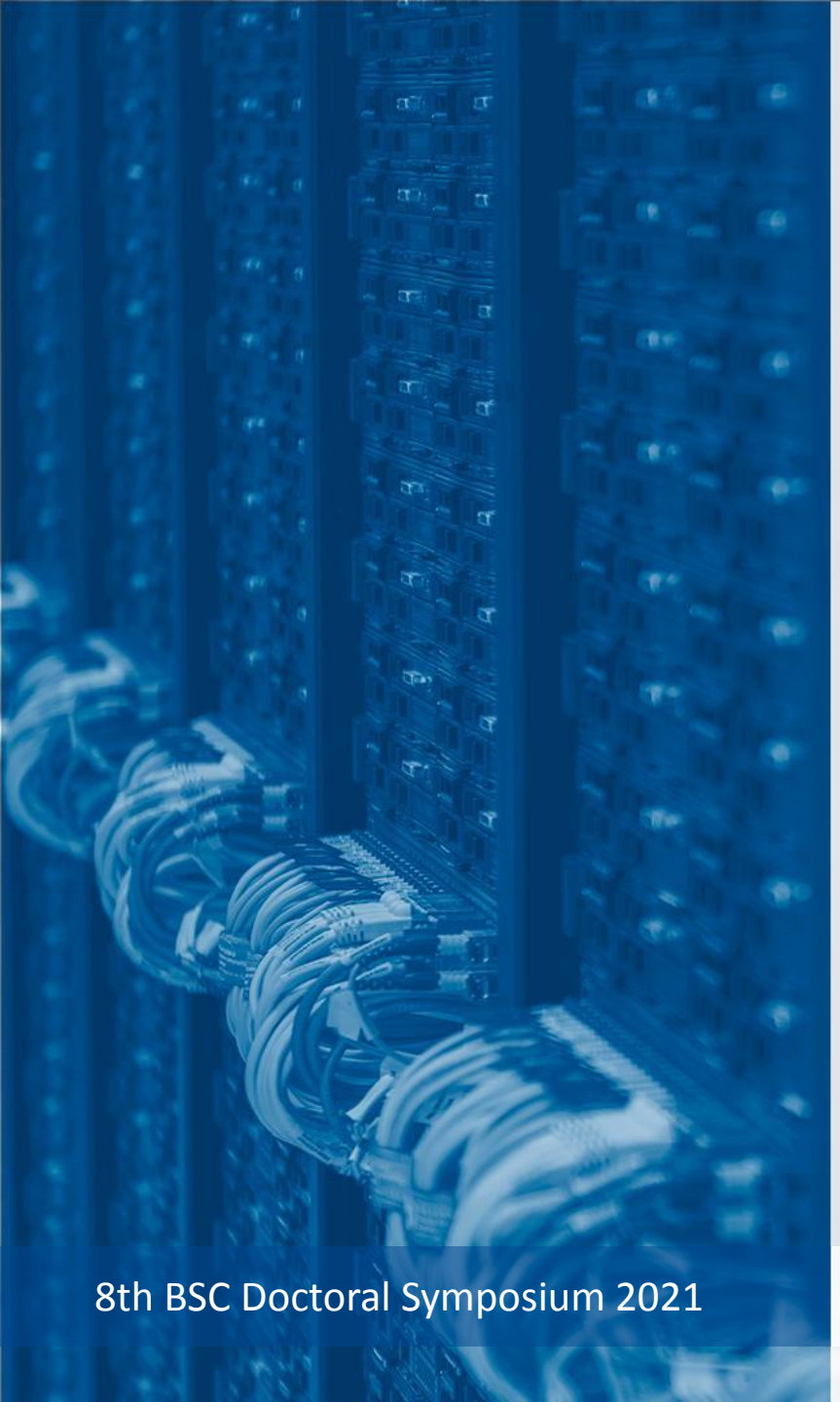

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Climate Forecast Analysis Tools Framework

Núria Pérez-Zanón, An-Chi Ho, Francesco Benincasa, Pierre-Antoine Bretonnière, Louis-Philippe Caron, Chihchung Chou, Carlos Delgado-Torres, Llorenç Lledó, Nicolau Manubens, Lluís Palma

8th BSC Doctoral Symposium 2021

Earth Science Department

Outline

1. Introduction to Climate Forecasts
2. Introduction to the Climate Forecast Analysis Tools
3. Case Study
4. Development Strategy
5. Last remarks and future work

Climate Forecasts

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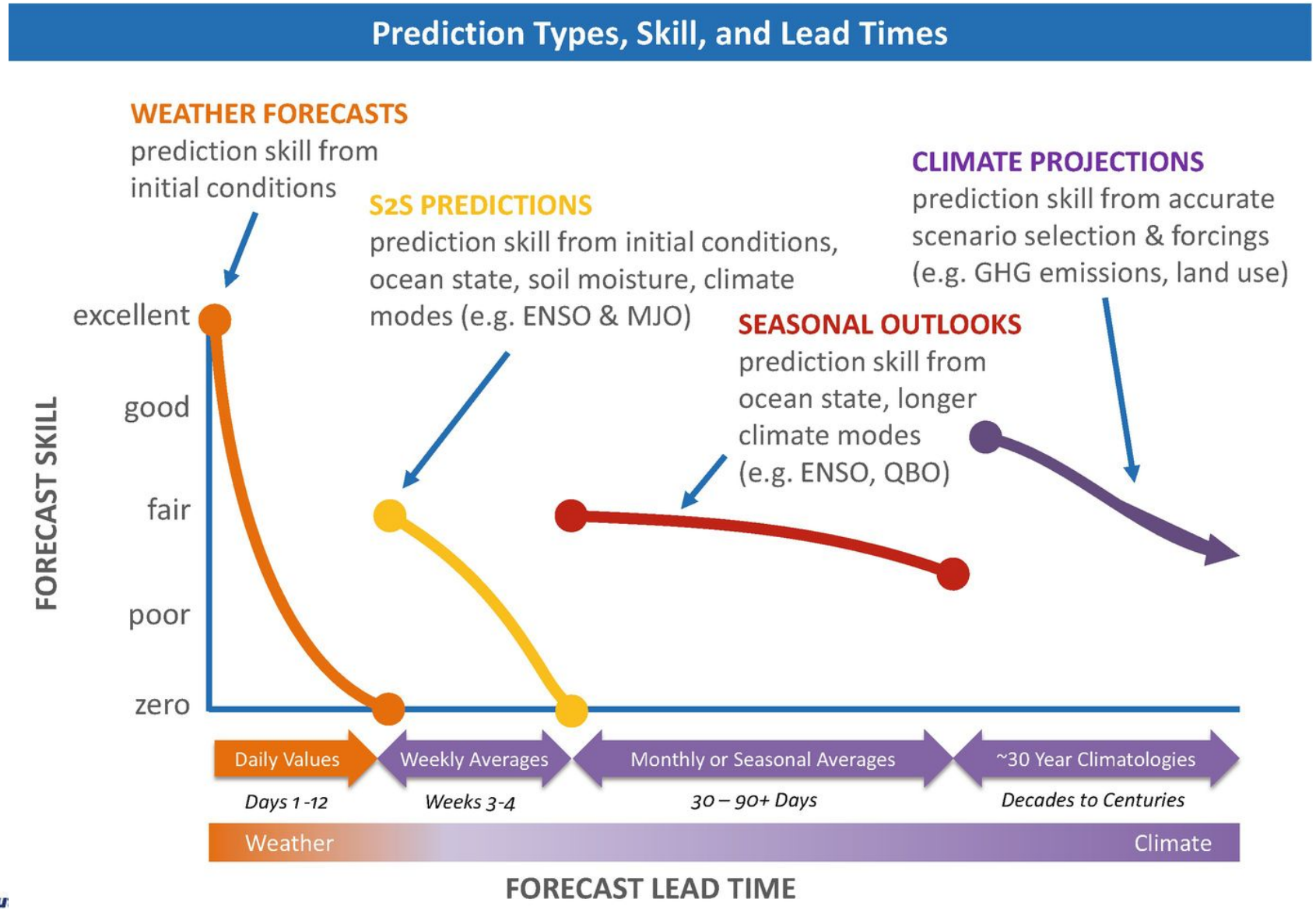
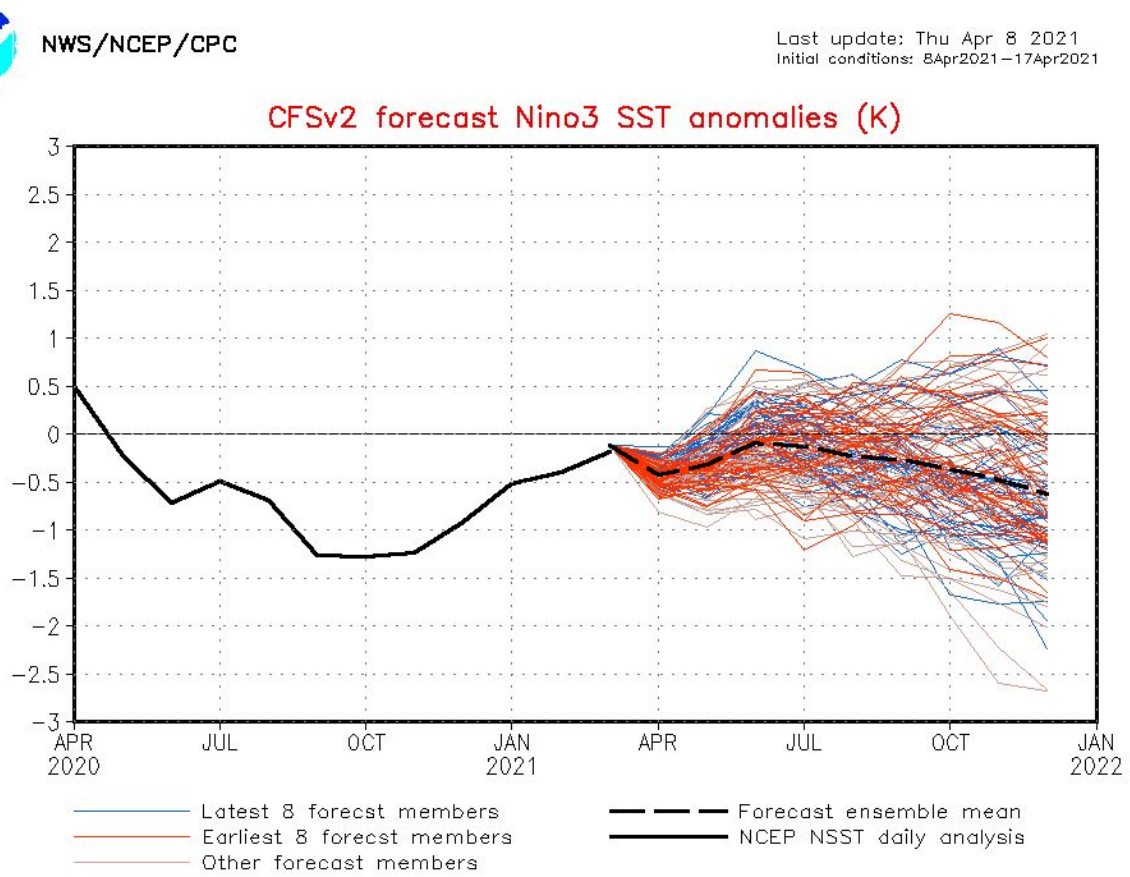
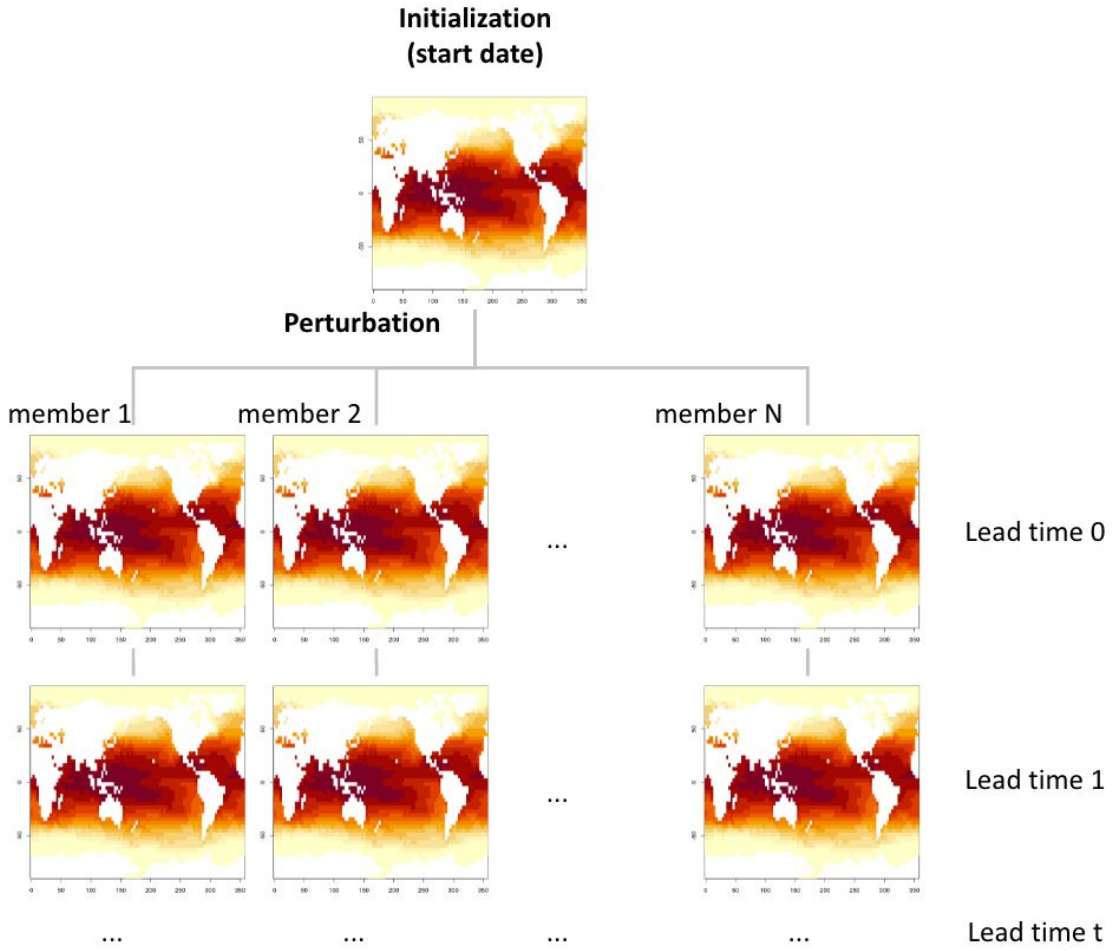
Climate Forecast: Forecast horizon



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

Climate Forecast: Ensemble generation





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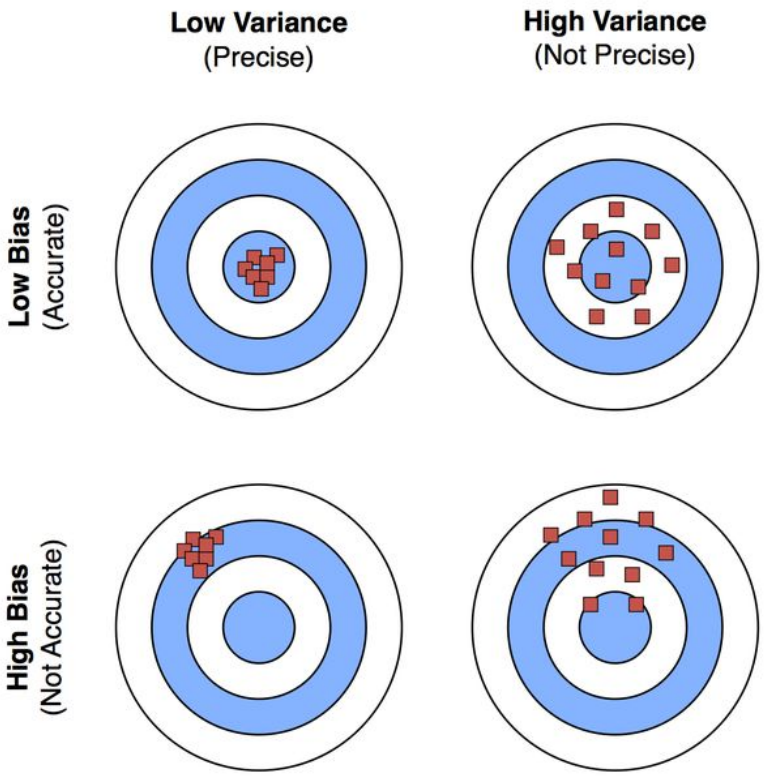
Climate Forecast: Processing

Bias Correction is an example of one method applied to raw forecast to improve their quality



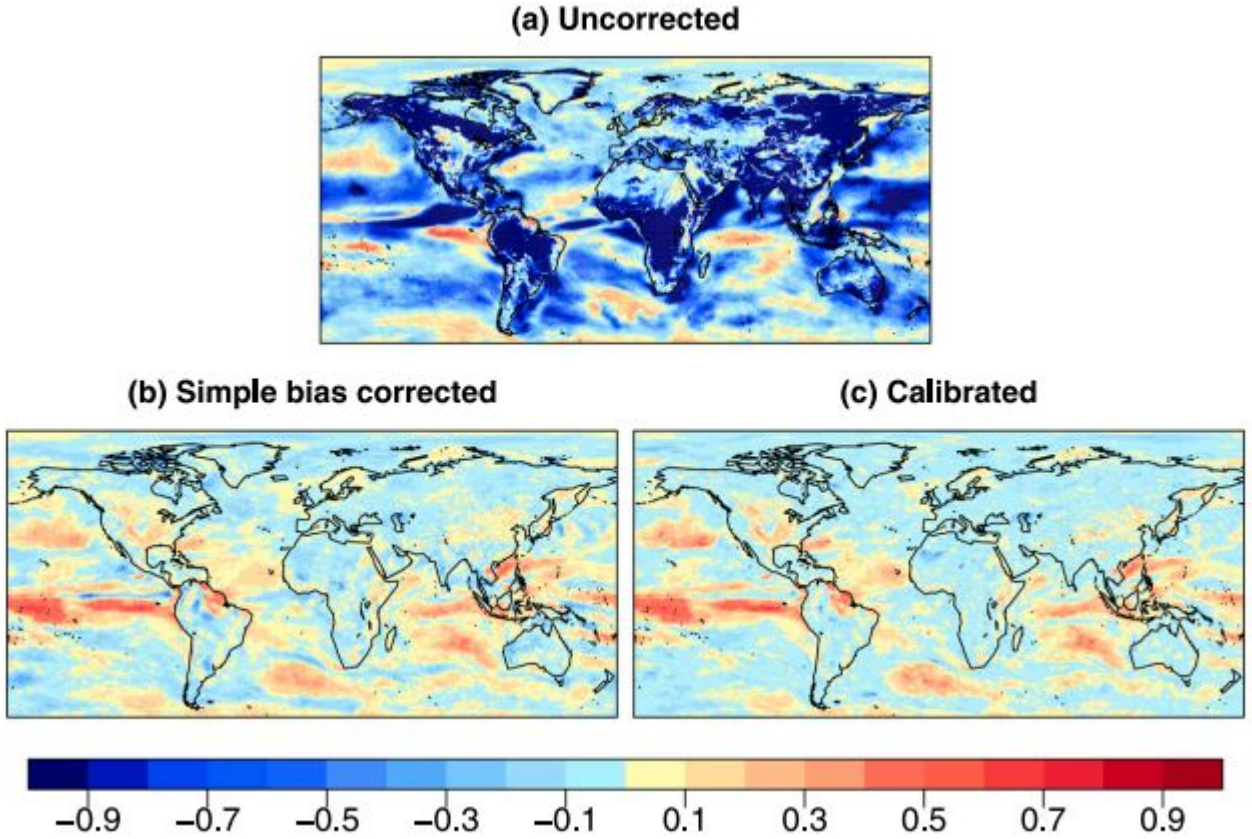


FIG. 4. Fair RPSS for tercile events of 10-m wind speed forecasts from ECMWF System 4 and ERA-Interim reanalysis in winter (DJF). These predictions have been initialized on 1 Nov for the period of 1981–2012.

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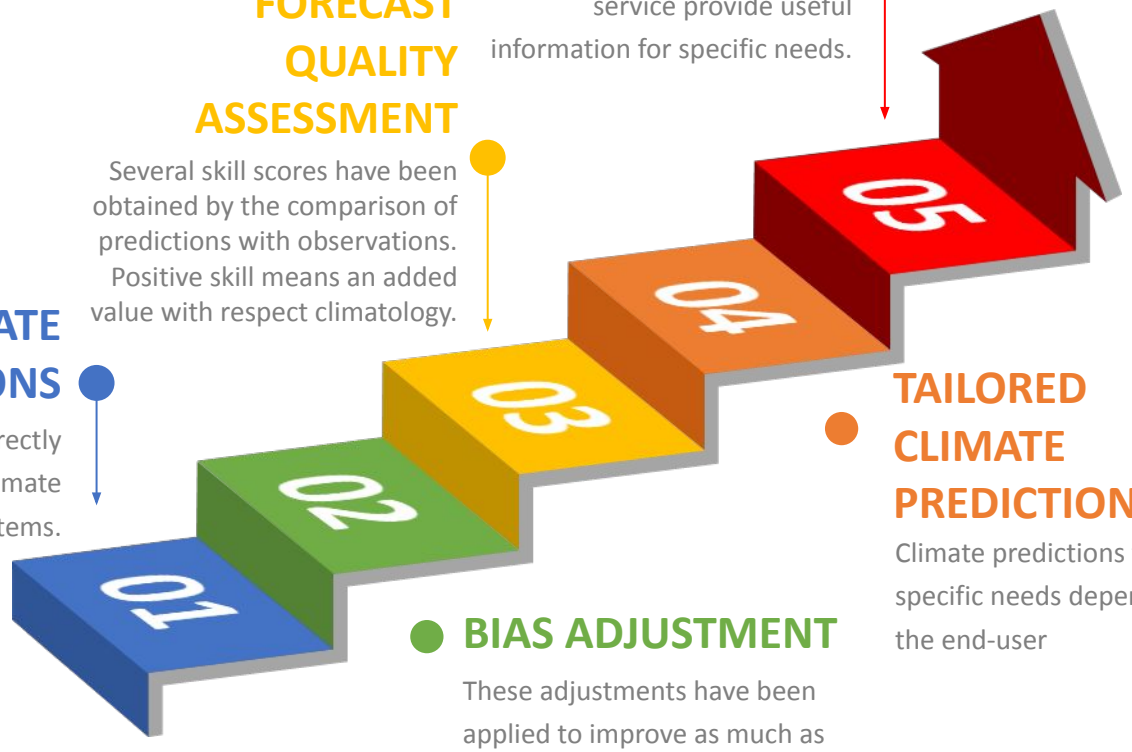
Torralba, V., Doblas-Reyes, F. J., MacLeod, D., Christel, I., & Davis, M. (2017). Seasonal Climate Prediction: A New Source of Information for the Management of Wind Energy Resources, *Journal of Applied Meteorology and Climatology*, *56*(5), 1231-1247. Retrieved Apr 9, 2021, from https://journals.ametsoc.org/view/journals/apme/56/5/jamc-d-16-0204.1.xml

Climate Forecast: From Climate data to Climate product



RAW CLIMATE PREDICTIONS

Predictions obtained directly from different climate prediction systems.

FORECAST QUALITY ASSESSMENT

Several skill scores have been obtained by the comparison of predictions with observations. Positive skill means an added value with respect climatology.

CLIMATE SERVICE PRODUCT

The final products from the service provide useful information for specific needs.

BIAS ADJUSTMENT

These adjustments have been applied to improve as much as possible reliability of the climate predictions.

TAILORED CLIMATE PREDICTIONS

Climate predictions tailored to specific needs depending on the end-user

★ Availability of climate data does not automatically imply to have access to useful climate information

★ Tools required to process climate forecast

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Climate Forecasts Analysis Tools Introduction

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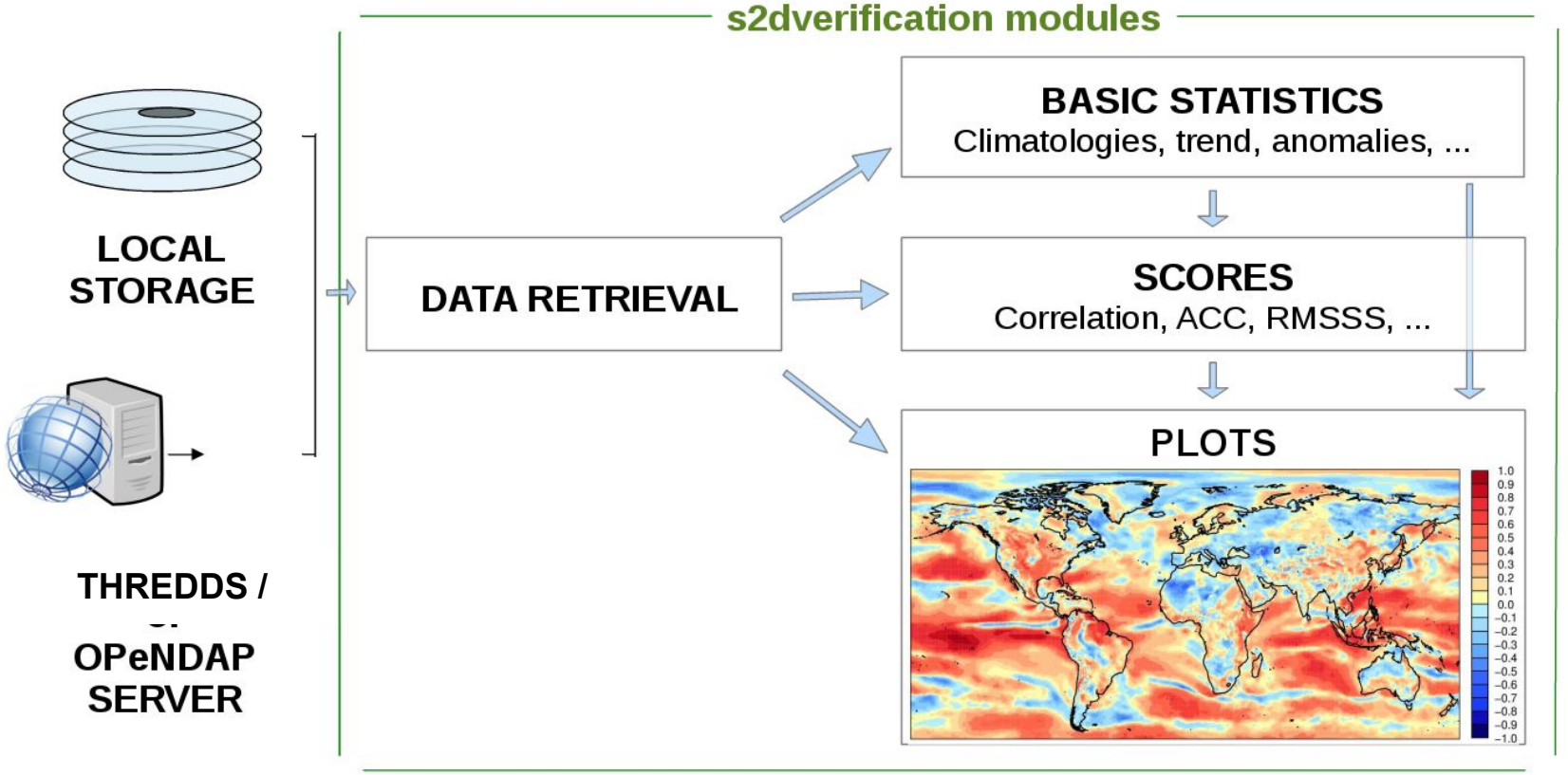
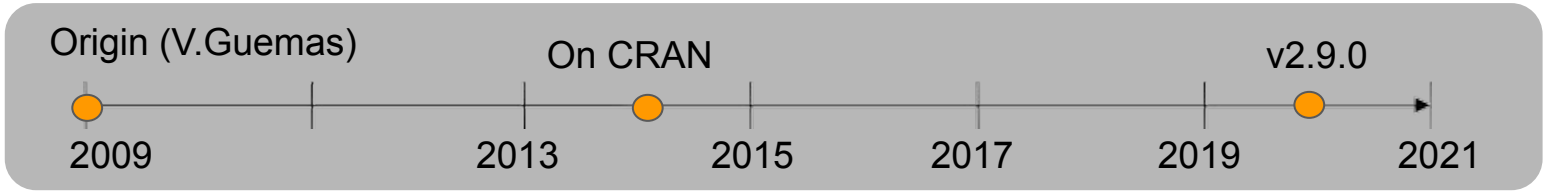
Climate Forecast Analysis Tools: Early version

- ★ 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
- ★ Common needs detected (e.g.: reading data from files and visualization tools)





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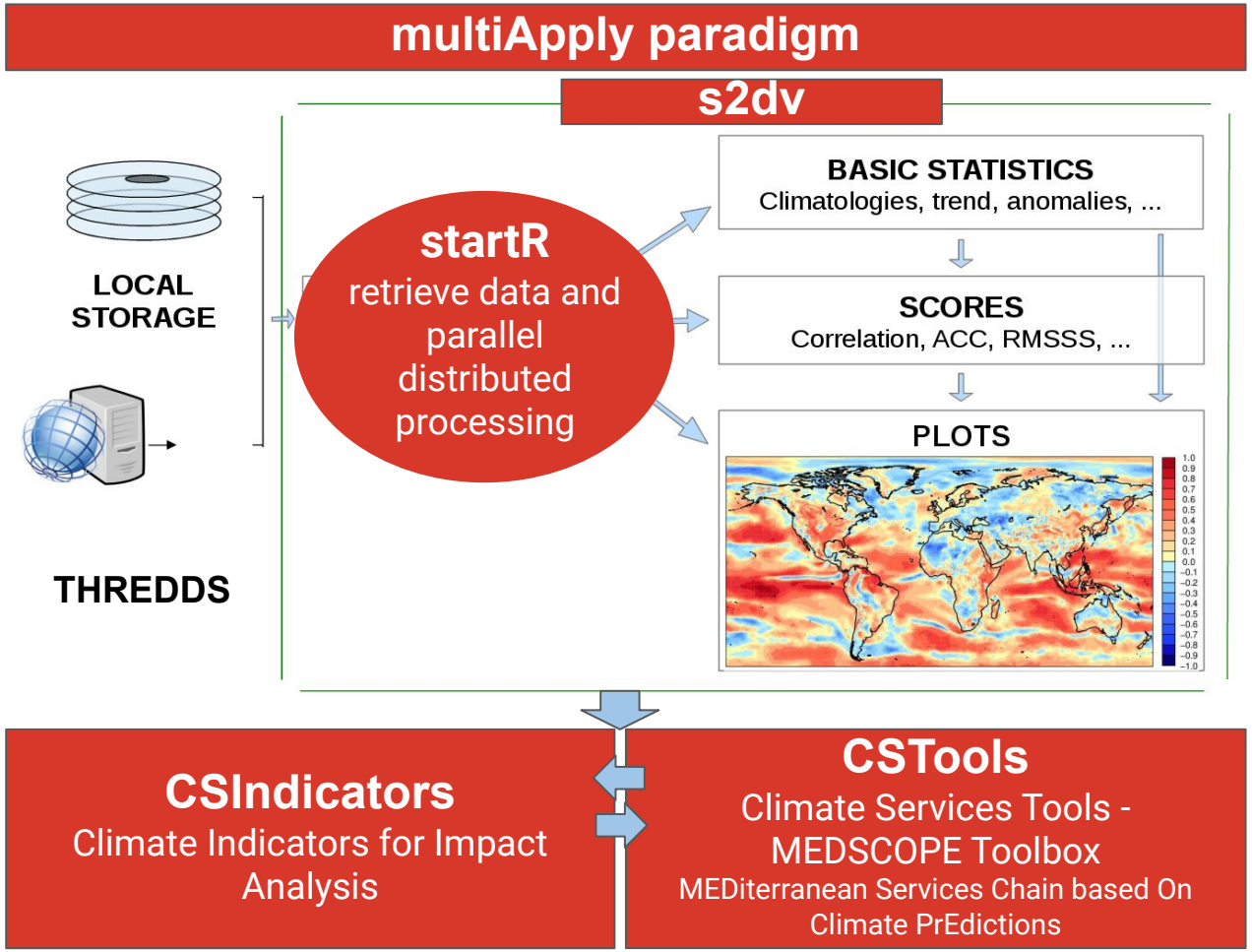
Climate Forecast Analysis Tools: Current version

- New forecast horizons to be analyzed
  - tools flexibility required
- Increase of data size (more members, finer grid resolution, multi-model analysis)
  - multi-core and multi-node analysis on HPC
- New methods to postprocess the forecast are being developed



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Climate Forecast Analysis Tools: Table of packages

- ★ Functions are split on packages depending on their objective
- ★ Functions from different packages (even external packages) can be used to perform an analysis or obtain a product

	Package name	Short description	Link to CRAN
Data manipulation	**easyNCDF**	Read/write netCDF files into/from multidimensional R array.	https://CRAN.R-project.org/package=easyNCDF
	startR	Data retrieval and processing tools	https://CRAN.R-project.org/package=startR
	multiApply	Apply functions to multiple multidimensional arrays or vectors allowing parallel computation	https://CRAN.R-project.org/package=multiApply
Analysis and processing	**s2dverification**	Functions for Forecast Verification and visualization	https://CRAN.R-project.org/package=s2dverification
	s2dv	Adaptation of s2dverification to multiApply	https://CRAN.R-project.org/package=s2dv
	CSTools	Methods for forecast calibration, statistical and stochastic downscaling, optimal forecast combination and tools to obtain tailored products.	https://CRAN.R-project.org/package=CSTools
Climate indicators	**CSIndicators**	Sectorial Indicators for Climate Service	https://CRAN.R-project.org/package=CSIndicators
	ClimProjDiags	Climate extreme indices, evaluation of the agreement between models, weight and combination functions.	https://CRAN.R-project.org/package=ClimProjDiags

Case studies

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Climate Forecast Analysis Tools: SNOWPACK

Snowpack is an essential water reservoir that is fed by snowfall during the **cold season** and then released in late spring and summer when the precipitation contribution is low and the water request has a peak.

Mountain meltwater is essential for several economic activities including **hydropower generation, agriculture, industry,** and **meltwater shortage can cause heavy economic loss**.

SNOWPACK model estimates snow depth and snow water equivalent at selected high-elevation sites.

REQUIREMENT: Postprocessed precipitation forecast

Digging a snowpit on Taku Glacier, in Alaska to measure snowpack depth and density (wikipedia)

Climate Forecast Analysis Tools: SNOWPACK

Step 1	Step 2	Step 3	Step 4
Load annual daily reference dataset in high resolution	Load daily reference datset and seasonal forecast both in the forecast grid	Get high resolution precipitation climatology	Downscaling with RainFARM
Slope	Quantile Mapping correction	RainFARM Weights	Save results
Functions from CSTools			
CST_Load CST_SplitDim CST_RFSlope	CST_Load CST_SplitDim CST_QuantilMapping	s2dv_cube CST_RFWeights	CST_RainFARM CST_SaveExp

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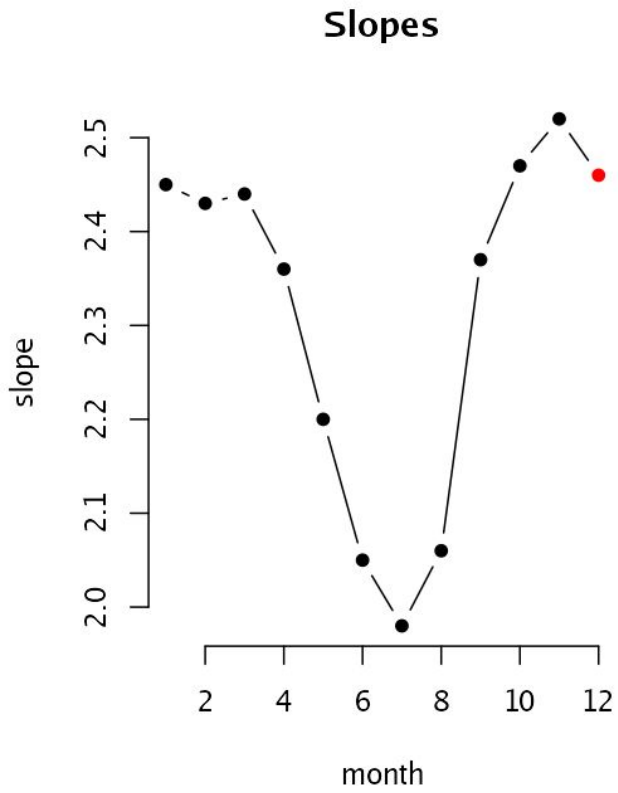
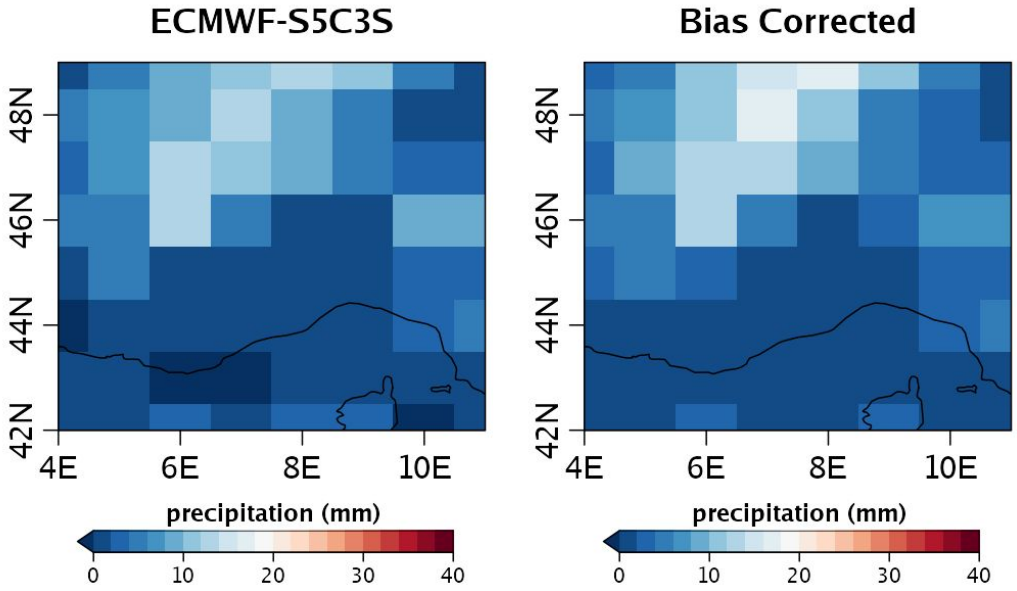
Step 1

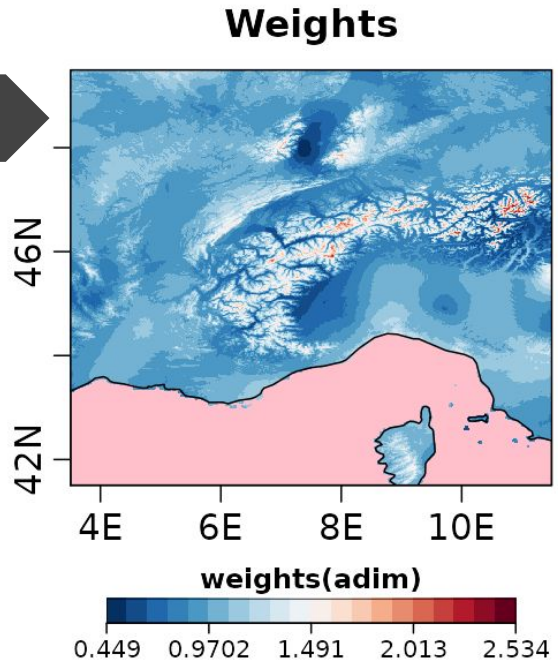


Climate Forecast Analysis Tools: SNOWPACK

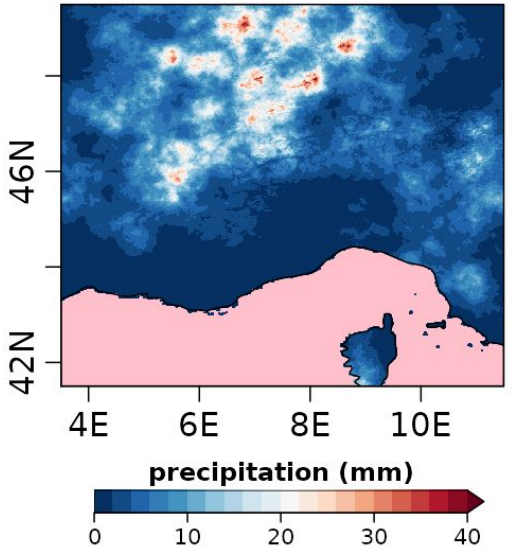


Step 2

Step 3

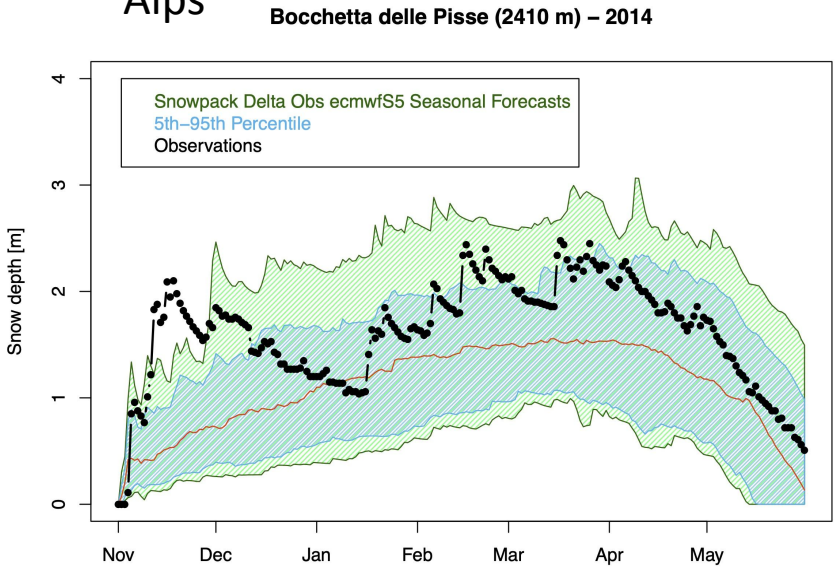


Step 4



Result

SNOWPACK model estimation of snow depth in a specific site on the Alps



★ **Using CSTools package**, the climate forecast data can be postprocessed to obtain **relevant information for the end-users.**

Development Strategy

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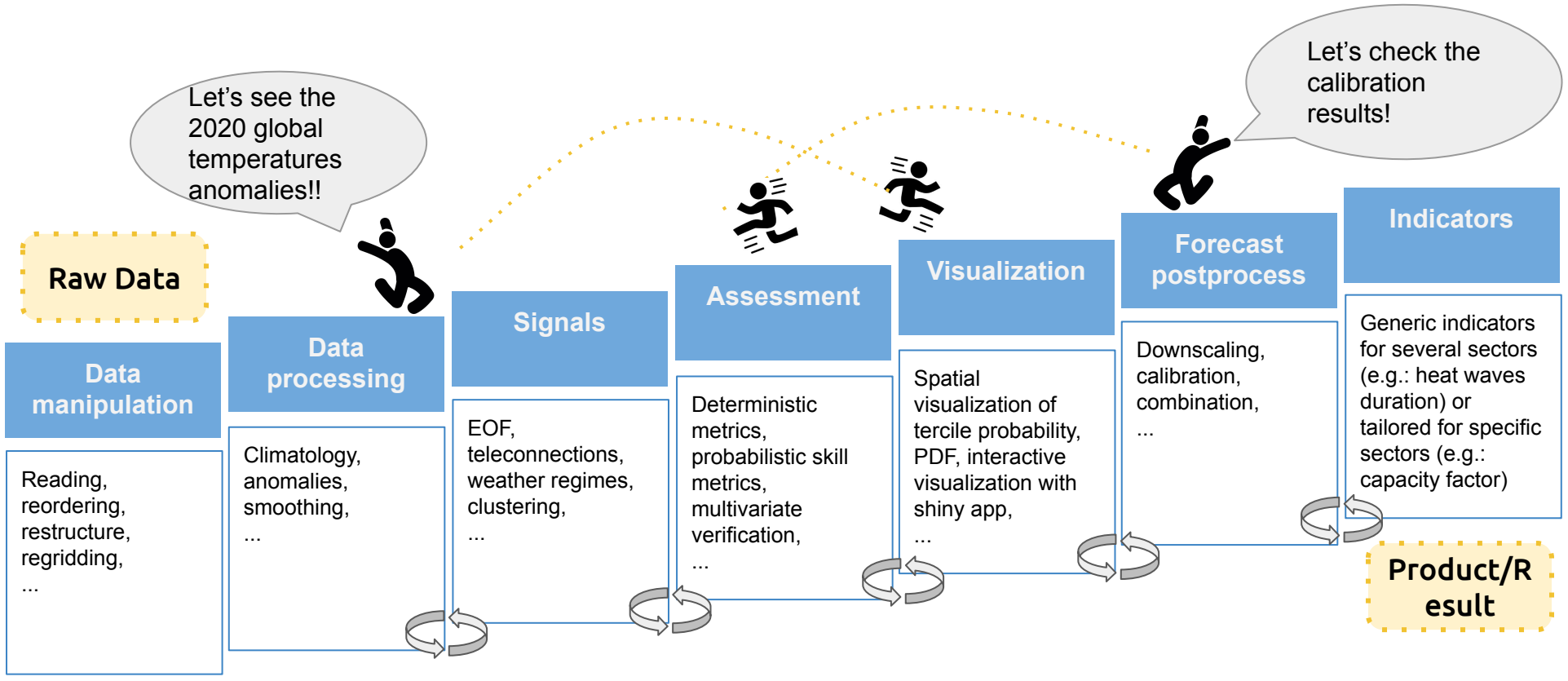
Climate Forecast Analysis Tools: Interoperability & Methods



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Climate Forecast Analysis Tools: Development Guidelines

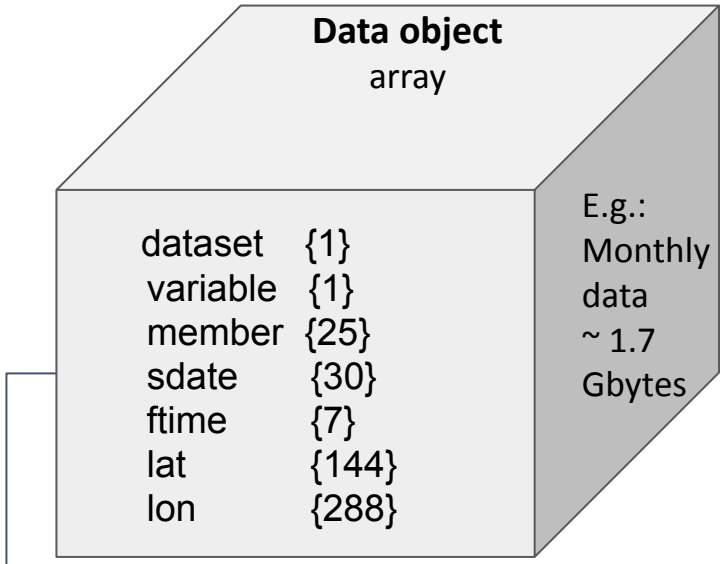
- ★ **Data** is read from (NetCDF) files on **multi-dimensional arrays with named dimensions**
- ★ The attributes of the data (**metadata**) can be also retrieved
- ★ An **atomic function** is defined working on the minimum number of dimensions required (e.g.: spatial mean requires 'lat' and 'lon' dimensions

```
sp_mean <- function(data) {
    mean(data)
}
```

- ★ Using **Apply function from multiApply package**, the function will be applied to the res of the dimensions:

```
SPMean <- function(data, ncores = 1) {
    Apply(list(data), target_dims = c('lat', 'lon'), fun = sp_mean,
          ncores = ncores)
}
```

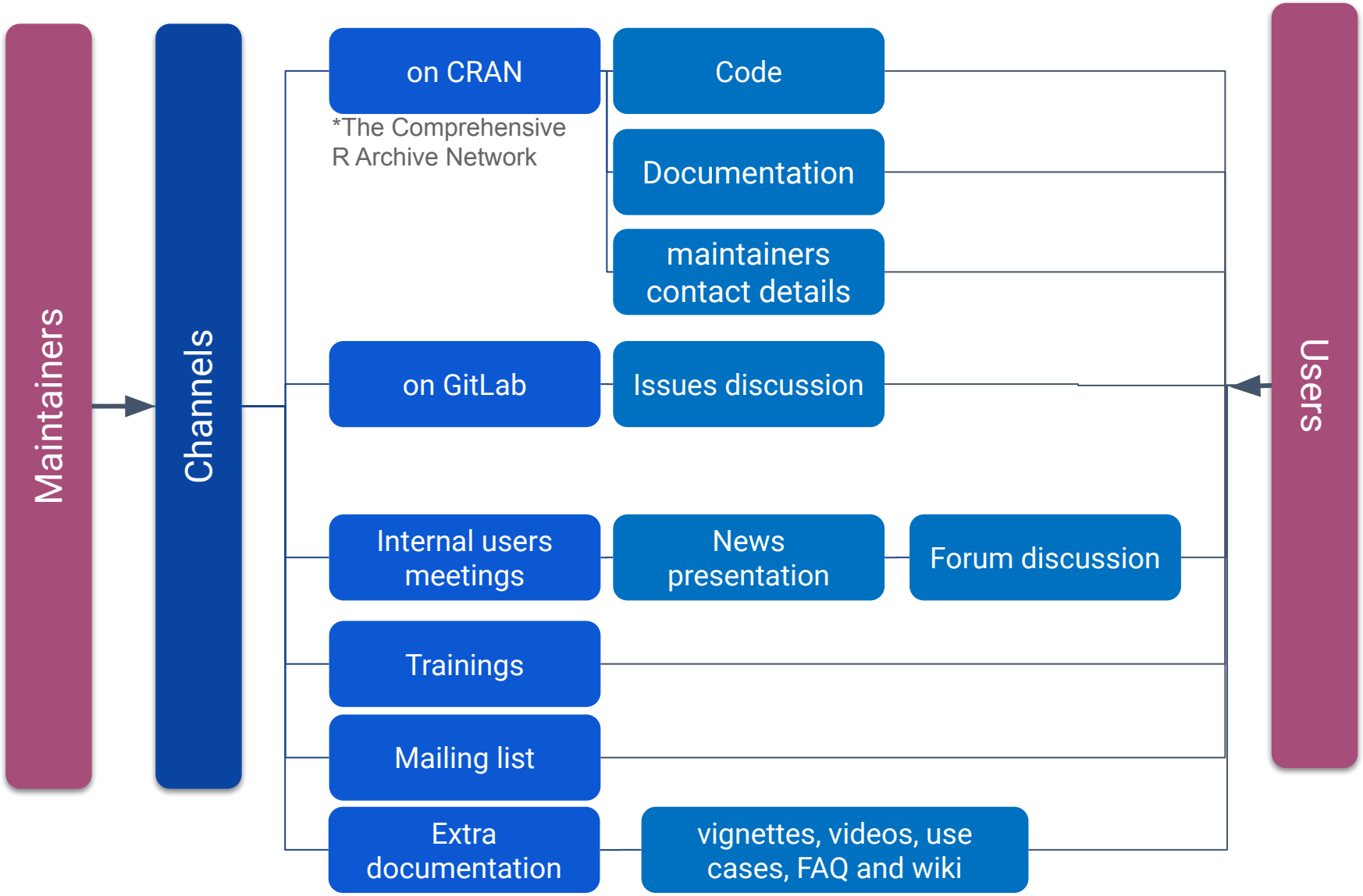
- ★ Parameter 'ncores' allows **parallel computing**
- ★ Extra guidance (e.g.: **checks, formatting, automatic tests, etc.**) is provided in the development guidelines



Metadata
List of information that characterizes the data:

- longitudes
- latitudes
- grid type
- time steps
- calendar
- model name
- model version
- variable name
- variable units

Climate Forecast Analysis Tools: Users support



https://earth.bsc.es/wiki/doku.php?id=tools:Rtools&s[]=Rtools

Climate Forecast Analysis Tools: Vignettes

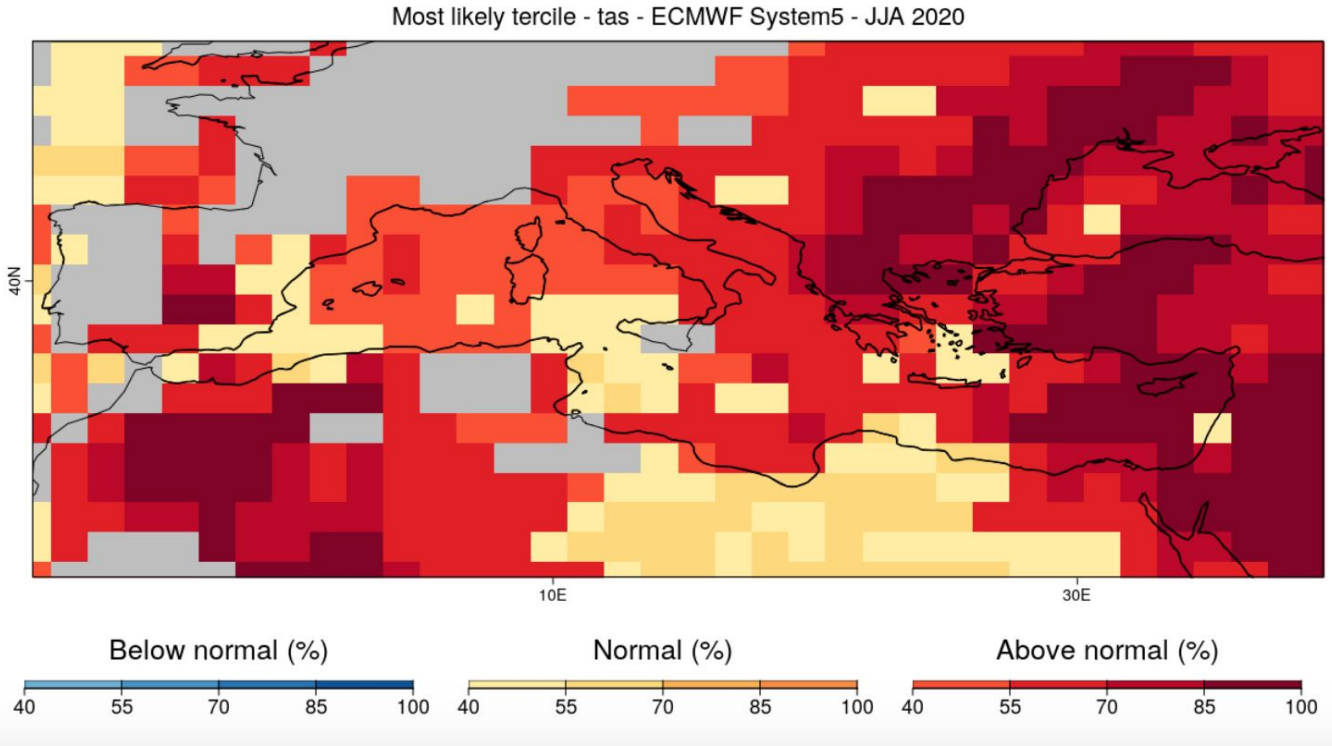
6. Simultaneous visualization of probabilities and skill scores

From the RPSS, we create a mask: regions with RPSS <= 0 will be masked.

```
mask_rpss <- RPSS[[1]]
mask_rpss[RPSS[[1]] <= 0] <- 1
mask_rpss[is.na(RPSS[[1]])] <- 1
mask_rpss[RPSS[[1]] > 0] <- 0
```

Finally, we plot the latest forecast, as in the previous step, but add the mask we just created.

```
PlotMostLikelyQuantileMap(probs = prob_map, lon = Lon, lat = Lat, coast_width = 1.5,
                          legend_scale = 0.8, mask = t(mask_rpss),
                          toptitle = paste('Most likely tercile -', clim_var,
                                           '- ECMWF System5 - JJA 2020'))
```



★ R packages allow to share a document including text, code and figures called **vignettes**.

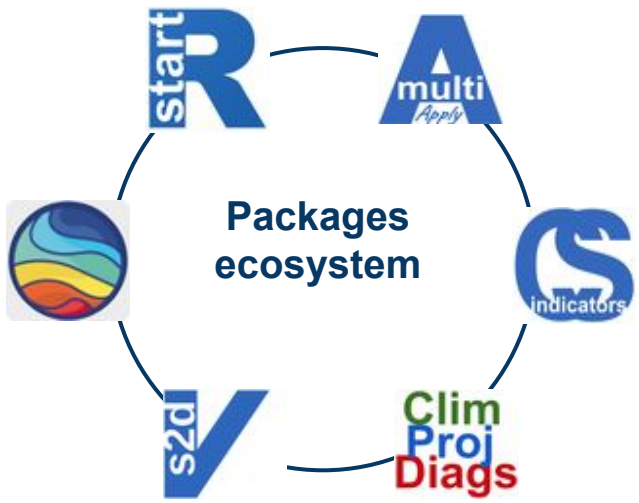
★ Users and researchers can follow them to obtain learn on how to use the tools or reproduce an example.

E.g.: Computing and displaying the most likely tercile of a seasonal forecast

See https://cran.r-project.org/web/packages/CSTools/vignettes/MostLikelyTercile_vignette.html

Climate Forecast Analysis Tools: Successful research

★ **R tools are being used in several research lines and operationals**



Research line	Projects	Publication e.g.
In-situ observations	Indecís, S2S4E	Tall towers and reanalysis Ramon et al. 2019
Atmospheric Composition	Ongoing collaboration in CALIOPE-Urban	
Sub-seasonal Forecast	S2S4E VITIGEOSS	Verification Manrique et al. 2020
Seasonal Forecast	S2S4E, Visca, Medscope, INTAROS, Medgold QA4Seas	Wind power generation Lledó et al., 2019
Decadal Predictions	EUCP, C3S 34c	CMIP6 Assessment Bilbao et al. 2021
Climate Projections	C3S MAGIC	ESMValTool papers: python and R synergy

Climate Forecast Analysis Tools: Last Remarks

The tools …

- ★ Don’t need to be use all at once
  - E.g.: Users can choose only to load the data but not use the methods
- ★ Common needs are a priority
  - E.g.: Calculating climatologies is common but exploring new methods can be done by the users

Future work

- ★ Special focus on the retrieving step which is a common need
  - E.g.: Increase the flexibility when retrieving multi-dimensional datasets
- ★ Keep increasing the quality of the support
  - E.g.: Exploring to create a readthedocs to allow searching for in-house functions
- ★ Collaborating with users to understand their needs

Climate Forecast Analysis Tools: Successful research

Data providers

Climate Change Service
climate.copernicus.eu

Subseasonal-to-Seasonal S2S Prediction Project

NOAA

Tools

multiApply

AUTOSUBMIT

startR

s2dv

CS indicators

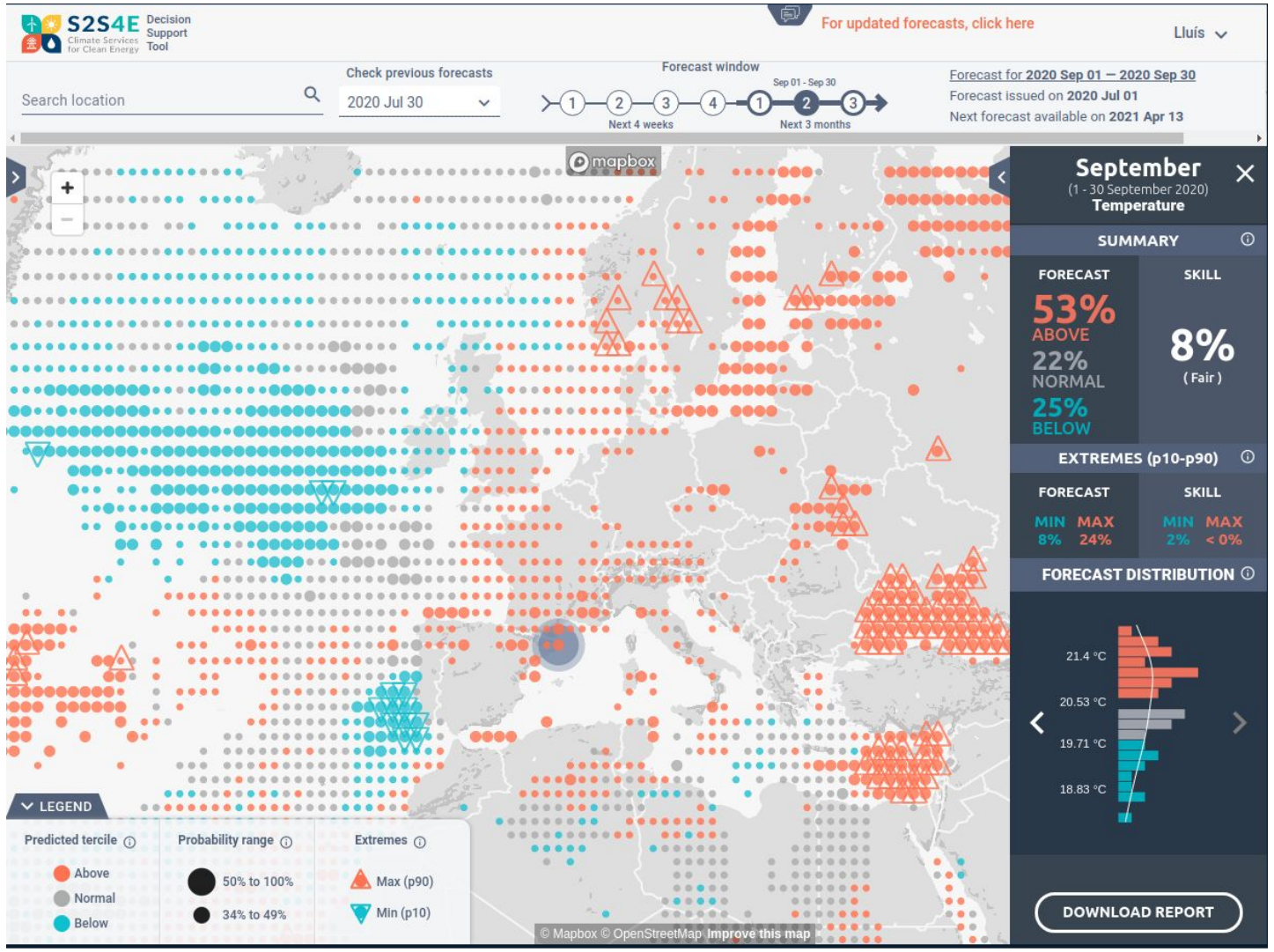
Services provided

S2S4E Climate Services for Clean Energy

VISCA VINEYARDS INTEGRATED SMART CLIMATE APPLICATION

VITI GEOSS

MED-GOLD



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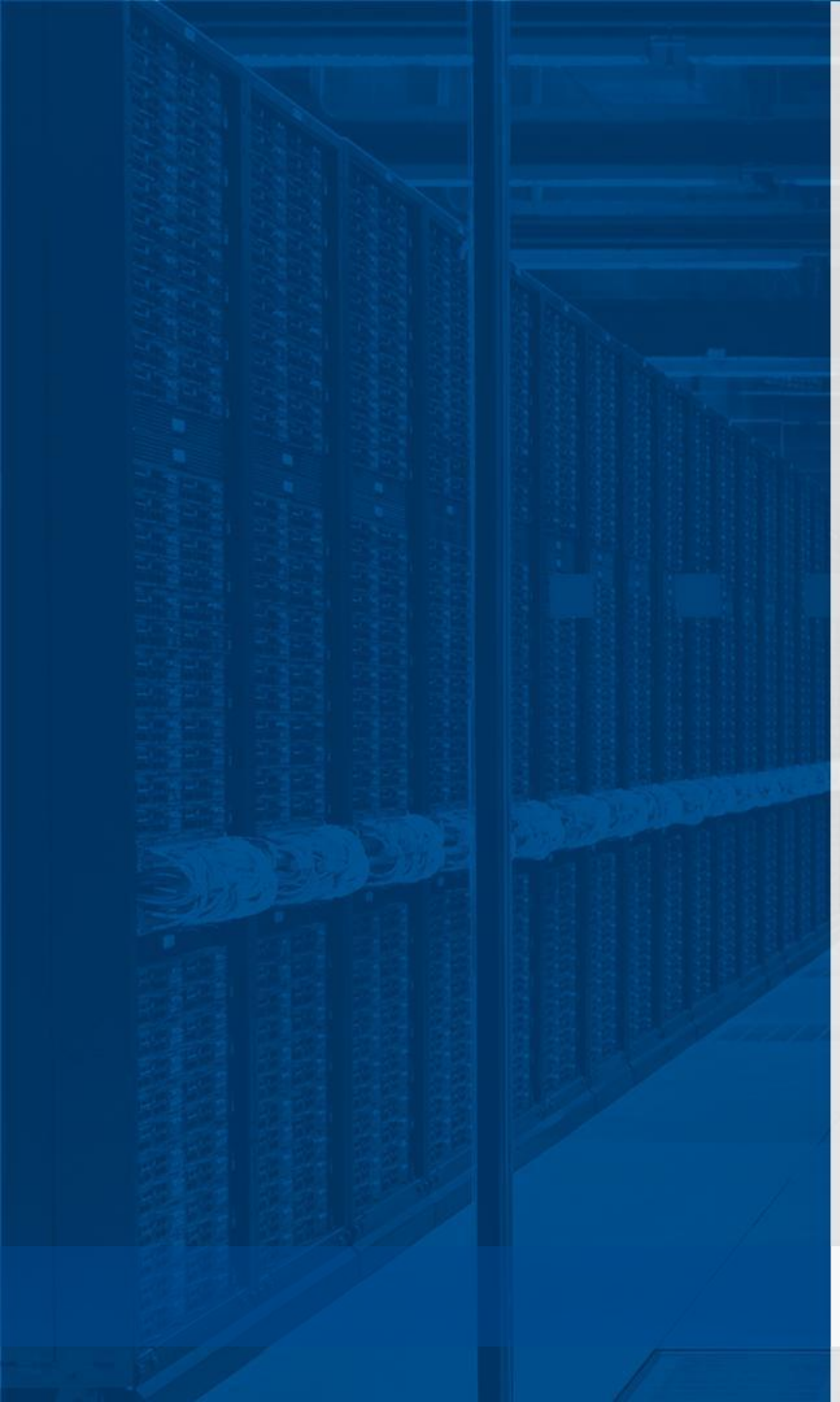

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Thanks for your attention and thanks to all contributors to the tools!

Contact

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- **An-Chi Ho** (an.ho@bsc.es)

Questions?