Capacity Building in Seasonal Hydrological Forecasting

Spatial and Spatio-temporal Data

AGRHYMET, Climate Regional Center for West-Africa and Sahel

@Arsène KIEMA / @Mandela HOUNGNIBO

2025-10-06



Pedagogical Objectives

i Learning outcomes

By the end of this session, participants will be able to:

- Understand what spatial and spatio-temporal data are.
- Read and explore shapefiles and vector data with sf.
- Work with raster data (gridded precipitation, temperature) with terra.
- Handle spatio-temporal raster cubes with stars.
- Extract values (e.g., average rainfall) for sub-basins defined by polygons.
- Visualize spatial data (maps, overlays).
- Apply these skills in a hydrological case study: rainfall over sub-basins.

Spatial data

Spatial data links attributes (e.g., rainfall, discharge) to geographic locations.

Two main types:

- Vector data: points (stations), lines (rivers), polygons (basins) → handled by sf.
- ullet Raster data: gridded values (precipitation, temperature, ETP) o handled by terra.
- ullet Spatio-temporal cubes: rasters changing over time ullet handled by stars.

Spatial data

Key concept

Spatial data always requires a **Coordinate Reference System (CRS)**. CRS ensures that layers align correctly. Always check CRS before analysis.

Vector Data with sf

```
library(sf)
basins <- st read("data/basins shapefile.shp")</pre>
head(basins)
st crs(basins) # Coordinate reference system
plot(basins["BASIN NAME"])
```

Vector Data with sf



Note

Use st_transform() to reproject your data into a common CRS.

basins utm <- st_transform(basins, crs = 32630) # UTM zone 30N

Visualization Vector Data

```
library(ggplot2)
basins df <- st as sf(basins)
ggplot() +
  geom sf(data = basins df, fill = "lightblue", color = "black")
  ggtitle("Hydrological Basins")
plot(rain raster)
plot(st geometry(basins), add = TRUE, border = "red")
```

Raster Data with terra

```
library(terra)

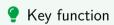
# Read a raster (precipitation grid)
rain_raster <- rast("data/precipitation_2020.tif")

# Explore raster
rain_raster
plot(rain_raster, main = "Daily Precipitation (mm)")</pre>
```

Spatio-temporal Data with stars

```
# Read a NetCDF file (daily precipitation)
precip <- read_stars("data/precipitation_daily.nc")

precip
st_dimensions(precip) # check dimensions
st_get_dimension_values(precip, "time")[1:10] # first 10 dates</pre>
```



read_stars() automatically reads NetCDF/GRIB and recognizes **time** as a dimension.

Exploring Spatio-temporal Cubes

```
# Select the first time slice (a map for one day)
precip_day1 <- precip[,,,1]
plot(precip_day1, main = "Precipitation on Day 1")

# Select a time period
precip_period <- precip[,,,1:30] # first 30 days
precip_period</pre>
```

Manipulating Dimensions

```
names(st dimensions(precip))
precip 2020 <- precip[,,, "2020-01-01/2020-12-31"]</pre>
precip monthly <- aggregate(precip, by = "month", FUN = mean, na.rm =
precip monthly
```

Manipulating Dimensions

i Dimension handling

In stars, dimensions are explicit (x, y, time).

This makes it easy to slice, aggregate, or filter by time.

Extracting Time Series

```
library(sf)

# Load station points (vector data)
stations <- st_read("data/stations.shp")

# Extract precipitation time series at station points
ts_station <- st_extract(precip, stations)
head(ts_station)</pre>
```

Basin-level Aggregation

```
# Load basins
basins <- st_read("data/basins_shapefile.shp")

# Average rainfall per basin (zonal statistics)
precip_basins <- st_extract(precip, basins, FUN = mean, na.rm = TRUE)
head(precip_basins)</pre>
```

Basin-level Aggregation

Application

This is the basis for **forcing hydrological models**: transforming gridded rainfall into basin-average inputs.

Visualization of Spatio-temporal Data

```
# Map of rainfall for a specific day
plot(precip[,,,10], main = "Precipitation on Day 10")

# Animation over time (requires gganimate or mapview)
library(ggplot2)
precip_df <- as.data.frame(precip[,,,1:5], xy = TRUE) # first 5 days
head(precip df)</pre>
```

Practical Exercises

Exercise 1

- Import precipitation_daily.nc with stars.
- Display the first 5 dates of the time dimension.
- Plot rainfall map for January 1st.

Exercise 2

- Aggregate daily rainfall into monthly totals.
- Plot the map for January and July.

Practical Exercises

Exercise 3

- Import stations.shp.
- Extract rainfall time series for each station.
- Plot the time series of Station A.

Exercise 4

- Import basins_shapefile.shp.
- Compute average daily rainfall per basin.
- Export results as outputs/rainfall_basins.csv.

Wrap-up

- Key takeaways
 - Spatio-temporal data = space (x,y) + time (t).
 - Use **stars** for NetCDF/GRIB cubes with a time dimension.
 - Always check dimensions and CRS.
 - Typical workflow:
 - Import \to Explore \to Subset \to Aggregate \to Extract \to Visualize \to Export.
 - Application: rainfall aggregated by basin, ready for hydrological modeling.

Mini-Project Day 3

Context

We want to create a spatio-temporal rainfall dataset aggregated at the basin level.

Tasks

- Import precipitation_daily.nc with stars.
- Import basins_shapefile.shp.
- Ensure CRS alignment between raster and polygons.
- Extract average daily rainfall per basin.
- Export the results as a CSV file (Date, Basin_ID, Rain).
- Open Plot rainfall time series for one basin of your choice.

THANK YOU FOR YOUR ATTENTATION

