



The role of HPC and open climate data for climate- proofing water and natural resources management



Highlander

High performance computing
to support smart land services

Gabriella Scipione, HPC Department, CINECA



Co-financed by the Connecting Europe
Facility of the European Union

HIGHLANDER: HIGH performance computing to support smart LAND sERvices



Highlander
High performance computing
to support smart land services

Connecting European Facilities - Telecom

CLIMATE-AGRICULTURE

National Open Data
Portal of Climate data

New services for a smart agriculture management:

- Soil erosion over Italy (CMCC)
- Crop water requirement sub-seasonal forecasts (ARPAE)



Co-financed by the Connecting Europe
Facility of the European Union



Highlander

High performance computing
to support smart land services

Coordinator



Partners





Supercomputing is the beating heart of Highlander

1.

To increase the forecast from 15 to 30 days and increase the resolution to 2.2 km, **6 million hours of HPC** calculations were used

2.

New climate projections will be **much more accurate** thanks to HPC

3.

An additional 8 million hours of supercomputing will be needed to realise projections up to 2050

The terms supercomputing and HPC are synonymous.

1.

Extension of climate forecasting capacity to 30 days

15 dd

3.

Calculated climate projection up to 2050

2050

2,2 Km

2.

Improved horizontal grid point resolution from 30 to 2.2 km

30 dd





Transition to convection-permitting models

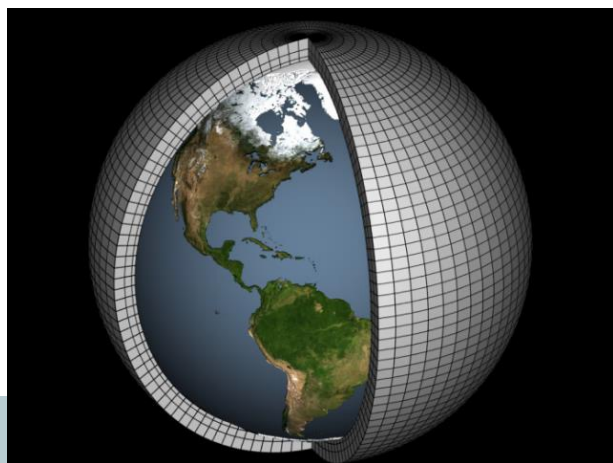
Highlander provides climate dataset with very high resolution (among 1-3 km).

These so called “**convection-permitting**” model (CPM) represents a **step forward in Regional Climate Model ability to simulate small scale behaviour seen in the real atmosphere**, in particular atmospheric **convection**, and the influence of mountains, coastlines and urban areas.

As a result, **the CPM is expected to provide access to detailed climate information on hourly timescales**, important for small-scale weather features that affect **flooding in summer**, and also on local (kilometer) scales, improving our understanding of **climate change in cities**.

60-300 km*

**Global Climate Model
(GCM)**



Source: Bengtsson et al. (2005)

10-50 km*

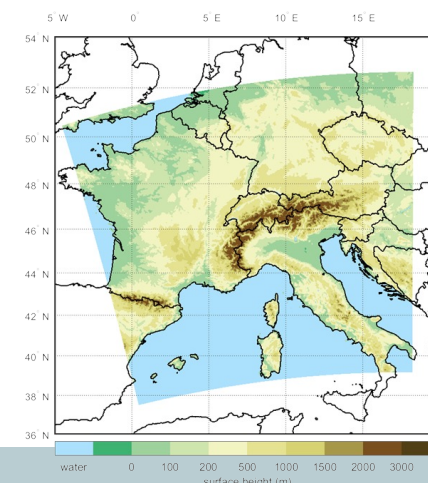
**Regional Climate Model
(RCM)**



Source: <https://www.euro-cordex.net/>

below 4-5 km

**Convection-permitting model
(CPM) at km-scale**



* Source: Kendon et al. (2019)



Why convection-permitting models?



Highlander

High performance computing
to support smart land services

“Convective” storms cause some of Earth’s most dramatic weather, including **extreme rainfall, hail, lightning and severe wind gusts.**

So being able to identify phenomena like hails, EE etc... at high resolution leads to great added value.



World | Africa | Asia | Australia | Europe | Latin America | Middle East | US & Canada

At least 120 killed and dozens missing after record rain in Western Europe

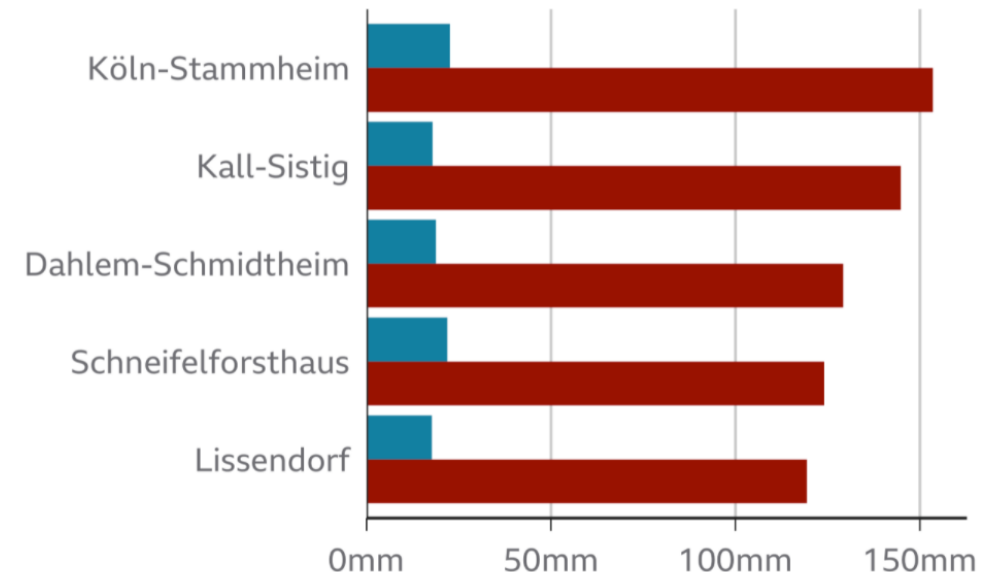


The deadly floods have left homes and cars destroyed

Among the worst-hit parts of Germany, the area of the city of Cologne known as Köln-Stammheim saw more than 153mm of rain on 14 July. To put that in context, it is six times higher than the average heaviest rainfall days for the area in July.

Worst-hit areas saw rainfall levels far above average high for July

30-year average high and 14 July 2021 compared



Source: <https://www.bbc.com/news/world-europe-57862894>
DWD German Weather Service



VHR-REA_IT dataset for HIGHLANDER project

Highlander

High performance computing
to support smart land services

Topic

Very high-resolution
dynamical
downscaling of ERA5
reanalysis over Italy

Main objective

Providing VHR
climate data over Italy
as input for
downstream services
(e.g., for decision
support system), in
different sectors highly
affected by changes in
climate trends,
variability, and
extreme events

Domain

Italian Peninsula

Periods

1989-2020 |
evaluation

Model

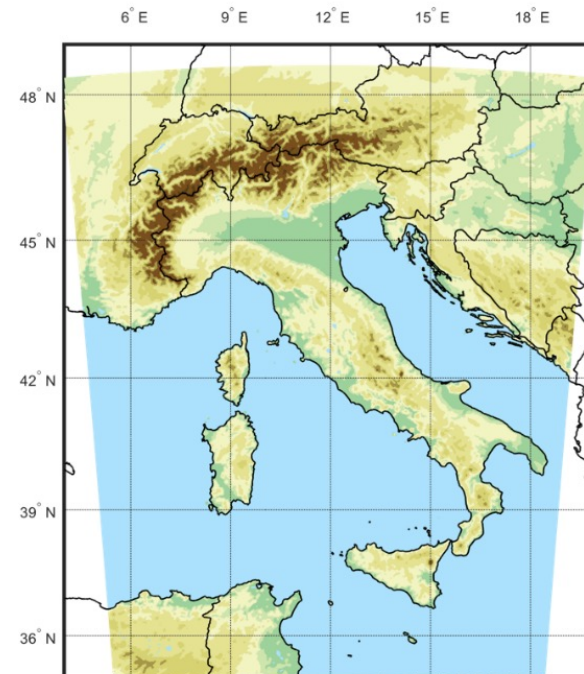
COSMO-CLM

Spatial
Resolution

2.2 km

HPC

GALILEO (Cineca)



water 0 100 200 500 1000 1500 2000 3000
surface height (m)

Raffa M., Reder A., Marras G., Mancini M., Scipione G., Santini M.,
and Mercogliano P., VHR-REA_IT dataset: very high resolution
dynamical downscaling of ERA5 reanalysis over Italy by COSMO-
CLM, 2021, Data, Volume 6, Issue 8, DOI: 10.3390/data6080088

Long-Name	Short-Name	Units
2m temperature	T_2M	K
2m dew point temperature	TD_2M	K
Total precipitation	TOT_PREC	kg m ⁻²
U-component of 10m wind	U_10M	m s ⁻¹
V-component of 10m wind	V_10M	m s ⁻¹
2m maximum temperature	TMAX_2M	K
2m minimum temperature	TMIN_2M	K
mean sea level pressure	PMSL	Pa
specific humidity	QV_2M	kg kg ⁻¹
total cloud cover	CLCT	1
Surface Evaporation	AEVAP_S	kg m ⁻²
Averaged surface net downward shortwave radiation	ASOB_S	W m ⁻²
Averaged surface net downward longwave radiation	ATHB_S	W m ⁻²
Surface snow amount	W_SNOW	m
Soil (multi levels) water content	W_SO	m



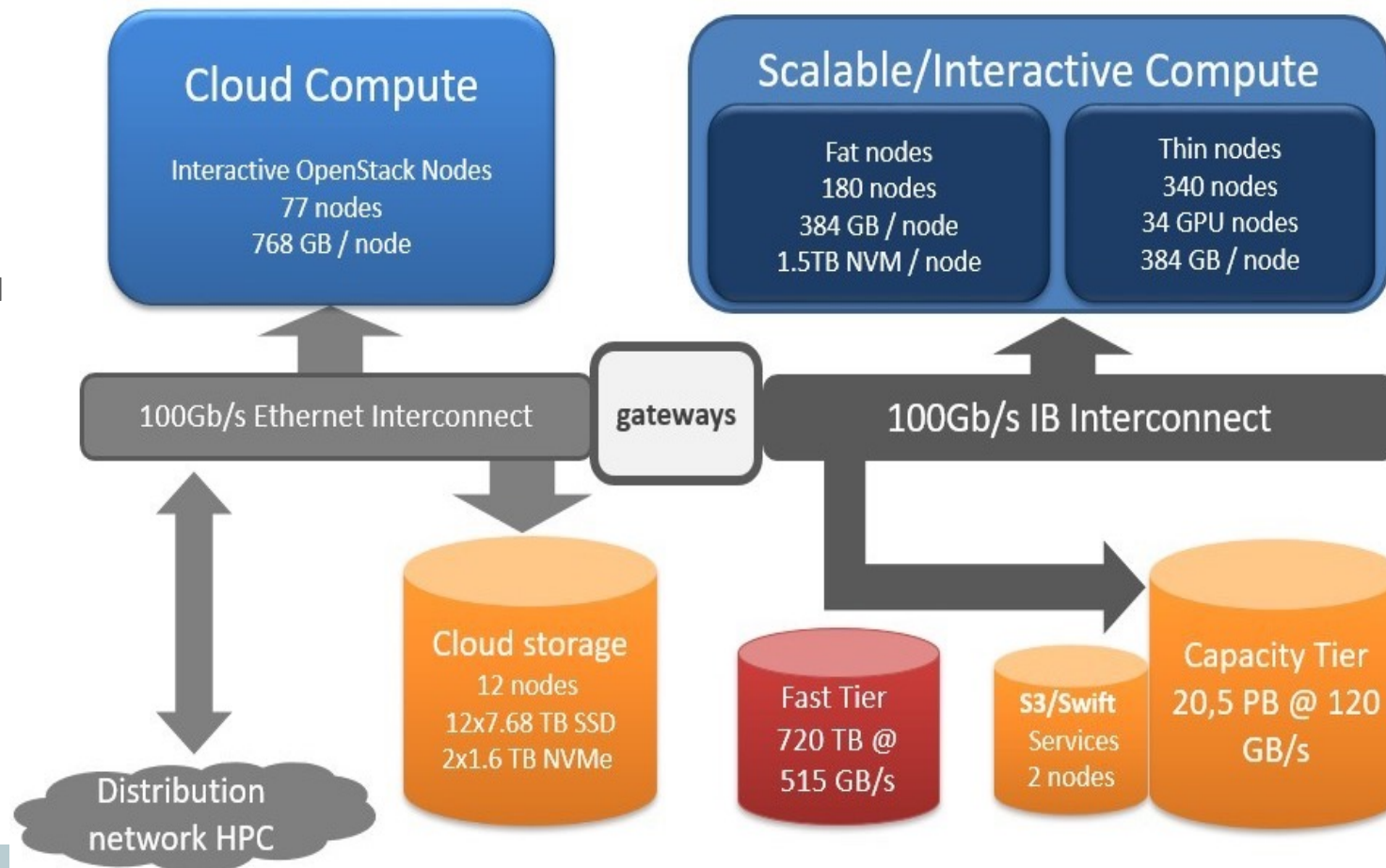
Galileo 100: Cineca Tier-1



G100: an infrastructure for data analysis and storage, scalable computing, and cloud computing.

Co-funded by the European ICEI project, system engineered by DELL.

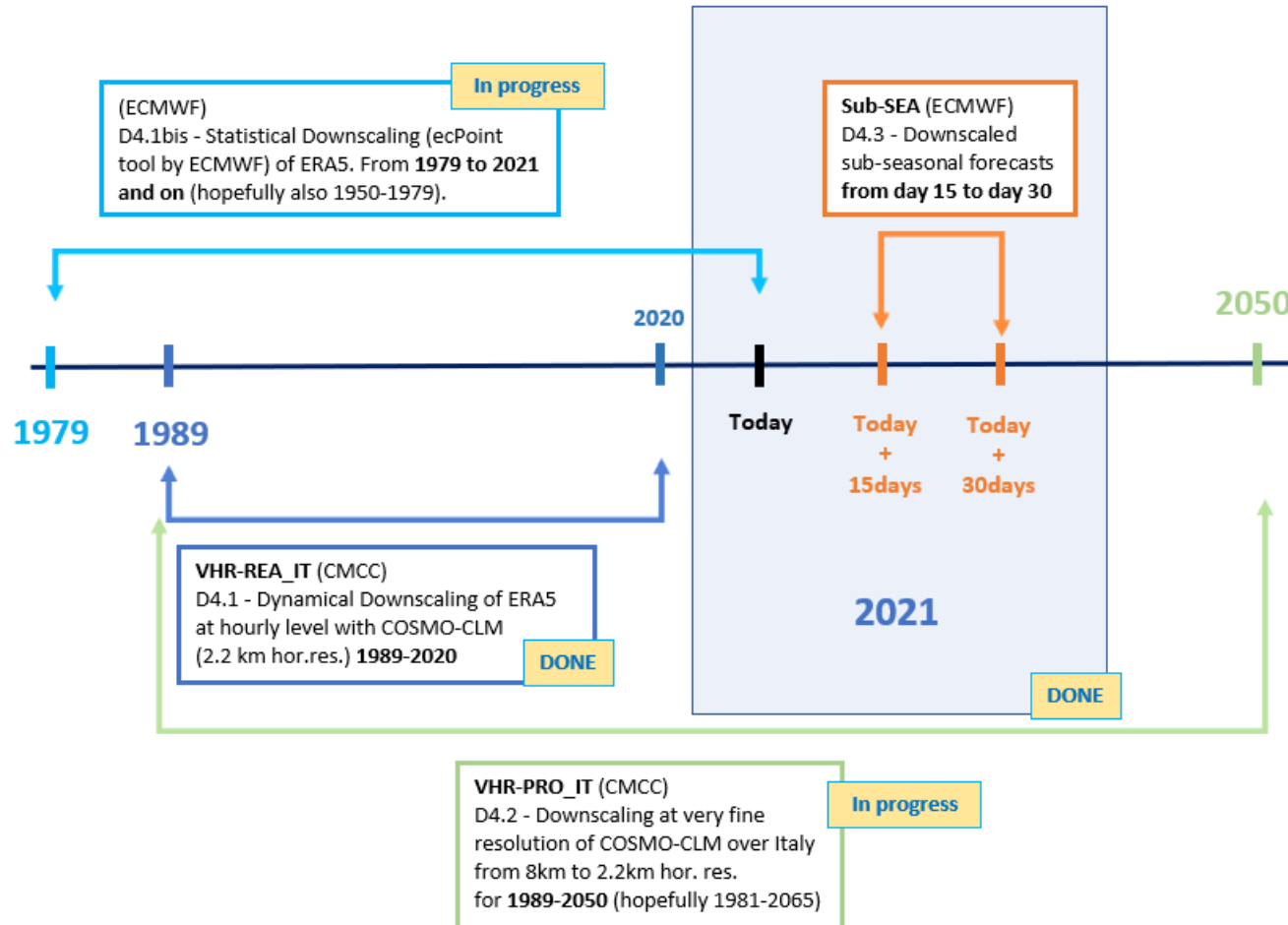
Cumulative computational
peak power of 2 PFlop/s
Over 27,000 cores
200 TB of system memory
available for user
computations.





Climate datasets time extension on Cineca HPC system

Highlander climate datasets time extension



HPC resources provided in Cineca:

VHR-REA: 60 nodes, 6Mh, 3-4 months
VHR-PRO: 60 nodes, 8Mh, 5 months, exstimated

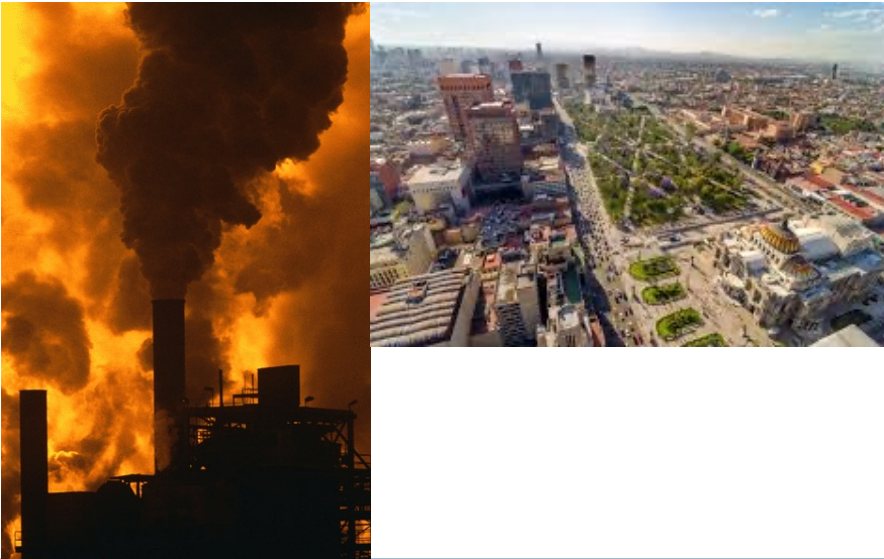


Urban parameterization

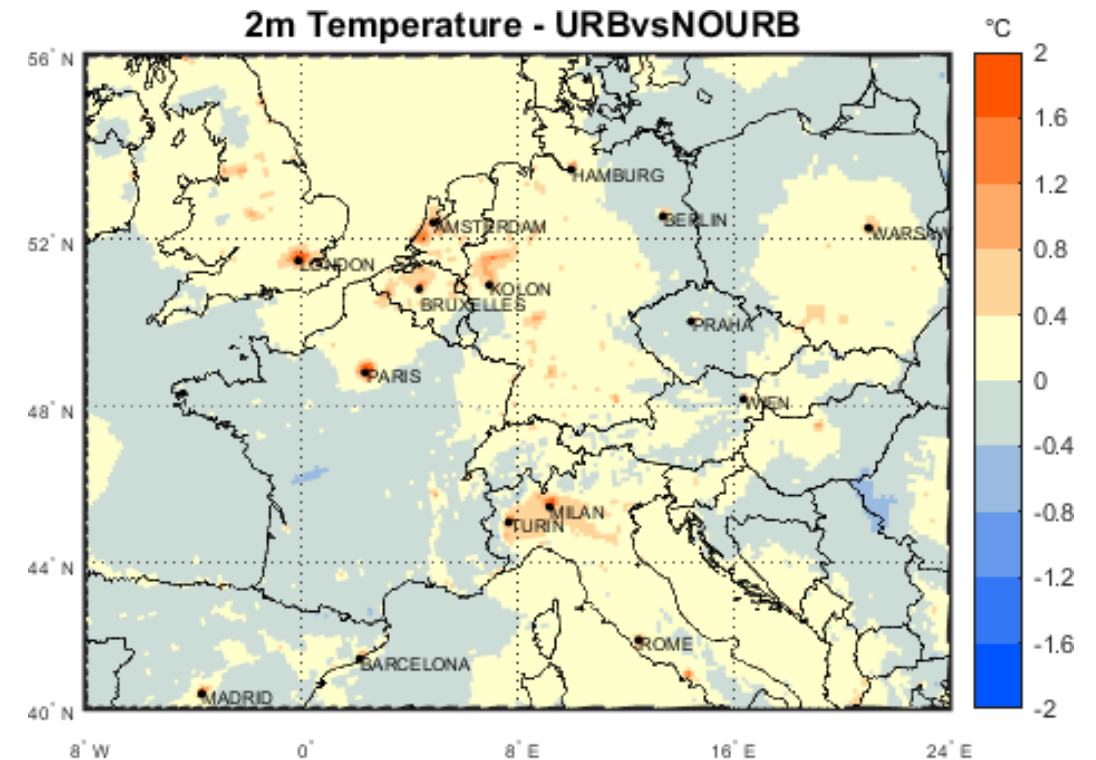


In order to look also at **urban context**, the climate simulation running in Highlander with COSMO-CLM also **includes specific parameterization** translating urban-canopy thermal parameters into bulk parameters describing urban features:

Input → **Anthropogenic heat flux (AHF)** and **Impervious surface area (ISA)**



- the model run on an area wider than Italy and you can see several cities
- Simulation particular relevant in a complex holographic context such as Italy



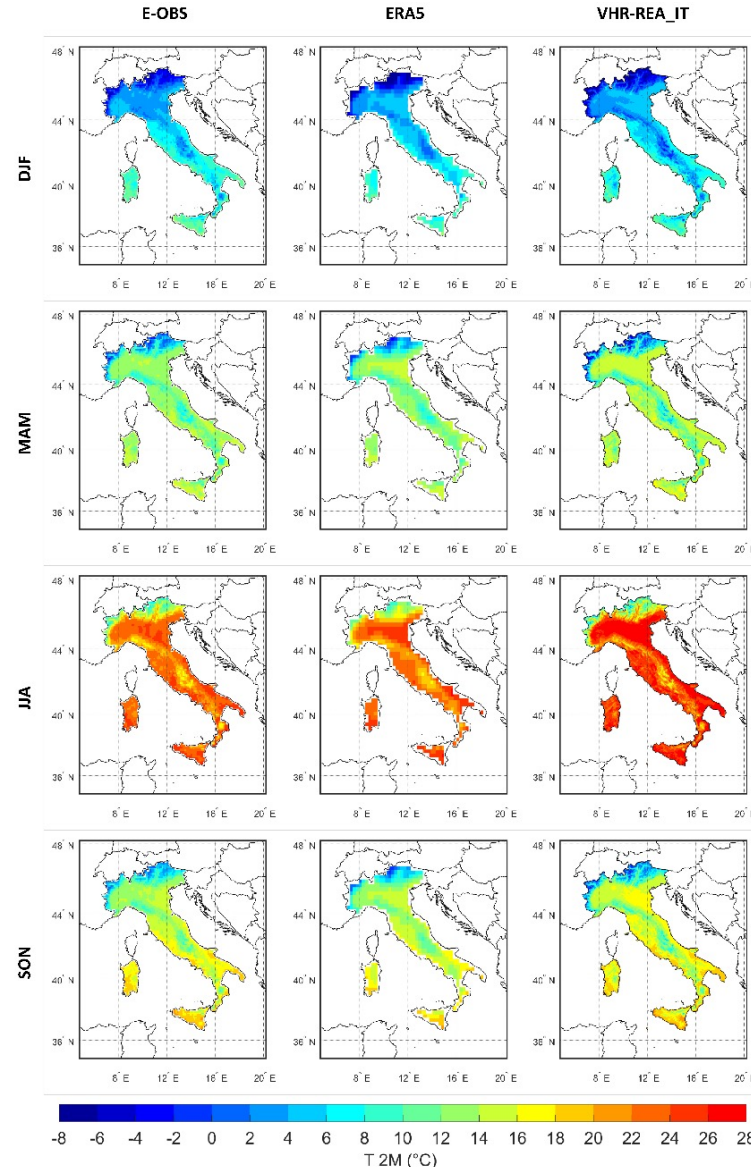


VHR-REA_IT dataset for HIGHLANDER project



Highlander

High performance computing
to support smart land services



	Bias (°C)				$\sigma_{mod}/\sigma_{obs}$			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
E-OBS	5.5	11.6	21.3	14.0	4.1	3.6	3.8	4.1
ERA5	-0.6	-0.2	0.0	-0.3	1.1	1.0	1.0	1.0
VHR-REA_IT	-0.7	0.5	1.7	0.3	1.0	1.2	1.2	1.1

	ID (days/year)	SU (days/year)	FD (days/year)	TR (days/year)
E-OBS	8	89	41	25
ERA5	10	75	42	32
VHR-REA_IT	12	106	34	54

ID: Number of icing days, count of days when TX (daily maximum temperature) < 0 °C

SU: Number of summer days, count of days when TX (daily maximum temperature) > 25°C

FD: Number of frost days, count of days when TN (daily minimum temperature) < 0°C

TR: number of tropical nights, count of days when TN (daily minimum temperature) > 20 °C

- E-OBS gridded dataset at about 11 km oh horizontal resolution
- ERA5 re-analysis provided by Copernicus @31 km
- The simulation at 2 km is able to see the complexity of the Italian climate very well.



Climate simulations at very high spatial detail over Italy

CMCC DDS

Data Delivery System

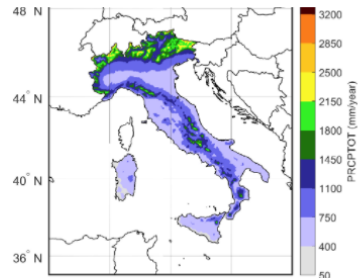
[Home](#) [Docs](#) [About](#) [Contact Us](#)

Login

ERA5 downscaling @2.2 km over Italy

[Home](#) / [ERA5 downscaling @2.2 km over Italy](#)

Dataset information



The dataset contains dynamically downscaled ERA5 reanalysis, originally available at ≈ 31 km x 31 km horizontal resolution, to 2.2 km x 2.2 km. Dynamical downscaling has been conducted directly for the project (foreground) through Regional Climate Model (RCM) COSMO5.0_CLM9 e INT2LM 2.06. The RCM COSMO CLM is currently developed by the CLM-Community, with which CMCC collaborates since 2008 (additional info on [COSMO CLM](#)). The temporal resolution of outputs is hourly (like for ERA5). Runs cover the whole Italian territory (and neighbouring areas according to the necessary computation boundary) so to provide a very detailed (in terms of space-time resolution) and comprehensive (in terms of meteorological fields) dataset of climatological data

for at least the last 30 years (01/1989-10/2020). Typical use of similar dataset is (applied) research and downstream services (e.g. for decision support system)

The temporal coverage of the dataset is from 01/01/1989 00:00 to 31/10/2020 23:00 and the temporal resolution is 1 hour. All output variables (reported in the following table) are on single levels except soil water content that is provided for 7 soil levels.

Contact:

Paola Mercogliano
paola.mercogliano@cmcc.it
[Webpage](#)

License:

[Dataset License](#)

Publication date:

2021-08-01

Update frequency:

None

DOI:

<https://doi.org/10.25424/cmcc/era5->

- Currently are on going simulation providing climate projections over Italy at 2.2 km over Galileo super computer
- The use of the COSMO CLM model is completely free of charge for all research applications. The use of COSMO-CLM generated data within HIGHLANDER is free for partners (acting as intermediate users) for the project's purposes; the use for other purposes (and by further external end-users) requires an appropriate disclaimer, including reference to COPERNICUS, CINECA, CLM Assembly and CMCC,



Issues of convection-permitting models



Issues of feasibility could be due to:

- **high-resolution data** are needed in CPMs to describe the details of the physiography of the region and associated **changes over time** (i.e. land use, land cover, urbanization);
- the computing and **data storage** requirements of CPM climate simulations;
- the increase in **computational requirements** of **2–3 orders** of magnitude compared to coarser resolution RCMs.
- the availability of very high resolution, **high quality data sets** and **observations** for the assessment and evaluation of the models, which is not there for most regions of the world;





Co-financed by the Connecting Europe
Facility of the European Union

Soil erosion over Italy



Highlander

High performance computing
to support smart land services

- Using very high resolution precipitation data
- 12 empirical models to calculate R

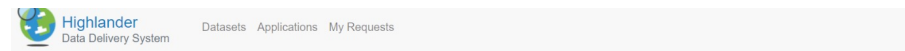


RUSLE

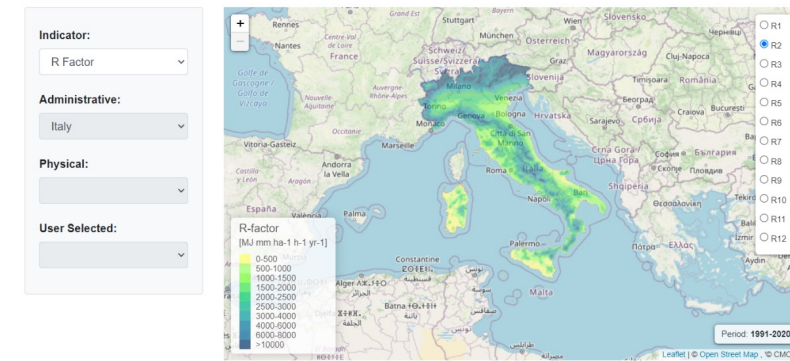
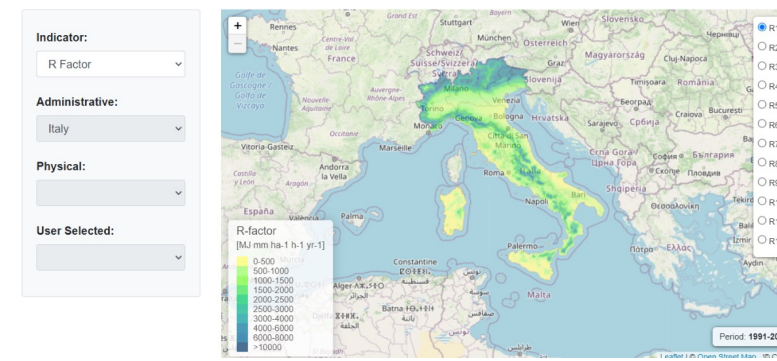
Revised Universal Soil Loss Equation

Wischmeier & Smith (1978) and Renard et al.
(1997)

$$\underbrace{\left(\underbrace{K}_{\text{Erodibility}} * \underbrace{L S}_{\text{Topograph}} * \underbrace{C}_{\text{Cover}} * \underbrace{P}_{\text{Support Practice}} \right)}_{\text{Soil susceptibility}} * \underbrace{R}_{\text{Rainfall erosivity}} = S L$$



Indicators of rainfall erosivity (R factor) and soil loss (SL) amount



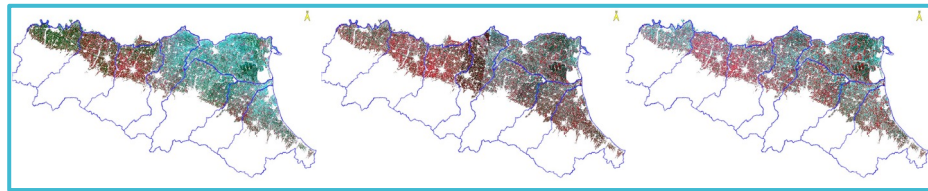


Crop water requirement sub-seasonal forecasts (ARPAE)

- This climate service is conceived to support **agricultural water providing organizations** like e.g. the Italian **Consorzi di bonifica** (land reclamation and irrigation boards)
- Water providers need support in their decision-making for both **water procurement** and **water allocation** to increase efficiency and reduce irrigation water and energy consumption.
- This **climate service** offers technical support producing **every month seasonal forecasts** (+3 months), **every week subseasonal forecasts (+1 month)** and **every day weekly forecasts** (+7 days) of water irrigation demand for specific areas during the irrigation season ranging from April to September.
- The pilot case study includes 3 out of eight **Consorzi di Bonifica** in Emilia-Romagna region (Consorzio di Bonifica della Burana, della Romagna e della Renana).



Climate Service of seasonal irrigation forecasts

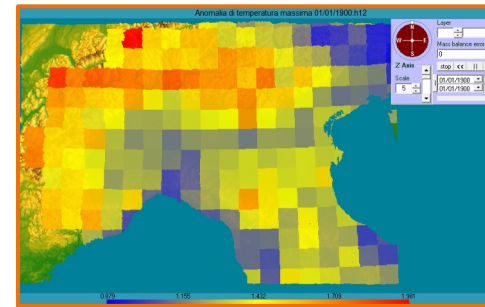


1st Window

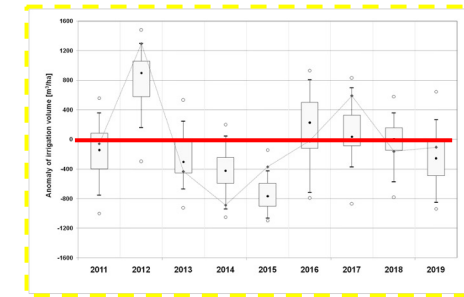
2nd Window

3rd Window

Multitemporal satellite data analysis



Probabilistic seasonal forecasts
JJA emission



Check of the irrigation
forecast

Field surveys

October-November
September

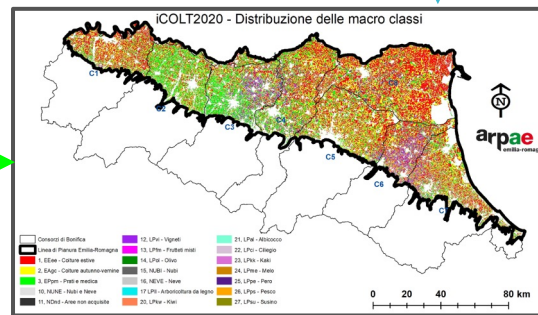
February

March-April

May

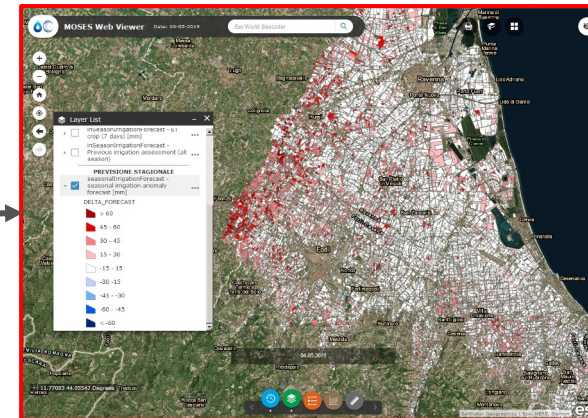
June

Product quality
assessment



Early Crop Map

The Early Crop Map (ECM) is an
agricultural herbaceous crop
classification map, obtained through the
analysis of multi-temporal optical
satellite image series.



Seasonal prediction of
irrigation water need

The seasonal irrigation forecasts
provide the anomaly of crop water
needs with respect to to reference
climate. The climate service is
addressed to water managers in
agriculture.

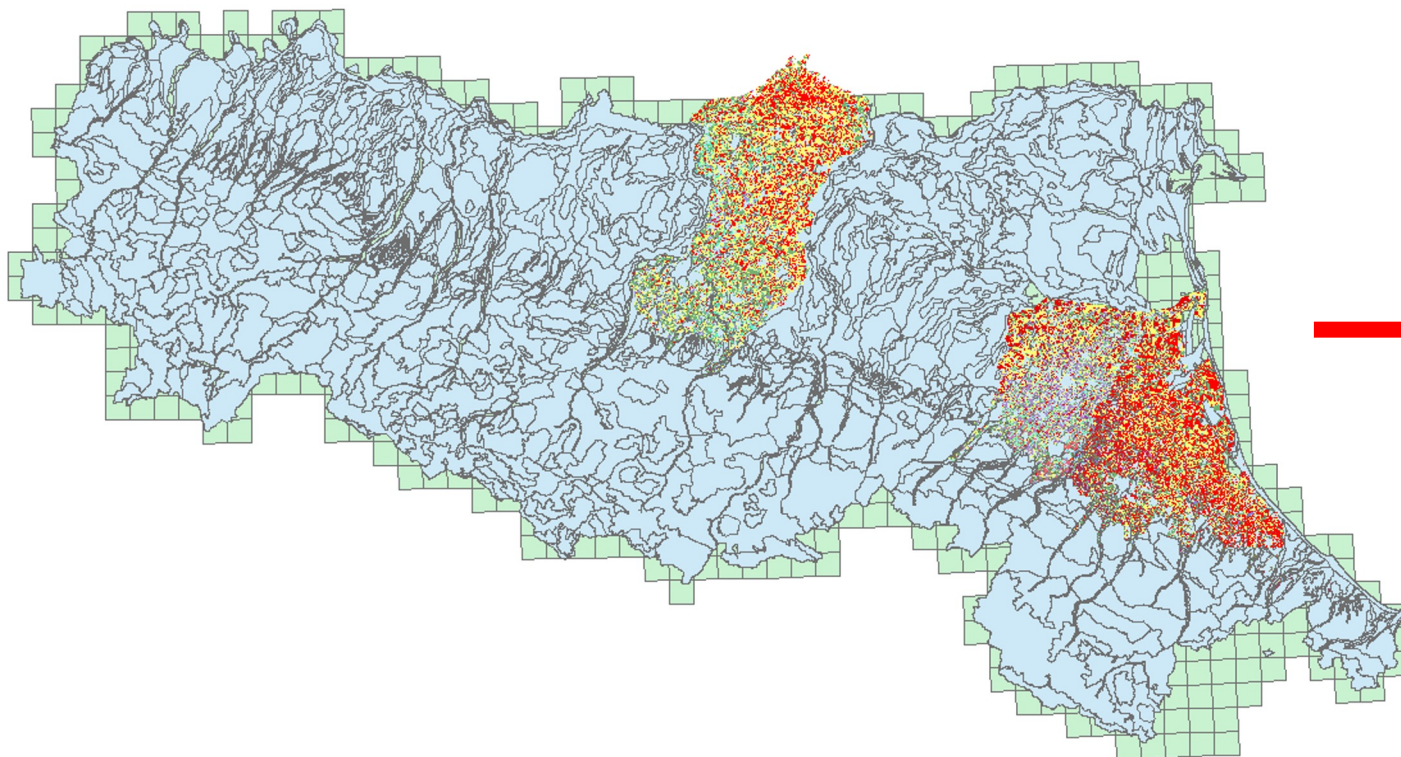




Co-financed by the Connecting Europe
Facility of the European Union

Input Data

- + Gridded weather data
- + Gridded weather forecasts
- + Regional Soil Map
- + Early crop Map
- + Criteria water balance model



Highlander
High performance computing
to support smart land services

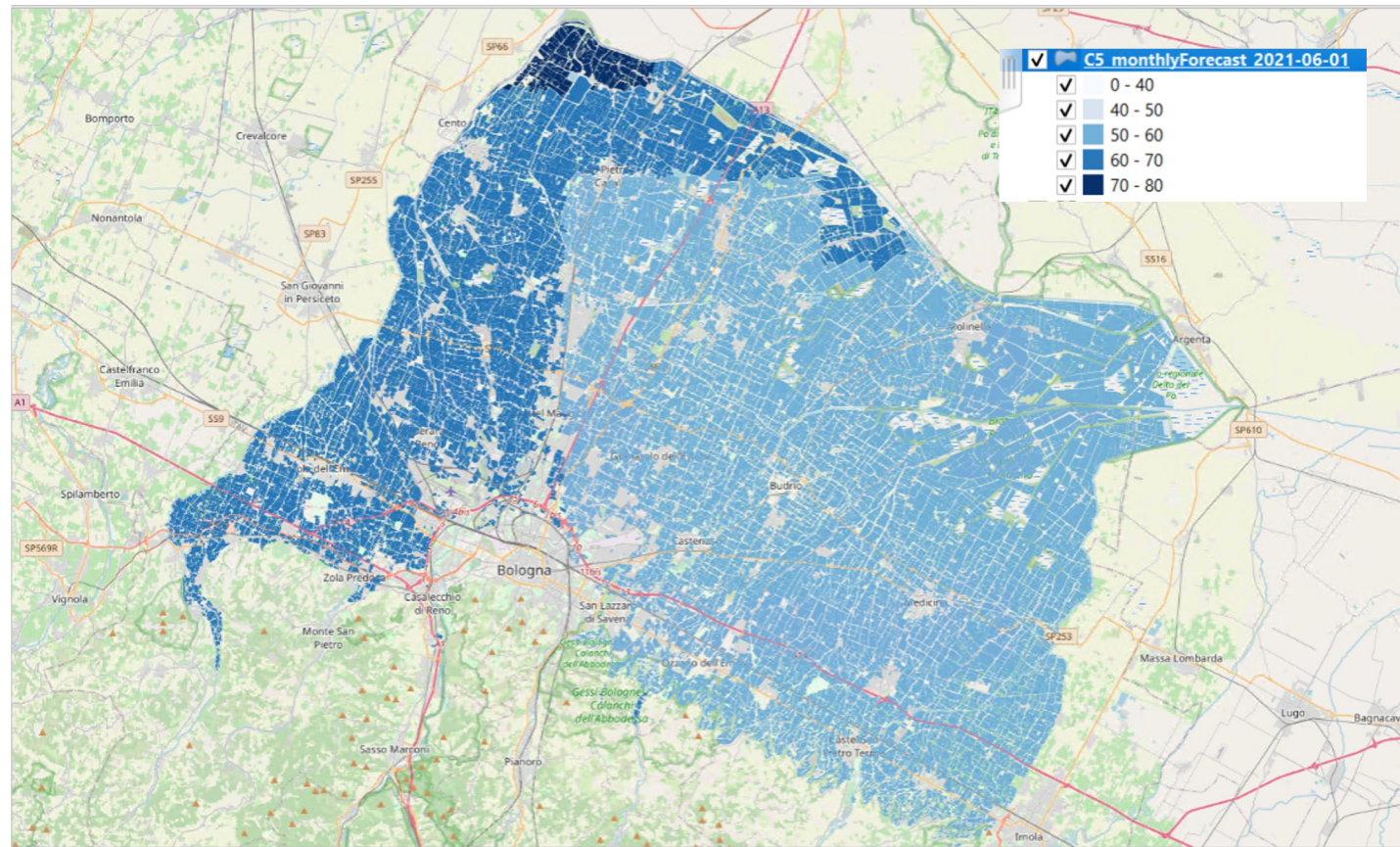
CRITERIA-1D

<https://github.com/ARPA-SIMC/CRITERIA3D>

Branch: master		New pull request	Find file	Clone or download
Latest commit 4a614ee 18 hours ago				
ftomei mapgraphics debug				
.github/ISSUE_TEMPLATE	Update issue templates			4 months ago
CRITERIA3D	add CRITERIA3D			5 days ago
DATA	path			20 hours ago
HEAT1D	restored previous version heat1d			10 months ago
Makeall_CRITERIA1D	rename test project criteria1d			3 months ago
Makeall_PRAGA	clean PRAGA project			8 days ago
MapGraphics	mapgraphics debug			18 hours ago
PRAGA	warning fixed			19 hours ago
TestCriteria1D	criteria-1d clean			16 days ago
TestSolarRadiation	fix testSolar			6 days ago
TestSunPosition	fix testSolar			6 days ago
climate	warning fixed			18 hours ago
crit3dDate	warning fixed			19 hours ago
criteria1D	clean parameters			14 days ago
crop	clean crop library			14 days ago
dbMeteoGrid	fix load loadGridHourlyVar to take 00:00 day after			21 hours ago

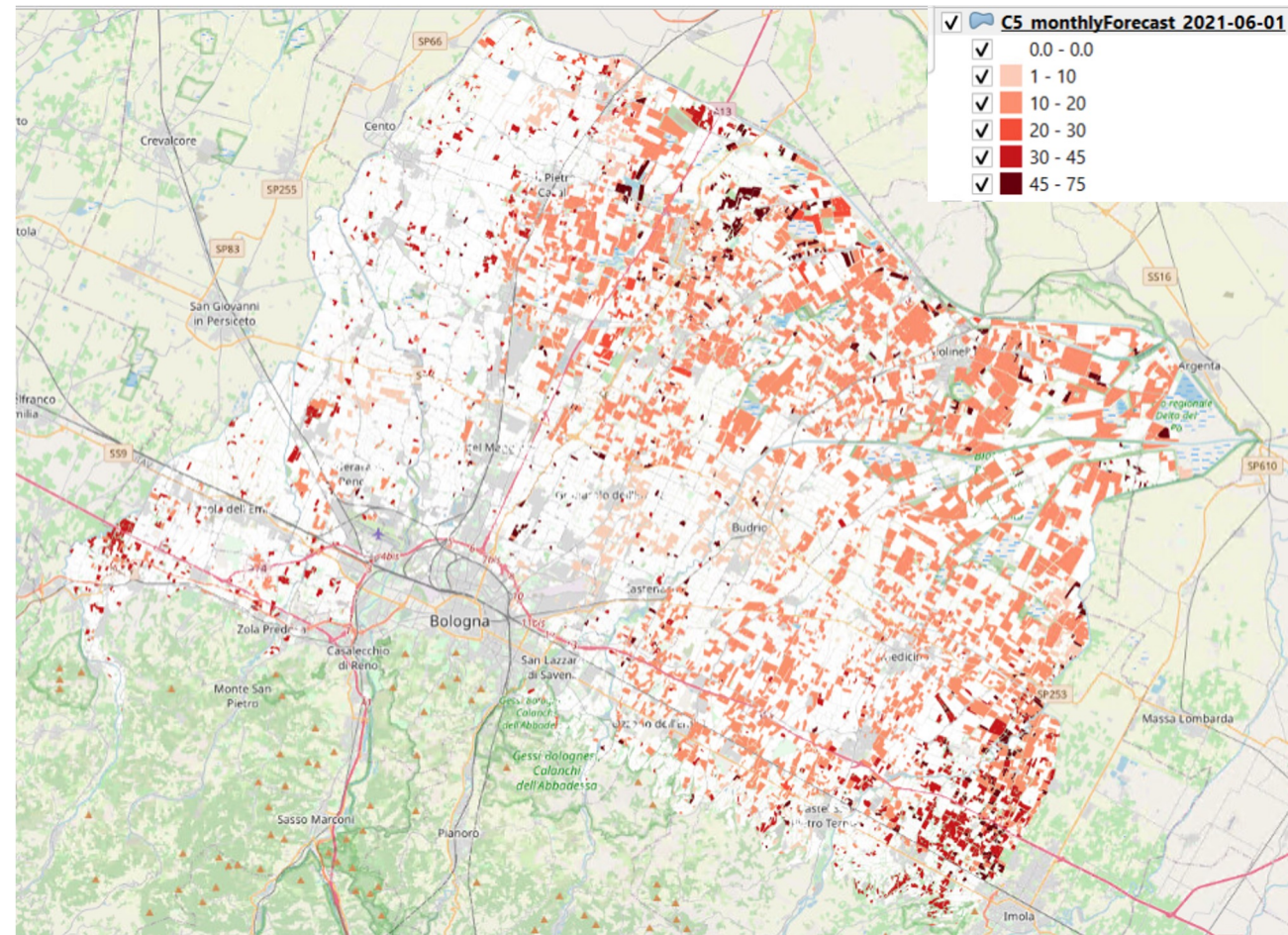


Monthly forecast of precipitation - June 2021





Monthly forecast of irrigation - June 2021





Co-financed by the Connecting Europe
Facility of the European Union

visit

highlanderproject.eu

follow

[#HIGHLANDERPROJECT](https://twitter.com/HIGHLANDERPROJECT)

info

info@highlanderproject.eu

Thank you



Highlander

High performance computing
to support smart land services