Indecis

Sectorial Climate Services

Integrated approach for the **d**evelopment across **E**urope of user oriented **c**limate **i**ndicators for GFCS high-priority **s**ectors: Agriculture, disaster risk reduction, energy, health, water and tourism

Work Package 6

Deliverable 6.1

Release of the datasets comparison software suite, including the description of statistical measures used for the datasets inter-comparison

This report arises from the Project INDECIS which is part of ERA4CS, an ERA-NET initiated by JPI Climate, and funded by FORMAS (SE), DLR (DE), BMWFW (AT), IFD (DK), MINECO (ES), ANR (FR), with co-funding by the European Union's Horizon 2020 research and innovation programme

TABLE OF CONTENTS

The aim of WP6 is to examine the limits and strengths of the available gridded, reanalysed and modelled datasets as alternative data sources from which to compute climate indices in the absence of observations, and to highlight the added-value of the newly developed indices produced in the framework of the WP4 of the INDECIS project.

To this end, the first task concerns an inventory and catalogue of selected hindcast climate simulations (e.g. FP6-CECILIA, CMIP5, ENSEMBLE or EURO-CORDEX), reanalysis products (e.g. ERAI, MERRA, JRA55, ERA-20C, 20CR; REAN6, MÉRA and MESCAN at regional level) as well as gridded observational datasets. Next, within WP6 a set of statistical measures, including the widely used Taylor diagram, for the inter-comparison of selected datasets, was defined. Finally, a software suite was designed and built for this purpose, focusing on the comparison of newly developed, sectorial indices defined in WP4.

The report summarizes the results obtained during the first 6 months of WP6.

1. Inventory and catalogue of selected hindcast climate simulations, reanalysis products, model-derived data and gridded observational datasets

A large number of hindcast, reanalysis and model-based datasets are available for Europe- either from global or regional reanalysis- or for limited European regions.

However, for the project objectives it is important that each of selected datasets meets the following criteria:

includes at least the Essential Climate Variables (ECVs) selected in the INDECIS project: air temperature, humidity, wind speed, precipitation and global shortwave radiation.

covers a long-enough (e.g. 30 yrs) period of time including the present time (e.g. up to at least 2016)

spans a temporal resolution at least daily

proposes a grid resolution as fine as possible (e.g. at least 30km) taking into account that datasets used as a reference in the project – E-OBS and ERA5 – have 25km and respectively 30km grid spacing. However, for verification of seasonal forecasting applications global datasets are typically used. At this scale only relatively-coarse datasets are available.

Gridded observational datasets at the regional level have also been identified during the WP6 activities; some of them are already available, others are still under evaluation. In any case, they generally cover limited (e.g. national) regions and their use is of particular interest to partners in those regions. For this reason, although they are presented here, only some datasets will be included in the inter-comparison exercise performed within WP6; the inter-comparison software developed in WP6 has a flexible structure and can be further adapted to include the gridded observation datasets – or any other dataset provided by any partner.

Table 1 presents an overview of the datasets satisfying the conditions described above for datasets with European coverage and newly identified gridded observational datasets.

Table 1. Catalogue of identified datasets.

Dataset name/ data format (if other than NetCDF)	*Data type (reanalysis, climate simulation, model-based, gridded observations)*	*Temporal coverage and resolution*	*Spatial coverage and resolution*	*Parameters included*					*Available from*
				T2m	**RH_2m**	**10m Wind speed**	**Total precipitation**	**Radiation**	
COSMO-REA6 (DWD grib)	Reanalysis	1995-2017	Europe 6km	x	x	U10m, V10m	x	-instantaneous direct radiation -instantaneous diffuse radiation	ftp://opendata.dwd.de/climate_environment/REA/COSMO_REA6/
UERRA-HARMONIE/V1 (WMO_GRIB2)	Reanalysis	1983-2017	Europe 5km (surface variables)	x	x	x	x	-	https://apps.ecmwf.int/datasets/data/uerra/levtype=sfc/stream=oper/type=an/
MÉRA	Reanalysis	1981-present hourly	Ireland 2.5km	x	x	x	x	Accumulated: Global downwelling SW radiation at the surface Direct SW downwelling at surface Net LW at surface Net SW at surface LW upwards at surface Instantaneous: Direct SW downwelling at surface LW upwards at surface TOA: Direct instantaneous Acc & instant net LW Acc and instant net SW	Met Éireann
MERRA2	Reanalysis	1980-present hourly	Global ~55 km latitude x ~70km longitude	x	x	x	x		NASA GMAO (https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/data_access/)

EUROCORDEX EUR-11	Hindcast Climate simulations (Evaluation runs)	1961-2010 daily	Europe 12 km	X	X	X	X	Surface downwelling shortwave radiation	CORDEX nodes
BELGIUM	Model-based	1990-2010 hourly	Belgium 1km	x	x	x	x		RMI, Belgium
SAFRAN FRANCE (not included in the inter-comparison exercise)	Gridded meteorological analysis system	1958-present Hourly	France 8x8 km	x	x	x	x	downward shortwave and longwave radiation	Météo France on request for research projects
ROCADA (not included in the inter-comparison exercise)	Gridded observations	1961-2010 daily	Romania 10km	x	x	x	x	Sunshine hours	https://doi.pangaea.de/10.1594/PANGAEA.833627
Spain02v5 (not included in the inter-comparison exercise)	Gridded observations	1951-2015 daily	Spain ~10km	x			x		http://www.meteo.unican.es/en/datasets/spain02
CZGrid (not included in the inter-comparison exercise)	Gridded observations	1981-2010 daily	12 km (EUR-11 grid points)	x	x	x	x	x	GCRI, Czech Republic

Apart from the datasets in Table 1, other possible candidates were identified but they did not meet the selection criteria. For example:

- The CFSR dataset produced by NCEP provides a large number of atmospheric parameters at global scale, with a spatial resolution of about 0.3 deg for the period 1979-2010 and 0.2 deg for period 2011-2019. However, air temperature and wind are provided only on the first model level, thus further processing is needed to obtain T2 and w10m, which are the parameters of interest for the project objectives. Also, relative humidity is available only at coarser spatial resolution (at most 0.5 deg).

- Regarding the available hindcast climate simulation data (e.g. FP6-CECILIA, CMIP5, ENSEMBLE, EUROCORDEX) only data from EUROCORDEX was selected, due to it being state-of-the art data and matching our selection criteria (e.g. spatial and temporal resolution). Furthermore, the climate projections available in EUROCORDEX will be used in other WP6 activities (Task 6.4)

- Some global reanalysis datasets (e.g. ERAI, MERRA, JRA55, ERA-20C, 20CR) presented coarser grid spacing than required for the project or have been superseded by newer products such as MERRA2 or ERA5. (i.e. ERAI-80km; ERA20C-125km; 20CR -2x2deg; JRA55-1.25x1.25deg; MERRA -0.5x0.66deg). In addition, for some index calculations hourly values are needed, which most global reanalyses do not supply.

Literature overview of selected datasets

As seen in the above table, a total of 5 datasets have been selected to be used in the inter-comparison exercise. Here we present a short overview of these focusing on their use in comparative analyses involving the selected ECVs.

The **COSMO-REA6** reanalysis dataset is a regional reanalysis for Europe based on the numerical weather prediction model COSMO (Consortium for Small-scale Modelling), providing a high grid spacing (6 km).

The dataset has been used in several studies aiming to evaluate its performance, for selected variables, in comparison to other available reanalysis data and/or observation-based datasets.

An assessment of solar radiation and wind speed variables of COSMO-REA6 data set, performed using data of the Bavarian agro-meteorological network and the Czech Hydrometeorological Institute, is presented by (Camargo et al, 2018). The study presents also the results of the assessment for COSMO-REA2 data set. This latter was not included in the WP6 work due to the shorter temporal coverage (2007-2013) and limited spatial coverage (Germany).

The COSMO-REA6 and COSMO-REA2 have temporal resolutions of at least one hour and grid spacing of six and two kilometers respectively. Despite the differences in the spatial resolution, no significant difference in the accuracy was identified between the two data sets, except in locations with highly uneven terrain. Furthermore, significant differences between measured and modelled wind speed data only exist where the terrain is highly inhomogeneous. In general, COSMO-REA wind speed data presents results comparable to evaluations of other reanalyses in international literature. Regarding the assessment of the global horizontal irradiance (GHI), both data sets show better performance than global reanalysis data sets when compared to measured values at particular locations, and very similar results to satellite imagery derived data that have been evaluated in international literature.

A comparative study between 6 datasets, including COSMO-REA6, focusing on the global horizontal irradiance, was performed by Urraca et al (2018). The study aimed to evaluate whether the two recently released reanalysis - the global ERA5 and the regional COSMO-REA6- are able to overcome the limitations of former reanalyses making them valid alternatives to estimate surface irradiance. The results show that in ERA5, the most relevant improvement is the reduction of the positive bias compared to ERAI, making its yearly bias comparable to that of satellite-based products in most inland regions with low occurrence of clouds where the variability of surface irradiance is low. However, a significant variation of the bias with cloudiness most likely related to a poor prediction of clouds is still observed. This leads to larger absolute errors in ERA5, and also in COSMO-REA6, than the ones obtained with satellite-based products. Besides, the study highlights the inadequacy of the grid used by ERA5 (31km) in coastal areas and mountains, while in these regions COSMO-REA6 clearly outperforms ERA5 thanks to its high-resolution grid (6.2km). COSMO-REA6 has a bias and absolute error comparable to ERA5 in Northern and Central Europe, but the quality of COSMO deteriorates in Southern Europe with biases exceeding −20 W/m2. The underestimation of COSMO-REA6 is more pronounced under clear-sky conditions and it is probably related to the use of an aerosol climatology that overestimates the aerosol content. ERA5 can be a valid alternative for regions not covered by geostationary satellites such as the polar regions, as well as to fill gaps in time series. The regional COSMO-REA6 can complement ERA5 in Northern and Central Europe mitigating the deficiencies of ERA5 in coastal areas and mountains.

The **UERRA-HARMONIE/V1** regional reanalysis was produced within the project UERRA (Uncertainties in Ensembles of Regional Re-Analyses). The data covers the entire Europe, for the period 1986-2017, at a fine grid spacing: 5km for surface variables and 11km for the rest of the outputs. Details on the modelling system, the data assimilation methods, and the production scheme are available [1], as well as a comprehensive assessment of its performance against independent datasets [2]. We present in the following a short summary of the latter assessment, focusing on the aspects relevant to the objectives of WP6 activities.

The evaluation of UERRA-HARMONIE/V1 reanalysis dataset includes the investigation of different parameters (wind speed, temperature, precipitation and radiation, as well as climate indices) on various spatial and temporal scales [2].

Overall, it has been shown that for some variables, like radiation and especially wind, the UERRA reanalyses, including HARMONIE, may outperform datasets based on observations only. The relative variability in the reanalyses is also comparable to that of observational datasets. In many respects, the regional reanalyses not only show more detail than global reanalyses but also resemble the observations better than global reanalysis, like ERAI and ERA-5.

The radiation fields in the reanalysis are, in general, biased and should be used with care. For temperature, the quality of the reanalysis is high and comparable to the E-OBS observational dataset. However, one issue with temperature relates to the representation of temperature extremes. While the general seasonal cycle in temperature is well captured by the reanalysis, the more extreme temperature events are rather poorly represented. The investigation of climate indices, (frost days, tropical nights, ice days and summer days), shows that HARMONIE tends to overestimate the four indices on large scales. Due to the strong local variations and discrepancies towards E-OBS the UERRA reanalysies seem not to be applicable for the computation of climate indices. This could be based on the fact, that absolute

thresholds are used for climate indices, which are not suitable for the reanalysis datasets, due to strong local biases and possibly their dependence on the nominal and actual spatial resolution.

The regional reanalysis MÉRA covers the Irish area at a very fine grid spacing. The dataset was produced by running the HARMONIE-AROME canonical configuration of the ALADIN-HIRLAM system on a 2.5 km horizontal grid for the period 1981–2018 forced by ERAI lateral boundary conditions. Hourly time resolution and over 200 parameters are available, including the selected ECVs. The data has been already used in several studies (Gleeson et al, 2017; Whelan et al, 2017; Whelan et al, 2018; Nielsen and Gleeson,2018; Gleeson et al, 2018) and has over 100 users in Ireland, UK, Germany, USA, Netherlands.

The **MERRA2** (Molod et al, 2015) reanalysis was first released in 2015 by NASA. It uses the Goddard Earth Observing System-5 (GEOS5) atmospheric model together with a 4D-Var assimilation method. Data are available at hourly resolution, produced in a global grid of 0.625º x 0.5º and 72 hybrid sigma levels. **EURO-CORDEX** is the European branch of the CORDEX initiative aiming to produce ensemble climate simulations based on multiple dynamical and empirical-statistical downscaling models forced by multiple global climate models from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The EURO-CORDEX simulations consider the global climate simulations from the CMIP5 long-term experiments up to the year 2100. They are based on greenhouse gas emission scenarios (Representative Concentration Pathways, RCPs) corresponding to stabilization of radiative forcing after the 21st century at 4,5 W/m² (RCP4.5), rising radiative forcing crossing 8,5 W/m² at the end of 21st century (RCP8.5), and peaking radiative forcing within the 21st century at 3,0 W/m² and declining afterwards (RCP2.6, also referred to as RCP3-PD) (Moss et al., 2010 and 2008; Nakicenovic et al., 2000; Van Vuuren et al., 2008). The data produced within EURO-CORDEX has been used in a large number of studies focusing on a vast range of application areas, from validation against observations and/or other datasets (e.g. Vautard et al, 2013; Jacob et al, 2014;) to analysis of impacts of climate changes in different social sectors (e.g. Štěpánek et al, 2016; Ouzeau et al, 2016; Bartok et al, 2017; Frei et al, 2018). For the project objectives, we will employ in the first part of WP6 activity the evaluation runs (hindcast simulations) available from EURO-CORDEX, for a limited number of simulations; during the activity for Task 6.4 we will also employ climate projections available from EURO-CORDEX, for the models included in the first part.

The model-based dataset over Belgium was produced by using the RCM ALARO-0 model coupled to land-surface model scheme SURFEX v5 to dynamically downscale ERAI data 20 km horizontal resolution over Western Europe; this was further downscaled to 4 km over a large domain covering Belgium. Next, the methodology of Hamdi et al. (2015) was used to dynamically downscale the regional climate over Belgium at 1km resolution. SURFEX was therefore employed in offline mode using the atmospheric forcing from the 4 km run. All relevant surface variables are therefore available at hourly frequency for the period 1990-2010.

The **SAFRAN** gridded meteorological analysis system provides precipitation, air temperature, surface pressure, air specific humidity, wind speed, and downward shortwave and longwave radiation, with a spatial resolution of 8 km ×8 km and an hourly temporal resolution over the French territory (Vidal et al. 2010). An application of SAFRAN has been performed to the north-eastern part of Spain (Quintana-Segui et al. 2016) that shown the well-known in France limitations of that analysis system, that are that the spatial structure of the fields is not realistic enough (the system performs better over flat areas than

over areas of steep relief) and wind speed is underestimated. Nevertheless, it provides an excellent meteorological data source for water resource modeling studies.

ROCADA (Romanian ClimAtic Dataset; Dumitrescu & Birsan, 2015) provides a daily gridded climatology at the spatial resolution of 0.1x0.1 degrees for 9 meteorological parameters, based on long-term observational records from 150 Romanian meteorological stations. The data is freely available on request on the PANGAEA data portal (doi.pangaea.de/10.1594/PANGAEA.833627). The dataset has been used in several studies focusing on the Romanian territory (e.g . Buzatu et al, 2016; Stanciu et al, 2017; Irimia et al, 2018; Velea and Bojariu, 2018).

Spain02V5, is the latest version of the Spain02 gridded dataset at 0.22° grid spacing on a rotated grid for peninsular Spain and the Balearic Islands (Herrera et al. 2012), that provides an improved 3-dimensional areal representative version (AA-3D) of the Spain02 on a rotated grid of improved resolution (~10 km, Herrera et al. 2016), end extends its geographical extent to the whole Iberian Peninsula, including conterminous Portugal. Spain02 is based on a very dense and quality-controlled station network consisting of 2756 and 237 stations for precipitation and temperature, respectively. The interpolation and gridding procedure are the same as applied for E-OBS (Haylock et al. 2008). As shown in Herrera et al. 2012, Spain02 is an appropriate dataset for analyzing extreme events. The study of some extreme value indicators shows the capability of the Spain02 grid to reproduce the intensity and spatial variability of the typical observed extreme indices, some of them to be addressed in INDECIS. An inter-comparison of Spain02V5 against other available gridded products is presented in Kotlarsky et al., 2017.

CZGrid is calculated from station observations in the area of the Czech Republic and is provided in the positions of grid points of the EUR-11 Euro-CORDEX simulations, in daily scale for various meteorological elements: air temperature (mean, maximum and minimum), precipitation, relative humidity (water vapor pressure), wind speed and sunshine duration. It is calculated based on the so-called technical series - station time series that are quality controlled, homogenized and with filled gaps (Stepanek et al., 2013). It is interpolated from station locations to regular network based on geostatistical techniques (Stepanek et al., 2011). It serves primarily for validation and correction of RCMs outputs (Euro-CORDEX simulations), but can be used for any relevant analysis of the climate within the Czech Republic.

2. Statistical measures for inter-comparison

The main objective of the inter-comparison exercise is to document the limits and strengths in using these data as alternative data sources for climate indices computation in the absence of observations. To this end, as a first step, the comparison focuses on differences (and similarities) between selected datasets and the observations (i.e. E-OBS) for the ECV selected in the project (t2m, rh, w10m, precipitation, radiation); this should help to interpret the differences between the climate indices derived from the selected alternative datasets and those based on observations/ERA5. In the second step, the comparison focuses on the climate indices- the ones derived from the alternative datasets against the reference once, derived within WP4.

The main characteristics of the inter-comparison are described in the following.

Method for comparison of selected datasets and E-OBS: grid point dataset versus closest grid point in E-OBS or ERA5

Metrics

A- for comparison of ECV

- mean (e.g. monthly)
- Taylor diagram (RMSE, STDEV, Pearson correlation coefficient)
- trend analysis

B- for comparison of climate indices derived from selected datasets

-mean differences (bias) (e.g. for 'discrete' indices)

-trend analysis

Period for comparison: 1980-2010 or the longest common period

Averaging period:

ECV: - monthly (for the means, STDEV, percentiles)

- entire period of record (RMSE, STDEV, Pearson correlation coefficient, trend analysis)

Indices: -entire period of record

3. Inter-comparison software package

INDECIS software for intercomparison of reanalysis datasets (**interdecis**) (https://github.com/alexdum/interdecis): this is an open-source software, stand-alone and designed in R with capabilities to analyse the various climatic datasets performance using as reference E-OBS gridded dataset and ERA5 reanalysis product. The functions can be applied to any NetCDF files, as long as they are regularly spaced in the lat/lon grid format. Accuracy measures can be computed from the values extracted from the cells (grids) of the reference (E-OBS/ERA5) and analysed datasets, in which a given coordinates (points) fall.

The development version of the **interdecis** can be installed in R environment from the GitHub repository, with sample data available on interdecisdata R package (see: https://github.com/alexdum/interdecis/wiki). The package is under development and currently provides common accuracy indicator for prediction models (i.e. mean error, mean absolute error, root mean squared error, correlation coefficients, index of agreement, etc). The indicators can be computed from daily data at yearly, seasonal and monthly scale. The routines implemented in the package can be applied for the ECV selected in the project (2m air temperature, relative humidity, 10m wind speed, daily total of precipitation and global solar radiation).

Glossary

20CR - 20th Century Reanalysis, https://www.esrl.noaa.gov/psd/data/20thC_Rean/#data

CFSR - Climate Forecast System Reanalysis https://climatedataguide.ucar.edu/climate-data/climate-forecast-system-reanalysis-cfsr

CMIP5 - Coupled Model Intercomparison Project Phase 5 https://cmip.llnl.gov/cmip5/

ENSEMBLE – FP6 project 'ENSEMBLES: Climate change and its impacts at seasonal, decadal and centennial timescales' http://ensembles-eu.metoffice.com

ERA-20C - ECMWF's first atmospheric reanalysis of the 20th century https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-20c

ERA5 - global atmospheric reanalysis from 1979, continuously updated in real time. https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

ERAI – (ERA-Interim) - global atmospheric reanalysis from 1979, continuously updated in real time. https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim

FP6-CECILIA – Project 'Central and Eastern Europe Climate Change Impact and Vulnerability Assessment' http://www.cecilia-eu.org/

JRA55 - The Japanese 55-year Reanalysis https://jra.kishou.go.jp/JRA-55/index_en.html

MERRA - Modern-Era Retrospective analysis for Research and Applications https://gmao.gsfc.nasa.gov/reanalysis/MERRA/

MERRA2 - Modern-Era Retrospective analysis for Research and Applications 2 https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/MESCAN - Météo-France surface downscaling reanalysis http://www.euro4m.eu/downloads/Factsheets/EURO4M_Factsheet_D2.06_MeteoFrance.pdf

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