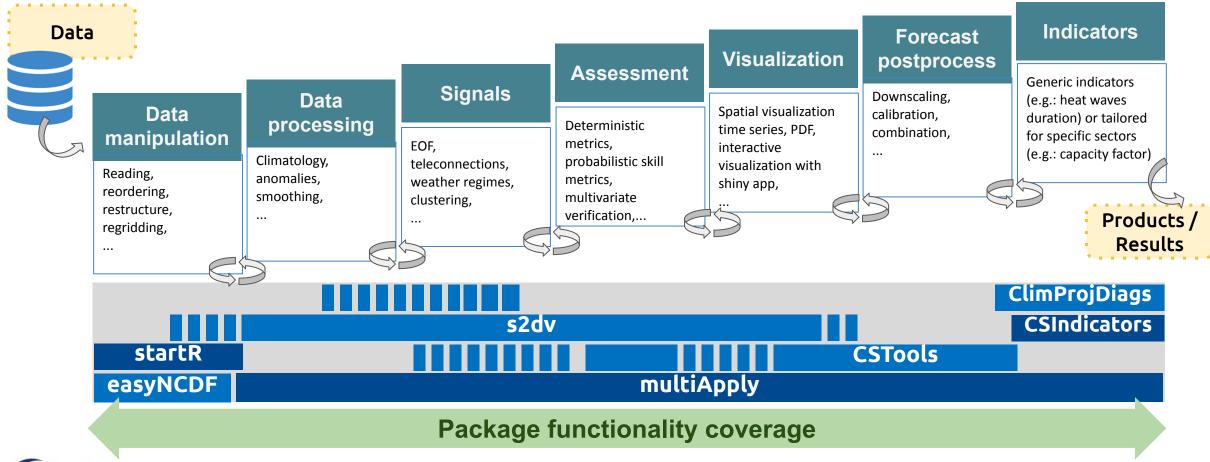
- ★ Functions are split into packages depending on their objective or project requirement
- ★ Functions from different packages can be used together to perform analyses or obtain climate service products

	Package name	Short description	Link to CRAN and GitLab
	easyNCDF	Read/write netCDF files into/from multidimensional R array	CRAN.R-project.org/package=easyNCDF earth.bsc.es/gitlab/es/easyNCDF
Data loading and	startR	Data retrieval and processing tools	<u>CRAN.R-project.org/package=startR</u> <u>earth.bsc.es/gitlab/es/startR</u>
manipulation	multiApply	Apply functions to multiple multidimensional arrays or vectors allowing parallel computation	<u>CRAN.R-project.org/package=multiApply</u> <u>earth.bsc.es/gitlab/ces/multiApply</u>
	s2dv	Functions for Forecast Verification and visualization	<u>CRAN.R-project.org/package=s2dv</u> <u>earth.bsc.es/gitlab/es/s2dv</u>
Analysis and processing	CSTools	Methods for forecast calibration, statistical and stochastic downscaling, optimal forecast combination and tools to obtain tailored products.	<u>CRAN.R-project.org/package=CSTools</u> earth.bsc.es/gitlab/external/cstools
Climate	CSIndicators	Sectorial Indicators for Climate Service	<u>CRAN.R-project.org/package=CSIndicators</u> <u>earth.bsc.es/gitlab/es/csindicators</u>
indicators	ClimProjDiags	Climate extreme indices, evaluation of the agreement between models, weight and combination functions.	<u>CRAN.R-project.org/package=ClimProjDiags</u> <u>earth.bsc.es/gitlab/es/ClimProjDiags</u>



Climate Forecast Data Analysis Procedure and Tools

- ★ The package ecosystem aims to cover the whole data analysis cycle.
- ★ The tools can be used interchangeably, depending on the needs.





Important Features in Our Tools

LOADING

- Input data format: netCDF
- Different datasets under convention can be loaded
 - Data loading flexibility required

ANALYZING

- Accepted R object type by functions: Named multi-dimensional array mainly
- Different forecast horizons and frequency to be analyzed
 - Function flexibility required
- Multiple-core/node and parallel computation on HPCs
 - use package "multiApply"





The packages are individual, but they can be integrated into a comprehensive data analysis workflow.

EXAMPLE 1 s2d Experiment Monitoring Tool

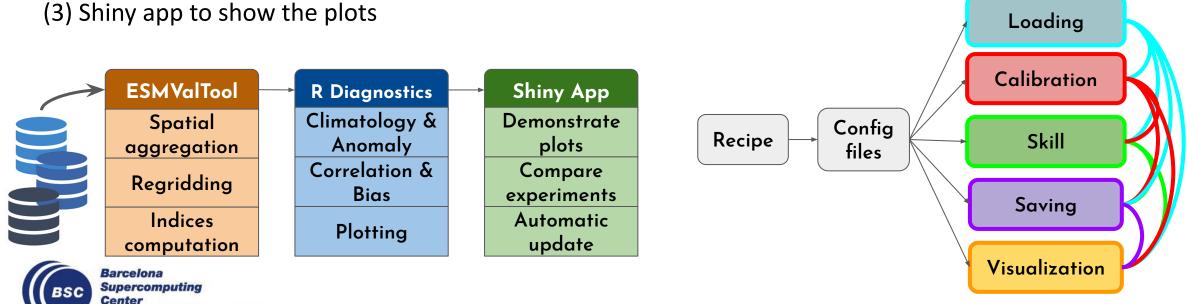
A workflow to monitor the seasonal/decadal predictions while they run. It consists of three parts:

(1) Raw data pre-processing by ESMValTool

(2) Diagnostics computed and plotted by our R packages

EXAMPLE 2 SUNSET: Climate Services Suite

This suite intakes a user-defined **recipe** and relies on configuration files. It has a modularized structure providing flexibility, so that parts of the workflow can be skipped or reordered.



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Hands-On Preparation



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Prepare the environment on VM and MN4

- If you use Windows, remember to open **Xming** first for showing the plots on the fly later. (download <u>here</u>)
- 2. log in VM: ssh -XY patc{xx}@bsceshandson01.bsc.es
- 3. ssh to mn4: ssh -XY mn4 (passwordless)
- 4. Require resources:

salloc -t 02:00:00 -n 1 -c 16 -J patc test --x11 --qos=training

5. Load the required modules:

module load gcc/7.2.0 pcre2 intel R/4.1.2 mkl impi CDO/1.8.2 netcdf/4.4.1.1

6. Open R: R



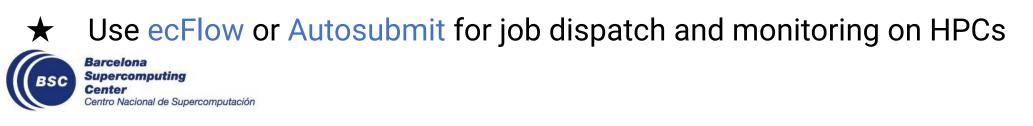
3. Hands-On I: Load data by startR



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startR features

- ★ An R package for data retrieval and processing into multi-dimensional array
- ★ Accepted data format: netCDF
- ★ Apply multiApply paradigm, which provides flexibility in multi-dimensional data processing and multiple-core usage
- ★ Pre-processing: data regridding and reordering/reshaping/renaming dimensions along with data loading
- ★ Automatically chunk the data and dispatch on HPCs for parallel data-processing and combine chunks back together in the end
- ★ Well-preserved metadata from netCDF files



★ Goal: Use the package startR to load and pre-processing data

Tools needed:

- R, NCO
- startR package (v2.3.0)
- lubridate

Follow the Markdown file:

https://earth.bsc.es/gitlab/es/startR/-/blob/master/inst/doc/tutorial/PATC2023/hands

on_1-data-loading.md

(Check the <u>answer</u> if needed)

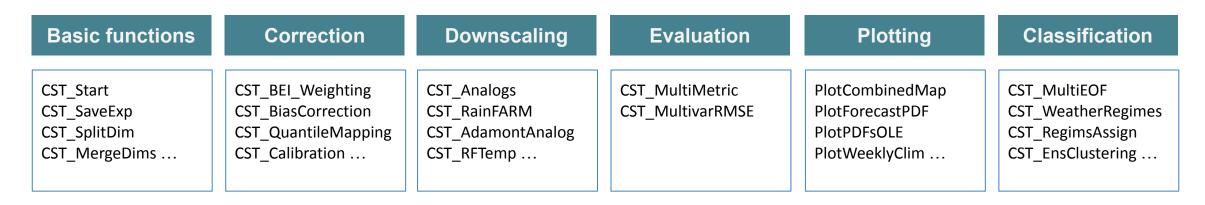
NOTE: Don't close the session when you finish the exercise! We will use the data in the next hands-on.

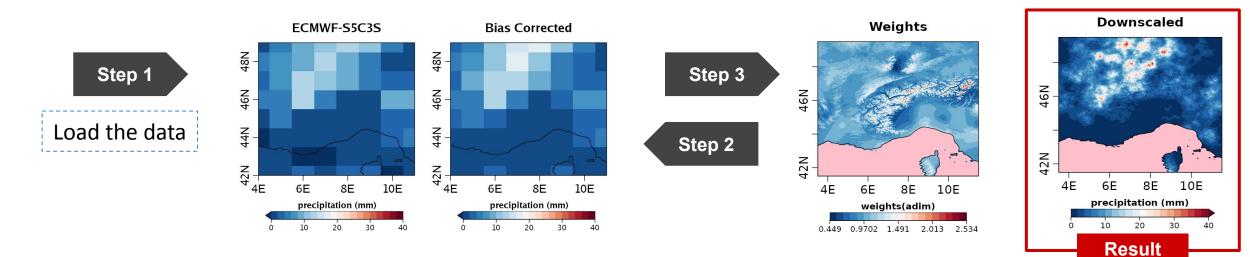


4. Hands-On II: Data assessment with CSTools and s2dv



Barcelona Supercomputing Center Centro Nacional de Supercomputación ★ Climate forecast data can be postprocessed to obtain relevant information for the end-users.







- GitLab repo: https://earth.bsc.es/gitlab/external/cstools
- On CRAN: <u>https://cran.r-project.org/web/packages/CSTools/index.html</u>

s2dv package

★ This package is designed to compare experimental and observational datasets. It covers from data retrieval, data post-processing, skill scores against observation, to visualization.

Verification • • •

Compute deterministic and probabilistic scores and skill scores and correlation with reliability indicators such as p-values and confidence intervals.

 Functions: NAO, RMSSS, RMS, BrierScore, RPS, RPSS, CRPSS, MSE, RPS, RPSS, ...

Visualisation

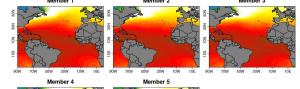
Plotting functions are also provided to plot the results obtained from any of the modules above.

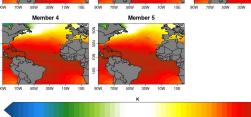
• **Functions:** PlotClim, PlotAno, PlotACC, PlotEquiMap, PlotStereoMap, AnimateMap, PlotLayout, ... Functions that are commonly used in the forecast verification process to modify, describe or generate fields, a field being a series of modelled or observed measurements for a certain physic variable of interest.

Statistics

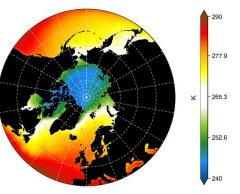
• **Functions:** Clim, Ano, Trend, Consist_Trend, Regression, Eno, Trend, ProbBins, ...

Exp. A 'tas', s. date: 1990-11-01, f.time: 1 month





Exp. A 'tas', s. date: 1990-11-01, f. time: 1 month

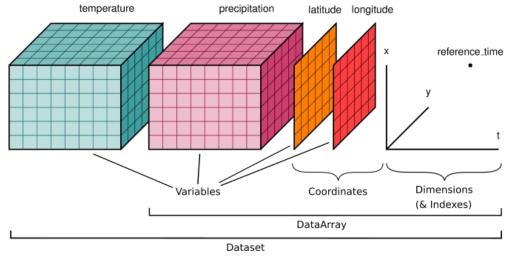




- GitLab repo: <u>https://earth.bsc.es/gitlab/es/s2dv</u>
 - On CRAN: <u>https://cran.r-project.org/web/packages/s2dv/</u>

s2dv_cube object

- **s2dv** cube is an object to store ordered multidimensional array with named dimensions, specific × coordinates and stored metadata.
- Its "methods" are **CST** prefix functions × from CSTools and CSIndicators



's2dv_cube'

```
[294.97520446, 295.9965820, 296.99915313, 296.87461853, ... ]
Data
Dimensions (syear = 24, ensemble = 25, time = 2, lat = 61, lon = 61)
Coordinates
 * syear : 19931101, 19941101, 19951101, 19961101, 19971101, ...
  ensemble : 1, 2, 3, 4, 5, 6, ...
  time : 1, 2
 * lat : 20, 21, 22, 23, 24, 25, 26, 27, ...
 * lon : -20, -19, -18, -17, -16, -15, ...
Attributes
   Dates : 1993-11-30 1994-11-30 1995-11-30 1996-11-30 1997-11-30 ...
   varName : tas
  metadata :
      time
       units : hours since 1993-11-01 00:00:00
      tas
       units : K
       long name : 2 metre temperature
   Datasets : dat1
   when : 2023-10-21 17:40:59
   source_files : /exp/meteofrance/system7c3s/monthly_mean/tas_f6h/ ...
   load_parameters :
```

(dat1) : dat = dat1, var = tas, syear = 19931101 ...



- ★ CSTools::CST_Calibration Used to correct biases as well as dispersion errors of the model. This function contain different methods of member-by-member bias correction.
- ★ CSTools::CST_Anomaly Compute deviations from the average conditions. This function computes the anomalies relative to a climatology computed along the selected dimension.
- ★ s2dv::RPSS Is the skill score based on the Ranked Probability Score. It can be used to assess whether a forecast presents an improvement or worsening with respect to a reference.
 - The RPSS ranges between minus infinite and 1. If the **RPSS > 0**, the forecast has higher skill than the reference, if **RPSS < 0** means that it has a lower skill.



★ Goal: Use the package CSTools and s2dv to perform the hindcast quality assessment

Tools needed:

- R
- CSTools package v5.1.0
- s2dv package v2.0.0

Follow the Markdown file:

<u>https://earth.bsc.es/gitlab/external/cstools/-/blob/doc-bsc_training_2023/inst/doc/tu</u> <u>torial/PATC2023/handson_2-data-assesment.md</u> (Check the <u>answer</u> if needed)



5. Hands-On III: SUNSET

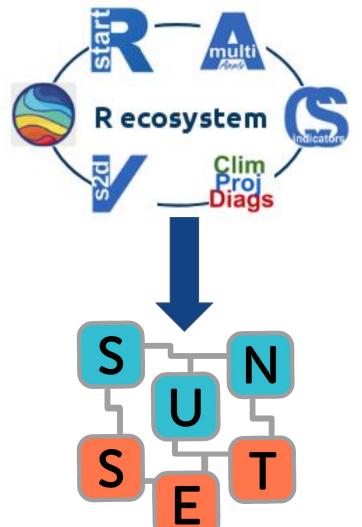


Barcelona Supercomputing Center Centro Nacional de Supercomputación SUNSET, or "SUbseasoNal to decadal climate forecast post-processIng and asSEssmenT suite", is an **R-based tool for forecast post-processing and skill assessment workflows** that takes advantage of the R ecosystem in the Earth Sciences department.

The purpose of this tool is to foster collaboration among people working on forecast verification analysis within the department, to facilitate code reusability and a common framework.

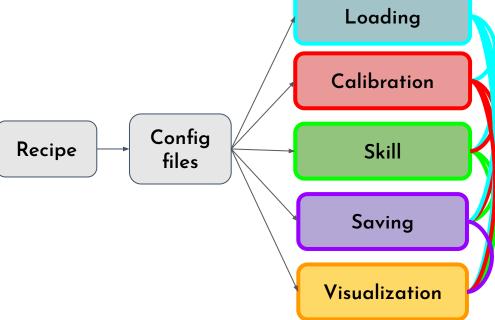
It **integrates** startR, CSTools, s2dv, multiApply... and many other packages in our R ecosystem.





SUNSET intakes a user-defined **recipe** with the information of the data to be loaded, and relies on configuration files and **modules**. Each module performs a different task: Loading, Downscaling, Calibration, Anomalies, computing Indices or Indicators, Skill Assessment, Visualization... The sequence of tasks in an analysis is called the **workflow** and is defined in an R script by the user.

The modularized structure provides flexibility, so that parts of the workflow can be skipped or executed at different points.





SUNSET is designed for Climate Services applications and therefore can be run in two ways:

- 1. **Parallelizing workflows:** Creating a recipe with one or multiple datasets that require the same analysis. When launching SUNSET, the recipe is split into individual verifications that are run in parallel on a computer cluster, with the option to use Autosubmit as a workflow manager.
- 2. Interactively on the terminal: Create an individual recipe directly and run the functions on the terminal (for small tests and individual one-time analysis).

For the hands-on tutorial, we will focus on the second approach, which allows us to observe every step of the workflow.



Method 1. Splitting the recipe and parallelizing workflows

U S E R	RECIPE Specifies the assessment to carry on a model output. For example: 2 variables (e.g. temperature at surface and mean sea level pressure) and 2 different initialization dates (e.g. 1st of May and 1st of November) for 1 region (e.g. Europe).												
Α	Atomic recipe 1 Assessment of 1st of May initialization day of the air temperature at surface	Atomic recipe 2 Assessment of 1st of May initialization day of the mean sea level pressure	Atomic recipe 3 Assessment of 1st of November initialization day of the air temperature at surface	Atomic recipe 4 Assessment of 1st of November initialization day of the mean sea level pressure									
U T O	Load Calibration	Load Calibration	Load Calibration	Load Calibration									
S U	Anomalies	Anomalies	Anomalies	Anomalies									
B M	Skill scores	Skill scores	Skill scores	Skill scores									
l T	Probability computation	Probability computation	Probability computation	Probability computation									
	Spatial visualization	Spatial visualization	Spatial visualization	Spatial visualization									
		Save logs a	and outputs										



Method 2. Running an individual workflow interactively

U S E R	RECIPE Specifies the assessment to carry on a model output for two variables (e.g. temperature at surface and mean sea level pressure) and 2 different initialization dates (e.g. 1st of May and 1st of November) on global scale.												
A	Atomic recipe 1 Assessment of 1st of May initialization day of the air temperature at surface	Atomic recipe 2 Assessment of 1st of May initialization day of the mean sea level pressure	Atomic recipe 3 Assessment of 1st of November initialization day of the air temperature at surface	Atomic recipe 4 Assessment of 1st of November initialization day of the mean sea level pressure									
U T C S U B	Load Calibration Anomalies	Load Calibration Anomalies	Load Calibration Anomalies	Load Calibration Anomalies									
M I	Skill scores	Skill scores	Skill scores	Skill scores									
	Probability computation Spatial visualization	Probability computation Spatial visualization	Probability computation Spatial visualization	Probability computation Spatial visualization									
		Save logs a	and outputs										



- ★ Goal: Create a SUNSET recipe and use the SUNSET functions to perform a climate forecast analysis
 Tools needed:
 - R
 - R packages: yaml, startR, CSTools, s2dv, docopt, log4r, multiApply, easyNCDF, abind, lubridate, PCICt, RColorBrewer, stringr

Steps

- 1. Copy and edit the SUNSET recipe template
- 2. Load the data and run the workflow
- 3. Review the output files and plots

SUNSET Hands-on tutorial





Barcelona Supercomputing Center Centro Nacional de Supercomputación

Thank you

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