HARMONIZE

clim4health: a new R package to harmonize climate datasets for health impact studies

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HARMONIZE toolkit course, November 2025

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

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Session Outline

9.30	Presentation
10.00	Hands on tutorial - workflow 1: downscaling and skill assessment
11.00	Coffee break?
11.30	Hands on tutorial - workflow 2 and 3: spatio-temporal aggregation, calibration and masking
12.30	End of session

Aims of the tutorial

1. Understand sources of climate data
2. Learn how to load climate data into R using clim4health
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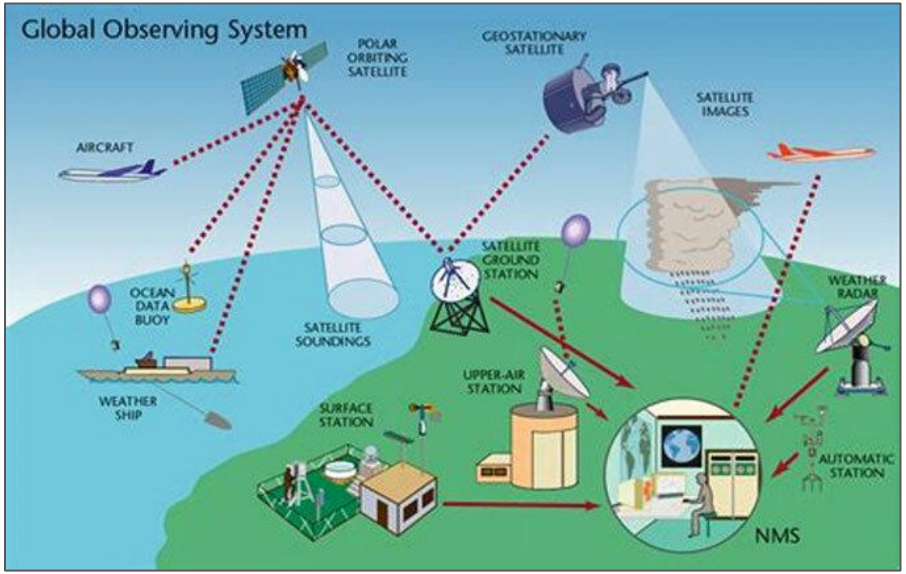
Is anyone familiar with climate data?

Observations

Direct observations come from many sources:

- Satellites
- Radar
- Meteorological stations
- Aircraft and balloons
- Buoys
- ... more!

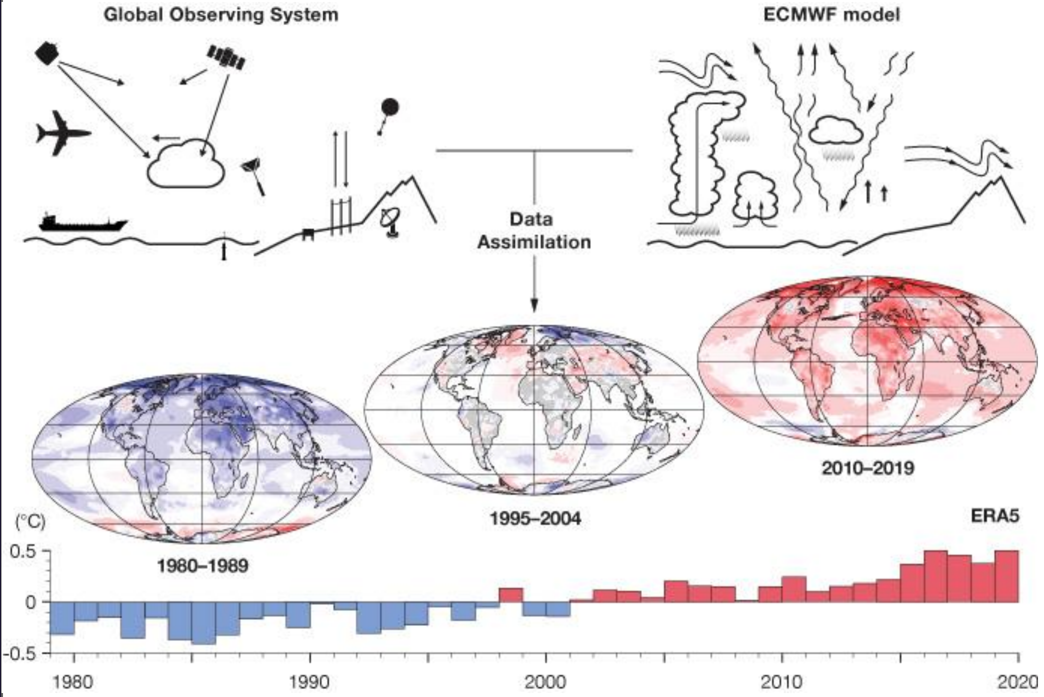


Reanalysis

Reanalysis is a type of "observation":

- We run a climate model and "nudge" (adjust) it towards historical observations
- physically consistent
- temporally/spatially gridded
- can provide estimates of variables that were not directly observed

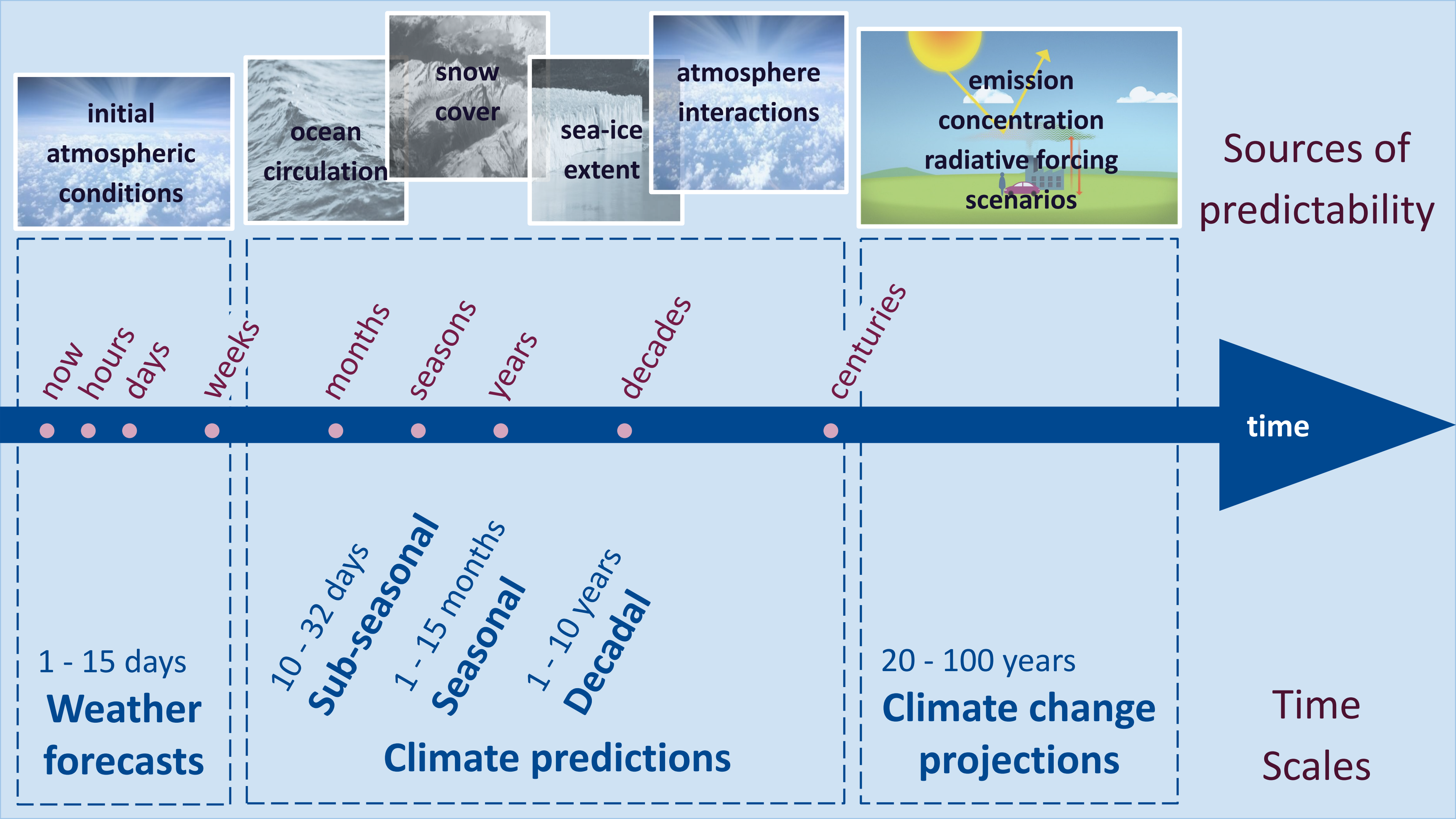
Note: in regions where direct observations are limited, reanalyses are more model-driven.

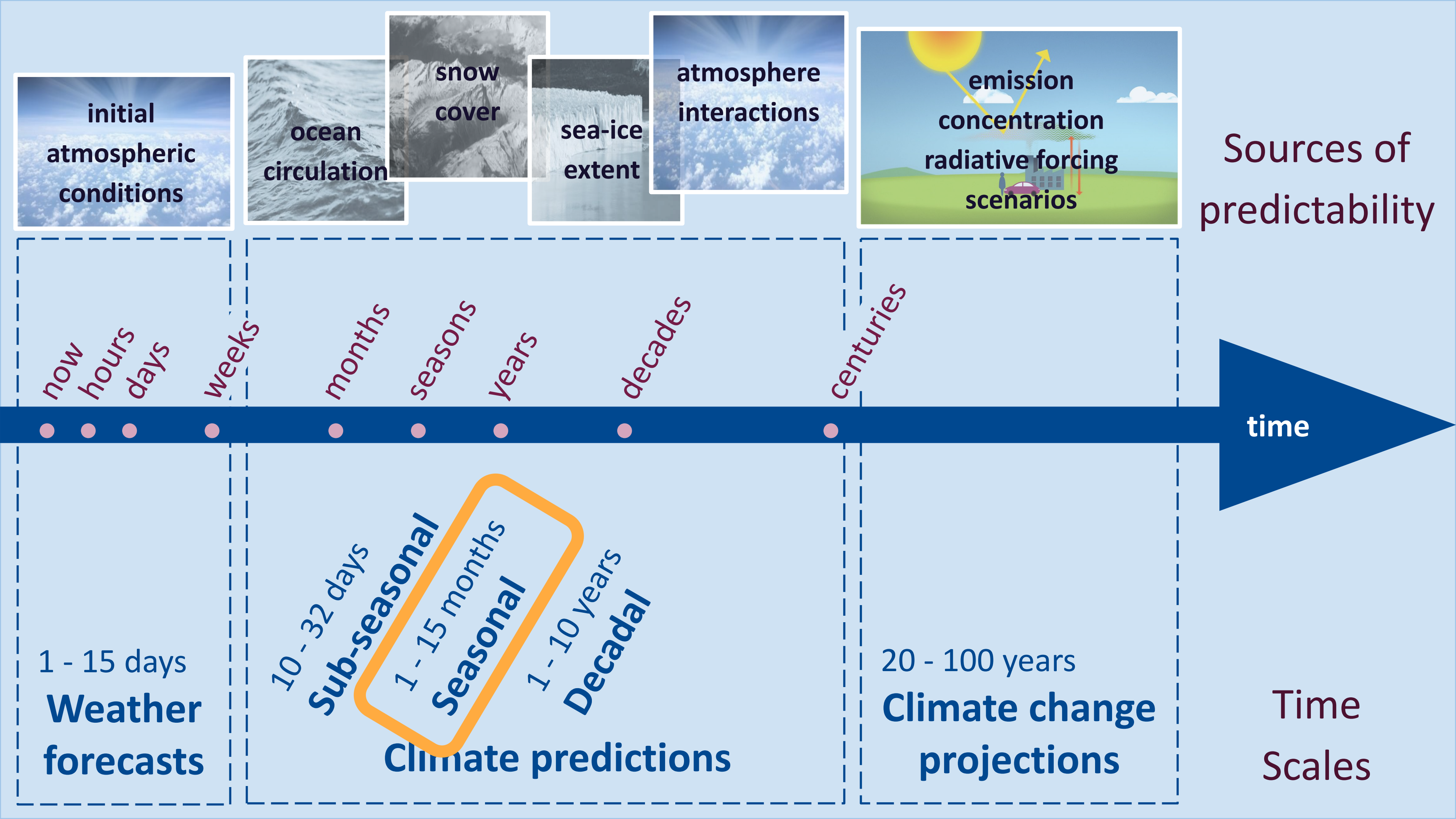


Predictions and Projections

These are model-based predictions of *future* climate.

- They are available at different timescales.
- They contain ***ensemble members*** that help us to capture some of the uncertainty in the predictions.
- Predictability comes from different sources…


initial atmospheric conditions
ocean circulation
snow cover
sea-ice extent
atmosphere interactions
emission
concentration
radiative forcing
scenarios
Sources of predictability
now
hours
days
weeks
months
seasons
years
decades
centuries
time
1 - 15 days
Weather forecasts
10 - 32 days
Sub-seasonal
1 - 15 months
Seasonal
1 - 10 years
Decadal
Climate predictions
20 - 100 years
Climate change projections
Time Scales



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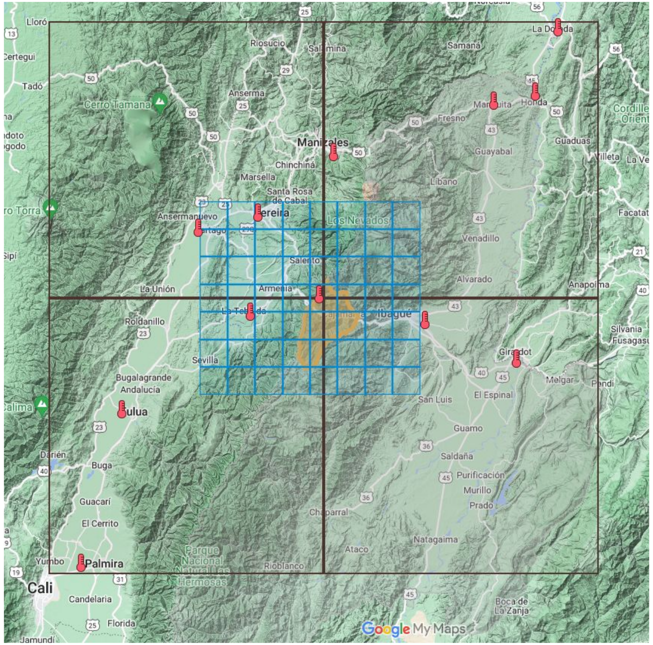
projections
Time
Scales

Example sources of climate data

	Seasonal forecast	Reanalysis		Ground-based observations
		ERA5	ERA5Land	
Centre/ System	ECMWF-SEAS5.1	Copernicus	Copernicus	Global Integrated Surface Database (ISD)
Spatial resolution	1° x 1° (~100km)	0.25° x 0.25°	0.1° x 0.1° (~10km)	Point data
Temporal frequency	6h, 12h, 24h, monthly statistics			Hourly
Temporal range	1981 - present (hindcast period = 1994-2016)	1979 - present	1950 - present	1901 - present



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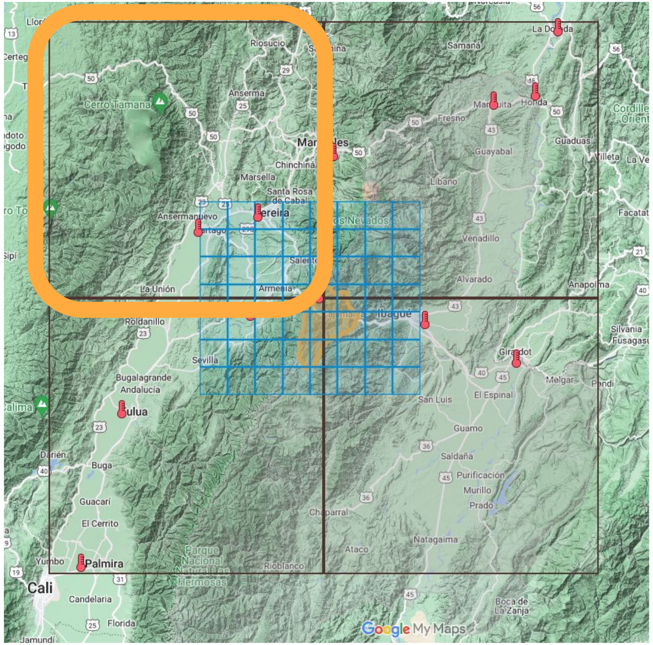

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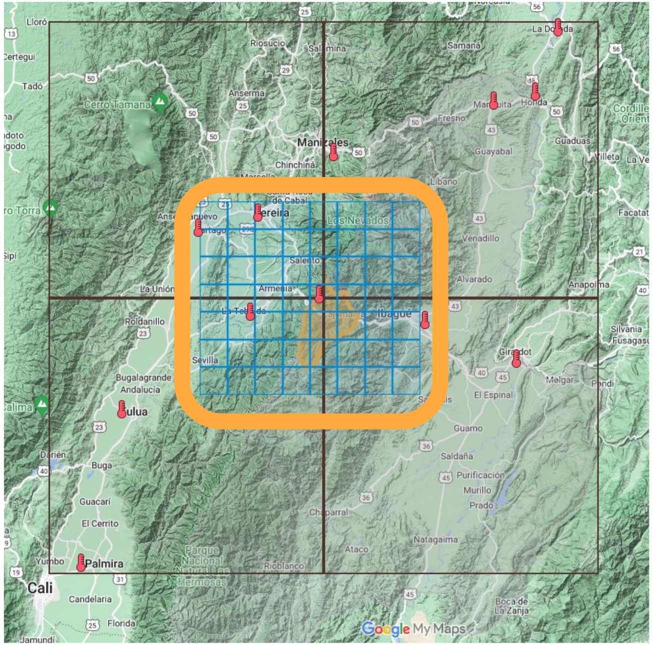

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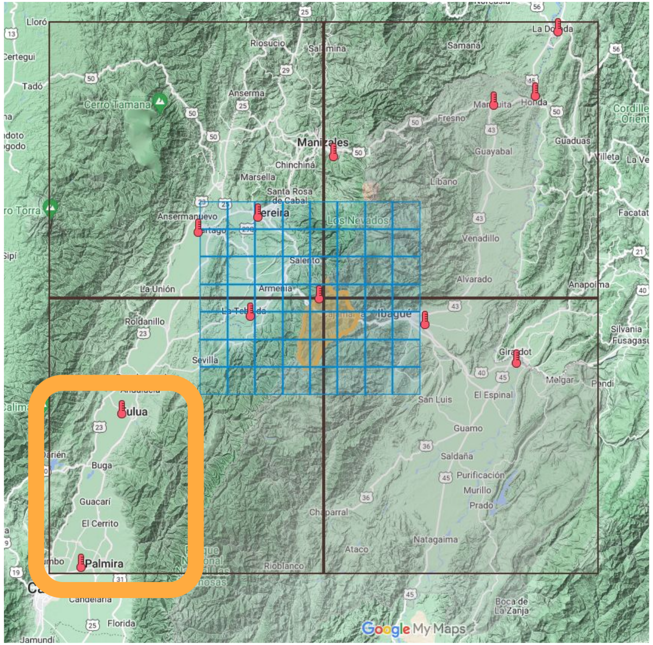


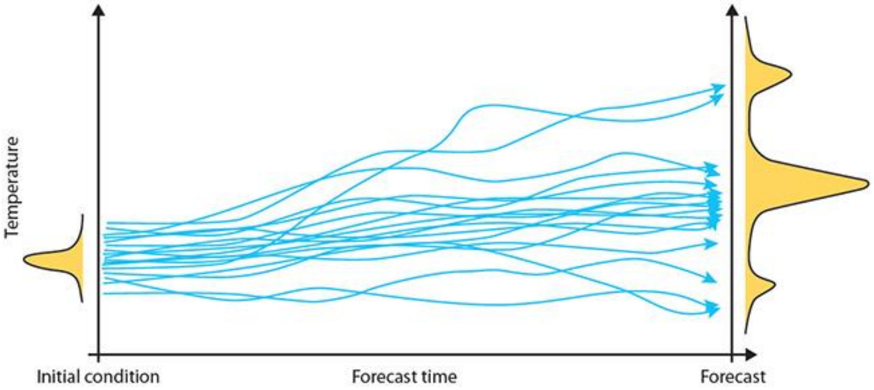
Hindcasts and ensembles

Hindcasts (past forecasts) are forecasts initialised in the past.

- Used to compare how well the forecast model predicts actual observed values.
- Allow us to quantify model **skill** - we do this by comparing the hindcast to the observations.

Ensemble members capture the envelope of uncertainty.

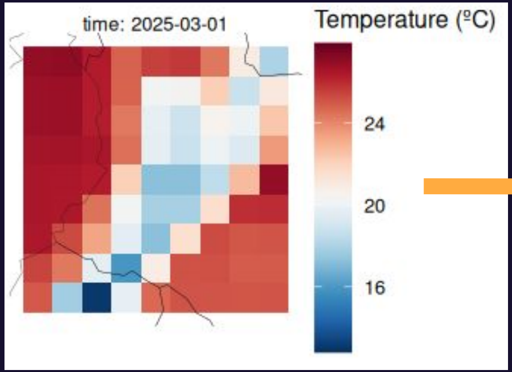
- Climate models are run with multiple slightly different initial conditions.

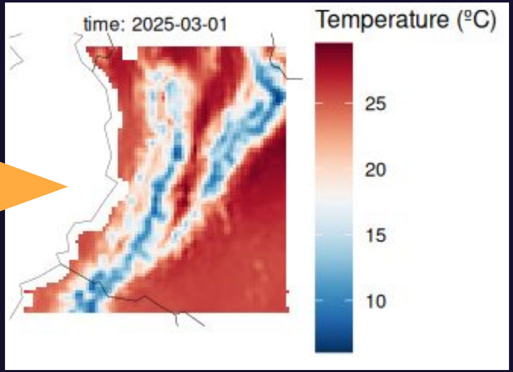


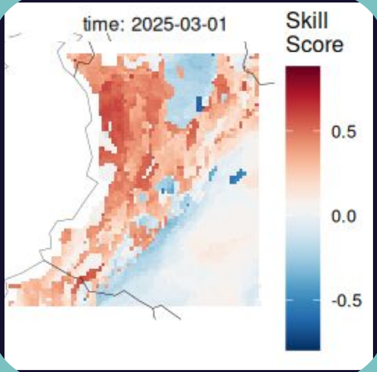
Downscaling and verification

We can identify statistical relationships between observations and hindcasts to **downscale** a forecast to finer spatial resolution

We can identify statistical relationships between observations and hindcasts to **assess the quality** of a forecast model







clim4health package structure

obtain input data

optional use

c4h_get
download climate data (reanalysis, observations and seasonal forecasts) from the Copernicus Climate Data Store

c4h_load
load data into R object and start to work with the data

transform

apply one or several in the desired order

c4h_space
spatial aggregation

c4h_time
temporal aggregation (from daily to weekly to monthly to annual)

c4h_downscale
calibration/downscaling

c4h_postprocess
verification and quality assessment

c4h_index
calculation of simple indices (threshold based)

prepare outputs

c4h_convert
transform s2dv to common formats

c4h_plot
visualise and save png

c4h_save
save as csv or grid

UTILS
additional helper functions

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Loading data

c4h_load: load climate data from netCDF or csv file format into an s2dv_cube object

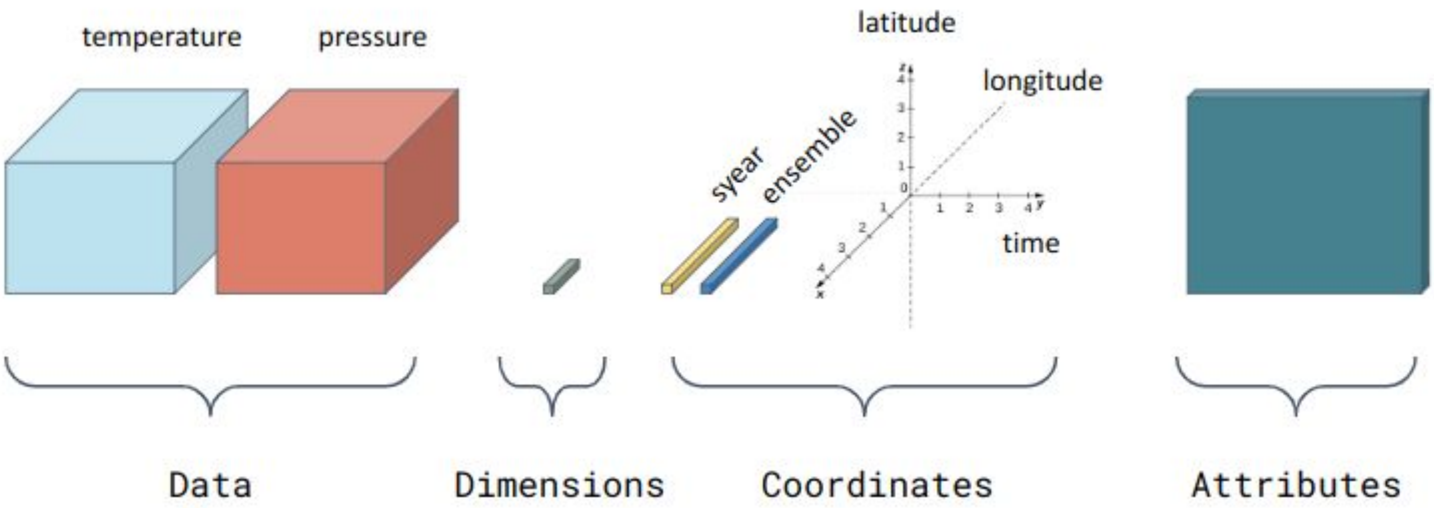
```
{r}
#| include: false
fcst <- clim4health::c4h_load(path = fcst_path,
                               variable = "t2m",        # variable to load
                               year = 2025,             # forecast initialisation year
                               month = 1,               # forecast initialisation month
                               leadtime_month = 1:3,    # load leadtimes 1-3
                               ext = "nc")              # file extension
```

- Key point: specify the dates and times using arguments “year”, “month”, “day”, and “time”
- Specify forecast leadtimes with “leadtime_month”
- We can use further parameters such as “bbox” to specify the region we want to load
- Output: an **s2dv_cube**

The s2dv_cube object

- Climate data is highly dimensional - often includes *latitude*, *longitude*, *time*, as well as potentially others such as *ensemble*, *height*

- It contains the climate variables, their dimensions, the coordinates, and any additional information



Exploring the data

- **dataset** — experiments, usually = 1
- **var** — loaded variables
- **sdate** — (forecast) initialisation time
- **time** — (forecast) lead time
- **ensemble** — model ensemble member
- **spatial dimension(s)**
  - latitude + longitude (gridded data)
  - location (point data)
  - area (polygon data)

clim4health always works with climate data in these dimensions

Exploring the data

Useful commands

str(fcst) — prints extended information about the elements of the s2dv_cube

dim(fcst$data) or fcst$dims — prints the dimensions of the data

```
print("print fcst class")
class(fcst)
print("print dimensions of the stored data")
dim(fcst$data)
print("print the names of the list elements in fcst")
names(fcst)
print("print a summary of the data stored in fcst")
summary(fcst$data)
print("print extended information about the list elements in fcst")
str(fcst)
```

```
[1] "print fcst class"
[1] "s2dv_cube"
[1] "print dimensions of the stored data"
  dataset       var     sdate      time  ensemble  latitude longitude
        1         1         1         3        51         5         5
[1] "print the names of the list elements in fcst"
[1] "data"   "dims"   "coords" "attrs"
```

How to specify time in c4h_load()

- **year** = 1994:2016
- **month** = 1
- **day** = 1
- **leadtime_month** = 1:3

chooses all the possible start (initialisation) dates. These will be the first elements in the time dimension

chooses how many months should be loaded in the time dimension

sdate = forecast start **date**

	time		
sdate	1994-01-01	1994-02-01	1994-03-01
	1995-01-01	1995-02-01	1995-03-01
	1996-01-01	1996-02-01	1996-03-01
	...	...	...
	2016-01-01	2016-02-01	2016-03-01

- year = 1994:2016
- month = 1:2
- day = 1
- leadtime_month = 1:3

chooses all the possible start (initialisation) dates. These will be the first elements in the time dimension

chooses how many months should be loaded in the time dimension

	time		
sdate	1994-01-01	1994-02-01	1994-03-01
	1994-02-01	1994-03-01	1994-04-01
	1995-01-01	1995-02-01	1995-03-01
	1995-02-01	1995-03-01	1995-04-01
	...	...	...
	2016-01-01	2016-02-01	2016-03-01
	2016-02-01	2016-03-01	2016-04-01

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Temporal aggregation

c4h_time: aggregate climate data to coarser temporal resolutions (e.g. hourly to daily, daily to weekly or monthly)

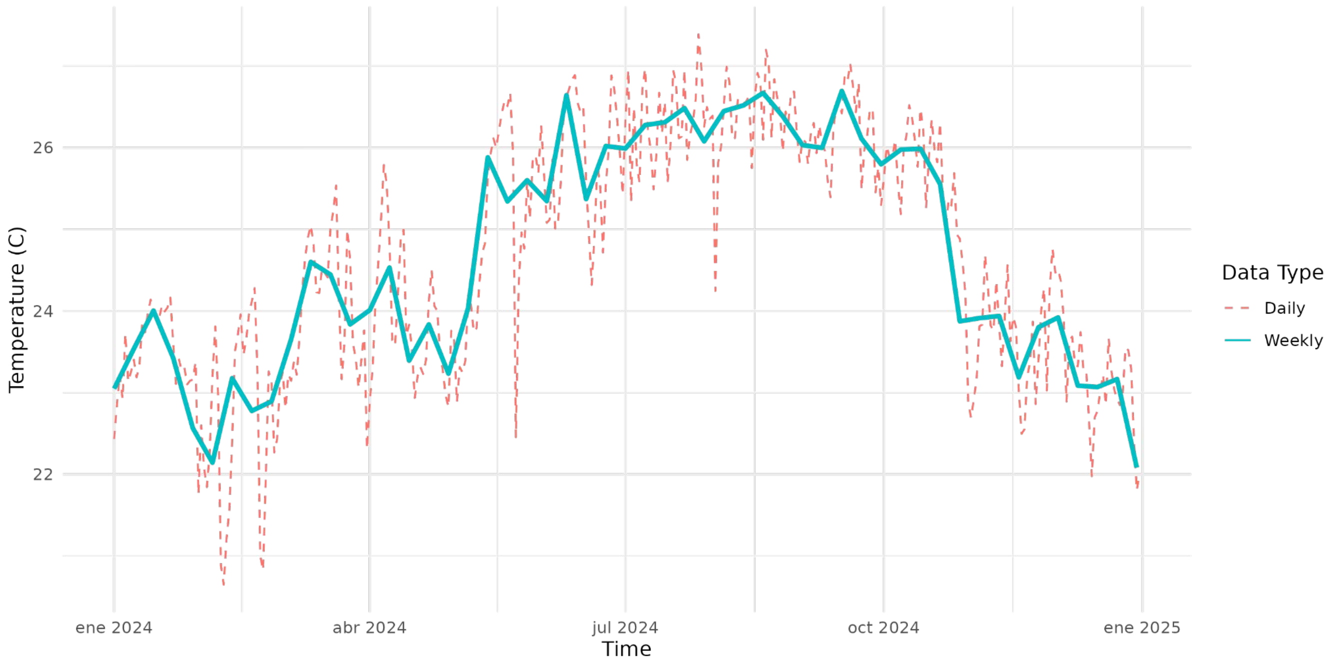
```r
{r}
obs_daily_mean <- clim4health::c4h_time(data = obs,
                                        time_aggregation = "daily",
                                        fun = "mean",
                                        dim_aggregation = "time")

dim(obs_daily_mean$data)

print(obs_daily_mean$attrs$Dates[1:10])
```

```
  dataset       var     sdate      time  ensemble  latitude longitude
        1         1         1        93         1        11        11
 [1] "2011-01-01 UTC" "2011-01-02 UTC" "2011-01-03 UTC" "2011-01-04 UTC" "2011-01-05 UTC"
"2011-01-06 UTC"
 [7] "2011-01-07 UTC" "2011-01-08 UTC" "2011-01-09 UTC" "2011-01-10 UTC"
```

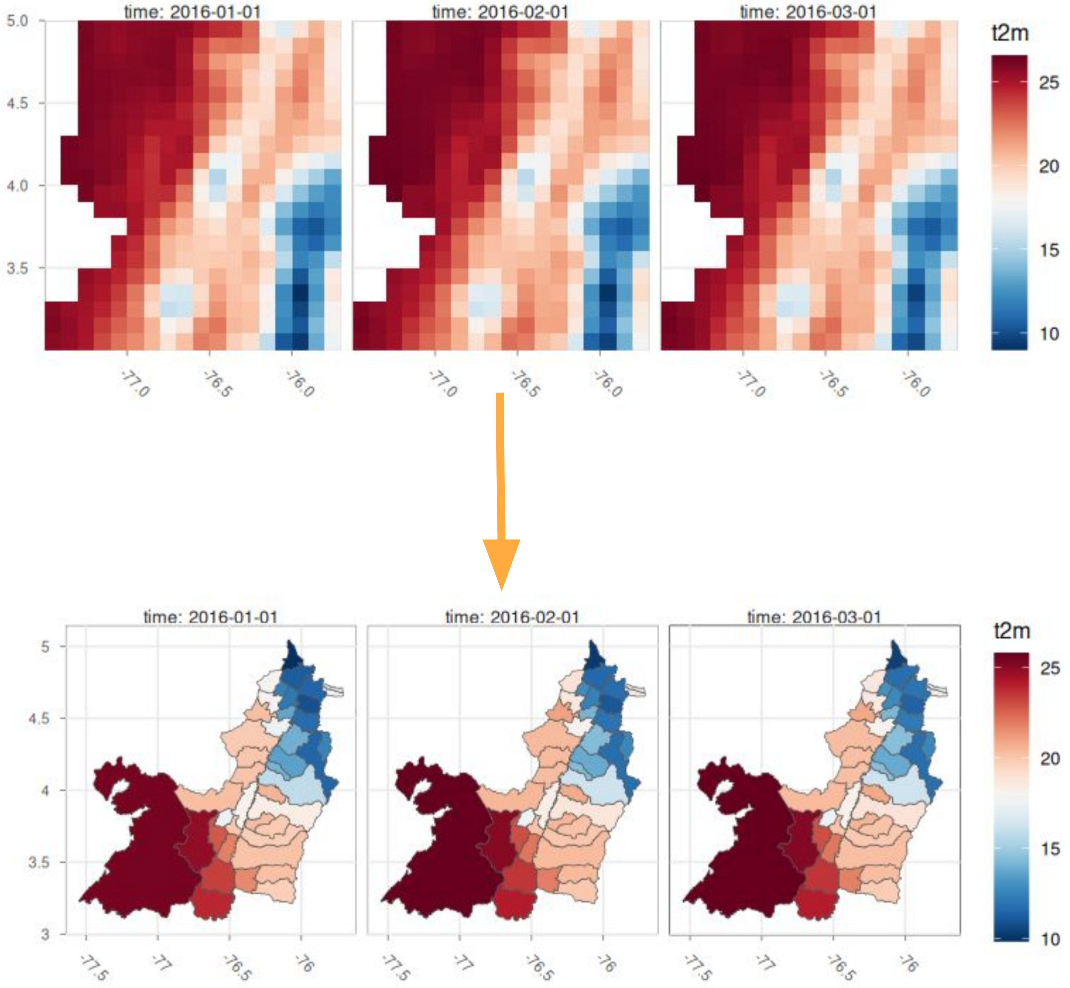
Temporal aggregation



Spatial aggregation

c4h_space: aggregate gridded climate data to spatial polygons

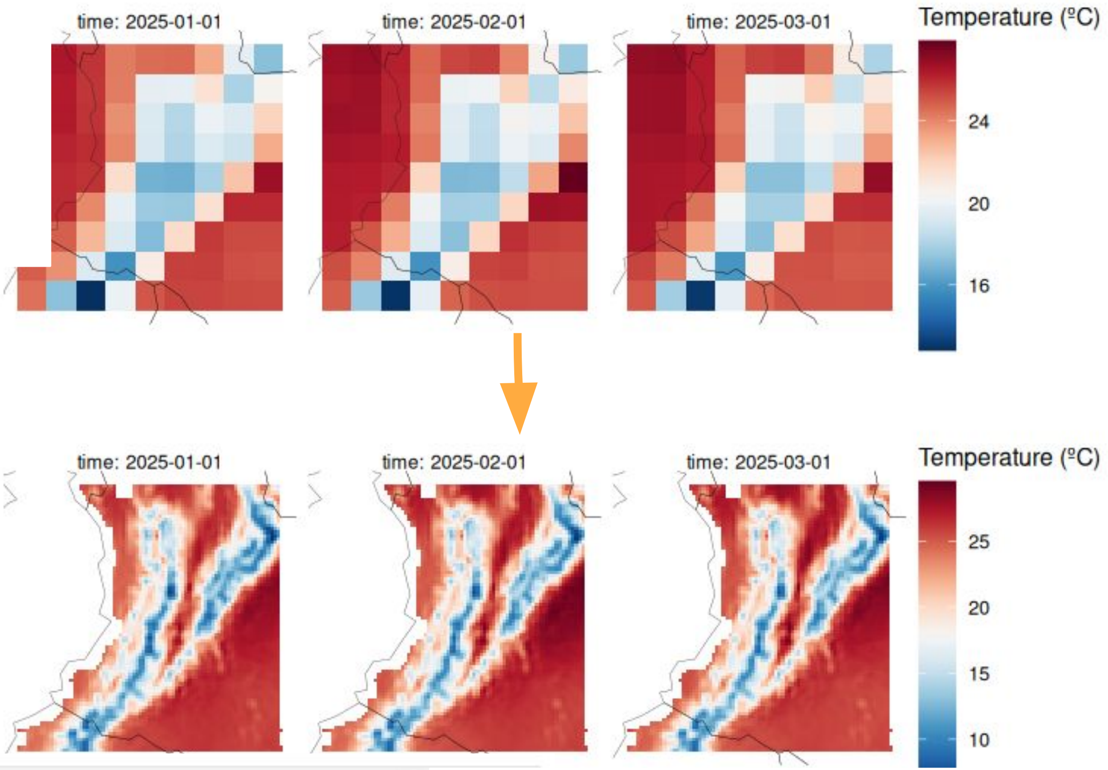
```
{r}
obs_agg <- c4h_space(obs,
                     areas = shp_path,
                     fun = "mean",
                     weighting = "none",
                     areas_id = "munip_code")
```



Downscaling

c4h_downscale: downscale climate data to finer spatial resolutions (often using observations to adjust the data)

- there are 4 main methods included in **c4h_downscale**
- it is designed to provide helpful notes and messages when it is used




```r
{r}
dwn <- c4h_downscale("Intbc", exp = hcst, obs = obs,
                     bc_method = "evmos",
                     method_remap = "bilinear")
```

```
Note: If using 'Intbc' and 'points' is not specified, downscaling is to a grid.
'target_grid' has not been specified. Downscaling will be done to the grid of 'obs'.
```

The key parameter is *downscale_function*, where you must specify the type of downscaling and calibration to be performed — **detailed information is available in the function vignette**

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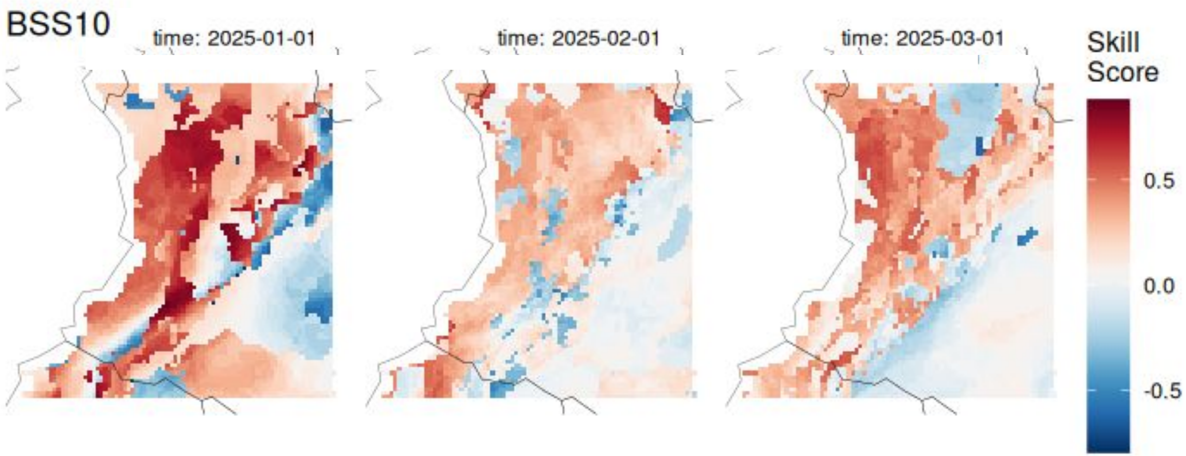
Verification

c4h_postprocess: calculate a variety of metrics to assess the quality of a forecast

Key idea: compare the hindcast and observations - how much do we trust our forecast?




```
{r}
skill <- c4h_postprocess(exp = hcst,
                         obs = obs,
                         metrics = c("BSS", "CRPSS"),
                         brier_thresholds = c(0.1, 0.9))
```

The key parameter is *metrics*, where you can specify a list of all the metrics to be calculated in the skill assessment — **detailed information is available in the function vignette**

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Plotting

c4h_plot: plot your climate data and skill assessments!

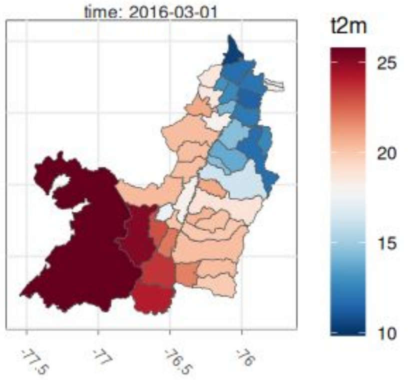
```
{r}
c4h_plot(fcst, time = 1:3, ensemble = 1:3)
```

`c4h_plot(data)` — simply plot all the data (this could be many dimensions!)

Add additional parameters to:

- slice dimensions
- take an ensemble mean
- choose your colour palette
- add the boundaries of the region you are interested in
- and more...

```
{r}
aoi <- sf::st_read(paste0(clim4health_path, "/inst/extdata/areas/munip_vallecauca.gpkg"))
c4h_plot(fcst, time = 1:3, ensemble = TRUE, boundaries = aoi, coordgrid = TRUE,
         palette = "Viridis")
```



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calculation of simple indices (threshold based)

c4h_convert_units
convert variable units

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transform s2dv to common formats

c4h_save
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Coming soon!

Let's begin!

1. **We can now open the Docker**
   a. Run the container either through the terminal/powershell or from Docker Desktop
   b. Go to http://localhost:8080

2. Please follow **HARMONIZE_training.Rmd**

3. Let us know if something doesn't work or doesn't make sense!
   a. Any unclear error messages?
   b. Any bugs?
   c. Anything you would like to see added?

clim4health

Thanks!

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