Development of an open-access code to harmonize forest-climate data

D1.3

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About OptFor-EU

OptFor-EU wants to co-develop a Decision Support System (DSS) with forest managers and other forest stakeholders, that provides them with suitable climate adaptation and mitigation options for science-based optimising forest ecosystem services (FES) (including decarbonisation) and enhancing forest resilience and its capacities to mitigate climate change across Europe.

The project 'OPTimising FORest management decisions for a low-carbon, climate resilient future in Europe (OptFor-EU)' will build a Decision Support System (DSS) to provide forest managers and other relevant stakeholders with tailored options for optimising decarbonisation and other Forest Ecosystem Services (FES) across Europe.

Based on exploitation of existing data sources, use of novel Essential Forest Mitigation Indicators and relationships between climate drivers, forest responses and ecosystem services, OptFor-EU has five specific objectives:

- Provide an improved characterisation of the Forest-Climate Nexus and FES;
- Utilise end-user focused process modelling;
- Empower forest end-users to make informed decisions to enhance forest resilience and decarbonisation;
- Provide a novel DSS service; and
- Bridging different EU strategic priorities, robust science, and stakeholders in the forest and forest-based sectors.

Based on a supply-demand approach, the methodology combines an iterative process of data consolidation, modelling, and co-development of solutions alongside forest managers and other practice stakeholders in all European Forest Types. The DSS will be designed and tested at 8 case study areas, to provide a ready-to-use service, near to operational (TRL7) at European level, while a user adoption and up-take plan will maximise the societal and business impact.

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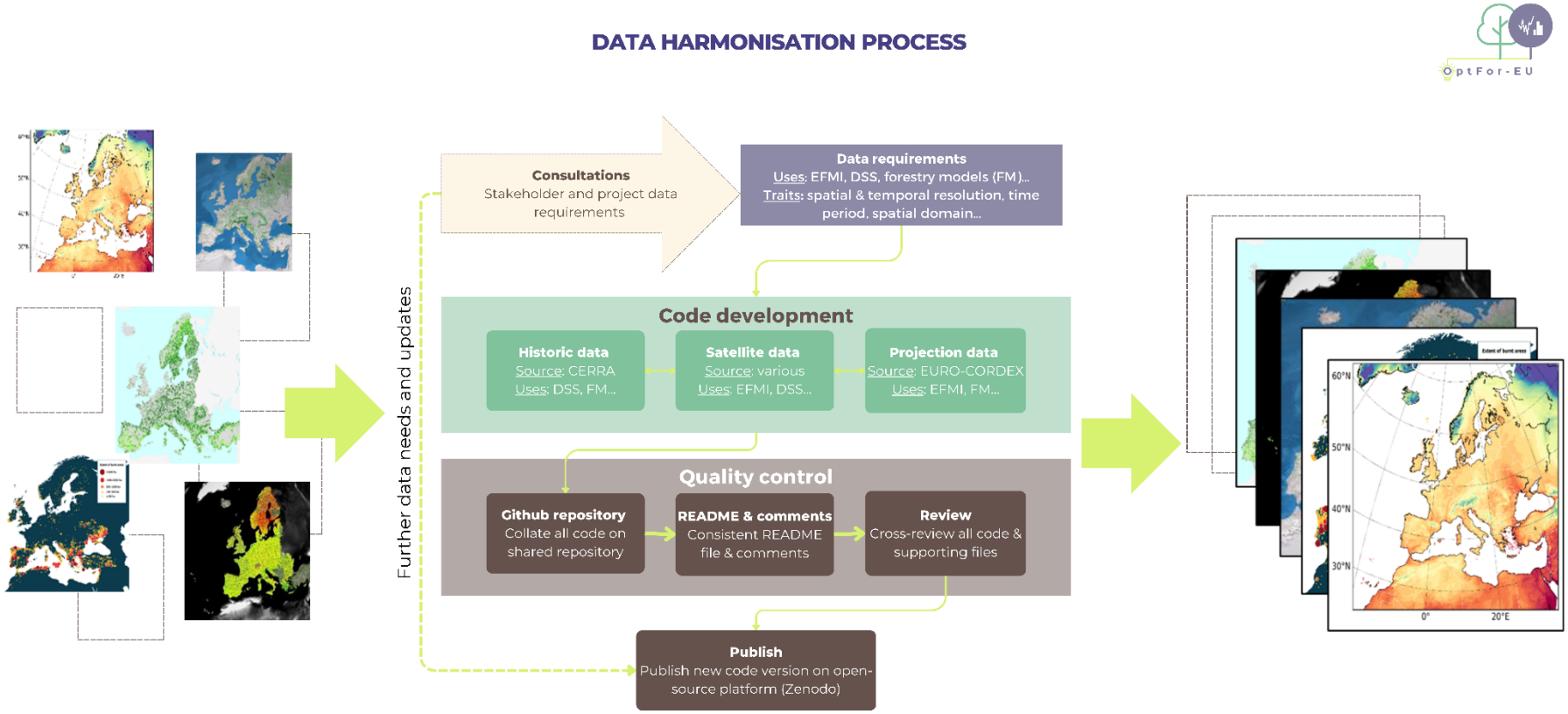
List of abbreviations

Acronym / Abbreviation	Meaning / Full text
CERRA	Copernicus European Regional ReAnalysis
D	Deliverable
Doi	Digital object identifier
DSS	Decision support system
EFMI	Essential forest mitigation indicator
EFT	European forest type
EU	European Union
EURO Cordex	European branch of the coordinated regional climate downscaling experiment
FM	Forestry models
MIT	Massachusetts Institute of Technology
OptFor-EU	OPTimising FORest management decisions for a low-carbon, climate resilient future in Europe
RCM	Regional climate model
RCP	Representative Concentration Pathways
WP	Work package

Graphical Abstract



Introduction

The OptFor-EU project (**OPTimising FORest management decisions for a low-carbon, climate resilient future in Europe**) aims to use robust science and novel analytical tools to support and enable forest managers and other stakeholders to optimize the resilience and decarbonization potential of European forests. Innovative and up-to-date modelling and data science are at the heart of OptFor-EU. To ensure that the diverse datasets utilised in the project are comparable and easily applied by project partners and end users, they first need to be carefully harmonized using logical and reproduceable processes.

Data harmonization has become an increasingly common and necessary approach for dealing with complex and multi-faceted data sources (Cheng *et al*., 2024). It can involve a wide range of different methods and considerations (Baume *et al*., 2009). For the purposes of the OptFor-EU project, data harmonization is considered to be the process of consolidating disparate data or datasets and making these compatible/comparable to be used together for a range of tasks, such as for estimation of Essential Forest Mitigation Indicators (EFMI), as input data for forestry and land surface models or for direct input into the Decision Support System (DSS). The major sources of data used in this work are recent historical meteorological observations and gridded reanalyses, satellite products, future climate model projections, Regional Climate Model (RCM) simulations, land surface model simulations and forest observations and model simulations.

This report and the associated code-set and guidance documents address OptFor-EU Deliverable 1.3 (**D1.3. Documented open-access code for harmonization of forest-climate data in open repository**), building on the report for M1.1. Harmonization code available for internal use (delivered in December 2023). D1.3 relates to work done as part of Work Package 1 (WP1), Task 1.1 (T1.1. Develop open-access code to harmonize forest-climate data*)* of the project work plan, and it is closely aligned with Task 1.2 (T1.2. Develop a set of novel EFMI and an open-access code for the related data) and the associated Deliverable 1.2 (**D1.2. Report on a novel set of Essential Forest Mitigation Indicators (EFMIs), including indicator factsheets with open-access code**) (Linser *et al.,* 2025).

This report: i) describes the approach taken to download and harmonize the major sources of data for use in OptFor-EU, and ii) provides an overview of the code developed using GitHub version control software (https://github.com/), and including an open-source Digital Object Identifier (DOI) link to the first release of this code set and guidance notes on the Zenodo repository (see https://help.zenodo.org/). It is anticipated that some updates which build on this code set will be needed throughout the course of the project, and these will be uploaded as new releases on the same Zenodo record at suitable intervals.

The OptFor-EU partners actively involved in the code development for this WP1 deliverable are:

- Met Office, UK (T1.1 **Lead**)
- University of Leicester, UK
- MeteoRo, Romania

Other partners providing information and linkages with the EFMIs (WP1), DSS (WP4), forest model developments (WP2) are: BOKU, Austria – WP1 (**Lead**): Harmonized Database; CNR, Italy – WP2 (**Lead**): Modelling the F-C Nexus; SIMAVI, Romania – WP4 (**Lead**): OptFor-EU Decision Support System.

1 Harmonization approach

1.1 Overview

Figure 1 outlines the major steps and interactions involved in the data harmonization process developed for OptFor-EU.

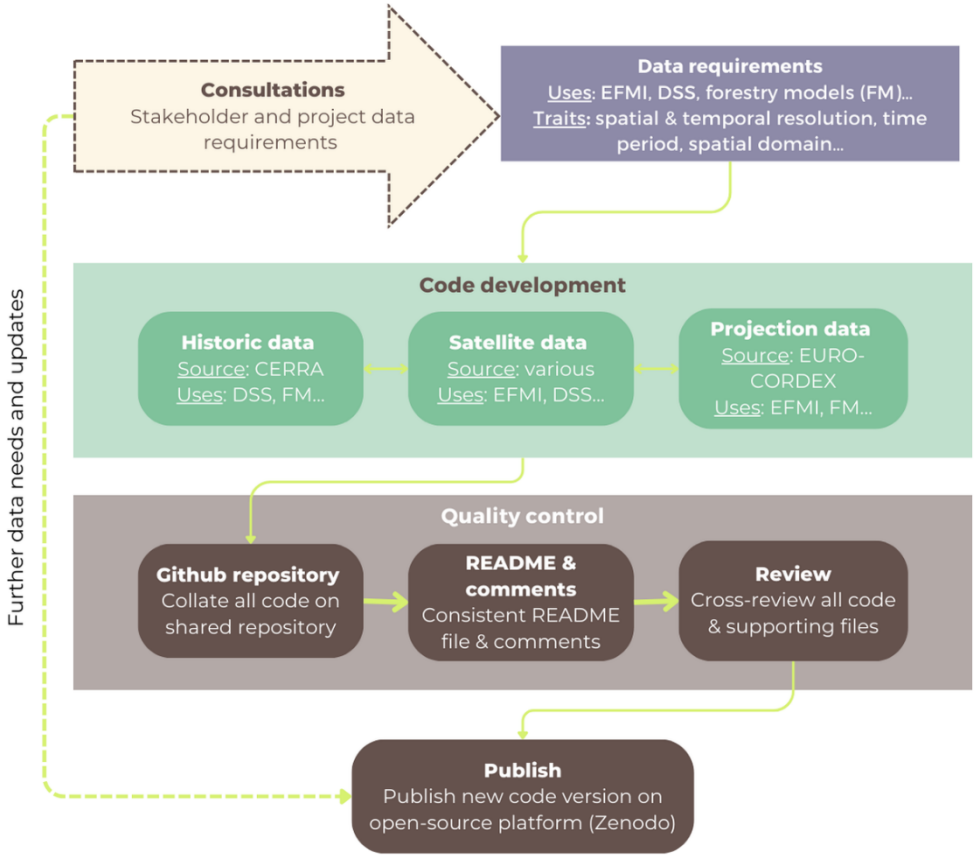


Figure 1 - Schematic showing major steps and interactions in the OptFor-EU data harmonization process.

Data requirements from across project partners and stakeholders are gathered by different teams throughout the project in meetings, consultations, interviews, questionnaires and other discussions (see **D3.1 Stakeholder engagement plan and mapping** for details, Tudose *et al.*, 2024). Initial data needs (including data traits such as spatial and temporal resolution, time period and spatial domain) have been identified for key uses in the project, e.g. EFMI and DSS development, and running of forestry and land surface models. These needs guided the development of the first version of code now released on the Zenodo open-source platform (see section 2.2 for code availability and section 3 for further details on the code).

Code development activities were partitioned into three streams (led by different project partners) according to the different data characteristics: 1) Historic data (MeteoRo), 2) Satellite data (University of Leicester) and 3) Projection data (Met Office). More detail on the code within each stream is provided in Section 3.

Code developments were made on local systems then the final code files for each stream were uploaded by each coding partner onto a common GitHub repository made available by the Met Office group. All code was then reviewed by the Met Office group and consistent comments and README files were included. It is expected that further code review and testing will be needed throughout the project to ensure all code is bug free and provides enough information for use by project partners or external users.

To note, following the publication of the Essential Forest Types (EFT) dataset (Giannetti and Zorzi 2023), discussions with WP2 partners (see Neumann et al. 2024a and Neumann et al. 2024b) concluded that the EFT maps didn't require further harmonisation and could be used directly as input to the DSS and the forest, land surface and regional climate models used in OptFor-EU.

Once the quality control stage was completed, this first version of the code, V1.0 was released and published on the open-source Zenodo platform, where it can be viewed and downloaded externally via the following DOI link: https://doi.org/10.5281/zenodo.14789833.

Release V1.0 of the OptFor-EU project code forms part of the project reports for deliverables:

- D1.2: Essential Forest Mitigation Indicators (EFMI) - Report on a novel set of EFMIs including indicator factsheets with open-access code, and
- D1.3: Documented open-access code for harmonisation of forest-climate data in open repository.

1.2 Code availability

Data download and harmonization code and guidance documentation are available from: https://doi.org/10.5281/zenodo.14789833. This is the first release, V1.0, of the code set, and further releases will be made available on the same Zenodo record at appropriate times throughout (including a final release at the end of) the OptFor-EU project.

As well as comprehensive commenting within the code files, each code stream has a README file that provides metadata, technical information and practical guidance about the code files within each stream. The README files for each of the three streams are also shown in Annex 1, below.

The OptFor-EU code files described her are released under the MIT License.

2 Code details

2.1 Historic data

The code to download and harmonize the historic (recent) CERRA data were written in R-language (https://www.r-project.org/) by Alexandru Dumitrescu and Vlad Amihaesei (MeteoRo, Romania). These code files and the associated README file ('README_Historic-Data.md') are available for download from the folder entitled 'Historic-Data' accessible *via* the open-access DOI link: https://doi.org/10.5281/zenodo.14789833.

A range of climate variables with data spanning the recent past, from 1st September 1984 to 30th June 2021, for the Europe domain at 5.5 km spatial resolution, and at different temporal resolutions, are provided from the CERRA reanalysis (see https://climate.copernicus.eu/copernicus-regional-reanalysis-europe-cerra).

The harmonization code performs the following functions to enable CERRA climate data to be utilized in the OptFor-EU project:

- Automate the download of CERRA climate variable data,
- Re-map and spatially crop data to align with the EURO-CORDEX grid,
- Time aggregate data (e.g., from daily to monthly, seasonal scales),
- Process CERRA climate variable data for use in the project.

Following discussions on data requirements with OptFor-EU partners and stakeholders and based on the availability of climate variables from the CERRA outputs, code are provided to download and harmonize the variables shown in Table 1. Further details and guidance on use of code are provided in the README_Historic-Data.md file (shown in Annex 1) and throughout the code files.

Table 1 - Overview of CERRA climate variables with harmonization code for use in OptFor-EU. Height refers to the sensor height and Temporal refers to the output time averaging in d-days, m-months, y-years, s-seasons. The spatial resolution of all data is 5.5 km.

Variables	Units	Height	Temporal	Time span
Downward longwave radiation	J/m^2	surface	d, m, y, s	1984-2021
Downward shortwave radiation	J/m^2	surface	d, m, y, s	1984-2021
Evaporation	Kg/m^2	surface	d, m, y, s	1984-2021
Maximum air temperature	K	2m	d, m, y, s	1984-2021
Minimum air temperature	K	2m	d, m, y, s	1984-2021
Mean air temperature	K	2m	d, m, y, s	1984-2021

Precipitation	kg/m^2	surface	d, m, y, s	1984-2021
Snow depth water equivalent	kg/m^2	surface	d, m, y, s	1984-2021
Snowfall water equivalent	kg/m^2	surface	d, m, y, s	1984-2021
Soil moisture	m^3/m^3	top layer	d, m, y, s	1984-2021
Surface runoff (calculated)	kg/m^2	surface	d, m, y, s	1984-2021
Specific humidity (calculated)	%	2m	d, m, y, s	1984-2021
Surface pressure	Pa	surface	d, m, y, s	1984-2021
Wind speed	m/s	10m	d, m, y, s	1984-2021

2.2 Satellite data

The code to download and harmonize satellite-derived data for use in OptFor-EU were written in Python language (https://www.python.org/) by Drs. Jasdeep Anand, Rocio Barrio Guillo and Darren Ghent (University of Leicester, UK). These code files and the associated README file ('README_Satellite-Data.md') are available for download from the 'Satellite-Data' folder *via* the open-access DOI link: https://doi.org/10.5281/zenodo.14789833.

The main advantages of satellite datasets are that they are a long-term stable time series and open access (free of cost). This means that the entire continent can be observed from only a single instrument, where terrestrial observation networks would be affected by issues like cross-calibration of instruments and siting. Additionally, the inclusion of timely, stable datasets offered by satellite data can be used to verify the accuracy of the models used in WP2, by comparing the same variables ascertained by both (e.g. temperature, precipitation). Most of the satellite datasets used in this work will also be extended to the future (either by the same instruments or by successor missions), ensuring that the DSS can be supported by robust and repeatable data beyond the end of the project.

Following discussions on data requirements with OptFor-EU partners and stakeholders and particularly considering the data needs for estimating the EFMIs (see Linser et al. 2025) code were developed to download satellite-derived climate- and forest-related variables and process these, where necessary, to estimate as many EFMIs as possible (see Table 2). Further details and guidance on downloading and use of the satellite code are provided in the 'README_Satellite-Data.md' file (shown in Annex 1) and throughout the code files.

Table 2 - Overview of satellite-derived EFMIs with harmonization code for use in OptFor-EU. Spatial refers to the spatial resolution in km of the output data. The time averaging of output data is monthly, except for EFMI #6.1 and #5.1 which are output as daily per event, and EFMI #8 and #4.1 which are output annually.

Variables (EFMI #)	Units	Spatial (km)	Time span	Data source
Carbon stored in forest soils (EFMI #4)	tC/ha	9	1915-2024	SMAP L4, see Kimball et al. (2022)
Land Surface Temperature (EFMI #17.6)	K	1	2000-2018	ESA-CCI MODIS Terra, see Ghent et al. (2022)
Leaf Area Index (EFMI #11)	m^2/m^2	1	2014-2023	Copernicus GLS LAI 300m, see LAI EU…
Forest area damaged by fire (EFMI #7)	ha/grid	1	2017-2022	Copernicus GLS burnt area, see Burnt area EU…
Forest area with damage caused by severe weather events (EFMI #6.1)	ha	1	2000-2018	FORWIND database, see Forzieri et al. (2019)
Forest area with damage caused by insects and diseases (EFMI #5.1)	ha	1	1963-2021	DEFID2 database, See Forzieri et al. (2023)
Changes in tree cover density (EFMI #8)	%	1	2015 & 2018*	Copernicus GLS tree cover, see Tree cover change EU…
Carbon stored in living biomass (EFMI #4.1)	t/ha	1	2010 & 2015-21	ESA-CCI biomass map v5, See Santoro & Cartus (2024)

* With respect to 2012.

The harmonization code performs the following functions on the satellite datasets:

- Automate or point to the download of data from various satellite products,
- Re-map and re-grid to the EURO-CORDEX grid and domain,

- Time aggregate data to relevant scales,
- Process (and combine where necessary) the native satellite data to estimate EFMIs.

2.3 Projection data

The code to harmonize future climate model projection data for use in OptFor-EU were written in Python language by Drs. Deborah Hemming and Murk Memon (Met Office Hadley Centre, UK). These code files and the associated README file ('README_Projection-Data.md') are available for download from the 'Projection-Data' folder *via* the open-access DOI link: https://doi.org/10.5281/zenodo.14789833. Instructions on how to download the projection data used in this project are detailed in the 'Download_Instructions.md' file also within the 'Projection-Data' folder.

The EURO-CORDEX RCM projection data were chosen because they represent the most up-to-date, high resolution coordinated regional climate projections across Europe. They are part of the internationally coordinated CORDEX framework to produce improved regional climate change projections for all land regions world-wide.

One of the key exercises regarding future climate model projection data was the selection of the CMIP5 EURO-CORDEX models. The CMIP5-driven models (instead of CMIP6) were selected mainly due to the relatively high spatial resolution, availability of climate variables and the range of scenarios. Two RCMs from the fine spatial resolution CMIP5 EURO-CORDEX simulations (EUR-11, 0.11 degree ~12.5km - https://euro-cordex.net/060378/index.php.en) were selected:

- RACMO22E (Royal Netherlands Meteorological Institute (KNMI)
  - https://www.wdc-climate.de/ui/entry?acronym=CXEU11KNRA)
- HIRHAM5 (Danish Meteorological Institute (DMI)
  - https://backend.orbit.dtu.dk/ws/portalfiles/portal/51950450/HIRHAM.pdf)

These RCMs were chosen because they provided the greatest number of common climate variables needed for OptFor-EU and the highest spatial resolutions to enable spatial variation within the case study areas. Three Representative Concentration Pathways (RCPs) - RCP2.6, RCP4.5, and RCP8.5, were selected to enable a wide range of future pathways to be explored in the project.

Code and guidance are provided to enable download and harmonization to match as many future projected climate variables as possible from those selected from the CERRA Historic data stream (see Section 3.1). Table 3 shows the details of the future projected RCM variables focused on with the Projection data code.

Table 3 - Overview of climate variables from future climate model projections with harmonization code for use in OptFor-EU. Height refers to the sensor height and Temporal refers to the output time averaging in m-months. The spatial resolution of all data is 0.11 degree ~12.5 km.

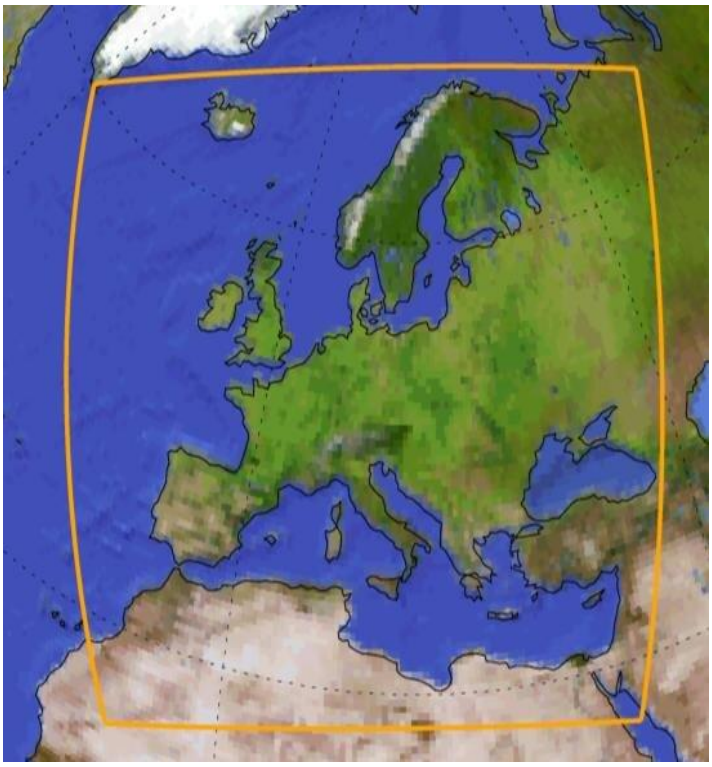
Variables	Units	Height	Temporal	Time span
Downward longwave radiation	J/m^2	surface	m	2006-2100
Downward shortwave radiation	J/m^2	surface	m	2006-2100
Evaporation	Kg/m^2	surface	m	2006-2100
Maximum air temperature	K	2m	m	2006-2100
Minimum air temperature	K	2m	m	2006-2100
Mean air temperature	K	2m	m	2006-2100
Precipitation	kg/m^2	surface	m	2006-2100
Runoff	kg/m^2	soil depth	m	2006-2100
Specific humidity	%	2m	m	2006-2100
Surface pressure	Pa	surface	m	2006-2100
Wind speed	m/s	10m	m	2006-2100

Three of the variables included from the CERRA outputs (Snow depth water equivalent, Snowfall water equivalent and Soil moisture) are not available from the RCM outputs, and Runoff (rather than Surface runoff – from CERRA) is provided from the RCMs.

To allow for a more efficient representation of the Europe area the EURO-CORDEX RCMs use a rotated polar coordinate system, where the position of the 'North Pole' is shifted to the centre of the European domain (Figure 2). Therefore, for use in OptFor-EU, these data were first converted to a regular latitude/longitude coordinate system maintaining as close to the Europe domain shown in Figure 2. This spatial domain was used as the minimum spatial extent for Europe data provided across all three code development streams.

Daily and monthly data are provided to forest modelling groups (WP2) as meteorological input data for model runs (Neumann et al., 2024a, 2024b). Only monthly average data are made available for use in the OptFor-EU DSS (WP4), because this is the shortest time averaging needed for DSS data and any longer time averages e.g. seasonal, annual, will be calculated during DSS development.

Figure 2 - The EURO-CORDEX spatial domain.



3 Conclusions and further work

The work described in this report provides the first release of code that has enabled key datasets to be made available for development of EFMIs and for the DSS and forest and land surface modelling. Most of the key data requirements identified across the project and through user workshops and questionnaires have been addressed by this work and are discussed in this report (and associated documentation). This report also details the repeatable approach that has been developed for OptFor-EU to enable further data harmonization code to be developed as needed in the future. Furthermore, it provides the open link to the harmonization code and the README files for each code stream which document the key points of each code file.

This work has also highlighted the challenge of linking user requirements with appropriate and available datasets. For example, we were not able to provide code to harmonize data for some of the EFMIs that have been identified, due to the lack of availability of suitable datasets.

The future plan for code development is for coding groups to continue to work with all OptFor-EU partners to understand the ongoing data requirements and provide modifications to the existing code and/or new code to enable the timely provision of datasets as and when needed. Further code releases will be made available on Zenodo (at the same location with different DOI links) at suitable times throughout the project.

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Annex – README files accompanying each code stream

README_Historic-Data.md

OptFor-EU_WP1 - Historic climate data (from CERRA reanalysis)

The scripts provided in this Historic-CERRA Data section provide code to download, re-project, time aggregate (e.g., monthly, seasonal scales), and spatially crop the Copernicus Regional Reanalyses for Europe - CERRA (https://climate.copernicus.eu/copernicus-regional-reanalysis-europe-cerra) reanalyses data covering the recent past (1984-2021) for use in the OptFor-EU project.

Please take a look below for more information on each script and visit the OptFor-EU project website (https://optforeu.eu/) for more details on the project.

+++

Authors: [Alex Dumitrescu; Vlad Amihaesei- MeteoRo]

Date: 10th December 2024

+++

Brief description of each file

Scripts for Downloading CERRA climate variables...

Filename: download_[EFMI_climate_variable]_CERRA.R

Description: Automates the retrieval of CERRA reanalyses data for climate variables to be used in OptFor-EU. Uses the R programming language with the "ecmwfr" library to download the CERRA climate data. Data are requested in 3-hour intervals from 1984 to 2021, excluding years which have already been downloaded.

Inputs: Years of interest: 1984 to 2021. Existing files in the directory: "nc/cerra/ws". CDS API key and user credentials

Outputs: GRIB files for the climate variable saved in the folder "nc/cerra/[name_of_variable]" with the naming format "ws_[year].grib"

Scripts for processing CERRA climate variables...

Filename: process_[EFMI_climate_variable]_CERRA_to_EURO-CORDEX_1984-2021_MonthlyMean.R

Description: Processes hourly precipitation data from the CERRA dataset. Performs temporal aggregation to generate daily, monthly, yearly, and seasonal summaries. Standardizes units and remaps the data to align with the EURO-CORDEX grid

Inputs: Hourly runoff data files in GRIB format located in the directory /media/vlad/Elements2/CERRA/raw/runoff/. EURO-CORDEX-compatible grid file: CERRA_lonlatgrid.txt

Outputs: NetCDF files for daily, monthly, yearly, and seasonal aggregated runoff data saved in the same directory. The naming convention for outputs follows the format: [climate_variable][TIMEFRAME][YEAR].nc

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README_Satellite-Data.md

OptFor-EU_WP1 - Satellite data

The scripts provided in this Satellite-Data section provide code to download, process, resample and spatially crop various satellite data for use in the OptFor-EU project.

Please take a look below for more information on each script and visit the OptFor-EU project website (https://optforeu.eu/) for more details on the project.

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Code developers: Dr. Jasdeep Anand and Dr. Rocio Barrio Guillo, University of Leicester, UK

Date of code release: 16th January 2025

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Brief description of each script file...

Scripts for downloading satellite data variables...

Filename: Download_Satellite_Global_EFMI-FIRES_2001_2022_Monthly.py

Description: Downloads data to calculate EFMI #7 Forest area damaged by fire

Inputs: C3S Copernicus burnt area dataset from OLCI, at 300m resolution, monthly for 2017-2022, unitless [presence/absence of fire within cell]

Outputs: Files named c3s_pixel_burned_area_v1_1_{year}_monthly.zip

Filename: Download_Satellite_EURO-CORDEX_EFMI-SoilCarbon_2015_2024_Daily.py

Description: Downloads data to calculate EFMI #4.3 Carbon stored in forest soils

Inputs: NASA SMAP L4 Global Daily 9 km EASE-Grid Carbon Net Ecosystem Exchange, Version 7, at 9km resolution, daily for 2015-2024, with units gC/m2

Outputs: Files named SMAP_L4_C_mdl_{yyymmdd}T000000_Vv7041_001.h5, at 9km resolution, daily for 2015-2024, subset to EURO-CORDEX region, with units gC/m2

Filename: Download_Satellite_Global_EFMI-ChangeTCD_2012_2015_2018_Annual.py

Description: Downloads data to calculate EFMI #8 Changes in Tree Cover Density

Inputs: Sentinel-2 Copernicus High-Resolution Layer Tree Cover Density dataset, at 100m resolution, annually for 2012, 2015 and 2018, with units %

Outputs: Files named TCD_{yyyy}_100m_eu_03035_d04_full.tif, at 100m resolution, annually for 2012, 2015 and 2018, with units %

Filename: Download_Satellite_Global_EFMI-LAI_2014_2024_10-Daily.py

Description: Downloads data to calculate EFMI #11 Leaf Area Index

Inputs: Copernicus Global Land Service LAI dataset, at 300m resolution, 10-daily for 2014 to present, globally, unitless. Note that data was used From January 2014 to August 2016 based upon RT5 PROBA-V and to June 2020 based upon RT0 PROBA-V data with version 1.0 and from July 2020 onwards based upon RT0 Sentinel-3/OLCI data with version 1.1. RT0 is the Near Real Time product while RT5 is the final consolidated Real Time product

Outputs: Files named c_gls_LAI300-RT0_{yyyymmdd}0000_GLOBE_OLCI_V1.1.2.nc or c_gls_LAI300-RT0_{yyymmdd}0000_GLOBE_PROBAV_V1.0.1.nc or c_gls_LAI300_{yyyymmdd}0000_GLOBE_PROBAV_V1.0.1.nc

Scripts for processing satellite data to Essential Forest Mitigation Indicators (EFMIs)...

Filename: Process_Satellite_EURO-CORDEX_EFMI-AGB_2010and2015-2021_Annual.py

Description: Produces EFMI #4.1 Carbon Stored in living biomass. Resamples the spatial resolution and subsets to the EURO CORDEX region domain, and is multiplied by 0,5 to get the Carbon stock

Inputs: ESA-CCI biomass map v5, at 100m resolution, for 2010 and 2015-2021, with units Mg/ha. Data were downloaded manually from https://data.ceda.ac.uk/neodc/esacci/biomass/data/agb/maps/v5.0/netcdf

Outputs: File named rs_veg_europe_agb_none_ann_2010_2021_v1_esacci.nc, at 1km resolution, for 2010 and 2015-2021, with units tonnes/ha

Filename: Process_Satellite_EURO-CORDEX_EFMI-FIRES_2001_2022_Monthly.py

Description: Produces EFMI #7 Forest area damaged by fire. Selects the 'forest' land cover classes, resamples the spatial resolution and subsets to the EURO CORDEX region domain

Inputs: C3S Copernicus burnt area dataset from OLCI, at 300m resolution, monthly for 2017-2022, unitless [presence/absence of fire within cell]

Outputs: File named rs_veg_europe_fires_none_mon_2010_2021_v1_esacci.nc, at 1km resolution, monthly for 2017-2022, with variables: 'fires' (unitless, presence/absence fire in the cell for all land cover classes), 'forest_fires' (unitless, presence/absence fire in the cell for forest land cover classes), 'cell_area_ha' (Ha, the area of each cell)

Filename: Process_Satellite_EURO-CORDEX_EFMI-SoilCarbon_2015_2024_Daily.py

Description: Produces EFMI #4.3 Carbon stored in forest soils. Resamples temporal resolution

Inputs: NASA SMAP L4 Global Daily 9 km EASE-Grid Carbon Net Ecosystem Exchange, Version 7, at 9km resolution, daily for 2015-2024, with units gC/m2

Outputs: File named rs_veg_europe_soilCarbon_none_mon_2015_2024_v1_smap.nc, at 9km resolution, monthly for 2015-2024, with units tonnes C/ha

Filename: Process_Satellite_EURO-CORDEX_EFMI-DisturbanceInsectsDisease_2010_2021_Events.py

Description: Produces EFMI #5.1 Forest area with damage caused by insects and diseases. Subsets to the EURO CORDEX region domain

Inputs: DEFID2 database, at day/event of disturbance resolution, for 1963-08-01 to 2021-09-30, with units ha. Data was downloaded from Data was downloaded manually from https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/FOREST/DISTURBANCES/DEFID2/VER1-0/

Outputs: File named rs_veg_europe_disturbanceInsectsDisease_none_event_1963_2021_v1_defid2.shp, area shapefile, daily/event for 1963-08-01 to 2021-09-30, with units ha; and a file named metadata_rs_veg_europe_disturbanceInsectsDisease_none_event_1963_2021_v1_defid2.txt with the metadata for the shapefile

Filename: Process_Satellite_EURO-CORDEX_EFMI-DisturbanceWeather_2010_2021_Events.py

Description: Produces EFMI #6.1 Forest area with damage caused by severe weather events. Subsets to the EURO CORDEX region domain

Inputs: FORWIND database, at day/event of disturbance resolution, for 2000-07-25 to 2018-10-28, with units ha. Data was downloaded manually from https://figshare.com/articles/dataset/A_spatially-explicit_database_of_wind_disturbances_in_European_forests_over_the_period_2000-2018/9555008

Outputs: File named rs_veg_europe_disturbanceWeather_none_event_2000_2018_v1_forwind.shp, area shapefile, daily/event for 2000-07-25 to 2018-10-28, with units ha; and a file named metadata_rs_veg_europe_disturbanceWeather_none_event_2000_2018_v1_forwind.txt with the metadata for the shapefile

Filename: Process_Satellite_EURO-CORDEX_EFMI-ChangeTCD_2012_2015_2018_Annual.py

Description: Produces EFMI #8 Changes in Tree Cover Density. Resamples spatial resolution and subsets to the EURO CORDEX region domain

Inputs: Sentinel-2 Copernicus High-Resolution Layer Tree Cover Density dataset, at 100m resolution, annually for 2012, 2015 and 2018, with units %

Outputs: Files named rs_veg_europe_changeTCD_none_ann_2015_v1_clms.tif and rs_veg_europe_changeTCD_none_ann_2018_v1_clms.tif, at 1km resolution, annually for 2015 and 2018 with respect to 2012, with units %

Filename: Process_Satellite_EURO-CORDEX_EFMI-LAI_2014_2024_10-Daily.py

Description: Produces EFMI #11 Leaf Area Index. Resamples spatial resolution, resampled temporal resolution and subsets to the EURO CORDEX region domain

Inputs: Copernicus Global Land Service LAI dataset, at 300m resolution, 10-daily for 2014 to present, unitless. Note that data was used From January 2014 to August 2016 based upon RT5 PROBA-V and to June 2020 based upon RT0 PROBA-V data with version 1.0 and from July 2020 onwards based upon RT0 Sentinel-3/OLCI data with version 1.1. RT0 is the Near Real Time product while RT5 is the final consolidated Real Time product

Outputs: File named rs_veg_europe_lai_none_mon_2014_2024_v1_clms.nc, at 1km resolution, monthly from January 2014 to December 2023, unitless

Filename: Process_Satellite_EURO-CORDEX_EFMI-LST_2000_2021_Daily.py

Description: Produces EFMI #17.6 Mean monthly land surface temperature. Subsets to the EURO CORDEX region domain and gets LST monthly mean by averaging daily day-time data and daily night-time and then taking the mean of daytime and night-time monthly averages

Inputs: ESA-CCI MODIS Terra dataset, at 1km resolution, daily for 2000 to 2018, with units of Kelvin, K. The data was already downloaded in a JASMIN server from the CEDA Archive

Outputs: Files named rs_veg_europe_lst_none_mon_2000_2018_v1_esacci.nc, at 1km resolution, monthly mean from March 2000 to December 2018, in Kelvin

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README_Projection-Data.md

OptFor-EU_WP1 - Future climate projections

The scripts provided in this Projection-Data section provide code and guidance to download, process and re-project the future climate projections data for use in the OptFor-EU project. Climate projection data are from the EURO-CORDEX (European focused COordinated Regional climate Downscaling EXperiment) Regional Climate Model (RCM) simulations (https://euro-cordex.net/) driven by Climate Model Intercomparison Project Phase 5 Global Climate Model (CMIP5 GCM - https://wcrp-cmip.org/cmip5/) experiments. Details on the EURO-CORDEX models and variables utilised in OptFor-EU can be found in the project deliverable D1.3: "Develop open-access code to harmonise forest-climate data".

Please take a look below for more information on each script and visit the OptFor-EU project website (https://optforeu.eu/) for more details on the project, including deliverables and outputs as they become available.

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Code developers: Dr Deborah Hemming and Dr Murk Memon, UK Met Office

Date of code release: 20th January 2025

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Brief description of each file:

Downloading future projection data...

Filename: Download_Instructions.md

Description: This file provides step-by-step instructions and guidance on how to download the future projected climate variables that are being used in OptFor-EU. These are from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, available from the Copernicus Data Store - CDS, https://cds.climate.copernicus.eu/

Inputs: List of RCMs, RCPs and variables needed and link to ESGF EURO-CORDEX portal at https://cordex.org/data-access/cordex-cmip5-data/cordex-cmip5-esgf/

Outputs: Data files for each variable, RCP and RCM downloaded

Scripts for processing future projection data variables...

Filename: Process_Projection_Europe_Downward_longradiation_2006_2050_Monthly.py

Description: Radiative longwave flux of energy incinding on the surface from the above per unit area. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable,

see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Surface thermal radiation downward" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Surface thermal radiation downward flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Downward_shortradiation_2006_2050_Monthly.py

Description: The downward shortwave radiative flux of energy per unit area. The data represents the mean over the aggregation period at the surface. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Surface solar radiation downward" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Surface solar radiation dowward flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Evaporation_2006_2050_Monthly.py

Description: Mass of surface and sub-surface liquid water per unit area ant time, which evaporates from land. The data includes conversion to vapour phase from both the liquid and solid phase, i.e., includes sublimation, and represents the mean over the aggregation period. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Evaporation" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Evaporation flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Max_airtemp_2006_2050_Monthly.py

Description: Maximum temperature of the air near the surface. The data represents the daily maximum at 2m above the surface. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Maximum 2m temperature in the last 24 hours" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Maximum air temperature flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Mean_airtemp_2006_2050_Monthly.py

Description: Mean temperature of the air near the surface. Ambient air temperature. The data represents the mean over the aggregation period at 2m above the surface. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "2m temperature" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Mean air temperature flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Min_airtemp_2006_2050_Monthly.py

Description: Minimum temperature of the air near the surface. The data represents the daily minimum at 2m above the surface. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Minimum 2m temperature in the last 24 hours" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Minimum air temperature flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Precipitation_2006_2050_Monthly.py

Description: Deposition of water to the Earth's surface in the form of rain, snow, ice or hail. The precipitation flux is the mass of water per unit area and time. The data represents the mean over the aggregation period. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Mean precipitation flux" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Mean precipitation flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Runoff_2006_2050_Monthly.py

Description: The mass of surface and sub-surface liquid water per unit area and time, which drains from land. The data represents the mean over the aggregation period. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Total run-off flux" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Total runoff flux monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Sealevel_pressure_2006_2050_Monthly.py

Description: Pressure of air at the lower boundary of the atmosphere. The data represents the mean over the aggregation period. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "Surface pressure" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Surface pressure monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Specific_humidity_2006_2050_Monthly.py

Description: Amount of moisture in the air at 2m above the surface divided by the amount of air plus moisture at that location. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "2m specific humidity" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Specific humidity monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

Filename: Process_Projection_Europe_Wind_speed_2006_2050_Monthly.py

Description: The magnitude of the two-dimensional horizontal air velocity. The data represents the mean over the aggregation period at 10m above the surface. This is from the CMIP5 EURO-CORDEX RCM simulations driven by future scenarios from 2006 to 2050, for details on the variable, see: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview

Inputs: "10m Wind Speed" variable monthly mean data for each MODEL and RCP used in OptFor-EU. The data can either be in 5-year chunks (directly from the EURO-CORDEX portal, see Download_Instructions.md) or as a concatenated time series file from 2006-2100.

Outputs: Wind speed monthly mean time series from 2006-2100 with European (West -44.75, East 65.25, South 21.75, North 72.75) lat/long coordinates.

OptFor-EU

Meteo Romania

BOKU

Helmholtz-Zentrum hereon

Consiglio Nazionale delle Ricerche

blue biloba

MRU Mykolas Romeris University

IEECP INSTITUTE FOR EUROPEAN ENERGY AND CLIMATE POLICY

USN University of South-Eastern Norway

ICAS

SIMAVI Software Imagination & Vision

WWF NATURA E ACASĂ

ambienta ingeniería y servicios agrarios y forestales

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